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Design of environmental decision support system and its application to water quality management

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Abstract: EDSS is a comprehensive software system for water quality management in tidal river networks in general and for the Pearl River Delta in particular. Its purpose is to provide a practical tool that could assist government agencies in decision making for the efficient management of water resources in terms of both quantity and quality. By combining the capabilities of geographical information system (GIS), database management system (DBMS), model base management system (MBMS) and expert system, the aim is to improve the quality of decision making in what is becoming an increasingly complex area. This paper first outlines the basic concepts and philosophy adopted in developing EDSS, the system architecture, design features, implementation techniques and facilities provided. Thereafter, the core part of the system—the hydrodynamic and water quality models are described briefly. The final contribution in this paper describes the application of EDSS to the Pearl River Delta, which has the most complicated tidal river network patterns as well as the fastest economic development in the world. Examples are given of the real-world problems that can be addressed using the system, including cross-boundary water pollution analysis, regional drinking water take-up site selection, screening of important polluters, environmental impact assessment, and water quality zoning and planning. It is illustrated that EDSS can provide efficient and scientific analytical tools for planning and decision-making purposes in the information era.

Design of environmental decision support system and its application to water quality management ZENG Fan-tang, DU Ling, LIN Kui, SHEN Qian (South China Institute of Environmental Sciences, SEPA, Guangzhou 510655, China) 1 Introduction Environmental decision support systems could be divided into two categories by their organizational form and system functions. One is regional environmental analytical system based on commercial GIS and assisted by environmental models, such as BASINS developed by the American NEPA using ARC/VIEW as its user platform and including QUAL2E and NPSM as its prediction tools. The other is environmental information and prediction system based on mathematical models, such as OILMAP[1]. Unfortunately, most of the systems can not break the constraints of technical details of commercial GIS and environmental models, and their interfaces are too complicated to those nonprofessional users. Furthermore, their functionality can not be extended easily by users themselves and thus limit their capabilities in information processing and problem analysis. This paper reports a successful development and application of an EDSS that has been developed by using the object-oriented approach and has the following characteristics: (1) Visual: all the interfacial operation, data processing, result display and inference are finished by extensive use of color-graphics, animation and diagram. (2) Integrated: the unity of system operation is guaranteed by the seamless combination of environmental geographical information system (EGIS), knowledge base management system (KBMS), MBMS, DBMS, problem processing system (PPS) and man-computer interface system (IS). (3) Concealed: as far as the user is concerned, the impression given is that of a seamless system, allowing effective use to be made of the planning capacities without being unduly concerned about the complexities of mathematical models. (4) Extendible: the users are allowed to add environmental models, inference rules and data resource to the system so that system function could be strengthened continuously during the process of application. 2 System structure and design features 2.1 Organizational principles and general structure In terms of system structure, the EDSS is organized from top to bottom in the order of man-computer interface, knowledge base and inference module, command interpreter/controller, kernel function module, database/model library, and user written programs as seen in Figure 1. In terms of user interface, the EDSS is arranged from left to righ t in the order of data-in, analysis and query, problem statement and inference, module invocation, result display and analysis. In Figure 1 the correlative relationship among input/output module, problem analysis module, command interpretation/control module and the other parts of the system are stressed. 2.1.1 Environmental model base management system Relevant models need to be organized within an EDSS in such a way that they can be appropriately selected and executed. The efficient management of models within the EDSS is realized by using a model index table. When a request for model calling is advanced, the EDSS searches the model index table first, then collects appropriate input data for the model from database and calls the specific model. A user who needs to add a new model to the system must have the new model registered in the index table as well as providing the proper model. 2.1.2 Problem processing and inference system (PPIS) PPIS in the EDSS is made up of two parts. One is built in the EDSS main program performing basic command decomposition and processing. The other part, independent of the core module, finishes the fuzzy logic inference for decision making of relatively high level by aid of the inference rule base. 2.1.3 Query system EDSS provides two ways of query, namely, random query based on graphic guidance and logic query based on conditional concept and value. 2.1.4 Data exchange mechanism An EDSS usually has two types of data exchange mechanism, namely, working-file exchange and dynamic data exchange (DDE). Working-file exchange is mainly applied to communications between the kernel module of the EDSS and those models that need enormous data at one time, and we have defined various types of format for text-file and binary-file which can convey environmental data in common use. Provided it is registered in the model index table, an external model can write and read the wanted data when necessary. When the kernel module of the EDSS needs to implement real-time transmit of data with other modules, DDE mechanism provided by Microsoft Windows is adopted to do data exchange. In this case the EDSS is defined as a client and the application program as a server. We have also defined various types of code for dynamic data exchange. 2.1.5 User interface design Usually an EDSS contains multiple application programs most of which are independently developed, to integrate them into one system organically requires elaborate interface design and system coordination. Within the EDSS, the user interface, graphic modules, DBMS and MBMS are combined together while the problem processing system and the mathematical models are excluded, which can achieve the maximum guarantee of interface unity with the minimum sacrifice of flexibility. What links the three parts is data exchange mechanism. Even the independent mathematical models and problem processors will contract to icons and be running in the background. What a user can see on the desktop will always be the map information of the regions concerned. The EDSS core system is designed to be of multiple document windows, so a user can open several projects at the same time to undertake comparison study, and even open different copies of the same region simultaneously to make decision analysis regarding different conditions. 2.2 EGIS suitable for EDSS 2.2.1 Object-oriented EGIS (OOEGIS) Most environmental information has its spatial characteristics that can be described and processed by aid of GIS technique. Generally, EGIS is established based on a conventional GIS and assisted by relavant environmental attribute data[3]. Theoretically, this kind of system can fully describe environmental data but for the user there exist disadvantages of vague environmental concepts. Taking a pollution source for example, it is a geographic point that contains attribute data of flow rate and water quality parameters from the point of view of GIS. But to the user, it is the location and values rather than which layer it belongs to in GIS that are his primary concerns. Therefore, it is necessary to describe and handle environmental information in the view of environmental science. Within EGIS, environmental information is encapsulated and processed from the bottom of data structure by employing object-oriented approach, so that not only are the environmental concepts highlighted, but also the data of non-environmental category packed. 2.2.2 Data encapsulation method of EGIS EGIS defines not only the abstract objects such as point, line and polygon of GIS category, but also real objects such as road and river. What ' s more important, some abstract or real objects of environmental perception such as environmental index, pollution source, and water quality zone are defined. What these objects encapsulate, besides spatial and attributive characteristics, are the input/output operations on data. 2.2.3 Object-class inheritance tree of EGIS The object-class inheritance tree of EGIS defines 6 key class libraries that are correlative and inherent. Among them, the GIS base class defines the conventional basic data such as attribute identification and index identification. The GIS abstract class, derived from the GIS base class, defines the abstract objects such as a point and a line that can be instantiated. The GIS real-object class, derived from the GIS abstract class, defines those geographic objects of real world such as a road or a river. The environmental base?class library contains such classes as environmental index names and their excursions that can not be instantiated. The environmental concept base-class library contains such classes as environmental factors and parameters of environmental perception. Those classes such as point pollution source and non-point pollution source in the environmental class library are derived from the environmental concept class library and the GIS class library. 2.2.4 Relationship between EGIS and other sub-systems Within the EDSS, EGIS is quite a complete system that can conduct map input a

nd modification by using a digitizer, and process all environmental information in an object-oriented manner. However, when compared with a commercial GIS, its functions seem far too simple, particularly in spatial analysis and processing abilities. The digitizing and processing of complicated maps usually have to be carried out with the help of a commercial GIS. Therefore, EDSS provides utilities to have a digital map of ARC/INFO format conversed to that of EGIS format. In EGIS, the data such as attribute, index, and map layer used by a conventional GIS are encapsulated in an object-oriented manner, but the relavant attribute data can be processed by the method of pointer index table as well. In fact, EDSS administrates its data in two ways simultaneously. Since some environmental information such as water quality prediction results may involve enormous spatial and temporal data, if they are encapsulated and administrated in an object-oriented manner, the system memory will be greatly wasted and thus affect the system performance. So EGIS adopts a non-object-oriented approach and an object-oriented technique as well. 3 Hydrodynamic and water quality models for tidal river networks (TNETWQ) Mathematical models have proved to be a powerful tool for water quality management. In recent years, a number of management systems for water quality models have been built, such as OILMAP, COASTMAP and WQMAP by ASA, and DIVAST, SALMON-Q and other systems by delft hydraulics. Unfortunately, these model management systems can only apply to two-dimensional analysis of water body or unidirectional river channels. Furthermore, they are not an integrated part of an EDSS having GIS or DBMS functionality[4]. In the following sections, the mathematical modeling of tidal river network will first be introduced. Then, model input, manipulation, output and system interfaces are described. Finally, the Pearl River Delta will be analyzed as an example to illustrate the utility of the EDSS for water quality management in a complicated river network region. 3.1 Major functions of TNETWQ TNETWQ is made up of two components, namely, the hydrodynamic model and the water quality model. The hydrodynamic model will produce the temporal-spatial tidal flow distribution under the designated boundary conditions and provide basic data-in for the water quality model. At present, TNETQW has six major functions: (l) To predict seasonal tidal flow conditions at various river sections, such as the times of high and low tide, which are very important to fishery and the selection of drinking water take-up sites. (2) To analyze the interplay of channel flow and tidal movement. (3) To analyze and predict the influence on down-stream water quality by channel construction and water diversion works. (4) To calibrate channel flow in dry seasons. (5) To analyze the impact on water quality from major pollution sources.
(6) Through trail and error, to determine the allowable discharge rates for cities and disposal sites. 3.2 Governing equations of TNETQW For river networks with a one-dimensional flow pattern, the governing equations for tidal flow and water quality are given as follows: where x = distance along the axis of a channel, t = time, u = velocity along the axis of channel, water surface elevation, Q = flow rate, A = cross-sectional area, g = acceleration of gravity, R = hydraulic radius, n = Manning roughness coefficient, e = eddy viscosity; K = decay rate; C = concentration of water quality constituent, Cs = balance concentration, Ex = longitudinal mixing coefficient, and SLB = loading rate. TNETOW utilizes the discrete algorithm made by Zeng et al.[5] to solve the above equation set. Furthermore, TNETOW is written in Visual Fortran with three major subroutines. The first subroutine is to pre-treat user-supplied data to fit the model format requirements. The second is for calculating the coefficients of the discrete equation set. The third is to solve the equation set by iterative method. 3.3 TNETWQ and EDSS communication method Usually, predictive models have stringent requirements for data-in format when used for practical purposes, and the data structure of these models and that of DBMS or GIS have to be compatible. In order to utilize these models effectively in the EDSS, it is necessary to establish a communication channel between the EDSS and the models. At present, there are three communication methods in existence[6]. The lowest level communication is to treat the GIS as a database management system (DBMS), and if data formats from both sides are compatible, communication between them will be straightforward. Otherwise, it is necessary to provide a protocol program. A higher level communication is to treat the GIS as a display of model calculation results. The highest level communication is to view the models and the GIS as interrelated components of an integrated system. Basically, the communication method adopted in the EDSS is an ingenious combination of the above three methods. 3.4 Data input for TNETWQ in EDSS environment 3.4.1 River network data River network data required by TNETWQ include surface distribution and water depth of river channels in the study area. These data can come from actual surveys or from computer scanning of the iso-depth lines on navigation charts. Since TNETWQ utilizes discrete algorithm, it is necessary to fragment the river channels into finite number of control parts, which needs much professional knowledge. The EDSS provides direct-view dialogue windows of all kinds to help the user implement river channel discretization and the input, modification and query of water depth data. 3.4.2 Boundary conditions In theory, all open boundaries shall be assigned with boundary conditions. TNETWQ accepts three types of flow boundary conditions, i.e., tidal level, tidal flow, or the both. TNETWQ can automatically identify which type the data belong to according to the usability of the information. But boundary conditions for water quality modeling require all pollutant

concentrations at flow-in boundaries to be specified. The EDSS provides two manipulations to carry out boundary data input, modification and query, one for tidal flow modeling and the other for water quality simulation. One thing deserves mentioning is that the spatial and temporal attributes of the boundary conditions are managed by its own GIS and DBMS respectively. For example, when the manipulation of tidal flow boundary conditions is selected, a discrete river network will immediately appear on the screen, and the boundary sections will be highlighted. When the user clicks on an interesting boundary section, database tables similar to EXCEL will turn up, where the user can directly input and modify boundary data, and undertake error-check and statistic analysis as well. 3.4.3 Initial conditions The initial conditions for TNETWQ can be extracted from empirical data, or can be made up if insufficient empirical data exist. Of course, more accurate initial conditions will lead to less computing time. The EDSS provides the manipulation of tidal flow and water quality initial conditions respectively to initialize data input and transfer the modified data to TNETWQ working files. Its user interfaces are quite similar to those of boundary conditions. 3.4.4 Waste sources Similarly, the GIS manages the spatial attribute of waste sources while the DBMS manages the temporal attribute. Not only can the user add, erase or modify a pollution source, but also carry out contact query, logic query or bulk edition towards pollution source quickly. When a pollution source is clicked, the EDSS will search the slope topographic data for the spatially nearest discrete cell as its acceptor. However, the EDSS also allows direct choice of pollution source acceptor manually. 3.4.5 Determination of model parameters The major model parameters of TNETWQ are the Manning coefficient and the pollutant decay coefficient. The Manning coefficient describes the resistance of river channels to water flow and the decay coefficient describes the way in which pollutants transform in a water body. In default state, the EDSS uses the model parameters calibrated based on tens of field measurements undertaken in the National Key Environmental Study during the period of 1986-1990. Provided with new field measurements, the EDSS can help the user update the parameters by trial-and-error method. 3.5 TNETWQ output in EDSS environment TNETWQ stores its calculation results in a group of temporary binary files. The EDSS can provide the user with the time process, spatial distribution, temporal-spatial change, and result query in order to obtain the calculation result in maps and graphs and to entertain query. The time process manipulation gives the user the information on how a certain physical quantity changes through time. The spatial distribution manipulation gives the user the information of a physical quantity in a two-dimensional space at a certain time. The temporal-spatial manipulation gives the user the information for both time and space of a physical quantity. In each output state, the user can conduct logic query or statistic analysis of various design conditions. For example, users will notice that the water quality of every river channel changes continuously with the rising and falling of tides. In the color plate, each color corresponds to a certain water quality concentration. The user can control the display speed by himself, select the interesting water quality parameters, or take a snapshot of a momentary picture for printing. Figure 2 is an example of logic query in which all river channels with BOD5 >4mg/L are marked with red color. 4 Example applications: water quality management in the Pearl River Delta The Pearl River Delta has an area of more than 20,000km2 with a total river length of over 2000km and embracing 12 cities or counties such as Guangzhou, Foshan, Dongguan, Zhongshan, Jiangmen, etc. The fact that three mighty rivers converge, eight major outlets rush down the South China Sea and thousands of water courses of different sizes crisscross earns it one of the most complex tidal river networks in the world. In recent years, rapid economic development has led to increasingly deterioration of water quality in the Pearl River Delta, and it has become a common sense that a water pollution control scheme on a systematic and scientific base is imperative. Figure 2 Typical user interface of spatial water quality query output 4.1 Modeling of the river network In modeling the tidal river network, a total of 160 rivers with a total length of 1600 km was used after generalization. The whole network is divided into 1207 control cells, of which 140 are of bifurcation and 19 boundary. The EDSS mainly uses the hydrological and water quality data collected by the regular monitoring stations in the Pearl River Delta since 1995. After calibration, the model parameters are set according to wet season and dry season. In fact, the EDSS can conveniently renew the parameters if new data are available. 4.2 Application to water quality zoning 4.2.1 Zoning objects and indexes Water quality zoning has to make clear the ambient standards that each river section shall attain. In this case, Class I is suitable for river sources and natural conservancy areas; Class II is suitable for No.1 conservancy areas of drinking water, precious and rare fish habitats and spawning sites; Class III is suitable for No.2 conservancy areas of drinking water, common fish habitats and body-contact recreation waters; Class IV is suitable for industrial and non-contact entertainment water uses; and Class V is suitable for agricultural and scenery water uses. Considering the impact of tides in the tidal river network, certain buffer reaches shall be set between two water quality zones of different objects. According to the local water pollution characteristics, the study focuses on the following water quality indexes, i.e., BOD5, pH, SS, DO, CODMn, total hardness, nonionic ammonia, NO2-N, NO3-N, volatile phenol, cyanide, water tem perature, As, Hg, Cr6+, Pb, Cd, and petroleum. Those who are interested in the classification standards for water quality zones and water quality indexes can consult the National Surface Water Ambient Standard of China (GHZB1-1999). 4.2.2 Fundamental steps for water quality zoning (1) Systematically analyze the water quality status, water use planning and salt-water line of the Delta, and initially work out a zoning scheme based on the general principles of environmental zoning. (2) Employ the EDSS to examine the scientific feasibility of the scheme and make necessary corrections. For example, water zone of Class III, before reaching Class II, needs an enough distance for the pollutants to decay. How long the enough length shall be depends on the hydrological and water quality features of a certain river channel, and the EDSS is expert at figuring out that length. (3) Systematically assess the water quality objectives in terms of three aspects of environmental, technical and economic conditions, and extensively solicit the opinions of decision-makers and water users. If necessary, go back to step (2) until a feasible scheme is finalized. 4.2.3 Zoning results After optimization analysis by EDSS, the zoning result for the Pearl River Delta is shown in Figure 3. Statistics releases that Class II accounts for 10.07%, Class II to Class III 23.15%, Class IV 37.5%, Class III to Class IV 17.44%, Class IV 5.65%, Class IV to Class V 5.92% and Class V 0.26%. The result has been reported in Guangdong Provincial Surface Water Zoning issued by the Government. Figure 3 The Pearl River Delta water quality zoning output after EDSS optimal analysis 4.3 Application to comprehensive decision making in water quality management As a software system developed with environmental management purpose, the EDSS has exhibited its power in many environmental studies. Listed as follows are only some examples: (1) To provide basic data for cross-boundary water pollution analysis between Gongdong, Hong Kong and Macao. (2) To provide a scientific base for water source planning. (3) To carry out waste source assessment and determine the major polluters of the Pearl River Delta. (4) To assist EIA studies on large construction projects. (4) To assist regional water quality planning, such as the formulation of “Guangdong Provincial Surface Water Quality Zoning Plan”, “Guangdong Provincial Clear Water Movement Plan” and “Regulations Regarding Water Quality Protection in the Pearl River Delta ”. 5 Conclusions This brief introduction to EDSS describes its design concept and salient features. These include the use of GIS and DBMS in association with various types of models, not only for predicting what is likely to happen under a given set of planning assumptions, but also for assisting the management in deciding the appropriate action. Emphasis has been placed on the importance of an EDSS being both comprehensive and easy to use, with all the complexity being hidden from the user. It is demonstrated that EDSS can be successfully applied to tidal flow and water quality simulation and thus assist water quality management in a region as complicated as the Pearl River Delta. Furthermore, the system can be made available to other parts of the world to tackle problems similar to those of the Pearl River Delta, and it will also equip governmental officials with the badly needed state-of-the-art technology in environmental decision making. References

关键词： EDSS; GIS; DBMS; water quality zoning; the Pearl River Delta

