MITIGATING THE IMPACTS OF COMBINED SEWER OVERFLOW TO AN URBAN RIVER SYSTEM VIA WEB-BASED SHARE-VISION MODELING

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Abstract

Storm water overflow from the combined sewer system might result in a sudden devastating impact to the local ecosystem in an urban river environment. In order to assess overflow pollution load during tropical rainfall, a web-based share vision modelling system is organized and designed in this study to investigate the resultant water quality impacts from both spatial and temporal aspects simultaneously. The study area covers the estuarine region in the Love River system in South Taiwan. The architecture of such a Decision Support System (DSS) requires applying, integrating, and linking the web-based database, Internet Geographic Information System (IGIS), and two well-calibrated water quality simulation models, including Storm Water Management Model (SWMM) and the Lover River Hydrodynamic and Water Quality model (LRHWQ). By properly sharing information, vision, and modelling outputs among different stakeholders and decision makers via a web-based platform, a more efficient emergency management action is achievable in response to mitigating possible ecological risk in the estuarine rehabilitation process.

Keywords: Water pollution control; Share-vision modelling; Decision support system; Environmental systems analysis; Information technology

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* corresponding author

The need for balanced environmental, ecological, and economic perspectives has led to the umbrella concept of sustainability that emphasizes decentralized and collaborative decision-making for overall ecosystem.

INTRODUCTION

Previous evidence confirmed that storm water overflow from the combined sewer system might result in a sudden devastating impact to the local ecosystem in the water environment

(Chen et al., 1999). The storm water management issue, therefore, has received wide attention in recent years due to wide spread water pollution impact in the estuarine and port region in the city of Kaohsiung, South Taiwan. In view of the inherent complexity involved in the process of rainfall, run-off, combined sewage collection, interception, temporary storage, and emergency release in many metropolitan regions, a new scientific-based management tool is needed to perform an integrated assessment in a timely manner. For decades, information-based technologies (IT) have been promising new capabilities for enhancing the potential of environmental management. Argent and Grayson (2001) referred that a well-design Decision Support System (DSS) own the capacity analyzing the potential outcomes of management alternatives. DSS covers a broad spectrum of activities that aim to help engineers, planners and administrators to make constructive decisions. Previous development of DSS to aid in environmental management has been performed with regard to municipal and industrial solid waste management, air and water quality management, and chemical emergency preparedness and response, which may result in as a consequence of higher managerial efficiency in public agencies (Chang and Wang, 1996; Chang, et al., 1997; Chen, et al., 2000). However, there are numerous benefits associated with developing a new generation of DSS with the aid of web-based platform to deal with waste management, disaster mitigation, and emergency response in an urban region (Chang, et al., 2001). In order to assess pollution load of combined sewer overflow and its resultant impact to river water quality during tropical rainfall, a web-based share vision modelling approach is worthwhile exploring.

It is the aim of this paper to present such a new architecture of DSS for achieving the objectives of disseminating real-time water quality monitoring data through web site, automating acquirement of predictions of storm water quality and surface water quality in the urban river system, creating a prototype share vision modelling analysis, and developing a decision-making framework in a web-based platform. The study area covers the estuarine region in the Love River system in South Taiwan. The architecture of such a Decision Support System (DSS) requires applying, integrating, and linking the web-enabled database management system (DBMS), Internet Geographic Information System (IGIS), and two types of calibrated and verified water pollution simulation models, including Storm Water Management Model (SWMM) and the Lover River Hydrodynamic and Water Quality model (LRHWQ). It utilizes user-supplied data, user-supplied tool, and user-supplied model for on-line and web site decision analysis. For satisfying the goals of sustainable management in a regional sense, the functionality of such DSS in totality could eventually lead to justify the correlated events, including the proper distribution of population density, the land-use pattern in urban planning, the control of point source discharge, the deployment of main trunk of sewer, and even the protection of source water for recreational purpose.

METHODOLOGY

Recent Advances of Web-based Information Technology

In view of various users located at distant sites, the idea of using the Internet as a communication mechanism could be the most competent solution to achieve the remote integrated assessment. Since World Wide Web (WWW) is evolving as a major component among the Internet applications for information storage, sharing, and retrieval, the proposed web-enabled DSS is comprised of IGIS, DBMS, and several types of modelling analysis, such as simulation model, statistic model, optimisation model, and knowledge base model. Figure 1 represents a schematic diagram of this web-enabled DSS.

Nowadays, many database systems have been developed for public environmental information management on the web-based platform. For example, Boston and Stockwell (1994) described that a WWW service provided by the Australian Environmental Resources Information Network (ERIN) may support people to easily access key environmental information for various applications. Without burdening end users with installing too complicated and expensive software, an Internet GIS enables equivalent geographic data manipulations by simply using web browsers via Internet to make data query, data acquirement, and data analysis. To achieve this functionality, the AutoDesk MapGuide$^{®}$, a client-side Internet GIS framework, has been chosen to implement the geographic information display function owing to its excellent performance in presenting real graphic data and database connection.

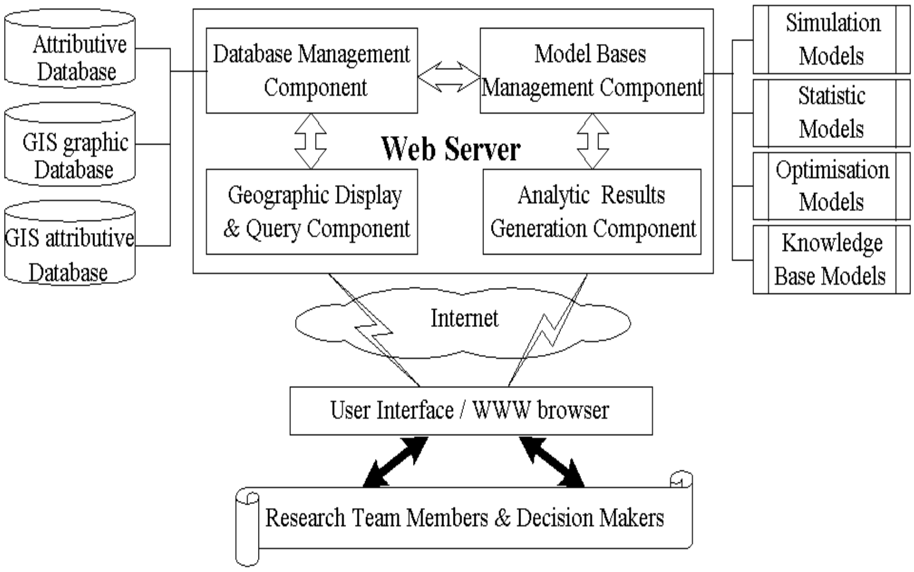


Figure 1 The schematic diagram of the DSS

In general, most state-of-the-art web-enabled databases are operated in a four-tier architecture environment to complete data transaction and query (see Figure 1). In terms of collecting and sharing attributive data to assist in decision-making, a client-server DBMS over a network environment with two-way interaction between the users and the system would be necessary. Remote users may use web browser to send requests through HyperText Transfer Protocol (HTTP) to a web server, and then get back these requests by the way using Common Gateway Interface (CGI) resulted in a script running on the web server. The script, such as ColdFusion®, Active Server Pages® (ASP), PHP®, and Perl®, deals with Structured Query Language (SQL) generation, which embeds users' requests of data manipulation. Finally, this application server routes the request to a DBMS and model base to actuate an integrated analysis, which generate a result set and sends it back to the user as the HTML document. The decision support routine mainly involves the techniques of data exchange through the Web. Currently there are several methods available ranging from the early direct file exchange, Dynamic Data Exchange (DDE®), Object Linkage Embedded (OLE®), and the recent developed Distributed Component Object Model (DCOM®) and Common Object Request Broker Architecture (CORBA®) techniques.

Study Area and Database Design

Kaohsiung City, located in the southwest part of Taiwan, is a rapidly growing international harbour and business centre. With an area of 154 sq km and a total population of approximately 1.5 million, the Love River, originated from the Kaohsiung County and destined to the Kaohsiung Harbour with a length of about 15 km (see Figure 2), provides the most beneficial area for sightseeing in this city. Both the harbour and the Love River regions, however, have long been polluted due to the discharge of untreated sewage and storm water overflow. As a consequence, various scales of environmental monitoring programs in this area have been undertaken by different governmental agencies for a decade, in which the parameters of concern are composed of pH, DO, BOD, SS, and temperature. A thorough survey in conjunction with environmental and biological sampling and assessment in several companion studies would enable us to provide vital information in the web-based DBMS. Table 1 summarizes the all the data sources that characterize environmental information in this system.

SWMM and LRHWQ Modelling Analyses

Modelling analysis essentially performs the core function of a DSS, which help users foresee the decision-making problem. The users may decide their desirable scenarios through web-based videoconference in terms of model inputs. The server site would support data query and model processing, and present outcome with user readable format, such as HTML file for remote users.

This analysis integrates the capacity of SWMM and LRHWQ as a whole to simulate the distribution of DO concentrations in the Love River in the presence of storm events selected. Figure 3 depicts the flow chart of such integration. Both models are calibrated and verified by the authors in two companion studies (Chen, J. C. et al., 2002a, 2002b). SWMM 4 is public domain software that can be run in personal computer. But PCSWMM 2000, a new version distributed by Computational Hydraulics Int. (CHI), owns a friendly interface based on SWMM modules. Calibration and verification of SWMM would require proper cooperation between the above two software programs.

Table 1 The environmental information around Love River

Site	Meteorology	Water quality monitoring	Storm run-off sampling	Fish catching
G1			■	
G2			■	
G3			■	
G4			■	
R1		◎		◇
R2		◎	■	◇
R3		◎	■	
R4		◎	■	◇
S1		◎		
S2		◎		
F				◇
M1	★			
M2	☆			
M3	☆			

★ : The official meteorological data consisting of rainfall, tide, wind, temperature, etc. (The average value at one hour) (National Weather Bureau, Taiwan)

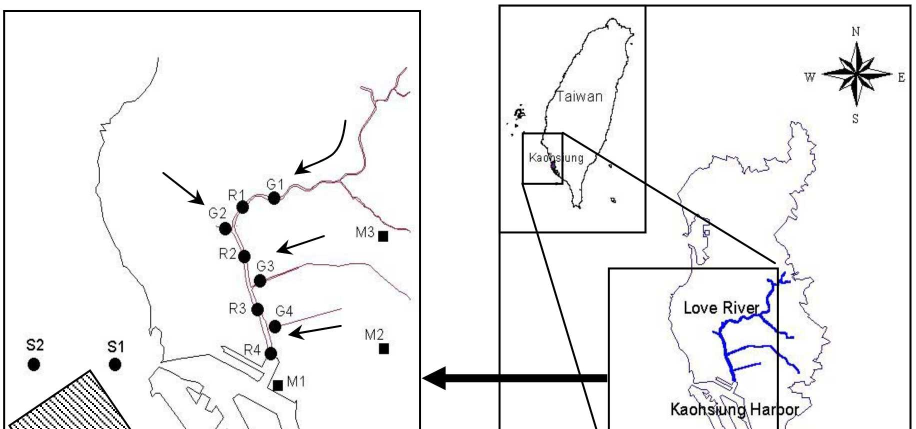
☆ : The rainfall record (storm events) (NCKU, Taiwan)

◎ : The water quality monitoring around Love River (EPA, Taiwan). (2-3 times/ month)

■ : The storm runoff (NCKU, Taiwan). (an intensive sampling of 3 hours after storm)

◇ : The fish catching (NKIMT, Taiwan). (1-2 times/ month)

Four sub-models of SWMM 4 for the subcatchments of G1, G2, G3, and G4, where the main gates of intercept system of Love River are located, were organized respectively in the beginning. With the aid of a shell of PCSWMM 2000, the calibration and verification of these sub-models become remarkably easier. After adjusting the key parameters, such as the width, the area, the length, the slope, and the impervious portion of subcatchment, to reach reasonable agreement between the simulated and observed data in PCSWMM 2000, the modelling outputs can be stored as a specific format of input file of SWMM 4. Two main source files, consisting of 'Mkrain.for' and ' Prpoll.for' in SWMM 4 are significant for web-based application. The former may provide the capacity of defining the rainfall pattern via the wed browser. The latter may produce the outputs that are composed of the runoff flow rate and the contaminant's concentrations that will be taken as the inputs in the subsequent LRHWQ modelling analysis.



LRHWQ is a 2-D lateral-integrated numerical pollution model. The simulation analysis of LRHWQ model include 42 river reaches, in which reach lengths were fixed by 100 m and each reach was partitioned into 6 layers in vertical direction. The sources of pollutants discharging into the river were assumed only from four main gates: one upstream flow (G1) and three lateral inflows (G2, G3, and G4). The hydrodynamic characteristics, including the velocities and elevation at each reach, can be calculated by a momentum equation:

$$\frac{\partial \bar{u}}{\partial t} + \bar{u}\,\frac{\partial \bar{u}}{\partial x} + \bar{v}\,\frac{\partial \bar{u}}{\partial z} + g\left[\frac{\partial \zeta}{\partial x} + \alpha(z+\zeta)\frac{\partial \bar{C}}{\partial x}\right] = \frac{1}{w}\,\frac{\partial}{\partial z}\left(w\,\varepsilon\,\frac{\partial \bar{u}}{\partial z}\right) - \frac{1}{w}\,\frac{f}{8}\bar{u}\,\left|\bar{u}\right|\left(\frac{db_1}{dz} + \frac{db_2}{dz}\right) \qquad (1)$$

where $\bar{u}$,$\bar{v}$ mean the average velocities in x- and z- directions (m s^{-1}); b_1,b_2 are the side length of river bank (m); ζ is the variance of elevation (m); w is the river width (m); z is the river depth (m); α = the coefficient of salinity (ppt^{-1}); ε_z means the eddy viscosity in z direction (m^2s^{-1}); f is the coefficient of friction (unitless); g is the gravity acceleration (m s^{-2}); $\bar{C}$ means the average concentration of pollutant (g m^{-3}). As a result, the water flow rate and elevation at each river reach may be figured out while the tidal effect has defined.

Mass balance principle must be taken into account in the estimation of water quality over river stretch. In addition to the inherent effect of advection and dispersion, the non-conservative water quality parameter, such as DO, may be reduced due to biochemical degradation and increased due to reaeration. The governing equation pertaining to mass balance relationship for a water quality constitutes is expressed as follow:

$$\frac{\partial\left(w\,\bar{C}\right)}{\partial t} + \frac{\partial\left(w\,\bar{u}\,\bar{C}\right)}{\partial x} + \frac{\partial\left(w\,\bar{v}\,\bar{C}\right)}{\partial z} = \frac{\partial}{\partial x}\left(w\,K_x\,\frac{\partial \bar{C}}{\partial x}\right) + \frac{\partial}{\partial z}\left(w\,K_z\,\frac{\partial \bar{C}}{\partial z}\right) + w\,P + \frac{QLP}{\Delta x \Delta z} \qquad (2)$$

where P means sink and source (g m^{-3} s^{-1}); QLP is the pollution loading from lateral discharge of sewage (g s^{-1}) ; K_x, K_z are the dispersion and turbulent diffusion coefficients in the axes x and z respectively (m^2s^{-1}).

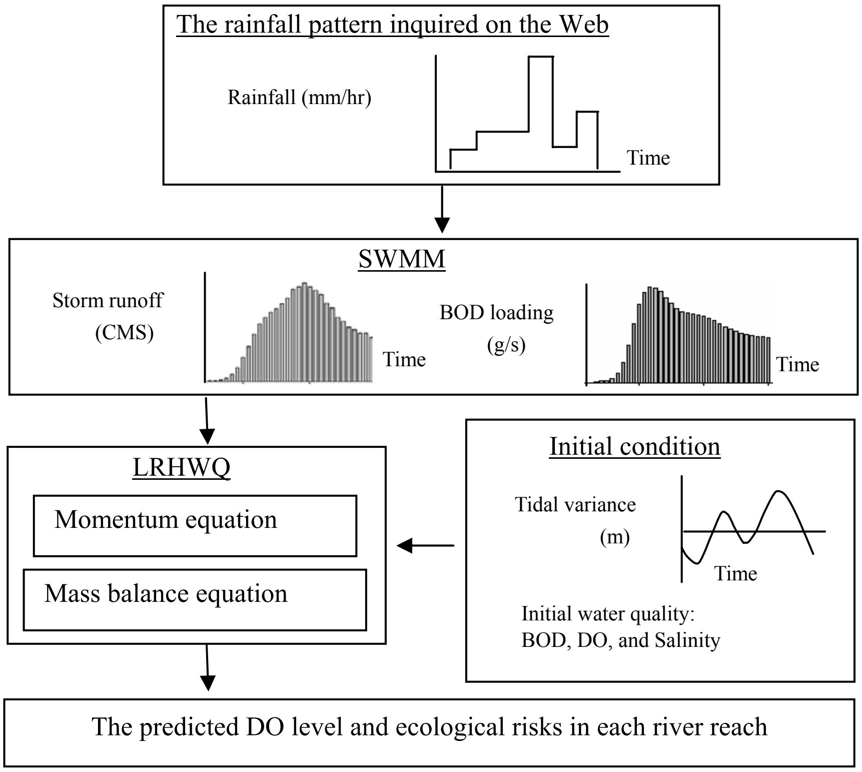


Figure 3 The flowchart of model integration

Finally, the integrated modelling analysis is capable of providing DO and BOD concentrations at any river reach dynamically on one hand and the possible flooding impact along Love River corridor if release is not allowed on the other hand. Ecological risk assessment would be performed in terms of harmful and lethal criteria with respect to the fish community. The decision-making in this regard could be analysed and inquired on the Internet Geographic Information System.

Decision Support System

The demand for rapid processing of information under urgent constraints of water environment in emergency situations of combined sewer overflow requires a dynamic operating environment for emergency planners or managers who bear legal responsibility for the protection of life and property in their society. A computer-assisted DSS may allow the user to explore a real-time problem in an on-line environment, develop a mutual understanding of its complexities in decision-making, and find a set of acceptable solutions quickly and correctly for those emergency events.

Figure 4 illustrates the design architecture of this web-based DSS in which the ASP script deals with Structured Query Language (SQL) generation, which embeds users' requests of data manipulation, and respond spatial information using MapGuide® as a tool. When receiving a remote job, the application server routes the request to a DBMS and model base to actuate an integrated analysis, which generate a result set and sends it back to the user as the HTML document. The decision support routine mainly involves the techniques of data exchange through the Web. However, a web-based share-vision DSS may provide more fascinating functionalities. Such a web-based share-vision DSS can be viewed as a joint cognitive decision-making process supported by an open-ended, interactive, and automated computer environment. Thus, this IGIS-based DSS is designed to assist management personnel (e.g., the city mayor, governor, or regional public officers) who are responsible for handling real-time large-scale flooding events and for initiating essential operational actions. In this DSS, two types of simulation exercises, that have been developed, combined, and applied cohesively, for capturing emergency features can be performed. One is the SWMM system that applies a standard rainfall/run-off model utilized for evaluation of storm events; the other is the LRHWQ system constructed by the authors for water quality management in the estuarine region.

IGIS-based graphic displays are prepared for the visual presentation of the selected and designed evaluation process. Operational parameters that are essential for assessment are collected in use-friendly interfaces as detailed as possible. In several cases, breakdown tables must be used to display a long parameterization process if necessary. Therefore, the using of graphic displays may support quick evaluation of process and parameter selections in an interactive manner. Several partially superimposed windows are designed to facilitate interrelated messages within the same system. Overall, as shown in Figure 5, the remote users may actuate an assessment and query activities at the front, and a server or several servers may receive and respond message at the end. It describes that the current version of this software owns the following functionalities:

- Store and classify the pollution information and accept various types of queries from remote users in the Internet system,
- Allow users to specify different assessment scenarios and assign various parameter values interactively on web site,
- Provide calculations of storm impact and Simulate the pollution of CSO on web site,
- Simulate the DO levels in the river reaches on web-site,
- Display the geographic information and the attributive pollution data on web-site,
- Display output data by simple tables or associated with graphics on web-site, and
- Proceed with possible selection of specific operational strategy on web-site.

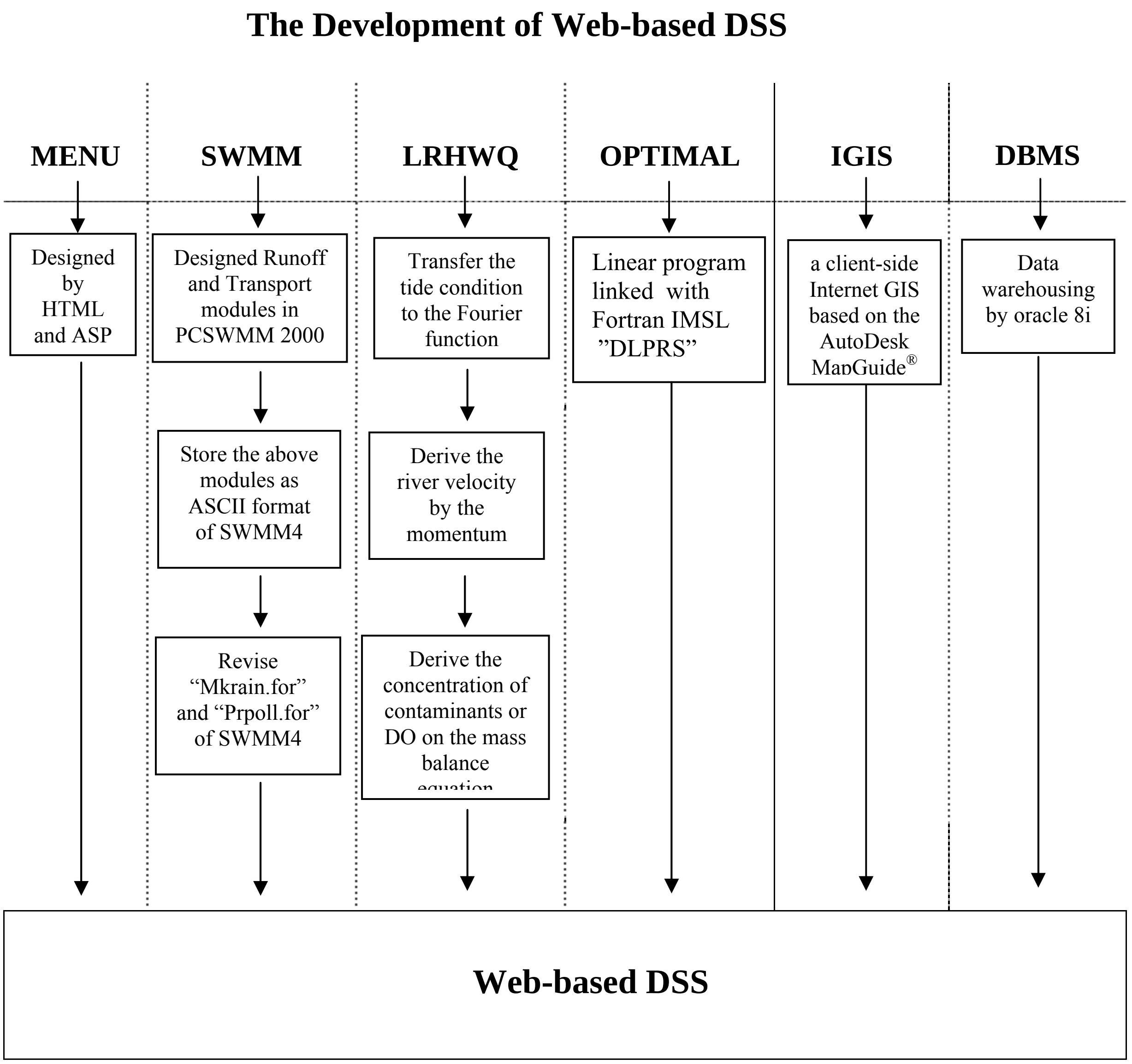


Figure 4 The design architecture of decision support system

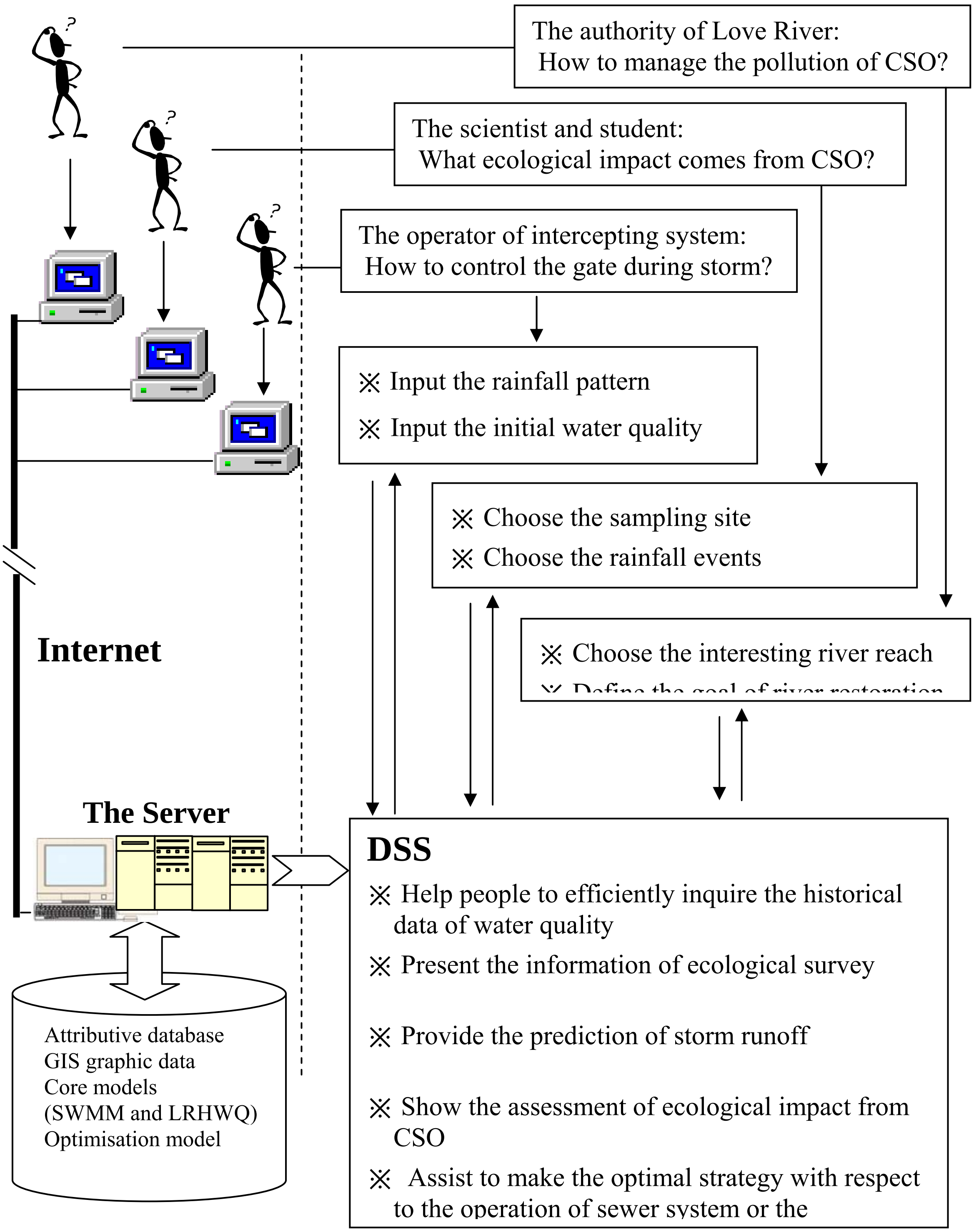


Figure 5 The application framework of decision system

The Procedure Process Flow of Web-based DSS

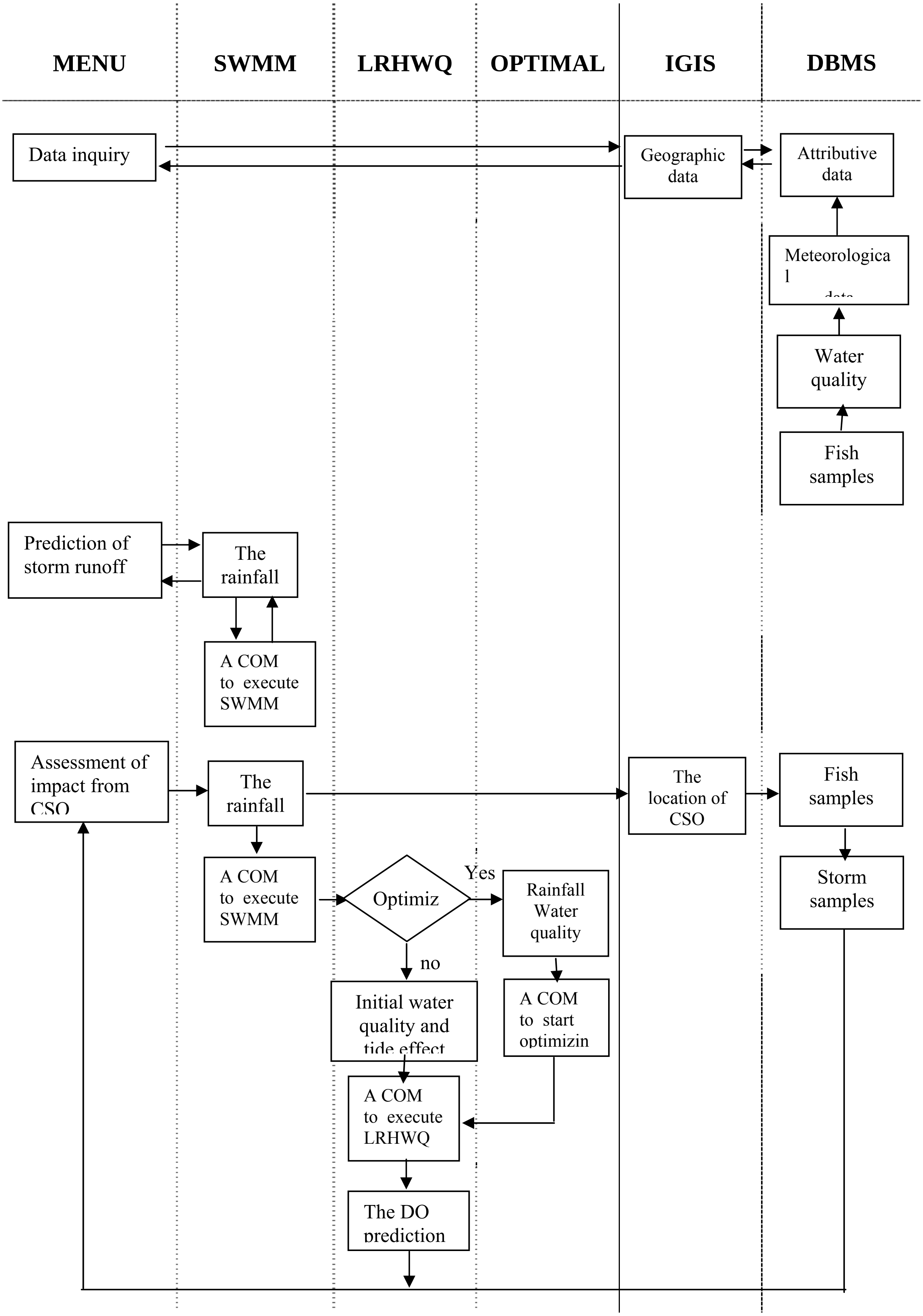
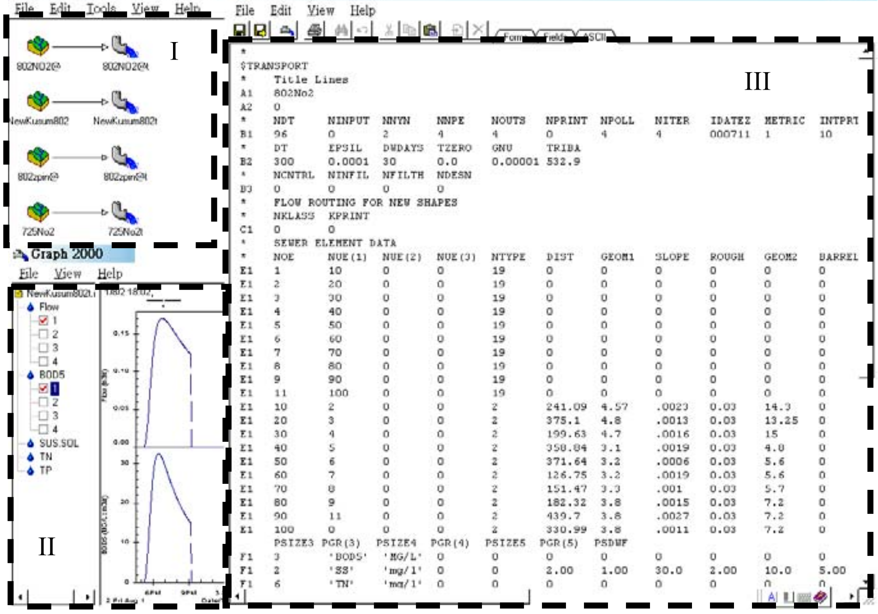


Figure 4 The flow chart of decision support system

RESULTS AND DISCUSSION

The Analysis in PCSWMM 2000

Figure 6 takes a snapshot of scenario planning in a storm event. The area on the upper left corner marked by (I) requires some inputs of ‘runoff’ and ‘transport’ processes with respect to each subcatchment considered. Calibration and verification of the SWMM practice can be accomplished immediately when those outputs present themselves on the lower left corner marked by (II). Finally, those information can be recorded and saved as an ASCII file as shown in the area marked by (III) for use as inputs in the subsequent LRHWQ modelling analysis. Figu al strategy.



```
*
$TRANSPORT
*    Title Lines
A1   802No2
A2   0
*    NDT      NINPUT  NNYN    NNPE    NOUTS   NPRINT  NPOLL   NITER   IDATEZ  METRIC  INTPRT
B1   96       0       2       4       4       0       4       4       000711  1       10
*    DT       EPSIL   DWDAYS  TZERO   GNU     TRIBA
B2   300      0.0001  30      0.0     0.00001 532.9
*    NCNTRL   NINFIL  NFILTH  NDESN
B3   0        0       0       0
*    FLOW ROUTING FOR NEW SHAPES
*    NKLASS   KPRINT
C1   0        0
*    SEWER ELEMENT DATA
*    NOE      NUE(1)  NUE(2)  NUE(3)  NTYPE   DIST    GEOM1   SLOPE   ROUGH   GEOM2   BARREL
E1   1        10      0       0       19      0       0       0       0       0       0
E1   2        20      0       0       19      0       0       0       0       0       0
E1   3        30      0       0       19      0       0       0       0       0       0
E1   4        40      0       0       19      0       0       0       0       0       0
E1   5        50      0       0       19      0       0       0       0       0       0
E1   6        60      0       0       19      0       0       0       0       0       0
E1   7        70      0       0       19      0       0       0       0       0       0
E1   8        80      0       0       19      0       0       0       0       0       0
E1   9        90      0       0       19      0       0       0       0       0       0
E1   11       100     0       0       19      0       0       0       0       0       0
E1   10       2       0       0       2       241.09  4.57    .0023   0.03    14.3    0
E1   20       3       0       0       2       375.1   4.8     .0013   0.03    13.25   0
E1   30       4       0       0       2       199.63  4.7     .0016   0.03    15      0
E1   40       5       0       0       2       358.84  3.1     .0019   0.03    4.0     0
E1   50       6       0       0       2       371.64  3.2     .0006   0.03    5.6     0
E1   60       7       0       0       2       126.75  3.2     .0019   0.03    5.6     0
E1   70       8       0       0       2       151.47  3.3     .001    0.03    5.7     0
E1   80       9       0       0       2       182.32  3.8     .0015   0.03    7.2     0
E1   90       11      0       0       2       439.7   3.8     .0027   0.03    7.2     0
E1   100      0       0       0       2       330.99  3.8     .0011   0.03    7.2     0
     PSIZE3 PGR(3)    PSIZE4  PGR(4)  PSIZE5  PGR(5)  PSDWF
F1   3        'BOD5'  'MG/L'  0       0       0       0       0       0       0       0
F1   2        'SS'    'mg/l'  0       0       2.00    1.00    30.0    2.00    10.0    5.00
F1   6        'TN'    'mg/l'  0       0       0       0       0       0       0       0
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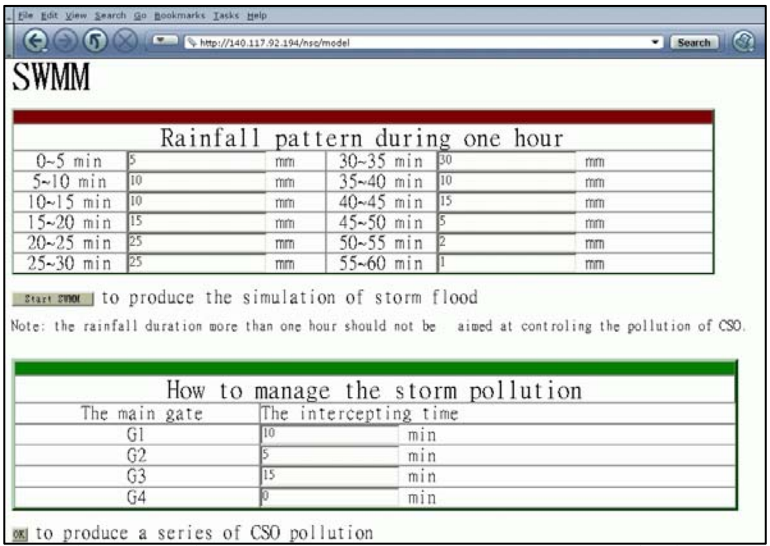
Figure 6 The user interface of PCSWMM 2000



Rainfall pattern during one hour

0~5 min	5	mm	30~35 min	30	mm
5~10 min	10	mm	35~40 min	10	mm
10~15 min	10	mm	40~45 min	15	mm
15~20 min	15	mm	45~50 min	5	mm
20~25 min	25	mm	50~55 min	2	mm
25~30 min	25	mm	55~60 min	1	mm

to produce the simulation of storm flood

Note: the rainfall duration more than one hour should not be aimed at controling the pollution of CSO.

How to manage the storm pollution

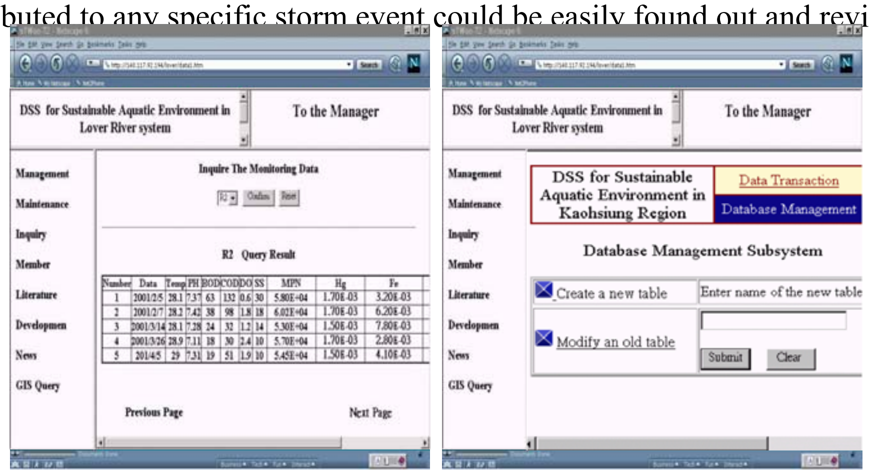
The main gate	The intercepting time	
G1	10	min
G2	5	min
G3	15	min
G4	0	min

to produce a series of CSO pollution

Figure 7 The user interface of SWMM on web site

Database Design and Management

The DSS designed for achieving sustainable management in the Love River region may support easy query of database stored for the authorized remote users. It grants part of the remote users the privilege to update their own database from distant sites. With a web browser connected to Internet, those remote users can easily create the new database or modify the existing one at any time. Therefore, the idea of using the Web-base DSS as a common information pool to track various consistent data sources is achievable. Figure 8 (a) shows how the remote users look up the environmental monitoring data sets; and Figure 8 (b) explains how to perform routine maintenance of this environmental information system. Therefore, any water quality impact associated with modelling outputs in the Love River system attributed to any specific storm event could be easily found out and reviewed.



R2 Query Result

Number	Data	Temp	PH	BOD	COD	DO	SS	MPN	Hg	Fe
1	2001/2/5	28.1	7.37	63	132	0.6	30	5.80E+04	1.70E-03	3.20E-03
2	2001/2/7	28.2	7.42	38	98	1.8	18	6.02E+04	1.70E-03	6.20E-03
3	2001/3/14	28.1	7.28	24	32	1.2	14	5.30E+04	1.50E-03	7.80E-03
4	2001/3/26	28.9	7.11	18	30	2.4	10	5.70E+04	1.70E-03	2.80E-03
5	201/4/5	29	7.31	19	51	1.9	10	5.45E+04	1.50E-03	4.10E-03

☒ Create a new table — Enter name of the new table

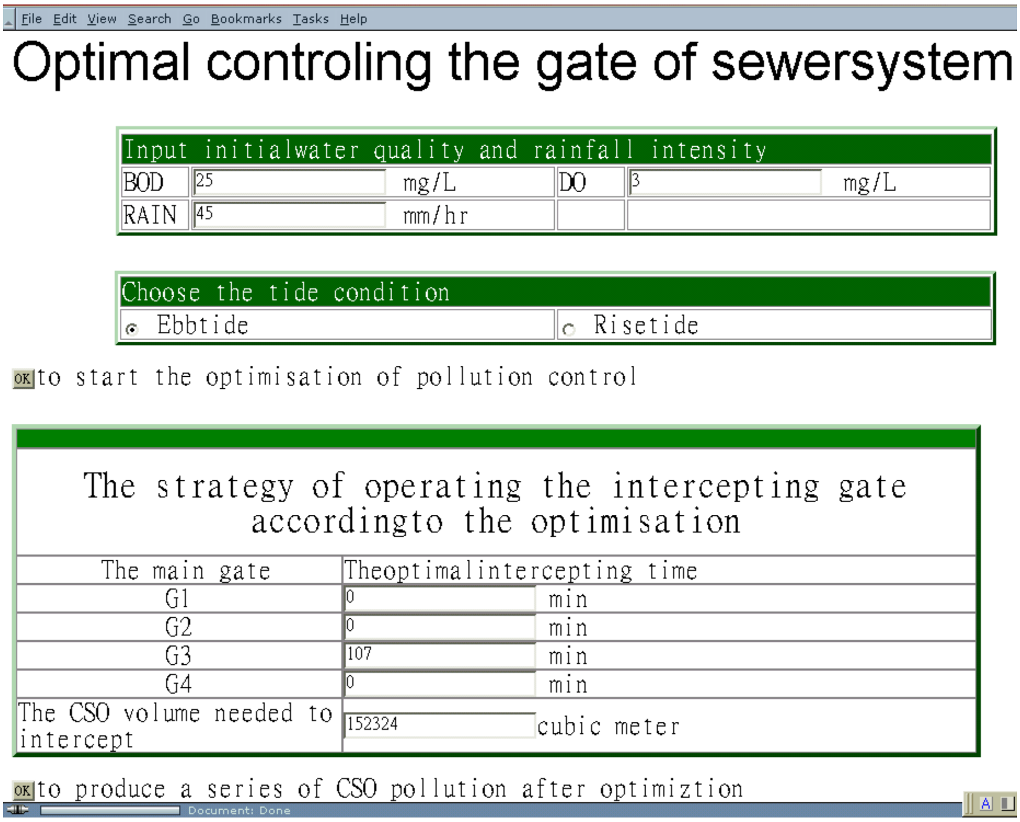
☒ Modify an old table

(a) Inquire the monitoring data (b) Maintain the information system

Figure 8 The inquiry and maintenance of database management system

Estimation of Ecological Risk in the Storm Events on Internet GIS

IGIS merits the credit to address the ecological and environmental data, such as aquatic life, environmental quality, land use, and public infrastructure, and perform a spatial analysis on a web platform. Based on the integrated modelling system of SWMM and LRHWQ, remote users would be able to share information and vision and apply hyperlink to create a desired operating scenario. Figures 9(a) and 9(b) display one scenario with the aid of AutoDesk MapGuide®.



Optimal controling the gate of sewersystem

Input initialwater quality and rainfall intensity					
BOD	25	mg/L	DO	3	mg/L
RAIN	45	mm/hr			

Choose the tide condition	
● Ebbtide	○ Risetide

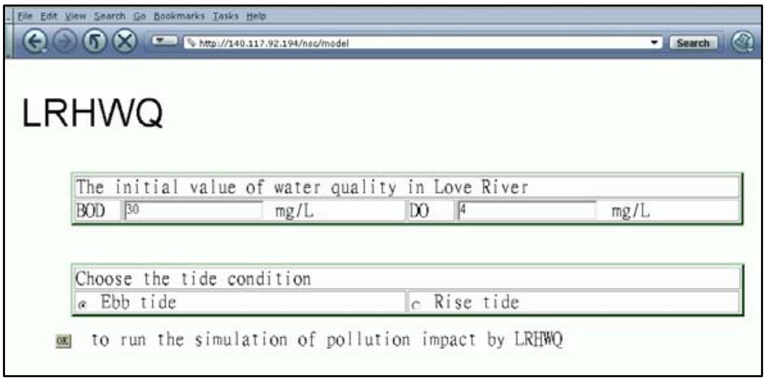
OK to start the optimisation of pollution control

The strategy of operating the intercepting gate accordingto the optimisation

The main gate	Theoptimalintercepting time	
G1	0	min
G2	0	min
G3	107	min
G4	0	min
The CSO volume needed to intercept	152324	cubic meter

OK to produce a series of CSO pollution after optimiztion

Optimization



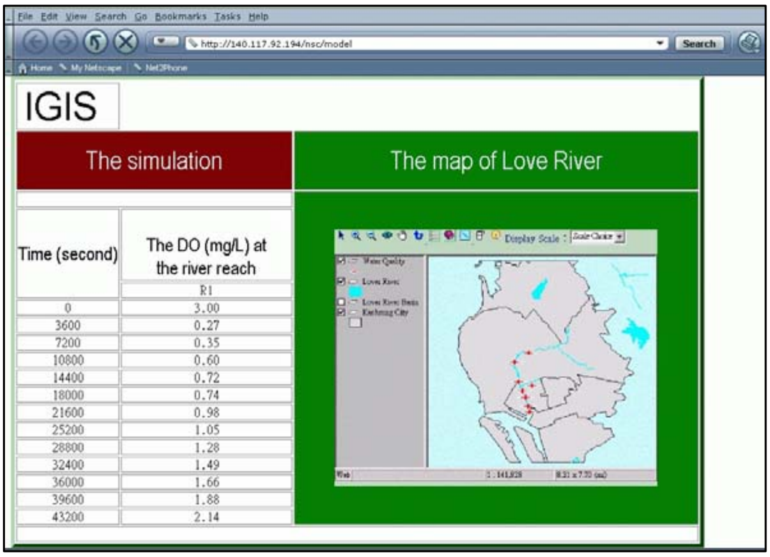
LRHWQ

The initial value of water quality in Love River
BOD 30 mg/L DO 4 mg/L

Choose the tide condition
● Ebb tide ○ Rise tide

OK to run the simulation of pollution impact by LRHWQ

(a) Define the operating scenario



IGIS

The simulation

Time (second)	The DO (mg/L) at the river reach
	R1
0	3.00
3600	0.27
7200	0.35
10800	0.60
14400	0.72
18000	0.74
21600	0.98
25200	1.05
28800	1.28
32400	1.49
36000	1.66
39600	1.88
43200	2.14

(b) Estimate the storm impact

Figure 9 Ecological risk assessment on IGIS platform

In a storm event, decision maker can see the on-line information on the web platform to ensure that the estimated DO level at any location and time should not be smaller than the desired DO level in all river reaches from a ecological sense. If the ecological risk does exist anywhere in the estuarine system, emergency response actions might include applying the optimal operational strategy of gate in the intercept system, sending residual storm water to a temporarily storage pond, and implementing an emergency bypassing operation in the coastal wastewater treatment plant.

CONCLUSIONS

This study serves as a pioneering work of share vision modelling analysis via the use of web-based platform. By means of properly sharing information, vision, and modelling outputs among different stakeholders and decision makers, such as port authority, river authority, city government, and Environmental Protection Administration (EPA) in central government, a more efficient emergency management action is achievable in response to mitigating possible ecological risk in the estuarine rehabilitation process. The inclusion of a high level modelling analysis, such as optimisation analysis, could be a valuable work in the future.

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on sustainable infrastructure systems. Candidates with research interests that are relevant to intelligent, cost-effective, damage-tolerant, and environmentally friendly infrastructure systems will be considered.

advanced instrumentation and sensors, and information technology with sustainable infrastructure systems