Design and Implementation of a Web-Based Flood Simulation and Decision Support System

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Abstract: - Flood is one of the most important natural disasters affect China greatly, especially for southeast cities. To help mitigate the loss brought by it, technologies such as simulation, visualization, decision support system, etc. could be utilized in the process of emergency management for city flood. Thus the Flood Simulation and Decision Support System (FSDSS) comes into being. It is an integrated decision support system that consists of sub-systems corresponding to most of the important parts of city flood emergency management, which include rainfall telemetry, flood forecasting, flood dispatching, flood visualization, resource deployment, disaster evaluation and so on. And it aims at providing information, tools, and solutions for the decision-makers during the whole process of city flood emergency management. This article describes the architecture, functions, implementation and construction of FSDSS in details and in the end an application case of this system in the city of Shenzhen is talked about.

Key-Words: - Flood simulation; Decision support system; Visualization; Web service; Flood Forecast; Flood Dispatch; Web-based

1 Introduction

Flood is one of the most important natural disasters in the world. To mitigate the loss and relieve the sufferings brought by flood, various technologies have been utilized to provide information and help make decisions during the process of flood emergency management which includes sub-processes such as rainfall telemetry, flood forecasting, flood dispatching, resource deployment, disaster evaluation and so on. Among these technologies, flood simulation and decision support system (DSS) are of great importance.

Applications of simulation technology cover a wide range in flood filed, from flood forecasting [1, 2, 3, 6, 11, 12], flood dispatching, flood routing, flood visualization, etc. By using some hydrological or hydraulic models, either statistical or numerical ones, and some given conditions and parameters, future situations can be figured out and presented to decision-makers in a visual way. Meanwhile, these simulations are often integrated into DSS systems as important modules to be more convenient for users. When running the DSS system to get support, the decision-makers only have to input some parameters and make some choices between items the DSS given, and need not to know the computational details.

A number of DSS systems for flood control have been provided in the world-wide scope. For example, the flood-warning decision-support system for Sacramento, California [1] increased warning lead time, thus providing an opportunity to reduce damage and save lives; Koussis et al. [2] presented a system of flood forecasts for urban basin with integrated hydro- meteorological model, which was proved to be a promising tool for forecasting flood risk in the Kifissos basin, Athens. These DSS systems contribute a lot to flood emergency management, both in research and practice, but they have a common shortcoming[3], which is that they are all standalone information systems, and geographically dispersed people and departments can not share information and cooperate with each other to accomplish decision tasks for flood control. The development of web and distributed computing technologies cast a light on this problem [4, 5].

This paper presents an integrated and web-based decision support system for flood control, which is Flood Simulation and Decision Support System (FSDSS). It aims at providing information, tools, and solutions for the decision-makers during the whole process of city flood emergency management, and includes several sub-systems such as rainfall telemetry, flood forecasting, flood visualization, flood dispatching, resource deployment, disaster evaluation and so on. The architecture of FSDSS is discussed in details firstly in this paper, then the implementation and construction, and finally, a case study of FSDSS application in the city of Shenzhen is also presented.

2 System Architecture

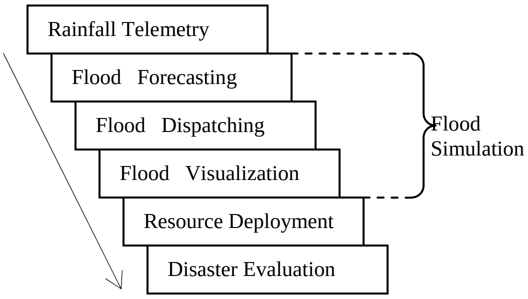

Fig.1. General logical framework of FSDSS

According to its business flow, FSDSS can be divided into 6 sub-systems as shown Fig.1. Actually, the logical relationship between these sub-systems is not just as simply sequent as the figure shows. For example, the forecasting flood can be visualized directly, and need not pass the dispatching step. Meanwhile, Disaster Evaluation can be accessed both before and after Resource Deployment, and is named Pre-evaluation and Post-evaluation separately. These details of business logic will be mentioned in the following paragraphs of this article.

The architecture of FSDSS is shown in Fig.2. It consists of five parts, including client, web server, application server, database and rainfall telemetry. Since the client and web server is quite common and simple, the other 3 parts are laid emphasis on here.

2.1 Application Server

It is the kernel part of FSDSS. The shell of FSDSS application, i.e. the user interface part is established on it. Major modules such as Flood Forecasting, Flood Dispatching, Flood Visualization, Resource Deployment and Disaster Evaluation run on it in the form of Web Services, too, and it is the same with some basic and supportive functions such as UDDI service. Application server is not necessarily a single computer physically but might be a group of computers that work together collaboratively like a single computer in logic view.

2.2 Databases

Databases here include the Real-time Rainfall Database, DSS Database and Spatial Database. The first one is used to store the real-time rainfall data from the gauged stations in the Real-time Rainfall Telemetry Sub-system. It is a basic database for the following flood simulation and decision support modules, and is read-only for them to keep rainfall data safe and primitive. The DSS Database and Spatial Database are used together to help accomplish flood simulation and decision support work, the difference between them is that the former one store the spatial data for example map layers, and the latter store the common attribute data like tables. These two databases are both readable and writeable for FSDSS system.

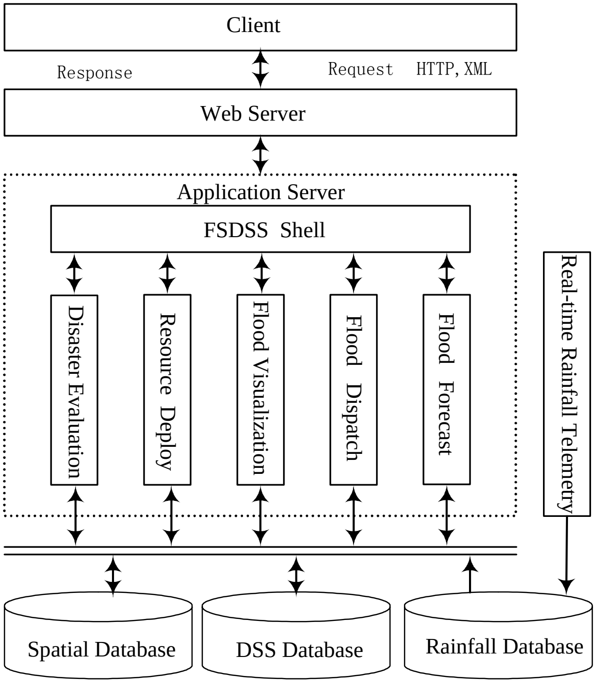

Fig.2. System Architecture of FSDSS

2.3 Rainfall telemetry

It is a sub-system mainly consists of rainfall gauged stations, central station and communication devices. Gauged stations acquire rainfall data periodically through instruments and transfer them to the central station. The central station receives the data via antennae, recodes them and stores them into the Rainfall Database.

In a rainy season, Flood Forecasting is executed periodically. If the forecasted hydrograph reaches some given values, an emergency response will be started. During the course of this response, the decision-maker can see the visual process of the forecasted flood, then dispatching the flood water by open/close a certain floodgates according to the solutions provided by FSDSS. And also he can see the visual process of flood after dispatching. With the help of Flood Dispatching and Visualization, and

Disaster pre-Evaluation, the decision-maker plots a resource deployment schema map with the tools provided by FSDSS, and hands it out to the emergency response forces as a basis or reference. After the flood, post-evaluation is executed to help with the relief work.

In all of above steps, when the decision-maker requests a decision-support task through the client, which is a browser, the request is received and then passed to the application server by the web server. Then the application server provokes the application shell of FSDSS. The shell collects related web services either in the same computer or distributed, accesses appropriate data from databases, then achieve an outcome by running those web services, and finally returns it to the web server to display through the browser.

3 System Construction

Both ASP.NET and COM technology are used in the construction of FSDSS. And ArcObjects, the famous GIS component libraries from ESRI Company, are also utilized here to complete spatial-related functions. The application shell of FSDSS is programmed with ASP.NET technology in C# language. Major modules such as Flood Forecasting, Flood Dispatching, Flood Visualization, Resource Deployment and Disaster Evaluation are programmed separately into COM components using VC++.NET and then published as web services on the UDDI server to be provoked by the application shell. Thus we can make use of the flexibility and convenience of C#, the power of ASP.NET in web presentation, and the efficiency of C++ in executing and processing basic tasks.

All the communications in the system are carried out by standard web protocols such as HTTP, XML, SOAP, WSDL, and UDDI and so on. For the database platform, Microsoft SQLServer 2000 is chosen, and ESRI ArcSDE is used as spatial data engine.

3.1 Flood Forecasting

Flood forecasting refers to the estimation of likely stream flow resulting from an actual storm and made during the course of that storm [6]. This sub-system aims at forecasting hydrographs or flow volume of some given sites the decision-makers care about. These sites are usually characteristic sites or control sites of a specific catchment, for example the entrances to reservoirs. The forecasted flood data can be directly shown in the form of curves and also can be used as input of Flood Dispatching or Flood Visualization for following uses.

The need for flood forecasting resulted in the development of the Antecedent Precipitation Index (API) method of estimating the start of surface runoff from storm rainfall [7]. API model is usually combined with UH to calculate rainfall ~ runoff through the catchments. The UH is defined as the hydrograph of surface runoff resulting from effective rainfall falling in a unit of time such as 1 hour or 1 day, and distributed uniformly in space and time over the total catchment's area [8], and it has been widely accepted for its efficiency and effectiveness in rainfall ~ runoff computation. Here in FSDSS, a 6 hour UH derived from historical data provided by the Rainfall Telemetry, is used to calculate runoff using the effective rainfall obtained from the API model. API is calculated on a daily basis and assumes that soil moisture declines exponentially when there is no rainfall, while the coefficient K differs for each month in a year. The formulas and other related content about API model can be acquired from [7] and [9].

3.2 Flood Dispatching

This sub-system provides solutions in regulating let-down flow rate and setting floodgate openness and pump number for reservoirs to escape from the flood peak and mitigate loss when there is forecasted flood.

All kinds of flood dispatching are based on the theory of water balance. In FSDSS, the process of flood dispatching simulation is shown as the flowchart in Fig.3. Forecasted flood hydrograph is used as input, and it is the same with reservior water level from Telemetry Sub-system, and the reservior capacity curve from previous references, etc. to calculate the let-down flow rate (V_0) on condition that the gate is fully open. Meanwhile, the safe pass-through flow rate of down stream (V_{max}) is put into FSDSS, and compared to V0, then we get the value of maximal let-down flow rate Q, as the expression below shows,

$$Q=\left\{\begin{matrix} V_{max} & (V_0 > V_{max}) \\ V_0 & (V_0 \le V_{max}) \end{matrix}\right\} \tag{1}$$

Then the openness of the gate can be acquired from the empiristic relations between openness and let-down flow rate acquired from historical records. Descriptions above might seem to be a little simple, but more details are not permissive and necessary here.

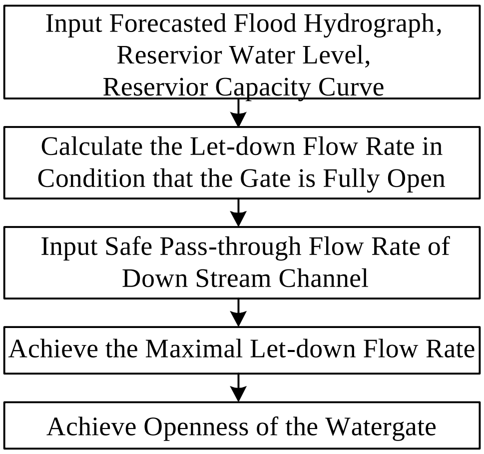

Fig.3. Flowchart of Flood Dispatching Simulation

3.3 Flood Visualization

This sub-system uses ESRI ArcGIS Scene Control to present a 3D scene for the process of flood development in a reservoir, show the change of submerged area, and provide visual decision tools for the decision-makers.

At first an original 3D scene of the reservoir is constructed with Scene Control using 1:1000 Digital Elevation Model (DEM) data as framework and 0.61m Quickbird remote sensing image as surface texture. To make it more vivid, some fine ground objects are modeled using 3D MAX, for example some buildings.

Then the forecasted or dispatched flood hydrograph is load into this sub-system to be compared with the DEM data. If the water level is lower than the elevation of the reservoir, nothing new will come into being. And if the water level is higher than the elevation of reservoir, a water surface will be created and put on the reservoir. Because the water level is changing during the process of the flood, the created water surface is elevated up and down, thus realizes the process of flood submergence.

It should be noted that this sub-system is not just for show or a qualitative tool; it is also able to provide quantitative support. Actually, the process of the visual presentation could be paused at any time, and create a 2D submerged area map for the Disaster Evaluation Sub-system to calculate the possible loss at that time.

3.4 Resource Deployment

After acquiring the data, hydrographs and visual scene of the forecasted or dispatched flood, the decision-maker might have formed a resource deployment plot in his head for flood control. To help him bring an ideal blueprint into a computerized plot, Resource Deployment Sub-system works.

This sub-system provides a base map of the concerned area and a symbol library for flood control resources, including warehouse for flood control resources, rescue people, residence of rescue force, rescuing route, escaping people, escaping route, refuge site and so on. With their help, the decision-makers can create a resource deployment map for the task force, and then flood control could be executed on this basis or reference.

A computer-automated resource deployment resolution may seem to be more advanced technically; nevertheless the solution here is proved to be more practical for use, since sometimes the decision-makers would rather believe their own heads than those mathematically optimizing models.

3.5 Disaster Evaluation

This is a tool for calculating the loss brought by the flood. If it is provoked after the ending of the flood, it is a post-evaluation, and if it is used before the flood begins, it is named a pre-evaluation, while used in the process of flood development it is called mid-evaluation. That’s to say, it can be used at any time when the decision-maker want to evaluate the loss of a potential or actual flood, given that the submerged area data can be acquired.

Disaster Evaluation is built on the ArcObjects component library, just the same with the Resource Deployment Sub-system. In this sub-system, the submerged area map provided by Flood Visualization is overlaid with basic spatial data, such as building distribution data, thus create a new map of submerged building, then the system read the building attribute data from the database, for example the insurance data, and get the total insurance of the submerged buildings.

With the method above, many kinds of evaluations can be done, given that there is appropriate and enough attribute data of the submerge area. But actually mass valuable data of these kinds is not quite easy to acquire.

4 Application

The city of Shenzhen is located in the coast of South China Sea along Guangdong Province, neighboring the Hong Kong, SAR on the south. It is the first Special Economic Zone in China. Shenzhen’s climate is of the sub-tropical maritime type, with an average temperature of 22 centigrade and an average rainfall of 1837mm one year [10]. Since Shenzhen is subject to typhoons in the rainy season and rainfall here is quite asymmetrical both spatially and temporally, flood control is a vital matter.

Buji River is the most important river for flood control in Shenzhen, because its watershed is the largest one among the total 9 rivers of Shenzhen, and it flows though an important trade and economic zone named Luohu Community. Meanwhile, historical flood records are abundant here. So we choose the area of Buji River watershed as study area, Fig.4 shows its location.

The Sungang Reservior and Luohu Community are the most important sites concerned. The former has a floodgate named Sungang Gate at its exit and is used to regulate flood; the latter is both an important business zone and a low-lying area vulnerable to flood.

While implementing FSDSS here, we first calculate the runoff flow into the Sungang Reservior with rainfall data from gauged stations named Dafen, Buji and Caopu, as is shown in Fig.4., using Flood Forecasting. The outcome is hydrograph as Fig.5 shows. Then the let-down flow rate and gate openness is calculated using Flood Dispatching. Both of the two sub-systems can provide data to Flood Visualization to see the forecasted or dispatched flood visually, as is show in Fig.6.

After visualization, the submerged area map is acquired, and then Disaster Evaluation can be executed, thus a submerged building map is accomplished after GIS overlaying. Because the submerged area is much more obvious in the Luohu Community than the Sungang Reservior, a submerged map of Luohu Community is shown here other than Sungang Reservior (Fig.7.). And it is the same with Resource Deployment, as shown in Fig.8.

Fig.4. Study Area

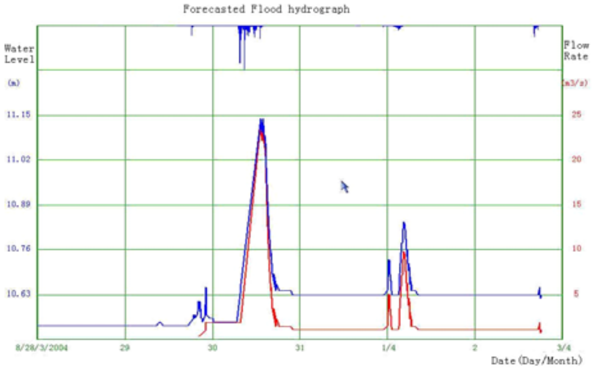

Fig.5. Forecasted Runoff Flow into Sungang Reservior

区域切换: 笋岗滞洪区

当前时间: 2005-5-15 10:15:00

当前水位: 5.386

说明: 笋岗滞洪区位于布吉河中游段，东西两侧为洪湖路和洪湖西路，南北两侧为泥岗路和笋岗路。防洪设计标准为50年一遇，可将洪峰流量469m3/s削减为250m3/s，设计洪水位11.3m（水位7m以下为死库容，黄海高程），相应库容250.6万立方米。对笋岗滞洪区的调度包括规则调度、补偿调度两种基本类型。本模块提供特定调度方案的笋岗滞洪区内洪水的演进情况。

Fig.6. Flood Visualization

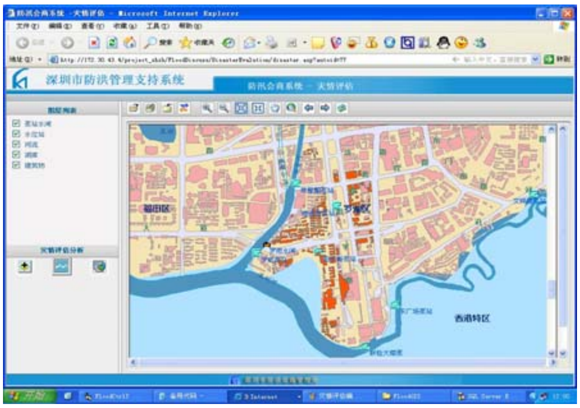

Fig.7. Disaster Evaluation

Fig.8. Resource Deployment

5 Conclusion

Flood suffers people greatly, and the loss brought by it can be enormous. So technologies should be utilized to mitigate the loss and suffering to the minimal extent. Simulation and DSS technologies applied in this filed can model the forecasting, dispatching, visualization of flood and provide data, tools and solutions for reference. This article not only carries out these steps just mentioned, but also establishes a web-based information system using ASP.NET, Web Service and ArcObjects to make those functions more convenient and practical for decision-makers to use in a distributed information environment, which agrees with the demands of customers. And at last an application case in Shenzhen is talked about.

In spite of the achievements mentioned above, lots of problems are still to be solved. Firstly, the architecture and performance of FSDSS should be considered together to make further improvements. If the system is totally constructed of Web Services, the performance especially the calculating speed might be a problem. So, FSDSS uses published COM components as Web Services to compromise between performance and architecture in order to realize a Web-based simulation and decision support system. This has left a large space for further considerations and attempts. At the same time, for the complexity of decision problems, to provide good support for decision-makers is not an easy matter. In the process of flood simulation and decision support, lots of those steps including resource deployment, disaster evaluation and so on, are semi-structured or even non-structured decision problems that should introduce into the idea of decision-makers themselves; other steps, for example flood forecasting and flood dispatching, seems to be structured and easily resolved in a mathematical way, but the reality is that there are enormous amount of new models emerging endlessly, and you must choose the one suites to your specific sites and conditions, in addition the precision and reliability problems last forever. These two aspects remind us that there are still lots of work should be carried on in the field of flood simulation and decision support for flood emergency management.

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