Development of A Real-Time Rainfall Monitoring and Flood Warning System

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Abstract

Since the courses of the rivers and creeks in Taiwan are short and steep, the process from the beginning of rainfall to the occurrence of inundation is quick accordingly. Furthermore, typhoons and severe storms in summer and fall seasons frequently result in serious floods in the alluvial plain located around the midstream and downstream of a basin. Although government agencies and the public can acquire rainfall tendency based on weather forecast issued by the Central Weather Bureau, the inundation zones and depths are not available for planning on flood mitigation. If, however, the hazard mitigation agencies have known in advance the rainfall tendencies of areas within their jurisdictions and retrieve the relevant inundation potential maps in a case-based reasoning fashion to match with the real-time rainfall patterns, people can be given advance warning to prepare for or evacuate from a flood. Currently, a collaborative project for planning and developing a rainfall monitoring and flood warning system has been undertaken by research teams of the National Science and Technology Program for Hazards Mitigation (NAPHM). The inundation potential maps, real-time rainfall data, and rainfall forecasting model are integrated into a whole system jointed with spatial information technologies and decision support systems for hazards mitigation. This automatic and real-time system is aimed at reducing the losses caused by flood and inundation.

Keywords: Rainfall Forecasting Model, Inundation Model, Geographic Information System, Flood Warning System, Decision Support System.

Introduction

Since the courses of the rivers and creeks in Taiwan are short and steep, the process from the beginning of rainfall to the occurrence of inundation is quick consequently. Besides, typhoons and severe storms in summer and fall seasons frequently result in serious floods in the alluvial plain located around the midstream and downstream of a basin. Although government agencies and the public can acquire rainfall tendency based on weather forecast issued by the Central Weather Bureau, the inundation zones and depths are not available for planning on flood mitigation. If, however, the hazard mitigation agencies have known in advance the information, i.e. the inundation potential, within their jurisdictions, the regional flood mitigation plans can be made.

The flood mitigation research team of the National Science & Technology Program for Hazards Mitigation (NAPHM) endeavors to analyze and produce the inundation potential maps of the entire Taiwan area based on hydrological models, and will complete such tremendous task until 2001 (Hsu *et al.* 1998). By giving the rainfall data, these maps provide useful information for prediction of inundation zones, which can be further utilized for flood mitigation, emergency response, as well as standard operation procedures. In conjunction with the real-time rainfall data provided by the Central Weather Bureau, an advance warning for evacuation can be issued ahead of the coming of a severe storm.

Accordingly, the information system research team of the NAPHM has collaborated with the other ones to undertake the development of a real-time rainfall monitoring and flood warning system. The inundation potential maps, real-time rainfall data, and rainfall forecasting model are integrated into a whole system jointed with spatial information technologies and decision support systems for hazards mitigation. This

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automatic and real-time system is aimed at reducing the losses caused by floods and inundation.

Planning

1. System Framework

On the basis of the framework made by the NAPHM, the research works on typhoon prevention comprise three aspects: meteorology, flood mitigation, and debris flow mitigation, as shown in Figure 1 (Yen *et al*, 1997). The dash line delineates the main body of the system, which is also a part of the decision support system for flood disaster management. The system provides a real-time and automatic data process flow to significantly simplify tedious jobs. In the mean time, intelligent extraction and identification of inundation zones facilitate the decision process in an electronic manner. The results can be efficiently applied to the other decision support systems for further uses. This paper thus emphasizes on planning and implementation of software system.

Like common spatial decision support systems (Sauter 1997, Malczewski 1999, Sun *et al.* 1999), the system consists of five fundamental components: database, model base, spatial information technologies, intelligent algorithms, and graphic user interface, as illustrated in Figure 2. The database stores all relevant data and supports potential analysis and scenario simulation using appropriate models from a model base. The simulation results combine with spatial information technologies and some optimization algorithms to generate an optimal solution for decision support. A successful design of graphic user interface not only seamlessly integrates these components into a software package, well-designed human-computer interface also provides an interactive mechanism for the users to evaluate the solution by giving a specific set of parameters. Simulation visualization may be a strong demand as well. Figure 3 demonstrates the automatic work flow of the system, including two kernel models, i.e. rainfall forecasting model and inundation model, which will be described in detail in the following sections.

2. Real-time Rainfall Monitoring Data

To clearly know the spatial and temporal patterns of rainfall distributed over a watershed, the first two important tasks for this system to work are continual acquisition of real-time rainfall data by way of network communication and rainfall forecast of the next 1~3 hours. For the purpose of rainfall monitoring, the system will integrate real-time rainfall data from rain gauge stations belonging to the Central Weather Bureau, the Water Conservancy Agency of Ministry of Economic Affairs, and the local government. As for the quantitative rainfall forecast, the statistical model for typhoon rainfall prediction derived by Wang (1983, 1985) is employed in this system. In this model, the estimated hourly typhoon rainfall at one location is simply regarded as a function of topography, the location and track of typhoon center. The historical data indicate that typhoons occurred within the region ranging from longitude 117° to 129° east and latitude 19° to 28° north would normally influence rainfall patterns over watersheds. Hence, this rectangular region is selected for study, as shown in Figure 4, and is divided into 108 squares with one degree per square. Each one is further divided equally into 4 small cells, and thus totally 432 cells are obtained. After statistical analysis, such as average, standard deviation, maximum, and minimum values of rainfall, for each cell, the rainfall prediction diagram for each rain gauge station can be generated for future uses if typhoon track is given. Figure 5 shows an example of the rainfall prediction diagram. The system also provides a calibration mechanism using real-time rainfall data to increase the accuracy of prediction. In combination with hourly rainfall data, the animation of 1~3 hours rainfall forecast benefits storm tracing. Given a scenario that a storm occurs over an upstream of a watershed and then causes flood around downstream area after a while, usually 3~4 hours in Taiwan, the system will be able to provide advance warnings for flood disaster preparedness, so as to reduce possible losses.

3. Inundation Potential Data

Thus far, the flood mitigation research team of the NAPHM has concrete results to be integrated into the system. Numbers of inundation potential maps covering western Taiwan have been generated. This belt region includes Keelung City, Taipei City and County, Taoyuan County, Hsinchu County, Yunlin County, Chiayi County, Tainan County, and Kaohsiung City and County. The resolutions of inundation potential maps are 120× 120 meters for Taipei City and County, 40× 40 meters for Keelung City, and 200× 200 meters for the rest of counties. Figure 6 gives an example of the inundation potential map.

The so-called inundation potential means a possible inundation caused by rainfall under a specific condition of existing drainage systems. For the computation of inundation potential, the mountain runoff model is adopted for the upstream of a watershed to calculate the runoff discharge caused by design storm, while 1-D river steady flow model and 2-D non-inertia wave overland-flow model are applied for the midstream and downstream areas to simulate river flow and surface overland flow, respectively. Besides, the river stages are included as the boundary conditions of surface overland flow outlets (Hsu *et al.* 1999).

Online simulation directly using the inundation model, however, is time-consuming and not able to provide real-time flood warning. Consequently, numbers of simulations with different conditions of rainfall and flood drainage systems should be done in advance to establish databases of inundation potential maps for different areas. Therefore, the function of flood warning can be achieved by extracting the total rainfall of a specific area from the rainfall monitoring data and by querying the corresponding inundation database. Figure 7 illustrates the work flow of the system, and can be divided into two parts. The major work for flood mitigation is to keep simulating different scenarios; while retrieving inundation maps for advance warnings is necessary if heavy rains or storms occur.

The limited number of inundation potential maps stored in the database may not be able to match with all of the cases. The problem can be solved in a case-base reasoning fashion by using back-propagation neural network to identify the most similar cases in the database. This type of neural network is commonly used as a learning algorithm, and has been successfully applied to many fields, such as pattern recognition, data classification, adaptive control, noise filtering, data compression, and expert systems (Zurada 1992). Overall, its merits are accurate learning , capable of handling complex problems, and fast recall. The network consists of three layers: input layer, hidden layer, and output layer. The input layer is used for the input parameters, and the number of neurons depends on the problem size. Taking the system as an example, the input parameters include total rainfall, gate stage, pumping station capacity, river stage, reservoir outflow, etc. The hidden layer takes care of the interaction among the input neurons, and the output layer shows the target data, i.e. inundation potential maps in this application.

Implementation

1. Database Establishment

One of the most important tasks in the development of this system is to establish and maintain a complete database. A variety of data used by the system can be roughly categorized as four classes: geographic data, attribute data, real-time monitoring data, and derived data for decision support. Basically, both the geographic and attribute data come from National Geographic Information System. The real-time monitoring data reflect the circumstances of rainfall, water conservancy facilities, and flood drainage systems. To support information for decision making, some kinds of derived data are essential, such as disaster potential maps, open spaces, shelters, etc.

2. Data Communication

To acquire real-time rainfall data, the point-to-point meteorological information service system provided by the Central Weather Bureau (1999) is adopted currently, while the data from recording rain gauge stations belonging to the Water Conservancy Agency of Ministry of Economic Affairs, and the local government will be integrated together in the near future. To utilize this information service system, it is required to install a small software package and set up parameters for automatic dial-up. The computer can then fetch the data periodically via a modem and along a phone line. The data are collected from more than 320 rain gauge stations throughout the island and sent in ASCII format to the users. Flood monitoring data, such as gate stage, pumping station capacity, river stage, and reservoir outflow, will be obtained in a similar way provided by relevant government agencies.

3. Software Development

As described above, such system is a part of the decision support system for flood disaster management, and will be set up in the disaster prevention and rescue command center. In order to provide the commander a whole picture when a disaster occurs, the primary functions of the system are receiving, processing, and displaying real-time data coming from different sources. Moreover, important information extracted from real-time data can be applied to the other disaster management information systems for further decision making. Accordingly, the system is designed to be automatic and laborsaving. Since the factors of compatibility, programmability, and deployment are taken into account, the system is mainly developed in MS Visual Basic and ESRI MapObjects. Auxiliary tools include MS Access, ESRI ArcView, ESRI Spatial Analyst, and Avenue scripts.

The processing procedure of rainfall data is shown in Figure 8. The original ASCII files are parsed and stored into the rainfall database to facilitate data manipulation. Different selections of rainfall data combine with geographic information of rain gauge stations to interpolate into image layer in Raster ASCII format, where the weights for interpolation have been calculated in advance. Such process significantly decreases the computation time and increases the performance of real-time monitoring of storm rains. Due to the limitation of software, the Raster ASCII files generated from the system must be converted into the GRID format in ArcView, and the newly created layers can then be efficiently used by the system. For each new data file, the system will generate 6 different rainfall duration maps with the size 222× 398 pixels. The entire process from parsing data to updating animation is fully automatic and takes less than 90 seconds on a Pentium II 400 MHz desktop computer. The performance is sufficient enough to provide real-time monitoring and the following flood warning. As shown in Figure 9, the user only needs to provide the path the real-time data reside and the time interval for receiving data, and leaves the rest to the system. Figure 10 and 11 show the monitoring system interfaces, including rainfall animation and rainfall histogram of a queried rain gauge station.

Conclusion

Due to the geographic and climatic characteristics, people in Taiwan suffer from natural disasters caused by the floods each year. In addition, overdeveloped slope lands and severe surface rupture after the devastating earthquake have become the sources of debris flow. Thus, heavy rainfalls and storms could trigger another disasters anytime. As a matter of fact, disasters could be reduced to a certain extent by taking some engineering and/or non-engineering measures. These are, however, not the absolute solutions. If, unfortunately, a disaster does occur inevitably, the only thing can do is to rely on high technology for providing advance warning and emergency response. This pilot project is aimed at developing a workable system, which requires seamless integration of different models and technologies. Most of components are close to completion and the whole system can be integrated soon. The accuracy and performance of the system should be evaluated and modified, if necessary.

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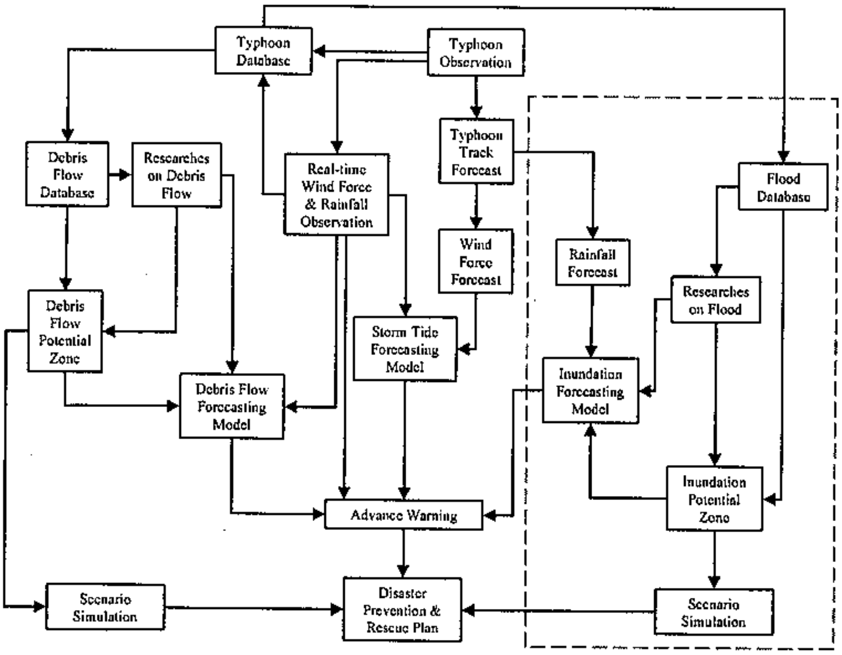


Figure 1 Framework of typhoon prevention

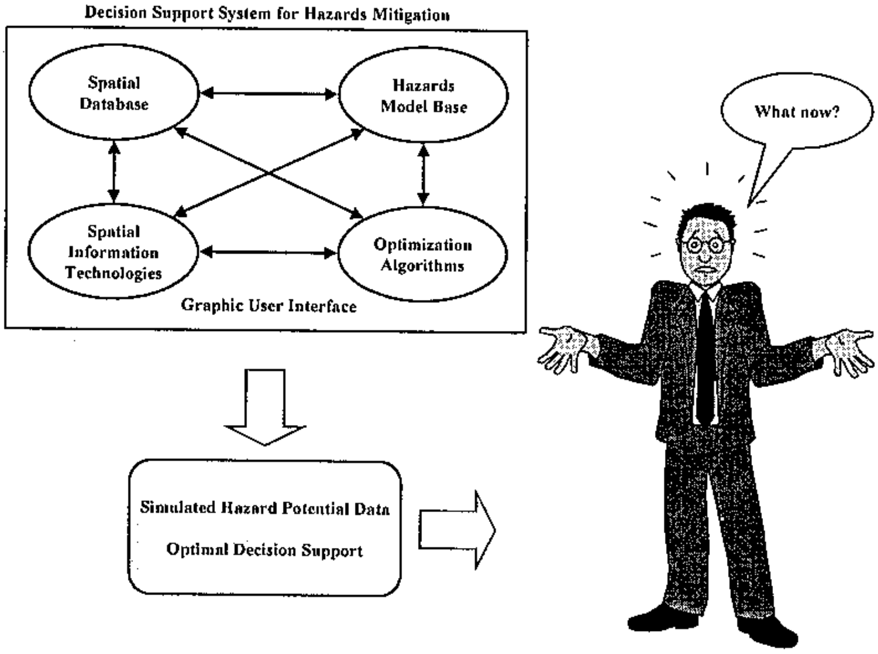


Figure 2 Framework of decision support system for hazards mitigation

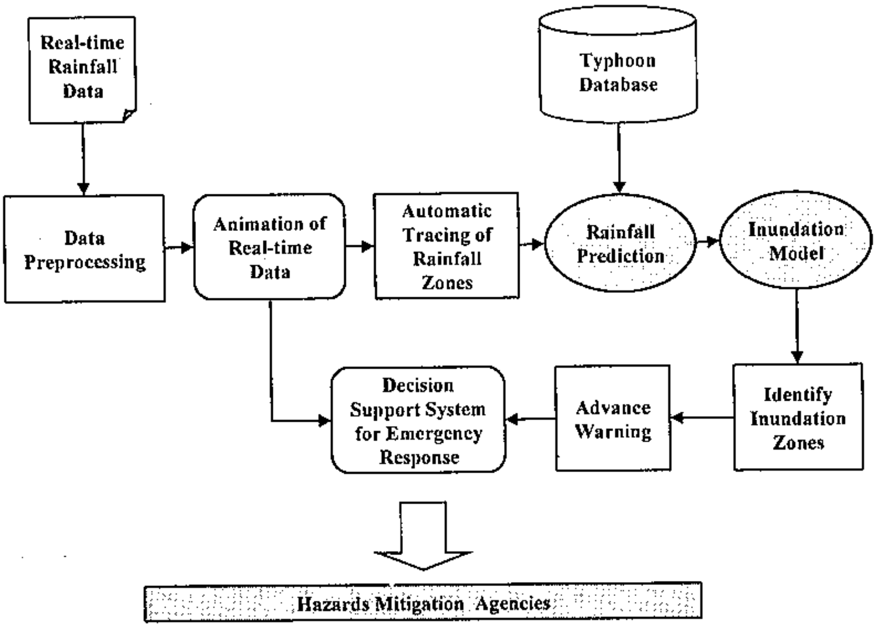


Figure 3 Overview of the flood warning system

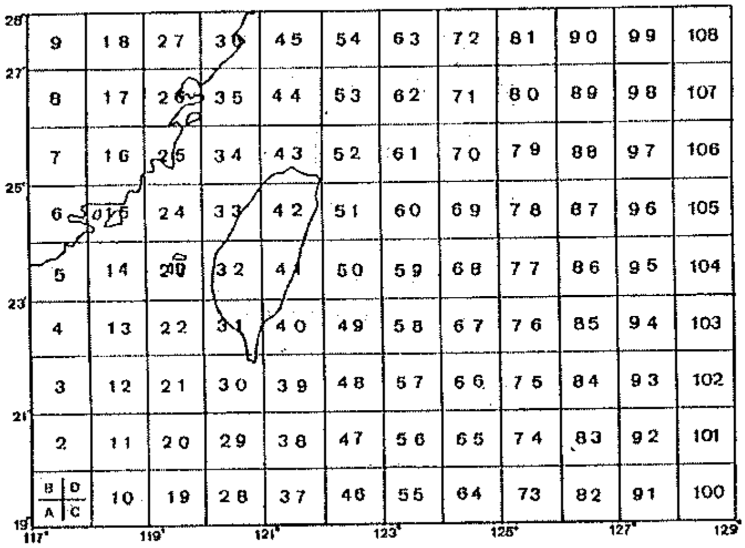


Figure 4 The influencing region of statistical rainfall prediction model

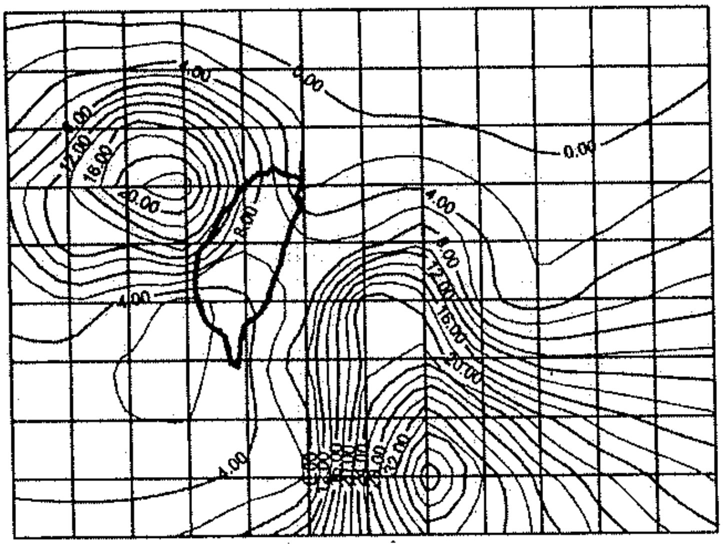


Figure 5 The rainfall prediction diagram

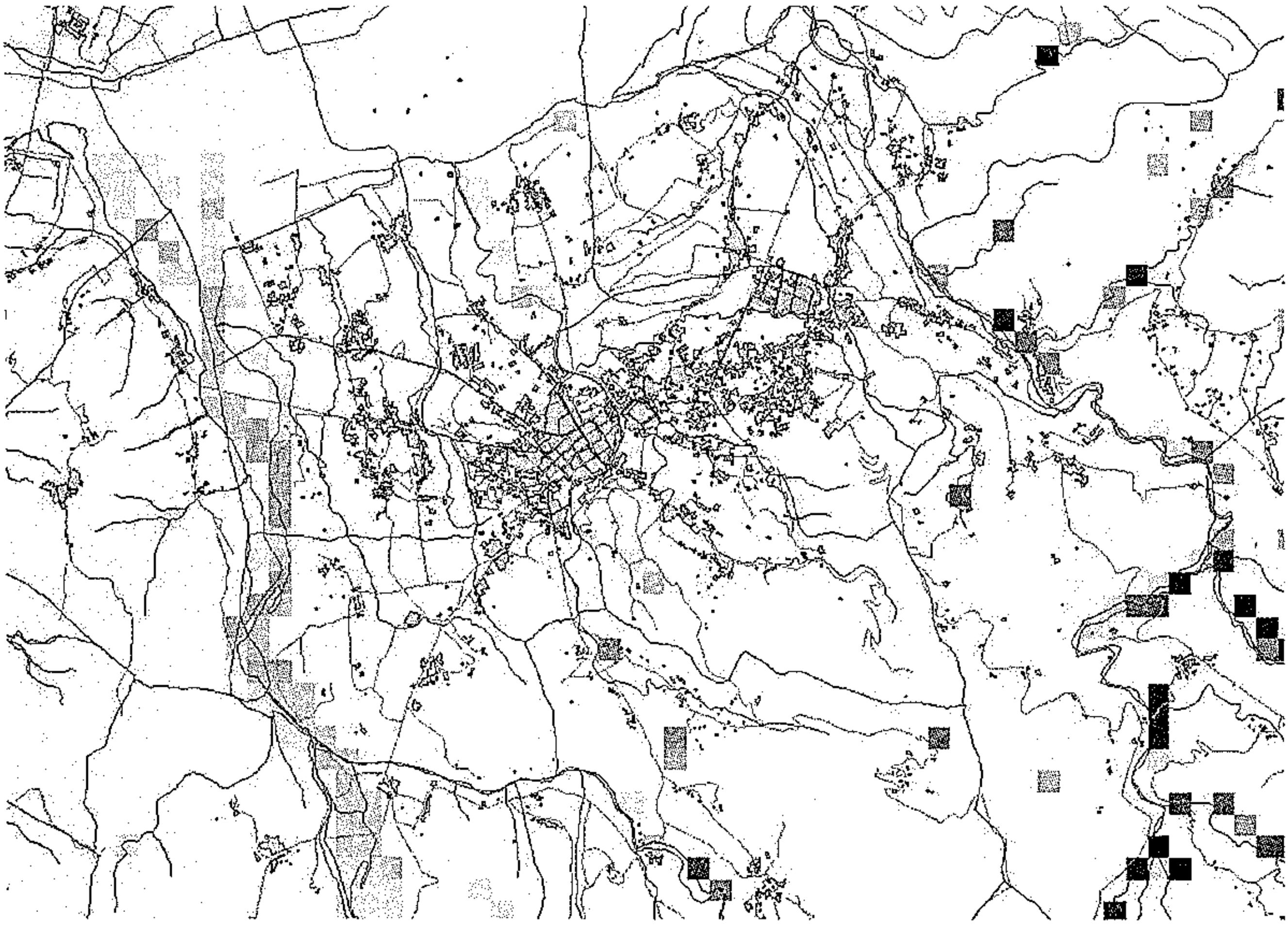


Figure 6 The inundation potential map

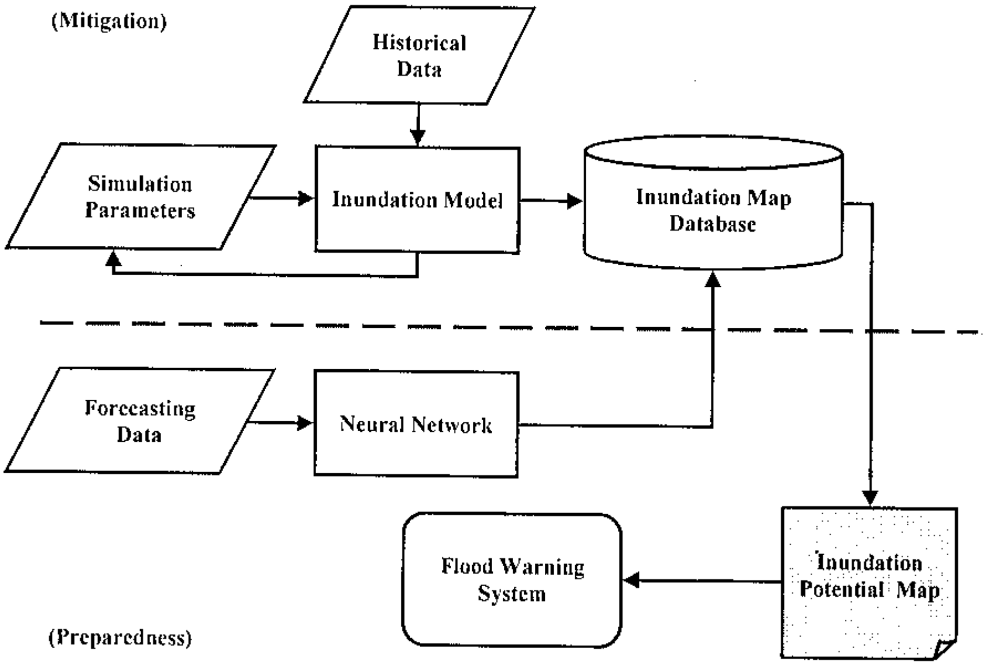


Figure 7 The work flow of inundation potential map

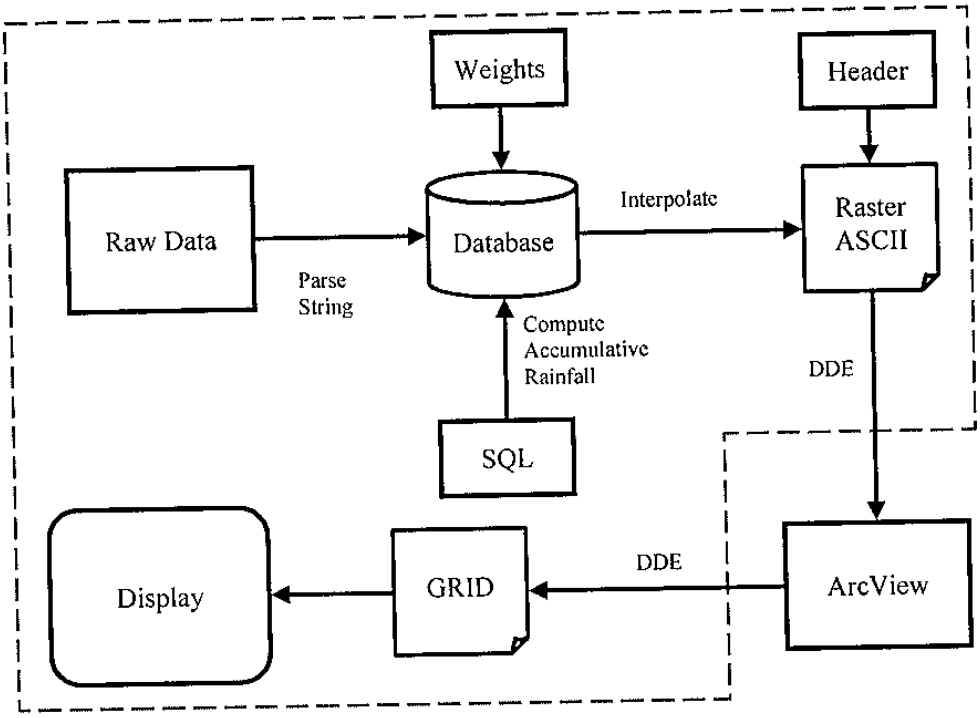
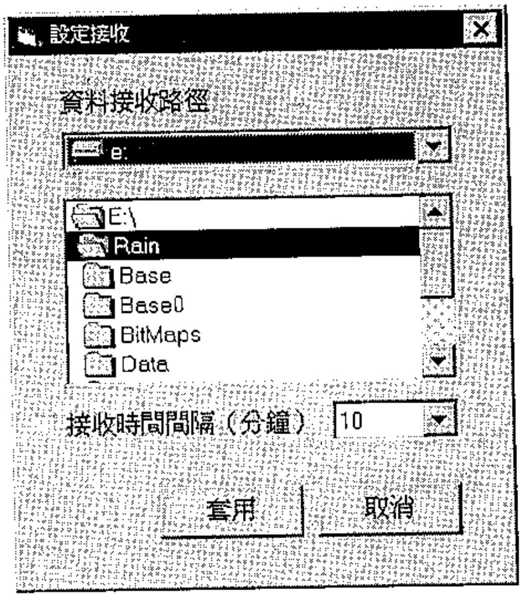


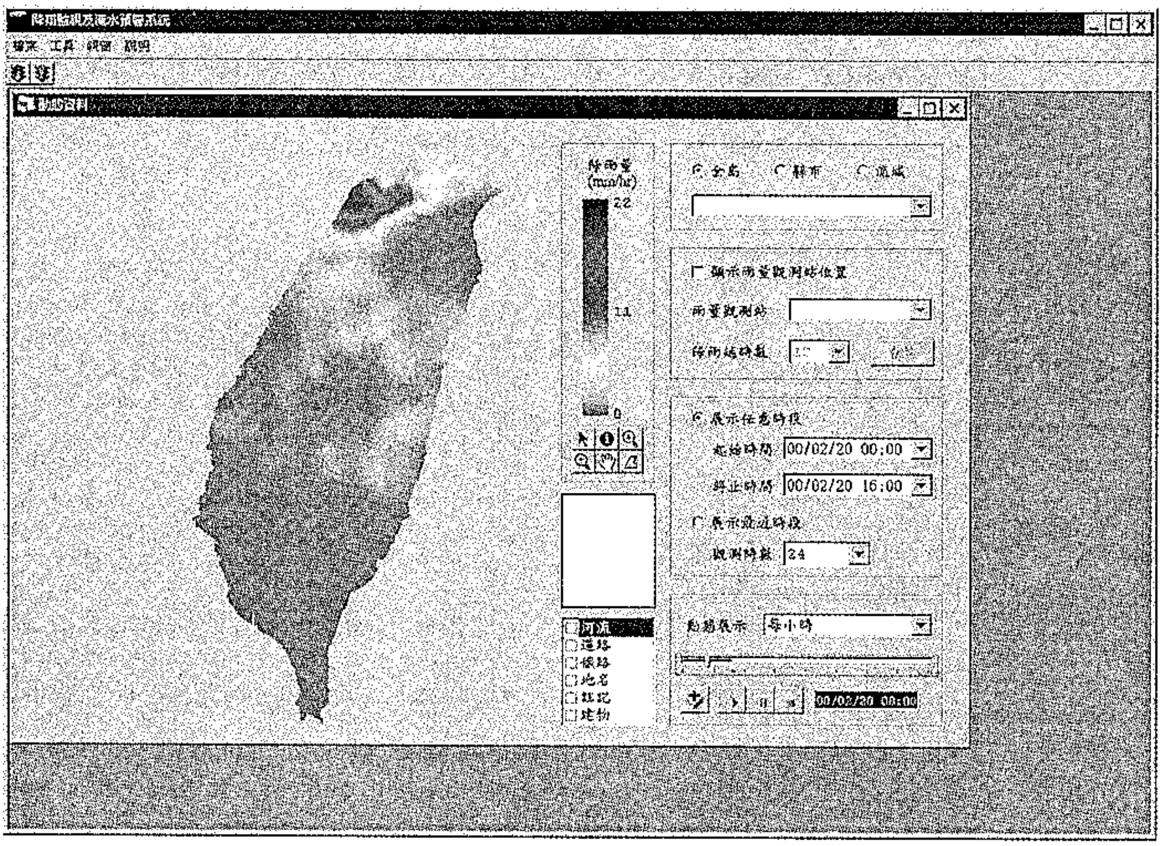
Figure 8 The processing procedure of real-time rainfall data



資料接收路徑
e:

接收時間間隔（分鐘） 10

Figure 9 Automatic processing setup



起始時間 00/02/20 00:00

終止時間 00/02/20 16:00

觀測時數 24

動態展示 每小時

00/02/20 00:00

Figure 10 System interface

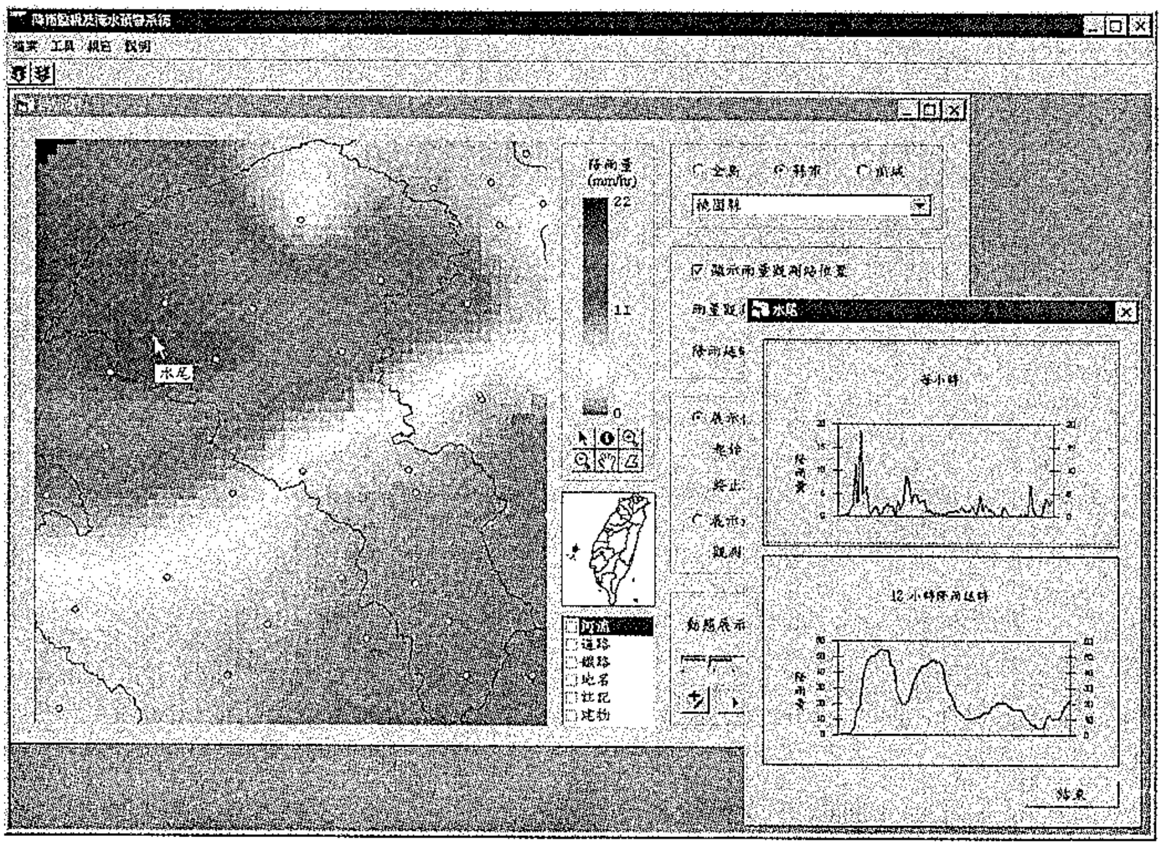


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Figure 11 System interface