AN URBAN FLOOD DYNAMIC SIMULATION MODEL WITH GIS

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ABSTRACT

An advanced model, Urban Flood Dynamic Simulation Model (UFDSM), has been developed. The UFDSM is a GIS-based distributed hydrological model, both surface flow and sewer flow are taken into account. The spatial and temporal distribution of the flooding water stage and flooding water flux are calculated. Therefore, the inundation area, flooding duration, flood hazard map, and the flood risk management can be analyzed through the UFDSM. Meanwhile, it presents the implementation of geographic information system (GIS) technology in UFDSM. It shows the steps of acquiring, storing, updating, analyzing, and displaying these data in conjunction with UFDSM. The viability of the UFDSM/GIS linkage in a microcomputing environment is demonstrated on a case study area in the Lihuahu subdivision in Guangzhou City, China.

Keywords: Urban runoff, Urban storm, Urban flood, GIS

INTRODUCTION

Right now there is a process of urbanization, especially in developing country. As a result, more and more people and properties have been concentrated in cities. Urban flood control has become a very severe problem. Urbanization has great influence on the rainfall-runoff process (Parker and Fordham, 1996). Since the increase of the impervious area and the improvement of the sewer system, the rainfall-runoff process has changed evidently: (1) runoff coefficient becoming bigger, (2) the value of flood crest becoming bigger, (3) total flood water quantity increasing, (4) flood crest occurring quicker. Meanwhile, the flood water flow has become complex because the structures and the distributions of the buildings of cities are so complicated. Therefore, we face a challenge to calculate and forecast the urban flood and disaster loss accurately and timely.

Urban Flood Dynamic Simulation Model (UFDSM) is a physically based distributed flood calculating and forecasting model (Hu et. al, 1997). The main characteristics of UFDSM are: (1) both surface flow and sewer flow have been taken into account and integrated into a coupled model, (2) the urban flood caused by either urban storm or river flood invasion can be dealt with, (3) dynamic model has been employed for both surface flow and subsurface flow, (4) the risk assessment of the flood can be carried out, (5) the flooding loss calculation and disaster mitigation measure can be conducted, and (6) the results can be applied in many aspects, such as flood hazard map, regional planning, flood disaster insurance, flood control planning, etc.
Since UFDSM is a distributed mode and has a large quantity data to be coped with and transferred, GIS is a best aided tool to achieve the model. GIS are becoming more widely used in various disciplines (Meyer et al, 1993, Leipnik et al, 1993). A GIS, Tsinghua Milestone GIS, provides the storage and preprocessing capabilities for the data needed in analysis and calculation.

**URBAN FLOOD DYNAMIC SIMULATION MODEL (UFDSM)**
UFDSM is composed of several models, which have the relationship of data connection and operation order. It is also a system combined by all models, such as infiltration model, overland flow model, channel flow model, sewer flow model, linkage model of surface flow and sewer flow, flood disaster loss calculation model, flood risk assessment model, etc. Some of the models are outlined below.

**INfiltration Model**
Usually there are sewer systems in cities, we adopt the following assumption when calculating the net rain for overland flow. When precipitation rate is less than infiltration rate, all rainfall infiltrates into soil; when precipitation rate is greater than infiltration rate, surface water occurs, but no overland flow occurs until surface water is bigger than sewer drainage capacity. The infiltration is calculated by Rechards Equation:

\[ q = \frac{D(q)}{K(q)} + (1) \]

where, \( q \) is the water content, \( D(q) \) is the water diffusion coefficient, \( K(q) \) is the water conductivity, \( t \) is the time, and \( z \) is the depth.

**Surface Flow Model**
Surface flow consists of two kinds of flows, one is overland flow, 2 dimensional unsteady flow; the other is channel flood flow, 1 dimensional unsteady flow. The dynamic model is employed either in overland flow or channel flood flow, so UFDSM is called dynamic model. Following is the introduction of overland flow, while the channel flood routing is carried out by St. Venant Equation, e.g. 1 dimensional unsteady flow. It is the same as given in sewer-network calculation.

(1) Conservation Equation

\[ \frac{\partial q}{\partial t} + \frac{\partial q}{\partial x} = 0 \]  

(2) Momentum Equation

\[ x \text{ direction:} \]

\[ \frac{\partial q}{\partial t} + \frac{\partial (q^2)}{\partial x} + g \left( q - q_{0} \right) = 0 \]
\[ \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + \frac{q}{A} + t_{xb} \frac{\partial h}{\partial x} = 0 \] (4)

where, \( u \) and \( v \) are average velocities for \( x \) and \( y \) direction, \( h \) is the water depth, \( H \) is the elevation of water surface, \( M \) and \( N \) are the flow rate in unit width for \( x \) and \( y \) direction, \( q \) is the net rain to runoff, \( t_{xb} \) and \( t_{yb} \) are the friction of the river bed for \( x \) and \( y \) direction, \( r \) is the density of the water, \( g \) is the gravitational acceleration, \( n \) is the roughness.

SEWER-NETWORK FLOW MODEL
The flow of sewer-network is quite complicated, including the open channel flow and pipe-pressure flow. These two kinds of flows are not fixed, they change their state at any moment and form a transient state sometimes. So far we have not solved the nonlinear partial differential equations for open channel flow and pipe-pressure flow simultaneously in a model, so we applied the open slot method (Preissmann, 1983) to solve the problem. It is assumed that there is an open slot in the top of the pipe, so that the pipe flow is equivalence to open channel flow, St. Venant equation given as following can be employed for both cases.

(1) Conservation Equation

\[ \frac{\partial Q}{\partial t} + \frac{\partial (QA)}{\partial x} + \frac{\partial (QA)}{\partial y} - q_i \frac{\partial h}{\partial x} = 0 \] (5)

(2) Momentum Equation

\[ \frac{\partial Q}{\partial t} + \frac{\partial (QA)}{\partial x} + \frac{\partial (QA)}{\partial y} - q_i \frac{\partial h}{\partial x} = 0 \] (6)

where, \( A \) is the area of the river or pipe section, \( Q \) is the discharge, \( q_i \) is the drainage water or lateral inflow or their summation, \( h \) is the water depth, \( i \) is the bed slope, \( l_i \) is friction slope.

LINKAGE MODEL
The connection of surface flow and sewer flow is conducted through a conceptual orifice, presenting the drainage capacity of the sewer system. The water flow direction of the orifice is determined by the water head difference between surface water and sewer water, meanwhile the flow rate is calculated by the head difference and the area of the orifice. The equation is:

\[ Q = k A \Delta h \] (7)

where, \( Q \) is the flow rate, \( A \) is the area of the conceptual orifice, \( \Delta h \) is the water head difference between surface water and sewer water, \( k \) and \( m \) are coefficients.
**TSINGHUA MILESTONE GIS**

GIS is a technological system that reflects all kinds of spatial data of the real world's state, transition and attribute information that describes these spatial data characters. It can input, output, store, search, display, analyze and be applied in certain format under the support of software and hardware. It is important to select a feasible, top-quality GIS software. For the following reasons, Tsinghua Milestone GIS Package has been chosen as the development platform of UFDSM model system:

- Fully supporting model UFDSM; compatible with UFDSM model system and also suitable for the management of other geographic maps and spatial information.
- Powerful input, output, storing, displaying and spatial analytical capabilities.
- Easy for using and convenient for GIS software second development with embedded or linked manner.
- Low cost, easy for prevalence and function extension.

Tsinghua Milestone GIS Package is composed of six separate executable program modules that are linked together through a convenient interactive menuing system. The modules are: image processing module; query module; data base management module; digitizer testing module; and spatial analysis module. Tsinghua Milestone GIS Package provides both vector and raster processing systems. This software also includes a database management module and a friendly user interface.

**MODELING SYSTEM INITIALIZATION**

The initialization efforts for modeling system should concentrate on obtaining accurate estimates of input data and parameters that appear to have the greatest impact on the modules stored in model base. The key step for doing this well is exerting GIS spatial analytical functionality and data management capacity to the most extent in mature modeling need. For UFDSM, detailed information and data sufficient for performing the GIS analysis should be acquired according to the following categories:

- Study area boundaries and constraints
- Overland slope and slope orientation
- Landuse of the all cells
- Gutter and drainage networks friction rate
- Overland infiltration rate
- Pervious and impervious area
- Structure value and property value relationships

The original data used for GIS spatial analysis can be acquired from the network with remote sensing (RS), and global positioning system (GPS) techniques. Considering the network technology not prevalent in China, and in order to extend the application of UFDSM model system, Tsinghua Milestone GIS software also allows user to digitize base maps as a collage of paper maps. The procedure for initializing model system with GIS is depicted in Fig.1.

**CASE STUDY OF UFDSM/GIS MODEL APPLICATION**

Guangzhou is a very important city in China. It is a political, cultural, business, and
economy center in southern China. Since the influence of typhoon, urban storm in Guangzhou is very severe. Moreover, the city is close to the Pearl River, river flood invasion is also a serious disaster of the city. In order to mitigate the disaster caused by water, both urban storm and river flood should be taken into consideration. The city can be divided into five subdivisions according to the distribution of artificial lake, gutter, sewer system, and the movement of the surface water. One of the subdivisions, namely Liuhuahu subdivision, is chosen as the case study area. A 100-year return-period urban storm is chosen as the typical rainfall, meanwhile the rainfall type of June 6, 1955 and sea water level of July 14, 1966 are employed in the simulation by UFDSM/GIS. Fig.2 shows the flooding area of 18 hours after the beginning of the rainfall.

CONCLUSIONS
UFDSM/GIS is a new type model to calculate and forecast urban storm water and flooding water, which has been applied primarily in some cities in China. Compared with traditional method, UFDSM/GIS is very efficient in data input, output, storing, searching, displaying, analyzing. Usually, the urban hydrological model seldom has the capability to handle a large quantity distributed data, so that hydrologists have to simplify the model and parameters. GIS is very powerful in deal with the spatial data, thus in the future GIS will play more and more important role in urban storm water management and urban flood control. Although some preparation work and pretraining have to be done in using GIS, it is worthwhile to utilize GIS's powerful functions. In the near future, one can easily get digital electronic map and database through Internet that will make it easy to apply GIS. A good GIS should finish all preprocessing work of the urban flood calculation, thus the real time flood forecasting will be more efficient and reliable.

REFERENCES


Fig. 1. Model System Initialization

Fig. 2 Flooding area of 18 hours after the beginning of the rainfall