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Simplified Flood Inundation Model Integrating with Rainfall-runoff Processes

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Synopsis

Flood hazard is the one of the most harmful disasters in the world, therefore it is significant to obtain reliable information on flood characteristics for flood hazard mitigation as well as flood vulnerability assessment. Hereby in order to obtain the temporal-spatial distribution of flood hazard vulnerability, a grid cell based simplified flood inundation simulation integrating with rainfall-runoff processes is developed in this study for flood inundation simulation of large watersheds, which is based on 1-D channel flow routing, and 2-D overland and slope flow routing simulation model. According to flood inundation simulation, flood characteristics can be analyzed, especially the flood-prone area is able to be identified and delineated. This paper describes the background of the model development and methodology.

Keywords: flood inundation, flood modeling, Geographical Information System

1. Introduction

Flood events during previous years have raised public, political and scientific awareness of flood risk and flood prevention (Becker and Grunewald 2003), and flooding threats are likely to increase given current climate change predictions. Many more intensive rainfall events happen, which suggests flooding becomes more frequent and potentially causes greater damage. As the occurrence of flood event has become common in many parts of the world, the needs to obtain reliable information on flood characteristics are increasing with the dramatically rising of people’s awareness. Whilst the increase of flood damage for singular event, partly caused by the tendency that much more people live in floodplains or low-lying areas, consequently results in society becomes more exposure to flood events.

Recently a shift in paradigms is observed from a technical oriented flood protection towards flood risk management, and the emphasis of disaster risk reduction has changed from an impacts-led approach to a vulnerability-led approach. Therefore it is necessary and significant to study on regional vulnerability for flood hazard. Consequently, in order to explore the spatial distribution of flood hazard vulnerability, a grid cell based simplified flood inundation simulation integrating with rainfall runoff processes is proposed. According to the simulation result, flood characteristics can be analyzed, especially which can identify the flood-prone area.

Various hydrologic models, especially commercial software, have been developed in the past to simulate flood inundation. In this research, physically based distributed modeling is focused for flood vulnerability assessment in watershed scale region. In addition to the development of computational capacities, Digital Elevation Model (DEM), digital data of soil type and land use classification, as well as Geographical Information System (GIS), are used for hydrologic hazard research.

2. Methodology

2.1 Description of flood inundation simulation

Distributed temporal-spatial information of flood events is of the utmost importance for flood disaster mitigation as well as for flood vulnerability assessment. A physically based flood inundation simulation model is developed in this study, which is based on simplified process representation capable of simulating dynamic flood inundation. This model consists of a one-dimensional channel flow and a two-dimensional overland flow model to enable simulation of flood water depth and hence inundation extent (Figure 1).

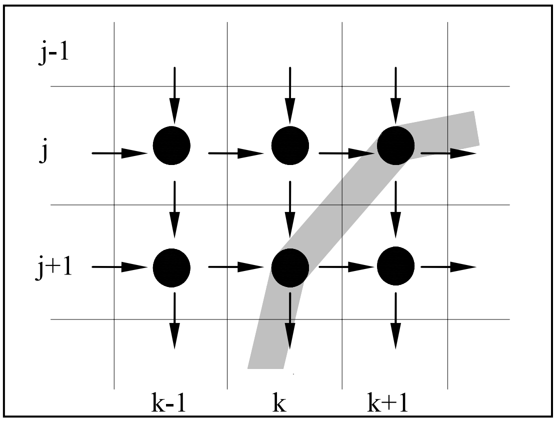

Fig. 1 Schematic drawing of 2-D overland flood routing and channel routing scheme.

When the bankful flow depth is reached in a flood event, water ceases to be contained solely in the main river channel and water spills onto adjacent floodplains. These floodplains act either as temporary stores for this water or additional routes for flow conveyance. In this process, the water surface elevation for river segments is calculated using the 1-D channel flow model solution. The overland surface flow routing is calculated by the 2-D model, which is to treat each cell as a storage volume, and the change in cell volume over time is equal to the fluxes into and out of it. Whilst at the channel–floodplain interface, the exchange of flow between channel network and floodplain or low-lying area is simulated in response to the relative water surface elevation, that is to say, surface flow can be either away from river or into river (Figure 2) (Horritt M.S., Bates P.D., 2001).

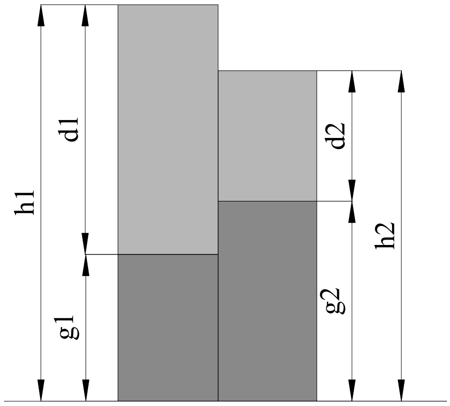

Fig. 2 Flow between grid node 1 and 2 (*d*, depth of water in the cell; *g*, ground elevation; *h*, water surface elevation in the cell).

2.2 Overland and channel flow

Overland flow can occur when the water depth on the floodplain exceeds the depression storage threshold. Generally overland flow can be governed by continuity and momentum equations (Equations 1 and 2). To solve the overland flow equations for continuity and momentum, explicit finite difference method is selected. In general, each grid cell is assumed as a homogeneous unit.

$$\frac{dh^{i,j}}{dt} = \frac{Q_{up} + Q_{down} + Q_{left} + Q_{right}}{\Delta x \Delta y} \quad (1)$$

$$Q_x^{i,j} = \pm \frac{h_{flow}^{5/3}}{n} \left| \frac{h^{i-1,j} - h^{i,j}}{\Delta x} \right|^{1/2} \Delta y \quad (2)$$

Where $h^{i,j}$ is the water free surface height at the grid cell (i,j); Δx and Δy are grid cell dimensions, which are equal; n is the Manning's friction coefficient; Q_x and Q_y are the volumetric flow rates between grid cells, Q_y is defined analogously to equation (2), whose sign depends on the flow direction; Q_{up} , Q_{down} , Q_{left} and Q_{right} are the flow rates (either positive or negative) from the up, down, left and right adjacent cells, respectively, which can be represented by Q_x or Q_y accordingly. The flow depth, h_{flow} , represents the depth through which water can flow between two cells.

Similarly, channel flow is also able to be represented by continuity and momentum equations (Equations 3 and 4). In the watershed it is convenient to represent channel flow as one-dimensional.

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=q \tag{3}$$

$$S_0-\frac{n^2P^{4/3}Q^2}{A^{10/3}}-\left[\frac{\partial h}{\partial x}\right]=0 \tag{4}$$

Where, t is time; x is distance along the longitudinal axis; A is cross-sectional area; Q is the volumetric flow rate in the channel; q is lateral flow into or out of the channel; P is wetted perimeter of channel flow; S_0 is bed slope.

3. Model development

3.1 Data sets and pre-processing

Flood inundation models require four key data principally: (1) topographic data or DEM to construct the model grid; (2) bulk flow data to provide model inflow and outflow boundary conditions; (3) an estimate of effective friction parameter for each model cell (often based on ground surface conditions and determined by remote sensing data) and (4) validation data.

This research focuses on watershed/catchment, there are generally two types of data sets that have been used: spatial and non-spatial data. Spatial data include digital elevation model (DEM), channel network, watershed boundary, soil type and land use classification. In this program, it will make full use of SRTM DEM data and some other remote sensing data, channel link and watershed/catchment boundary mask data will be generated by DEM. Non-spatial data are inflow discharge, weather data and channel cross-sectional data. Actually weather data also can be recorded as the same as spatial data. These data sets are available which are able to be edited and preprocessed before they are used in flood inundation simulation program.

3.2 Approach

The objective of this research is to develop an integrated flood inundation simulation model to predict and assess flood hazard. Here a loose coupling method of program development is selected. In such case, GIS and flood inundation simulation model remain separate, but loosely linked through data input and output.

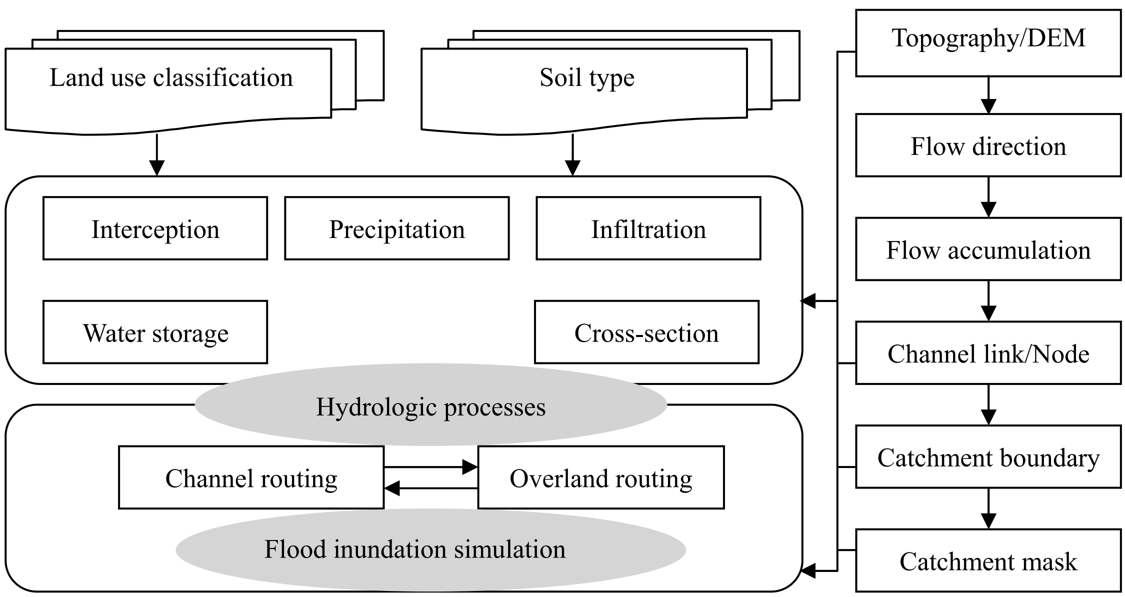

Fig. 3 Flowchart of data processing and modelling procedure.

The program is developed according to Fig. 3 (Chow et al, 1998; David R. Maidment, 1993) under the environment of Microsoft Visual C++ and Windows XP operating system, the initial input data such as DEM, catchment mask and channel link are organized by GIS, and simulation output from the model consists of the water depth in each grid cell at each given time step, which also can be visualized by GIS. And in the model, the hydrologic processes including precipitation, infiltration and interception are considered, however at the present the evapotranspiration process is neglected. The channel cross-sectional parameters required to run the simulation are channel width, depth, slope and Manning's friction coefficient. Here the width and depth of river channel are assumed to be uniform along one channel segment.

4. Conclusions

In this research, the route and procedure of simplified flood inundation simulation program integrating with rainfall-runoff processes for watershed scale context are constructed to simulate flooding over a digital elevation model which is significant of flood vulnerability assessment. Simulation may be of watershed/catchment scale flooding where floodplain and river are coupled. In this program, the channel characteristics are represented by rectangle or trapezoid, and drainage network is extracted from DEM data, only a simple treatment of river channel is incorporated. Therefore it is easier to be handled in data poor environment especially where limited channel information is available. Furthermore the mechanism can be improved in terms of stage-discharge relationship (Tachikawa, Y. et al., 2004) in further research.

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降雨流出過程を統合した簡易型洪水氾濫モデル

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要　旨

洪水災害はもっとも害を及ぼす災害の一つであり，洪水災害軽減のためには洪水特性および洪水に対する脆弱性の評価に関する情報が極めて重要となる。ここでは，洪水脆弱性の時空間的な分布情報を得るために，降雨流出過程を統合したグリッド型の洪水氾濫シミュレーションモデルを構築し，大流域における洪水氾濫シミュレーションを目指す。シミュレーションモデルは，1次元の河道流追跡モデル，2次元の表面流・斜面流モデルから構成される。本モデルは，洪水特性の分析や洪水地域の導出に用いられる。本論では，本モデル開発の背景と手法を述べる。

キーワード：洪水氾濫，洪水モデデリング，地理情報システム