Introduction to Grid Based Distributed Rainfall-Runoff Model with HyGIS Frame

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ABSTRACT

Recently in Korea, HyGIS(Hydro Geographic Information System) have been developed to construct GIS based water resources system. HyGIS is based on GEOMania which is Korean GIS engine, and its core function is developed by GDK(GEOMania Development Kits) as component. HyGIS can calculate geographic characteristics of watershed from DEM and construct framework data for watershed spatial database. GRM(Grid based Rainfall-runoff Model) is a physical based distributed rainfall-runoff model. Kinematic wave equation is used to simulate overland flow and channel flow, and Green-Ampt model is used to simulate infiltration. GRM is operated as extension module of GMMap, and its input data such as flow direction, flow accumulation, stream, and watershed are created from HyGIS. This paper introduces HyGIS and GRM for grid based distributed rainfall-runoff modeling.

Keywords : HyGIS, GRM, distributed model, rainfall-runoff

1. Introduction

Demand for spatial and temporal data management for water resources models has been increasing. This has brought greater attention to integrated GIS based water resources system. HyGIS is a software application developed by Korean technology for easy and effective use of GIS in hydraulics, hydrology, water quality analysis, and watershed management(KICT, 2007). HyGIS can also be used to develop new database systems for individual goals and the systems linking GIS and water resources models(HyGIS-Model).

GRM is grid based distributed rainfall-runoff model. It uses kinematic wave equation to simulate overland flow and channel flow, and Green-Ampt model to simulate infiltration. GRM is fully coupled with GIS based on HyGIS. GRM input data is created from HyGIS as grid layer, and data management is carried out with HyGIS-Model data management framework on the basis of database.

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2. HyGIS Overview

HyGIS has been developed for easy and effective use of GIS to diverse software applications in water resources area, including hydraulics, hydrology, water quality analysis, and watershed management. HyGIS enables hydrological DEM analysis, generation of stream network with linear referencing function, and the management of watershed facilities. HyGIS is a database system, and it uses GSS(GEOMania Storage System) which is a characteristic database of the GEOMania for spatial database and MDB(Microsoft Access Database) for non-spatial and time series database.

All the models operated in HyGIS environment are commonly called HyGIS-Model. HyGIS-Model obtains input data required for hydraulic, hydrological, and water quality models from database(spatial or non-spatial DB/static or dynamic DB), and also the modeling results are saved in database. HyGIS and HyGIS-Model are operated as extension modules of GMMap. GMMap is general GIS software developed by using GDK(GEOMania Development Kits) and .NET framework. Figure 1 shows the running windows of HyGIS, and figure 2 shows database relationships of the integrated operation environment of the HyGIS-Model.

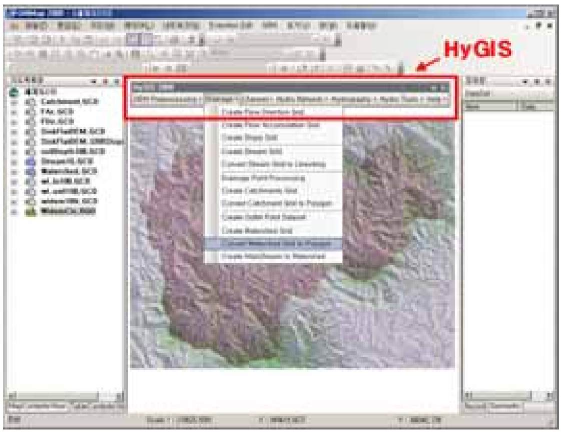

FIGURE 1. Screen capture of running HyGIS

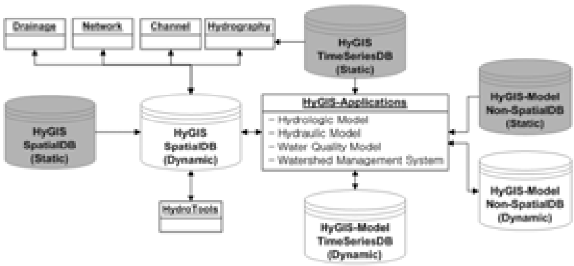

FIGURE 2. Database and its flows in HyGIS-Model

3. Distributed Rainfall-runoff Model

3.1 GRM

GRM is grid based distributed rainfall-runoff model to simulate short term rainfall-runoff events. Main hydrological components of GRM are rainfall, infiltration, overland flow, channel flow, and subsurface flow. GRM inputs are grid layers from HyGIS, or constant values and text files user defined. GRM was developed by using Visual Studio 2005 and GDK. It is also operated as an extension module of GMMap. Figure 3 shows hydrological components of GRM, and figure 4 is the running windows of GRM.

3.2 Governing equation

GRM uses kinematic wave equation to analyze overland flow and channel flow, and Green-Ampt model to simulate infiltration. Simplified continuity equation for overland flow and momentum equation for kinematic wave equation are Eq. (1) ~ Eq. (4).

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = Pr - IFr \qquad (1)$$

$$\frac{\partial A_x}{\partial t} + \frac{\partial Q}{\partial x} = Pr\, dy + q_L \qquad (2)$$

$$S_0 = S_f \qquad (3)$$

$$u = \frac{R^{2/3} S_0^{1/2}}{n} \qquad (4)$$

where q is flow per unit width(=uh), h is flow depth, u is overland flow velocity, Q is discharge in the channel, S_0 is bed slope or land surface slope, S_f is friction slope, Pr is rainfall intensity, IFr is infiltration rate, t is time, A_x is channel cross sectional area, q_L is lateral flow rate per unit length, n is roughness coefficient, and R is hydraulic radius.

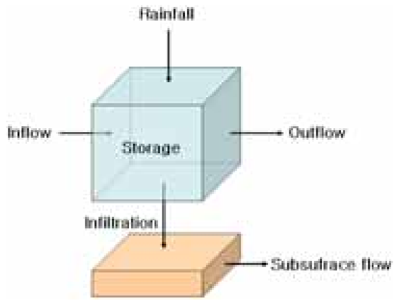

FIGURE 3. Hydrological components of GRM

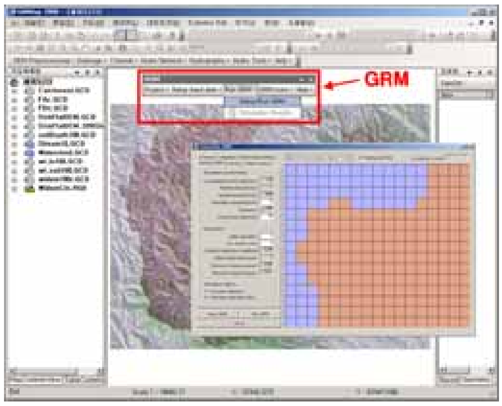

FIGURE 4. Screen capture of running GRM

GRM simulates infiltration excess runoff and saturation excess runoff, and it uses Green-Ampt model to estimate infiltration. Cumulative infiltration and infiltration rate are calculated by Eq. (5) and Eq. (6).

$$F(t) = Kt + \Delta\theta\varphi \ln\left(1 + \frac{F(t)}{\Delta\theta\varphi}\right) \qquad (5)$$

$$f(t) = K\left(\frac{\varphi\Delta\theta}{F(t)} + 1\right) \qquad (6)$$

where $F(t)$ is cumulative infiltration, $f(t)$ is infiltration rate, $\Delta\theta$ is the change in the moisture content($\Delta\theta = (1 - S_e)\theta_e$),

S_e is effective saturation($S_e = (\theta - \theta_r)/(\eta - \theta_r)$), θ is moisture content($\theta_r \le \theta \le \eta$), θ_r is residual soil moisture content($\theta_r = \eta - \theta_e$), η is porosity, θ_e is effective porosity, and K is hydraulic conductivity.

3.3 Discretization equation

GRM solves kinematic wave equation by employing FVM(finite volume method). The control volumes for FVM are shown in Figure 5. The integral form of Eq. (1) for CV*i* can be written as Eq. (7). Eq. (8) can be derived from Eq. (7) for calculating flow depth of CVi at j+1 time step.

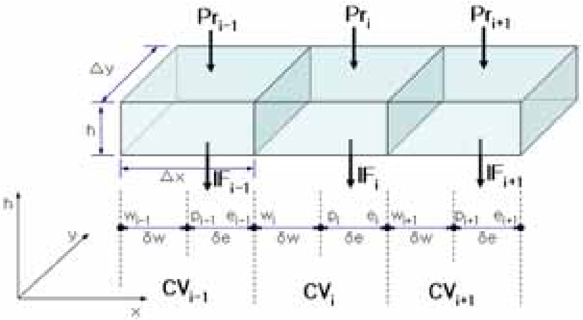

FIGURE 5. Control volumes for discretization

$$\int_{w_i}^{e_i}\int_{j}^{j+1}\frac{\partial h}{\partial t}dtdx + \int_{j}^{j+1}\int_{w_i}^{e_i}\frac{\partial uh}{\partial x}dxdt = \int_{j}^{j+1}\int_{w_i}^{e_i}\left(Pr_i - IFr_i\right)dxdt \qquad (7)$$

$$h_{ip}^{j+1} = h_{ip}^{j} - \left[\alpha\left\{\left(\overline{uh}\right)_{ie}^{j+1} - \left(\overline{uh}\right)_{iw}^{j+1}\right\} + (1-\alpha)\left\{\left(\overline{uh}\right)_{ie}^{j} - \left(\overline{uh}\right)_{iw}^{j}\right\}\frac{\Delta t}{\Delta x}\right] + \left\{\alpha S_i^{j+1} + (1-\alpha)S_i^{j+1}\right\}\Delta t \qquad (8)$$

where S_i is source term($S_i = Pr_i - IFr_i$), and α is the weighting factor for temporal dimension.

4. Application of GRM

Study area to apply GRM is Wicheon watershed of Nakdong river in Korea. Wicheon watershed is mainly composed of mountain and agricultural area, and its area is about 472km^2. 4 rainfall events are selected from rainfall-runoff data observed in 2007(Table 1).

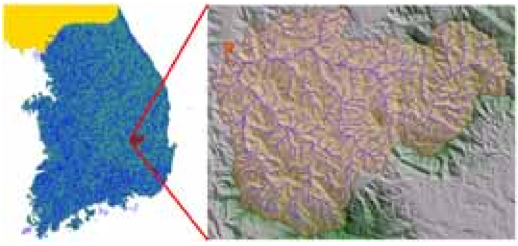

FIGURE 6. Wicheon watershed

TABLE 1. Selected rainfall events

Event number	Rainfall period	Total rainfall[mm]	Time interval[min]
Event 1	2007/06/23/18:00 - 06/25/00:00	42	60
Event 2	2007/08/31/20:00 - 09/02/21:00	100	60
Event 3	2007/09/04/10:00 - 09/08/03:00	112	60
Event 4	2007/09/15/05:00 - 09/18/02:00	143	60

Figure 7 ~ figure 10 show the application results of 4 rainfall events. In these figures, simulation results shows very good agreement with observed hydrograph, and runoff response to rainfall is also proper. The results of calibration and verification for each rainfall event are listed in table 2. The simulated runoff volume, peak discharge and time to peak discharge were found within 20% relative error of their corresponding observed values.

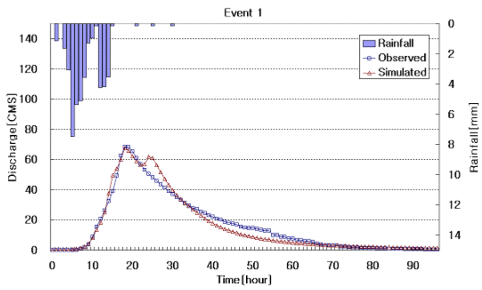

FIGURE 7. Simulation results - Event 1

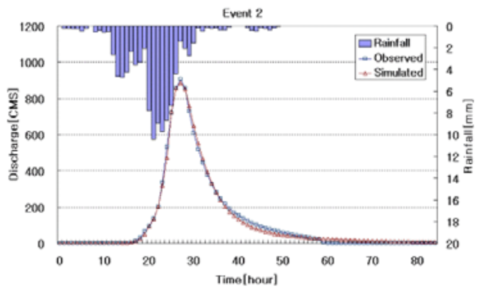

FIGURE 8. Simulation results - Event 2

TABLE 2. Comparison with observed data and simulated data

Event number	Comp. time step [min]	Running time [min]	Parameters			Total discharge			Peak discharge			Time to peak discharge		
			Initial saturation	Dry stream order	Channel roughness coeff.	Obs. [m^3]	Sim. [m^3]	Relative error [%]	Obs. [m^3/s]	Sim. [m^3/s]	Relative error [%]	Obs. [hour]	Sim. [hour]	Relative error [%]
Event 1	2	9.4	0.30	1	0.045	1,574	1,546	1.8	67.6	68.2	0.9	18	18	0.0
Event 2	2	9.3	0.82	0	0.045	10,270	10,345	0.7	906.3	886.4	2.2	27	27	0.0
Event 3	2	13.0	0.78	0	0.045	12,714	11,218	11.8	692.5	685.6	1.0	26	26	0.0
Event 4	2	10.8	0.40	0	0.045	16,153	12,861	20.4	1,050.5	1,098.	4.6	45	45	0.0

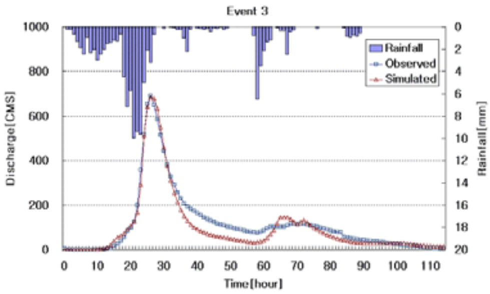

FIGURE 9. Simulation results - Event 3

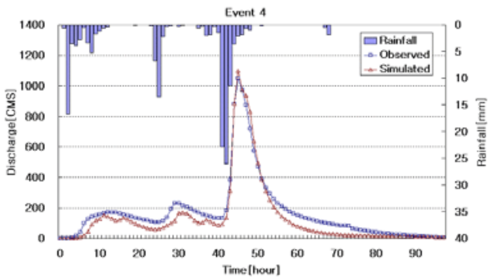

FIGURE 10. Simulation results - Event 4

5. Conclusions

Grid based distributed model needs grided geographic data and hydrological time series. HyGIS can provide effectively these grid data, and HyGIS-Model system can operate model fully coupled with GIS.

GRM is grid based distributed rainfall-runoff model operated on the basis of HyGIS-Model system. Its inputs are created from HyGIS and all of the data for running GRM are managed in HyGIS-Model system.

GRM simulates overland flow, channel flow, infiltration, and subsurface flow for short term rainfall-runoff events. The application results showed very good agreement with observed hydrographs. Relative errors of peak discharge and total discharge are 0.9% ~ 4.6% and 0.7%~20.4% respectively. And computed time to peak discharge is exactly the same as corresponding observed value.

Although we have successful application of distributed rainfall-runoff modeling, future studies require more convenient functionality for distributed modeling and more detailed guideline for various applications.

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References

Beven, K., (1981). Kinematic subsurface stormflow, Water Resources Research, 17, 5, 1419-1424.

Chow, V.T., (1959) Open-channel hydraulics, McGraw-Hill.

Chow, V.T., Maidment, D.R., and Mays, L.W., (1988) Applied hydrology, McGraw-Hill.

KICT(Korea Institute of Construction Technology), (1995) Development of Two-Dimensional Stream Flow Model(I), KICT/95-WR-1103-1.

KICT(Korea Institute of Construction Technology), (2007) Development of HyGIS. Ministry of Science and Technology.

Patankar, S.V., (1980) Numerical Heat Transfer and Fluid Flow, Hemisphere Publishing Corporation.

SFWMD(South Florida Water Management District), (2005) Regional Simulation Model(RSM) - Theory manual, South Florida Water Management District Office of Modeling.

Vieux, B.E., (2004) Distributed Hydrologic Modeling Using GIS, Kluwer Academic Publishers.