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Effects of DEM Resolution on Hydrological Simulation in BASINS-HSPF Modeling

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Abstract □ In this study, the effect of DEM (Digital Elevation Model) resolution (15 m, 30 m, 50 m, 70 m, 100 m, 200 m, 300 m) on the hydrological simulation was examined using the BASINS (Better Assessment Science Integrating point and Nonpoint Source) for the Heukcheon watershed (303.3 km^2) data from 1998 to 1999. Generally, as the cell size of DEM increased, topographical changes were observed as the original range of elevation decreased. The processing time of watershed delineation and river network needed more time and effort on smaller cell size of DEM. The larger DEM demonstrated had some errors in the junction of river network which might affect on the simulation of water quantity and quality. The area weighted average watershed slope became milder but the length weighted average channel slope became steeper as the DEM size increased. DEM resolution affected substantially on the topographical parameter but less on the hydrological simulation. Considering processing time and accuracy on hydrological simulation, DEM grid size of 100m is recommended for this range of watershed size.

Keywords □ DEM, Resolution, BASINS, HSPF, Hydrological simulation, GIS

I. Introduction

The advent of GIS has already profoundly affected the hydrologic modeling community. GIS provides excellent capabilities of data preparation for watershed and receiving water modeling. More recently, models are being tightly linked with GIS, allowing users to modify data and analyze resulting model output within the GIS environment. Distributed models such as AGNPS (Young *et al*, 1989), ANSWERS (Beasley, 1986), CHDM (Lopes, 1995), CASC2D (Ogden and Saghafian, 1995), KIMSTORM (Kim, 1998) are well suited for linkage with GIS and have been developed. Similar to the GIS linkage, integrated modeling systems are being developed that provide the user with a fully integrated data, analysis, and modeling frame-work. The BASINS (Better Assessment Science Intergrating point and Nonpoint Sources) and

WSTT (Watershed Screening/Targeting Tool) are examples of such systems (Shoemaker *et. al.*, 1997).

In GIS modeling system, topography such as DEM (digital elevation model) defines the effect of gravity on the flow of water in a watershed, and affects the hydrologic system and soil erosion (Wolock and Price, 1994). Topography has been shown to affect the flow path that precipitation follows before it becomes streamflow (Wolock et. al., 1990), the spatial distribution of soil moisture within a watershed (Burt and Butcher, 1985), and the chemical characteristics of streamflow (Wolock et al., 1989, 1990).

Walker and Willgoose (1999) suggested that the accuracy of published DEM data is very questionable for estimating the topographical and geomorphologic parameters. It is necessary to analyze the sensitivity of topographical and geomorphologic parameters to the DEM resolutions when they are used in hydrological simulations. Zhang and Montgomery (1994) investigated the effect of DEM resolution on the topographical index and the simulated hydrological response of the TOPMODEL to a simple short-duration rainfall event in two catchments studied, which have the area of 0.3 km^2 and 1.2 km^2 respectively. The results showed that increasing the coarseness of DEM resolution tended to decrease the mean depth from surface to the water table and increase the peak flow. Wolock and Price (1994) examined the similar study, and concluded that increasing the DEM grid size tended to decrease the mean depth to the water table and increased the ratio of overland flow to total flow, the variance of daily flow, the skew of daily flow, and the maximum daily flow. Yang *et al.* (2001) studied the effect of DEM resolution on the geomorphologic characteristics and hydrological simulations using GBNM. They concluded that topography tended to be flat, hydrological response became quicker, yearly runoff became lower, and the effect of the DEM resolution of the hourly response was more significant than the daily response when the DEM grid size increased. Kim and Steenhuis (2001) evaluated a grid-based model, GRISTRRM, behavior was sensitive to DEM resolution. The detail scaling information used in GIS modeling system will achieve more accurate simulation, but need more time, effort, and higher performance computer (Maidment and Djokic, 2000). So modelers need to decide adequate data resolution considering cost and accuracy. However, these models are not continues models and can not fully simulate hydrological phenomena like as upper or low zone storage of soil, ground water recession, interflow and evapotranspiration.

In this study, the sensitivity of geomorphologic parameters and hydrological responses to some kinds of different DEM resolution was investigated in the Heukcheon watershed using two years data of 1998 and 1999. The effect of DEM resolution on the catchment hydrological response in the BASINS-HSPF model simulation which is continues and detail model was also presented in this paper.

II. STUDY AREA and RESEARCH METHODS

1. Description of study area

The study area is a Heukcheon watershed located in Yangpyeong-gun, Gyunggi-do, Korea

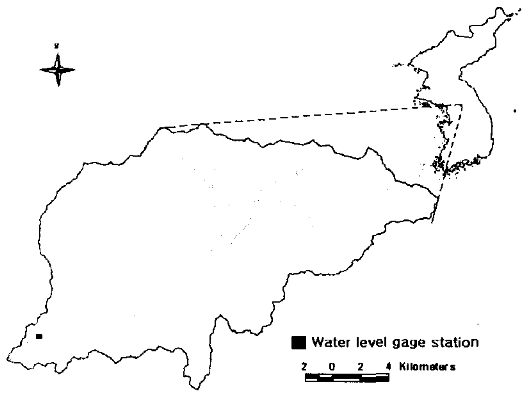


Fig. 1 Location of study area and water level gage station

(Fig. 1). The catchment area is 303.3 km^2 and length of main channel is 37.7 km. The study area consists of typical non-urban land-use types. which residential area is 8.7 km^2 (3%), agricultural land 56.3 km^2 (19%), forest 229.2 km^2 (76%), and stream 6 km^2 (2%). Yearly average precipitation, temperature and relative humidity are 1,034.1 mm, 11.6 ℃ and 67%, respectively (Korea Meteorological Administration, 2002).

In this study, water-level data was used from national water level monitoring station which is located at Heukcheon watershed (Water Resources Management Information System, 2002).

2. Research methods

DEMs for the study area were derived independently at 15 m, 30 m, 50 m, 70 m, 100 m, 200 m, and 300 m resolution by interpolation from a 1: 25,000 scale digital map using a GIS program, ArcView 3.2a. Watershed delineation and stream definition were generated by BASINS-Delineation tool, and geomorphologic parameters were extracted for each DEM. A Land-use map provided by M.O.E (Ministry of Environment) was used for the BASINS-Utility tool. HSPF input file was produced automatically in the BASINS system for each DEM, using geomorphologic, land-use and hourly weather data.

The BASINS-HSPF model by the 15m-DEM was calibrated for the monitoring data of 1998 and validated for 1999 monitoring data, respectively. The degree of calibration and verification was evaluated in terms of the model efficiency (E_m) ;

$$E_m(\%) = [1.0-\{\Sigma(O-P)^2/\Sigma(O-O(-))^2\}] \cdot 100 \quad (1)$$

where O, P and O(-) represents observed, predicted and average observed data, respectively. The efficiency statistic is related to the determination of coefficient used in regression analysis, and can be considered as an index of "goodness-of-fit", where a value of 100% indicates error-free prediction (Nash and Sutcliffe, 1970). Servert and Dezetter (1991) proposed that the function of model efficiency can be the best object function that expresses the fitness of hydrological simulation.

To examine the response of geomorphologic parameters on DEM resolution, geomorphologic parameters of area weighted slope of watershed (S_A) and length weighted slope of main stream (S_L) are used in the form as follow.

$$S_A = \frac{\Sigma A_i \cdot S_{Ai}}{\Sigma A_i} \cdot 100 \quad (2)$$

$$S_L = \frac{\Sigma L_i \cdot L_{Li}}{\Sigma L_i} \cdot 100 \quad (3)$$

Where, S_A, S_L, A and L present slope of watershed, slope of stream, area and length of stream, and denote i means each subbasin.

The 15 m DEM is supposed to be the most accurate, therefore, calibration parameters from 15m DEM were used as a reference to evaluate the effect of DEM grid size on the hydrological response by relative error;

$$\text{Relative error}(\%) = \frac{15\ \text{DEM-LARGEDEM}}{15\text{DEM}} \cdot 100 \quad (4)$$

where, 15 DEM and LARGEDEM present the result from 15 m DEM and larger DEM grid size, respectively.

3. BASINS (Better Assessment Science Integrating point and Nonpoint Sources) overview

The BASINS comprises a suite of interrelated components for performing the various aspects of environmental analysis, and is also conceived as a system for supporting the development of total maximum daily loads. The components include (1) nationally derived databases with *Data Extraction* tools and *Project Builders*; (2) assessment tools (*TARGET, ASSESS* and *Data Mining*) that address large- and small-scale characterization needs; (3) utilities to facilitate organizing and evaluating data; (4) tools for Watershed Delineation; (5) utilities for classifying DEMs, land use, soils, and water quality observations; (6) Watershed Characterization Reports that facilitate compilation and output of information on selected watersheds; (7) an instream water quality model, QUAL2E; (8) two watershed loading and transport models, HSPF and Soil and Water Assessment Tool; and (9) a simplified GIS based model that estimates nonpoint loads of pollution on an annual average basis. The assessment component, working under the GIS umbrella, allows users to quickly evaluate selected areas, organize information, and display results. The modeling component module allows users to examine the impacts of pollutant loadings from point and nonpoint sources (Lahlou *et. al.*, 1998). In this study, BASINS-HSPF was used to examine the effect of DEM resolution of the hydrologic response for watershed simulation.

4. Overview runoff algorism in HSPF

Overland flow is treated as a turbulent flow process in HSPF model. It is simulated using the Chezy-Manning equation and an empirical expression which relates outflow depth to detention storage. The rate of overland flow discharge is determined by the equations:

for *SURSM* < *SURSE*

$$SURO = DELT60 \times SRC \times (SURSM \times (1.0 + 0.6(SURSM/SURSE)^{3})^{1.67} \quad (5)$$

for SURSM >= SURSE

$$SURO = DELT60 \times SRC \times (SURSM \times 1.6)^{1.67} \quad (6)$$

$$SURSE = DEC \times SSUPR^{0.6}$$

$$DEC = 0.00982 \times (NSUR \times LSUR/SQRT(SLSUR))^{0.6} (14)$$

$$SRC = 1020.0 \times (SQRT(SLSUR)/(NSUR \times LSUR))(15)$$

Where,

SURO = surface outflow (in/interval)
DELT60 = DELT/60.0 (hr/interval)
SRC = routing variable, described below
SURSM = mean surface detention storage

over the time interval (in)

SURSE = equilibrium surface detention storage (inches) for current supply rate

DEC = calculated routing variable, described below

SSUPR = rate of moisture supply to the overland flow surface

NSUR = Manning' s n for the overland flow plane

LSUR = length of the overland flow plane (ft)

SLSUR = slope of the overland flow plane (ft/ft)

The routing technique falls in the class known as "storage routing" or "kinematic wave" methods.

Ⅲ. RESULTS

1. Watershed delineation and stream definition

The threshold area was set as 600 ha to be near the real stream so the 17 subbasins were generated within the watershed (Fig. 2).

The processing times for watershed delineation tasks was decreased as the DEM resolution became coarser (Table 1). Among the watershed delineation processes, the calculation process of subbasins which extracts watershed parameters for each subbasin needs more time than any other processes. Working with a personal computer having the Pentium Ⅲ-800MHz processor and 256MB RAM, the total processing time of 15 m resolution was about 46 minutes and those of 30 m, 100 m, 200 m and 300 m resolution substantially were decreased about 12, 4, 2, and 1minutes respectively.

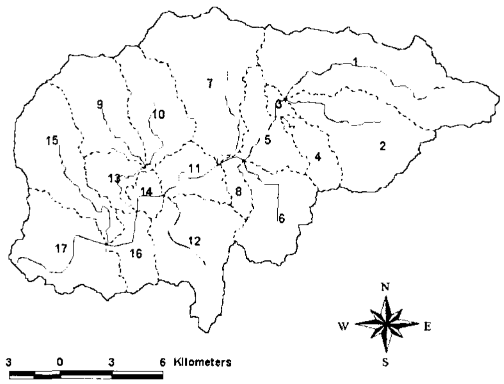


Fig. 2 The result of subbasins delineation with 15 m-DEM

According to DEM resolution, the overlay maps of stream accumulation grid and stream vector are shown Fig. 3. The coarser the DEM grid size became, the poorer accuracy of stream became. The shape of stream was not smooth

Table 1 Comparison of processing times for watershed delineation tasks with different DEM resolution

(Unit : seconds)

	15 m	30 m	50 m	70 m	100 m	200 m	300 m
The number of cells	1,355,825	338,971	121,862	62,177	30,486	7,627	3,379
Precedure							
Remove sink	817	162	66	33	21	13	12
Stream definition	119	23	9	8	6	5	4
Outlet inlet definition	197	41	17	11	9	7	6
Calculation of subbasins	1,662	537	332	255	189	88	57
Total	2,795	763	424	307	225	113	79

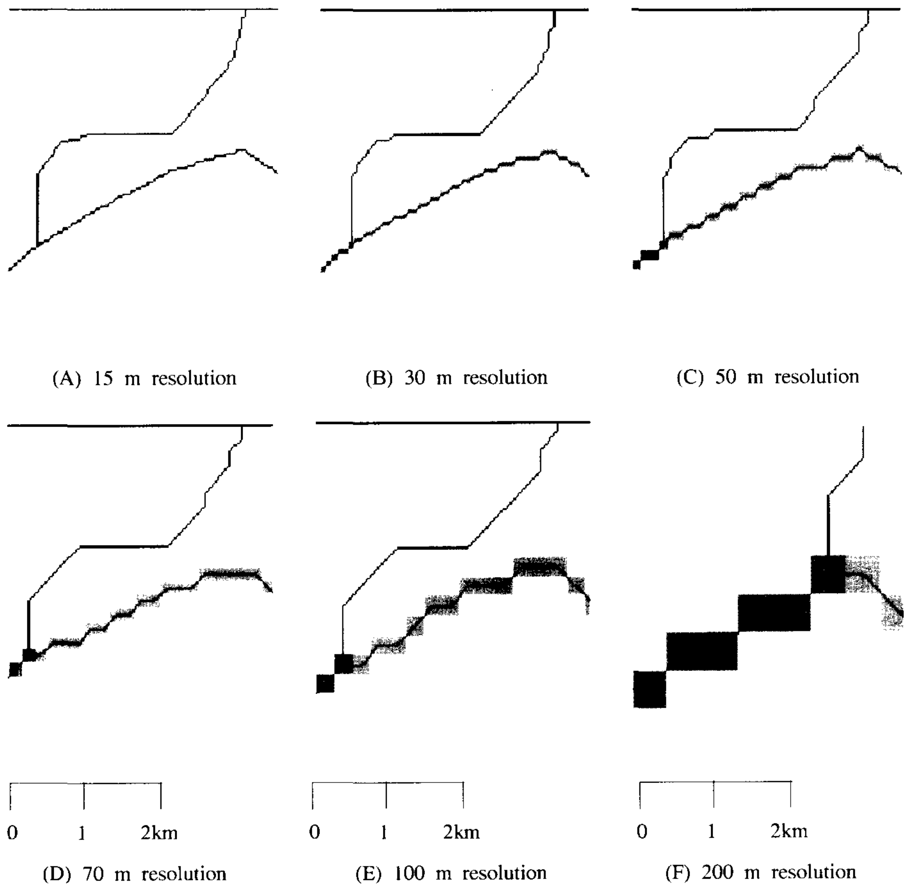
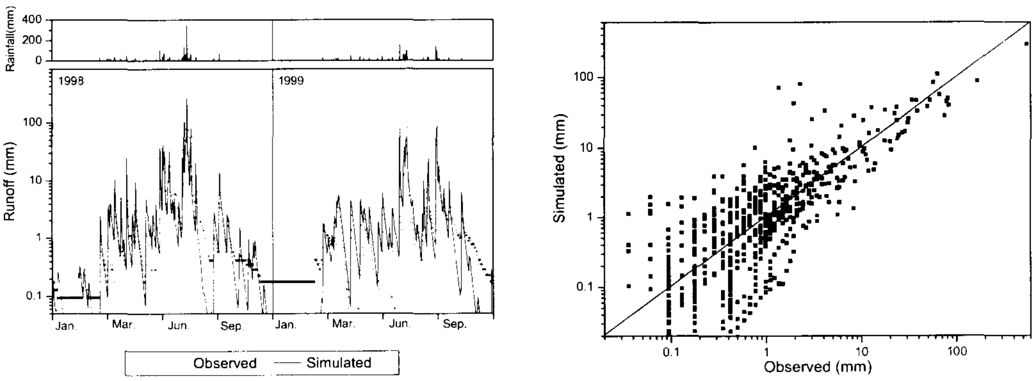


Fig. 3 Overlay with stream accumulation grid and vector of stream network according to different DEM scales



(a) Simulated and observed daily runoff.

(b) Scatterplot of simulated versus observed runoff.

Fig. 4 Calibration and verification of daily runoff depth using BASINS-HSPF during 1998~1999 at Heukcheon watershed

Table 2 Hydrological calibration and validation during 1998~1999 at Heukcheon watershed

(Unit : mm)

	Calibration (1998)			Verification (1999)		
	Rainfall	Observed	Simulated	Rainfall	Observed	Simulated
Yearly runoff	1,969	1,632.5	1,530.7	1,502	945.8	1,105.4

in 70 m and over resolution and the junction of stream network was distorted in 200 m and 300 m resolution, which might result errors in the water quantity and quality simulation.

The hydrological simulation was carried out for the monitoring data of 1998 and 1999 in the study area. Initially, the 15 m DEM was used to provide the spatial parameterisation for input file, and the results of calibration and validation of runoff are shown in Fig. 4 and Table 2 where model efficiency, RMS (root mean square) error and coefficient of determination (R^2) were 75.6%, 11.64 mm and 0.81, respectively. The main calibration parameters were shown in Table 3.

2. The effect of DEM resolution on the topographical parameter

The highest elevation became low and the lowest elevation became high according to an increase in the DEM grid size (Table 4). The highest and lowest elevation were 1,157 m and 20 m on the 15 m DEM, respectively, but they are changed significantly to 1,113 m for the highest elevation at the 200 m DEM, and 40 m for the lowest elevation at the 50 m DEM.

Table 4 Comparison of maximum and minimum elevation from different resolution of DEMs

(Unit : m)

	15 m	30 m	50 m	70 m	100 m	200 m	300 m
Max.	1,157	1,157	1,146	1,149	1,146	1,113	1,115
Min.	20	20	40	40	40	40	40

The area weighted slope of watershed became flat and the length weighted main slope of stream became steep systematically as the DEM grid size increased (Fig. 5). Comparing with the slope of watershed of 15 m DEM, the relative errors for the watershed slope of 50 m, 100 m, 200 m and 300 m resolution were 17.0%, 32.0%, 48.9%, and 58.9%, and those for the stream slope were -0.6%, -2.1%, -25.2% and -49.7%, respectively.

3. The sensitivity analysis of DEM resolution on hydrological simulation

The maximum yearly runoff amount of 1999 simulated was 1,105.4 mm by 15 m resolution. The yearly runoff amount raining from 15 m to 100 m resolution was decreased from 1,105.4 mm to 1099.0 mm, while that from 200 m to

Table 3 The used input parameter value for hydrological calibration and validation in this study

Description	Symbol	Unit	Value	Range
Fraction of coverage by forest	FOREST	-	0.0~1.0	0.0~1.0
Groundwater recession rate	AGWRC	-	0.8	E-4~0.999
Lower zone nominal storage	LZSN	ft	0.01~4.00	0.01~100.00
Upper zone nominal storage	UZSN	in	1.128	0.01~100
Infiltration rate	INFILT	in/h	0.4	E-4~100
Manning's n	NSUR	-	0.001~0.2	E-4~1.0
Interflow recession parameter	IRC	-	0.05	E-30~0.999

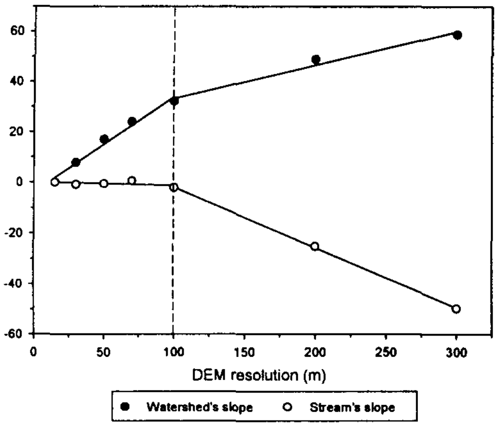


Fig. 5 The effect of DEM resolution on the characteristics of watershed factors

Table 5 Comparison of yearly runoff simulation from different DEM grid size

(Unit : mm)

	15 m	30 m	50 m	70 m	100 m	200 m	300 m
1998	1,530.7	1,529.8	1,528.8	1,529.1	1,521.3	1,526.3	1,531.0
1999	1,105.4	1,105.1	1,103.7	1,103.8	1,099.0	1,102.9	1,105.4

300 m resolution was re-increased from 1,102.9 mm to 1,105.4 mm for a coarser scale (Table 5). Almost similar pattern appeared for 1998. However, the relative errors of yearly runoff amount for the all case to 15m resolution were within 0.6%.

The comparison results of hourly hydrographs between the 15 m, 100 m and 300 m grid size were shown in Fig. 6. During the first event, (a), the peak flow of case using coarse DEM was equal to or less than that using fine DEM, while during the second and third events which had short duration of dry day, (b) and (c), peak flow of coarse DEM was higher than that of fine DEM.

This result can be explained by the hydrological circulation that; when the soil moisture

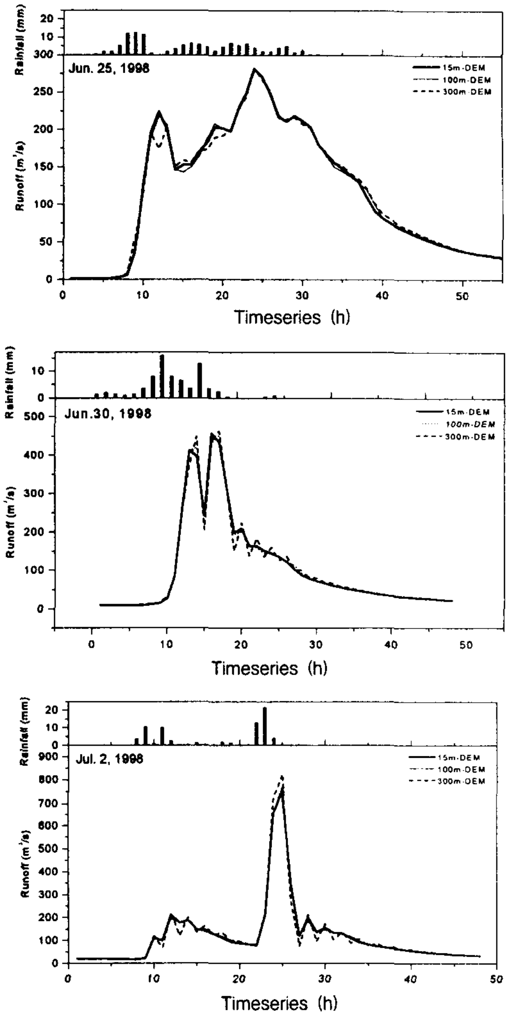


Fig. 6 Hourly hydrographs of Heukcheon simulated by HSPF using DEMs of different resolutions

condition is same such as case (a), the peak flow of the fine DEM resolution is higher than that of coarse DEM, but when the short dry day such as case (b) and (c) subsurface flow of coarse DEM decrease because of plat slope of watershed so more water is stored in the subsurface. As a result, less water is needed to saturate the subsurface soil, the saturated surface runoff responds higher peak flow in coarse DEM.

During the second and the third rainfall events, the interflow storage of 300 m DEM resolution was higher than that of 15 m DEM at the day before of rainfall events, so the peak flow of 300 m DEM was higher than 15 m DEM (Fig. 7). The relative errors of hourly peak flow between 15 m and 300 m resolution was within 9~22%.

This study demonstrated that DEM resolution much influenced topographical parameter such as the slope of watershed and stream; the slope of stream appeared significant difference over 200 m, and the processing time of 15 m resolution was much more than that of 100 m resolution. However it influenced less on hydrological simulation; yearly and hourly hydrological simulation did not appear between 15 m and 300 m DEM resolution, and between 15 m and 100 m DEM resolution, respectively. Therefore, the adequate DEM resolution for BASINS-HSPF hydrological simulation might be about 100 m in larger than mid-scale watershed (>300 km^2) considering efficiency and accuracy.

Ⅳ. CONCLUSION

The effect of DEM resolution on the hydrological simulation was examined using BASINS for Heukcheon watershed data from 1998 to 1999. Generally, as the cell size of DEM increased, topographical changes were observed as the original range of elevation decreased. The area weighted average watershed slope became milder but the length weighted average channel slope became steeper as the DEM size increased. The processing time of watershed delineation and river network needed more time and effort on smaller cell size of DEM. The larger DEM

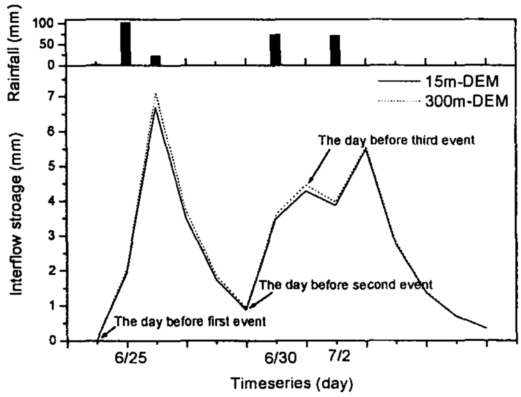


Fig. 7 Variation of interflow storage (mm) during wet day at forest land

demonstrated had some errors in the junction of river network which might effects on the simulation of water quantity and quality. As the DEM grid size increase, the slope of watershed become flat so the peak flow is lower than the fine DEM for the event after long-term dry day. The event after short-term dry day appear opposite phenomena because interflow movement is slower so soil water storage is larger than steep slope of watershed. However, DEM resolution affected less on the hydrological simulation comparing with topographical parameter. Considering processing time and accuracy on hydrological simulation, DEM grid size of 100m is recommended for this range of watershed.

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