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Analysis of Land Use Change Impact on Storm Runoff in Anseongcheon Watershed

Geun-Ae Park, In Kyun Jung*, Mi Seon Lee**, Hyung Jin Shin*,**
Jong-Yoon Park*, and Seong Joon Kim*†

*Dept. of Civil and Environmental System Engineering, Konkuk University, Seoul, Korea
**Dept. of Rural Engineering, Konkuk University, Seoul, Korea

Abstract : The purpose of this study is to evaluate the hydrological impact due to temporal land cover change by gradual urbanization of upstream watershed of Pyeongtaek gauging station of Anseong-cheon. WMS HEC-1 was adopted, and DEM with 200 m resolution and hydrologic soil group from 1:50,000 scale soil map were prepared. Land covers of 1986, 1990, 1994 and 1999 Landsat TM images were classified by maximum likelihood method. The watershed showed a trend that forest & paddy areas decreased and urban/residential area gradually increased during the four selected years. The model was calibrated at 2 locations (Pyeongtaek and Gongdo) by comparing observed with simulated discharge results for 5 summer storm events from 1998 to 2001. The watershed average CN values varied from 61.7 to 62.3 for the 4 selected years. To identify the impact of streamflow by temporal area change of a target land use, a simple evaluation method that the CN values of areas except the target land use are unified as one representative CN value was suggested. By applying the method, watershed average CN value was affected in the order of paddy, forest and urban/residential, respectively.

Key Words : Land cover change, WMS HEC-1, CN.

1. Introduction

During the past two decades in South Korea, land use pattern has been gradually/rapidly changed by human activities in rural and suburban areas, respectively. These include forest reclamation, upland area reclamation, paddy field readjustment, and deforestation & paddy field reduction by building up residential/commercial/industrial areas and road construction.

We can infer that changes of land use pattern affect hydrologic components such as the amount of interception & evapotranspiration, infiltration capacity, which result in the change of soil storage capacity, surface/subsurface runoff process and recharge amount to groundwater. Under rainfall condition, impervious surface decreases infiltration rate, thus accelerates surface runoff. Therefore, it is presumed that increase of impervious areas within watershed affects the hydrograph at a stream location,

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† Corresponding Author: Seong-Joon Kim (kimsj@konkuk.ac.kr)

which result in the reduction of time of concentration and increase of peak runoff and runoff volume. From a viewpoint of relatively long-term hydrologic behavior, impervious surface take away the chance of evapotranspiration and soil moisture storage, changing the process of subsurface runoff and groundwater recharge.

To evaluate long-term hydrologic impacts of land use changes, two fundamental elements are required: a suitable hydrologic model and available data (Choi *et al.*, 2003). Hydrological models are being developed and applied in an increasing number and variety of ways as a means to represent the complex physical processes of the real world in a simplified format (Refsgaard, 1996). These days, the rapid advancement of geographical information systems and their applicability to modellers has matured in hydrologic modelling research based on basic spatial land use, soil and topographical data. To understand the hydrologic effects of urbanization and land use changes, it is better to consider a long-term hydrologic model in preference to a single-event hydrologic model. As argued by McClintock *et al.* (1995), it is important to recognize that the long-term impacts of land use change on water quantity is dominated by the cumulative effects of smaller storm events rather than by rare high-magnitude storm events. In order to trace the land use changes of a watershed during several decades, remote sensing images by Landsat earth resources observation satellite can be used. Remote sensing is recognized as important tool for characterizing land use dynamics, especially for input to hydrologic models.

The purpose of this study is to assess the quantitative effect of stream discharge due to agricultural land use changes including paddy field. To accomplish the purpose, trace land use changes of the selected watershed by using multi-temporal Landsat images during the last two decades. Secondly, analyze the quantitative effect of stream discharge due to agricultural land use changes by applying GIS-based hydrologic model, WMS (Watershed Modeling System) HEC-1 (1999).

2. Tracing the last two decades land cover changes of study watershed using Landsat TM multi-temporal images

To trace how much land use has been changed by human activities in suburban areas, the Anseong-cheon watershed (592.6 km^2) about 70 km away from Seoul in the south direction (Fig. 1) was selected. By the government statistics, the forest and paddy areas of the watershed have decreased by the gradual urbanization.

Table 1 shows the selected Landsat images (April 15 of 1986, April 10 of 1990, April 5 of 1994, April 19 of 1999) and the land use of 4 selected years was classified into 7 categories (forest, paddy field, upland crop, urban, grassland, bare field, water).

By applying Tasseled Cap coefficient (Crist, 1985), the Brightness, Greenness and Moisture bands that show the information of vegetation exactly were

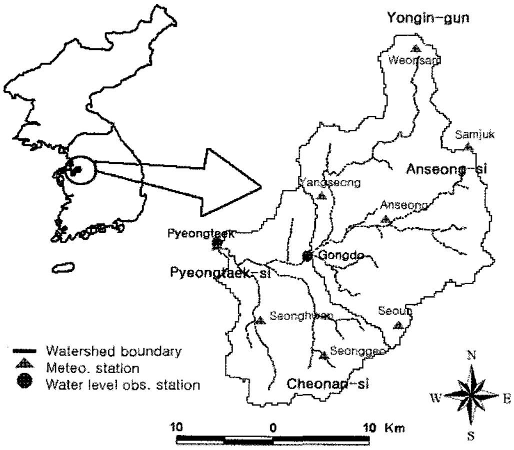


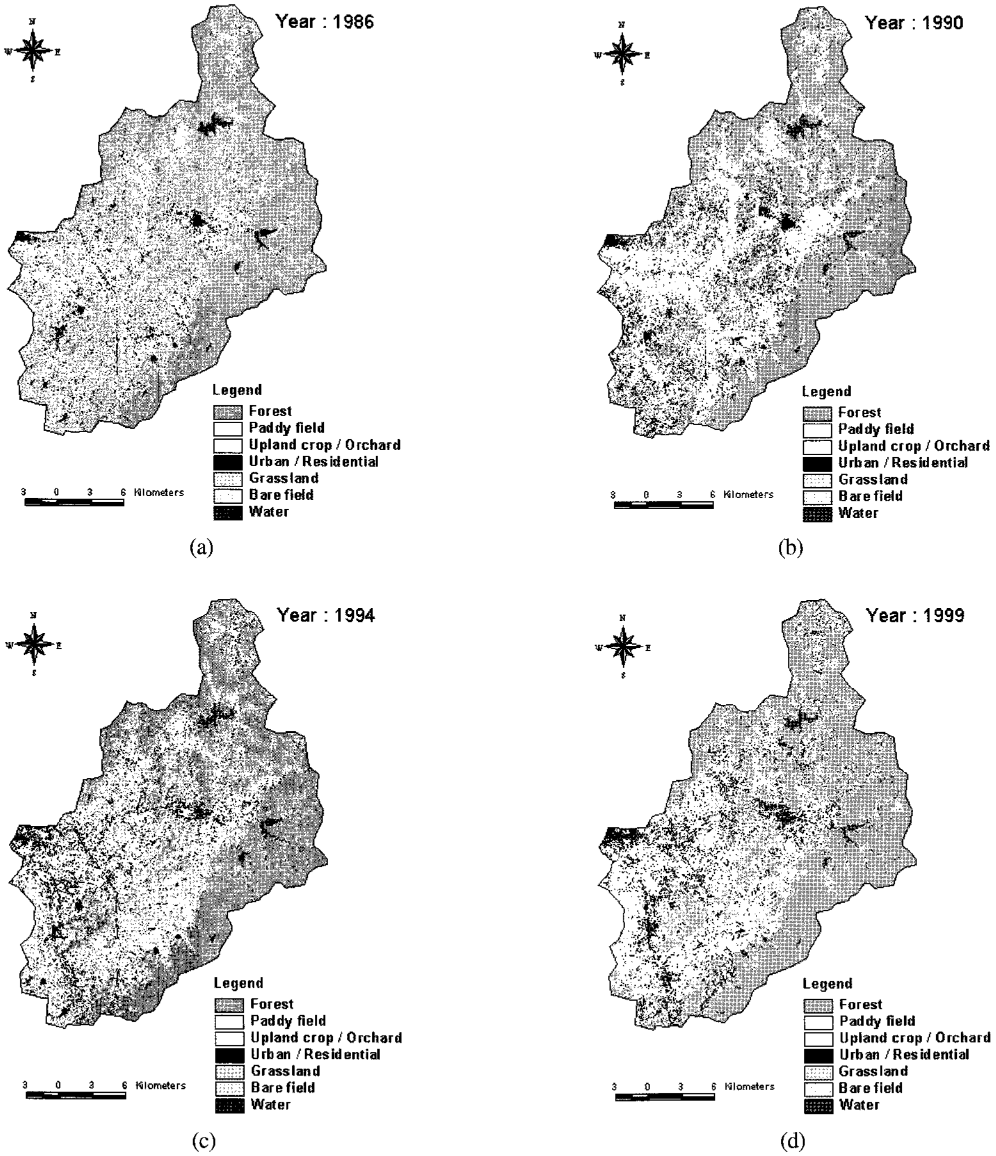
Fig. 1. Anseong-cheon study watershed.

Table 1. Accuracy assessment using error matrix and Kappa coefficient

Date	Overall accuracy (%)	Kappa coefficient
April 15, 1986	98.58	0.98
April 10, 1990	89.45	0.87
April 5, 1994	98.78	0.98
April 19, 1999	92.08	0.90
Average	94.72	0.93

generated. Total six bands (three bands - Brightness, Greenness and Moisture, band 2 for classification of vegetation through the green peak of vegetation reflection, band 4 that is the index of moisture, band 5 for the classification of flood inundation) were applied and classified by using maximum likelihood supervised classification method.

Fig. 2 shows the result of land cover classification for the four selected images. The Kappa coefficients



(a) (b)

(c) (d)

Fig. 2. The classified land cover maps of the study watershed in 4 selected years: (a) 1986, (b) 1990, (c) 1994, (d) 1999.

Table 2. The classified results of land use for 4 selected years

Items	Area (km^2)				Ratio of Area (%)			
	1986	1990	1994	1999	1986	1990	1994	1999
1. Forest	274.6	255.3	251.0	246.2	46.3	43.1	42.4	41.5
2. Paddy field	157.3	149.1	141.9	133.6	26.5	25.2	23.9	22.5
3. Upland crop / Orchard	69.6	78.7	78.9	78.0	11.7	13.3	13.3	13.2
4. Urban / Residential	19.8	42.6	44.1	55.2	3.3	7.2	7.4	9.3
5. Grassland	53.5	55.5	56.2	60.2	9.0	9.4	9.5	10.2
6. Bare field	11.0	1.5	13.2	14.1	1.9	0.3	2.2	2.4
7. Water	6.8	9.9	7.3	5.3	1.1	1.7	1.2	0.9
Total	592.6	592.6	592.6	592.6	100.0	100.0	100.0	100.0

for April 15 of 1986, April 10 of 1990, April 5 of 1994, April 19 of 1999 were 0.98, 0.87, 0.98, 0.90, respectively (Table 1). Table 2 summarizes the area of each category for four images.

During the period of 4 sampled years, it was observed that the urban area and grassland increased 35.4 km^2 (6.0 %) and 6.7 km^2 (1.2 %), respectively. The grassland was developed mainly as golf courses and pasture of livestock farm. According to the increase of urban and grassland areas, forest and paddy field area decreased 28.4 km^2 (-4.8 %) and 23.7 km^2 (-4.0 %) during the past 15 years, respectively.

3. GIS data preparation

1) DEM (Digital Elevation Model) and stream network

Elevation data of 30 m resolution were rasterized from vector map at a 1:5,000 scale that was supplied by the Korea National Geography Institute. Fillburn, one of the stream burning algorithm suggested by Maidment and Djokic (2000) was applied to remove sinks and generate a proper stream network in flat areas. The stream burning process solves the erroneous introduction of artificial parallel streams in the drainage network. This is possible to incorporate streamline data into the DEM to force flow through the grid cells corresponding to the streamline network. DEM and the generated stream network in the study area are shown is Fig. 3.

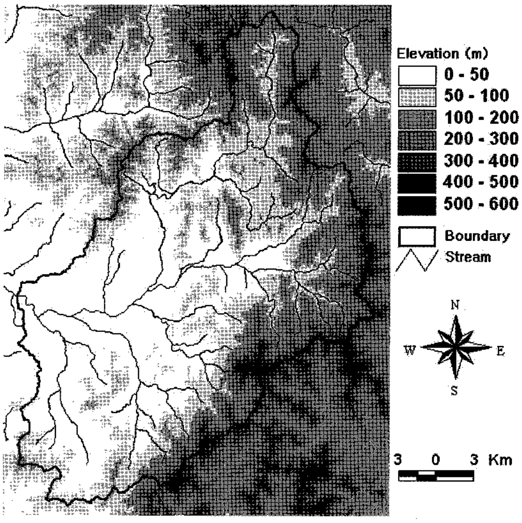


Fig. 3. DEM and the stream network.

2) Soil map and thiessen network

The soil map of 1: 50,000 was rasterized to a 30 m grid size from the vector files supplied by the KRC (Korea Rural Community & Agriculture Corporation). Fig. 4 shows the hydrologic soil group map for WMS input data.

Thiessen polygons were generated from the point vector file using the common function of GIS software, and it was geo-referenced to TM (Transverse Mercator) coordinate system (Fig. 5).

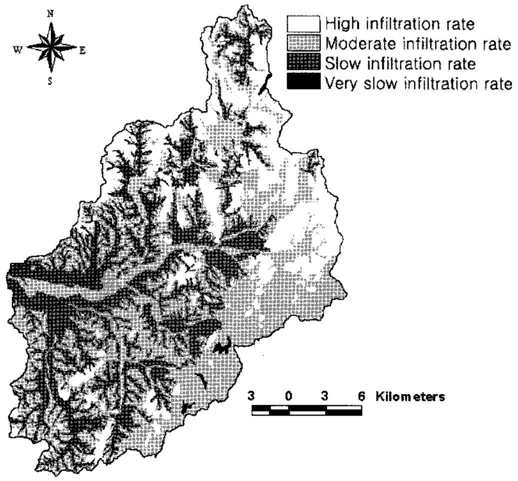


Fig. 4. Hydrologic soil group of the study watershed.

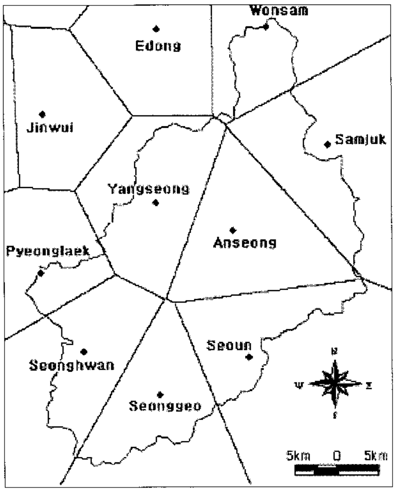


Fig. 5. Thiessen network for the study area.

4. WMS HEC-1 calibration

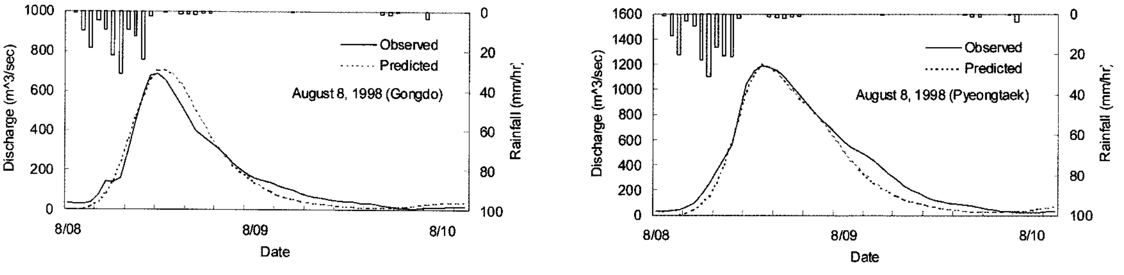
WMS is a computer program that utilizes digital terrain data to delineate watershed and sub-basin boundaries and computes geometric parameters used in hydrologic modeling. WMS includes the HEC-1 flood hydrograph programs used by many hydrologic engineers to model the rainfall-runoff process.

The watershed (WS) was constituted by 2 subwatersheds based on the water level observation stations (Pyeongtaek and Gongdo) as shown in Fig. 1. One subwatershed (WS1) is the upstream area of Gongdo station and the other one (WS2) is the area between Gongdo and Pyeongtaek stations. The model was calibrated by comparing observed with simulated discharge results for 5 summer storm events from 1998 to 2001. The CN (curve number) value was

Table 3. Summary of model calibration and its parameters

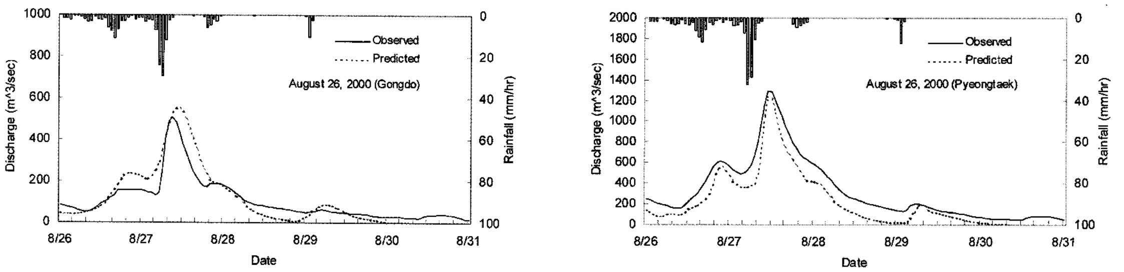
Storm event	Station	Rain-fall (mm)	AMC	Parameters			Peak runoff (m^3/s)		Peak time (hr)		Total runoff (mm)		Peak runoff relative error (%)	Nash-Sutcliffe model efficiency
				Lag time (hr)	K	x	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.		
Aug. 8-13, 1998	GD	196.2	III	8.0	3.0	0.2	684.0	706.7	29	30	96.7	105.2	3.3	0.953
	PT	206.6		4.7			1183.0	1193.7	31	31	130.3	126.3	0.9	0.965
Aug. 2-5, 1999	GD	228.2	II	7.8	1.0	0.2	557.0	562.7	20	21	114.5	96.7	1.0	0.943
	PT	238.3		7.6			1000.0	1016.3	22	23	148.8	111.0	1.6	0.891
Aug.23-Sep. 6, 2000	GD	331.3	II	8.9	0.5	0.5	510.0	546.9	89	91	157.6	180.0	7.2	0.720
	PT	344.0		3.0			1289.0	1238.2	91	91	303.8	229.4	3.9	0.858
Sep. 12-24,2000	GD	211.6	II	9.2	1.0	0.5	209.0	208.6	66	87	108.1	84.3	0.2	0.861
	PT	209.0		2.0			454.0	454.5	69	89	167.5	112.9	0.1	0.864
July.29-Aug. 4, 2001	GD	104.2	III	7.5	1.0	0.5	153.0	155.5	38	38	33.5	30.2	1.6	0.630
	PT	103.8		4.7			453.0	457.2	41	41	60.3	49.6	0.9	0.935
Mean	GD	214.3		8.3	1.3	0.4	422.6	436.1	48.4	53.4	102.1	99.3	2.7	0.821
	PT	241.4		4.4			875.8	872.0	50.8	55	162.1	125.8	1.5	0.903

Note) GD: Gongdo, PT: Pyeongtaek, AMC: antecedent moisture condition, K: Muskingum storage constant, x: weighing coefficient



(a) Gongdo (1998/8/08-1998/8/13)

(b) Pyeongtaek (1998/8/08-1998/8/13)



(c) Gongdo (2000/8/23-2000/9/06)

(d) Pyeongtaek (2000/8/23-2000/9/06)

Fig. 6. Comparison of simulated result with observed data (calibration).

evaluated by using 1999 land cover condition. The CNs for WS1, WS2, the whole watershed were 57.9, 68.0 and 61.7, respectively. Paddy CN (AMC I-63, AMC II- 78, AMC III- 88) was adopted from Im and Park (1997). The CN of WS2 is greater than the CN of WS1 because WS2 has large portions of paddy fields over the flat areas. Table 3 shows the summary of model calibration and its parameters. The average lag time for WS1 and WS2 was 8.3 hours and 4.4 hours, and the average Muskingum storage constant (K) and weighing coefficient (x) were 1.3 and 0.4, respectively. The Nash-Sutcliffe model efficiency (Nash and Sutcliffe, 1970) ranged from 0.630 to 0.965. This means that the model predicted 63.0 % - 96.5 % better than simply using the average streamflow value for the storm event. Fig. 6 shows the simulated streamflow vs. observed one. In this study, the storage capacity of paddy was treated as the antecedent moisture condition, but it depends largely on the time of irrigation before rain. Other sources of error come from the land classification errors and the use of discrete CN values for just 3 antecedent moisture conditions.

5. Assessment of the quantitative effect of stream discharge due to agricultural land use changes

The watershed average CN values of 1986, 1990, 1994, 1999 land cover condition were 61.8, 62.1, 62.3 and 61.7, respectively. Table 4 shows the comparison result of 8/02/1998-8/13/1998 storm runoff by applying each land cover data for 4 selected years. The peak discharge and runoff volume showed 32.7 m^3/sec and 1.7 mm differences for the 1998 August storm. We could not find a certain trend for storm discharge by the 28.4 km^2 decrease of forest and 23.7 km^2 decrease of paddy during the 14 years. This is mainly because the decreased portion of forest CN values (25 77) is compensated by the decreased portion of paddy CN value (78).

Table 4. Comparison of 8/02/1998-8/13/1998 storm runoff by applying each land cover data for 4 selected years

Year	Watershed name (Station)	Average CN	Peak discharge (m^3/sec)	Runoff depth (mm)
1986	WS1 (Gongdo)	59.0	472.4	76.6
	WS2 (Pyeongtaek)	66.5	480.6	120.4
	Total	61.8	920.9	92.9
1990	WS1 (Gongdo)	58.4	456.5	75.1
	WS2 (Pyeongtaek)	68.3	524.8	126.0
	Total	62.1	931.8	94.1
1994	WS1 (Gongdo)	59.0	474.6	76.8
	WS2 (Pyeongtaek)	67.8	513.5	124.5
	Total	62.3	944.2	94.6
1999	WS1 (Gongdo)	57.9	444.3	73.8
	WS2 (Pyeongtaek)	68.0	518.9	125.2
	Total	61.7	911.5	93.0

To identify the impact of streamflow by temporal area change of a target land use, a simple evaluation method was suggested as follows;

a. determines a base year and selects a target land use item to analyse,

b. calculate representative CN value of areas except the target land use (ex, paddy) area of the year and use the CN value to other years (Eq. (1)),

$$\text{RepresentativeCN} = \frac{\Sigma(\text{AreaExceptPaddy TIMES CNExceptPaddy})}{\Sigma\text{AreaExceptPaddy}}$$

$$= \frac{(\text{AreaOfForest TIMES CNOfForest})+(\text{AreaOfUpland TIMES CNOfUpland})+(\text{AreaOfUrban TIMES CNOfUrban})+\cdots}{\text{AreaOfForest}+\text{AreaOfUpland}+\text{AreaOfUrban}+\cdots} \quad (1)$$

c. build an equation for calculating watershed average CN value by using CN of target land use and representative CN of "b",

d. calculates watershed average CN value of other year by applying the changed area of target land use (ex, paddy) (Eq. (2)).

$$\text{WatershedAverageCN} = \frac{(\text{AreaOfPaddy TIMES CNOfPaddy})+(\text{AreaExceptPaddy TIMES RepresentativeCNExceptPaddy})}{\text{WatershedTotalArea}} \quad (2)$$

e. evaluates streamflow of each year by applying SCS-CN method.

Table 5 shows the result of streamflow impact by the area change of paddy, forest, and urban areas, respectively. By applying the method, the watershed average CN decreased 1.0 for 23.7 km^2 decrease of paddy areas. On the other hand, the watershed average CN increased 1.1 and 1.0 for 28.4 km^2 decrease of forest areas and 35.4 km^2 increase of urban areas. The changing rate of watershed average CN per unit area (1 km^2) change is 0.042 for paddy, 0.039 for forest, and 0.028 for urban area. The watershed average CN value and was affected in the order of paddy, forest and urban areas, and it affected proportionally to the peak runoff. The changing rate of peak runoff per unit area (1 km^2) change was 0.72 m^3/sec for paddy, 0.68 m^3/sec for forest, and 0.49

Table 5. Hydrologic impact of streamflow due to area change of one land use item

Year	Paddy				Forest				Urban			
	Area (km^2)	Basin average CN	Peak runoff (m^3/s)	Runoff volume (mm)	Area (km^2)	Basin average CN	Peak runoff (m^3/s)	Runoff volume (mm)	Area (km^2)	Basin average CN	Peak runoff (m^3/s)	Runoff volume (mm)
1986	157.3	60.7	360.8	38.1	274.6	60.0	349.8	37.4	19.8	60.6	360.1	38.1
1990	149.1	60.3	354.5	37.7	255.3	60.8	363.3	38.3	42.6	61.2	371.5	38.8
1999	133.6	59.7	343.8	37.4	246.2	61.1	369.0	38.6	55.2	61.6	377.6	38.9

m^3/sec for urban area.

6. Conclusions

A GIS and RS-based hydrologic modeling approach was tried to assess the quantitative effect of stream discharge due to agricultural land use changes. To identify land use changes of a 592.6 km^2 watershed, Landsat TM images of 4 selected years (1986, 1990, 1994, 1999) of the watershed were used. From the classification results, forest and paddy field area of the study watershed decreased 28.4 km^2 (-4.8 %) and 23.7 km^2 (-4.0 %) during the past 15 years, respectively. Paddy area still covers 22.5 % of the watershed in 1999 even though it has decreased gradually. As input data necessary for hydrologic model, DEM, stream network, soil information map and Thiessen network were prepared.

WMS HEC-1 model was calibrated by comparing observed with simulated discharge results for 5 summer storm events from 1998 to 2001. The Nash-Sutcliffe model efficiency ranged from 0.630 to 0.965. The errors caused by the storage capacity of paddy before rain, and the additional drainage from paddy by farmers. The interactions between a paddy and rainfall dynamics should be conceptualized and incorporated in a hydrologic model, for example by treating as a model parameter.

To identify the impact of streamflow by temporal area change of a target land use, a simple evaluation method that the CN values of areas except the target land use are unified as one representative CN value was suggested. By applying the method, the changing rate of watershed average CN per unit area (1 km^2) change is 0.042 for paddy, 0.039 for forest, and 0.028 for urban area, respectively. Because the CN value of paddy is greater than the watershed average CN, the peak runoff decreased by the decrease of paddy areas.

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