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Impact of land-use changes on stream runoff in Jeju Island, Korea

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Jeju Island, the region with the highest level of rainfall in Korea, is formed by vesicular volcanic rocks and ash causing half of the total rainfall to permeate underground, which gives the Island rich groundwater resources, although most of the streams are dried. The expansion of agricultural land and the massive establishment of tourist development and road construction in the lower area of the streams increase the damage occurring near the lower area of the streams. To achieve the important integration of Jeju Island's water resources, a stable water supply from surface water is needed along with preserving and managing of the groundwater. The changes in the stream flow amount due to prolonged land-cover need to be understood by creating and using a map for rational development and utilization. In this study, the four major streams in Jeju Island were selected for the hydrologic analysis by the The Soil and Water Assessment Tool (SWAT) model according to the change in land use. A land use data from 1975 to 2000 from landsat satellite images provided by the Ministry of Environment and Arcview program was used. Due to the change in land-coverage in four major streams between the past and the present, the areas of impermeable land in the lower area of the streams were generally extended approximately two times higher than in the past. Accordingly, it was proved that the amount of direct runoff has been increasing by at least 1 to 6%. Especially, in the lower part of Oaedo stream, the increase in surface discharge was highest. The quantitative hydrological analysis due to land use change by SWAT model is thought to be a good approach for identifying the impact of land use in Jeju island.

Key words: Jeju Island, soil and water assessment tool (SWAT), land use change, stream runoff.

INTRODUCTION

Although, Jeju Island depends entirely on groundwater for its water resources, the need for a supply of surface water is becoming more and more important to meet the increasing water demands from population growth and the tourism industry (Jeju Special Self-Governing Province, 2003). Especially, the increase in surface water runoff rate by the increase of impermeable land and road construction, ground water pollution caused by urbanization have become serious issues for today. Hydrological monitoring and a hydrological modeling are necessary in order to evaluate the influence of land use changes on runoff. The hydrologic analysis on change of land use has a tendency to prefer a physically based distributed or semi-distributed model to determine the temporal and spatial changes in most watersheds.

Hurkmans et al. (2009) investigated the effect of projected land use change scenarios on river discharge in the Rhine basin, and the sensitivity of mean and extreme discharge in the Rhine basin to land use changes at various spatial scales. Hundecha and Ba´rdossy (2004) assessed the impact of hypothetical land use

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changes by using a conceptual rainfall-runoff model with regionalized parameters.

Mango et al. (2011) assessed the land use and climate change impacts on the hydrology of the upper Mara river basin, Kenya by means of the SWAT (The Soil and Water Assessment Tool) (Arnold et al., 1993) modeling. There have been a few studies on ground water characteristics, and some basic studies of estimating runoff in major streams of Jeju Island. However, few studies have been performed on physically based hydrological modeling on the streams in Jeju Island (Jeju Special Self-Governing Province, 2003). This study focuses on how the land changes due to land developments such as tourist complexes, cultivation of land, development of residential properties, and construction of impermeable layer roads, has any effect on the amount of direct runoff in major streams of Jeju Island between the past and present using the SWAT model. SWAT is thought to be a proper model, because it was developed as a continuous long-term watershed model capable of simulating the movement of water, sediment, and pollutant using watershed status data including soil, land use, pollution source, etc. on a daily basis in gauged watershed as well as even for ungauged watershed (Arnold et al., 1993; Arnold and Forher, 2005; Neitsch et al., 2005; Gassman et al., 2007).

MATERIALS AND METHODS

For SWAT modeling, the watershed of interest is divided into several sub-watersheds with similar hydrologic runoff characteristics. The sub-watershed is further divided into a Hydrologic Response Unit (HRU) commonly using the GIS technique by superposing watershed soil map over land use and extracting an area with similar soil and land use type. All hydrologic components including surface, subsurface, and groundwater flow for each HRU are estimated and summed over a sub-watershed level. In SWAT, soil water is determined by carrying out a water balance in three soil profile zones; soil water zone to plant root depth, unsaturated zone (vadose zone), and saturated zone (Chung et al., 2011). USDA Natural Resources Conservation Service (NRCS) curve number (CN) method (USDA-NRCS, 2004) and Green-Ampt methods (Green and Ampt, 1911) are used for surface runoff estimation, while evapotranspiriation was estimated by various empirical equations including the Penman-Monteith method (Monteith, 1965). Storage routing, kinematic storage model, variable storage method and Muskingum routing methods (Linsley et al., 1982) are used to calculate deep percolation, intermediate runoff, and stream routing, respectively. The relationship between deep percolation and aquifer recharge is expressed by an exponential weight function (Chung et al., 2011).

ArcView GIS, extended and integrated with a hydrologic non-point pollution model (SWAT), provides a comprehensive watershed assessment tool (AVSWAT) designed to assist water resource managers (Di Luzio et al., 2000). The watershed modeling framework for major streams in Jeju Island is delineated starting from the digital description of the landscape [DEM(Digital Elevation Model), land use and soil data sets] using ArcView Spatial Analyst with geomorphological assessment procedures and can integrate databases as well as operate on user provided input data. The hydrological and meteorological data (precipitation, solar radiation, wind speed, climate and humidity), 100 m grid-scale geographical data, land cover map and soil type map were integrated into the AVSWAT model. For the model calibration and verification, the steam flow measurement data of major streams were collected. (Jung and Yang, 2007).

Watershed description

Most streams on Jeju Island are dry streams and consist of small scale streams running along the V-shape valley formed by erosion from the north to the south at the center of the Baek-Rok-Dam at the top of Mt. Halla. These streams show very different characteristics depending on the conditions of topography and rainfall, the stiffness of the slope in the south and north directions, and whether they are considered curvy or direct type streams. Among the 143 streams on Jeju, the four major streams were selected such as Chunmi stream in the East, Oaedo stream in the North, Ongpo stream in the West, and Yeonoae stream in the South (Figure 1). Each stream shows the representative stream types in Jeju Island.

Chunmi stream, which is located in the East, is the longest stream on Jeju, with a length of 25 km. Oaedo stream in the North is 18.3 km, Ongpo stream in the West is 9.6 km, and Yeonoae stream is 9 km. The watershed area of Chunmi stream is 127.64 km^2, the area of Oaedo stream is 44.54 km^2, the area of Ongpo stream is 20.09 km^2, and the area of Yeonoae stream is 19.61 km^2, respectively.

Establishment of input data on SWAT model

Hydrological and meteorological data set up in the watersheds

Meteorological data used for the SWAT model are temperature, solar radiation, wind speed, albedo and humidity. Precipitation and stream flow measurement data are also needed. We used the meteorological data from four weather stations (Jeju, Seogwipo, Sungsan, Kosan) and precipitation data from 67 gauging stations. The four major watershed models were divided into past and present. The status of applying period and rainfall data for each stream is shown in Table 1.

It has been possible to apply past data of rainfall since 1975 to the watersheds in Oaedo stream and Yeonoae stream. For Chunmi stream and Ongpo stream, the record in 1975 was not found, thus for those streams we used data from 1988 to 1997 for each model.

GIS input data

A DEM (30 × 30 m), which provided by Ministry of Environment was used with modification. The results of the DEM showed that Jeju had an altitude of 0 to 1950, the mean elevations of watersheds were 283.69 m, and the mean slopes in streams were 9.04% (Figure 2).

The watershed in Chunmi stream has 394 m of mean elevations, with 7.11% of mean slopes. Oaedo stream has of 468 m mean elevations, with 17.12% of mean slope. Yeonoae stream had 313.5 m of mean elevations and 11.07% of mean slopes. Ongpo stream had 188 m of mean elevations, and 4.86% of mean slopes. The land use map data was offered by the National Water Resources Information System (http://www.wamis.go.kr). These data were classified on the Landsat satellite image in 2000 according to land cover types transformed into a GRID file on Arcinfo and Arcview

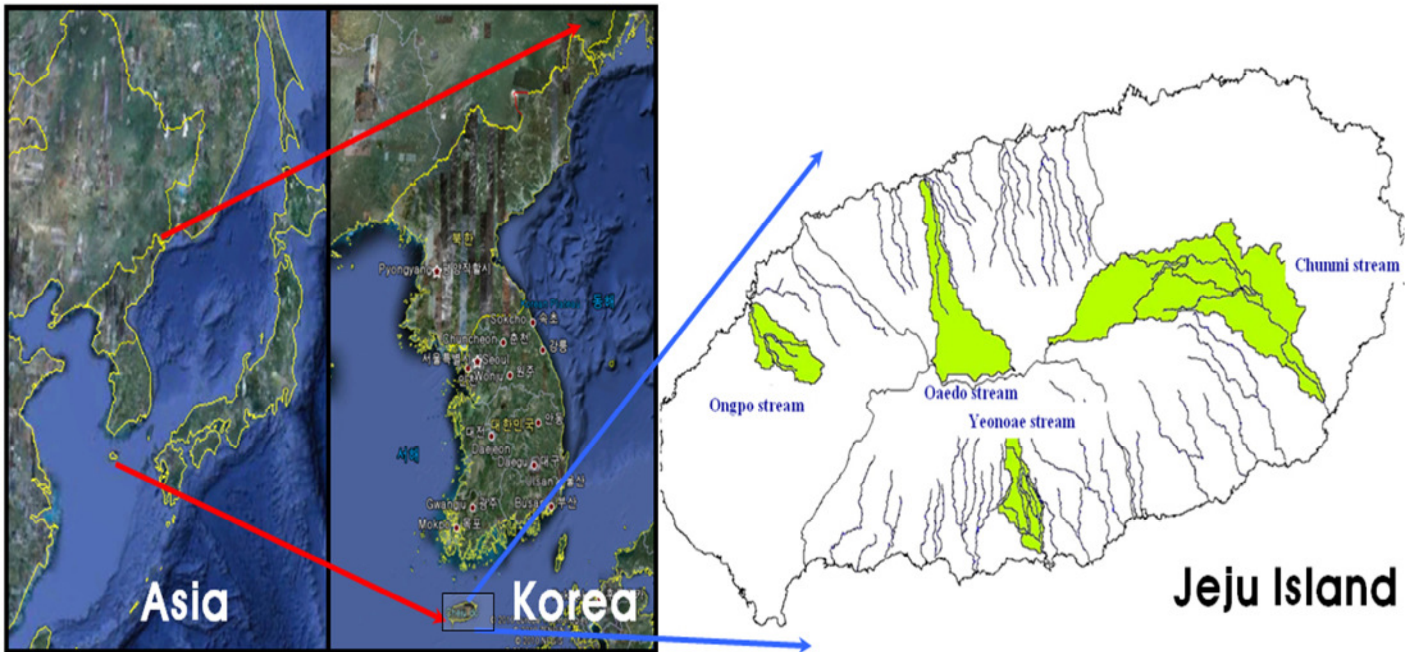


Figure 1. Basin for the study

Table 1. Status of rainfall station at the basins.

Watershed	Period		Rainfall observatory
	Past	Present	
Chunmi	1988. 1. 1~ 1997. 12. 31	2000. 1. 1~ 2009. 12. 31	Sungsan, Pyoson, Gyorae, Songdang
Oaedo	1975. 1. 1~ 1984. 12. 31	2000. 1. 1~ 2009. 12. 31	Jeju, Hangpa, Chunback, Aewol
Ongpo	1988. 1. 1~ 1997. 12. 31	2000. 1. 1~ 2009. 12. 31	Gosan, hanrim, Aewol
Yeonoae	1975. 1. 1~ 1984. 12. 31	2000. 1. 1~ 2009. 12. 31	Seogwipo, Songsandong, Doneko

GIS 3.3. Land use data was used for the model by setting up as 100 × 100m grids (Figure 3). The land use change in Jeju Island from past to present is shown in Table 2. As shown in Table 2, the city area is greatly increased. The detailed land use changes in target watersheds are shown in Tables 3 and 4, respectively. Land use maps of target watersheds are shown in Figure 4.

Soil type map data were designed as input data as 31 types of soil in a series shown on a 1:25000 detailed soil type map offered from the Agricultural Soil Information in the National Academy of Agriculture Science. The soil type map was also transformed as a shape file and attributed values were arranged in the same way as the land use map as shown in Figure 5.

RESULTS

The model validation

SWAT model calibration in Chunmi stream was carried out using the limited measured stream flow data from June to July of 2006. The annual mean runoff rate of 34.11% in Chunmi watershed was obtained (Figure 6). Also, the model calibration in Oaedo stream was carried out using the limited measured stream flow data in 2007

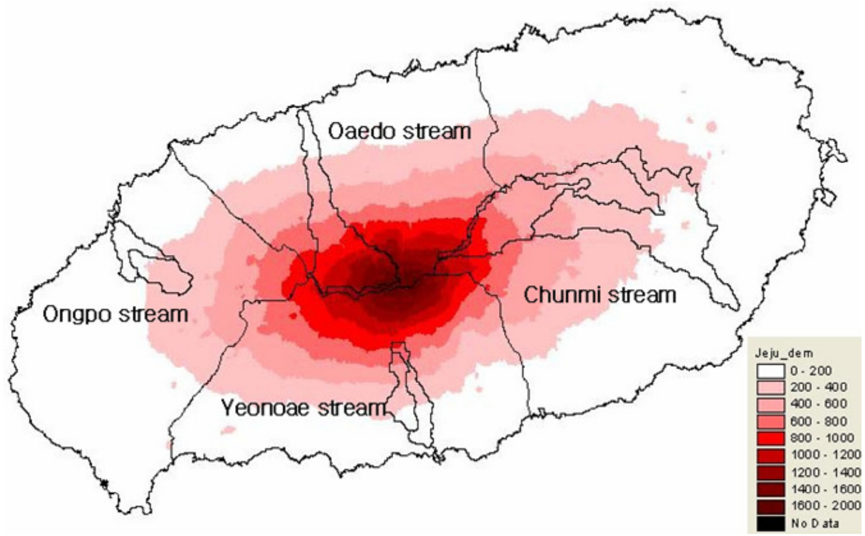


Figure 2. DEM in Jeju Island.

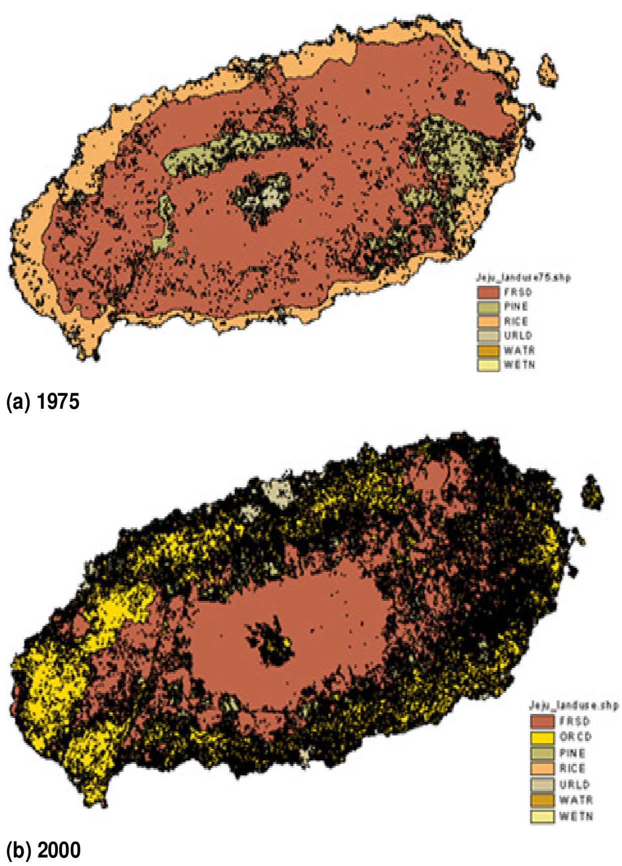


Figure 3. Jeju Landuse Map .

and the simulated mean runoff rate of 35.62% was obtained (Figure 7). For the Ongpo stream which has relatively a long term measured stream flow data, the calibration was performed throughout the two years (2002 to 2003). The result shows good correlation (R^2 = 0.86) and model efficiency (Nash and Sutcliffe, 1970) of 0.56. The mean runoff rate is 26.22% (Figure 8). For the Yeonoae stream, the calibration was performed for the limited measured stream flow data in 2003 (Moon, 2004). The result shows that the runoff rate is 32.38% (Figure 9).

The past and the present comparison of direct runoff

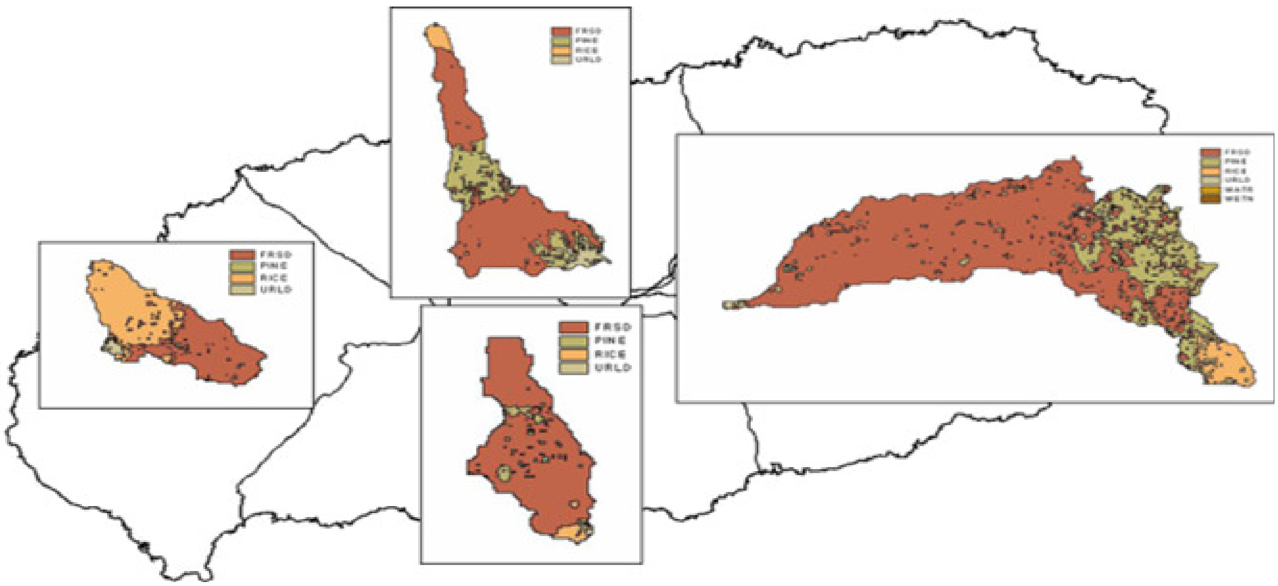
The land cover data used for the SWAT model were classified into past (the land cover of Landset satellite images, 1975) and present (the land cover of Landset satellite images 2000) data. To estimate the amount of stream discharge according to land cover of the past, a model based on actual observation data needed to be calibrated. Since there was no measured stream discharge data for the past while applying the model in the four major watersheds, the stream discharge in the past was estimated by using the parameters used to calibrate the current stream discharge in order to compare stream discharge changes (Figure 10).

Chunmi stream is the region with the highest level of rainfall of the four major streams. A comparison of the amount of stream discharge between the past and present shows that the amount of discharge increases by about 1% compared to the past amount. The result of calculation is listed below in Table 5.

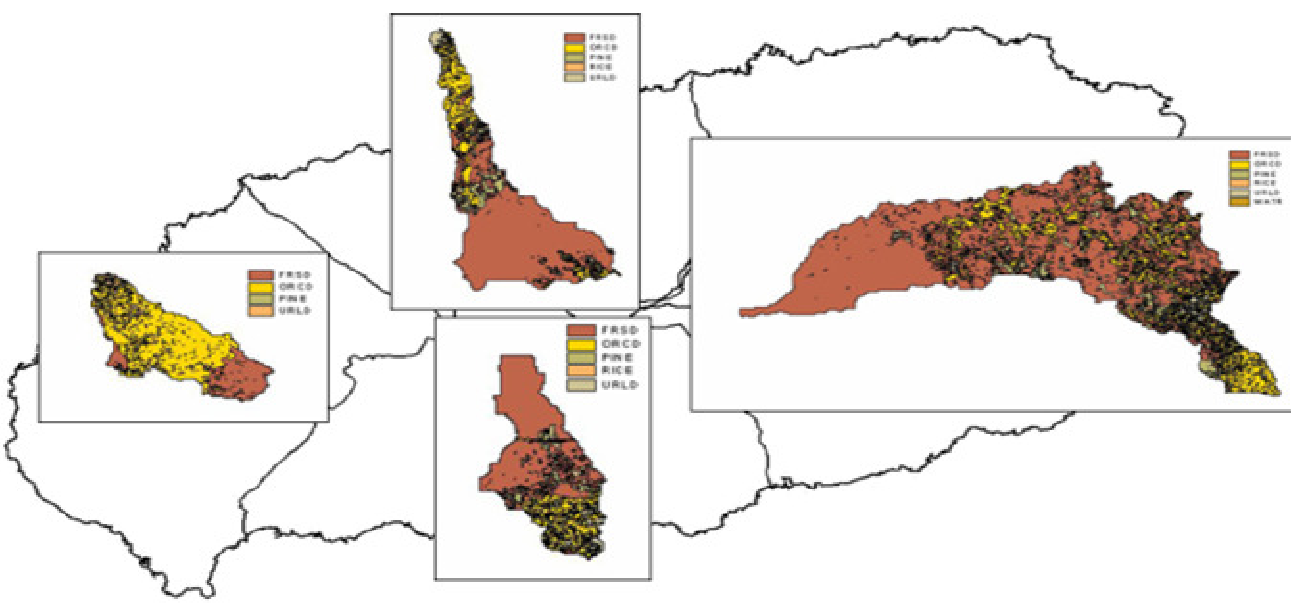
The results obtained using land cover data between past and present in the Oaedo stream showed 16% average runoff rate for a 10 year period in the past (1975

Table 2. Jeju Landuse.

Parameter	Past(1975)		Present (2000)	
	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)
Paddy field	317.4	17.2	282.4	15.3
Grassland	407.8	22.1	432	23.4
Field	148.8	8.06	1.9	0.1
Forest	725.3	39.3	745.6	40.4
City	236.4	12.8	376.5	20.4



(a) Past (1975)



(b) Present (2000)

Figure 4. Land use maps of target watersheds.

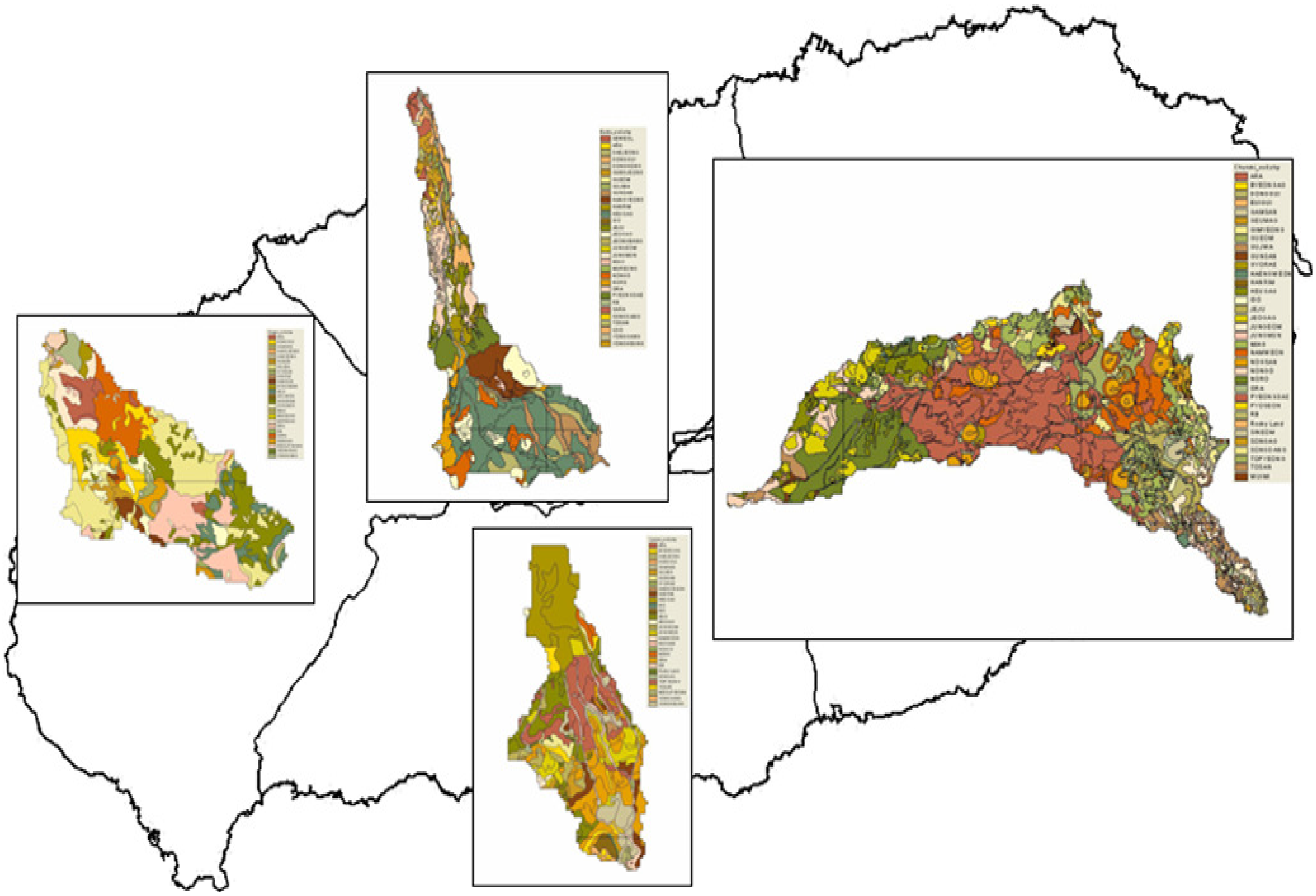


Figure 5. Soil type map for the target watersheds.

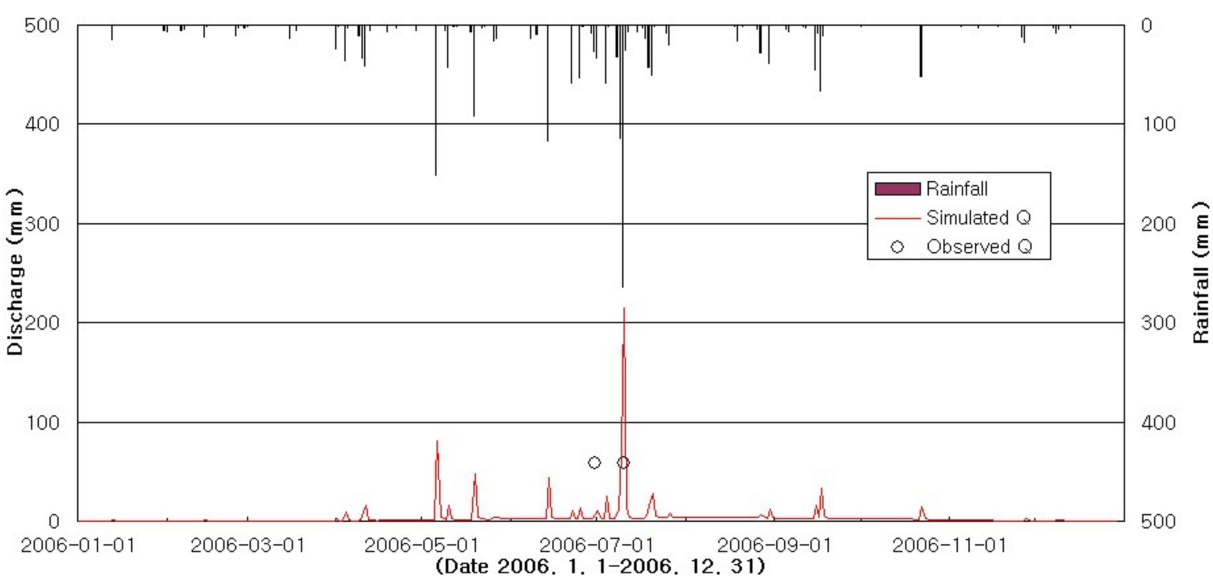


Figure 6. Result of the present runoff simulation of the basin of Chunmi watershed.

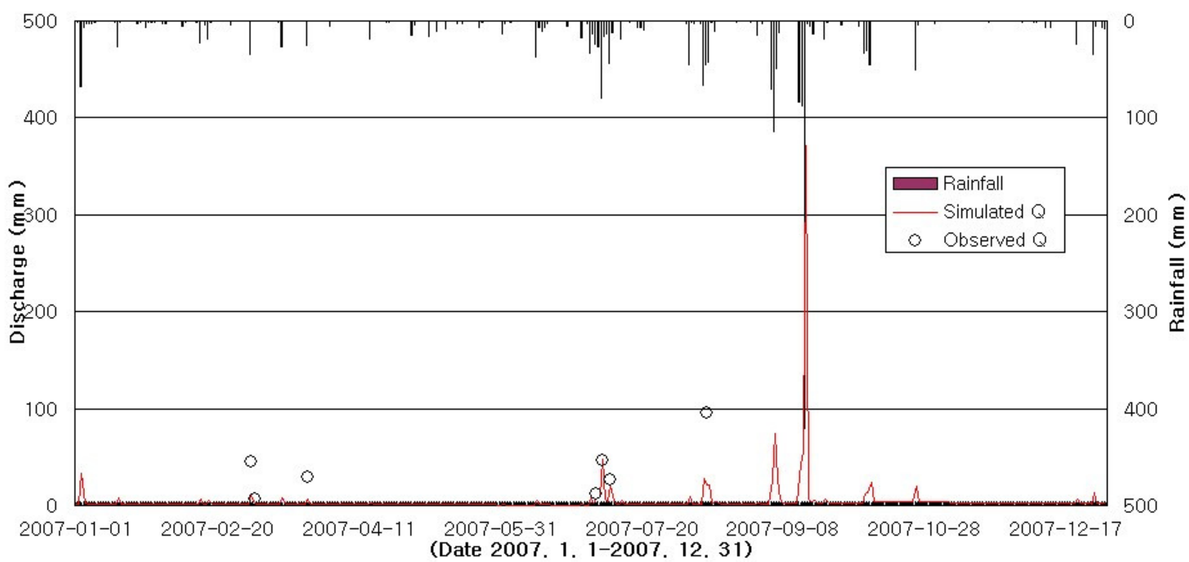


Figure 7. Result of the present runoff simulation of the basin of Oaedo watershed.

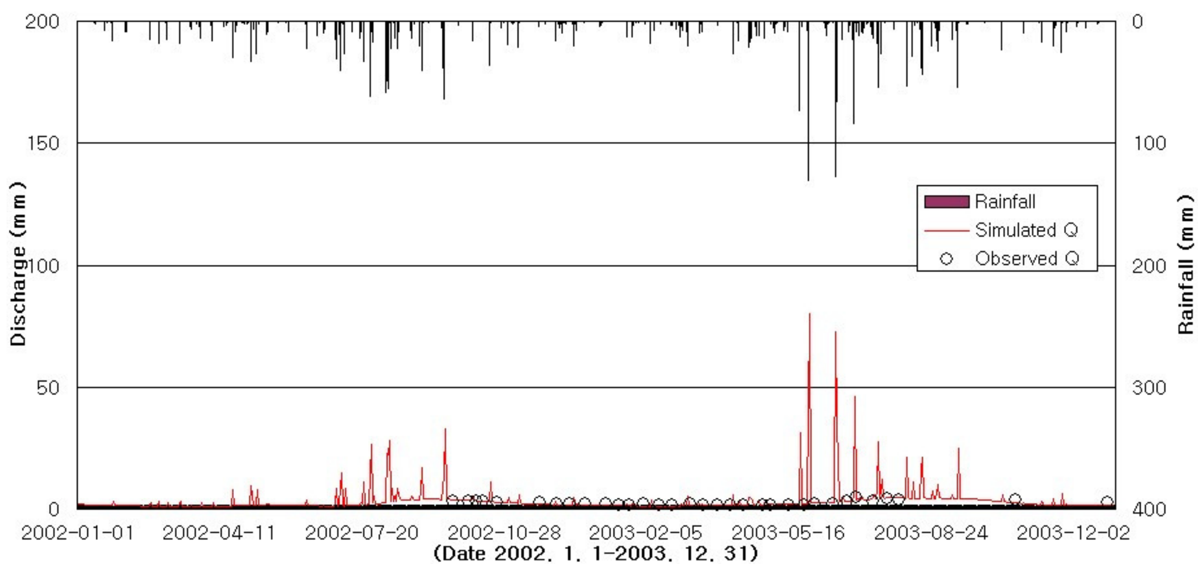


Figure 8. Result of the present runoff simulation of the basin of Ongpo watershed.

to 1984) and 22% for the last 10 years (Table 6 and Figure 11). Impermeable land cover is a major factor with the increase in the runoff rate.

As impermeable land increased, the amount of direct flow discharge grew considerably. Oaedo stream showed the most significant changes of the four major streams, increasing by about 6%.

Ongpo watershed, with the lightest rainfall of the four major streams, had insufficient meteorological data for the past. For this reason, the data from 1988 to 1997 from the other watersheds was used and analyzed for the past runoff data for the Ongpo watershed (Figure 12). The data for land use changes did not show significant differences among the watersheds and the comparative results of direct flow increased by about 1% (Table 7).

The runoff results obtained from the modeling for the past and the present in the Yeanoae stream showed 25.54% average runoff rates for a10 year period in the past (1975 to 1984) and 27.80% for the last 10 years (Figure 13 and Table 8).

Of the 4 major streams, the land-cover changes were most extreme in the Oaedo stream (Figure 14). So the

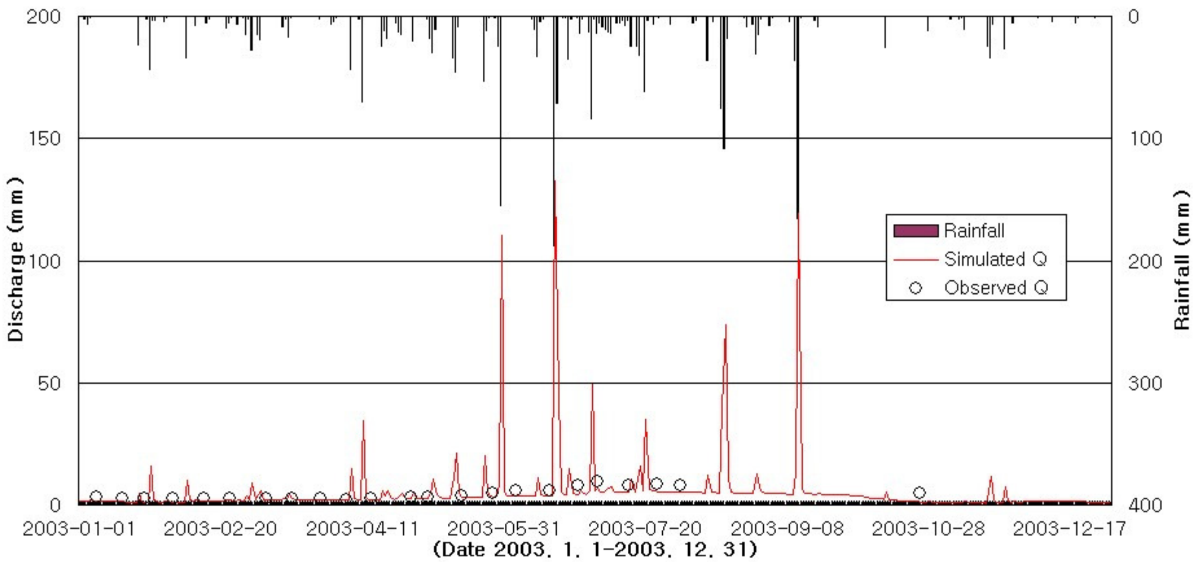


Figure 9. Result of the present runoff simulation of the basin of Yeonoae watershed.

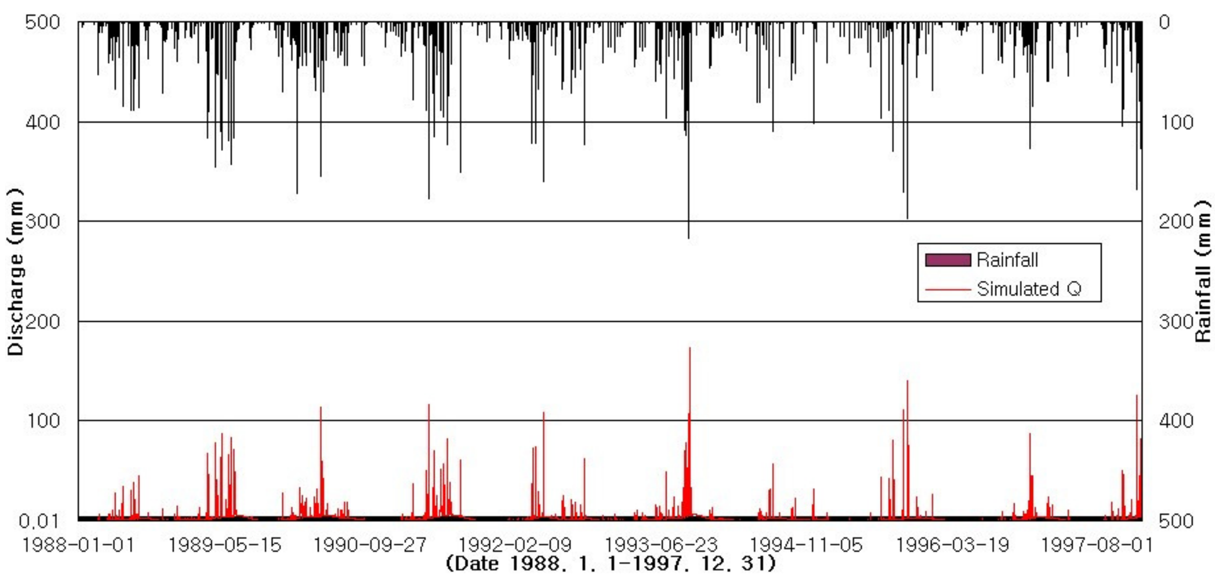


Figure 10. Result of the past runoff simulation of the basin of Chunmi watershed.

Table 3. Land use area at the target watersheds (Past).

Parameter	Chunmi stream		Oaedo stream		Ongpo stream		Younoae stream	
	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)	Area (km^2)	Ratio(%)
Paddy field	0.03	0.02	1.4	2.98	-	-	-	-
Grassland	28.4	21.62	10.3	22.99	0.1	0.52	0.8	3.83
field	6.2	4.68	1.9	4.15	8.3	45.55	0.2	0.63
Forest	95.7	72.88	30.4	68.24	9.2	50.74	17.6	90.09
City	1.1	0.8	0.7	1.64	0.5	3.18	0.2	0.63

Table 4. Land use area at the target watersheds (Present).

Parameter	Chunmi stream		Oaedo stream		Ongpo stream		Younoae stream	
	Area(km^2)	Ratio (%)	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)
Paddy field	0.01	0.01	0.07	0.16	-	-	3.68	0.14
Grassland	11.14	8.73	4.71	10.58	0.30	1.48	2.22	11.32
Field	25.4	19.9	7.31	16.42	13.84	68.87	1.35	18.78
Forest	86.86	68.05	31.52	70.77	4.56	22.70	12.37	6.91
City	4.24	3.32	0.92	2.07	1.40	6.95	0.03	6.86

Table 5. Past and present comparison of direct runoff (Chunmi watershed).

Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff (%)	Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff (%)
1988	1450	288.08	19.87	2000	1854.5	378.12	20.39
1989	2223	737.72	33.19	2001	1584.4	462.81	29.21
1990	1922.9	538.77	28.02	2002	2291.5	829	36.18
1991	2202.4	742.12	33.70	2003	2729.5	1054.65	38.64
1992	1844.5	523.16	28.36	2004	1730.5	483.11	27.92
1993	2043.8	682.99	33.42	2005	1617	409.06	25.30
1994	1222.7	262.86	21.5	2006	1889.9	644.71	34.11
1995	1458	487.92	33.47	2007	2632.1	1061.59	40.33
1996	1161.6	287.3	24.73	2008	1558.2	374.84	24.06
1997	1704.3	576.34	33.82	2009	1753.5	466.51	26.60
Average	1723.3	512.726	29.01	Average	1964.1	616.44	30.27

Table 6. Past and present comparison of direct runoff (Oaedo watershed).

Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff (%)	Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff (%)
1975	1279.5	128.4	10.04	2000	1195	244.9	20.50
1976	1452.5	180.34	12.42	2001	1400	199.6	14.26
1977	1180.8	112.42	9.52	2002	1723	483.4	28.05
1978	1079.8	164.14	15.20	2003	2028	614.5	30.30
1979	1838	471.82	25.67	2004	1356	350	25.79
1980	1545.6	185.52	12.00	2005	900	87.3	9.70
1981	1612.4	431.06	26.73	2006	1555	341.5	21.96
1982	1248	161.29	12.92	2007	2164	770.8	35.62
1983	1373.6	322.2	23.46	2008	1336	227.7	17.04
1984	878.5	136.98	15.59	2009	1328	247.4	18.63
Average	1348.87	229.42	16.36	Average	1498.5	356.7	22.18

Oaedo watershed was selected to be analyzed for comparing the runoff related to land use changes. As shown in the Figure 14, the land use changes rarely appeared in the upper watershed but appeared in the lower watershed. To understand the runoff characteristics, a comparison of runoffs between the upper and lower watersheds was carried out. The model applied to the Oaedo stream was divided into the upper and lower watersheds, and there was little difference in the rates of runoff between the past and present in the upper watershed where the land use hardly changed (Table 9).

As shown in Table 10, there is about 6% increase of runoff in the Oaedo downstream. This coincides with the 6% direct flow increase of the entire Oaedo stream

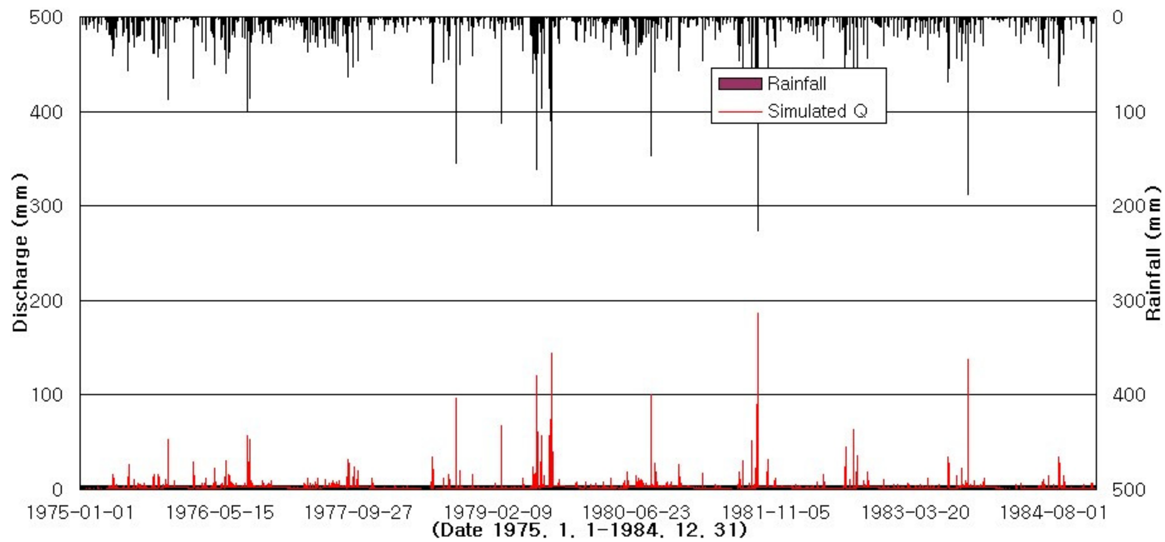


Figure 11. Result of the past runoff simulation of the basin of Oaedo watershed.

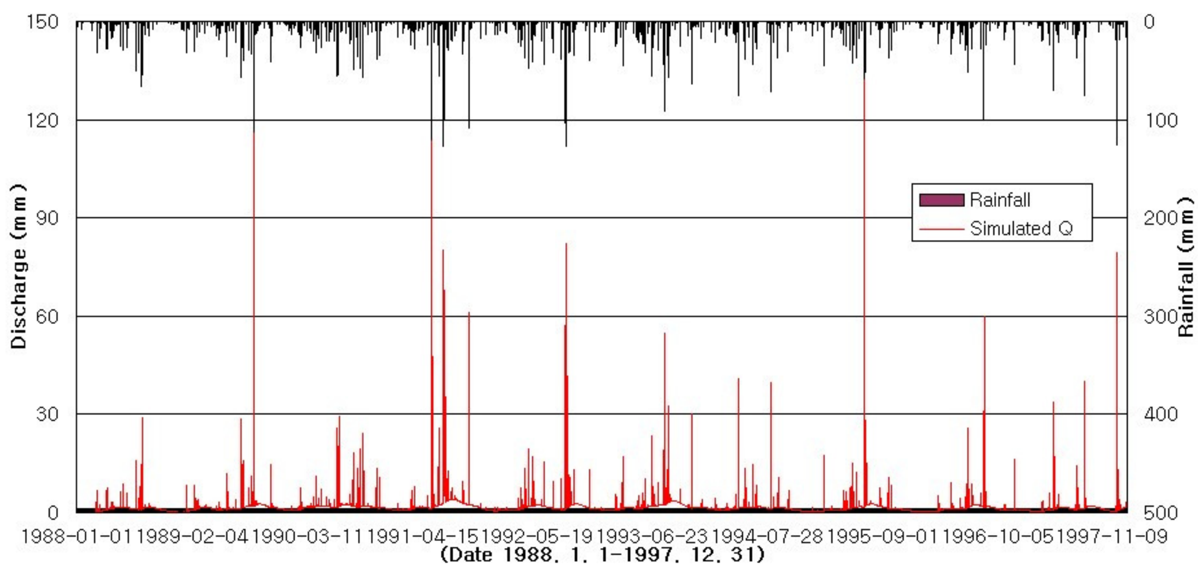


Figure 12. Result of the past runoff simulation of the basin of Ongpo watershed.

modeling. It means that most of runoff increase was produced in the downstream where the major land use change had happened.

DISCUSSION

Jeju Island, the region with the highest level of rainfall in Korea, is formed by vesicular volcanic rocks and ash causing half of the total rainfall to recharge underground, which gives the Island rich groundwater resources, although most of the streams are dried. The expansion of agricultural land and the impermeable area in the downstream area might cause the flood disaster these days. To investigate this land use impact on hydrological change, long term hydrologic analysis for the four major streams in Jeju Island were performed by SWAT (Soil and Water Assessment Tool) model. A land use data from 1975 to 2000 from landsat satellite images provided by the Ministry of Environment and Arcview program was used. Due to the change of land-coverage in four major streams between the past and present, the areas of impermeable land in the lower area of the streams were generally extended approximately two times higher than

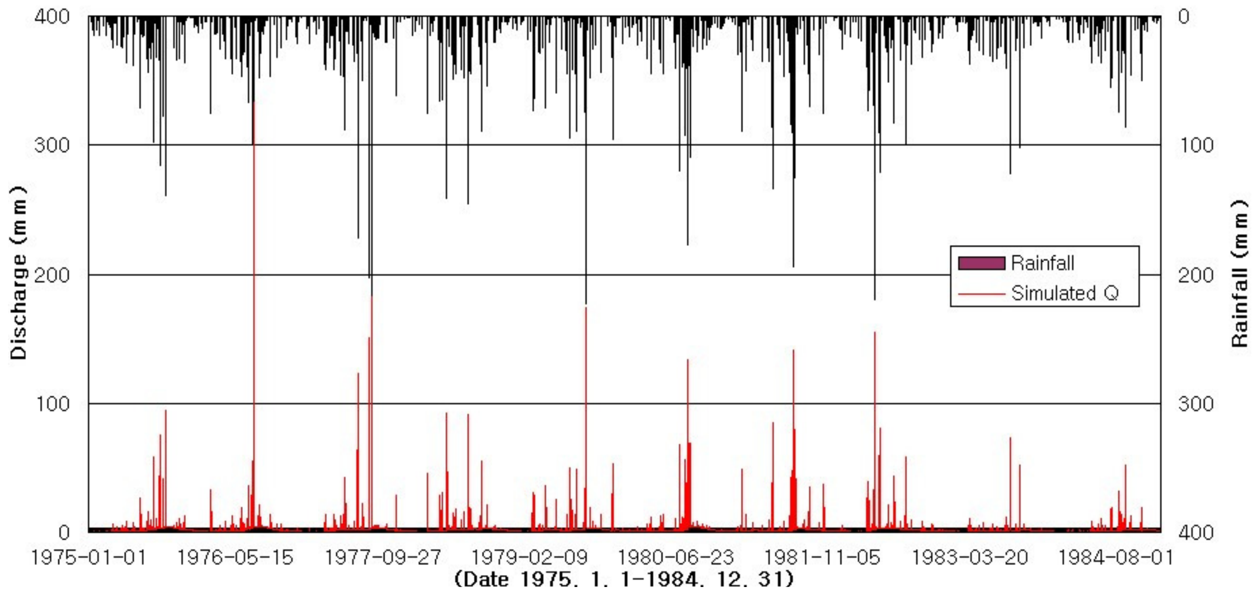


Figure 13. Result of the past runoff simulation of the basin of Yeanoae watershed.

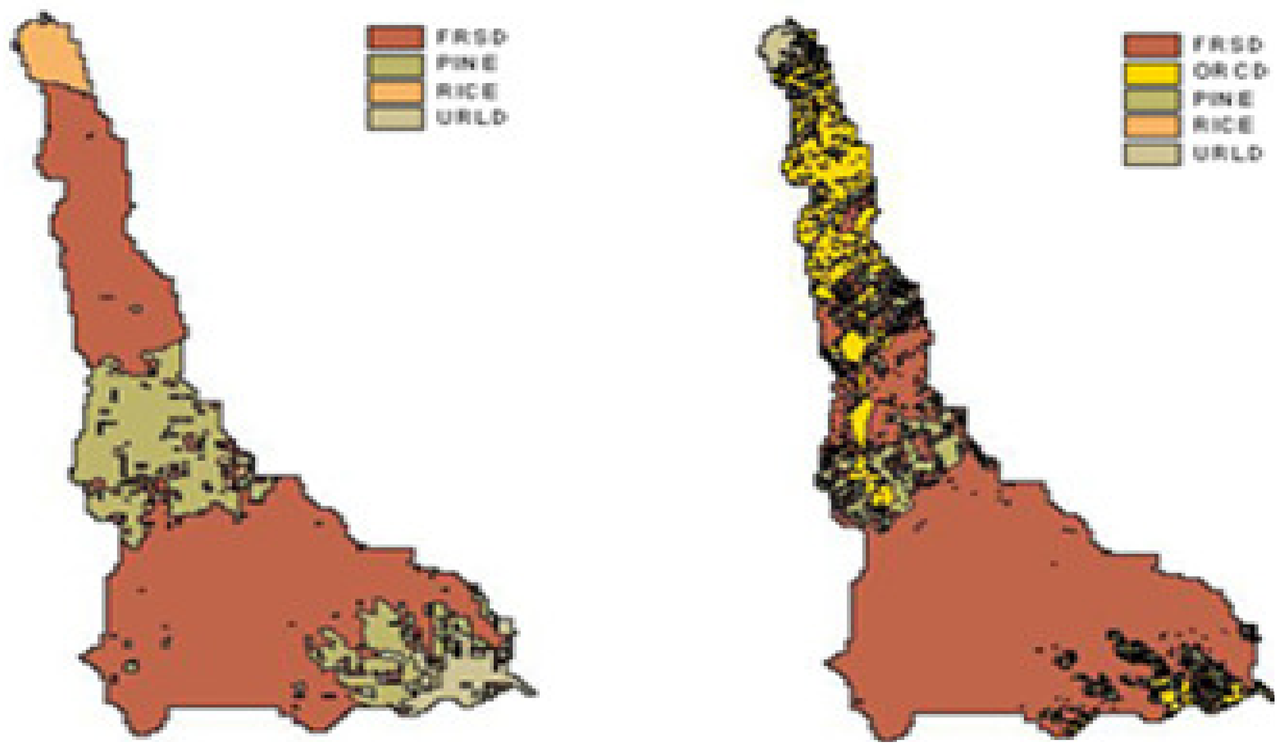


Figure 14. Land-cover map of study watershed (Oaedo 1975, 2000).

in the past. Accordingly, it was proved that the amount of direct runoff has been increasing by at least 1 to 6%.

Especially, in the lower part of Oaedo stream, the increase of surface discharge was highest.

Table 7. Past and present comparison of direct runoff (Ongpo watershed).

Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff (%)	Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff (%)
1988	735.5	132.37	18.00	2000	1018	273.32	26.85
1989	1081.5	257.87	23.84	2001	1124	265.09	23.58
1990	1162.3	232.38	19.99	2002	1252	287.81	22.99
1991	1504	555.35	36.92	2003	1531	450.77	29.44
1992	1107.6	292.77	26.43	2004	1288	397.88	30.89
1993	1151.4	271.71	23.60	2005	848	151.76	17.90
1994	834.3	187.95	22.53	2006	1372	377.52	27.52
1995	1003	280.13	27.93	2007	1320	404.67	30.66
1996	837.4	173.93	20.77	2008	991	193.15	19.49
1997	875.1	223.86	25.58	2009	1149	306.48	26.67
Average	1029.21	264.94	24.45	Average	1189.3	310.84	25.60

Table 8. Past and present comparison of direct runoff (Yeanoae watershed).

Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff (%)	Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff (%)
1975	1833.6	410.23	22.37	2000	1379	309.2	22.42
1976	1987.9	636.61	32.02	2001	1794	471.7	26.29
1977	2009.9	647.8	32.23	2002	1899	515.4	27.14
1978	1827.3	461.3	25.24	2003	2309	747.8	32.38
1979	1899.3	530.5	27.93	2004	2309	740.1	32.05
1980	1699.9	448.9	26.40	2005	1413	321.0	22.72
1981	1833.5	573.6	31.28	2006	1781	432.4	24.28
1982	1887.6	519.1	27.50	2007	2195	728.4	33.18
1983	1149.0	171.0	14.88	2008	1693	464.9	27.46
1984	1232.6	191.4	15.53	2009	2035	612.4	30.09
Average	1736.1	459.0	25.54	Average	1880.7	534.3	27.80

Table 9. Past and present comparison of direct runoff (Oaedo upper stream).

Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff (%)	Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff (%)
1975	1279.5	209.3	15.36	2000	1195	201.7	19.64
1976	1452.5	288.6	18.87	2001	1400	152.6	14.68
1977	1180.8	180.1	14.25	2002	1723	370.3	25.64
1978	1079.8	255.8	22.84	2003	2028	457.3	24.56
1979	1838	647.9	32.50	2004	1356	296.0	24.53
1980	1545.6	288.4	16.44	2005	900	87.3	11.25
1981	1612.4	567.2	28.64	2006	1555	281.1	22.65
1982	1248	248.8	19.85	2007	2164	601.4	29.54
1983	1373.6	311.2	20.65	2008	1336	177.5	17.59
1984	878.5	118.2	13.45	2009	1328	191.4	17.32
Average	1348.9	311.5	20.29	Average	1498.5	281.7	20.74

Table 10. Past and present comparison of direct runoff (Oaedo down stream).

Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff (%)	Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff (%)
1975	1279.5	252.1	19.70	2000	1195	366.5	30.67
1976	1452.5	337.3	23.22	2001	1400	330.6	23.61
1977	1180.8	218.4	18.50	2002	1723	657.9	38.19
1978	1079.8	305.2	28.26	2003	2028	800.5	39.47
1979	1838	733.3	39.90	2004	1356	494.6	36.48
1980	1545.6	335.0	21.67	2005	900	186.7	20.75
1981	1612.4	643.3	39.90	2006	1555	509.2	32.75
1982	1248	294.8	23.62	2007	2164	974.1	45.01
1983	1373.6	361.0	26.28	2008	1336	364.9	27.31
1984	878.5	152.5	17.36	2009	1328	384.8	28.98
Average	1348.9	363.3	25.84	Average	1498.5	507.0	32.32

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