HYDROLOGIC IMPACT ASSESSMENT OF LAND COVER CHANGES BY 2002 TYPHOON RUSA USING LANDSAT IMAGES AND STORM RUNOFF MODEL

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ABSTRACT ... To investigate the streamflow impact of land cover changes by a typhoon, WMS HEC-1 storm runoff model was applied by using land cover information before and after the typhoon. The model was calibrated with three storm events of 1985 to 1988 based on 1985 land cover condition for a 192.7 ㎢ watershed in northeast coast of South Korea. After the model was tested, it was run to estimate impacts of land cover change by the typhoon RUSA occurred in 2002 (31 August - 1 September) with 897.5 mm rainfall. The land covers before and after the typhoon were prepared using Landsat 7 ETM+ of September 11 of 2000 and Landsat 5 TM of September 29 of 2002 respectively. For the 6.9 ㎢ damaged area (3.6 % of the watershed), the peak runoff and total runoff by the changed land cover condition increased 12.5 % and 12.7 % for 50 years rainfall frequency and 1.4 % and 1.8 % for 500 years rainfall frequency respectively based on AMC (Antecedent Moisture Condition)-I condition.

KEY WORDS: Land Cover, Damaged Area, Huff's 4th Quantiles Method, Curve Number, WMS HEC-1

1. INTRODUCTION

Typhoons usually pass over South Korea in late summer, especially in August, and bring torrential rains. Flooding occasionally causes considerable damage. In September 1984, record floods caused the deaths of 190 people and left 200,000 homeless. Recently, flood damage caused by typhoon has occurred frequently in South Korea.

Typhoon Rusa in 2002, the Malaysian word for deer, was the most powerful typhoon to hit South Korea since Sarah in 1959, which left over 840 people dead or missing. More than 17,000 houses and buildings in low-lying areas were submerged, forcing 27,474 residents to take shelter at public buildings and schools. One of the hardest hit areas was the east coast province of Gangwon, where 128 people were killed or missing. The province seat of Gangneung, a city of 220,000, was swamped by waist-high floods after 897.5 mm of rain fell in less than two days (from 31 August to 1 September). Soil erosion, landslide, two dam breaks and flood inundation by stream bank collapses caused a terrible damage in agricultural fields and residential areas. Misfortune on top of misfortune, the damaged area was damaged again by typhoon Meami in 2003.

A speedy rehabilitation of the damaged area through the spatial investigation is necessary for the preparation of a next disaster. Satellite image has the ability to identify the flood disaster area if a field survey is difficult because the disaster area is quite expanded and transport accesses were destroyed. Further, the damaged land cover condition certainly influences the stream discharge. The analysis of hydrological impact on land cover changes by the typhoon can give information for the priority and level of the stream banks rehabilitation.

In this study, land cover maps before and after the typhoon were developed using Landsat images for the severe damaged area, and a hydrological analysis was conducted to understand the influence of land cover changes for several rainfall frequencies.

2. THE STUDY WATERSHED

Figure 1 shows the study watershed. The latitude ranges from 37° 34′ to 37° 46′ and the longitude ranges from 128° 42′ to 128° 55′. The watershed area is 192.7 ㎢ and the longest stream length is 42.9 ㎞. For the hydrological analysis, the watershed is divided into four sub-watersheds and each watershed characteristics is shown in Table 1. The stream discharge data at the watershed outlet has not been collected continually. The collected rainfall-runoff events for the calibration and verification of the hydrological model are shown Table 2.

Within the watershed, Gangneung agricultural reservoir was collapsed by the typhoon Rusa. This intensified the damage for the agricultural lands and the residential areas in the WS # 1.

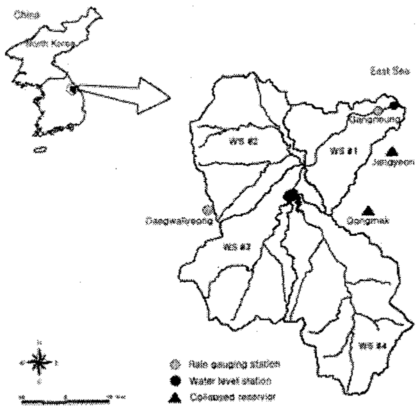


Figure 1. Study area.

Table 1. The watershed characteristics

Watershed	Area (km^2)	Slop (m/m)	Length (km)
WS #1	31.6	0.199	8.7
WS #2	42.3	0.378	8.1
WS #3	57.2	0.467	12.0
WS #4	61.6	0.486	14.1
Total	192.7	0.383	42.9

Table 2. The collected rainfall-runoff events for model calibration and verification

Storm event	Average rainfall (mm)	Rainfall duration (hr)	Max. rainfall intensity (mm/hr)	Note
September 18, 1985	64.1	36	8.5	Calibration
August 29, 1987	140.7	76	15.6	Calibration
August 17, 1988	52.0	92	7.5	Calibration
September 23, 1999	94.2	35	9.0	Verification

3. INPUT DATA PREPARATION

3.1 RS data

Table 3 shows the selected Landsat images. As the rainfall events from 1985 to 1988 are used for hydrologic model calibration, the land cover information as model input was prepared using the image of 1985. Land cover map of 2000 was used as model input as the 1999 rainfall event was used for model verification.

The September 11 of 2002 image was selected as the after typhoon image that passes 10 days after the typhoon. The image was selected because the study watershed has just 1 % cloud cover. The September 29 of 2000 image was selected as before typhoon image because the image is fine for cloud status and it has the seasonal similarity with the after typhoon image.

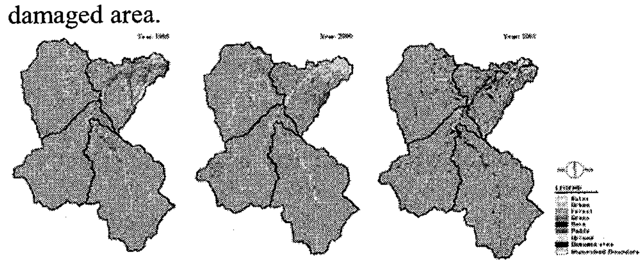
Table 3. The selected Landsat images

Date	Sensor	Path/Row	Cloud (%)	Remarks
October 14, 1985	TM	115/34	0	for model calibration
September 29, 2000	ETM^+	115/34	0	before typhoon, for model calibration
September 11, 2002	TM	115/34	1	after typhoon

For the before typhoon image, the land cover was classified with 7 categories (forest, paddy field, upland crop, urban, water, bare soil, grassland). For the after typhoon image, 8 categories including the category of 'damaged' was used for classification.

By applying Tasseled Cap coefficient (Crist, 1985), the Brightness, Greenness and Moisture bands that show the information of vegetation exactly were generated. These bands are applied for the classification to extract the damaged area by typhoon as accurate as possible. 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.

Figure 2 shows the result of land cover classification for three selected images. The Kappa coefficients for October 14 of 1985, September 29 of 2000, September 11 of 2002 were 0.84, 0.97, 0.99, respectively. Table 4 summarizes the area of each category for three images. After the typhoon, area of 6.9 ㎢ was classified as damaged area.



(a) (b) (c)

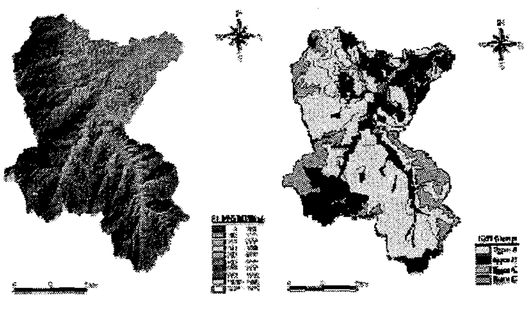
Figure 2. Land cover map (a) for model calibration (1985), (b) before typhoon (2000), (c) after typhoon (2002).

Table 4. The results of land cover classification

Item	Area (㎢)			Ratio of Area (%)		
	1985	2000	2002	1985	2000	2002
Water	0.8	0.5	0.5	0.4	0.3	0.3
Urban	1.8	6.4	6.0	0.9	3.3	3.1
Forest	162.5	159.6	156.1	84.3	82.8	81.0
Grassland	1.8	0.7	1.9	0.9	0.4	1.0
Bare	0.3	1.0	1.0	0.2	0.5	0.5
Paddy	13.3	14.9	11.1	6.9	7.7	5.8
Upland	12.2	9.6	9.2	6.3	5.0	4.8
Damaged	-	-	6.9	-	-	3.6
Total	192.7	192.7	192.7	100.0	100.0	100.0

3.2 GIS data

Elevation data of 30 m resolution were rasterized from a vector map at a 1:5,000 scale that was supplied by the Korea National Geography Institute (Figure 3a). The watershed boundaries and stream networks were generated using WMS TOPAZ (TOpagrahic PArameteriZation). Soil data were rasterized from a 1:50,000 scale vector map that was supplied by the Korea Rural Development Administration. Using the soil information (degree of drainage) obtained from soil survey data of the Korea Rural Development Administration, the soil was reclassified into SCS hydrologic soil group A, B, C, D as in Figure 3b.



(a) (b)
Figure 3. (a) DEM, (b) Hydrologic soil group.

4. APPLICATION OF WMS HEC-1 MODEL

4.1 Calibration and verification

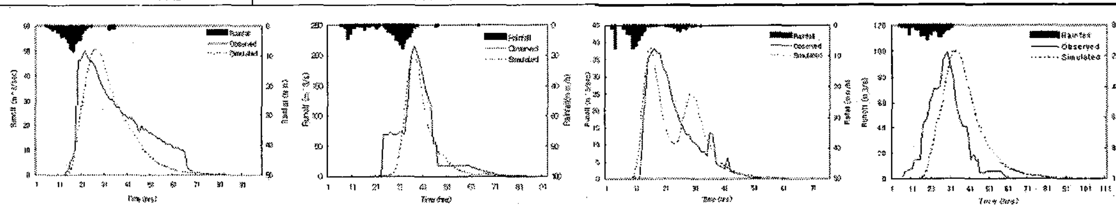
WMS HEC-1 model was adopted for hydrological analysis. WMS (1999) is a computer program that utilizes digital terrain data to delineate watershed and sub-basin boundaries and computes geometric parameters used in hydrologic modeling. WMS includes the HEC-1 flood hydrograph programs used by many hydrologic engineers to model the rainfall-runoff process.

Before model calibration to find proper synthetic unit hydrograph for the study area, SCS unit hydrograph, Clark method and Snyder method are applied. Kirpich empirical equation of Clark method was adopted for WS # 2, WS # 3, WS # 4, and SCS unit hydrograph was adopted for WS # 1.

In order to calibrate the model, sensitivity analysis was used for 4 model parameters [time of concentration (T_c), storage constant (K), lag time (T_g), weighted index (x)]. As a result, T_c and K were sensitive for model calibration. Table 5 shows the result of model calibration and verification. The model verification was executed by the mean value of the parameter through the model calibration.

Table 5. Summary of model calibration and verification

Storm events	Watershed	Rainfall (mm)	AMC	Parameters					Peak runoff (m^3/s)		Total runoff (mm)		Nash-Sutcliffe Model efficiency	Remarks
				Tc	R	Tg	K	x	Obs.	Sim.	Obs.	Sim.		
September 18, 1985	WS 1	64.1	III	-	-	4	81.0	-	50.1	50.9	27.2	21.9	0.81	
	WS 2			5	4	-	-	0.2						
	WS 3			5	8	-	-	0.4						
	WS 4			7	10	-	-	-						
August 29, 1987	WS 1	140.7	II	-	-	5	84.0		216.1	200	63.7	49.0	0.84	Calibration
	WS 2			3	1	-	-	0.2						
	WS 3			3	5	-	-	0.2						
	WS 4			5	7	-	-	-						
August 17, 1988	WS 1	52.0	III	-	-	4	62.0	-	38.4	38.9	11.6	11.8	0.62	
	WS 2			4	1	-	-	0.2						
	WS 3			3	5	-	-	0.3						
	WS 4			5	7	-	-	-						
Mean	WS 1	85.6		-	-	4.3	75.7	-	101.5	96.6	34.2	27.6	0.76	
	WS 2			4.0	2.0	-	-	0.2						
	WS 3			3.7	6.0	-	-	0.3						
	WS 4			5.7	8.0	-	-	-						
September 23, 1999	WS 1	94.2	II	-	-	4.3	75.7	-	100.0	100.6	38.9	46.9	0.66	Verification
	WS 2			4.0	2.0	-	-	0.2						
	WS 3			3.7	6.0	-	-	0.3						
	WS 4			5.7	8.0	-	-	-						



(a) 1985/09/18 ~ 1985/09/20 (b) 1987/08/29 ~ 1987/09/02 (c) 1988/08/17 ~ 1988/08/21 (d) 1999/09/21 ~ 1999/09/25
Figure 4. Comparison of simulated result with observed data.

5. ANALYSIS OF HYDROLOGICAL IMPACT BY TYPHOON RUSA USING HUFF'S 4TH QUANTILES METHOD

To analyze the hydrologic impact on land cover changes before and after typhoon, rainfall by Huff's 4th quantiles method was applied. After the calculation of 24 hours duration probabilistic rainfall of 4 frequencies (50, 100, 300, and 500 years) of Gangneung rain gauge station, rainfall for each frequency was distributed using Huff's 4th quantiles method. Among the Huff's 4th quantiles, 2nd quantile was selected because the number of 2nd quantile storm is the highest from 1961 to 1998 (Table 6).

Table 6. The storm number of each quantile from 1961 to 1998

Duration	1st	2nd	3rd	4th	Total
Total	312(27)	331(29)	270(24)	228(20)	1,141
~ 6 hr	103(29)	101(29)	74(21)	76(21)	354
7hr~12hr	94(31)	69(22)	70(23)	75(24)	308
13hr~18hr	53(29)	53(29)	40(22)	34(19)	180
19hr~24hr	23(23)	34(33)	30(29)	15(15)	102
25hr ~	39(20)	74(38)	56(28)	28(14)	197
X 〉MEAN	80(20)	137(35)	123(31)	55(14)	395
X ≤ MEAN	232(31)	194(26)	147(20)	173(23)	746

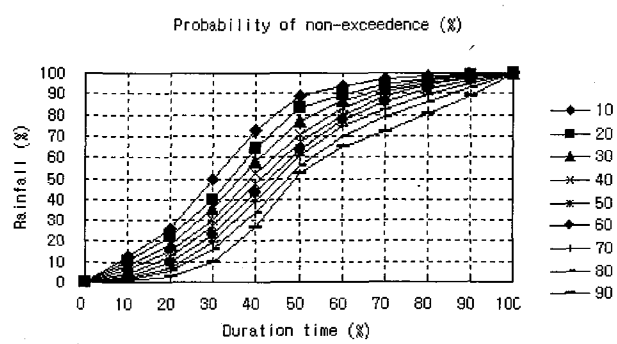


Figure 5. Dimensionless rainfall mass curve of 2nd quantile story.

After the distribution of 24 hrs probability rainfall, rainfall mass curve of 50 % probability of non-exceedance was applied for each frequency. Figure 5 shows the dimensionless rainfall mass curve of rainfall. For each rainfall frequency, AMC (antecedent moisture condition) was applied to analyze the stream runoff impact on land use changes. Table 7 shows the summary of the analysis. As the rainfall frequency increases, the difference of peak runoff before and after land cover condition by typhoon increased and converged in AMC I. There was little increase in AMC II and no difference in AMC III. The difference of total runoff before and after land cover condition by typhoon also showed similar trend but they had little increase even in AMC III. The reason of high difference in AMC I before and after typhoon is that the soil water storage capacity decreased as the land cover of bare soil increased after typhoon.

Table 7. Runoff comparison before and after typhoon

Rainfall			Peak runoff (m^3/s)			Total runoff (mm)		
Frequency (years)	Amount (mm)	AMC	Before	After	Difference	Before	After	Difference
		Ⅰ	399.5	449.6	50.1	118.6	133.7	15.1
50	344.1	Ⅱ	663.4	696.8	33.4	198.1	208.8	10.7
		Ⅲ	867.9	886.4	18.5	262.3	268.6	6.3
		Ⅰ	489.2	545.9	56.7	145.6	162.4	16.7
100	383.1	Ⅱ	774.9	809.9	35.0	232.2	243.6	11.5
		Ⅲ	988.7	1007.3	18.6	299.7	306.2	6.5
		Ⅰ	694.8	765.3	70.5	206.6	221.1	17.5
300	444.7	Ⅱ	955.9	993.1	37.2	287.5	299.7	12.2
		Ⅲ	1181.0	1199.5	18.5	359.3	366.1	6.8
		Ⅰ	712.9	780.5	67.6	212.8	232.8	20.0
500	473.3	Ⅱ	1039.1	1078.8	39.7	313.6	326.2	12.6
		Ⅲ	1269.0	1287.4	18.4	387.1	394.0	6.9

6. CONCLUSIONS

Land cover classification method before and after the damage by typhoon was suggested by using Landsat image. Also, to identify the hydrological impact by land cover changes before and after typhoon RUSA, hydrological analysis considering 24 hrs probabilistic rainfall of Huff's 4th quantiles method was conducted using WMS HEC-1 model. For a 192.7 ㎢ watershed, the damaged area was extracted using 6 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) as 6.9 ㎢. For the hydrological analysis, the model was calibrated and verified using 4 rainfall events. The Nash-Sutcliffe model efficiency for model calibration and verification was 0.76 and 0.66 respectively. The difference of runoff before and after land cover condition by typhoon was more sensitive in Antecedent Moisture Condition before storm than in rainfall frequency.

6.1 References

Crist, E. P., 1985. A thematic mapper tasseled cap equivalent for reflectance factor data, *Remote Sensing of Environment*, Vol. 17, pp. 301-306.

Kojima, T., 2003. Identification of flood disaster area using satellite images on the South Korea flood disaster in 2002, The South Korea and Japan Flood seminar, *Korea Water Resources Corporation*, pp. 23-28.

Nash, J. E., Sutcliffe, J. V., 1970. River flow forecasting through conceptual model, Part I - A discussion of principles, *Journal of Hydrology*, Vol. 10, pp. 283-290.

Watershed Modeling System., 1999. *Brigham Young University Environmental Modeling Research Laboratory.*

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