Analysis on Curve Number, Land Use and Land Cover Changes and the Impact to the Peak Flow in the Jobaru River Basin, Japan

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***Abstract*—The curve number (CN) is a hydrologic parameter used to describe the storm water runoff potential for drainage area, and it is a function of land use, soil type, and soil moisture. Therefore, the land use and land cover changes can be represented by this parameter. This study describes how to estimate the CN due to land use and land cover changes in Jobaru River basin. We applied the ArcGIS tool to delineate river basin and sub-basin, and HEC-GeoHMS tool for estimating the CN. MIKE 11-RR model is used to simulate the rainfall-runoff. The result shows that from 1948 to 2005 the CN of the Jobaru River basin decreased, which indicates that the land capability of reducing flooding was increased during this period. However, in the sub-basin the result is different. In mountainous sub-basin, the CN also decreased but in plain sub-basin the CN increased. This indicates that the land capability of reducing flooding was increased in mountainous sub-basin but decreased in the plain sub-basin. From 1948 to 2005, with the same amount of rainfall applied to the different land use, the peak flow decreased. This shows that the decreasing of CN caused the decreasing of peak flow.**

***Index Terms*—Jobaru river basin, curve number, land use change, peak flow.**

I. INTRODUCTION

Land use change is one of the main boundary conditions which influence many hydrologic processes. The effect of land use changes on river flow is one of the most important environmental problems of our time. Expanding cities due to economic growth and population growth both often come at the expenses of increased risk of flooding and decreased quality and quantity of water. Since the 20th century, the frequency of global flood disaster has been higher than any other centuries. One of the main reasons for this is land use changed by human activities. The land use changes can be represented in curve number (CN).

The CN is a hydrologic parameter used to describe the storm water runoff potential for drainage area. The CN is a function of land use, soil type, and soil moisture.

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Jobaru River basin is one of the most important rivers in Saga Prefecture. During 1948 to 2005, due to the increasing needs of residential area, the Jobaru River basin has been affected by the changes in land use and land cover; especially the decreasing number of paddy fields and the increasing number of urban or built-up land. Several cases had been recorded that there has been major flooding which resulted in loss and damages to the Jobaru River. It was believed that one of the major causes were due to the changes in land use. Jobaru River basin can be grouped into two sub-basins; Jobaru mountainous sub-basin and plains sub-basin. Both parts have very different topography and land use. Data from 1948 to 2005 showed that the land use has changed in Jobaru River basin. For example, barren area tended to turn into forestry in mountainous sub-basin, while in the plain sub-basin, paddy fields tended to turn into urban or built-up land. The changes in land use in both sub-basins would give a different effect. Changes from paddy fields to urban areas in the plains sub-basin will likely continue. It is feared that it will affect the flow of the Jobaru River.

Previous study (H. Matsui, 2008) showed the effect of changing land use on the entire Jobaru River basin, but did not determine the influence of each sub-basin.

From this background, it is important to examine the CN due to land use changes not only in mountainous sub-basin but also in plains one which can be further utilized to analyze floods.

II. MATERIALS AND METHODS

A. The Study Area

Jobaru River basin is located in one of the main islands of Japan called Kyushu. It is in Saga Prefecture (Fig.1). Jobaru River is one of the Chikugo River tributaries. It originates in Sefuri Mountain and flowing to the south east to join the Chikugo River and pour to the Ariake Sea. The geographical position is approximately between 129.9 to 131.0 degrees east and 33.08 to 33.58 degrees north. The area of the basin is 72.8 km^2 and the length of the main channel is 31.9 km. Average annual precipitation is about 2266 mm. The water resources of the basin are heavily developed for irrigation, fire protection, maintaining the environment and waterways. There are a

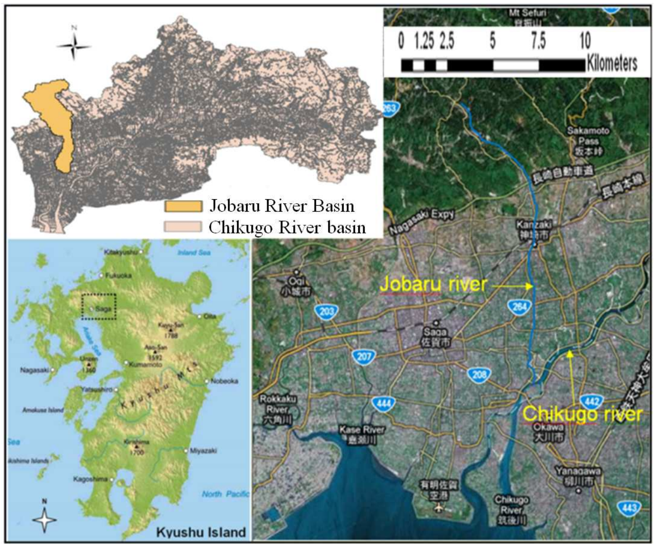

Fig. 1. Study area

number of irrigation schemes supplying water to paddy fields. Jobaru River basin has a varied natural environment. In the middle and lower basins there are a wide variety of plants and animals living there; the upper part contains flora and fauna; the middle part has plants and animals; and downstreams; there are flora and fauna. Floods are normally experienced during the rainy season which has more intense rainfall caused by typhoons. The maximum discharge recorded at Hideki Bridge was 690m^3/s from 1948 to 2005 occurred in rainy season of 1953. Between 1948 and 2005, there were several floods in Jobaru River that caused damages. The discharge was recorded at Hideki Bridge point, from Hideki Bridge Observatory Station.

B. Data Sources

In this section, the details of required data are explained. They are used to estimate CN on land use and land cover change and the peak flow at Jobaru River basin. Digital elevation model (DEM) was provided by Japan digital map 50m grid (Elevation), 1997. The available land use data is the Chikugo Watershed land use was obtained from Ryuiki Shizen Kankyou Chousa Sagyou, for the years of 1948, 1975 and 2005. Soil data was derived from Geological map of Japan (AIST-2003), Soil regions map of Japan based on reclassification, and Digital soil map of the world (FAO). Meteorological data are obtained from MLIT, Japan.

TABLE I
BASIN/ SUB-BASIN CHARACTERISTICS

	Plain sub-basin	*Mount sub-basin*	*Jobaru basin*
Area (km^2)	23.15	51.05	74.2
Length of main Channel (km)	11.4	20.5	31.9

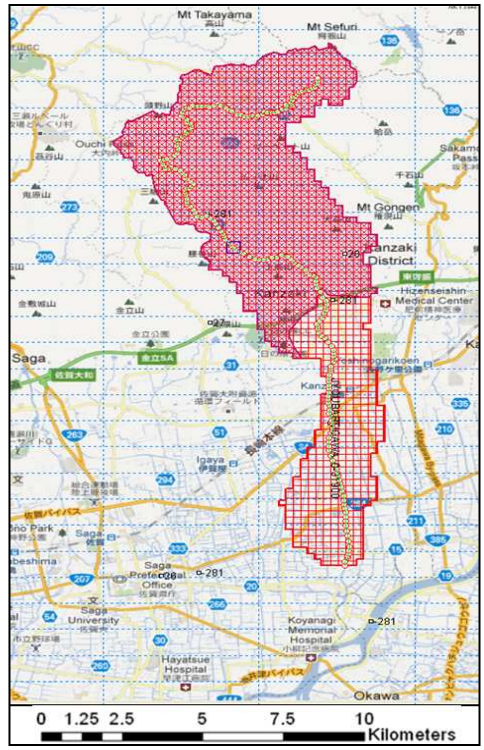

Fig. 2. Jobaru basin and sub-basin

C. River Basin Delineation

The first step in this analysis is to delineate the Jobaru River basin and sub-basin (Fig. 2) using the HEC-GeoHMS. Data needed in this step is DEM data. Jobaru River basin outlet is determined in the downstream near the confluent point with Chikugo River, while mountainous sub-basin outlet is determined in Niiyama. The basin and sub-basin characteristics are shown in Table I.

D. Land Use Analysis

The next step is to define the Jobaru River basin land use map by intersecting the Jobaru basin map with the land use map. The original land use of Jobaru River basin in 1948 is divided

TABLE II
LAND USE RECLASSIFICATION

Code	*Land use description*
1	Water
2	Urban or built-up land
	Forest:
3	Broadleaf forest
4	Coniferous forest
5	Bamboo forest
6	Mixture forest
	Agricultural land:
7	Paddy field
8	Other agricultural
9	Pasture
10	Barren
11	Others

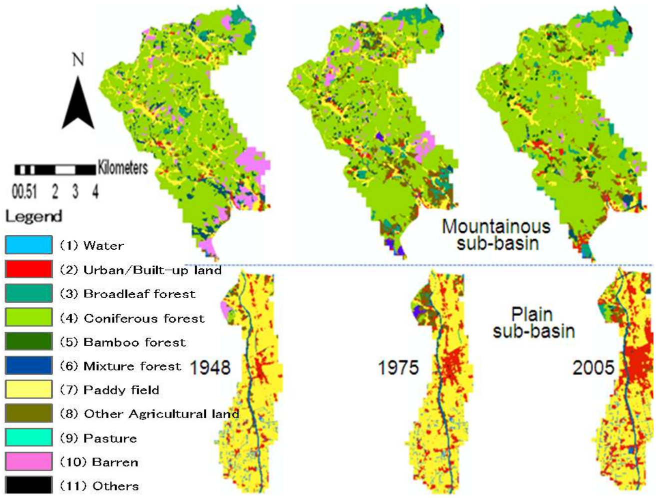

Fig. 3. Basin/ sub-basin land use

into 18 classes, whereas in 1975 and 2005 they are divided into 20 classes. For the purpose of flood analysis, it is necessary to reclassify the land use categories. Land use such as urban, housing, public facilities, schools can be considered the same and can be grouped into one group and classified into urban or built-up land, as well as rivers, lakes, ponds and swamps can be grouped into another, that is classified into water. The Jobaru River basin is reclassified into 11 classes as shown in Table II. Using ArcGIS tool a reclassification map for the Jobaru River basin and sub-basin land use is defined (Fig. 3). The land use change is analyzed between 1948, 1975 and 2005 by using ArcGIS tools.

E. Soil Type Analysis

The next step is to analyze the type of soil. The soil data from Geological map of Japan (AIST) was analyzed by using ArcGIS to obtain the Jobaru soil map, and then it is compared with the soil map of Japan based on reclassification and also digital soil map of the world to obtain the soil types at Jobaru River basin. From this analysis, it obtained that there are three soil types: Fluvic soils, Brown forest soils and Red-yellow soils (Fig.4).

F. Curve Number (CN) Analysis

The next step is to analyze the CN. The CN is estimated for a drainage basin using a combination of river basin DEM, land use, soil and Antecedent Soil Moisture Condition (AMC). The CN generator requires three shape files: (1) the drainage basin boundaries for which CN will be calculated, (2) the soil type map, and (3) the land use map (Fig. 4). The information needed to determine a CN is the hydrologic soil group (HSG), which indicates the amount of infiltration the soil will allow. There are four hydrologic soil groups (USDA, 1986): A; soil having high

TABLE III
HSG OF JOBARU RIVER BASIN

Soil class	*HSG*
Fluvic soils	A
Brown forest soils	A
Red-Yellow soils	C

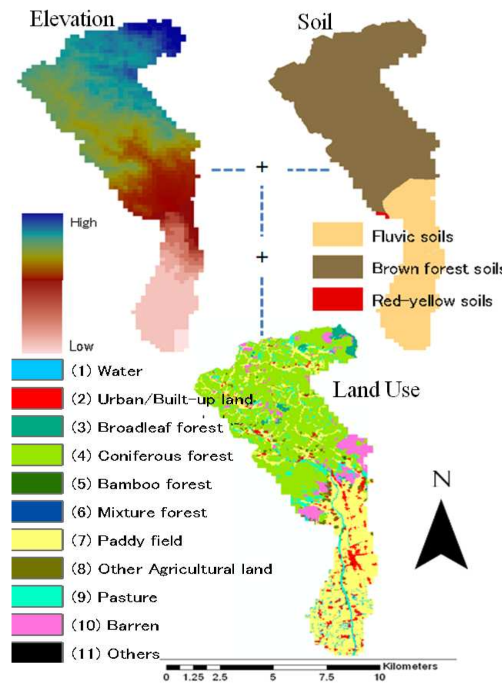

Fig. 4. Three data sets for generating CN

infiltration rates, B; soils having moderate infiltration rates, C; soils having slow infiltration rates, and D; soils having very slow infiltration rates. The hydrologic soil group of Jobaru River basin corresponds to the soil class that was obtained as shown in Table III. Standard Soil Conservation Service (SCS) curve numbers are assigned for each possible land use-soil group combination. Table IV presents the typical land use categories used for hydrologic analysis, along with corresponding curve numbers for each land use-soil group combination. The AMC is defined as the initial moisture condition of the soil prior to the storm event of interest. SCS methodology expresses this parameter as an index based on seasonal limits for the total 5-day antecedent rainfall (McCuen, 1982), as follows: AMC I conditions represent dry soil with a dormant season rainfall (5-day) of less than 0.5 inches and a growing season rainfall (5-day) of less than 1.4 inches. AMC II conditions represent average soil moisture conditions with dormant season rainfall averaging from 0.5 to 1.1 inches and

TABLE IV
LAND USE CATAGORIES AND ASSOCIATED CN

Land use	*Curve Number by Hydrologic Soil*			
	A	B	C	D
Water	100	100	100	100
Urban	77	85	90	92
Broadleaf forest	36	60	73	79
Coniferous forest	40	66	77	85
Bamboo forest	40	66	77	85
Mixture forest	38	63	75	82
Paddy field	67	78	85	89
Other agricultural land	67	78	85	89
Pasture	39	61	74	80
Barren	68	79	86	89
Others	98	98	98	98

growing season rainfall from 1.4 to 2.1 inches, and AMC III conditions represent saturated soil with dormant season rainfall of over 1.1 inches and growing season rainfall over 2.1 inches. In general, CN are calculated for AMC II, then adjusted up to simulate AMC III or down to simulate AMC I. The CN shown in Table IV corresponds to AMC II.

Once the data has been gathered, the typical process for estimating the CN for a drainage area is done as follows:
(a) Define and map the boundaries of the drainage basin(s) for which CN(s) will be calculated. (b) Determine the area of the drainage basin(s). Map the soil types and land use for the drainage basin(s) of interest. (c) Convert the soil types to hydrologic soil groups. (d) Overlay the land use and hydrologic soil group maps, identify each unique land use-soil group polygon, and determine the area of each polygon. (e) Assign a CN to each unique polygon, based on SCS curve number tables (Table IV). (f) Overlay the drainage basin map on the land use-soil group polygons. (g) Calculate the CN for each drainage basin by area-weighting the land use-soil group polygons within the drainage basin boundaries.

The basic equation for CN calculation is

$$CN_{aw} = \frac{\sum_{i=1}^{n} (CN_i \times A_i)}{\sum_{i=1}^{n} A_i} \quad (1)$$

Where CN_{aw} is the area-weighted CN for the drainage basin, CN_i and A_i are CN and area respectively for each land use-soil group polygon, and n is the number of polygons in each drainage basin.

G. *Rainfall-Runoff Analysis*

MIKE 11-RR model is used to simulate the rainfall-runoff processes in Jobaru basin. MIKE 11 tools were developed by DHI Denmark. Within the Jobaru River MIKE11 modeling framework, two hydrology modules are available for use in modeling the rainfall-runoff process. The Unit Hydrograph Model (UHM), which is suitable for the simulations of runoff

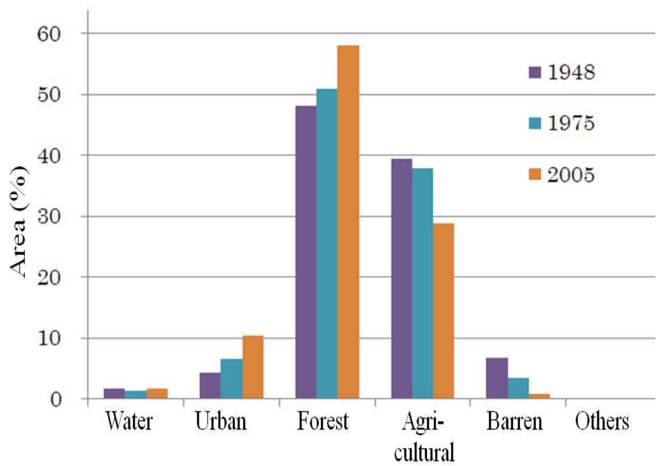

Fig. 5. Land use change in Jobaru River basin

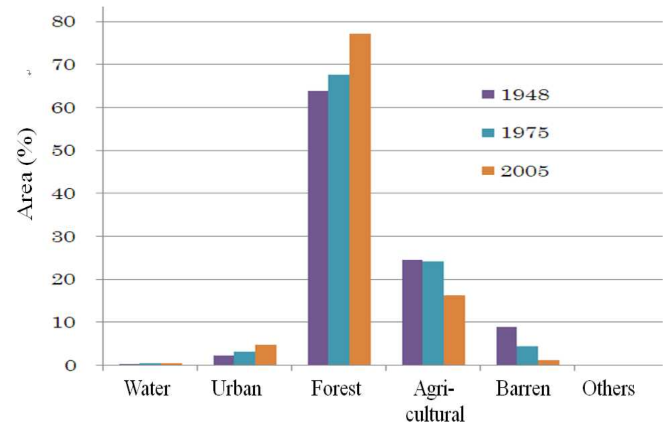

Fig. 6. Land use change in mountainous sub- basin

from a single storm event, and the SCS loss method, is used to calculate the excessive rainfall and the dimensionless hydrograph method is used to generate the time series runoff.

The UHM Module provides for several options for hydrologic modeling including the use of the SCS method to determine runoff volume and hydrograph shape. This work helped to define SCS runoff curve numbers as a function of three types and ages. The excess rain is calculated assuming that the losses to infiltration can be described by the SCS curve number method. The excess rainfall is routed to the river by unit hydrograph methods.

During a storm a part of the total rainfall infiltrates the soil. Large parts of the infiltration evaporate or reach the river a long time after the end of the storm as baseflow. Hence, in event models as the one presented, it is reasonable to describe the major part of the infiltration as loss. The amount of rain actually reaching the river, i.e. the total amount of rainfall less the loss is termed as the excess rainfall.

Data needed are the hourly observed rainfall and hourly observed discharge data.

III. RESULTS AND DISCUSSIONS

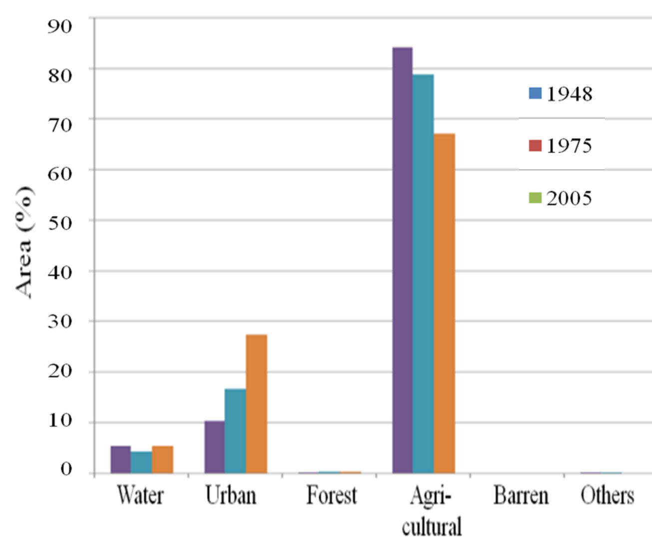

Fig. 7. Land use change in plain sub- basin

TABLE V
AVERAGE CN

River basin/ sub-basin	*Average CN*		
	1948	1975	2005
Jobaru	53.29	53.54	52.03
Mountainous	48.24	48.43	46.07
Plain	68.81	69.04	70.41

A. *Land Use Change*

Jobaru River Basin

According to the analysis, in Jobaru River basin, land use changes significantly in urban area, forestry, agricultural land and barren area, while water and others remained relatively unchanged (Fig. 5). The result of land use changes in 1948, 1975 and 2005 showed that the barren area tended to turn into a forest. After World War II, Japan consumed a lot of wood to build houses, many trees were cut down to be used as construction materials, so many of those forest areas turned barren. This resulted in land use in 1948. Forest area is relatively small and barren area is relatively large compared to the year 1975 and 2005. The land use in 1975 showed that barren area decreased, turning into forest. The results indicates that there is no longer a booming demand for wood as construction materials at that time, reforestation were even made in barren areas, so it turned barren areas into forests and the same thing happened to land use in 2005. On the other hand, the data of land use changes in 1948, 1975 and 2005 showed that the paddy fields tended to turn into a built-up land. This is due to the increased demand of land for residential. Getting land in urban areas becomes difficult and costly so that it forces the expansion into the countryside. One of the options is a paddy field. Paddy field is chosen because this area is still relatively close to urban area with flat terrain, and usually already has existing of small group of housing. Changes from barren into forest will lead to an increase land capability in reducing flooding. The increasing of forest is predominantly caused by changes in barren into forest. Currently almost all of barren area has been turned into a forest, so the possibility of increasing forests in the future is extremely small. On the other hand, the need for residential area will increase continuously; therefore

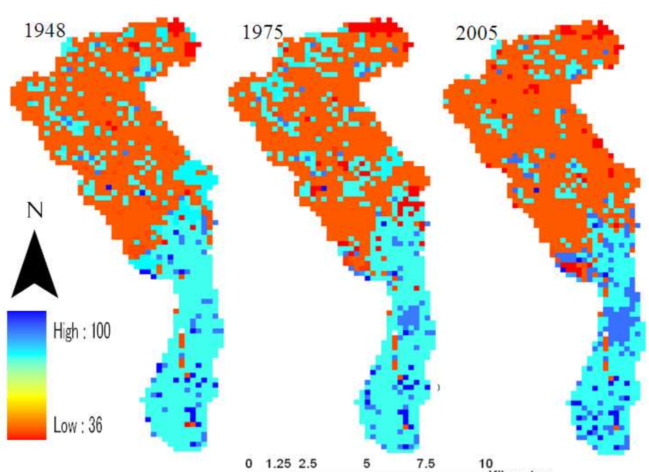

Fig. 8. Land use change in mountainous sub- basin

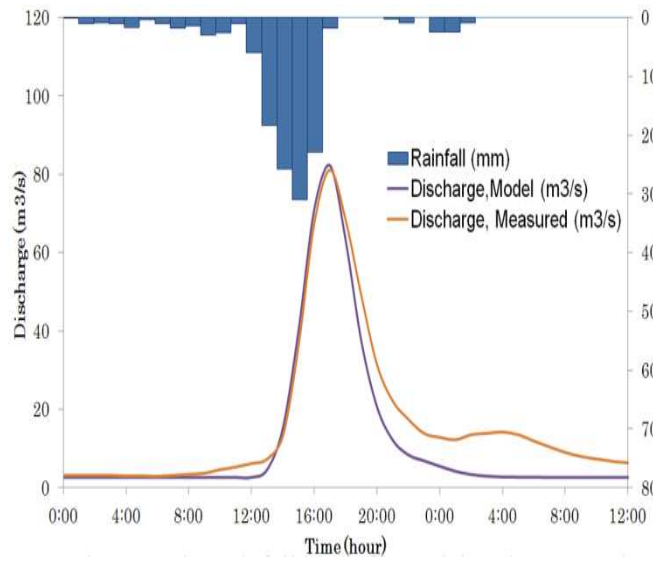

Fig. 9. Basin rainfall-runoff, model and measured, 2005

the tendency of changes in paddy fields into residential area will be very substantial later.

The changes from paddy fields into residential area resulted in the decrease of land capability of reducing flooding. If these land use changes continue to happen, then the peak flow in the Jobaru River will also continue to increase.

Jobaru Mountainous Sub- Basin

In mountainous sub-basin, the land use has changed significantly in forest, barren area, agricultural land, and urban area, while water and others remained relatively unchanged (Fig. 6). Dominantly, barren area turns into forest.

Jobaru Plain Sub- Basin

The land use has changed significantly in urban and agricultural land, while water, forest, barren area and others are relatively unchanged in Jobaru plain sub-basin (Fig. 7). Dominantly, the agricultural land turns into urban areas.

B. *Curve Number*

From the analysis, it indicated that the Jobaru mountainous and plain sub-basin has many unique polygons. Each polygon representing one of the catchment areas and this area-weighted curve number. Each CN is representing a unique sub-basin, soil, land use and topography, therefore the average CN of the basin and sub-basins can be defined. The average CN of each basin and sub-basin are shown in Table V.

The average CN of Jobaru River basin has decreased from 53.29 in 1948 to 52.03 in 2005. In this period, the main land use changes are due to an increase of urban area and forest, while agricultural land and barren decreased. The increases in forestry were caused by changes from barren area turning into forest, while the decreasing of agricultural land was due to the increasing of residential area. The increasing of urban area and the decreasing of agricultural land caused the increasing of CN, on the other hand, the increasing of forest and the decreasing of barren area caused the decreasing of CN. This shows that in this

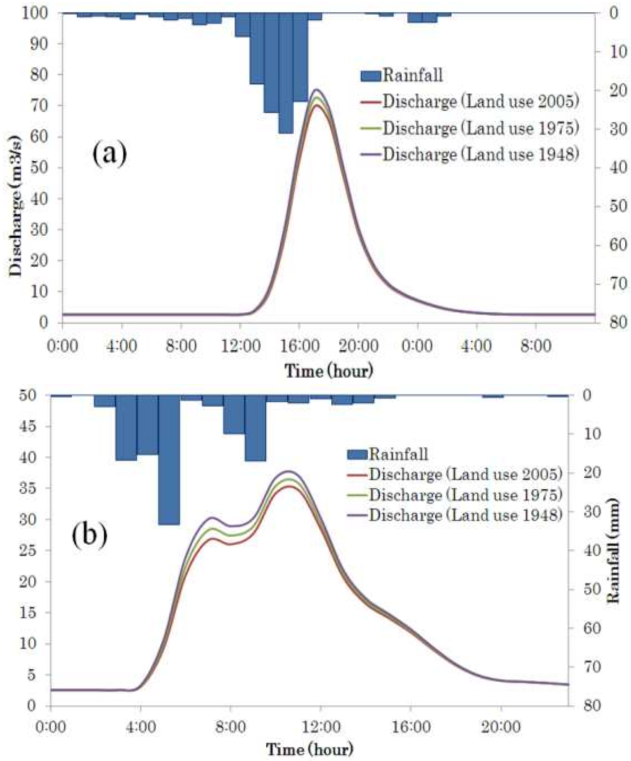

Fig. 10. Basin rainfall-runoff, different land uses, (a) Rainfall model Sept. 6-7, 2005, (b) July 9, 2005

period the whole Jobaru River basin was changed from barren area to forest was more dominant then the changes in agricultural land to urban area. The decreasing of CN indicates that the potential storm water runoff decreased while the increasing of CN means that the potential storm runoff increased so in Jobaru River basin, the potential storm runoff

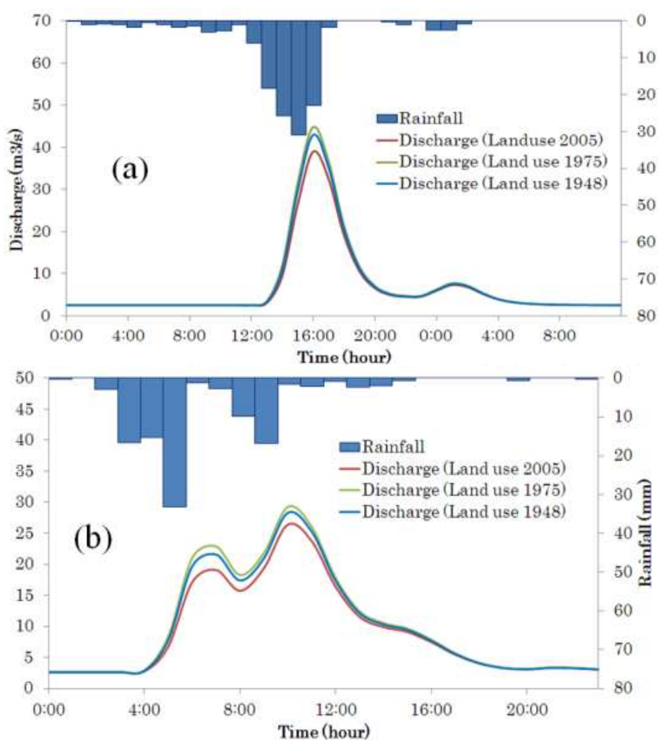

Fig. 11. Mountainous sub-basin rainfall-runoff, different land uses, (a) Rainfall Sept. 6-7, 2005, (b) July 9, 2005

decreased from 1948 to 2005. In each sub-basin, the changes in the average CN are different. In Jobaru mountainous sub-basin, the average CN decreased from 48.24 in 1948 to 46.07 in 2005. This is because in mountainous area the land use and land cover were predominantly forest, and also most of the barren areas were there. In this period almost all barren areas turned into forest, so it causes the CN in mountainous area to decreased. This means the potential storm runoff in Jobaru Mountainous sub-basin decreased. However in Jobaru plain sub-basin, the average CN increased from 68.81 in 1948 to 70.41 in 2005. This is because in that area, the dominant land use and land cover were agricultural land used especially for paddy field and residential area. In this period, a lot of agricultural land changed into residential area, and caused the increase of CN in plain area. This means that in the Jobaru plain sub-basin, the potential runoff increased. From 1948 to 2005, the land use quality in all of the Jobaru River basin changed for the better, but if we considered the sub-basin, it shows that in the plain sub-basin, the land use quality changes was worse. For anticipating the flood in Jobaru River due to the land use change, it is better to consider the sub basins. Currently, almost all barren area have already changed into forest, so the tendency of increasing forestry is limited but the demand for residential area are increasing, therefore the tendency of decreasing agricultural land and increasing urban area becomes a larger problem in the future.

C. River Flow

The rainfall-runoff processes during the period of July 9, 2005 and September 6-7, 2005 under the land use in 1948, 1975 and 2005 were simulated to analyze the response of flood to land use changes. With the same rainfall applied to the different land uses, from 1948 to 2005 in the Jobaru basin and mountainous sub-basin, the peak flow decreased (Fig. 10-11). This shows that the decreasing of CN caused the decreasing of peak flow. The pattern of the discharge hydrograph in both Jobaru River basin and mountainous sub-basin are similar, it shows that in Jobaru River, the runoff predominantly was influenced by the runoff from the Mountainous sub-basin. The CN method is good to analyze the rainfall-runoff in the mountain area, but not in the plain. The impact of the plain sub-basin to the runoff should be analyzed separately by using another method.

IV. CONCLUSIONS

(1) Land use changes during 1948, 1975 and 2005 in Jobaru River basin; urban area and forestry increased, agricultural land and barren area decreased, while water and others remained relatively unchanged. In Mountainous sub-basin; urban area and forestry increased, agricultural land and barren area decreased, and water and others remained relatively unchanged. In Plain sub-basin; urban area increased, agricultural land decreased, while water, forest, barren and others remained relatively unchanged.
(2) The average CN decreased for the whole Jobaru River

basin. This means that the potential runoff decreased. In the Mountainous sub-basin, the average CN also decreased but in the Plain sub-basin, the average CN increased which means that the potential storm runoff increased.

(3) The result indicates that different land uses with different CN remarkably influenced peak flow in Jobaru River. The decreasing of CN caused the decreasing of peak flow.

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