THE EFFECT OF LAND COVER CHANGES ON THE HYDROLOGICAL PROCESS IN JOBARU RIVER BASIN - A STEP FOR INTEGRATED RIVER BASIN MANAGEMENT

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Department of Engineering Systems and Technology
Graduate School of Science and Engineering
Saga University

JEFFRY SWINGLY FRANS SUMARAUW

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by

JEFFRY SWINGLY FRANS SUMARAUW

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Department of Engineering Systems and Technology
Graduate School of Science and Engineering
Saga University
JAPAN

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THESIS EXAMINATION COMMITTEE

Professor Koichiro OHGUSHI
Department of Civil Engineering and Architecture
Saga University
JAPAN

Professor Kenichi KOGA
Department of Civil Engineering and Architecture
Saga University
JAPAN

Professor Hiroyuki ARAKI
Institute of Lowland and Marine Research
Saga University
JAPAN

and

Professor Hiroyuki YAMANISHI
Institute of Lowland and Marine Research
Saga University
JAPAN

ABSTRACT

The effect of land cover change on river flow and inundation is one of the most important issues on river basin management. Jobaru River locates 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 cover. Barren area tended to turn into forest in the mountainous sub-basin, while in the plain sub-basin, paddy field turned into urban or built-up land. Changes from the paddy field to urban area will likely continue. It is feared that it will affect the flow of Jobaru River.

The purpose of this study is to analyze the effect of the land cover changes on the hydrological process in the Jobaru River basin in order to utilize its result as a step for integrated river basin management planning.

The results of this research show that curve number (*CN*) of the entire Jobaru River basin increased during 1948 to 2005 so that the *CN* in the plain sub-basin also increases but in the mountainous sub-basin the *CN* decreases. The land cover changes can be represented by *CN*. The different land covers with different *CN* remarkably influenced a peak flow. The hourly rainfall is used to simulate the peak flow. The result shows that the decrease of *CN* 4.5% from 1948 to 2005 in the mountainous sub-basin causes the decrease of the peak flow 15% at Hideki Bridge.

The discharge in Jobaru River is just influenced by the changing of land cover in the mountainous sub-basin, not by the plain sub-basin. This is because the runoff from the plain sub-basin does not affect the river flow so much because the river dyke in the plain sub-basin is higher than the land surface. The discharge in the river is almost from the mountainous sub-basin. The land cover change in the plain sub-basin influences the discharge that caused by the runoff in the plain area at the down border of the basin on the right side and on the left side of the Jobaru River basin.

Two land cover scenarios were created to get the future land cover effect. The result shows that the discharge at Hideki Bridge and Jobaru River outlet are almost same but the discharge caused by the runoff in the plain area at the down border of the basin on the right side

and on the left side of the Jobaru River basin increases. The total increase from land cover 2005 to land cover scenario 2 was 330%. Actually land cover changes are just one aspect that affects the discharge in Jobaru River.

The initial soil moisture condition also affects the peak flow. The result shows that the difference of rainfall initial depth causes the increase of discharge although the same rainfall patterns are given.

The land cover changed especially during the urbanization causes changes in the hydrograph characteristics. The result shows that the Time Base (*Tb*) and Time to Peak decrease, whereas the peak flow increases.

The land cover changes in the Jobaru River basin affect the hydrological component. There is an increase in total overland flow, but on the other hand there were decreases in infiltrations and evapotranspiration as a response to the land cover change. This situation is due primarily to the expansion of the impervious surface in urban areas. The amount of impervious areas is primarily controlled through the amount of runoff generated from the watershed by decreasing the rates of infiltration and evapotranspiration.

All this time, handling of the Jobaru River environment has been more focused on the mountainous sub-basin. Reforestation in mountainous area turns almost all barren area into forest area. On the other hand there was less attention to the plain sub-basin. Changing from agricultural land to urban area is still continuing. The changes of land cover from agricultural land to urban area in the plain sub-basin gave significant effects to the increasing of the discharge in the down border of Jobaru River basin but it does not influence to the discharge in the Jobaru River outlet. Therefore to manage the flood in Jobaru River, we should consider the land cover changes not only in the mountainous sub-basin but also in the plain sub-basin, and the discharge should be considered not only in the river but also in the land area. This result can be applied to the river basin management.

The increase of discharge in Jobaru River and in the down border of the basin due to the urbanization in the plain sub-basin can be used as a reference for river basin management planning. Many aspects should be considered for the river basin management, not only land cover change. This study provides a reference of the effect of land cover changes as one of the important parts of the integrated Jobaru River basin management. This research will be a useful step for future integrated river basin management which is expected to be used as the foundation for the sustainable development of the Jobaru River basin in the future.

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INTRODUCTION

1.1. BACKGROUND

During the last few decades, frequency of flood, as one of nature's natural hazard that has a great impact on human life, has been increasing. There are various things that contribute to this phenomenon. For example the land cover change, which is inevitable due to the fast growing needs of area for development. One of the most common processes in the land cover change is urbanization. When an area is being urbanized, impervious surface covers the land and reduces rainfall to infiltrate the soil, hence, it increases the amount of water on surface runoff. Moreover, interception loss also occurs and influences water balance. All of these occurrences will lead to flood intensification.

Changes in land cover frequently result in significant impacts to hydrology by affecting the amount of runoff, soil moisture, and groundwater recharge over a range of temporal and spatial scales (Calder, 1992; Im et al., 2003). However, the hydrologic effect of alteration in land cover at a watershed scale is still an unresolved problem and is now a primary concern for most countries, which are commonly experiencing changes in land cover patterns caused by increasing populations and demand for accommodations.

The average annual precipitation in Japan is about 1,750 mm, nearly twice the world's average. About 70 percent of the total land area of Japan is steep mountains, and rivers which are so short and steep that water in rivers reaches the sea in a short time period.

Jobaru River 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 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 damages to the Jobaru River. It is believed that one of the major causes were due to the changes in land cover. Data from 1948 to 2005 showed that the land cover has changed in the Jobaru River basin. For example, barren area turned into forestry in the mountainous sub-basin, while in the plain sub-basin, the paddy fields turned into urban or built-up land. Changes from barren area into forestry will lead to an increase in land capability in reducing flooding but changes from the paddy fields into urban area will lead to a decrease in land capability in reducing flooding. Currently almost all of the barren area has been turned into forests, 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 the tendency of changes in the paddy fields into residential area will be very substantial later. If these land use changes continue to happen, it is feared that it will affect the flow of Jobaru River. From this background it is important to have a research about the effect of the land cover changes on the hydrological process in the Jobaru River basin.

1.2. OBJECTIVES

The purpose of this study is to analyze the effect of the land cover changes on the hydrological process in the Jobaru River basin, in order to utilize its result as a step for integrated river basin management planning.

1.3. OUTLINE OF DISSERTATION

This dissertation was composed of eight chapters, which are briefly outlined below.

Chapter 1 discusses the introduction of this study. It mentions the problem statement, and the expected outcome of this research. It also shows the outline of the dissertation.

Chapter 2 summarizes literature regarding various model of hydrological modeling. It also describes about models that will be used in this research. It describes the Curve Number (*CN*) for representing the land cover change, and the integrated hydrological modeling MIKE SHE and MIKE 11 model for simulating the river flow and hydrological processes in the river basin.

Chapter 3 summarizes about the Jobaru River basin: the problems, history, natural disaster, population, industry, nature and the river management.

Chapter 4 analyzes the Curve Number (*CN*) on the Jobaru River basin. It describes how to estimate the *CN* due to land cover changes in the Jobaru River basin. It also discusses about the land cover changes that can be represented by *CN*. The ArcGIS tool is applied to delineate the river basin and the sub-basin, and HEC-GeoHMS tool for estimating the *CN*.

Chapter 5 describes the effect of the land cover changes on the Jobaru River flow. It describes how to build-up the MIKE 11 Rainfall-Runoff (RR) model for the Jobaru River basin and how the model simulates the peak flow. This chapter also shows the rainfall applied to the various land covers to get the effect of land cover change to peak flow.

Chapter 6 discusses the assessment of the effect of land cover changes on hydrological processes in the Jobaru River basin. It describes the MIKE SHE numerical integrated hydrology modeling, how to set-up the model for the Jobaru River basin. This chapter also describes the combination usage of the MIKE 11 and MIKE SHE to analyze the hydrological processes due to the land cover change. It shows the result of overland flow, evapotranspiration and infiltration in the Jobaru River basin with various land cover simulation.

Chapter 7 summarizes and discusses the finding from the previous chapters. It also highlights the implications of the study.

Chapter 2
LITERATURE REVIEW

This chapter consists of four parts. The first part focuses on related researches, second part focuses on curve number, third part focuses on hydrological modeling and the fourth is about integrated hydrological modeling.

2.1. RELATED RESEARCHES

Changes in land cover frequently result in significant impacts to hydrology by affecting the amount of runoff, soil moisture, and groundwater recharge over a range of temporal and spatial scales (Calder, 1992; Im et al., 2003). However, the hydrologic effect of alteration in land cover at a watershed scale is still an unresolved problem and is now a primary concern of most developing countries, which are commonly experiencing changes in land cover patterns caused by increasing populations and demand for accommodations.

In recent years different types of hydrological models are being used to quantify the effects of land cover changes on hydrological cycle (Fohrer et al., 2001; Lørup et al., 1998). Lørup et al. (1998) used the lumped hydrological model, NAM, to assess the long-term impacts of land cover changes on runoff in six medium-sized (200–1,000 km^2) rural watersheds in Zimbabwe. The NAM hydrological model was utilized to distinguish between the effects of climate variability and the effects of land cover changes. On the same way, Wegehenkel (2002) applied the calibrated THESEUS model with afforestation scenarios in assessing the impact of land cover changes on a watershed hydrology. The investigation found a significant discharge reduction and an increase in evapotranspiration. A few more attempts to implement lumped hydrological models for quantitative assessment of the influence of land cover change have been reported (Hundecha and Bárdossy, 2004; Siriwardena et al., 2006). A lumped model has been successfully applied to predict effects of land cover changes on watershed hydrology around the world. Nevertheless, the hydrological processes are not well represented. Kuczera et al. (1993) and Beverly et al. (2005) stated that a particular care must be taken when applying such a model in a large watershed due to limitations in the conceptualization of hydrological processes involved.

Distributed physically-based models have the predictive capacity to assess the effect of land cover changes on runoff across a range of scales, but require more intensive input data (Beven, 1989; Refsgaard, 1997). Typical examples of the distributed physically-based models are the Distributed Hydrology Soil Vegetation Model (DHSVM) (Thanapakpawin et al., 2007), THALES (Grayson et al., 1992), SHETRAN (Ewen and Parkin, 1996), and MIKE SHE (DHI, 1999). These models contain equations which have originally been developed for point scales and which provide detailed descriptions of flows of water and solutes. The variability of watershed characteristics is accounted for explicitly through the variations of hydrological parameter values among the different computational grid points (Refsgaard, 1997). Recently, Thanapakpawin et al. (2007) used the DHSVM model in assessing hydrologic regimes with land cover changes of the Mae Chame River in Thailand.

(Kimaro, Tachikawa and Takara, 2003) deals with effects of land cover changes on river flow in the Yasu River basin. The land cover changes were determined from 100 m resolution land cover data. A distributed hydrological model utilizing this data was developed with the help of GIS and Object orient programming techniques. Analysis of effects of observed land cover changes on the river flow is presented and possible future effects are studied using assumed future land cover scenarios. They classify the land cover into six classes: paddy fields, forest, agricultural land, grass land, water bodies, urban. The different land cover classes assumed and each type has their roughness value.

(Wan, Yang, 2007) study to reveal the influences of LUCC on the short term scale flood process, and to provide the technical methods for reflecting regional difference and basin parameter variation of hydrologic process under different land covers. HEC-HMS of U.S. Army corps of engineers, this system delineation a basin using a series of connective hydrologic and hydraulic components, and simulates direct runoff and flow routing processes applying precipitation data. The mean-areal precipitation depth in each sub-basin was calculated by inverse-distance-squared method. The Soil Conservation Service (SCS) Curve Number (*CN*) model was selected to estimate precipitation excess. Kinematic-wave model was chosen to model direct runoff and channel routing. Exponential recession model was utilized to count base flow**.** They classify the land cover into five classes: Woodland, Shrub, grassland, arable land, built-up land.

(Im, Kim and Jang, 2008) utilized the MIKE SHE modeling system to evaluate hydrologic impacts of land cover changes in a watershed with mixed land cover. The overall objective was to quantitatively evaluate the effects of land cover changes on watershed hydrology within the 257.9 km^2 Gyeongancheon watershed in Korea. This study specifically sought to: (1) test the capabilities of the MIKE SHE modeling system for simulating streamflow from a mixed land cover watershed; and (2) estimate hydrological responses under historical land cover scenarios taken from multi-temporal satellite imageries. They classify the land cover into five classes: Forest, paddy field, upland area, urban, grassland.

(Homdee, Pongput and Kanae, 2011) Study how hydrological cycle response on climate and land cover change in Chi river basin Thailand. The focus is only on effects of land cover conversion, the effect of climate variability has not considered yet. The conversion of farmland to forest affects flow variation, while a change of agricultural lands to bare ground brings a reduction in ET, reflecting an increasing of discharge. Also, it is likely that such changes can significantly alter the seasonal and annual water balance. However, intensity of land cover change impacts on water balance depends on the changes of vegetation type. The SWAT model is applied to estimate response of seasonal and annual water yields and ET to the changes of vegetation cover on existing basin. Five land use change scenarios were evaluated.

2.2 HYDROLOGICAL MODELING

The process-based hydrological model MIKE11-Rainfall runoff was used to simulate rainfall-runoff processes in the Jobaru watershed. Within the Jobaru River MIKE11 modeling framework, two hydrology modules are available for use in modeling the rainfall-runoff process. The UHM model, which is suitable for the simulations of runoff 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.

2.2.1 UHM (Unit Hydrograph Model)

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 tree type and age. The output from the module can further be used as lateral inflow to the advanced hydrodynamic module in MIKE 11. The excess rain is calculated assuming that the losses to infiltration can be described as a fixed initial and constant loss (the rational method) or by the SCS curve number method. The excess rainfall is routed to the river by unit hydrograph methods. The module includes the SCS-dimensionless hydrographs as well as facilities for establishing and management of databases with user defined unit hydrographs and time series of recorded rainfall and streamflow.

2.2.1.1 The Loss Model

During a storm a part of the total rainfall infiltrates the soil. A large part of the infiltration evaporates or reaches the river a long time after the end of storm as baseflow. Hence in event models as the present one, 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 the excess rainfall.

The unit hydrograph module includes three optional methods for calculation of the excess rainfall. They are all lumped models considering each catchment as one unit and hence the parameters represent average values for the catchment.

All the methods include an area adjustment factor accounting, to some extent, for non uniform distribution the precipitation over the catchment.

2.2.1.1.1 Proportional Loss (the rational method)

In this method the losses are assumed to be proportional to the rainfall rate and thus the excess rainfall is given by

$$P_{excess} = a \cdot A_f \cdot P \qquad (2.1)$$

where

P_{excess} = Excess rainfall (mm/hr),

a = User defined runoff coefficient between 0 and 1,

A_f = Areal adjustment factor,

P = Rainfall (mm/hr).

2.2.1.1.2 Fixed Initial Loss and Constant Loss

Following this method no excess rainfall will be generated before a user specified initial loss demand has been met. Subsequently excess rainfall will be generated whenever rainfall rate exceeds a specified constant loss rate.

2.2.1.1.3 SCS Loss Method

The US Soil Conservation Service developed this method for computing losses from storm rainfall. For the storm as a whole, the depth of excess precipitation or direct runoff (*Pe*) is always less than or equal to the depth of precipitation *P*; likewise, after runoff begins, the additional depth of water retained in the watershed, *Fa*, is less than or equal to some potential maximum retention *S*. There is some of rainfall *Ia*, (initial loss before ponding) for which no runoff will occur, so the potential runoff is *P-Ia*. The variable in the SCS method is shown in Figure 2.1.

The hypothesis of the SCS method is that the ratios of the two actual to the two potential quantities are equal, that is

$$\frac{Fa}{S} = \frac{Pe}{P-Ia} \quad . \tag{2.2}$$

From the continuity principle

$$P = Pe + Ia + Fa \quad . \tag{2.3}$$

Combining equation (2.2) and (2.3) gives

$$Pe = \frac{(P-Ia)^2}{P-Ia+S} \quad . \tag{2.4}$$

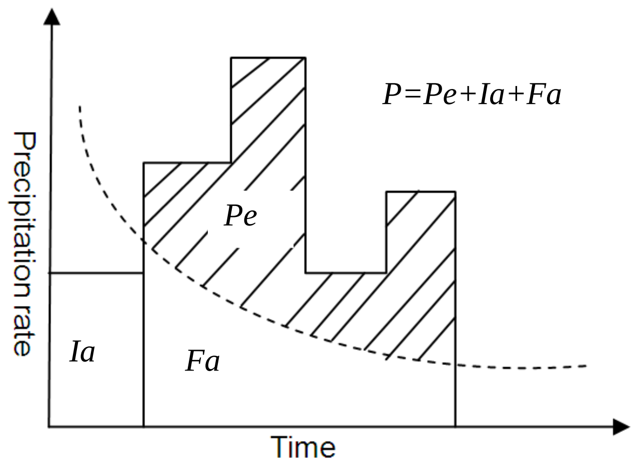


Figure 2.1 Variable in the SCS method of rainfall abstractions

where

- *Ia* = initial abstraction,
- *Pe* = accumulated excess rain,
- *Fa* = continuing abstraction,
- *P* = total rainfall,

which is the basic equation for computing the depth of excess rainfall or direct runoff from a storm by the SCS method. By the study of results from many small experimental watersheds, the following empirical relation was developed.

$$Ia = 0.2S \tag{2.5}$$

Combining equations (2.4) and (2.5) the basic equation used in this model is derived.

$$Pe = \frac{(P-0.2S)^2}{P+0.8S} \tag{2.6}$$

The potential maximum retention *S* is calculated from a dimensionless curve number (*CN*) using the empirical formula derived by SCS on the basis of rainfall runoff analyses of a large number of catchments.

$$S = 25.4\left(\left(\frac{1000}{CN}\right) - 10\right) \tag{2.7}$$

The curve number depends on the soil type, the land use and the antecedent moisture condition (AMD) at the start of the storm. *CN* varies between 0, resulting in no runoff, and 100 which generates an excess rain equal to the rainfall. For natural catchments normally 50<*CN*<100. The model operates with three different antecedent moisture conditions namely:

- AMC(1) : Dry conditions close to wilting point
- AMC(II) : Average wet conditions close to field capacity
- AMC(III) : Wet conditions close to saturation.

2.2.1.2 The Unit Hydrograph Routing Model

2.2.1.2.1 Basic Assumptions

The unit hydrograph method is a simple linear model that can be used to derive the resulting hydrograph from any amount of excess rainfall.

The unit hydrograph is the unit pulse response function of a linear hydrological system, i.e. the direct runoff hydrograph resulting from one unit of excess rain with the duration.

The following basic assumptions are inherent in this model:

a. The excess rainfall has a constant intensity within the effective duration.
b. The excess rainfall is uniformly distributed over the whole catchment area.
c. The base time of the direct runoff hydrograph resulting from an excess rain with a given duration is constant.
d. The ordinates of all direct runoff hydrograph of a common base time are directly proportional to the total amount of excess rain represented by each hydrograph.

e. The principle of superposition applies to hydrographs resulting from continuous and/or isolated periods of uniform-intensity excess rain as illustrated on (see Figure 2.2).
f. For a given catchment, the hydrographs resulting from a given excess rainfall reflects the unchanging conditions of the catchment.

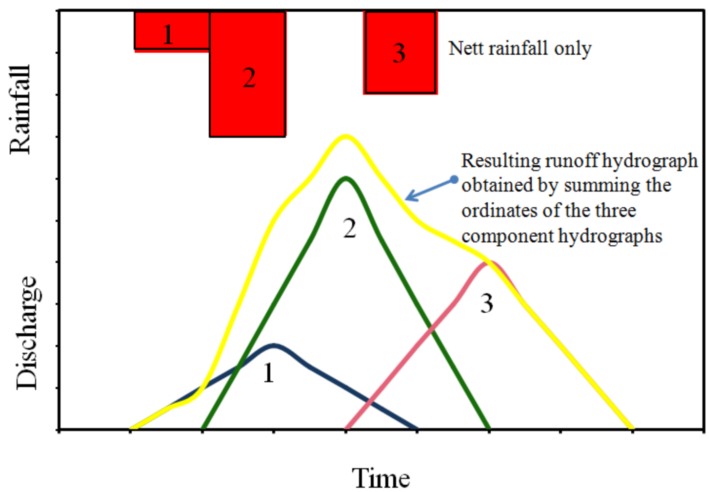


Figure 2.2 Principle of superposition applied to hydrographs

2.2.1.2 .2 Principle of calculation

In accordance with the principle of superposition, the models for each calculation time step determines the responding hydrograph to the excess rainfall, as generated by the loss model during this time step, and add the response to the flow contributions generated in previous time steps.

2.2.1.2.3 Types of unit hydrographs

A unit hydrograph can be characterized by the duration of the unit rainfall (*tr*) resulting in the hydrograph and the lag time (*tl*) defined as the time difference between the centre of the unit rainfall event and the runoff peak. From the two characteristics the time to peak (*Tp*), i.e. the time from the start of the storm event until the occurrence of peak runoff can be calculated as:

$$Tp = \frac{tr}{2} + tl \quad . \tag{2.8}$$

The SCS dimensionless hydrograph is pre-specified in the model. Dimensionless hydrograph specified as the flow divided by the peak flow (*q/qp*) as a function of the time divided by the time to peak (*T/Tp*). The SCS dimensionless hydrograph is shown in Figure 2.3.

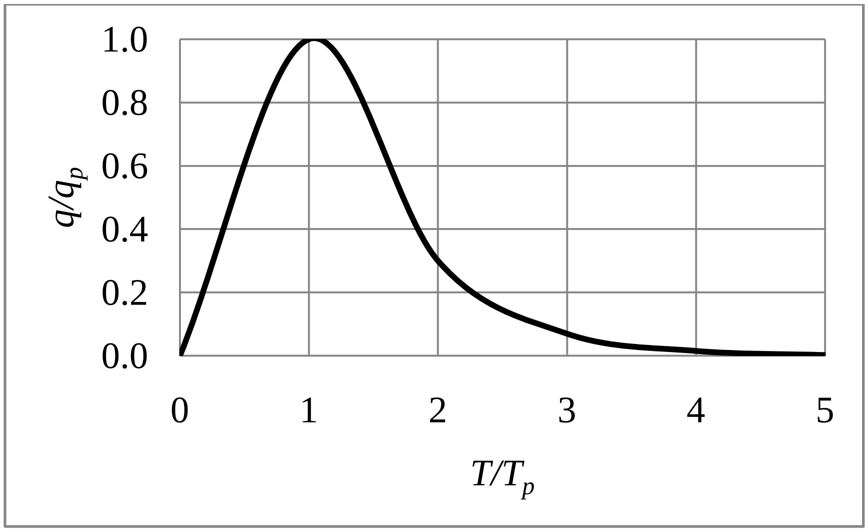


Figure 2.3 SCS Dimensionless hydrograph

2.2.1.2.4 Lag time

The lag time can either be specified directly or maybe calculated from catchment characteristics using the standard SCS formula:

$$tl = (3.28\text{x}10^3 L)^{0.8} . \left(\frac{1000}{CN} - 9\right)^{0.7} / (1900 Y^{0.5}) \tag{2.9}$$

where

tl : Lag time in hours,

L : Hydraulic length of the catchment in km,

CN : SCS curve number,

Y : Average catchment slope in per cent.

2.3 CURVE NUMBER

The curve number is an index developed by the Soil Conservation Service (SCS), now called the Natural Resource Conservation Service (NRCS), to represent the potential for storm water runoff within a drainage area. In calculating the quantity of runoff from a drainage basin, the curve number is used determine the amount of precipitation excess that results from a rainfall event over the basin. This methodology is a standard hydrologic analysis technique that has been applied in a variety of different settings throughout the United States, and the development and application of the curve number is well documented (SCS, 1986). Because it is a function of the soil and land cover of a drainage basin, estimation of a curve number requires mapping of the soil and land cover within the drainage basin boundaries, and specification of unique soil types and unique land cover categories.

The *CN* is estimated for a drainage basin using a combination of land cover, soil, and antecedent soil moisture condition (AMC). Typically, soil surveys list soil types by name, which is based on certain physical characteristics of the soils. However, the information needed to determine a curve number is the hydrologic soil group, which indicates amount of infiltration the soil will allow. Significant infiltration occurs in sandy soils while no infiltration occurs on heavy clay or rock formations. There are four hydrologic soil groups: A, B, C and D. The definition of each is given in Table 2.1. As a result of urbanization, the soil profile may be considerably altered and the listed group classification may no longer apply. In these circumstances, use the definition in Table 2.2 to determine HSG according to the texture of the new surface soil (Brakensiek and Rawls 1983).

Land cover categories are defined based on the level of detail required for the study. Standard SCS curve numbers are assigned for each possible land cover-soil group combination. Table 2.3 and 2.4 presents an example of typical land cover categories used for hydrologic analysis, along with corresponding curve numbers for each land cover-soil group combination.

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 infiltration rates,
B) soils having moderate infiltration rates,
C) soils having slow infiltration rates,
D) soils having very slow infiltration rates.

Table 2.1 Definition of Hydrologic Soil Groups

Hydrologic Soil Group	**Soil Group Characteristics**
A	Soils having high infiltration rates, even when thoroughly wetted and consisting chiefly of deep, well to excessively-drained sands or gravels. These soils have a high rate of water transmission.
B	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission
C	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission
D	Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission

Table 2.2 Definition of Hydrologic Soil Groups by soil texture

HSG	**Soil texture**
A	Sand, loamy sand, or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay

Table 2.3 Land cover categories and associated CN

Land cover	**Soil type**			
	A	**B**	**C**	**D**
Meadow	30	58	71	78
Woods – Grass (Fair)	43	65	76	82
Woods (Fair)	36	60	73	79
Deciduous Forest	36	60	73	79
Evergreen Forest	40	66	77	85
Mix Forest	38	63	75	82
Urban	68	80	88	94
Cropland	49	69	79	84
Cropland (terraced)	65	74	82	86
Shrub / Brush Tundra	48	67	77	83

Table 2.4 Land cover categories and associated Curve Numbers

Description	Average % Impervious	Curve number by Hydrologic Soil				Typical land cover
		A	B	C	D	
Residential (High density)	65	77	85	90	92	Multi-family, Apartments, Condos, Trailer Parks
Residential (Med density)	30	57	72	81	86	Single-family, Lot size 1/4 to 1 acre
Residential (Low density)	15	48	66	78	83	Single-family, Lot size 1 acre and greater
Commercial	85	89	92	94	95	Strip commercial, Shopping, Convenience stores
Industrial	72	81	88	91	93	Light industrial, Schools, Prisons, Treatment plants
Disturbed / Transitional	5	76	85	89	91	Gravel parking, Quarries, Land under development
Agricultural	5	67	77	83	87	Cultivated land, Row crops, Broadcast legumes
Open land - Good	5	39	61	74	80	Parks, Golf courses, Greenways, Grazed pasture
Meadow	5	30	58	71	78	Hay fields, Tall grass, Ungrazed pasture
Woods (Thick cover)	5	30	55	70	77	Forest litter and brush adequately cover soil
Woods (Thin cover)	5	43	65	76	82	Light woods, Woods grass combination, Tree farms
Impervious	95	98	98	98	98	Paved parking, Shopping malls, Major roadways
Water	100	100	100	100	100	Water bodies, Lakes, Ponds, Wetlands

The *CN* shown in Table 2.3 and 2.4 correspond to antecedent moisture condition II (AMC II). 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.

a. 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,
b. AMC II conditions represent average soil moisture conditions with dormant season rainfall averaging from 0.5 to 1.1 inches and growing season rainfall from 1.4 to 2.1 inches, and
c. 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, curve numbers are calculated for AMC II, then adjusted up to simulate AMC III or down to simulate AMC I.

Once the data has been gathered, the typical process for estimating the curve number for a drainage area is as follows.

a. Define and map the boundaries of the drainage basin(s) for which curve number(s) will be calculated. Determine the area of the drainage basin(s).
b. 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 cover and hydrologic soil group maps, identify each unique land cover-soil group polygon, and determine the area of each polygon.
e. Assign a curve number to each unique polygon, based on SCS curve number tables.
f. Overlay the drainage basin map on the land cover-soil group polygons.
g. Calculate the curve number for each drainage basin by area-weighting the land cover-soil group polygons within the drainage basin boundaries.

The hydrologic soil group of Jobaru River basin corresponds to the soil class that was obtained as shown in Table 2.5. Table 2.6 present the typical land cover categories used for hydrologic analysis, along with corresponding *CN* for each land cover-soil group combination for Jobaru River basin.

Table 2.5 HSG of Jobaru River basin

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

Table 2.6 Land cover categories and associated *CN*

Land cover	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

The basic equation for *CN* calculation is:

$$CN_{aw} = \frac{\sum_{i=1}^{n}(CN_i.A_i)}{\sum_{i=1}^{n}A_i} \tag{4.1}$$

where

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

2.4. INTEGRATED HYDOLOGICAL MODELLING

2.4.1. MIKE 11- River and channel hydraulics

MIKE 11 is a software package for simulating flow and water level, water quality and sediment transport in rivers, flood plains, irrigation canals, reservoirs and other inland water bodies. MIKE 11 is a 1 dimensional river model. It was developed by DHI Water & Environment Denmark. MIKE11 has long been known as a software tool with advanced interface facilities.

2.4.1.1 Modules

The computational core of MIKE 11 is hydrodynamic simulation engine, and this is complemented by a wide range of additional modules and extensions covering almost all conceivable aspects of river modeling.

HD module: it provides fully dynamic solution to the complete nonlinear Saint Venant equations, diffusive wave approximation and kinematic wave approximation, Muskingum method and Muskingum-Cunge method for simplified channel routing. It can automatically adapt to subcritical flow and supercritical flow. It has ability to simulate standard hydraulic structures such as weirs, culverts, bridges, pumps, energy loss and sluice gates.

GIS Extension: it is an extension of ArcMap from ESRI providing features for catchment/river delineation, cross-section and Digital Elevation Model(DEM) data, pollution load estimates, flood visualization/animation as 2D maps and results presentation/analysis using temporal analyst.

RR module: it is rainfall runoff module, including the unit hydrograph method (UHM), a lumped conceptual continuous hydrological model and a monthly soil moisture accounting model. It includes an auto-calibration tool to estimate model parameter based on statistic data of comparison of simulated water levels/discharges and observations.

SO module: it is structure operation module. It simulates operational structures such as sluice gates, weirs, culverts, pumps, bridges with operating strategies.

DB module: it is dam break module. It provides complete facilities for definition of dam geometry, breach development in time and space as well as failure mode.

AUTOCAL module: it is automatic calibration tool. It allows automisation of the calibration process for a wide range of parameters, including rainfall runoff parameters, Manning's number, head loss coefficients, water quality parameters etc.

AD module: it is advection dispersion module. It simulates transport and spreading of conservative pollutants and constituents as well as heat with linear decay.

ST/GST module: it is noncohesive sediment module. It simulates transport, erosion and deposition of non-cohesive and graded noncohesive sediments, including simulations of river morphology.

ACS module: it is cohesive sediment module. It has 3-layer bed description, including quasi-2D erosion.

ECO Lab module: it is ecological modeling. It can simulate BOD/DO, Ammonia, Nitrate, Eutrophication, Heavy metal and Wetlands. It includes standard templates that are well documented and have been used extensively in numerous applications worldwide. Based on predefined process templated, one can develop his/her own templates.

MIKE11 Stratified module: it models vertical density differences such as salinity or temperature in two-layer or multi-layered stratified water bodies.

MIKE11 Real Time module: it is a simulation package and GIS front-end for setting up operational flood forecasting systems. It includes real-time updating and kalman filtering.

2.4.1.2 Development of Model

The processing of the data for the simulation in the MIKE 11 hydrodynamic module involves; preparation of the network (can assume a straight stream channel), cross section, and hydrodynamic and, boundary parameters. The data hourly rainfall, water levels and flows are created in compatible MIKE 11 time series in a separate file as the input for the parameter editors.

a. The River Network file

The River Network file allows the modeler to:

- define the river network and reference cross-sections and control structures to the network, and
- graphically obtain an overview of the model of information in the current simulation.

b. The Cross-Section File

The Cross-Section file contains streambed cross-sections as specified locations along a river network. The geometry of cross-sections is usually obtained from field-surveyed data.

c. The Boundary Files

The Boundary file consists of boundary conditions in a time-series format for the river network's boundaries. The water-level boundary must be applied to either the upstream or downstream boundary condition in the model. The discharge boundary can be applied to either the upstream or downstream boundary condition and can also be applied to a side Tributary flow (lateral inflow). The lateral inflow is used to depict the runoff for this study. The Q / h Relation boundary can only be applied to the downstream boundary.

d. The Hydrodynamic Parameter File

The Hydrodynamic Parameter file bed and floodplain resistance requires the data for the river network. The differentiation between the streambed and flood plain along the river network is accomplished at each cross-section in the cross-section file.

2.4.1.3 MIKE 11 Data Requirements

The different types of data that are required for application of various modules in MIKE 11 can be grouped as follows:

a. Basic data

This is mainly data that describes the physical layout of the river or the catchment being modeled. This includes for instance cross section, weir crest level and dimensions, catchment area etc.

b. Parameters

This covers parameters that are used in the equations being solved by MIKE 11. Examples of such parameters are Manning's number and weir construction/expansion loss coefficient for the HD module, root zone storage capacity for NAM rainfall-runoff module, dispersion coefficient for the AD module, decay rate for BOD for the WQ module. A few of the parameters can be partly or fully determined through fields' measurements. For instance, the sediment grain diameter can be fairly accurately estimated through laboratory analysis of sediment samples, where as the Manning's number for the HD model only to some extend can be estimated based on knowledge about the riverbed. However, most parameters have to be estimated through calibration/verification, literature review, or from experience.

c. Boundary data

Any MIKE 11 model requires boundary conditions, and typically these are times series of measurements such as rainfall, discharge, water level, concentration, sediment transport etc.

d. Calibration and verification data

This data are actually not required to run the model, i.e. to produce simulation results. Having the data group 1-3 available is sufficient assuming that the parameters have been estimated properly. However, this is most often not possible without calibration and verification, and to do so additional data are required. This is for instance time series of measurements of discharge, water level, concentration, and riverbed level.

MIKE 11 comprises a number of different editors which is implemented and the data can be edited Independently of each other. As a consequence of the system of editor-separated files, no direct linkage exists between the different editors if they are opened individually. That is, it will not be possible to e.g. view the locations of cross-sections specified in the cross-section file in the graphical view of the network editor (plot plan) if these editors are opened individually. The integration and exchange of information between each of the individual data editors is Achieved by use of the MIKE 11 Simulation editor. The Simulation Editor serves two purposes:

- It contains simulation and computation control parameters and is used to start the simulation.
- It provides a linkage between the graphical view of the network editor and the other MIKE 11 editors.

Editing of cross-sections could be a typical example, where cross-sections can be selected from the graphical view in order to open the cross-sections for editing in the cross-section editor. The linkage requires a file name to be specified for each of the editors. File names are specified on the Input Property Page of the simulation editor. Once the editor filenames are specified on the Input page, the information from each of the editors is automatically linked. That is, you will be Able to display and access all the data from the individual editors (such as cross-sectional data, boundary conditions and different types of parameter information file) on the graphical view of the river network editor.

2.4.1.4 Applications

MIKE11 has been used in hundreds of application around the world. Its main application areas are flood analysis and alleviation design, real-time flood forecasting, dam break analysis, optimization of reservoir and canal gate/structure operations, ecological and water quality assessments in rivers and wetlands, sediment transport and river morphology studies, salinity intrusion in rivers and estuaries. Presentation of results from MIKE 11 is carried out with MIKE View. MIKE View is a Windows-based result presentation and reporting tool for MIKE 11.

2.4.2. MIKE SHE – Numerical integrated hydrological modeling

MIKE SHE is an advanced integrated hydrological modeling system. It simulates water flow in the entire land based phase of the hydrological cycle from rainfall to river flow, via various flow processes such as, overland flow, infiltration into soils, evapotranspiration from vegetation, and groundwater flow.

MIKE SHE has been applied in a large number of studies world-wide focusing on e.g. conjunctive use of surface water and ground water for domestic and industrial consumption and irrigation, dynamics in wetlands, and water quality studies in connection with point and non-point pollution. It is used in regional studies covering entire river basins as well as in local studies focusing on specific problems on small scale.

2.4.2.1 MIKE SHE model

MIKE SHE is a deterministic, fully-distributed and physically-based hydrological and water quality modeling system (DHI 2011). It is capable of simulating hydrology and water quality processes occurring in watersheds and their underlying aquifers.

The MIKE SHE modeling system was designed with a modular structure. The water movement (WM) module in MIKE SHE is the basic module of the entire modeling system. It represents the finite differences and solutions of the partial differential equations that describe processes of overland, channel, saturated, and unsaturated flows. The watershed is represented by two analogous horizontal-grid square networks for surface and groundwater flow components. These are linked by vertical columns of nodes at each grid representing the unsaturated zone. The hydrologic simulations consists of subcomponents describing the processes of evapotranspiration, overland and channel flow, unsaturated flow, saturated flow, and channel/surface aquifer exchanges. In MIKE SHE the catchment is represented in an integrated fashion by the major processes and their interactions (Figure 2.4).

A detailed description of the MIKE SHE can be found in DHI (2011). Several additional components comprise other hydrological processes in the modeling system. Rainfall interception is modeled by using a modified Rutter model (Rutter et al. 1971), which is an essential accounting procedure for canopy storage. The MIKE SHE uses the Kristensen and Jenses (1975) method for calculating actual evapotranspiration, leaf area index, root depth for each vegetation type, and a set of empirical parameters. A finite difference approximation of the St. Venant equation is employed for solving two-dimensional overland flow and one-dimensional channel flow. Movement of water in unsaturated zone is assumed to be vertical and is modeled by the one-dimensional Richards equation using an implicit finite difference solution. Saturation zone computations are performed using the three dimensional Boussinesq equation for groundwater flow.

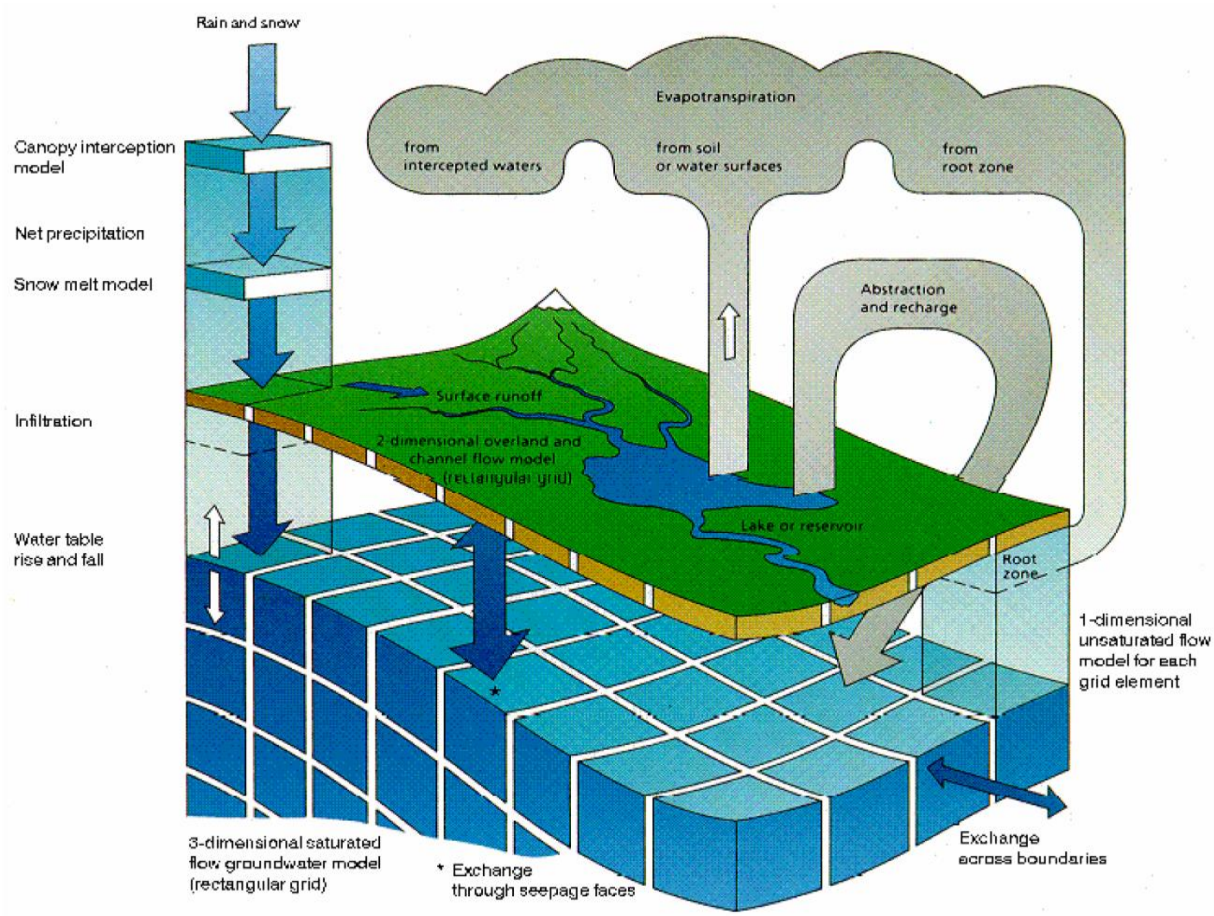


Figure 2.4 Hydrologic processes simulated by MIKE SHE

(Applied Research Center, Florida International University)

2,4,2,1,1 Model Philosophy

MIKE SHE is a characterized as being:

- **Integrated** Fully dynamic exchange of water between all major hydrological components is included, e.g. surface water, soil water and groundwater
- **Physically based.** It solves basic equations governing the major flow processes within the study area

- **Fully distributed.** The spatial and temporal variation of meteorological, hydrological, geological and hydrogeological data across the model area is described in gridded form for the input as well as the output from the model
- **Modular.** MIKE SHE has been given a modular structure, which allows expanding water quantity simulations to cover e.g. solute transport, particle tracking, geochemical reactions etc. The modular architecture allows user only to focus on the processes, which are important for the study.

2.4.2.1.2 Model History

The original MIKE SHE (DHI, 1998) model was developed and became operational in 1982, under the name Système Hydrologique Europeen (SHE). The model was sponsored and developed by three European organizations: the Danish Hydraulic Institute (DHI), the British Institute of Hydrology, and the French consulting company SOGREAH. The model was developed for water resource managers who were concerned with rapidly changing land cover practices in agriculture and forestry. In several European countries, surface and ground water resources were being polluted by fertilizers and pesticides associated with intensive agricultural practices. Transport of contaminants from waste disposal sites and the effects of acid rain posed additional threats to water quality. As new modeling ideas developed, DHI continued to enhance the model and currently provides support and service to this evolving system modeling. The MIKE SHE modeling system consists of a water movement water quality module and several modules. The water movement module simulates the hydrological components including evapotranspiration, soil water movement, overland flow, channel flow, and ground water flow. The related water quality modules are: 1) advection-dispersion, 2) particle tracking, 3) sorption and degradation, 4) Geochemistry, 5) biodegradation, and 6) crop yield and nitrogen consumption. The most recent model of enhancement was the development of integrated surface water and ground water models by linking the water movement module of MIKE SHE with the channel simulation component of MIKE 11 (DHI, 1998) for the South Florida Water Management District (SFWMD) (Yan et al., 1998, 1999). MIKE 11 is a model for simulating flows, water quality, and sediment transport in channels, rivers, irrigation systems, and estuaries. The original channel simulation in MIKE SHE was relatively simple and had limited capabilities. MIKE SHE and MIKE 11 can be used independently or together.

The most important difference between the MIKE SHE modeling system and previous models used by the SFWMD is that MIKE SHE is an integrated, physically based, distributed models that simulates hydrological and water quality processes on a basin scale. MIKE SHE is Able to simulate both surface and ground water with precision equal to that of models focused separately on either surface water or ground water. The MIKE SHE modeling system simulates most major hydrological processes of water movement, Including canopy interception and land surface after precipitation, snowmelt, evapotranspiration, overland flow, channel flow, unsaturated subsurface flow, and saturated ground water flow. It also simulates the major water quality components. A grid network represents the spatial distributions of the model parameters, inputs, and results with vertical layers for each grid.

2.4.2.1.3 Model Description

The MIKE SHE modeling system is able to simulate surface and ground water movement, the interactions between the surface water and ground water systems, and the associated point and non-point source water quality problems. The system has no limitations regarding watershed size. A summary of the model components and features is shown in Table 1. First, the modeling area is divided into polygons based on land use, soil type, and precipitation region; the polygons are then assigned identification numbers. Model input files can be generated by overlaying the model input parameters with a grid network. Most of data preparation and model set-up can be completed using Geographic Information System (GIS) software, ArcView, or MIKE SHE's built-in graphic pre-processor. The MIKE SHE hydrological modeling system simulates components, including the movement of surface water, subsurface water unsaturated,

saturated ground water, and exchanges between surface water and ground water. With regard to water quality, the system simulates sediment, nutrient, and pesticide transport in the area models. The model also simulates water use and management operations, including irrigation systems, pumping wells, and various water control structures. A variety of agricultural practices and environmental protection alternatives may be evaluated using the many add-on modules developed at DHI. The system has a built-in graphics and digital post-processor for the model calibration and evaluation of both current conditions and management alternatives. Animation of the model scenarios is another useful tool for analyzing and presenting results.

2.4.2.1.4 Model Characteristics

The MIKE SHE modeling system was designed with a modular structure. Its core module is the MIKE SHE water movement module (MIKE SHE WM). MIKE SHE other modules are built around the core module.

a. MIKE SHE Water Movement Module (MIKE SHE WM)

MIKE SHE WM includes hydrologic process components for unsaturated and saturated ground water flow, overland flow, channel flow, and evapotranspiration. Each component solves a corresponding equation is as follows:

- 3-D Boussinesq Equation for saturated ground water flow,
- 1-D Richards' equation for unsaturated ground water flow,
- 2-D diffusion wave approximation of the Saint Venant equations for overland flow,
- 1-D diffusion wave approximation of the Saint Venant equations for river flow.

b. Evapotranspiration / interception

MIKE SHE uses the Kristensen and Jensen (1975) method for calculating actual evapotranspiration based on potential evaporation, leaf area index, root depth for each vegetation type, and a set of empirical parameters. The model also includes the following features:

- sources / sinks, time variable head boundaries, and other types of boundary conditions,

- river / aquifer exchange,
- complete coupling of the unsaturated and saturated zones.

c. MIKE SHE Advection-Dispersion Module (MIKE SHE AD)

The MIKE SHE AD module simulates the major solute transport processes on and below the ground surface, saturated and unsaturated Including ground water transport, overland transport and transport channel. MIKE SHE AD uses the flow regime simulated by MIKE SHE WM, and the following equations:

- 3-D and 1-D equations for advection and dispersion of solutes (conservative) in saturated and unsaturated ground water zones, respectively,
- 2-D and 1-D equations for advection and dispersion of solutes (conservative) in overland and river flow, respectively.

2.5. CONCLUSIONS OF CHAPTER 2

Changes in land cover frequently result in significant impacts to hydrology by affecting the amount of runoff, soil moisture, and groundwater recharge over a range of temporal and spatial scales (Calder 1992; Im et al. 2003). However, the hydrologic effect of alteration in land cover at a watershed scale is still an unresolved problem and is now a primary concern of most developing countries, which are commonly experiencing changes in land cover patterns caused by increasing populations and demand for accommodations.

In recent years different types of hydrological models are being used to quantify the effects of land cover changes on hydrological cycle. Most of the previous study used lumped hydrological model or distributed physically-based to quantify the effect of land cover changes on hydrological cycle. But coupling the distributed physically-based models with the river and channel hydraulics models are still rare in the literature. In this research the distributed physically-based model MIKE-SHE, coupled with MIKE-11 river and channel hydraulics are use to assess the impact of land cover changes to the hydrological processes in Jobaru River basin.

CN is a function of land cover, soil type, and soil moisture. Therefore, the land cover changes can be represented by this parameter. The greater the value of CN, the greater the amount of rainfall becomes runoff. To simulate the R-R process due to the land cover change, some models for example MIKE 11-UHM need CN as input.

Computer models for river simulations require: 1) a hydrologic model which develops rainfall-runoff, and 2) a hydraulic model which routes the runoff through stream channels. Most of previous hydraulic modelling techniques use1-D steady state flows measured at a specified point in time, they are subject to human error and very time consuming. Developments in fully dynamic, unsteady models have provided engineers with highly accurate hydraulic modelling methods. MIKE 11 hydrodynamic models uses 1-D implicit, dynamic wave routing based on the St.Venant equations for unsteady flow. MIKE11-Rainfall runoff will used to simulate rainfall-runoff processes. Hydrology modules that used in modelling RR process are; 1) UHM model, for the simulations of runoff, 2) SCS loss method to calculate the excessive rainfall, and 3) the dimensionless hydrograph method to generate the time series runoff.

Changes in land cover frequently result in significant impacts to hydrology by affecting the amount of runoff, soil moisture, and groundwater recharge. A lumped model has been successfully applied to predict effects of land cover changes on watershed hydrology around the world. Nevertheless, the hydrological processes are not well represented. Distributed physically-based models have the predictive capacity to assess the effect of land cover changes on runoff across a range of scales. In this study, coupled MIKE SHE-MIKE 11 modeling systems will utilize to evaluate the hydrologic impacts of land cover changes in a watershed with mixed land cover.

Chapter 3

SUMMARY OF THE JOBARU RIVER BASIN

3.1 PROBLEMS

Jobaru River 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 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 cover. The 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 cover. Data from 1948 to 2005 showed that the land cover has changed in The 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 cover 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 is will affect the flow of Jobaru River.

3.2 HISTORY

The full-scale countermeasures against flood disasters were carried out since 17th century in Japan. In Saga Plain, the flood control including catchment basin operations have been adopted 400 year ago. Jobaru River is located in east Saga Plain. The history of the Jobaru River is shown in the Table 3.1.

Table 3.1 History of Jobaru River

Era	Year	Matter	Notes
Ancient		Creek grass weir forming installations	

Table 3.1 (Continued)

Edo	1624	Sanzengokuiseki construction	- Installation over the field in order to protect the Sanzengokuiseki - Separating the Jobaru River and Baba River - Installation of Komagari and Oomagari meandering
	1740	Ochaya Weir construction	
Meiji	1889	Cataclysm of unprecedented	
Taisho	1921	Daily rainfall floods	
Showa	1948	Floods (1948)	-
	1949	Floods (1949)	- Flow rate, 450 m^3/s
	1953	Floods (1953)	- Flow rate 690m3/s
		Jobaru River subsidized disaster recovery	- Expansion about three times the width of the river, weir, grass field - Not comes to terms with the status quo with residents
	1961	Saga water conveyance project plan	
	1967	Raised over the complete field	
	1976	Chikugo River downstream land improvement project	
	1978	Prefectural irrigation drainage projects	

Table 3.1 (Continued)

	1979	Chikugo downstream water business	
		Jobaru River Dam project	
		- (H7) Chikugo River water system construction basic plan implementation	
Heisei		690 m^3/s design flood discharge (River: 330 m^3/s, Flood control: 360 m^3/s)	
		Chikugo river water system improvement plan (H15)	
		690 m^3/s design flood discharge (River: 330 m^3/s, Flood control: 360 m^3/s)	

3.3 PRESENT STATE

3.3.1 Overview of Jobaru River

3.3.1.1 The river basin and topography

Jobaru River flows to the Saga Plains with Mount Sefuri (1,055m above sea level) being the source of the river, and merges with Chikugo River's branch streams Sagae River and flow to the Ariake Sea. River Basin's area is 87.46km^2, the length of main river stream channel is 31.9km. The Ministry of Land, Infrastructure, Transport and Tourism manages the lower river section 9.1km from the point in which the river merges with Sagae River, and Saga Prefecture manages the rest of the river upstream. About 70% of basin is mountainous, and approximately 10,000 people live at the basin. It is said that in the Jobaru River, an alluvial fan developed to the south of the vicinity of Kanzaki City's Niiyama, and made it a high bedded river, dividing into several streams, and repeatedly flooded. After that, during the Edo era the eastern stream was adjusted as an irrigation canal, and the western stream became the current Jobaru River. The ancient coastline was 10km or so further in Sefuri Mountain District, and the former downstream portion of Jobaru River was an ebb-water route. After that, due to the accumulation of gutter dirt and land reclamation works, the coastline extended further south and the river's shape became what it is today.

Kanzaki City, where Joubaru River flows, was formed in March, 2006, after merging old Kanzaki Town, Chiyoda Town, and Sefuri Village. The plains of Kanzaki City, beginning with Yoshinogari Ruins, has archaeologically important excavations taking place in various places, and in addition, castle ruins of a powerful family of the Muromachi era (currently conserved as Yokotake Creek Park), and Anegawa Castle Ruins and Naotori Castle ruins' moat settlements are left.

By the Edo era, there was a highway that connected Kokura and Nagasaki running east and west, and it's inn towns such as Kanzakisyuku and Sakaibarusyuku mark has left old townscapes and historical landmarks, and the vestiges of those days can be recollected. Kanzaki City's mountainous region is nature abundant and designated as a Saga Prefecture natural park, and is the south side of Mount Sefuri; and during the Heian era, through mountain worship centered around Mount Sefuri, it had become the center of a Buddhist culture called Sefuri Senbou. In that vicinity, there are tourist spots such as Takatoriyama Park and Sakura main road were one can go to experience nature. Saga City's Hasuikemachi, in the vicinity of where Jobaru River meets Sagae River, was Saga domain's subsidiary domain: Hasuike Clan's castle town, and the castle ruins are currently maintained as Hasuike Park, is a famous place for its cherry blossoms, Azaleas and Irises.

3.3.1.2 Posture of the river

Three km upstream from the merging point with Sagae River (Kanzaki City's Naotori) is a dam for drawing water called Ochaya weir. The section of the river downstream from Ochaya Weir is affected by the tide of the Ariake Sea, and at the riverbed, gutter dirt accumulates from the rising and falling of the tide; and creature characteristic of the Ariake Sea such as hazekuchi and haradakurechigogani (Crab) inhabit the area. Because flooding may occur when too much gutter dirt accumulates, management via activities such as dredging is necessary. Further upstream from Ochaya Weir are Kusaseki (grass weirs) where water has been drawn since old times, and in the vicinity from Naotori Bridge to Kyouwa Bridge, there are 13 consecutive points in which water collects (floods) via Kusaseki weir. At the riverbank, emergent plants such as

Yoshi (Common Reed) and Tsuruyoshi can be seen, and is inhabited by precious creatures such as Oyanirami (Aucha Perch) and Kazetogetanago (Rhodeus Atremius). Also, the river is a high bedded river from Naotori Bridge to Kanzaki Bridge, and if the water overflows from flooding, the water will flow down from high places, and for this reason there is a fear that such flooding will cause great damage to surrounding houses. Upper stream from Hideke Bridge, there are 9 Nokoshi (for flood control), and the Sanzengokuiseki (for sending water in the direction of today's Saga City) built by Naritomi Hyougo Shigeyasu during the Edo era. Moreover, upper stream from Nagasaki Expressway, the river takes the form of a beautiful ravine flowing in zigzag, and along the river there is a Meiji era stone arched bridge, and Kyushu's first hydroelectric plant: Hirotaki Power Plant.

3.3.2 Flood control measures

Full-scale countermeasures against flood disasters were implemented in the Jobaru River Basin of the Saga Plain in Japan during 17th century by riparian technical groups including Chief Retainer Hyogo Naritomi (Kashihara, 2007, in Ohgushi, 2012). There are many flood damage reduction facilities in the river or near the river of the Saga Plain. For examples, there had been many retarding basins, overflow embankments (Nokoshi), open levees (Kasumi-Tei), flood restraining forest belt, and auxiliary levees in the residential area. Original flood control technology of the whole river basin with collaborations of these flood damage reduction facilities is gradually elucidated.

3.3.2.1 Overflow embankment (Nokoshi)

The overflow embankments are called "Nokoshi" in Saga Prefecture. The Nokoshi of Joubaru River was built by Naritomi Hyougo Shigeyasu in order to protect Sanzengoku Dam and the towns downstream, and was built by lowering portions of the banks upstream so that water would overflow outside the river during a flood, and thus preventing the floodwaters from flowing downstream all at once.

Along the midstream Jobaru River, there are 5 overflow embankments that were used aggressively to introduce the river water into the retarding basin in order to decrease the water surface level of the Jobaru River downstream. Figure 3.1 shows Nokoshi in Tsurunishi District, Kanzaki City. Figure 3.2 shows the flood management in the residential area.

Figure 3.1 Overflow embankment of Jobaru River (Tsurunishi District, Kanzaki City, Saga Prefecture). (Ohgushi K., 2012)

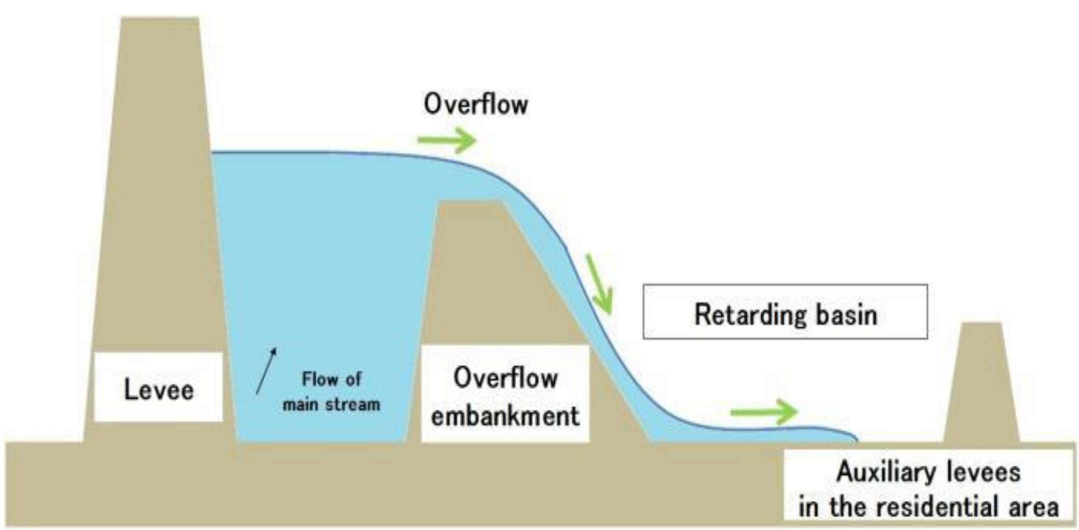


Figure 3.2 Flood management using overflow embankment, retarding basin and auxiliary levees in the residential area. (Ohgushi K. et al., 2012)

3.3.2.2 Open levee (Kasumi-Tei)

Not only the overflow embankments but also 4 open levees exist along the Jobaru River. The open levees are one of the discontinuous levees and are called “Kasumi-Tei” in Japan. They were used especially in the steep stream. For the drainage of landside water or inundated water due to upstream levee breach to the main stream and tentative storage of flooded water, the open levees gave significant roles. When the water level in the landside reaches to the crest of the open levee, the water behaves as one body with fluid in the main stream.

3.3.3 Postwar Flood Disasters and Flood Disaster Prevention

At the Chikugo River basin, which includes Joubaru River, there was a flood disaster soon after the war in 1949; even more, on June 25th through 28th, 1953, an unprecedented major flood disaster had occurred. This flood disaster was the worst in Chikugo River basin’s history. The damage caused by the flood with Saga City, Sagagun, and Kanzakigun combined, totals to 14,920 homes with below the floor flooding, and 14,597 homes flooded above the floor. In Jobaru River, in reaction to the 1949 flood, a river repair project called Saigai Josei Jigyou (Disaster Assistance Project) had begun; and despite having been visited by flood disasters in both 1953 and 1955 while construction work was still in progress, construction was completed in 1962. The river’s width had been expanded by this project and is now 3 times wider than its original size. Even after the Disaster Assistance Project’s river repair work was completed, in 1963, 1972, 1982, and so on, there has been occasional flooding; however, major flood disasters like the ones seen during the construction work has not occurred again.

Various flood disaster prevention work have continued after the Disaster Assistance Project, such as lowering the riverbed by digging, and river dike construction work; but at the end of 2003, among Jobaru River’s banks, only about half have reached the height specified by Chikugo River System River Improvement Project’s plan for Jobaru River. Moreover, it is possible that the banks currently being constructed are made with sand that water can easily permeate; and thus there is concern that, in the event of a flood, water may leak out of the bank, and that the bank itself may break. Furthermore, the maintenance mark capacity of Jobaru River, as indicated in the Chikugo River System River Improvement Project, is 330m^3/s, but Jobaru River’s present flow rate (capacity of flow) in which water can safely flow through the river is only (240m^3/s). With the influence of severe rainfall in recent years, there have been 5 floods that drew near the design high water level, and in July 4, 2006 at Hideki Bridge, the highest water level since beginning observation in 1963 have been recorded. Also, floods that exceed the overflow warning water level are occurring frequently, and thus there is a urgent need to make improvements in flood related safety.

3.4 NATURAL DISASTER

Between 1948 and 2005, there were several floods in Jobaru River that caused damage as shown in Table 3.2. The maximum discharge recorded from 1948 to 2005 was 690m^3/s which occurred in rainy season of 1953. Discharge was recorded at Hideki Bridge point, from Hideki Bridge Observatory station.

Table 3.2 The major flooding and damage that occurred in Jobaru River

Date	Name of the abnormal weather	Damages	Estimated Peak flow (m^3/s)
08/16-18/1949	Typhoon (Typhoon Judith)	- Jobaru river surrounding communities flooded. - Kanzaki bridge falls - Dyke in the levee near the Nokoshi No. 2, broken - Levee near the Asahi Bridge, broken	
06/25~28/ 1953	Rainy season	- Nokoshi No. 2, overflow. - Dyke near Nokoshi no.3 broken - Flooding in downstream area - Naotori district, the water level below of the floor	690
09/23~25/ 1954	Typhoon	Downstream area in Naotori district, the water levels almost reached the floor	300

Table 3.2 (Continued)

07/07/1955	Very heavy rain	- Mother and her child were dead. - In Naotori district, 15m and 300m downstream of the bridge the left side dyke broken. - Flooding for many houses; 1500 houses (water level below the floor), 300 houses (water level above the floor)	
1963	Heavy rain	Nokoshi No.8, overflow. The overflow time : 2-3 hours Highest water level : 50 cm	285
06/06~07/23 /1972.	Intermittent heavy rain, Typhoon No. 6, 7, 9	Flooding the area around Chiyoda	281
08/01~09/05 /1980	Heavy rain	- Flooded floor: 17 units - Inundation above floor level : 32 units - Farmlands damaged : 17 ha	130
07/05~08/03 /1982	Heavy rain, Typhoon	Farmlands damaged : 60 ha Including Sanbonmatsu and Baba river farmland damaged.	194
07/02/1990	Heavy rain	- Highest Water level : 3.97m - Difference between highest water level planning: 0.54m	207
08/14/1996	Heavy rain	- Highest Water level : 4.10m - Difference between highest water level planning: 0.41m	236

Table 3.2 (Continued)

06/29/1999	Heavy rain	- Highest Water level : 3.94m - Difference between highest water level planning: 0.57m - Nokoshi no. 6, almost overflow.	163
07/19/2003	Heavy rain	- Highest Water level: 4.32m - Difference between highest water level planning: 0.19	
07/04/2006	Heavy rain	- Highest Water level : 4.40m - Difference between highest water level planning: 0.11m	212

Source: Matsui H., 2008

3.5 POPULATION

Kanzaki City, where Joubaru River flows, was formed in March, 2006, after merging Kyuukanzakimachi, Chiyodachou, and Sefurimura, having a population of approximately 34,000, and a total area of 125km^2: comprised of 66% mountain forests and waste lands, 28% farm lands, and 5% residential land. Looking at the main industries through the number of employed persons, 56% belong to the tertiary sector (service industry), 32% secondary sector (industrial sector), and 12% primary sector (agriculture, forestry, fishing). Even though Saga prefectures population has been decreasing as a whole, Kanzaki City's population has increased approximately 5% from 1985 to 2006. Not all the Kanzaki city`s area belong to Jobaru River basin. The population in Jobaru River basin is about 10,000.

3.6 INDUSTRY

In Jobaru River basin, the primary industries such as agriculture, forestry and fisheries. Kanzaki City, where Joubaru River flows comprised of 66% mountain forests and waste lands, 28% farm lands, and 5% residential land. Looking at the main industries through the number of employed persons, 56% belong to the tertiary sector (service industry), 32% secondary sector (industrial sector), and 12% primary sector (agriculture, forestry, fishing).

3.7 NATURE

Jobaru River basin is affected by the Ariake Sea with tidal variation 6 m. The tide rises at high tide, the section downstream at low tide becomes brackish waters where tidal flats appear Ochaya weir of Jobarugawa. The organisms' specific in Ariake Sea, such as Harada Kure Chigogani and Hazekuchi are living, such as contact force and the Great Reed Warbler has been used as a nesting location in brackish. This reed which spreads through dry riverbed from the water's edge due to flooding interval is a continuous grass weirs, emergent vegetation such as Ogi Tsuruyoshi can grow. From the fact that until the tide rises beyond the Ochaya weir upstream, in the Ariake Sea due to the impact of specific large tide ebb and flow of the Ariake Sea have been found in fish body and Yamano. Near the upstream end zone management direct control is also confirmed Kawadesha the emergent plant such as Tsuruyoshi can grow to the water's edge, growing in places wet, fish such as Oyanirami and Kazetogetanago. It is important to continue to preserve the rich natural environment of Jobaru River like this. The landscape of Jobaru River is shown in Figure 3.3.

Figure 3.3 Landscape of Jobaru River

3.7.1 Section Sagae River confluence point – Ochaya weir (brackish water)

The environment of the plants, birds and aquatic organism that live in this section is shown in the Figure 3.4.

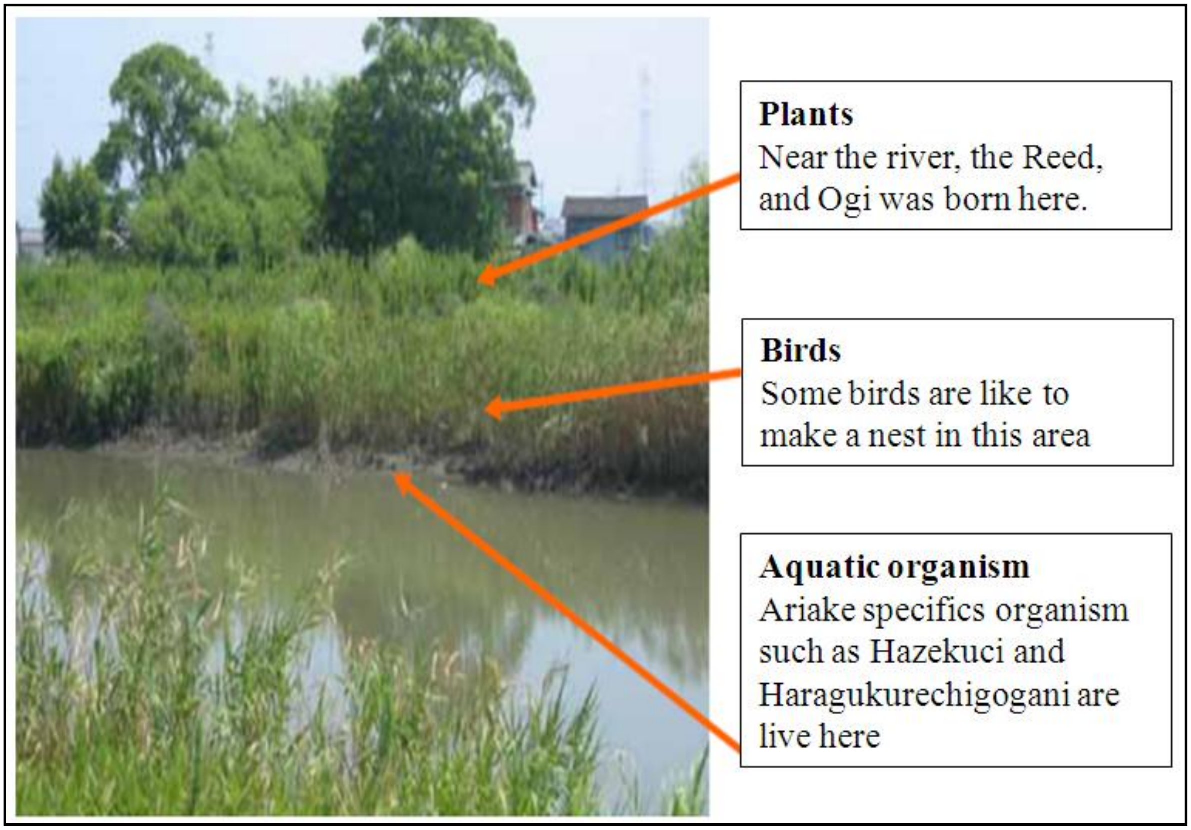


Figure 3.4 Plant, bird and aquatic organism' environment in section Sagae River-Ochaya Weir (brakish water)

The organism that living in this section are: Haragukurechigogani, Setsuka, Reed, Hazekuchi, and Ohyoshikiri.

3.7.2 Section Ochaya Weir – Kanzaki Bridge downstream

The environment of the plants, birds and aquatic organism that live in this section is shown in the Figure 3.5.

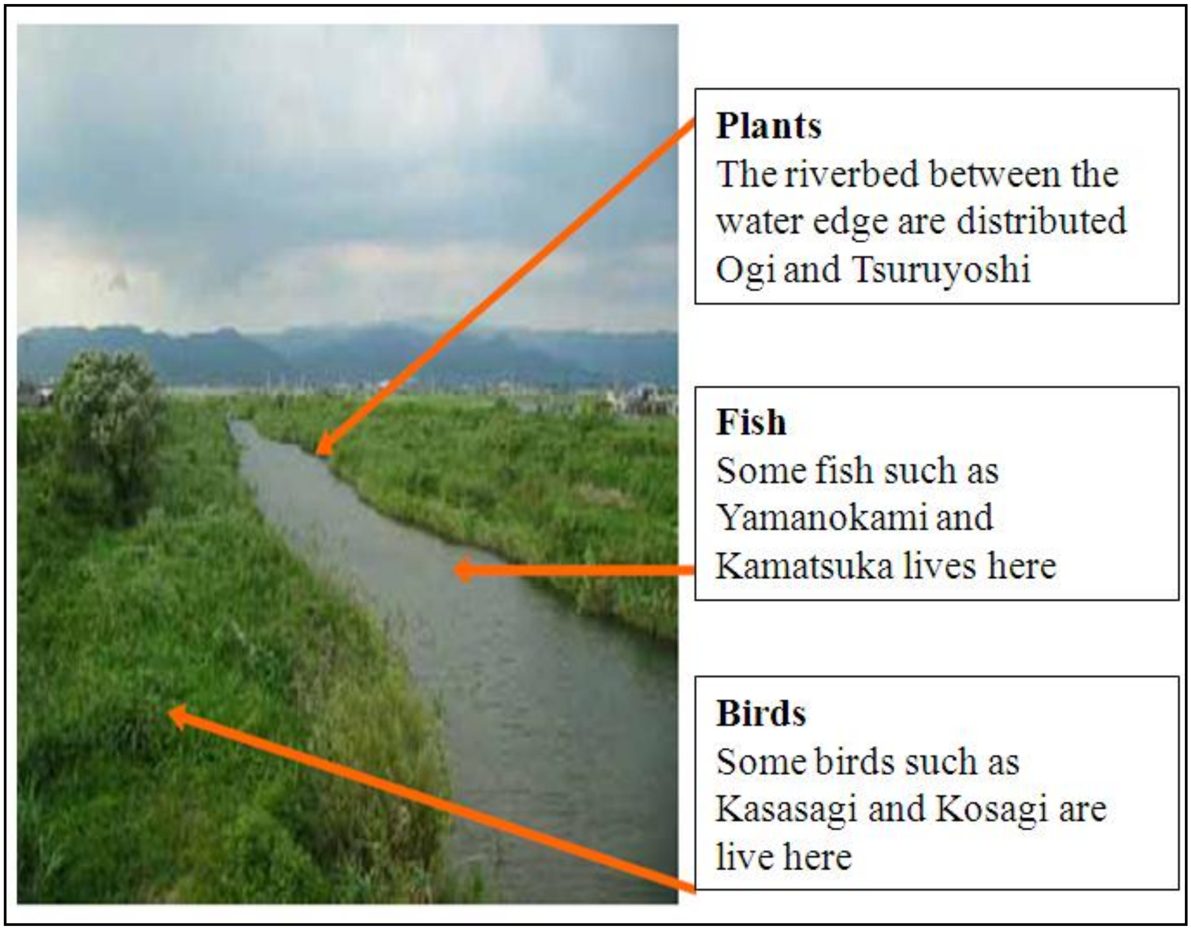


Figure 3.5 Plant, bird and aquatic organism' environment in section Ochaya Weir – Kanzaki Bridge downstream

The organism that living in this section are: Ogi, Tsuruyoshi, Kosagi, Yamanokami, Kamatsuka, and Kasasagi.

3.7.3 Section Kanzaki Bridge downstream – Direct control upstream (fresh water)

The environment of the plants, birds and aquatic organism that live in this section is shown in the Figure 3.6.

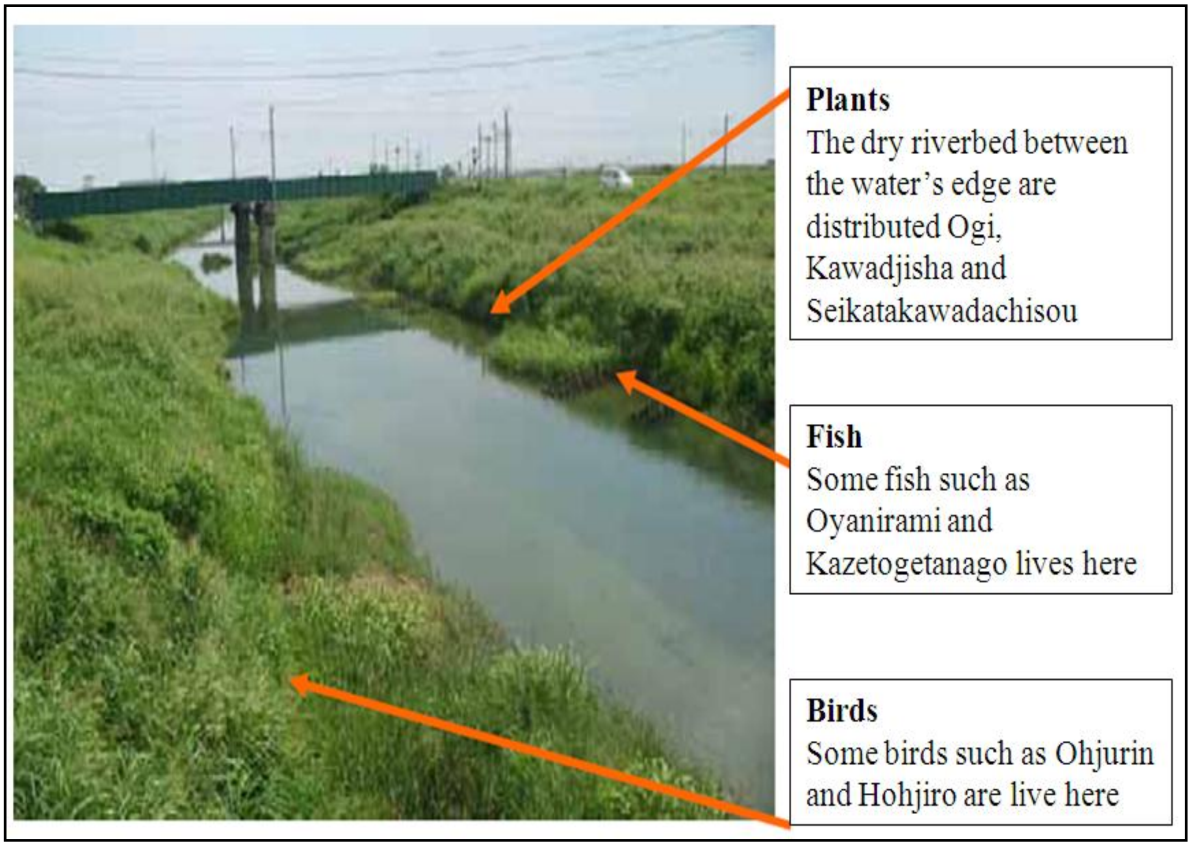


Figure 3.6 Plant, bird and aquatic organism' environment in section Kanzaki Bridge downstream – Direct control upstream (fresh water)

The organism that living in this section are: Oyanirami, Kawadjisha, Ohjurin, Hohjiro, Kazetogetanago, and Seikatakawadachisou.

3.8 RIVER MANAGEMENT PLAN

3.8.1 Chikugo river development project

In July, 2006, Chikugo river system's river improvement project (plan) was settled on. A river improvement project is based on river laws, and is where the contents of river improvement target (objective), riparian works, and river maintenance are decided, and the river's manager asks the local public body's chief, people of learning and experience, and local residents for their opinion; and for the Chikugo River system, it generally decides the contents for the next 30 years for the river section under the management of the Ministry of Land, Infrastructure, Transport and Tourism (River section under the jurisdiction of the Ministry of Construction).

Detailed contents on the Jobaru River are shown in the reference data, but the amount of flood water to go through the river is planned at 330m^3/s, and there is also a plan for building Jobaru River Dam, where they plan to temporarily stop the water headed downstream. The river section under the jurisdiction of the Ministry of Construction (the 9.1km section starting from the confluence with Sagae River) mostly has an insufficient cross section for passing through the maintenance target capacity flood water, and therefore, activities such as enlarging the cross section by digging inside the river, and reconstruction of the Ochaya Weir and Fuufuido Dam are planned. Besides that, there is also a plan to enhance portions of banks that are not high enough, wide enough, or made with easily permeable sad.

Because the Jobaru River is inhabited by such precious creatures as the Oyanirami, the river bank and riverbed, which is their habitat, will not be dug out to the fullest extent, and mainly the dry riverbed will be dug out. Also, work for raising the banks of the upper stream section will only begin after the downstream section is outfitted with the cross sections and banks capable of safely passing through the maintenance target capacity.

3.8.2 Water conveyance project in Saga

Business aqueduct Saga and water shortages and floods by connecting waterway 23 km about extending the small rivers flowing between Chikugo River, Jobaru River, and Kase River, it will communicate with each other the water of the river at the time of water shortage and flooding business is to resolve, it is planned to be completed in FY 2008.

Measures in (flood control measures), the construction of the town Kinryu City Saga (regulating pond) pond to save temporarily flood the river Kase during heavy rain, due to flooding of the city Saga to reduce the damage caused by floods. It is plans and shed Chikugo River, Jobaru River, to Kase River water small rivers that cannot with reducing the damage, shed a flood of mass to build a drainage pump around, reduce the damage caused by flooding of small rivers. During heavy rains, often flooded and rivers overflowing from Baba River and Sanbonmatsu, around Jobaru River Castle, Harakawa is made to the planning and flow 27m^3/s up to some of the flooding of these rivers from aircraft parking areas in the tubes and jade Sagae

River Jobaru River gutter. If the measures in (anti-water use), there is less water Kase River or Jobaru River, there is enough water in the river either that aims to eliminate, such as water shortage, to the river less water from the river which is generous it is planned to send the water. In addition, there is little of either river or water, if there is enough water in the Chikugo River has become a plan to increase the amount of water in the river to send the water of the Chikugo River.

In addition, the supply of water for purification is carried out of the Saga city to the river worsening water supply and water quality of water to the western district Saga has become a problem.

Chapter 4

ANALYSIS ON CURVE NUMBER AND LAND COVER CHANGES IN THE JOBARU RIVER BASIN

4.1 INTRODUCTION

The Curve Number (*CN*) is a hydrologic parameter used to describe the storm water runoff potential for drainage area. In calculating the quantity of runoff from a drainage basin, the *CN* is used determine the amount of precipitation excess that results from a rainfall event over the basin. The greater the value of *CN* means the greater the amount of rainfall becomes runoff. This methodology is a standard hydrologic analysis technique that has been applied in a variety of different settings throughout the United States, and the development and application of the *CN* is well documented. The *CN* is a function of land cover, soil type, and soil moisture.

Jobaru River basin is one of the most important rivers in Saga Prefecture (Figure 4.1). During 1948 to 2005, due to the increasing needs of residential area, the Jobaru River basin has been affected by the changes in land cover; especially the decreasing number of paddy fields and the increasing number of urban or built-up land.

CN is a function of land cover, soil type, and soil moisture. Therefore, the land cover changes can be represented by this parameter. To simulate the Rainfall-runoff process due to the land cover change, some models for example MIKE 11-UHM need *CN* as data input.

The study in this chapter is to estimate the *CN* due to land cover changes in Jobaru River basin. HEC-GeoHMS tool is applied for estimating the *CN*.

4.2 MATERIALS AND METHODS

4.2.1 Data sources

In this section the details of required data are explained. They are used to estimate *CN* on land cover change on Jobaru River basin. Digital elevation model (DEM) was provided by Japan digital map 50m grid (Elevation), 1997. The available land cover data is the Chikugo Watershed land cover 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).

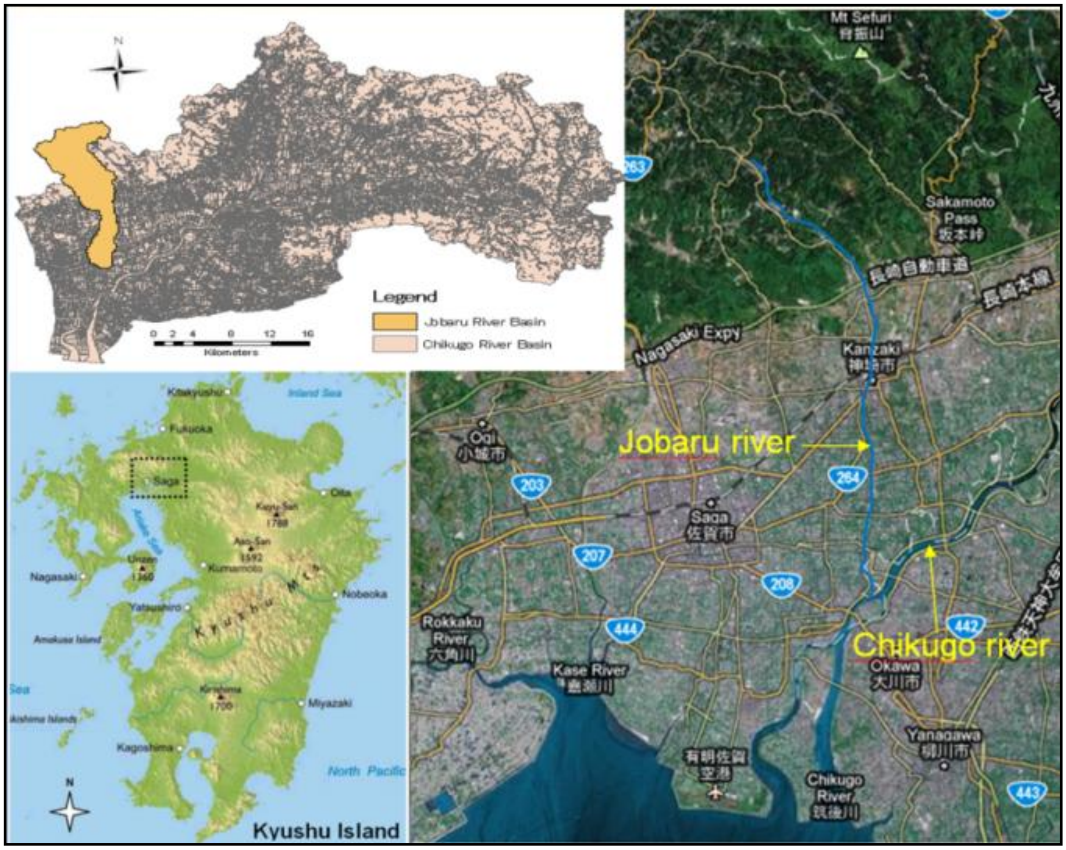


Figure 4.1 Study area

4.2.2 River basin delineation

The first step in doing any kind of hydrologic modeling involves delineating streams and river basin, and getting some basic river basin properties such as area, slope, flow length, and stream network density. To analyze flood response to land cover changes needed basin and sub-basin delineation, and some basic basin properties. The Hydrologic Engineering Center`s Geospatial Hydrologic Modeling System (HEC-GeoHMS) will be used to delineate the river basin in Jobaru river.

A river basin boundary defines the drainage or catchment areas that contribute to a specified outlet channel such as a creek or river. A specific catchment area includes all the land that contribute (drain) to a central point. The overland drainage pattern is based on the topography of an area. This drainage behavior can be modeled within a GIS environment using a combination of datasets and analysis tools. The process described here will use Digital Elevation Model (DEM) datasets and ArcGIS tool.

Flow across a surface will always be in the steepest downslope direction. Once the direction of flow out of each cell is known, it is possible to determine which and how many cells flow into any given cell. This information can be used to define river basin boundaries and stream networks. The flowchart in Figure 4.2 shows the process of extracting hydrologic information, such as river basin boundaries and stream networks, from a DEM.

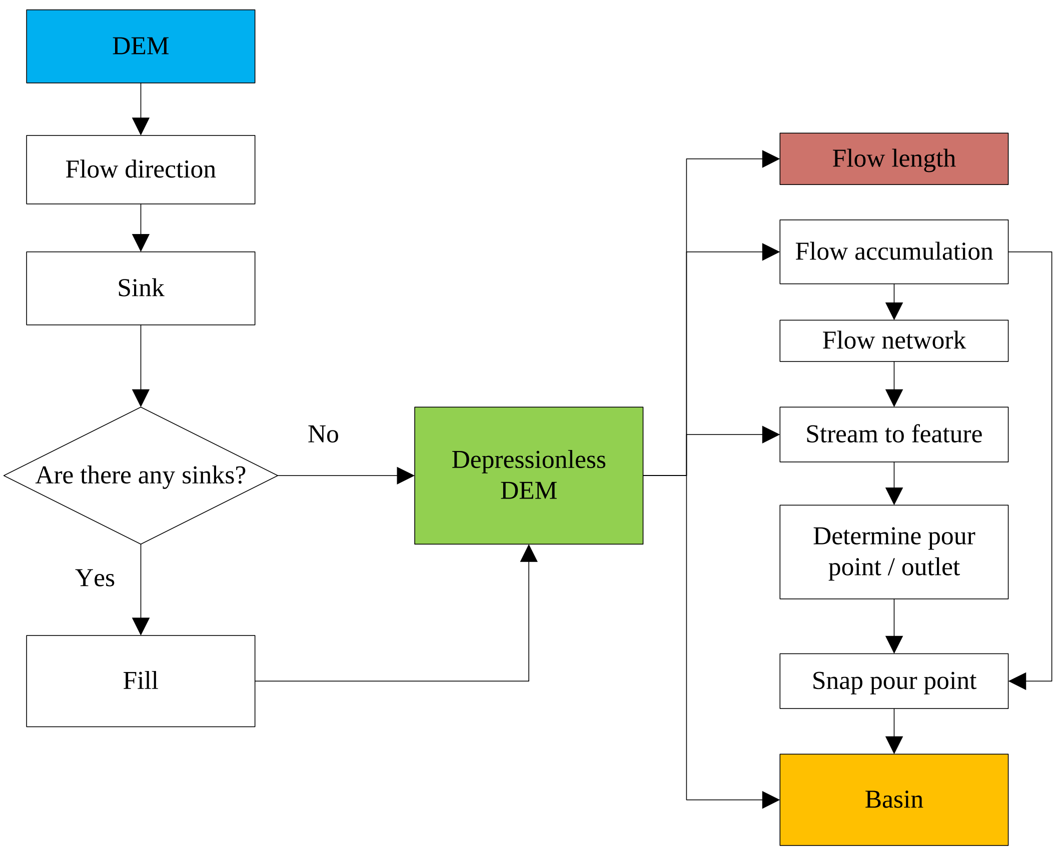


Figure 4.2 River basin delineation flowchart

4.2.2.1 DEM data

DEM data are from Nippon-III 50 m grid elevation of digital map. The Jobaru river basin including Kumamoto frame and Fukuoka frame (Figure 4.3).

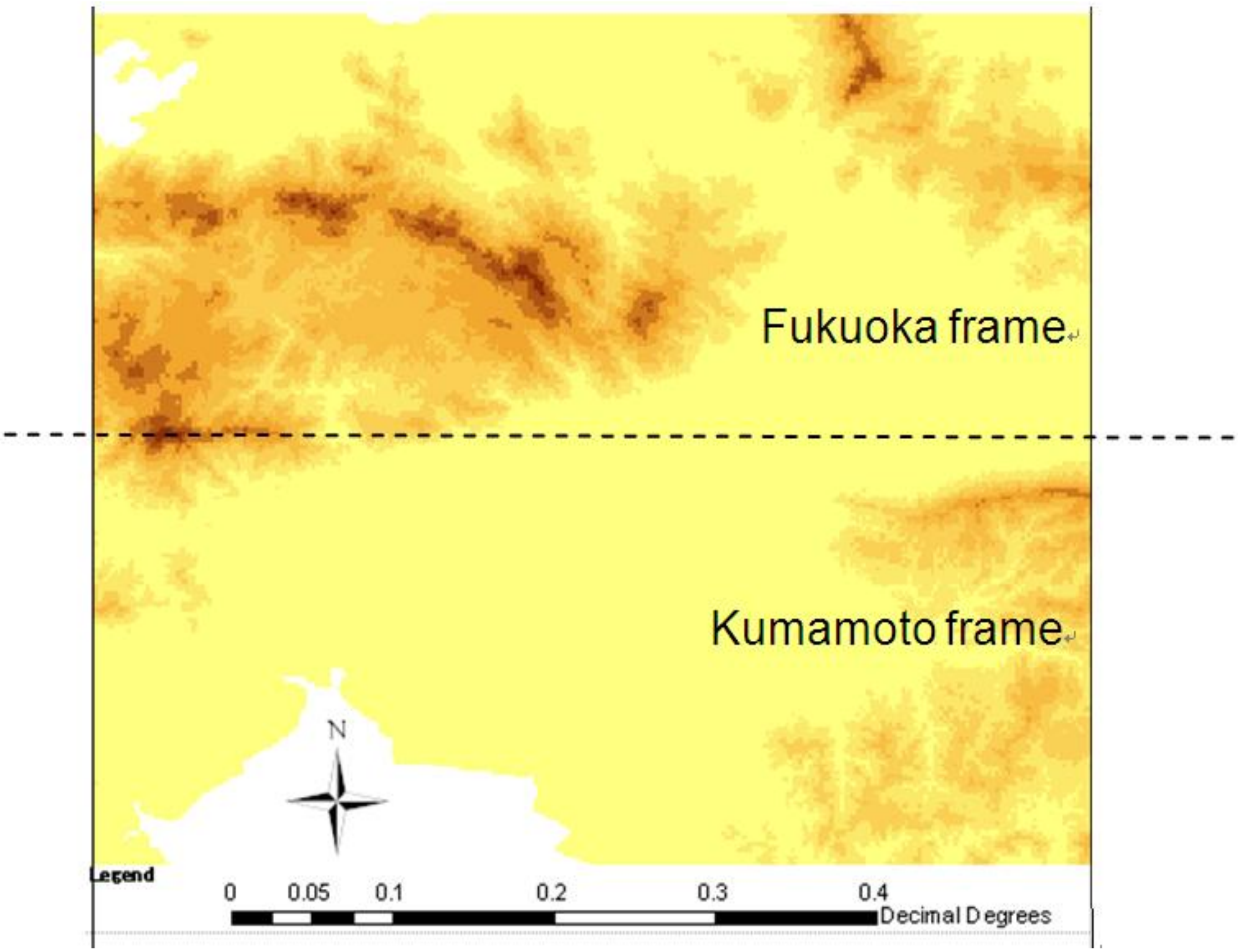


Figure 4.3 Kumamoto-Fukuoka DEM

4.2.2.2 Pour point

A pour point or outlet is the point at which water flows out of an area. Jobaru River pour point is determined in the downstream of the river near the confluent point with Chikugo River, as shown in Figure 4.4.

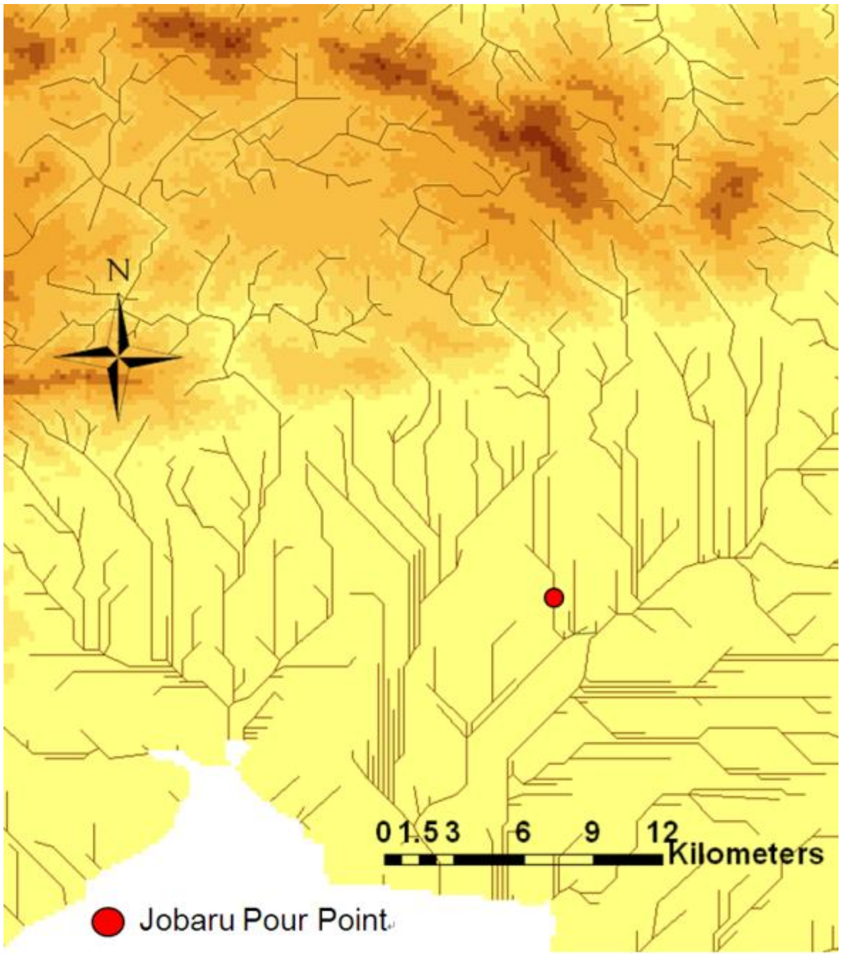


Figure 4.4 Jobaru River basin and sub-basin outlet

4.2.2.3 Basin

A basin is an area that drains water and other substances to a common outlet. Other common terms for a basin are watershed, drainage basin, catchment, or contributing area. This area is normally defined as the total area flowing to a given outlet, or pour point. The boundary between two basins is referred to as a drainage divide or basin boundary.

4.2.2.4 Sub-basin outlet

According to the area, Jobaru basin will be divided into two sub-basins; Mountainous sub-basin and Plain sub-basin. The mountainous sub-basin outlet is determined in Niiyama. The basin and sub-basin characteristics are shown in Table 4.1.

4.2.2.5 Basin re-delineation

In the previous step, the Jobaru River basin was delineated base on the topography map (DEM), so the surface water automatically flowing based on the elevation. Actually the Jobaru Plain sub-basin is a very flat area predominantly paddy fields. The surface water does not flow based on the surface elevation, but based on the paddy field's pond configurations. The farmers arrange the paddy field`s ponds and they arrange the configurations of water flow direction depend on the needs. Therefore it needed to re-delineate the Jobaru River basin base on the paddy field ponds' configurations, and also the nearest river-neighbourhood dyke. From the re-delineation it obtained that the area of Jobaru River basin is about 87.46 km^2 (Figure 4.5).

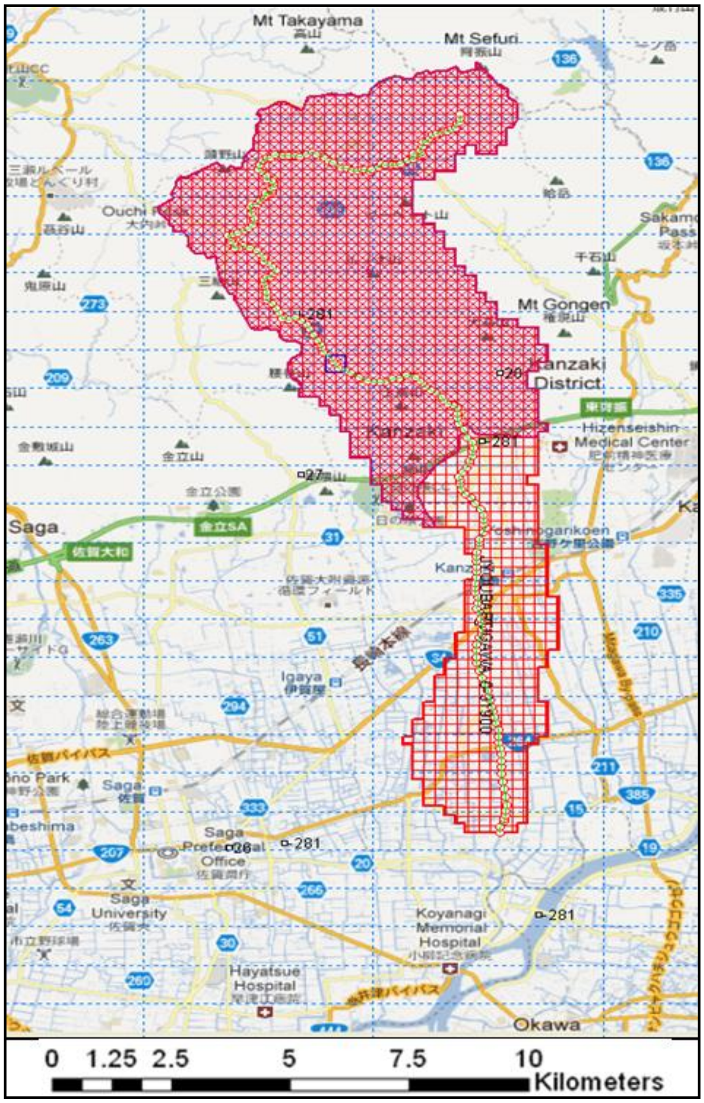


Figure 4.5 Jobaru River basin and sub-basin

Table 4.1 Basin/sub-basin characteristics

	Plain sub-basin	Mount sub-basin	Jobaru basin
Area (km^2)	37.06	50.4	87.46
Length of main Channel (km)	11.4	20.5	31.9

4.2.3 Land cover analysis

The next step is to define the Jobaru River basin land use map by intersecting the Jobaru basin map with the land cover map. The original land cover of Jobaru River basin in 1948 is divided 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 cover categories. Land cover 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 4.2. Using ArcGIS tool a reclassification map for the Jobaru River basin and sub-basin land cover is defined (Figure 4.6). The land cover change is analyzed between 1948, 1975 and 2005 by using ArcGIS tools.

Table 4.2 Land cover reclassification

Code	**Land cover 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

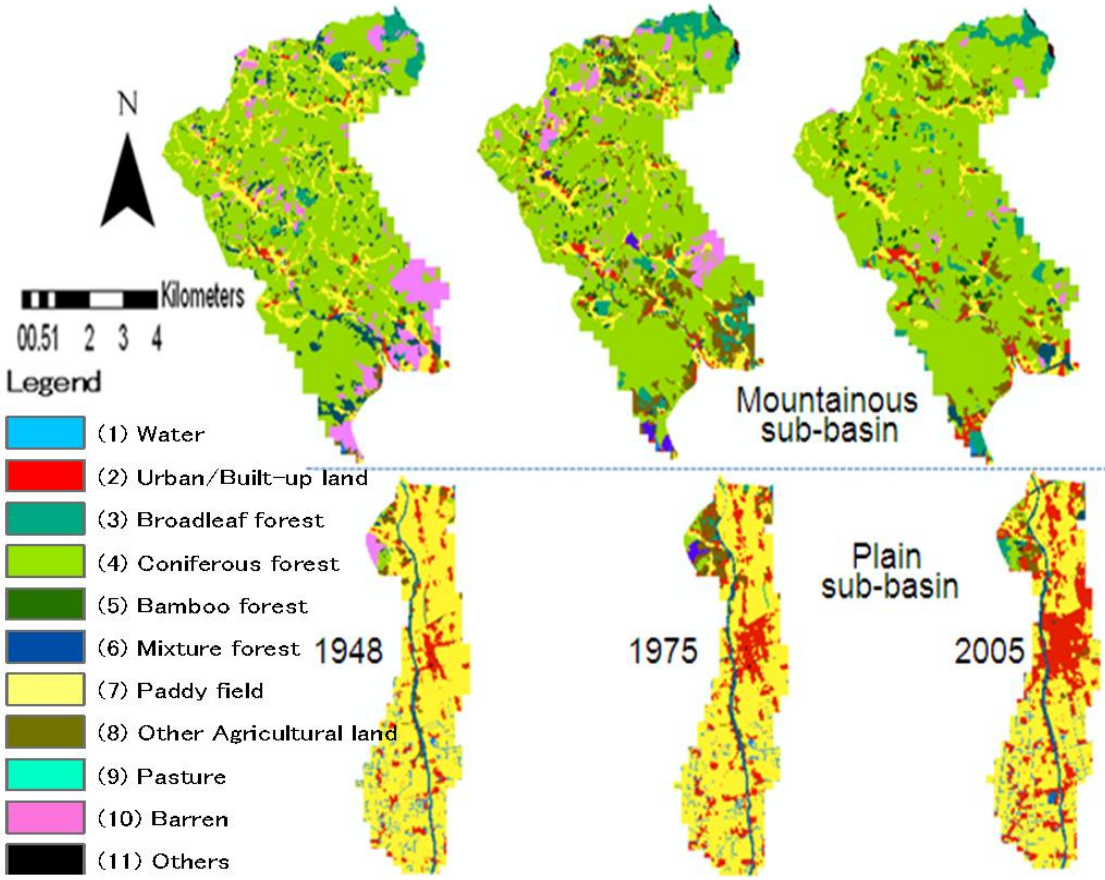


Figure 4.6 Basin/ sub-basin land cover

4.2.4 Soil type analysis

The next step is to analyze the type of soil. Soil data of Jobaru River basin was derived from:

a. Geological map of Japan, AIST-2003 (Figure 4.7).
b. Soil regions map of Japan based on a reclassification, Tohoku University (Figure 4.8). http://www.agri.tohoku.ac.jp/soil/eng/index.html
c. Digital soil map of the world ,FAO (Figure 4.9).
http://www.fao.org/fileadmin/templates/nr/images/resources/images/SoilMap_hires.pdf

At first, the soil data from Geological map of Japan (AIST) was analyzed by using ArcGIS to obtain the Jobaru soil map. The next step is to compare the Jobaru soil map with the soil map of Japan based on reclassification and the digital soil map of the world to obtain the name of the soil types at Jobaru River basin.

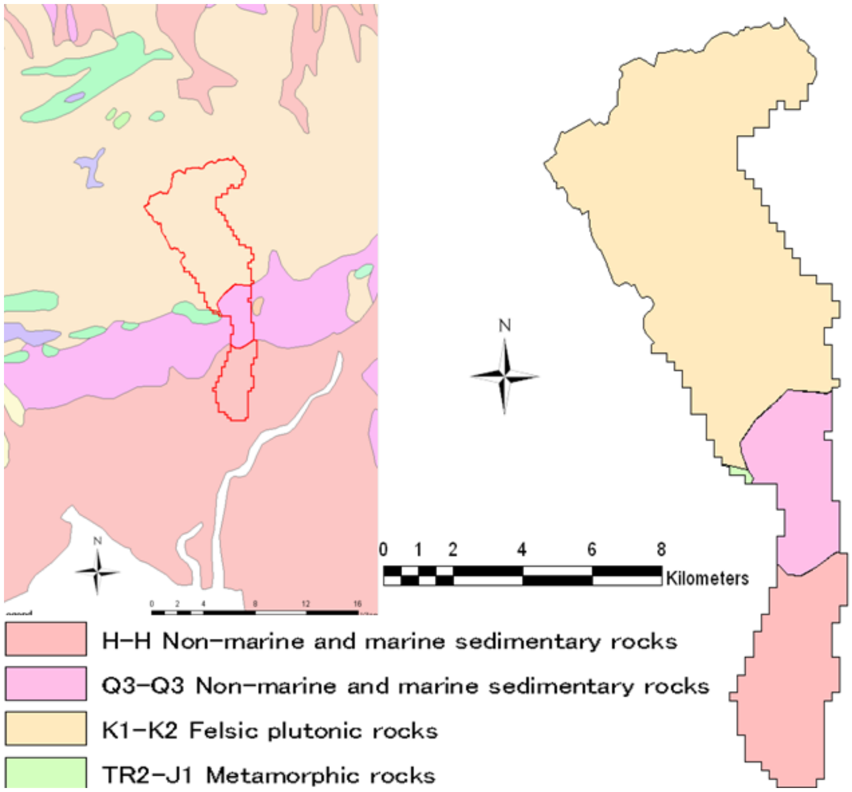


Figure 4.7 Jobaru Geological map from Geological map of Japan

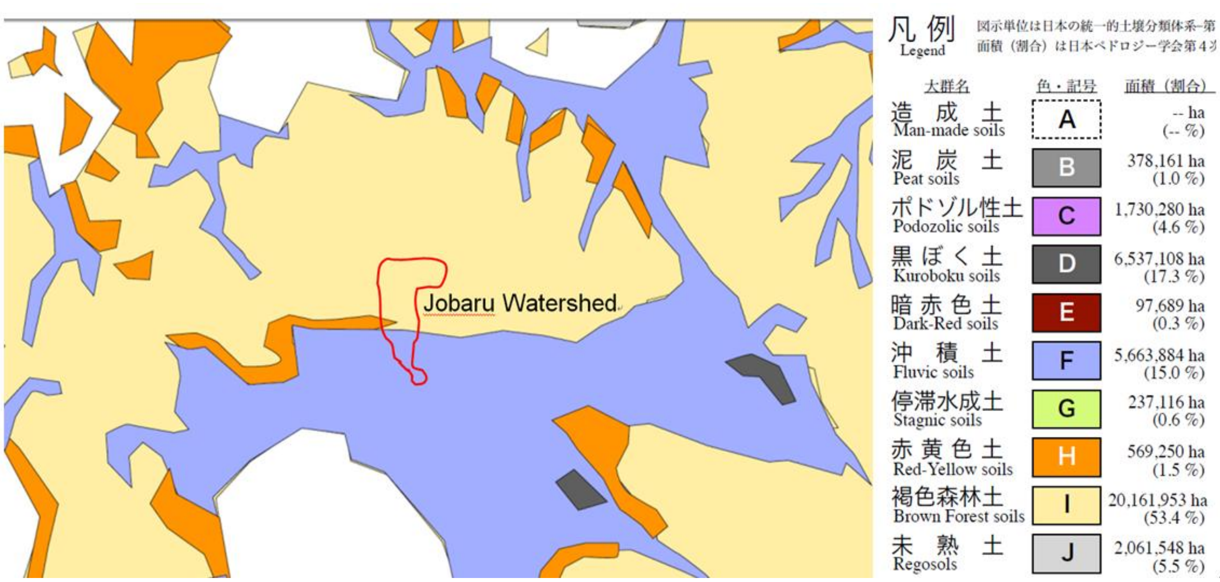


Figure 4.8 Jobaru soil class map from soil regions map of Japan based on a reclassification

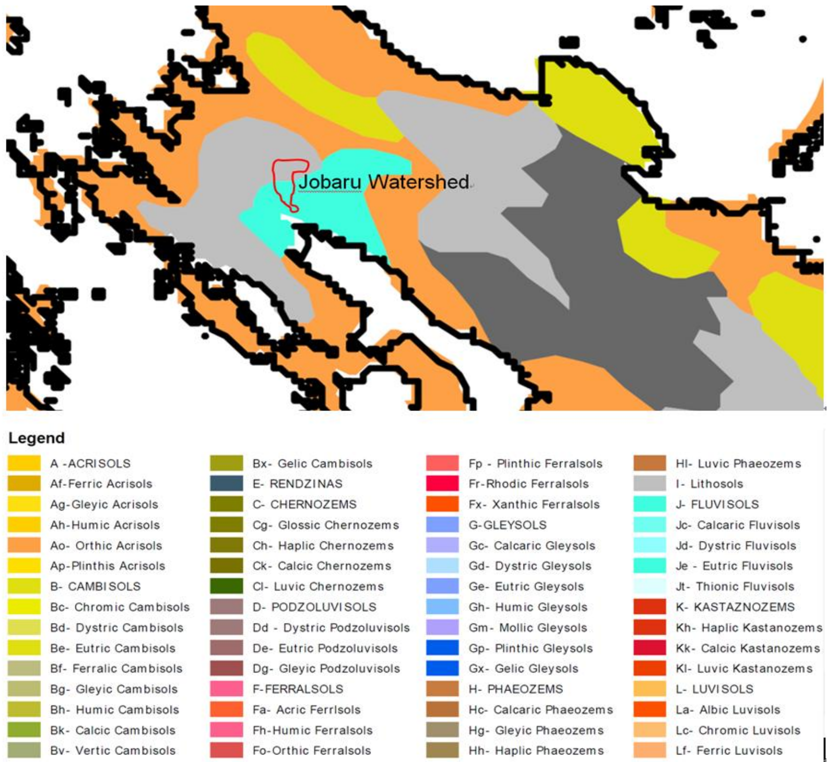


Figure 4.9 Jobaru soil map from digital soil map of the world

From the analyses it obtained that the soil type in Jobaru River basin are (Figure 4.10):

- Fluvic soils,
- Brown forest soils,
- Red-Yellow soils.

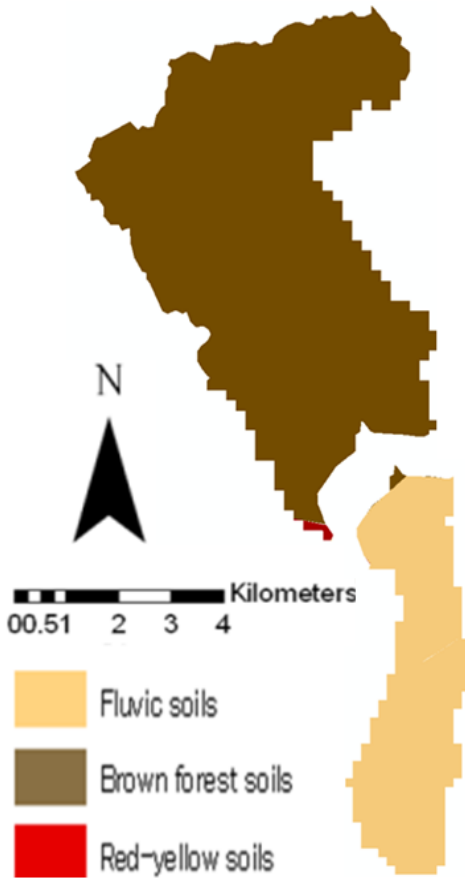


Figure 4.10 Jobaru River basin soil type

4.2.5 *CN* analysis

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 (Figure 4.11):

(1) the drainage basin boundaries for which *CN* will be calculated,
(2) the soil type map,
(3) the land use map.

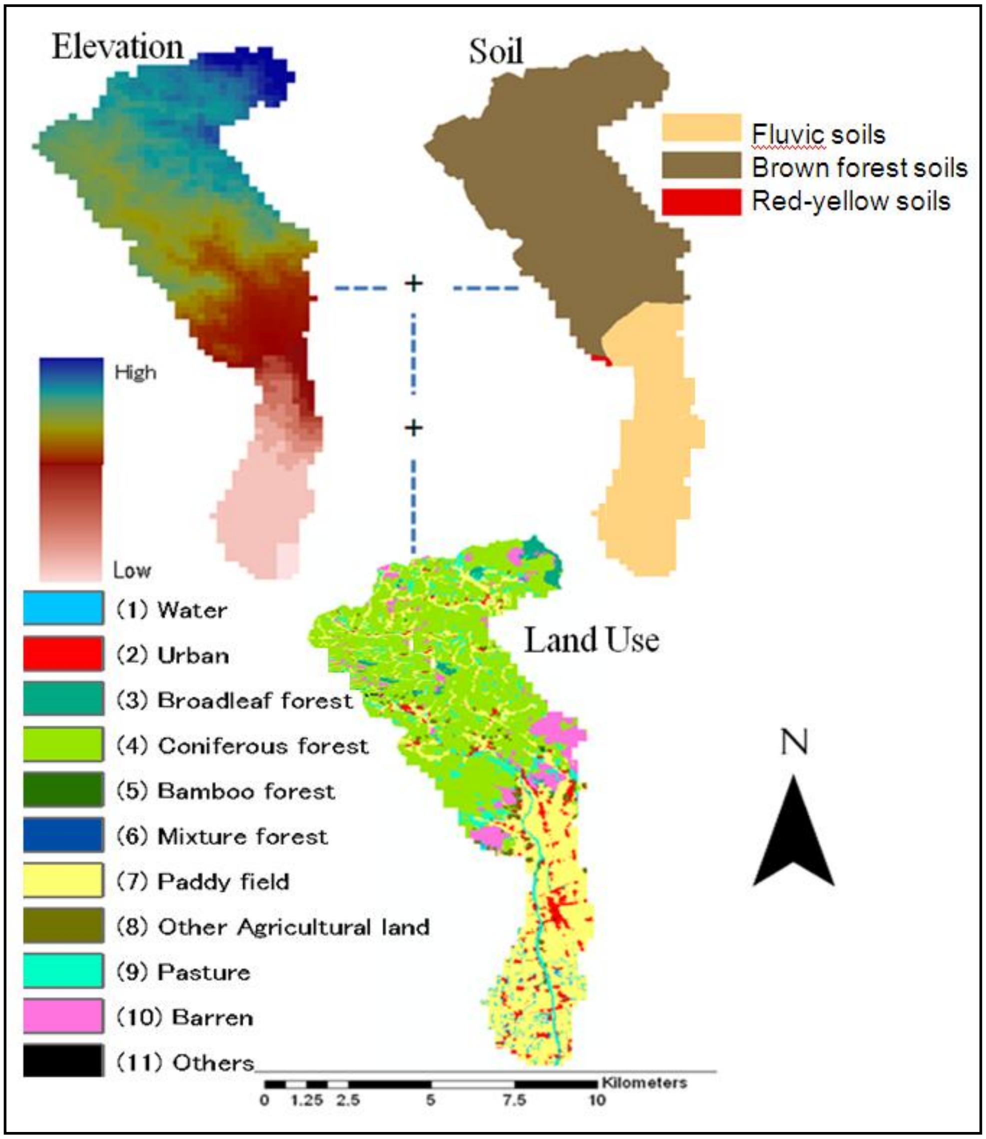


Figure 4.11 Three data sets for generating *CN*

4.2.6 *CN* Estimation

The *CN* is estimated for a drainage basin using a combination of land cover, soil, and antecedent soil moisture condition (AMC). Soil data are obtained from the geological map of Japan-AIST 2003, Soil regions map of Japan-Tohoku University and Digital Soil Map of the world-FAO. Typically, soil surveys list soil types by name, which is based on certain physical characteristics of the soils. However, the information needed to determine a curve number is the hydrologic soil group, which indicates amount of infiltration the soil will allow. Significant infiltration occurs in sandy soils while no infiltration occurs on heavy clay or rock formations. As a result of urbanization, the soil profile may be considerably altered and the listed group classification may no longer apply.

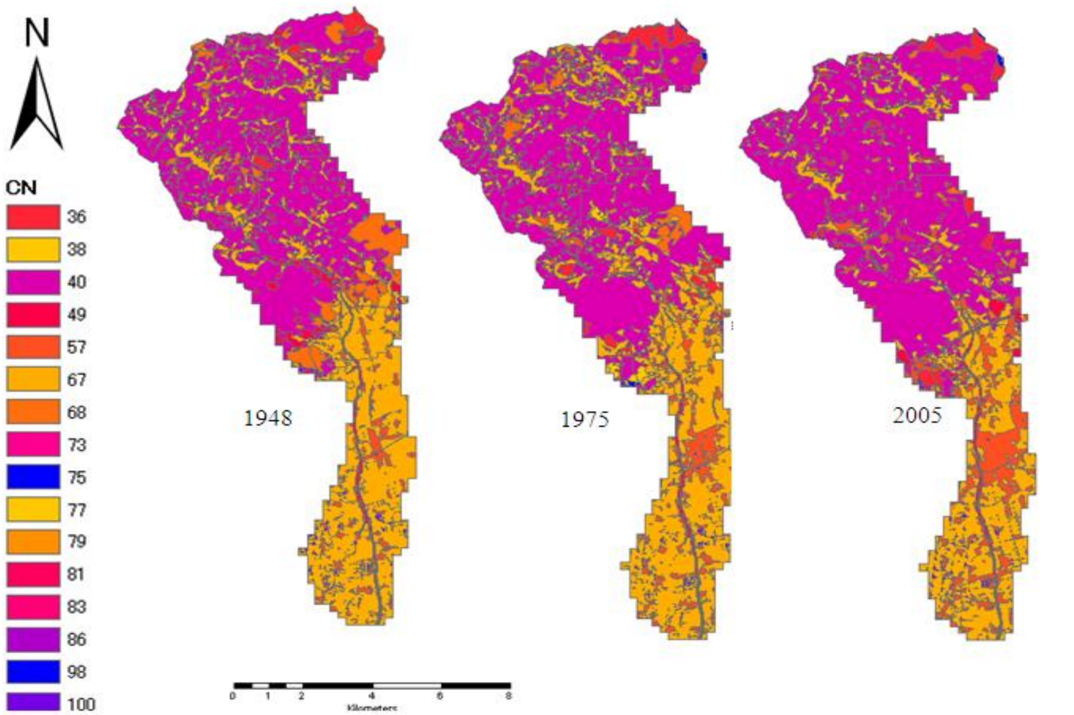
The land cover distribution map for Jobaru River basin is obtained from Ryuki shizen kankyou chousa sagyou for years 1948, 1975 and 2005. Land cover categories are defined based on the level of detail required for the study. Standard SCS curve numbers are assigned for each possible land cover-soil group combination. The typical land cover categories corresponding curve number are from: NRCS Curve Number-Kyoto University, Determinations of complexes and Curve Number-Hydrology National Engineering Handbook and The standard categories typically used for hydrologic analysis using the SCS methodology (SCS, 1986).

4.2.6.1 The ArcGIS Curve Number Generator

An ArcGIS extension, henceforth termed the Curve Number Generator, was created to facilitate calculation of curve numbers for large watersheds. Upon startup, the user is asked to define the path and name for all required shapefiles and look-up tables. The Curve Number Generator requires three shapefiles: (1) the watershed or drainage basin boundaries for which curve number(s) will be calculated, (2) the land use map, and (3) the soil type map. The Curve Number Generator also requires two user defined look-up tables: (1) the soil group table that provides the conversion from soil types to hydrologic soil groups, and (2) the Curve Number table that defines the land cover-soil group categories and curve numbers, similar to Table 4.8 shown previously. The look-up tables can be modified by the user as appropriate for each project. For example, the NRCS might provide a soil map with abbreviated soil names instead of the formal soil names. The user can modify the soil group look-up table to accommodate the map if necessary.

4.2.6.2 Curve Number Generator output

Figures 4.12 present the final results of the Curve Number Generator. The output consists of a new shapefile for the drainage basin boundaries. Each drainage basin has a record in the following fields: basin name, area-weighted curve number, and the area.



Attributes of SubWatershed-Soil-Landuse(2005.)

FID	Shape *	Shape_Leng	Shape_Area	HSG	PctA	PctB	PctC	PctD	CathmentID	Landuse	CN
0	Polygon	19409.809912	13182450.7391	A	100	0	0	0	Lower	1	100
1	Polygon	19409.809912	13182450.7391	A	100	0	0	0	Lower	1	100
2	Polygon	19409.809912	13182450.7391	A	100	0	0	0	Lower	7	67
3	Polygon	19409.809912	13182450.7391	A	100	0	0	0	Lower	1	100
4	Polygon	19409.809912	13182450.7391	A	100	0	0	0	Lower	1	100
5	Polygon	19409.809912	13182450.7391	A	100	0	0	0	Lower	2	57
6	Polygon	19409.809912	13182450.7391	A	100	0	0	0	Lower	7	67
7	Polygon	19409.809912	13182450.7391	A	100	0	0	0	Lower	8	67
8	Polygon	19409.809912	13182450.7391	A	100	0	0	0	Lower	7	67
9	Polygon	19409.809912	13182450.7391	A	100	0	0	0	Lower	2	57
10	Polygon	19409.809912	13182450.7391	A	100	0	0	0	Lower	1	100
11	Polygon	19409.809912	13182450.7391	A	100	0	0	0	Lower	1	100
1581	Polygon	2541.033801	155703.379222	C	0	0	100	0	Midle	4	77
1582	Polygon	2541.033801	155703.379222	C	0	0	100	0	Midle	4	77
1583	Polygon	2541.033801	155703.379222	C	0	0	100	0	Midle	1	100
1584	Polygon	2541.033801	155703.379222	C	0	0	100	0	Midle	3	73
1585	Polygon	2541.033801	155703.379222	C	0	0	100	0	Midle	2	81
1586	Polygon	2541.033801	155703.379222	C	0	0	100	0	Midle	4	77
1587	Polygon	2541.033801	155703.379222	C	0	0	100	0	Midle	2	81
1588	Polygon	2541.033801	155703.379222	C	0	0	100	0	Midle	7	67
1589	Polygon	2541.033801	155703.379222	C	0	0	100	0	Midle	2	81
1590	Polygon	2541.033801	155703.379222	C	0	0	100	0	Midle	4	77

Figure 4.12 Jobaru River basin *CN* correspond to land cover 1948, 1975 and 2005

From the analyses, it obtained that the Jobaru River basin has many unique polygons, each polygon has a *CN* that represents a unique sub-basin, soil, land cover and topography Table 4.3).

Table 4.3 Amount of unique polygon

River basin/ sub-basin	Unique polygon, year		
	1948	1975	2005
Mountainous	849	828	516
Plain	985	936	

4.3 RESULTS AND DISCUSION

4.3.1 Land cover change

4.3.1.1 Jobaru River basin

According to the analysis, in Jobaru River basin, land cover changes significantly in urban area, forestry, agricultural land and barren area, while water and others remained relatively unchanged (Figure 4.7). The result of land cover changes in 1948, 1975 and 2005 showed that the barren area tended to turn into a forest. After World War II, Japan consumes a lot of wood to build houses, many trees were cut down to be used as construction materials, so many of that forest areas turned barren. This resulted in land cover in 1948. Forest area is relatively small and barren area is relatively large compared to the year 1975 and 2005. The land cover in 1975 showed that barren area decreased, turning into forest. The results indicates that there is no longer booming demand for wood for construction materials at that time, reforestation were even made in barren areas, so it turns barren areas into forests and the same thing happened to the land cover in 2005. On the other hand, the result of land cover 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 have 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 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 cover changes continue to happen, then it is feared that the peak flow in the Jobaru River will also continue to increase.

4.3.1.2 Jobaru Mountainous sub-basin

In mountainous sub-basin, the land cover has changed significantly in forest, barren area, agricultural land, and urban area, while water and others remained relatively unchanged (Figure 4.13). Dominantly, barren area turns into forest.

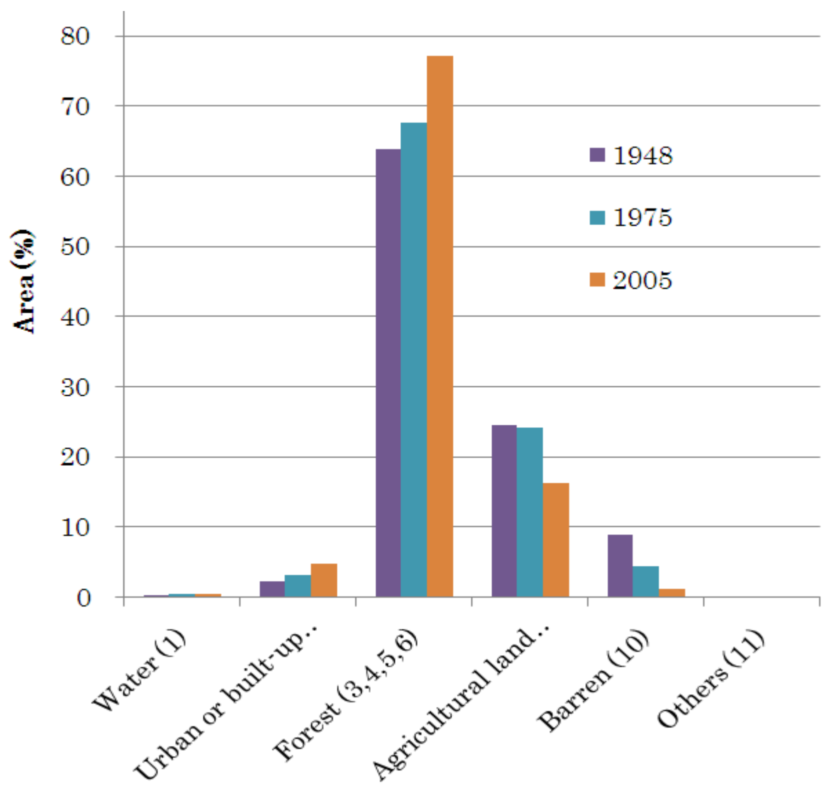


Figure 4.13 Land cover change on Jobaru mountainous sub-basin

4.3.1.3 Jobaru Plain sub-basin

The land cover has changed significantly in urban and agricultural land, while water, forest, barren area and others are relatively unchanged in Jobaru plain sub-basin (Figure 4.14). Dominantly, the agricultural land turns into urban areas.

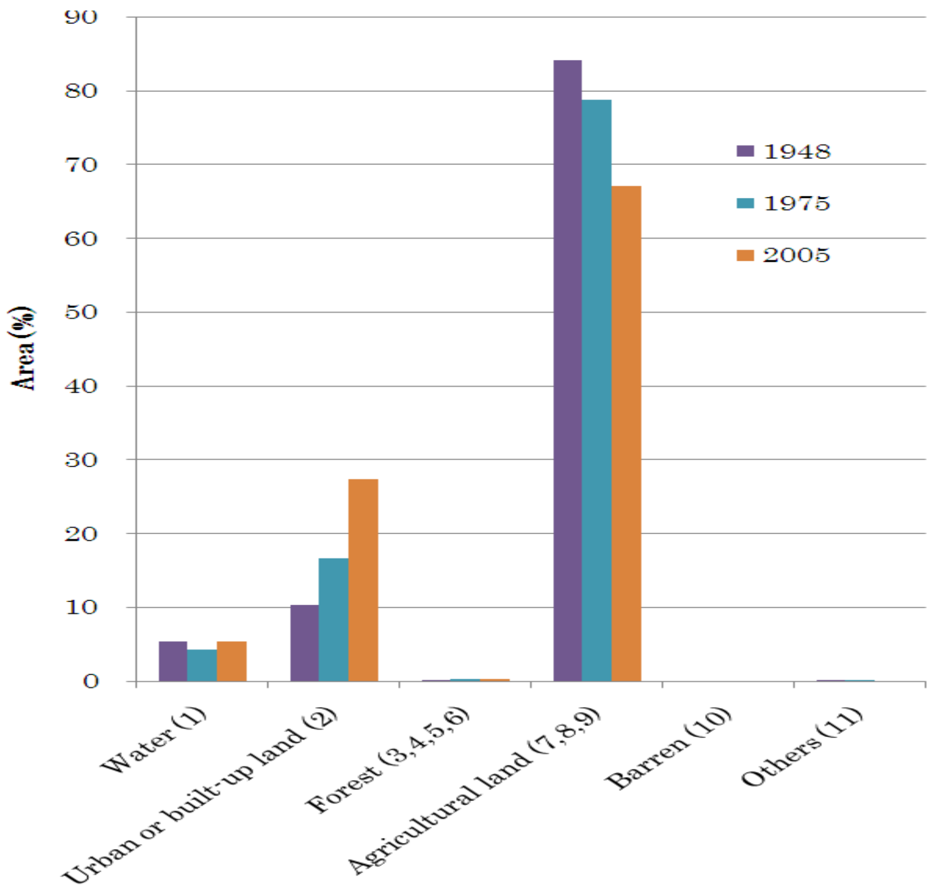


Figure 4.14 Land cover change on Jobaru plain sub-basin

4.3.1.4 Jobaru River basin curve number

From the *CN* analysis, it indicated that the Jobaru mountainous and plain sub-basin has many unique polygons (Table 4.3). Each polygon representing one of the catchment areas and it's area-weighted curve number. Each *CN* is representing a unique sub-basin, soil, land cover and topography, therefore the average *CN* of the basin and sub-basin can be defined. The average *CN* of each basin and sub-basin are shown in Table 4.4. The average *CN* of Jobaru River basin has increased from 53.97 in 1948 to 56.25 in 2005. In this period, the main land cover changes are due to an increasing 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 the 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*. 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 increased 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 covers were predominantly forest, and also most of the barren areas were there. In this period almost all barren area turned into forest, so it causes the *CN* in mountainous area to decrease. However in Jobaru plain sub-basin, the average *CN* increased from 67.53 in 1948 to 69.72 in 2005. This is because in that area, the dominant land covers were agricultural 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. From 1948 to 2005, the land use quality in the mountainous sub-basin changed for the better, but in the plain sub-basin, and entire the Jobaru River basin, the land cover quality changes was worse. For anticipating the flood in Jobaru River due to the land cover change it is better to consider the sub basins, especially in the plain sub-basin. 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.

Table 4.4 Average *CN*

River basin/ sub-basin	Average *CN*		
	1948	1975	2005
Jobaru	53.97	55.82	56.25
Mountainous	48.24	48.43	46.07
Plain	67.53	69.07	69.72

4.4 CONCLUSIONS OF CHAPTER 4

Land cover changes during 1948, 1975 and 2005 in The 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.

The increasing of forest is predominantly caused by changes in barren into forest, while the decreasing of agricultural land this is due to the increased demand of land for residential.

The changes of the land cover can be represented by the changes of the *CN*. In the Jobaru River basin the average *CN* has increased. In the mountainous sub-basin, the average *CN* has decreased but in the plain sub-basin, the average *CN* has increased.

The result of the *CN* change can be finally utilized to analyze floods.

Chapter 5

EFFECT OF LAND COVER CHANGES ON THE JOBARU RIVER FLOW

5.1 INTRODUCTION

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 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 cover. Data from 1948 to 2005 showed that the land cover has changed in the Jobaru River basin. 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 cover 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.

River modelling assists decision makers in the prevention and prediction of flood events (flood analysis), and the design and operation of hydraulic structures along rivers. Computer modelling techniques assists engineers by determining the data about the hydrologic and hydraulic behaviour of the rivers more accurately. Computer models for river simulations require: 1) a hydrologic model which develops rainfall-runoff from a design storm or historic storm event, and 2) a hydraulic model which routes the runoff through stream channels to determine the water surface profiles at specific locations along stream network (Harding (2001)). Most of the previous hydraulic modelling techniques use one-dimensional (1-D) steady state flows measured at a specified point in time (Ahmad, et al., 1999). Since flows in streambeds are naturally random and unsteady, steady-state methods do not always accurately depict surface water profiles. The steady-state modelling technique is also limited by how the modeller spatially synchronizes the rainfall-runoff routing for multiple drainage basins at a specified point in time. Such methods are subject to human error and can be very time consuming (Snead, 2000). Developments in fully dynamic, unsteady models have provided engineers with highly accurate hydraulic modelling methods. The Danish Hydraulic Institute (DHI) is one of the world's leading software developers for incorporating water resources-related time series data into modelling.

DHI's MIKE 11 hydrodynamic models uses 1-D implicit, dynamic wave routing based on the St.Venant equations for unsteady flow.

The process-based hydrological model MIKE11-Rainfall runoff was used to simulate rainfall-runoff processes in the Jobaru River basin. Within the Jobaru river MIKE11 modelling framework, two hydrology modules are available for use in modelling the rainfall-runoff process. The UHM model, which is suitable for the simulations of runoff 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 study in this chapter is to analyze the effect of land cover change on the river flow in Jobaru River basin.

5.2 MATERIALS AND METHODS

5.2.1 Data sources

Meteorological data are obtained from MLIT, Japan. It includes hourly rainfall data observed from Mitani, Basekibaba and Saga Raingage station, and hourly discharge data from Hideki bridge observation point (Figure 5.1 and Table 5.1). Jobaru river cross section data were collected from MLIT, Japan and Saga prefectural office, includes 70 cross sections along the 14 km length of Jobaru River. Jobaru basin and sub-basin map and *CN* were analyzed in the Chapter 4.

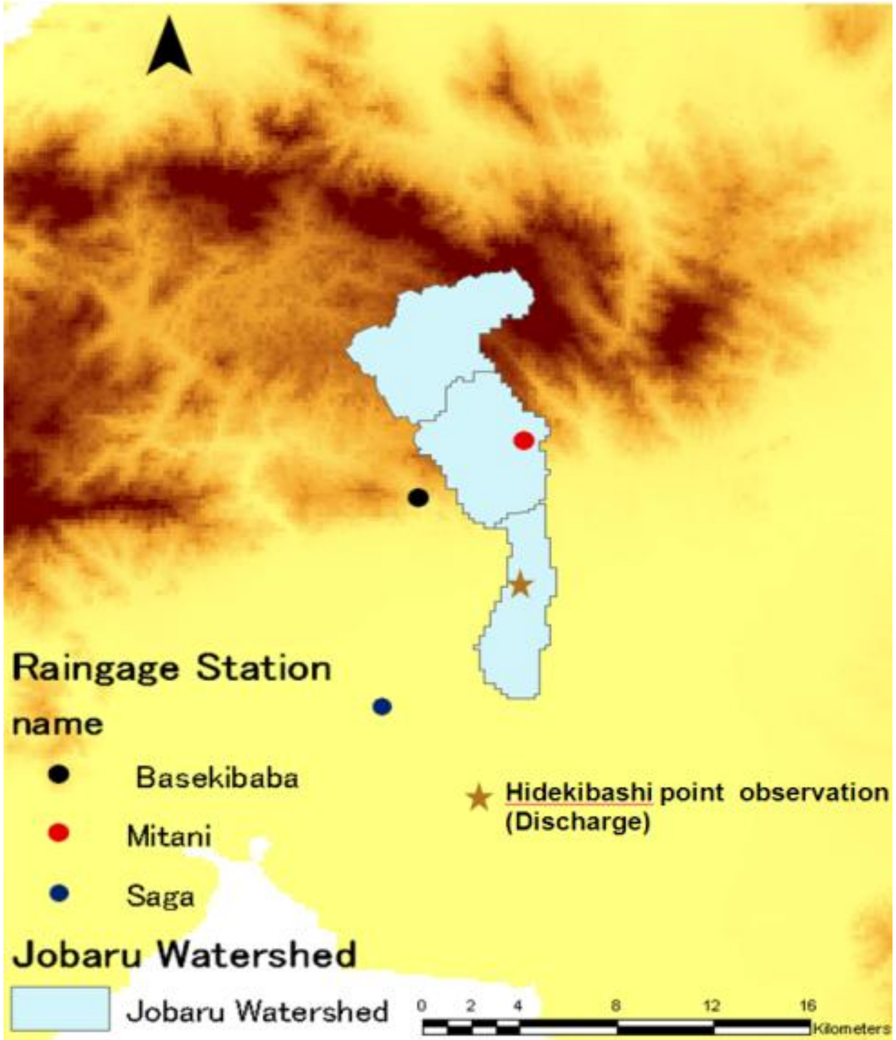


Figure 5.1 Meteorological stations

Table 5.1 Meteorological stations

Raingage station	Latitude	Longitude
Saga	$130^0$18’30’’	$33^0$15’10’’
Basekibaba	$130^0$19’35’’	$33^0$20’24’’
Mitani	$130^0$22’24’’	$33^0$21’48’’

5.2.2 Rainfall-Runoff and Hydrodynamic model

5.2.2.1 MIKE 11 Rainfall-Runoff (RR)

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 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 base flow. 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.

The data needed to input to the MIKE 11-RR model are; 1) catchment file which includes *CN* and slope of the basin, and 2) rainfall and discharge time series file. Hourly rainfall data is from Saga, Basekibaba and Mitani raingages station. Hourly discharge data is from Hideki bridge point observation.

5.2.2.2 MIKE 11 Hydrodynamic (HD)

The MIKE 11 is an implicit finite difference model for one dimensional unsteady flow computation and can be applied to looped networks and quasi-two-dimensional flow simulation on floodplains. The model has been designed to perform detailed modeling of rivers, including special treatment of floodplains, road overtopping, culverts, weirs and gate openings. MIKE 11 is capable of using Kinematic, diffusive or fully dynamic, vertically integrated mass and momentum equations (the "Saint Venant "equations). The solution of the continuity and momentum equations is based on an implicit finite difference scheme. This scheme is structured so as to be independent of the wave description specified (i.e. Kinematic, Diffusive or dynamic). Boundary types include water level (h), Discharge (Q), Q / h relation, wind field, dambreak, and resistance factor. The water-level boundary must be applied to either the upstream or downstream boundary condition in the model. The discharge boundary can be applied to either the upstream or downstream boundary condition, and can also be applied to the side Tributary flow (lateral inflow). The lateral inflow is used to depict runoff. The Q / h relation boundary can only be applied to the downstream boundary. MIKE 11 is a modeling package for the simulation of surface runoff, flow, sediment transport, and water quality in rivers, channels, Estuaries, and floodplains. The most commonly applied hydrodynamic (HD) the model is a flood management tool simulating the unsteady flows in river branched and looped networks and quasi two-dimensional flows in floodplains. When using a fully dynamic wave description, MIKE 11 HD solves the equations of conservation of continuity and momentum (the 'Saint Venant' equations). The solutions to the equations are based on the following Assumptions (MIKE 11, 2005).

- The water is incompressible and homogeneous (ie, negligible variation in density).
- The bottom slope is small, thus the cosine of the angle it makes with the horizontal may be taken as one.
- The wave lengths are large Compared to the water depth, assuming that the flow everywhere can be assumed to flow parallel to the bottom (ie vertical accelerations can be ignored, and a hydrostatic pressure variation in the vertical direction can be assumed).
- The flow is sub-critical (a super-critical flow is modeled in MIKE 11; however, more restrictive conditions are applied).

The basic equations used are:

Continuity:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \qquad (5.1)$$

Momentum:

$$\frac{\partial Q}{\partial t} + \frac{\partial (\frac{\propto Q^2}{A})}{\partial x} + gA\frac{\partial h}{\partial x} + \frac{gQ|Q|}{C^2 AR} = 0 \qquad (5.2)$$

where

Q = discharge (m^3/s),

A = flow area (m^2),

q = lateral inflow per unit width (m^2/s),

h = stage above datum (m),

C = Chezy resistance coefficient ($m^{1/2}/s$),

R = hydraulic or resistance radius (m),

α = momentum distribution coefficient.

The solution of the equations of continuity and momentum is based on an implicit finite difference scheme developed by Abbott and Ionescu (1967). The scheme is structured in order to be independent of the wave description specified (i.e., kinematic, diffusive or dynamic). A computational grid of alternating *Q* (discharge) and *h* (water level) points is used as illustrated in Figure 5.2. The computational grid is automatically generated on the basis of the user requirements. *Q*-points are placed midway between neighboring *h*-points and at structures, while h-points are located at cross-sections, or at equidistant intervals in between if the distance between cross-sections is greater than maximum *dx*. The discharge is defined by convention as positive in the positive x-direction (increasing chainage).

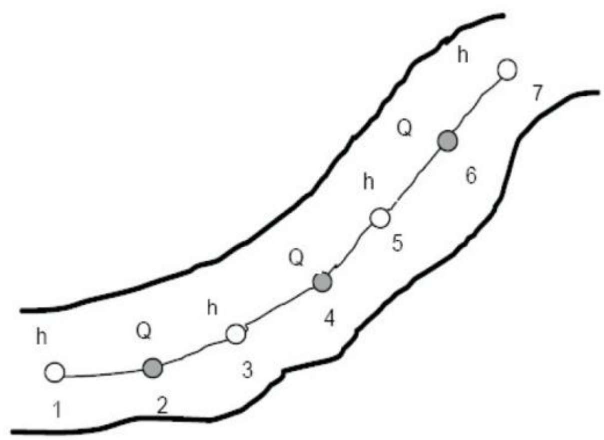


Figure 5.2 Channel section with computational grid

The four terms in the momentum equation are local acceleration, convective acceleration, pressure, and friction. In MIKE 11, a network configuration depicts the rivers and floodplains as a system of interconnected branches. Water levels and discharges (*h* and *Q*) are calculated at alternating points along the river branches as a function of time. It operates on basic information from the river and floodplain topography to include man-made features and boundary conditions.

The data needed for the simulation in the MIKE 11 hydrodynamic module involves; 1) the river network, 2) Cross section, the cross-section file contains streambed cross-sections as specified locations along a river network, and 3) boundary parameters, the boundary file consists of boundary conditions in a time series format for the river network's boundaries, and 4) . The hydrodynamic parameter, the hydrodynamic parameter file requires bed and floodplain resistance data for the river network. The differentiation between the streambed and flood plain along the river network is accomplished at each cross-section in the Cross-section file.

The hourly rainfall, water level and flows data are created in compatible MIKE 11 time series in a separate file as the input for the parameter editors. The Cross-Section file contains streambed cross-sections as specified locations along a river network. The geometry of cross-sections of Jobaru River was obtained from MLIT, Japan and Saga Prefectural office.

5.2.2.3 Model calibration

The data were used for model calibration are the hourly rainfall data from three rain stations; Saga Meteorological station, Basekibaba rain station and Mitani rain station, and hourly discharge data from Hideki Bridge point observation, on the period September 6-7, 2005. Figure 5.3 shows the calibrations result for the peak discharge in Jobaru River (Hideki Bridge point). Although there were some discrepancies between the observations and simulations, overall the simulated peak discharge coordinated well with the observed data.

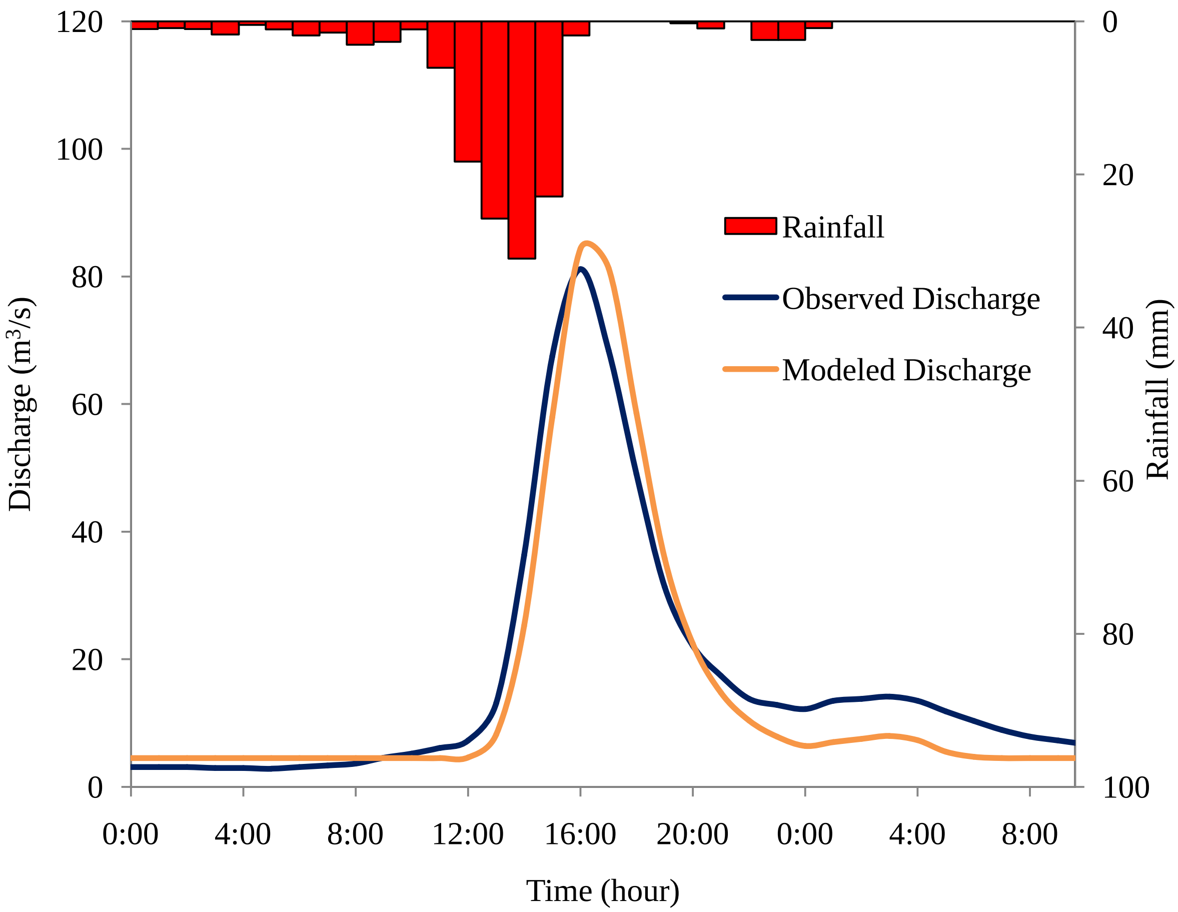


Figure 5.3 Basin rainfall-runoff, modeled and measured, September 6-7, 2005

5.3 RESULTS AND DISCUSION

5.3.1 Land cover change

5.3.1.1 Jobaru River basin

According to the analysis, in Jobaru River basin, land cover changes significantly in urban area, forestry, agricultural land and barren area, while water and others remained relatively unchanged. The result of land cover 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 cover 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 cover 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 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.

5.3.1.2 Jobaru Mountainous Sub- Basin

In mountainous sub-basin, the land cover has changed significantly in forest, barren area, agricultural land, and urban area, while water and others remained relatively unchanged (Figure 5.4). Dominantly, barren area turns into forest.

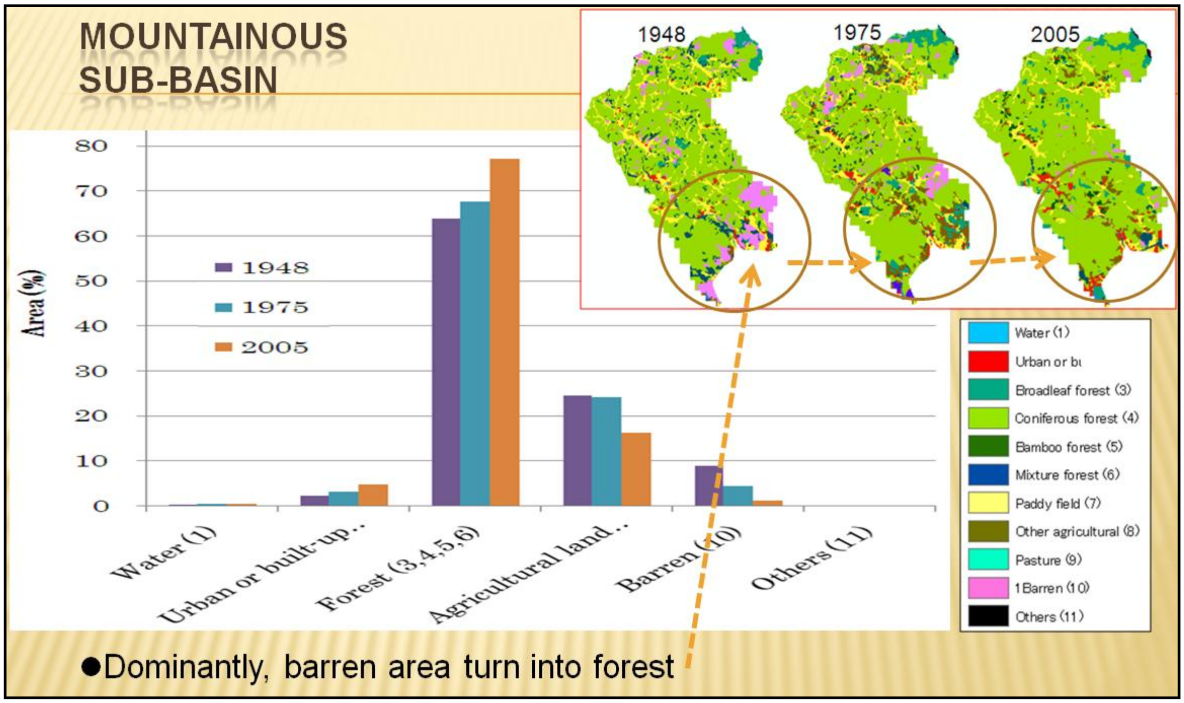


Figure 5.4 Land cover change in Mountainous sub-basin

5.3.1.3 Jobaru Plain Sub- basin

The land cover has changed significantly in urban and agricultural land, while water, forest, barren area and others are relatively unchanged in Jobaru plain sub-basin (Figure 5.5). Dominantly, the agricultural land turns into urban areas.

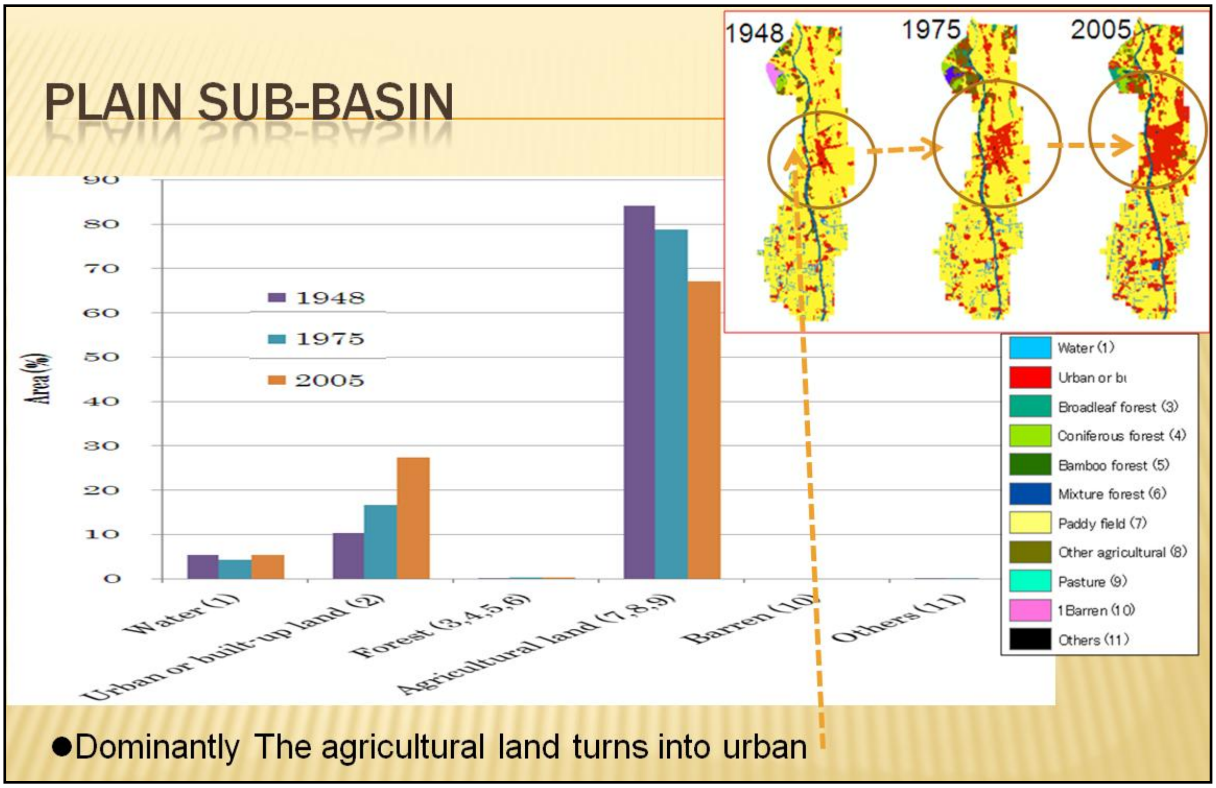


Figure 5.5 Land cover changes in plain sub-basin

5.3.2 Peak Flow

The rainfall during the period of July 9, 2005 and September 6-7, 2005 is applied to the different land covers which correspond with each *CN* to get the effect of land cover changes on peak flow. With the same rainfall applied to the different land covers, from 1948 to 2005 in the Jobaru basin, the peak flow decreased. The changes of land cover from land cover 1948 (*CN* = 48.24) to land cover 1975 (*CN* = 48.43) cause the increasing of peak flow 7.5%. The changes of land cover from 1975 (*CN* = 48.43) to land cover 2005 (*CN* = 46.07) cause the decreasing of peak flow 20.9%. This shows that the decreasing of *CN* 4.5% from 1948 to 2005 caused the decreasing of peak flow 15%. The result is shown in Figure 5.6.

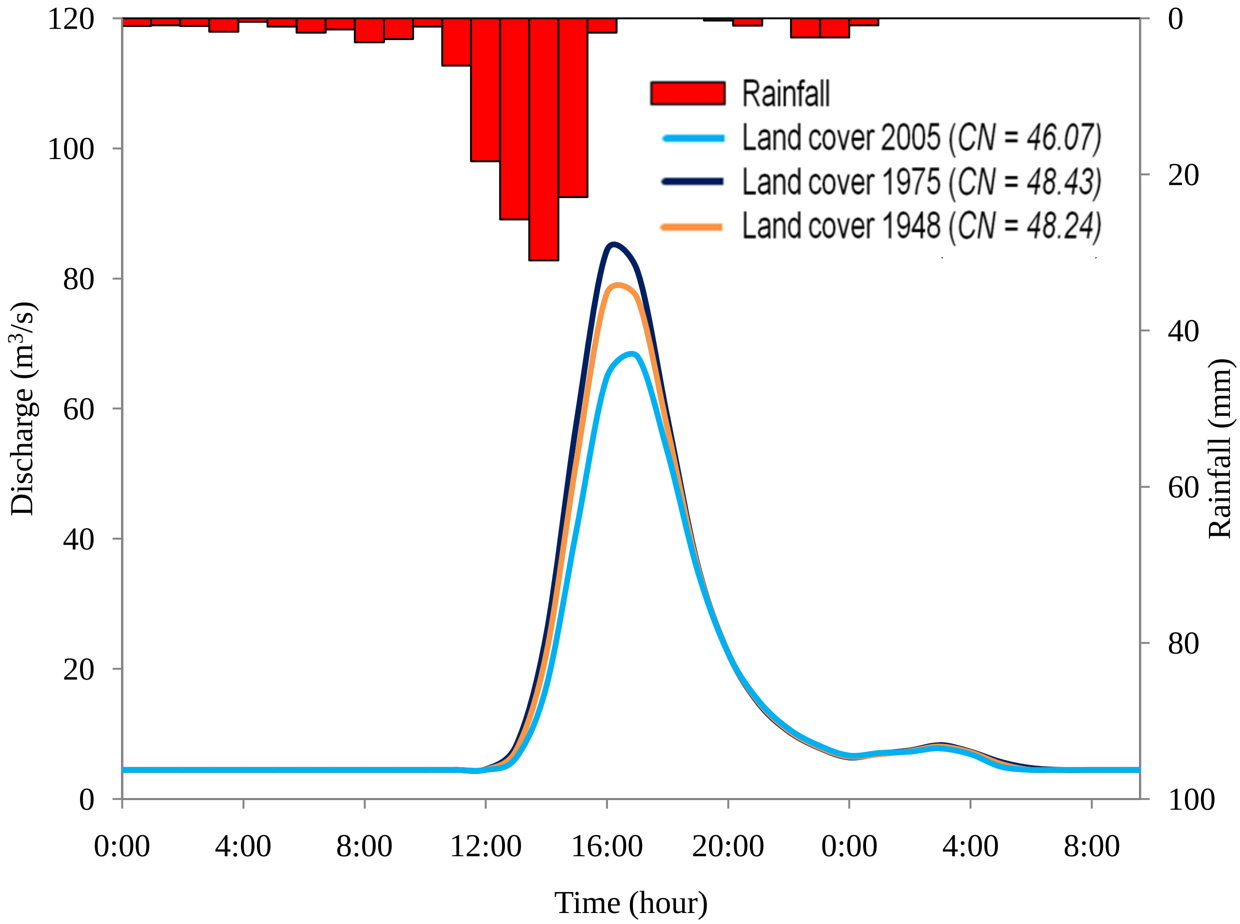


Figure 5.6 Discharge hydrograph of Rainfall Sept. 6-7, 2005, applied to the different land cover

5.4 CONCLUSIONS OF CHAPTER 5

Land cover 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.

The average *CN* increased for the whole Jobaru River basin. This means that the potential runoff increased. In the Mountainous sub-basin, the average *CN* decreased but in the Plain sub-basin, the average *CN* increased which means that the potential storm runoff increased.

The rainfall during the period of July 9, 2005 and September 6-7, 2005 is applied to the different land covers which correspond with each *CN* to get the effect of land cover changes on peak flow. With the same rainfall applied to the different land covers, from 1948 to 2005 in the Jobaru basin, the peak flow decreased. The changes of land cover from land cover 1948 (*CN* = 48.24) to land cover 1975 (*CN* = 48.43) cause the increasing of peak flow 7.5%. The changes of land cover from 1975 (*CN* = 48.43) to land cover 2005 (*CN* = 46.07) cause the decreasing of peak flow 20.9%. This shows that the decreasing of *CN* 4.5% from 1948 to 2005 caused the decreasing of peak flow 15%.

The result indicates that different land covers with different *CN* remarkably influenced peak flow in Jobaru River.

Chapter 6

ASSESSMENT OF THE EFFECT OF LAND COVER CHANGES ON HYDROLOGICAL PROCESS IN THE JOBARU RIVER BASIN

6.1 INTRODUCTION

During 1948 to 2005, due to the increasing needs of residential area, the Jobaru River basin has been affected by the changes in land cover; especially the decreasing number of agricultural land and the increasing number of urban or built-up land.

Changes in land cover frequently result in significant impacts to hydrology by affecting the amount of runoff, soil moisture, and groundwater recharge over a range of temporal and spatial scales (Calder 1992; Im et al. 2003). However, the hydrologic effect of alteration in land cover at a watershed scale is still an unresolved problem and is now a primary concern of most developing countries, which are commonly experiencing changes in land cover patterns caused by increasing populations and demand for accommodations.

In recent years different types of hydrological models are being used to quantify the effects of land cover changes on hydrological cycle (Fohrer et al. 2001, Lørup et al.1998). Lørup et al. (1998) used the lumped hydrological model, NAM, to assess the long-term impacts of land cover changes on runoff in six medium-sized (200–1,000 km2) rural watersheds in Zimbabwe. The NAM hydrological model was utilized to distinguish between the effects of climate variability and the effects of land cover changes. On the same way, Wegehenkel (2002) applied the calibrated THESEUS model with afforestation scenarios in assessing the impact of land cover changes on a watershed hydrology. The investigation found a significant discharge reduction and an increase in evapotranspiration. A few more attempts to implement lumped hydrological models for quantitative assessment of the influence of land cover change have been reported (Hundecha and Ba´rdossy 2004; Siriwardena et al. 2006). A lumped model has been successfully applied to predict effects of land cover changes on watershed hydrology around the world. Nevertheless, the hydrological processes are not well represented. Kuczera et al.(1993) and Beverlyet al. (2005) stated that a particular care must be taken when applying such a model in a large watershed due to limitations in the conceptualization of hydrological processes involved.

Distributed physically-based models have the predictive capacity to assess the effect of land cover changes on runoff across a range of scales, but require more intensive input data (Beven 1989; Refsgaard 1997). Typical examples of the distributed physically-based models are the Distributed Hydrology Soil Vegetation Model (DHSVM) (Thanapakpawin et al. 2007), THALES (Grayson et al. 1992), SHETRAN (Ewen and Parkin 1996), and MIKE SHE (DHI 1999). These models contain equations which have originally been developed for point scales and which provide detailed descriptions of flows of water and solutes. The variability of watershed characteristics is accounted for explicitly through the variations of hydrological parameter values among the different computational grid points (Refsgaard 1997). Recently, Thanapakpawin et al. (2007) used the DHSVM model in assessing hydrologic regimes with land cover changes of the Mae Chame River in Thailand.

In this study, we utilized the MIKE SHE modeling system to evaluate hydrologic effect of land cover changes in a watershed with mixed land cover.

The study in this chapter is to quantitatively evaluate the effects of land cover changes on watershed hydrology within the 87.46 km^2 Jobaru River basin in Saga Prefecture, Japan. This study specifically sought to: (1) test the capabilities of the MIKE SHE modeling system for simulating streamflow from a mixed land cover watershed; and (2) estimate hydrological responses under historical land cover scenarios.

6.2 METHODOLOGY

6.2.1 Jobaru River basin re-delineation

The Jobaru mountainous sub-basin was delineated base on the topography map (DEM), so the surface water automatically flowing based on the elevation. Actually the Jobaru Plain sub-basin is a very flat area predominantly paddy fields. The surface water does not flow based on the surface elevation, but based on the paddy field’s pond configurations. The farmers arrange the paddy field`s ponds and they arrange the configurations of water flow direction depend on the needs. Therefore the plain sub-basin was delineated base on the paddy field ponds’ configurations, and also the nearest river-neighbourhood dyke. The area of Jobaru River basin is about 87.46 km^2 (Figure 6.1).

Figure 6.1 Jobaru River basin based on paddy fields configuration

6.2.2 The MIKE-SHE model

MIKE SHE is a deterministic, fully-distributed and physically-based hydrological and water quality modeling system (DHI 1999). It is capable of simulating hydrology and water quality processes occurring in watersheds and their underlying aquifers. The MIKE SHE modeling system was designed with a modular structure. The water movement (WM) module in MIKE SHE is the basic module of the entire modeling system. It represents the finite differences and solutions of the partial differential equations that describe processes of overland, channel, saturated, and unsaturated flows. The watershed is represented by two analogous horizontal-grid square networks for surface and groundwater flow components. These are linked by vertical columns of nodes at each grid representing the unsaturated zone. The hydrologic simulation consists of subcomponents describing the processes of evapotranspiration, overland and channel flow, unsaturated flow, saturated flow, and channel/surface aquifer exchanges (Figure 6.2). A detailed description of the MIKE SHE can be found in DHI (1999). Several additional components comprise other hydrological processes in the modeling system. Rainfall interception is modeled by using a modified Rutter model (Rutter et al. 1971), which is an essential accounting procedure for canopy storage. The MIKE SHE uses the Kristensen and Jensen (1975) method for calculating actual evapotranspiration based on potential evapotranspiration, leaf area index, root depth for each vegetation type, and a set of empirical parameters. A finite difference approximation of the St.Venant equation is employed for solving two-dimensional overland flow and one-dimensional channel flow. Movement of water in unsaturated zones is assumed to be vertical and is modeled by the one-dimensional Richards equation using an implicit finite difference solution. Saturation zone computations are performed using the three dimensional Boussinesq equation for groundwater flow.

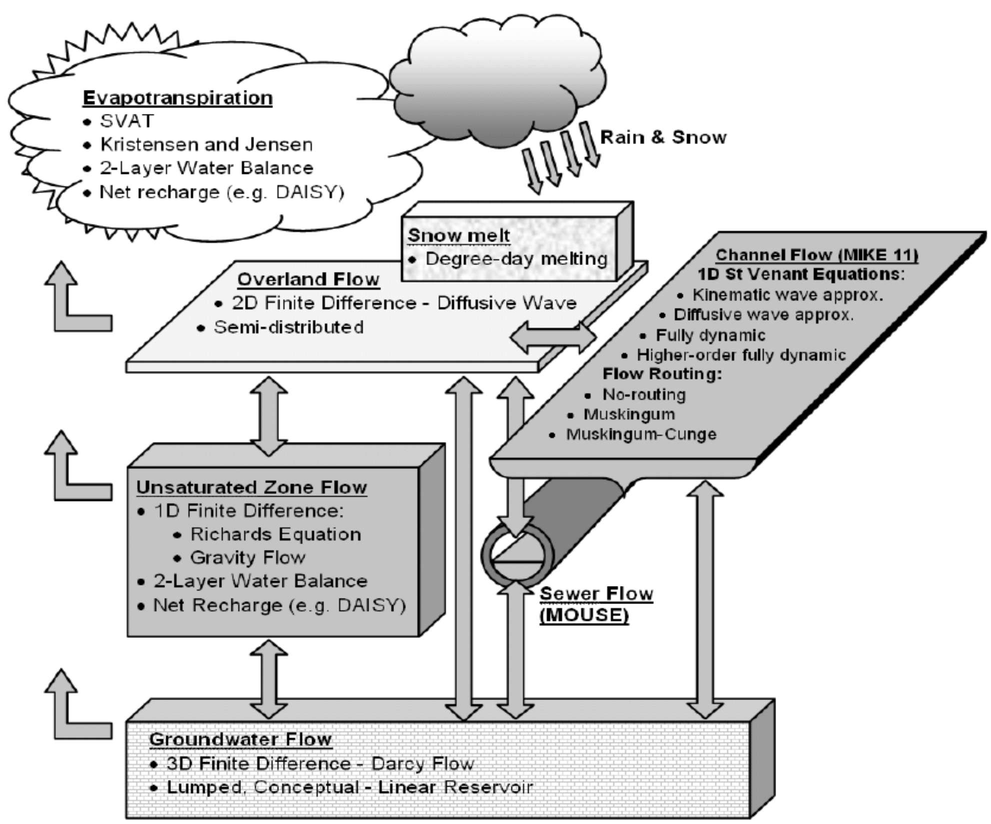


Figure 6.2 Schematic view of the process in MIKE-SHE

6.2.3 Model construction

6.2.3.1 Watershed description

Jobaru River basin is located in one of the main islands of Japan called Kyushu. It is in Saga Prefecture. 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 87.46 km^2 and the length of the main channel is 31.9 km. Average annual precipitation is about 2,266 mm. The water resources of the basin are heavily developed for irrigation, fire protection, maintaining the environment and waterways. There are a 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.

6.2.3.2 Meteorological data

The MIKE SHE model required rainfall and potential evapotranspiration as climatic input data. Rainfall data is a daily rainfall records were collected from five rain gauges within and adjacent the watershed: Ifuku, Fukumaki, Mitani, Basekibaba, and Kanzaki rain gage stations (Figure 6.3). Rainfall data were used as an input in each grid on a daily basis for model set-up. It was spatially distributed according to a Thiessen polygon technique. The watershed was divided into Thiessen polygons enclosing a specific rain gauge in the middle of the polygon. Rainfall data of each grid was obtained from the point rainfall of rain gauge within the polygon. A time series of potential evapotranspiration rates was also required for estimating soil evaporation and plant transpiration. The potential evapotranspiration was calculated using the FAO Penman-Monteith method. The equations air temperature, relative humidity, wind speed, and radiation data. These meteorological data were obtained from the Saga weather station. Unlike rainfall data, these meteorological data can be assumed to be the same for the entire watershed.

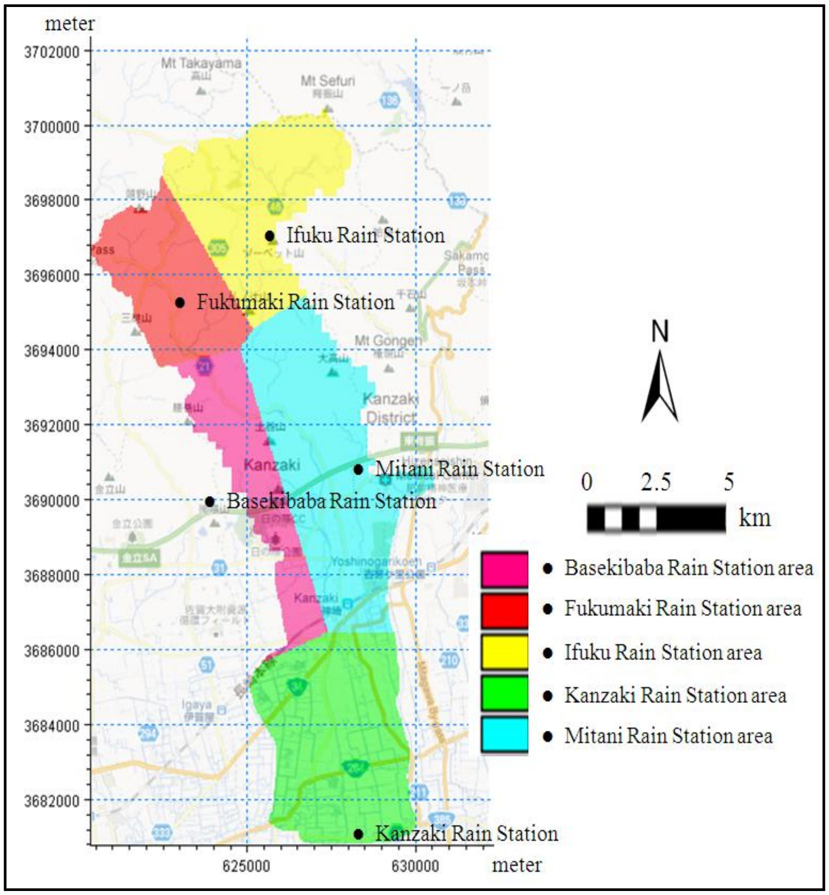


Figure 6.3 Meteorological stations

6.2.3.3 Land cover data

Land cover data were primarily used to define vegetation-specific parameters in the model. Six land covers such as forest, agricultural land, barren, urban area, water and others were identified in the Jobaru River basin for simulation purposes. The distribution of land cover in 2005 are 49.2 % forestry, 36.59% Agricultural land, 11.62% urban area and less than 2% Water, Barren and others. For each land cover type, a set of parameters was entered in the MIKE SHE vegetation database. Parameters included empirical constants used in the simulation of actual evapotranspiration (C1, C2, Cint), and a time series for leaf area index (LAI) and root distribution function (RDF) that are given at each growth stage of the crop or vegetation. Parameter values vary with a vegetation type for each land cover classification and ranges have wide variability. LAI and RDF were estimated for each type of land cover classification.

6.2.3.4 Soil data

Soil types were identified for modeling water flow through soil layers. Soil profiles were reviewed for differences in soil texture, hydraulic conductivity, and depth to a horizon that would impede percolation. The Jobaru River basin soil types were derived from Geological map of Japan (AIST-2003), Soil regions map of Japan based on a reclassification, and Digital soil map of the world (FAO). Three different types of soils were identified in the basin; Fluvic soils, Brown forest soils, and Red-Yellow soils

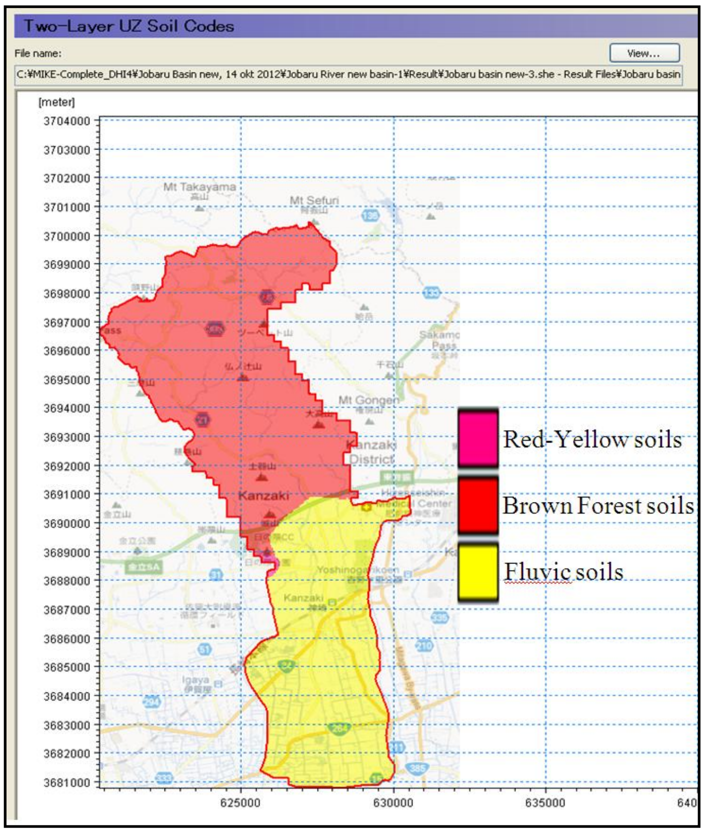


Figure 6.4 Soil map

6.2.3.5 Overland flow component

Overland flow occurs when net rainfall exceeds the infiltration capacity of soil. The direction and velocity of overland flow are determined by ground surface slope. The input topography map is derived from the 50m grid Digital Elevation Model (DEM) data processed by Japan digital map 1997. The governing equation for overland flow requires specification of a Manning coefficient, detention storage, and a leakage coefficient. The Manning coefficient describes ground surface resistance within each computational grid, which depends mainly on land use.

6.2.3.6 River and channel component

Flow and water levels were simulated within all reaches by MIKE 11 that is a fully unsteady river hydraulic model, dynamically coupled to MIKE SHE. There is one branch totaling 31.9 km in length were established as part of the river hydraulic model. The geometry of the river branch, which is specified in terms of cross sections, was obtained from MLIT, Japan and Saga Prefectural office. A constant flow boundary condition was applied to the upstream open ends of the main stream and four tributaries in the MIKE 11 river network. A water stage-discharge relationship was used for the boundary condition at the downstream end of the main stream. The water stage-discharge data was recorded at Shibaobashi point was taken From MLIT, Japan.

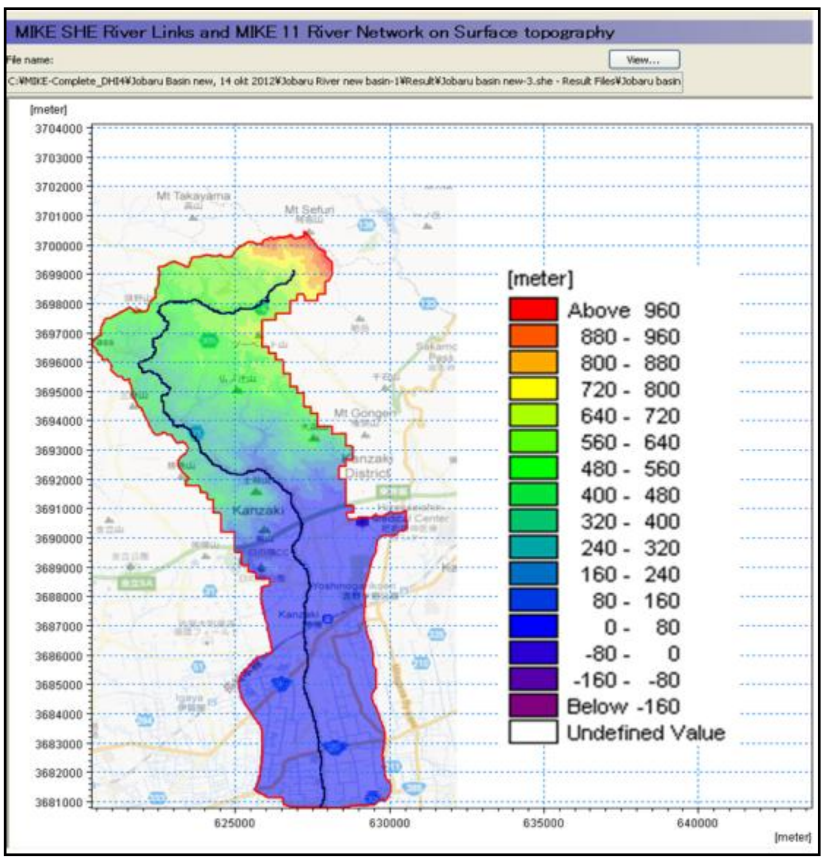


Figure 6.5 River networks

6.2.4 Model calibration

A distributed modeling system such as MIKE SHE requires a large number of model parameters to be specified. Parameters of MIKE SHE have a clear physical interpretation and can be explicitly defined from field measurements. However, calibration is frequently required to better reproduce measured watershed variables and to improve simulation results as measured values may not always be readily available. Initial values and ranges (minimum and maximum values) of primary parameters were assessed from measured field data, general characteristics of the model structure, and modeling experience prior to calibration.

For the calibration process, a “trial and error” procedure was applied to examine the influence of various model parameters, step by step, through statistical criteria. In this study, the model was calibrated and evaluated using a split sample procedure (McCuen, 2002) against streamflow data collected at the outlet of the watershed. The interval of the calibration period was chosen on the basis of availability of observations. Meteorologic and hydrologic data for the period of one year were available in the Jobaru Basin. The average daily discharge data is measured at Hideki Bridge observation point. Data from January 2005 to December 2005 were used for the calibration effort. In the first step, surface and channel flow coefficient were calibrated. In the second step, hydraulic conductivity of the soil was adjusted by comparing sets of simulated and observed stream flow at monitoring stations.

Primary parameters available for calibration and a possible range of each parameter are detailed in Table 6.1. Figure 6.6 shows the calibration result for flow at the basin during 2005. Although there were some discrepancies between the observations and simulations, overall the simulated daily flows coordinated well with the observed flows (R^2 = 0.78 And Nash-Sutcliffe (1970) NSI = 0.68). The R^2 value is a marker of strength from the correlation between the observed and simulated values (Figure 6.7). The NSI value is commonly used in modeling figures and marks how closely the simulated versus observed data points resembles the 1:1 line. The ranges of NSI value is between minus infinity and one. Values that are less than or closely to zero for R^2 and NSI, marks model performance is poor and unacceptable, and values equals to one indicates the model prediction is perfect. Our simulations perform sufficiently acceptable of the model.

Table 6.1 Parameter and each ranges used in the model calibration

Parameters	Parameter values	
	Min	Max
Surface Strickler coefficient ($m^{1/3}\ s^{-1}$)	1	30
Horizontal hydraulic conductivity ($m\ s^{-1}$)	1×10^{-8}	1×10^{-3}
Vertical hydraulic conductivity ($m\ s^{-1}$)	1×10^{-8}	1×10^{-3}
Specific yield	0.01	0.50
Channel flow manning coefficient ($m^{1/3}\ s^{-1}$)	10	35

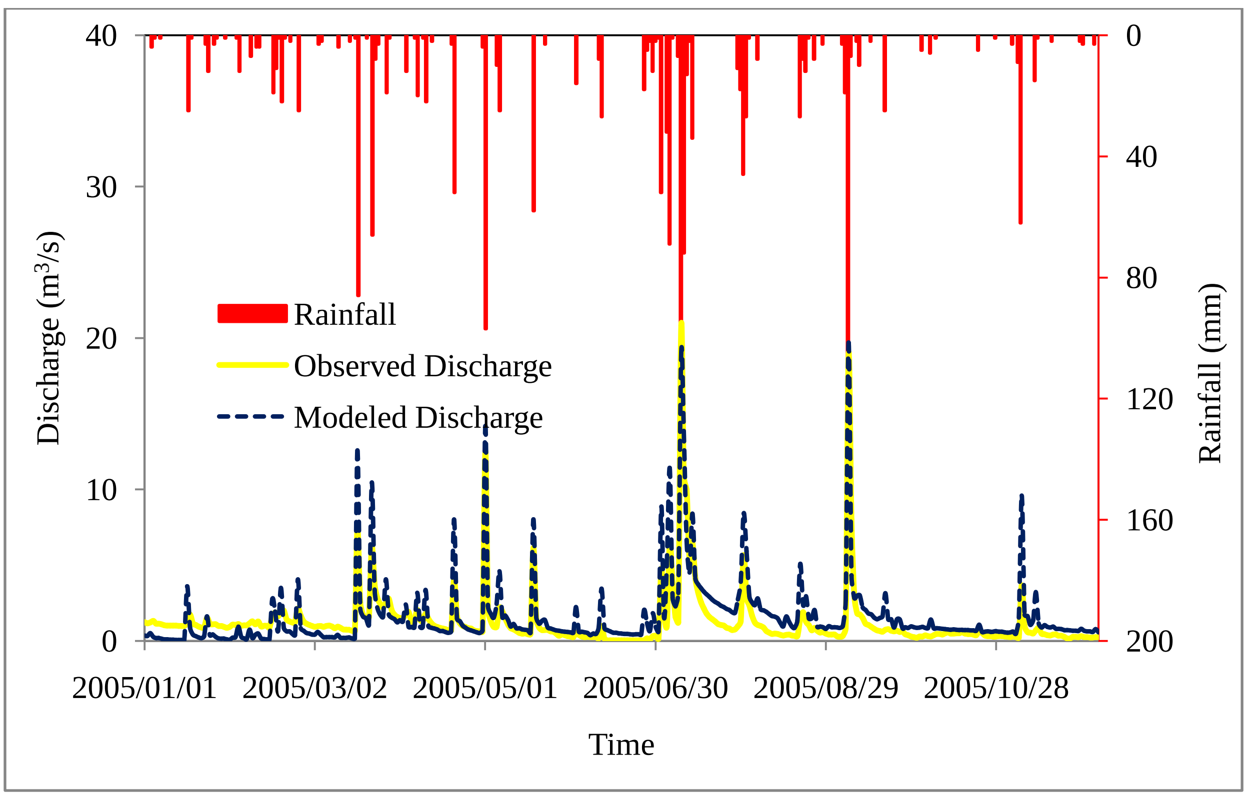


Figure 6.6 Observed and modelled average daily discharge in Jobaru River at Hideki Bridge point, a calibration. Nash-Sutcliffe = 0.68, R^2 = 0.78

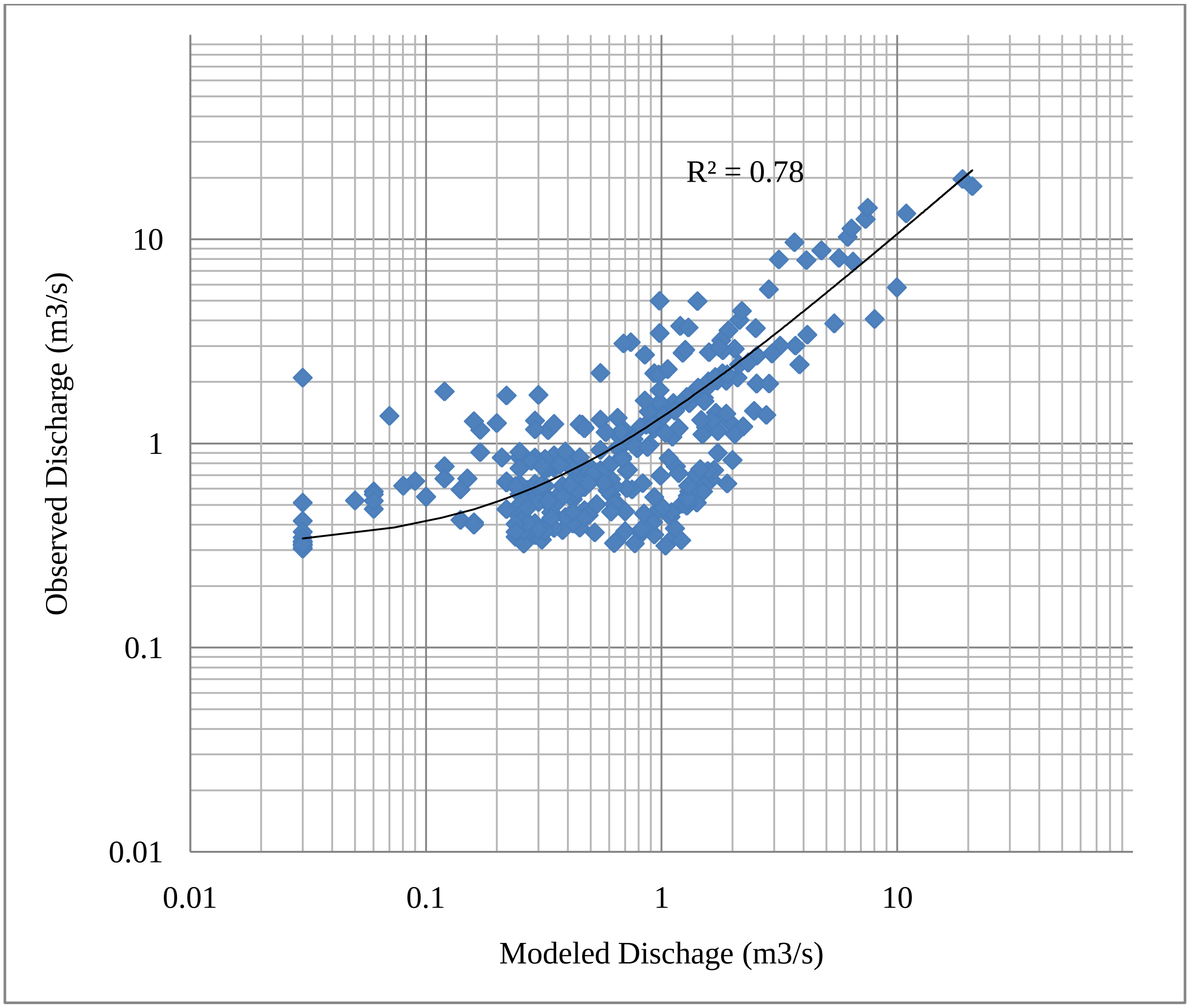


Figure 6.7 Plots of observed and modelled discharges at Hideki Bridge point

6.3 RESULT AND DISCUSION

6.3.1 Hydrologic effects of land cover changes

The reclassify land covers from GIS analysis were used in this study to identify changes in land cover distribution in the Jobaru River basin over a 57-year period from 1948 to 2005. The available land cover data is the Chikugo watershed land cover from Ryuki Shizen Kankyou Chousa Sagyou, for years 1948, 1975 and 2005. A supervised classification was performed to identify six land cover features such as water, urban, forest, agricultural, barren, and others. Proportional changes in land cover during the period are shown in Table 6.2.

Table 6.2 Land cover identification for the Jobaru River basin

Land cover classification	% land cover, year		
	1948	1975	2005
Water	1.77	1.52	1.83
Urban	4.70	6.96	11.62
Forest	41.06	43.11	49.20
Agricultural	46.99	45.60	36.59
Barren	5.47	2.72	0.66
Others	0.02	0.11	0.09

To know the effect of land cover changes on river flow, the rainfall on 2005 is applied to the three different land covers (corresponding to CN of Jobaru basin); land cover 1948 with correspond to CN = 53.97, land cover 1975 with correspond to CN = 55.82, and land cover 2005 with correspond to CN = 56.25. The result is shown in Figure 6.8 and 6.9. The result shows that the changes of land cover from 1948 to 2005 which indicated with the increasing of CN, caused the increasing of the average daily discharge and water flow volume in Jobaru River. Changes of land cover from land cover 1948 (CN = 53.97) to land cover 1975 (CN = 55.82) causing the increasing in average daily discharge 13%, and increasing in water flow volume 3%. Changes of land cover from land cover 1975 (CN = 55.82) to land cover 2005 (CN = 56.25) causing the increasing in average daily discharge 2.1%, and increasing in water flow volume 1.5%.

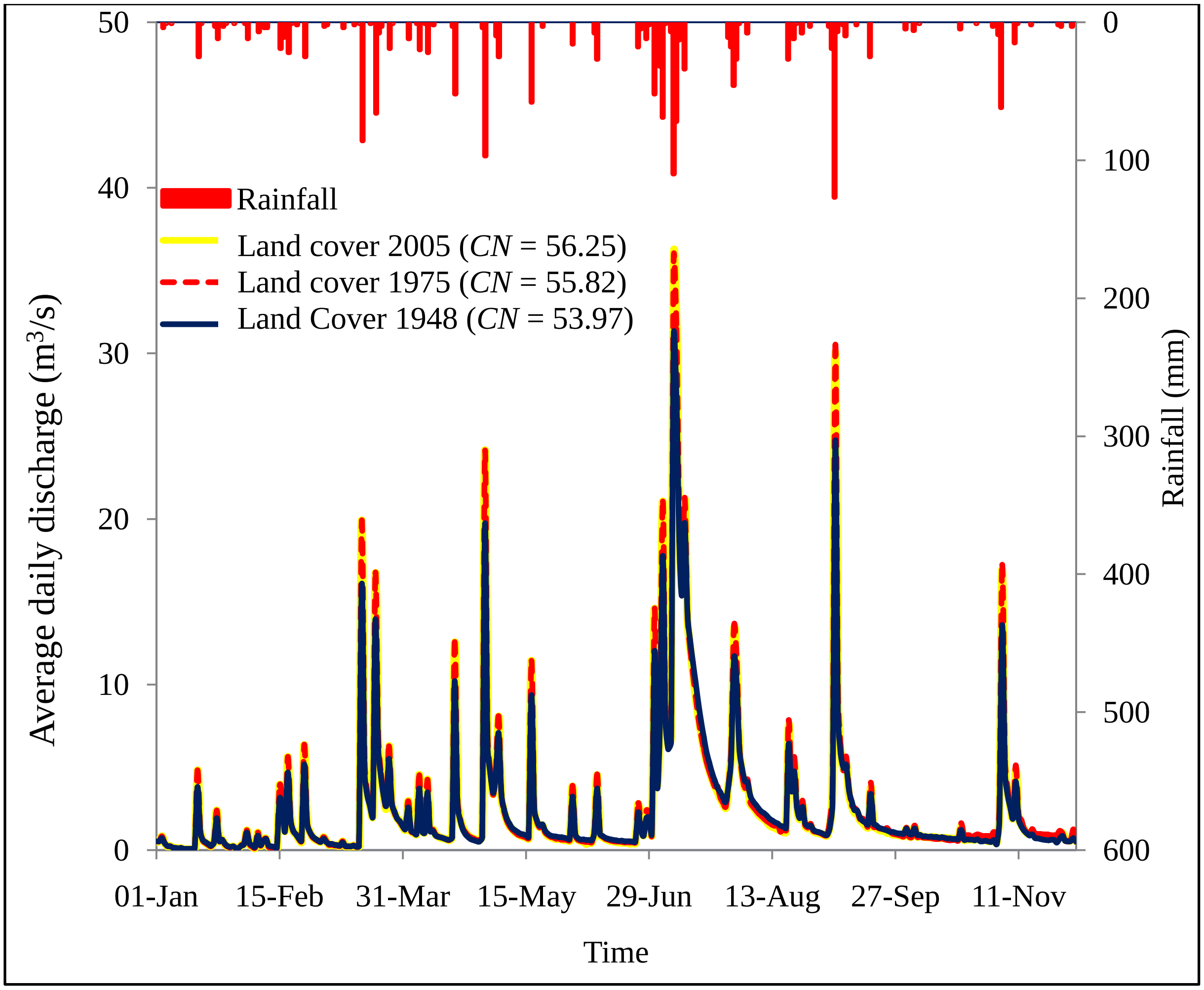


Figure 6.8 Average daily discharge at Jobaru outlet, rainfall 2005 applied to different land covers

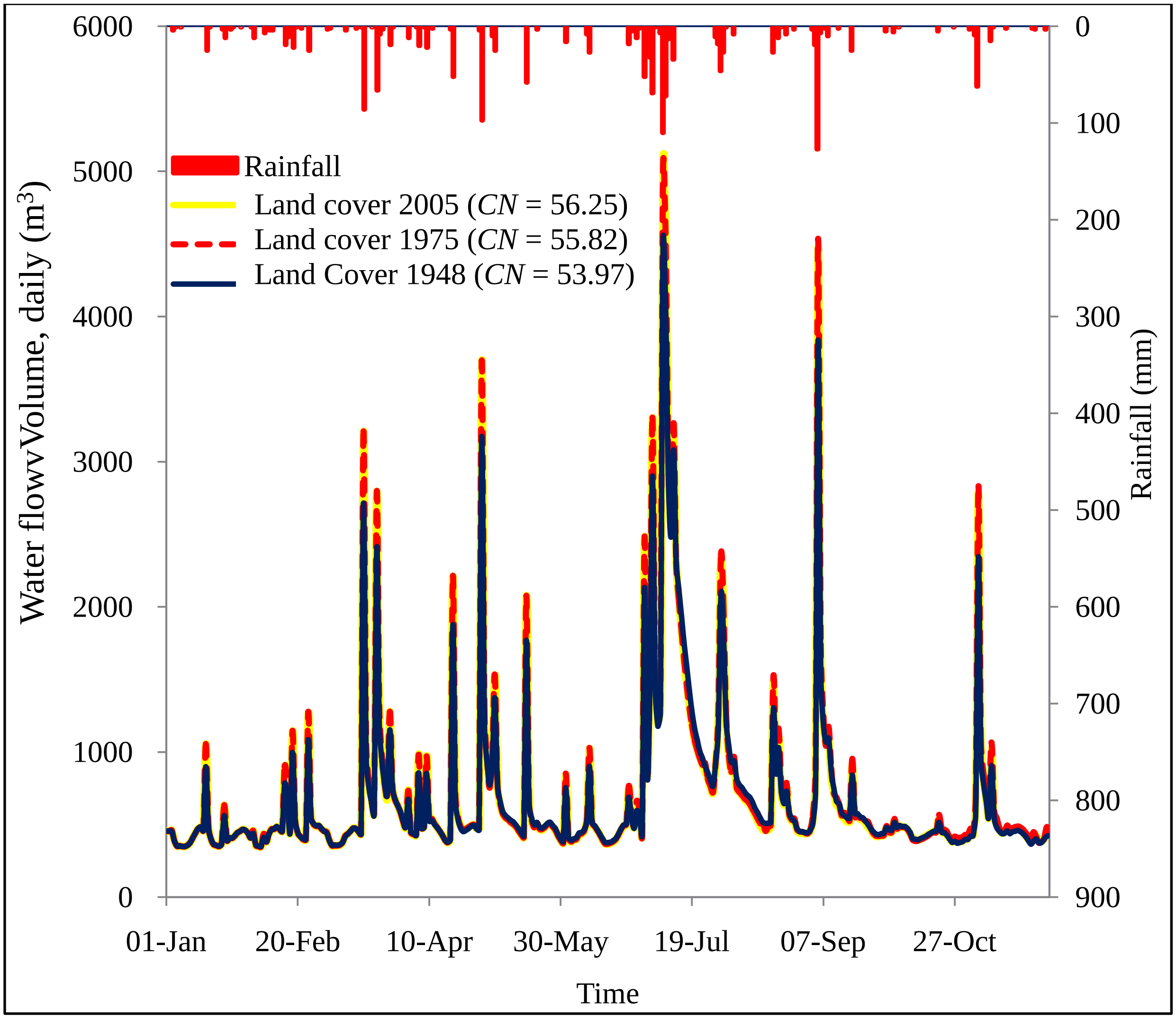


Figure 6.9 Daily water flow volume at Jobaru outlet, rainfall 2005 applied to different land covers

Initial soil moisture condition

In this research, the initial soil moisture condition is represented by the initial rainfall depth before the main rainfall. The same rainfall pattern with different rainfall initial depth is applied to the same land cover (land cover 2005) to get the effect of initial soil moisture condition to peak flow. The result shows that with the same rainfall pattern but different rainfall initial depth causing the increasing of discharge. The results are shown in Figure 6.10 and Figure 6.11. With the same rainfall pattern which have two peaks with different initial rainfall depth 1mm, 2 mm, and 3mm each hour along 20 hours before the main rainfall, causing the increasing of peak discharge in both peaks. The increasing of 1 mm initial rainfall depth causing the increasing of the first peak 7.5%, and 1.2% to the second peak (Figure 6.12). The results show that the different initial soil moisture condition causing the different peak discharge.

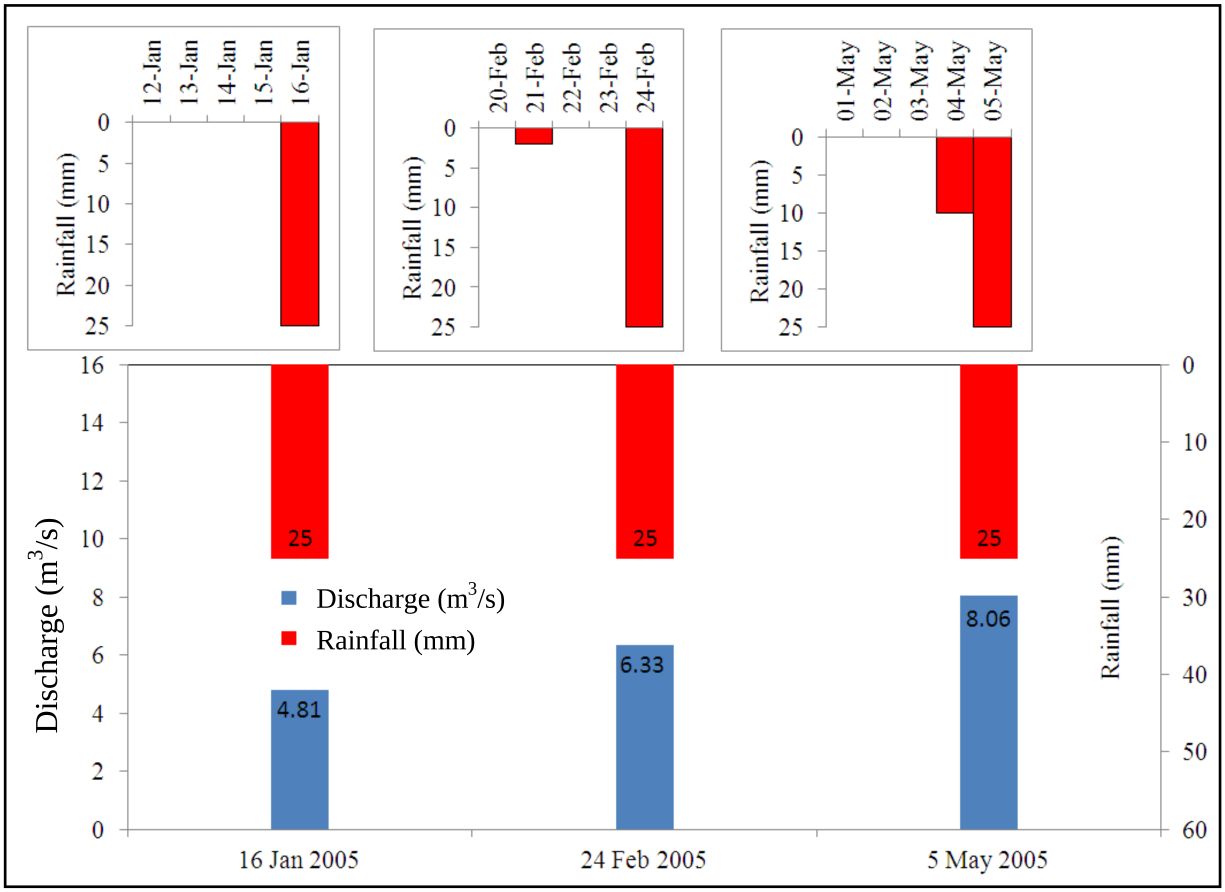


Figure 6.10 Discharge, same rainfall depth applied to the same land cover (2005) with different soil moisture condition (Rainfall depth = 25 mm)

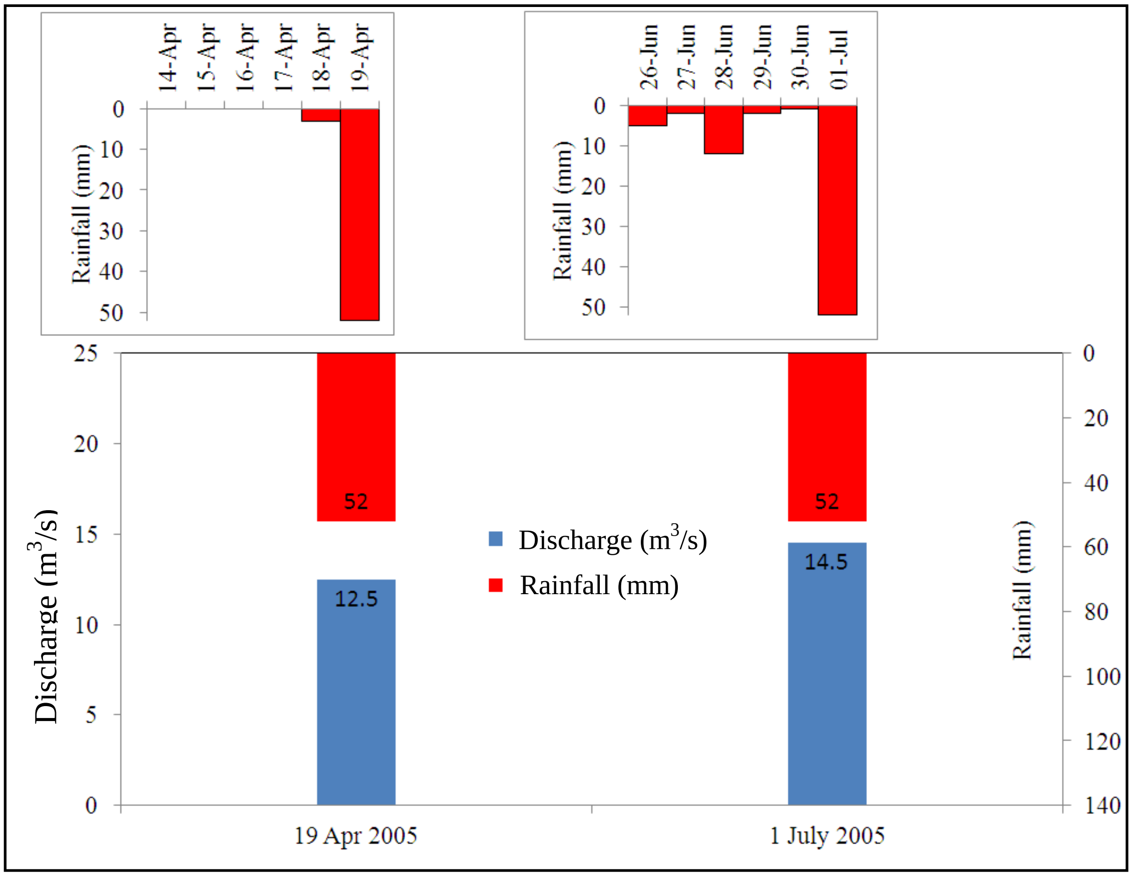


Figure 6.11 Discharge, same rainfall depth applied to the same land cover (2005) with different soil moisture condition (Rainfall depth = 52 mm)

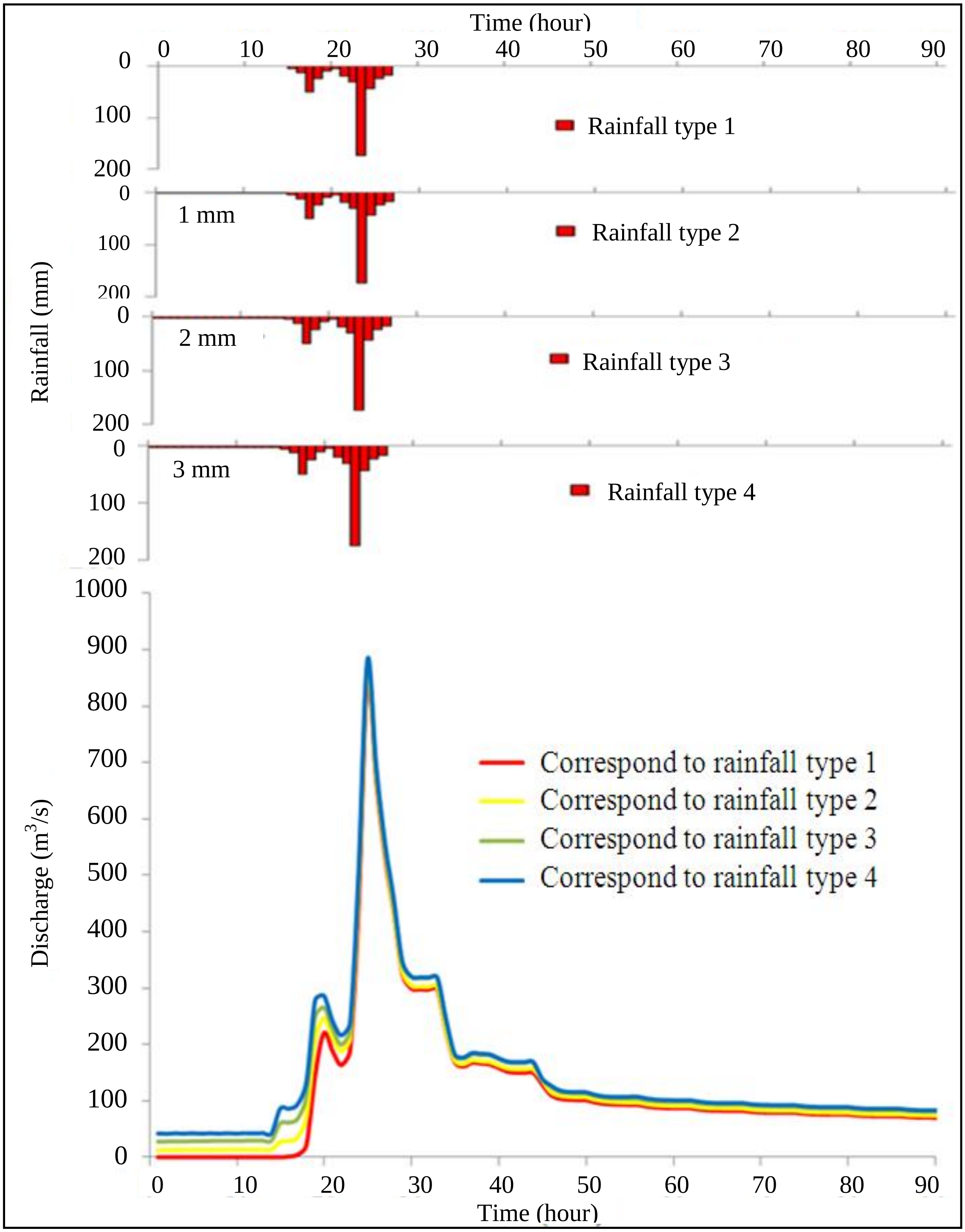


Figure 6.12 Modeled discharge at Jobaru outlet, same rainfall with different initial depth applied to land cover 2005

Land cover scenarios

Two land cover scenarios of Jobaru River basin was created to show the effect of land cover changes on river flow in the future.

a. Land cover scenario 1

Scenario 1 is if the agricultural area in the plain sub-basin around Kanzaki City, turns into urban (Figure 6.13).

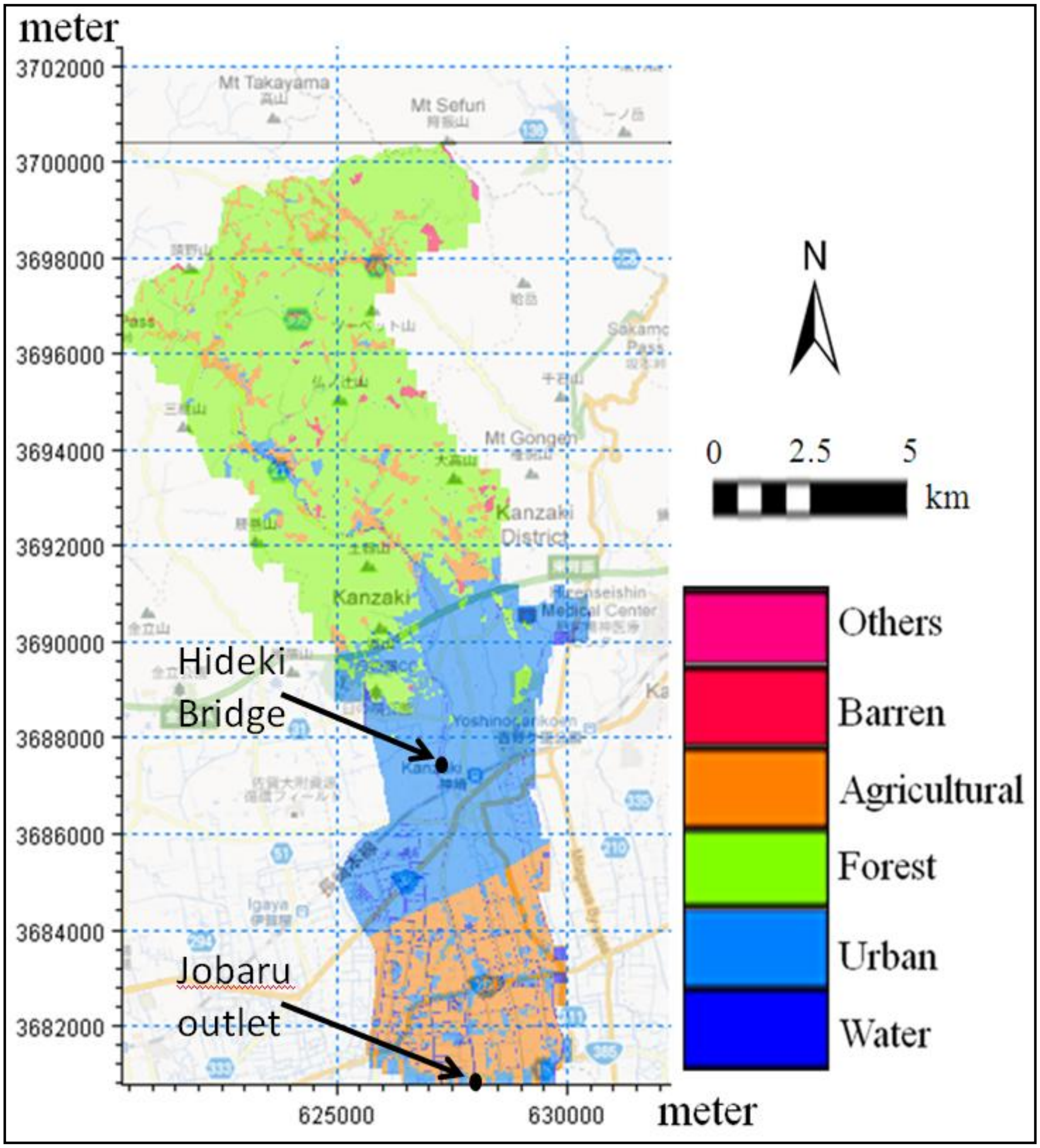


Figure 6.13 Land cover scenario 1

b. Land cover scenario 2

Scenario 2 is if all the agricultural area in Jobaru plain sub-basin turns into urban (Figure 6.14).

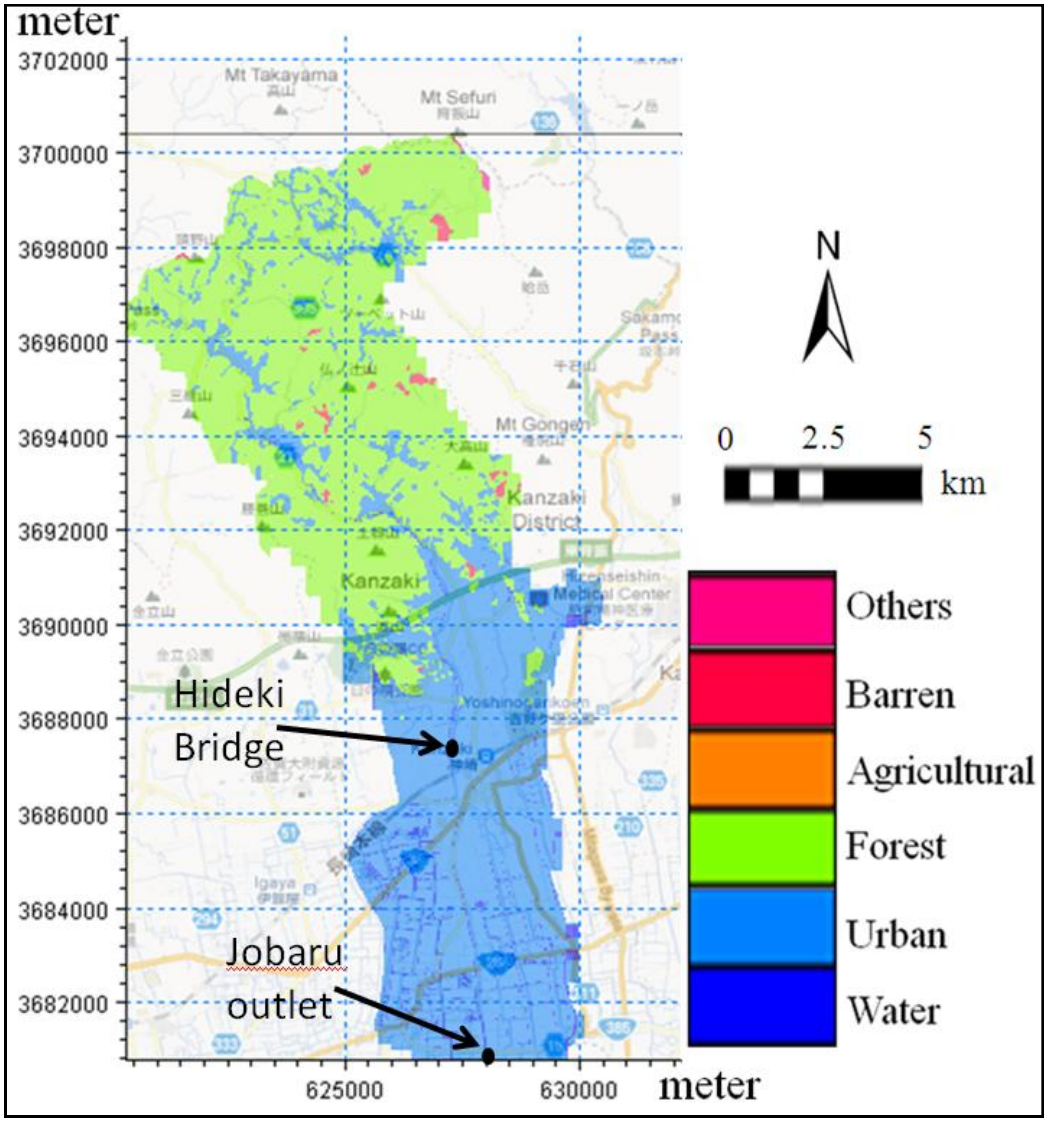


Figure 6.14 Land cover scenario 2

The rainfall on 2005 is applied to the land cover 2005, land cover scenario 1, and land cover scenario 2. The result is shown in Figure 6.15 and 6.16. The result shows that the changes of land cover from 2005 to scenario 1 and scenario 2 caused the increasing of average daily discharge and water flow volume in Jobaru River. This is due to the increasing of the urban areas. Urbanization may cause the expansion of impervious surface, which controlled runoff by decreasing the rate of infiltration. The changes of land cover from land cover 2005 to land cover scenario 1, causing the increasing in water flow volume 11.9%, and from land cover scenario 1 to land cover scenario 2 causing the increasing of water flow volume 9.7%. The changes of land cover from land cover 2005 to land cover scenario 1, causing the increasing in average daily discharge 16%, and from land cover scenario 1 to land cover scenario 2 causing the increasing of average daily discharge 68%.

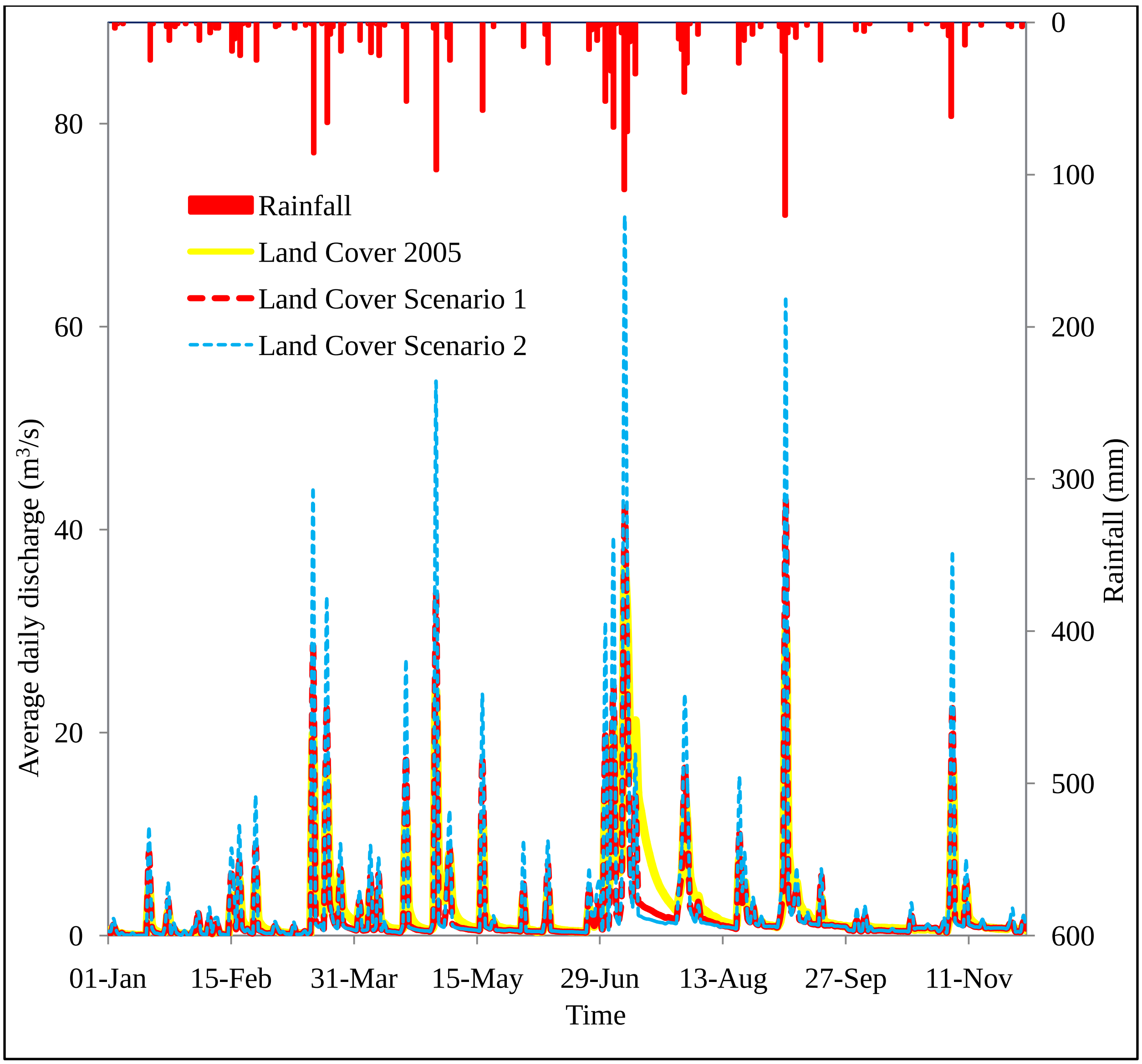


Figure 6.15 Average daily discharge at Jobaru outlet, rainfall 2005 applied to the land cover scenarios

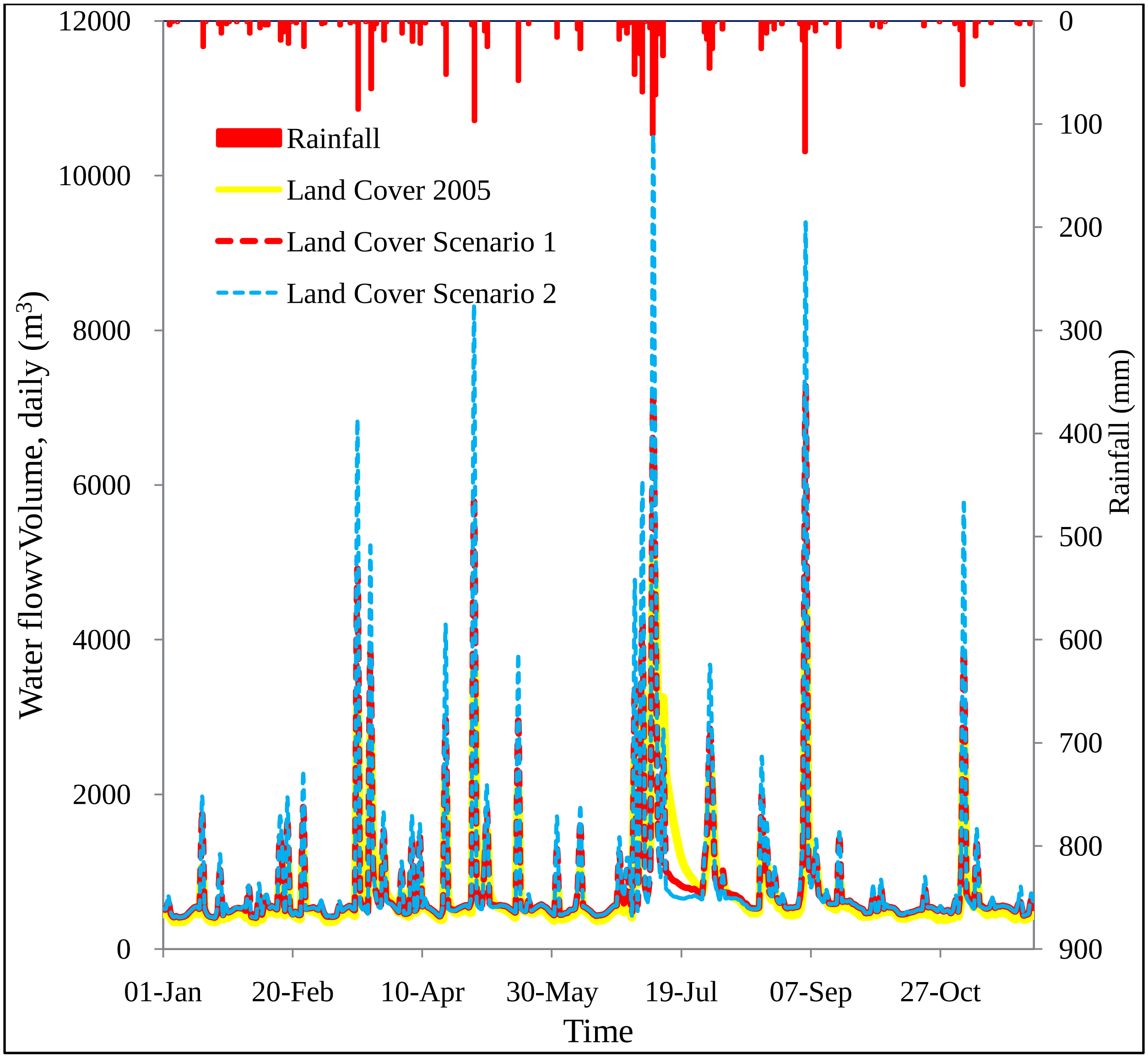


Figure 6.16 Daily water flow volume at Jobaru outlet, rainfall 2005 applied to the land cover scenarios

The land cover changes especially the urbanization also causing the changes in hydrograph characteristics. With the same rainfall is applied to the different land covers (land cover 2005, land cover scenario 1 and land cover scenario 2), the result shows that the Time Base (*Tb*) decrease, but the peak hydrograph is increase. The results are shown in Figure 6.17 and 6.18.

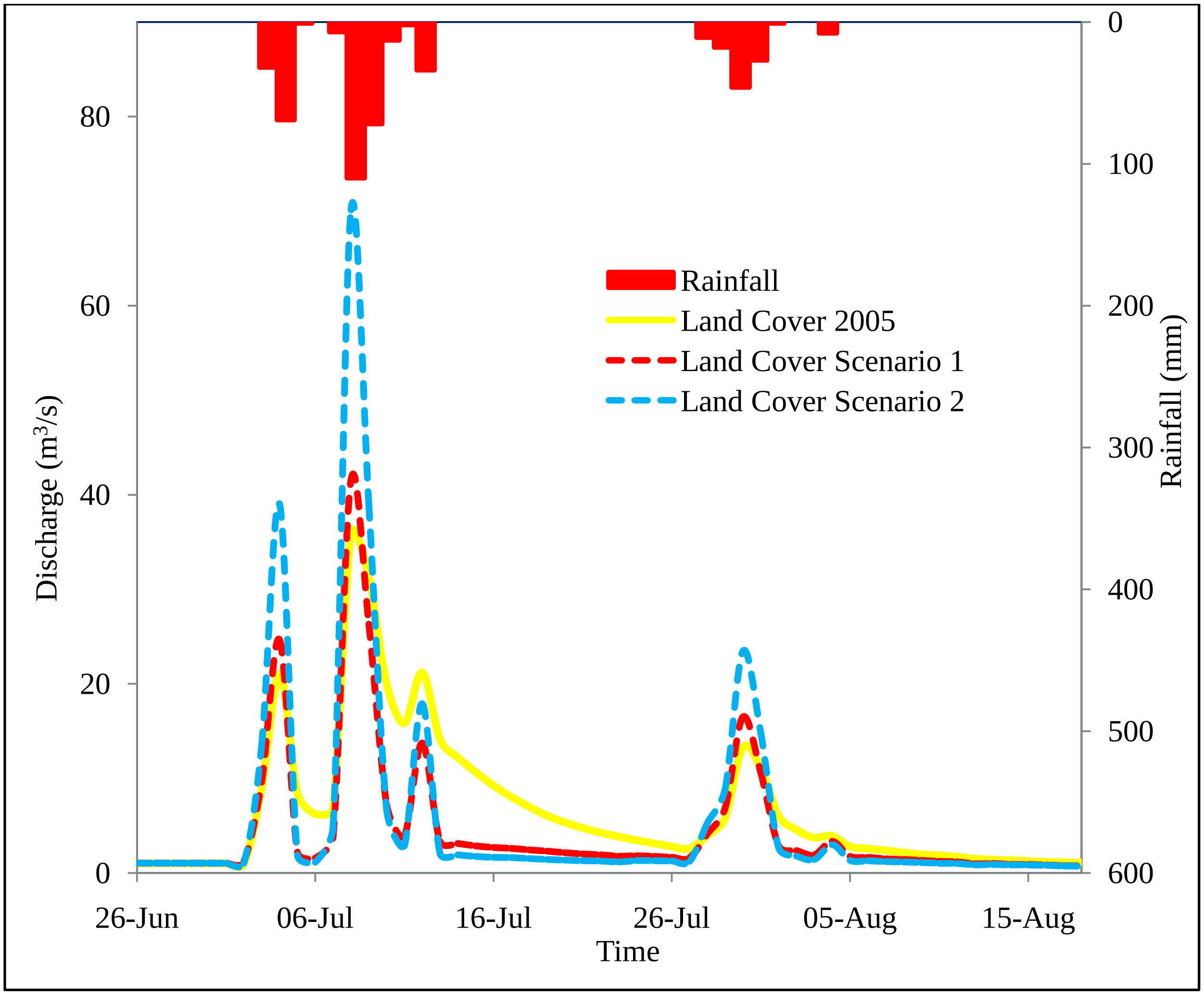


Figure 6.17 Discharge at Jobaru outlet with different land cover scenarios (Rainfall July-August, 2005)

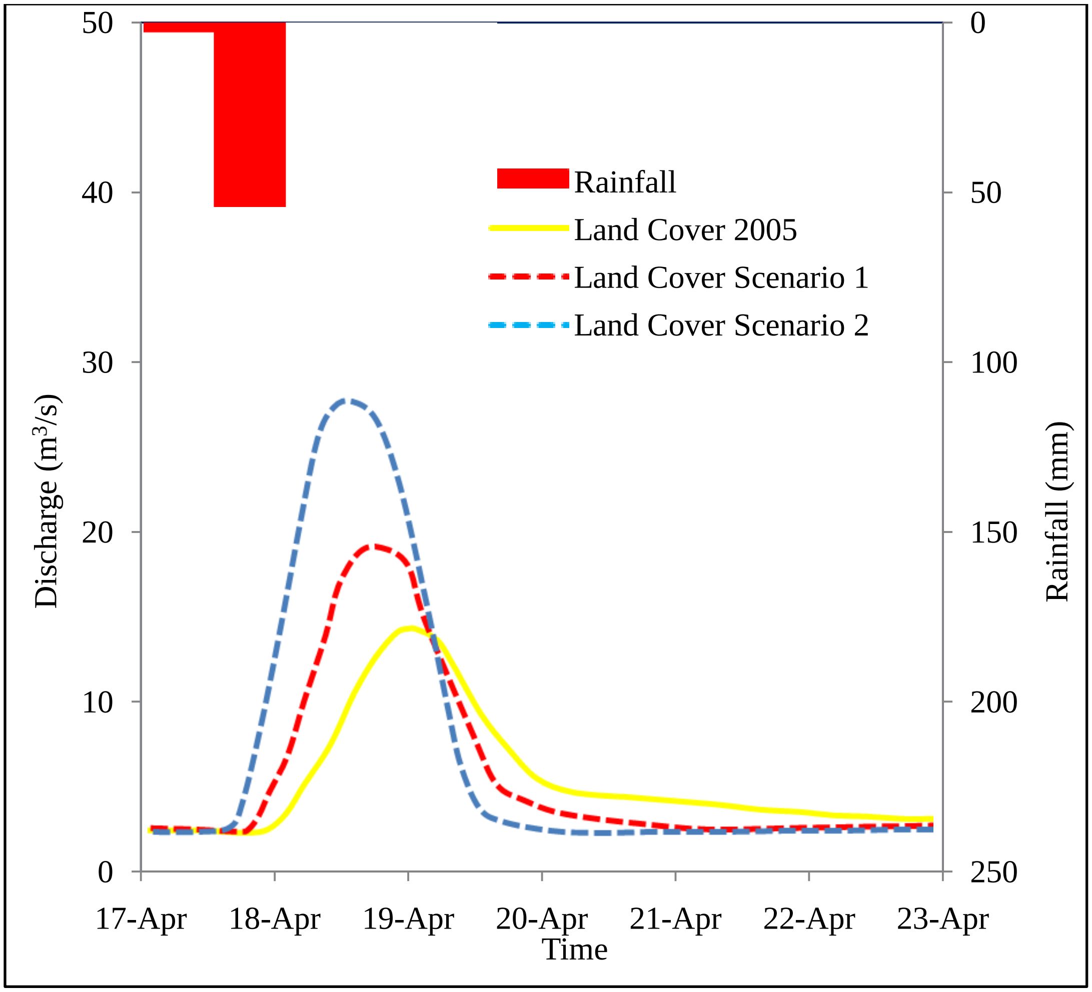


Figure 6.18 Discharge at Jobaru outlet with different land cover scenarios (Rainfall April, 2005)

Design Rainfall

The maximum discharge in Jobaru River is about 690 m^3/s which correspond to the Return Period (*Tr*) 150 years (Management plan of Chikugo River system, MLIT, 2006). With the assumption that the return period of the discharge is same as the return period of the rainfall, is necessary to calculate the rainfall with *Tr* 150. The data needed is annual maximum daily rainfall. The available data is the annual maximum daily rainfall from 1974 to 2007. To calculate the rainfall with the specific *Tr*, by using the frequency analysis Gumbel distribution, the result shown in Table 6.3.

Alternating Block Method is used to calculate the rainfall design hyetograph. The result is shown in Table 6.4.

Table 6.3 Design rainfall

Return period, *Tr* (year)	Design rainfall (mm)
50	278.418
150	319.514

Table 6.4 Rainfall design hyetograph

Time (Hour)	Hyetograph (mm)	
	Tr 50	*Tr* 150
1	16.78	19.55
2	25.94	30.06
3	151.22	173.84
4	37.82	43.70
5	20.24	23.52
6	14.42	16.84

Peak Flow

The Jobaru River in the plain area, the river dyke is higher than the land surface therefore the runoff from the land surface cannot flow to the river. The discharge in the river is just from the mountainous sub-basin. The runoff from the land area in the plain sub-basin will flow to the down border of the basin. The land area is divided into two sides; the right side, and the left side of the Jobaru River. For analyzing the peak flow in the Jobaru River basin is necessary to calculate the discharge in the Jobaru River, and the discharge that caused by runoff in the plain area at the down border of the basin on the right side and on the left side of the Jobaru River.

The design rainfall with return period (*Tr*) 150 are applied to the land cover 1948, 1975 and 2005, to get the effect of land cover changes to the peak flood during storm. The result shows that the changes of land cover which indicated by the decreasing of *CN* in mountainous sub-basin, cause the decreasing of peak flow during the storm. At Hideki Bridge, during 1948 to 1975, the discharge increase 13.8%. During 1975 to 2005, the discharge decrease 16.3%. Total decreasing from 1948 to 2005 is 2.2%. The results are shown in Figure 6.19.

The discharge at Jobaru River outlet is almost same as at the Hideki Bridge. This is because of the runoff from the plain sub-basin does not flow to the river because the river dyke in the plain sub-basin is higher than the land surface. The discharge in the river is just from the mountainous sub-basin. The result is showed in Figure 6.20.

The runoff from the land area in the plain sub-basin will flow to the down border of the basin. The land area is divided into two sides; the right side, and the left side of the Jobaru River. The discharge that caused by runoff in the plain area at the down border of the basin on the right side and on the left side of the Jobaru River are showed in the Figure 6.21 and 6.22. During 1948 to 1975, the discharge increased 30%. During 1975 to 2005, the discharge increased by 39%. The total increase from 1948 to 2005 is 81%. The discharge increased because the *CN* in the plain sub-basin increased. The results are showed in the figure 6.25 and 6.26.

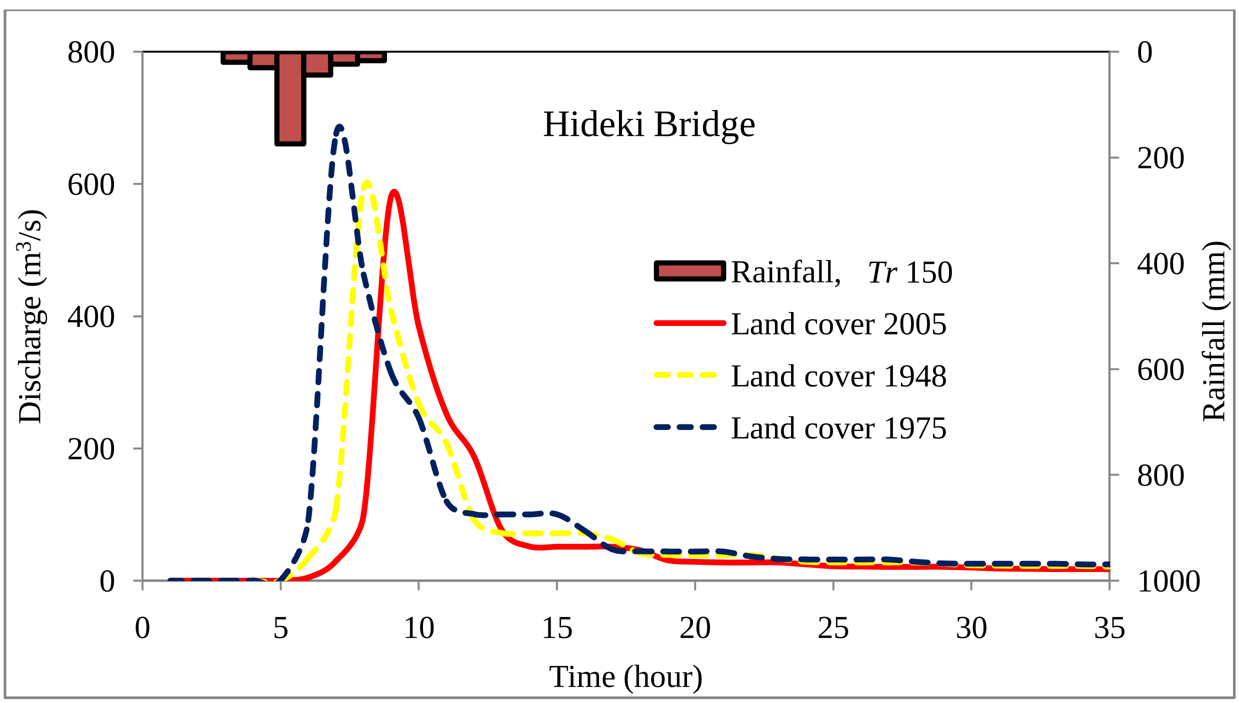


Figure 6.19 Modeled discharge at Hideki Bridge, with rainfall *Tr* 150 applied to land cover 1948, 1975, 2005

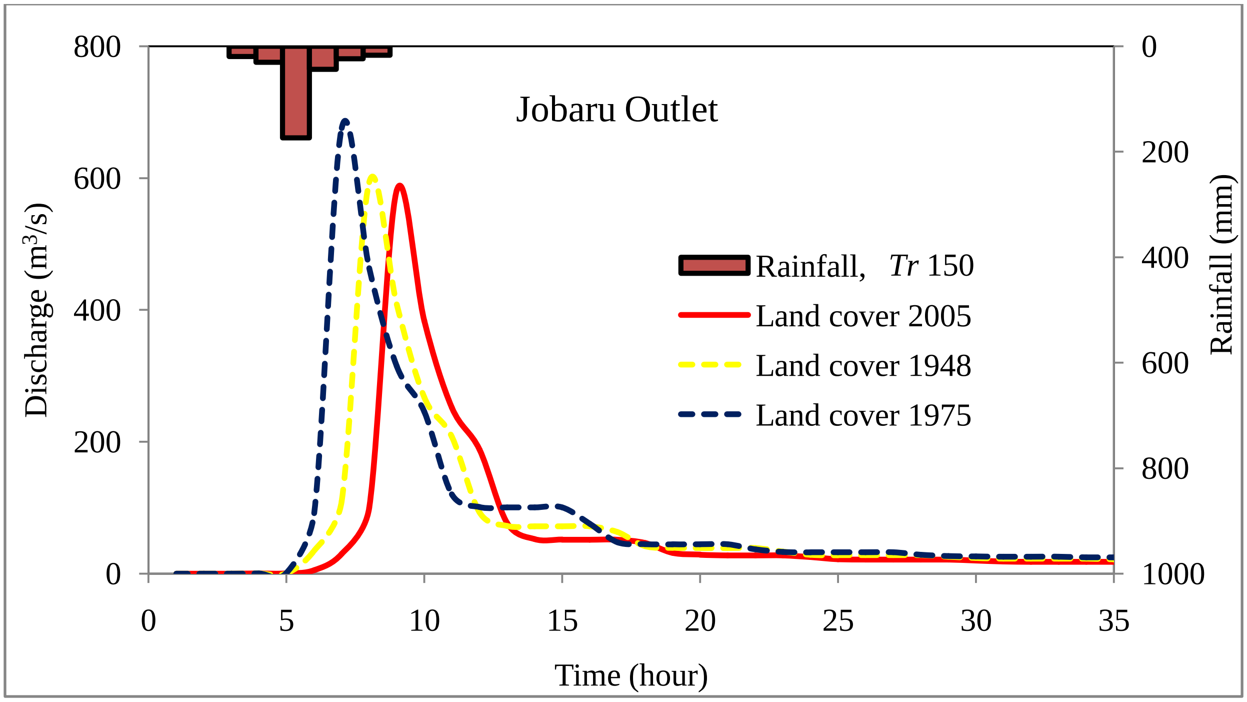


Figure 6.20 Modeled discharge at Jobaru outlet, with rainfall *Tr* 150 applied to land cover 1948, 1975, 2005

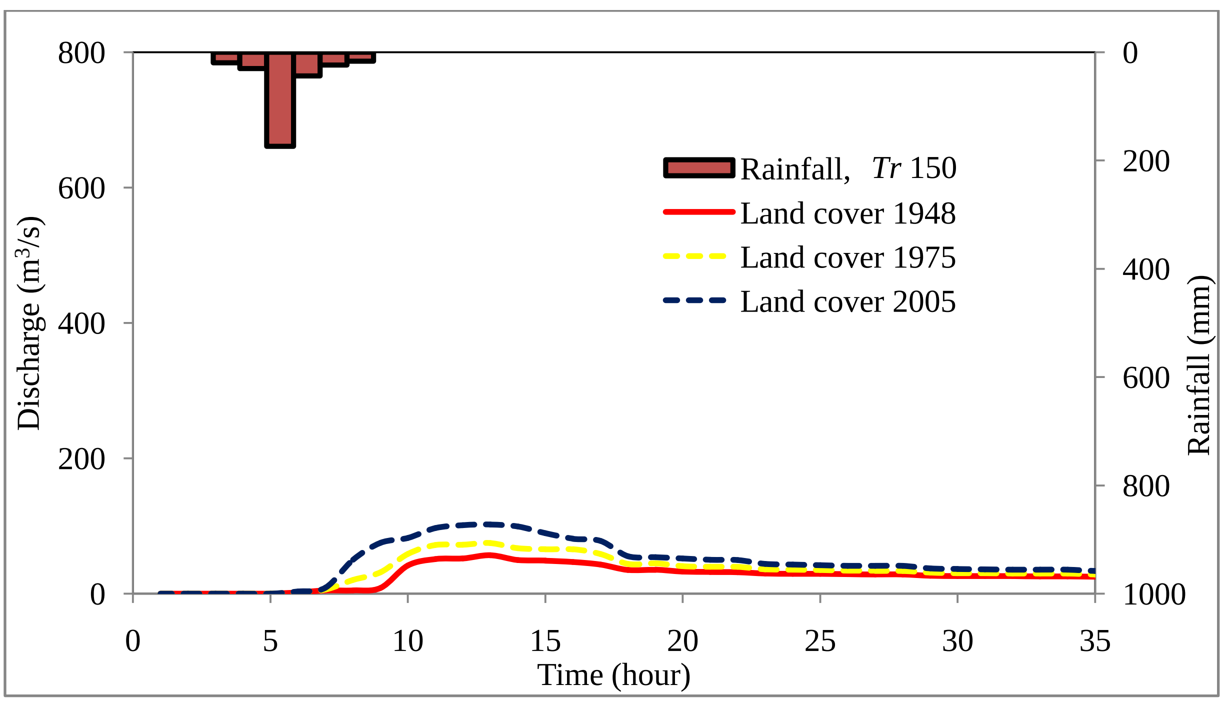


Figure 6.21 Modeled discharge at the bottom of the Jobaru basin border (right side), with rainfall *Tr* 150 applied to land cover 1948, 1975, 2005

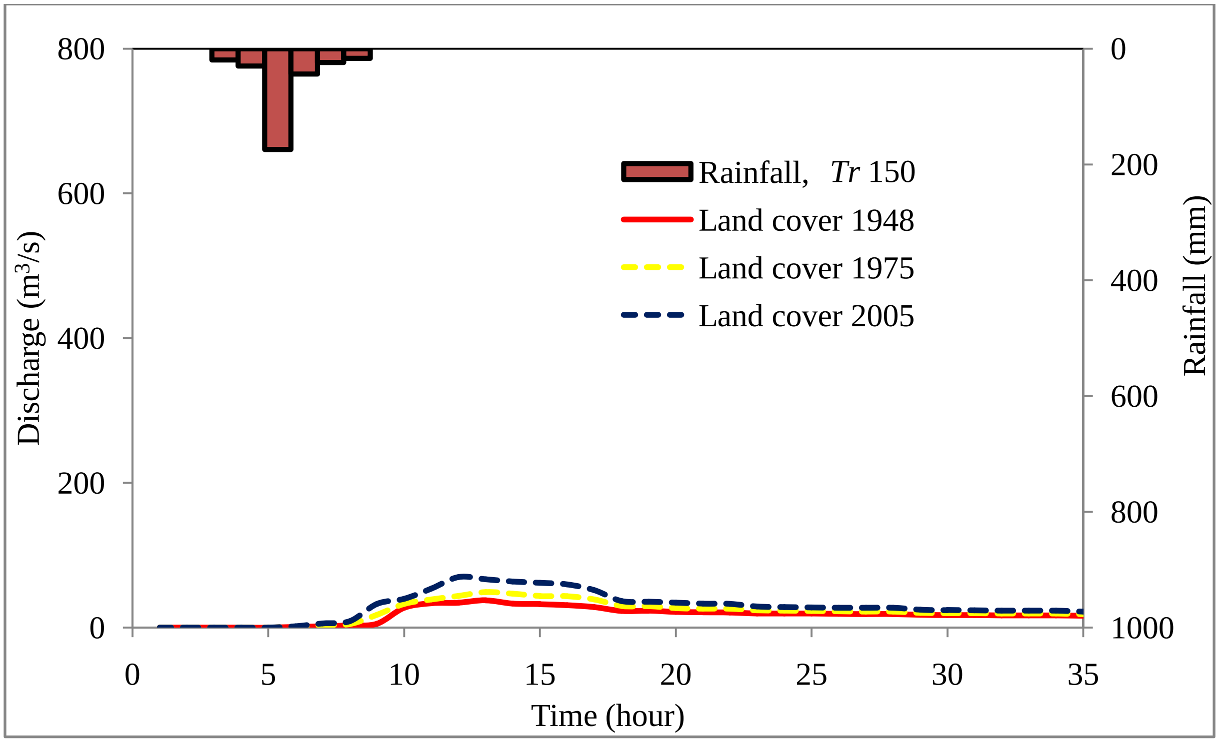


Figure 6.22 Modeled discharge at the bottom of the Jobaru basin border (left side), with rainfall *Tr* 150 applied to land cover 1948, 1975, 2005

Peak Flow in the future

The rainfall *Tr* 150 is applied to land cover 2005, land cover scenario 1 and land cover scenario 2 to get the effect of future land cover with big storm. The result shows that at Hideki Bridge and Jobaru River outlet, changing from land cover 2005 to land cover scenario 1 and land cover scenario 2, the discharge does not change (Figure 6.23 and 6.24). This is because of the runoff from the plain sub-basin does not flow to the river because the river dyke in the plain sub-basin is higher than the land surface. The discharge in the river is just from the mountainous sub-basin. The land cover scenario 1 and 2 are just applied in the plain sub-basin, not include the mountainous sub-basin therefore the discharge of the mountainous sub-basin does not influenced by land cover scenario 1 and 2.

The runoff from the land area in the plain sub-basin will flow to the down border of the basin. The land area is divided into two sides; the right side, and the left side of the Jobaru River. The results shows that the discharge that caused by runoff in the plain area at the down border of the basin on the right side and on the left side of the Jobaru River are increase. Changing the land cover from the land cover 2005 to the land cover scenario 1, the discharge increased 33%. From land cover scenario 1 to land cover scenario 2, the discharge increased by 223%. The total increase from land cover 2005 to land cover scenario 2 is 330%. The results are showed in the Figure 6.25 and 6.26.

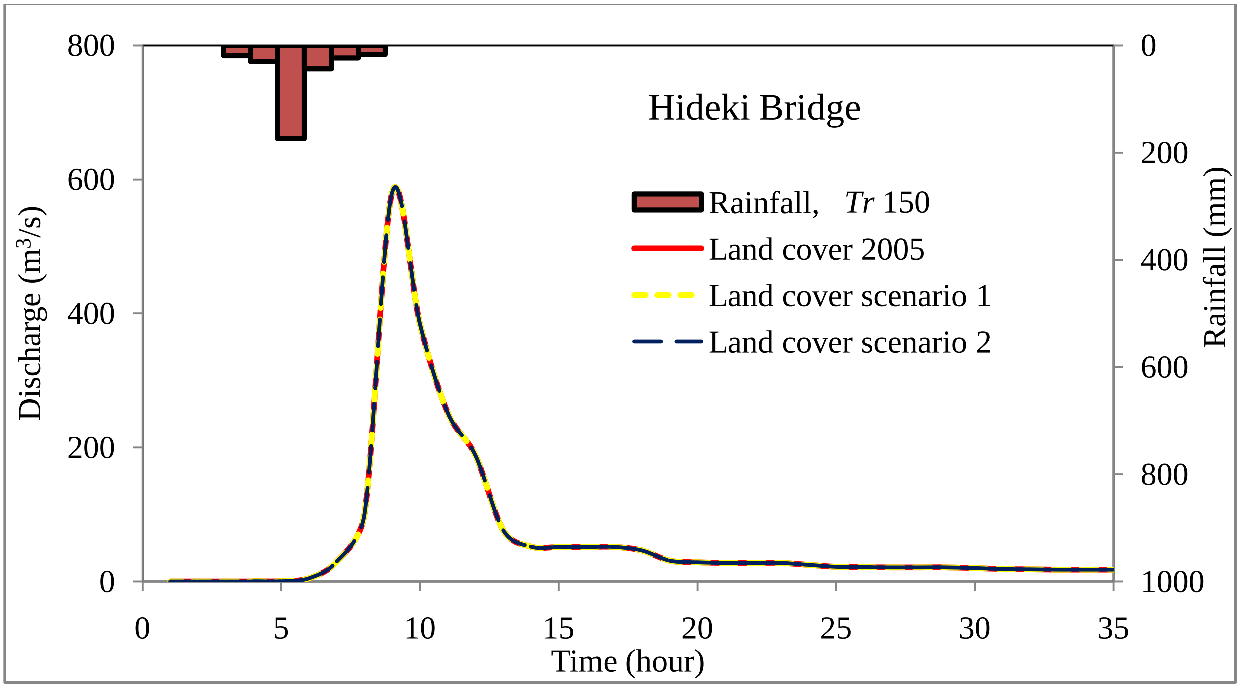


Figure 6.23 Modeled discharge Hideki Bridge, with rainfall *Tr* 150 applied to land cover 2005, land cover scenario 1, and land cover scenario 2

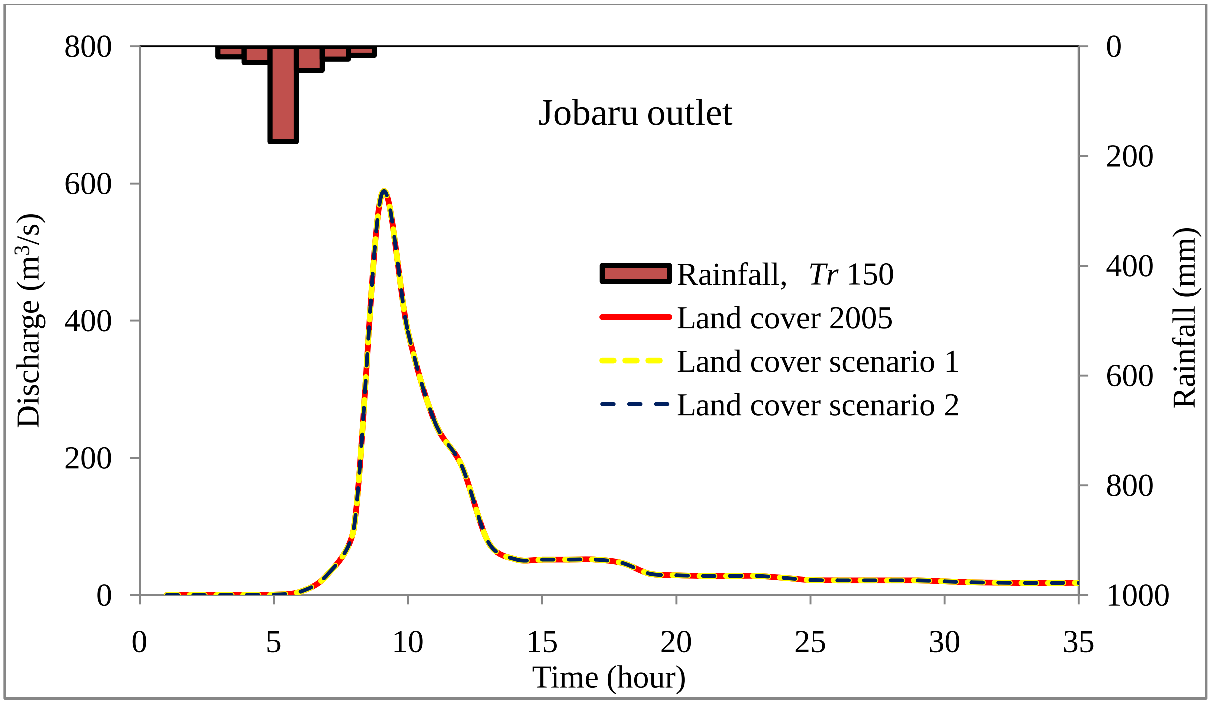


Figure 6.24 Modeled discharge Jobaru River outlet, with rainfall *Tr* 150 applied to land cover 2005, land cover scenario 1, and land cover scenario 2

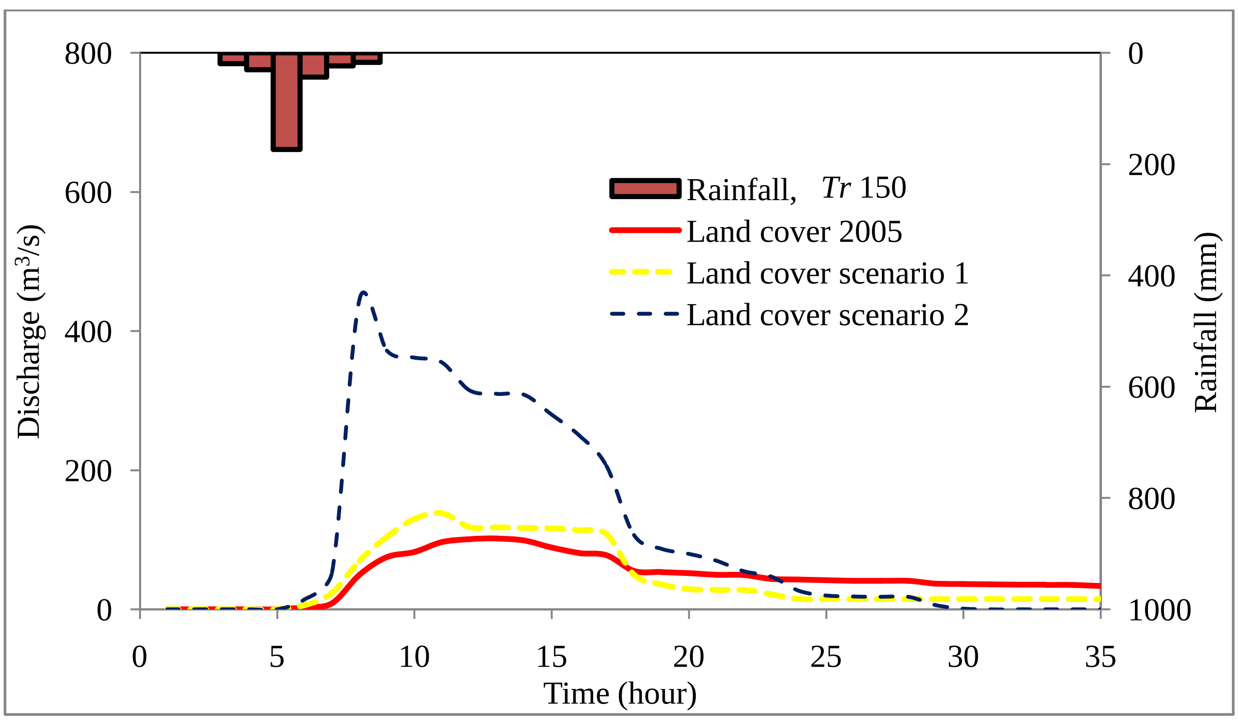


Figure 6.25 Modeled discharge at the bottom of the Jobaru basin border (right side), with rainfall *Tr* 150 applied to land cover 2005, scenario 1, and scenario 2

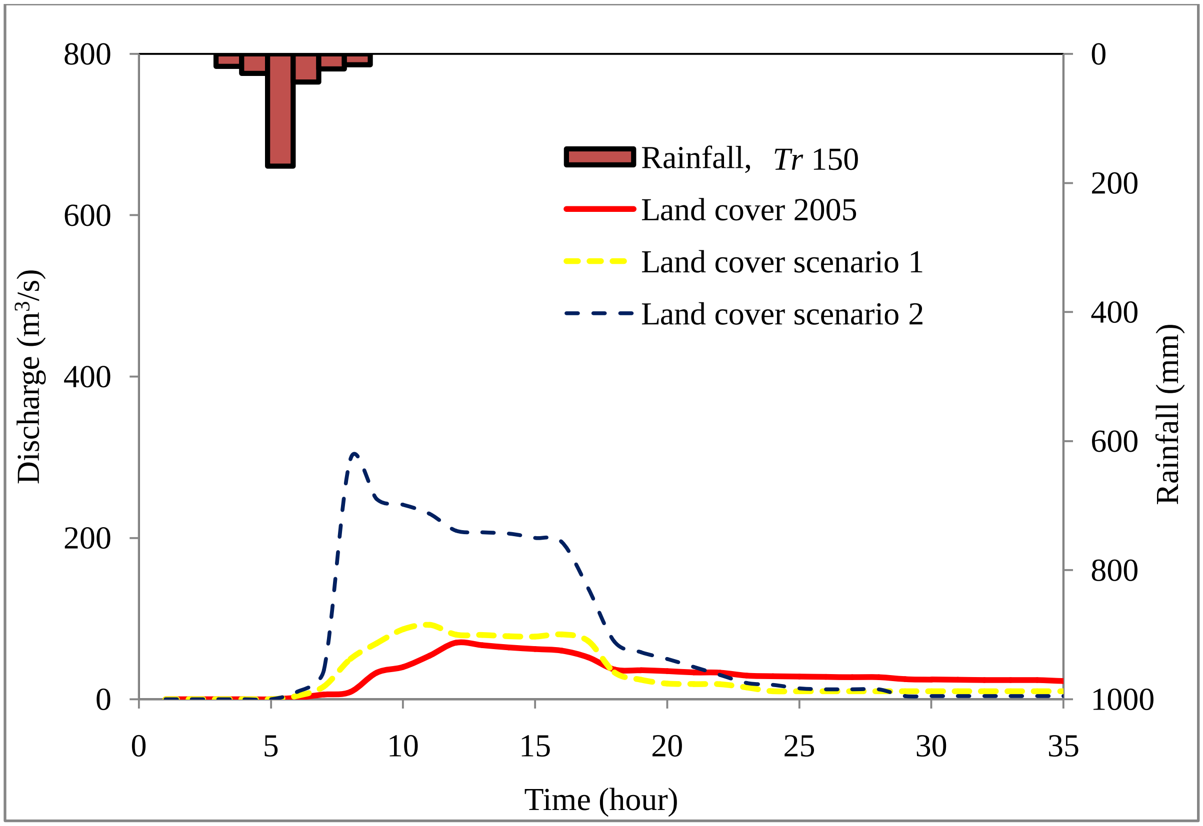


Figure 6.26 Modeled discharge at the bottom of the Jobaru basin border (left side), with rainfall *Tr* 150 applied to land cover 2005, scenario 1, and scenario 2

Between 1948 and 2005, the Jobaru River basin experienced conversion of non-urban area to residential and commercial areas as a result of urban sprawl. The dominant land area in 1948 was agricultural land, which covered 46.99% of the entire watershed, forest (41.06%), and barren (5.47%). Urban area played only a minor role (4.70%) and also water and others (less than 2%) in year 1948. In 2005, urban area covered 11.62% of the entire basin, increased 7% from 1948. Forest also slightly increase 8.14% in this period while agricultural land and barren have decreased. Agricultural land decreased 10.4% and Barren decreased 4.81%.

In the Jobaru River basin, land cover changes significantly in urban area, forestry, agricultural land and barren area, while water and others remained relatively unchanged. The result of land cover changes in 1948, 1975 and 2005 showed that the barren area tended to turn into a forest. After World War II, Japan consumes a lot of wood to build houses, many trees were cut down to be used as construction materials, so many of that forest areas turned barren.

This resulted in land cover in 1948. Forest area is relatively small and barren area is relatively large compared to the year 1975 and 2005. The land cover in 1975 showed that barren area decreased, turning into forest. The results indicates that there is no longer booming demand for wood for construction materials at that time, reforestation were even made in barren areas, so it turns barren areas into forests and the same thing happened to the land use in 2005. On the other hand, the result of land cover 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 have small group of housing. The land cover changes in Jobaru River basin in 1948, 1975 and 2005 is shown in the Figure 6.27.

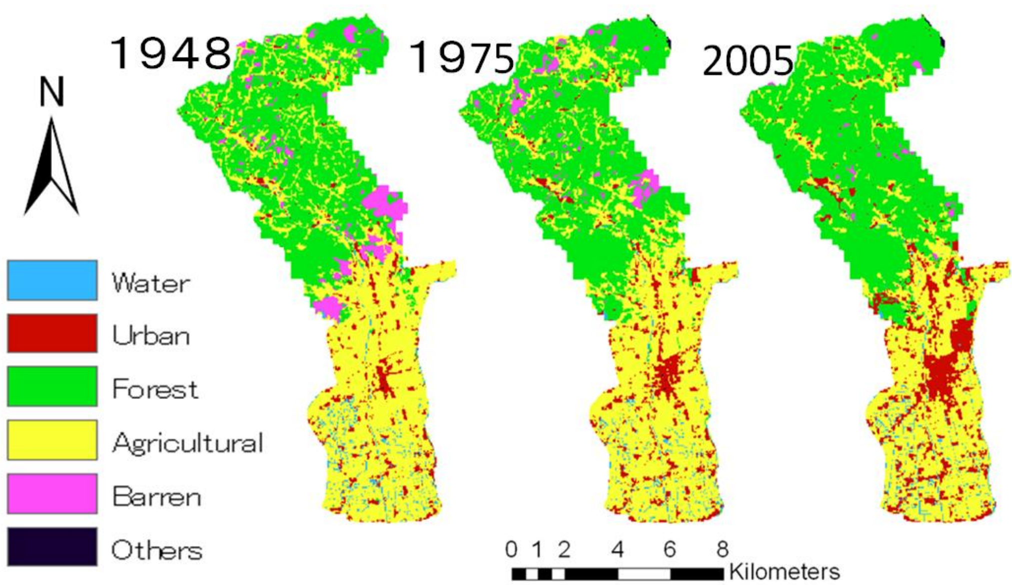


Figure 6.27 Land cover changes in Jobaru River basin

Effects of land cover changes on hydrology were evaluated using MIKE SHE. Data derived from each of three years land cover-related input parameters in the MIKE SHE model. All other model parameters were kept constant during model runs. Measured time series of rainfall and meteorological data in the period 2005 was utilized during that period.

Table 6.5 shows the average annual values of modeled hydrological components and changes attributable to alterations in land cover 1948 and 2005 on the Jobaru River basin. There were increases in total overland flow on the other hand there were decreases in infiltrations and evapotranspiration as a response to the land cover change. Percent increase in average total overland flow was 7.0% over a period between 1948 and 1975, and 3.5% over a period between 1975 and 2005. This situation was due primarily to the expansion of impervious surface in urban areas. The amount of impervious areas primarily controlled the amount of runoff generated from the watershed by decreasing the rates of infiltration and evapotranspiration.

Table 6.5 Hydrological components in year 1948, 1975 and 2005

Land cover	Precipitation (mm)	Evapotranspiration (mm)	Overland flow (mm)	Infiltration (mm)	Ground water recharge (mm)
1948	1786	619	720	311	136
1975	1786	595	769	302	120
2005	1786	582	796	297	111

Results obtained the same pattern and trend from other studies (Lørup et al., 1998; Fohrer et al., 2001; Klöcking and Haberlandt, 2002; Im et al., 2003). Klöcking and Haberlandt, 2002 showed that urbanization causes an increase of surface runoff with a decrease in ground water recharge and a reduction of evapotranspiration. In addition, Im et al., 2003 found that an increases in impervious areas of up to 10.1% may lead to increases of 15.8% in streamflow volume with modelling approach for the future land use scenarios in the Polecat Creek watershed, US.

6.4 CONCLUSIONS OF CHAPTER 6

The MIKE SHE modeling system was applied to investigate the basin-scale hydrologic effect of land cover changes within 87.5 km^2 of the Jobaru River basin.

Between 1948 and 2005, the Jobaru River basin experienced conversion of non-urban area to residential and commercial areas as a result of urban sprawl. The dominant land area in 1948 was agricultural land, which covered (46.99%) of the entire watershed, forest (41.06%), and barren (5.47%). Urban area played only a minor role of only (4.70%) and also water and others (less than 2%) in the year 1948. In 2005, urban area covered 11.62% of the entire basin, but increased 7% from 1948. Forest also slightly increased by 8.14% in this period while agricultural land and barren area have decreased. Agricultural land decreased 10.4% and barren area decreased 4.81%.

To know the effect of land cover changes on river flow, the rainfall in 2005 is applied to three different land covers; land cover 1948 which corresponds to *CN* = 53.97, land cover 1975 which corresponds to *CN* = 55.82, and land cover 2005 which corresponds to *CN* = 56.25. The result shows that the changes of land cover from 1948 to 2005 which indicated with the increasing of *CN* in the plain sub-basin, caused the increase of average daily discharge and water flow volume in the Jobaru River (at Jobaru outlet). Changes of land cover from the land cover in 1948 (*CN* = 53.97) to the land cover 1975 (*CN* = 55.82) caused the increase in average daily discharge of 13%, and increasing in water flow volume by 3%. Changes of land cover from the land cover in 1975 (*CN* = 55.82) to the land cover in 2005 (*CN* = 56.25) caused the increase in average daily discharge of 2.1%, and increasing in water flow volume of 1.5%.

In this research, the initial soil moisture condition is represented by the initial rainfall depth before the main rainfall. The same rainfall pattern with different rainfall initial depth is applied to the same land cover (Land cover 2005) to get the effect of initial soil moisture condition to peak flow. The result shows that having the same rainfall pattern but different rainfall initial depth causes the increase of discharge. With the same rainfall pattern which have two peaks with different initial rainfall depth 1 mm, 2 mm, and 3 mm each hour along 20 hours before the main rainfall, causes the increasing of peak discharge in both peaks. Increasing 1 mm of the initial rainfall depth caused the increase from the first peak by 7.5% and 1.2% to the second peak. The results show that the different initial soil moisture condition caused the different peak discharge.

The rainfall in 2005 is applied to the land covers in 2005, the land cover scenario 1, and the land cover scenario 2. The results show that the changes of land cover from 2005 to scenario 1 and scenario 2 caused the increase of daily discharge and water flow volume in the Jobaru River. This is due to the increasing of the urban areas. Urbanization may cause the expansion of impervious surface, which controlled runoff by decreasing the rate of infiltration. The changes of land cover from land cover in 2005 to land cover scenario 1, caused the increase in water flow volume to 11.9%, and from land cover scenario 1 to land cover scenario 2 caused the increase of water flow volume to 9.7%. The changes of land cover from land cover in 2005 to land cover scenario 1, caused the increase in average daily discharge by 16%, and from land cover scenario 1 to land cover scenario 2 caused the increase of average daily discharge by 68%.

The land cover changed especially during the urbanization causing the changes in the hydrograph characteristics. When the same rainfall is applied to the different land covers (land cover 2005, land cover scenario 1 and land cover scenario 2), the result showed that the Time Base (Tb) decreased, time to peak decreased, and the peak flow increased.

For analyzing the peak flow in the Jobaru River basin is necessary to calculate the discharge in the Jobaru River, and the discharge that caused by runoff in the plain area at the down border of the basin on the right side and on the left side of the Jobaru River.

The design rainfall with return period (*Tr*) 50 and 150 are applied to the land cover 1948, 1975 and 2005, to get the effect of land cover changes to the peak flood during storm in the Jobaru River and in the down border of the basin. The result shows that the changes of land cover which indicated by the decreasing of *CN* in mountainous sub-basin, cause the decreasing of peak flow during the storm. At Hideki Bridge, during 1948 to 1975, the discharge increase 13.8%. During 1975 to 2005, the discharge decrease 16.3%. Total decreasing from 1948 to 2005 is 2.2%.

The discharge at Jobaru River outlet is almost same as at the Hideki Bridge. This is because of the runoff from the plain sub-basin does not flow to the river because the river dyke in the plain sub-basin is higher than the land surface. The discharge in the river is just from the mountainous sub-basin.

The discharge that caused by runoff in the plain area at the down border of the basin on the right side and on the left side of the Jobaru River are increase. During 1948 to 1975, the discharge increased 30%. During 1975 to 2005, the discharge increased by 39%. The total increase from 1948 to 2005 is 81%.

The rainfall *Tr* 150 is applied to land cover 2005, land cover scenario 1 and land cover scenario 2 to get the effect of future land cover with big storm. The result shows that the discharge at Hideki Bridge and Jobaru River outlet are almost same. This is because of the runoff from the plain sub-basin does not flow to the river because the river dyke in the plain sub-basin is higher than the land surface. The discharge in the river is just from the mountainous sub-basin. The land cover scenario 1 and 2 are just applied in the plain sub-basin, not include the mountainous sub-basin therefore the discharge of the mountainous sub-basin does not influenced by land cover scenario 1 and 2.

The runoff from the land area in the plain sub-basin will flow to the down border of the basin. The land area is divided into two sides; the right side, and the left side of the Jobaru River. The results shows that the discharge that caused by runoff in the plain area at the down border of the basin on the right side and on the left side of the Jobaru River are increase. Changing the land cover from the land cover 2005 to the land cover scenario 1, the discharge increased 33%. From land cover scenario 1 to land cover scenario 2, the discharge increased by 223%. The total increase from land cover 2005 to land cover scenario 2 is 330%.

There was an increase in total overland flow but on the other hand there were decreases in infiltrations and evapotranspiration as a response to the land cover change. The percent increase in average total overland flow was 7.0% over a period between 1948 and 1975, and 3.5% over a period between 1975 and 2005. This situation was due primarily to the expansion of the impervious surface in urban areas. The amount of impervious areas is primarily controlled through the amount of runoff generated from the watershed by decreasing the rates of infiltration and evapotranspiration.

In this chapter, the MIKE SHE model was used as a tool for analyzing the effect of agricultural-to-urban land cover conversion on river basin hydrology and water availability at the river basin outlet. There were increases in the whole river basin overland flow and decreases in infiltrations and evapotranspiration as a response to land use changes. These were due primarily to the growth and sprawl of urban areas. Urbanization may cause the expansion of impervious surface, which controlled runoff by decreasing the rates of infiltration and evapotranspiration.

The whole river basin assessment of the hydrologic effects of land cover changes is a vital prerequisite for water resources development and management. Adoption of distributed models like MIKE SHE requires detailed information on temporal and spatial scales, but can precisely identify the effects of changing land cover on hydrologic function in river basin.

Chapter 7
CONCLUSIONS

During 1948 to 2005, there were land cover changes in the Jobaru River basin. Urban area and Forest area increased, while the Agricultural and Barren decreased. The increasing of forests is predominantly caused by the changes of the Barren turning into Forest, while there is a decrease of agricultural area due to the increased demand of land for residential area. The *CN* of the entire Jobaru River basin increased, however, in the sub-basin the result is different. In the mountainous sub-basin, the *CN* decreased but in the plain sub-basin the *CN* increased.

Changes in land cover causes changes in discharge on Jobaru River. The land cover type determined the impervious surface which controlled the runoff. Changes barren area to forestry causes the decreasing of impervious surface. On the other hand, urbanization may cause the expansion of impervious surface, which controlled runoff by decreasing the rates of infiltration and evapotranspiration. The amount of impervious areas primarily controlled the amount of runoff generated from the river basin by decreasing the rates of infiltration and evapotranspiration.

The different land covers with different *CN* remarkably influenced a peak flow. The hourly rainfall is used to simulate the peak flow. With the same rainfall applied to the different land covers corresponding to *CN* of Jobaru mountainous sub-basin (land cover 1948 corresponding to *CN* = 48.24, land cover 1975 corresponding to *CN* = 48.43, and land cover 2005 corresponding to *CN* = 46.07), the result shows that the decreasing of *CN* 4.5% from 1948 to 2005 caused the decreasing of the peak flow 15% at Hideki Bridge.

The discharge in the Jobaru River is just influenced by the changing of land cover in the mountainous sub-basin, not the plain sub-basin. This is because of the runoff from the plain sub-basin does not flow to the river because the river dyke in the plain sub-basin is higher than the land surface. The discharge in the river is just from the mountainous sub-basin. The land cover changed in the plain sub-basin influences the discharge that caused by runoff in the plain area at the down border of the basin on the right side and on the left side of the Jobaru River basin. The result shows that the discharge at Jobaru River outlet is almost same as at the Hideki Bridge. On the other hand, the discharge caused by runoff in the plain area at the down border of the basin on the right side and on the left side of the Jobaru River basin increases. During 1948 to 1975, the discharge increased 30%. During 1975 to 2005, the discharge increased by 39%. The total increase from 1948 to 2005 was 81%.

Two land cover scenarios were created to get the future land cover effect. Scenario 1: if the agricultural area nears the Kanzaki city became urban. Scenario 2: if all the agricultural areas in the plain sub-basin became urban. The effect of future land cover scenarios with big storm shows that the discharge at Hideki Bridge and Jobaru River outlet are almost same but the discharge caused by runoff in the plain area at the down border of the basin on the right side and on the left side of the Jobaru River increased. Changing the land cover from the land cover 2005 to the land cover scenario 1, the discharge increased 33%. From land cover scenario 1 to land cover scenario 2, the discharge increased by 223%. The total increase from land cover 2005 to land cover scenario 2 was 330%. Actually land cover changes are just one aspect that affects the discharge in Jobaru River.

The initial soil moisture condition also affects the peak flow. The results show that with the same rainfall pattern but with the difference of rainfall initial depth caused the increase of discharge. Having the same rainfall pattern, which have two peaks with different initial rainfall depth, before the main rainfall, caused the increase of peak discharge in both peaks. Increasing of 1 mm of the initial rainfall depth caused the increase from the first peak by 7.5%, and 1.2% to the second peak.

The land cover changed especially during the urbanization causing changes in the hydrograph characteristics. When the same rainfall applied to the different land covers, the result showed that the Time base (*Tb*) and Time to peak decreased, and the peak flow increased.

The land cover changes in the Jobaru River basin affect the hydrological component. There was an increase in total overland flow, but on the other hand there were decreases in infiltrations and evapotranspiration as a response to the land cover change. The percent increase in average total overland flow was 7.0% over a period between 1948 and 1975, and 3.5% over a period between 1975 and 2005. This situation was due primarily to the expansion of the impervious surface in urban areas. The amount of impervious areas is primarily controlled through the amount of runoff generated from the watershed by decreasing the rates of infiltration and evapotranspiration. To manage the flood in Jobaru River basin should consider not only in the river but also in the land area especially in the plain sub-basin because the runoff from the land area in the plain sub-basin cannot flow to the river.

The same rainfall return period (*Tr* 150) is used to simulate the discharge in the river and also in the land area (residential area). In the Jobaru River basin especially in the plain sub-basin, the river dyke is higher than the land area surface therefore the runoff from the land area cannot flow to the river directly. If the design rainfall return period of the land area is less than the design rainfall return period of river flood, when the big storm occurs, the water from the river may not overflowing to the land area but the runoff from the land area will inundate the land itself. With the same rainfall design for the river flood discharge and the land area, the flood management planning will be better.

All this time, handling of the Jobaru River environment has been more focused on the mountainous sub-basin. Reforestation in mountainous area turns almost all barren area into forest area. On the other hand there was less attention to the plain sub-basin. Changing from agricultural land to urban area is still continuing. The changes of land cover from agricultural land to urban area in the plain sub-basin gave significant effects to the increasing of the discharge in the down border of Jobaru River basin but it does not influence to the discharge in the Jobaru River outlet. Therefore to manage the flood in Jobaru River, we should consider the land cover changes not only in the mountainous sub-basin but also in the plain sub-basin, and the discharge should be considered not only in the river but also in the land area. This result can be applied to the river basin management.

The increase of discharge in the Jobaru River and in the down border of the basin due to the urbanization in the plain sub-basin can be used as a reference for river basin management planning. Many aspects should be considered for the river basin management, not only land cover change. This study provides a reference of the effect of land cover changes as one of the important parts of the integrated Jobaru River basin management. This research will be a useful step for future integrated river basin management which is expected to be used as the foundation for the sustainable development of the Jobaru River basin in the future.

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