Annual Journal of Hydraulic Engineering, JSCE, Vol.54, 2010, February

FLOOD RUNOFF CHARACTERISTICS DUE TO LAND COVER CHANGE IN UPPER CILIWUNG RIVER BASIN INDONESIA USING 2D DISTRIBUTED MODEL COUPLED WITH NCF TANK MODEL

Mohammad FARID[1], Akira MANO[2] and Keiko UDO[3]

[1] Member of JSCE, M. Eng., Graduate School of Engineering, Tohoku University (6-6-11-1110 Aoba Aramaki Aoba-ku, Sendai 980-8579, Japan)
[2] Member of JSCE, Professor, Graduate School of Engineering, Tohoku University (6-6-11-1110 Aoba Aramaki Aoba-ku, Sendai 980-8579, Japan)
[3] Member of JSCE, Dr. Eng., Graduate School of Engineering, Tohoku University (6-6-11-1110 Aoba Aramaki Aoba-ku, Sendai 980-8579, Japan)

This paper describes effects of land cover change on flood discharge production in the upstream of the Ciliwung River basin, Indonesia, in terms of both hydraulic effect of overland flow process and the hydrologic effect of infiltration and interception, comparing flood events in 1996 and 2002. The model developed in this study is a combination of hydraulic and hydrology model. Dynamic hydraulic model is used to simulate surface run off and tank model is used to simulate hydrology parameters. The model is validated with field observation measurement data. The result shows that land cover change in study area during 1996 and 2002 has greatly increased the peak discharge. It is shown that peak discharge in flood event of 1996 will increased 1.4 times when the same event is simulated with the 2002 land cover. In conjunction, the peak discharge of 2002 flood event will decrease to 0.6 times when the same event is simulated with 1996 land cover.

Key Words **:** *Land cover change, flood, hydrology, hydraulic*

1. INTRODUCTION

Indonesia has been developing rapidly in the past decades. The uncontrolled growth leads to significant change in the environment. The impact can be observed in the changing of runoff and hydrological characteristics. Flood frequency in Jakarta, the capital of Indonesia, has been increasing during the past decades. Records show that the city was flooded in 1996 and 2002. It is said that one of the factors caused those floods is high discharge from upstream area of the Ciliwung River. Carlow et al.[1)] considered the flood in 2002 to be one of the worst in the city history and had severely damaged the city infrastructures and municipalities.

The increasing flood frequency was considered to be one of the rapid urbanization impacts, especially urbanization in the upstream area. The development in upstream area has decreased the permeable area and changed the overland flow process. The government in Indonesia has issued regulations on development in this area to conserve the basin capacity. The increasing need of urban development must not neglect the environment. Therefore, present condition should be evaluated to determine the future development. Furthermore, future development should be addressed in location which has insignificant impact to the flood production. The evaluation and decision making process requires a more comprehensive study in the upper catchment area of the Ciliwung river basin which involves hydraulic and hydrology aspects.

Satellite data are commonly used to assess the land cover change of an area. Landsat images are available for this purpose. Chen et al.[2)] had conducted analysis on land cover change using

Landsat images for the Xiling River basin where they classified the basin surface condition into 5 types. Their results showed that the Landsat data is reliable for analysis. In general, landcover identification can be observed using two methods, the supervised method and the unsupervised method. The unsupervised method provides an easier way to classified land cover with slightly reducing the accuracy[3)]. The spatial land cover data combined with the hydrology and hydraulic model would be a very powerful tool in studying the effect of land cover change on discharge production.

Hydrologic models are often used for discharge production modeling and analysis. This type of model mainly based on the water balance principle. Muthukrishman et al.[4)] analyzed the impact of land cover change using simple hydrological model based on Curve Number method for long term evaluation. The land cover type will determine the Curve Number of the corresponding sub basin. Another type of hydrologic model was used by Niehoff et al.[5)] with application of sealed surface and urban sewer system to represent land cover condition.

Yu et al.[6)] studied land use change effect by applying hydrologic process on rainfall runoff model. Land cover analysis was conducted using remote sensing and GIS. The model is based on Horton overland flow. However, subsurface flow is ignored in this model. Land use change effect was also studied by Kimaro et al.[7)]. They emphasized the effect of roughness value to the surface runoff and discharge production. Net rainfall and infiltration are calculated by Green and Ampt model whereas kinematic wave model is used for flow routing. Another model commonly used for modeling hydrology process in a basin or sub basins is tank model. A combination of tank model and kinematic channel routing was used by Kardhana[8),9)] for flood forecasting in two river basin areas in Japan, Shichikasuku and Ookawa. However, a model combining dynamic overland flow process with hydrology model has not been studied widely.

The overland flow process becomes important in flood production because it plays an important role in the flow direction which might lead to a change of inundation or concentration time of an area in the basin. Hydraulic model based on shallow water equations are commonly used for this purpose. Zhang et al.[10)] had used 2D shallow water equation model for levee breach analysis in the Fuji River basin. Cea et al.[11)] have shown that similiar model can be applied for flood simulation in natural river basin with various slope. Farid et al.[12)] had simulated flood due to dam break using the same equation. An attempt to apply an advanced hydraulic with hydrology model was done by Gandolfi and Savi[13)]. They have tried to combine the unsteady shallow water equation with hydrology process. They accommodated infiltration rate with subsurface flow in the model with application to synthetic basin. By using the overland flow model, the flow pattern on surface can resemble the actual event and therefore, the contribution of each area to the flood production can be obtained more accurately. However, a more detail hydrology model is required for analyzing discharge production in a real basin.

In this present study, a combination of 2D runoff model with the nearly calibration free tank model (NCF TANK MODEL)[9)] is developed in order to satisfy the run off process along with the hydrology process that can be used to simulate the land cover change effect to discharge production in the study area. The hydrology parameter in the model is interception rate, infiltration rate and interflow. There are 3 parameters need to be calibrated in the model, the Manning roughness coefficient based on the land cover type, the infiltration rate coefficient in urban area based on the density of impermeable area and the interflow coefficient. The model parameters are calibrated using a single event of hydrograph, and the parameters are used to simulate discharge production in case study area.

2. STUDY AREA

The location of study area is the upper reach of the capital city Jakarta in West Java, Indonesia which only has 2 seasons per year, dry season (May – September) and wet season (October – April). However, this study focuses on the upper part of the river basin area. The domain for the model is limited to the upstream catchments area. The domain area is 234 km^2 with the 46 km length of river.

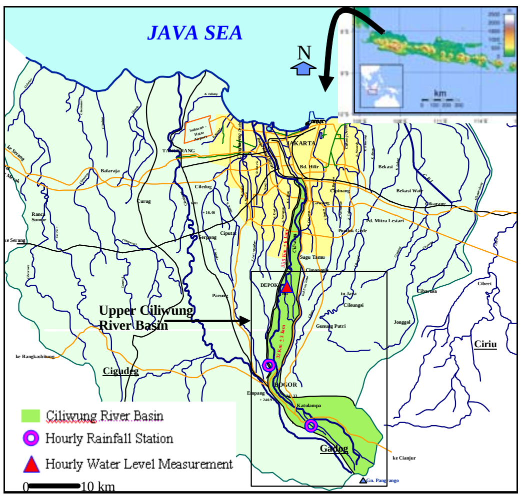

Fig. 1 Study area

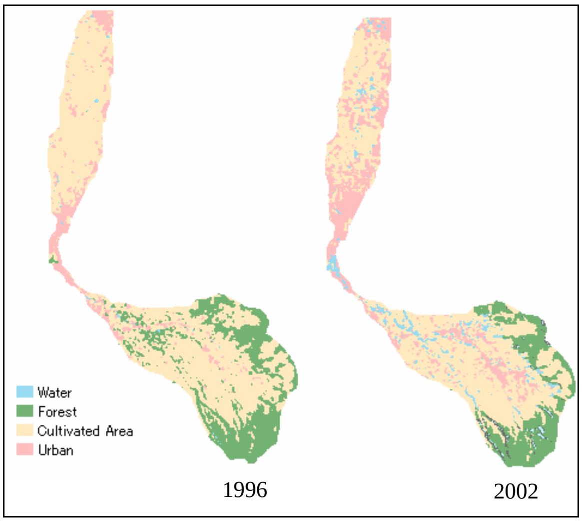

Fig. 2 Upper Ciliwung land cover (1996, 2002)

Table 1 Land cover area

Year	Cultivated	Forest	Urban
	km^2		
1996	152.38	43.81	38.13
2002	151.06	37.75	45.50

The domain consists of mountainous area with slope up to 40%. However, there are some mild slope areas around 2% - 15% near city of Bogor which is located in the downstream of the domain.

There are two hourly rainfall gauges, Citeko and Darmaga, and an hourly discharge measurement station in the study area. The location can be seen in **Fig. 1**.

Land cover data[14] is obtained from Center for Regional Systems Analysis Planning and Development, Indonesia for the year of 2002 and 1996.

The land cover are classified into 4 classes, they are water, forest, cultivated area, and urban area. The classified maps are analyzed to obtain the area of each class. The result is given in the **Table 1.**

During the period, urban area increase by 19%, the forest area decrease by 14% and the cultivated area also decrease by 1%.

3. MODEL DEVELOPMENT

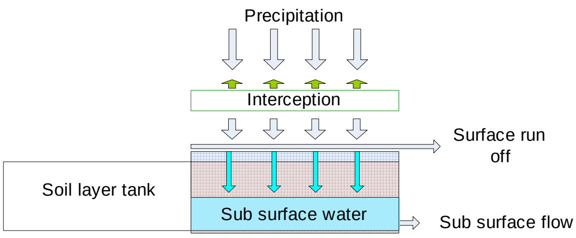

Fig. 3 Model concept

The basic concept for the model is shown in **Fig. 3**. Precipitation will be intercepted by the canopy. However in the urban zone, this process is neglected. The rest of precipitation will fall to the surface and become surface runoff, but some of them will be infiltrate through the soil layer and recharge the sub surface water.

The soil layer is considered to be 1 meter thick for the whole domain. This value is determined based on data and information obtained from local sources in study area. The effective top soil layer is said to be 1 meter on average. This thickness should be adequate to hold the infiltrated water due to runoff with the time scale of several days. The surface run off is simulated by the shallow water equation and the tank model is applied at each grid.

The governing equation for the shallow water equation consists of continuity equation and momentum equation. The continuity equation is shown as follow,

$$\frac{\partial h}{\partial t}+\frac{\partial (uh)}{\partial x}+\frac{\partial (vh)}{\partial y}=q \tag{1}$$

and the momentum equation are shown as follow,

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+gh\frac{\partial (h+z)}{\partial x}=-ghS_{fx} \tag{2}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+gh\frac{\partial (h+z)}{\partial y}=-ghS_{fy} \tag{3}$$

where u and v are velocities in the corresponding axes, h is the water depth, q is the outsource term, z is the elevation, and S_f is the friction slope calculated with Manning equation as follows:

$$S_{fx}=n^2u\left(u^2+v^2\right)^{1/2}/h^{4/3} \tag{4}$$

$$S_{fy}=n^2v\left(u^2+v^2\right)^{1/2}/h^{4/3} \tag{5}$$

The governing equations for the surface run off above are solved using the Mc Cormack predictor and corrector scheme.

The hydrology parameter will be added into outsource term that is infiltration, precipitation, and interception. Interception is calculated using this following equation:

$$P=KEt_D+S \tag{6}$$

where P is the amount of intercepted precipitation for 1 period of rain. KE is vegetation interception rate during rainfall. This value depends on land use type as proposed by Hattori et al.[15] and Tsukamoto[16], for forest the value is 0.2 and for cultivated area the value is 0.1. t_d is rainfall duration, while the canopy storage is symbolized by S with values of 1.5. So the interception rate can be obtained by P/t_D.

Infiltration and sub surface flow calculation are based on tank model concept, applied to each grid point. The infiltration rate is determined by soil hydraulic conductivity and water content in top tank. If the precipitation rate exceeds the hydraulic conductivity then the infiltration rate equals to the hydraulic conductivity, if the rain is less than hydraulic conductivity then the infiltration rate depends on the water content in the soil. A new coefficient is added in this equation to accommodate the urban density, assuming that there is still some recharging in the urban zone. The infiltrated water will fill the soil layer. The subsurface flow is governed by this following equation.

$$q_{\inf} = c_{density}(1-\lambda_1)q_{re} \tag{7}$$

$$q_{re} > k^*_{h_1} \rightarrow q_{\inf} = c_{density}k^*_{h_1} \tag{8}$$

$$\lambda_i = \frac{H_i}{H_{i\max}} \tag{9}$$

where $k^*_{h_1}$ is the saturated hydraulic conductivity, λ_i is water content in the top tank, and $c_{density}$ is the density ratio of impervious area which is defined as the ratio of the permeable area in the urban type land cover to the urban land cover total area. In this model, $c_{density}$ was determined by detecting the urbanization in study area. Urbanization is defined by analyzing the ratio of impervious area to the total area of a district. Thus the $c_{density}$ can be approached by this value.

The subsurface flow is calculated by using Darcy approach.

$$q_i = ck^*_{h_i}I\lambda_i \tag{10}$$

with c is the interflow coefficient and I is the surface slope.

4. SIMULATION

The model is applied to the case study area. Three scenarios are simulated for different purposes. The first scenario is simulated to calibrate the model parameters. The second scenario is simulated to verify the chosen parameters. The last scenario is simulated to study the effect of land cover change to the flood discharge. The computational domain is divided in to grids with spacing of 250 meter. The total number of grids for the domain is 101 x 169. The total number of grids which is located within the basin is 3741. The domain is bounded to the outlet discharge measurement at Depok Station. Simulation is conducted with 0.5 second time step. Hourly rainfall data are available at Darmaga Station and Citeko Station. In this simulation, the regional rainfall value from the two stations is applied in each grid of the basin domain. Nash–Sutcliffe Index (NSI) value is used to evaluate the model performance in comparison to the measured data. The NSI value can be calculated using the following formula.

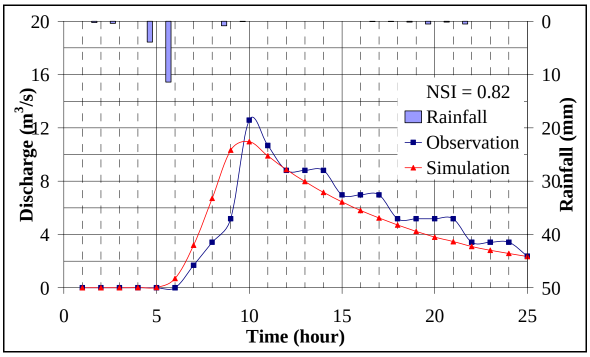

Fig. 4 Calibration with a runoff event in wet season 2002

$$NSI = 1 - \frac{\frac{1}{n}\sum\left(Q_{observation} - Q_{simulation}\right)^2}{\frac{1}{n}\sum\left(Q_{observation} - \overline{Q_{observation}}\right)^2} \tag{11}$$

(1) Calibration

One day event of rainfall from wet season 2002 in the study area for the period of 1/2/02 13:00-1/3/02 13:00 is used to calibrate the model. The following parameters are set based on this simulation: Manning value of 0.08 for urban area, 0.03 for forest area, 0.025 for cultivated area and others meanwhile the density ratio in urban land cover is determined by the value of 0.1. The interflow coefficient is set at 10 as the standard value of NCF TANK MODEL.

The result from the simulation is shown in **Fig. 4**. The NSI index of 0.82 shows the good performance of the model.

(2) Validation

The parameters above are used for validation of the model during the flood event. For this purpose, two flood events are simulated, 1996 flood and 2002 flood. The flood period between 1/5/96 0:00 to 1/8/96 23:00 is simulated for 1996 and the flood period between 1/29/02 0:00 to 2/3/02 7:00 is simulated for 2002. The result from this simulation can be seen in **Fig. 5** and **Fig. 6**.

The simulation result gives a good agreement to the measurement data for both scenarios. The flood reproduction for 2002 flood shows an NSI index of 0.8 and the flood reproduction for 2002 flood shows an NSI index of 0.86. Therefore, the parameters that were determined in the calibration process are acceptable regardless the year of the flood.

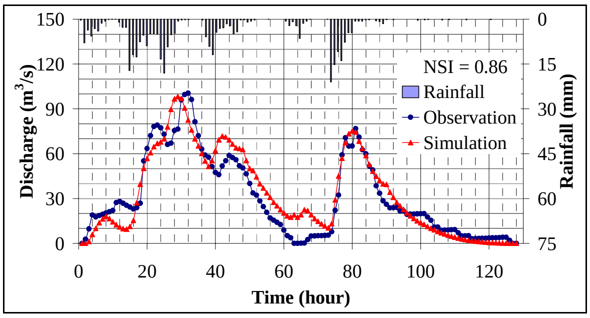

Fig. 5 Validation with 2002 flood

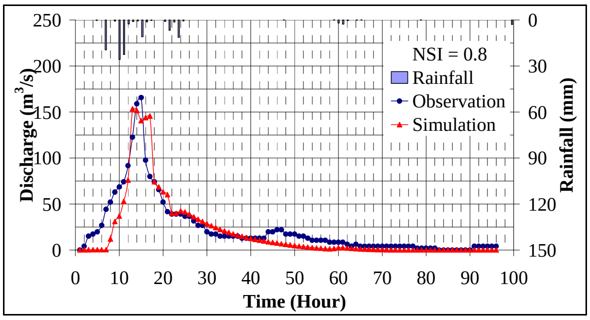

Fig. 6 Validation with 1996 flood

(3) Land covers change simulation

Land cover change effect to flood production is investigated by simulating flood event using different year of land cover condition. The flood of 1996 is simulated using land covers in 1996 and 2002. The flood of 2002 is also simulated using 1996 and 2002 land cover.

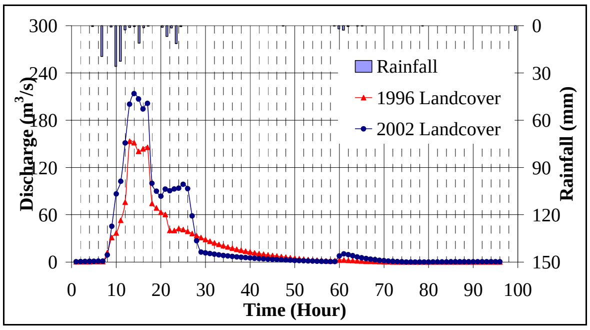

Fig. 7 Comparison of 1996 flood; simulated using 1996 and 2002 land cover

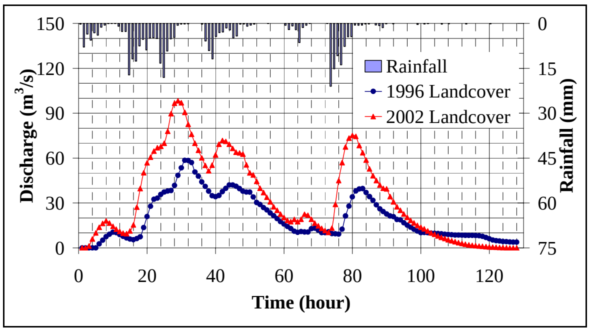

Fig. 8 Comparison of 2002 flood; simulated using 1996 and 2002 land cover

The results for both cases are shown in **Fig. 7** and **Fig. 8**. The land cover change effect in the flood discharge production can easily be observed in the peak discharge and volume of hydrograph. The increasing number of impermeable area along with deforestation in the latest year data has significant impact in the increase of the peak discharge.

In the case of 1996 flood, the simulated peak discharge using the corresponding land cover is 153.40 m^3/s with 24% of precipitation become outflow discharge. This value increase to 213.78 m^3/s with 34% of precipitation become outflow discharge, or 1.4 times of the original discharge, when the same precipitation with 2002 land cover was simulated. By the end of simulation time, the soil layer was filled around 20% of its capacity, which was downed to 18% of capacity when simulated using the 2002 land cover. This shows that the amount of water stored in the soil is lesser in the 2002 land cover. The flood hydrograph obtained using 2002 land cover data shows the rising limb and falling limb change abruptly compare to simulation using 1996 data. An effect of groundwater storage to flood production can be observed in the falling limb of the curve which is also confirmed from the differences in the amount of water stored in the soil layer. 1996 land cover simulation shows a slower decay which is caused by some amount of the ground water storage release to surface. The 2002 land cover simulation is more sensitive to precipitation, as an increase in precipitation will cause high increase in the discharge.

Similar effect is observed in the case of 2002 flood. The simulated actual peak discharge was 98.20 m^3/s and 41% of precipitation became outflow discharge. However, when the same input was applied to the 1996 land cover, the peak discharge was down to 58.51 m^3/s or approximately 0.6 times the original discharge and only 25% of precipitation became outflow. This means that for this flood event, the peak discharge obtained from the newer land cover data is 1.6 times of the peak discharge obtained from the older land cover data. In the case of 1996, it was 1.4 times respectively. By the end simulation time, the soil layer was filled around 21% of its capacity, and 27% of capacity when simulated using the 1996 land cover. As has been stated previously, the discharge would be more sensitive to precipitation for a newer land cover data, thus along with that, the higher multiplying factor in the 2002 case was the result of a higher precipitation. More water infiltrate the soil in the 1996 land cover and therefore, the infiltrated water which was release to surface is also bigger which can be seen at the falling limb near the end of simulation.

5. CONCLUSION

It has been shown here the performance of the developed model, combination of dynamic hydraulic and tank model, in assessing the land cover change effect to flood discharge production. A density ratio coefficient ($c_{density}$) can be considered for modeling the effect of impervious area density in urban land cover. The development of urban area does not mean that zero infiltration rates should always be applied. This coefficient can be determined by detecting the urbanization in study area which was conducted through analyzing the ratio of impervious area in each district. The model has been calibrated and verified to field observation data with good comparison, shown by the high value of NSI index.

The model was applied in two flood events, 1996 and 2002. Each event was simulated under two conditions, the 1996 land cover and 2002 land cover. Land cover where classified in to water, forest, cultivated and urban area. Simulation of 1996 event using the 2002 land cover showed that the land cover changes would increase the peak discharge 1.4 times. Simulation of 2002 event using the 1996 land cover data shows that the peaks discharge would decrease to 0.6 times.

Based on the results, it can be concluded that the current development has significantly increased the flood discharge. Each scenario had already caused flood in Jakarta at the downstream area of the domain due to over capacity on river cross section. In 1996, the peak discharge and maximum precipitation are bigger than those in 2002 but more severe damages occurred in 2002 due to urbanization and longer time scale of precipitation. Climate change is said to be one of factors that causes change in this precipitation behavior. Thus, the best thing to do is to control development and land cover change to avoid more severe damages. Development should be conducted carefully to decrease contribution to flood in Jakarta.

REFERENCES

1) Caljouw, M., Peter, J.M. Nas, P. J. M. and Pratiwo: Flooding in Jakarta, *The 1st International Conference on Urban History*, Surabaya, Indonesia, August 23rd-25th, 2004.

2) Siqing, C., Jiyuan, L., Dafang, Z. and Xiangming, X.: Characterization of Land Cover Types in Xilin River Basin Using Multi-Temporal Landsat Images, *Journal of Geographical Sciences 13*, Vol.2, pp.131-138, 2003.

3) Thapa, R. J. and Murayama, Y.: Urban Mapping, Accuracy, and Image Classification: A Comparison of Multiple Approaches in Tsukuba City, Japan, *Journal of Applied Geography*, Elsevier, Vol.29, pp.135–144, 2009.

4) Muthukrishnan, S., Harbor, J., Lim, K. J. and Engel, B. A.: Calibration of A Simple Rainfall-Runoff Model for Long-Term Hydrological Impact Evaluation, *URISA Journal*, Vol.18, No.2, pp.35-42, 2006.

5) Niehoff, D., Fritsch, U. and Bronstert, A.: Land-Use Impacts on Storm-Runoff Generation: Scenarios of Land-Use Change and Simulation of Hydrological Response in A Meso-Scale Catchment in SW-Germany, *Journal of Hydrology*, Elsevier, Vol.267, pp.80-93, 2002.

6) Yu, P. S., Wang, Y. C., and Kuo, C. C.: Effects of Land Use Change on Runoff Response in The Ungauged Ta-Chou Basin, Erosion Prediction in Ungauged Basins: Integrating Methods and Techniques, *Proceedings of Symposium HS01 Held During IUGG 2003 at Sapporo*, July 2003, IAHS Publ. No.279, pp.162-170, Japan, 2003.

7) Kimaro, T., Tachikawa, Y., and Takara, K.: Hydrological Effects of Land Use Change in The Yasu River Basin, *Annual of Disaster Prevention Research Institute*, Kyoto University, No.46B, pp.203-211, Japan, 2003.

8) Kardhana, H.: A Short Term Flood Forecast Based on Distributed Runoff Model, *Doctoral Dissertation*, Graduate School of Engineering, Civil Engineering Department, Disaster Potential Research Laboratory, Tohoku University, 2008.

9) Kardhana, H. and Mano, A.: Uncertainty Evaluation in A Flood Forecasting Model Using JMA Numerical Weather Prediction, *Journal of Disaster Research*, Vol.4 No.4, pp.272-277, 2009.

10) Xinhua, Z., Wenfei, L., Heping, X., Jiahua, Z. and Jiangping, W.: Numerical Simulation of Flood Inundation Processes by 2D Shallow Water Equations, *Frontiers of Architecture and Civil Engineering in China*, Springerlink, Vol.1(1), pp.107–113, 2007.

11) Gandolfi, C. and Savi, F.: A Mathematical Model for The Coupled of Surface Runoff and Infiltration, *Journal Agricultural Engineering Research*, Vol.75, pp.49-55, 2000.

12) Kusuma M.S.B., Farid, M. and Adityawan, M.B.: Numerical Model Study of Two Dimension Flow Generated by A Dam Break, *International Conference on Earthquake Engineering and Disaster Mitigation*, Jakarta, Indonesia, 2008.

13) Cea, L., Puertas, J., Pena, L. and Garrido, M.: Hydrologic Forecasting of Fast Flood Events in Small Catchments with a 2D-SWE Model, Numerical Model, and Experimental Validation, *13th World Water Congress*, Montpellier, France, 1-4 September 2008.

14) Center for Regional Systems Analysis Planning and Development, Bogor Agricultural University, *Land Cover Map in Jabotabek Region*, 1996 and 2002.

15) Hattori, S., Chikaarashi, H. and Takeuchi, N.: Measurement of The Rainfall Interception and Its Micrometeorological Analysis in Hinoki Stand, *Bulletin of the Forestry and Forest Products Research Institute*, Vol.318, pp.79-102, 1982.

16) Tsukamoto: *Conservation of Forest, Water and Soil*, Asakura Pubishing Co., Ltd., pp.21-28, 1998.

(Received September 30, 2009)