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THE INFLUENCE OF LAND-USE CHANGES ON WATER RESOURCES PROPERTIES IN THE HUMUYA RIVER WATERSHED, HONDURAS

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ABSTRACT

Change of the land-use due to human activities may adversely affect the watershed and the hydrologic cycle. Land use changes in a watershed can impair water supply by altering hydrological processes such as infiltration, groundwater recharge, base flow and runoff. To achieve the planning and management of water resources as a general objective of this study, a conceptual lumped hydrologic model by Horton's infiltration theory and Shuffled Complex Evolution (SCE) optimization was applied to analyse the influence of land use change on water resource properties in Humuya River watershed in Honduras. Daily data from 1978 to 1994 were used for this study. This study described the influences of temporal land-use changes on hydrology in the Humuya River by conceptual type hydrological model. The possibility of change in land use during the period of analysis was discussed because it was noticed that the differences between the observed and measured discharge became greater following the prediction in Humuya and results illustrate that there were great differences of model parameters which has been influenced by land-use pattern, between three scenarios; 1978-982, 1984-1988 and 1992-1994. It was found that land-use change would reduce maximum soil moisture and percolation rate in the upper layer by 229 mm and 5.6 mm/day in scenario of 1978-1982 and 120 mm and 0.67 mm/day in scenario of 1992-1994 respectively and would increase first layer runoff coefficient by 12% from period 1978-1982 to 1992-1994. The results supposed that the change in land use might be caused in Humuya watershed during the years. The approach is very flexible and could easily be applied to other watersheds.

KEYWORDS: Conceptual type hydrological model, Runoff, Water resource management.

INTRODUCTION

According to the Food and Agriculture Organization of the United Nations, a great challenge for the coming decades will be the task of increasing food production to ensure food security for the steadily growing world population. Since agriculture is one of the biggest users of a country's water resources, particular attention should be paid to how the water resource sector is planned and managed to meet future water demands. Most of the changes caused by the human activities may lead to adverse effects in water resources properties in watersheds. In order for better planning and management of water resources which become a very important issue everywhere in the world, hydrologic analysis in watersheds play an important role (FAO, 2002).

From the viewpoint of the hydrologic cycle, it has been considered that a well-managed watershed is very important for hazard protection and water resources management. Many floods have been reported in causing great damage in Humuya river periodically. Also, the Humuya River area is faced with a big pressure of expansion for agriculture and settlement and has been associated with numerous social-economic benefits in the area. Multiple use of watershed includes agricultural irrigation, domestic, municipal, wildlife and generating geothermal power. It is generally acknowledged that it would be risky to manage such area if there is no proper information on hydrological conditions and the impact of management activities on water resources.

Recent research in hydrologic modeling tries to have a more global approach to the understanding of the behaviour of hydrologic systems to make better predictions and to face the major challenges in water resources management. Land use change can be characterized by the complex interaction of behavioral and structural factors associated with demand, technological capacity, and social relations, which affect both demand and environmental capacity, as well as the nature of the environment in question. Land use changes in a watershed can impact water supply by altering hydrological processes such as infiltration, groundwater recharge, base flow and runoff (Yu-Pin Lin *et al.*, 2007). One of the recent thrusts in hydrologic modeling is the assessment of the effects of land use and land cover changes on water resources (Bathurst *et al.*, 2004). Therefore, application of a hydrologic model is vital to the study on influences of land-use changes on water resources properties for the planning and management of water resources in this watershed.

The only long-term hydrological data available in Honduras is for precipitation and water discharge. Thus, we used the lumped conceptual tank rainfall–runoff model (Tank model) to evaluate land-use impacts on hydrological processes, since the development of Tank models, has been widely used for discharge analysis. Thus, Tank model is widely used to predict short-and long-term runoff (Okunishi *et al.*, 1990). Therefore, the aim of this study was to investigate the influence of land-use changes on the water resource properties in Humuya river watershed, Honduras.

MATERIALS AND METHODS

Description of study area

The Humuya River watershed is located in Honduras, in Central America (Fig. 1).

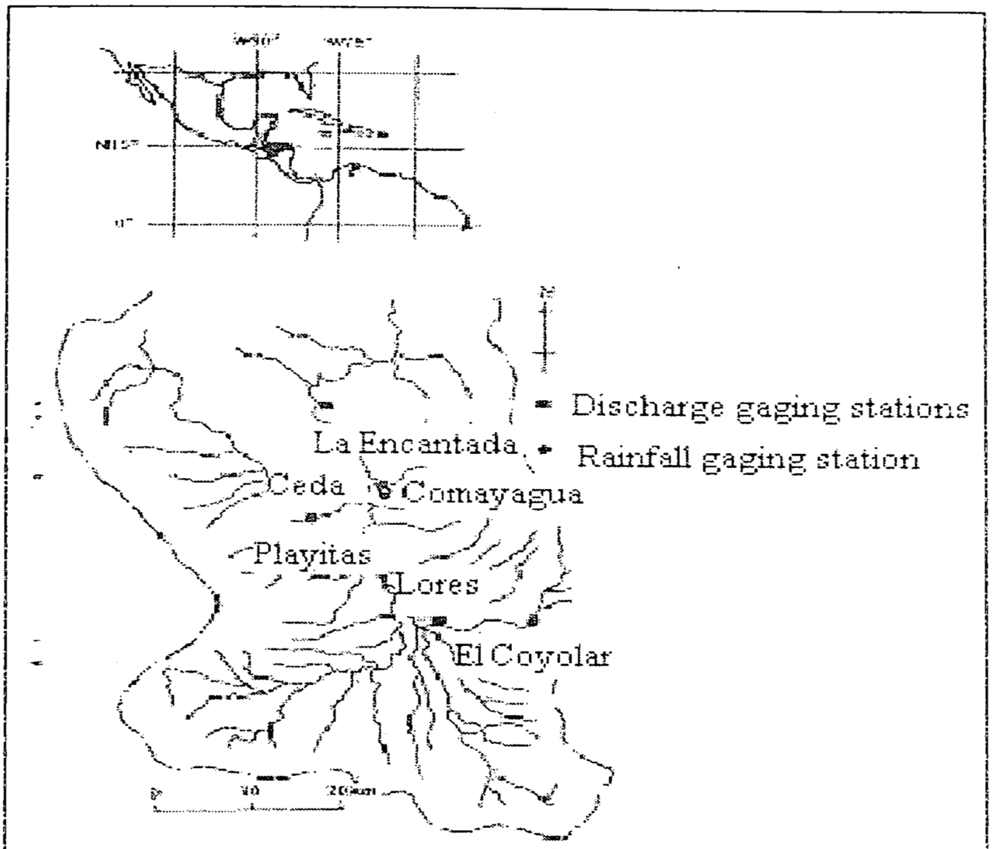

Figure 1. Humuya river watershed in Honduras.

The total watershed area is about 2,100 km^2 and it is largely mountainous with narrow coastal lowlands in the north and south. The climate is subtropical with the mean annual rainfall of less than 800 mm/yr. The rainy season usually lasts from May to October and the dry season from November to April (Martin, 2002). The mean annual temperature is about 24°C. In 1993, approximately 54 percent of the study area was covered by forests and woodland, 18 percent by crops, and 14 percent by pasture (Central Intelligence Agency, 2001).

Data collection and preparation

Three kinds of data were used in the conceptual lumped rainfall-runoff model for parameter optimization.

Rainfall data

In the Humuya river, the rainfall data was observed from four gauging stations which were located at Coyolar, Playitas, Flores and Cedar station as shown in Figure 1 and the arithmetic averaged values of them were used for the analysis.

Discharge data

In the Humuya river watershed, the discharge data were collected by using the relationship between stream depth and discharge in the river.

Potential evapotranspiration data

Data of class A-pan were collected as potential evaporation in the Humuya river watershed.

Model description

A conceptual lumped rainfall-runoff model which includes an infiltration curve has been adopted in long term analysis (Takeshita *et al.*, 2001). The analysis focuses on the dynamic of long-term discharge by considering the results of conceptual lumped hydrologic model which includes tank sub-model where the major hydrological processes were analysed and the physically based equations or simulation processes were used to analyse the important factors of hydrologic systems, as shown in Figure 2. Tank model was a simplified model which was composed of several tanks laid vertically in series. There were some side outlets and bottom outlets in each tank, the side outlets mean runoff and the bottom outlets mean infiltration and percolation. The tanks were three types of parameters which included the height of the side outlet, the coefficient of the side outlet and the percolation. It included most of the important processes such as interception by the trees, evapotraspiration, infiltration, percolation, and surface flow in the permeable and impermeable area, subsurface and base flow in different soil layers.

In this study, the tank model of six layers of tank was adopted. The surface runoff was expressed by the 1st tank and 2nd tank, the prompt subsurface layer was expressed by the 3rd tank, the delayed sub surface layer was expressed by the 4th tank and the 5th tank, and the ground flow was expressed by the 6th tank (Wang, 2007). In principle, rainfall falling on the surface of the watershed can cause four kinds of hydrologic processes namely, surface runoff, infiltration, storage and evapotranspiration. The infiltrated rainfall contributes to soil moisture, surface flow, and evapotranspiration from soil layers and ground water percolation.

In the model, in each layer (or tank), input was rainfall (R) or percolation (G_i) and outputs were evapotranspiration (Eti) and outflow as discharge (Q_i). So, continuous equations were given by equations 1 and dynamic equation was by equation 2.

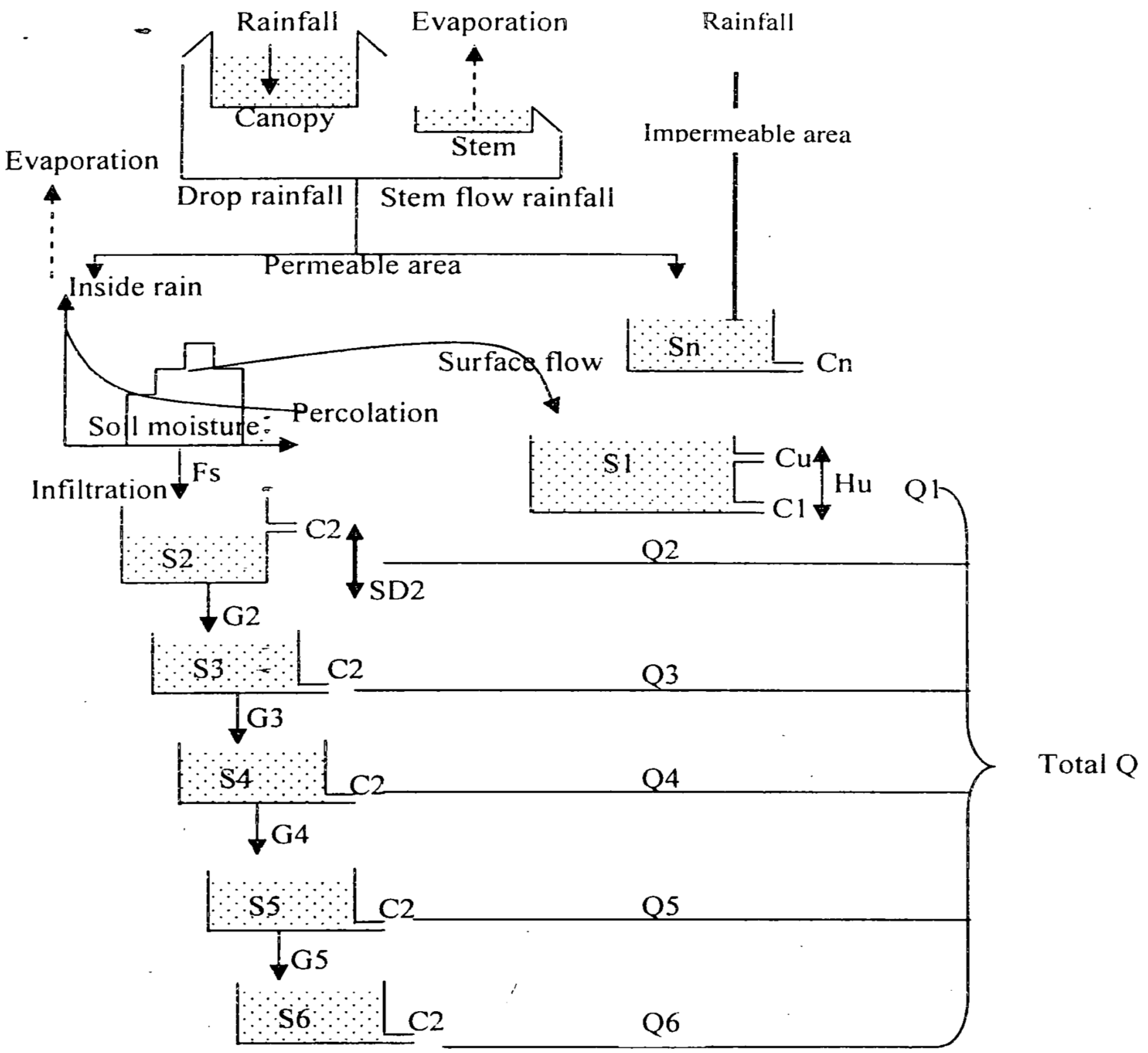

Figure 2. Illustration of the rainfall-runoff model structure.

Sn, S1 ~ S6 : storage in tank (mm), Fs : final infiltration rate (mm/hr),

G2 ~ G5 : percolation rates (mm/hr), Cn,- runoff coefficient of impermeable area, Cu, -runoff coefficient of upper hole-1st tank,

C1 ~ C6 : runoff coefficient (/hr),

Hu,SD2 : maximum storable moisture

$$\Delta S1(t)/\Delta t = R - E1 - G1 - Q1$$
$$\Delta S2(t)/\Delta t = G1 - E2 - Q2 - G2$$
$$\Delta S3(t)/\Delta t = G2 - E3 - Q3 - G3 \qquad (1)$$
$$\Delta S4(t)/\Delta t = G3 - E4 - Q4 - G4$$
$$\Delta S5(t)/\Delta t = G4 - E5 - Q5$$
$$Q_i = C_i . S_i \qquad (2)$$

Where, ΔS = The storage of the i^{th} layer of the tanks

R = Rainfall intensity
E = Evapotranspiration of i^{th} the tank
G = Percolation rate from i^{th} t the tank
Q = Discharges from the i^{th} tank; (i=1... 4)
C= runoff coefficient

Although, for the case of two side outlet in the 1st tank of discharge (Fig. 3), it can be explained as follows.

S_1 is less than Hu $\qquad Q_1 = C_1.S_1 \qquad (3)$

S_1 is higher than Hu, $\qquad Q_1 = Cu(S_1 - Hu) + C_1.S_1 \qquad (4)$

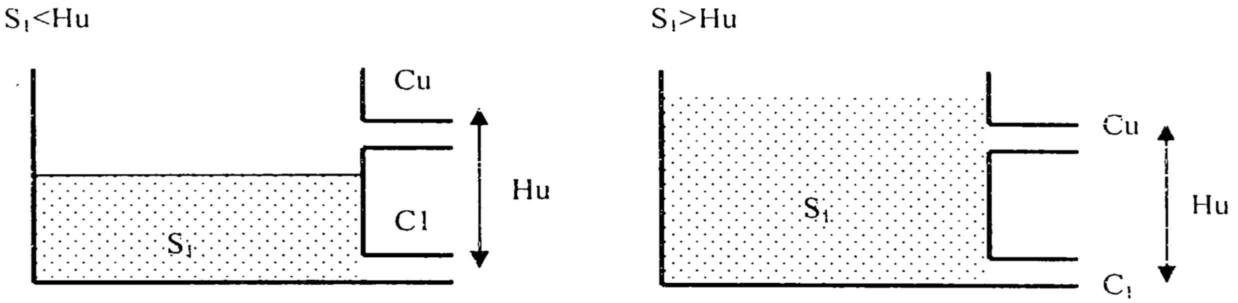

Figure 3. Structure of 1st tank in the model.

In the model, Horton's infiltration theory was used to distribute actual rainfall into excess rainfall and infiltrated water into the soil. Horton recognized that the infiltration capacity decreased with time until it approached a constant rate. The Horton's equation (Horton, 1938) is shown as follows.

$$INF(t) = F_s + (INF_{\max} - F_s)\exp^{-B.t} \qquad (5)$$

Where;

$INF(t)$ – infiltration rate at any time t
$INF_{\max}$ - maximum rate infiltration rate
F_s - the final infiltration rate
B - the infiltration decay factor

B is a proportionality factor that dependent on soil type and initial moisture content.

The infiltration curve which shows in Figure 4, represents the concept of the Horton's infiltration. This figure shows that when infiltration rate is less than gravity, drainage pF1.8 which is saturated condition of soil, (in Fig. 4, represented by F18), the percolation equals to the final infiltration rate. will occur.

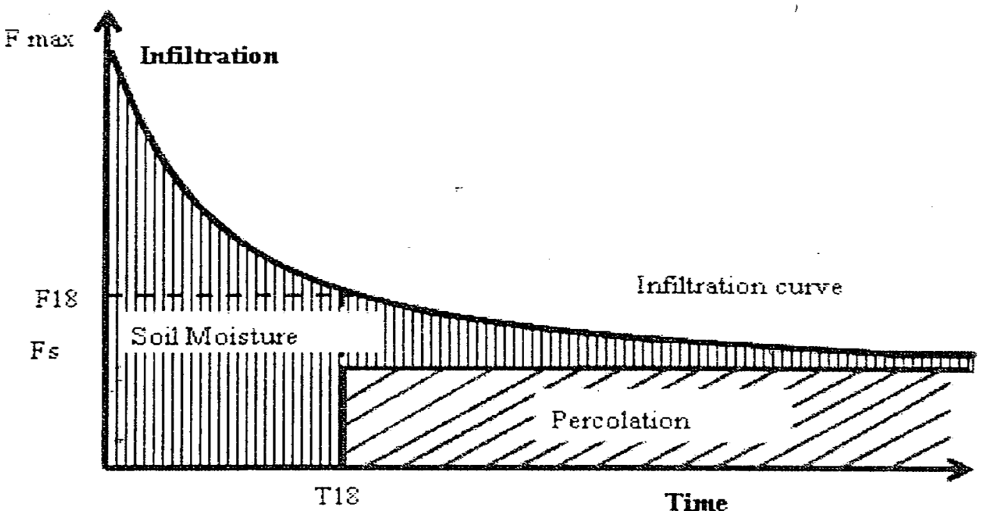

Figure 4. Concept of infiltration and percolation used in the model. F max -Maximum infiltration rate (mm/hr), F18 -Infiltration rate at pF1.8 condition (mm/hr), Fs - Final infiltration rate (mm/hr)

To predict the influences of land-use changes on water resources properties in the Humuya River Watershed, Honduras, this model was verified by fitting the predicted water discharges to several examples of the real runoff in three scenarios; 1978–1982, 1984- 1988 and 1992-1994. In this study, we used the discharge, rainfall and potential evaporation data as input during three scenarios in Humuya river watersheds to identify the model parameters using model optimization. In the process of parameter determination, some of parameters such as soil test, canopy and stem retention factors and experiences were fixed according to the experiment. Other parameters were optimized by the SCE (Shuffled Complex Evolution) method using the following error function (Eq. 6) as the fitting criteria (Duan *et al.*, 1992; Gan and Biftu, 1996).

$$Error\% = \frac{\sum |QC_i - QM_i|}{QM_i} X100 \qquad (6)$$

Where, QCi: calculated discharge,
QMi: observed discharge.

The objective of parameter optimization was to analyse the physical parameters of the water resources. Some model parameters which were fully or partially affected by the land use pattern were considered fixed and others were optimized in different periods.

RESULTS AND DISCUSSION

The impact of land use on hydrological function

The difference between annual total rainfall and discharge of area varied with land-use change (Fig. 5). The decrease in forested area was mostly caused by agricultural land use and animal husbandry in this watershed. The annual maximum discharge/rainfall ratio representing the conveyance efficiency increased from 1985 to 1995 (Fig. 6). This figure indicates that land-use pattern has been affected.

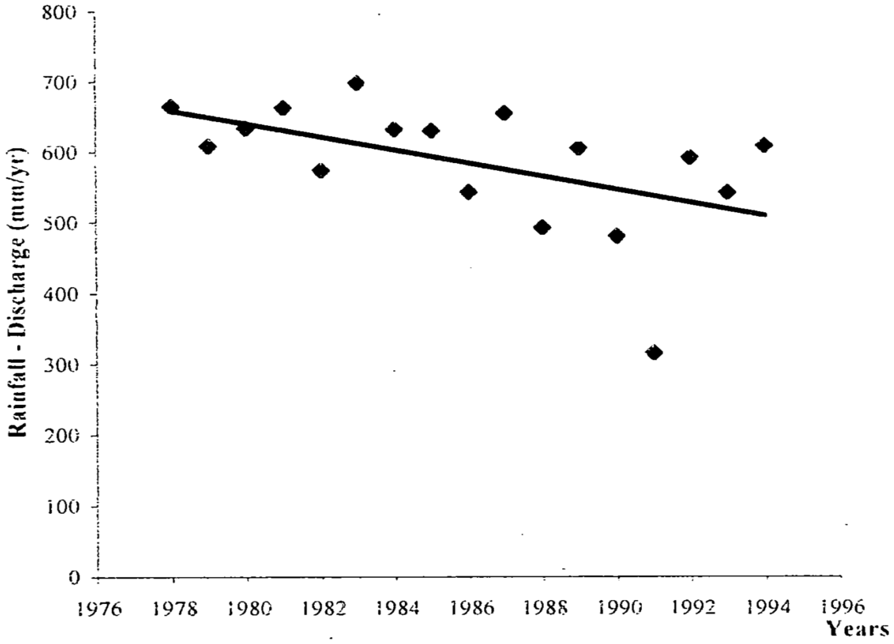

Figure 5. Changing of deference between rainfall and discharge from 1978 to 1994.

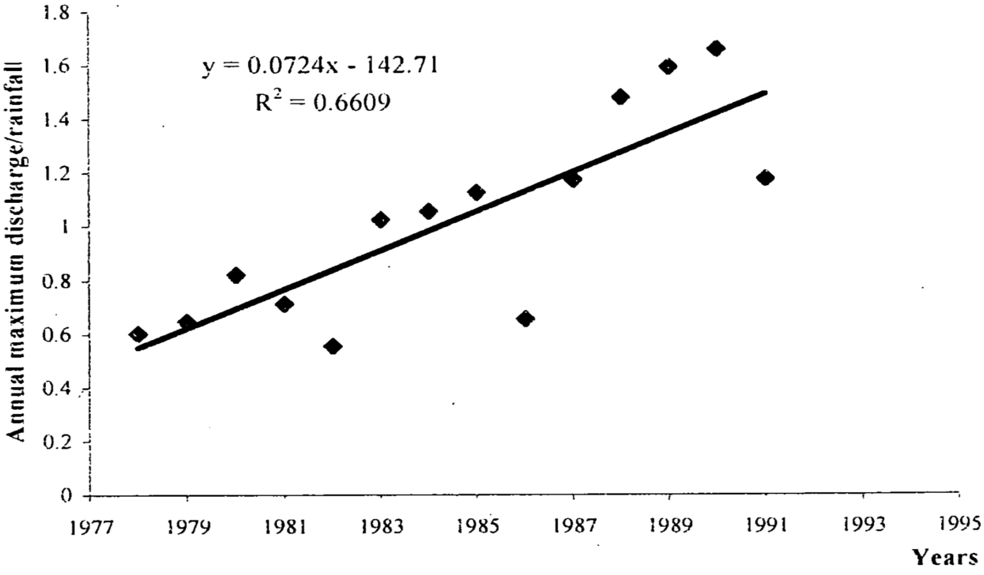

Figure 6. Changing of ratio between annual maximum discharge and rainfall from 1978 to 1994.

Model application in runoff prediction in deferent periods

The overall structure of the model did not differ for all periods. Generally, land use change affects top layers of soil than lower layers of soil. Therefore, in this study, lower layers' soil parameters have been considered as constant. The optimized hydrographs by the model almost matched the observed ones in the three scenarios (Fig. 7).

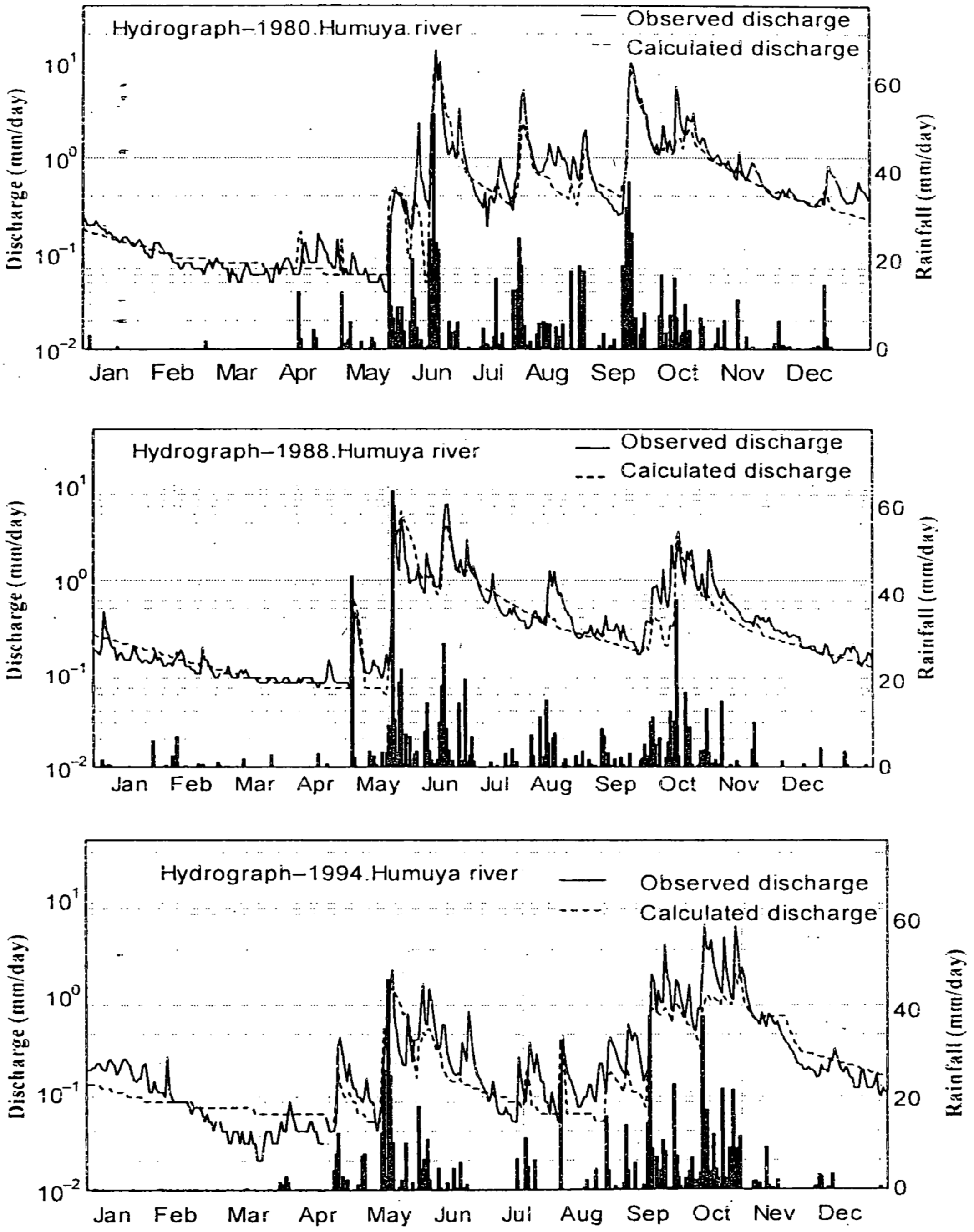

Figure 7. Model application of runoff prediction in deferent periods in Humuya river watershed.

The influences of land-use changes on water resources properties

The probability of change in the land use pattern during the period under study was discussed due to the differences between the observed and measured discharge of water which became greater following the prediction in Humuya. Results illustrated that there were great differences of model parameters such as maximum soil moisture, final infiltration rate, soil moisture at the pF value 1.8 conditions and runoff coefficients which was influenced by land-use pattern, among the three scenarios; 1978–1982, 1984-1988 and 1992-1994. After 1983, in the Humuya river upper watershed, Central Intelligence Agency (2001) has noted that the vegetation is largely agricultural fields, pastures and secondary growth. Most of the forest had been cleared for agriculture and cattle. People depended on these lands for growing maize, beans and rice and raising cattle meaning that there is considerable land use change in Humuya river watershed from 1984 to 1994.

In the period of 1978-1982, when the rainfall intensity was less that 18 mm (HU), water did not spill out of the top storage (meaning no surface runoff) but it decreased from 1984 to 1994 which indicates that water holding capacity in the top layer of soil has decreased.

Table 1 shows that land-use change would reduce maximum soil moisture (SMMAX), final infiltration rate (FS) which illustrated that amount of surface runoff had become higher and percolation rate in upper layer (GG2) would increase first layer runoff coefficient (C1) by 12% in the period 1978-1982 to 1992-1994. Also, soil moisture at the pF value 1.8 conditions had decreased and watershed had become more dry and dry. In contrast, the flood events in the past (1978-1982) represented a slow runoff and a long duration, because the watershed retained a high storage capacity (Table 1), whilst the other two periods consists of shallow storages having very low percolation coefficients, meaning that it generates a rapid runoff even if the rainfall intensity is relatively small.

The results supposed that the change in land use might be caused in Humuya watershed during the years.

Table 1. Related parameters on surface runoff in the different periods.

Periods	*Storage*	*Runoff*	*Infiltration*	*Percolation*
-	*SMMAX (mm)*	*C1 (1/day)*	*FS (mm/day)*	*GG2(mm/day)*
1978-1982	228.5	0.1	9.97	5.68
1984-1988	205.5	0.101	1.61	1.2
1992-1994	120.5	0.113	1.08	0.68

CONCLUSIONS

As a result of its application to this watershed, this model can be used to address the hydrological impacts of land-use changes and results illustrate that there were great differences of model parameters which has influenced land-use pattern, between the three scenarios; 1978–1982, 1984-1988 and 1992-1994. The results indicated that the change in land use might be caused in Humuya watershed during the years. The calculated runoff conducted using the rainfall-runoff model also revealed that extensive land use had significantly altered the rainfall-runoff system with a decrease in percolation and an increase in surface runoff. These results are all accurate reflection of the present Humuya river watershed condition, which increase the conveyance efficiency. However, the results by the rainfall-runoff model demonstrated that the possibility of flooding may increase because the peak discharge itself is dependent on land use changes. The approach is very flexible and could easily be applied to other watersheds.

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REFERENCES

Bathurst, J.C., J. Ewen, G. Parkin, P.E. O'Connell and J.D. Cooper. 2004. Validation of catchment models for predicting land-use and climate change impacts. Blind validation for internal and outlet responses, Journal of Hydrology 287:74–94.

Central Intelligence Agency, 2001, The World Fact book 2001, http://www.cia.gov/cia/publications/factbook/geos/ho.html (accessed October 1, 2001).

Duan, Q., S. Sorooshian and V. Gupta. 1992. Effective and efficient global optimization for conceptual rainfall–runoff models. Water Resource Research 28 (4):1015–1031.

FAO, 2002. World Agriculture: Towards 2015/2030, an FAO Study. Rome. 21-54 p,

Gan, T.Y. and G.F. Biftu. 1996. Automatic calibration of conceptual rainfall–runoff models: optimization algorithms, catchment conditions, and model structure. Water Resource Research 32 (12):3513–3524.

Horton, R.I. 1938. The interpretation and application of runoff plot experiments with reference to soil erosion problem. Soil Science Society of America 3:340-349.

Mark C. Mastin. 2002. Flood-Hazard Mapping in Honduras in Response to Hurricane Mitch. U.S. Geological Survey Water-Resources Investigations Report 01-42-77p . Tacoma, Washington.

Okunishi, K., D.E. Walling and T. Saito, 1990. Discharge of suspended sediment and solutes from a hilly drainage basin in Devon, UK, as analyzed by a Cascade Tank Model. Disaster Prevention Research Institute. Kyoto University, Japan. Bulletin No. 40(4):143–160.

Takeshita, S., K. Takase and K. Ihara. 2001. Development of Long term runoff Model including Infiltration sub-model. Translation of Japan Society of Irrigation and Drainage Research Engineering, 212:71-7(in Japanese with English summary).

Wang Yi., K. Takase. 2007. Storm runoff analysis using the modified model considering the improved infiltration capacity curve. Japan Society of Hydrology and Water resource 20:116-124.

Yu-Pin Lin, Nien-Ming Hong, Pei-Jung Wu, Chen-Fa Wu and Peter H. Verburg. 2007. Impacts of land use change scenarios on hydrology and land use patterns in the Wu-Tu watershed in Northern Taiwan. Landscape and Urban Planning 80:111-126.