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# DETERMINATION OF DIRECT RUNOFF FROM RAINSTORM ON NATURAL HILL-EVERGREEN FOREST IN NORTHERN THAILAND

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## บทคัดย่อ

การวิเคราะห์ทางสถิติโดยใช้ stepwise regression ในการคาดหมายสมการการอุทกวิทยาของลุ่มน้ำขนาดเล็ก ๓ ลุ่มน้ำห้วยคอกม้า ดอยปุย จังหวัดเชียงใหม่ โดยใช้ข้อมูลตั้งแต่ พ.ศ. ๒๕๑๕-๒๕๒๒ ข้อมูลตัวแปรอิสระ ได้แก่ ปริมาณน้ำฝน (EP) ระยะเวลาที่ฝนตก (ED) ความหนักเบาของฝนสูงสุด และเฉลี่ย (EImax EIavg) ระดับปริมาณน้ำที่ไหลอยู่ก่อนฝนตก (QB) และความหนักเบาของฝนที่ตกครั้งก่อนสะสม (CAI) ภายใน ๓ ๖ ๙ ๑๒ ๑๕ ๑๘ ๒๑ ๒๔ ๓๖ ๔๘ ๖๐ ๗๒ ๘๔ ๙๖ ๑๐๘ และ ๑๒๐ ชั่วโมง สำหรับตัวแปรตามอันได้แก่ ปริมาณน้ำทั้งหมดของ storm hydrograph (QT) ปริมาณน้ำ direct flow (QR) ความสูงจุดยอดของ hydrograph (HP) ระยะเวลาที่ hydrograph เริ่มขึ้นถึงจุดสุดยอด (TP) ระยะเวลาที่ปริมาณน้ำไหลจากจุดสูงสุดต่ำสุดของกราฟ (TR) และระยะเวลาที่แตกต่างระหว่างฝนเริ่มตกจนถึงปริมาณน้ำเริ่มเพิ่มขึ้นในลำธาร (TL) ผลการวิเคราะห์แสดงไว้ดังสมการข้างล่างนี้

| | F-Value | $R^2$ | n |
|---|---|---|---|
| $QT = -20.5205 + 1.0936\,QB + 3.7121\,EP$ | 94,299** | 0.9991 | 175 |
| $QR = -20.5632 - 3.7158\,EP - 0.0936\,QB$ | 2,862** | 0.9710 | 175 |
| $HP = 0.4593 + 0.3486\,EP - 8.137\,ED$ | 439** | 0.8362 | 175 |
| $TP = 18.3818 + 0.2993\,ED - 0.4736\,EP + 4.2022\,CAI9$ | 1,267** | 0.9570 | 175 |
| $TR = 444.7192 - 29.5963\,EP + 0.6237\,QB - 84.1228\,CAI6$ | 534** | 0.9036 | 175 |
| $TL = 22.8702 - 0.0565\,EImax + 0.0913\,ED - 0.3620\,EP$ | 561** | 0.9079 | 175 |

มีตัวแปรอิสระเพียง 6 ตัวแปรเท่านั้นที่เหมาะสมนำมาใช้ในสมการคาดหมายทางอุทกวิทยานี้ โดยค่า QT และ QR นั้น มีความสัมพันธ์โดยตรงกับ QB และ EP ค่า HP มีความสัมพันธ์โดยตรงกับ EP แต่ผกผันกับ ED ค่า TP มีความสัมพันธ์โดยตรงกับ ED และ CAI9 แต่ผกผันกับ EP ค่า TR มีความสัมพันธ์โดยตรงกับ EP และ QB แต่ผกผันกับ CAI6 ค่า TL แปรผกผันกับ EImax และ EP แต่แปรผันตรงกับ ED

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## ABSTRACT

Stepwise regression analysis of the Microstat Software Program was applied to develop selected hydrologic prediction equations of 175 observations from small watershed at Kog-Ma watershed, Doi Pui, Chiangmai, Northern Thailand from 1966-1985. Data for both the independent and dependent variables were taken from weighing-type recording raingage and drum-type recording staffgage. Total flow, QT; direct flow, QR; peak of direct flow, HP; time to peak, TP; recession time, TR; and lagtime, TL, of a storm hydrograph were the dependent variables while the independent variables were: rainfall amount, EP; rainfall duration, ED; maximum and average rainfall intensity (EImax and EIavg); initial baseflow of storm hydrograph, QB; cumulative antecedent rainfall intensity, CAI, within 3, 6, 9, 12, 15, 18, 21, 24, 36, 48, 60, 72, 84, 96, 108 and 120 hours. Six independent variables fitted the suitable prediction equations. The prediction equations are as follows:

| | F-Value | $R^2$ | n |
|---|---|---|---|
| $QT = -20.5205 + 1.0936\,QB - 3.7121\,EP$ | 94,799** | 0.9991 | 175 |
| $QR = -20.5632 + 3.7158\,EP - 0.0936\,QB$ | 2,882** | 0.9710 | 175 |
| $HP = 0.4593 + 0.3486\,EP - 0.137\,ED$ | 439** | 0.8362 | 175 |
| $TP = 18.3818 + 0.2992\,ED - 0.4716\,EP + 4.2022\,CAI9$ | 1,257** | 0.9570 | 175 |
| $TR = 444.7192 + 39.5963\,EP - 0.6237\,QB - 84.1228\,CAI6$ | 534** | 0.9036 | 175 |
| $TL = 22.8702 - 0.0565\,EImax + 0.0913\,ED - 0.3620\,EP$ | 561** | 0.9079 | 175 |

Total flow (QT) and direct flow (QR) were directly correlated with baseflow (QB) as well as rainfall amount (EP). Peak of direct flow (HP) was also directly correlated with rainfall amount (EP) but inversely correlated with rainfall duration (ED). Time to peak (TP) was directly correlated with rainfall duration and 9 hour cumulative antecedent rainfall intensity (CAI9) but inversely correlated with rainfall amount.

Recession time (TR) was directly correlated with amount of rainfall (EP) and baseflow (QB) but was inversely correlated with 6-hr cumulative rainfall intensity. Lagtime (TL) was inversely correlated with maximum rainfall intensity (EImax) and amount of rainfall and directly correlated with rainfall duration.

## INTRODUCTION

Located in the tropics, Thailand has a high rainfall and humidity, a warm climate, with a total land area of 513,115 sq. km. With these climatic characteristics, the whole country is covered with tropical rain forests. In the past, forest areas practically covered from the lowlands up to the highlands. But due to high population growth coupled with the nation's predominantly agricultural needs, uncontrolled deforestation and rapid expansion of destructive practices into the watershed areas caused a critical depletion of the forest area especially in the mountains north of Thailand, an area formerly covered with dense natural hill-evergreen forest (Chunkao, et al., 1983). Northern Thailand is mountainous. In these mountains lie the headwater of the nation's main water supply for the north itself and the central rice plain, the Chao Praya River, the most important river of the country, which passes through Bangkok.

At present, forest areas in the lowlands are converted to agriculture and other purposes while the highland forests are deforested by the hill-tribes both for planting their agricultural crops and settlement area (Sheng, 1980). The rate of forest destruction in the Northern Region from 1976 to 1978, 1978 to 1982, and 1982 to 1985 were 2.17; 1.06; and 0.71 percent, respectively (Klankamsorn and Jurupatra, 1981; Royal Forest Department, 1985). The Royal Forest Department (1985) reported that the forest area in northern Thailand declined from 87,756 sq.km. in 1982 to 84,126 sq.km. in 1985.

As a consequence, deforestation has caused the problems of water degradation in terms of quantity, quality and regime. Likewise, this also led to soil erosion, water shortage, and drought during the summer season and flooding in the rainy season. Theoretically speaking, it could be said that the water in the hydrologic cycle was neither lost nor conserved but land or water misuse with no proper conservation strategies surely aggravate the problems mentioned above. The objectives of this study are (1) To analyze rainfall characteristics and direct runoff relationships of a small watershed in Northern Thailand; (2) To develop prediction equations for the amount of total flow and direct runoff, peakflow, time to peak, recession time, and lag time of a storm hydrograph; and (3) To generate baseline data on selected hydrological events from the watershed.

## METHODOLOGY

### Study Area

The area selected for the study is located at Doi Pui, Chiangmai Province, Northern Thailand at latitude 18 45' N and longitude 98 54' E; about 20 km. from the city of Chiangmai. The experimental area has an elevation of 1,320-1,405 m.MSL with the mean at 1,320 m.MSL. The mean slope was estimated at 39.8%. The area is about 0.0879 sq.km. or 8.79 ha. with a perennial stream as the origin of the headwater of the Chao Praya River. Soil of the small watersheds in the study area belong to the family Tropohumults of the Great Soil Group Ultisols having a depth of more than 150 cm. All soil horizons are sandy clay loam with a pH-value ranging from 5.3 to 5.7. Bulk density of the topsoil (0-45 cm.) was less than 1.0 gm/cc. The percentage of organic matter abruptly decreased with increased soil depth.

Chunkao and Naksiri (1976) found that the initial infiltration of dry, moist, and wet soils are 1,112; 821; and 519 mm/hr. timed at about 4; 2; and 1 hour, respectively, with a constant infiltration rate of about 280 mm/hr. The average minimum soil moisture occurs in February and March and the maximum takes place in September. This could be due to the small amount of rainfall during the dry season and heavy rainfall during the rainy season. The characteristics of the soil moisture constant showed that water can be absorbed from the topsoil as gravitational water and then released to the streamflow and subsequently becomes as lateral flow (Chunkao and Makarabhirom, 1979).

The Kog-Ma Watershed is covered by natural hill evergreen forest. The whole watershed is located in the Mae-Sa and Doi Pui National Park behind the Bhubing Royal Palace. The forest is composed of 43 tree species with 18 undergrowth species and 21 phreatophytic species. The average percentage of crown cover is about 90% which varied with altitude. The main species consist of trees of the Family Fagaceae, such as *Castanopsis, Lithocarpus,* and *Quercus* species. Stand density increased with increasing altitude but not in basal area due to smaller trees in higher elevations. Stand density for tree, seedling and undergrowth were estimated to be about 15,491; 179,400; and 964,000 stems/ha, respectively, with average basal area of 222.1 sq.m/ha. The undergrowths comprise of ferns along the bottom land, Yasamkom *(Fuirena umbellata)* on the hill slope and Yafack *(Vativeria zizanoides)* associated with Yaka *(Imperata cylindrica)* on the ridge top (Chunkao et al., 1981).

Streamflow characteristics investigated by 120-V-notch weir with recording staffgage indicated that about 1,378 mm/yr. or 1,378,000 cu.m/sq.km. of annual streamflow feeds the streams throughout the year. Of this amount, about 71% (or about 978,000 cu.m/sq.km.) occurred during the wet season and about 29% (or about 400,000 cu.m/sq.km.) happened in summer. Runoff potential, which is the percentage of runoff to rainfall, was about 65%. During the study period, there was no surface runoff in the watershed. The acute shape of crest segment with the steep slope of the rising limb, therefore, indicated rapid lateral flow. Loose texture with high amount of gravel in soil profiles together with high gradient of overland slope and bed rock were responsible for these characteristics (Chunkao et al., 1981). And the recession coefficient of direct and baseflow (Kr) are 0.40 and 0.98, respectively.

## Materials

The following materials were used to conduct the study :

1. Map of the study area;
2. Rainfall recording chart;

3. Streamflow recording chart;

4. Diskettes of programs on Microstat and Lotus 1-2-3;

5. Microcomputer IBM-XT or AT; and

6. Other school supplies.

### Methods

The rainfall and runoff data were obtained from the Department of Conservation, Faculty of Forestry, Kasetsart University, Thailand.

The experimental watershed used for the validation of data is located in the Kog-Ma Watershed Research Station subwatershed D.

A detailed description of the sources of data are as follows :

**Map.** A topographic map of the study area was obtained to determine the boundary of watershed D. It was printed by the Royal Thai Army (RTA) with the scale of 1:50,000 and enlarged up to the scale 1:2,500.

**Rainfall data.** Rainfall data were gathered using a weighing type recording raingage located in the average zone of the watershed. Data on selected individual rainstorms were gathered from the Kog-Ma Watershed Research Station (subwatershed D). The effective rainfall for a period of 20 years (1966-1985) from the recording chart were used as secondary data.

The rainfall data measurement recorded were (Figure 1) as follows :

1. Date/month/year of each selected storm;

2. Initial time of rainstorm;

3. Time and cumulative amount of rainstorm of any break point :

4. Rainfall increament between any break points;

5. Rainfall intensity for each break point and cumulative average rainfall intensity;

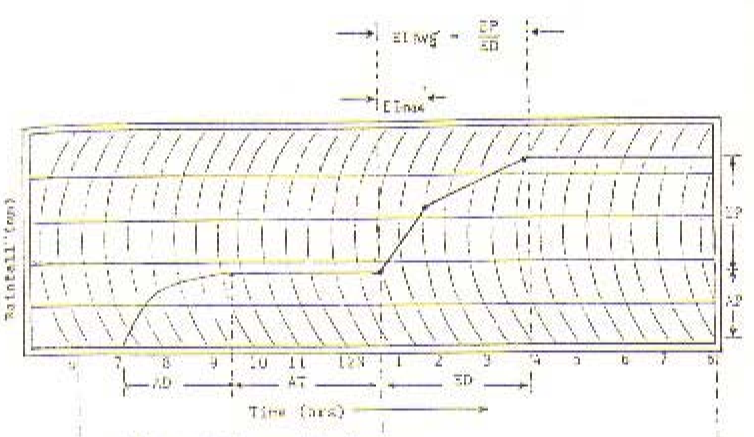
6. Effective rainfall duration (ED; min) is the sum of the initial to the final time that the rain stopped;

7. Effective amount of rainstorm (EP; mm) is the sum of amount of rainfall from the time it starts until it stops; and

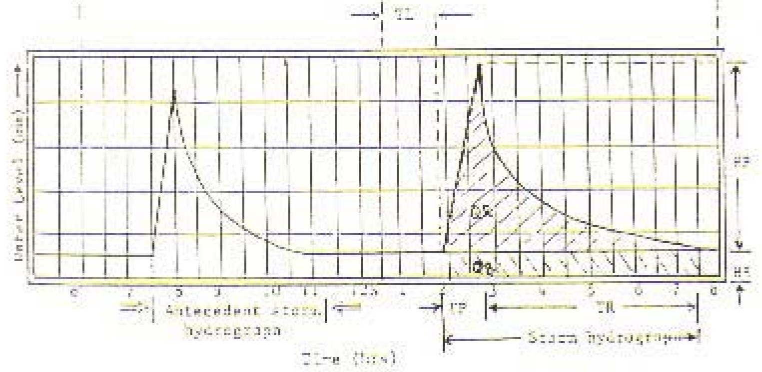
8. Maximum effective rainfall intensity of all break points (EImax;mm/hr.) and the final cumulative effective rainfall intensity of the whole storm (EIavg; mm/hr.) as variables for developing the prediction equation.

9. Antecedent rainfall was modified in the form of the cumulative antecedent rainfall intensity, CAI (mm/hr.) for 3, 6, 9, 12, 15, 18, 21, 24, 36, 48, 60, 72, 84, 96, 108 and 120 hours from the selected effective rainstorms previously mentioned.

The 175 observations of individual rainstorms of small amount up to available effective rainstorms were gathered for the period 1966-1985 to develop the multiple regression equation using Lotus 1-2-3 software.



(a) Rainfall recording chart



(b) Water level recording chart

**Figure 1** Relationship of effective rainstorm variables that affect storm hydrograph variables corresponding to the same observations.

**Streamflow data.** Streamflow data measured from 120-V-notch weir were graphed as shown in Figure 1 with the automatic drumtype Steven water level recorder. Data on individual effective hydrograph corresponding to the same observations of effective rainstorms mentioned above were also gathered from the Kog-Ma Watershed. The water level recording chart of 120°-V-north weir was also obtained as a secondary data for a 20 years period from 1966 to 1985.

Streamflow data measurements were conducted as follows :

1. The date/month/year of each selected hydrograph were read and recorded;

2. Both the initial time and water level of the hydrograph before it rises up were read and recorded;

3. Both the time and water level of the recording chart for each break point for both rising and falling limbs including the peak of hydrograph until the water level declined to the same initial water level reading were read and recorded;

4. The average height of water level between break points were computed;

5. The discharge between break points multiplied by each duration was computed;

6. The summation of discharge from the initial to the end of the storm hydrograph called the total flow, QT (cu.m.) was obtained;

7. The baseflow QB (cu.m.) using the initial reading of water level in the equation multiplied by the total time of the storm hydrograph (TP + TR), were computed.

8. The difference between total flow (QT) and baseflow (QB) is called direct flow, QR (cu.m.) was likewise determined.

9. The height between the initial water level up to the peak called peak of direct flow, HP (cm.), was also determined.

10. The time from initial to the peak of storm hydrograph is called time to peak, TP (min.).

11. The time from the peak to the end of storm hydrograph is called recession time, TR (min.);

12. Lagtime, TL (min.), is the duration of the time between the initial reading time of rainstorm and the initial reading time of storm hydrograph.

Among the streamflow variables, only baseflow (QB) was classified as the independent variable.

The 175 observations of individual storm hydrograph during the same period (1966-1985) corresponding to the same observation of rainstorms previously mentioned were noted.

**Statistical Analysis**

Stepwise Multiple Linear Regression technique was used to develop acceptable statistical relationships between and among each dependent variable : QT, QR, HP, TP, TR, and TL as a function of the independent variables : EP, ED, EImax, EIavg, QB, CAI3, CAI6, CAI9, CAI12, CAI15, CAI18, CAI21, CAI24, CAI36, CAI48, CAI60, CAI72, CAI84, CAI96, CAI108, and CAI120 in all selected rainstorms.

Each multiple linear regression equation was carried out using a Microstat Software Program and an IBM computer. Throughout the entire study period, the multiple linear regression equation of 179 observations with 20 independent variables were analyzed using the stepwise regression model to find out the order by which independent variables highly correlate with dependent variables. The selected final equation is the most suitable that could explain the highland streamflow characteristics from the headwater of northern Thailand that release water to the lower areas of the country.

## RESULTS AND DISSCUSSION

In this study, stepwise regression of Microstat Software program was applied to develop prediction equations for selected hydrologic variables from 175 observations of a small headwatershed at Kog-Ma Watershed, Doi Pui, Chiangmai, Northern Thailand during the period 1966 to 1985. The Kog-Ma Watershed is under the supervision of the Department of Conservation, Faculty of Forestry, Kasetsart University.

The sources of data for both independent and dependent variables were drawn from the weighing type recording raingage charts and drum type recording staffgage charts. The 21 independent variables are : rainfall amount (EP), rainfall duration (ED), maximum and average rainfall intensity (EImax and EIavg), baseflow, QB, CAI ... 3, 6, 9, 12, 21, 24, 36, 48, 60, 72, 84, 96, 108, and 120-hour cummulative antecedent rainfall intensities. The dependent variables are : total flow (QT); direct flow (QR); peak of direct flow (HP); time to peak (TP); recession time (TR); and lagtime (TL) of the individual storm.

The prediction equations developed from full models shown in Table 1 were as follows :

| | F-Value | $R^2$ | n |
|---|---|---|---|
| $QT = -20.5205 + 1.0936\ QB + 3.3121\ EP$ | 94,799** | 0.9991 | 175 |
| $QR = -20.5632 + 3.3158\ EP + 0.0936\ QB$ | 2,852** | 0.9710 | 175 |
| $HP = 0.4592 + 0.3486\ EP - 0.0137\ ED$ | 439** | 0.8362 | 175 |
| $TP = 18.3818 + 0.2992\ ED - 0.4716\ EP + 4.2022\ CAI9$ | 1,267** | 0.9570 | 175 |
| $TR = 444.7192 + 39.5962\ EP + 0.6237\ QB - 84.1228\ CAI6$ | 534** | 0.9036 | 175 |
| $TL = 22.8702 - 0.0565\ EImax - 0.0913\ ED - 0.3620\ EP$ | 561** | 0.9079 | 175 |

**Table 1 Full model of stepwise regression equation of subwatershed D, Doi Pui, Chiangmai, Northern Thailand.**

| DEPENDENT VARIABLES | STEP NO. | Intercepted Constant Value | RIGHT HAND SIDE OF THE EQUATION Independent Variables 1st | 2nd | 3rd | STATISTICAL PARAMETERS Std. Err. of Estimate | F-Value | $R^2$ | Mul-R |
|---|---|---|---|---|---|---|---|---|---|
| | | | QB | EP | | | | | |
| QT | 1 | 20.2242 | 1.1389 | | | 35.8723 | 10,266** | 0.9834 | 0.9917 |
| | 2 | −20.5205 | 1.0936 | 3.7121 | | 8.4136 | 94,799** | 0.9991 | 0.9995 |
| | | | EP | QB | | | | | |
| QR | 1 | 6.5272 | 4.4083 | | | 23.2249 | 604** | 0.7776 | 0.8818 |
| | 2 | −20.5632 | 2.7158 | 0.0936 | | 8.4064 | 2,882** | 0.9710 | 0.9854 |
| | | | EP | ED | | | | | |
| HP | 1 | 0.3878 | 0.3295 | | | 1.5285 | 780** | 0.8185 | 0.9047 |
| | 2 | 0.4593 | 0.3486 | −0.0137 | | 1.4561 | 439** | 0.8362 | 0.9145 |
| | | | ED | EP | CAI9 | | | | |
| TP | 1 | 14.6777 | 0.2548 | | | 5.2304 | 572** | 0.7681 | 0.8764 |
| | 2 | 19.6181 | 0.3011 | −0.4803 | | 2.8312 | 1,187** | 0.9324 | 0.9656 |
| | 3 | 18.3818 | 0.2995 | −0.4716 | 4.2022 | 2.2662 | 1,267** | 0.9570 | 0.8792 |
| | | | EP | QB | CAI6 | | | | |
| ER | 1 | 517.5115 | 44.0112 | | | 220.3351 | 669** | 0.7947 | 0.8915 |
| | 2 | 423.0496 | 39.3515 | 0.6298 | | 165.7035 | 659** | 0.8846 | 0.9405 |
| | 3 | 444.7192 | 39.5963 | 0.6237 | −84.1228 | 151.8850 | 534** | 0.9036 | 0.9506 |
| | | | EImax | ED | EP | | | | |
| TL | 1 | 24.9014 | −0.1268 | | | 3.4598 | 308** | 0.6407 | 0.8004 |
| | 2 | 22.6850 | −0.1190 | 0.0464 | | 3.0158 | 230** | 0.7286 | 0.8536 |
| | 3 | 22.8702 | −0.0565 | 0.0913 | −0.3620 | 1.7618 | 561** | 0.9079 | 0.9528 |

All the prediction equations are highly significant.

**Total flow.** Based on Figure 1, the total flow consists of baseflow and direct flow. Direct flow is directly affected by the effective rainstorm only but baseflow is the main source of total flow througtout the year and the most important flow during the dry season of the perennial stream of Kog-Ma watershed. So, baseflow should be the first priority of the independent variables that has the highest correlation with the total flow of the stream as long as there is no surface runoff occurring in this watershed during the whole year. This situation can be explained by the high infiltration rate in the watershed.

**Direct flow.** The direct flow of the hydrograph is directly related with the amount of rainstorm and supported by baseflow. From Figure 1, without effective rainstorm, there is no direct flow. Thus, rainfall amount is a priority variable to affect direct flow while continued baseflow was derived from soil moisture released slowly during the day. The soil moisture in the whole watershed is the biggest source of water for the perennial stream especially during the dry season (Chunkao, 1982).

**Peak of direct flow (HP).** The peak of direct flow is directed affected by the amount of rainfall. From the prediction equation for peak of direct flow, the amount of rainstorm is the first priority variable directly correlated with the peak of direct flow followed by the reversed rainfall duration. Chunkao et al. (1981) reported that the amount of rainfall directly affected direct flow and baseflow. Baseflow supported the flow in the stream. This baseflow comes from soil moisture which is slowly released to the stream.

**Time to peak (TP).** Time to peak of the hydrograph is directly affected by duration, inversely by rainfall amount but directly affected by 9-hour cumulative antecedent rainfall intensity. This finding supports the result of the study by Chantanasmith (1982) and Boonyawat and Chunkao (1975) when they reported that the amount of rainfall increases directly with rainfall intensity but inversely by rainfall duration. This is why the time to peak increases with the duration of rainfall but decreases with the amount of rainfall.

**Recession time (TR).** Recession time is directly related to the amount of rainfall and baseflow but it is inversely related with 6-hour cumulative antecedent rainfall intensity.

**Lagtime (TL).** Lagtime is the reflection of the effects of physical characteristics of the watershed such as topography, soil and vegetation cover on rainfall. Furthermore, lagtime has a strong inverse relationship with rainfall intensity. From the results of this study, lagtime is inversely correlated with maximum effective rainfall intensity (EImax) and the amount of rainfall, but directly correlated with rainfall duration. The order of priority of these independent variables are maximum effective rainfall intensity (EImax), as first, duration of effective rainfall (ED) as second and, and amount of effective rainfall (EP) as third. Maximum effective rainfall intensity has an inverse relationship with the lagtime. Inversely, it is highly correlated with rainfall duration considering the general characteristics of the rain in tropical regions.

## RECOMMENDATIONS

Based on the results of this study, the following recommendations are made :

1. The model needs to be tested on watersheds with different land use types and in different parts of the tropical region to determine its applicability in these situations. Caution shall be exercised in using the models outside the study area;

2. Rainfall distribution analysis within the watershed is necessary to determine the optimum size of watershed that would provide reliable data for better model development;

3. An extension of the study using the depth-area-duration analysis of rainstorm from several raingage stations within the watersheds would be useful to gather more reliable data and develop a more suitable prediction model. Streamflow routing would be useful in the model to determine the effect of travel time or time of concentration; and

4. For future studies, other physical watershed characteristics such as slope and length of the stream, initial soil moisture, land use type and other factors could be useful :

However, the study has the following limitations :

1. The results of the study may be applied only on a small headwatershed with streamflow fed by high intensity rainfall;

2. The models are designed for perennial streams. As such, they may not be applicable to intermittent streams; and

3. There must be a high correlation between rainfall and streamflow to achieve best fit for the models.

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