E-3.2 Runoff characteristics of Tropical Rainforests

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Abstract Some hydrological observations were conducted at Bukit Tarek Experimental Watershed in tropical rainforest. Soil physical properties, soil depth and water flow patterns in soil were investigated. The detail obtained information are useful in order to analyze water flow and slope stability in tropical rainforest. In addition, rainfall characteristics, runoff characteristics, role of soil moisture variations in rainfall-runoff responses and evapotranspiration from a basin were analyzed using hydrological data.

There is a distinct diurnal cycle in precipitation at BT, in which about 60 % of the rainfall occurred between 13:00 hr and 19:00 hr. The rainfall at BT was characterized by short duration and high intensity. The stormflow generation depended strongly on the antecedent wetness which represented by initial runoff rate. For storms with initial runoff rate $\geq$ 0.1 mm h^{-1}, rain water excess over the initial loss, that is about 30 mm in this case, seems to become stormflow. Confined and unconfined recession constants are 0.02290-0.05315 (mean: 0.04265) and 0.01095-0.01962 (mean: 0.01590), respectively. Though heavy rain normally occurred every month at BT, there were occasional short dry spells during dry months and the soil moisture decreased for the periods. The streamflow hydrograph responded quickly to rain event but declined rapidly during dry conditions. The streamflow hydrograph responded quickly to rain event and declined gently during wet conditions. The daily mean evapotranspiration was calculated by the short-term period water-budget method considered water storage. The values varied from 2.74 to 4.86 mm day^{-1}. There isn't distinct seasonal variation.

Key Words Tropical rainforest, Rainfall characteristics, Runoff characteristics, Hydrological responses, Evapotranspiration

1. Introduction

Higher rate of deforestation in tropical regions has become a cause of concern (FAO, 1993) and its effect on overland flow and erosion have been highlighted (Bonell, 1993). In the past, much attention have been given to the forests in terms of sediment disaster prevention and regional role of water resources. It is important to clarify hydrological processes in tropical rain forests and to evaluate their roles through hydrological observations Therefore, some hydrological observations were conducted at Bukit Tarek Experimental Watershed in Peninsular Malaysia.

2. Site Description and Instrument and Data Collection

Bukit Tarek Experimental Watershed (BT) is located in Selangor Darul Ehsan of Peninsular Malaysia (latitude: 3° 31' N, longitude: 101° 35' E, altitude: 48-213 m; Figure 1). Vegetation of this area is dominated by *Koompassia malaccencis*, *Eugenia* spp., and *Canarium* spp. Surficial geology is metamorphic rocks consisting of quartzite, quarts mica schist,

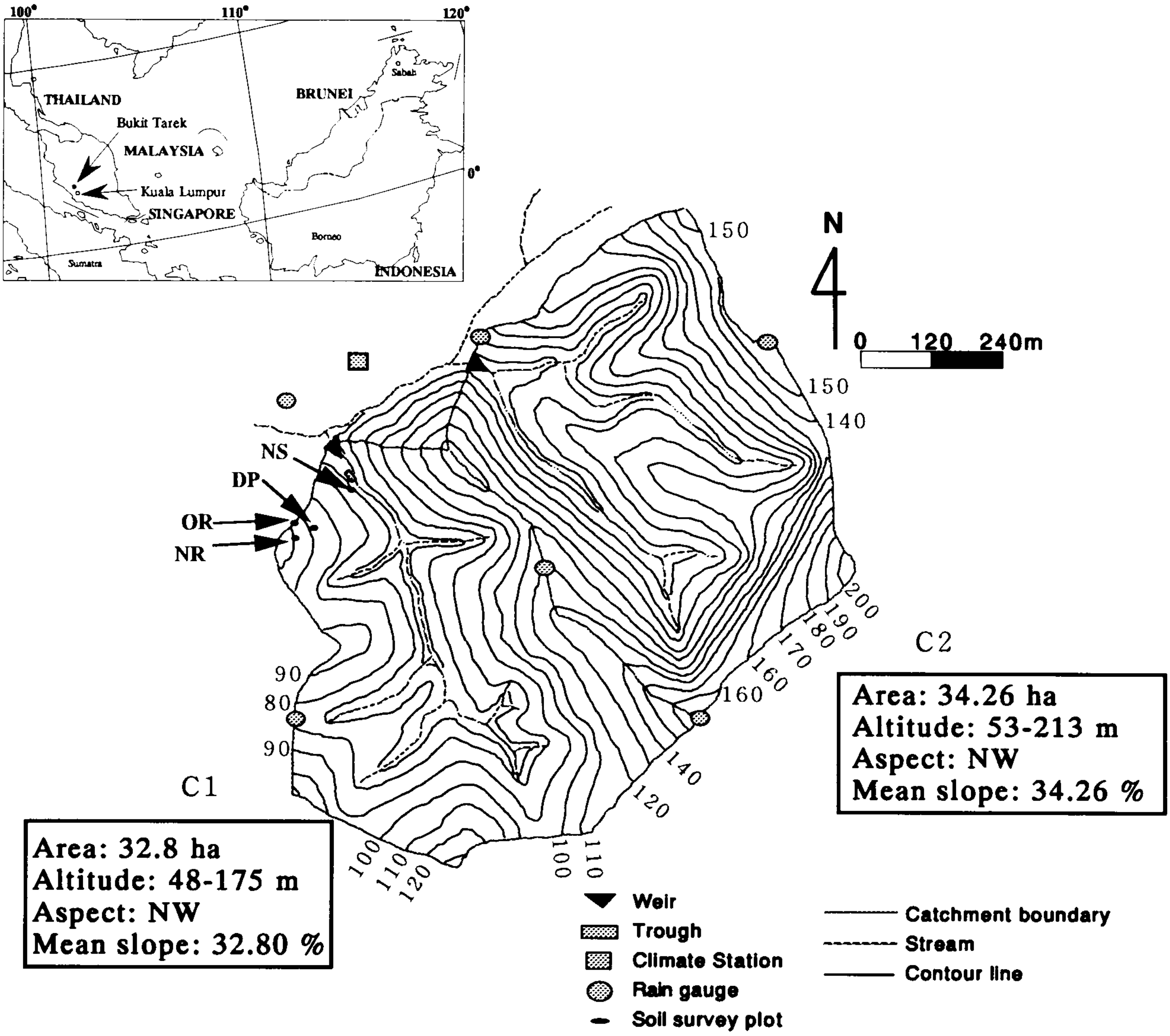


Figure 1. Map of the Bukit Tarek Experimental Watershed showing the locations of basin and their instrumentations.

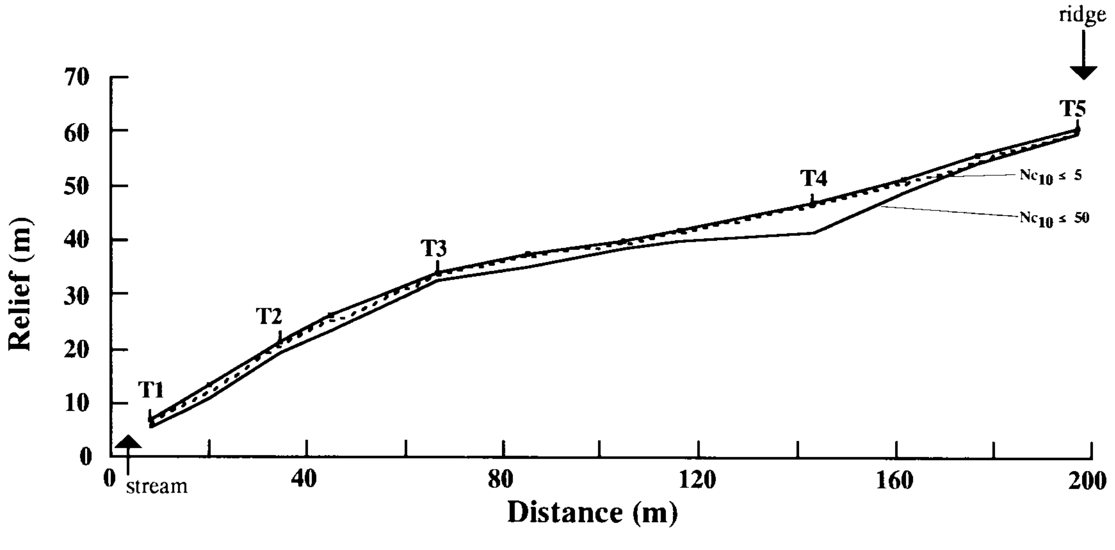


Figure 2. Soil depth along the longitudinal axis of the experimental slope and the locations of tensiometer nests.

graphitic schist, and phyllite from the Arenaceous Series (Saifuddin et al., 1991). The average annual precipitation is 2414 mm, based on 3 yr (1992 - 1994) of record.

Runoff discharge is measured by the 120 degree V-notch at the outlet of C1 basin. Precipitation is measured by a weighing-type recording rain gauge and a tipping-bucket rain gauge near the weir C1. An experimental slope was established at about 130 m upstream of weir C1 (Figure 1). Pressure heads of soil water were measured at five sites on the slope by 24 mercury manometer tensiometers at daily intervals. Location of the sites are shown in Figure 2.

3. Result and Discussion

(1) Soil physical properties

Undisturbed soil cores (ϕ113 mm, H=40 mm) were collected at NS, NR, DP and OR at depths of 10, 20, 40, and 80 cm, respectively (Figure 1). Saturated hydraulic conductivity (Ks) ranged from 4.34×10^{-2} cm s^{-1} (10 cm) to 4.98×10^{-3} cm s^{-1} (80 cm). Clearly Ks values decreased with increasing soil depth. The Ks values at BT are higher than those at respective depth in other tropical regions. The high conductivities were due to the macropores which were predominantly present as decomposed root channel and existed continuously in vertical direction. The shapes of θ-ψ curves at BT resembled to the results of the forest soil type which had rather large changes in θ when ψ was smaller than 30 cmH_2O. Macroporosity and mesoporosity have large changes between 20 cm and 40 cm. The porosities over 20 cm are greater than those under 40 cm. Concentration of lateral roots above 40 cm indicates the possibility of difference of the porosity.

(2) Soil depth

Soil depth was measured at 23 points using a portable dynamic cone penetrometer. The number of impacts needed to drive for the cone 10 cm into the soil (Nc_{10}) was used to define depth of surface soil layer ($Nc_{10} \leq 5$) and total soil depth ($Nc_{10} \leq 50$), respectively. While this depth dose not exactly represent the thickness of soil layers, it provides an estimate of the topographic distribution of hydrologic impeding layers in the subsurface (Ohta, 1988). The total soil depth varied depending on locations within the hillslope (range: 118-571 cm, mean: 221.9 cm, S. D.: 126.9 cm) whereas the surface soil layer was less variable (range: 64-105 cm, mean: 89.0 cm, S. D.: 13.9 cm).

(3) Investigation of water flow patterns in soil

Dyes allow direct observation of patterns of water movement in soil (e.g., Bouma and Dekker, 1978; Tsujimura, 1991). A simple infiltration test using methylene blue and white liquid paint was conducted on a hillslope. The result indicated the methylene blue was not efficiency on the forest because it was absorbed in A_0 and A layers. On the other hand, the white liquid paint was useful to investigate the patterns of water movement in soil . The white liquid paint was therefore used in this study to characterize infiltration patterns in soil. A dilute solution of white liquid paint in water (10% by volume) was sprayed on a plot of 1 by 0.5 m after water was sprayed. A wooden frame was placed on the plot to be sprayed. Both application rates are 80 (mm/h). Amount of water and the dilute solution of white liquid paint are 10 ℓ and 20 ℓ, respectively. Twenty-four hours after the dye application, the plot was trenched from the downslope end of the plot and the vertical distribution patterns of the dyes were described. In addition to photographing, accurate traces of the stained dye patterns on the soil profile were sketched. This process was repeated by cutting the pit face successively farther into the plot at 10 cm increment up to the end of the plot. A scanner allowed us to capture and sent the image of photographs (256 colors) to a computer. Colors images were converted to black and white images. Dye distribution areas were calculated the number of pixels of the black and white images. The hydrologic impeding layer existed between A layer and B layer. Not only decayed roots but also living roots has an effect on preferential flow in vertical and lateral (toward downslope) directions. The detail obtained information are important in order to analyze water flow and slope stability in tropical rain forest.

(4) Rainfall Characteristics

We investigated both rainfall of BT and that of Hitachi Ohta (HO; temperate forest) in Japan from 1992 to 1994. There are no pronounced peaks in diurnal cycle in precipitation at HO throughout the year, however, there is a distinct diurnal cycle in precipitation at BT, in which about 60 % of the rainfall occurred between 13:00 hr and 19:00 hr (Figure 3). As the sine wave, which was decomposed by Fourier transform consisting of 24-h, 12-h, and 8-h cycles, was applied to the observed data at BT, the result was useful (r=0.9734) in order to rethink the diurnal cycle of precipitation. The mean amount of rainfall in each rain event at BT and HO were almost the same (14 mm) but BT had a lower maximum value (less than 100 mm). The rainfall at BT was characterized by short duration and high intensity; about 55 % of rain events fell within 1 hour period. There was a high positive correlation at BT (r=0.9489) between amount of rainfall in each rain event and maximum hourly rainfall intensity during rain event. Though only four rain events with more than 50 mm h^{-1} for 10 min. occurred for three years at HO, such high intensity rain events occurred every month at BT.

(5) Runoff Characteristics

Discharge was plotted over time in hours on semilogarithmic paper. A point of inflection was found on the falling limb of the hydrograph between 12 and 36 hours after a storm. The stromflow defined as the upper area of hydrograph divided by hydrograph separation line which connect a point of rise to the point of inflection. Stormflow has little relations with the initial runoff rate when storm period rainfall is less than 30 mm and less than 10 % of rainfall appears as stormflow. It is estimated that stream channel and riparian areas may be the source of stormflow production. For storms with initial runoff rate ≥ 0.1 mm h^{-1}, rain water excess over the initial loss, that is about 30 mm in this case, seems to become stormflow. Thus, the stormflow generation depended strongly on the antecedent wetness which represented by initial runoff rate.

The falling limbs of hydrographs can be expressed by following formulas (Takagi, 1965):

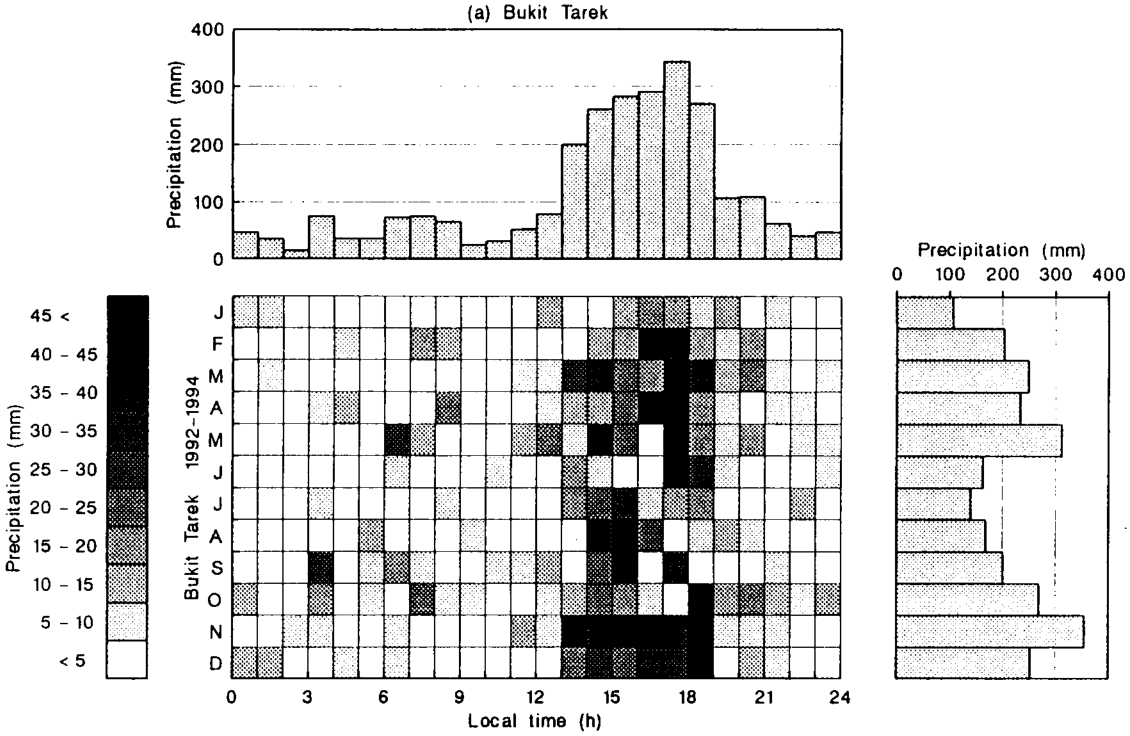
$$Q = Q_0 e^{-\alpha t}$$

$$Q = \frac{Q_0}{\left(1 + \beta \sqrt{Q_0}\, t\right)^2}$$

where Q_0 is initial flow, Q is the flow t time after Q_0, α and β are confined and unconfined recession constants, respectively.

The runoff 3 days after the end of a rainfall and thereafter was considered, and the falling limbs of hydrograph has more than 8 days without rainfall was selected as the analyzing data. Furthermore, the days have less than 2.0 mm day^{-1} were dealt with no rain days in order to get the number of sampling. α and β are 0.02290-0.05315 (mean: 0.04265) and 0.01095-0.01962 (mean: 0.01590), respectively. There was a positive correlation between α and initial runoff but β was independent on the initial runoff and nearly constant. The recession constants are depend on topograph, geological structure and soil depth. As the result of comparison of the values between Cunha watershed in Brazil and 17 forested watersheds in Japan, the values in Cunha was low (Fujieda,1995). Because it was considered that deep soil and large riparian area in it were causes. On the other, BT is similar to Ananomiya watershed at Aichi in Japan. Further investigation is necessary before we come to the reason.

(6) Responses of streamflow and tensiometric heads



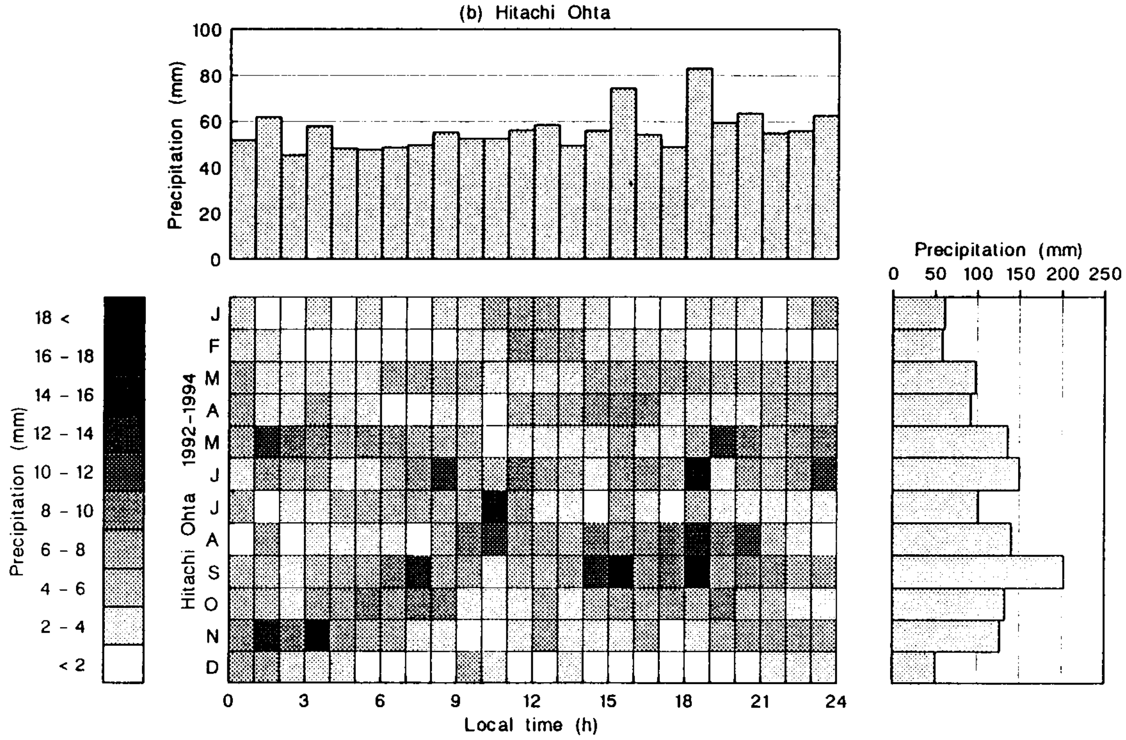


Figure 3. Total precipitation at each time of day in each month at Bukit Tarek and Hitachi Ohta. Mean for three years (1992-1994).

Hyetograph and changes of tensiometric heads with time are shown in Figure 4. Though heavy rain normally occurred every month at BT, there were occasional short dry spells during dry months and the soil moisture decreased for the periods. The streamflow hydrograph responded quickly to rain event but declined rapidly during dry conditions. It suggested that the rain water was mostly retained in the soil and didn't produce substantial stormflow. As soil moisture conditions became wetter, the hydrograph volume became larger with gentler recession limbs. The streamflow hydrograph responded quickly to rain event and declined gently during wet conditions. The pressure heads at all depth maintained low pressure. The hydraulic gradient was around 1.0 and downward flow of soil water flux, which corresponded to the pressure heads, occurred at each site on hillslope. The soil conditions were wetter on the whole hillslope and the rain water was transported to deeper depth and downslope. Therefore, the rain water on upward hillslope is likely to contribute to a delayed discharge which may occur many hours after the rainfall input.

(7) Evapotranspiration

The relation between the water storage in a basin $S(t)$ and discharge rate $q(t)$ can be written as

$$S(t) = \mathrm{f}[q(t), dq/dt]$$

Assuming the water storage $S(t_1)$ and $S(t_2)$ are equal when both $q(t)$ and dq/dt become equal at times t_1 and t_2, that is change of water storage ΔS is zero. Evapotranspiration can be calculated using the following expression :

$$E = P - Q = \int_{t1}^{t2} p(t)dt - \int_{t1}^{t2} q(t)dt$$

Where E, P, and Q are total evapotranspiration, total precipitation, total discharge from t_1 to t_2 ,and $p(t)$ and $q(t)$ are rainfall intensity and discharge rate, respectively. The procedure proposed by Suzuki (1985) was used in this research to decide the water budget periods t_1 and t_2.:

1) Dates are chosen before there has been no rain for two days and also on which there is no rain, as dates proposed for t_1 or t_2.

   In another case, the days have less than 2.0 mm day^{-1} were dealt with no rain days as dates proposed for t_1 or t_2.
2) From the above dates 1), pairs of dates are selected between which the difference in the daily discharge rate is less than 2% or 5%.
3) The pairs are excluded in which the intervening period is less than eight days or more than 60, 90, 120 or 150 days.

Tables 1 and 2, and Figure 5 show the daily mean evapotranspiration calculated by the short-term period water-budget (SPWB) method through 1992 to 1994. The daily mean evapotranspiration was indicated by a thick line which varied from 2.78 to 5.85 mm day^{-1} (control period: 150 days, Criterion for discharge: 5 %). There isn't a distinct seasonal variation at BT. As the results were compared with soil moisture observation data, the values might underestimate evapotranspiration for the water budget period from dry season to rainy season and overestimate for the water budget period from rainy season to dry season. Although there is no defined rainy and dry seasons in Bukit Tarek, it is clear to exhibit wet and dry conditions. We have to pay attention to the variation of soil content at surface soil when evapotranspiration is calculated by the SPWB method.

Water storage was calculated using tensiometer data and soil moisture characteristics curves. Change of water storage varied from -53.8 mm to 51.8 mm between the beginning

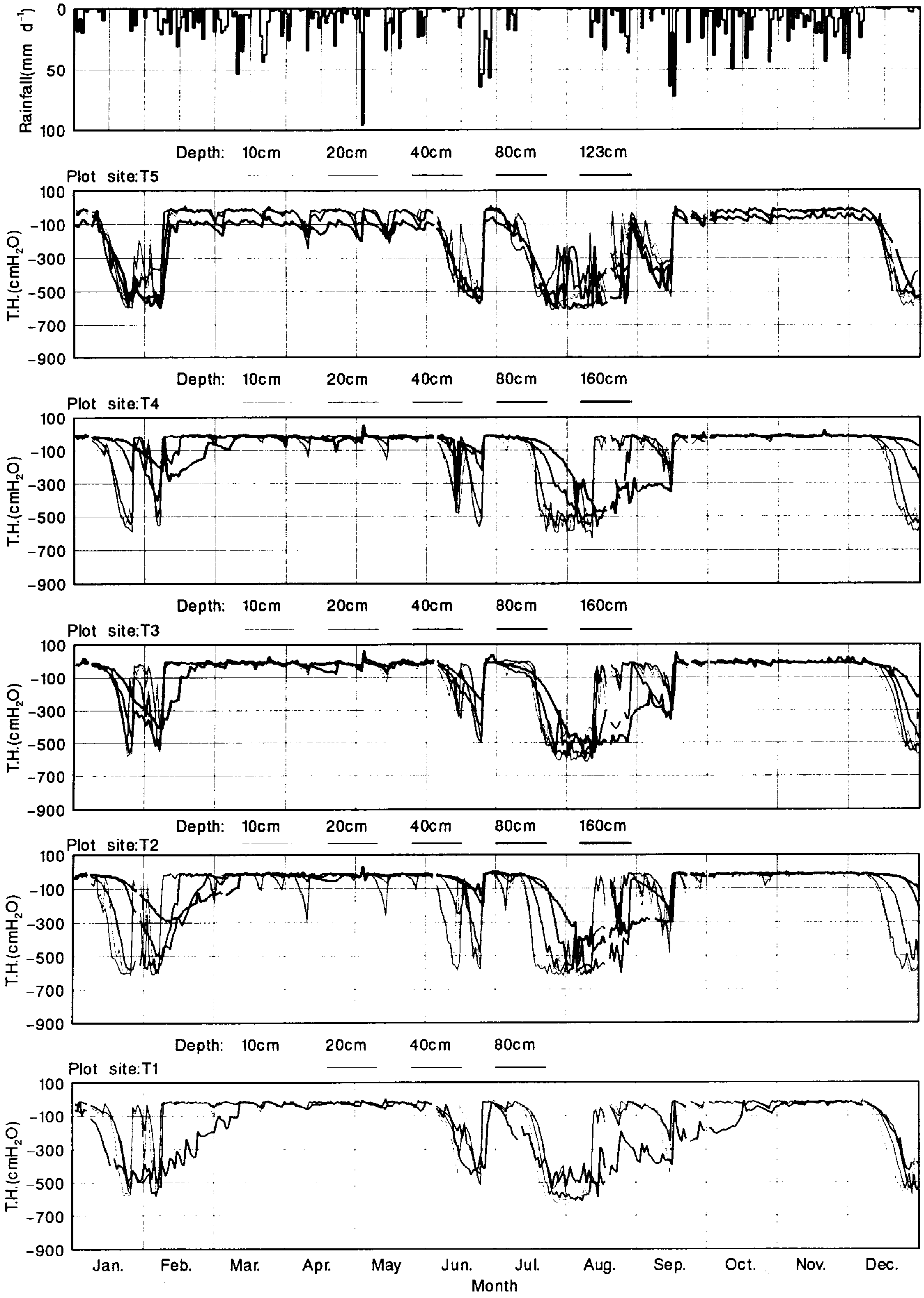


Figure 4. Hyetograph and changes in tensiometric heads with time (Year:1993).

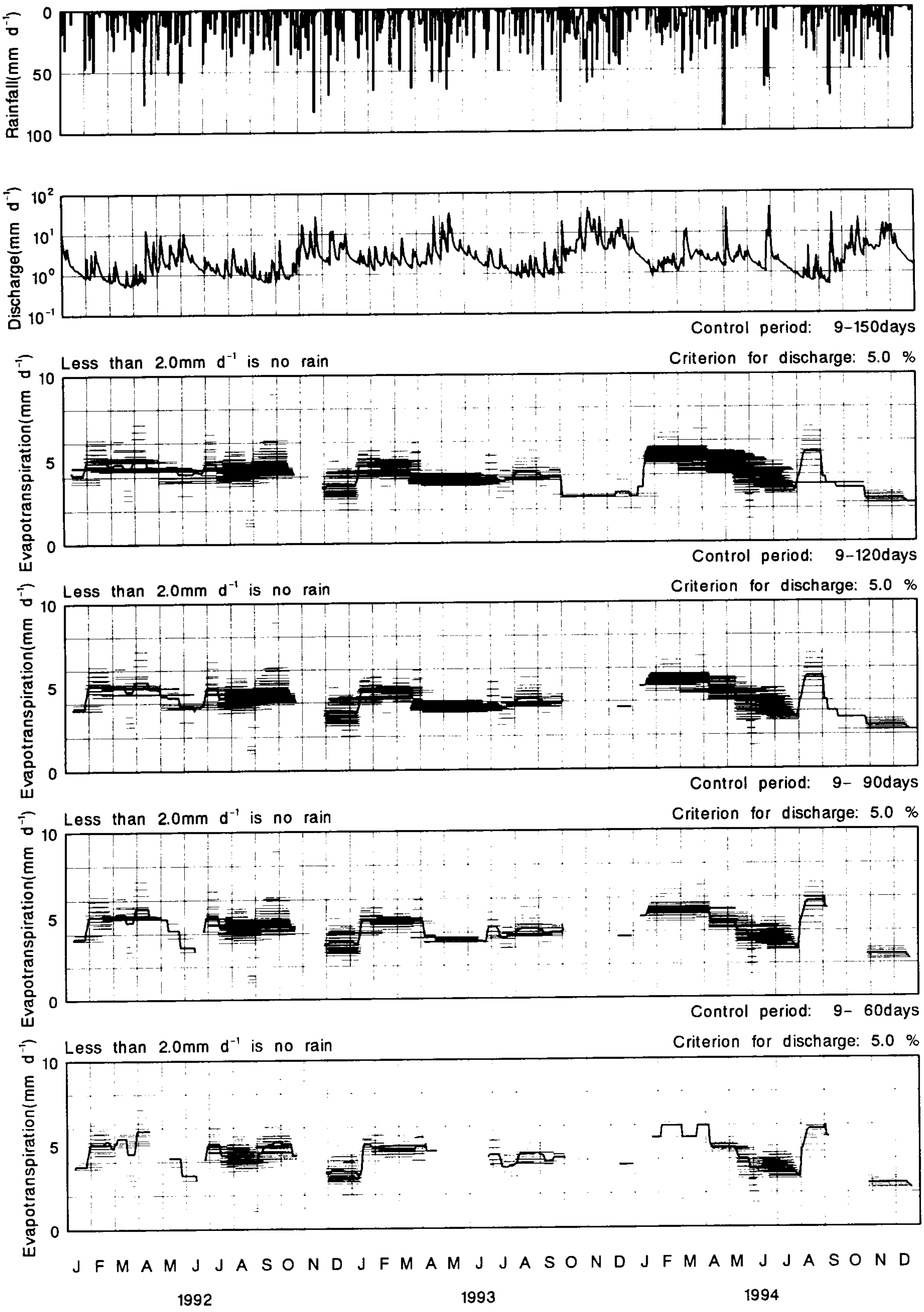


Figure 5. Evapotranspiration rate derived from the method of the short-time period water-budget on Bukit Tarek (Result-4).

Table 3. Evapotranspiration rate derived from the method of the short-time period water-budget.

	Criterion for discharge	Control period	Resutl Range (mm)	Mean (mm)
Result -1	Less than 2 %	9-60 days	3.10 - 6.43	4.53
	Less than 2 %	9-90days	3.10 - 6.43	4.43
	Less than 2 %	9-120 days	3.10 - 6.43	4.47
	Less than 2 %	9-150 days	2.80 - 6.43	4.23
Result - 2	Less than 5 %	9 - 60 days	2.66 - 5.85	4.47
	Less than 5 %	9 - 90 days	2.66 - 5.85	4.33
	Less than 5 %	9 - 120 days	2.78 - 5.85	4.35
	Less than 5 %	9 - 150 days	2.78 - 5.85	4.18

Dates are chosen before there has been no rain for two days and also on which there is no rain, as dates proposed for the beginning day and the ending day.

Table 4. Evapotranspiration rate derived from the method of the short-time period water-budget.

	Criterion for discharge	Control period	Resutl Range (mm)	Mean (mm)
Result -3	Less than 2 %	9 - 60 days	2.42 - 6.71	4.45
	Less than 2 %	9 - 90 days	2.42 - 6.50	4.36
	Less than 2 %	9 - 120 days	2.42 - 6.50	4.32
	Less than 2 %	9 - 150 days	2.42 - 6.50	4.13
Result -4	Less than 5 %	9 - 60 days	2.25 - 5.99	4.36
	Less than 5 %	9 - 90 days	2.25 - 5.92	4.26
	Less than 5 %	9 - 120 days	2.26 - 5.51	4.15
	Less than 5 %	9 - 150 days	2.26 - 5.32	4.01

Dates are chosen before there has been no rain for two days and also on which there is no rain, as dates proposed for the beginning and ending day. The days have less than 2.0 mm day^{-1} were dealt with no rain days as dates proposed for the beginning and ending days.

Table 3. Evapotranspiration rate derived from the method of the short-time period water-budget.

	Criterion for discharge	Control period	Resutl Range (mm)	Mean (mm)	Note
Result -5	Less than 5 %	9 - 150 days	2.74 - 4.86	3.83	Condition 1
	Less than 5 %	9 - 150 days	2.26 - 5.32	3.85	Condition 2
	Less than 5 %	9 - 150 days	2.83 - 6.50	4.09	Condition 3

Condition 1, 2: The days have less than 2.0 mm day^{-1} were dealt with no rain days as dates proposed for the beginning and ending days. Condition 1:Water storage was calculated using tensiometric data.

and ending days for control period. The daily mean evapotranspiration was calculated by the SPWB method considered water storage. The results varied from 2.74 mm/day to 4.86 mm day^{-1} (Table 3).

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