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Hydrological characteristics influenced by deforestation in tropical areas: the Mae Tang River basin, Thailand

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Abstract Forest cover in tropical areas is being reduced as a result of deforestation for timber resources or shifting cultivation. Previous studies of the influence of deforestation on floods and sediment yields are insufficient. In order to investigate this influence further, the authors have conducted hydrological observations and basic data analysis. The main points arising from this study are as follows. Firstly because the runoff ratio is around 20%, it is important to estimate loss to discharge in order to understand the discharge process. The runoff ratio is influenced by the initial discharge of each flood. Secondly, sheet erosion or raindrop erosion is the dominant source of the suspended sediment load. Thirdly, the grain size distribution of the surface soil is different between different vegetation types. Forest soils contain relatively less silt and clay. It is supposed that weathering rates differ between vegetation covers.

INTRODUCTION

It is commonly supposed that deforestation in tropical areas causes a sudden change in soil condition, because of exposure to intense sunlight. As a result of this change, the characteristics of floods and sediment discharge will also change. However, many aspects of these processes remain uncertain. In order to study these characteristics in more detail, the authors have undertaken an investigation in the Mae Tang River basin, in the northern part of Thailand.

From 1991 to 1994 the authors assembled basic data on precipitation, discharge and concentration of suspended sediment collected by national agencies such as the Royal Irrigation Department (RID), the Royal Forest Department (RFD), the Department of Energy Development and Promotion (DEDP), and the Electricity Generating Authority of Thailand (EGAT) and undertook a general analysis of the characteristics of sediment yields and flood discharges. In order to study the processes of floods, sediment discharge and sediment yield more precisely, hydrological observations in the upper reaches of the Mae Tang River were initiated in 1991. Raingauges and a water level gauge have been installed in a small basin and hydrological observations in the upper reaches of the Mae Tang River were initiated in 1991. Raingauges and a water level gauge have been installed in a small basin and erosion observations have been conducted on an experimental slope. The results obtained are being used to clarify the influence of deforestation on sediment and flood discharges.

THE MAE TANG RIVER BASIN

The Mae Tang River basin (*ca.* 1900 km^2) is located in north west Thailand at latitude 19°N and longitude 98°E. The basin is surrounded by steep mountains rising to heights of between 1000 m and 2000 m above sea level. The mean annual rainfall is 1700 mm and the maximum 2300 mm. The wet season generally extends from May to October. The warm and humid monsoon from the Indian Ocean usually brings the precipitation, but heavy rain caused by tropical depressions occurs repeatedly in July and August. Almost all flood disasters are caused by this type of rain, because the precipitation continues for several days and has a high intensity. These high discharges cause damage to irrigation facilities by erosion and sedimentation.

METHODS

Hydrological data and analysis Several public agencies in Thailand such as RID, DEDP, RFD, EGAT have undertaken hydrological observations in the study catchment. Fig. 1 shows the observation points. Basic hydrological information relating to precipitation, discharge and sediment discharge are available.

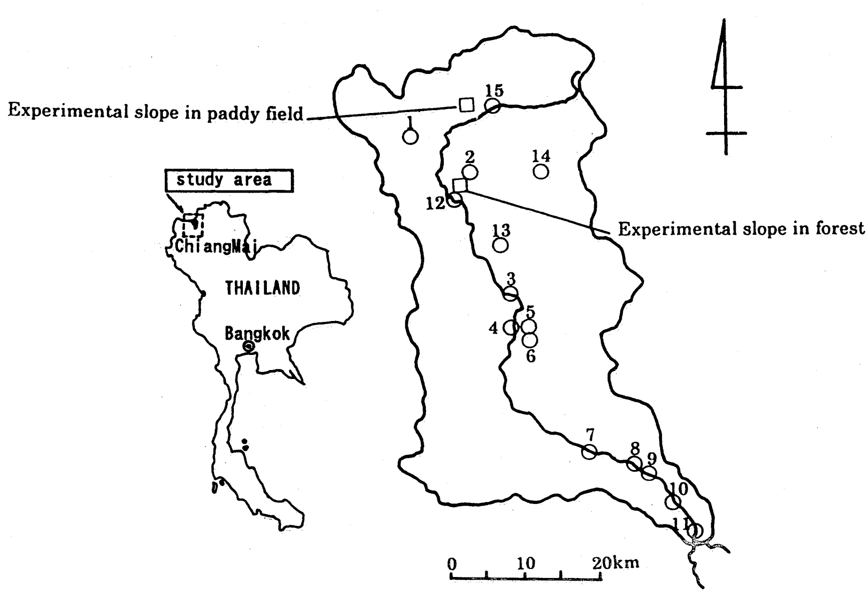

Fig. 1 The hydrological monitoring network in the Mae Tang River basin.

Hydrological monitoring in the upper reaches The authors have installed and started hourly observations at stations 12 and 13. Rainfall measurements started in 1991 at station 13 and in 1994 at station 12. Discharge observations started in 1991 at station 13. Suspended load measurements were also commenced in 1995 at station 12. Sediment samples were collected once a day for 100days from August to November, and once every hour during the flood of 31 July 1995.

Laboratory analysis of soil samples In order to study soil condition which is thought to be affected by deforestation, soil samples were collected using a metal tube (diameter 75 mm) for laboratory tests. Soil samples were collected from forest, shifting cultivation fields and grassland. The depth of sampling was 15 cm from the surface.

Soil erosion observations In order to study differences in erodibility associated with land use, we have installed two sets of erosion plots (cf Fig. 2) on hillslopes under forest and paddy field. The experimental plots (2 m wide, 4 m long) are surrounded by a metal strip inserted into the soil surface. Sediment which is caught in the trap is examined in the laboratory.

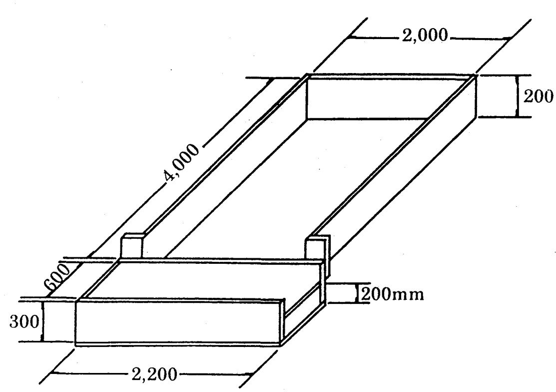

Fig. 2 The experimental plots.

RESULTS AND DISCUSSION

Flood and sediment discharge characteristics

Precipitation and discharge Figure 3 shows three hyetographs for 1992. The stations involved are no. 1 (upper reach), no. 4 (middle reach), and no. 10 (lower reach). These hyetographs differ for the rainy season, but are similar for the dry season. The reason for this feature is that precipitation during the rainy season occurs over small areas compared to the observation network, whereas precipitation in the dry season has a larger spatial extent.

Table 1 shows the annual runoff of station 7 from 1980 to 1993. The runoff is

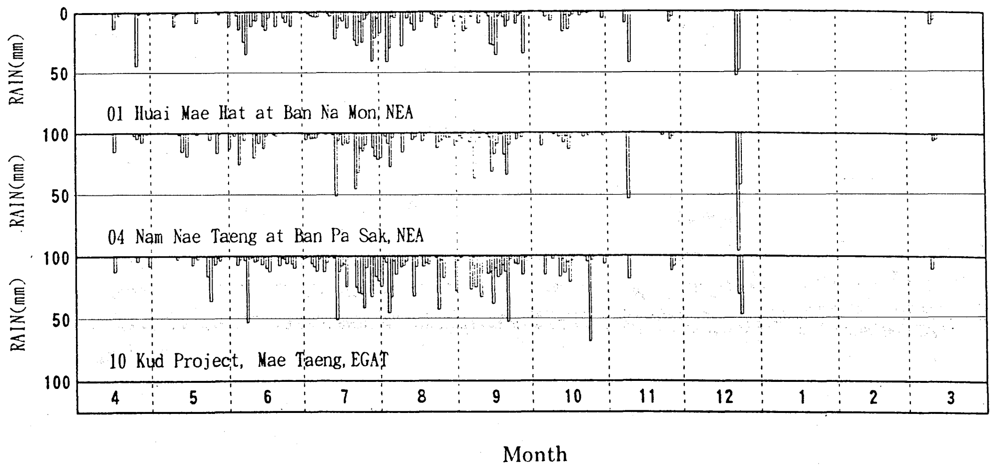

Fig. 3 Daily rainfall in the upper, middle and lower reaches of the Mae Tang River basin during 1992.

around 20% and considerably smaller than that of Japanese rivers with almost the same precipitation. One of the implications of this result is that the gradient of the Mae Tang River is very gentle, ranging from less than 1° to 6°, and that this promotes storage and evaporation of water from the basin.

Figure 4 shows an example of annual rainfall and runoff data for station 7. In the middle of the rainy season (when baseflow is high), several floods with peak discharges exceeding 80 m^3 s^{-1} occurred as a result of *ca.* 40 mm rainfall. In contrast, during the dry season and the first part of the rainy season, there is no apparent increase in discharge for storm events with 40 mm rainfall. It is suggested that water storage in the basin influences discharge. Baseflow presumably represents such water storage. In the case of dry conditions, losses of precipitation increase and the runoff ratio decreases.

Table 1 Annual runoff at station 7.

Year	Precipitation (mm)	Runoff (mm)	*P*/*R*
1980	1580.0	314.8	0.199
1981	1916.4	426.8	0.223
1982	1430.4	333.3	0.233
1983	1750.5	380.9	0.218
1984	1663.5	336.0	0.202
1985	1914.9	417.6	0.218
1986	1423.1	364.8	0.256
1987	1521.5	391.9	0.258
1988	1881.8	350.5	0.186
1989	1500.4	340.1	0.227
1990	1134.7	249.3	0.220
1991	1228.8	249.5	0.203
1992	1504.4	262.9	0.175
1993	1198.6	219.6	0.183
Mean	1546.4	331.3	0.214

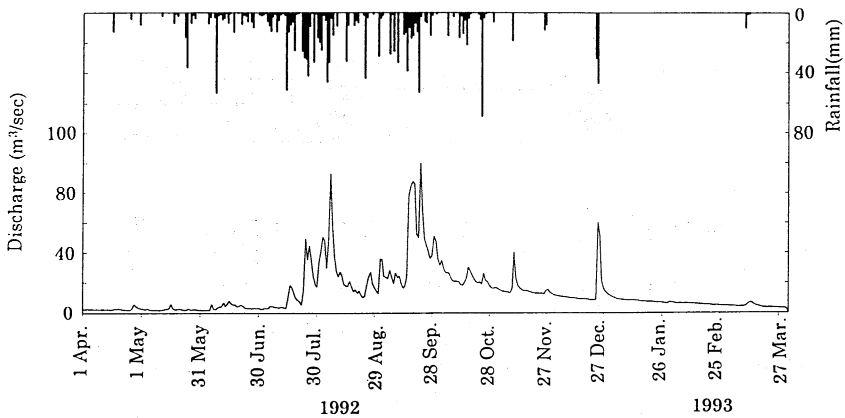

Fig. 4 The relationship between rainfall and discharge at station 7 in 1992.

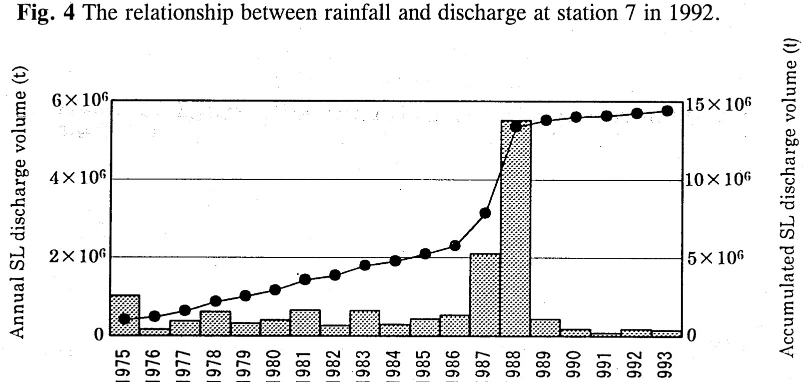

Fig. 5 Annual suspended sediment loads and the accumulated suspended sediment load for station 7.

Suspended load discharge Figure 5 shows the annual suspended sediment load at station 7 for the period 1975-1993. The mean annual load is *ca.* 320 000 t. The total load for the 19 year period is 14 400 000 t. This sediment causes serious damage to irrigation facilities and water pollution.

Figure 6 shows the relationship between discharge and suspended sediment concentration for station 4 (middle reaches). Sampling of suspended load was conducted 148 times between 1985 and 1992. Points plotted as (×) indicate data for the dry season (from November to April) whereas (o) values represent rainy season data (from May to October). This plot shows that the concentration of suspended sediment is related to discharge in the rainy season but not in the dry season.

Figure 7 illustrates the seasonal change of discharge and suspended sediment concentration at station 4. High concentrations of suspended sediment occur during the first part of the rainy season.

Figure 8 presents relationships between water discharge and suspended sediment discharge for the Mae Tang River and representative Japanese rivers. The data for the Japanese rivers almost all plot between two lines ($Qwl = 4 \times 10^{-8} \times Q^2$ and $Qwl = 6 \times 10^{-6} \times Q^2$). The data for the Mae Tang River show almost the same tendency, but cover a greater range.

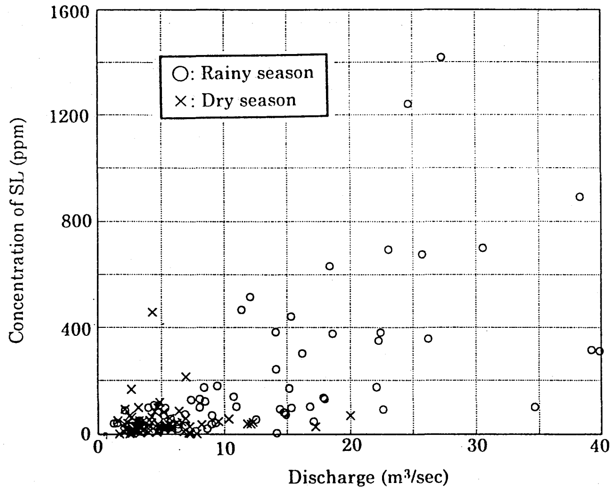

Fig. 6 Relationship between discharge and suspended sediment concentration at station 4.

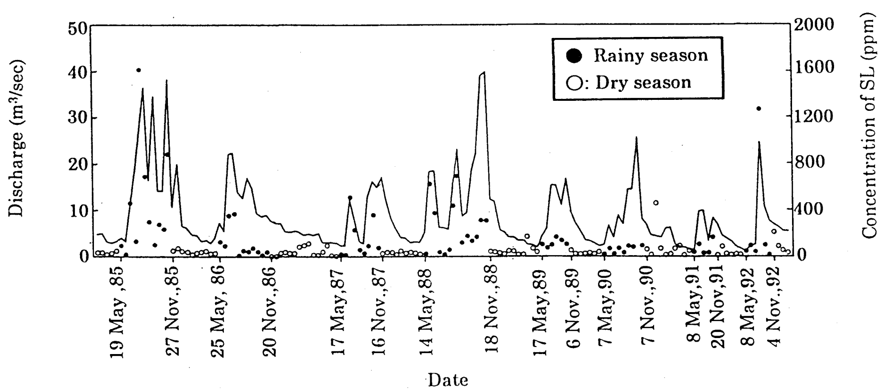

Fig. 7 Change of discharge and suspended sediment concentration at station 4.

Characteristics of runoff and sediment discharge in the upper reaches

Runoff characteristics From previous observations the authors have found that the relationship between rainfall and runoff is different for each event. For example, there are cases where discharge scarcely changes when large amounts of precipitation are recorded. Conversely, there are other cases where discharge definitely increases when precipitation is recorded. We believe that rainfall which occurs over only part of the basin causes these situations. In order to try to exclude the effects of such events, we selected storms which fulfilled two conditions. The first condition is that more than 20 mm precipitation should have been recorded at both station 12 and station 13. The second condition is that both stations should have recorded almost the same amount of precipitation.

Figure 9 shows the relationship between initial discharge and runoff ratio observed at station 12. Each flood was selected using the conditions previously

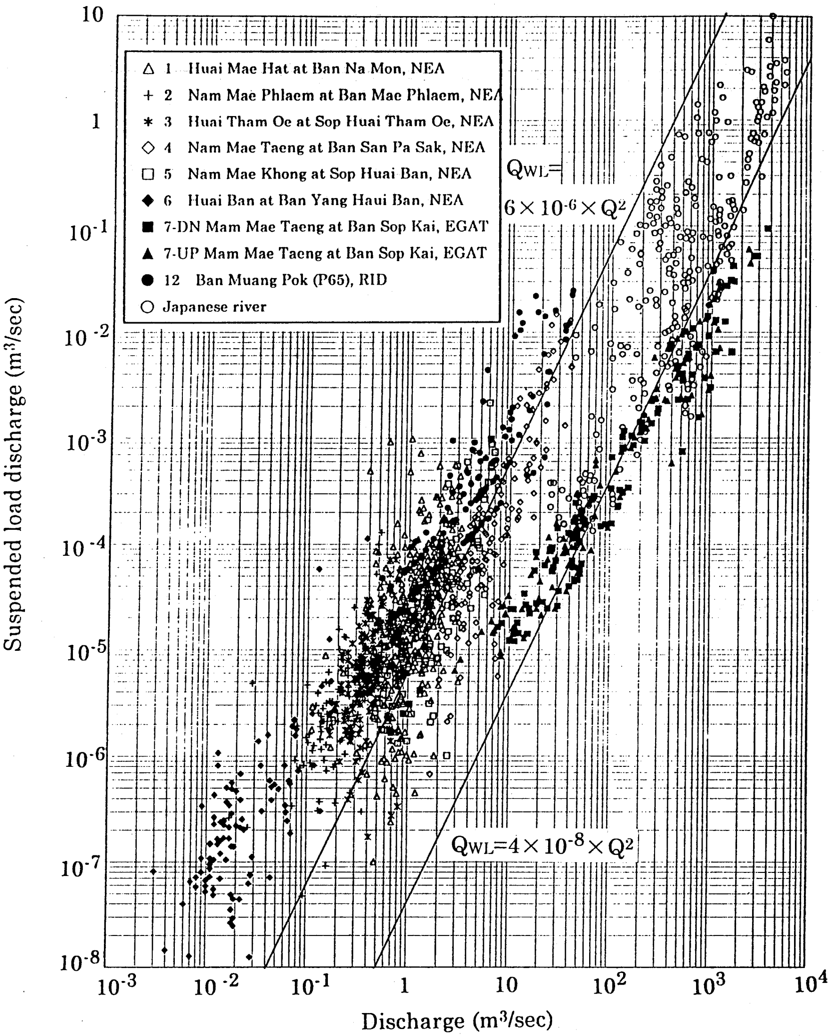

Fig. 8 The relationship between water and suspended sediment discharge for the Mae Tang River and for representative Japanese rivers.

mentioned. Initial discharge refers to the discharge occurring just before the flood. The runoff ratio varies seasonally in accordance with changes in the initial discharge and increases from a few percent to 20% in parallel with the increase of initial discharge. This trend is also evident in Fig. 10. Even though rainfall of over 50 mm day^{-1} occurs in the first part of the rainy season, the discharge scarcely changes. Conversely, discharge is closely related to rainfall in August and September.

Characteristics of suspended sediment discharge during floods Figure 11 presents the hyeto-hydrograph for the flood of 31 July 1995 which recorded the maximum daily discharge in that year. The time lag between the peak rainfall intensity and the peak suspended sediment concentration is very short compared with the lag between the peak rainfall intensity and peak discharge. It is difficult to draw

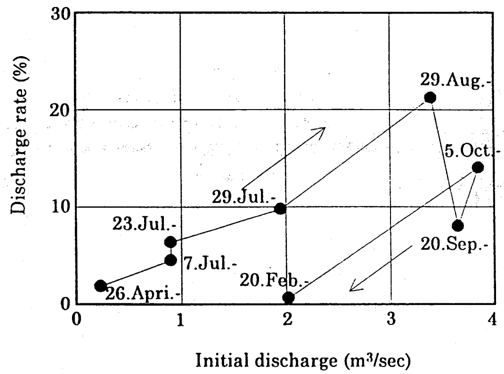

Fig. 9 The relationship between runoff ratio and initial discharge for station 12 in 1995.

general conclusions from limited data. However, we think that this result indicates that the dominant source of the suspended load is not the stream channels but that sheet erosion or raindrop erosion on the slopes is dominant.

Soil condition and erosion from the experimental plots

Soil condition Soil properties such as retentivity and hydraulic conductivity exert a key influence on runoff and sediment production. In this study attention focused on differences in soil properties under different land uses. Soil sampling and laboratory tests were undertaken. Table 2 shows the land use of the sampling sites and the results of the laboratory tests. Specific gravity, organic content and permeability show little difference according to land use. However, the mean silt and clay content is higher for paddy field and grassland. It is assumed that soil weathering under poor

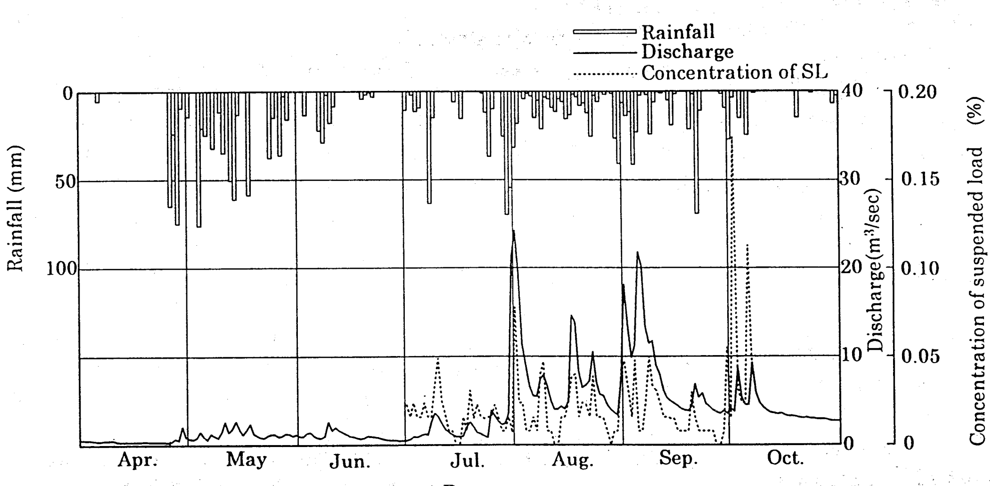

Fig. 10 The record of rainfall, discharge and suspended sediment concentration for station 12 in 1995.

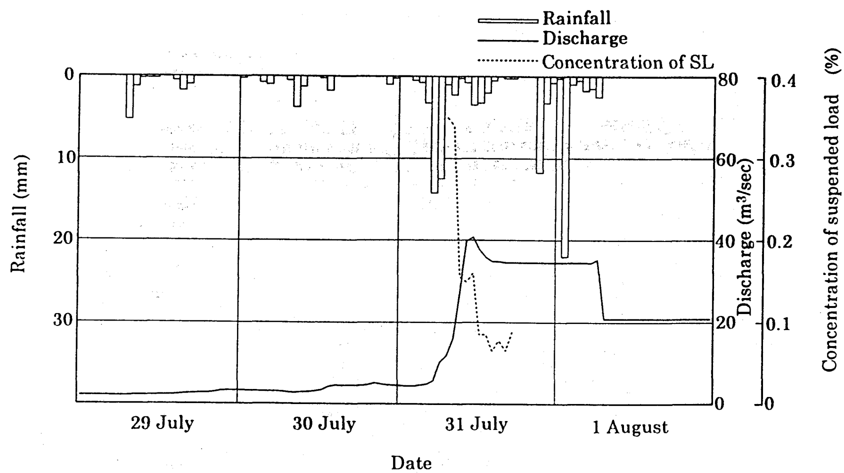

Fig. 11 The relationship between rainfall, discharge and suspended sediment concentration during a flood at station 12 on 31 July 1995.

vegetation cover is more active than under forest. Soil erosion will occur more readily on slopes with finer soils.

Erosion from experimental plots Table 3 shows the results obtained from the experimental plots (Fig. 2). When the experiments were started it was assumed that erosion from the paddy fields would be greater. However, the results obtained are the opposite. The results indicate that surface runoff occurs even from slopes which are covered by forest and that these slopes can be a source of suspended sediment. The results obtained from the forest site are however, unnaturally high. Further work with these experiments and careful observation are required to clarify these results.

Table 2 Summary of laboratory tests on soil samples.

No.	Place	Depth (cm)	Specific gravity	Organic content (%)	Silt and clay content (%)	Permeability (10-2 cm s-1)
1	Forest	15	2.50	1.40	56	2.00
2	Forest	15	2.63	0.78	33	3.40
3	Forest	15	2.62	4.75	57	0.70
4	Forest	15	2.62	1.32	48	3.10
5	Forest	15	2.62	1.90	31	1.40
6	Forest	15	2.63	3.70	34	3.90
7	Forest	15	2.57	6.00	44	3.80
8	Forest	15	2.35	14.9	54	7.20
9	Forest	15	2.51	3.00	31	1.60
Avg			**2.56**	**4.19**	**43.11**	**3.01**
10	Paddy	15	2.60	3.50	86	0.29
11	Paddy	15	2.61	4.49	74	1.00
12	Paddy	15	2.61	4.01	40	0.30
13	Paddy	15	2.60	5.70	57	9.80
Avg			**2.61**	**4.43**	**64.25**	**2.85**
14	Grass	15	2.50	3.10	67	3.20
15	Grass	15	2.62	4.12	88	1.20
16	Grass	15	2.67	4.70	65	7.10
Avg			**2.60**	**3.97**	**73.33**	**3.83**

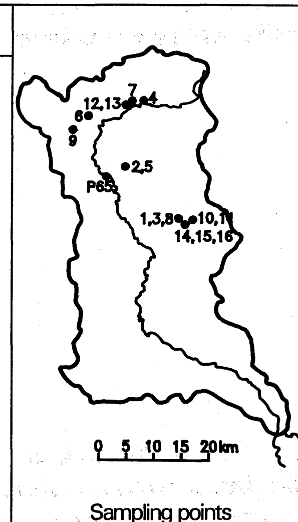

Table 3 Results from the erosion plots.

Division	Vegetation	Slope (°)	Annual erosion (g year^{-1})
Forest	Pine trees, bushes	22.4	**31 904**
Paddy	Dry-and-rice, weeds	21.4	**3 120**

CONCLUSIONS

In order to study the influence of deforestation on flood and sediment discharges, the authors have undertaken field observations and analysis of available hydrological data. The results obtained are as follows:

(a) The annual runoff ratio for the Mae Tang River is about 20%. This is quite low compared with Japanese rivers (*ca.* 70%) which have almost the same annual precipitation. One of the implications of this result is that the gradient of the Mae Tang River is very gentle and that this enhances water storage and promotes evaporation of water from the basin.

(b) It is shown that the discharge of each flood is related to the water storage in the basin. In the case of dry conditions, which are indicated by low levels of baseflow, the initial loss of precipitation increases. This initial loss is one of the causes of the poor correspondence between precipitation and discharge.

(c) The relationship between discharge and suspended sediment concentration is clearly defined for the rainy season. In contrast, in the dry season, the relationship is not clear because of the low discharges. There is a clear tendency for higher concentrations of suspended sediment to be recorded in the first part of the rainy season.

(d) The runoff ratio for individual floods varies seasonally from 10% to 20% in accordance with changes in the initial discharge.

(e) The authors believe that sheet erosion or raindrop erosion are dominant in the basin. This conclusion is supported by observations of discharge and suspended sediment load during floods and by observations with experimental plots.

(f) The grain size composition of soils differs between the sampling sites. Soils from the forest contain less silt and clay compared with paddy fields and grassland. It is supposed that weathering is more active under poor vegetation cover.

(g) Erosion from experimental plots was observed. The results indicate that surface runoff and sheet erosion occur in this area. Long term observations and quantitative evaluation of the results obtained are required for future study.

The following points are identified for further study

(a) In order to estimate flood discharges, it is important to construct a discharge model which incorporates the initial loss.

(b) It is important to study the physical properties of the surface soil and their geographical distribution, since existing results indicate that sheet erosion or raindrop erosion is dominant in this area. Further investigations of soil permeability and of short term rainfall intensities are required.

(c) There is a need to establish the influence of deforestation on soil properties.