SUSPENDED SEDIMENT YIELD RESULTING FROM SELECTIVE LOGGING PRACTICES IN A SMALL WATERSHED IN PENINSULAR MALAYSIA

Baharuddin Kasran & Abdul Rahim Nik

Forest Research Institute Malaysia, Kepong, 52109 Kuala Lumpur, Malaysia

Received December 1992

BAHARUDDIN, K. & ABDUL RAHIM , N. 1994. Suspended sediment yield resulting from selective logging practices in a small watershed in Peninsular Malaysia. Selective logging was carried out in a 28.4 ha forested catchment of Jengka Experimental Basin, Peninsular Malaysia. After six years of the calibration period the catchment was logged by commercial selective logging method. Significant increases in suspended sediment yield were observed. In the first year after logging, the suspended sediment yield increased from 100 to 277 kg ha^{-1} y^{-1} (177%) and further increased to 397 kg ha^{-1} y^{-1} (297%) in the following year. In the fourth year the yield recovered to the pre-logging level.

Key words: Selective logging - suspended sediment concentration - suspended sediment yield

BAHARUDDIN, K. & ABDUL RAHIM, N. 1994. Hasil enapan terampai kesan daripada amalan tebangan memilih di kawasan tadahan kecil di Semenanjung Malaysia. Tebangan memilih telah dijalankan di tadahan berhutan seluas 28.4 ha di Kawasan Penyelidikan Jengka, Semenanjung Malaysia. Selepas enam tahun jangkamasa tentukuran dijalankan tadahan tersebut dibalak secara tebangan memilih. Pertambahan bererti telah dikesan bagi hasil enapan terampai. Dalam tahun pertama selepas tebangan, hasil enapan terampai meningkat dari 100 ke 277 kg ha^{-1} th^{-1} (177%) dan terus meningkat ke 397 kg ha^{-1} th^{-1} (297%) bagi tahun berikutnya. Dalam tahun keempat enapan turun ke paras sebelum tebangan.

Introduction

Forest harvesting is a basic operation in the timber industry. This operation involves construction of logging roads and skid trails, tree cutting, log skidding and transportation. Timber logging activities have been reported as one of the factors causing soil erosion and sedimentation in rivers downstream (Anderson & Potts 1987, Rice *et al.* 1972). Consequently, they may lead to impairment of water quality and degradation of site productivity, affecting fish and wildlife habitats, changing of recreational opportunities and thus the aesthetic value of the forest.

Many studies have indicated that timber harvesting causes increases in sediment concentrations and turbidity in the stream water. For example, Megahan (1972) reported that sediment yield from the entire watershed was increased by 45 times after forest harvesting. In Sri Lanka, selective logging in a Wet Zone forest catchment increased the sediment yield by about 74% as compared to the unlogged catchment (Ponnadurai 1982).

In Malaysian conditions, the effects of forest selective logging on soil erosion and sedimentation have been reported by a number of investigators including Salleh *et al.* (1981, 1983), Abdul Rahim *et al.* (1985), Lai and Shamsuddin (1985) and Baharuddin (1988). However, most of the reports discussed the suspended sediment production and turbidity in the stream channel following logging activities. This paper aims at quantifying the suspended sediment yield resulting from selective logging activity in a forested catchment which is underlain by sedimentary rocks.

Materials and methods

Study area

The study was conducted at the Jengka Experimental Basin located in Tekam Forest Reserve, Pahang, approximately 250 km to the northeast of Kuala Lumpur (Figure 1). It is situated at about 4° 15' N latitude and 102° 37' E longitude with elevations ranging from 80 to 280 m above sea level. The catchment has a total area of 28.4 ha and a southeastern aspect. The topography of the area can be described as undulating to hilly with an average slope of 28%.

The catchment is underlain by upper to middle Triassic sedimentary rocks with parent materials predominantly made up of shale and sandstones. The soil in this area was derived from pyroclastic and volcanic rocks which are interbeded mainly with shales and sandstones of argillaceous strata and arenaceous materials which rise to clayey and sandy texture respectively (Amir Husni 1989). The vegetation is typical of hill dipterocarp forest comprising a three-layered canopy, namely upper, middle and lower layers. The dominant species are *Shorea leprosula, Shorea bracteolate, Dipterocarpus cornutus, Euglina* species and *Cryptocarya* species. The lower layer is dominated by saplings of the upper canopy species and includes palms and shrubs.

After a six-year calibration period, from July 1980 to June 1986, the catchment was selectively logged. During the logging operations crawler tractors were used for construction of logging roads, skid trails and to haul logs to temporary landing points. The cutting regimes were 60 and 45 cm DBH for dipterocarp and non-dipterocarp respectively. Approximately 25% of the stocking was removed during the logging operation from July to August 1986. Measurements of hydrological parameters were continued during the post-treatment period until June 1989. The whole catchment was surveyed for the extent of disturbance as soon as the logging operation had been completed. The soil was considered seriously disturbed when it possessed certain criteria as adopted by Kamaruzaman (1987). The criteria were exposure of B-horizon, the appearance of mineral soil on top of forest floor and evidence of obvious compaction due to the passage of log or mobile ground-based equipment.

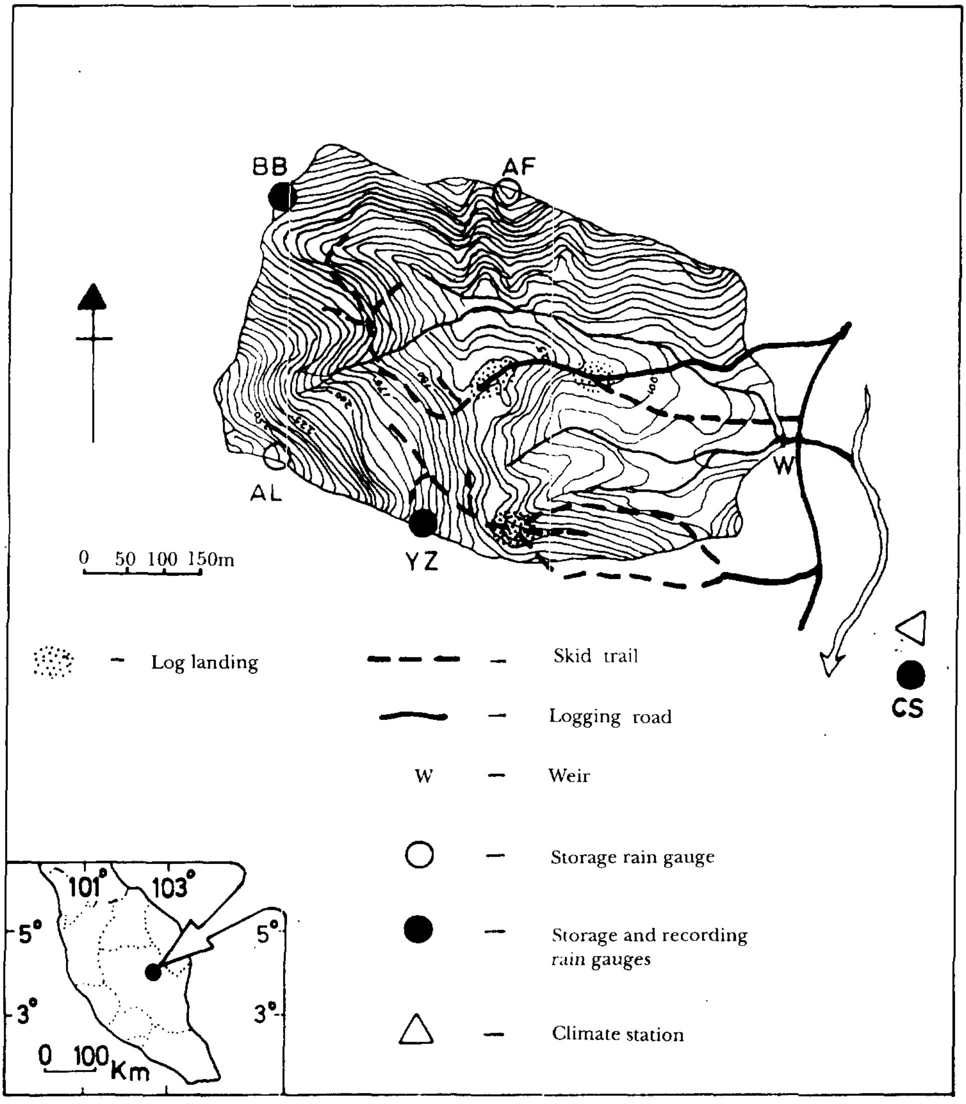

Figure 1. Instrumentation in the Jengka Catchment

Rainfall was measured using standard gauges at five stations, three of which were equipped with tipping-bucket recording gauges (Figure 1). The standard gauges were installed on the top of poles of 11 m height located at the catchment boundaries in order to obtain needed exposure in the forest environment. Streamflow from the catchment was measured with a 120° V-notch weir and water-stage recorder.

Water samples were taken at the V-notch during peak flows and base flows to compute the suspended sediment concentration. The former was carried out during storm events while the latter was on a weekly basis. Weighted mean concentration was calculated by the following equation:

$$\text{Weighted mean suspended sediment (mg l}^{-1}\text{)} = \frac{\Sigma(SS \times Q)}{\Sigma Q}$$

where SS is daily suspended sediment concentration (mg l^{-1}) and Q is daily discharge (l s^{-1}).

Results and discussion

Rainfall

Monthly rainfall distribution of the study area generally showed a two-peak pattern which normally coincided with the northeast monsoon and the transitional period (Abdul Rahim 1983). This pattern occurred in the months of November and May (Figure 2). The annual rainfall total and the number of days of rain for a nine-year period from 1980/81 to 1988/89 water year (WY) are shown in Table 1. The annual rainfall totals ranged from 1789 to 3190 mm with an average of 2508 mm. The 1983/84 WY was the wettest year during the study period and 1982/83 WY was driest with rainfall amounting to 3190 and 1789 mm respectively. Both phenomena occurred in the pre-treatment period. The average days of rain per year was 180 days and the highest was 210 in 1987/88 WY.

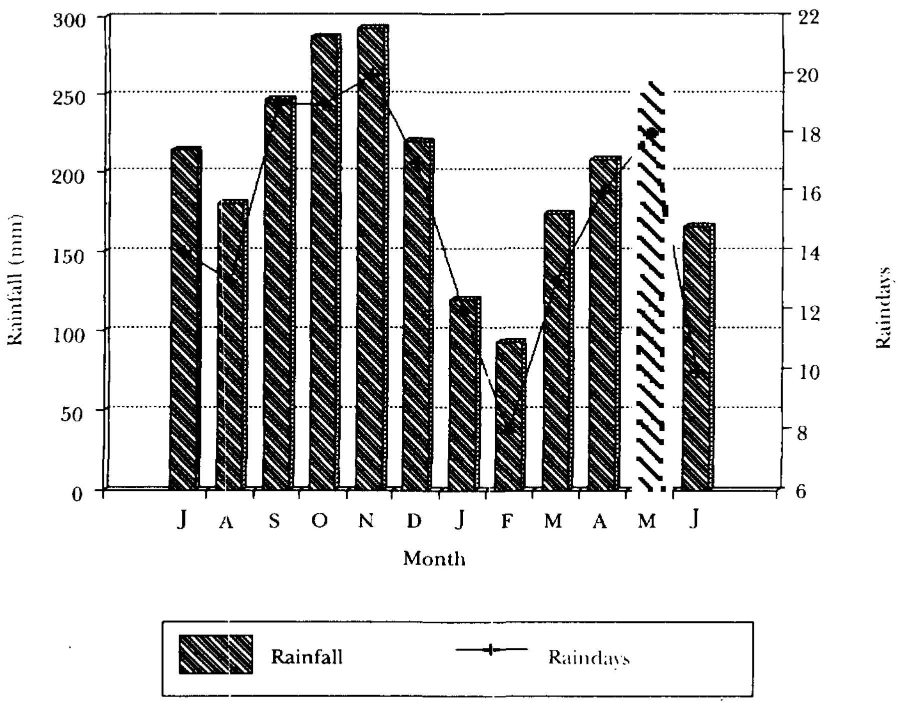

Figure 2. Monthly mean rainfall at Jengka Catchment

Table 1. Annual total rainfall and number of raindays at Jengka Catchment

Water-year	Rainfall (*mm*)	Raindays
1980/81	2066	184
1981/82	2016	148
1982/83	1789	142
1983/84	3190	207
1984/85	2383	174
1985/86	2420	188
1986/87	2551	172
1987/88	3084	210
1988/89	3070	198
Mean	2508	180

Soil damage

Based on the survey, it was found that about 1800 m of skid trails and logging roads were constructed in the catchment (Figure 1). If the temporary landing sites were included, the total soil damage only amounted to 6% of the catchment considered as seriously disturbed due to tractor paths and temporary landing sites. This is lower than the soil damage due to tractor paths in hill forest logging in Sabah which amounted to 12.4% (Philips 1986). The lower level of soil damage in this study can be attributed to a rather less intensive logging operation due to a low forest stocking.

Sediment concentration and yield

Commercial selective logging increased the monthly weighted mean concentration of suspended sediment. Significant increase ($p < 0.05$) in sediment concentration was detected between pre- and post-treatment periods (Table 2). During the pre-treatment period the weighted mean suspended sediment concentration ranged from 1.3 to 47.4 mg l^{-1} with an average of 12.2 mg l^{-1}. In the post-treatment period the concentration ranged from 5.3 to 69.6 mg l^{-1} with an average of 19.5 mg l^{-1}. Surprisingly the suspended sediment concentration both before and after logging was quite low as compared to another study (Peh 1981). This can be associated with relatively low soil disturbance in the catchment and probably also with a high proportion of arenaceous and argillaceous materials which are relatively resistant to weathering. Similar observation was given by Douglas (1968) based on his study at Sungai Gombak Catchment.

Table 2. Sediment yield from Jengka Catchment

	Pre-treatment		Post-treatment	
	Mean	Range	Mean	Range
Rainfall (mm mth^{-1})	191.0 a*	4 - 539	238.0 a	6 - 670
Wt. mean conc. (mg l^{-1})	12.2 a	1.3 - 47.4	19.5 b	5.3 - 69.6
S. sediment yield (kg ha^{-1} y^{-1})	100.0 a	39.5 - 217.9	300.6 b	227.4 - 397.0

* Means in the same row bearing the same letters are not significantly different at 0.05 level as determined by the Scheffe Multiple Range Test.

Although the sediment concentration from the catchment was low, significant increase in suspended sediment yield was observed after logging. The mean annual suspended sediment load increased by 200% from 100.0 kg ha^{-1} y^{-1} during calibration period to 300.6 kg ha^{-1} y^{-1} for post-logging period.

The annual suspended sediment yield during pre-treatment period ranged from 39.5 to 217.9 kg $ha^{-1} y^{-1}$. The highest annual sediment yield during the pre-treatment period was recorded in 1983/84 WY (217.9 kg $ha^{-1} y^{-1}$) and followed by 1984/85 WY (160.2 kg $ha^{-1} y^{-1}$) (Figure 3). It is interesting to note that about 25% of the sediment yield in the 1983/84 WY was generated during a series of large storms over eight days in late December, 1983 when 470 mm of rain was recorded. A 121 mm storm rainfall occurred intermittently within 23 hours in the middle of October 1984, and produced about 15% of total sediment yield in the water year 1984/85. The temporal pattern of the sediment transport generally coincided with the heavy and intense rainfall during the monsoon months from October to December. The importance of large storms in transporting sediment from forest catchments was prominently noted. For example, Beasley and Granillo (1988) observed that large storms of 12.4 cm and 15 cm that accounted for 25% of annual rainfall and 40% of rainfall energy, increased the annual soil loss by 60%. Peh (1981) noted that between 44 and 61% of the annual sediment load totals from three small catchment in Sungai Tekam, Malaysia were transported during the monsoon months.

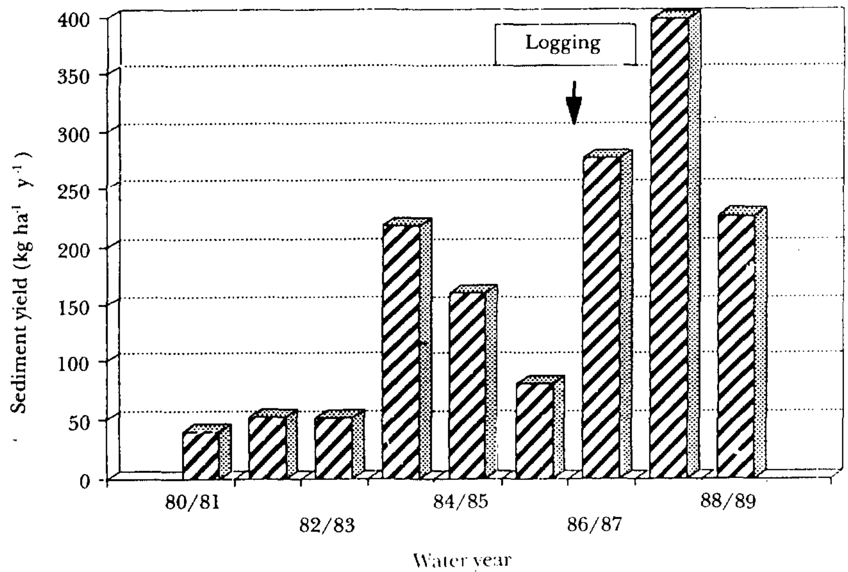

Figure 3. Annual suspended sediment yield at Jengka Catchment

Comparison of mean annual suspended sediment yield before and after logging indicates an increase of about 177% in the first year after logging. A further increase in sediment yield was observed at 397.0 kg ha^{-1}y^{-1} (297%) in the second year, but decreased towards the pre-treatment level thereafter, despite similar rainfall totals. Reduction of sediment yield could be associated with the rapid re-establishment of ground cover and the emergence of seedlings on logging roads and landing areas. Rapid re-establishment of ground cover and fast emergence of pioneering species within one or two years after harvesting is a common sight in tropical rainforest (Zulkifli 1990). The presence of vegetation provides a cover of organic matter over the soil, improves the soil structure and thus increases infiltration capacity. All these factors could reduce the erosive impact of raindrops on the ground surface. Furthermore, the relatively low intensity of logging operation evaluated in this study may have enabled rapid stabilization of sediment sources and reduction of sediment yield.

Table 3 summarizes the suspended sediment concentrations and sediment loads from forested catchments in Peninsular Malaysia. Although the suspended sediment concentration from Jengka is low, the sediment load is comparable to those of other catchments (Sungai Tekam and Berembun Forest Reserves). It seems that the sediment concentration increases drastically during and immediately after logging has completed. However, the sediment concentration tends to recover to pre-logging levels within three to five years. A relatively faster recovery was observed in both logged-over Catchment 1 and Catchment 3 of Berembun Forest Reserve, in which logging roads and skid trails occupied about 6 - 7% of the respective catchments. The amount of sediment produced from watershed is a function of climatic and several physical factors including the amount of bare soil exposed.

Table 3. Stream suspended sediment concentration and sediment yield of undisturbed and logged-over forested catchments in Peninsular Malaysia

	Catchment	Area	Condition	Sediment Conc. (mg l^{-1})	Sediment Load (t ha^{-1} y^{-1})
1.	Kedah				
	Sg. T.Pawang	1810	Forested	2 - 14	na
	Sg. Bujang	875	Logged-over	3 - 172	na
2.	Ulu Gombak F.R., Selangor				
	Sg. Gabok	574	Forested	2 - 388	na
	Sg. Semaping	326	Recently logged	3 - 1132	na
	Sg. Batu Asah	356	Logged-over	3 - 1585	na
3.	Sg. Tekam F.R., Pahang				
	Catchment A	36	Logged-over	21 - 112	0.20
	Catchment B	95	Logged-over	31 - 110	0.45
	Catchment C	57	Logged-over	28 - 90	0.37
4.	Air Hitam F.R., Selangor				
	Catchment A	730	Recently logged	2 - 1305	0.07 - 487
	Catchment B	470	Logged-over	1 - 292	0.13 - 48
5.	Ulu Langat F.R., Selangor				
	Catchment A	309	Logged-over	1 - 1669	0.01 - 197
	Catchment B	136	Logged in progress	4 - 7688	0.04 - 1053
6.	Berembun F.R., Negri Sembilan				
	Catchment 1	12.9	Forested	4 - 386	0.14
			Logged-over	3 - 844	0.27
	Catchment 2	4.2	Forested	4 - 217	0.19
	Catchment 3	29.7	Forested	5 - 158	0.07
			Logged-over	4 - 218	0.11
7.	Jengka Catchment, Pahang (Present study)	28.4	Forested	1 - 47	0.10
			Logged-over	5 - 70	0.30

References:
1. & 2. Salleh *et al.* (1981), 3. Peh (1981), 4. Lai & Shamsuddin (1985), 5. Lai & Rentap (1987), 6. Baharuddin (1988).

Conclusion

Selective forest harvesting in the tropical rain forest significantly increased suspended sediment yield. Marked increase was detected in the first two years after logging was completed. However, the sediment concentration and yield returned to the pre-logging level in the fourth year. A low level of ground disturbance and a rapid rate of ground cover establishment were closely responsible for a fast recovery of sedimentation. In addition, prevailing climatic conditions and physical factors in the forest influenced the amount of sediment yield.

Acknowledgements

We wish to express our gratitude to all staff members of the Hydrology Unit of the Forest Research Institute Malaysia for their effort in data collection, and Zulkifli Yusop for his comments on the manuscript.

References

ABDUL RAHIM, N. 1983. Rainfall characteristics in forested catchments of Peninsular Malaysia. *Malaysian Forester* 46(2): 233 - 243.

ABDUL RAHIM, N., BAHARUDDIN, K. & AZMAN, H. 1985. Hydrological regimes of dipterocarp forest catchments in Peninsular Malaysia. Pp. 25-44 in Saplaco, S.R., Baltazor, E.M., Gorospe, M.V. & Cavandang, V.Q. (Eds.) *Proceedings of Seminar on Watershed Research and Management Practices*. Serdang, 28 Oct. to 1 Nov. 1985. ASEAN-US Watershed Project.

AMIR HUSNI, M. S. 1989. Nutrient cycling under tropical rainforest of Peninsular Malaysia with a special reference to Tekam Forest Reserve, Pahang Darul Makmor. Paper presented at Regional Seminar on Tropical Forest Hydrology. Kuala Lumpur, Malaysia, 4 - 8 September 1989.

ANDERSON, B. & POTTS, D. F. 1987. Suspended sediment and turbidity following road construction and logging in Western Montana. *Water Resource Bulletin* 23(4): 681 - 690.

BAHARUDDIN, K. 1988. Effect of logging and sediment yield in a hill dipterocarp forest in Peninsular Malaysia. *Journal of Tropical Forest Science* 1(1): 56 - 66.

BEASLEY, R.S. & GRANILLO, A.B. 1988. Sediment and water yields from managed forests on flat coastal plain sites. *Water Resources Bulletin* 24(2): 361 - 366.

DOUGLAS, I. 1968. Erosion in the Sg. Gombak catchment, Selangor, Malaysia. *Journal of Tropical Geography* 26: 1 - 6.

KAMARUZAMAN, J. 1987. Impact of ground-based logging machine on soil physical properties and tree growth. M.Sc. thesis, University of Agriculture Malaysia, Serdang.

LAI, F. S. & SHAMSUDDIN, M. 1985. Suspended and dissolved sediment concentration of two disturbed lowland forested watersheds in Air Hitam Forest Reserve, Puchong, Selangor. *Pertanika* 8(1): 155-122.

LAI, F. S. & RENTAP, S. 1987. Sediment concentration from two logged-over watersheds. Pp. 321-333 in Yusof, H., Kamis, A., Nik, M.M. & Shukri, M. (Eds.) *Proceedings of Workshop on Impact of Man's Activities on Tropical Upland Forest Ecosystems. 3 - 6* February 1986, University of Agriculture Malaysia, Serdang, Selangor, Malaysia.

MEGAHAN, W.F. 1972. Logging, erosion, sedimentation - are they dirty words?. *Journal of Forestry* 70: 403 - 407.

PEH, C.H. 1981. The suspended sediment and dissolved sediment load of three small forested drainage basins in Peninsular Malaysia. *Malaysian Forester* 44(4): 438 - 452.

PHILIPS, C. 1986. Preliminary observations on the effects of logging on a hill forest in Sabah. Pp. 187-215 in Yusof, H., Kamis, A., Nik, M.M. & Shukri, M. (Eds.) *Proceedings of Workshop on Impact of Man's Activities on Tropical Upland Forest Ecosystems.* 3 - 6 February 1986, University of Agriculture Malaysia, Serdang, Selangor, Malaysia

PONNADURAI, D. K. 1982. Effect of selective felling on the hydrological parameters of a wet zone forest catchment. *Sri Lanka Forester* 15(3): 139 - 153.

RICE, R. M., ROTHACTER, J. S. & MEGAHAN, W. F. 1972. Erosional consequences of timber harvesting. An appraisal. Pp. 321 - 329 in *Proceedings of National Symposium on Watershed in Transition.* Fort Collins.

SALLEH, M. N., ABDUL RAHIM, N. & MUSHRIFAH, I. 1981. Logging and water quality. A Malaysian experience. Paper presented in the International MAB Symposium on Man's Impact on Ecosystem Dynamics - with Emphasis on Influences on Environment Pollution. 15 - 17 December, Tokyo, Japan.

SALLEH, M. N., ABDUL RAHIM, N. & MUSHRIFAH, I. 1983. The effect of logging on sediment yield in two forested catchment areas. Pp. 61- 69 in Kamis, A., Lai, F.S., Lee, S.S. & Abdul Rahman, M.D. (Eds.) *Proceedings of the Regional Workshop on Hydrological Impacts on Forestry Practices and Reforestation.* 2 - 6 November 1981, University of Agriculture Malaysia, Serdang, Selangor, Malaysia.

ZULKIFLI, Y. 1990. Effects of logging on stream quality and solute input-output budgets in small watersheds in Peninsular Malaysia. M.Sc. thesis, University of Agriculture Malaysia.