Sediment Budgets 2 (Proceedings of symposium S1 held during the Seventh IAHS Scientific Assembly at Foz do Iguaçu, Brazil, April 2005). IAHS Publ. 292, 2005.

Impact of ground-based timber harvesting on suspended sediment yield in the Sungai Weng Experimental Watersheds, Kedah, Peninsular Malaysia

F. S. LAI[1], I. AKKHARATH[1] & K. S. LOW[2]

1 *Department of Forest Management, Universiti Putra Malaysia, 43400 UPM, Serdang Selangor DE, Malaysia*
lfsee@forr.upm.edu.my

2 *Hydrology Division, Drainage and Irrigation Department, Km 7, Jalan Ampang, 68000 Ampang, Kuala Lumpur, Malaysia*

Abstract This paper reports on changes in suspended sediment production in the Sungai Weng Experimental Watersheds, in particular, watersheds W2 and W3, due to ground-based timber harvesting from 1997 to 2002. W3 was logged under normal practice using the crawler tractor-winch-lorry system, whereas W2 was logged using reduced impact logging guides such as a wider 30-m stream buffer strip and 40° slope limit, among others. Logging operations in W3 ran from February 1998 until the end of 2000 and in W2 from June 2000 to March 2003. Suspended sediment concentrations varied within the period of study, increasing dramatically during logging. For instance, the maximum concentration levels sampled in W3 increased from 1980 mg l^{-1} in 1997 to a peak of 92 500 mg l^{-1} in 1999. After logging ceased, concentration levels fell to 30 200 mg l^{-1} in 2001 and to a much lower 19 500 mg l^{-1} the following year. Peak suspended sediment concentrations were lower in W2, however, suggesting that the extra measures taken to lower the logging impact had some influence on sediment yield in the affected basin. Based on pre-harvesting conditions, data from the Sungai Weng experimental watersheds suggest that conventional logging can increase the suspended sediment yield some 42 times during peak periods, but declines as the watershed recovers.

Key words conventional logging; experimental watersheds; ground-based harvesting; Malaysia; reduced impact logging; suspended sediment

INTRODUCTION

The effects of forestry practices on catchment sediment production have always been a major concern in Malaysia. Various studies conducted in the past suggest that selective timber harvesting in the hill forests, using conventional ground-based systems, generates high sediment loads (Lai, 1993; Lai *et al.*, 1995). Results from such activities in forested lowland watersheds in the peninsula (Baharuddin *et al.*, 1988; Zulkifli *et al.*, 1990) and Sabah, East Malaysia (Douglas *et al.*, 1992; Greer *et al.*, 1996) also suggest marked increases in sediment loads over undisturbed forested watersheds. The scale of disturbance appears to depend on logging intensity, construction of roads, skid trails, and log landings and the extent of the open spaces created, particularly bare soil, during operations. There have been on-going efforts on the part of the Forest Department to improve timber harvesting practices so as to reduce environmental impacts, notably in soil erosion and sedimentation. However, there is very little information on the responses to improved logging methods, especially in hill-forest watersheds.

The need to obtain quantitative information on such impacts led to the establishment of the Sungai Weng Experimental Watersheds, conceived largely to determine the magnitude of sediment production resulting from selective timber felling and extraction using conventional and reduced impact logging (RIL) methods. Instrumented in 1996, additional work related to forest management, impact on wildlife, and economic evaluation were also studied. This paper reports on some of the findings on suspended sediment production obtained using the paired catchment approach, with particular attention to the treated watersheds.

MATERIALS AND METHODS

General description

The study area, located south of the Muda water catchment, is part of the Ulu Muda Forest Reserve (Fig. 1). Streams draining the study watersheds are tributaries of the Sungai Weng, hence the given name Sungai Weng Experimental Watersheds. The eastern drainage divide represents the political boundary of Peninsular Malaysia and Thailand.

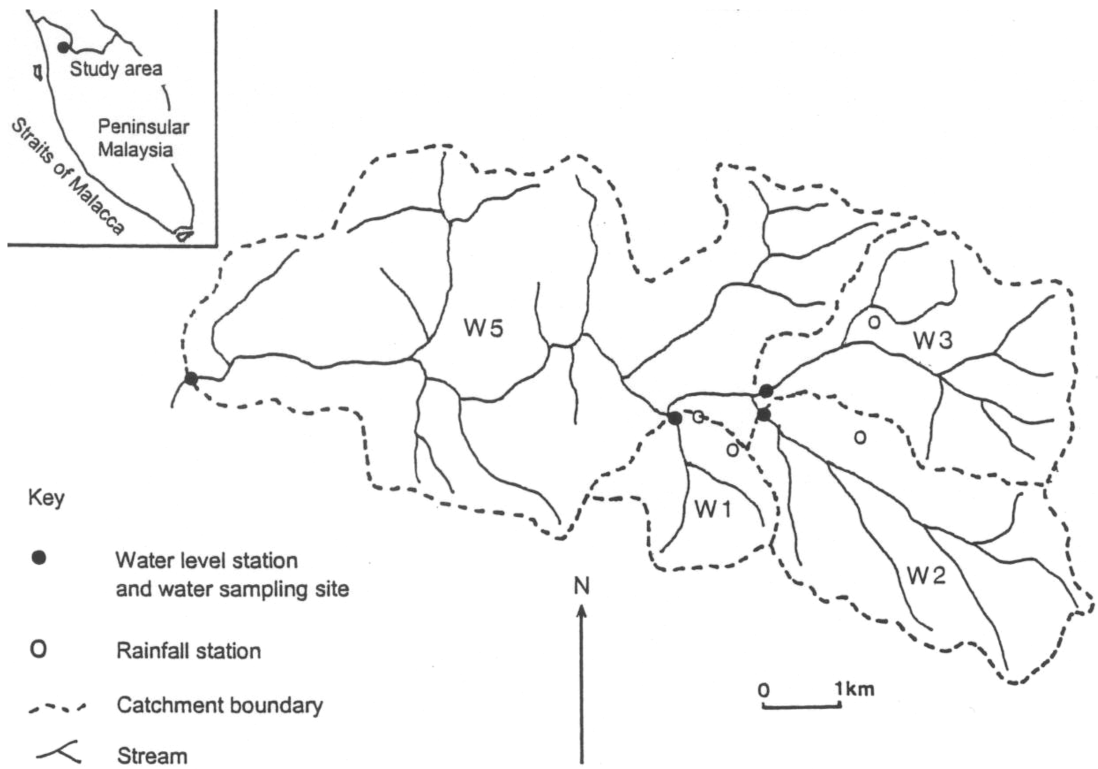

Fig. 1 Location of the study area.

The underlying geology of the study area is Main Range granitic batholith. The oldest rocks found in much of the area are the arenaceous, calcareous, and argillaceous Baling Formation. Based on radiometric dating of granite samples taken in southern Thailand and parts of the peninsula, the Main Range is mainly Triassic or older (Burton & Bignell, 1969).

The study area is predominantly of the Hill (350–750 m) and Upper Dipterocarp (750–1200 m) forest type, based on Symington's (1943) and Whitmore's (1975) Malaysian floristic classification. From the forestry inventory data collected, the former is dominated by the *Shorea curtisii* followed by other Dipterocarp species such as *Anisoptera curtisii, Shorea leprosula, Shorea parvifoli*a, and *Hopea* species. The Upper Dipterocarp forests are mainly comprised of *Shorea platyclados* and *Anisoptera curtisii*. In the lower areas, below 350 m, Lowland Dipterocarp Forests are mainly comprised of Shoreas (*S. acuminata, S. leprosula* and *S. macroptera*), as well as some *Dipterocarpus* species such as *D. cornutus* and *D. kerii*.

Climate is typically equatorial, characterized by high rainfall and humidity, with a fairly uniform annual temperature between 26 and 29°C. Influenced by the southwest and northeast monsoons, the rainfall distribution in the study area falls between the northwest and west rainfall region (Dale, 1959), typified by two maxima and two minima per year. The maxima occur during the transitional seasons of April and October/November; the October/November maximum usually is the larger. Average rainfall is about 2300 mm.

Study site

The Sungai Weng Experimental Watersheds comprise four third- to fifth-order basins (Strahler, 1957; based on 1:50 000 topographic map). Watershed W1 was a control site; timber harvesting was not allowed throughout the study period; W2 was logged using RIL guidelines developed by the Forest Department (Table 1); W3 was logged using conventional practices; and W5, is a larger watershed within which the smaller experimental basins are nested, and was included to examine the downstream and cumulative effects of logging operations and includes areas that had been selectively logged previously.

Rainfall and water level recorders, as well as automatic samplers with predetermined stage float switches, were installed in each watershed. Stream water samples

Table 1 Watershed characteristics.

Description	W1	W2	W3	W5
Area (km^2)	2.8	8.6	7.6	42.1
Watershed slope	0.42	0.39	0.39	0.38
Main channel slope	0.09	0.13	0.11	0.03
Lowest elevation at basin outlet (m)	350	410	390	150
Highest elevation (m)	720	1113	1054	1113
Drainage density (km km^{-2})	3.1	3.4	2.5	3.5
Stream order	3	4	4	5

collected from grab samples and the automatic samplers were analysed for sediment concentrations using a gravimetric method. Millipore 0.45-μm membrane filters were used. The samples were ashed at 550°C for 2 h to remove organic matter.

Stream stage-discharge rating curves, for individual study watersheds were derived from periodic current metering, especially during the wet months. For each basin, individual sediment rating curves were developed using data collected on the rising and falling limbs of hydrographs. The sediment rating curves were applied at hourly intervals to obtain suspended sediment load estimates.

Treatment description

Timber harvesting in permanent forest estates in Malaysia is carried out selectively. The intensity is usually determined by a cutting regime which specifies the tree girth size for extraction. This recommendation comes from the respective State Forest Departments. In the study area, the treatment in conventional logging was consistent with timber licenses granted in this part of the country. Under the conventional method, 60 cm diameter at breast height (dbh) for Dipterocarp, and 40 cm dbh for non-Dipterocarp merchantable timber were prescribed. In W2, the cutting regime was 80 and 65 cm, respectively. The lower intensity timber harvest was deliberate to assess the severity and extent of the impact. Additional specifications imposed in W2 included: (a) the use of front-end excavators for road building; (b) the need for proper road alignment; (c) side-drain diversions; and (d) wooden bridges, proper culverts and water bars on roads closed after operations. Additional restrictions on operations in areas where slopes are greater than 40° and 1000 m in elevation, and directional felling, also were imposed. A bigger 30-m wide buffer strip, from the stream bank, also was prescribed in place of the normal 20-m wide riparian protection zone.

Logging phases

Although an ideal approach was to have W2 and W3 treated at the same time, so as to assess responses under similar climatic conditions, this was precluded for logistical reasons. As a result, forest operations in the study watersheds were carried out over two phases. Conventional logging was first carried out in W3 on 11 February 1998. The watershed was divided into six blocks of between 110 and 150 ha, and harvesting operations took approximately two years to complete. In W2, five blocks were demarcated, and were logged following the reduced impact logging guidelines described previously; forest operations began on 18 June 2000 and ceased in March 2003.

At both sites, initial work began with a pre-felling inventory and tree marking to ascertain the stock in each block. Road construction and tree felling followed. Felled logs were then hauled from the stumpage areas to log landings by bulldozers, and eventually transported out using locally modified logging trucks for further production inventory, before commercial distribution.

RESULTS AND DISCUSSION

Suspended sediment concentrations

Under primary forest conditions, suspended concentrations during baseflow were low for all the study basins. This was expected since sediment supply from the forest floor is small due to the presence of dense undergrowth and forest litter that offer natural protection from soil erosion. Higher concentrations are usually recorded with increased discharge, as the source of much of the suspended sediment would be from reworked material in the stream channel and from bank erosion. The highest concentrations sampled were between 1280 and 1890 mg l^{-1} for W1 (the control site) during the six-year study period (Table 2).

During the very early stages of treatment in W3, there was little evidence of high suspended sediment concentrations from road construction because of dry weather. However, about a week after the first few kilometres of road were built, and with the onset of rain, concentrations increased. A stormflow sample on 17 February 1998 recorded a peak of 8640 mg l^{-1} at 1.4 m^3 s^{-1}. Gradually, as more roads and skid trails were built, to facilitate hauling logs felled further into the watershed, suspended sediment concentrations progressively increased. The highest for the year was about 48 000 mg l^{-1} recorded on 31 October for a 4.0 m^3 s^{-1} peak flow (Table 2). During the study period, the highest recorded suspended sediment concentration was about 92 500 mg l^{-1}, recorded on 17 March 1999, about a year after operations began. Presumably, this was the period of greatest impact, as peak flow concentrations began to decline in the following years, although they remained relatively high. About 19 500 mg l^{-1} was recorded in October 2002, about two years after logging stopped. At the end of the treatment period, about 30 km of road had been built.

For about three years before merchantable timber was extracted in W2, the highest suspended sediment concentrations were between 1940 and 2430 mg l^{-1}. However, suspended sediment concentrations, particularly during storms, were higher than pre-treatment conditions, as roads gradually were built. The first relatively large storm samples, after seven weeks into road construction in the basin, registered a high of 8000 mg l^{-1} at 8.3 m^3 s^{-1} flow. Note that the longer lag time in contrast to W3, probably occurred because July and August are among the driest months of the year.

Table 2 Highest suspended sediment concentrations sampled each study year.

Year	W1		W2		W3		W5	
	Sus. Sed. (mg l^{-1})	Spec. disch. (m^3 s^{-1} km^{-2})	Sus. Sed. (mg l^{-1})	Spec. disch. (m^3 s^{-1} km^{-2})	Sus. Sed. (mg l^{-1})	Spec. disch. (m^3 s^{-1} km^{-2})	Sus. Sed. (mg l^{-1})	Spec. disch. (m^3 s^{-1} km^{-2})
1997	1280	0.378	2130	0.456	1980	0.241	12700	0.182
1998	1790	0.843	2430	0.393	48000	0.542	21500	0.194
1999	1660	1.263	1940	0.456	92500	0.678	23800	0.125
2000	1890	1.390	14300	0.272	36000	0.707	11800	0.131
2001	1760	0.679	38900	0.413	30200	0.540	13300	0.131
2002	1830	1.527	47000	0.337	19500	0.185	18200	0.264

Nevertheless, there appears to have been comparatively less soil erosion and sediment delivery into the W2 stream system, probably as a result of lower timber production, with improved road construction and stream crossings, and with attention given to riparian protection. Although concentrations progressively increased, they were less dramatic compared to the conventionally logged area. The highest concentration of 47 000 mg l^{-1} occurred on 7 October 2002, more than two years after operations began, when the discharge was 2.9 $m^3 s^{-1}$.

Suspended sediment yield

Suspended sediment concentrations alone, do not reveal much about watershed conditions and responses over a specific period. They do, however, provide some insight into the dynamics of sediment transport, especially during storms which have short time frames and which are very much tied to discharge. To better reflect overall cause and effect changes in watershed conditions, suspended sediment loads, computed from continuous discharge records, were developed. Essentially, catchment sediment yield, as opposed to suspended sediment concentration, provides a more useful index of the severity and temporal trends of erosion.

Suspended sediment yields resulting from conventional timber harvesting were high (Fig. 2). In W3, the yield rose to about 2130 t km^{-2} $year^{-1}$ by the end of 1998, and peaked at 5390 t km^{-2} $year^{-1}$ in 1999, before declining in the following three years. Using the W1 (control site) mean annual load of 127 t km^{-2} $year^{-1}$ as a comparison, the increase in yield was about 42 times higher than pre-harvest conditions. A plot of the cumulative sediment yield against time, for the study period, very clearly shows the marked difference in sediment output for individual basins (Fig. 3). The high sediment

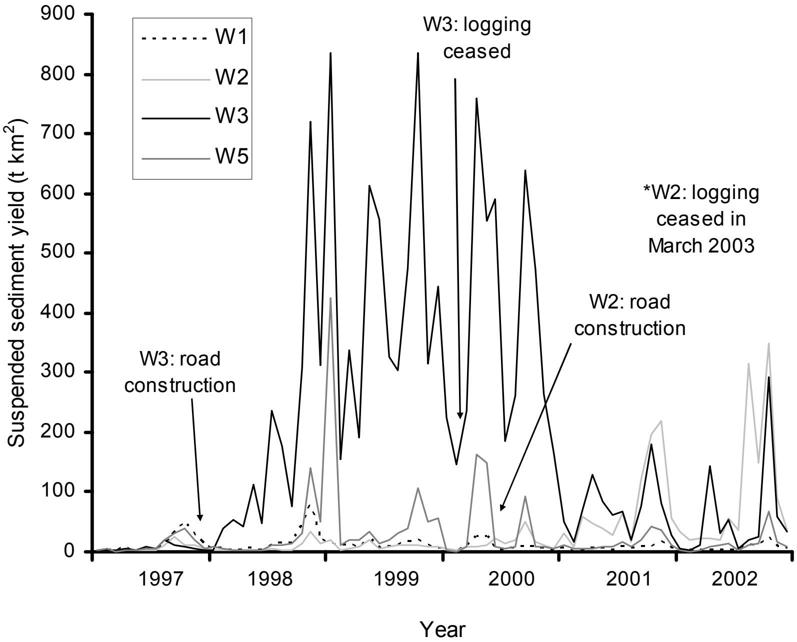

Fig. 2 Monthly suspended sediment yield in the Sungai Weng watersheds.

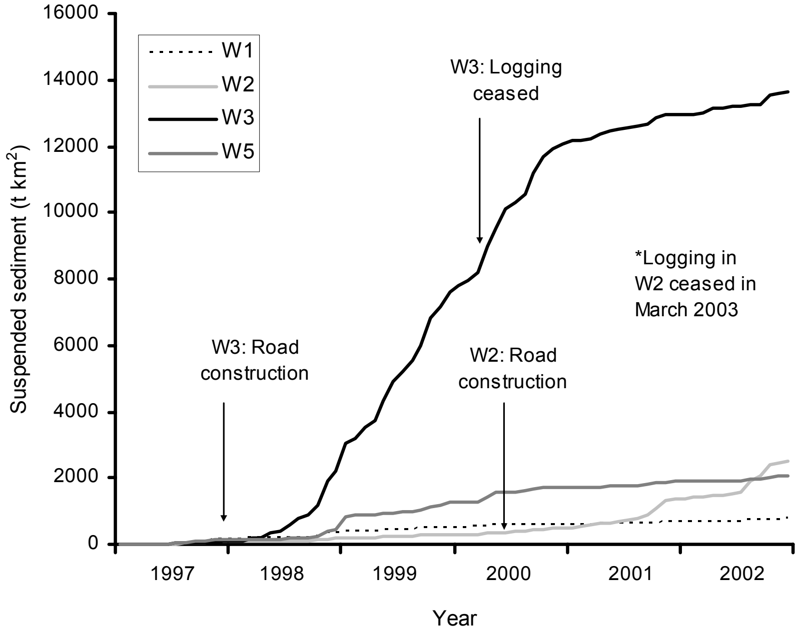

Fig. 3 Cumulative sediment yield for the study watersheds.

output was mainly due to large amounts of eroded soil delivered into the streams from road and skid trail construction. Although road and skid trail widths measured between 4 to 5 m along most stretches, cut and fill during construction to improve road grades, usually required movement of large amounts of soil. Improper soil disposition along road shoulders often resulted in loose materials being carried away from slope areas by runoff.

There also is the likelihood of landslides during rainy spells, particularly in the right-of-way clearings along road cuts; these would have contributed to overall sediment delivery into nearby streams. Unfortunately, this was not quantified during the study.

Interestingly, although operations ceased in February 2000, the annual yield was still high, about 4500 t km^{-2} year^{-1}. Although all forms of vehicular movement within the watershed had virtually ceased, active soil erosion remained, especially on exposed roads and skid trails, and to a smaller extent, from log landings. Vegetative re-growth in the exposed areas takes time, even longer in areas where soil compaction had been severe. Small gullies usually develop along road shoulders, particularly those built on weaker slopes. Soil erosion from such exposed areas will only decline over time, and only ceases if vegetation, particularly the grasses, creepers, and ferns, provide adequate foliage cover and only if their roots are well established.

Data from W2, where RIL had been instituted, indicated that the sediment output was much lower, about nine times above the background mean yield of W1 (compared to 42 times for W3). These results suggest that RIL had achieved a high degree of success in reducing sediment production. The connection between sediment output and increased amounts of exposed areas was made by measuring the extent of roads, skid trails, and log landings built in both watersheds. Results suggest that the exposed areas, in proportion to watershed area in W3 and W2, were about 9 and 5% respectively.

In addition, lowering timber harvest intensity inadvertently exercised an important influence in reducing the risk of loss of canopy cover which, in turn, offered better protection against soil erosion. Fewer tree removals also meant less potential damage to ground cover. In addition, restrictions placed on relatively sensitive areas, such as extremely steep sloping land, and the provision for wider buffer strips had, in many ways, prevented more sediment from moving into streams. Field checks suggested that although some sediment did reach stream channels, these usually were found along steep slopes where the effectiveness of sediment filtering was reduced. However, much more sediment got into stream channels at stream crossings. This was unavoidable, but the use of small diameter logs to stabilize stream banks, was effective at minimizing siltation. Subsequent vegetative growth on these banks further stabilized soil movement. In many places, directional felling helped reduced stand damage; hence, unnecessary canopy cover openings were avoided. However, a more detailed analysis on W2 is essential because logging operations ceased in March 2003, and the data collected in 2003 were not analysed in this paper.

Downstream sediment yields from both treated watersheds were similar, and appeared to be relatively minor, despite the marked local differences. This appeared to result from dilution from unaffected streams within otherwise recovered or recovering sub-basins. Deposition of sediment along stream channels as flow receded is another variable worth examining. Such levels were anticipated since impact is attenuated with distance. The distance from the treated watershed outlets to the sampling station at W5 is about 12 km.

CONCLUDING REMARKS

Results from six years of data collection in the Sungai Weng Experimental Watersheds demonstrate that suspended sediment output resulting from conventional ground-based timber harvesting can be high. This is especially so since the ground operations commonly involve land exposure and earth work, particularly in road and skid trail construction. As illustrated earlier, the extent of exposed area created was an important determinant in watershed sediment production.

The impact of tree felling, on the other hand, is usually negligible because the under-storey tree cover, usually comprising smaller diameter trees, leaves the overlying canopy essentially untouched. The effect is even less when the forest is lightly logged. The collapse of a dead or diseased tree would have the same effect, for example. RIL also is practiced to minimize stand damage, and therefore maintains effective canopy cover. Thus, timber extraction methods would be the main factor controlling sediment production, among other environmental concerns. The impact from using aerial methods for extracting timber, for instance, would be very much lower.

Data obtained in the study watersheds are continuously assessed, and further work is being carried out to determine potential long-term effects, and lengths of recovery from forest harvesting. Results from a separate study in Selangor suggest that recovery will take more than five years before sediment yields return to background levels (Lai, 1993). Such information will be valuable for forest management purposes, both at the stand and at catchment levels.

Acknowledgements The authors wish to thank the Drainage and Irrigation Department Malaysia and Muda Agricultural Development Board (MADA) for funding and support. We are grateful to Ir. Foong Kam Chong, Ir. Geh Yean Lian, En. Asnor Ishak for logistical support. We are also thankful to Zaim Rashid, Zuki Harun, Khairul Said and many individuals at MADA and Muda Dam for their assistance in the field, for without which, data collection would have been a very much more difficult task.

REFERENCES

Baharuddin, K. (1988) Effects of logging on sediment yield in a hill dipterocarp forest in Peninsular Malaysia. *J. Trop. For. Sci*. **1**, 56–77.

Burton, C. K. & Bignell, J. D. (1969) Cretaceous-Tertiary event in southeast Asia. *Geol. Soc. Am. Bull.* **80**, 681–688.

Dale, W. L. (1959) The rainfall of Malaya I. *J. Trop. Geogr*. **13**, 23–37.

Douglas, I., Spencer, T., Greer, A., Bidin, K., Sinun, W. & Meng, W. W. (1992) The impact of selective commercial logging on stream hydrology, chemistry and sediment loads in the Ulu Segama rainforest, Sabah, Malaysia. *Phil. Trans. Roy. Soc. Lond. B*, **335**, 395–406.

Greer, T., Waidi, S., Douglas, I. & Kawi, B. (1996) Long term natural forest management and land-use change in a developing tropical catchment, Sabah, Malaysia. In: *Erosion and Sediment Yield: Global and Regional Perspectives* (ed. by D. E. Walling & B. W. Webb) (Proc. Exeter Symp., July 1996), 453–462. IAHS Publ. 236. IAHS Press, Wallingford, UK.

Lai, F. S. (1993) Sediment yield from logged, steep upland catchments in Peninsular Malaysia. In: *Hydrology of Warm Humid Regions* (ed. by J. S. Gladwell) (Proc. Yokohama Symp., July 1993), 219–229. IAHS Publ. 216. IAHS Press, Wallingford, UK.

Lai, F. S., Lee, M. J. & Mohd, R. (1995) Changes in sediment discharge resulting from commercial logging in the Sg. Lawing basin, Selangor, Malaysia. In: *Effects of Scale on Interpretation and Management of Water Quality* (ed. by W. R. Osterkamp) (Proc. Boulder Symp., July 1995), 55–62. IAHS Publ. 226. IAHS Press, Wallingford, UK.

Strahler, A. N. (1957) Quantitative analysis of watershed geomorphology. *Trans. Am. Geophys. Union* **38**, 913–920.

Symington, C. F. (1943) *Forester's Manual of Dipterocarps*. Malayan For. Rec. no. 16. Kuala Lumpur, Malaysia.

Whitmore, T. C. (1986) *Tropical Rain Forests of the Far East* (second edn). Oxford University Press, Oxford, UK.

Zulkifli Y., Abdul Rahim, N. & Baharuddin, K. (1990) Hydrological impacts of forestry and land use practices in Malaysia. In: *Proceedings on Forestry and Forest Products Research CFFPR-90*, 146–160. Forest Research Institute Malaysia, Kuala Lumpur, Malaysia.