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WATER YIELD CHANGES AFTER FOREST CONVERSION TO AGRICULTURAL LANDUSE IN PENINSULAR MALAYSIA

Abdul Rahim Nik

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

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ABDUL RAHIM NIK. 1988. **Water yield changes after forest conversion to agricultural landuse in Peninsular Malaysia.** A paired-watershed experiment, comprising three small catchments in Sungai Tekam, Pahang, Peninsular Malaysia, was carried out from 1977 to 1986 to determine and quantify the effect on water yield of a typical forest land conversion to agricultural landuse. Two Catchments, A and B, were treated after five and three years of calibration and subsequently planted with cocoa and oil palm, respectively. Significant increases in water yield were observed in both catchments. The highest increase occurred in the second and fourth year after treatment, amounting to 706 *mm* (157%) and 822 *mm* (470%) in Catchments A and B, respectively. Different magnitudes of annual yield increment apparently reflected the various activities of land conversion including timber harvesting, under-brushing, clear felling, road construction and planting of cover crops. Management implications of these yield increases are discussed.

Key words: Water yield – paired catchment – forest conversion – land use – management.

Introduction

Rapid land development programmes initiated during the early 1960's in Malaysia entailed a large scale conversion of forest land to other landuses, primarily agriculture. As agriculture is still the backbone of the Malaysian economy, the trend remains. As a result, in the past two decades, more than 1.5 million *ha* of lowland forests have been systematically converted to agriculture, primarily rubber and oil palm. Rural development, urbanisation and water reservoir needs will also maintain pressure on forest land in the next few years. Consequently, forest land area in Peninsular Malaysia has been drastically reduced, from 60% in 1974 to 49% in 1987 (MPI 1988). As a result, today, logging for timber occurs mostly in hill dipterocarp forests, areas which invariably constitute headwater catchments.

Effects of forest conversion

Despite the long history of forest land conversions in Malaysia, the quantitative impacts of such conversions on the environmental resources, particularly water and soil, have received little attention. Past reviews on the potential effects of land conversions were merely qualitative, and highlighted on the magnitude and intensity of forest transformations on soil, water quantity and quality (Daniel & Kulasingam 1974, Toebes & Goh 1973, Low & Peh 1985). Relatively little information is available to date on which quantification of the effects of such conversions are to be based with reasonable accuracy except for this study at Sungai Tekam Experimental Basin (STEB) in Pahang, Peninsular Malaysia (DID 1982, 1986), as well as on-going studies conducted by the Forest Research Institute Malaysia (Abdul Rahim & Zulkifli 1987).

Studies from temperate countries show a variation of responses resulting from forest clearance or conversions. In general, these studies reveal significant increases in water yield (Bosch & Hewlett 1982, Reinhart *et al.* 1963, Rothacher 1970, Pearce *et al.* 1980), as well as an increase in the stormflow volume (Hewlett & Helvey 1970). However, results from temperate areas may not be readily extrapolated to the humid tropics.

Recently, Bruijnzeel (1986) reviewed the effect of forest conversion on water yield for some humid tropical countries (Table 1). Conversion of rain forests to other land uses in Australia (Gilmour 1977), Tanzania (Edwards 1979) and Taiwan (Hsia & Koh 1983) characteristically revealed increases in water yield afterwards. Bruijnzeel (1986) concluded that regardless of the type of conversion, the highest increase is normally observed in the year immediately after the treatment, followed by more or less a regular decline with the establishment of the new cover. In Malaysia, from the information available, Toebes and Goh (1975) report that 10% or 120 *mm* increase in water yield resulted from forest clear cutting. However, this conclusion was derived based on desultory observations from different catchments.

In this paper, I describe and quantify the effect of forest conversion and associated operations on water yield characteristics based on the STEB study.

Description of study area

The Sungai Tekam Experimental Basin (STEB) study, an inter-agency research project, was initiated in 1973 but the actual calibration commenced in 1977 after completion of instrument installation. The main objective of this study was to determine the effects of landuse changes on the hydrology of the basin, focussing on various components of surface flow as affected by the conversion from logged-over forest to agricultural plantations, namely oil palm and cocoa (DID 1982, 1986). Most of the land development schemes undertaken in Malaysia are carried out on logged-over forests after all commercial timbers have been extracted.

Basin description

The STEB is located in a logged-over dipterocarp forest within the Tun Razak Agricultural Research Centre (TRARC) in Jerantut, Pahang. The basin consists of three catchments, A, B and C, in which Catchment A is nested within the larger

Table 1. Forest cover transformations in the humid tropics and changes in water yield

Location Location	Type of transformation Type of transformation	Catchment size *(ha)*	M.A.P* *(mm)*	Elevation (m.a.s.l.)	Change in water *(mm.yr*^{1}*)* 1st *yr*	2nd *yr*	rd *yr*	4th *yr*	nth *yr*	Reference
Babinda, Queensland	Lowland rain forest to grass (35%) & scrub (35%)	18.3	4035	10–200	+264 (7.0%)	+323[a] (13.4%)				Gilmour, 1977b
Lien-Hua-Chi Taiwan	Clearcutting of mixed evergreen hill forest; regeneration	5.9	2100	725–785	+448 (58%)	+204[b] (51%)				Hsia & Koh
Mbeya, Tanzania	Evergreen montane forest (1/3 grass and shrub) vs. agriculture land-use (50% annual cropping and 50% grazing land)	16 vs 20	1900	2500					+408	Edwards, 1979
Java, Indonesia	Slightly disturbed lowland rain forest vs. c. 20-*yr*-old plantation of *Agathis dammara* (moderately stocked)	19	3000	70 vs 560					+175[c]	Murdiyarso, 1985 Bruijnzeel 1983[a]
Sg. Tekam (A) Malaysia	Dipterocarp forest to cocoa	37.7 vs 56.3	1878	72.5	110 (117%)	706 (157%)	353 (94%)	263 (158%)		This study
Sg. Tekam (B) Malaysia	Dipterocarp forest to oil palm plantation (60%) and cocoa (40%)	96.9 vs 56.3	1878	68.5	+145 (85%)	+155 (142%)	137 (97%)	822 (470%)		This study

* Mean Annual Precipitation   [a] wet year;   [b] dry year;   [c] computed via difference in ratio's between forest evapo-transpiration and Penman open water evaporation. (corrected for altitudinal effects)

Source: Bruijnzeel (1986)

Catchment B (Figure 1). Catchments A and B have been treated in 1982 and 1980 respectively while Catchment C is the control. The catchments, drained by second-order streams, are in the headwater of Sungai Tekam, a tributary of Sungai Pahang. The slopes of the basin are mostly gentle, about 6° – 8° gradient, while moderately steep slopes (12° – 15°) are found along the valley sides of the stream.

The dominant rock types are andesitic tuff and andesites, believed to be Permian, and occur interbedded with sedimentary rocks. Six soil series have been identified in the basin, the series Munchong (Tropeptic Haplic), Segamat (Haplic Acrorthox) and Katong (Tropeptic Haplorthox) constitute 90% of the area. Vegetation of the basin and its composition have been described by DID (1982). Physical characteristics of the three catchments are given in Table 2.

Table 2. Some physical descriptions of the basin

Catchment	A	B	C
Area (*ha*)	37.7	96.9	56.3
Mean elevation (*m*)	72.5	68.5	70.0
Morphometric properties:			
i) Drainage density (*m/ha*)	43.3	46.6	37.0
ii) Hypsometric integral	0.36	0.26	0.38
iii) Length of overland flow (*m*)	115	107	135
iv) Mainstream gradient (*m/m*)	0.013	0.119	0.008
Main soil series	Segamat	Katong	Munchong
Geology:			
(Parent material of main series)	Andesitic Tuff	Quartz Andesite	Lateritic Shales

General climatic conditions of the experimental basin based on a 12-year record are as follows:

Mean Annual rainfall	:	1916 *mm*
No. of rainy day/*y*	:	159
Air temperature		
Maximum	:	32.1°C
Minimum	:	21.4°C
Relative Humidity (Avg.)	:	80.5%
Pan Evaporation	:	3.5 *mm/day*
Sunshine hours	:	5.62 *h/day*
Windrun	:	52.3 *km/day*

This study adopted the classical 'paired-catchment approach' which comprises

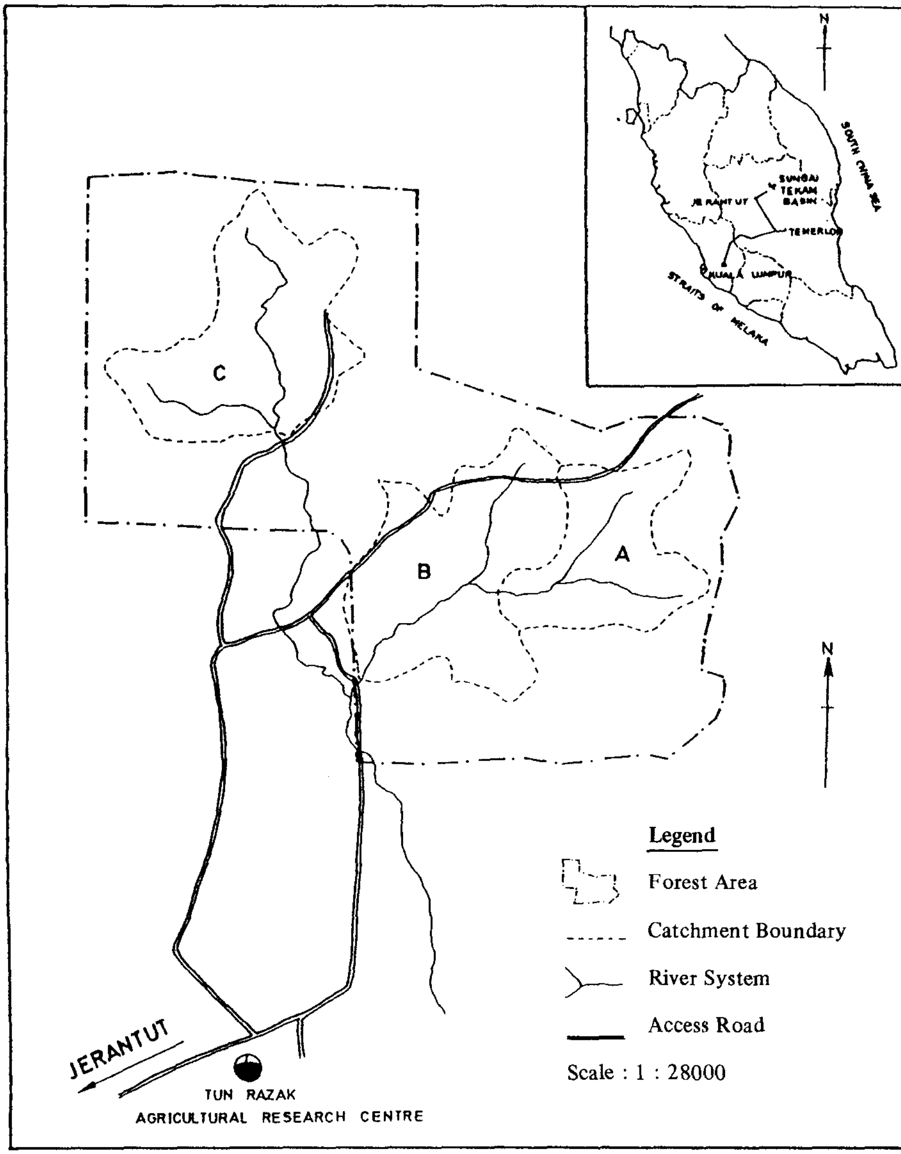


Figure 1. Location of Sungai Tekam Experimental Basin, Peninsular Malaysia (Source: DID, 1986)

three phases of monitoring: calibration, transition and evaluation phases. During the calibration phase, basic hydrologic and climatic data were continuously monitored. This formed the basis upon which to establish a normal relationship between control and treated catchments and subsequently to predict the watershed behaviour after treatment. The catchment treatment, carried out during the transition phase, comprised forest felling, burning and initial establishment of oil palm and cocoa plantations. The evaluation phase involved monitoring of the same parameters during crop establishment.

Instrumentation

The basin has been instrumented with necessary equipment for continuous monitoring of hydrologic as well as climatic parameters. Areal rainfall is measured by tipping-bucket recording gauges at five stations. These stations are located randomly in the basin in order to obtain a representative measure of rainfall. It is measured to ± 0.5 *mm*.

Streamflow is measured at a 120° V-notch weir fitted to a concrete cut-off wall. Stage heights are recorded by float-type water level recorders to ± 0.2 *mm*. Field volumetric calibration for every weir is regularly conducted to establish and verify rating tables.

Rainfall and streamflow stations are serviced weekly. Charts from the recorders are digitised and processed using computer facilities at the Drainage and Irrigation Department Headquarters.

Catchment Treatments

After three years of calibration (July – June 1980) and sufficient basic data had been collected, Sub-Catchment B was logged and subsequently clear-felled in July 1980. Since Sub-Catchment B and Catchment A form the larger Catchment B, in effect, the treatment imposed only covered 60% of the area. On the other hand, treatment of Catchment A was carried out in October 1982 with the logging of commercial timbers and then clear felling. The sequence of land conversion operations for Catchments A and B are shown in Table 3.

Generally in the conversion of logged-over forests to agriculture, four major activities are involved, namely under-brushing, felling, major burning and finally pruning, stacking and reburning. During under-brushing, all brush and under-growth are completely cleared in order to ease the subsequent operation of clear felling. After the clear felling, fallen trees are burned, preferably during a dry spell. If the burning is not successful, as was in the present case, partially burnt logs were stacked using bulldozers for the next burning. Subsequently, Catchment A and Sub-Catchment B were planted with cocoa and oil palm, respectively.

Table 3. Forest Conversion Schedules in Catchments A and B

Operation	Catchment A	Catchment B
Logging & under-brushing	OCT 82 – JAN 83	JUL 80 – OCT 80
Clear felling	FEB 83 – MAR 83	OCT 80 – NOV 80
Burning & stacking & reburning of logs	APR 83 – JUN 83	FEB 81 – APR 81
Planting of cover crops/shade trees & agricultural road constructions	JUN 83 – NOV 83	APR 81 – AUG 81
Planting of cocoa/oil palm	NOV 83 – JAN 84	AUG 82 – NOV 82

(Source: DID 1986)

Statistical Analysis on Water Yield Changes

One of the most direct methods of analysis is the plotting of double mass curves. Essentially this method involves the plotting of cumulative totals of a characteristic under study in a treated catchment against cumulative totals from a control catchment. In the present analysis, monthly runoffs of Catchments A and B were used.

Statistical regression analysis provides a quantitative approach to describing treatment changes in hydrological parameters. This method consists of fitting regression models for the calibration as well as post-treatment periods. Subsequently, the fitted regression models are employed to predict runoff of the treated catchment based on selected predictor variables of the control catchment.

Several regression models were fitted for calibration periods using different predictor variables including monthly runoff, rainfall and one-month antecedent runoff. Rigorous statistical tests were performed in selecting the best fit, thus giving a reliable prediction model. Due to inherent variability of monthly runoff, calibration models employed only a segment of the entire period of the calibration in order to maintain statistical reliability and accuracy. Accordingly, the calibration equations for Catchments A and B used 36 and 32 months of observation, respectively.

In addition, a dummy technique was used in the regression analysis to test the significance of responses of forest conversion as described by Gujarati (1978). The above test involves comparing of the residual error from a full model containing a treatment effect with a reduced model without the treatment effect by treating calibration and treatment periods in the same regression. The dummy variable is assigned and coded 0 during calibration and 1 during the transition as well as evaluation periods. The null hypothesis that treatment has no effect on the monthly runoff is tested by F-statistic as applied by Hewlett *et al.* (1984).

Results and discussion

Rainfall

The study area received a relatively low annual rainfall during the study period, ranging from 1428 to 2430 *mm* with an average of 1878 *mm*, compared to Peninsular Malaysia's average of 2400 *mm*. Water year 1982/83 could be considered a dry-year for the three catchments: their annual rainfalls were less than 1500 *mm* (Figure 2). Monthly rainfall distribution of the basin generally showed a two-peak pattern which occurred in the months of October and April, the former being higher (Figure 3). February was the driest month. The average number of rain days was 159. Approximately 50% of the rain fell within the depth class of 0.5 to 5.0 *mm* with the greatest intensity occurring during the first 30 *min* (DID 1986).

Streamflow

Monthly runoff was highly variable throughout the pre-treatment period, ranging from 0 to 91 *mm*. Occasionally, the three catchments experienced zero flows, particularly Catchments A and C. However, after the treatment, the pattern of monthly flows changed drastically, and zero flows ceased to occur (Figure 4).

Mean monthly runoffs of the three catchments show that the maximum normally occurred in either November or December while the minimum was in August. The fluctuation in runoff reflects the direct influence of rainfall on the monthly discharges as shown by the strong rainfall-runoff relationships ($R > 0.9$). In addition, it is interesting to note that generally there is at least a 1-month lag between rainfall and corresponding runoff of a particular month (Figure 3). Annual runoff for the three catchments ranged from 105 to 317 *mm* during the calibration and transition periods (DID 1986). A relatively low runoff coefficient (runoff as a percentage of rainfall) was observed; it ranged between 9 to 14%. Approximately the same magnitude of coefficent was obtained for headwater catchments in Negri Sembilan (Abdul Rahim *et al.* 1985). Significant increases in runoff coefficient were observed immediately after the treatment, ranging from 10 to 18%. A detailed discussion of the climatic and hydrologic aspects of the three catchments covering all three periods are reported by DID (in press).

Water Yield Changes

Double mass curves of Catchments A and B against Catchment C, a control, clearly show a break in the trends of runoff commencing with the initiation of treatment and it continued thereafter (Figures 5 & 6). Nevertheless, the rate of deviations varied between the two catchments, possibly reflecting different response intensities. The above behaviour suggests the effect of forest conversion on the flow regimes immediately after the clearing has taken place. However, with this method, Reinhart

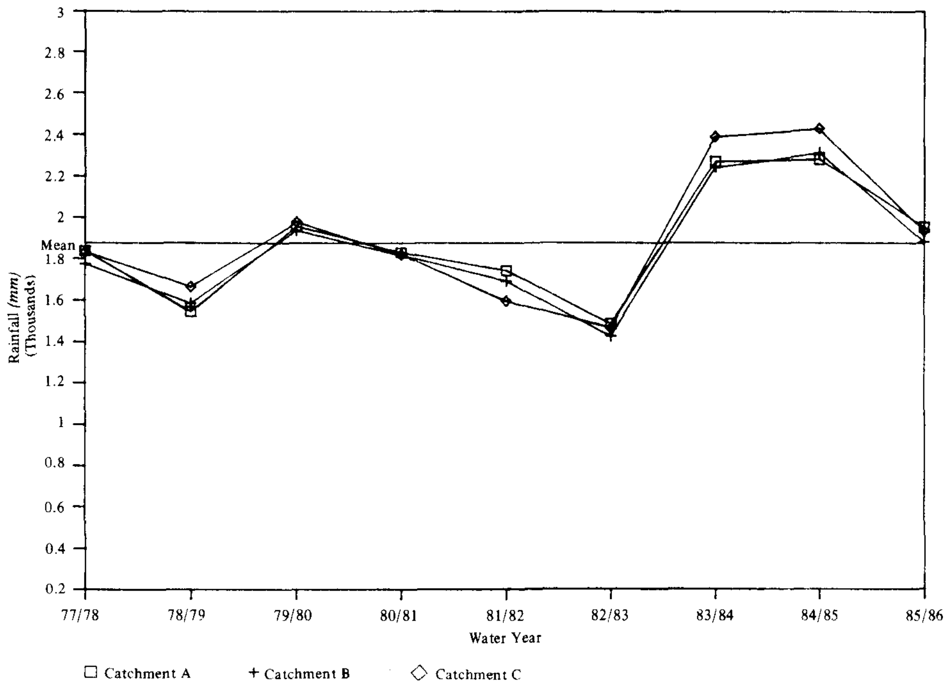


Figure 2. Annual Rainfalls for Catchments A, B and C

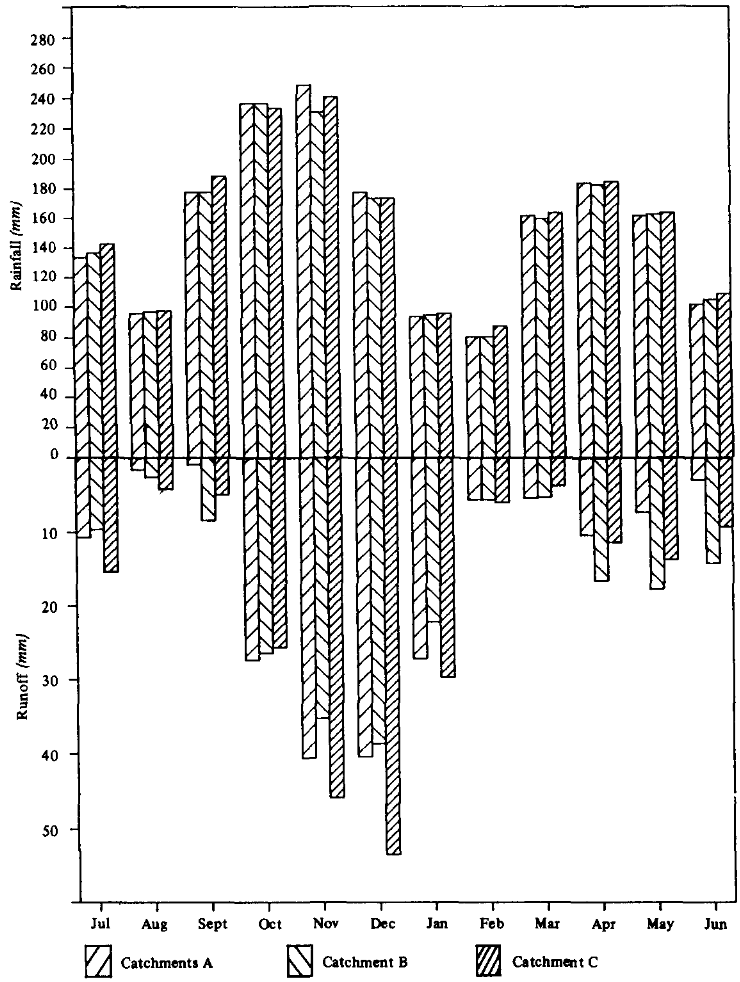


Figure 3. Mean monthly rainfall and runoff for Catchments A, B and C

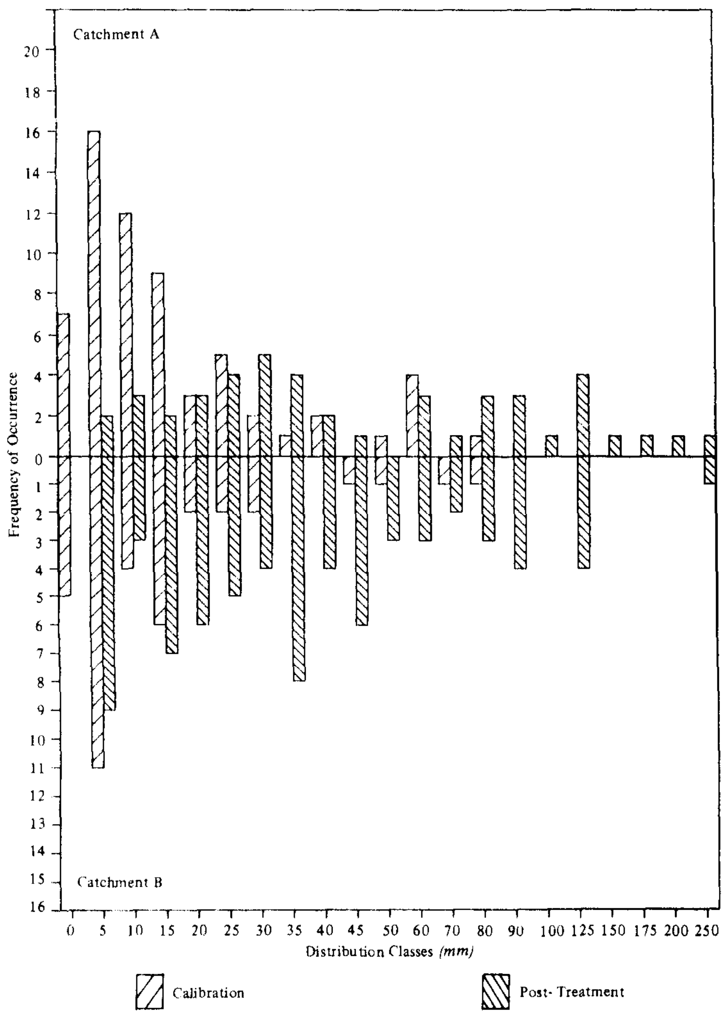


Figure 4. Frequency and distribution of monthly runoff (*mm*) during Calibration and Post-Treatment for Catchments A and B

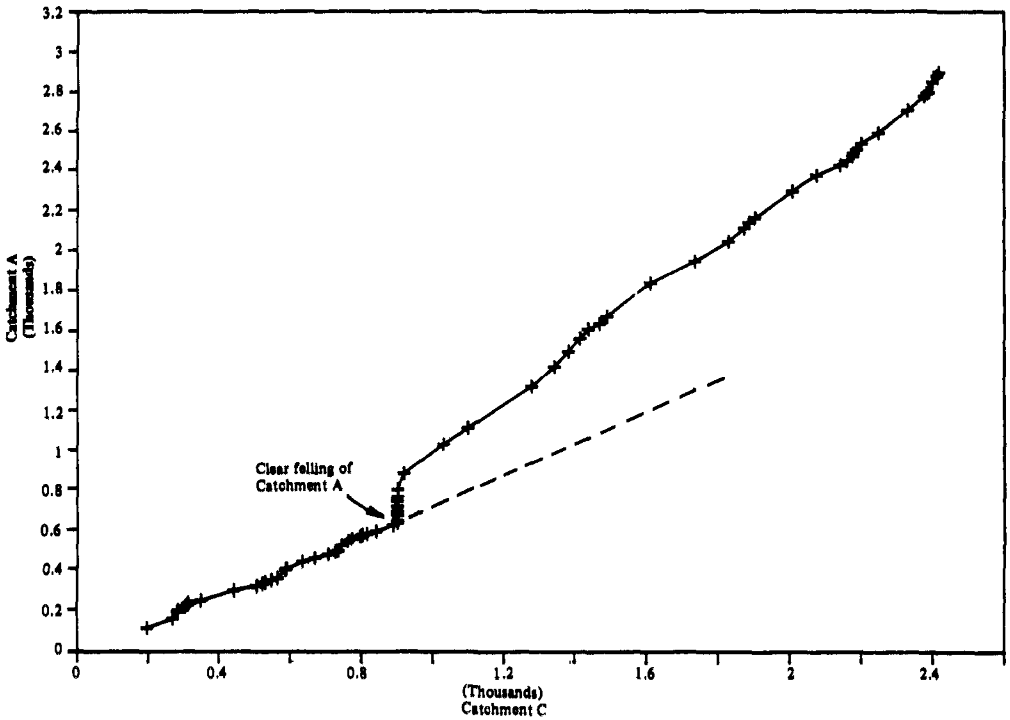


Figure 5. Double Mass Curve of monthly runoff (*mm*) of Catchment A against Catchment C, a control

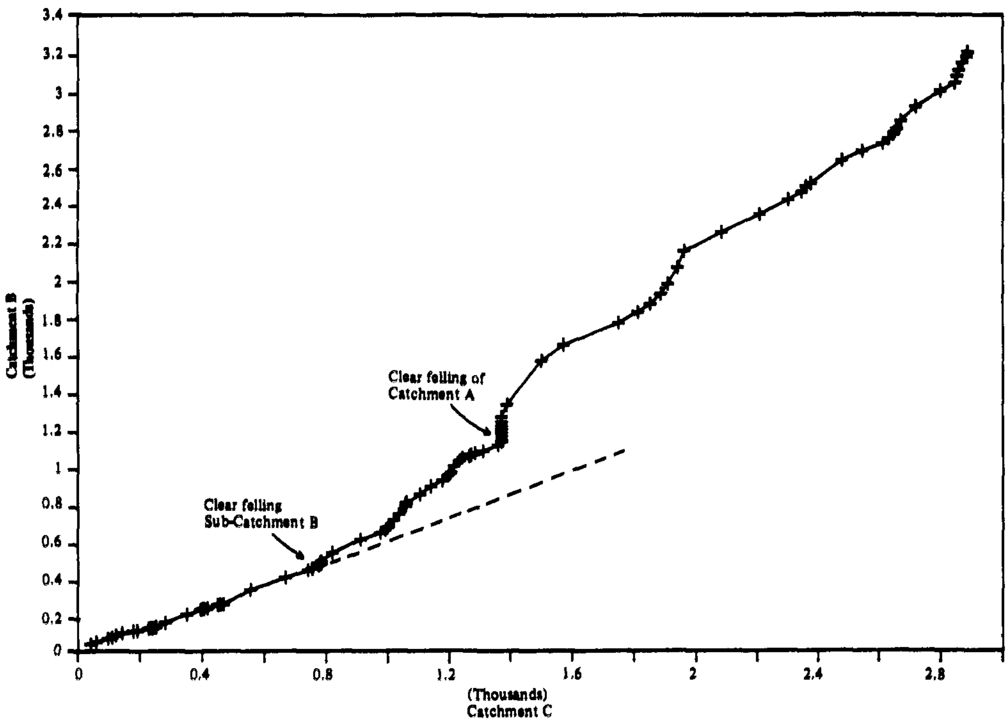


Figure 6. Double Mass Curve of monthly runoff (*mm*) of Catchment B against Catchment C, a control

(1965) believes, it may be difficult to reach an objective conclusion except provide some general trends.

Extreme variability of flow is quite common in all catchments as explained by the coefficient of runoffs, in part due to the small size of the catchments. This inherent characteristic provides another qualitative method of detecting hydrological changes – which is the frequency of flow distribution. Frequency of monthly runoff of Catchments A and B was computed and compared between the calibration and post-calibration periods (Figure 4). Different patterns of runoff frequency were clearly discernible between the two periods for the same catchment, particularly for the low runoff classes. A change occurred in the zero flow distributions which were prominent during the dry months of the calibration period. Conversely, zero flow phenomenon disappeared immediately after the treatment in both catchments.

The final models which gave the best fit comprise multiple linear regressions with monthly runoff and rainfall as the predictor variables. The calibration equations for Catchments A and B are as follows:

$$Q_a = 1.150 + 0.57\,Q_c + 0.017P_c \qquad (1)$$

R–Square = 0.915 n = 36 s.e. = 5.526

$$Q_b = 4.891 + 0.614Q_c + 0.034P_c \qquad (2)$$

R–Square = 0.937 n = 32 s.e. = 5.025

where	Q	– monthly discharge;
	P	– monthly rainfall;
	a, b, c	– names of catchments;
	s.e.	– standard error of estimates; and
	n	– number of samples.

Fitted regression models explained for 92 and 94% of the variation in the monthly runoffs of Catchments A and B, respectively. Relatively high R–square and low standard error of estimates are measures of adequacy of the calibration equations in both catchments.

Water Yield Changes in Catchment A

The equation 1 was eventually used to predict monthly runoff in Catchment A for the entire period. Deviations in monthly runoffs between observed and predicted values are shown in Figure 7. The monthly runoff, and hence annual water yield, increased substantially after the forest conversion, particularly following clear felling. The water yield increased by 110 (117%) and 706 *mm* (157%) in the first and second years respectively. The third and fourth years showed a lower rate of increase: 353 (94%) and 263 *mm* (158%) respectively. The first-year increase was rather low; it is possibly because only selective logging and under brushing was carried out during the

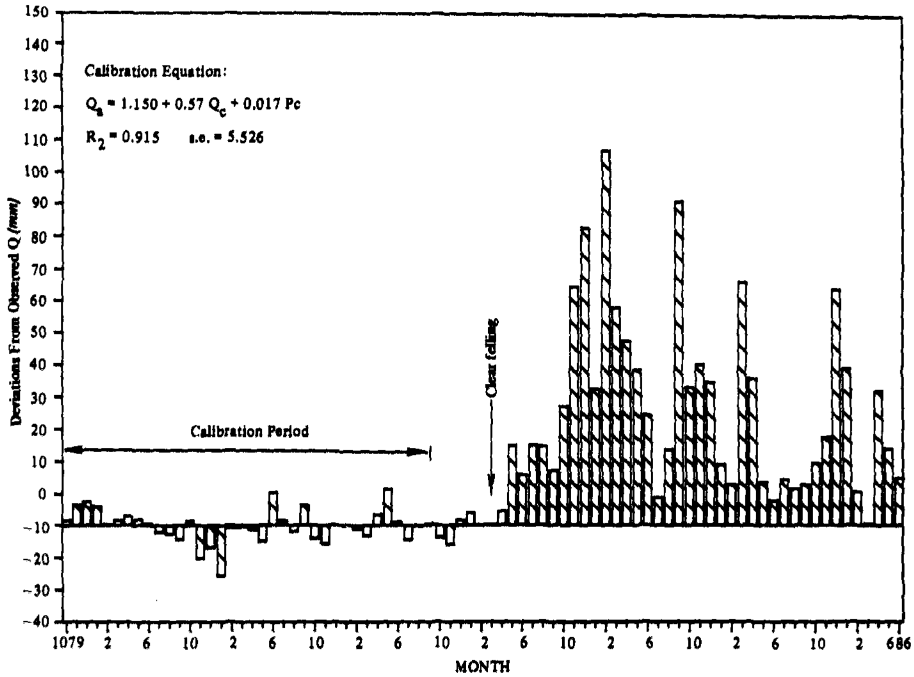


Figure 7. Deviations between observed and predicted runoff (*mm*) for Catchment A

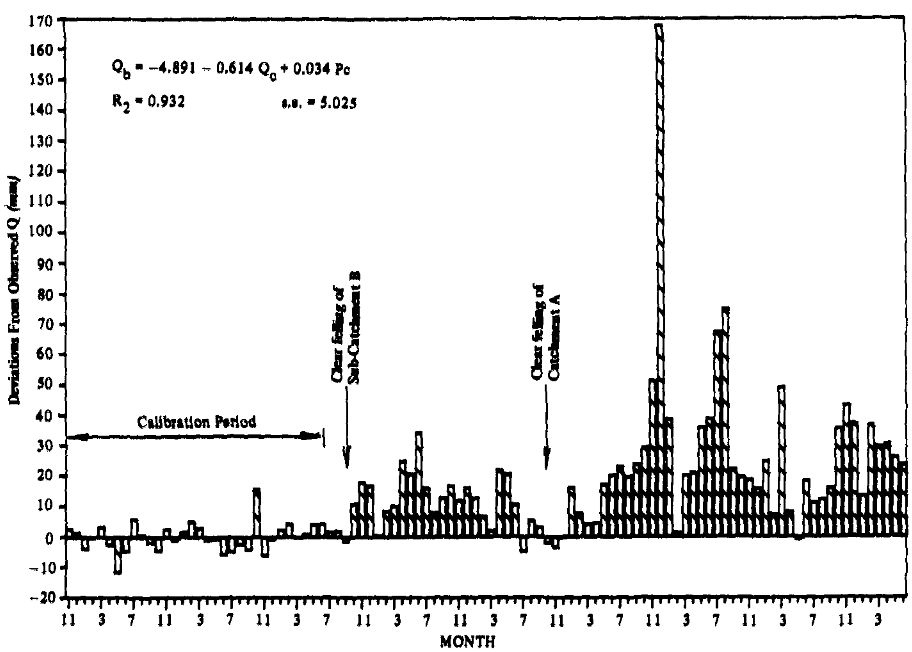


Figure 8. Deviations between observed and predicted runoff (*mm*) for Catchment B

first-half of the year. Clear felling of the entire catchment and burning of fallen logs was carried out in the second-half of the year. Accordingly, the full effect of clear felling and burning is clearly depicted in the second year of treatment and the years following. Water yield increase during the transition and evaluation periods was statistically significant ($p < 0.01$; F–value 22 and d.f of 5 & 75).

Water Yield Changes in Catchment B

In this analysis, Catchment B includes both Catchment A and sub-Catchment B. The two catchments were treated at different times, and this should be considered in reviewing the water yield changes observed. Equation 2 was used to predict the monthly runoffs of Catchment B and subsequently subtracted from observed values to get the deviations in monthly runoffs for the entire period (Figure 8). Owing to the physical set-up of this catchment, the first two to three years following treatment included responses occurring in sub-Catchment B, in which 60% of the forest was removed. The water yields for the first three years were 145 (85%), 155 (142%) and 137 *mm* (97%). The fourth-year increment coincided with the logging and clear felling of sub-Catchment A: this amounted to 822 *mm* or 470%. The fifth and sixth years saw further increases in water yield but at decreasing rates: they were 793 (270%) and 476 *mm* (314%) respectively. The increase in water yield during transition and evaluation periods was significant ($p < 0.01$; F–value 9.21; and d.f of 5 & 98).

The various types of operations undertaken during the conversion largely influenced the magnitude of water yield changes after treatment. In addition, the water yield was influenced by the prevailing rainfall regimes. In this respect, water years 1983/84 and 1984/85 received a slightly higher annual rainfall; this may contribute to a slight increase in the water yield. However, the net increase of approximately 25% in rainfall was experienced in all catchments including the control. Therefore, the changes in water yield observed in the transition and evaluation periods are more the resultant of forest transformation to other landuse.

The present study recorded the highest increase in water yield, up to 800 *mm/y*, compared to similar studies in other tropical regions (Table 1). It is higher than that in temperate countries too. The highest increase previously recorded in the tropics is 440 *mm*, based in Taiwan (Hsia & Koh 1983), and 660 *mm* in a temperate area (Bosch & Hewlett 1982). A rather large water yield increase is not unexpected from Malaysia, conceivably due to the tremendous reduction in evaporative loss from dipterocarp forests, the dominant vegetation of the study area (DID, 1982). The large increase was also consistent with observed interception loss under this forest type of approximately 25%. Potential evapotranspiration of the area as estimated by Penman Method was 1515 mm/y, ranging from 1449 to 1509 *mm* (DID, in press).

The fact that different crops were planted in Catchment A and sub-Catchment B should permit a good comparison in water yield responses to different post-treatments. Unfortunately, the two catchments are nested into the larger Catchment B, and this forbids easy comparison.

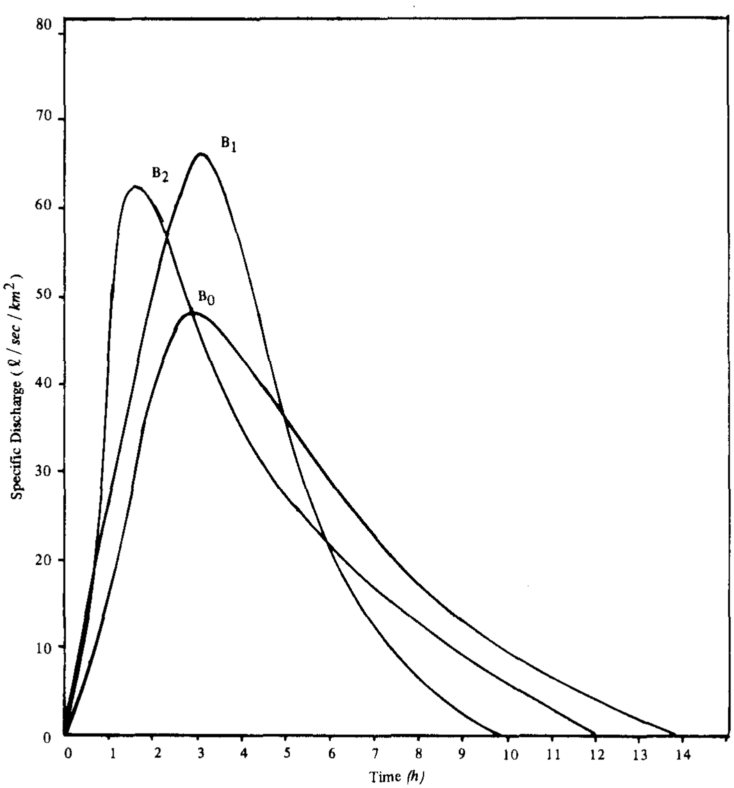
However, the different rates of water yield changes during transition and evaluation periods between catchments can be alluded to the influence of the crops to a certain extent. Since the crops require more time to fully establish, a longer observation period is required to monitor and document further responses, particularly the time taken for the water regime to revert to the pre-conversion characteristic, if it ever will.

The effect of forest conversion should be simultaneously analysed with stormflow characteristics in order to ascertain the flood potential of apparent increase in runoff volumes as elicited in the present study. However, such an analysis is only briefly discussed in this paper, with regards to the unit hydrograph. One-hour unit hydrographs covering various phases of conversion for Catchment B are shown in Figure 9. The specific peak discharge drastically increased by 37% after treatment compared to that of forested conditions, and subsequently decreased by 6% during the establishment of cover crops. However, the apparent increase in peak flows has not been statistically proven. Another interesting observation is that no apparent change in time-to-peak was associated with an increase in peak discharge following clear felling. On the other hand, time-to-peak associated with the establishment of cover crops decreased by 50%. Obviously, stormflow response needs detailed analysis based on individual storms in order to further quantify the actual effect of the individual sequence of forest conversion.

Management Implications

The results of this investigation confirm the findings of paired catchment studies conducted elsewhere, both in tropical and temperate regions, in which forest conversion normally leads to a water yield increase. The rate may vary according to site and climatic conditions though. However, the present results only cover the first three years of post-treatment, while the complete establishment of agricultural crops such as oil palm and cocoa takes a much longer period. Therefore the quantification of subsequent responses of streamflow until the crops reach maturity are equally important.

The implications of the present findings to water resource planners or managers are several. One is that forest conversion for agricultural purposes may make considerable amounts of water available for other uses considering the massive land converted. Next are the problems of environmental degradation that ensue the increased water yield, such as greater on-site erosion, sedimentation and impairment of water quality (see Wiersum 1984). In most land development undertakings, due recognition is seldom given to the importance of drainage channels in the area. In addition, poor felling methods, unsupervised road construction and timber extraction often aggravate the problems of soil erosion and sedimentation. Tremendous soil compaction occurs with the use of heavy machinery, and this reduces soil infiltration capacity, and often causes greater surface runoff. All these processes lead to a much greater rate of soil detachment and sediment transport, especially in an environment



Legent:
B_0 – Calibration Period
B_1 -- Period Immediately after clearfelling
B_2 – Period after establishment of cover crop and planting of oil palm

Figure 9. One-hour unit hydrograph of Catchment B

of high rainfall amounts and intensities like Malaysia. In this relation, the STEB study shows that sediment yield increased from 24 to 414 $t/km^2/y$ in Catchment B, a 16-fold increase after the area had been clear-felled (DID, in press).

This strongly points to the need for a thorough evaluation of the present approaches in land clearance and for a practical conservation guide for land clearance operations which takes into consideration the site conditions, topographic limits and watershed values. Until such guidelines have been drawn and enforced, the anticipated increases in water yield would not have any beneficial implications.

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