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Keynote Paper

Land use changes, soil erosion and decreased base flow of rivers at Cameron Highlands, Peninsular Malaysia

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Abstract: The hydrological cycle within any drainage basin can be viewed simply as inputs of precipitation distributed through a number of storages by a series of transfers, leading to outputs of basin channel runoff, evapo-transpiration and outflow of groundwater. Changes in land use within the basin have a profound effect upon the hydrological cycle as they directly influence interception, surface and soil moisture storages, as well as infiltration and overland flow. In highland drainage basins, the most visible impact of changes in land use is soil erosion, whilst other impacts include the lowering of groundwater tables and the decreased base flow of rivers.

Changes in land use at Cameron Highlands between 1947 and 1974 involved mainly an increase in area of tea estates and orchards at the expense of forests, but between 1974 and 1982, an increase in area of market gardens and residential/urban centers at the expense of forests. Between 1982 and 1990, there was a further increase in area of market gardens and residential/urban centers, but at the expense of tea estates and orchards. These changes in land use from forests through tea estates and orchards to market gardens and residential/urban centers, have had successively greater impacts on the ground surface, resulting in increasing rates of soil erosion. The eroded sediments have been, and continue to be, deposited along river channels and diversion tunnels in the area as well as in the Ringlet Reservoir. Increasing overland flow as a result of the changes in land use is also reflected by the rising trend (relative to the annual rainfall) of the annual discharge of the Sg. Bertam at Robinson's Falls for the period 1964-1997; a trend that has led to decreased base flows of the Sg. Bertam during periods of several weeks without rain.

INTRODUCTION

The hydrological cycle within any drainage basin can be viewed simply as inputs of precipitation, distributed through a number of storages by a series of transfers, leading to outputs of basin channel runoff, evapo-transpiration and deep outflow of groundwater. If the deep outflow of groundwater is ignored, the gross operation of the basin hydrological cycle may be simply written as (More, 1969):-

Precipitation = Basin channel runoff + Evapo-transpiration + Changes in storage

In humid tropical areas, precipitation in the form of rain falls on vegetation, soil, debris and more rarely rock, surfaces as well as directly into bodies of standing water and stream channels. Water in transit is stored on vegetation leaf and stem surfaces as interception storage, which either evaporates or reaches the ground by stem flow and drip. The drainage of water from vegetation, together with direct precipitation onto the ground surface and surface water, contributes to surface storage, which evaporates directly, or flows over the surface to reach adjacent stream channels as overland flow, or infiltrates into the soil. The water in the soil (soil moisture storage) is depleted by the transpiration of plants, by throughflow of water downslope within the soil profile to augment channel storage (itself depleted by evaporation), or by vertical seepage into the aeration zone (More, 1969).

Water below the soil profile and the water table (aeration zone storage) is depleted by interflow, that reaches adjacent stream channels by flow sub-parallel to the surface without becoming groundwater, and by deeper percolation downwards to the water table as groundwater recharge. From groundwater storage, water either flows laterally into stream channels as base-flow, or slowly percolates into deep storage, some of which may ultimately discharge at depth into the ocean or augment the groundwater storage of an adjacent basin (More, 1969)

Given this scenario, changes in land use will have profound impacts upon the hydrological cycle within a drainage basin as they directly influence interception, surface and soil moisture storages as well as infiltration and overland flow. In highland drainage basins, the most visible impact of land use changes is soil erosion; an impact that has been more than amply demonstrated and discussed in several studies (Morgan, 1979). Apart from soil erosion, there can also occur the lowering of groundwater tables and the decreased base flow of rivers; impacts that have often not been discussed. In this paper, land use changes at Cameron Highlands over the past fifty years are discussed in terms of their impact on soil erosion and the decreased base flow of rivers.

STUDY AREA — ENVIRONMENTAL SETTING

Cameron Highlands is the smallest district of Pahang State and is located within the Main Range at an elevation of between 1,000 and 1,830 m above sea level (Fig. 1). Prior to the recent completion of the Simpang Pulai-Kg. Raja-Lojing Highway, the only access was by the Pahang Road from Tapah town in Perak State. The district comprises three Mukims (Mukim Ulu Telom, Mukim Tanah Rata and Mukim Ringlet) with several small towns that are located at different elevations along the Pahang Road. In the south is Ringlet at an elevation of 1,200 m, whilst in the north is Kg. Raja at 1,600 m. In the centre, are the two largest towns, Tanah Rata and Brincang, located at elevations of about 1,400 m above sea-level.

Most of the study area is hilly with natural ground slopes of between 20° and 30°. Steep-sided, narrow valleys with mostly convex slopes are present, though in places as at Tanah Rata and Brincang, broad valleys with more gentle ground slopes are found. In the north, at elevations exceeding 1,600 m, the natural ground slopes are steep to

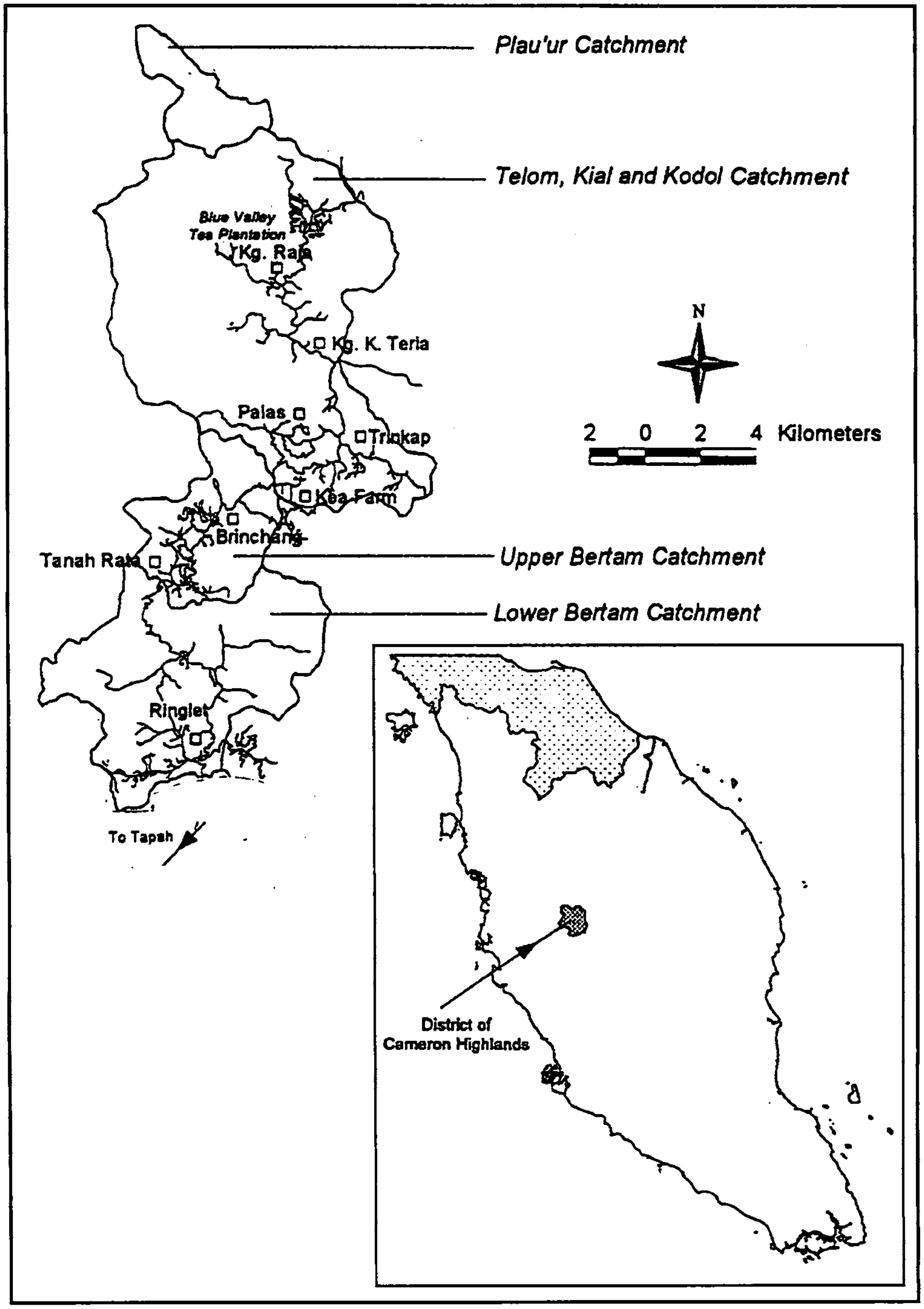

Figure 1. Location map of Cameron Highlands.

very steep, ranging from 30° to 45°.

Cameron Highlands has a tropical climate with a mean annual rainfall of 2,400 mm, though there are two distinct periods of maximum and minimum monthly rainfall. The primary maximum occurs in October and November, whilst the secondary maximum is in April and May. The periods with minimum rainfall, though they are not really dry as monthly rainfall still averages 100 mm, are between January and March, and from June to August. The highest mean daily temperatures are in April and May (about 21°C), whilst the lowest ones (about 17°C) are in December and January.

Although the idea of developing Cameron Highlands as a hill resort was first proposed in 1887, it was only in

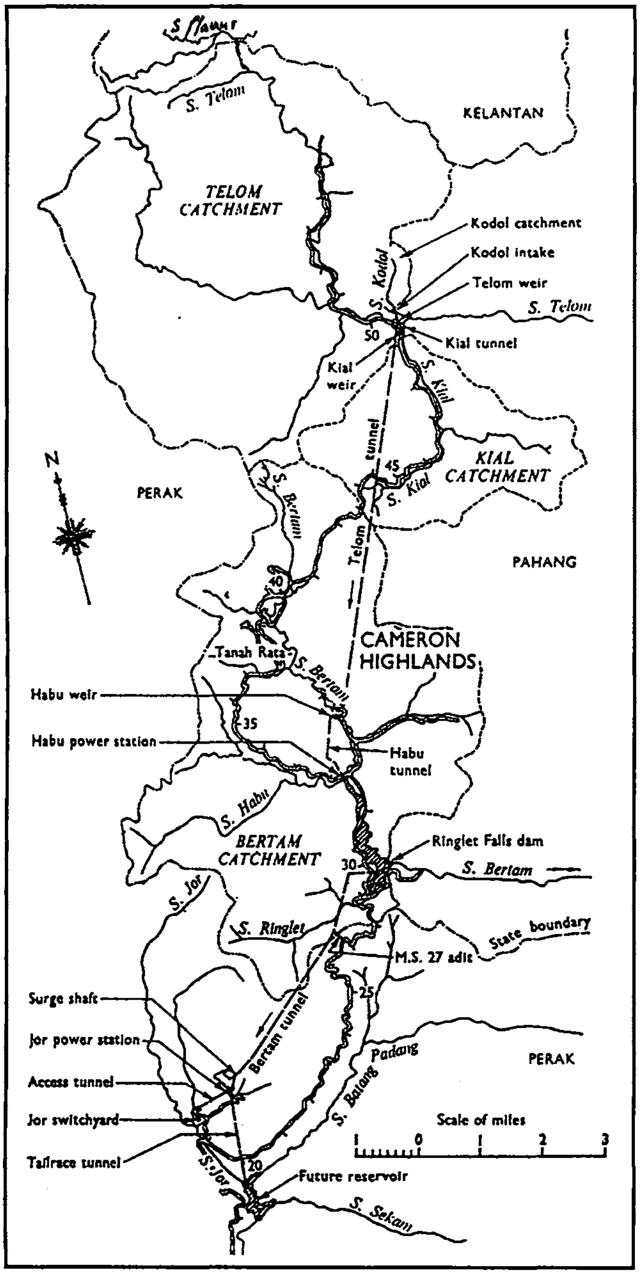

Figure 2. Main features of Cameron Highlands Hydro-Electric Power Scheme (from Dickson 7 Gerrad, 1963 — Fig. 1).

1930 that a road was constructed from Tapah. By the early 1930's, most of the larger tea estates had been established as were several market gardens. This pattern of land use remained basically the same for several decades due to the constraints imposed by the terrain. The most extensive land use was that of the tea estates which were mostly located between 1,100 and 1,600 m above sea-level, whilst land above 1,600 m mainly remained under forest except in isolated areas where holiday homes were built (Leong, 1991).

Since the early 1970's, however, there have been changes in land use due to the encouragement of tourism and an intensification of agricultural activities. Besides large hotels and other recreational facilities as golf courses, there has also been a great increase in the number of holiday homes. The development of agriculture for the production of temperate type vegetables and flowers has also been on the increase since 1982, with many of the new farms situated on steep slopes (Ko *et al.*, 1987). In the early 1990's, there was a shift in emphasis from vegetable farming to flower gardening, though this trend has reversed in more recent years.

In the study area is located the Cameron Highlands Hydro-Electric Power Scheme; a Scheme that utilizes the combined headwaters of several large rivers that drain eastward into the South China Sea by diverting them into the Sg. Batang Padang which flows west into the Malacca Strait (Fig. 2). Starting from the north, the headwaters of Sg. Plau'ur are first diverted into the upper Sg. Telom by the Plau'ur Tunnel. The headwaters of two tributaries of the Sg. Telom (i.e. Sg. Kodol and Sg. Kial), which actually meet it further downstream, are then diverted into the upper Sg. Telom by the Kial Tunnel. The combined waters of all these rivers are then transferred through the Telom Tunnel to join the Sg. Bertam just below the hydro-electric power station at Robinson Falls. At the outfall of the Telom tunnel, a mass concrete weir diverts the water (plus the discharge of the Robinson Falls Power Station) through the Habu tunnel to feed the turbines of the Habu Power Station. After passing through the Habu Station, the water enters the Ringlet Reservoir from which it is led through the Bertam Low Pressure Tunnel into a Surge Shaft, from the bottom of which, two steel-pipe lined shafts lead to the turbines at the Jor Power Station. After leaving the Jor Power Station, the spent waters of all the rivers are carried through the Tailrace Tunnel into the Sg. Batang Padang, where a number of other hydro-electric power stations are located, before flowing westward into the Malacca Strait (Dickinson & Gerrard, 1963).

STUDY AREA — GEOLOGICAL SETTING

Granitic and meta-sedimentary rocks are found in the study area; the granites forming parts of several large batholiths, whilst the meta-sediments occur as roof pendants. The granites, of an Upper Permian to Upper Jurassic age, show minor variations in textures and compositions and have been separated into three main types. A non-porphyritic, medium to coarse grained, biotite adamellite, outcrops in the north, whilst a porphyritic, medium to coarse grained biotite granite is found in the south (Md. Nor Han, 1996; Shamsul Nizar, 1997). In the central part of the area, a porphyritic, medium grained tourmaline granite is present. . The meta-sedimentary rocks, of a likely Carboniferous age, have resulted from regional and contact metamorphism and consist of phyllites and slates as well as quartz-mica, and amphibole-pyroxene, schists (Mohd. Shaari, 1982). Several major fault zones of variable orientations are found and marked by brecciated and sheared bedrock.

As a result of prolonged exposure and favourable environmental and tectonic factors, the granitic rocks are deeply weathered with chemical alteration in particular persisting to great depths along discontinuity planes (Preece *et al.*, 1962). Where the granitic rocks contain widely spaced joints, spheroidal weathering has led to core boulders separated by narrow to broad bands of friable, gravelly silty sands. The depth of weathering varies, but is greatest (>50 m thick) below ridge crests and thins towards valley floors where fresh bedrock may outcrop. The schists have also been weathered, though the depth of weathering is much less than that over granite.

At elevations above 1,600 m, accumulation of organic materials at the ground surface has led to the formation of mainly Troposaprist soils whilst at elevations between 1,200 and 1,600 m, the lesser accumulation of organic materials has led to Tropaquods. At elevations below 1,200 m, highly leached soils are found that are classified as Tropohumults (Paramananthan, 1977).

SEDIMENTATION IN THE RINGLET RESERVOIR

The Ringlet Reservoir, which was created by the 40 m high concrete buttress and rockfill, Sultan Abu Bakar Dam on the Sg. Bertam at Ringlet Falls is an important part of the Cameron Highlands Hydro-Electric Power Scheme for it serves to regulate the supply of water to the Jor Station. The Reservoir has a total volume of 6.3 x 106 m^3; dead storage being 1.6 x 106 m^3 and live storage 4.7 x 106 m^3.

Two main rivers drain into the Reservoir; the Sg. Bertam and its many tributaries from the north, and the Sg. Ringlet from the south. The Sg. Ringlet has a catchment area of 8.3 km^2, whilst the Sg. Bertam, upstream of Robinson's Falls, has a catchment area of some 21.4 km^2. Downstream of Robinson Falls, the Sg. Bertam and its tributaries have a catchment area of 42.9 km^2, though to this total has to be added the catchment areas of Sg. Plau'ur (9.7 km^2), Sg. Kial (22.7 km^2), Sg. Kodol (1.3 km^2) and Sg. Telom (76.7 km^2) for their discharge is diverted into the Sg. Bertam via the Telom Tunnel. The total catchment area of rivers draining into the Ringlet Reservoir is thus some 183 km^2.

In 1956, before construction work on the Hydro-Electric Power Scheme started, studies showed that some 732 m^3/km^2/yr (10.09 ton/ha/yr) of 'soil loss' occurred from areas planted with vegetables, 488 m3/km2/yr (6.73 ton/ha/yr) from areas covered with tea and only some 24.5 m3/km^2/yr (0.33 ton/ha/yr) from forested areas (Shallow, 1956). Based on the percentage of the different land use within the catchment areas of rivers draining into the Ringlet Reservoir at that time, it was calculated that the Reservoir would have a useful life of about 80 years at a mean sedimentation rate of 109 m^3/km^2/year (Dickinson & Gerrard, 1963).

In recent years, however, there has been a rapid decrease in the total dead storage of the Reservoir as a result of sedimentation; its' storage capacity having been reduced some 31% by 1991 (Table 1). Sediments have also accumulated along the channels of all rivers draining into the Reservoir as well as in the various diversion tunnels; some of which have had to be periodically excavated (Ahmad Nazri, 1996). Sedimentation is most obvious at the north end of the Reservoir, where a large delta has developed at the mouth of the Sg. Bertam. The deposited sediments show variable textures that are dependent upon location, though sands and gravels are found along the channels of all rivers draining into the Reservoir. These sediments are in continuous, but seasonal, downstream transport and have led to shallowing of the channels.

Sands and gravels have, and continue to be, deposited at several specific sites along the various rivers, as upstream of Robinson Falls, and at the inlets to the various diversion tunnels. At these sites, daily excavations of the accumulated sediments have been, and are being, carried out, particularly during the months with high rainfall. Within the Reservoir, silts and clays have been, and continue to be, deposited, whilst coarser sediments are found along its' sides and at the mouths of rivers discharging into the Reservoir. In the south, sands and gravels have been, and continue to be, deposited by the Sg. Ringlet at its outlet into the Reservoir, though a distinct delta is not seen due to the deep water here.

CAUSES OF SEDIMENTATION

The sediments that have been, and continue to be, deposited within the Ringlet Reservoir and channels of all its' contributing rivers, are locally derived in view of their granitic and meta-sedimentary provenances. Soil erosion has thus occurred, and continues to occur, within the drainage basins of all the rivers (Leong, 1991; Hj. Ahmad Jamalluddin & Chong, 1991). Rates of sedimentation within the Reservoir are furthermore, not constant but have generally increased over the years indicating a similar increase in rates of soil erosion; increases that are not unexpected when land use changes are considered.

There is unfortunately a lack of land use data, particularly for the years before 1990; the most detailed data being that of agricultural surveys carried out in 1966 and 1974 (Wong, 1967, 1974). This data and other available

Table 1. Sedimentation in the Ringlet Reservoir (From Ahmad Nazri, 1996).

Year of survey	Measured deposits (x 1,000 m^3)	Deposits between 2 consecutive dates (x 1,000 m^3)	Volume excavated by annual contract (x 1,000 m^3)	Period in years	Sedimentation Rate (m^3/km^2/yr)	Capacity loss (cumulative) (Cum %)
1965	33.5	74.1	NA	2	202.46	0.53
1967	107.6	19.3	NA	2	52.73	1.71
1969	126.9	20.9	NA	1	114.21	2.01
1970	147.8	267.2	NA	5	292.02	2.35
1975	415.0	116.7	NA	6	106.28	6.59
1981	531.7	154.3	172.8	3	595.81	8.44
1984	686.0	164	169.5	2	911.20	10.89
1986	850.0	153	66.7	1	1200.55	13.49
1987	1003	714	233.6	3	1726.05	15.92
1990	1717	244	88	1	1814.21	27.25
1991	1961					31.13

Note: NA – Not available. Desilting contract started 1981.

data is summarized in Table 2 where four main classes of land use have been differentiated, i.e. Forests, Tea estates and orchards, Market gardens and Residential/urban centers. It is to be noted that these four classes have successively greater impacts on the physical environment; there being increasing ground surface disturbance and overland flow leading to increased soil erosion. As noted by Shallow (1956), soil loss is least in forested areas where the extensive canopy promotes interception storage and minimizes overland flow. In areas of tea estates and orchards, although there is much soil loss during their initial establishment, the increase in canopy cover with time leads to lower rates of soil erosion. In areas of market gardens (i.e. flower and vegetable gardens), however, there is much soil erosion due to the widely spaced vegetation cover and short-term nature of the crops which results in frequent ground disturbance. In residential/urban centers, there is also considerable soil erosion due to exposed ground surfaces as well as decreased infiltration and interception storage that leads to increased overland flow during rainfall.

In the Sg. Telom drainage basin, land use changes between 1947 and 1974, involved an increase in area of tea estates and orchards as well as market gardens, at the expense of forests, but between 1974 and 1982, an increase in area of market gardens at the expense of forests (Table 2A). Between 1974 and 1982, there was a slight increase in area of residential/urban centers, whilst between 1982 and 1990, there have been few changes in areas of different land use. There was also after 1982, an increase in the area of flower gardens at the expense of vegetable gardens (Ko *et al.*, 1991).

In the upper Sg. Bertam drainage basin, i.e. upstream of Robinson Falls, land use changes between 1947 and 1966 involved an increase in area of market gardens and residential /urban centers at the expense of forests, but in later years, an increase in areas of residential/urban centers at the expense of market gardens and forests (Table 2B).

In the lower Sg. Bertam drainage basin, downstream of Robinson Falls, and including the Sg. Ringlet basin, changes in land use between 1947 and 1974, mainly involved an increase in area of tea estates and orchards at the expense of forests, but between 1974 and 1982, an increase in area of market gardens at the expense of tea estates and orchards; this trend continuing between 1982 and 1990 (Table 2C). Between 1974 and 1982, there was also an increase in the area of residential/urban centers.

When the changes in land use (Table 2) are compared with rates of sedimentation within the Ringlet Reservoir (Table 1), a good correlation is seen with the relatively low rates prior to 1975 coinciding with the large area of forests as well as tea estates and orchards then present. The increase in rates of sedimentation in the 1980's furthermore, can be correlated with the increase in areas of market gardens and residential/urban centers at the expense of tea estates and orchards. Changes in land use from forests through tea estates and orchards to market gardens and residential/urban centers, with their successively greater impacts on the ground surface have thus led to increased soil erosion within the drainage basins; the eroded sediments being, and continuing to be, deposited along river channels and diversion tunnels in the area, and in the Ringlet Reservoir.

DECREASED BASE FLOW OF RIVERS

Apart from soil erosion, the changes in land use have led to the lowering of groundwater tables and the decreased base flows of rivers, though these impacts have only surfaced in very recent years. Recognition of these impacts is furthermore, difficult as long term records of rainfall and river discharge are only available to some extent as the upper Sg. Bertam, whose discharge has been measured daily at Robinson Falls since 1964. Continuous daily rainfall records are also available for its drainage basin;

Table 2. Land use within the Cameron Highlands area [From 1947 topographic map, Wong (1966, 1974), 1982 and 1990 land use maps]

A: Sg. Telom Drainage Basin					
Year	1947	1966	1974	1982	1990
Forests	103.8 km^2	98.2 km^2	96.6 km^2	90.4 km^2	90.3 km^2
Tea estates & orchards	1.1 km^2	5.2 km^2	5.6 km^2	6.3 km^2	6.2 km^2
Market gardens	5.5 km^2	6.8 km^2	8.0 km^2	13.2 km^2	13.4 km^2
Residential/urban centers	< 0.1 km^2	0.2 km^2	0.2 km^2	0.5 km^2	0.5 km^2
B: Upper Sg. Bertam Drainage Basin (upstream of Robinson Falls)					
Year	1947	1966	1974	1982	1990
Forests	19.5 km^2	16.7 km^2	16.5 km^2	16.2 km^2	15.9 km^2
Tea estates & orchards	0.0 km^2	0.0 km^2	0.0 km^2	0.1 km^2	0.1 km^2
Market gardens	1.9 km^2	3.0 km^2	3.0 km^2	2.2 km^2	2.4 km^2
Residential/urban centers	<0.1 km^2	1.7 km^2	1.9 km^2	2.9 km^2	3.0 km^2
C: Lower Sg. Bertam Drainage Basin (downstream of Robinson Falls)					
Year	1947	1966	1974	1982	1990
Forests	43.8 km^2	35.4 km^2	30.0 km^2	29.2 km^2	29.1 km^2
Tea estates and orchards	4.8 km^2	12.5 km^2	16.3 km^2	10.6 km^2	10.1 km^2
Market gardens	2.6 km2	3.0 km^2	3.8 km^2	9.7 km^2	10.2 km2
Residential/urban centers	0.0 km^2	0.3 km^2	0.4 km^2	1.0 km^2	1.1 km^2
Ponds	0.0 km^2	0.0 km^2	0.7 km^2	0.7 km^2	0.7 km^2

there being rainfall stations at Tanah Rata and the Robinson Falls Power Station.

When the total annual rainfall in the upper Sg. Bertam drainage basin (based on the mean rainfall at the two stations) for the period 1964-1997 is compared with the total annual discharge at Robinson Falls, there appears to be an almost direct correlation with high rainfalls corresponding to large discharges, and vice versa (Fig. 3A). There are, however, some exceptions as in 1967, 1973, 1981 and 1997, when relatively large discharges were associated with low rainfalls. For these particular years, there were relatively high rainfalls in the immediately preceding year (i.e. 1966, 1972, 1980 and 1996), suggesting that base flow contributed substantially to the discharge of the following year. In the case of 1989 and 1995, however, high rainfalls are associated with low discharges, even though there were relatively high rainfalls in the immediately preceding year. A likely explanation for this anomaly maybe in the increasing use of retention ponds on hill slopes at Cameron Highlands since the mid 1980's; these ponds serving to store rainfall and overland flow. With increased use of these retention ponds, it can be expected that there will be a gradual decrease in river discharge with time, though such a pattern is not discernible (Fig. 3A).

When 5 year moving average trend lines for the total annual rainfall and discharge are plotted furthermore, more distinct long term patterns are seen within two broad periods, i.e. the years before, and after, 1980/81 (Fig. 3B). Before 1980/81, the trend lines of both rainfall and discharge are closely parallel, though after 1980/81, they diverge slightly with the trend of discharge rising relative to the rainfall. The annual discharge of the upper Sg. Bertam thus appears to be increasing relative to the annual rainfall; a trend that is most likely due to the greater overland flow during rainfall associated with the earlier described successive changes in land use. Increased overland flow during rainfall is furthermore, expected to have resulted in decreased infiltration and the gradual lowering of groundwater tables; impacts that have been high-lighted in the recent newspaper reports of rivers at Cameron Highlands having decreased flows and drying-out during periods of several weeks without rain.

CONCLUSION

Changes in land use at Cameron Highlands between 1947 and 1974 involved mainly an increase in area of tea estates and orchards at the expense of forests, but between 1974 and 1982, an increase in area of market gardens and residential/urban centers at the expense of forests. Between 1982 and 1990, there was a further increase in area of market gardens and residential/urban centers, but at the expense of tea estates and orchards. These changes in land use from forests through tea estates and orchards to market gardens and residential/urban centers, have had successively greater impacts on the ground surface, resulting in increasing

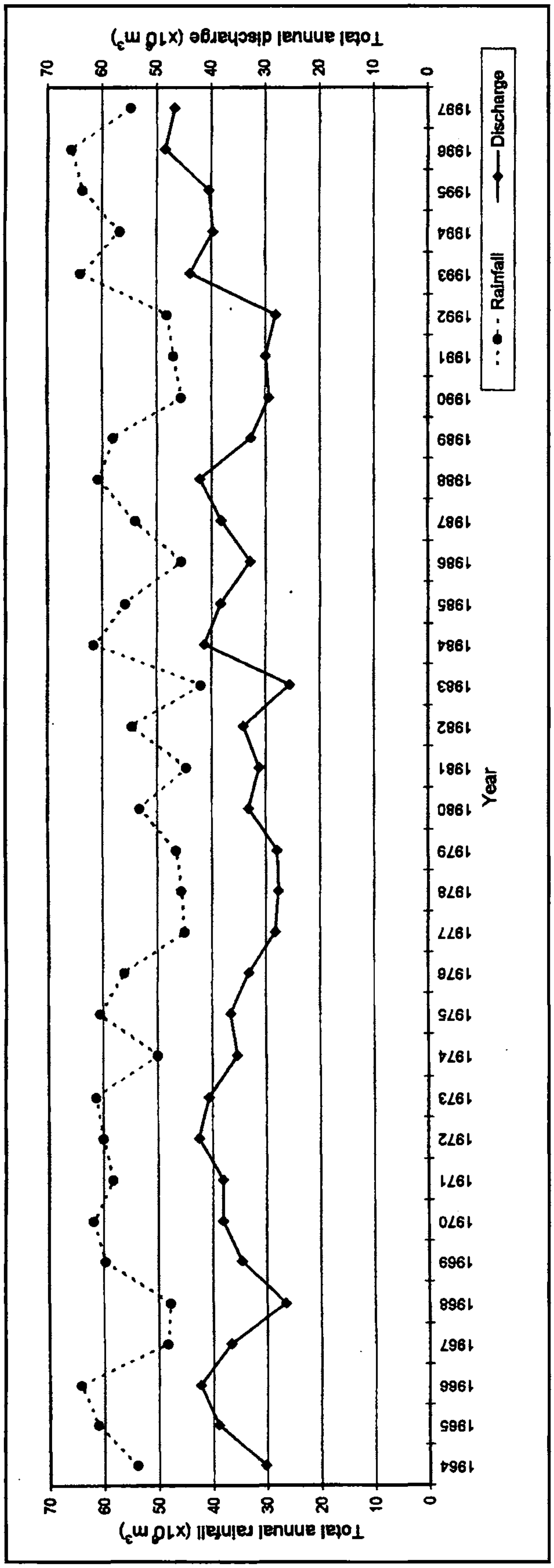

Figure 3A. Total annual rainfall and annual discharge — upper Sg. Bertam drainage basin (1964–1997).

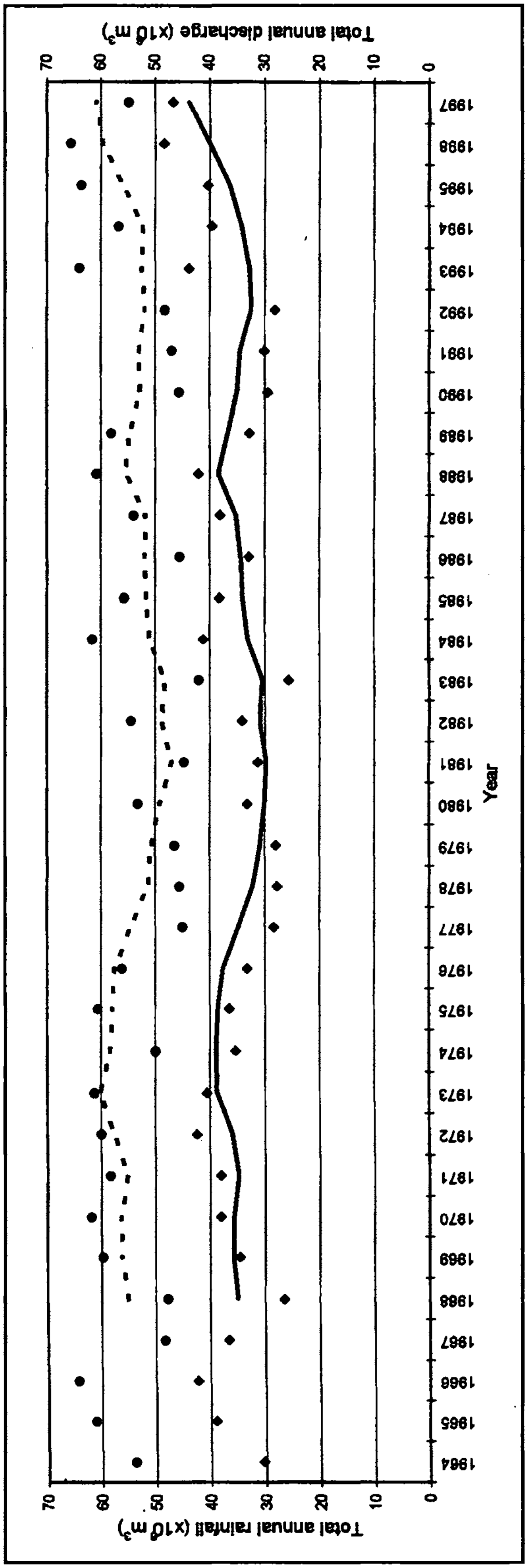

Figure 3B. Total annual rainfall and total annual discharge — 5 year moving average trend lines.

rates of soil erosion. The eroded sediments have been, and continue to be, deposited along river channels and diversion tunnels in the area as well as in the Ringlet Reservoir. Increasing overland flow as a result of the changes in land use is also reflected by the rising trend (relative to the annual rainfall) of the annual discharge of the Sg. Bertam at Robinson's Falls for the period 1964-1997; a trend that has led to decreased base flows of the Sg. Bertam during periods of several weeks without rain.

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