Chapter Six

ASSESSMENT OF ENVIRONMENTAL QUALITY CHANGES

Chapter 6.0 Assessment of Environmental Quality Changes

As discussed in the previous chapter, the anthropogenic activities in CH demonstrate an intimate interrelation with the natural environment. These activities exert pressures on the nature environment and these pressures induce changes of biological and physical components of the environment. This chapter concentrates on the investigation and evaluation of the state of the environmental quality and its changes.

The major environmental parameters evaluated are relevant to the case of CH, which covers the land, the atmosphere and water. The parameters assessed include deforestation, air temperature, rainfall, surface runoff, water quality and soil erosion. Other important environmental qualities such as quality of soil and biodiversity are not being assessed in this study due to insufficient information.

6.1 Deforestation

6.1.1 Deforestation in General

Forest ecosystems are among the most important components of the biosphere. Goods and services provided by the forest include not only timber and non-timber products but also the services in stabilizing the flow of water, improving water quality, modifying the chemistry of the atmosphere, and affecting climate as well as the habitats for flora and fauna.

Global tropical deforestation occurs at an alarming rate. The Food and Agriculture Organization of the United Nations has estimated that the annual rates of deforestation at 15.5 million hectares (FAO 1993) for the period 1980-1990 and 13.7 million hectares for 1990-1995 (FAO 1997). The total forest area lost during the 15 years period was approximately 200 million hectares at about the size of Indonesia. The estimated total area of tropical rain forest was 1, 838 million hectares in 1970s, where there were about 58% of closed forests and the rest were open woodland or savanna-type forest as estimated by Brown & Lugo (1982), using the data of Persson (1974).

By using the FAO data in 1997, Roper & Roberts (1999) ranked Malaysia as the 7th largest deforestation country in terms of total annual forest loss, with 0.4 million hectare in 1995. However, Brown (1993) indicated that most of the deforestation in Malaysia occurred on previously logged forests rather than on mature forest. Conversion of forest is mainly for agriculture such as rubber and oil palm plantation. In the period of 1972 to 1982, 8.6% of the mature forest and 34% of the previously logged forest were converted to non-forest. Forest area in Peninsular Malaysia compiled by the Forest Economic Unit of Malaysia was 6.2 million hectares in 1982. The total forest area is 19.37 million hectares (59% of total land area) for Malaysia, as estimated by Soepadmo (1995) from various sources.

There are various significant impacts as the consequences of deforestation. The economic losses include the loss of timber production, hardship and social disruptions for forest dwelling and forest dependent people. Productivity in adjacent land might be affected due to sedimentation problem of waterways, floods and changes in local climate. Soil losses due to deforestation will cause siltation of major rivers, which will degrade the watershed development, impedes hydroelectric power development, and endangers aquatic lives and reduces income from fisheries, reduces income from ecotourism and endangers flora which might have potential values in pharmaceutical products. Social concern of deforestation is intense as it is affecting the livelihood, traditional knowledge and cultural survival of indigenous communities. Other concerns of tropical deforestation are those of global effects. They include the loss of carbon sink, the irreplaceable loss of species and the changes in the water cycle, heat balance and climate of the earth.

The effect of deforestation to local climate is mainly due to changes in surface characteristics. By removing rainforest with large leaf and stem area, and replaced with grassland, scrub, vegetable or concrete building and tar road, it will lead to three primary changes in the land surface properties such as:

(a) the surface albedo is increased, which directly causes a reduction in the surface net radiation absorption;

(b) the reductions in the leaf area and stem area lead to a decrease in the water holding capacity of the vegetation, thus the evaporation of the intercepted precipitation and, also the vegetation transpiration are decreased due to deforestation; and

(c) modification of surface roughness. Decreased of surface roughness and weakened surface frictional forces will alter the aerodynamic exchange, between the land surface and the lower atmosphere, and decreased the surface evapotranspiration. It will then cause changes in the net surface energy and the surface temperature.

Beside the effects of the changes in surface characteristics, local climate changes also depend on some other factors, such as regional climate phenomenon, landscape and the scale of degraded area. For example, the Asian Monsoon plays a dominant role in the climate of Southeast Asia, and the Indian Ocean and the warm pool in the west Pacific Ocean provide warm and humid air over this 'marine continent'. For these reasons, the reduction in rainforest acreage is unlikely to be the dominant factor in the regional climate system (Henderson-Seller *et. al.*, 1996). Various results from climate simulation (e.g. Henderson-Seller *et. al.*, 1993; McGuffie *et. al.*, 1995) suggest that only small-scale impact on the local and regional climate are resulting from deforestation in Southeast Asia.

6.1.2 Forest Area Changes in the Hydroelectric Catchment

In CH, deforestation occurred due to increase demand of land area for agriculture, urbanization and infrastructure development. ***Plate F*** shows newly cleared forested areas in CH. Forest-cover changes for about 50 years is analyzed for the CH catchment area. The forest areas were estimated by UM and TNBR (2001) from the topographic maps from the Department of Survey for the years 1947 and 1966 as well as the land use maps from the Department of Agriculture for the years 1974, 1982, 1990, and 1997. Geographical Information System, ArcView is used to analyze the digitized maps and tabulated in **Table 6.1.1.**

Table 6.1.1.

Deforestation in the Hydroelectric Catchment from 1947 to 1997.

Catchment	Total Catchment Area (ha)	1947 (ha)	1966 (ha)	1974 (ha)	1982 (ha)	1990 (ha)	1997 (ha)
Telom	10068	10068	8782	8582	8137	8057	6437
		100%	87%	85%	81%	80%	64%
Upper Bertam	2098	1900	1607	1638	1598	1560	1504
		91%	77%	78%	76%	74%	72%
Lower Bertam	4945	4222	2985	2845	2749	2754	2658
		85%	60%	58%	56%	56%	54%
Total	**17111**	**16190**	**13373**	**13065**	**12483**	**12371**	**10599**
		95%	**78%**	**76%**	**73%**	**72%**	**62%**

Source: modified from (UM and TNBR, 2001)

In 1947, there was no record of land use in Telom catchment and it is assumed that Telom was fully covered by forest (10, 068 ha) then. Survey map of 1947 indicated that the forested areas in Upper Bertam and Lower Bertam were 1, 900 ha (85%) and 4, 222 ha (95%) respectively. Thus, in 1947, the total forest area in the hydroelectric catchment was 16, 190 ha (95%).

However, records since 1966 indicated a massive deforestation. From 1966 to 1997, forest in Upper and Lower Bertam catchments was cleared for residential, market gardening and tea cultivation with a very high rate. Forest cover in Telom was 8, 782 ha (87%), where 5.8% was under tea cultivation and 2% was cultivated with vegetable. Forested areas left in these two catchments were 77% and 60% respectively. The total forested area in these three catchments was 13, 373 ha (78%).

After this period, deforestation rate was lower in the Upper and Lower Bertam catchments. It is probably due to limited land with a suitable topography for agricultural activities. However, deforestation activity migrated to Telom and occurred in a rapid rate in the later years as the government's policies of encouraging vegetable farming and floriculture. From 1966, forested area reduced gradually to 8,057 ha (80%) in 1990. Rapid deforestation occurred from 1990 to 1997, where 1,620 ha (or 20% of 1990) of forest was destroyed. The average annual deforestation rate in this period was 231.4 ha (2.9%) in Telom. The remaining forest area is only 64% of the total land area. **Fig. 6.1.1** shows the rapid encroachment of farming and newly cleared land into the natural forest in Telom during 1990 to 1997.

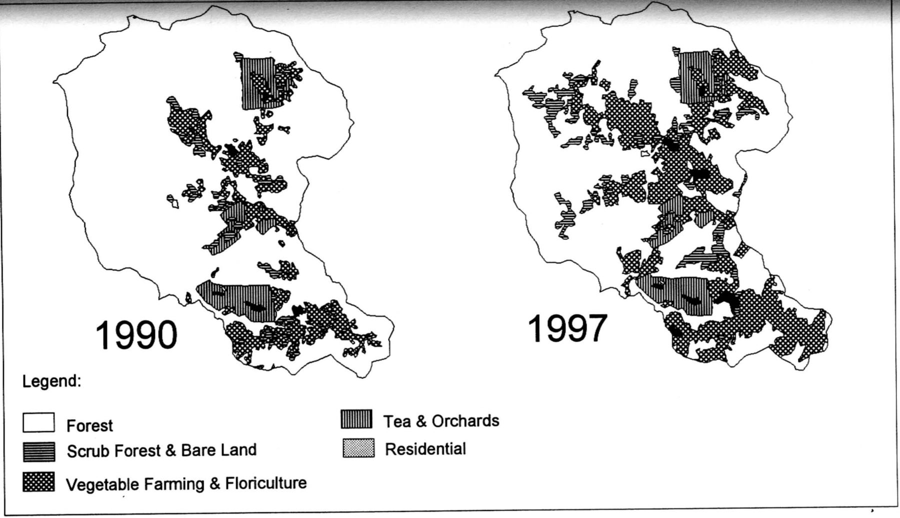


Fig. 6.1.1 Land use Changes in Telom Catchment for 1990 to 1997

Source: Modified from UM and TNRD (2001).

Forest cover has thus been reduced from 16,190 ha (95%) in 1947 to 12,483.2 ha (73%) in 1982 and to 10,599.3 ha (62%) in 1997. Thus, the total deforestation in 50 years was 5, 591 ha (34.5%), in other words, at an average rate of 112 ha (0.7%) per year. Expansion in agriculture, urbanization as well as increases in grassland, scrub forest and shifting agriculture contributed to the deforestation.

6.1.3 Discussions on Deforestation

Rapid land use changes occurred in the hydroelectric catchment where natural vegetation has been replaced with vegetable or flower garden. This has tremendously reduced the are of the dense tropical forest, resulting in a loss of primary productivity, a decline in carbon sequestration capacity, and the destruction of the biodiversity of the natural forest. The removal of trees with large stem and leaf area in a multi-layered canopy forest will alter the surface characteristic of the catchment as the forest is replaced with small and scattered vegetable plants or the plastic shelters of floriculture.

Associated with this rapid deforestation and land use changea, there are significant changes to the environmental quality of this highland. These changes will influence the hydrological cycle and water balance, surface air temperature, soil fertility, slope stability, which will indirectly undermine the human activities and livelihood. ***Plate G*** shows examples of the scene of landslide, which are very common in CH and widely reported in the literature such as in Roslan *et. al.* (1996). It will also bring about irreparable damages to the habitats and biodiversity of this delicate highland ecosystem with its long-term impacts on the socioeconomic well being of all the stakeholders in the highlands.

6.2 Surface Temperature Variability

6.2.1 Introduction to Temperature Changes

Climate variability on various spatial and temporal scales has drawn the attention of climatologists for over a century. Researchers in the past concentrated on the study of the changes in climatic elements and their implications on human ecology. However, recent trends acknowledge the interrelation of climate and anthropogenic activities. Nevertheless, the resultant effects of deforestation and development in CH on local climate have not yet been well established. Local press reported increase of temperature of up to 4°C in Tanah Rata and the surrounding areas as a result of over building and removal of vegetation (Leong, 1992). Wong (1999) reported on a survey that 100% of the farmers interviewed cited air temperature increase and the reasons given were forest clearing, population increase and El-Nino effect.

6.2.2 Analysis of Temperature Variability

Yearly temperature published by the Malaysian government for the town of Tanah Rata as shown in **Fig. 6.2.1** suggests warming in this mountainous highland. For the period of 1976 to 1998, both absolute and mean temperature indicated an incremental linear trend. The absolute lowest temperature increased in a trend by more than 3°C during this period. The absolute lowest temperature for the year 1976 and 1998 were 9.3°C and 12.78°C respectively. The absolute lowest temperature in CH reported by Dale (1963) is 36 °F (2.2°C). However, the absolute lowest temperature never went down to 10.0 °C in the 1980s and 11.4 °C in the 1990s (in this study). The absolute highest temperature data also suggested a trend of more than 1°C warming. Both mean maximum and mean minimum temperature also increased by a magnitude of 1°C for the same period of time.

This study also examined the long-term records of monthly mean temperature. The monthly mean temperature data for Tanah Rata (1,471 m above mean sea level) from 1974 to 1998 was obtained from the Department of Malaysian Meteorological Service. The location of the meteorological station is on a hill beside the town of Tanah Rata. The mean monthly temperature data recorded in TNB's meteorological station in Habu Power Station (1,080 m above mean sea level, beside the main road from Ringlet to Tanah Rata) for the Jun 1964 to 1999. Besides plotting the linear regression trends, temperature anomaly (deviation from the mean) from the reference mean of the data periods were also analyzed.

The linear trend analysis indicates a nearly 2°C of increase for the mean minimum temperature and 1°C for mean maximum monthly temperature in Tanah Rata **(Fig. 6.2.2)**. The magnitude of increase in mean daily temperature was 0.6°C in 25 years. At a slightly lower altitude, air temperature in the town of Habu has also increased over the years. The mean temperature data recorded at the Habu Power Station is suggesting an increase of 1.5°C **(Fig. 6.2.3)**.

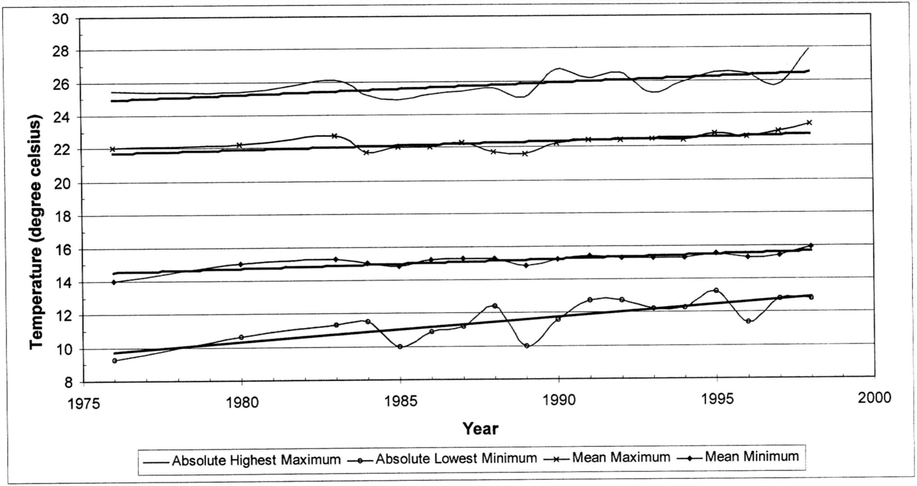


Fig. 6.2.1: Absolute and Mean Annual Temperature for 1976 to 1998 in Tanah Rata, Cameron Highlands.

Source: Year Book of Statistic, Statistical Department, Malaysia.

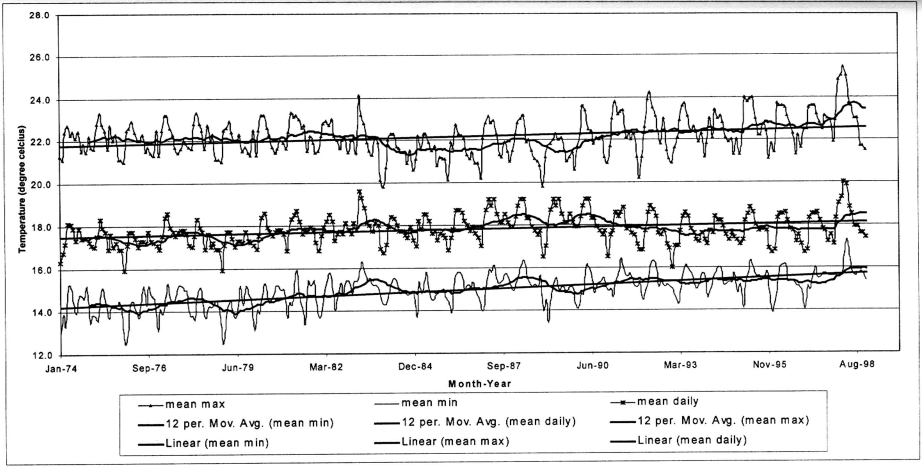


Fig. 6.2.2: Monthly Mean Temperature for 1974 to 1998 in Tanah Rata, Cameron Highlands.

Source: Malaysian Meteorological Service Department

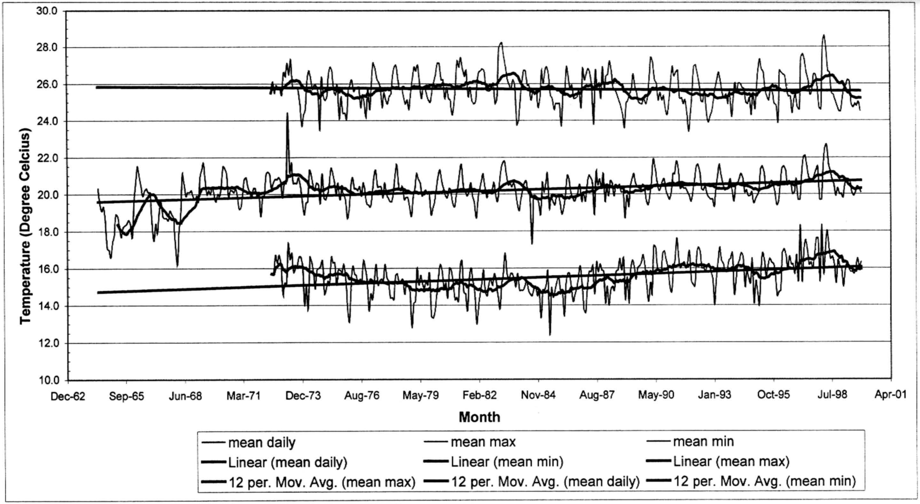


Fig. 6.2.3: Monthly Mean Temperature for July 1972 (June 1964 for the Mean Daily) to 1999 in Habu, Cameron Highlands.

Source: Habu Power Station, TNB Generation Berhad

The monthly mean temperature anomalies (departures from the long-term reference mean) for both Tanah Rata and Habu in CH shows warming trends over the years. In the early 1980s, temperature migrated from below the reference mean to above the mean. The warming persisted until 1990. The high occurrence of temperature anomalies with more than one standard deviations above the reference mean are observed in the late 1980's and late 1990's (**Fig. 6.2.4**).

On the other hand, monthly mean temperature anomalies for Habu was analyzed from 1964 to 1999. In the early years of this temperature series, the anomalies were in the negative side. There were high occurrences of anomalies with more than one standard deviation below the reference mean. In the late 1960s to the early 1970s, temperature increased tremendously and then fluctuating about the reference mean. In the late 1980s, the temperature anomalies migrated above the reference mean. The trend has shown increasing occurrence of anomalies with more than one standard deviation above the reference mean (**Fig. 6.2.5**).

6.2.3 Discussions on Surface Temperature Variability

The localized warming of CH has received sufficient evidence. CH no longer experiences temperature as low as in the early days. This has a definite negative effect on tourism, as the most important attraction in CH is the cool weather. Furthermore, farming activities are also depending on the temperate like climate. The warmer temperature may have an effect on the quality of the agricultural products. Unfortunately, scientific understanding of the consequences of warming is not yet available in CH. On the other hand, tourists and locals complaints of the warming have been recorded.

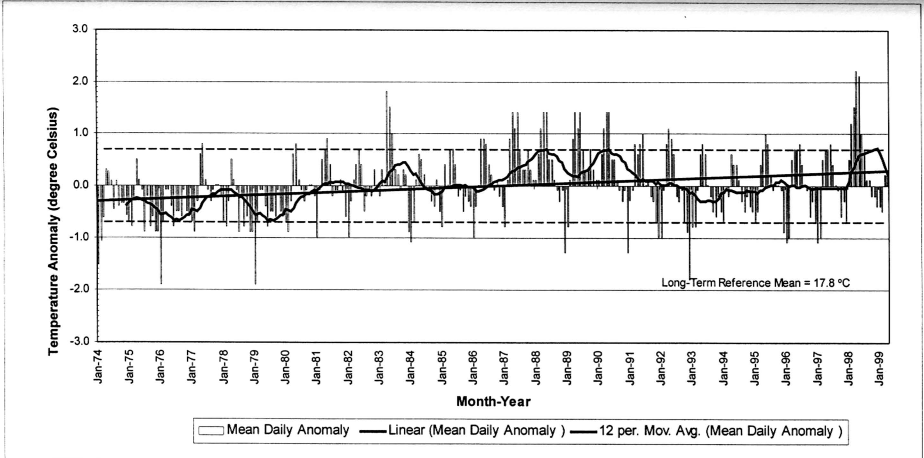


Fig. 6.2.4: Variation of monthly mean temperature anomalies for Tanah Rata, Cameron Highlands during 1974-1999. The horizontal dashed lines indicate one standard deviation above and below the reference mean. The thick line is the linear trend line and the thick curve is a 12 months moving average curve.

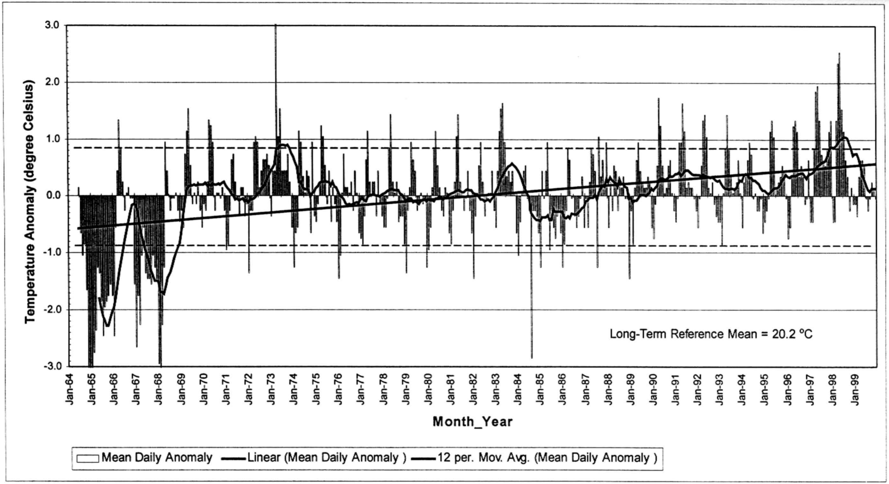


Fig. 6.2.5: Variation of monthly mean temperature anomalies for Habu, Cameron Highlands during 1964-1999. The horizontal dashed lines indicate one standard deviation above and below the reference mean. The thick line is the linear trend line and the thick curve is a 12 months moving average curve.

Nevertheless, the causes of these changes have not yet been firmly established, whether it is a local or global phenomenon, or merely due to a cyclic variation. However, the increase of air temperature in CH cannot be attributed solely to the phenomenon of global warming. There is no observed correlation between the trend of global temperature anomalies and those of CH. The year 1998 was recorded the warmest year in recent global temperature series, with the 1998 global temperature anomaly 0.57°C above the 1961-1990 reference period mean temperature (Jones *et. al.,* 2000). The seven warmest years of the global record have all occurred in the 1990s, with a descending order of 1998, 1997, 1995, 1990, 1999, 1991 and 1994 (Jones *et. al.* 2000). However, temperature anomalies in CH do not suggest similar trends. Severe warming only occurred in the end of 1990's.

Therefore, warming in CH cannot primarily be attributed to global effects. It is a complicated phenomenon that required further study to quantify the influence of the changes in local surface characteristics to the surface air temperature. Climate simulation model will be helpful to quantify the influence of the local land characteristic changes on the surface air temperature.

6.3 Rainfall Variability

6.3.1 Introduction

Rainfall is one of the most important and conspicuous atmospheric processes and has direct implication on the survival of the ecosystem, the flora and fauna, as well as creates stress on the social economic dimension of mankind. As an important component in the hydrological cycle, the quantity of rainfall determines the availability of water in the upstream catchment such as in CH. On the other hand, the intensity of rainfall will have significant effects on soil erosion rates in the open agricultural land in CH.

As a water catchment reserve for hydroelectric power generation, records of rainfall are extensive in both temporally and spatially. Rainfall records for the Bertam and Telom catchment were dated back to the year 1948 and 1954 respectively. There are 12 rainfall stations in both Telom and Bertam catchments. All these stations have rainfall gauges to measure the daily rainfall. The locations of these stations are shown in **Appendix B: Figure B-1.** However, the areal rainfall data is compiled from only nine out of the 12 available stations. The areal rainfall of the monthly mean precipitation of both catchments was calculated by averaging the gauged amounts in the area (UM and TNBR, 2001). **Appendix A: Table A-6** shows the available rainfall stations within the two major catchments in CH.

6.3.2 Analysis of Rainfall Variability

The monthly mean areal rainfall for Bertam catchment from the years 1948 to 1997, and for Telom catchment from the year 1954 to 1997 are shown in **Appendix A: Table A-7** and **Table A-8** respectively. The long-term mean annual rainfall is 2, 444 mm and 2, 280 mm in the Bertam and Telom catchments, respectively. The long-term changes are measured by a linear trend for the entire data series. Ten-year moving average is also plotted for the both catchments. The linear trend lines as shown in **Fig. 6.3.1** and **Fig. 6.3.2** suggest that there is a slight decrease in rainfall over the last 50 years in the Bertam and Telom catchment. On the average, the annual decrease is about 4.4 mm per year and 2.4 mm per year for the two catchments respectively.

Fig. 6.3.3 and **Fig. 6.3.4** show the rainfall anomalies (deviation from 50 year reference mean) for Bertam and Telom catchment respectively. Negative annual rainfall anomalies occurred with a high frequency since mid 1970s for both catchment. There were numerous years where the deficiencies in rainfall were more than one standard deviation. However, direct correlation of rainfall and deforestation rate is not strong (**Fig. 6.3.3** and **Fig. 6.3.4**). There was severe deforestation during the 1990s in Telom catchment but there was no indication of decreased rainfall.

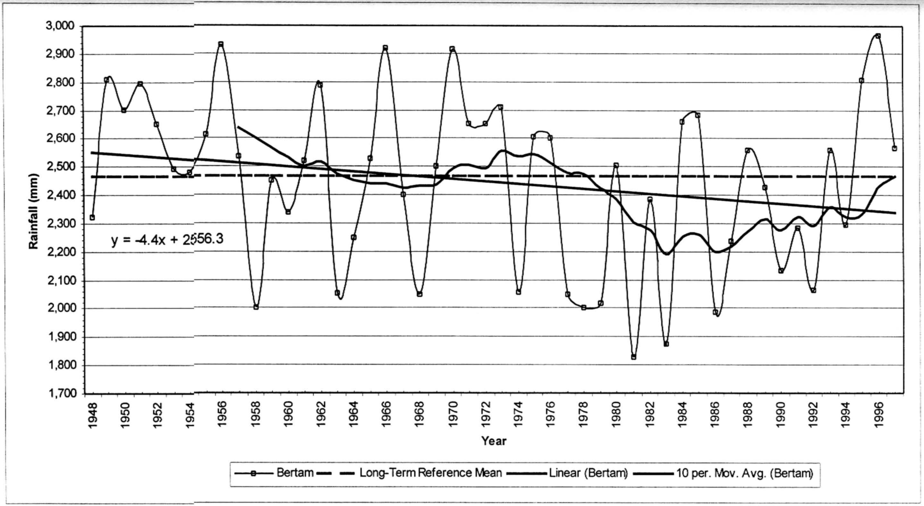


Fig. 6.3.1: Annual Areal Rainfall of Bertam Catchment, Cameron Highlands for 1948-1997.

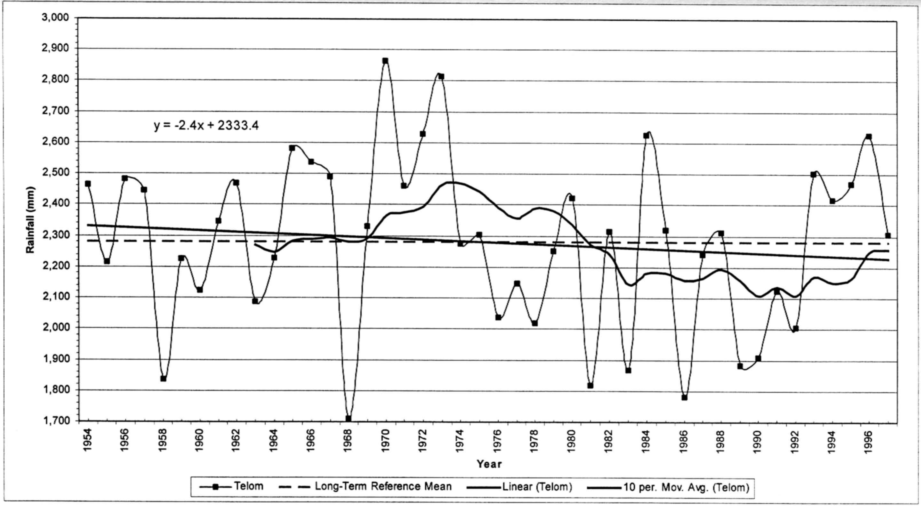


Fig. 6.3.2: Annual Areal Rainfall of Telom Catchment, Cameron Highlands for 1954-1997.

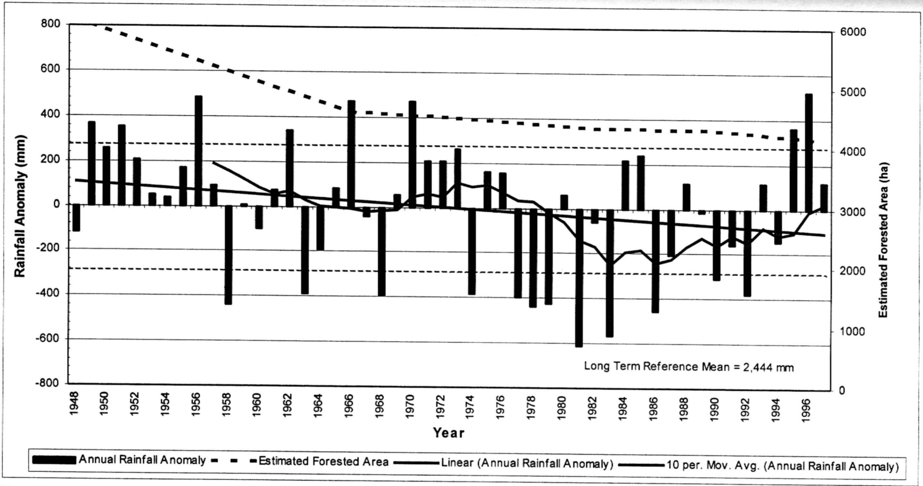


Fig. 6.3.3. Variation of annual areal rainfall anomalies for Bertam Catchment during 1948-1997. The horizontal dashed lines indicate one standard deviation above and below the reference mean. The thick line is the linear trend line and the thick curve is a 10 years moving average curve.

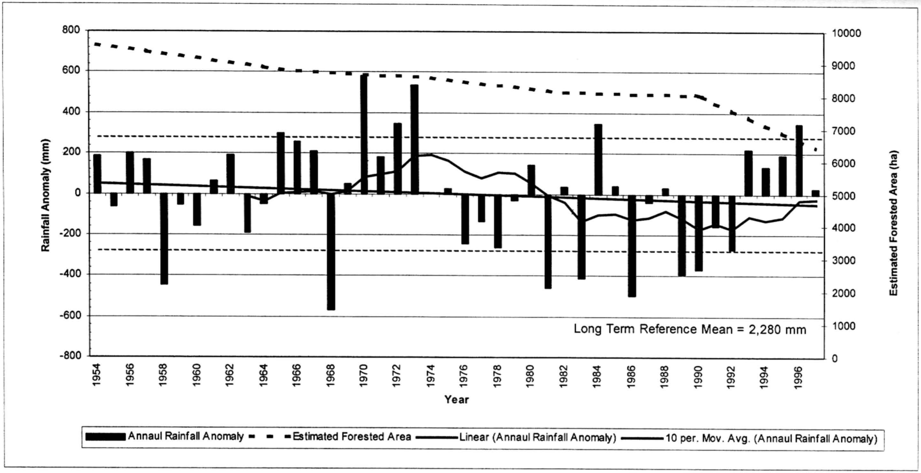


Fig. 6.3.4. Variation of annual areal rainfall anomalies for Telom Catchment during 1954-1997. The horizontal dashed lines indicate one standard deviation above and below the reference mean. The thick line is the linear trend line and the thick curve is a 10 years moving average curve.

6.3.3 Discussions on Rainfall Variability

The increase in frequency and severity of annual rainfall deficiency in the last two decades when compared to the 1950s and 1960s are evident. The 50 year linear trend indicated that a reduction of mean annual rainfall of 4.4 mm/year for Bertam catchment and 2.4mm/year for Telom catchment. Overall, the mean annual rainfall of Bertam catchment has been reduced by 220 mm (8.9% of mean annual rainfall of 2,444 mm) while Telom catchment by 120 mm (5.3% of mean annual rainfall of 2,280 mm) over a span of 50 years.

However, the cause of decreasing in rainfall may not be solely attributed to the deforestation. Contradictory, the rapid deforestation of 36% in Telom in the 1990's did not have an immediate effect on the annual rainfall. It is in line with the earlier conclusion that monsoon, rather than rain forest, is the decisive factor in influencing the rainfall regime in Peninsular Malaysia. Although the dominant factor is not the forest, the study does elucidate on the possibility of long-term negative effect of deforestation on rainfall in CH.

The consequence of the reduction in rainfall is the corresponding reduction of runoff. The deficiency in water resources will be more severe, especially during the dry seasons. As water is the essential life support element, and the demand for water resources is increasing, the phenomenon of rainfall reduction in CH requires attention. Proper and sustainable management of water resources to meet the demands of agriculture, domestic, hydroelectric power generation and the natural ecosystem is crucial.

6.4 Streamflow Variability

6.4.1 Introduction

Analysis of rainfall variability in the previous section suggests a reduction trend in CH. Moreover, surface characteristics and vegetation cover also influence the water balance of the catchment. Land use changes with tremendous deforestation and urbanization will yield an effect on the water holding capacity and water availability in these mountain areas. In view of the increasing conflict of utilization of water for power generation, agriculture and domestic usage, sustainable water management is of utmost importance. Agricultural land use area increases from 1931.7 ha to 4,338.9 ha in the year 1966 and 1997, respectively (UM and TNBR, 2001). On the other hand, domestic potable water requirement is expected to increase from 2 million gallons to 3.5 million gallons from the year 2000 to 2020 (CHDC, 1996).

There are two primary hydrometric stations located within the CH basin, which are operated by TNB Berhad. The locations of these stations are shown in **Appendix B: Fig. B-1** and are summarized in **Appendix A: Table A-9**. Flow type water stage recorder gauging station was installed on Telom River at miles 49 in 1955 (UM and TNBR, 2001). In 1964, there is an additional flow diverted from Plau'ur catchment that contributed to the quantity of water. Thus, the streamflow measured in Telom River comprises of four sub-catchments, which include Plau'ur River, Telom River @ Miles 49, Kial River and Kodol River. In 1956, another gauging station with continuous chart recorder was installed on Bertam River at Robinson Falls. The streamflow data at Bertam River @ Robinson Falls and Telom River @ Miles 49 is shown in **Appendix A: Table A-10** and **Table A-11**, respectively (UM and TNBR, 2001).

6.4.2 Analysis of Streamflow Variability

Long term records of streamflow for both Bertam Catchment at Robinsons Fall and Telom Catchment at Miles 49 are presented in **Fig. 6.4.1** and **Fig 6.4.2** respectively (UM and TNBR, 2001). Linear trend analysis indicated a reduction of streamflow in both catchments.

In Bertam, the average reduction rate of streamflow is 7.2 mm per year, while the annual streamflow anomaly analysis in **Fig. 6.4.3** also indicated a more intense negative anomaly after the mid 1970s in Bertam. **Fig. 6.4.1** also indicates the reduction of the ratio of streamflow to rainfalls over this period of 50 years.

In Telom, the average reduction is less than that recorded in Bertam. The average reduction of streamflow in Telom is 1.6 mm per year, while the annual streamflow anomaly analysis in **Fig. 6.4.4** also indicated a more intense negative anomaly after the mid 1970s in Telom. Contradictory to the Bertam catchment, the ratio of streamflow to rainfall as shown in **Fig 6.4.2** is increasing.

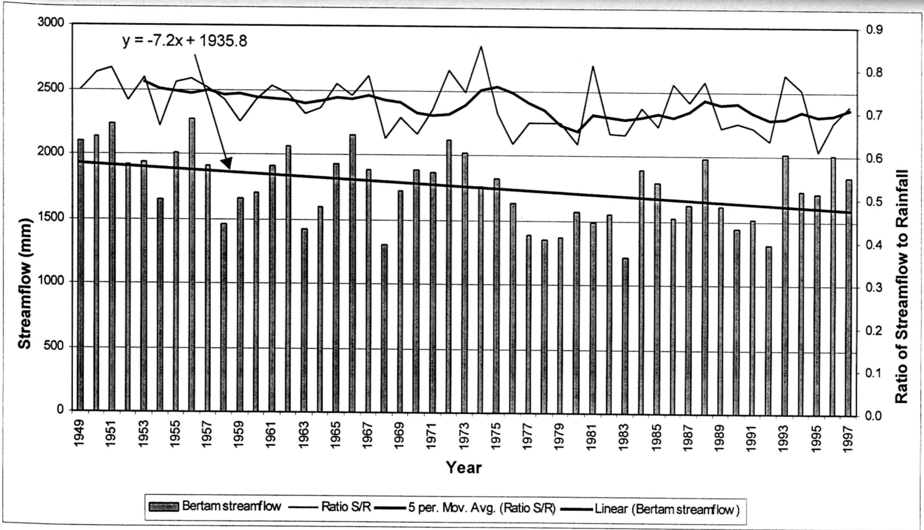


Fig. 6.4.1: Streamflow of Bertam at Robinson Falls, Cameron Highlands for 1949-1997.

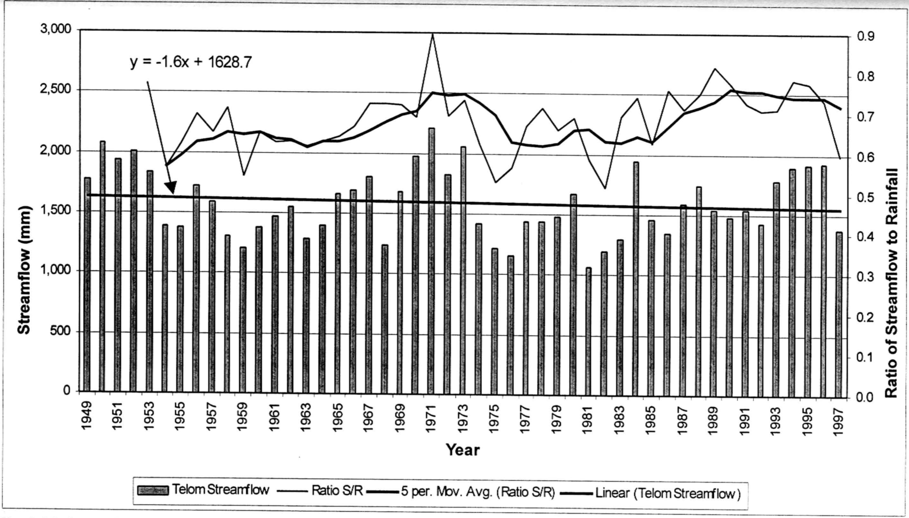


Fig. 6.4.2: Streamflow of Telom at Miles 49, Cameron Highlands for 1949-1997.

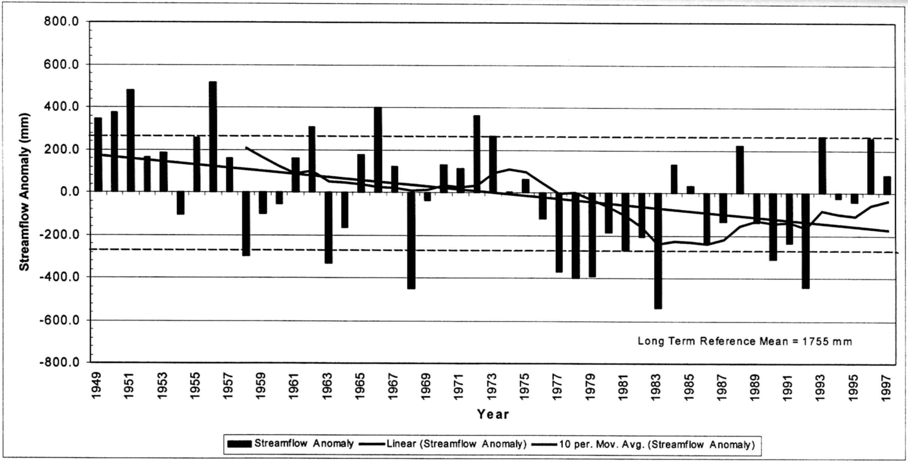


Fig. 6.4.3. Variation of annual streamflow anomalies for Bertam Catchment at Robinson Falls during 1949-1997. The horizontal dashed lines indicate one standard deviation above and below the reference mean. The thick line is the linear trend line and the thick curve is a 10 years moving average curve.

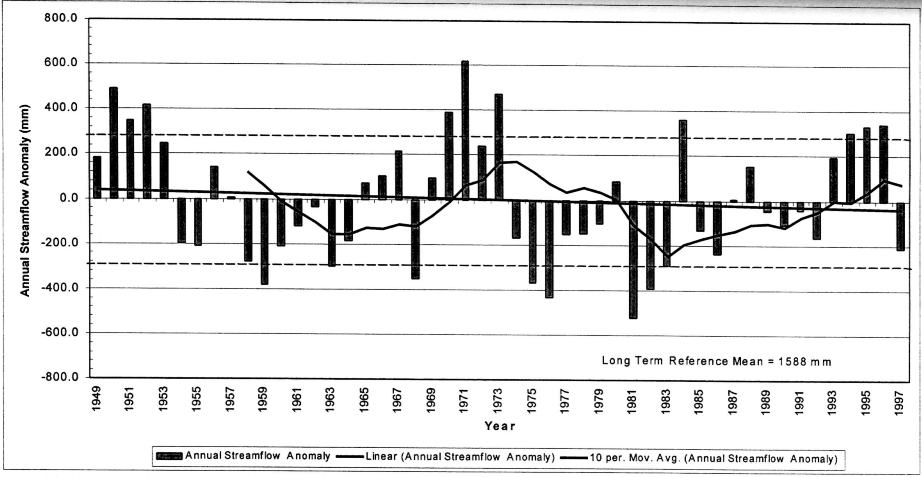


Fig. 6.4.4. Variation of annual streamflow anomalies for Telom Catchment at miles 49 during 1949-1997. The horizontal dashed lines indicate one standard deviation above and below the reference mean. The thick line is the linear trend line and the thick curve is a 10 years moving average curve.

6.4.3 Discussions on Streamflow Variability

The streamflow reduction in the Bertam catchment (7.2 mm per year) is more than the decreased rainfall (4.4 mm per year). It is also supported by the analysis of the changes in the ratio of streamflow to rainfall for the period of 50 years. The ratio is reducing, which indicates a lower streamflow per unit of rainfall at Robinson Falls. This is probably due to the increase in domestic water extraction for the increasing population and tourists in the Upper Bertam valley.

On the other hand, a lower reduction rate of streamflow (1.6 mm per year) when compared to the decreasing rainfall (2.4 mm per year) in Telom indicates the effect of reducing water-holding capacity in a deforested catchment. This is confirmed by the analysis of the ratio of streamflow to rainfall, which concludes that the ratio is increasing. There is a larger quantity of streamflow per unit of rainfall in recent years. The runoff is higher in quantity and takes a shorter time to peak flow in a deforested catchment. Preliminary study by UM and TNBR (2001), who modeled the unit hydrograph of the hydroelectric catchment, suggests an increase of 2% peak flow and shortening of time to peak by 30 minutes.

The alteration of hydrological regime in CH has received sufficient evidence. The reduction of water resources will definitely impose negative effects on the sustainability of the catchment with impacts on hydropower generation, irrigation in agricultural activities as well as domestic demands. The authority has to increase the protected water catchment areas for yielding enough quantity of water for domestic demands. Thus, this will leads to greater land use competition. Therefore, sustainable management of water resources and land use planning are required to avoid greater social conflicts.

6.5 Water Quality Changes

6.5.1 Introduction

Water flowing down rivers, or stored in lakes and reservoirs, sustains a complex ecosystem of biota feeding, growing, reproducing, excreting, dying, and decomposing. Besides, surface water in CH is also used for irrigation, domestic consumption, power generation and recreational activities.

Land use changes due to urbanization, infrastructure development, deforestation, tourism and agricultural activities may cause deterioration of river water quality. Bad practices and poor management of these activities will increase the sedimentation load in the river. On the other hand, the use of pesticide, herbicide and fertilizer in agricultural activities and golf course will cause chemical contamination of the river water. Urbanization will increase the effluent discharged such as domestic sewage, kitchen waste and also solid waste into the waterway. This will increase the coliform count, BOD, suspended solids, ammonia, nitrate, and phosphate level. These will become the pollutants that can cause harm to living creatures, disruption to ecosystems, damage to environmental resources and anthropogenic structures, and even hazardous to human health, both local and downstream.

Plate H shows crystal clear river water at the outlet of Plau'ur River diversion channel. In 1997, about 97% of Plau'ur catchment is still under forest cover. ***Plate H*** also shows high turbidity water at Ringlet River. Analysis of the land use map in 1997 suggested that Ringlet catchment drains 830 ha of mostly former tea plantation, some areas were planted with vegetable and others deserted as scrub forest. In 1997, there was only about 200 ha of forested area left in the Ringlet Catchment.

6.5.2 Reported Water Quality

Below are findings of other studies that indicate the deterioration of water quality of rivers in CH: -

☐ UM and TNBR (2001)

The records of sediment load in a few rivers in CH quantified the observation of high turbidity. There were significant increases in the sediment loads of the runoff over the hydroelectric catchment. The analysis of sediment rating curves for Bertam River at Robinson Falls and Telom River at Miles 49 showed the suspended sediment discharge loads at both locations increased drastically over the last 43 years (see **Appendix B: Figure B-2** and **Figure B-3**).

For the three periods of 1956, 1986-1989 and 1990-1998, there was significant increase in the sediment discharge for all measured monthly average of river discharge at Robinson Falls. The average suspended load concentration in Telom River increased from 15 ppm in the 1960s to 251 ppm in the 1990s. On the other hand, the average suspended load in Upper Bertam River increased 15 fold from 15 ppm in the mid 1950s to 231 ppm in the 1990s. This drastic increase in river sediment load has dire consequences in the long-term operation of the hydroelectric scheme. Moreover, increases of sedimentation also indicated severe soil erosion and degradation of land, in particular the agricultural land.

❐ The Department of Environment reported that the Water Quality Index for Bertam River was deteriorating in the 1990s (**Table 6.5.1**). In agreement with the conclusion of severe soil erosion studies (Aminuddin *et. al.*, 1999/a; UM and TNBR, 2001), the Department of Environment identified high levels of suspended solids concentrations in the rivers as the main parameter that contributed to the degrading of the index.

Table 6.5.1: Water Quality Index for Bertam River.

Water Quality Index : Bertam River	
1993	86
1994	86
1995	84
1998	82

Source: Various years, *Malaysia Environmental Quality Report*, Department of Environment.

❐ Norhazni & Pauza Hanum (1996) from the Department of Environment surveyed five rivers in CH from May to July 1994. Six water quality parameters were measured, which were suspended solids, ammoniacal nitrogen, phosphorous, nitrate, iron and chromium. The results strongly suggested that Ringlet River had been badly polluted with Iron, Nitrate, Phosphorous, Ammoniacal Nitrogen and suspended solids. Nitrate contamination was high in four rivers and Phosphorous in two out of five rivers (**Table 6.5.2**). Due to the study has been conducted during the dry period of the year, the level of suspended solids was expected to be lower than the yearly average. The concentration for suspended solids was expected to increase drastically during high flow.

Table 6.5.2: Water Quality Status of Selected Rivers in Cameron Highlands.

Station (River)	**Suspended Solid (mg/l)**	**Ammoniacal Nitrogen (mg/l)**	**Nutrient**		**Heavy Metal**	
			Phosphorous (mg/l)	**Nitrate (mg/l)**	**Iron (mg/l)**	**Chromium (mg/l)**
Std. Class III†	**150**	**0.9**	**0.1**	**0.37**	**1**	**1.45**
Ringlet	*368.50*	*1.08*	*0.83*	*2.35*	*2.36*	0.02
Bertam	96.00	0.47	*0.18*	*1.14*	*2.18*	0.08
Habu	21.30	0.24	*0.10*	*0.62*	0.26	0.02
Mensun	6.00	0.05	*0.23*	0.08	0.00	0.02
Tringkap	62.30	0.34	*0.44*	*3.25*	0.00	0.04

Note: †Class III: –Interim Ambient Water Quality Standard, Department of Environment, Malaysia.

Source: Norhazni and Pauziah Hanum (1996), Department of Environment.

- Aminuddin *et. al.* (1999/a) reported that the sediment concentration in the stream and river was high for catchment with intensive agricultural activities (up to 0.30 g/100 ml). Runoff and leaching of nutrient was also considerably high. The amount of total applied fertiliser lost through the runoff were 1.5%, 5.5% and <1% for N, P and K, respectively, while the respective leaching recorded in lysimeter were 7.7%, 16.8% and 0.2%. During peak runoff period, NO_3 concentration reached 25 ppm, while leachate concentration was 40 ppm.

- Wan Marina (1990) sampled river water in seven stations in CH and tested for various physical and chemical properties. Her sampling sites include stations within pristine forest and those in the vicinity of agricultural activities. Wan also carried out population count and species identification for invertebrate and alga. Wan recorded that pesticide DDT, Heptachlor and HCH were found in all stations except for the station within pristine forest catchment. Alga *Achnanthes* species, a clean water alga was found abundant in the pristine catchment. However, alga *Navicula cryptocephala* were found in the other stations, which indicated the existence of organic pollutants like N, P and C. Wan concluded that the clean water invertebrate species were only found in the station within pristine forest catchment. On the other hand, species that lived in polluted habitat were found in the other stations.

6.5.3 Discussions on Water Quality

Even though information from the above studies is not comprehensive enough to represent the water quality for the entire catchment, it is evident that river water at CH is polluted. Organic and pesticide pollutants can be attributed to agricultural activities. High levels of total suspended solids in the river and severe sedimentation of the reservoir indicate high erosion rates, due to deforestation, unsustainable agricultural practice, poor soil conservation practices in road and building construction. The state of water pollution gives a very strong indication regarding the problem of sustainable development of the hydroelectric catchment.

On the other hand, rivers in the hydroelectric catchments, i.e. Telom, Upper Bertam and Lower Bertam, are redirected to Perak River. Therefore, all the pollutants and sedimentation will be carried downstream besides being trapped by the reservoirs. The effect of this river diversion to the aquatic environment downstream of the Perak River has not yet been assessed.

6.6 Soil Erosion

6.6.1 Introduction

Soil erosion is a two-phase process that consists of the detachment of individual particles from the soil mass and their transport by erosive agents such as running water and wind (Morgan 1995). In a drainage basin, soil erosion begins with the detachment of soil particles on slopes by rainfall splashing on soil masses and transported by surface runoff; the sediments being transported down-slope and ending-up in stream channels. These sediments, as well as those soil particles detached from the banks and floors of the stream channels, are also transported further down-stream and either temporarily, or permanently, deposited wherever stream velocities decrease.

Soil erosion is a hazard associated with agriculture in the region of high rainfalls. The consequences of soil erosion are both on-site and off-site. The on-site effects include the redistribution of soil within a field, the loss of soil in a field, the break down of soil structure and the decline in organic matter and nutrient. In particular, it reduces the fertility of the land and the depth of cultivable soil. The changes in soil texture also reduce the moisture content and induce a draught-prone condition. The loss of land productivity will restrict the planting of certain crop types and imposes a demand for increasing usage of fertilizer and other input. If the conditions worsen and threaten the food production, a productive farmland might be transformed into an abandoned wasteland. Thus, severe soil erosion is a sign of unsustainable agricultural development.

The off-site problems of soil erosion are the consequences of sedimentation in waterway downstream. The sedimentation in the riverbed, reservoir or lake changes these ecosystems. Biologically, it might destroy the living organism, flora and fauna that also have direct economic impacts to the downstream communities. Physically, sedimentation will reduce the channel capacities of rivers and the storage capacity of reservoir, thus enhances the risk of flooding and disrupts the operation of irrigation and hydroelectric setup.

6.6.2 Reported Soil Erosion Rate

Although there were studies of soil erosion in the 1950's, there is very little published data on the rates of soil loss in CH and also other humid tropical areas. Dickinson and Gerrard (1963) reported that approximately **732 m^3/km^2/year** (about 11 ton/ha/year) of 'soil loss' occurred from areas planted with vegetables, **488 m^3/km^2/year** (about 7.3 ton/ha/year) from areas covered with tea and only approximately **24.5 m^3/km^2/year** (about 0.37 ton/ha/year) from forested areas in CH. Douglas *et al.* (1992) reported comparable values in terms of sediment yields as shown in **Appendix A: Table 12**. The high soil erosion yield rate recorded for tropical catchment was ranging from 10 ton/ha/year to 110 ton/ha/year in places such as Cigulung, East Java and Cikeruh, Java.

A more recent study by Aminuddin *et. al.* (1999/a) reported soil loss rate from open vegetable farm is about 40 tons/ha/year, while soil loss from rain-sheltered farms is about 1.4 tons/ha/year. Thus, with the worst-case scenario, annual soil loss for 3,000 ha of market gardening is 120,000 tons/year. Research on soil erosion simulation using Revised Universal Soil Loss (RUSLE) equation carried out by UM and TNBR (2001) gives a more comprehensive scenario regarding the soil erosion rate in the hydroelectric catchment in CH. The calculation and value for the parameters used by the UM and TNBR are shown in **Appendix C**.

Table 6.6.1 and **Table 6.6.2** shows the simulated soil loss in m^3/year, m^3/km^2/year and ton/ha/year. The total soil loss rate is the sum of soil erosion rate of Telom (and its contributing catchments), Upper Bertam and Lower Bertam. The total soil erosion of the 180.1 km^2 catchment had increased from 128, 000 m^3/year in 1947 to 614, 000 m^3/year in 1997. This shows that soil erosion rate has increased 5 folds in 50 years from about 10.6 ton/ha/year in 1947 to 51 ton/ha/year in 1997.

The main contributor of soil erosion is the market gardening. **Table 6.6.3** shows the calculated soil erosion rate of market gardening in ton per hectare per year. Based on the simulation, the soil erosion rate is maintained relatively at 230 – 260 ton/hectare/year for market gardening over the past 50 years. In the past two decades, soil erosion rates in market gardening contributed more than 80% of the total soil erosion.

Table 6.6.1.

Simulated Soil Loss (m^3/year) from Different Land Use Types.

Land Use Type	1947	1966	1974	1982	1990	1997
Bare Land	63,210	0	26,200	0	14,500	20,500
Residential Area	0	21	298	486	489	640
Tea	2,300	13,900	11,400	8,790	8,690	6,590
Market Gardening	44,500	66,300	100,800	250,100	270,200	546,900
Grassland	0	9,950	12,400	12,800	12,600	25,600
Forest	18,400	15,400	15,400	15,300	15,300	13,700
Total	128,390	105,600	166,500	287,400	321,800	613,900

Source: Modified from UM and TNBR, 2001

Table 6.6.2.

Simulated Total Soil Loss Rate of the Hydroelectric Catchment.

Year	1947	1966	1974	1982	1990	1997
Total Soil Loss (m^3/km^2/yr)	710	584	920	1,589	1,779	3,400
Total Soil Loss (ton/ha/yr)*	10.65	8.76	13.80	23.84	26.69	51.00

Note: * Using the assuming mean sediment density of 1,500 kg/m^3
Source: Modified from UM and TNBR, 2001

Table 6.6.3
Soil Erosion Rate of Market Gardening.

Market Gardening	Erosion Rate (m^3/year)				Land Use Area (ha)	Erosion Rate * (ton/hectare/year)
	Telom	Upper Bertam	Lower Bertam	Total		
1947	0	9,280	35,200	44,500	291.3	230.3
1966	29,800	19,600	16,900	66,300	407.0	244.3
1974	54,800	17,200	28,800	100,800	653.5	231.4
1982	141,000	18,400	90,700	250,100	1595.4	235.1
1990	143,000	22,200	105,000	270,200	1743.4	232.5
1997	400,000	30,900	116,000	546,900	3048.6	269.1

Note: * Using the assuming mean sediment density of 1,500 kg/m^3
Source: Modified from UM and TNBR, 2001

6.6.3 Quantification of Total Sediment Yield

Sediments generated by soil erosion in the hydroelectric catchment are transported by flowing water. Loose soil is washed down to the valley yielding into streams. In the case of CH hydroelectric catchment, there are human factors in the intervention of the flow of stream and eroded soil. This includes river diversion, flushing of sediment, sediment excavation and settling in pond and reservoir. **Fig. 6.6.1** is the schematic drawing showing the possible flow of eroded soil in the catchment.

From the schematic drawing, soil yielded from the surface and riverbank erosion ended up in a few locations. The majority of the soil either settled in the Ringlet Reservoir or was excavated in Telom Weir, Robinson Falls, Habu Weir and the Ringlet Reservoir. There is also some sediment flowing back to the original Plau'ur River channel because of the manual closure of diversion tunnel by the operator when the turbidity of the river is high. This is also practiced in Telom Weir at Miles 49. The Telom Desander will also trap sediments and flushed to the original river channel. These processes are manually controlled at the discretion of the operator. During high flow, water will be spilled over the Telom Weir and carried along the sediment back to the original river channel. All these circumstances will export sediments out of the hydroelectric catchment boundary.

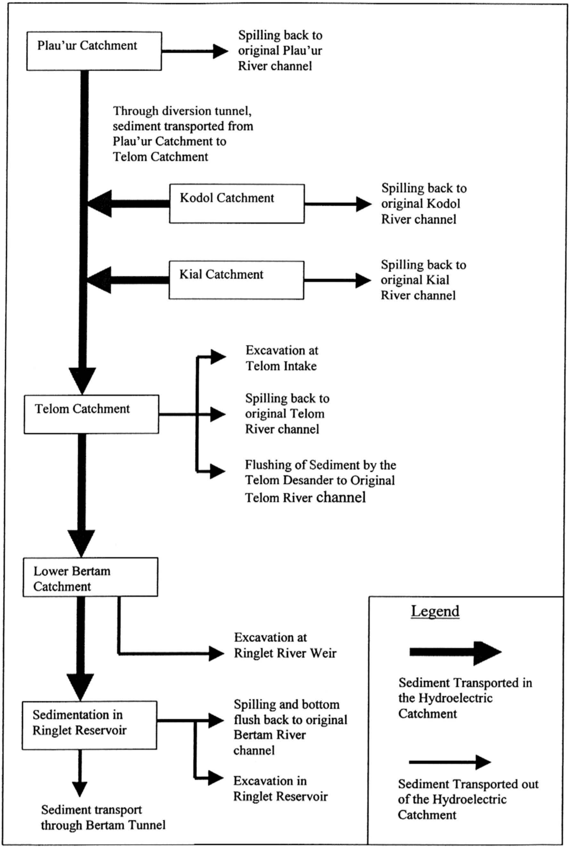


Figure 6.6.1: Schematic Drawing of Sediment Transport In and Out of the Hydroelectric Catchment of Cameron Highlands

Nevertheless, the bulk of the sediment will still end up in the Ringlet Reservoir. ***Plate I*** shows the heavily silted Ringlet Reservoir and the excavation activities. Ringlet Reservoir provides longer settling time for sediment to deposit. There is also some sediment flowing into the Bertam Tunnel and settles in the Jor Reservoir downstream of the hydroelectric catchment in CH. This is evident from the accumulation of sediment in the Jor Reservoir and also the commencement of excavation operation there. Thus, the sediment balance equation can be written as the following:

Total Soil Yield = Excavated + Deposited + Spilled + Flushed + Tunnel Discharged

Where,

Total Soil Yield is the total sediment contributed from erosion process in the hydroelectric catchment in CH such as Telom including Plau'ur, Upper Bertam and Lower Bertam Catchment.

Excavated Sediment includes sediment excavated from (Telom and Plau'ur, Robinson Falls, Ringlet River and Ringlet Reservoir)

Deposited Sediment is the sediment deposited in Ringlet Reservoir – accumulated from Plau'ur, Kodol, Kial, Telom and Bertam catchments.

Spilled Sediment includes sediment spilled over during high flow in weirs (Plau'ur, Kodol and Kial) as well as bottom flushing and reservoir spilling at the Bertam River.

Flushed Sediment is the sediment that flushed back to original Telom River channel by the operation of Telom desander.

Tunnel Discharge is the sediment that escaped from the hydroelectric catchment through the Bertam Tunnel.

Sediment excavated and deposited will be quantified as below. However, there is no data available for the quantities of sediment spilled out at various locations, flushed out at Telom desander and also those that escaped through the Bertam tunnel. Therefore, a minimum soil erosion yield can be calculated from the available data.

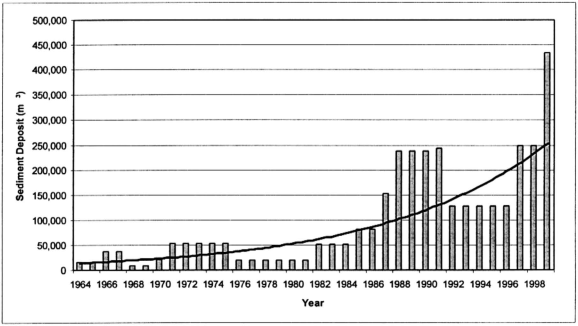
6.6.3.1 Quantification of Excavated Sediment

Quantification of sediment excavated in the hydroelectric catchments is based on data provided by TNB and compiled by UM and TNBR (2001). Excavation operation started in 1983 and the sediments excavated are shown in **Appendix A: Table A-13.** There are many variables that can influence the excavation quantity in a specific location, which include the amount of accumulated deposition before excavation, the quantity of sediment yield of that catchment as well as technical and management factors of the excavation operation. Therefore, correlation of excavated quantity with other processes of the catchments does not seem to offer much help in understanding the sedimentation process. The average annual total sand excavated at the four sites within the hydroelectric catchment of CH is about 156, 000 m^3. As discussed above, there is no significant trend in the excavation data that can be deducted.

However, the quantity excavated from the specific location will portray the severity of soil erosion of these particular catchments. For example, the largest amount of sediments excavated annually comes from the Ringlet river basin, despite its smaller catchment size (987 ha). This was due to extensive development in agriculture (250 ha). A big piece of land formerly planted with tea was converted to vegetable farming in the last two decade (345 ha in 1974; 23.5 ha in 1982 and 3.7 ha in 1997 of tea plantation). Vegetable farming is expected to have a higher potential for soil erosion due to less canopy cover to protect the soil. With the estimated 987 ha of the Ringlet River catchment, excluding the reservoir, the soil erosion rate based only on average excavated sediment was as high as 65.9 ton/ha/year (see **Appendix A: Table A-13**). The actual erosion yield rate is expected to be very much higher than 65.9 ton/ha/year because this value excluded the suspended solids transported to the reservoir.

6.6.3.2 Quantification of Deposited Sediment in Ringlet Reservoir

Periodically, TNB Berhad conducts survey of the sediments deposited in Ringlet Reservoir. **Appendix A: Table A-14** shows the data of sediment deposited between consecutive surveys (UM and TNBR, 2001). **Fig. 6.6.2** is the averaged annual sediment deposited at Ringlet Reservoir and the corresponding loss in storage capacity. The result indicates an exponential increase of the accumulation of sediment despite excavation operation, which is commenced in a number of locations including in the reservoir itself. In 1999, the annual sedimentation in the reservoir was estimated at 433,000 m^3. It is equivalent to 649,500 ton of soil (assume mean sediment density of 1,500 kg/m^3).



Source: Modified from UM and TNBR, 2001

Fig. 6.6.2: Annual Sediment Deposition in Ringlet Reservoir

6.6.4 Discussions on Soil Erosion

6.6.4.1 Soil Erosion Yield Rate

With reference to the sediment balance equation in **Section 6.6.3**, it can be simplified as the following:

Total Soil Erosion Yield = Excavated + Deposited + Discharged

With the measured total excavated and deposited sediments, the minimum measured sediment yield can be obtained. **Table 6.6.4** shows the minimum measured sediment yield and the soil erosion rate for about 39 years in the hydroelectric catchment. In 1997, the minimum total measured sediment yield was 394,000 m^3/year (591,000 ton/year).

Despite difficulties in quantifying the discharged sediment, estimation can be made based on the incidence of the commencement of Telom De-sander in 1992. A sharp drop of 30% in the measured sediment yield was recorded after 1992 (see **Table 6.6.4**). Thus, it can be estimated that the de-sander is capable to trap and flush out about 30% of the total sediment. Therefore, the discharged sediment can be conservatively estimated to be 30% of the total measured sediment.

The estimated measured sediment yield rates were lower than the calculated rates in the year 1966, 1974 and 1982 (**Table 6.6.5**). This was due to no excavation operation in those years. In 1990, the estimated measured yield rate was as high as 42.4 ton/ha/year compared to the simulated rate of 26.7 ton/ha/year (**Table 6.6.5**). This was due to commencement of excavation operation. Sediments accumulated since the early years were excavated then.

Table 6.6.4

Minimum Soil Erosion Yield Rate in the Hydroelectric Catchment.

Year	Annual Sedimentation in Ringlet Reservoir (m^3/yr)	Total Sediment Excavated (m^3/yr)	Minimum Total Measured Sediment (m^3/yr)	Minimum Total Measured Sediment (ton/yr)	Minimum Soil Erosion Yield Rate (m^3/km^2/yr)	Minimum Soil Erosion Yield Rate (ton/ha/yr)
1964	16,750	-	16,750	25,125	92.7	1.4
1965	16,750	-	16,750	25,125	92.7	1.4
1966	37,050	-	37,050	55,575	205.1	3.1
1967	37,050	-	37,050	55,575	205.1	3.1
1968	9,650	-	9,650	14,475	53.4	0.8
1969	9,650	-	9,650	14,475	53.4	0.8
1970	20,900	-	20,900	31,350	115.7	1.7
1971	53,440	-	53,440	80,160	295.9	4.4
1972	53,440	-	53,440	80,160	295.9	4.4
1973	53,440	-	53,440	80,160	295.9	4.4
1974	53,440	-	53,440	80,160	295.9	4.4
1975	53,440	-	53,440	80,160	295.9	4.4
1976	19,450	-	19,450	29,175	107.7	1.6
1977	19,450	-	19,450	29,175	107.7	1.6
1978	19,450	-	19,450	29,175	107.7	1.6
1979	19,450	-	19,450	29,175	107.7	1.6
1980	19,450	-	19,450	29,175	107.7	1.6
1981	19,450	-	19,450	29,175	107.7	1.6
1982	51,433	-	51,433	77,150	284.8	4.3
1983	51,433	182,465	233,898	350,847	1295.0	19.4
1984	51,433	180,975	232,408	348,613	1286.8	19.3
1985	82,000	144,760	226,760	340,140	1255.5	18.8
1986	82,000	167,174	249,174	373,761	1379.6	20.7
1987	153,000	139,496	292,496	438,744	1619.5	24.3
1988	238,000	155,753	393,753	590,630	2180.1	32.7
1989	238,000	176,076	414,076	621,114	2292.7	34.4
1990	238,000	119,521	357,521	536,282	1979.5	29.7
1991	244,000	176,773	420,773	631,160	2329.7	34.9
1992	127,800	156,850	284,650	426,975	1576.0	23.6
1993	127,800	136,569	264,369	396,554	1463.8	22.0
1994	127,800	123,813	251,613	377,420	1393.1	20.9
1995	127,800	119,193	246,993	370,490	1367.5	20.5
1996	127,800	169,695	297,495	446,243	1647.2	24.7
1997	249,742	144,422	394,164	591,246	2182.4	32.7
1998	249,743	158,411	408,154	612,231	2259.9	33.9
1999	433,841	158,411	592,252	888,378	3279.2	49.2

Table 6.6.5
Comparison of Simulated and Measured Average Soil Erosion
Yield Rate for the Hydroelectric Catchment of Cameron Highlands

Average Soil Erosion Yield Rate	**1966**	**1974**	**1982**	**1990**	**1997**
Simulated Rate (ton/ha/year)	8.8	13.8	23.8	26.7	51.0
Measured Minimum Rate (ton/ha/year)	3.1	4.4	4.3	29.7	32.7
Estimated Measured Rate (ton/ha/year) *	4.4	6.3	6.1	42.4	46.7

Note: * estimates the discharged sediment is 30% of total sediment yield.

However, the simulated soil erosion yield rate is still higher compared to the estimated rate (**Table 6.6.5**). The dominant factor of high-simulated soil erosion rate is due to market gardening. Soil erosion rate for market gardening is about 230 ton/ha/year, which is very high compared to the experimental soil erosion rate of 40 tons/ha/year for open vegetable farms as suggested by Aminuddin *et. al.* (1999/a). Furthermore, market gardening is inclusive of floriculture that is planted under rain shelter. The percentage of farming area under rain shelter is unclear. It is expected that farming under rain shelter will significantly reduce the soil erosion rate. As measured by Wan Abdullah *et. al.* (1999), soil erosion rate is as low as about 1.4 tons/ha/year for farming system under rain shelter. Therefore, CP factor of 0.25 for market gardening in CH as suggested by Roslan and Tew (1996) is rather too high.

On the other hand, tremendous soil erosion is expected from the source that is not captured in the land use map such as mass movement of soil. Due to wide interval of land use survey, the land use map might not be able to capture transitional changes such as land clearing for farming and construction of building and road, in particularly the usage of heavy machinery in earth works. This practice generates vast amount of loose soil and is left bare for a number of years. Mass movement of loose soil contributes very significantly to the erosion and sedimentation problems. It is very significant in the 1990s, especially in the Telom catchment where high intensity of land use change.

Nevertheless, soil erosion in the hydroelectric catchment is very high compared to other disturbed humid tropical catchments as shown in **Appendix A: Table A-12**. Even the forested cover is 62%, the estimated measured erosion yield rate was 46.7 ton/ha/year in the late 1990s (See **Table 6.6.4**), based on this conservative estimation.

6.6.4.2 Impacts of Soil Erosion on the Hydroelectric Generation

Soil erosion in the hydroelectric catchment generates negative impacts on the power generation in a number of ways. Basically, two important aspects that affect the power generation are the high levels of suspended load and the reducing storage capacity of the Ringlet Reservoir. The impacts include loss of generating capacity and increase in operating cost of the stations.

1) Reduction in Power Generation of Run-of River Schemes

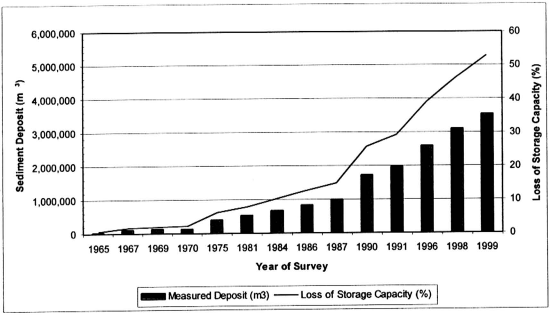
High levels of suspended solids in the river increases the damage to mechanical parts of the generating units in the run-of-river power stations of the scheme. The scours gates at various intakes are normally opened to discharge the silt-laden stream water, by-passing the intakes. It is also reported of frequent spilling of water over the intake weirs. This is due to increase incidences of high peak flow during storms. The consequences are loss in water utilization and reduced in the energy generation per unit river runoff. The result has been analyzed by UM and TNBR (2001) as in **Appendix B: Figure B-4** and **Figure B-5**. In 1960s, energy generation at Robinson Falls power station was 0.18 kwh/m^3 of the runoff. However, it was reduced gradually to 0.13 kwh/m^3 in the 1980s. The generation in Habu power station also experienced the same magnitude of reduction. Nevertheless, the efficiency increased to 0.15 kwh/m^3 after 1993. This was expected after the commencement of desilting operation at the upstream areas.

2) Reduction in Storage Capacity of Ringlet Reservoir

The second effect is the reduction in storage capacity of Ringlet Reservoir. The storage capacity reduces because of the accumulation of sediment in the bed of the reservoir. The original full supply level of the Ringlet Reservoir was designed to be 1,071 m with a total storage capacity of 6.7 million m^3, with 2.0 million m^3 as dead storage and 4.7 million m^3 as live storage. As shown in **Appendix A: Table A-15**, the effective storage volume of the Ringlet Reservoir as a function of water elevation has drastically been reduced to 3.6 million m^3 in 1998. Effectively, this represents a 46.3% loss of the total storage volume of the reservoir. The remaining storage volume has been further reduced to 3.17 million m^3 in 1999 representing 47.3% storage capacity remaining (see **Fig. 6.6.3**). Thus, the estimated present live storage capacity is less than 2.8 million m^3.

With the reduction in storage capacity, the effectiveness of the reservoir to function as a settling basin for suspended solid is greatly affected. With sufficient storage capacity, more sediment will settle in the reservoir. Thus reduces in flow of coarser particulate content into the tunnel and minimize the damage to the turbine plates. With the live storage capacity reduced from 4.7 to 2.8 million m^3, the mean transit time of inflow of water to the reservoir has been significantly reduced. Assuming a long-channel geometry for the reservoir, the estimated mean transit time from the inflow end to the intake tunnel of the reservoir has been reduced from the initial period of 5.9 days to 2.3 days, with a mean daily water discharge of 0.77 million m^3/day (UM and TNBR 2001).

Therefore, with this substantial reduction of mean transit time, it is expected that the inlet water that flows into the tunnel will contain higher suspended solid concentration with larger particle sizes. However, the impact of this increased suspended solid load to tunnel and turbine wears and tear has not yet been determined. Therefore, the mitigation measure employed by the station is to increase the drawdown operation level of the reservoir. In other words, at the vicinity of Ringlet River closed to the intake tunnel where the suspended loads concentration are very high, TNB has been forced to raise the minimum operating level. **Table 6.6.6** shows the operating levels over the different periods, indicating that the lower operating level has risen significantly to the present level of 1,065 m, a loss of 6.4 m height of water storage.



Source: Modified from UM and TNBR, 2001

Fig. 6.6.3: Total Sediment Deposit in Ringlet Reservoir

Table 6.6.6.
Operating Levels of Ringlet Reservoir.

Period	Operation Level
1960s	1,058.9 m – 1,070.8 m
1980s	1,059.2 m – 1,070.8 m
1997	1,060.7 m – 1,070.8 m
2000	1,065.3 m – 1,070.8 m

Source: Modified from UM and TNBR, 2001

Furthermore, the raising of lowest operating level of the reservoir by 6.4 m has further reduced the useful storage capacity of the reservoir by another 1 million m^3. Due to the combined effect of reservoir sedimentation and raising minimum operation level, the current useful storage is estimated to be 1.8 million m^3 effectively, which is lower than the optimum storage estimated by UM and TNBR (2001). The minimum storage for optimized power generation with buffer of 60 hrs of weekend runoff is estimated at 2.09 million m^3.

The immediate concern on power generation is the loss of load peaking capacity for the Jor and also the Woh Power Station. The average annual energy generation for both stations is about 280 GWh and 450 GWh respectively. Assuming energy value of RM0.094 per kWh for base load and RM0.225 per kWh for peak load, TNB will suffer RM95.4 million per year if both stations are forced to operate as a run-of river stations for base load due to loss of storage capacity of Ringlet Reservoir. Moreover, TNB also has to look for alternative power source for load peaking function, which might be more costly and environment unfriendly.

6.6.4.3 Loss of Flood Prevention Function of Ringlet Reservoir

The Sultan Abu Bakar Dam impounds Ringlet Reservoir with a gated spillway at Robinson Falls at Bertam River. The water stored at Ringlet Reservoir is diverted through the Bertam Tunnel to Batang Padang River, a tributary of the Perak River. On the other hand, the dried up river bed and river reserve of Bertam River just downstream of the Ringlet Reservoir is presently occupied with vegetable farms.

In the event of heavy rainfall, streamflow into the reservoir has been increased tremendously due to reduced holding capacity and the shortened time to peak flow, as a result of deforestation. Thus, the possibility of topping of the Ringlet Reservoir and forcing the spill gate to open increases, which can cause severe economic damage to the farms downstream. There were already a few cases of reservoir spillage in the late

1980's (Choy and Hamzah, 1997) due to a combination of heavy rainfall and power generation equipment failure. The farmers suffered great economic losses due to damages to crops and infrastructure, and the incidence had drawn tremendous public attention. On top of deforestation, drastic losses of storage capacity further increase the probability of reservoir spillage. The following section provides an assessment of the current risk of reservoir spillage.

The spillage event can be estimated based on the following assumptions:

i) The daily rainfall recorded at Tanah Rata was examined for the period of 1975 to 1998. Over the 24-year period, the number of days with 24-hr rainfall exceeding 50-100 mm is tabulated in **Table 6.6.7**. There were three occasions of daily rainfall exceeding 100 mm (100.9 mm on 18th May 1988, 104.7 mm on 8th August 1995 and 101.3 mm on 13th February 1997). During the same period, the number of days with rainfall more than 80 mm was 13 days.

Table 6.6.7.

Assessment of Spillage at Sultan Abu Bakar Dam.

Rainfall (24 hrs) (mm)	**Number of days exceeding rainfall (1975 - 1998)**	**Average number of days per year**	**Discharge within 24 hrs**		**Fraction of streamflow from Telom for spillage at Sultan Abu Bakar Dam**	
			Bertam	**Telom**	**Design Storage + 24-hr Tunnel Discharge**	**Existing Storage + 24-hr Tunnel Discharge**
50	133	5.54	1.70	2.64	*No spill*	0.91
60	56	2.33	2.04	3.17	*No spill*	0.65
70	30	1.25	2.39	3.70	*No spill*	0.46
80	13	0.54	2.73	4.22	*No spill*	0.32
90	6	0.25	3.07	4.75	0.83	0.22
100	3	0.125	3.41	5.28	0.68	0.13

ii) The quantity of rainwater conveyed into the river can be estimated based on the last 50 years of stream flow and rainfall data. The ratio of stream flow to rainfall is in the range of between 0.6 and 0.8. Hence, a conservative ratio of 0.6 is applied.

iii) Based on the preliminary hydrographic analysis by UM and TNBR (2001), the estimated time to peak of the Telom catchment is 7.5 hours and more than 80% of the volume is discharged in 20 hours. Estimation for the Lower Bertam catchment is given 5.5 hours time to peak and 15 hours to discharge 80% of the volume. For the Upper Bertam catchment, the time to peak is approximately 4.1 hours and more than 80% of volume is discharged in 12 hours.

iv) It is also conservatively assumed that the reservoir is at its lowest operational level at the start of the heavy rainfall. It can be otherwise at some higher reservoir levels.

v) Assumption has also been made that the power generating equipment is operating at full capacity. Any equipment failure can further compound the risk of the spillage.

Due to the relatively short retention time of the catchment, the calculation is made based on the following summary of conservative assumptions:

- Catchment area for Telom @ Batu 49 = 110 million m^2, and Bertam at Ringlet Reservoir = 71 million m^2.
- The ratio of streamflow to rainfall is assumed to be 0.6.
- Assuming that 80% of the streamflow occurs on the same day as the rainfall. Thus, the fraction of discharge in the first 24 hours of rainfall = 0.8 × 0.6 = 0.48.
- Design reservoir life storage = 4.7 million m^3, existing effective storage capacity = 1.8 million m^3.
- Assuming that on a 24-hour full operation of the 100 MW power generator, the estimated Bertam Tunnel discharge is 2.3 million m^3 (UM and TNBR 2001).

The results show that the reservoir will spill if the quantity of total streamflow exceeds the sum of the available reservoir storage capacity and the 24-hr full operational discharge of the power generating Bertam Tunnel. It is reminded that this threshold value for spillage has thus decreased from the original design value of 7.0 million m^3 (design life storage + Bertam Tunnel discharge rate) the existing value of about 4.1 million m^3 (effective life storage + Bertam Tunnel discharge rate).

The expected streamflow into the Ringlet Reservoir for various 24-hr rainfalls at the Bertam and Telom catchments are shown in **Table 6.6.7** and **Fig. 6.6.3**. It is noted here that while rainfall in Bertam catchment will deliver streamflow to Ringlet Reservoir, streamflow of Telom River can be bypassed at the Telom Tunnel Intake. Furthermore, despite their close proximity, rainfall in both catchments may not be fully correlated.

To quantify the scenario of reservoir spillage, it is thus necessary to assess the fraction of Telom discharge that enters the reservoir, which will cause spillage. Based on the design and present reservoir storage capacity, **Table 6.6.7** shows the necessary fraction of Telom streamflow that enters the intake tunnel, which will cause spillage of the Sultan Abu Bakar Dam.

As shown in **Table 6.6.7** and **Fig. 6.6.4**, it is almost impossible for the reservoir to spill at the designed storage capacity, except at a combination of very high rainfall and external factors such as equipment failure or human error of not being able to close the Telom tunnel accordingly.

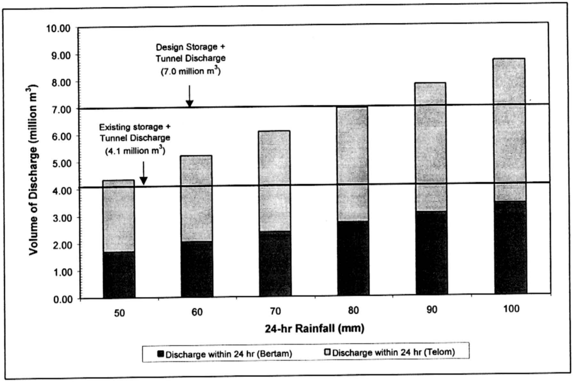


Fig. 6.6.4: Volume of Inflow to Ringlet Reservoir at Various Rainfalls.

However, at the current much reduced storage capacity of the reservoir, the risk of reservoir spillage is greatly increased. At 70 mm of 24-hr rainfall, there will be a forced spillage at the reservoir, if there is a corresponding intake of 46% of the Telom streamflow at the Telom Tunnel. At 80 mm and 100 mm rainfall, reservoir spillage will occur with only corresponding 32% and 13% intake respectively from the Telom Tunnel. Since 24-hr rainfall exceeding 80 mm occurs once in two years on the average, the risk of reservoir spillage is thus very high. Moreover, the Telom Tunnel operators may only recognize the abnormal high rainfall many hours after the start of the downpour, thus allowing substantial intake at the Telom Tunnel. If the sedimentation rate continues to increase, the situation is expected to deteriorate further. Therefore, there is an increasing risk of spillage, which is hazardous to lives and properties.

6.6.4.4 Land Degradation and Ecosystem Stress

Besides impacts on the hydroelectric power generation, severe soil erosion has tremendous negative impacts on the land and stream ecosystem. The removal of topsoil and fertile organic matters will reduce the productivity of the land. Moreover, severe soil erosion might irreversibly damage the land, or extremely high cost is required in order to rehabilitate the land, if it is not technologically infeasible.

Due to poor soil, the production cost has increased tremendously and high fertilizer input is required to sustain the productivity. The long-term effect will be losing the cultivatable soil depth and finally total abandonment of land. Therefore, soil erosion and land degradation will undermine the socioeconomic well being of the local communities, and thus it deserves serious attention.

On the other hand, severe soil erosion will destroy the stream ecology. As suspended particle increases, the turbidity of the river water will increase and it will shade off sunlight. The will destroy the original species that live in clear and unpolluted water. Affected organisms include fish, stream invertebrates and alga. The deterioration of river ecology not only reduces the biodiversity but generate visual pollution in this tourist destination as well as economic losses for those depending on the natural resources of the river. However, the impacts of soil erosion to areas further downstream are expected to be minimized due to the buffering effect of the reservoirs of the hydroelectric scheme.