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SOIL EROSION MODELING USING RUSLE AND GIS ON CAMERON HIGHLANDS, MALAYSIA FOR HYDROPOWER DEVELOPMENT

Soo Huey Teh

UNIVERSITY OF ICELAND

University of Akureyri

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A 30 ECTS credit units Master´s thesis

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A Master´s thesis done at

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ABSTRACT

Sedimentation is one of the major problems in the hydropower scheme in Malaysia. Cameron Highlands is known to have one of the worse if not the worst sedimentation problem in Malaysia. Uncontrolled deforestation and indiscriminate land clearing for agricultural, housing development and road construction resulted in widespread soil erosion over the land surface of Cameron Highlands leading to sedimentation of the rivers and of the Ringlet Reservoir. The objective of this thesis is to determine the mean annual soil loss rate using the RUSLE model for the Upper Catchment of Cameron Highlands for the years 1997 and 2006. Data such as rainfall pattern, soil type, topography, cover management and support practice were utilized for soil modeling using the integration of RUSLE and ArcGIS. The sub-catchments of Telom, Kial and Kodol, Upper Bertam, Middle Bertam, Lower Bertam, Habu, Ringlet and Reservoir catchments were studied. The sub-catchment of Plau'ur was excluded from this study because data from the region was not sufficient. Sediments were detached and transported from the upper catchment and were eventually deposited in the Ringlet Reservoir. The sediment yield of the Ringlet Reservoir was predicted to be 282,465.5 m^3/ year for 1997 and 334,853.5 m^3/ year for 2006 from this study. This number is expected to increase with time as agriculture activities and deforestation continues to take place. Hence, the life expectancy for the dead storage was decreased tremendously because of the increasing sediment yield with time compared to the design life expectancy of the dead storage. The drastic situation in Ringlet Reservoir suggests that if nothing is done, the reservoir will lose its entire storage in the next three to five years. In the immediate and medium term, it is expected that any effective strategy for management of the sediments would have to be based on the 'concentrate and remove' approach, in which most practical and effective sedimentation concentration and removal points along the streams are identified in the Ringlet End and Habu End. In the longer term, the 'control at source' strategy should be implemented, based on modifications to the current land use practices, to encourage soil conservation and minimize soil loss from the contributing catchments, this reducing sediment loads into the streams and reservoir.

PREFACE

I would like to express my gratitude to all those who gave me the possibility to complete this thesis. I would like to thank my advisors, Dr. Lariyah Mohd Sidek and Dr. Pierre Julien, for their generous assistance, patience, guidance, knowledge, time, enthusiasm, execution and completion of this project. The associate experience was truly a valuable one and help broadened my perspective on research. I would also like to acknowledge those who shared their time and expertise throughout this process: Dr. Rohayu Che Omar and Mohd Firdaus for teaching and assisting me with the use of ArcGIS, and Wesentera MJ for helping me with data and travelling with me to the study site and Jansen Luis Alexander for helping me with data as well as discussing the results of this thesis. I would also like to thank the faculty of Renewable Energy Science program, especially Sigrún Lóa Kristjánsdóttir and Jónas Elíasson for their guidance and assistance in the process of completing this thesis project. Lastly, my deepest gratitude goes to my family for their unflagging love and support throughout my life.

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1 INTRODUCTION

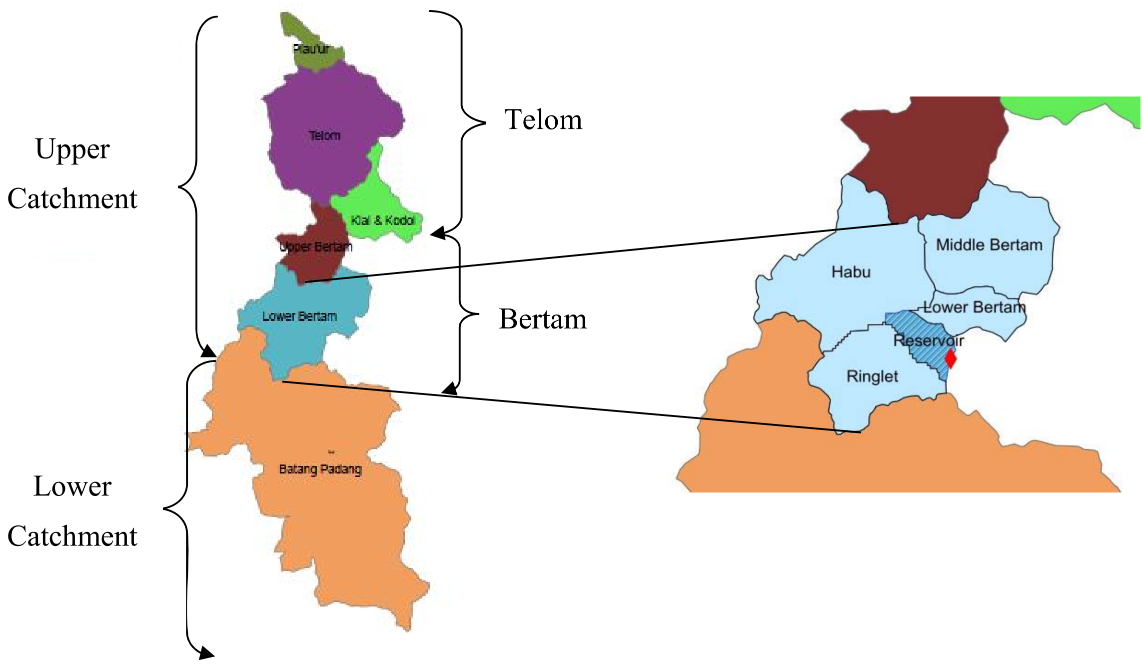
1.1 Overview of Cameron Highlands

Malaysia is separated by the South China Sea into two regions- Peninsular Malaysia and Malaysian Borneo. Cameron Highlands is situated in the Pahang State of Peninsular Malaysia (Figure 1) and occupies an area of approximately 712 km^2 (Fortuin, 2006). This Highlands is situated on the Titiwangsa Range of Peninsular Malaysia which is generally narrow and sharply defined and broadens out into a dissected massif of approximately 24 km long from north to south and 6 km wide from east to west (Tenaga National Berhad , 2000). The average elevation of the catchment is approximately 1,180 m and the highest peak is Mount Brinchang at 2,032 m (Tenaga National Berhad Research, 2009) . Cameron Highlands is one of the largest hill resorts in Malaysia and is referred to as the 'Green Bowl', growing a wide variety of vegetables, flowers and other ornamental plants and supplying them to major cities in Malaysia and Singapore. In addition to offering refuge to the heat and humidity known to Malaysians, Cameron Highlands also provides many tourist attractions such as tea plantations, tea factories, rose gardens, strawberry farms, natural waterfalls, golf courses and aging colonial-style homes offering a glimpse of the past. The main towns situated in Cameron Highlands are Ringlet, Tanah Rata, Brinchang and Kampung Raja.

Figure 1: Map of Cameron Highlands (Passion Asia, n.d.)

1.2 Cameron Highlands Catchments

Cameron Highlands is divided into the Upper and the Lower Catchment (Map 1). The Upper Catchment of Cameron Highlands consists of the Telom and the Bertam catchment (Map 1). The Telom catchment is further divided into sub-catchments of Plau'ur, Telom and Kial & Kodol with the total area of 110.3 km^2. The Bertam catchment consists of Upper Bertam, Middle Bertam, Lower Bertam, Habu, Ringlet and Reservoir as sub-catchments with the total area of 70.4 km^2. Finally, the Lower Catchment consists of the Batang Padang catchment. All the catchments of Cameron Highlands are shown in Map 1: Cameron Highlands Catchments and Sub-catchmentsMap 1 and the red diamond in the ıb-catchment is the Sultan Abu Bakar Dam.



Map 1: Cameron Highlands Catchments and Sub-catchments

Table 1: Sub-catchments of Cameron Highlands Upper Catchments (Tenaga National Berhad, 2010)

Upper Catchment	Sub-Catchment	Area (km^2)
Telom	Plau'ur	9.7
	Kial & Kodol	22.8
	Telom	77.8
	Total	**110.3**
Bertam	Upper Bertam	20.98
	Middle Bertam	13.44
	Lower Bertam	4.34
	Habu	19.12
	Ringlet	9.72
	Reservoir	2.8

	Total	70.4

1.3 Cameron Highlands – Batang Padang Scheme

Cameron Highlands is home to the Cameron Highlands - Batang Padang Hydroelectric scheme; one of the three hydro-power schemes developed by the national utility Tenaga Nasional Berhad (TNB) in Peninsular Malaysia. The Scheme is designed as a peaking power station with a total installed capacity of 262 MW (Tenaga National Berhad Research, 2009). The remaining two hydro-power schemes are Sungai Perak Hydro Power Scheme (1,249 MW) in the state of Perak and Sultan Mahmud Hydro Power Scheme, Kenyir (400 MW) in the State of Terengganu (Tenaga National Berhad Research, 2009).

The Cameron Highlands - Batang Padang Hydroelectric Scheme sprawls across several river systems in the State of Pahang and Batang Padang River in the State of Perak. The Cameron Highlands scheme utilizes the water of Telom River and Bertam River in the Pahang State. The other portion of the hydroelectric scheme, which is the Batang Padang scheme utilizes the water of Telom and Bertam Rivers diverted from the Ringlet Reservoir as well as the water of Batang Padang River and its tributaries. Water flows from the upper to lower catchment area through a series of transfer tunnels to augment the supply to the power plants built in the Scheme.

There are seven power stations in the Cameron Highlands - Batang Padang Hydroelectric Scheme shown in Figure 2. The power stations are Kampung Raja (0.8 MW), Kuala Terla (0.5 MW), Robinson Falls (0.9 MW), Habu (5.5 MW) and Jor (100 MW) of the Cameron Highlands Scheme, and Woh (150 MW) and Odak (4.2 MW) of the Batang Padang Scheme (Choy & Darul, 2004). The Cameron Highland - Batang Padang Hydroelectric Scheme includes the construction of the three dams listed below (Choy & Darul, 2004):

I. The Sultan Abu Bakar Dam – this dam impounds water of Bertam River and water diverted from Telom River, creating the Ringlet Reservoir which supplies the Jor Power Station.

II. The Jor dam – this dam impounds the water of Batang Padang River and the water discharged from the Jor Power Station to create the Jor Reservoir which supplies the Woh Power Station.

III. The Mahang Dam – this dam impounds the water discharged from the Woh Power Station and stores water to supply the Odak Power Station

Table 2: Breakdown of Cameron Highlands - Batang Padang Scheme (Tenaga National Berhad Research, 2009)

River Systems	Power Plants
Cameron Highlands Scheme / Upper Catchment • Telom River (76.7 km^2) • Kodol River (1.3 km^2) • Kial River (22.7 km^2)	• Kampung Raja (0.8 MW) • Kuala Terla (0.5 MW)

Cameron Highlands Scheme / Upper Catchment • Bertam River (72.6 km^2) • Ringlet Reservoir impounded by Sultan Abu Bakar dam	• Robinson Falls (0.9 MW) • Habu (5.5 MW) • Sultan Yussof or Jor (100 MW)
Batang Padang Scheme / Lower Catchment • Batang Padang River (121.9 km^2) • Lengkok River (13.1 km^2) • Bot River (9.0 km^2) • Tidong River (5.6 km^2) • Who River (56.1 km^2) • Semai River (12.5 km^2) • Chenes River (1.8 km^2) • Bemban River (10.5 km^2)	• Sultan Idris II or Woh (150 MW) • Odak (4.8 MW)

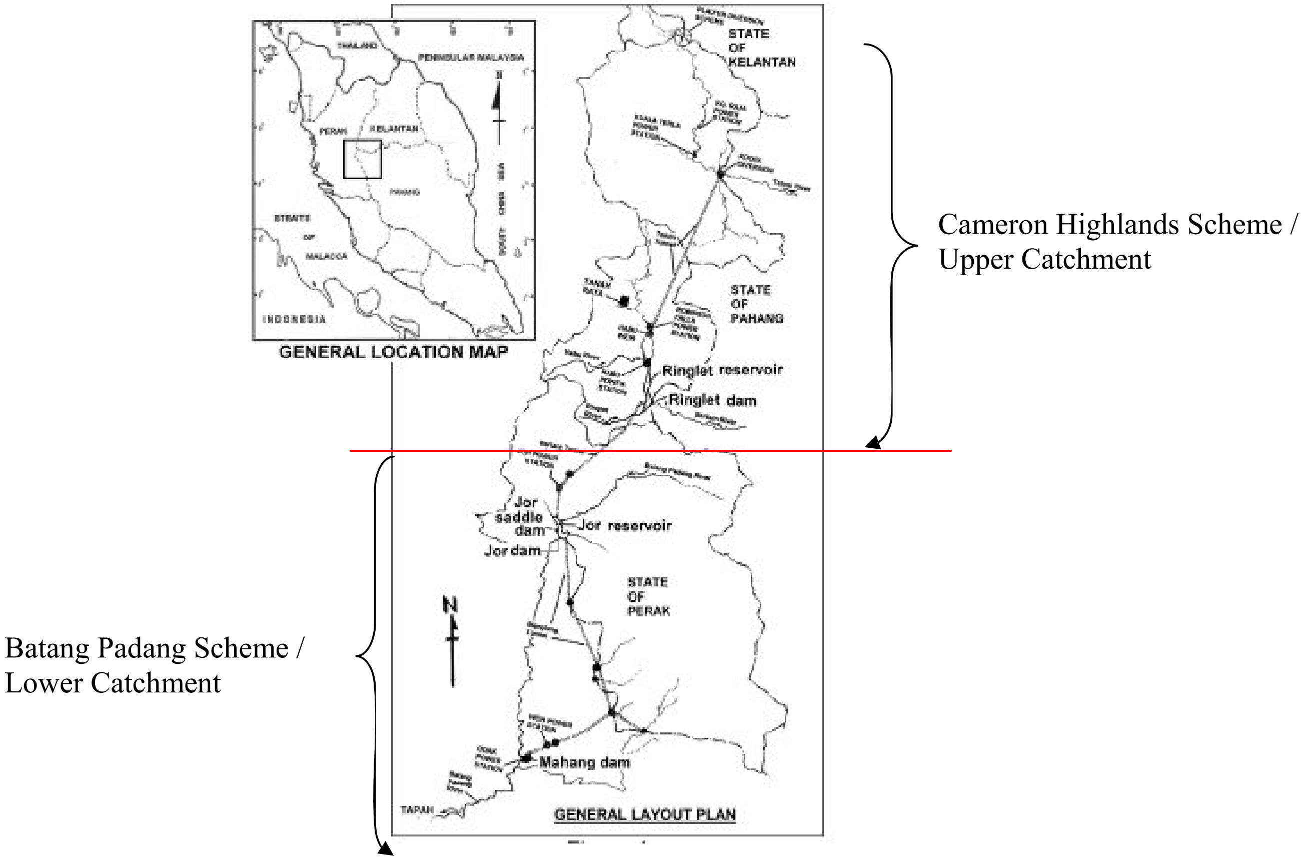


Figure 2: Cameron Highlands – Batang Padang Scheme (Choy & Darul, 2004)

The details of the seven power plants of the Cameron Highlands – Batang Padang Hydroelectric Scheme such as the turbine type, average annual units generated and head are shown below in Table 3.

Table 3: Plant names and details of Cameron Highlands – Batang Padang Hydroelectric Scheme (Kaushish & Naidu, 2002)

Power Plants	**Year comm..**	**Turbine Type**	**Average Annual units gen. (GWh)**	**Head (m)**	**Catchment Area (km^2)**	**Remarks**
Kampung Raja	Nov 1964	Horiz. Francis	6.2	83.8	30.8	Run-of River
Kuala Terla	Nov 1964	Horiz. Francis	4.2	39.3	43.3	Run-of-River
Robinson Falls	Nov 1959	Pelton Wheel	7.6	234.7	21.4	Run-of-River
Habu	Jan 1964	Horiz. Francis	34.0	97.5	132.7	Habu pond

Jor (SYPS)	Dec 1963	Pelton Wheel	324.0	573.0	183.4	SAB dam
Woh (SIPS)	Dec 1967	Vertical Francis	480.0	420.6	393.9	Jor dam
Odak	Dec 1967	Vertical Francis	14.0	12.2	394.4	Mahang dam

1.3 Study Site: Ringlet Reservoir and Sultan Abu Bakar Dam

The Ringlet Reservoir is located within the Bertam catchment and the sub-catchment of the Reservoir. The Ringlet Reservoir is situated approximately 500 m to the north of Ringlet town shown in Figure 3. The reservoir is impounded by the Sultan Abu Bakar Dam constructed on the Bertam River in 1963, and was designed to regulate the flow of water to the underground Sultan Yussof also known as the Jor Power Station situated in a separate catchment in the District of Batang Padang located in the State of Perak.

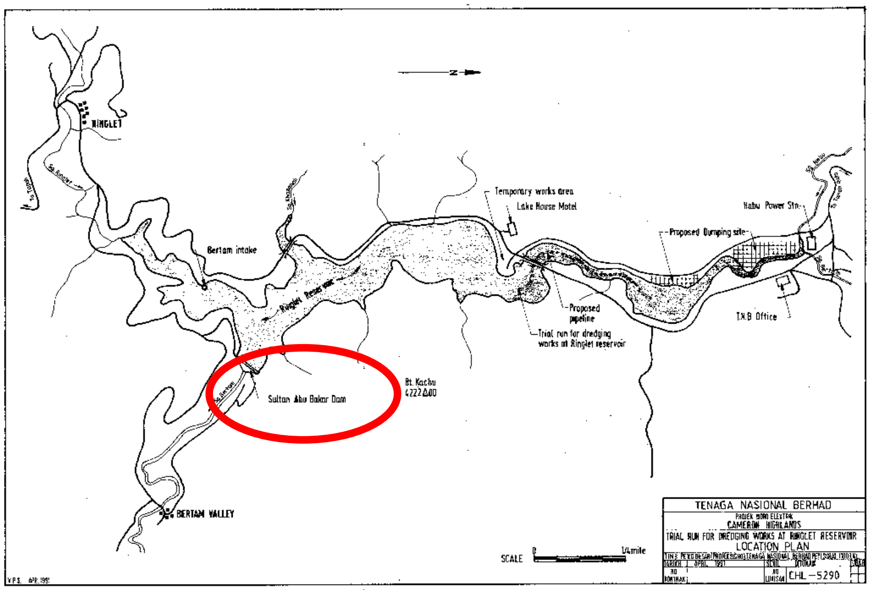


Figure 3: Ringlet Reservoir and Sultan Abu Bakar Dam (Tenaga National Berhad, n.d.)

Specifications of the Sultan Abu Bakar Dam are shown in **Error! Reference source not found.** below. The designed gross storage of the Ringlet Reservoir is about 6.7 million m^3, of which 4.7 million m^3 is live storage (Choy & Darul, 2004). It impounds the water from the Bertam River and from the Telom River, Plau'ur River, Kodol River and Kial River which have been diverted from the Telom catchment through the 10.25 km long Telom tunnel into the Bertam catchment. Sultan Abu Bakar Dam is a concrete buttress and rockfill dam constructed of 52,000 m^3 of concrete and 19,000 m^3 of rockfill (Choy & Darul, 2004). The left bank is mass concrete gravity section whilst the right bank is made of rockfill, which is contained behind the mass concrete retaining wall with an upstream concrete faced wall (Choy & Darul, 2004). The dam has a height of 40m with a crest length of 140 m (Choy & Darul, 2004). It has a 1.8 m diameter concrete-lined steel drain pipe at EL 1037.64 m (Choy & Darul, 2004). The gated spillway structure is equipped with 1 tilting and 3 radial gates which are float-operated with a manual override (Choy & Darul, 2004). The Ringlet Reservoir holds 4.7 million m^3 of water storage with a surface area totaling 60 ha with a "full supply level" (FSL) at EL 1071.71 m (Choy & Darul, 2004).

Table 4: Specifications of Sultan Abu Bakar Dam (Tenaga National Berhad, 2010)

Dam Type	[m]	Concrete (52000 m^3) and Rockfill (19000 m^3)
Crest Level	[EL. m]	EL. 1074.42 m
Dam Height	[m]	40
Length of Dam	[m]	140
Gross Storage	[MCM]	6.7
Usable Storage	[MCM]	4.7
Surface area at FSL	[km^2]	60 ha at EL 1071.71 m
Catchment area	[km^2]	183.4
Normal operating level	[EL. m]	EL. 1068.3 m
Min. operating level	[EL. m]	EL. 1065.2 m
Max. operating level	[EL. m]	EL. 1070.4 m
<u>Spillway</u> Type No. of spillway gates		 Controlled gated spillway 3 radial gates, 1 tilting gate
<u>Spillway Gates</u> Titling Gate		6.1 m. wide x 3.3m. Height (20 ft.x 11 ft.) • Bottom hinged at EL. 1068.0 m (EL. 3504.0 ft.) • Opens at reservoir level EL. 1070.7 m • (EL. 3513.0 ft) • Fully open at reservoir level EL. 1071.0 m. • (EL. 3514.0 ft) ≈ 65.1 m^3/s (2,300 cusecs)
Radial Gates		12.2 m. wide x 5.0m. Height (40 ft. x 16 ft.-6 in.) • Open at reservoir level level EL. 1071.1 m. • (EL. 3514.08 ft) • Fully open at reservoir level EL. 1071.4 m. • (EL. 3515.00 ft) ≈ 300.2 m^3/s per gate (10,600 cusecs) or 900.5 m^3/s for 3 gates (31,800 cusecs)

Water from the Ringlet Reservoir is channeled through a tunnel to the Sultan Yussof (Jor) Power Station and is then discharged though a tailrace tunnel into the Jor Reservoir of the

Batang Padang Hydroelectric Scheme. The Ringlet Reservoir has a dead storage of about 2.0 million m^3, is estimated to have a useful life of approximately 80 years (Choy & Darul, 2004).

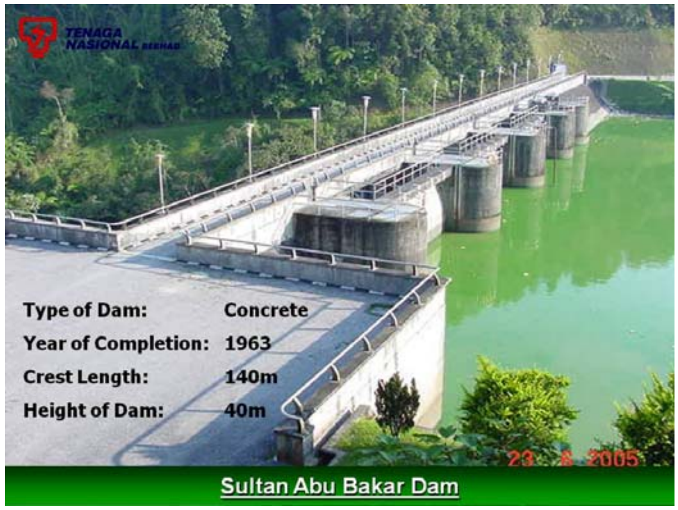


Figure 4: Sultan Abu Bakar Dam (Tenaga National Berhad, 2005)

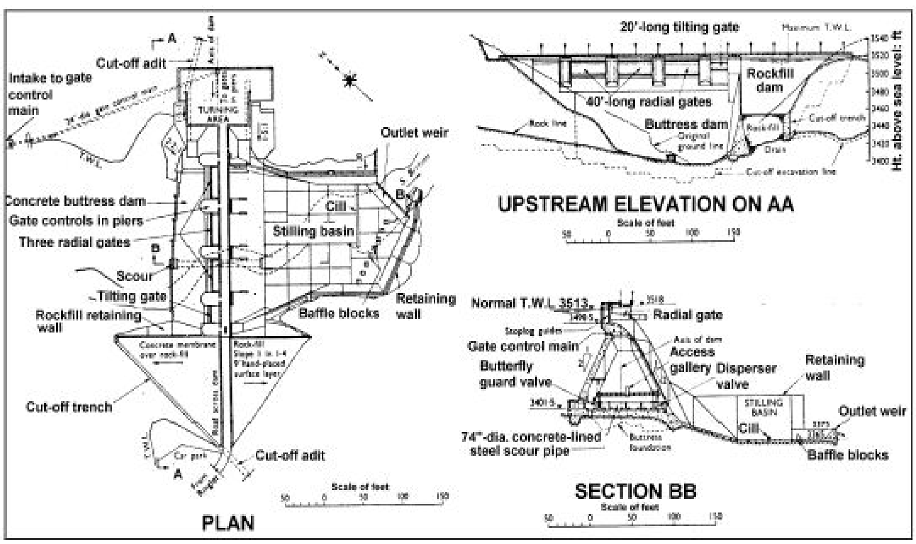


Figure 5: Cross Section of Sultan Abu Bakar Dam (Choy & Darul, 2004)

1.4 Problem

Sedimentation in a reservoir is a natural consequence from the construction of a dam, which slows down the stream flow and thus causes sediment deposition in the impoundment. As a result of the increased sediment loads carried by the rivers feeding into the reservoir, Ringlet Reservoir has been silting up at an alarming rate. This has been brought about by the significant changes in land use within the upper catchment of Cameron Highlands over the years. The land use changes associated with the farming of vegetables, fruits and flowers on steep valleys appears to have increased significantly.

Prior to the completion of the hydropower scheme, it was estimated that about 90% of the Telom catchment and 65% of the Bertam catchment were covered in forest (Tenaga National Berhad , 2000). These now developed areas consist mainly of tea plantations, vegetable farms and residential areas. The measured sediment contents of the rivers in the scheme at that time were not very high and it was estimated that the Ringlet Reservoir would have a useful life of approximately 80 years, with no special provisions to cope with sedimentation (Tenaga National Berhad , 2000).

Agricultural activities have increased from approximately 10% to 34% in the Telom catchment and from 28% to 36% in the Bertam catchment between 1960 and 1990. (Tenaga National Berhad Research, 2004). About 40% of the farmland is tea plantation and the rest is cultivated for vegetables, flowers, fruits and other crops. The number of residential houses in Cameron Highlands has reportedly increased from 3860 units in 1980 to 5526 units in 1991. By 1999, approximately 700 hotels and 185 units of apartments were reportedly completed (Tenaga National Berhad Research, 2005a).

The rate of sediment filling increased from 30,000 m^3/ year in the 1960's to 50,000 m^3/ year in the early 1980's (Tenaga National Berhad Research, 2009). At 1999, Ringlet Reservoir has lost all of its dead storage (2 million m^3) plus 70% of its live storage (4.7 million m^3) to sedimentation (Tenaga National Berhad Research, 2009). These statistics suggest that, in order to maintain the reservoir operation at a satisfactory level, a minimum rate of 100,000 m^3 of sediment must be dredged or removed annually from both the reservoir and the settling ponds above the check dams (Tenaga National Berhad Research, 2009).

The power station is currently operating mainly as a run-of-river for a short time period during peak hours. It is estimated that without proper sedimentation removal measures, the scheme will cease to operate for load peaking and become an unregulated run-of-river scheme, where generation will be subjected only to immediate availability of water (Tenaga National Berhad Research, 2005b). This will result in a sharp drop in annual revenue from RM 175 Million to a mere RM 78.5 Million (Tenaga National Berhad Research, 2005b). Heavy sedimentation has also incurred costs in terms of the early replacement of abraded turbine blade, construction of the Telom desander structure in 1992, frequent desilting works of Ringlet reservoir, loss of stored water due to overflow due to the displacement of water by sediment, and outages due to clogging of the Kampung Raja's intake and during the de-silting of the Telom tunnel (Tenaga National Berhad , 2000). The reduced storage of Ringlet Reservoir has also increased the risk of spilling and flooding to the farms and settlement areas located downstream of Sultan Abu Bakar Dam (Tenaga National Berhad Research, 2005b). Also, the dumping of dredged materials has recently become an environmental concern because there are no proper dumping sites for the growing amount of dredged material (Tenaga National Berhad Research, 2005b).

In a nutshell, there are various socio-economic and environmental costs and damages associated with excessive soil erosion, sediment transport and deposition. These include (Tenaga National Berhad Research, 2009):

- Loss of peaking power revenues
- Replacement costs for the turbine units due to sand abrasion
- Loss of flood control storage volume
- Potential threat to dam safety
- Adverse environmental impact to the ecological system along the streams and flood plains

1.5 Objective

Sedimentation is a major concern to the hydropower scheme in Malaysia. Cameron Highlands is known to have one of the worse if not the worst sedimentation problem in Malaysia. Extensive deforestation and indiscriminate earth bulldozing for agricultural and housing development as well as road construction has resulted in widespread soil erosion over the land surface of Cameron Highlands leading to sedimentation of the streams and of the Ringlet Reservoir.

The objective of this thesis is to determine the average annual soil loss rate using the RUSLE model for the Upper Catchment of Cameron Highlands for the years 1997 and 2006. Data such as rainfall pattern, soil type, topography, cover management and support practice were utilized for soil modeling using RUSLE and ArcGIS. The sub-catchments of Telom, Kial and Kodol, Upper Bertam, Middle Bertam, Lower Bertam, Habu, Ringlet and Reservoir were studied. The sub-catchment of Plau'ur was excluded from this study because data from the region was not sufficient. The results from this study will represent the sediment yield in the Ringlet Reservoir where Sultan Abu Bakar Dam is located. The results of this thesis will be used to propose a sediment mitigation plan to solve the sedimentation problem at Ringlet Reservoir.

The advantage of using the RUSLE model is that it has been widely used and tested over many years; subsequently the validity and limitations of this model are already known. The disadvantage of this model is that it had been developed using data from the U.S., and therefore significant adjustments to the algorithms used to derive the key factors are required before the model can be applied to other areas such as Malaysia. This thesis follows the RUSLE model guidelines for Malaysia from a report titled "Preparation of Design Guides for Erosion and Sediment Control in Malaysia" published by the Ministry of Natural Resources and Environment Malaysia on 2010.

2 LITERATURE REVIEW

2.1 Soil Erosion

Water and wind are the main agents responsible for soil erosion. Sedimentation and soil erosion includes the processes of detachment, transportation and deposition of solid particles also known as sediments (Julien, 2002). These soil erosion sequences are demonstrated in Figure 6. The forms of water responsible for soil erosion are raindrop impact, runoff and flowing water (Wischmeier & Smith, 1978). Erosion from mountainous areas and agricultural lands are the major source of sediment transported by streams and deposited in reservoirs, flood plains and deltas. Sediment load is also generated by erosion of beds and banks of streams, by the mass movements of sediment such as landslides, rockslides and mud flows, and by construction activity of roads, buildings and dams.

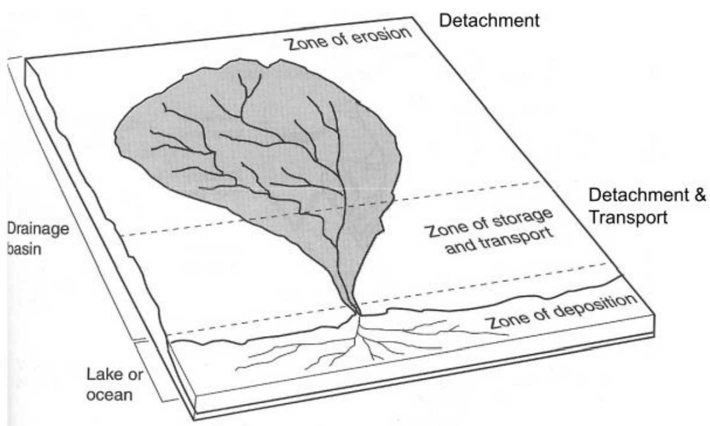


Figure 6: Soil Erosion (Iowa Stormwater Runoff Control, n.d.)

The processes of soil erosion are shown in Figure 7. Sheet erosion happens when raindrop impact transports particles and becomes runoff traveling over the surface of the ground (Fortuin, 2006). Rill erosion occurs when water from sheet erosion combines to form small concentrated channels (Fortuin, 2006). Erosion rates increase due to higher velocity flows as rill erosion starts. When water in rills concentrates to form larger channels, it results in gully erosion (Fortuin, 2006). Finally, stream channel erosion takes place when water flows cut into the bottom of the channel and makes it deeper (Fortuin, 2006). Soil erosion may not be obvious on the ground surface as raindrops are transporting some amount of particles but soil erosion will be more noticeable when water flow concentrates to form rills and gullies (Kim, 2006).

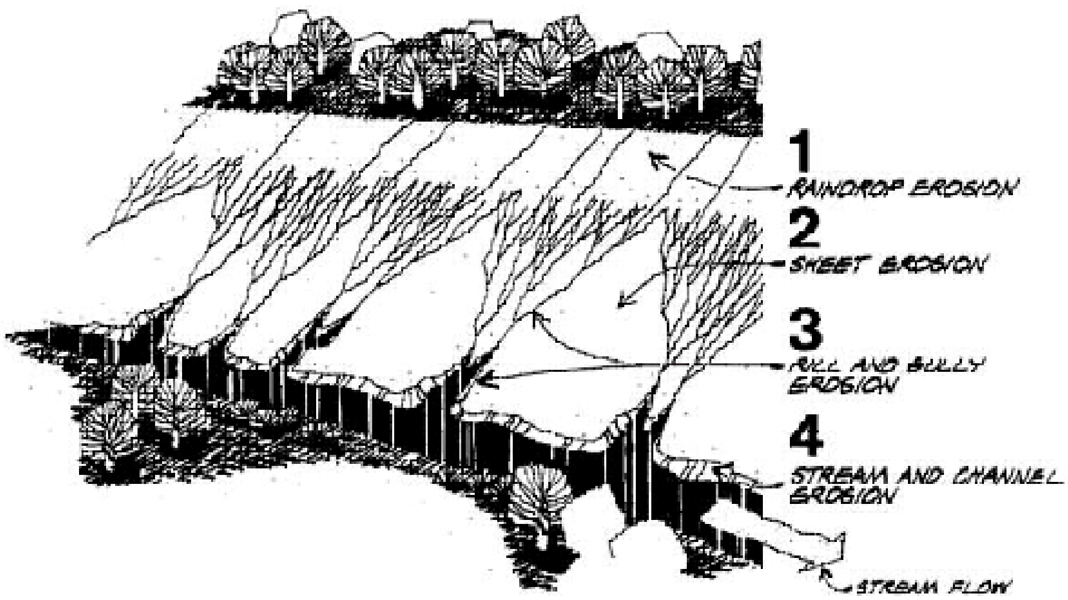


Figure 7: Types of Water Erosion (Iowa Stormwater Runoff control, n.d.)

The common erosion features found in Cameron Highland are (Tenaga National Berhad Research, 2004):

I. Flow driven soil erosion:

- Rills
- Gullies
- Flow pathways
- Raindrop marks
- Deposition sites
- Pedestals
- Distribution of leaf litter
- Debris dams

II. Mass movement:

- Landslide (usually large scale)
- Landslip
- Wall/ bund collapse
- Drain widening
- Large accumulations of sediment
- Slumping

2.2 Soil Erosion Models

The soil erosion prediction methods were first developed in the U.S.; consequently many soil loss estimation equations were developed by a number of researchers. Over the years, these equations improved as new variables and factors were added to the soil erosion equation. Smith and Whitt presented one of the first rational soil erosion equation and it is a method of estimating soil losses from fields of claypan soils (Smith & Whitt, 1947). This equation (equation 1) is shown below (Smith & Whitt, 1947):

$$A = C.S.L.K.P \qquad (1)$$

Where:

A – Annual soil loss, in tones ha^{-1} $year^{-1}$

C – Average annual soil loss from claypan soils for a specific rotation, slope length, slope steepness, and row direction

S – Slope steepness

L – Slope length

K – Soil erodibility

P – Support practice

Then, the Universal Soil Loss Equation model (USLE) was adopted by the Soil Conservation Service in U.S. in 1958 and became the most widely used and accepted model to make long term assessments of soil erosion. The USLE model was developed by Wischmeier & Smith based on data from more than 10,000 test plots throughout the East of the U.S. in 20 years (Wischmeier & Smith, 1965). The test plots were managed with a standard of 22 m flow lengths allowing this method to be more accurate and reliable (Wischmeier & Smith, 1965). The USLE has six factors and is applicable to calculate sheet and rill erosion only. However, the USLE is known to have a few shortcomings. If just one of the input data is not accurately specified, the multiplication of the six factors will lead to a large error of results (Sonneveld & Nearing, 2003). There are also questions about the reliability of the parameter values assigned to the model (Sonneveld & Nearing, 2003).

Additional research and experience have resulted in an upgrade of the USLE from the past 30 years. The improved equations developed based on the USLE model are such as the Modified Universal Soil Loss Equation (MUSLE) by J.R. Williams (Williams, 1975), the Areal Nonpoint Source Watershed Environmental Resources Simulation (ANSWERS) by D.B. Beasley (Beasley, Huggins, & Monke, 1980), the Unit Stream Power – based Erosion Deposition (USPED) by H. Mitasova (Mitasova, Hofierka, Zlocha, & Iverson, 1996) and Revised Universal Soil Loss Equation (RUSLE) by K.G. Renard (Renard, Foster, Weesies, McDool, & Yoder, 1997).

Among the newly developed equations mentioned above, the most extensive work that focuses on better parameter estimations is undoubtedly the Revised Universal Soil Loss Equation (RUSLE) by K.G. Renard (1997). The RUSLE incorporates improvements in the factors based on new and better data but keeps the basis of the USLE equation. The RUSLE was enhanced by revising the weather factor, the soil erodibility factor depending on seasons, revising the gradient and length of slope and developing a new method to calculate the cover management factor (Renard, Foster, Weesies, McDool, & Yoder, 1997). The RUSLE assumes that detachment and deposition are controlled by the sediment content of the flow (Pitt, 2007). Erosion is limited by the carrying capacity of the flow but is not source limited (Pitt, 2007). Detachment will no longer take place when the sediment load has reached the carrying capacity of the flow (Pitt, 2007). The RUSLE equation (equation 2) is shown below (Renard, Foster, Weesies, McDool, & Yoder, 1997) :

$$A = R.K.LS.C.P \tag{2}$$

Where:

A – Annual soil loss, in tons ha^{-1} year^{-1}

R – Rainfall erosivity factor, an erosion index for the given storm period in MJ.mm/(ha.hr. year)

K – Soil erodibility factor, the erosion rate for a specific soil in continuous fallow condition on a 9% slope having a length of 22.1m in ton.ha.hr/ (MJ.mm.ha)

LS – Topographic factor which represent the slope length and slope steepness. It is the ratio of soil loss from a specific site to that from a unit site having the same soil and slope but with a length of 22.1m

C – Cover management factor, which represents the protective coverage of canopy and organic material in direct contact with the ground. It is measured as the ratio of soil loss from land cropped under specific conditions to the corresponding loss from tilled land under clean-tilled continuous fallow conditions (Renard, Foster, Weesies, McDool, & Yoder, 1997).

P – Support practice factor which represents the soil conservation operations or other measures that control the erosion. It is measured as the ratio of soil loss with a specific support practice to the corresponding loss with plowing up and down slope (Renard, Foster, Weesies, McDool, & Yoder, 1997).

L, S, C and P factors are dimensionless parameters and they are normalized relative to standard plot conditions. The USLE and the RUSLE is currently a globally accepted method for soil erosion prediction in the U.S. and in other countries all over the world. These models have been accepted to be useful, accurate and reliable.

2.3 Geographic Information System and Soil Erosion Modeling

A Geographic Information System (GIS) is a system that captures, stores, integrates, analyzes, manages and visualizes data that are linked to coordinates or locations. GIS is a combination of statistical analysis, database and cartography that allows the user to identify geographic information, relationships, patterns and trends (Omar, 2010). For this study, ArcGIS version 9.3 was utilized. Figure 8 shows the procedures of RUSLE model integrated with ArcGIS.

Since 1970s, GIS has been utilized in the field of environmental management (Kim, 2006). GIS application to hydrologic and hydraulic modeling as well as flood mapping and management only began about 20 years later (Kim, 2006). The Digital Elevation Model (DEM) is a breakthrough in the field of geomorphological analysis because of its ability to portray elevation and topography (Kim, 2006). The DEM is able to demonstrate changes in landscape with time because of the relocation of soil leading to sediment deposition. This process naturally affects the hydrological processes that occur within and over hill slopes (Kim, 2006).

GIS is a very helpful program for soil erosion modeling. GIS application in soil erosion analysis is increasing because of the advantages of combining GIS and soil erosion models. Firstly, interfacing GIS capabilities with the RUSLE provides a relatively fast analysis and visualization of likely sheet and rill soil erosion potential (Blaszczynski, 2001). This is useful because it will allow simulation of large scale studies using large amounts of data requiring only a relatively short processing time (Blaszczynski, 2001). This is because GIS acquires a spatial function that will perform the georeferencing and spatial overlays without consuming too much time (Sharma, Menenti, & Huygen, 1996).

Secondly, GIS also permits simulation of different scenarios from various changing land use conditions and management alternatives in space and time (Blaszczynski, 2001). This will allow the evaluation of the possible effects of each management practice on soil erosion. GIS is also a sophisticated tool where animate sequences of model output images across time and space can be displayed enabling the model output to be visualized from external perspectives (Tim, 1996). The catchment can also be modelled with more specific aspects because GIS enables the use of large catchments with various resolution or more pixels (Dee Roo, 1996).

Next, the integration of RUSLE and GIS can also be used as an automation tool to assist in the standardization of the application of the RUSLE to large areas. When the procedure is normalized and the input data is of comparable quality, automated processing allows the same procedure to be repeated with the normalized procedure on different areas so the areas can be compared without bias (Blaszczynski, 2001). The integration of RUSLE and GIS can be further applied as a core procedure for other geomorphologic and hydrologic applications such as watershed condition analysis, water quality monitoring of environmental pollutants in soils, sediment loading of streams and rivers and non-point source pollution (Blaszczynski, 2001).

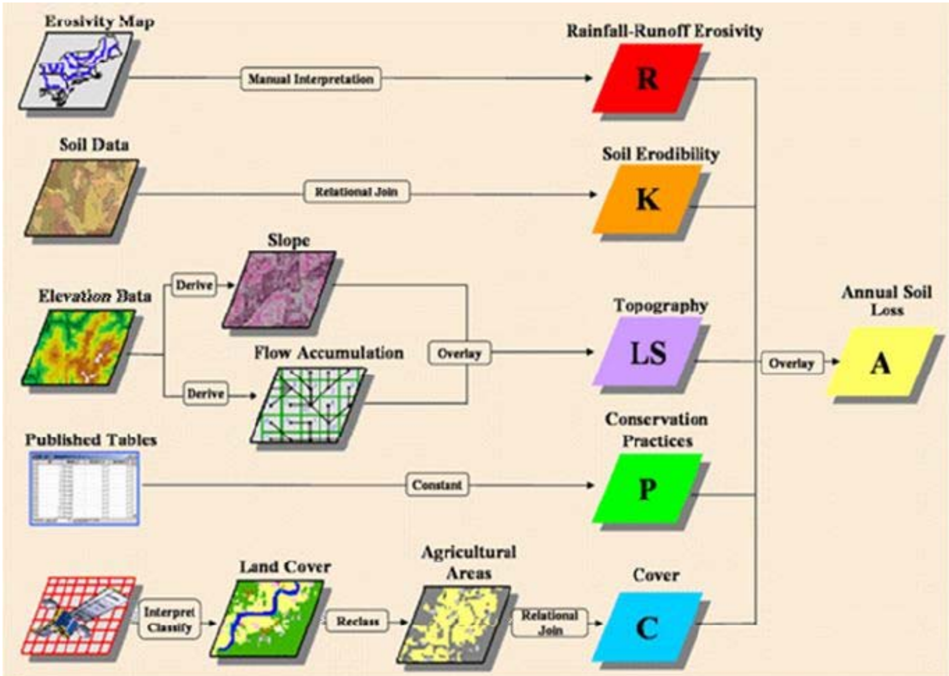


Figure 8: Procedures of RUSLE integrated in ArcGIS (Omar, 2010)

3 RAINFALL EROSIVITY FACTOR (R)

3.1 Literature Review

Malaysia is geographically lying along the equator where the amount and intensity of the rainfall is high causing soil to be more susceptible to water erosion. Factors such as total rainfall, rainfall intensity, rainfall duration, size, velocity and shape of raindrops and the kinetic energy of the rain contribute a great influence on erosion (Ministry of Natural Resources and Environment Malaysia, 2010). Upon reaching the ground, the raindrops supply the main energy for soil detachment. Other rainfall characteristics such as intensity, duration and total rainfall have influence on the resulting runoff.

The rainfall erosivity factor (R factor) represents the erosion potential caused by rainfall (Renard, Foster, Weesies, McDool, & Yoder, 1997). The rainfall erosivity factor (R factor) for the particular locality is the average annual total of the storm EI_{30} values for that locality (Renard, Foster, Weesies, McDool, & Yoder, 1997). EI_{30} is the individual storm index values which equals to E which is the total kinetic energy of a storm multiplied by I_{30} which is the maximum rainfall intensity in 30 minutes. The multiplication of EI reflects the total energy and peak intensity combined in each particular storm. Continuous rainfall records are neccessary to calculate the maximum 30 minute rainfall intensity (EI_{30}). To obtain an accurate R factor, EI_{30} needs to be calculated with continuous records over multiple years for multiple stations located at the area of the study site. The best equation for R factor was developed by Wischmeier and Smith shown in equation 3 below (Wischmeier & Smith, 1965):

$$R = \frac{1}{n}\sum_{j=1}^{n}\left[\sum_{k=1}^{m}(E)(I_{30})_k\right] \quad (3)$$

Where:

R – Rainfall erosivity factor

E – The total storm kinetic energy (MJ/ha)

I_{30} – The maximum 30 minutes rainfall intensity

j – The index for the number of years used to compute the average

k – The index of the number of storms in each year

n – The number of years to obtain average

m – The number of storms in each year

The total storm kinetic energy for each storm, E is obtained by summation of the product of unit kinetic energy and the respective rainfall volume of all the increments in a rainfall event, as given below in equation 4 (Ministry of Natural Resources and Environment Malaysia, 2010):

$$E = \sum_{r=1}^{k} e_r V_r \quad (4)$$

Where:

E – Total storm kinetic energy (MJ/ha)

K – Number of storm intervals

R – Index number of storm intervals

e_r – Unit kinetic energy for r^{th} interval

V_r – Total rainfall depth for r^{th} interval

The energy of a rainstorm is closely related to rainfall amount and all of the storm's component intensities (Wischmeier & Smith, 1978). Higher intensity and terminal velocity of a rainfall generally results in the increase in the median raindrop size (Wischmeier & Smith, 1978). Rainfall energy is directly related to rain intensity since the energy of a given mass in motion is proportional to velocity squared. Equations 5 and 6 (Zainal, 1992) describe the relationship, where e_r is the kinetic energy for r^{th} interval:

$$e_r = 210 + 89 \log_{10}(i_m) \qquad i_m \leq 7.6\frac{cm}{hr} \tag{5}$$

$$e_r = 288.4 \qquad i_m > 7.6\frac{cm}{hr} \tag{6}$$

However, large variations exist in the estimation of soil erosion. This is due to the availability of limited data and relevant information for calculating the factors; especially the rainfall erosivity factor. Realistic estimation of monthly rainfall erosivity EI_{30} values requires long term pluviographic data at 15 min intervals or less. In many parts of the world, especially developing countries such as Malaysia, spatial coverage of pluviographic data is often difficult to obtain. Monthly, seasonal and annual rainfall data are usually available for longer periods and are generally used to calculate R factor (Ministry of Natural Resources and Environment Malaysia, 2010), hence are likely to result in a less accurate estimation of rainfall erosivity.

In the Urban Stormwater Management Manual for Malaysia, rainfall design methods have been adjusted to suit Malaysian conditions. The frequency and intensity of rainfall in Malaysia is much higher than in most countries. Based on Volume 4 (Chapter 13- Design Rainfall), the maximum 30-minutes rainfall intensity (I_{30}) for the storm of required ARI were determined by using 20 years ARI design. The Average Recurrence Interval (ARI) is referred to as the return period, is the average length of time between events that have the same magnitude, or volume and duration (Department of Irrigation and Drainage Malaysia, 2000). Equation 7 (Department of Irrigation and Drainage Malaysia, 2000) can be used to get rainfall intensity values for a given duration and ARI, once the values of coefficients *a, b, c,* and *d* are known. **Error! Reference source not found.** gives derived values of the coefficients in equation below for the Cameron Highlands in the state of Pahang from the Department of Irrigation and Drainage Malaysia.

$$\ln({}^{R}I_t) = a + b\ln(t) + c(\ln(t))^2 + d(\ln(t))^3 \tag{7}$$

Where:

${}^{R}I_t$ – The average rainfall intensity (mm/hr) for ARI and duration t

R – Average return interval (years)

t – Duration (minutes)

a, b, c and *d* are fitting constants dependent on ARI

Table 5: Fitted coefficient a, b, c and d for Cameron Highlands (Department of Irrigation and Drainage Malaysia, 2000)

State	***Location***	***Data Period***	***ARI (year)***	***Coefficients of the IDF Polynomial Equations***			
				a	**b**	**C**	**D**
Pahang	Cameron Highlands	1951-1990	2	4.9396	0.2645	-0.1638	0.0082
			5	4.6471	0.4968	-0.2002	0.0099
			10	4.3258	0.7684	-0.2549	0.0134
			20	4.8178	0.5093	-0.2022	0.0100
			50	5.3234	0.2213	-0.1402	0.0059
			100	5.0166	0.4675	-0.1887	0.0089

After determining the I_{30}, R factor is obtained by using the equation 8 (Forest Research Institute Malaysia, 1999) and equation 9 (Morgan & Davidson, 1986) below. EI_{30} in equation 8 is the individual storm index values similar to equation 4 but using a different equation developed by Morgan (1986). Based on Volume 4 (Chapter 13- Design Rainfall) in the Urban Stormwater Management Manual for Malaysia, the maximum 30-minutes rainfall intensity (I_{30}) for the storm of required ARI were determined by using 20 years ARI design.

$$R = \frac{EI_{30}}{170.2} \tag{8}$$

$$E = 9.28P - 8838.15 \tag{9}$$

E – Annual erosivity (J/m^2)

I_{30} – The maximum 30-minutes rainfall intensity (mm/hr) for the storm of required ARI

P – Annual rainfall (mm)

Another similar equation is also proposed by Bols (1978) for calculation of the R value based on empirical study in Indonesia as shown below where P is the annual precipitation in mm. This equation is applicable to Malaysia because of similar climatic conditions to Indonesia and data for annual precipitation is easier to obtain than pluviographic data at 15 min intervals or less in a developing country. Equation 10 (Bols, 1978) is shown below:

$$R = \frac{2.5P^2}{100(0.073P + 0.73)} \tag{10}$$

P – Annual rainfall (mm)

3.2 Data

The amount of rainfall and the number of rainy days are higher in Cameron Highlands because of the higher humidity and the lower evaporation in the highlands compared to the lowlands (Fortuin, 2006). The average annual rainfall of Cameron Highlands is approximately 2,800 mm and the average monthly rainfall amount is roughly between 150 to 250 mm (Fortuin, 2006). Precipitation happens frequently in Cameron Highlands with more rainfall amount during the two major monsoons- Northeast and Southwest (Toriman, Karim, Mokhtar, Gazim, & Abdullah, 2010). The months of January and February are the most arid with monthly rainfall amount of about 100 mm while October and November are the moistest months with monthly rainfall amount of about 350 mm (Fortuin, 2006).

1) Automatic Rainfall Gauge Station

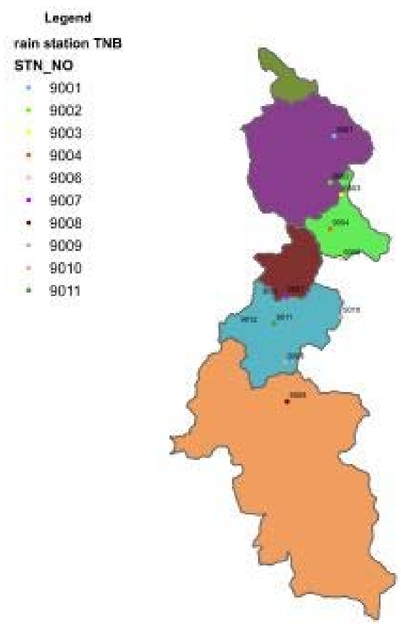
Hydrological data can be obtained from the Hydrological Station of the Department of Irrigation and Drainage (DID) Malaysia. There are only 31 automatic rainfall gauge stations installed in the State of Pahang where Cameron Highlands is located, and only one automatic rainfall gauge station in Cameron Highlands itself situated on Mount Brinchang (Ministry of Natural Resources and Environment Malaysia, 2010). This data provides continuous 10-minute interval rainfall records to calculate the maximum 30 minute rainfall intensity (EI_{30}). The data collected dates from 1999 to 2008. Therefore, data from one automatic rainfall gauge station does not provide enough spatial coverage of pluviographic data to obtain an accurate R factor using equation 3, 4, 5 and 6 which requires the computation of $EI_{30.}$

2) Manual Rainfall Gauge Station

Table 6 presents station name and location of the 10 manual rainfall gauge stations in the Cameron Highlands. These manual rainfall gauge stations are managed by Tenaga National Berhad (TNB) shown in Map 2. Daily precipitation records are available for 8 years starting from 1999 to 2006 shown in **Error! Reference source not found.**. R factor can be calculated using equation 8 and 9 after obtaining I_{30} value using equation 7. The fitting constants (a, b, c, d) for the ${}^{R}I_{t}$ value is shown in Table 5 for the 20 years ARI design to be calculated in equation 7 where R is 20 years and t is 30 minutes, this would provide the I_{30} value to be placed in equation 8. The other way of calculating R factor is by using equation 10 by utilizing the annual precipitation.

Table 6: TNB Manual Rainfall Gauge Stations

STN_NO	STN_NAME	LONG_DMS	LAT_DMS
9001	Blue Valley Tea Estate	101.4194	4.5861
9002	Kampung Raja	101.4167	4.5514
9003	Telom Intake	101.4250	4.5422
9004	Sungai Palas Tea Estate	101.4167	4.5167
9006	Station Janaletrik Bintang	101.4250	4.4944
9007	Balai Kaji Iklim Tanah Rata	101.3833	4.4667
9008	Station MARDI Tanah Rata	101.3850	4.3875
9009	Station Janaletrik Habu	101.3833	4.4167
9010	Boh Tea Estate (Kilang)	101.4250	4.4514
9111	Balai Kajicuaca Tanah Rata	101.3667	4.4667



Map 2: Location of TNB Manual Rainfall Gauge Stations

Table 7: Annual Precipitation Records from TNB (mm)

Station No.	1999	2000	2001	2002	2003	2004	2005	2006	Average
9001	2183.7	2077.7	1852.8	1417.4	1788.5	1397.0	1827.0	2970.0	1939.26
9002	2663.9	2429.6	2289.6	2023.2	2404.2	2177.6	1716.3	2529.3	2279.21
9003	1638.5	1341.0	1471.0	1867.0	2432.5	1417.0	1967.1	2340.5	1809.33
9004	3654.4	2873.0	2382.0	2411.5	2894.0	2907.0	2201.0	2704.0	2753.36
9006	3516.5	2921.5	2452.0	2537.5	2099.0	2222.0	2225.5	2590.5	2570.56
9007	3369.0	2934.2	2488.5	2338.0	2544.2	2283.2	2210.3	2556.0	2590.43
9008	3309.4	2908.3	2433.0	2226.3	2733.5	2456.8	2158.9	2698.4	2615.58
9009	3096.5	3017.0	2206.5	2006.0	2406.7	1929.0	2108.0	2459.0	2403.59
9010	2949.0	2407.0	2021.0	1866.5	2508.5	2121.2	1833.1	2316.6	2252.86
9111	3707.1	3172.0	2631.7	2816.9	2975.8	2411.6	2883.4	2776.9	2921.93

3.3 Method

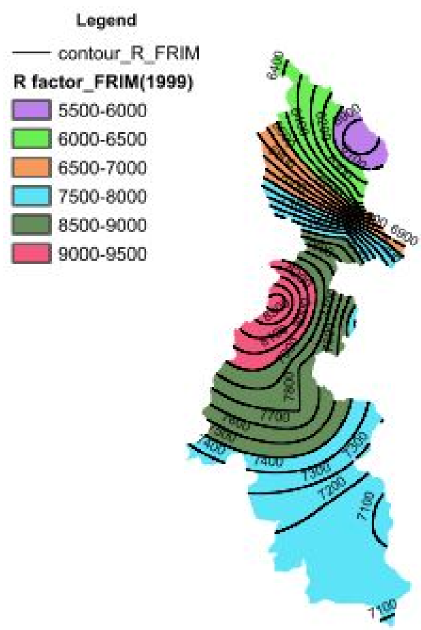
After data collection, R factor was determined for each year for all selected rainfall gauge stations using the equations listed above. Then, the average R factor for each rainfall gauge station was inserted into ArcGIS. Isohyet maps for R factor were generated using ArcGIS. All the data points were interpolated spatially using the Ordinary Kringing method found in the ArcGIS Spatial Analyst tool to make the same resolution or grid cell size as the other maps inserted in the ArcGIS (Ministry of Natural Resources and Environment Malaysia, 2010). The parameters used for Kringing method are shown in Table 8. Kringing is based on statistical models that include autocorrelation – that is, the statistical relationships among the measured points. Because of this, not only do geostatistical techniques have the capability of producing a prediction surface, they also provide some measure of certainty or accuracy of predictions.

Table 8: Summary of interpolation parameters using simple Kringing (Ministry of Natural Resources and Environment Malaysia, 2010)

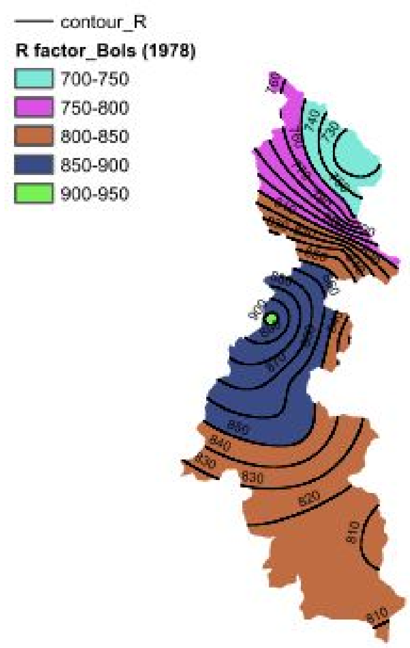
Parameter	**Values**
Value to be interpolated	R factor
Semivariograms Properties A. Kringing Method B. Semivariogram Model	 Ordinary Kringing Spherical
Interpolation cell size	5 x 5 km
Kringing Parameter A. Search Type B. Number of Points C. Maximum Search Distance	 Fixed 15 150 km

3.4 Results

Rainfall erosivity or isohyet map for the R factor was developed using the method described above. There was not enough spatial coverage of pluviographic data from the automatic rain gauge station to obtain an accurate R factor using equation 3, 4, 5 and 6 because data for one rainfall station is not enough for interpolation of R factor for the area of the upper catchment of Cameron Highlands. The R factor produced from equation 7, 8 and 9 was too big shown in Map 3. The most accurate R factor was obtained using equation 10 for Cameron Highlands shown in Map 4. The value of R factor for Cameron Highlands was compared with other methods by Harper, 1987 from Thailand which yield the results of 993 MJ.mm/(ha.hr.year), Merritt, 2002 from Thailand which yield the results of 1003 MJ.mm/(ha.hr.year) and Morgan, 1974 from Malaysia which yield the results of 1379 MJ.mm/(ha.hr.year). Cell size of 20m was used for this map.



Map 3: R Factor using the FRIM,1999 method (Equation 7, 8, 9)



Map 4: R factor using Bols, 1978 method (Equation 10)

4 SOIL ERODIBILITY FACTOR (K)

4.1 Literature Review

The soil erodibility factor (K factor) measures the susceptibility of soil particles or surface materials to transportation and detachment by the amount of rainfall and runoff input (Renard, Foster, Weesies, McDool, & Yoder, 1997). It is known that the most easily eroded soil particles are silt and very fine sand and the less erodible soil particles are aggregated soils because they are accrued together making it more resistible (Kim, 2006).

The K factor soil survey data comprises measurement under a standard unit plot; the standard unit plot has a 9 percent gradient slope and a length of 22.1 m in a continuous fallow condition (Weesies, 1998). The most widely used and frequently cited relationship to estimate the K factor is the soil-erodibility nomograph using measurable properties. The soil erodibility nomograph comprises five soil profile parameters: percent of modified silt (0.002-0.1mm), percent of modified sand (0.1-2mm), percent of organic matter (OM), class for soil structure (s) and permeability (p). Extensive work is done by Tew, 1999 to produce a Malaysian condition soil erodibility nomograph, based on unmodified nomograph by Wischmeier, 1978 and relative K values obtained from experimental work using a portable rainfall simulator. Modifications are carried out to get the best correlation between relative K value and the predicted K value from the existing nomograph to produce a nomograph for Malaysian soil series by modifying the four parameters in the nomograph accordingly: percentage of sand passing 0.06-2.0 mm, percentage of organic matter content, soil structure and permeability. The resulted nomograph is shown in Figure 9 (Tew, 1999). A similar equation is also derived for the calculation of soil erodibility for Malaysian Soil Series shown in equation 11 (Tew, 1999):

$$K = \frac{\left[1.0 \times 10^{-4}(12 - OM)M^{1.14} + 4.5(s - 3) + 8.0(p - 2)\right]}{100} \tag{11}$$

Where:

K – Soil Erodibility Factor (ton/ha)(ha.hr/MJ.mm)

M – (% silt +% very fine sand) x (100 – % clay)

OM – % of organic matter

S – soil structure code

P – permeability code

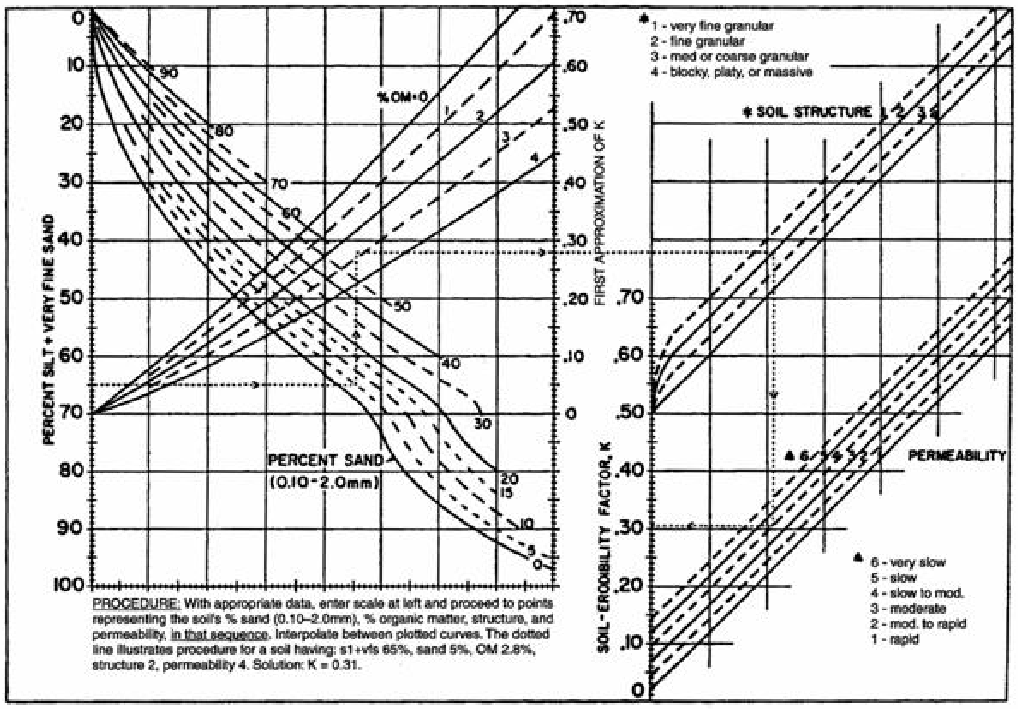


Figure 9: Soil Erodibility Nomograph (Tew, 1999)

In Malaysia, the values of K factor for soil series have been determined by the Department of Agriculture (DOA). The most recent values from 2010 are obtained from DOA consisting 289 soil series type and the respective K values. The first 15 soil series are shown in Table 9:

NO	SOIL SERIES	CODE	K Value
1	ASAHAN	AHN	0.002621
2	AKOB	AKB	0.002200
3	ALMA	AMA	0.002210
4	APEK	APK	0.002591
5	ALOR SEMAT	AST	0.002200
6	AWANG	AWG	0.003079
7	BUKIT AJIL	BAL	0.002200
8	BENDA NYIOR	BAR	0.002200
9	BEMBAN	BBN	0.002200
10	BERINCHANG	BCG	0.002205
11	BELADING	BDG	0.002257
12	BADAK	BDK	0.002252
13	BEDUP	BDP	0.002200
14	BEOH	BEH	0.002200
15	BAGING	BGG	0.002571

Table 9: K factor for Malaysian Soils (Department of Agriculture,2010)

4.2 Data

The Malaysian soil series map was available for Peninsular Malaysia from the Department of Agriculture (DOA) shown in Figure 10. Figure 11 shows the close up of Cameron Highlands located in the state of Pahang. In Figure 11, the red represents urban land and the green represents soil group B which means soils having a moderate infiltration rate when thoroughly wet and have moderately fine texture to moderately coarse texture. The surface soils in Cameron Highlands are highly weathered; they are approximately 50% sand and 30% silt or clay (Fortuin, 2006). The soil group for the Cameron Highlands was not specifically defined in Figure 10 from DOA. The Cameron Highlands soil series shape file for ArcGIS input was requested and obtained from the Department of Agriculture as shown in Map 5. The soil series shape file shows three soil categories: mined land, steep land and urban land.

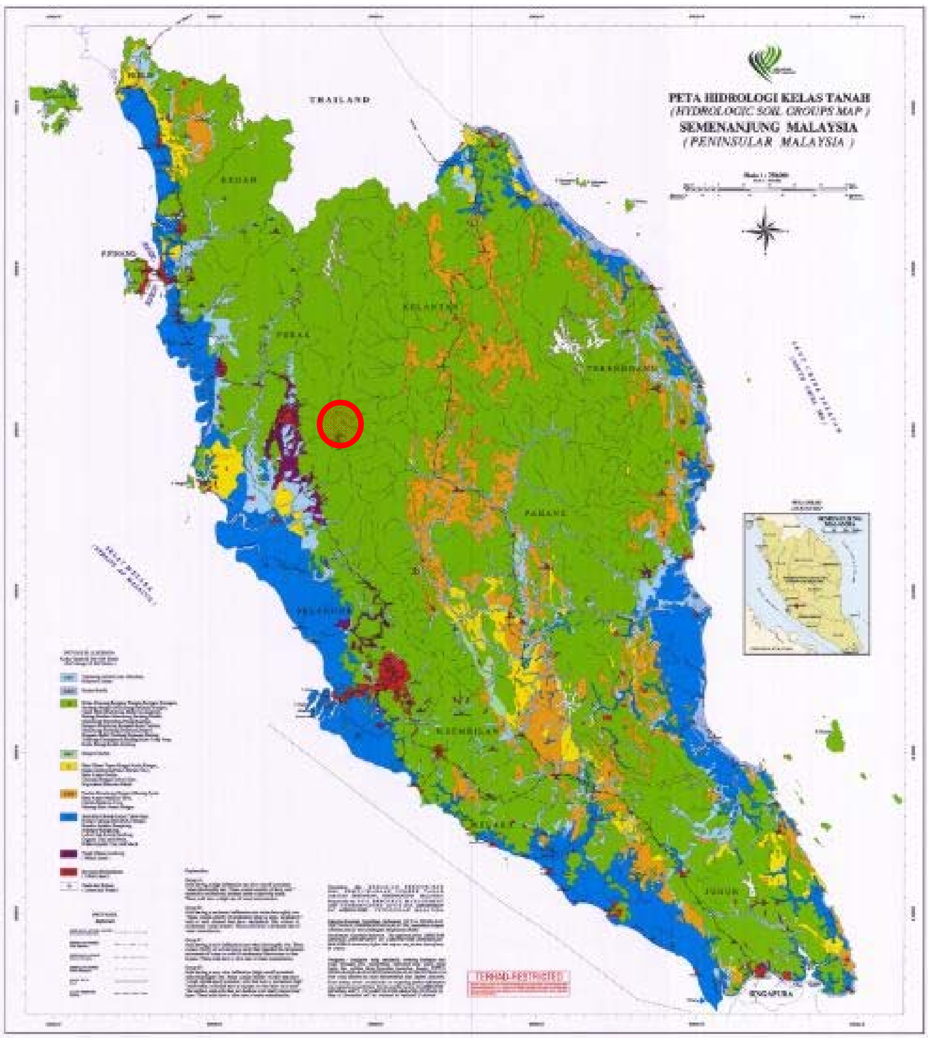
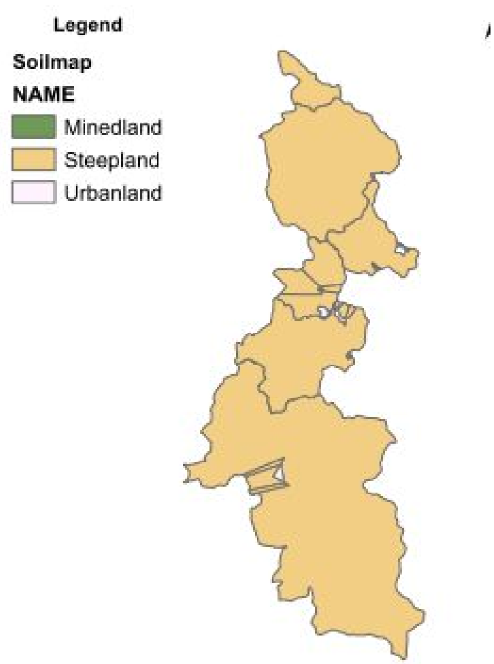


Figure 10: Peninsular Malaysia Soil Group Map (Department of Agriculture, 2007)

Figure 11: Cameron Highlands Soil Group Map from Figure 10 (Department of Agriculture)



Map 5: Cameron Highlands Soil Group Shape File from Department of Agriculture

4.3 Method

Figure 12 shows the two procedures to determine the K factor. For this study, K factor was not produced from equation 11 or the soil nomograph. The Cameron Highlands soil map shape file was obtained from the Department of Agriculture. After the soil map shape file was added as a layer into ArcGIS, the soil map attribute table was edited with adding a new field of K values under the Edit menu at attribute view before K factor were produced. The K factor used for steep land, urban land and mined land was 0.066; this value was adopted from the K factor list from the Department of Agriculture, 2007. This value was assigned to urban land, mined land and steep land by Department of Agriculture, 2007. This is a poor estimation of K factor because detailed soil map of Cameron highlands is not available yet. Soil map of Cameron Highlands can be obtained only after rigorous soil survey study for multiple years at the site. With a more detailed soil map of Cameron Highlands, values from Table 9 can be assigned to each soil series in Cameron Highlands for a better K factor result. The theme was in vector form and was converted to grid form with cell size of 20m.

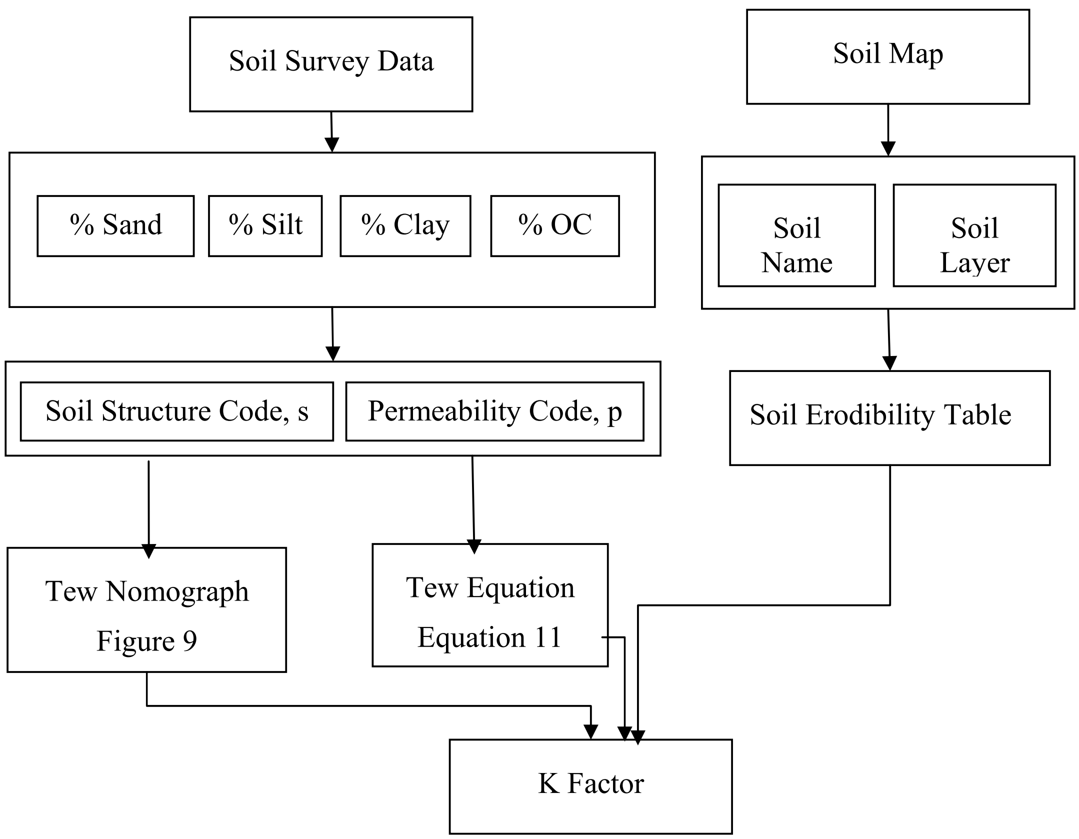


Figure 12: Schematic diagram for determination of K factor (Ministry of Natural Resources and Environment Malaysia, 2010)

4.4 Results

Soil erodibility map for K factor was developed using the method described above. The theme produced is shown in Map 6.

Map 6: K factor (Department of Agriculture)

5 SLOPE LENGTH AND SLOPE STEEPNESS FACTOR (LS)

5.1 Literature Review

The effect of topography on soil erosion is accounted for by the LS factor in RUSLE, which combines the effects of a slope length factor (L) and a slope steepness factor (S). Wishmeier and Smith (1978) defined slope length as the distance from the point of origin of overland flow to the point where the slope decreases enough that deposition begins or the point where runoff becomes concentrated in a defined channel. Slope steepness reflects the influence of slope gradient on soil erosion (Wischmeier & Smith, 1965). It is known that the amount of runoff increases due to the continuous accumulation down the slope as the slope length (L factor) increases; the velocity of runoff increases as the slope steepness (S factor) increases (Kim, 2006).

There are many different equations available to calculate the LS factor. Urban Stormwater Management Manual (Chapter 15) applied the equation defined by Wischmeier (1975) for Malaysia as shown in equation 12 (Department of Irrigation and Drainage Malaysia, 2000) below:

$$LS = \left(\frac{\lambda}{\psi}\right)^m (0.065 + 0.045s + 0.0065s^2) \tag{12}$$

Where:

λ – Sheet flow path length (m)

Ψ – Constant 22.13

s – Average slope gradient (%)

m - Refer to Table 10

For ArcGIS, Bizuwerk et al. (2008) presented that the slope length and slope steepness can be used in a single index, which expresses the ratio of soil loss as defined by Wischmeier and Smith (1978). Equation 13 (Bizuwerk, Taddese, & Getahun, 2008) for ArcGIS purpose is shown below:

$$LS = \left(\frac{X}{22.1}\right)^m (0.065 + 0.045S + 0.0065S^2) \tag{13}$$

Where:

X – slope length (m)

S – slope gradient (%)

The values of X and S can be derived from Digital Elevation Model (DEM). To calculate the X value, Flow Accumulation was derived from the DEM after conducting Fill and Flow Direction processes in ArcGIS.

$$X = (Flow\ accumulation * Cell\ value) \quad (14)$$

By substituting X value, LS equation will be:

$$LS = \left(Flow\ accumulation * Cell\frac{value}{22.1}\right)^{m} (0.065 + 0.045S + 0.0065S^{2}) \quad (15)$$

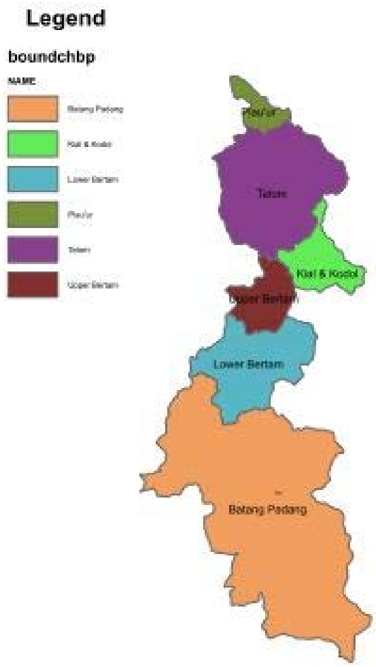
Slope (%) is also directly derived from the DEM using the same software (Ministry of Natural Resources and Environment Malaysia, 2010). The value of m varies from 0.2-0.5 depending of the slope as shown in Table 10.

Table 10: m value for LS factor (Ministry of Natural Resources and Environment Malaysia, 2010)

m value	Slope (%)
0.5	>5
0.4	3-5
0.3	1-3
0.2	<1

5.2 Data

LS factor is based on topography map. For this study, boundary and contour themes were used to generate triangulated irregular network (TIN) and digital elevation model (DEM). The boundary and contour shape files of Cameron Highlands were obtained from the Department of Agriculture, Malaysia shown in Map 7 and Map 8Map 8. These shape files were added as data into ArcGIS.



Map 7: Boundary Shape File of Cameron Highlands

Map 8: Contour Shape File of Cameron Highlands

5.3 Method

TIN was generated using the 3D Analyst function using two themes which were the boundary and contour maps. TIN is a representation of the 3D vector point file. In the next step TIN file was converted to raster file with the grid cell size of 20m x 20m which then becomes DEM. DEM represents the surface terrain of the catchment and permits to retrieve geographical information. Slopes of DEM in percentage were also generated using Surface Analysis under the Spatial Analyst function.

As the first step, the elevation value was modified by filling the sinks in the grid. This is done to avoid the problem of discontinuous flow when water is trapped in a cell, which is surrounded by cells with higher elevation. This was done by using the Fill tool under Hydrology section found under Spatial Analyst Tool Function in ArcGIS.

Then, Flow direction was generated from the Fill grid. The Flow direction tool takes a terrain surface and identifies the down-slope direction for each cell. This grid shows the on surface water flow direction from one cell to one of the eight neighbouring cells. This was done by using the Flow direction tool under Hydrology section found under Spatial Analyst Tool Function in ArcGIS.

Based on the Flow direction, Flow accumulation was calculated. Flow accumulation tool identifies how much surface flow accumulates in each cell; cells with high accumulation values are usually stream or river channels. It also identifies local topographic highs (areas of zero flow accumulation) such as mountain peaks and ridgelines. This was done by using the Flow accumulation tool under Hydrology section found under Spatial Analyst Tool Function in ArcGIS.

Finally, Raster calculator function under Spatial Analyst feature was used to input the modified equation 13 to compute LS factor. Themes of slope of DEM in percentage and flow accumulation were activated to run the process as shown in equation 14 and 15. Cell value of 20m was utilized in equation 14. The m value of 0.5 from Table 10 was selected for equation 13 because 86% of the terrain of Cameron Highlands was steeper than 20º (Fortuin, 2006). Figure 13 shows the summary of the methodology along with the GIS maps created at each step to calculate the LS factor.

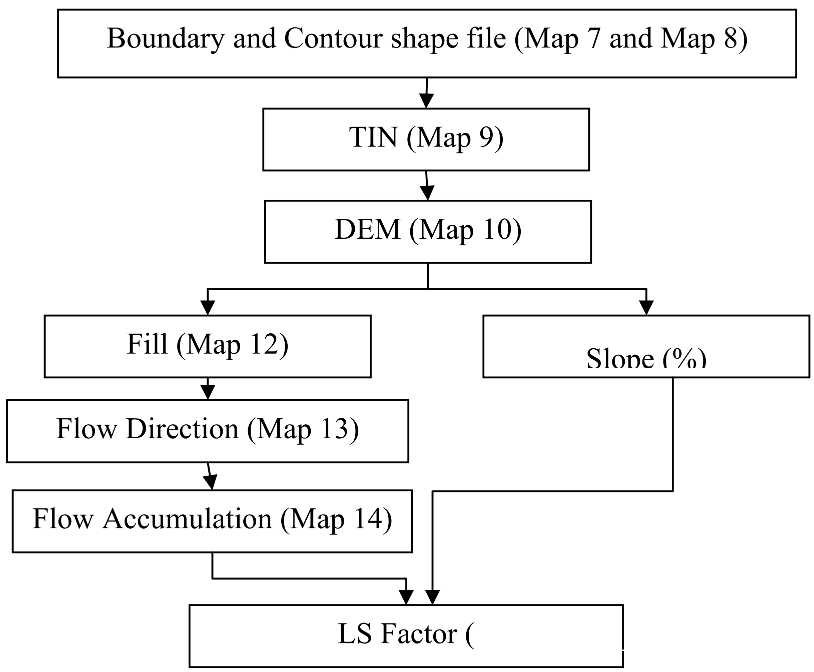
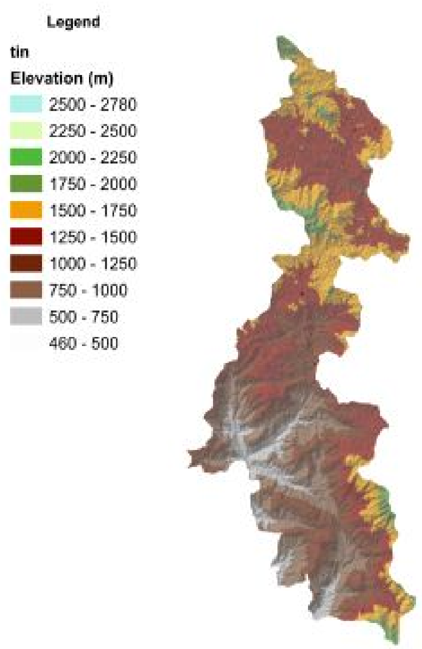
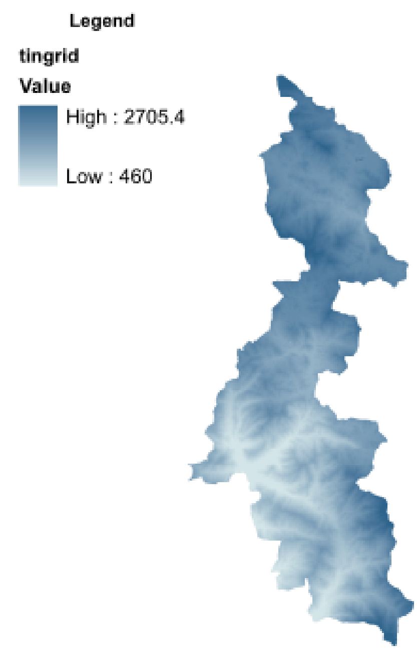


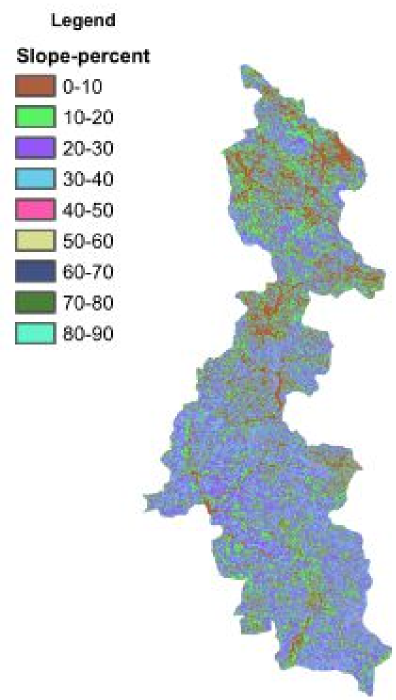
Figure 13: LS factor methodology using ArcGIS (Ministry of Natural Resources and Environment Malaysia, 2010)



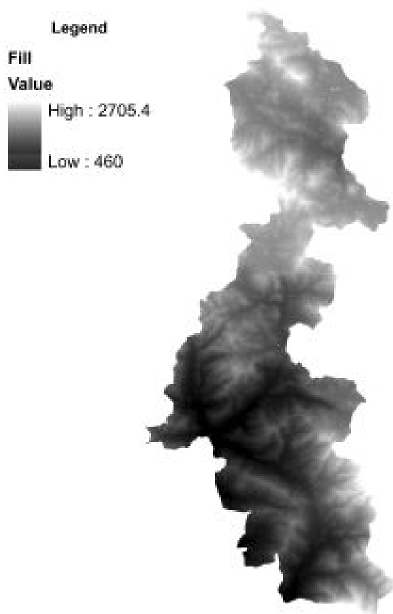
Map 9: TIN



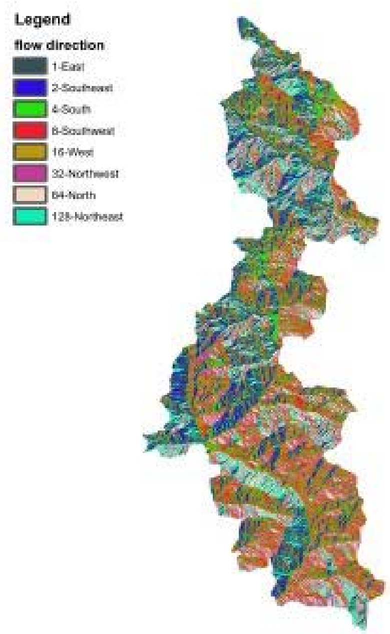
Map 10: DEM



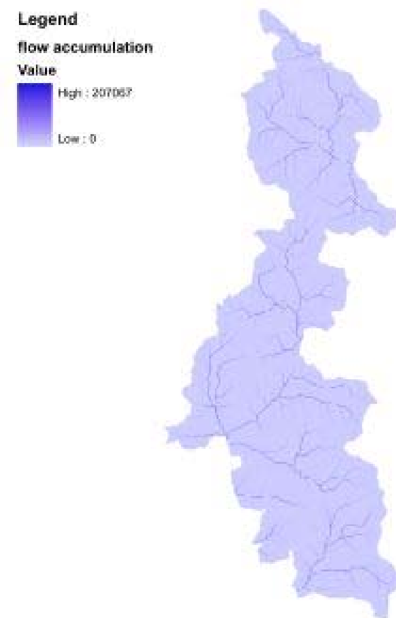
Map 11: Slope (%)



Map 12: Fill



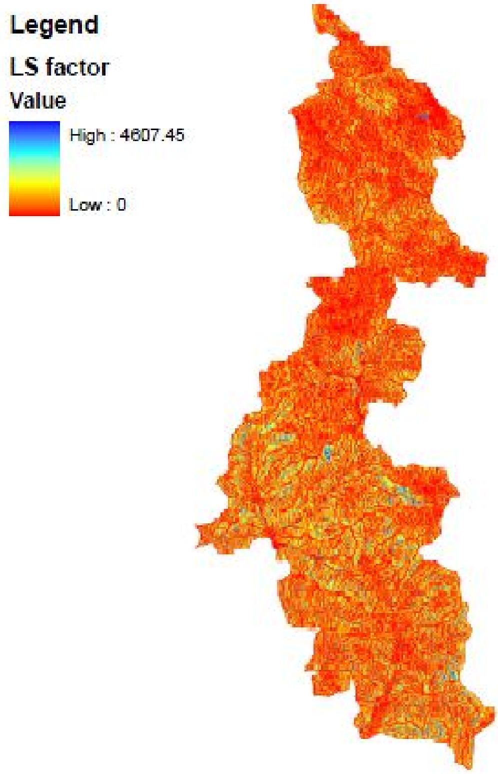
Map 13: Flow Direction

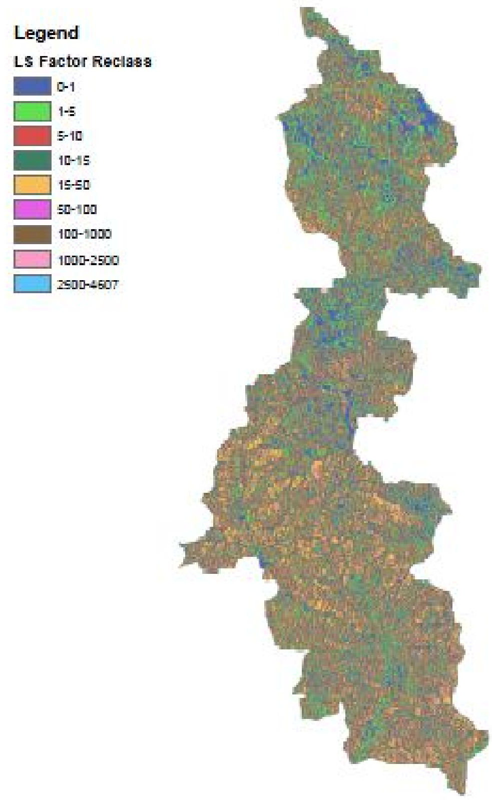


Map 14: Flow Accumulation

5.4 Results

Slope length and steepness for LS factor was developed using the method described above. The theme produced is shown in

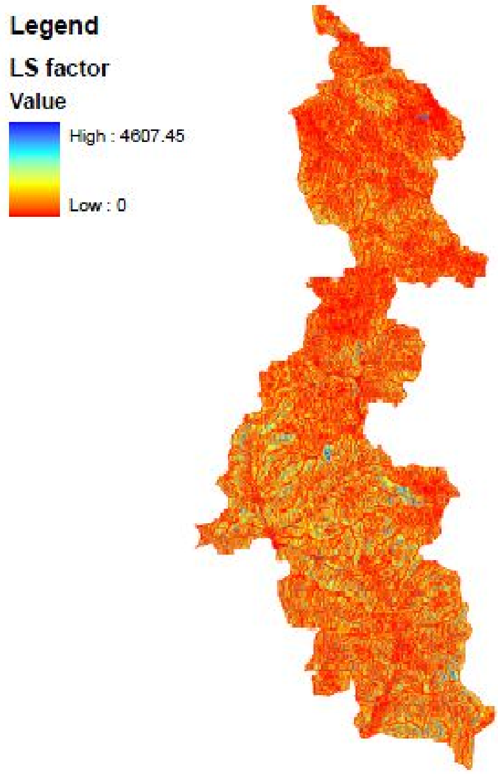




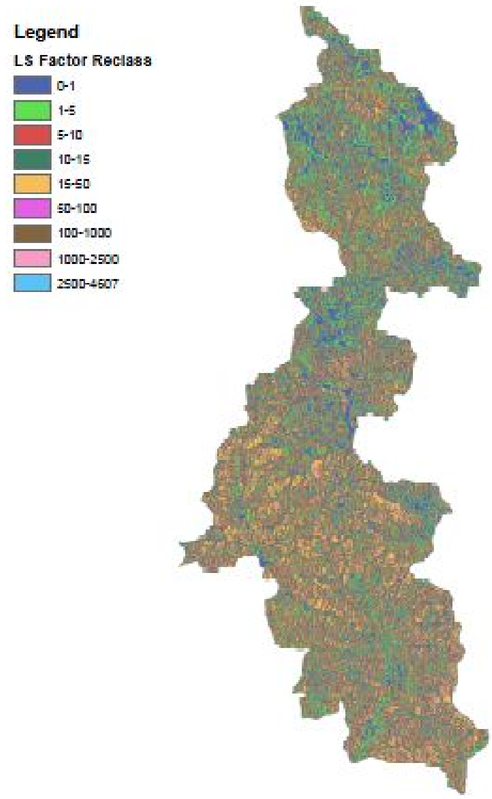
Map 15: LS Factor

Map 16: LS Factor Reclass

Map 16 and Map 16.



Map 15: LS Factor



Map 16: LS Factor Reclass

6 COVER MANAGEMENT FACTOR (C) AND SUPPORT PRACTICE FACTOR (P)

6.1 Literature Review

Cover Management Factor (C) and Support Practice Factor (P) are two management factors that can be used to control soil loss at a specific site. The Cover Management Factor (C) represents the effect of vegetation and management on the soil erosion rates (Renard, Foster, Weesies, McDool, & Yoder, 1997). The Support Practice factor (P) represents the impact of support practices on the soil erosion rates (Renard, Foster, Weesies, McDool, & Yoder, 1997).

Cover Management Factor (C) is the ratio of soil loss of a specific crop to the soil loss under the condition of continuous bare fallow (Renard, Foster, Weesies, McDool, & Yoder, 1997). The amount of protective coverage of a crop for the surface of the soil influences the soil erosion rate. C value is equal to 1 when the land has continuous bare fallow and have no coverage. C value is lower when there is more coverage of a crop for the soil surface resulting in less soil erosion. In Malaysia, the values of C factor based on land use have been determined by the Department of Agriculture (DOA). Based on ground conditions, the C factor has been categorized into three groups.

I. C factor for forested and undisturbed lands (Table 11**Error! Reference source not found.**)
II. C factor for agricultural and urbanized areas (Table 12**Error! Reference source not found.**)
III. C factor for BMPs at Construction sites (Table 13)

Table 11: C factor for forested and undisturbed lands (Department of Agriculture, 2010)

I. Forested and undisturbed lands	
Erosion control treatment	**C factor**
Rangeland	0.23
Forest/ tree	
25% cover	0.42
50% cover	0.39
75% cover	0.36
100% cover	0.03
Bushes/ scrub	
25% cover	0.40
50% cover	0.35
75% cover	0.30
100% cover	0.03
Grassland (100% coverage)	0.03
Swamps/ mangrove	0.01
Water body	0.01

Table 12: C factor for agricultural and urbanized areas (Department of Agriculture, 2010)

II. Agriculture and urbanized areas	
Erosion control treatment	**C factor**
Mining areas	1.00
Agricultural areas	
Agricultural crop	0.38
Horticulture	0.25
Cocoa	0.20
Coconut	0.20
Oil palm	0.20
Rubber	0.20
Paddy (with water)	0.01
Urbanized areas	
Residential	
Low density (50% green area)	0.25
Medium density (25% green area)	0.15
High density (5% green area)	0.05
Commercial, Educational and Industrial	
Low density (50% green area)	0.25
Medium density (25% green area)	0.15
High density (5% green area)	0.05
Impervious (Parking lot, road, etc)	0.01

Table 13: C factor for BMPs at Construction sites (Department of Agriculture, 2010)

III. Construction sites	
Erosion control treatment	**C factor**
Bare soil/ Newly clear land	1.00
Cut and fill at construction site	
Fill	
Packed, smooth	1.00
Freshly disked	0.95
Rough (offset disk)	0.85
Cut	
Below root zone	0.80
Mulch	
Plant fibers, stockpiled native materials/ chipped	
50% cover	0.25
75% cover	0.13
100% cover	0.03
Grass-seeding and sod	
40% cover	0.10
60% cover	0.05
>90% cover	0.02

Turfing 40% cover 60% cover >90% cover	 0.10 0.05 0.02
Compacted gravel layer	0.05
Geo-cell	0.05
Rolled Erosion Control Product: Erosion control blankets Plastic sheeting Turf reinforcement mats	 0.02 0.02 0.02

Support Practice factor (P) is the soil loss of a specific practice relative to the soil loss incurred when plowing up and down the slope (Renard, Foster, Weesies, McDool, & Yoder, 1997). P value is equal to 1 when the land is plowed on the slope directly. This is also known as the worst practice. P value is lower and less than 1 when the adopted conservation practice reduces soil erosion. P values are chosen based on land use or soil management. The values of P factor based on land use in Malaysia have been determined by Troeh et al (1999) as shown in Table 14. The values of P factor based on soil management have been determined by Department of Agriculture (DOA) as shown in Table 15.

Table 14: P factor for different land use in Malaysia (Troeh, Hobbs, & Donahue, 1999)

Land Use	P factor
Agricultural Stations	0.40
Coconut	0.50
Diversified Crops	0.45
Estate Buildings and Associated Areas	0.40
Fish and Hyacinth Ponds	0.50
Forest	0.10
Lalang	0.60
Mixed Horticulture	0.40
Newly Cleared Land	0.70
Orchards	0.40
Other Mining Areas	1.00
Paddy	0.50
Reclaimed Area	0.70
Recreational Area	0.60
Rubber	0.40
Scrub	0.20
Swamps	0.50
Unused Land	0.45
Urban Associated Areas	1.00
Water	0.50
Dipterocarp Forest	0.10
Lowland Forest	0.10

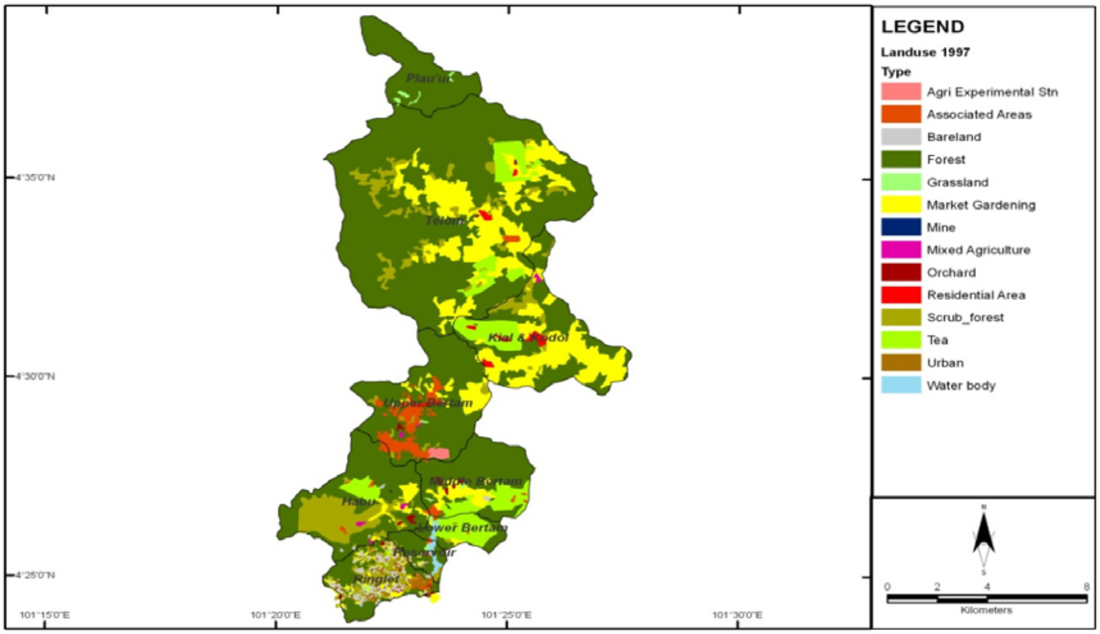
Bareland	0.70

Table 15: P factor based on soil management (Department of Agriculture, 2010)

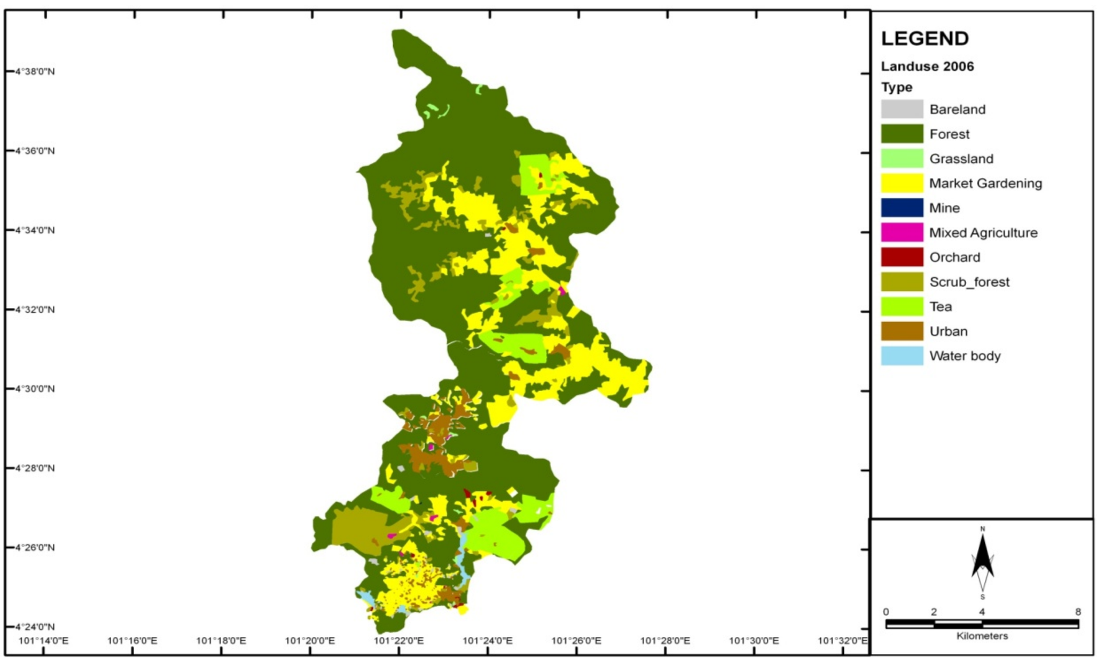
Structure/ Practices	P factor
Planting Beds against/ perpendicular to contour	0.85
Planting Beds along Contour	0.30
Grass Strip	0.50
Contour Ditches	0.50
Hillside Trench (Silt Trap)	0.60
Rain Shelter	0.10
Contour Planning	0.80
Mulching	0.20
Terraces (Continuous)	0.20
Terraces (Discontinuous)	0.40
Individual Basin	0.50
Traditional Terraces	0.60
Vertiver-Contour Hedgerow	0.60

6.2 Data

The Malaysian land use map was available for Peninsular Malaysia from the Department of Agriculture (DOA). The Cameron Highlands land use shape file for ArcGIS input was requested and obtained from the Department of Agriculture for 1997 and 2006 as shown in Map 17 and Map 18. The maps below do not include the area of Batang Padang, also known as the lower catchment of Cameron Highlands.



Map 17: 1997 Landuse Shape File of Cameron Highlands from Department of Agriculture



Map 18: 2006 Landuse Shape File of Cameron Highlands from Department of Agriculture

6.3 Method

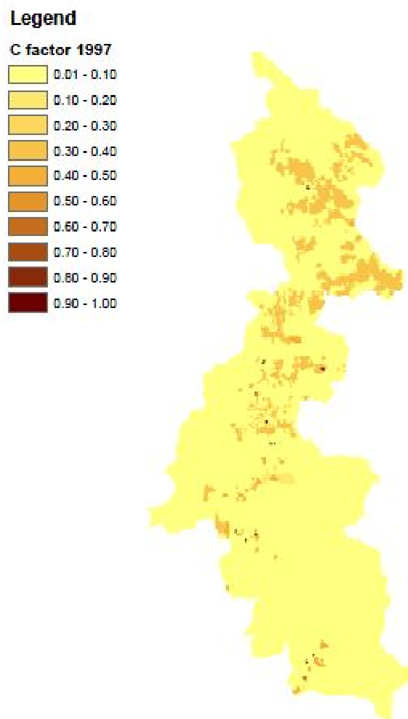
To produce C and P factor maps, the land use shape file was added to ArcGIS. C and P factors were generated the same way as K factor by auditing the attribute table. The land use attribute table was edited with adding a new field of C and P values under the Edit menu at attribute view before the C and P factor was produced (Table 16). The values of C were adopted from the Department of Agriculture shown in Table 11, Table 12 and Table 13**Error! Reference source not found.**. For this study, P values were chosen based on the land use instead of soil management shown in **Error! Reference source not found.**. The theme was converted from vector form to grid form with the cell size of 20m.

Table 16: C and P factors for Cameron Highlands

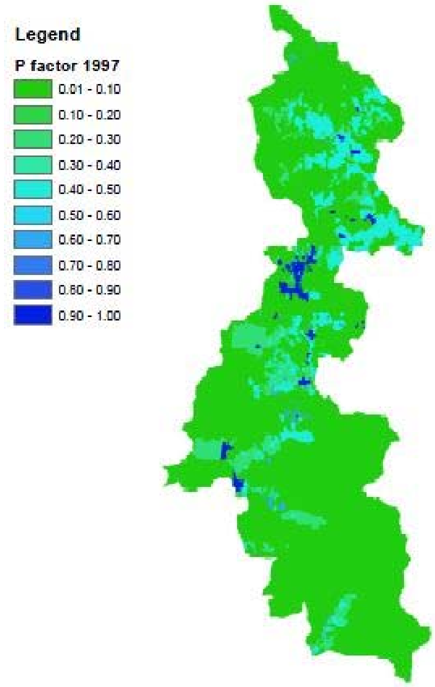
Land Use	**C Factor**	**P Factor**	**CP Factor**
Bareland	1.00	0.70	0.70
Urban	0.25	1.00	0.25
Grassland	0.03	0.60	0.02
Forest	0.03	0.10	0.003
Market gardening	0.38	0.40	0.15
Scrub forest	0.03	0.20	0.01
Orchard	0.35	0.40	0.14
Mixed agriculture	0.45	0.45	0.20
Tea	0.10	0.10	0.01
Water body	0.01	0.50	0.01
Agriculture experimental station	0.50	0.40	0.20

6.4 Results

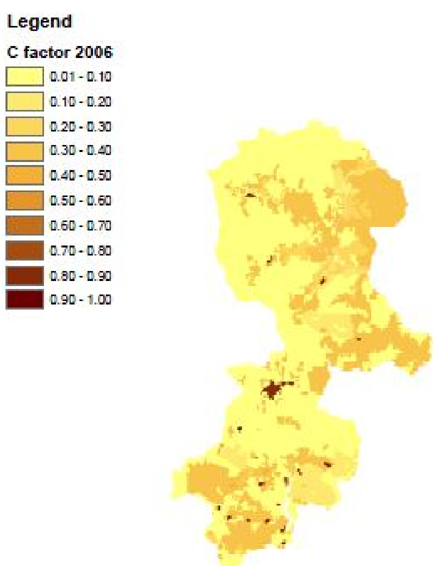
Cover Management factor (C) and Support Practice factor (P) were developed using the method described above for 1997 and 2006. The theme produced for 1997 is shown in Map 19 and Map 20. The theme produced for 2006 is shown in Map 21 and Map 22. The maps produced for 2006 excludes the area of Plau'ur sub-catchment and Cameron Highlands Lower Catchment.



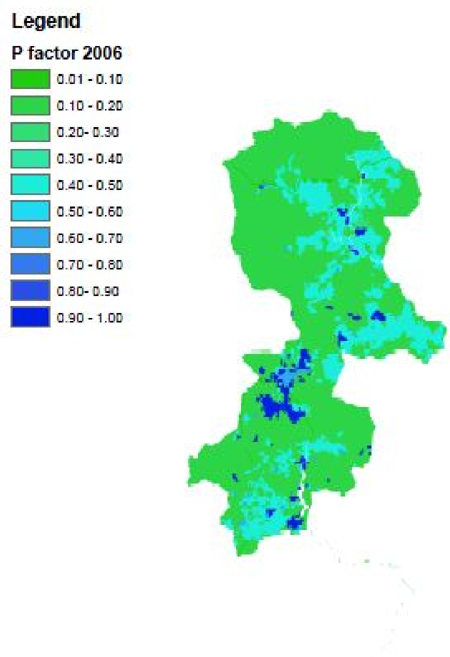
Map 19: C factor 1997



Map 20: P factor 1997



Map 21: C factor 2006



Map 22: P factor 2006

7 RESULTS

The RUSLE equation (equation 2) was used to calculate the annual average soil loss rate (A) in ton/ha/year. In order to predict the annual average soil loss rate in the upper catchment of Cameron Highlands, the R, K, LS, C and P factors from the earlier chapters were multiplied using the raster calculator function tool of ArcGIS as shown in Figure 14. The annual soil loss maps for the upper catchment of Cameron Highlands were produced for the year 1997 (Map 23) and year 2006 (Map 24). For ease of interpretation, the values of erosion potential were divided into 7 classes as shown in Table 1. The Cameron Highlands Upper Catchment in 2006 (Map 24) showed an increase in yellow, orange and red, which means there was an increase in severe, extreme to exceptional erosion compared to year 1997 (Map 23). The Plau'ur sub-catchment was excluded from the computation because of insufficient data and the area is still relatively undeveloped, so it is not a big contributor to soil erosion.Map 24: RUSLE Cameron Highlands Upper Catchment (2006

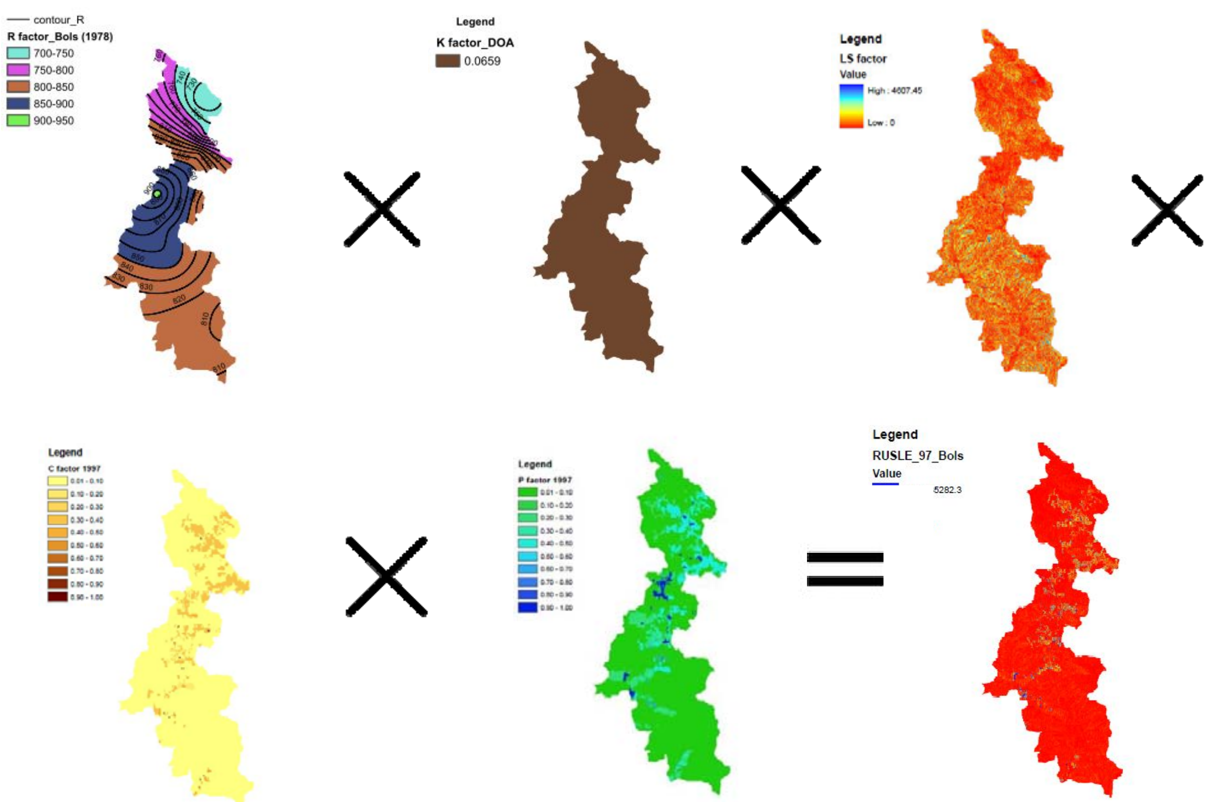
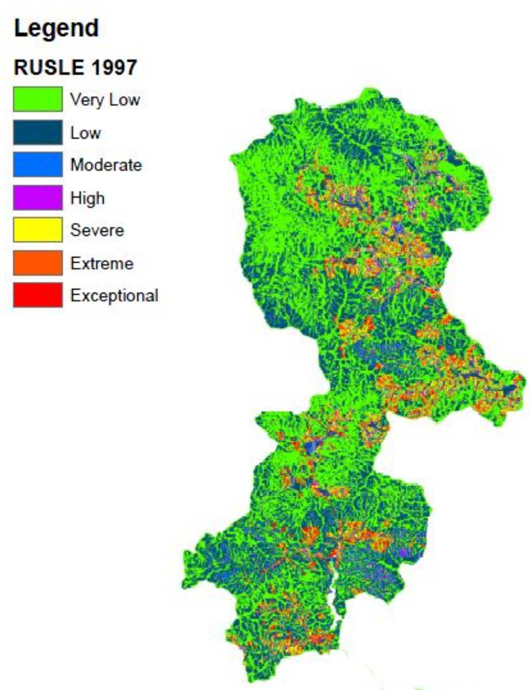


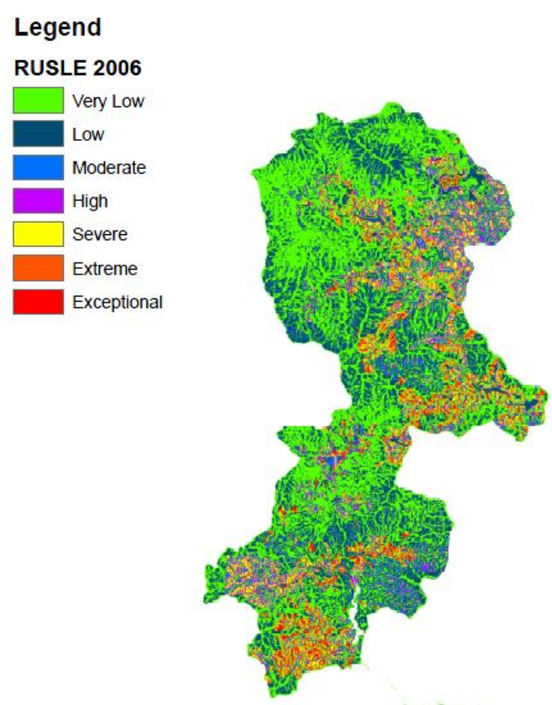
Figure 14: RUSLE Equation to produce the Average Annual Soil Loss Map

Table 17: Derivation of the ordinal categories of soil erosion potential

Erosion Class	Numeric Range (ton/ha/year)	Erosion Potential
1	0-1	Very Low
2	1-5	Low
3	5-10	Moderate
4	10-20	High
5	20-50	Severe
6	50-100	Extreme
7	>100	Exceptional



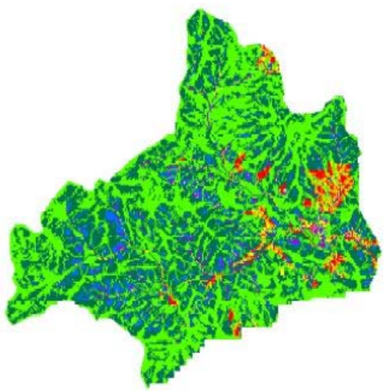
Map 23: RUSLE Cameron Highlands Upper Catchment (1997)



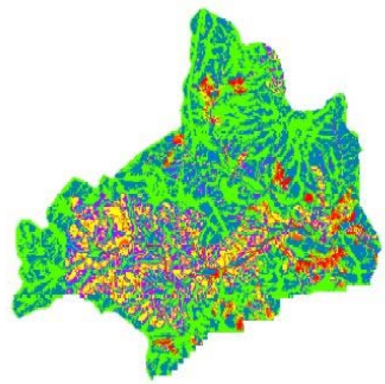
Map 24: RUSLE Cameron Highlands Upper Catchment (2006)

Then the annual soil loss map for each sub-catchment in Cameron Highlands were produced by clipping each R, K, LS, C and P values of the selected catchment area from the original factor which includes the whole area of Cameron Highlands. The raster calculator was used again to overlay the clipped factors to produce the annual soil loss map each sub-catchment of the Cameron Highlands Upper Catchment for the years 1997 and 2006. The annual soil loss maps were produced for the sub-catchments of Telom, Kial & Kodol, Upper Bertam, Middle Bertam, Lower Bertam, Habu, Ringlet and Reservoir.

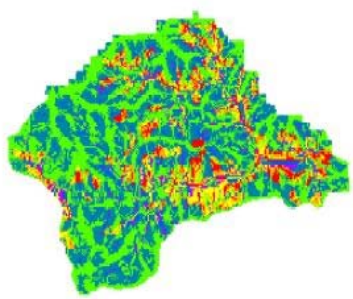
Examples of the annual soil loss map of Habu and Ringlet sub-catchments located in the Bertam catchment (Refer to Map 1) for 1997 and 2006 are shown in Map 25, Map 26, Map 27 and Map 28. The two main rivers flowing into the Ringlet Reservoir are Habu River and Ringlet River. Hence, Habu and Ringlet sub-catchments are important areas of study for soil erosion. The Habu sub-catchment in 2006 (Map 26) shows more areas of high to exceptional erosion compared to 1997 (Map 25). The Ringlet sub-catchment in 2006 (Map 28) is almost covered in severe to exceptional erosion compared to 1997 (Map 27). It is clear that the land use of both Habu and Ringlet sub-catchment has changed substantially over this time frame leading to major soil erosion problems.



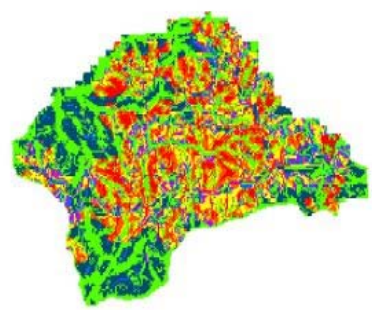
Map 25: RUSLE Habu (1997)



Map 26: RUSLE Habu (2006)



Map 27: RUSLE Ringlet (1997)



Map 28: RUSLE Ringlet (2006)

The annual average soil loss rate of the sub-catchments of the Cameron Highlands Upper Catchment using the RUSLE method was summarized in **Error! Reference source not found.** and **Error! Reference source not found.**. **Error! Reference source not found.** presents the results for 1997 and Table 19 presents the results for 2006. The upper catchment consists of the Telom and Bertam catchments, of which the sediments from the upper catchment will be transported and deposited in the Ringlet Reservoir. First the mean value of annual average soil loss rate for each catchment was determined in ton/ha/year, and then the values were converted to m^3/km^2/year. Finally, the sediment yield is determined by multiplying the annual average soil loss rate and the area of the sub-catchment. The total sediment yield was calculated by summing the sediment yield of all the sub-catchments of the Cameron Highlands Upper Catchment.

The rate of sediment filling increased from 30,000 m^3/ year in the 1960's to 50,000 m^3/ year in early 1980's (Tenaga National Berhad Research, 2009). The Ringlet Reservoir deposition rate in 1990 is estimated to be 200,000 m^3/ year (Tenaga National Berhad Research, 2009). From this study using the RUSLE model, the annual average soil loss rate of the upper catchment of Cameron Highlands was predicted to be 110 ton/ ha/ year for 1997 and 137 ton/ ha/ year for 2006. The average annual soil loss rate for each sub-catchment in the Cameron Highlands Upper Catchment for 1997 and 2006 is shown in Figure 15. Most of the sub-catchments have an increasing trend in soil loss rate from 1997 to 2006 except Upper Bertam, Lower Bertam and Middle Bertam. The sediment yield for the Ringlet Reservoir was predicted to be 282,465 m^3/ year for 1997 and 334,853 m^3/ year for 2006 shown in Figure 16. The calculation of the annual rate of sediment yield in the Ringlet Reservoir suggests that the reservoir would have lost all the storage capacity by now but it is not the case because dredging activity takes place in the reservoir frequently. TNB tries to remove a minimum rate of 100,000 m^3 of sediment annually from the Ringlet Reservoir although the actual amount of sediment removal varies annually.

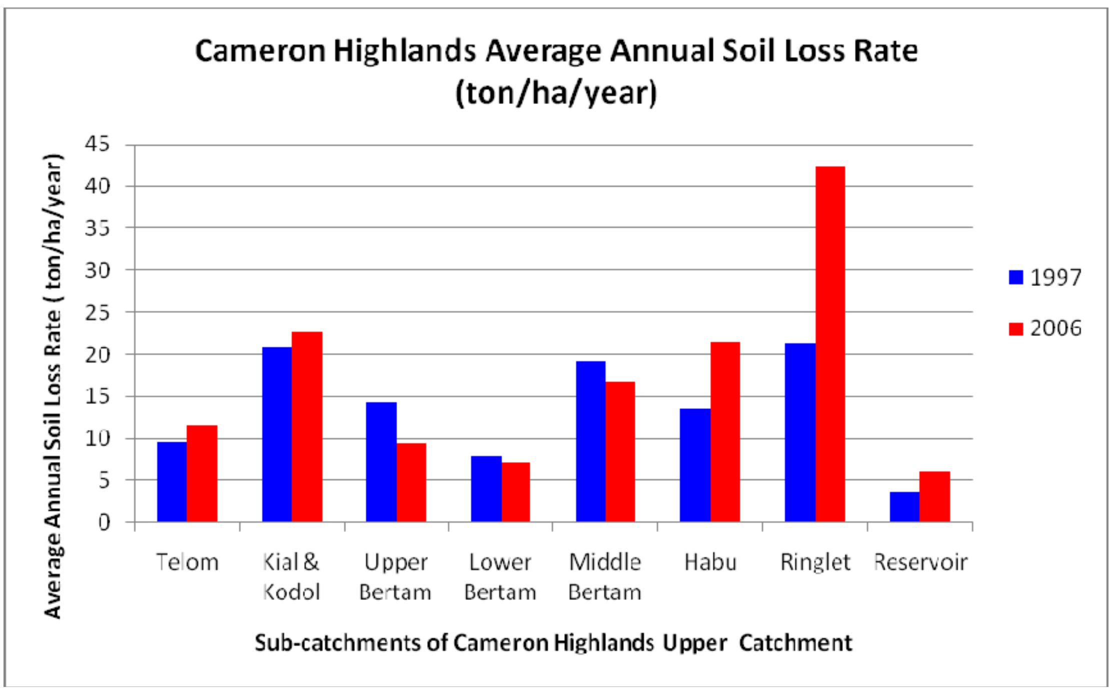


Figure 15: Annual Average Soil Loss Rate for the sub-catchments of Cameron Highlands Upper Catchment

When the Sultan Abu Bakar Dam was constructed in 1963, the designed gross storage of the Ringlet Reservoir was about 6.7 million m^3, of which 4.7 million m^3 was live storage, leaving the estimated dead storage of 2.0 million m^3 that would give a useful life of approximately 80 years since 1963 with no special provisions to cope with sedimentation (Choy & Darul, 2004). The life expectancy of a reservoir is the anticipated time at which the reservoir will be occupied with sediments (Julien, 2002). The life expectancy of a reservoir is computed by dividing the storage capacity of the reservoir by the mean annual sediment yield in a reservoir (Julien & Frenette, 1996). Hence, the life expectancy for the dead storage was decreased tremendously because of the higher sediment yield with time compared to the design life expectancy of the dead storage. As of 1999, Ringlet Reservoir has lost all its dead storage and nearly 70% of its live storage to sedimentation (Tenaga National Berhad Research, 2009). Figure 17 from the Tenaga National Berhad provides a very good description and idea of the drastic sedimentation problem in the Ringlet Reservoir. From Figure 17, it is shown that all the dead storage has been occupied by sediments and the live storage is almost completely filled with sediments. The minimum operation level of the reservoir has been increased from 1059m to 1067m due to the sedimentation problem (Figure 17). The drastic situation in Ringlet Reservoir suggests that if nothing is done, the reservoir will lose its entire storage in the next three to five years.

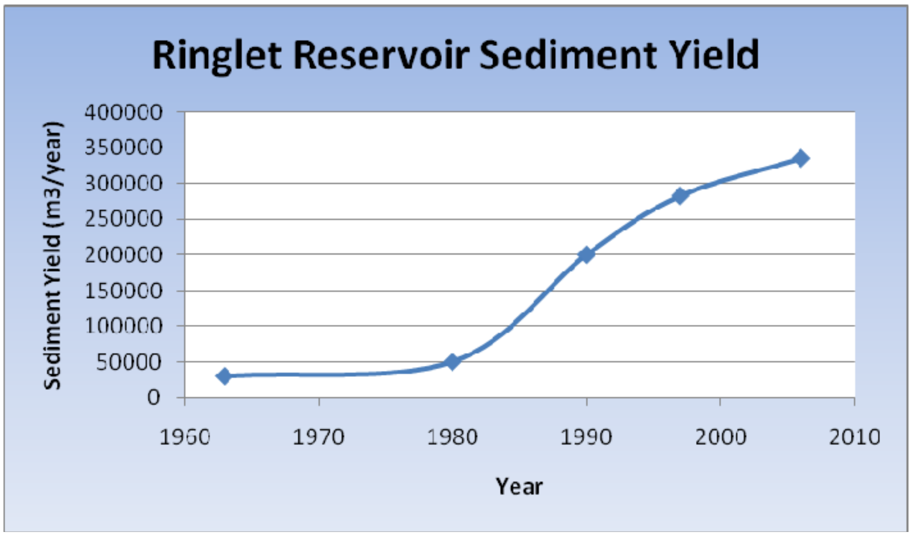


Figure 16: Ringlet Reservoir Sediment Yield

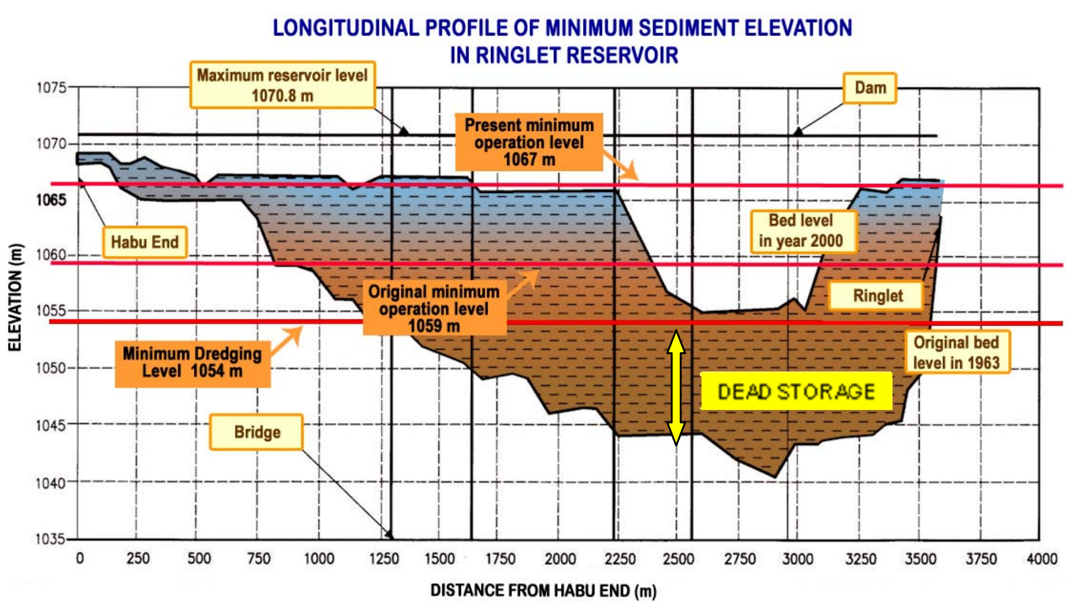


Figure 17: Profile of Sediment Elevation in Ringlet Reservoir (Tenaga National Berhad, 2010)

The development of soil erosion is very closely related to the change in land use, the agricultural management situation along with the terrain features such as slope length and slope steepness (Toriman, Karim, Mokhtar, Gazim, & Abdullah, 2010). The percentage of each land use type in the Upper Catchment of Cameron Highlands for 1997 and 2006 is shown in **Error! Reference source not found.** and **Error! Reference source not found.** obtained from Department of Agriculture. From the results, the sediment yield from Telom, Kial and Kodol, Habu, Ringlet and Reservoir sub-catchments has increased since 1997 whereas the sediment yield from Upper Bertam, Middle Bertam and Lower Bertam sub-catchments has decreased since 1997 shown in Figure 18.

The Bertam catchment consists of Upper Bertam, Lower Bertam, Middle Bertam, Ringlet, Habu and Reservoir sub-catchments. For Habu sub-catchment, the forested area reduced from 57% in 1997 to 51% in 2006 (Figure 19) and activities such as market gardening and tea plantation increased since 1997. Therefore, Map 26Map 26 (2006) for Habu sub-catchment showed more areas of high to exceptional erosion compared to Map 25 (1997). For Ringlet sub-catchment, forested area reduced from 37% in 1997 to 34% in 2006 (Figure 19) and activities such as market gardening increased tremendously from 8% to 42% since 1997 (Figure 20). Hence, Map 28 (2006) showed the area almost covered with extreme to exceptional erosion compared to Map 27 (1997). For Reservoir sub-catchment, urban areas increased from 1% to 4% (Figure 21) and agricultural activities increased from 2% to 5% (Figure 20), giving a higher sediment yield in 2006. This is important because the main rivers feeding Ringlet Reservoir are Bertam River, Habu River and Ringlet River. Sediment coming from the Habu End comprises majority of the total sediment loading to the Ringlet Reservoir. Sediment from Habu End is known to consist of fine material to a degree that makes trapping efficiency difficult (Tenaga National Berhad , 2000). Sediment loading to Ringlet Reservoir from the Ringlet End seems to be based on relative coarse material, indicating a potential for high trapping efficiency (Tenaga National Berhad , 2000).

However, the results of the sediment yield for the sub-catchments of Telom, Kial and Kodol, Upper Bertam, Middle Bertam and Lower Bertam were inconsistent. The sediment yield for Upper, Middle and Lower Bertam decreased although urban area in the region increased greatly. The sediment yield for Telom and Kial and Kodol increased eventhough there were not much land use change between 1997 and 2006. The possible explanation for this is the large selection of C and P factors available that yields different results according to different methods. The C and P factors used in this study were according to Department of Agriculture (DOA) and Troeh (1999). Better average annual soil loss and sediment yield results can be obtained with more detailed soil series map of Cameron Highlands which is not developed yet for the K factor and data of 10-minute interval rainfall series data by installing more automatic rainfall gauge stations in Cameron Highlands for the R factor.

Cameron Highlands has been rapidly deforested (legally and illegally) and substituted with agriculture, urbanization and infrastructure development, all of which has contributed to severe soil erosion (Toriman, Karim, Mokhtar, Gazim, & Abdullah, 2010). In the last 40 years, the forest reserve of Cameron Highlands Upper Catchment has decreased rapidly as shown in Figure 19. Forest, scrub forest and grassland have a low CP value (Table 16). When the area is deforested, leaving the land exposed and bare, the CP value becomes high posing huge erosion risk (Table 16). The first largest contributor of soil erosion in Cameron Highlands is agricultural activities such as market gardening, mixed agriculture, tea plantation, floriculture and orchard which covers a total land area of 110 km^2 (out of 712 km^2) (Toriman, Karim, Mokhtar, Gazim, & Abdullah, 2010). Different agricultural activities pose different erosion risks; the most damaging practice appeared to be agricultural experimental stations and mixed agriculture, followed by market gardening and orchard according to the CP values in Table 16. However, tea plantation yield a very low CP value indicating it is a low erosion risk agricultural activity according to Table 16. The second biggest contributor of soil erosion is urbanization which includes construction activities to develop houses, shops and hotels shown in Figure 21 (Troeh, Hobbs, & Donahue, 1999). The last contributor of soil erosion is infrastructure which includes roadwork, building highways and water supply pipelines (Toriman, Karim, Mokhtar, Gazim, & Abdullah, 2010). My analysis agrees with Toriman et. al , 2010 suggesting that agricultural activity is the main contributor of soil erosion followed by urbanization according to Table 20 and Table 21. This was determined by multiplying the CP value and the percentage of area. For 1997, the soil erosion potential for agriculture was 16% and urbanization 4%. For 2006, the soil erosion potential for agriculture was 22% and urbanization 10%. However, my data did not include statistics for infrastructure.

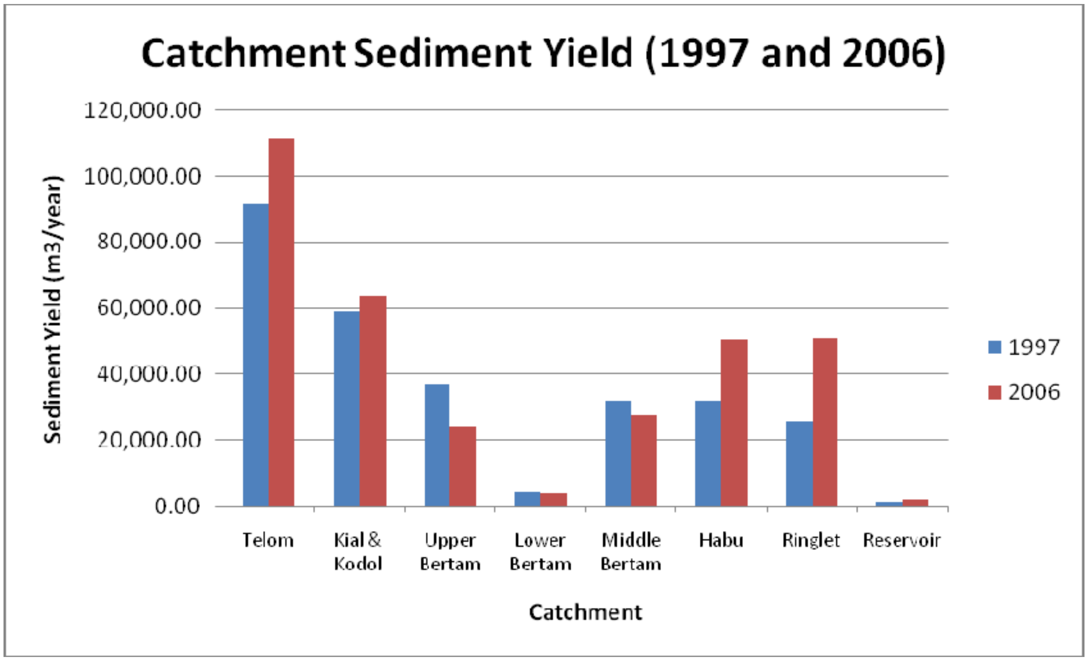


Figure 18: Sediment Yield of Cameron Highlands Upper Catchments for 1997 and 2006 from ***Error! Reference source not found.*** *and* ***Error! Reference source not found.***

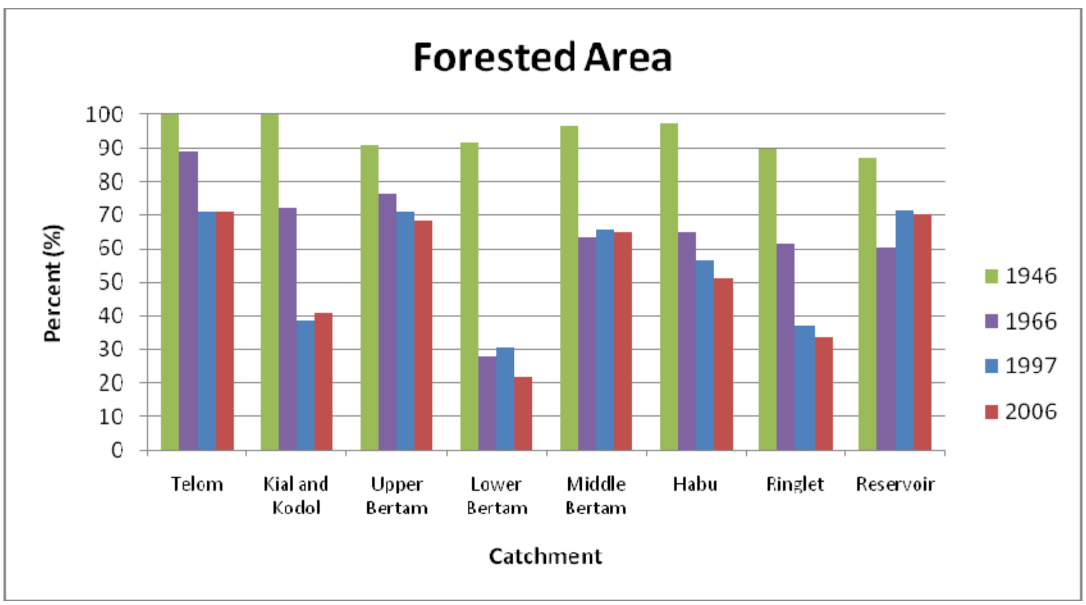


Figure 19: Percentage of Forested Area of Cameron Highlands Upper Catchments for 1946, 1966, 1997 and 2006 from ***Error! Reference source not found.*** *and* ***Error! Reference source not found.*** *(Department of Agriculture)*

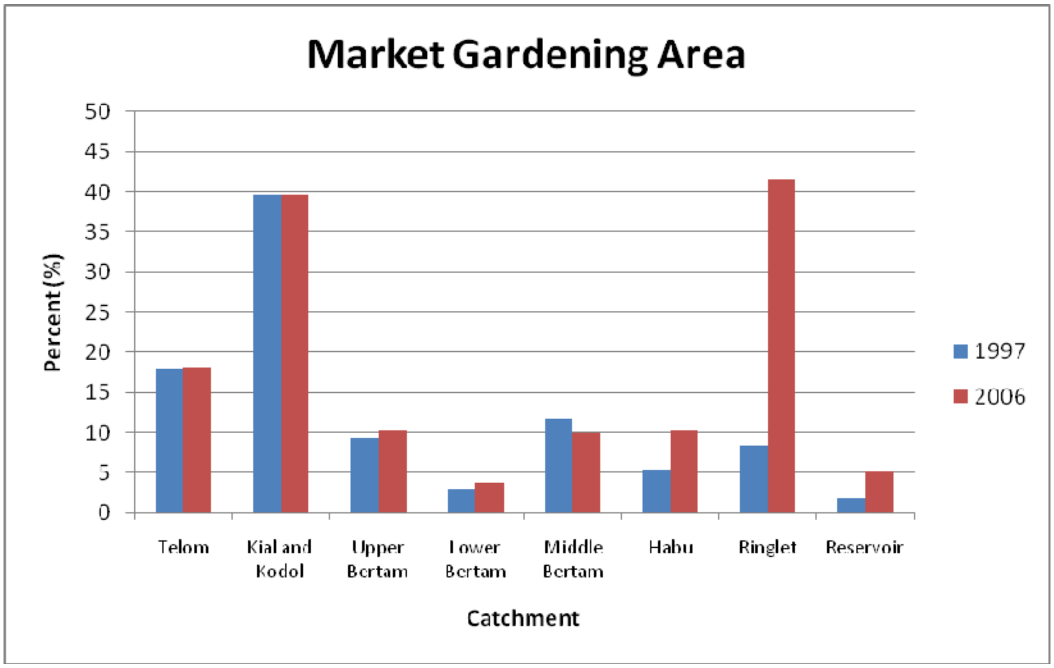


Figure 20: Percentage of Market Gardening Area of Cameron Highlands Upper Catchment for 1997 and 2006 from ***Error! Reference source not found.*** *and* ***Error! Reference source not found.*** *(Department of Agriculture)*

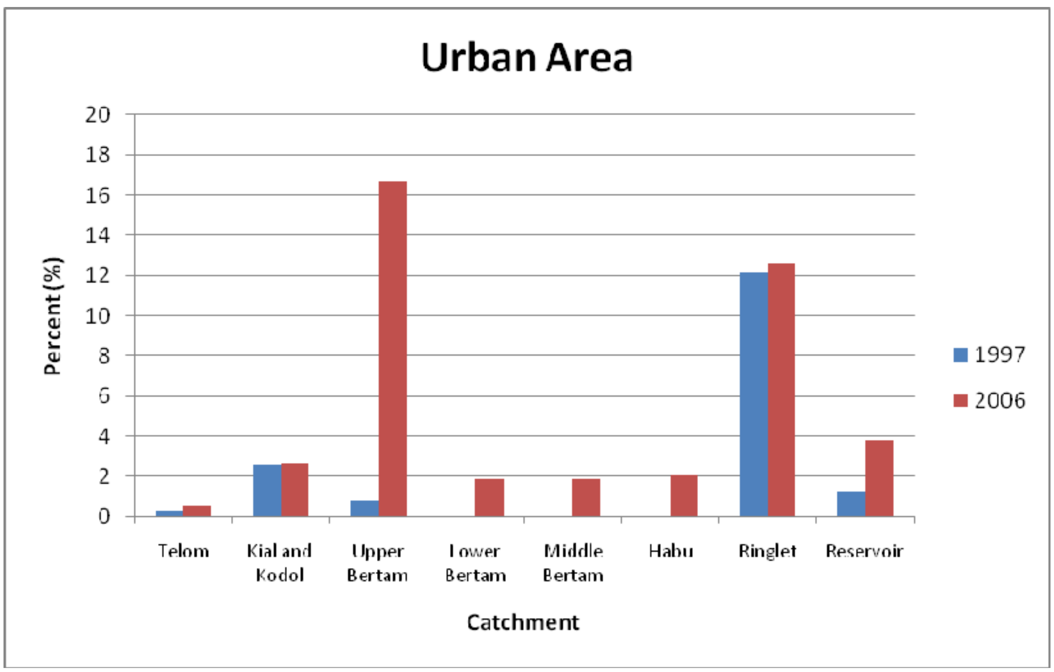


Figure 21: Percentage of Urban Area of Cameron Highlands Upper Catchment for 1997 and 2006 from ***Error! Reference source not found.*** *and* ***Error! Reference source not found.*** *(Department of Agriculture)*

Table 18: Average Annual Soil Loss and Sediment Yield of Cameron Highlands Upper Catchment for 1997

1997	**Area (km^2)**	**Annual Soil Loss (ton/ha/year)**			**Average Annual Soil Loss (m^3/km^2/year)**	**Sediment Yield (m^3/yr)**
		min	**max**	**weighted mean**	**mean**	
Telom	77.81	0	11849.48	9.52	1,175.72	91,482.77
Kial & Kodol	22.84	0	10270.93	20.88	2,578.68	58,897.05
Upper Bertam	20.98	0	5015.57	14.33	1,769.76	37,129.46
Lower Bertam	4.34	0	2847.77	7.88	973.18	4,223.60
Middle Bertam	13.44	0	16000.68	19.2	2,371.20	31,868.93
Habu	19.12	0	35282.31	13.56	1,674.66	32,019.50
Ringlet	9.72	0	4241.15	21.32	2,633.02	25,592.95
Reservoir	2.83	0	182.22	3.58	442.13	1,251.23
Total	**171.08**			**110.27**	**13,618.35**	**282,465.50**

Table 19: Average Annual Soil Loss and Sediment Yield of Cameron Highlands Upper Catchment for 2006

2006	**Area (km^2)**	**Annual Soil Loss (ton/ha/year)**			**Average Annual Soil Loss (m^3/km^2/year)**	**Sediment Yield (m^3/yr)**
		min	**max**	**weighted mean**	**mean**	
Telom	77.81	0	11849.18	11.62	1,435.07	111,662.80
Kial & Kodol	22.84	0	11412.15	22.59	2,789.87	63,720.52
Upper Bertam	20.98	0	2276.9	9.39	1,159.67	24,329.77
Lower Bertam	4.34	0	1569.88	7.13	880.56	3,821.61
Middle Bertam	13.44	0	7423.03	16.69	2,061.22	27,702.73
Habu	19.12	0	58366.96	21.44	2,647.84	50,626.70
Ringlet	9.72	0	11176.33	42.41	5,237.64	50,909.81
Reservoir	2.83	0	122.2	5.95	734.83	2,079.55
Total	**171.08**			**137.22**	**16,946.67**	**334,853.49**

Table 20: Percentage of each land use type in Cameron Highlands Upper Catchment for 1997 (Department of Agriculture, 2010)

Catchment	Area (km^2)	Bareland	Urban	Grassland	Forest	Market Gardening	Scrub forest	Orchard	Mixed Agriculture	Tea	Water Body	Associated Areas / Agri. Exp. Stn.	Total (%)
Habu	19.12	0.50	0.00	0.00	56.60	5.50	28.80	0.60	0.70	5.70		1.40	100
Kial Dodol	22.84		2.60		40.60	39.60	5.50		0.30	11.40			100
Lower Bertam	4.34			1.10	30.70	3.10	1.80			57.50	4.50	1.30	100
Middle Bertam	13.44	0.40		0.60	65.90	11.80		1.30		18.00		2.00	100
Plaur	9.72			2.60	97.40								100
Reservoir	2.83	3.10	1.30	1.50	71.50	1.80	6.40				11.80	2.50	100
Ringlet	9.72	18.60	12.20	0.80	37.30	8.40	19.50	0.80		0.40	0.10	1.70	100
Telom	77.81	0.00	0.30	0.00	70.80	18.00	5.80	0.10		4.70		0.30	100
Upper Bertam	20.98		0.80	0.30	71.80	9.30	2.30	0.30				15.30	100

Table 21: Percentage of each land use type in Cameron Highlands Upper Catchment for 2006 (Department of Agriculture, 2010)

Catchment	Area (km^2)	Bareland	Urban	Grassland	Forest	Market Gardening	Scrub forest	Orchard	Mixed Agriculture	Tea	Water Body	Total (%)
Habu	19.12	1.23	2.04		51.31	10.31	27.39		0.75	6.92		100
Kial Dodol	22.84		2.63		40.59	39.59	5.48		0.33	11.38		100
Lower_Bertam	4.34	1.11	1.87		21.76	3.82	1.76			65.2	4.49	100
Middle_Bertam	13.44	0.68	1.9	0.26	64.85	9.88	0.94	1.26		19.74		100
Plaur	9.72			2.64	97.36							100
Reservoir	2.83	2.46	3.79	1.53	70.22	5.11	5.16				11.78	100
Ringlet	9.72	3.05	12.57	0.4	33.62	41.57	3.53	0.78	0.07	0.37	4.03	100
Telom	77.81	0.05	0.53	0.01	70.68	18.17	5.79	0.05		4.71		100
Upper Bertam	20.98		16.66	0.35	68.34	10.39	3.39		0.37			100

8 CONCLUSION

Vast deforestation and indiscriminate land clearing in the Cameron Highlands for agricultural, urbanization and infrastructure development has resulted in widespread soil erosion over the land surface. The extent of soil erosion occurring in the area is still increasing and is now a major cause for concern. Excessive sediment deposited in the Ringlet Reservoir affects the storage and the useful life of the reservoir.

The rate of sediment filling increased from 30,000 m^3/ year in the 1960's to 50,000 m^3/ year in early 1980's (Tenaga National Berhad Research, 2009). The Ringlet Reservoir deposition rate in 1990 is estimated to be 200,000 m^3/ year (Tenaga National Berhad Research, 2009). Using the RUSLE method, this study predicted the sediment yield for the Ringlet Reservoir for 1997 to be 282,465.5 m^3/ year and 2006 to be 334,853.5 m^3/ year. This number is expected to increase with time as agriculture activities and deforestation continues to take place.

When the Sultan Abu Bakar Dam was constructed, the designed gross storage of the Ringlet Reservoir was about 6.7 million cubic meters, of which 4.7 million cubic meters was live storage, leaving the estimated dead storage of 2.0 million cubic meters (Choy & Darul, 2004). This would give a useful life of approximately 80 years since 1963 with no special provisions to cope with sedimentation (Choy & Darul, 2004). Hence, the life expectancy for the dead storage was decreased tremendously because of the increasing sediment yield with time compared to the design life expectancy of the dead storage. The drastic situation in Ringlet Reservoir suggests that if nothing is done, the reservoir will lose its entire storage in the next three to five years.

This means that sooner or later, the Jor power station would be forced to operate as a run-of-river plant with little peaking ability. If the Ringlet Reservoir is completely silted up, coarse sediment will deposit near the Bertam intake and sand will start to be conveyed into the Jor headrace tunnel. The mechanical parts of the Jor Power Station Pelton units such as the buckets and the needle valves will suffer from the accelerated wear and will need to be replaced at short intervals. The sediment transported through the Jor power station will eventually be carried to the Jor Reservoir which will also silt up at an accelerated pace. This will have repercussions on the operation of Woh Power Station which will also lose most of its peaking capacity. If the peaking capacity of Jor and Woh Power Station is lost, replacement such as thermal units (coal, diesel or gas turbine) has to be considered at a significantly higher estimated cost.

The silting of Ringlet Reservoir and later of Jor Reservoir suggests that these two reservoirs will always operate at full supply level with no storage capacity in the future. The absence of storage for flood control may oblige the authorities to keep the Sultan Abu Bakar dam spillway gates open. It is known that the flooding is likely to increase due to intense deforestation in the watershed. There was known to be some spilling in the late 1980's downstream of the Sultan Abu Bakar dam and the residents such as the farmers claimed to have suffered financial losses due to the damage to the crops and to the infrastructures (Tenaga National Berhad , 2000). The high level of sediment deposit reached in the dam will also raise concern for the stability of the dam. It is uncertain that the dam could resist the forces exerted by a combination of high sediment load and of a high flood level.

In order to increase the life expectancy of the Ringlet Reservoir, appropriate measures should be performed as soon as possible. In order to maintain the Ringlet Reservoir operation at a satisfactory level, a minimum rate of 100,000 m^3 of sediment must be dredged or removed annually from the Ringlet Reservoir and the settling ponds above the check dams (Tenaga National Berhad Research, 2009). To minimize the rate of sedimentation deposition in the Ringlet Reservoir, the options that can be considered includes (Tenaga National Berhad Research, 2009):

a) Reduction of the source of sediment production from catchments, including erosion from the overland areas and the stream banks, through soil conservation practices and stream bank protections.
b) Diversion of the sediment laden flood discharges into wetlands or lowlands in the flood plains upstream of the reservoir, or bypassing the sediment loads to the stream channel downstream of the dam through an open channel, pipeline or tunnel conveyance.
c) Creation of forebays or settling basins in suitable upstream reaches of the reservoir. This method has the advantage of intercepting the coarser sediments in the shallower pond area, and thus facilitating a more cost effective means of maintenance removal of sediment in comparison with dredging from the deeper reservoir pool.
d) Inducing deposition of finer sediments in the settling basin areas through proper mixing of chemical flocculants into the upstream channel flow during the storm or high flow events.
e) Dredging of deposited sediments from the reservoir
f) Removing sediment deposits by flushing or sluicing through the outlet works such as conduits for flood control, power generation, and water supply functions, and spillways.

So far, extensive dredging activities have been carried out at the Habu end of Ringlet Reservoir. All dredging is made mechanically, using excavators and draglines allowing only the coarsest particles to be dredged with this method. The excavated sediment is deposited on the river banks. The rate of dredging in the mid 1980’s at the Habu End of Ringlet Reservoir was about 6,000 m^3/ year (Tenaga National Berhad Research, 2009). Continuous and extensive dredging is carried out at the Ringlet end of Ringlet Reservoir as well but there are few disposal areas. Up to 57,000 m^3/ year was excavated at the Ringlet End of Ringlet Reservoir in the mid 1980’s when a settling basin was constructed to trap the sediment (Tenaga National Berhad Research, 2009). Regular flushing is also carried out at the low level outlet located at the bottom of the Sultan Abu Bakar dam. The discharge capacity of the 1.8m diameter concrete lined outlet is 36.5 m^3/ s (Tenaga National Berhad Research, 2009).

To conclude the sediment mitigation plans mentioned above, there are two measures that can be considered, the ‘concentrate and remove’ approach and the ‘control at source’ approach. In the immediate and medium term, it is expected that any effective strategy for management of the sediments would have to be based on a ‘concentrate and remove’ approach (Tenaga National Berhad Research, 2009). For this approach, the most practical and effective sedimentation concentration and removal points along the streams are identified in the Ringlet End and Habu End of the Ringlet Reservoir, where more quiescent flow conditions encourage sediments to settle naturally. The natural sedimentation will be enhanced by check dams or other devices to concentrate the sediments and increase the natural trap efficiency. The concentrated sediments would have to be dredged and removed periodically. This would help reduce the sediment loads into the Ringlet Reservoir. In the longer term, a ‘control at source’ strategy should be implemented, based on modifications to the current land use practices especially illegal deforestation, to encourage soil conservation and minimize soil loss from the contributing catchments, reducing sediment loads into the streams and reservoir (Tenaga National Berhad Research, 2009).

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