Use of InfoWork RS in modeling the impact of urbanisation on sediment yield in Cameron Highlands, Malaysia

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Abstract: Hydrodynamic model and sediment transport model were investigated in the Sg Telom and Sg Bertam, Cameron Highlands as a result of rapid urbanization and agriculture activities over the past 30 years. This article, from the point of view of the river catchment as a whole system, presents an integrated approach by combining the hydraulic and hydrology simulations with numerical model of sediment transport and change in river bed level before and after the Ringlet reservoir. To accomplish this purpose, InfoWork RS, a well developed numerical model for sediment transport and river bed variations were used. The application shows that it can properly simulate change of river bed variation over 10 months simulation period.
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Key words: dynamic simulation; model; composting; urbanization; sediment

1. Introduction

Flow and sediment transport are important in relation to several hydrology-hydraulic and engineering topics, e.g. erosion around structures, backfilling of dredging channels and river morphological change (Wilson, 1981; Cooper, et al. 1987; Woolhiser, 1990). It closely related to soil erosion or soil loss although the process mechanism is not the same as sediment yield- A unit which is defined as the total sediment outflow from a catchment, and normally expressed in absolute terms t ha^{-1} $year^{-1}$. Eroded soil may be redeposited a few meters from where it was dislodged, whereas sediment yield from a basin is that portion of the eroded soil which leaves the basin. In the context of river basin sediment models, the principal objective is to link the on-site rates of erosion and soil loss within the basin to the outlet sediment yield. In is clear from field studies that the dominant response mechanisms behind the link, along with the sediment yield itself, was the process of sediment being transported from the source to the outlet. This includes the sediment transport modes (wash load, bed load or suspended load), sediment properties (size and shape of grain), bedforms (ripple, dunes and antidunes), bed roughness, ks and effective shear stress, τb. Combination of these factors with other physical aspects such as basin area scale and hydro-meteorological conditions have been shown to influence the sediment transport of many catchment areas as studied by Bruijnzeel, 1990, Wan Ruslan, 1996, Mohd Ekhwan, 1997; 2002; Mohd Ekhwan & Noorazuan, 2003. Reports of the impact of urbanization on sediment yield have been reported by many researchers in Malaysia and elsewhere (Wan Ruslan 1997; Douglas, 1967; Mohd Ekhwan, 2005). The reports are particularly important not only for project formulation but also in land use planning. Most of the previous studies agreed that rapid urbanization such as land clearance for agriculture activities and industralisation have accelerated it impact on sediment yield as studied by Wan Ruslan (1997) in Sg Relau, Penang (30 times greater of sediment output), Krishnaswamy, et al (2001) in Costa Rica (15 times), Mozzherin (1994) in Russia (21 times) and Walling & Gregory (1970) in Devon, England (10 times). In this respects, knowledge of sediment behaviors including its yield potential can allow more accurate land use decisions to be made.

Over the last 30 years, an advance in computer modeling provides large opportunity to study the sediment behavior particularly in relation to hydrologic (i.e SHETRAN, HEC-6, MIKE SHE) or by combination of hydrology and hydraulic models (i.e. InfoWork RS, SWMM, SED2D, XP-STORM, BASINS). The use of such computer modeling can simulate event-based or continuous periods, much larger river or basins and more importantly was its capability to integrate with other spatial modeling such as Geographical Information System (GIS) data interface. The proposed of the article is to discuss both hydrodynamics and sediment transport mechanism which later will be transformed into the sediment yield in Cameron Highland Pahang, specifically the process of bed level changed before and after the Ringlet reservoir. The objective is to model the sediment transport characteristics of Sg Telom and Sg Bertam as a result of rapid urbanization (established or on-going property development such as housing, shop lots, hotels, etc) and agricultural activities which generate most of the eroded soils and sediments to Sg Telom.

2. Study Area and Sedimentation Issue

Cameron Highlands is a district located in the state of Pahang (Figure 1). With a total area of approximately 71,218 hectares (175,978 acres), it occupies around 2 per cent of the state area and is bordered by Kelantan on the north, by Perak on the west and the Pahang's District of Raub on the south and east. The area experienced daily temperatures which fluctuated between 27.4^{0}C in February/April, and 13.5^{0}C in January. Precipitation is generally common throughout the year with most of it recorded during the Northeast and Southwest monsoons. Record obtained from the Malaysian Meteorological Services (MMS) shows that the Cameron Highlands receives an average rainfall of 2,800mm with the western foothills area receiving higher precipitation compared to the higher mountainous area. Topographically, Cameron Highlands is located on the main mountain range of Banjaran Titiwangsa with elevations ranging from 100 metres above m.s.l. at the eastern part, to 2031 metres above m.s.l. at the western part of the area, and with the highest peak being Gunung Brinchang (2,031m).

Cameron Highlands is drained by three main river systems namely Sg. Telom, Sg. Bertam and Sg. Lemoi which drain the northern, middle and southern parts of the district, respectively. These rivers flow eastwardly and joining up with Sg. Pahang. Sg Telom and Sg Bertam, in particular play a vital role to Cameron Highlands as freshwater supply sources, irrigation water sources for the agricultural activities, and as sources for hydroelectricity generation and recreational activities.

For decades, Cameron Highlands rapid land development and human activities like agriculture, urbanisation, infrastructure development, deforestation and etc. have contributed to severe upland soil erosions. These activities have led to tremendous pressure to the existing river system and water courses. Forest coverage in Cameron Highlands has reduced quite tremendously in the last 5 years. From the current land use, almost 2,000 hectares of forest have been converted to agricultural lands within the catchments of Upper Telom and Upper Bertam. This is a reduction to 51% from the total land area in the two catchments compared to 62% in 1997. For years during heavy rainfall rivers in Cameron Highlands have to imbue the high rate of eroded sediments coming from these sources. Agricultural activities generate most of the eroded soils in Cameron Highlands. Activities like market gardening, floriculture, mixed agriculture, tea and orchard constitute more than 11,000 hectares of active land that produces silts to the water courses. Agricultural activities almost 36% of the total land use in Upper Telom and Upper Bertam catchments while constitute of more than 16% of the total land area in Cameron Highlands.

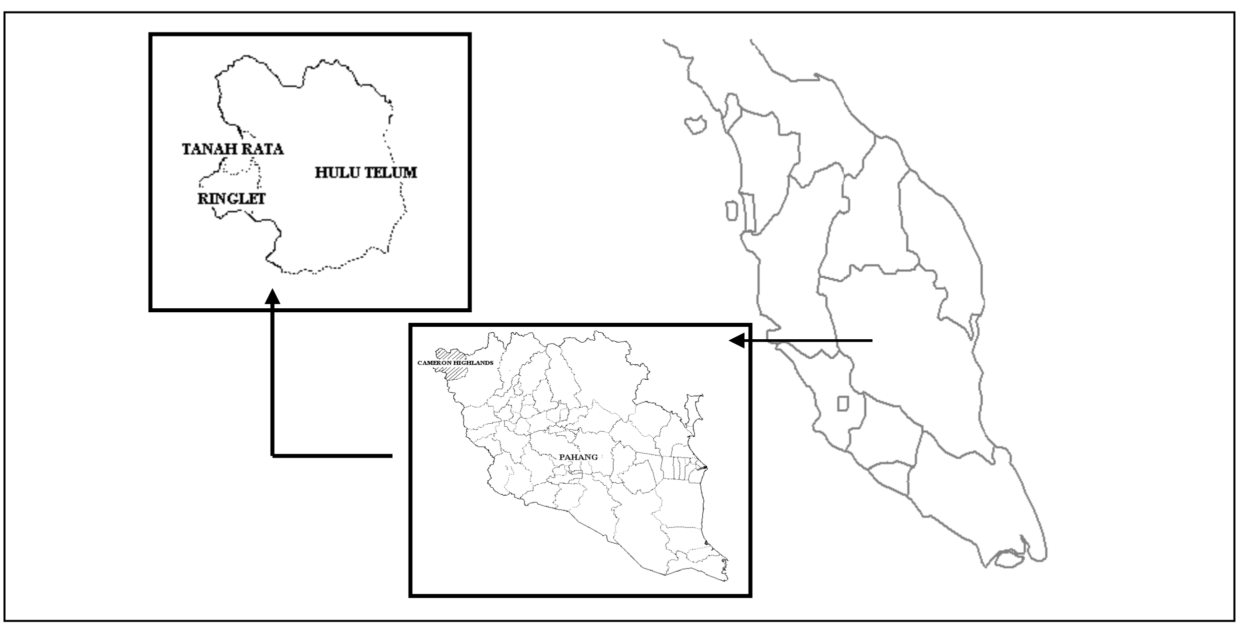

Figure 1. Location of Cameron Highlands

The land developments (housing, shop lots, hotels and etc.) within the urban areas and others constructions activities were identified as the second largest sediment contributor to the existing river in Cameron Highland. Table 1 shows the ranking of activities which significantly generated the sediment loading to the existing river systems in Cameron Highland (Tew, 2003). Next is followed by infrastructure like road construction, water supply pipeline contracts and etc. These activities have reduced the once ample forest reserve in the Cameron Highlands areas. Out of the three river systems, Sg Telom and Sg Bertam are the one receives intensively developed for agriculture and urbanization. The sediments within this catchment will directly enter the Ringlet Reservoir. Figure 2 indicates that the sediment accumulated inside the reservoir started to increase slightly between 1966 and 1967, decrease between 1968 and 1969, increase again between 1970 and 1975, decrease again between 1976 and 1981 and increase substantially 1982 onwards.

Table 1: The lists of activities, which identified as the major sediment contributor to the existing rivers in Cameron Highland

Activities	Estimated Soil Loss	
	Tons/yr	Rank
Agriculture	218,150	1
Mixed Residential	14,260	2
Road	10,642	3
Private Bungalows	10,117	4
Water Body/River	8,887	5
Govt. Institution/Quarters	7,945	6
Apartment/Hotel	5,070	7
Forest	2,573	8
Commercial	1,597	9
Golf/Recreational	1,381	10
Orang Asli Settlement	941	11

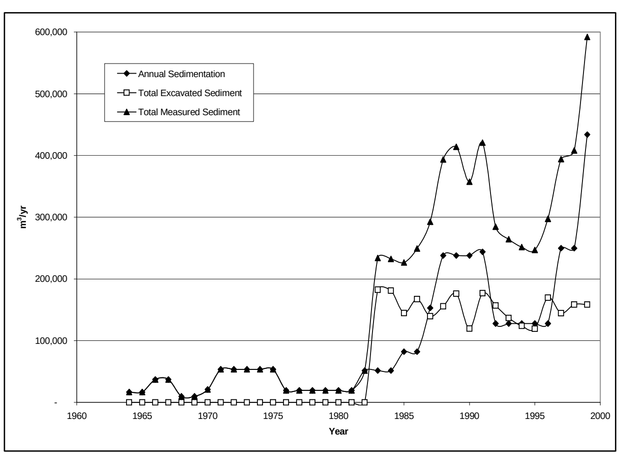

Figure 2: Ringlet reservoir sedimentation

3. Model Development

During the hydrographic survey, it was found that Sg Telom and Sg Bertam are one of the major contributions of sediment yield to Ringlet dam. Therefore, for sediment transport modeling, this study only engaged both rivers. In this study, InfoWork RS, a one-dimensional hydrodynamic simulation program developed by the Wellingford, UK was utilised to model sediment transport in Sg Telom and Sg Bertam. The software simulates one-dimensional channel flow by solving the fully dynamic de Saint-Venant equations, which define the conservations of mass and momentum. The computational grids are created with alternating Q (discharge) and h (water level) points. The h points are created at the location where cross sectional data are available, and Q points are generated automatically in between the h points. The InfoWork RS provides an option where bed resistance (Manning's n) can be calculated as a function of hydraulic parameters such as water depth, hydraulic radius, and flow velocity. To initiate the process of modeling all the identified streams of the study area, the following information and data is compiled and analysed:

- Details of the main catchments of Sg. Telom and Sg Bertam (including data from hydrographic survey and riverbed sediment- these samples were dried, weighed and then run through sieves of various sizes.).
- Physical characteristics of the rivers, such as cross-sectional levels and dimensions, longitudinal bed profiles and slopes.
- Meteorological and hydrological data, such as rainfall, for Cameron Highlands and surrounding areas.

A detailed chart for modeling process is shown in Figure 3.

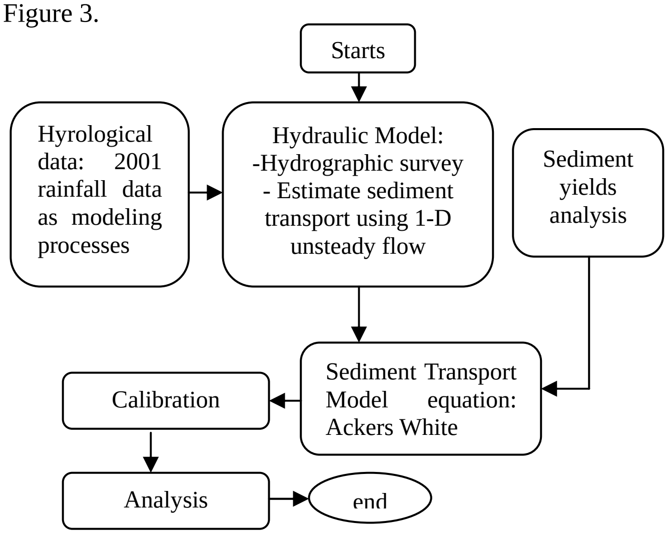

Figure 3: Modeling flow chart

4. Results and Discussion

There are numbers of research findings show that, the impact of a particular land use activity on the increase of sediment yields. These studies confirmed that the sediment loads of many rivers may have increased by an order of magnitude or more as a result of cultural land use changes within the watershed. Table 2 shows the rate of sediments entering the river for each catchment. Based on the current output, Upper Telom catchment was found to have very high degree of erosion estimated at almost 140 tonne/ha/yr. Due to the fact that almost all the sediments produced in this catchment flow into Ringlet Reservoir, Upper Telom only contributed as much as 450,000 m^3 of silts into Ringlet in 2003. Due to this sediment reduction, Sungai Telom has received almost 380,000 m^3 of sediments in the same year.

For the case of Sungai Bertam, the existence of Ringlet Reservoir has stopped the sediments from flowing downstream. The production of sediments from Plau'ur (very small catchment flowing into Sungai Nenggiri, Kelantan), Upper Telom and Upper Bertam catchments have reached almost 600,000 m^3. The remaining sediment flow into Sungai Bertam generated from Middle and Lower Bertam catchments have been estimated to be 280,000 m^3.

Table 2: Rate of sediment entering river system

Sub-catchment	Catchment area (km^2)	Soil loss (m^3/yr)	Soil loss (m^3/km^2/yr)	Estimated sediment rate (m^3/km^2/yr)
Upper Telom	100.33	529, 712	5, 279.70	3, 827.78
Lower Telom	194.23	616, 094	3, 171.98	2, 299.69
Upper Bertam	78.58	304, 847	3, 879.45	2, 812.60
Moddle Bertam	101	328, 130	3, 248.81	2, 355.39
Lower Bertam	94.33	58, 626	621.50	450.59

The riverbed analysis indicates that the materials in the upstream of the Sg Bertam are gravels of granite or metasediment and few sand and silt. Meanwhile, the riverbed materials of the Sg Telom and its tributaries are mainly boulders of granite and minor metasedimentary rocks, sand and silt. The size of the boulders varies from few centimeters to few ten centimeters. The results of particle size distribution for both river systems are illustrated in Table 3.

To provide suitable sediment concentration profile in the model, an assumption was made that low flow has to be generated from the ground water (base flow), which could transport less sediment. Some trials were made and sediment concentration in Table 4 below was used in the calibration process. Depending on the amount of flow, sediment concentration rises as the flow capacity rises.

Table 3: Median particle sizes of sampled river bed material

River	Reach	Slope	Sampling Location	d_{50} (mm)	average d_{50} (mm)
Sg. Telom	T1	> 10%	14	2.64	2.64
	T2	7 - 10%	15	1.06	1.06
	T3	4 - 7%	28	2.64	2.64
	T4	2 - 4%	27	1.50	1.50
	T5	< 2%	25	1.41	1.41
Sg. Bertam	B1	> 10%	34	0.52	0.48
			41	0.44	
	B2	< 2%	37	1.54	1.65
			39	1.77	

Table 4: Sediment concentration vs flow

Flow (m3/s)	Sediment concentration mg/l
1	10
2	20
3	50
4	100
5	200
6	500
7	1500
8	3000
10	6000
15	10000
25	16000
35	22000
60	35000

The simulation process was carried out for a period of 10 month. Figures 4 and 5 below show the result of the bed level changed at upstream and downstream sites of the Ringlet reservoir while the subsequent figures (Figures 6-9) illustrate bed level and flow in different scenarios.

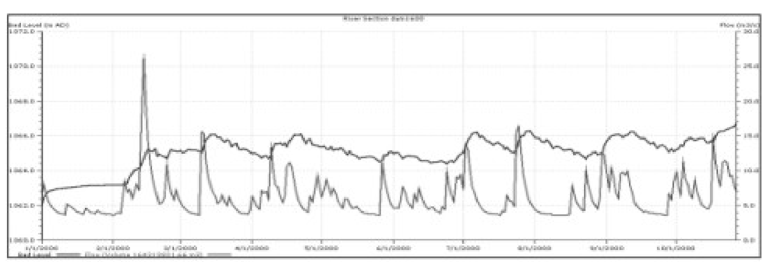

Figure 4: Bed level change at upstream of the reservoir

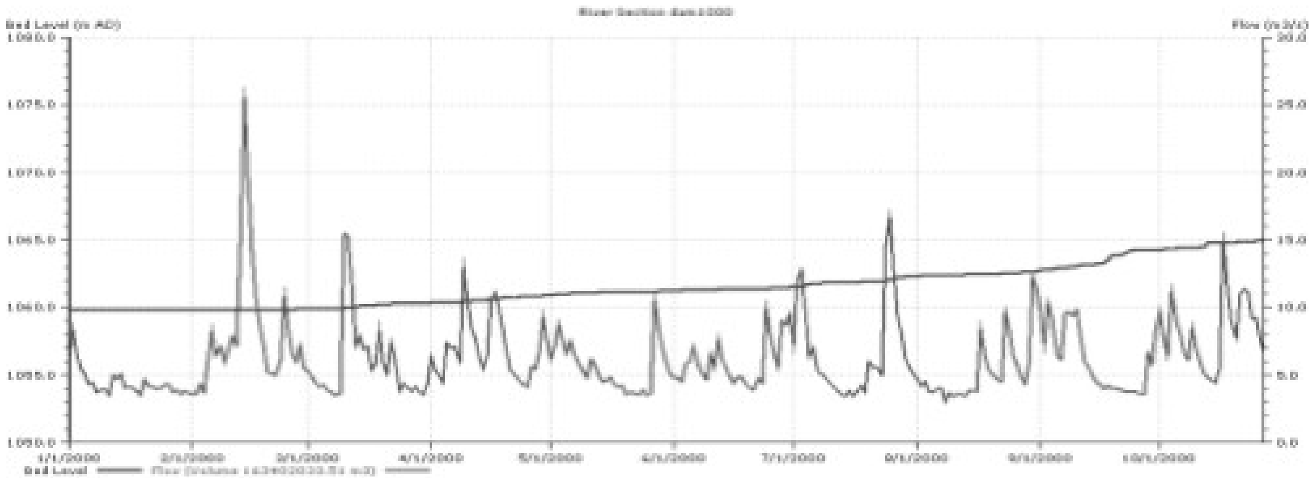

Figure 5: Bed level change further downstream of the reservoir

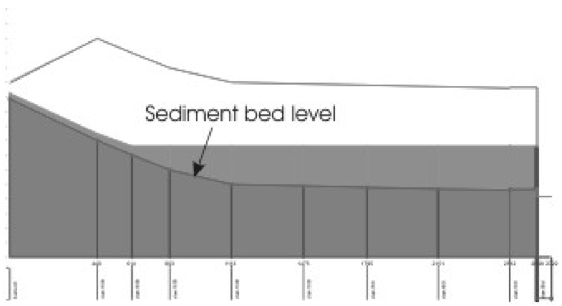

Figure 7: Simulation start

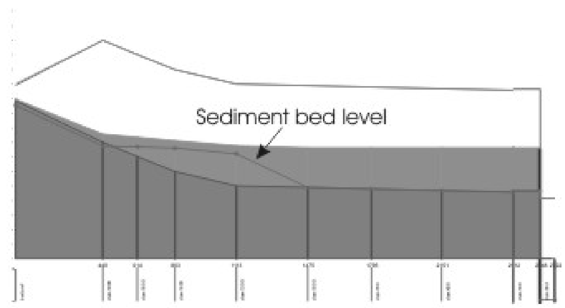

Figure 8: After 2 month

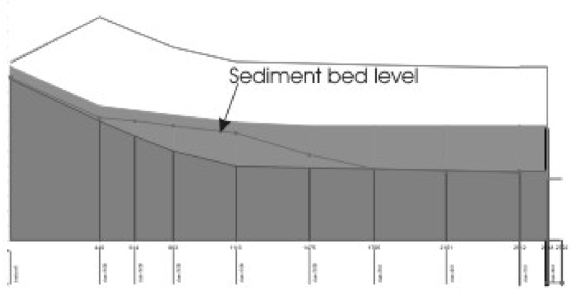

Figure 9: After 7 months

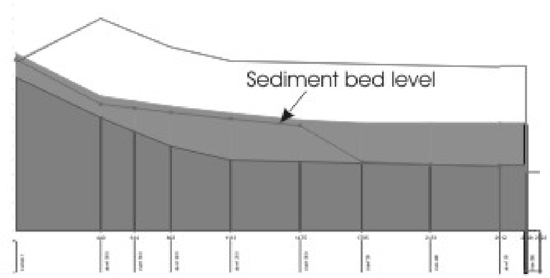

Figure 10: After 10 months

Total volume of sediment accumulated in the dam is equivalent to 530000 m^3/year. This value is about 70% from the estimation obtained using the USLE model, which was 800,000 m^3/yr (Adroit, 2006). The reasons for these discrepancies may be deduced to the particles size utilized in the model itself. The particle size distribution obtained from sample 11 (The utilized bed material was taken from sample 11, which originates near the dam site) fell short from indicating the profile of silts and clay i.e. sediments size less than 0.0625mm. With the current sediment profile (sample 11), the transport model would under estimated the amount of sediments accumulated inside the reservoir. In reality, with smaller silt and clay inserted into the model, the contribution of accumulated sediments inside the reservoir would increase substantially.

With these results, the calibration process for the current exercise should be considered as successful. In the future exercise, further analysis can be carried out for other scenarios especially within the sub-catchments.

5. Conclusion

Rapid developments such as agriculture, urbanisation, infrastructure development, and deforestation in Cameron Highlands have contributed to severe upland soil erosions and sedimentation in the river. These activities have led to tremendous pressure to the existing river system and water courses. For years, during heavy rainfall, rivers in Cameron Highlands have to accommodate the high rate of eroded sediments coming from these sources. Poor sediment control has resulted in the filling up of the Ringlet Reservoir just after 30 years of it's commissioning in the 1960's. This is very much less than the expected design life span of the storage capacity of such structure, which is normally designed to accommodate for sedimentation between 50 to 100 years. In fact, the Ringlet Reservoir was designed with a targeted life-span of 80 years. In environmental point of view, the agricultural activities and construction activities within the Cameron Highlands Rivers basin are known to be significantly impacting on the natural environment as a consequence of increasing runoff peak, accelerated sedimentation, the removal of vegetation filters and increased pollutant loading of nutrients into waterways. The major settlement areas and rapid land development within that areas, such as at Blue Valley, Kg Raja, Brinchang, Tanah Rata, Ringlet and Bertam Valley has also contributed significantly to the sediment loading into the existing rivers system. This has led to severe localised flood as a result of shallow bed level of the major rivers.

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