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# Erosion and Sedimentation at Headwater Stream: A Case Study for Pergau Water Intake

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**Abstract.** Headwater stream can be defined as colluvial and fluvial system located at mountainous areas where stream order of less than four is recorded from the source to the outlet point of interest. This river system is crucial not only for impounding activities but high kinetic energy at highland areas able to entrain and transport large amount of sediment particles from upstream to the downstream river reach. Due to strategic location for water intake facilities, a study was carried out to determine the extent of erosion and sedimentation process at Pergau water intakes that conveyed water into Pergau Lake. Three specific aims were formulated: Soil loss determination at catchment scale, sediment load determination at reach scale and river bank stability and toe erosion near the intake facility. A desktop study using remote sensing and GIS tools was executed to determine the extent of soil loss at catchment scale. The sediment load and river bank stability were measured in the field using wading technique. It was concluded that all seven TNB water intake are having low soil loss rate (<10 ton/ha.year) should the current settings of forest land cover is maintained. The recorded sediment load (bed load) only occurred at Suda and Renyok 1 water intake with a rate of 0.0024 kg/s and 0.03 kg/s, respectively. High eroded material at toe was simulated at Renyok 1 and Suda Intake. The high sediment load at Renyok 1 is a manifest from unstable toe material near the water intake. Therefore, a close monitoring should be attained at the upstream from Renyok 1 intake to assess any land use change or disturbance activities.

## 1. Introduction

Surrounded by a lush green tropical rainforest, Pergau lake is said to be older than the Amazon Basin, Brazil. At night, the temperature at Pergau Lake could be as low as 18 degrees Celsius, similar to the temperature in the Cameron Highlands [1]. The rivers near Pergau Lake can be considered as mountain river systems or headwater streams due to their location, geomorphological appearances and stream order status.

River's classification has been proposed and applied for centuries for the purpose of organizing information on ecological, hydrological and morphological systems. Yet the classification of fluvial systems remains a difficult topic because running waters exhibit such dynamic changes with time and



space [2]. Each stream possesses a set of characteristics (e.g., morphology, hydrology, productivity, and so forth) which change in response to the local climate, geology, and disturbance regime. However, the river's classifications are not easy and straightforward. It is due to indistinct boundaries, longitudinal and lateral variation, present of patches that occur over times [2, 3]. However, river's classification is essential for understanding the distribution of ecological patterns within drainage networks and for developing management strategies that are responsive to the ecological patterns. The in-depth discussion on classification themes are given by [3]. Two broad themes are biological and physical features spanning few meters to hundreds of kilometers. Physical features mainly based on geomorphic characteristics as previously proposed by Horton [4], Leopold *et al.* [5], Montgomery and Buffington [6] and Rosgen [3]. Table 1 shows the summary of physical based classification proposed by previous researchers.

**Table 1.** Physical-based classification

Researchers	Concept	Drawbacks	Application
Horton [4], Strahler [7]	Stream order concept	Provides little information on processes controlling longitudinal and lateral patterns	Useful for stream segment and spatial location of a river system within a basin
Davis [8]	Stream classification as young, mature, or old on the basis of observed erosion patterns	Too simplistic	Little use because of longitudinal differences
Warren [9], Hawkins [10]	Hierarchical perspective linking large regional scales (ecoregions) with small microhabitat scales	A hierarchical approach requires fewer variables at any one level for classification which is not the case at current classification	The value of hierarchical stream classification is greatest when broadly applied (e.g., global, national, regional scales)
Montgomery and Buffington [6]	Morphological description of mountain drainage at reach scale	This method only applicable at mountain basin	Useful for rapid identification of a mountain river

Classification and hydrological settings of Pergau Lake is crucial to determine the behavioural pattern of erosion and sedimentation near the river system. The river system is not only crucial for impounding activities but high kinetic energy at highland areas able to entrain and transport large amount of sediment particles from upstream to the downstream river reach. Sulaiman et al. [11, 12] pointed out that erosion and sedimentation at mountain rivers are differs significantly from their lowland counterparts due to elevation, bed material, stream power, channel geometry etc.

To investigate those behavioural pattern of rivers near Pergau Lake, a research was carried out to determine (1) Soil loss at catchment scale; (2) Sediment load at reach scale and (3) River bank stability & toe erosion near the intake facility.

## 2. Materials and Methods

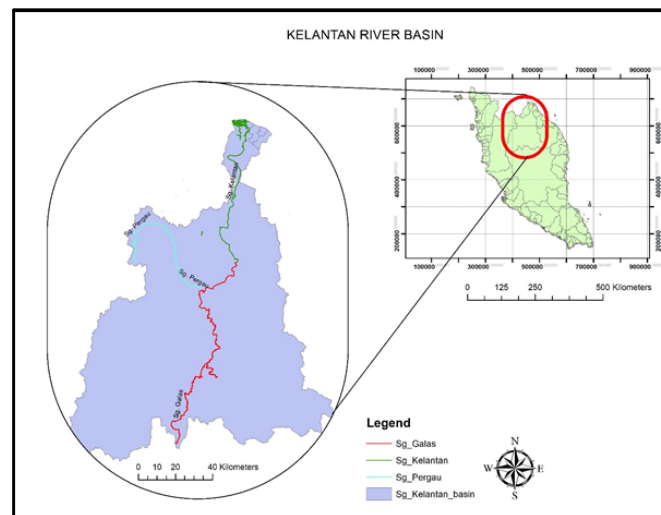
This section entails the study area and methodology to answer research aims. Two approaches were formulated namely desktop study and field sampling. Identification of study area and mapping of soil loss at catchment scale was performed at desktop study while the rest of research outcomes are based on the field sampling and computational simulation.

### 2.1. Study Area

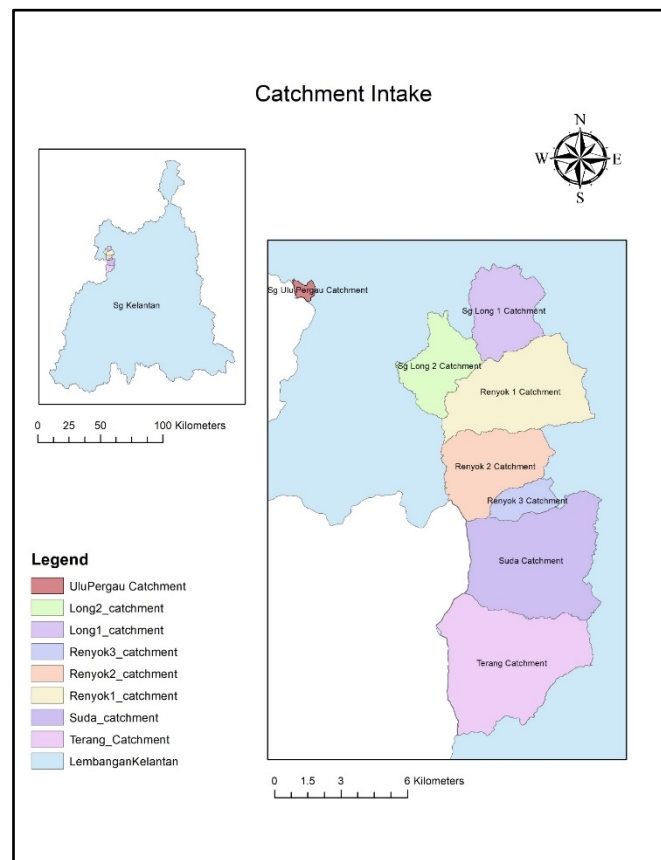
Sungai Pergau is main river system apart from Sungai Galas that finally drained into Sungai Kelantan (see Figure 1). Seven (7) water intakes were identified as a study area namely Suda Water Intake, Terang Water Intake, Renyok 1, 2 and 3 Water Intake and Long 1, 2 Water Intake. Catchment delineation was performed using SWAT software and ARCGIS 10.2 application. Three main information were crucial to be obtained prior to catchment delineation namely digital elevation model (DEM), river network and catchment outlet (Water Intake Point). It is proven from Figure 2 and Table 2 that Terang Intake accommodate the biggest catchment area compared to another catchment. Although Long 2 Intake comprises the biggest sub-catchment, but the area is small. It is due to presence of intermittent small stream that separated by distinct catchment boundary.

**Table 2.** Summary of Catchment Boundary at Pergau Water Intake

Water Intake	No of Sub-catchment	Area (ha)	Min Elevation (m)	Max Elevation (m)
Suda Intake	1	2641	637	1762
Terang Intake	1	2791	617	1608
Renyok 1 Intake	1	2057	418	1514
Renyok 2 Intake	1	1387	555	1761
Renyok 3 Intake	1	379	703	1632
Long 1 Intake	9	1086	622	1394
Long 2 Intake	72	918	681	1444



**Figure 1.** Sg. Pergau and Kelantan River Basin



**Figure 2.** Delineated Catchment for Water Intake

### 2.2. Field Works

Field works were executed to determine sediment transport rates at water intakes as described in the previous section. The location for field sampling were executed at both upstream and downstream from water intake. Due to accessibility, some river transects were unable to attain namely Renyok3@downstream, Long1@downstream and Long1@downstream. The field sampling involved three main themes; river surveys, sediment data and hydraulic data as listed in Table 3.

**Table 3.** Data Themes for Field Sampling

Data Theme	Types of Data	Data Category
River Surveys	1) Cross-section of river 2) Slope of river (water surface slope) 3) River Morphology (Cascade, Step-pool, Plane-bed & Pool-riffle)	Primary Data
Sediment Data	1) Bed Load Concentration 2) Representative Bed Material	Primary Data
Hydraulic Data	1) Discharge 2) Velocity	Primary Data

The equipment used to measure the rate of bed load sediment transport is Halley-Smith sampler. The sampler has a 76 mm x 76 mm opening to a 0.25 mm mesh sampling bag that is supported by a metal frame. consists of an expanding nozzle mated to a frame, and a sampler bag. When the sampler is submerged and sitting on the streambed with the nozzle pointed into the flow, the water sediment

mixture flows through the nozzle into the bag. The mesh openings in the bag allow water and fine sediment to flow through the bag while trapping the coarse sediment. The time taken to measure the bed load is between 5 to 10 minutes with number of the sampling points are determined based on the width of the channel. The rate of bed load transport was calculated after the samples dried and weighted. The formulation used to calculate bed load transport rate are as in equation (1) and (2) as follows:

$$T_b = \sum_{n=1} G_b \quad (1)$$

$$G_b = \frac{W_i}{(T \times h_s)} b \quad (2)$$

where

$T_b$	=	Total bed load for 1 cross section (kg/s)
$G_b$	=	Bed load for 1 section (kg/s)
$b$	=	$B/n$
$W_i$	=	Sample weight for 1 point (kg)
$T$	=	Time
$h_s$	=	Width of sampler opening (m)
$B$	=	Width of river (m)
$n$	=	Number of section

### 2.3. Soil Loss Determination

Universal Soil Loss Equation (USLE) has been used worldwide to determine the soil loss at catchment scale. USLE consist of four (4) parameters namely rainfall erosivity (R), soil erodibility (K), slope steepness (LS) and cropping & management practice factor (CP). Since Terang Water Intake is the biggest catchment that drain into Pergau Lake, thus a case study for Terang catchment is considered. The rainfall intensity, soil types and land cover for all catchments are the same except for slope steepness. The Rainfall erosivity (R) stem on the rainfall data at study area. The analysis of rainfall pattern at Pergau intake was analysed using the statistical analysis to observe the daily, monthly and yearly rainfall distribution. The estimation of rainfall intensity R was performed using Roose [13], Morgan [14], Foster et al. [15] and Teh [16] formula. Soil erodibility (K) was inferred based on Reconnaissance Soil Map of Peninsular Malaysia. The nomograph from JPS was used to find the value of K based on type of soil. By definition, LS is a 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. The steepest the slope, the higher LS value will be expected. Bizuwerk et al. [17] proposed the following equation (3) to compute slope steepness (LS).

$$LS = \frac{X^m}{22.1} \times (0.065 + 0.045S + 0.0065S^2) \quad (3)$$

where  $X$ =slope length (m) and  $S$ =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 (ArcHydro ext.). Thus, slope length  $X$  became

$$X = (\text{Flow Accumulation} \times \text{Cell value}) \quad (4)$$

By substituting  $X$  value, LS equation will be:

$$LS = \left( \text{Flow Accumulation} \times \frac{\text{Cell value}}{22.1} \right)^m \times (0.065 + 0.045S + 0.0065S^2) \quad (5)$$

where  $m$  is the coefficient value representing dominant slope in the area as shown in Table 4.

**Table 4.** Proposed Coefficient  $m$

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

The USLE equation was used to calculate the annual soil loss rate (A) in ton/ha/year. In order to predict the annual soil loss rate at the Terang water catchment, R, K, LS and CP factors were multiplied using the raster calculator tools under map algebra of ArcGIS.

#### 2.4. BSTEM Simulation

BSTEM is an acronym for Bank Stability and Toe Erosion Model. The model consists 6 structural elements namely input geometry, bank material, bank vegetation and protection, bank model output, toe model output and unit converter page. The basic data entry and expected outcome for those six elements can be inferred in Table 5.

**Table 5.** Data Entry for BSTEM Simulation

No	Element	Remarks / Definition
1	Input Geometry Page	Coordinates for bank profile, soil layer thickness, and flow parameters
2	Bank Material page	Bank-material properties (geotechnical and hydraulic)
3	Bank Vegetation and Protection page	To run root reinforcement (RipRoot) model and to input default values of bank and toe protection.
4	Bank Model Output page	Water-table depth and obtain results
5	Toe Model Output page	To run shear stress macro and obtain toe-erosion results
6	Unit Converter page	Conversion from imperial (English) to metric units

### 3. Results and Discussions

Three main results will be discussed herein: soil loss at catchment scale, sediment transport at reach scale and bank stability & toe erosion at selected reaches.

#### 3.1. Rainfall Erosivity

It was estimated that the mean annual rainfall for the study area is 3325.5 mm from the year 2017-2018. Table 6 shows the summary of rainfall erosivity using those four aforementioned equations and the adopted rainfall erosivity among those four. Since the variations of R values are apparent in Table 6, thus the values from Teh [16] was adopted due to two reasons: 1) this empirical equation was developed in Malaysia; 2) the obtained values are almost similar to the previous reported values by Department of Irrigation and Drainage Malaysia. To visualize a case study, a raster map for Terang Intake catchment will be shown to illustrate the distribution of rainfall erosivity throughout the catchment (see Figure 3). Since a single rainfall value was used, thus R factor for the whole catchment is uniform as shown in Figure 3.

**Table 6.** Summary of Rainfall Erosivity

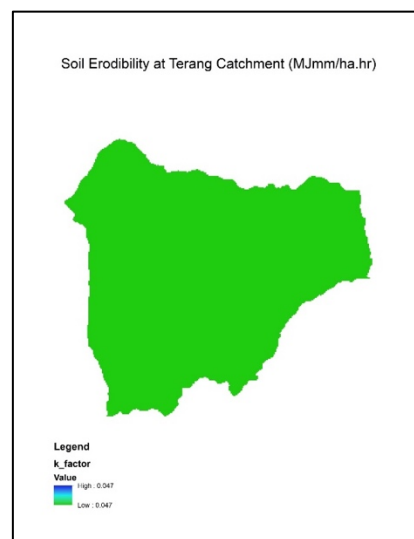
No	Method	Value
1	Roose [13]	1662.75 ton.inch <sup>2</sup> /ha.hr
2	Morgan [14]	970.4677189 ton.inch <sup>2</sup> /ha.hr
3	Foster, et al. [15]	396.531394 ton.inch <sup>2</sup> /ha.hr
4	Teh [16]	1135.455473 MJ.mm/ha.hr



**Figure 3.** Rainfall Erosivity at Terang Water Catchment

*3.2. Soil Erodibility*

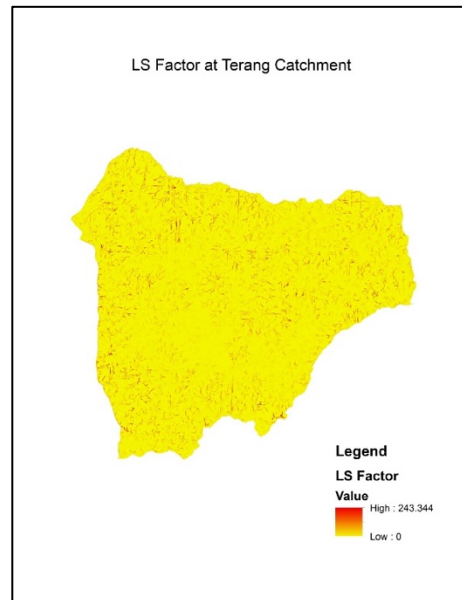
Based on the Reconnaissance Soil Map of Peninsular Malaysia, Terang Intake catchment and all other intakes were located within the Steepland Series. The soil erodibility K for steepland serie is 0.047 as shown Figure 4.



**Figure 4.** Soil Erodibility for Terang Intake Catchment

### 3.3. Slope Steepness

Figure 5 shows the LS factor for Terang water catchment.



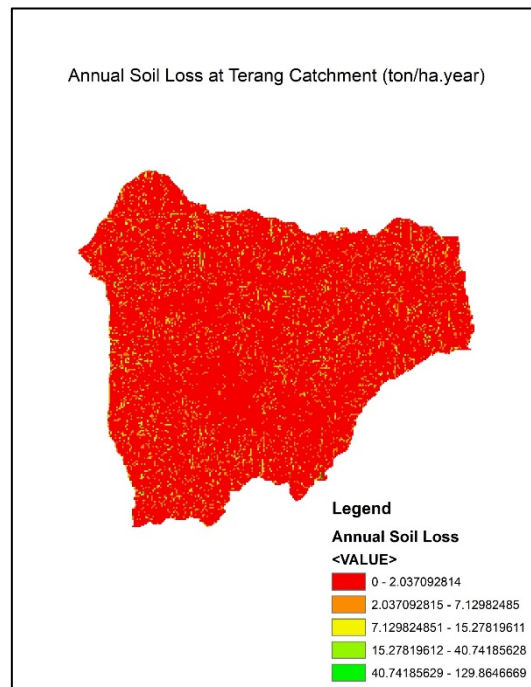
**Figure 5.** LS Factor for Terang Catchment

### 3.4. Annual Soil Loss

For the cropping and management practices factor, CP, the values were adopted from Abidin, et al. [18] where the CP for forest and water body are 0.010 and 0.000 respectively. The USLE equation was used to calculate the annual soil loss rate (A) in ton/ha/year. In order to predict the annual soil loss rate at the Terang water catchment, R, K, LS and CP factors were multiplied using the raster calculator tools under map algebra of ArcGIS. The final output is shown in Figure 6. Should the mean annual rainfall (3325.5 mm) and cropping management of forest (Cp=0.010) remain the same, the expected maximum of annual soil loss at Terang water catchment is 130 ton/ha.year and the average soil loss is <10 ton/ha.year. Any encroachment on the land use/land cover will increase the soil loss in the future. However, majority of Terang Intake catchment recorded soil loss average of <10 ton/ha.year as depicted in Figure 6. These values fall under either low or very low soil erosion class as shown in Table 7.

**Table 7.** Soil Erosion Class

Soil Erosion Class	Potential Soil Loss (ton/ha/year)
Very low	<10
Low	10-50
Moderate high	50-100
High	100-150
Very high	>150



**Figure 6.** Annual Soil Loss at Terang Catchment

### 3.5. Sediment Transport At Reach Scale

Knowing the soil loss at catchment scale, it is very important to investigate the sediment load at reach scale. Prior to sediment load computation, it is vital to obtain dry weight of trapped sediment and the associate hydraulic database. The sediment load computation was performed using the equation 2 and 3 respectively. Table 8 shows the complete database for hydraulic and sediment load at all water intake. The average water depth is denoted by  $Y_0$  (m) during the sampling time. The range of water depth at all intake points were less than a meter during dry period. The effective river width is denoted by  $W$  (m) which signify the width that correspond to water edge at both river bank. Average velocity  $V$  (m/s) is water speed along the streamline while river discharge  $Q$  ( $m^3/s$ ) is a product between flow area and velocity. Friction slope  $S$  (m/m) is water surface slope at upstream and downstream river reach. Sediment load is denoted by  $T_b$  where the unit was computed in mass rate, kg/s. As previously stated by Sinnakaudan et al. [19], sediment load consist of two parts; bed load and suspended load. The values in table 8 is the former where Renyok 1, Suda and Long 1 intake recorded transport rates of  $30 \times 10^{-3}$ ,  $2.4 \times 10^{-3}$  and  $0.4 \times 10^{-3}$  kg/s respectively. This values are associated with dry period where there is rainfall event recorded during and before the sampling. However, the transport rates might get higher during rainfall event due to high stream power as previously demonstrated by Duan & Scott [20]. Hendrick et al. [21] elucidated that the exponential increase of sediment load can be expected with the increase of river discharge.

**Table 8.** Hydraulic and Sediment Datasets

	$Y_0$	$W$	$V$	$Q$	$S$	$T_b$
Terang Intake (upstream)	0.310	30	1.374	0.419	0.054	N/A
Terang Intake (downstream)	0.470	39	0.811	0.383	0.054	N/A
Suda Intake (upstream)	0.296	23	0.774	0.229	0.039	$2.4 \times 10^{-3}$
Suda Intake (downstream)	0.383	17	0.491	0.383	0.039	N/A
Renyok 3 (upstream)	0.293	16	0.918	0.269	0.138	N/A
Renyok 2 (upstream)	0.220	16	2.143	0.471	0.075	N/A
Renyok 2 (downstream)	0.312	19	1.199	0.374	0.075	N/A

	$Y_0$	W	V	Q	S	$T_b$
Renyok 1 (upstream)	0.204	29	0.913	0.186	0.052	$30 \times 10^{-3}$
Renyok 1 (downstream)	0.153	21	0.508	0.078	0.052	$30 \times 10^{-3}$
Long 1 (upstream)	0.147	8	1.02	0.150	0.091	$0.4 \times 10^{-3}$
Long 2 (downstream)	0.150	18	1.235	0.185	0.074	N/A

Since three water intakes recorded transport rates, a detailed investigation is performed on the river bank and toe stability to determine the source of sediment.

### 3.6. Bank Stability and Toe Erosion

Running BSTEM simulation acquire information on bank profile, water level, friction slope, bank material and toe material as compulsory data entry into BSTEM tool.

The simulation of BSTEM consists of two parts: bank stability and toe erosion. Bank material is susceptible to erosion due to bank angle and friction slope while bank toe material is susceptible towards erosion due to hydraulic force of water. The simulation was performed at upstream section of water intake due to presence of revetment downstream from water intake. Presence of revetment will stabilize river bank for a long run. Table 9 summarized the bank stability and toe erosion for Suda Intake and Renyok 1 Intake due to high amount of sediment load as shown in Table 9. The maximum lateral retreat of toe and total amount eroded materials are consistent with the distribution of sediment load as depicted in Table 9. Highest lateral retreat and maximum eroded materials are expected to be recorded at Renyok 1 Intake (see Figure 7-8).

**Table 9.** Summary of bank Stability and Toe Erosion

Location	Bank Stability			
	Factor of Safety	Failure width (m)	Failure volume ( $m^3$ )	Sediment Loading (kg)
Suda Intake@upstream	4.26	-	-	-
Renyok 1 Intake @ upstream	31.13	-	-	-

Location	Toe Erosion				
	Boundary Shear Stress (Pa)	Maximum Lateral Retreat (cm)	Eroded Area-Bank ( $m^2$ )	Eroded Area-Bank Toe ( $m^2$ )	Eroded Area-Bank ( $m^2$ )
Suda Intake	33.57	5.028	0.000	0.088	0.052
Renyok 1 Intake	291.01	150.64	0.249	0.783	0.082

### Conclusion

This study reported the initial findings and baseline database on erosion and sedimentation behaviour at Pergau water intake. The Pergau lake received water from those seven (7) intake points as stipulated in Table 2. Therefore, the sustainability of water intake that drains water into Pergau lake must be given high priority. A few conclusions can be drawn from this research. All water intakes were located at upstream part from Sungai Pergau which finally drained into Sungai Kelantan. The average of total monthly rainfall for the month of January is the highest followed by November and December respectively. It is postulated that the dry season occurred from Feb-May, normal season from Jun-Sep while wet season occurred from Oct-Jan. Should the mean annual rainfall (3325.5 mm) and cropping management of forest ( $C_p=0.010$ ) remain the same, the expected maximum of annual soil loss at Terang water catchment is 130 ton/ha.year. Any encroachment on the land use/land cover will increase

the soil loss in the future. However, the average of <10 ton/ha.year was expected as shown in Figure 6. These values fall either low or very low soil erosion class.

Renyok 1, Suda and Long 1 intake recorded transport rates during clear day. However, the transport rates at Renyok 1 is considered higher for a headwater stream. A simulation on river bank stability and toe erosion reveal that toe material at Renyok 1 intake was susceptible towards erosion which might explain high amount of transport rates.

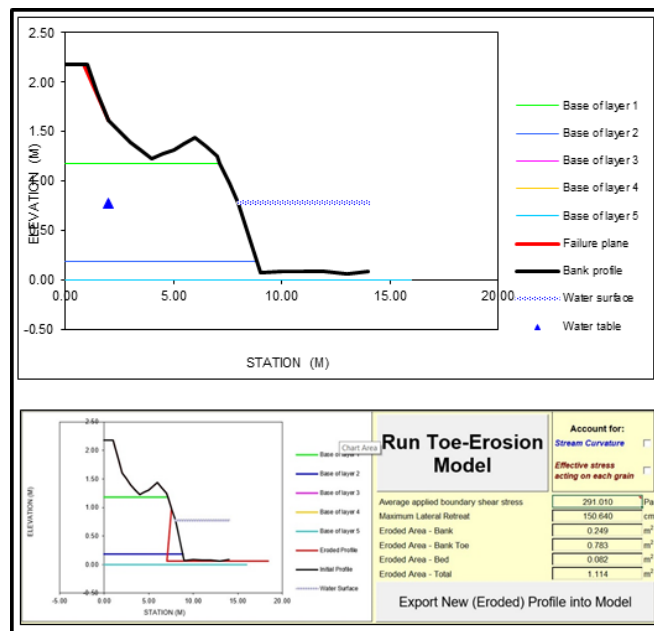


Figure 7. Possible Failure Plane at river bank (top) and Erosion at Toe (bottom) for Renyok 1 Intake

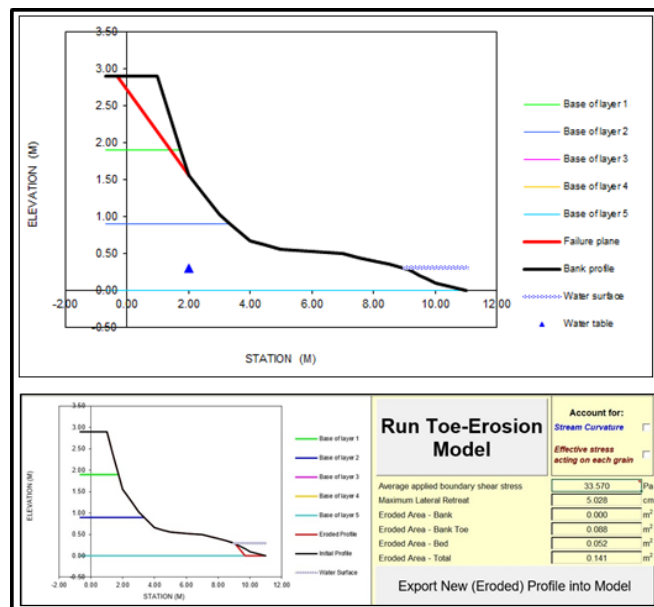


Figure 8. Possible Failure Plane at river bank (top) and Erosion at Toe (bottom) for Suda Intake

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