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Application of HEC-RAS for Sediment Transport in Sg. Muda River

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Abstract: Sedimentation in rivers leads to the raising of bed level resulting in flash flood during heavy rainfall. Sg. Muda has suffered extensive environmental degradation, mostly as a result of significant erosion and sedimentation due to the effect of rapid urbanization. Excessive sediments can harm the ecological health of waterways and reduce their ecological, social and cultural values. Large accumulations of sediment can cause further erosion by causing upstream flooding or diverting the flow to adjacent river banks or even adjacent land. This study is carried out to simulate analysis of the sediment transport rates at Sg. Muda, Kedah river area by using (1D) quasi unsteady flow HEC-RAS. Flow discharge, geometric data of river cross section and bed gradations are needed to run the HEC-RAS simulation. The 24.4km of selected sample area in Sg. Muda analysis is done by using Laursen-Copeland method as it performs in the very fine sand and very coarse silt range. The result shows the location of erosion and deposition occurs. The velocity along the river and sedimentation concentration are one of the output from HEC-RAS model analysis. The maximum depth of erosion in these reaches is about -1.51m which happens in STN 6669m river reach stations and the maximum deposition is about 1.47m in downstream STN 21474.5m reach of river having wide cross section. The maximum velocity measured is 2.27 m/sec while the maximum sediment concentration along Sg. Muda is obtained to be 5828 mg/L/year. The main advantage of this study is that it will help in achieving successful strategies for reducing sediment can be used for a long time.

Keywords: Sediment Transport, Sg. Muda, HEC-RAS

1. Introduction

River sedimentation causes the bed level to rise, resulting in flash floods with heavy rains. It occurs when the water flow is strong enough to withstand the weight and cohesion of the sediment. Sediment load is another name for sediment transport. All particles moving as bedload, suspended load and wash load includes in sediment load categories.

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Sg. Muda's catchment region provides a significant source of water and sand mining for the northern states. Sand mining sites have been established to harvest sand from the river bed. Three major floods occur in 1988,1998 and 2003 within the 15-year span in Sg. Muda. The flooding in the Sg. Muda caused extensive damage in built-up and agricultural regions, particularly during the flood event. This issue of sedimentation can lead in increasing of the magnitude of floods in Sg. Muda catchment and causing inconvenience and serious harm to the community [1]. Changes in upstream sediment flow or influent change the rate at which sediment moves and where sediment is deposited or eroded.

The aim of this research is to determine the flow characteristics (velocity) of sediment transport within the Sg. Muda catchment area and to simulate the sediment transport concentration in Sg. Muda river by using HEC-RAS software. Sedimentation is a natural process that occurs in all bodies of water. Large accumulations of sediment can cause further erosion by causing upstream flooding or diverting the flow to adjacent river banks or even adjacent land. The simulation is using the secondary data and insert in the HEC-RAS mapping software to run the sediment transport analysis.

2. Literature Review

This chapter provides a summary of previous research that has led to the current understanding of characteristics of sediment and sediment transport as well as the use of HEC-RAS to investigate the sediment movement in Sg. Muda that can provide the overview about the studies.

2.1 Characteristics of Sediment

Sediment refers to the process of allowing suspended material to settle naturally due to gravity and comprised of silt, clay and sand loose particles [2]. Sediments may have an impact on the river's characteristics and flow rate.

Particle size, density and many more are some of the natural factor that affect the condition of the river. Sediment comes in a variety of sizes ranging from large particles to tiny particles which are boulders, cobbles, gravel, sand, silt, and clays and classified in different grain size in unit called "Phi". The most important part of sediment particles is grain size, which affects the calculation of transport, and deposition. Course sediment have a greater size 2mm while fine sediment has size particle that less than 2mm. The ability of a rock to hold a fluid is referred to porosity. It is the volume of voids space in a rock [3]. It is important to determine porosity as it determines how much sediment can be carried by a rock. In sediment transport modelling, the density of the sediment is usually set to 2600 kg/m^3 [4].

2.2 Sediment Transport

Sediment transport is the movement of solid particles under influence of gravity acting on the sediment. The fundamental source of particle sedimentation is gravity, which is caused by changes in density between particles and the fluid. Gravity forces are stronger than upward-acting lifting forces for particles denser than water, and the particles fall through standing water. Sediment transport may be affected by high water velocity because more sediment is transported in the river. Sediment concentrations are higher during high intensity rainfalls event than during low intensity rainfall. This is due to increasing amount of rainfall in causing soil particle detachment. As volumes and velocities increase, a river's capacity tends to increase with distance downstream [5].

The sediment transport is flow in one of three ways which are as bed load, suspended load or dissolved load. Bed load transport consists of the coarse sediments and move by rolling, slide and saltate along its bed. Suspended load transport refers to the movement of fine particles suspended and transported by the flow of the river. As with suspended load, the sediment is retrained in the water column because of the fluid turbulence. The previous Sg. Muda river survey, flow measurement and field data collection were conducted at the six selected cross section along Sg. Muda. The data collection includes flow discharge, bed and bank material, bed load and water surface slope. The location starting from Jambatan Ladang Victoria until Jambatan Nami. All the cross sections are single thread channel with the top width ranging between 94.0 and 134.0m representing medium size river. The range of average sediment size (d_{50}) shows that the Sg. Muda is made up of sand and gravel with the size between 0.29 and 3.0m [1].

2.3 HEC-RAS

HEC-RAS has four main river stimulations such as constant flow of water, sediment transport calculations, river bed modifications, and water quality analysis. This component of modelling system used to be evaluate deposition, flooding and sediment and widely used in variety of disciplines. Other than that, it functioning in flood maps with variety of application and can be used to stimulate flood estimation in one dimensional or two dimensional [6].

HEC-RAS can be used to generate water surface profiles and determine whether the water surfaces profiles are subcritical, supercritical and mixed flow regime can be calculated based on the flow rate and velocity calculation. The critical depth for the cross section will be show in the program by checking the flow regime to ensure the correct flow regime. Additional tools such as ArcView GISs can also be utilized to create floodplain map and with depth of flooding at any point in the floodplain and extents of flooding can be compared.

The HEC-RAS sediment transport model uses hydraulic variables such as velocity, flow depth, and sediment properties to calculate sediment transport capacity. Geometry data, quasi-unsteady flow data, sediment data, and a sediment analysis plan are needed to run the sediment model.

3. Methodology

A research project was done to select the most suitable way to simulate sediment transport concentration and evaluate features of sediment transported within the Sg. Muda catchment area. The simulation was conducted using HEC-RAS mapping programs created by the United States Army Corps of Engineers (USACE). The methodology of this research includes the data collection, data processing and sediment transport simulation was carried out.

3.1 Data Acquisition

The Sg. Muda river floods every year and often during the rainy seasons around April to May and September to November. In October 2003 flood caused devastating damage to 45,000 individuals as well as damaging several vehicles. The secondary data such as flow discharge, bed gradation and geometry data are obtained from the Department of Irrigation and Drainage (DID) and the United States Geological Survey (USGS). The beginning state and sediment characteristics must be specified in order to replicate sediment transport.

3.2 Development of HEC-RAS mapping software

HEC-RAS is applied in this research to operate the hydraulic calculations of one- dimensional Sg. Muda sediment transport model. For the model to be able to simulate the sediment data analysis for a particular river reach, specific data input are required. It is able to calculating the water surface profile based on the geometric data for 1D flow consideration. Sediment transport analysis then use to simulated for current discharge and sediment supply using HEC-RAS. There are three main components for the HEC-RAS hydraulic model which are geometric data, flow discharge and sediment data.

DEM is used in this study to provide geometric data such as cross-sections, reach lengths, and bank placements, which are then imported from Arc-GIS to HEC-RAS. This shape file, as shown in Figure 1, is in the form of a TIFF file, which is then converted into a GIS file for read and use by the HEC-RAS which show in Figure 2. The geometric data in this study consists of cross section between the river downstream (STN 3597.67) and the upstream of Sg. Muda (STN 24670). Cross section within the reach from the highest upstream to the lowest downstream in river section.

Figure 1: DEM of Selected Sg Muda in Raster format

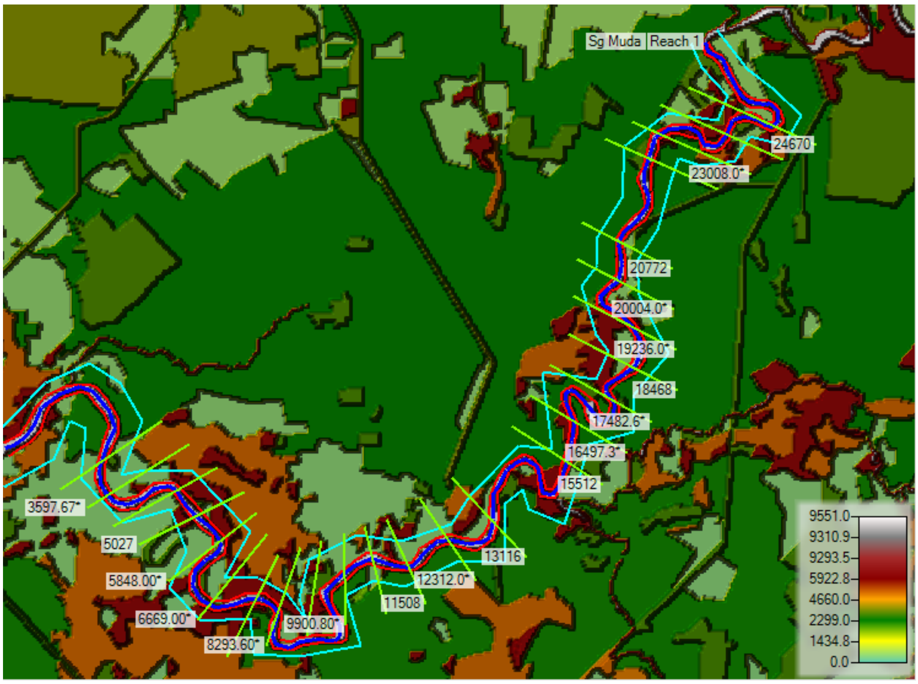
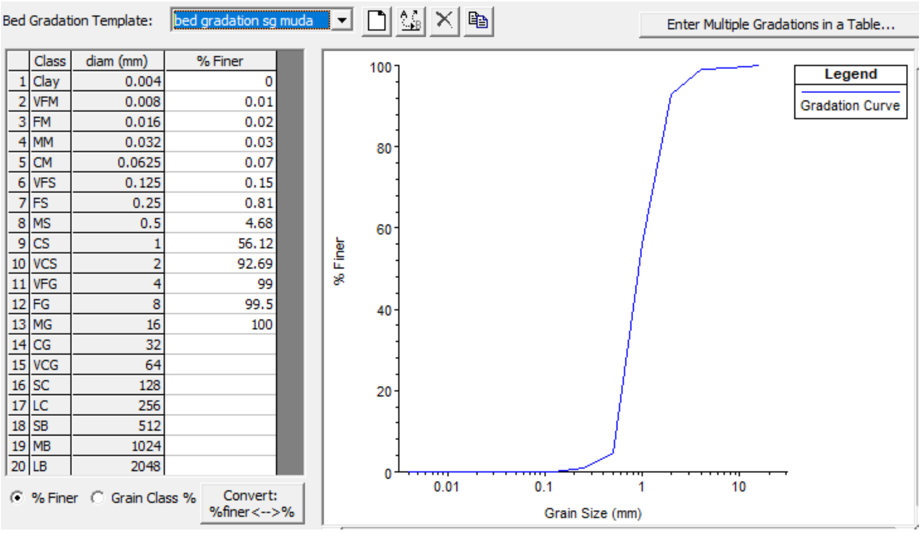


Figure 2: Plan View of Selected Sg Muda in GIS Format

The quasi-unsteady approach approximates a flow hydrograph by a series of steady flow profiles with corresponding flow duration. The flow data is upstream and downstream boundary. In this study, a normal depth was selected for downstream boundary condition. The input flow hydrograph that was used in model simulation period was from January 2003 to December 2003. STN 24670 is the upstream boundary and STN 3597.67 is the downstream boundary of Sg. Muda.

Sediment data consist of river bed gradation transport function and sediment boundary condition. The grain size distribution of the class particles is represented by bed gradation. Laursen-Copeland transport function equation are used to simulates the sediment transport mechanism. After all the required computation limits and inputs were set, the HEC-RAS simulation were conducted using the sediment analysis module.



	Class	diam (mm)	% Finer
1	Clay	0.004	0
2	VFM	0.008	0.01
3	FM	0.016	0.02
4	MM	0.032	0.03
5	CM	0.0625	0.07
6	VFS	0.125	0.15
7	FS	0.25	0.81
8	MS	0.5	4.68
9	CS	1	56.12
10	VCS	2	92.69
11	VFG	4	99
12	FG	8	99.5
13	MG	16	100
14	CG	32	
15	VCG	64	
16	SC	128	
17	LC	256	
18	SB	512	
19	MB	1024	
20	LB	2048	

Figure 3: Bed gradation of Sg. Muda

3.3 Manning Equation

The Manning's n value use for the river is 0.030 in this study. In order to perform further studies to assess the quality and location of sediment deposition, it is important to know Manning's coefficient. The model used empirical Manning's equation, in the equation (1) below, to provide the relationship between the river discharge, hydraulic resistance, river geometry, and the friction energy loss [7].

$$Q = KS_f^{1/2} \quad (1)$$

Where: Q = Flow
Sf = Friction slope
K = Conveyance

3.4 Laursen-Copeland Function Equation

The Laursen technique predicts sediment load using qualitative analysis, original tests, and extra data. Transport of sediments is determined by mean channel velocity, flow depth, energy gradient, and sediment gradation and fall velocity. Copeland (1989) extends applicability to gravel-sized sediments. Median particle diameter is 0.011mm to 29mm. For a single grain size, the general transport equation for the Laursen (Copeland) function is expressed by:

$$C_m = 0.01\,\gamma\left(\frac{d_s}{D}\right)^{7/6}\left(\frac{\tau'_o}{\tau_c}-1\right)f\left(\frac{u_*}{\omega}\right) \quad (2)$$

Where: C_m = Sediment discharge concentration, in weight/volume

D_s = Mean particle diameter
D = Effective depth of flow
τ'_o = Bed shear stress due to grain resistance
τ_c = Critical bed shear stress
$f(\frac{u_*}{\omega})$ = Function of the ratio shear velocity to fall velocity

4. Results and Discussion

This chapter discuss about the finding from research of data observed from the study area that were obtained from the study on the use of HEC-RAS to simulate sediment modelling in the Sg. Muda. The process of analyzing the data is essential to a study since the findings of the study will indicates to the research whether or not be able to accomplish the objective of the study. In order to guarantee the objectives accomplish, the completion of simulation it is necessary and need to be observed.

4.1 Flow Characteristic along Sg. Muda

The flow characteristics (velocity) along Sg. Muda was displayed in the form graph in Figure 4. The x-axis indicates main channel distance (m)of selected Sg. Muda while y-axis indicates velocity (m/s). The legend shows the velocity in black line for 1st January and blue line for 31st December 2003.

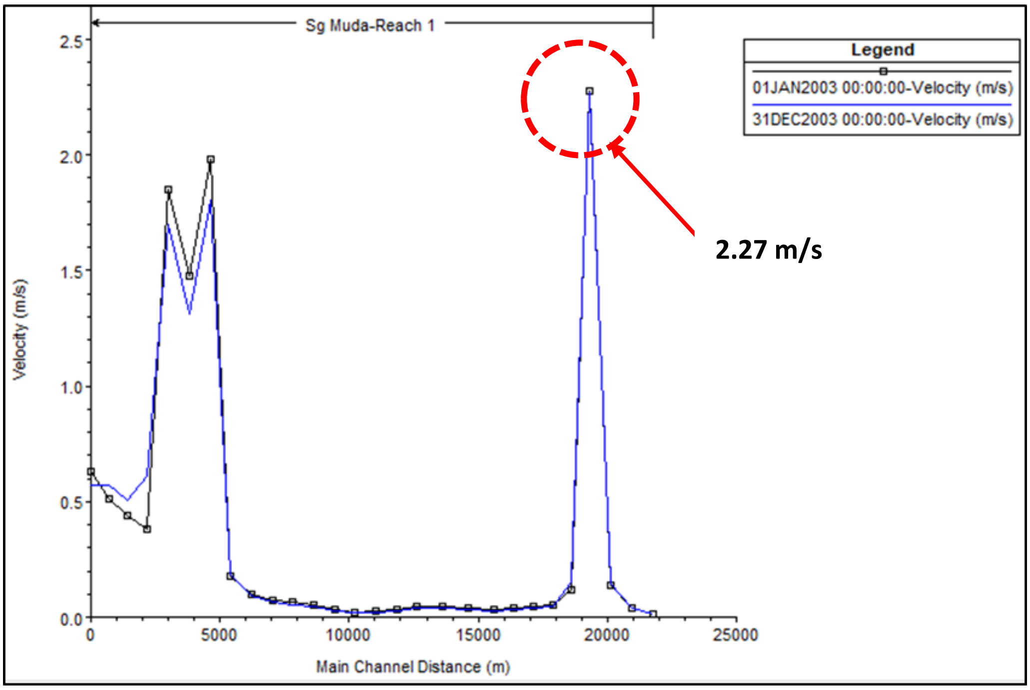


Figure 4: Flow Characteristics along Sg. Muda

Figure 4 illustrates the variation of velocity along the length of Sg. Muda. The velocity distributions show the flow characteristic along Sg. Muda. Along the entire channel reach, there is a significant fluctuation in velocity. In certain areas where the depth of water is greater and the surface area is larger, the minimum velocity is quite low. Due to possible changes in the channel slope, increased flow strength, and sediment mobilization, the maximum velocity observed is 2.27 m/sec, which could have big impacts on the Sg. Muda. The increased amount of flow velocity being carried by Sg. Muda may produce more erosion of the banks or bed, resulting sedimentation in the downstream.

4.7 Sediment Concentration in Sg. Muda

The sediment transport concentration in Sg. Muda at STN 6669 was displayed in the form graph in Figure 5. The x-axis indicates main channel distance (m) of selected Sg. Muda while y-axis indicates sediment concentration (mg/l). The legend shows the sediment concentration (mg/l) in black line for 3st January 2003.

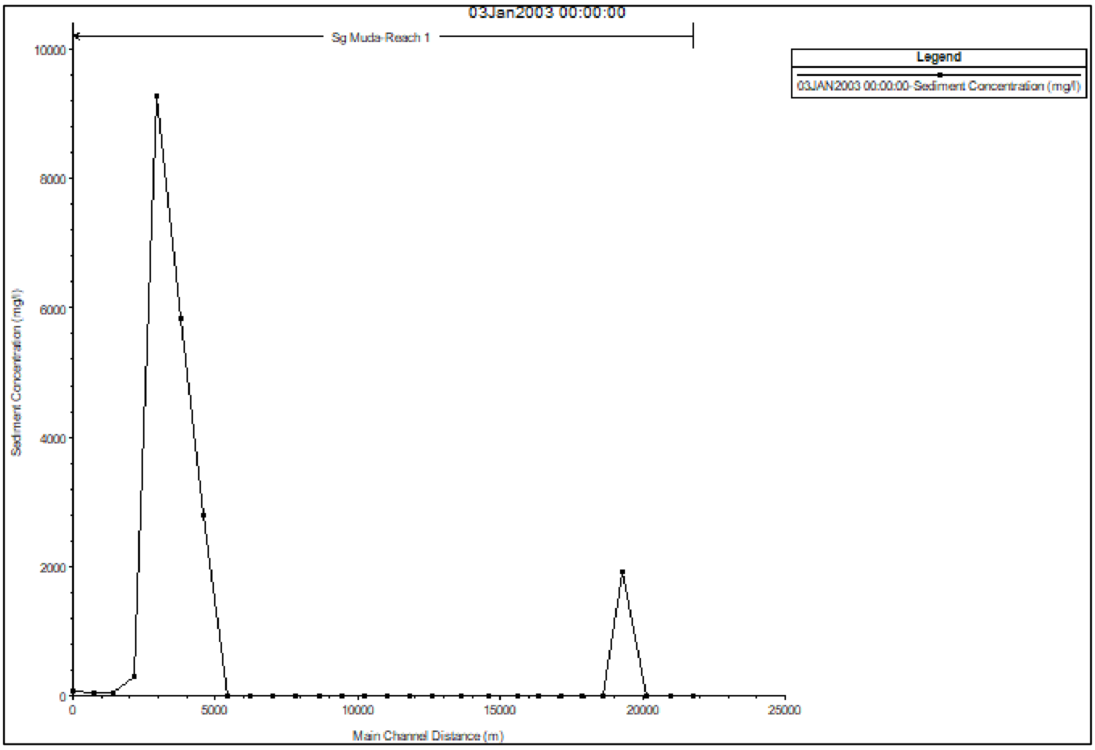


Figure 5: Sediment Concentration in Sg. Muda at STN 6669

Sediment concentration rate is the total sediment concentration in mg/L leaving of the sediment control volume at the end of the computational time step. This parameter is computed from the Mass Out and Flow results. Sediments were carried by the river as dissolved suspended load, saltation, wash load, and bed load. Suspended sediments are part of the elastic load that flows via channels in the water column. The channel bed's upward turbulent flow, in particular, keeps silt and sand suspended. The maximum sediment concentration occur in Sg Muda was found to be 5828 mg/L at downstream STN 6669 m. The change in suspended load concentration along Sg. Muda is given in Figure 5. The concentration of sediment determines its transportability via surface runoff.

5. Conclusion and Recommendation

The DEM of 1/3 arc-second resolution that was use has a significant impact on the quality of the river cross-section forms that are generated. There are a lot of positive aspects associated with the use of this data, such as reduced time spent preparing and analysis of river geometry. The approach was the use of ArcGIS together with Hec-GeoRAS to draw the river and extract cross-sections from a DEM of the River Sg. Muda. HEC-RAS results indicate that the Sg. Muda has majorly experienced sedimentation and the bed level increase has been widely observed during the simulation period. The highest erosion and deposition are observed around STN 2217 m to STN 7490 m reach.

The velocity distributions show the flow characteristic where there is a large fluctuation in velocity along the estimated reach of the channel. The maximum velocity measured is 2.27 m/sec while the minimum velocity is quite low in areas with greater water depth and a larger surface area. The sediment distribution through the reach of the channel is non-uniform and the maximum sediment concentration along Sg Muda is obtained to be 5828 mg/L. The advantages of HEC-RAS include its strong visual capabilities and comprehensive output results with exact tables, making the model well-known among industry specialists. Furthermore, anyone interested in copyright constraints can download and use it for free. It is suggested that the model's capabilities be further investigated and that any issues be reported to the developers.

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