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EFFECTS OF TIDES ON THE HYDROLOGY AND GEOMETRY OF A FRESHWATER CHANNEL

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ABSTRACT

The situation of Sungai Sengkuang becomes worse because it is under tidal influence. Flood was reduced after removing the temporary culvert. Analysis is carried out for the existing system to investigate whether it is still able to accommodate the volume of water comprises the discharge from upstream and high tide from downstream. The computer program such as HEC-HMS 2.2.2 will be used to carry out the Hydrologic Model Calibration. By using HEC-RAS, Hydraulic Model Calibration will be carried out for the channel. The discharge with different ARI will be used as the upstream boundary condition during the flow analysis. Frequency analysis for the tide level which is collected from JUPEM. The tide level with different ARI is used as the downstream boundary condition. From the Energy Grade Line of the channel, which energy is dominant, the energy from downstream or the energy from upstream.

Keywords: tidal influence; dominant energy; flow analysis; hydraulic and hydrology model analysis.

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1. INTRODUCTION

Recent study shows that the hydro geomorphic processes have been altered drastically by human actions [9], resulting a dramatic change to the tidal habitat types over the past century. The alterations involve several characteristics such as the volume of tidal exchange, the extent of area under tidal influence, the speed of tidal currents, the amount of sediment in the main channel and the inputs of freshwater and sediment from the watershed [8]. As the result of these alterations, flood became frequent and it became more serious especially at the downstream part of the channel that have a low topographic profile. Channel that is affected by the tide will experience the worse conditions. Further studies need to be performed in order to recognize the impact of urbanization to the surrounding area [7]. More details and thorough investigation to the existing system of the channel should be carried out in order to reduce the number of flood effectively [3].

1.1. Problem Statement

Sungai Sengkuang is a channel located near to the Sungai Tebrau in Johor Bharu. There was a swamp area with low topography before it was developed into housing area. Sungai Sengkuang was a channel with tidal influenced before. It has been straightened up under the urbanization process. The area straightened up area is started from CH 0 at the downstream to CH 1350 at upstream. Not only this, the reclamation work also has been carried out at the surrounding area of Sungai Sengkuang causing the water level in the river became higher. A temporary culvert built on CH 600 had worsened the flood situation in the settlements nearby. The culvert that acts as a temporary access from the left channel area. According to the previous analysis to the channel, the temporary culvert had brought significant effect to the flow of channel and causes flooding to the nearby residential area. When the flow of the channel comes across the high tide from the downstream, back water will be created. Flood occurred because the channel cannot accommodate the volume of back water due to the tide and the insufficient design of temporary culvert. After removing the temporary culvert, the flood problem seems to be reduced. But, the capacity of the existing channel is still have not been determined whether able to accommodate the flow from upstream and downstream.

Therefore, hydraulic and hydrology model analysis will be carry out in order to determine whether flood will occur after the temporary culvert is removed.

1.2. Objectives

The objectives of the study are to investigate the hydraulic characteristic of channel that experiences flood problem due to heavy rainfall and tide influence. The energy line along the channel reach shall be evaluated to determine the dominant energy from either upstream boundary condition or downstream boundary condition. Therefore, this study is conducted to investigate the optimum channel geometry.

1.3. Scope of Study

To carry out the hydraulic and hydrology model analysis, the scopes of study are as stated below:

i. Delineation of catchment boundary and schematization of channel section of the study area.
ii. Data collection that include rainfall, stream flow, water level and tide fluctuation in order to evaluate the fundamental understanding of hydraulic and hydrologic principles.
iii. Hydraulic and hydrologic model calibration.
iv. Evaluate the causes of flood in terms of hydraulic principles.
v. Evaluate and analyze channel hydraulic characteristics for the system under tidal influence.

1.4. Research Background

The Sungai Sengkuang estuary is located 6 km away from the center of Johor Bahru and about 20 km away from Pasir Gudang. Once, it was a horse-shoe shape estuary situated inside the area of Plentong, Johor Bahru. The exact location is within the latitude 1^0 28’45” to 103^0’00” north and from longitude $103^0$45’30” to $103^0$47’30” east in between the Sungai Plentong and Sungai Tebrau. Connected to Selat Johor, it is the main channel that carry storm water runoff from the catchment area towards the estuary of Sungai Tebrau about 1371.6 meter away. The main residential areas around are Kampung Bakar Batu and Taman Iskandar. The highest point of the contour line is about 44 m and the lowest point is about 7.7 m from Mean Sea Level. This steep catchment area has created a rapid surface runoff towards the lower land downstream.

There are two main types of soil at the research area, i.e. a group of clay at the east part and the group of sand the west part. The surrounding area has been developed as residential area, business and industrial area resulting that 90% of the study area is impervious surface.

The Sungai Sengkuang with the catchment area of 4 km^2 is affected by flood lies along the downstream portion of the river. It is also influenced by tide fluctuation. A series of flood in the Sungai Sengkuang flood plain had necessitated re-evaluation of the Sungai Sengkuang flood-control channel analysis, taking the effect of surface runoff and tidal flow. Several acres of land were flooded, homes and MBJB landscaping works were affected. By virtue of their lower topography, some house were significantly affected.

Flooding in this river system might be due to the combination of high surface flow and high tide that might result to the insufficient channel capacity. Under these circumstances, therefore, an analytical review is needed to investigate the hydraulic principles of the system to provide a better fundamental understanding. Basic hydraulic principles will be used to analyses the system as well as utilizing steady state of numerical models for checking purposes.

2. LITERATURE REVIEW

2.1. Open Channel Flow

Open channel hydraulics deals with flows having a free surface in channels constructed for water supply, irrigation, drainage and hydroelectric power generation, in sewers, culverts and tunnels flowing partially full, in natural streams and rivers. According to [1], open channel hydraulics includes i) steady flows that are unchanging in time, ii) varied flows that have changes in depth and velocity along the channel and iii) transient flows that are time dependent.

Open channel flow is also described as the flow of a single phase liquid with a free surface in a gravitational field neglecting the effects of surface tension and of the overlying gas. In this case, only turbulent flows will be considered since laminar open channel flows are hardly encountered in civil engineering practice. To study the open channel flows, the assumption have been made that the mean streamlines are nearly parallel. This assumption allows a one-dimensional analysis since that it the piezometric head is nearly constant on planes normal to the flow. Control volume arguments are used for a nonparallel streamlines regions. This assumptions are inadequate in some cases, causing a much more complicated two- or three-dimensional analysis is to be used [4].

As shown below, this implies that the piezometric head is nearly constant on planes normal to the flow and allows a one-dimensional analysis. Regions of nonparallel streamlines are considered by using control volume arguments. In some cases, these assumptions are inadequate and a much more complicated two- or three-dimensional analysis must be used [4].

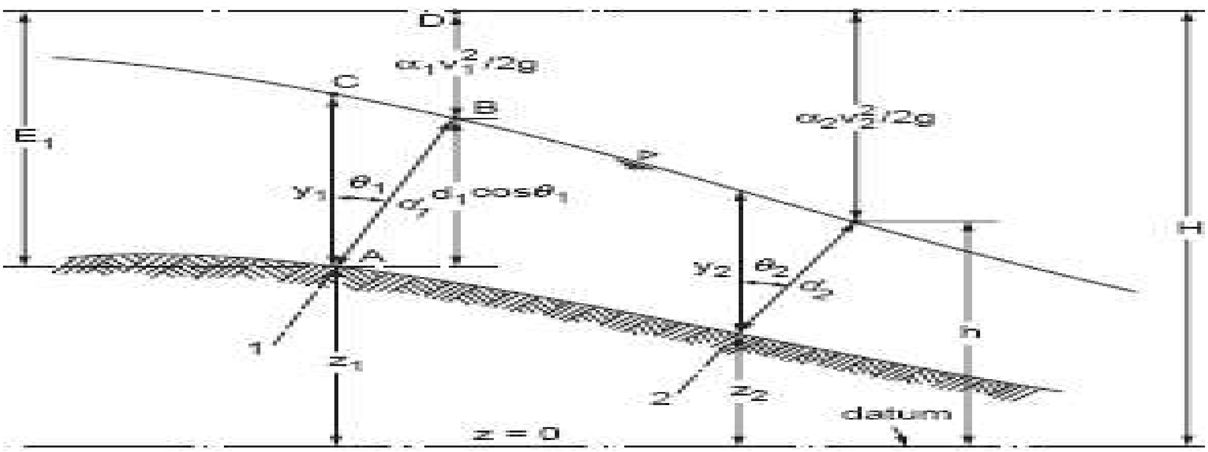

Fig.1. Open channel flow definition diagram

According to Fig. 1, y = depth of stream, d = thickness of stream, z = bottom elevation, θ = angle between channel bottom and horizontal, E = specific energy, h = piezometric head and water surface elevation, H = total head and $\alpha V^2/2g$ = velocity head.

Since assumptions that the mean streamlines are nearly parallel is made, the studies can be related to the theory of prismatic channels. Prismatic channel is a type of channel with a constant cross sectional shape, throughout the length of channel. The most common prismatic channel cross sections are trapezoids, rectangles and partially full circles. Constructed channels often consist of long prismatic reaches connected by short transition sections. Natural channels are never prismatic, but it is acceptable to assume that they are. The direction of flow is indicated by the spatial variable x; the two coordinates orthogonal to each other and to x are called y' and z'. For a parallel flow, the total volume of water flowing per unit time across an orthogonal flow area is the flow rate or discharge (Q) is given by:

$$Q(x,t) = \iint_A v(x, y', z', t) dy' dz' = V(x,t) A(x,t) \qquad (1)$$

where v (x, y’, z’, t) is the local x-velocity at coordinates x, y’, z’ and time (t). The integral extends across the whole flow area and V is the mean velocity.

Unsteady flow is formed when the flow velocity at a point varies with time. These flows can occur in natural and manmade channels and are basically produced by changes in the water levels or changes in the inflow or outflow rates. There are some typical examples of these flows which are floods in streams and rivers, surges in power canals, unsteady flows in irrigation canals and channels, storm runoff in sewers and of course the tidal flows influence at the estuaries and downstream. Unsteady flow can be divided into two types: gradually varied flow and rapidly varied flow. It is depending on the rate of variation of depth. During the rapidly varied flow occurs, the flow may be disturbed by shocks or bores and a wave may be created. There are two important equations which under the governing equations which are continuity equations and dynamic equations [6].

2.2. Tide

The word tides is defined by the alternating rise and fall in sea level with respect to the land, produced by the gravitational attraction of the moon and the sun system, local bathymetry and shape of basin. Basically, there are three types of tides phenomenon that occur at the beaches, i.e. semi-diurnal tides, diurnal tides and mixed tide. This phenomenon can cause flood at the downstream of a river when there is an inflow of the tide, also known as rising tide. Flooding in this river area always becomes severe due to the combination of high surface flow of the river and high tide that might result to the insufficient channel capacity.

2.3. Software

Numerous software packages have been developed to solve problems of open channel hydraulics under the approximation of one-dimensional flow. Among the software involved are HEC-HMS and HEC-RAS.

The US Army Corps of Engineers Hydrologic Engineering Center River Analysis System

(HEC-RAS) is a Windows-based program that can solve both steady and unsteady flows in single channels, dendritic systems or complex networks. This software allows the user to perform one-dimensional steady flow, one and two-dimensional unsteady flow calculations, sediment transport/mobile bed computations [5] and water temperature/water quality modelling. It can handle mixed subcritical and supercritical flows with hydraulic jumps, and can model the effects of obstructions such as bridge piers, culverts and weirs. HEC-RAS has superseded the US Army Corps of Engineers' HEC-2 (formerly the industry standard) and the Natural Resources Conservation Service's WSP-2, both of which are limited to steady state simulations.

On the other hand, Hydrologic Modelling System (HEC-HMS) is designed to simulate the complete hydrologic processes and the precipitation-runoff of dendritic watershed system. The range of problem that can be solved includes large river basin water supply and flood hydrology, small urban or natural watershed runoff. It also includes procedures necessary for continuous simulation including evapo-transpiration, snowmelt and soil moisture accounting. The hydrograph produced by the program are used directly or in conjunction with other software. The program features a completely integrated work environment including a database, data entry utilities, computation engine and result reporting tool [2].

3. METHODOLOGY

Sungai Sengkuang is one of the main tributary of Sg Tebrau as shown in Fig. 2. The river is proposed to be straightened to improve the land use within the vicinity of prime development area of MBJB, as shown as reclamation area in Fig. 2. The reclamation work has caused a series of flood in the Sungai Sengkuang flood plain that requires channel analysis, taking the effect of surface runoff and tidal flow.

The following analysis have been done in order to provide a better understanding of the behaviour and basic characteristics of the channel:

a. Study the relationship of the rainfall and runoff by measuring the stream flow in respond to the recorded rainfall. The result is to be used as the upstream input boundary data. This basic relationship is to be used for further analysis.

b. Obtain correlation of tide level at TLDM and JUPEM gaged stations to site. This downstream water level time series fluctuation is useful to study the basic behaviour of the channel under the influence of tide.

c. Determine the energy line along the channel reach in order to evaluate the dominant energy from either upstream boundary condition of stream flow or downstream boundary condition of tide fluctuation using different analytical methods. It will be calibrated by hydraulic models.

A few studies on scenarios was carried out to understand the basic hydrologic and hydraulic principles. Fig. 3-5 schematized the overall components of analysis.

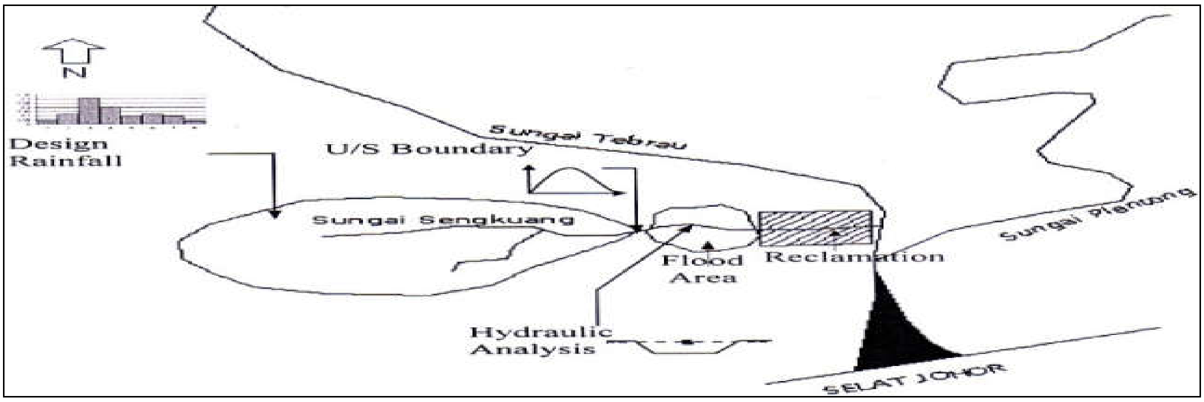

Fig.2. Location of study area

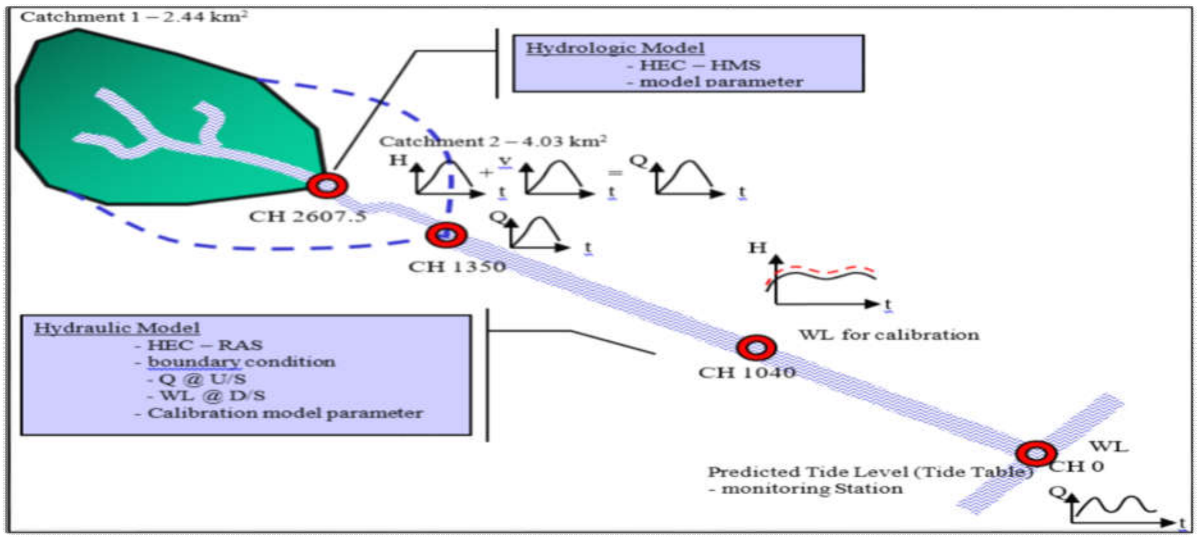

Fig.3. Schematization of hydrologic and hydraulic analysis

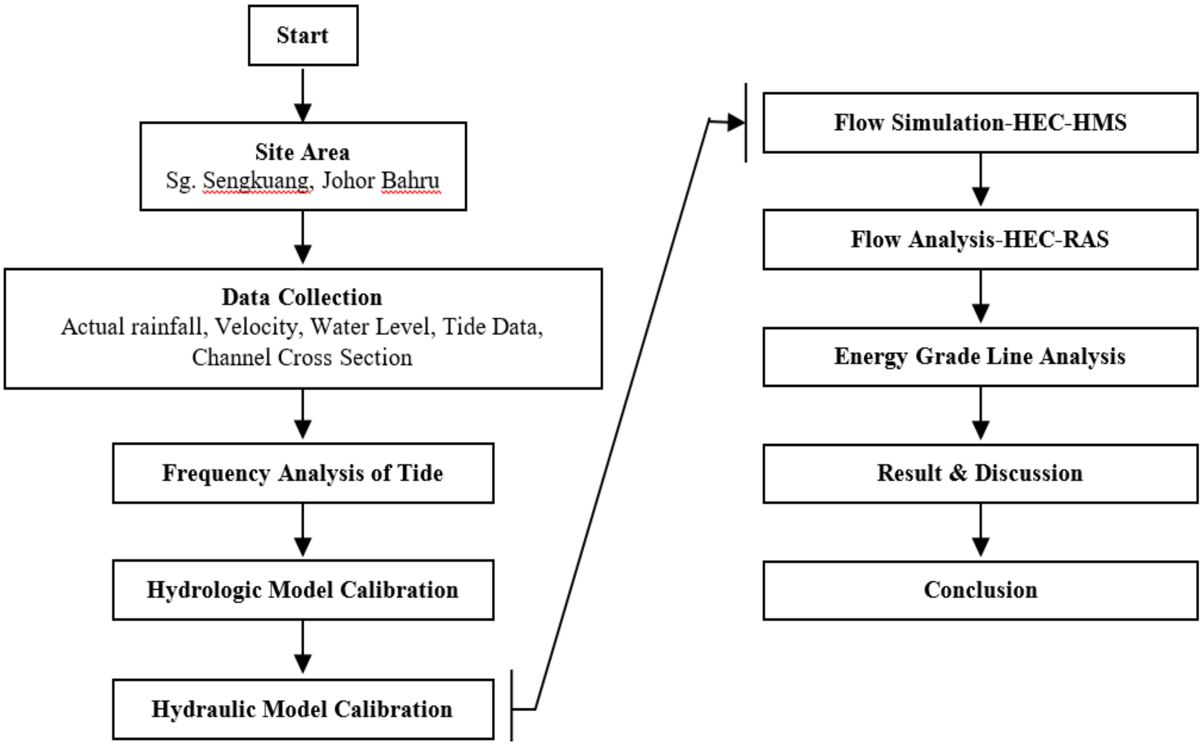

Fig.4. Hydrologic and hydraulic analysis of Sungai Sengkuang

4. RESULTS AND DISCUSSION

Some actual data need to be collected as the input of the model in order to carry out the hydrologic and hydraulic model calibrations and validation.

4.1. Data Collection

Fig. 5 shows the sites where the data have been collected. Table 1 represented the brief explanation for the data to be collected and the sampling station for each type of data collection.

Table 1. Data collection details

Location	Data	Equipment
Catchment 1 (CH 2607.5)	Actual rainfall, velocity, water level, channel cross section	Rain gauge, current meter, measure tape
Jetty (CH 1040)	Water level	Global water
Downstream (CH 0)	Water level (tide level)	Global water
Along Sg Sengkuang	Reduced level	Levelling equipment

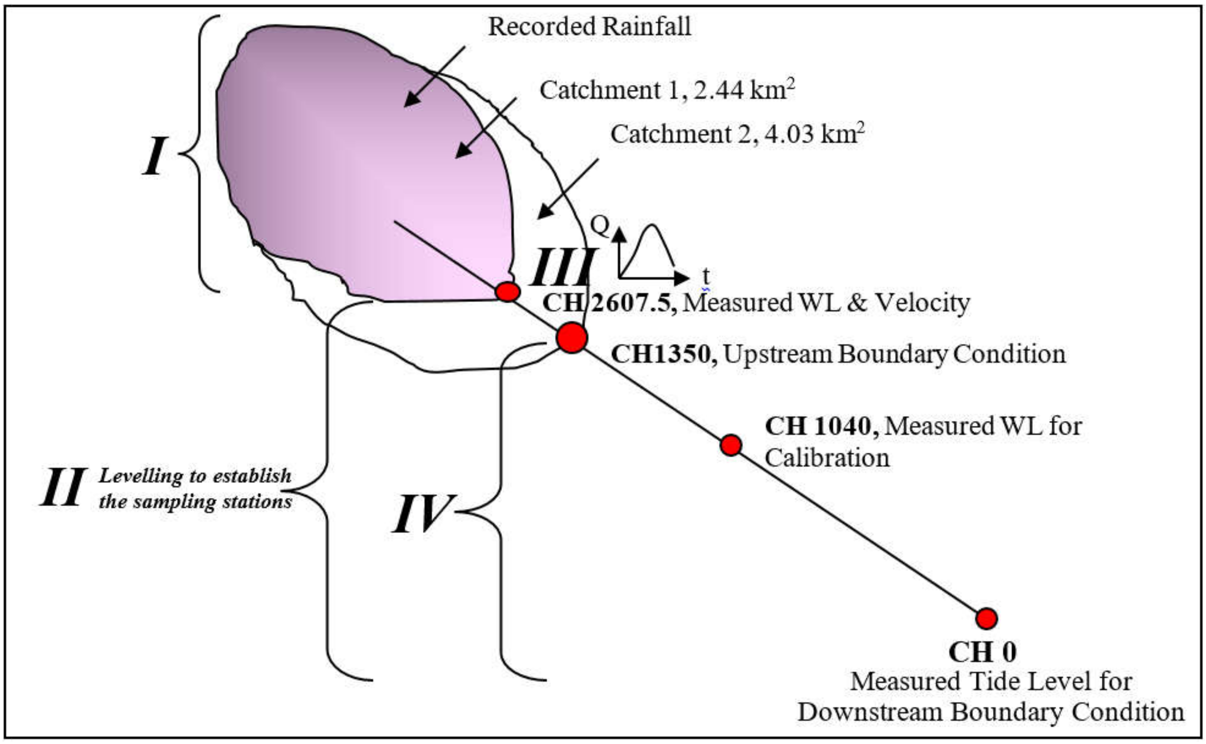

Fig.5. Sampling station for hydrologic and hydraulic model calibration and validation

4.2. Part I-Hydrologic Model Calibration at Catchment 1, CH 2607.5-HEC-HMS

To simulate the discharge of catchment 2 which start from CH 1350, calibration has been carried out. Recorded rainfall and observed hydrograph have been entered to obtain the affecting parameter of the channel by entering different values of storage coefficient (R) until the model hydrograph similar to the observed hydrograph. During the calibration, the data that need to be entered into HEC-HMS as shown in Table 2. Fig. 6 shows the result where the peak discharge are similar for both observed and model hydrograph. Validations of this study involved 2 event data. Fig. 7 shows the results for validation.

Table 2. Data needed in the basin model of HEC-HMS

Loss Rate	Initial/Constant	Initial Loss	1.3 mm
		Constant rate	0.5 mm/hr
		Imperviousness	90%
Transform	Clark	Time of Concentration	0.42
		Storage Coefficient	0.535*
Base flow	Constant	Constant Base flow	0.5 cms

*The value of storage coefficient (R) above is obtained from the calibration

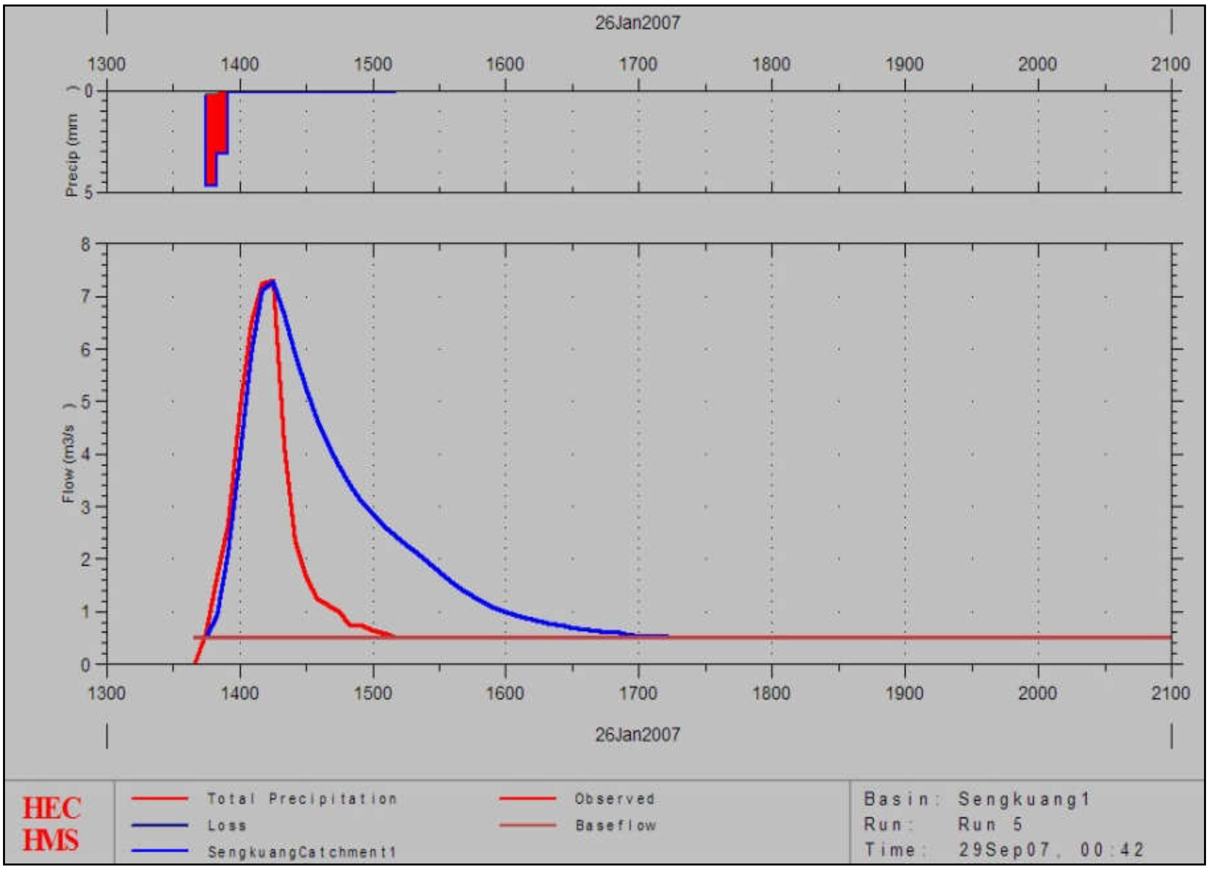

Fig.6. Result of hydrologic model calibration

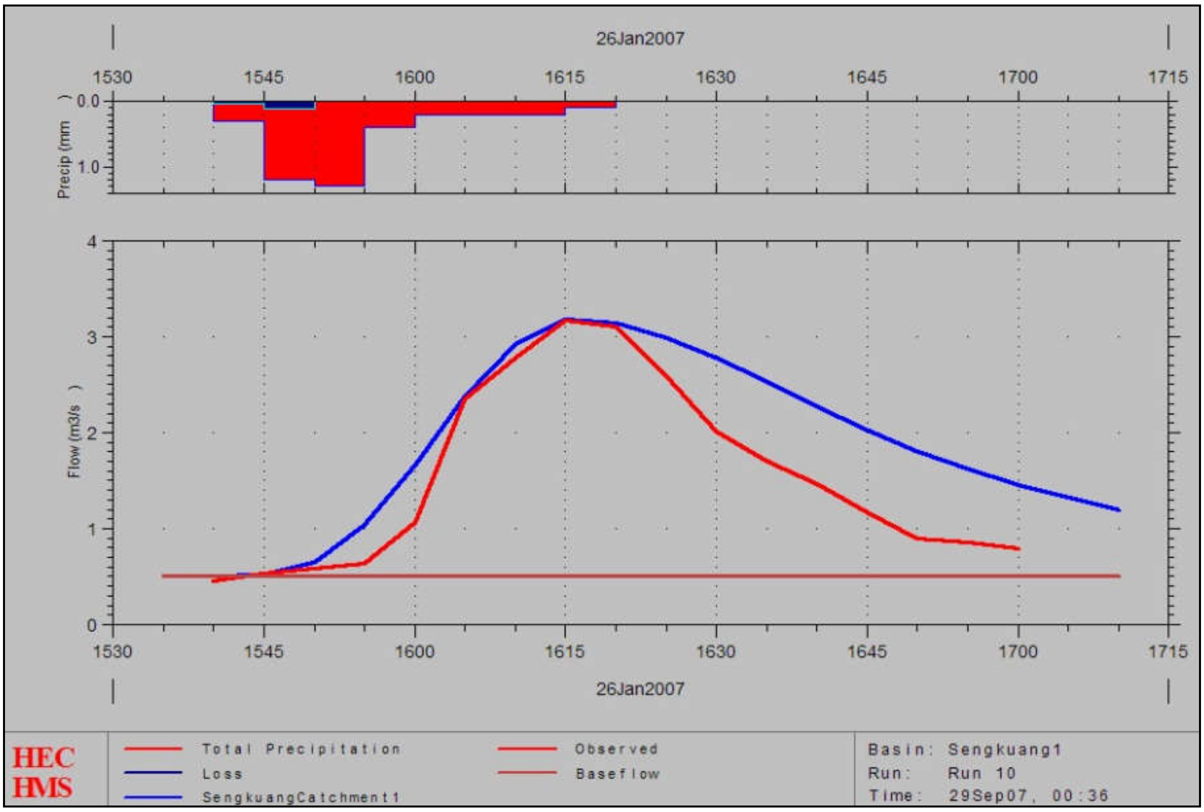

Fig.7. Result of hydrologic model validation

4.3. Part II-Hydraulic Model Calibration at CH 1040-HEC-RAS

CH 1040 is the calibration station to calibrate the channel in unsteady flow analysis. The actual discharge from the catchment 1 at CH 2607.5 and actual tide level has been entered as the upstream and downstream boundary condition. The model water level has been adjusted so that it was similar to the actual water level at jetty CH 1040), giving different values of Manning's entered into the software. From the result, the Manning's is 0.03 for CH 2607.5 to CH 1350 and 0.02 for CH 1350 to CH 0. It gives the different of about 0.06 m between model water level and actual water level. The result represented that the peak stage occurred at 3.00pm, the peak flow is 4.99 m^3/s and the volume of water is about $1000m^3$. The calibrated water level at CH 1040 as shown in Fig. 8. The results for validation are showed on Fig. 9 using the event 2 data.

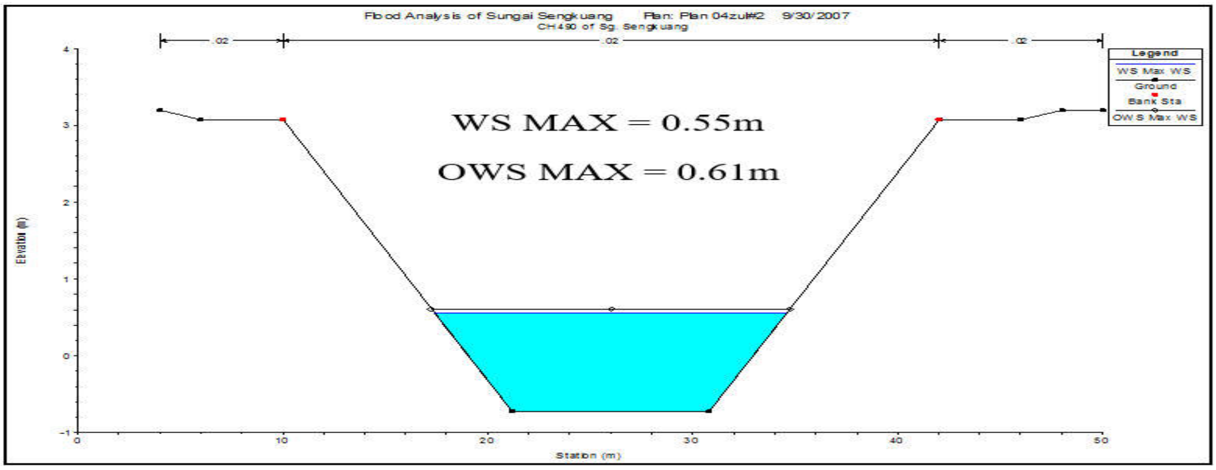

Fig.8. Calibrated water level at CH 1040

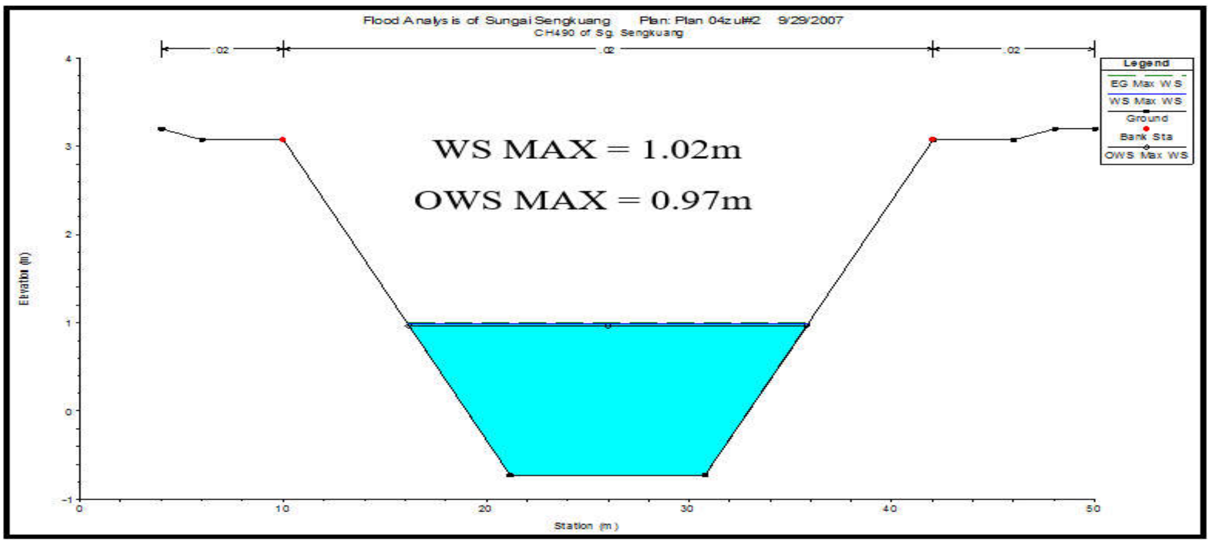

Fig.9. Result of hydraulic model validation at CH 1040

4.4. Part III-Flow Simulation CH 1350-HEC-HMS

Flow simulation are carried out to determine the discharge from catchment 2 with 5 ARI, 20 ARI, 50 ARI and 100 ARI which is representing the actual catchment of Sungai Sengkuang. Assumption has been made that catchment 1 and catchment 2 are having the same characteristics or hydrologic response. This assumption is made due to the interest point of catchment 2 is located right beside the roadway. Therefore, data collection has been carried out at catchment 1 to avoid the heavy traffic and unnecessary disturbance from the public. Design rainfall with different ARI are entered as the precipitation data in the software and the discharge are shown in Fig. 10.

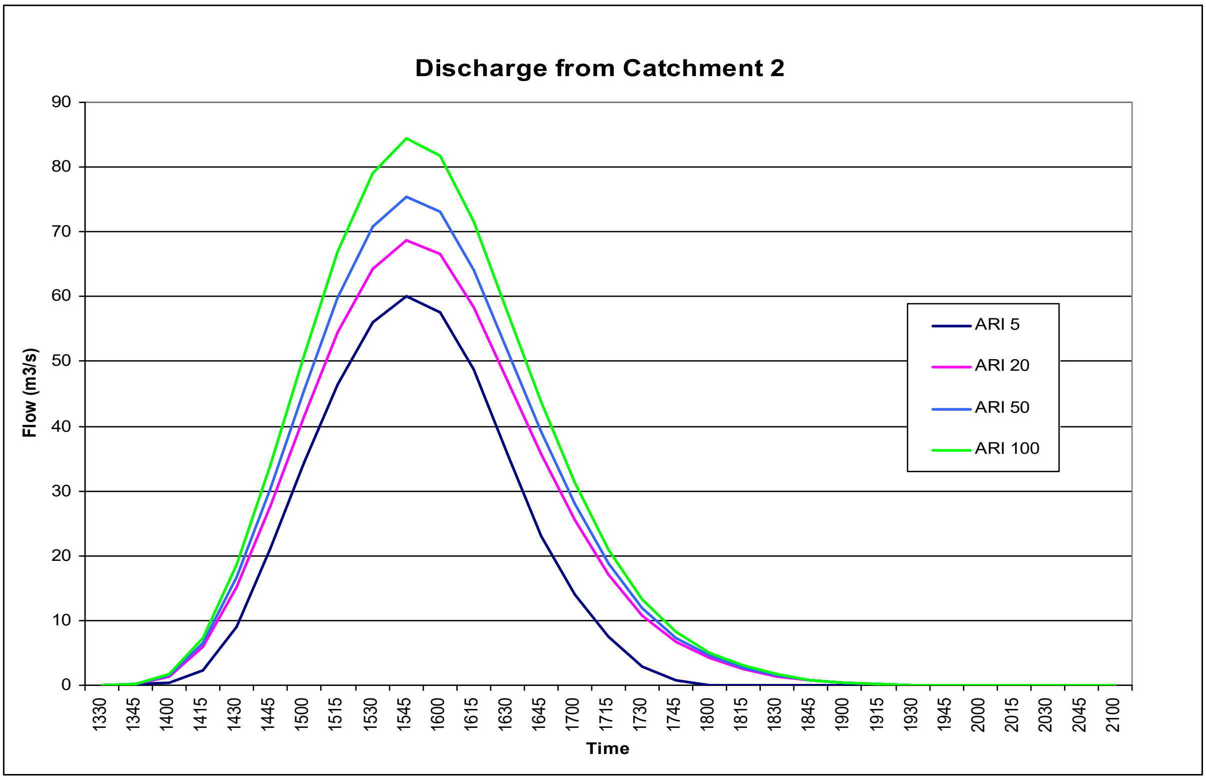

Fig.10. Discharges with 5 ARI, 20 ARI, 50 ARI and 100 ARI

4.5. Part IV-Steady Flow Analysis-HEC-RAS

Using the Manning's n value that obtained from hydraulic model calibration, the steady flow analysis was carried out from CH 0 to CH 1350. The input data from upstream boundary condition are the peak discharge with different ARI (PART III). The tide levels with different ARI which obtained from frequency analysis for the past 23 years (1984-2004) at the station of Johor Bharu are used as the downstream boundary conditions as shown in Table 3. y_o is larger than the y_c for all the ARI indicating that the flow regime of the channel is subcritical.

Table 3. Upstream and downstream boundary conditions with normal and critical depth

ARI (Year)	Upstream Peak Flow (m^3/s)	Downstream, Tide Level (m)	Normal Depth, y_o (m)	Critical Depth, y_c (m)
5	60.10	2.893	0.526	0.245
20	68.69	2.995	0.618	0.294
50	75.48	3.060	0.652	0.312
100	84.34	3.106	0.696	0.335

From the result of analysis as shown in Fig. 11, the height of water level which represented by the blue colour line in the figure is lower than the channel bank indicating that the existing channel is still able to accommodate the flow from upstream and downstream.

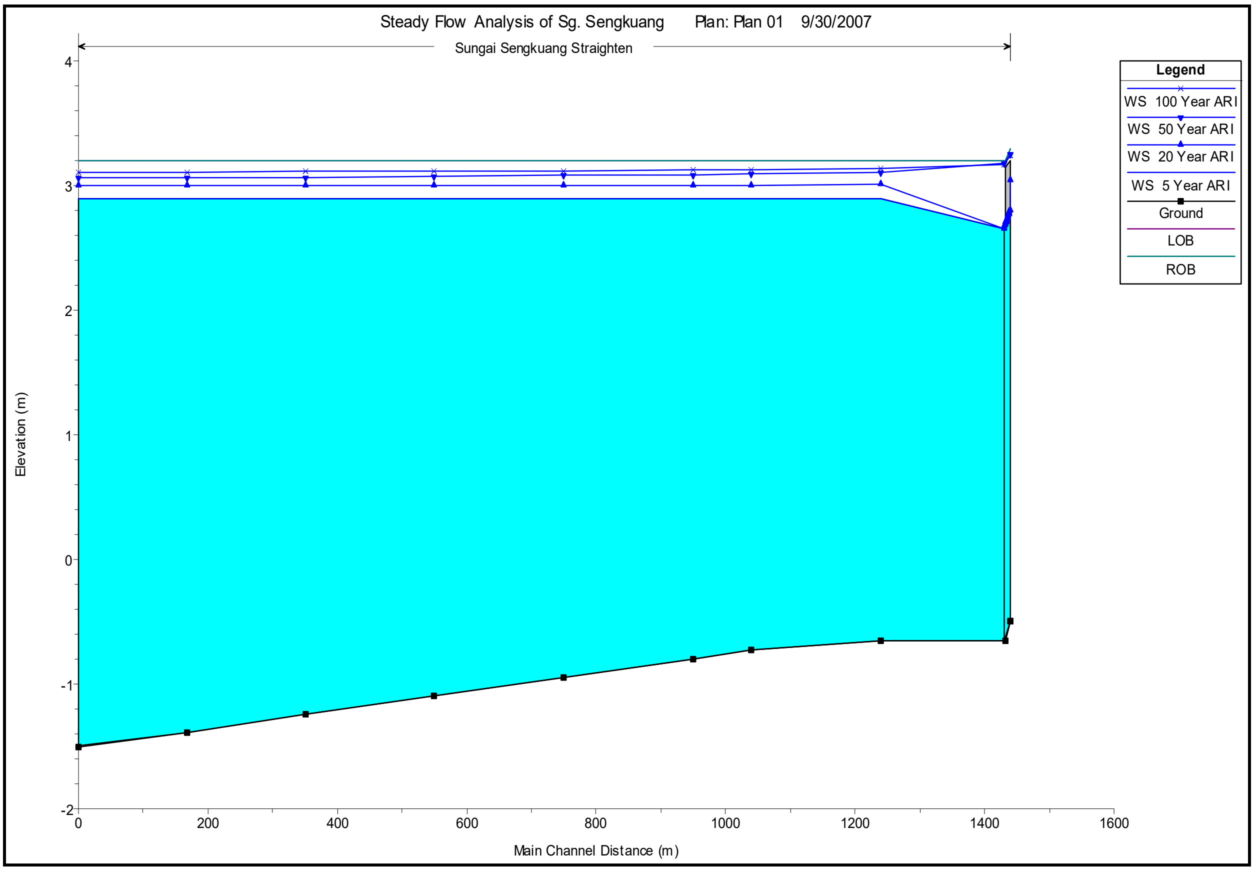

Fig.11. Water surface profile plot

As shown in Fig. 11 and Table 4, for 20 ARI, 50 ARI and 100 ARI, the channel freeboard are 0.26, 0.10 and 0.06 accordingly. This values are less than 300 mm and do not meet the standard freeboard. This result indicate that to avoid the occurrence of flood, a cross section resizing works are needed to be done to the channel.

Table 4. Water levels with different ARI

ARI (Year)	Water Level (m) LSD	Freeboard (m)
5	2.91	0.39
20	3.04	0.26
50	3.20	0.10
100	3.24	0.06

4.6. Bund Introduction

The cross section of channel needs to be improved due to the inadequate freeboard of Sungai Sengkuang. By using HEC-RAS, the steady flow analysis of existing cross section of Sungai Sengkuang with proposed bund has been carried out. The comparison between existing system and proposed system as shown in Table 5, Fig. 12 and 13.

Table 5. Comparison between existing system and proposed system

Items	Existing Details	Proposed Details	Explanation
Bank Level (m)	3.2	3.5	A 0.3 m height of bund will be added.
Invert Level (m)	-0.5 (CH 1350) -1.5 (CH 0)	-0.5 (CH 1350) -1.5 (CH 0)	It is limited by the existing invert level at u/stream and d/stream
Channel Length (m)	1350	1350	
Cross Section	Fig. 9	Fig. 12 and 13	New cross section and bund has been added to the existing channel

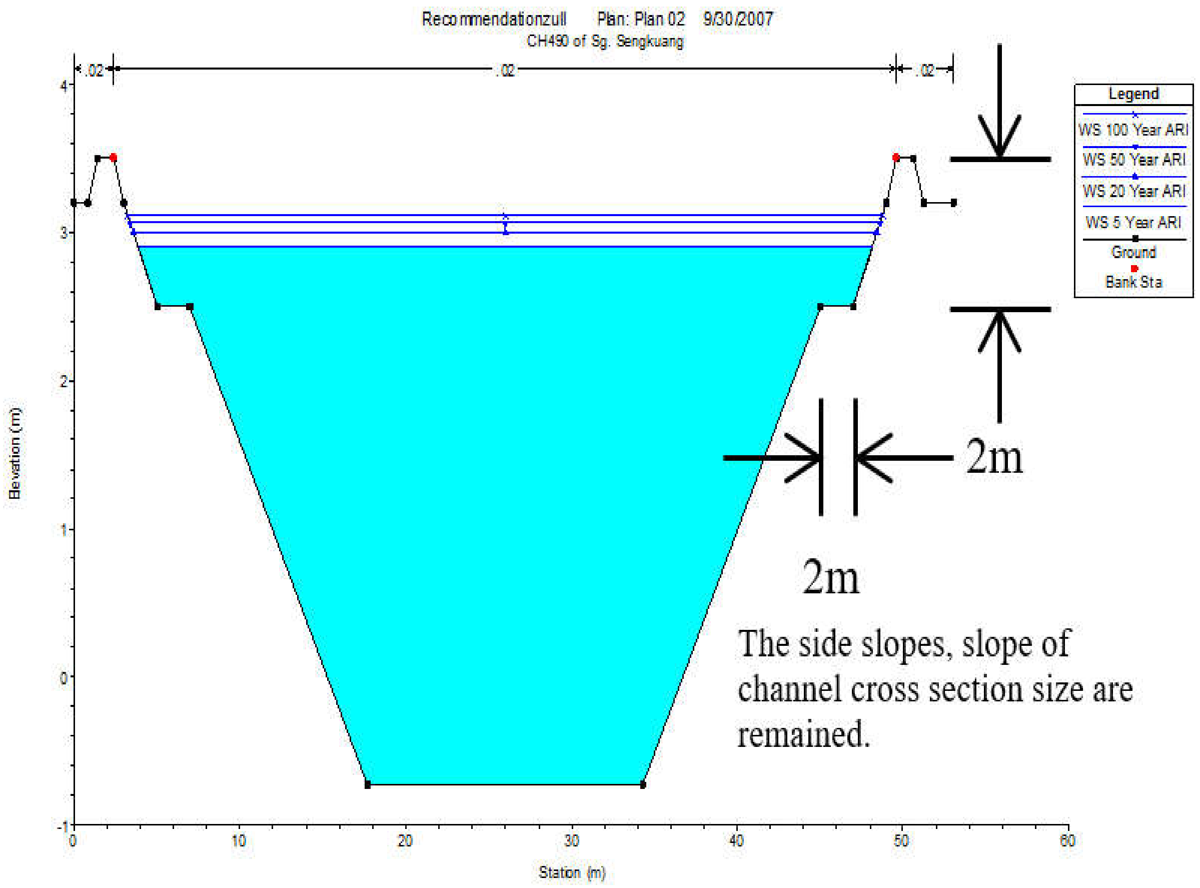

Fig.12. New cross section of proposed channel

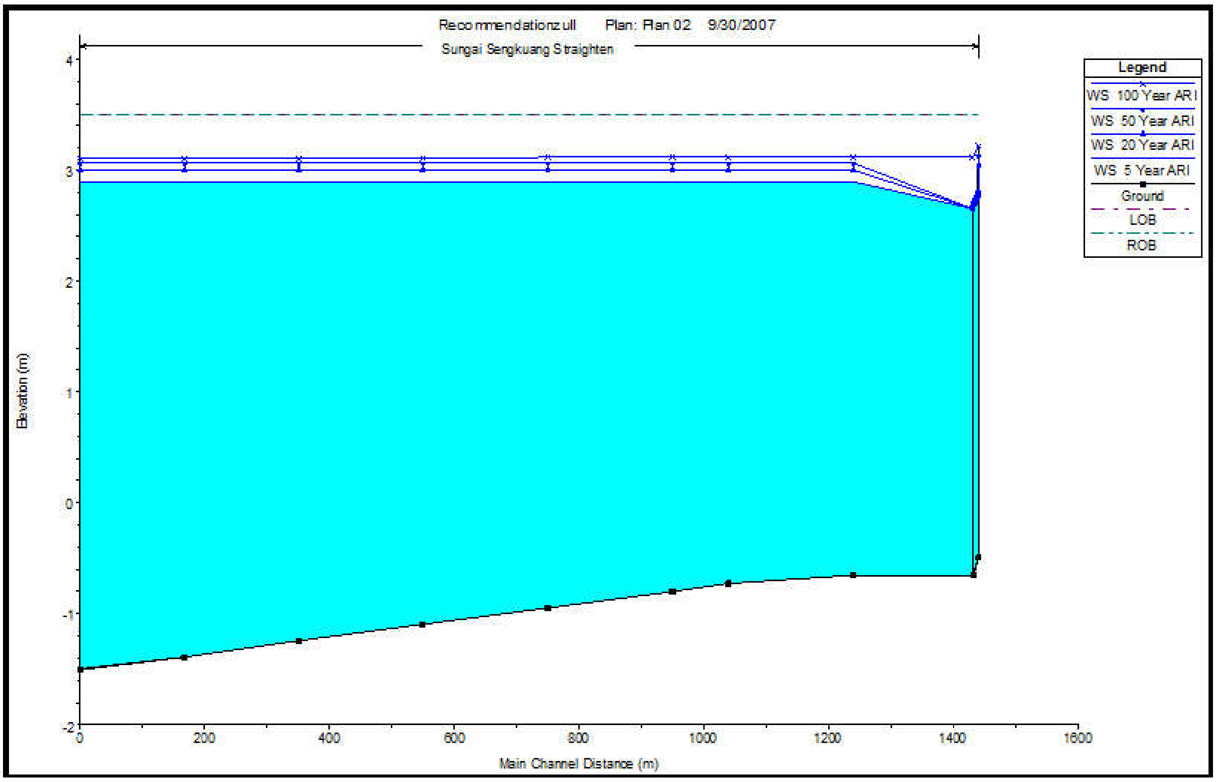

Fig.13. Water surface profile plot of proposed channel

4.7. Energy Grade Line, E

Energy grade line analysis has been carried out to determine the dominant energy whether from upstream or downstream. The analysis is carried out by comparing the results: (1) only with flow from upstream, (2) only with high tide from downstream and (3) comprises flow upstream and tide from downstream.

From the result in the first analysis, the energy grade line along the channel is quite constant until CH 167. The energy is typically dropped from CH 167-CH 0. The specific energy changes along a channel is frequently due to the changes of the bottom elevation and energy losses such as friction loss. From Fig. 14, the slope along the channel is considered gentle and constant from upstream to downstream which is 1: 1350. It is believed that the changes of energy grade line caused by the friction loss. Friction has been created by the gravel bottom of Sg Sengkuang when the water flow to the downstream. Therefore, the energy is gradually reduced when the water flows from upstream to downstream.

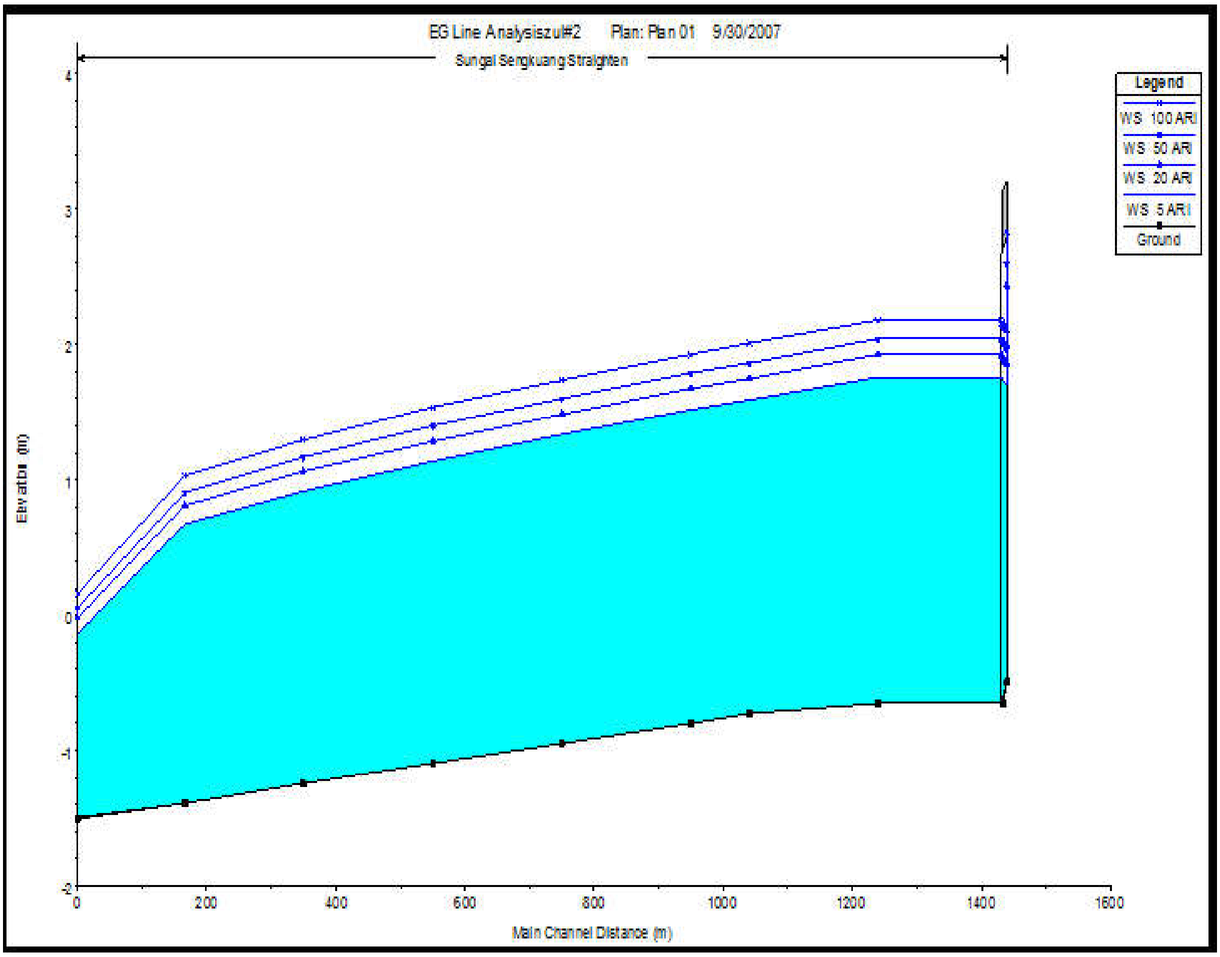

Fig.14. Energy grade line without tide

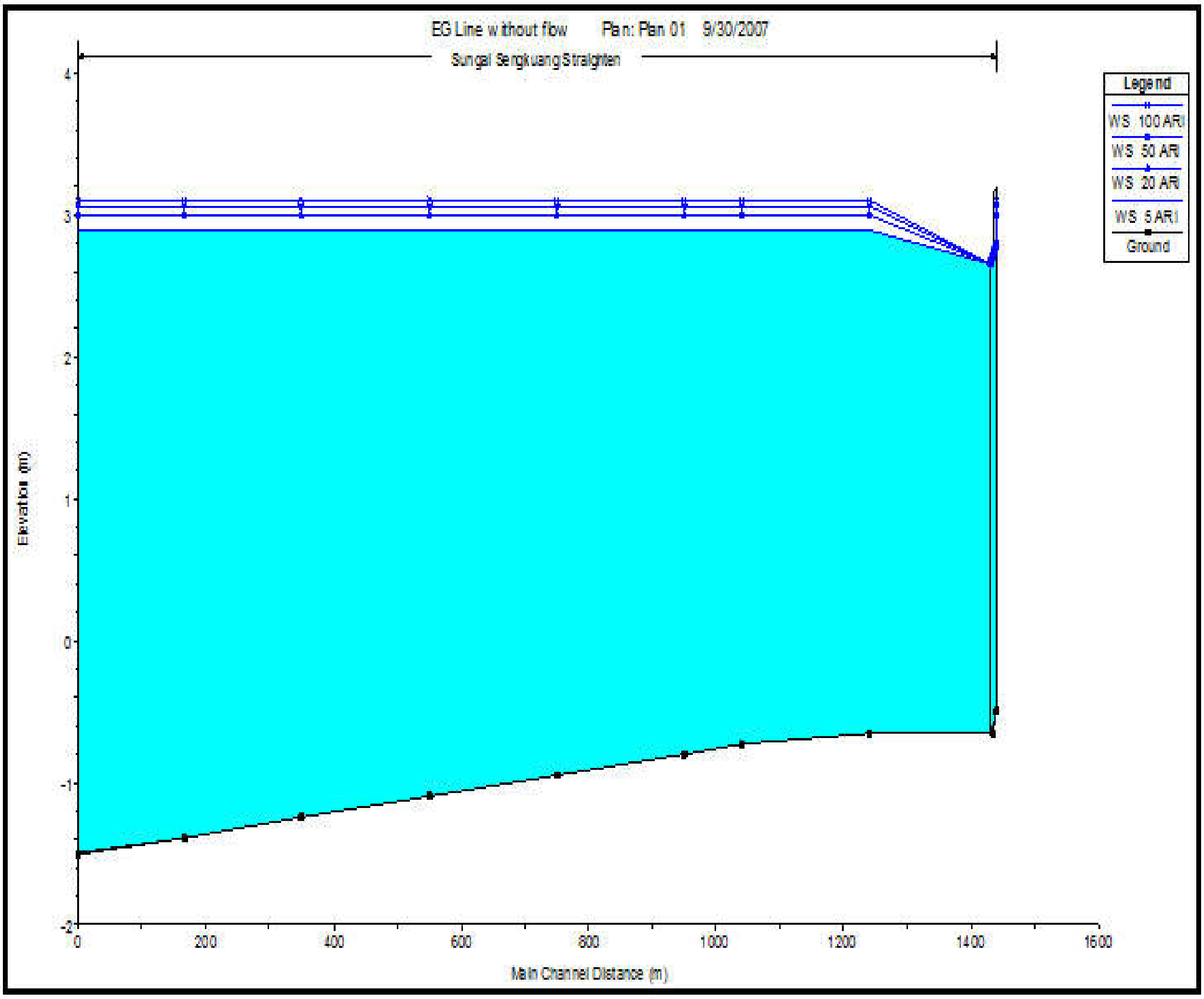

Fig.15. Energy grade line without flow

The second analysis is carried out by considering high tide from downstream, whereas the third analysis is considering both the flow from upstream and downstream. Both analyses are giving the same result as shown in Fig. 11 and Fig. 15.

From the result, the energy from downstream is obviously higher than the energy from upstream. The energy grade line is constant from CH 0 to CH 1350. In this case, the changes of bottom elevation of the channel and friction loss do not bring many effects to the energy grade line. It is because of the energy of high tide from downstream is much higher than the energy from upstream.

In conclusion, the energy of high tide from downstream is more dominant than the flow or discharge from upstream. The flat and constant energy grade line proves that the changes of energy grade line do not occur between CH 0 to CH 1350. It might occur at upstream above CH 1350 which possesses the weakest energy from downstream.

5. CONCLUSION

From the result of hydrologic and hydraulic model analysis at Sg Sengkuang shows that there was no overflow occurrence along the channel. This indicate that flow from upstream and downstream can still be accommodated by the existing channel. However, the freeboard of the channel is less than 300 mm and inadequate to the standard freeboard for open channel. Therefore, it was proposed to build a bund of 300 mm height at both sides of the channel.

The energy grade line analysis shows that the changes of energy grade line do not occur between CH 0 to CH 1350. It also has proved that the dominant energy is from downstream of the channel, which means that the tidal influence is more significant than the discharge from upstream.

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