EVALUATION OF ALLUVIAL RIVER STABILITY FOR RIVER RESTORATION:
CASE STUDY OF RAIA RIVER AND PARI RIVER

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ABSTRACT

As a result of increasing economic growth of the country, areas within river catchments are being developed into new commercial, industrialization and housing purposes. Effect of this rapid urbanization has accelerated its impact on the hydrology and geomorphology. These developments have caused dramatically increase in the surface runoff and the behaviour of their sediment output hence resulting higher sediment yield.

Since any flood mitigation works would likely affect channel modification, knowledge of predicting the geometry changes involving the sediment transport movement to maintain the channel stability and design capacity are significant and necessary.

Comparisons on several empirical design methods including regime theory and mathematical model (FLUVIAL-12) were carried out for Raia River that is considered as a natural river and Pari River, which has been canalized. Such evaluations were used to find out the appropriate method that will minimize the morphological changes in river channel.

The results indicate that mathematical model (FLUVIAL-12) comprising component of water and sediment routing is capable of predicting instability effects such as significant erosion and sedimentation along river channel.

The simulation results from FLUVIAL-12 also indicate that this model is capable of producing stable design section based on maintaining the maximum section capacity and high bank stability.

INTRODUCTION

Human-induced disturbances brought about by land use activities undoubtedly have the greatest potential for introducing enduring changes to the ecological structure and functions of river corridors. Such activities especially in urbanized areas liked converting of forested land into impervious surfaces such as roadways, rooftops and parking lots (Wolman, 1967) may ultimately result changes in hydrological and morphological impact to the river regime and it surroundings. One of the consequences is that more of a river's annual flow is delivered as storm water runoff rather than baseflow. Depending on the degree of watershed impervious cover, the annual volume of storm water runoff can increase by up to 16 times that for natural areas (Schueler, 1995). In addition, since impervious cover prevents rainfall from infiltrating into the soil, less flow is available to recharge ground water (Figure 1). Therefore, during extended periods without rainfall, baseflow levels are often reduced in urban rivers (Simmons and Reynolds, 1982).

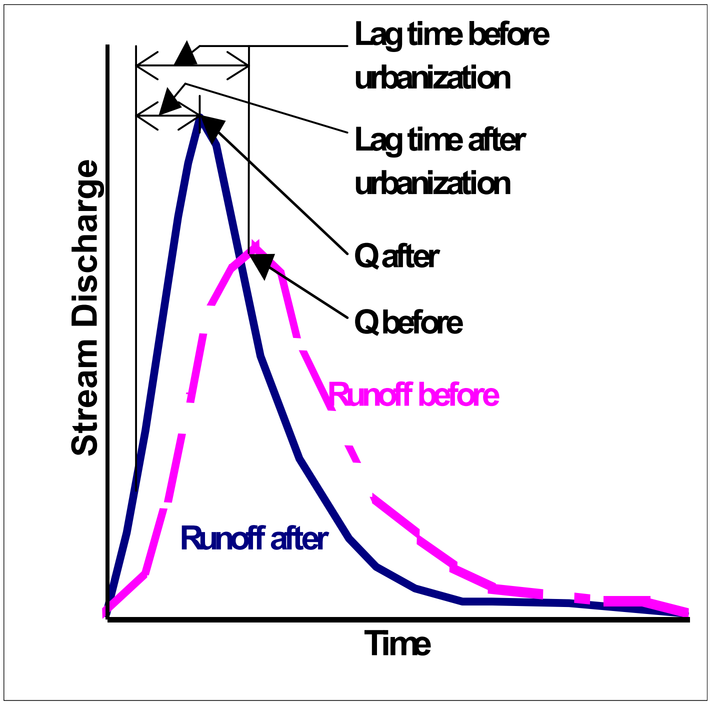


Figure 1: A Comparison of Hydrographs Before and After Urbanization (USDA, 2000).

The peak discharge due to altered hydrology associated with the bankfull flow (i.e. 1.5 to 2 years return storm) increases sharply in magnitude in urban rivers. In addition, channels experience more bankfull flood events each year and are exposed to critical erosive velocities for longer intervals (Hollis 1975, Macrae 1996, Booth and Jackson 1997). Urban rivers react by adjusting their cross-sectional area (width and depth) as well as their gradient and meanders to accommodate the higher flows (Riley, 1998).

The variability of river flow due to land use conversion is a primary influence on the geomorphic processes forming their drainage pattern, channel, floodplain, terraces and other watershed and river corridor features. No matter the size, all particles in the channel are subject to being transported downstream. The energy that sets sediment particles into motion is derived from the effect of faster water flowing past slower water. Particle movement on the channel bottom begins as a sliding, rolling and skipping motion, which transports particles along the riverbed in the direction of flow. All such processes within the river channel are a basic fact governing the behaviour of alluvial river to attain their state of equilibrium (Mackin, 1948).

Channel equilibrium involves the interplay of four basic factors;

- Sediment discharge (Q_s)
- Sediment particle size (D_{50})
- Streamflow (Q_w)
- Stream slope (S)

Lane (1955) showed this relationship qualitatively as;

$$Q_s \times D_{50} \propto Q_w \times S$$

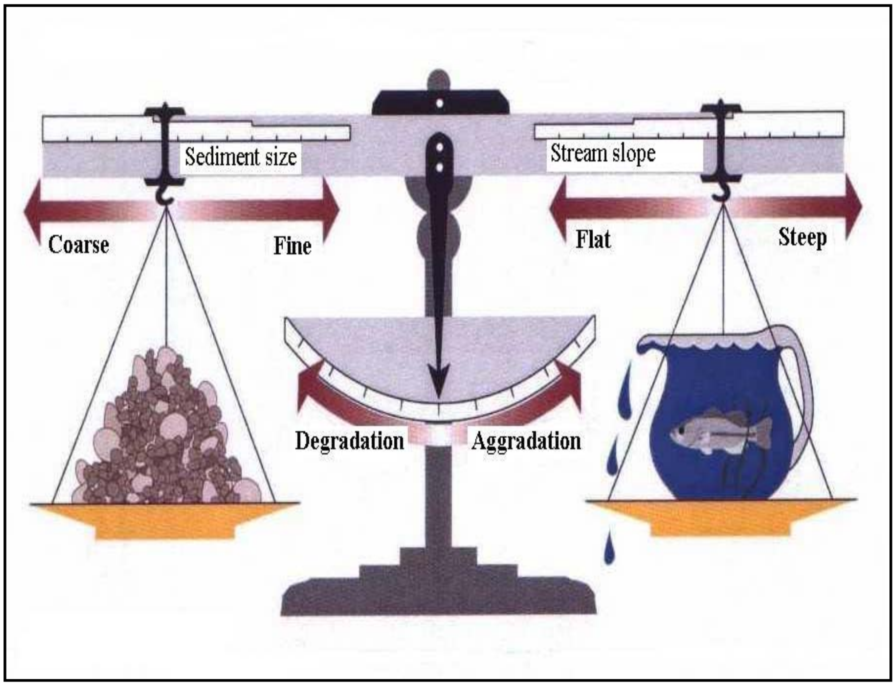


Figure 2: Factors Affecting Channel Equilibrium (Lane, 1955).

Channel equilibrium occurs when all four variables are in balance (Figure 2). If a change occurs, the balance will temporarily be tipped and equilibrium lost. If one variable changes, one or more of the other variables must increase or decrease proportionally if equilibrium is to be maintained. Alluvial rivers that are free to adjust to changes in these four variables generally do so and reestablish new equilibrium conditions. Non-alluvial rivers such as bedrock or artificial, concrete channels are unable to follow Lane's relationship because of their inability to adjust the sediment size and quantity variables. The river balance equation is useful for making qualitative predictions concerning channel impacts due to changes in runoff or sediment loads from the watershed.

MODEL DESCRIPTION

The FLUVIAL-12 model (Chang 1982, 1984, 1985) has been formulated and developed for water and sediment routing in natural and man-made channels. It is used to stimulate the combined effects of flow hydraulics, sediment transport and the associated river channel changes for a given flow period. River channel changes stimulated by the model include

channel-bed fill and scour (aggradation and degradation), width variation, and changes in bed topography induced by curvature effects.

Input data

Input to the model includes features as follows;

- the initial cross sections
- channel roughness
- time increment Δt
- sediment characteristics
- inflow hydrograph
- downstream stage-discharge relationship
- physical constraints such as bedrock outcrops, check dams and rigid banks

Output Parameters

These parameters may be requested for any selected time interval during the flow period, including;

- the stage
- discharge
- width
- depth
- sediment discharge
- energy gradient
- Froude number
- Cross-sectional profile

for each of the cross sections.

CASE STUDY

Two river reach in Kinta District i.e Raia and Pari River were selected for this study (Figure 3). Possible solution was carried out to identify the appropriate channel geometry in maintaining the existing natural channel section.

A reach of Raia River (Figure 4) in Kinta District went through significant changes and was badly damaged by the January 1999 flood (Figure 5). The natural channel configuration was distorted prior to recent flood events and also by man's activities such as sand mining at the upstream section.

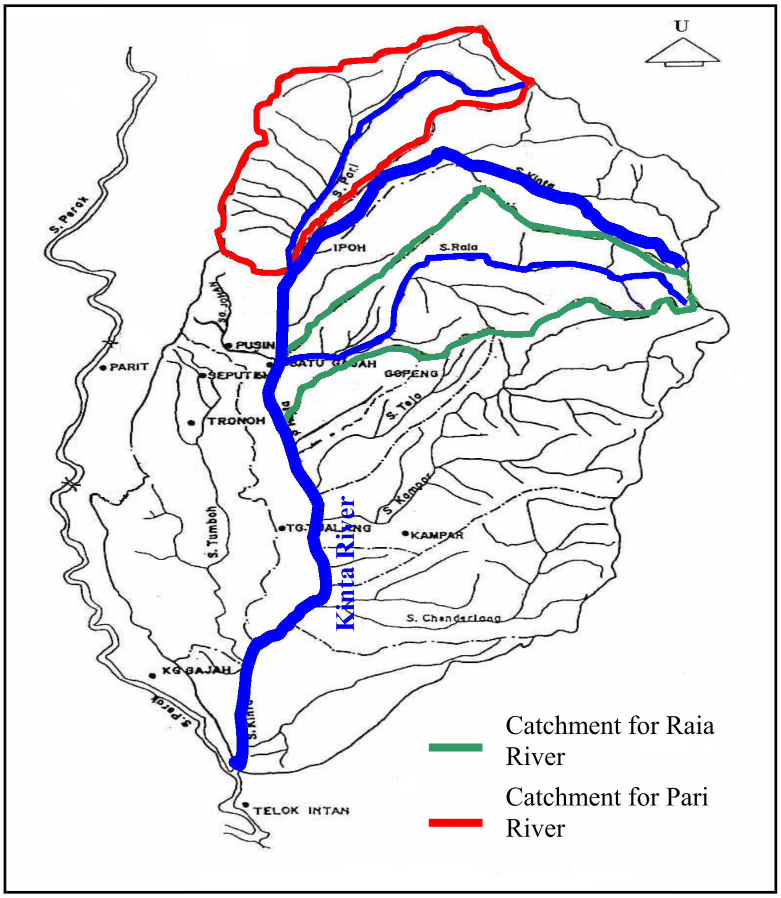


Figure 3: Catchment for Raia and Pari River (DID, Perak).

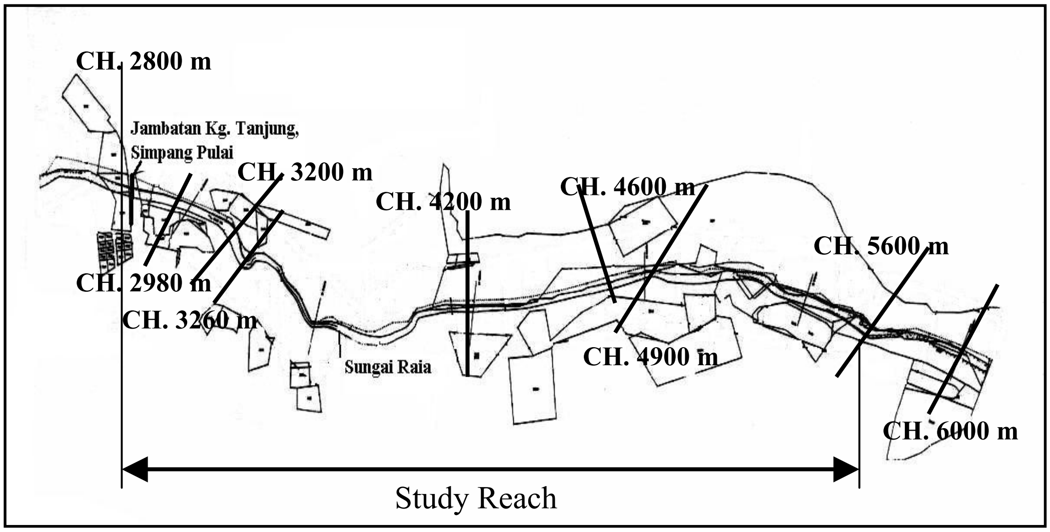


Figure 4: Study Reach for Raia River (DID Kinta/Batang Padang, 2001).

Figure 5: Flood Event of Raia River on 6 Jan. 1999 (DID Kinta/ Batang Padang, 2002).

Similarly, a reach of Pari River (Figure 6) was channelized for flood control in 1997 due to severe damage by recent flood. Low-lying areas along the river were inundated due to stagnant water effect from the existing river that could not cater the increasing discharge from the nearby development. The design channel is a rigid bank concrete and leaving the bed as natural (sand).

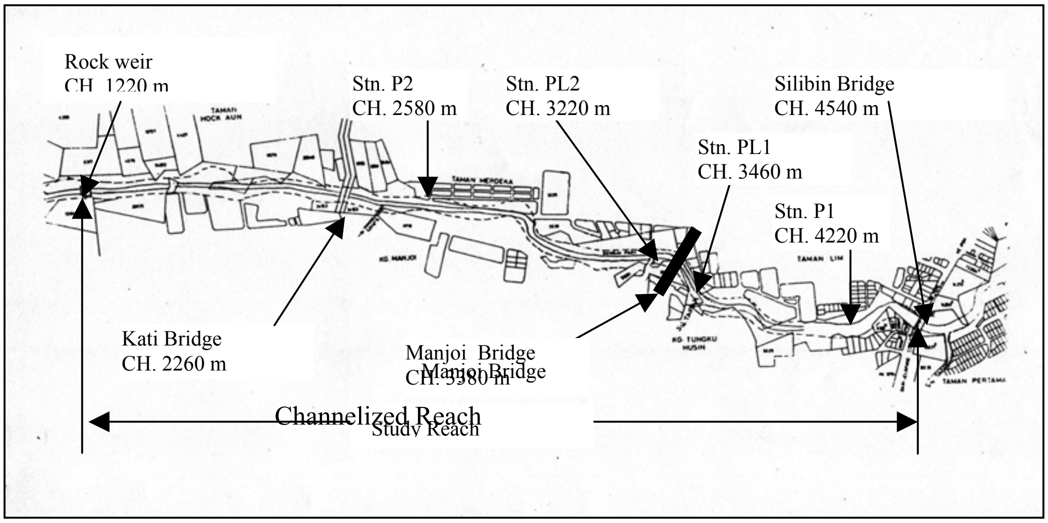


Figure 6: Study Reach of Pari River (DID Kinta/Batang Padang, 2001).

Figure 7: Flood Event of Pari River on 3 Jun. 1991 (DID Kinta/ Batang Padang, 1991).

SIMULATION PROCESS

The mathematical model FLUVIAL-12 was used to simulate river channel changes in the selected river using predicted hydrograph (Figure 8 and 9) until years 2020 obtained from Department of Irrigation and Drainage (DID). The equation by Graf is used to compute the sediment load. Variability of Manning' s n value i.e 0.045 and 0.025 was used to identify the adequacy and changes in the channel section.

Flow rating curve for each particular river was derived from downstream section using Manning's formula (Figure 9). Bed material samples from each section i.e downstream and upstream of study reach were used for simulation process (Figure 10). Each sample is divided into five size fractions and the size for each fraction is represented by its geometric mean diameter.

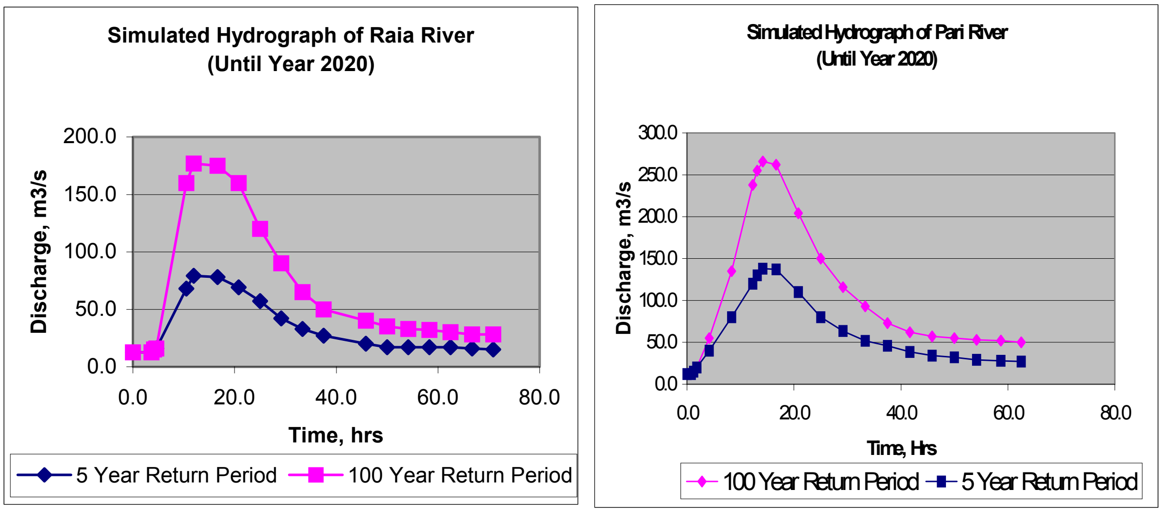


Figure 8: 100-year Flood Hydrograph For Raia and Pari River (DID, 2000).

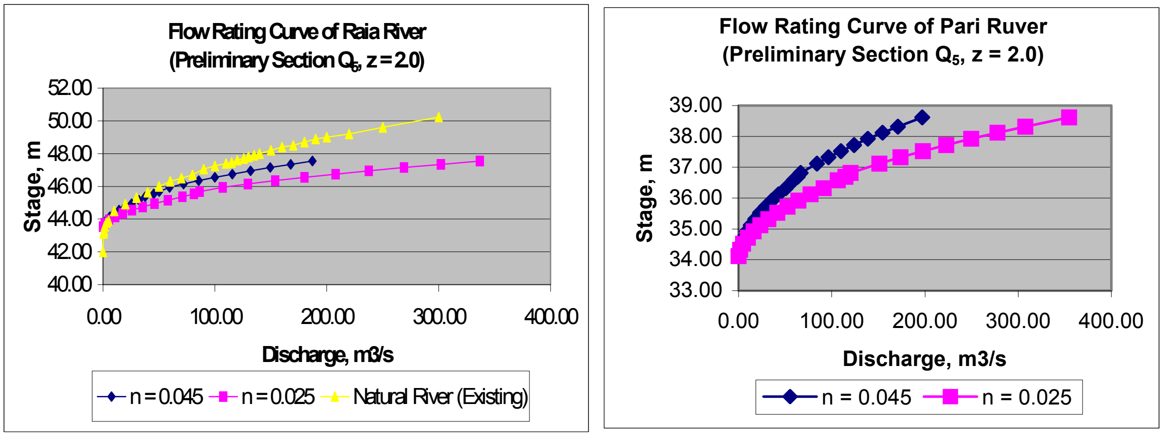


Figure 9: Flow Rating Curve for Raia and Pari River (DID, 2000).

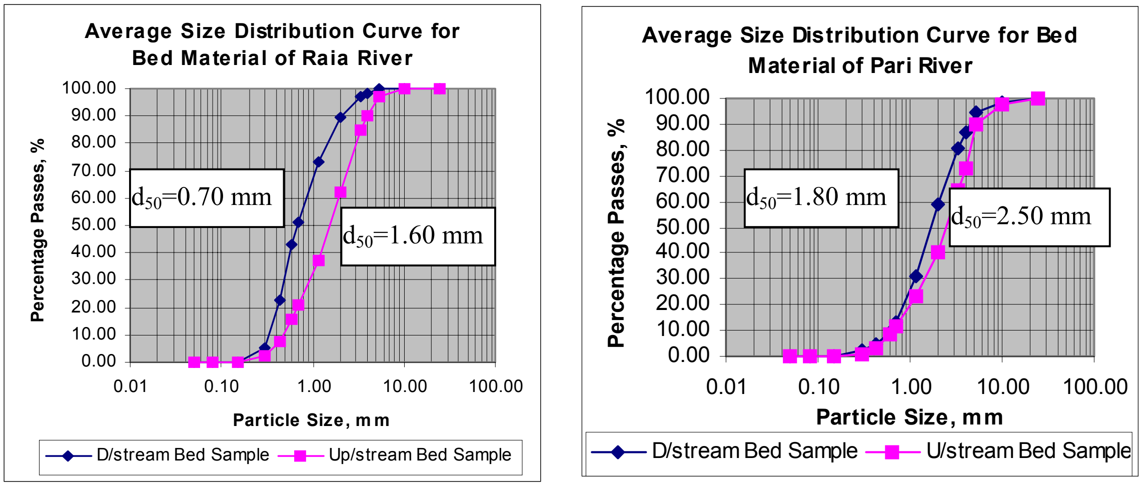
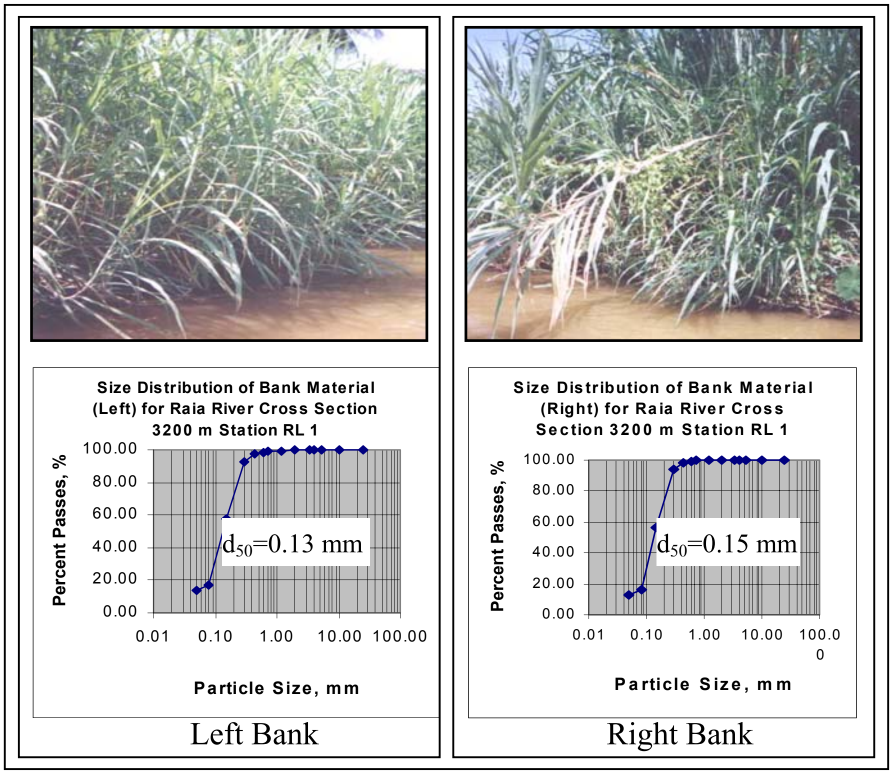


Figure 10: Average Size Distribution Curve of Bed Material for Raia and Pari River.

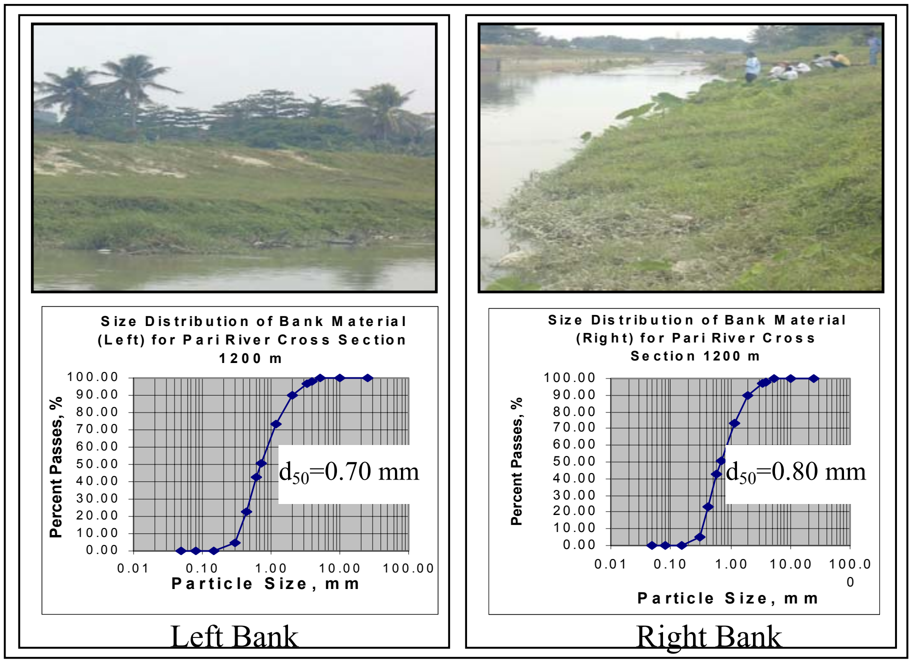
Sample of bank materials for each station, left and right bank was taken at mid-point between bed and water level. The characteristics of these sample associated with bank cover will determine the erodibility factor Fh value for each particular river section (Figure 11 and 12).



Left Bank

Right Bank

Figure 11: Characteristics of Bank Material For Raia River.



Left Bank

Right Bank

Figure 12: Characteristics of Bank Material For Pari River.

Parameters used in the simulation process are as follows;

a). Different design cross section were used in the simulation process ranging from side slope of z = 2.0, z =1.5 and z = 1.0. The purpose of these processes is to identify which section produces the best natural stable section that has minimum erosion and sedimentation in the channel.

b). Comparison of two bank erodibility factor of Fh = 1.0 and Fh = 0.5 were also used to established the various changes occurred at the bed and bank section.

c). Roughness in terms of Manning 's n obtained from calibration results of 0.045 and 0.025 were used in the model process to identify the variation in the channel capacity.

SIMULATION RESULTS

Simulation results using mathematical model (FLUVIAL-12) for Raia River and Pari River are presented as follows;

Figure 13 shows that simulated water surface profile (n=0.045) of Raia River for cross section side slope z = 2.0 is below design bund level compared to cross section side slope z = 1.5 and z = 1.0 which is above design bund level.

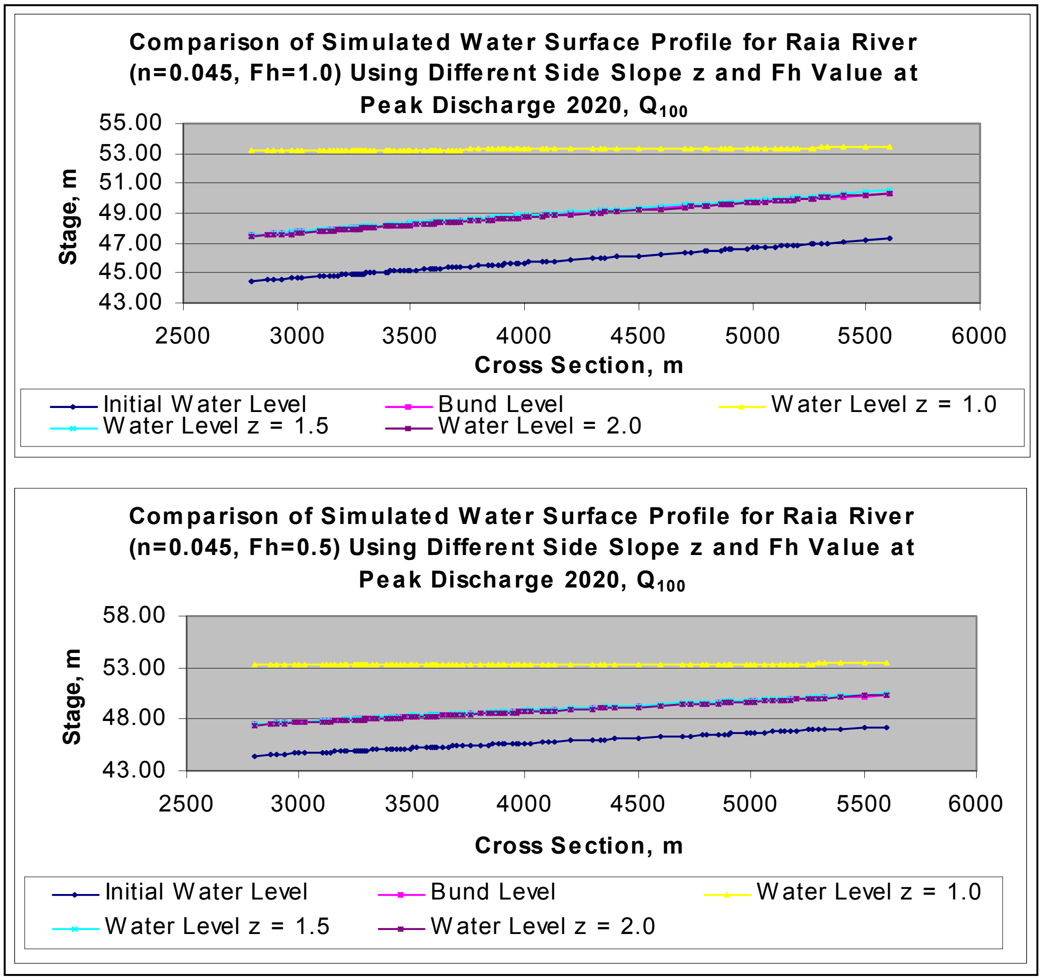
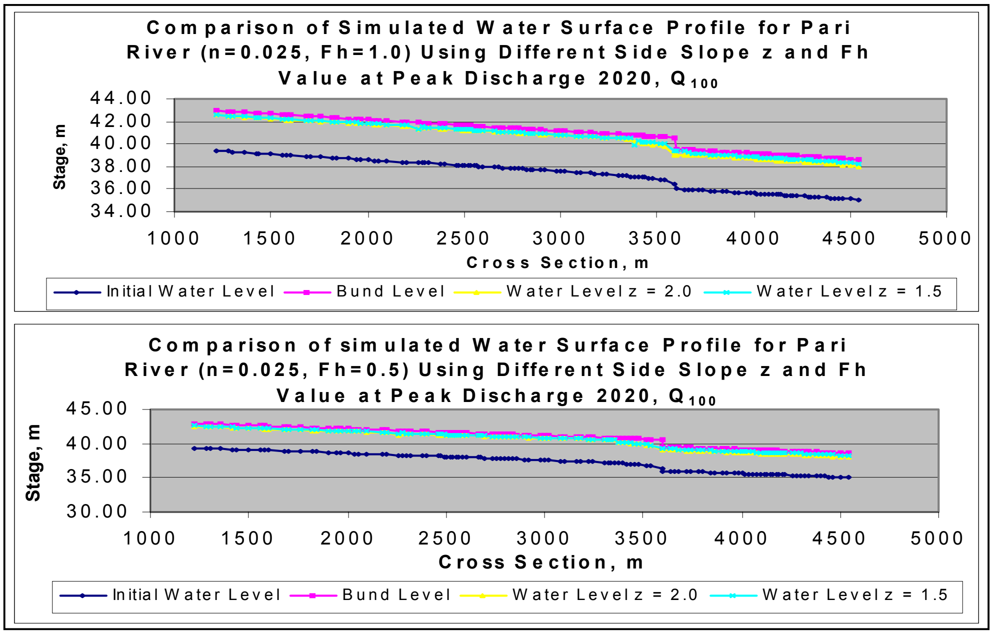


Figure 13: Comparison of Simulated Water Surface Profile Of Raia River (n=0.045) Using Different Side Slope z and Fh Value at Peak Discharge 2020, Q_{100}.

Similarly Figure 14 shows that simulated water surface profile using Manning's n=0.025 of Pari River for cross section side slope z = 2.0 is well below design bund level compared to other cross section.

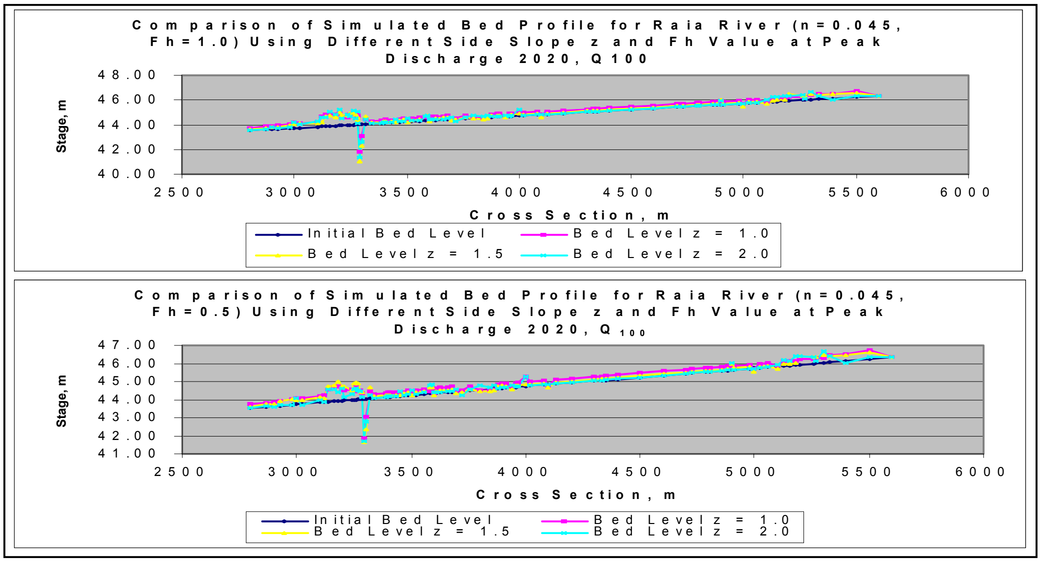


Comparison of Simulated Water Surface Profile for Pari River (n=0.025, Fh=1.0) Using Different Side Slope z and Fh Value at Peak Discharge 2020, Q_{100}

Comparison of simulated Water Surface Profile for Pari River (n=0.025, Fh=0.5) Using Different Side Slope z and Fh Value at Peak Discharge 2020, Q_{100}

Figure 14: Comparison of Simulated Water Profile for Pari River (n=0.025) Using Different Side Slope z and Fh Value at peak Discharge 2020, Q_{100}.

Figure 15 indicate that the simulated bed profile for Raia River (n=0.045) cross-section side slope z = 2.0 demonstrate a minimum changes in bed level compared to cross section side slope z = 1.5 and z = 1.0.



Comparison of Simulated Bed Profile for Raia River (n=0.045, Fh=1.0) Using Different Side Slope z and Fh Value at Peak Discharge 2020, Q 100

Comparison of Simulated Bed Profile for Raia River (n=0.045, Fh=0.5) Using Different Side Slope z and Fh Value at Peak Discharge 2020, Q_{100}

Figure 15: Simulated Bed Level Changes of Raia River (n=0.045) Using Different Side Slope and Fh Value At Peak Discharges 2020, Q_{100}.

Figure 16 shows that simulated bed profile for Pari River using Manning's n = 0.025 experiencing a minimum changes in bed level changes compared to other cross section.

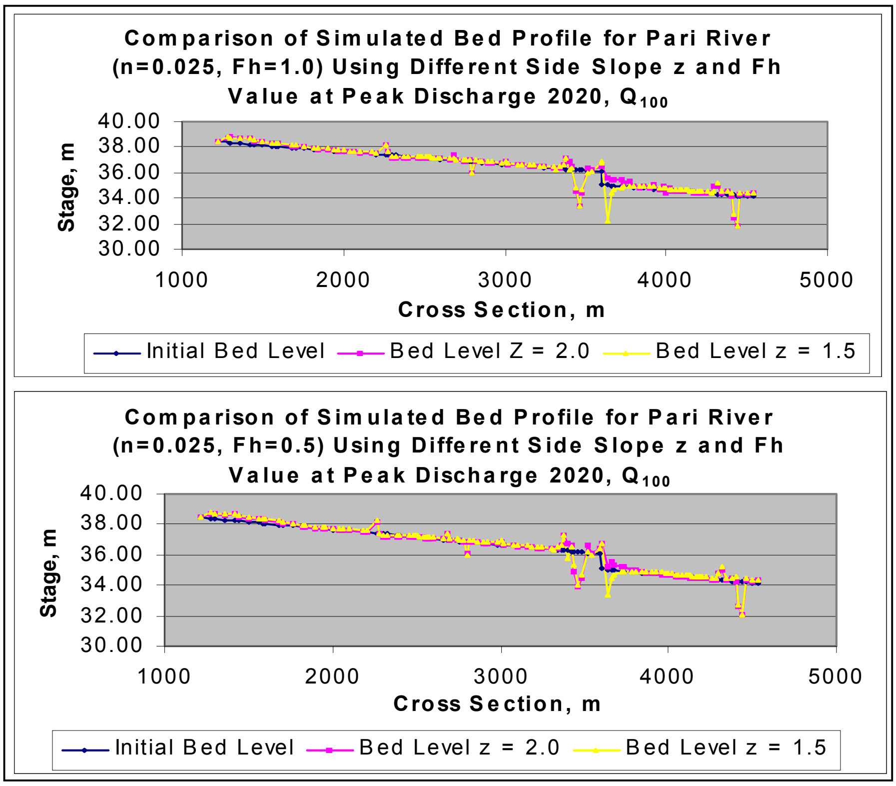


Figure 16: Simulated Bed Level Changes for Pari River (n=0.025) Using Different Side Slope z and Fh Value at Peak Discharge 2020, Q_{100}.

Figure 17 demonstrates different method of designing natural stable channel and FLUVIAL-12 seem to produce and agreements with the measured cross-section at site.

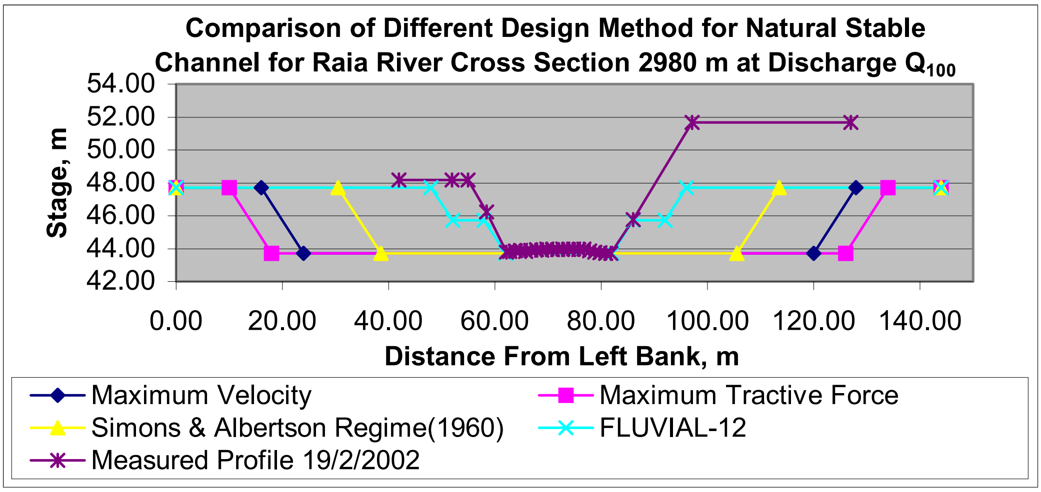


Figure 17: Comparison of Different Design Method for Natural Stable Channel for Raia River.

SUMMARY AND CONCLUSIONS

A mathematical model for water and sediment routing through alluvial channels was employed to simulate cross section changes and instability problem during specified flow, thereby providing the necessary information whether a river section can still be maintained in a natural state in order to carry maximum discharge.

These simulated results show that Raia River can still be maintained as natural condition while for Pari River few options can be implemented in order to retain the natural cross section. As for Pari River, chances of retaining to it natural state need to be done by assuring the flow resistance to the value of Manning's n = 0.025.

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