BACHELOR OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING

Flow Simulation Using One Dimensional HEC-RAS Model: A Case Study on Jamuna River

by

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October, 2013

DECLARATION OF CANDIDATE

It is hereby declared that this Thesis or any part of it has not been submitted elsewhere for the award of any Degree or Diploma.

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DEDICATION

This thesis is dedicated to our beloved parents and all our well wishers helping us to accomplish this work.

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ACKNOWLEDGEMENTS

Every honor and every victory on earth is due to the Great Almighty, descended from Him and must be ascribed to Him. He has given us the capability to do all this work. This thesis is a result of research of one year and this is by far the most significant scientific accomplishment of our lives. It would be almost impossible without support and appreciation of those who mattered most. We would like to express our heartiest gratitude to our supervisor, Professor. Dr. Md. Munsur Rahman for his supervision, inspiration and unbounded support for doing this work. We would also like to pay our heartiest gratitude to Professor Dr. Rezaul Karim, for his support and guidance. We would like to extend our thanks to Mr. Ali Mohammed Rezaie for helping us by providing important data of Jamuna river. We are also thankful to the Head of the Department Prof. Prof. Dr. A.K.M. Sadrul Islam for his guideline and support for our thesis. Last but not the least we are thankful to our parents and our respected elder brothers, colleagues, friends and relatives who have always supported us in our work.

Abstract

This study represents the result of flow simulation in the Jamuna River using one dimensional HEC-RAS model. The Water bed profile is different in different cross section of a river. This study determines the differences in water level elevation for different years and determines the changes in bed profile in different cross-section of the river Jamuna. In this study, cross section of river, river depth, wetted perimeter, water depth in different cross sections were used to simulate the flow using one dimensional HEC-RAS. From the result of simulation, we can assume the increase or decrease in the bed profile for future years.

1. Introduction

1.1 Purpose of the paper

One of the major purposes for using HEC-RAS is to compute water surface elevations. This is where Hydrology and Hydraulics come together; hydrology allows us to calculate information such as 100-year flood flow, probable maximum flood flow (PMF), etc., then using this information in HEC-RAS we can figure out what the possible hydraulic conditions will be for a given study area. Therefore, knowing the water surface elevation under various flow conditions can be helpful for many reasons, some of which are: to evaluate possible flooding; for bridge/culvert design work; for riprap placement; to determine construction risk; for obtaining permits from natural resource agencies; when building structures such as bridges, culverts, homes, erosion control measures, etc., to evaluate the differences in water surface elevation before and after construction in order to comply with local, county, and FEMA regulations. HEC-RAS may also be used to generate flow velocities for use in studying erosion and scour or for obtaining permits.

In this thesis, we simulated the flow of braided Jamuna river to determine the water level elevation by comparing the simulation results for the year 2011 and 2012. We also focused on different sides of analysis using HEC RAS. All the data (upstream and downstream) inserted in this analysis are related to braided Jamuna river.

1.2 Project Agenda

The primary agenda of our thesis is to simulate the flow of upstream and downstream of the river Jamuna for the year 2011 and 2012 and from that simulation identify the difference (increase/decrease) in water level elevation in those two years using one-dimensional HEC RAS modeling. We’ll consider at least fifteen to seventeen cross section of the river Jamuna for the simulation purpose. The model setup will be accomplished taking into account the special requirements and goals that have been defined for the whole project. The morphological features i.e. Water Level, Channel top width, maximum channel depth from water level, maximum channel depth location from left bank pillar, average channel depth from water level, cross sectional area of the channel, hydraulic radius of the channel.

1.3 Deliverables

The deliverables that'll be provided along with our thesis are following:

(1) A power point presentation including the demonstration of modeling process
(2) A paper including the simulation of the flow of the river of Jamuna for the year 2011 and 2012 and comparing the results to assume the future raise in water level.
(3) Details of different types of analysis using HEC RAS which includes Steady Flow Analysis, Unsteady Flow Analysis, Sediment Analysis, Water Quality Analysis, Hydraulic Design Functions

2. Literature Review

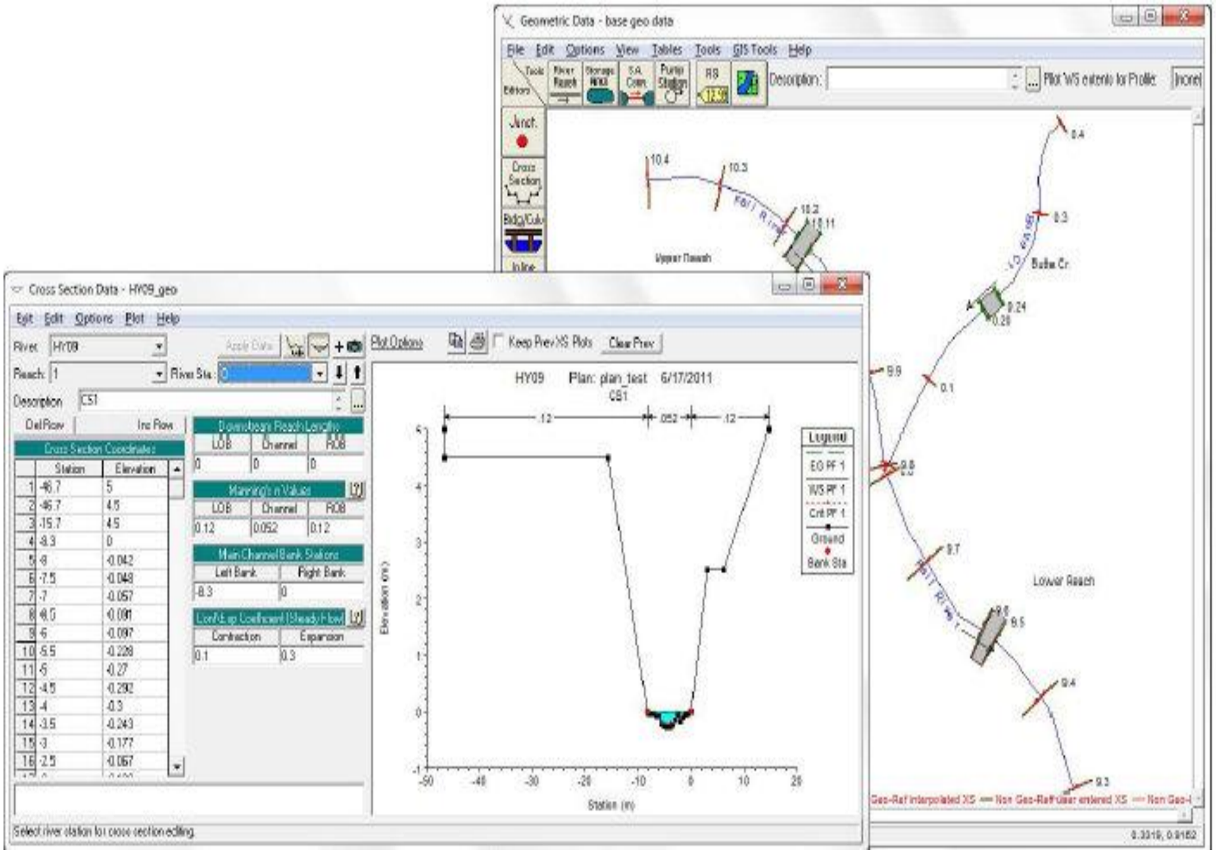
Some study has been carried out in the braided Jamuna river before this project. But all those project were related to sediment transport analysis using the one dimensional HEC-RAS model.

A study by M.R Kabir and Nasir Ahmed was conducted in the year 1996 regarding the sediment transport analysis in braided Jamuna River. In that study they determined the amount of sediment transported per year in the braided Jamuna river using the HEC-RAS model.

"MODEL-BASED HYDRAULIC ANALYSIS OF FLOW AND SEDIMENT TRANSPORT IN THE CHANGJIANG BASIN IN THE POYANG LAKE REGION, CHINA" conducted by Alexander Strehmel also aimed at determining the sediment transport using HEC-RAS model. It also aimed at simulating the flow of the river CHANGJIANG Basin by one dimensional HEC-RAS Model.

3. The Model HEC-RAS

The one-dimensional model HEC-RAS (Hydraulic Engineering Center – River Analysis System) is a mainly physically-based modelling system to analyze river flow, sediment, and water quality dynamics. It was developed as part of the Hydraulic Engineering Center's project "NextGeneration" (NexGen) and first released in the year 1995. The project's goal was the development of several state-of-the-art software systems for hydrologic engineering. It included new software solutions for rainfall-runoff-modelling (HEC-HMS), reservoir system simulation (HEC-ResSim), flood damage analysis (HEC-FIA and HEC-FDA), real-time river forecasting for reservoir operations (CWMS) and river hydraulics (HEC-RAS). Due to its development within a larger set of software solutions for hydrologic engineers, HEC-RAS therefore is also highly compatible with the other model solutions and data exchange is made easy in order to be able to couple different modeling approaches for the analysis of complex hydrological problems (USACE, 2010a). The release of the first version of HEC-RAS (1.0) in 1995 was followed by numerous improvements of the software during the following years, including not only an improved user interface, but also crucial improvements to the functionality and possibilities of analysis within HEC-RAS. The latest HEC-RAS version is available free-of-charge under a public domain license from the website of the U.S. Army Corps of Engineers1. The current version (4.1) was released in January 2010. This version includes four main analysis modules, as well as a module to implement the geometry of the river system under examination (Fig. 2). The four analysis modules will be introduced briefly in the following section.



River: HY09
Reach: 1
River Sta.: 0
Description: CS1

Cross Section Coordinates

	Station	Elevation
1	-46.7	5
2	-46.7	4.5
3	-15.7	4.5
4	-8.3	0
5	-8	-0.042
6	-7.5	-0.048
7	-7	-0.057
8	-6.5	-0.091
9	-6	-0.097
10	-5.5	-0.228
11	-5	-0.27
12	-4.5	-0.292
13	-4	-0.3
14	-3.5	-0.243
15	-3	-0.177
16	-2.5	-0.067

Downstream Reach Lengths

LOB	Channel	ROB
0	0	0

Manning's n Values

LOB	Channel	ROB
0.12	0.052	0.12

Main Channel Bank Stations

Left Bank	Right Bank
-8.3	0

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Select river station for cross section editing

Figure 1: HEC-RAS Modeling Interface

3.1 Modeling Modules

Steady Flow Analysis

This component calculates water surface profiles from steady input discharge data at an upstream cross-section, from river geometry as well as surface roughness data for the river section under examination. The main output variables of this analysis are the water surface elevation above a base altitude for the defined river cross-sections as well as the flow velocity. It is possible to gradually alter the discharge at every defined cross-section (quasi unsteady flow). The analysis module is capable of handling not only single reaches, but whole river networks. Furthermore it is possible to model also mixed and supercritical conditions aside from subcritical conditions. The calculations in this component of the model are performed using the one-dimensional energy equation. For river junctions, the hydraulic simulation of bridges or mixed flow regime calculations furthermore the momentum equation is employed (Chapter 4.1, Equation 4-9). The steady flow analysis is especially useful for floodplain management, flood insurance studies, but also to assess the effect of channel modifications on water level heights at certain discharge values (USACE, 2010a). For this thesis the steady flow module will mainly be used to calibrate the models for the river sections.

Unsteady Flow Analysis

With this component it is possible to simulate unsteady discharge conditions within a river network. It is therefore possible with this module of the HEC-RAS software to analyze the effect of a storm flow hydrographs flood wave on the stream network. The main model output consists, as in the steady flow analysis, also of water surface elevations at the defined cross-sections and the flow velocity, but in this analysis printed as a graph over time. For unsteady channel flow analysis the HEC-RAS model solves the 1D St. Venant equations for continuity and momentum. Special features of the unsteady flow module include dam break analysis, levee breaching and overtopping as well as simulation of pressurized pipe systems (USACE, 2010a). In the context of this thesis the unsteady flow analysis is used to simulate flow dynamics in the river sections under examination for the simulated hydrographs that are handed over from the SWAT model of the catchment.

Sediment Transport Analysis

Within this component of HEC-RAS it is possible to analyze sediment transport dynamics, based on erosion and accumulation processes within the river bed. At the same time the module considers alterations in the channel geometry due to scouring or deposition. The component is designed to calculate the sediment dynamics of single reaches, but also whole river networks, over longer time periods, usually several years. Nevertheless an application based on single flooding events is possible (USACE, 2010a). The main input data for the sediment transport simulation are, besides the basic discharge and geometry information, the grain size fractions for the defined cross-sections. The user can choose between several sediment transport and sorting functions in order to fit the model output as good as possible to the conditions of the real river system. The component is usually used 18 to assess deposition in reservoirs, estimate scour during flood events, but also to design channels in a way to keep depths within a limit for the river to be navigable (USACE, 2010a). In this thesis the sediment transport simulation will be used to assess sediment discharge and grain size dynamics within the examined river sections.

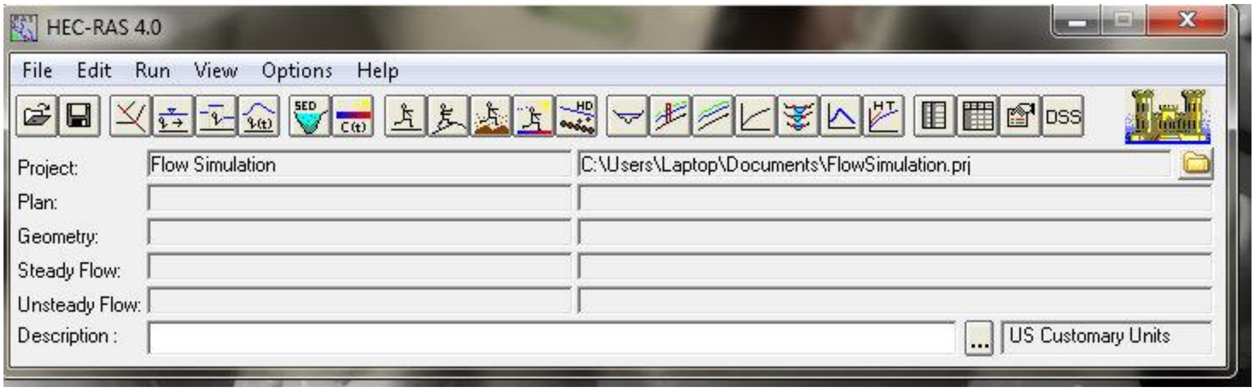
Water Quality Analysis

This component of HEC-RAS allows mainly for detailed water temperature analysis. Nevertheless it is also possible to model transport processes for a limited number of water constituents relevant for information on the water quality of a river. These include algae, dissolved oxygen and dissolved compounds of phosphate or nitrogen. The water quality analysis tool was first implemented in HECRAS 4.0. It is therefore planned to develop this component towards a higher functionality for future versions of the software (USACE, 2010a). In the course of this thesis the water quality component of HEC-RAS is not used.

3.2 Model properties

User Interface

All functionalities for model setup, running and result analysis within HEC-RAS are operated using a graphical user interface (GUI) (see Fig. 3). The design of that interface is intended to be intuitive and enables also inexperienced users to get a feeling for the way, how the modelling system works and what possibilities it encompasses. During the application of the model it becomes clear however that the way the interface is designed makes it sometimes difficult to find very specific functions of the model, as it is not always possible to call desired functions in the presumed context of the GUI. All-in-all nevertheless the interface eases the data management through well-defined data input masks, and a lot of data management work is taken off the user's hands, which is helpful during the model setup, especially to avoid unnecessary errors during data input.



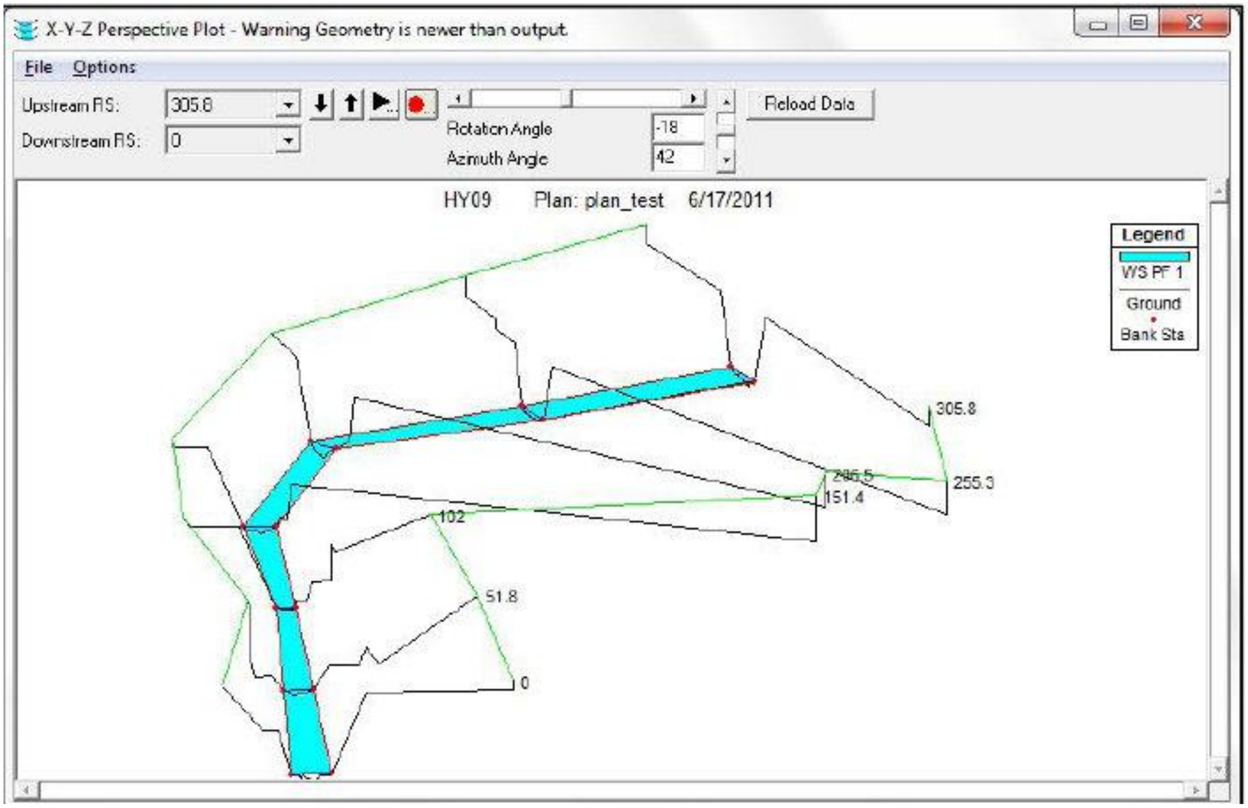
Project: Flow Simulation C:\Users\Laptop\Documents\FlowSimulation.prj
Plan:
Geometry:
Steady Flow:
Unsteady Flow:
Description : US Customary Units

Figure 2: HEC-RAS main window

Data Management

The input data components (e.g. river geometry, steady flow data, etc.) are all organized in separate files to allow for a better overview of the multitude of input data, but also to enable for different combinations of, e.g. geometry and flow information for different modelling attempts. The information that is relevant for the whole modelling project is saved in a project file. This file however contains no input data of the model. It just links the input data files to the project. Separate input data files are created for all four analysis modules of HEC-RAS as well as for the river network geometry. In order to perform a model run the input data files needed for the kind of analysis are brought together and saved in a plan file.

Data storage is achieved by using ASCII and binary file formats. Additionally the HEC-DSS format is used to export data to other applications. Output data are usually stored using separate binary files(USACE, 2010a)


X-Y-Z Perspective Plot - Warning Geometry is newer than output

Upstream RS: 305.8

Downstream RS: 0

Rotation Angle -18

Azimuth Angle 42

Figure 3: Geometric data representation in HEC-RAS

HEC-GeoRAS

To make easy implementation of GIS-based data into HEC-RAS possible, the ArcGIS (ESRI, 2000) extension HEC-GeoRAS was developed. The current version of HEC-GeoRAS (4.3) was released in February 2011. The main functionality of the software is to derive geometric data for input into HECRAS from digital terrain data. Additionally, it is possible to define cross-section locations, stream junctions, in-stream structures, but also roughness parameters for river sections. All these parameters can be brought in the specific input format necessary for HEC-RAS from raster or vector input GIS data. Additionally, the HEC-GeoRAS tool automatically adopts the coordinate system of the GIS data for use in HEC-RAS. Therefore the stream networks and geometries can be handed over already in a georeferenced format to the HEC-RAS geometry data file. But not only for the transfer of GIS data into the HEC-RAS geometry input data editor, but also for the display of HEC-RAS result data in GIS, the HEC-GeoRAS software offers a comprehensive toolset. For that purpose it enables especially for inundation, flow velocity, shear stress and stream power mapping.

3.3. Discussion of Strengths and Weaknesses of HEC-RAS

The main strength of HEC-RAS is that the model's source code is oriented close to the physical laws of flow hydraulics in open-channels which makes the model mainly physically-based. In the sediment module also conceptual and empirical relations are implemented though. The physical basis for the flow modules however makes the way, how the results are generated, not only easily comprehensible, but is also an asset to experienced users with a background in flow hydraulics, as the result analysis as well as the search for modelling errors is eased significantly, if a sound understanding of the underlying physical processes is available (HAESTAD ET AL., 2003). The modeling system is distributed free-of-charge as public domain software. This also includes the publication of the entire source code of the product, which enables experienced users to alter the code according to their specific conditions and requirements, which makes the modelling system flexible not only towards special applications, but also concerning the linkage to other modelling or software environments. Since the release of the first HEC-RAS version in 1995 the model has undergone numerous improvements of the functionality and towards the depiction of hydraulic processes in channels (USACE, 2010a). With these improvements the model is to a certain extent by now therefore sufficiently stable and robust concerning the accurate prediction of in-stream dynamics.

This can also be seen as an advantage towards other hydraulic modelling systems which have not undergone this improving development over many years yet. Furthermore the modelling system is through its graphical user interface also accessible to users with little experience in environmental modeling, or that are just getting started engaging in the topic of open-channel hydraulics (HAESTADET AL., 2003). In fact, this design of HEC-RAS can encourage inexperienced users to experiment with the model's functionalities, not only to get to know the modelling system better, but also to help them to develop an understanding of the basic principles of river hydraulics and develop a feeling for its processes and interrelations.

At the same time the physical orientation of HEC-RAS can also be a constraint to inexperienced users. Especially for the unsteady modeling of highly dynamic rivers (e.g. in steep terrain), numerical instabilities occur frequently (USACE, 2010a), distorting the model results. For inexperienced users it is almost impossible to diagnose these instabilities and to deal with them in a satisfying way, to allow for satisfactory model results. Therefore it is highly recommended to familiarize with the basic underlying assumptions and equations of flow hydraulics, before more complex analyses are performed. Another problem associated with HEC-RAS, which applies to almost all physically based models, is its high data demand. Not only detailed data about the shape of the river system and the cross-section geometries, but also accurate information about river slopes and roughness's of river beds, banks and floodplains are necessary input data. All these data have to be of a high level of accuracy for the model to be able to produce valid results, as it is usually the case for hydraulic models (NOVAK ET AL, 2010). The collection of these data in the field in the required quality is often not achieved due to a lack of time or financial constraints. In general, the input data collection for HEC-RAS is very resource-intensive due to a lack of global databases for river shape layers, or high resolution DEM data. All-in-all nevertheless the model HEC-RAS fulfills the purpose to model river hydraulics in a very comprehensive and user-friendly way, yet yielding satisfying and promising results, if properly used. Therefore it is also easy to understand that HEC-RAS is one of the most widely used river hydraulics modeling systems worldwide.

4. Basics of Flow Hydraulics

The calculations performed by the model HEC-RAS are mainly based on the physical basis of river mechanics and fluvial hydraulics. In this study the model modes for steady and unsteady conditions as well as the model's sediment transport routine are employed. The underlying theoretical foundation of these modules will be introduced in this chapter, as a basic understanding of the operations performed by the model for the calculation of the output variables is crucial for the reasonable and sound setup of the model as well as the interpretation of the result data.

4.1. Steady Flow Simulation

Steady flow analysis in this thesis is only used for the calibration of the river section models. The calibrated parameters are then used for the unsteady flow simulation. The basis for the steady flow calculation in HEC-RAS is defined by the first law of thermodynamics, namely the conservation of energy in a closed system, with energy losses only possible through the generation or disposal of heat to the environment or work being done by the system itself. This thermodynamic principle is expressed in the Bernoulli energy equation for channel flow without energy losses (after CHOW,1959):

$$z_1 + y_1 + \frac{V_1^2}{2g} = z_2 + y_2 + \frac{V_2^2}{2g} = const \qquad (4\text{-}1)$$

The terms *z1* and *z2* represent the elevations of the channel inverts at two different cross-sections within the channel, *y1* and *y2* are the water heights from the invert to the water surface (compare Fig.6) and the fraction term on each side of the equation defines the velocity head for the specific velocities *V1* and *V2* at every cross-section. The term *g* represents the gravitational acceleration. In HEC-RAS this equation is slightly adjusted to account for energy losses and the possibility of weighing the velocities according to subdivisions of velocity within the cross-sectional area (USACE, 2010b):

$$z_2 + y_2 + \frac{a_2 V_2^2}{2g} = z_1 + y_1 + \frac{a_1 V_1^2}{2g} + h_e \qquad (4\text{-}2)$$

with *a1* and *a2* being the velocity weighting coefficients and *he* representing the energy head loss at the downstream cross-section.

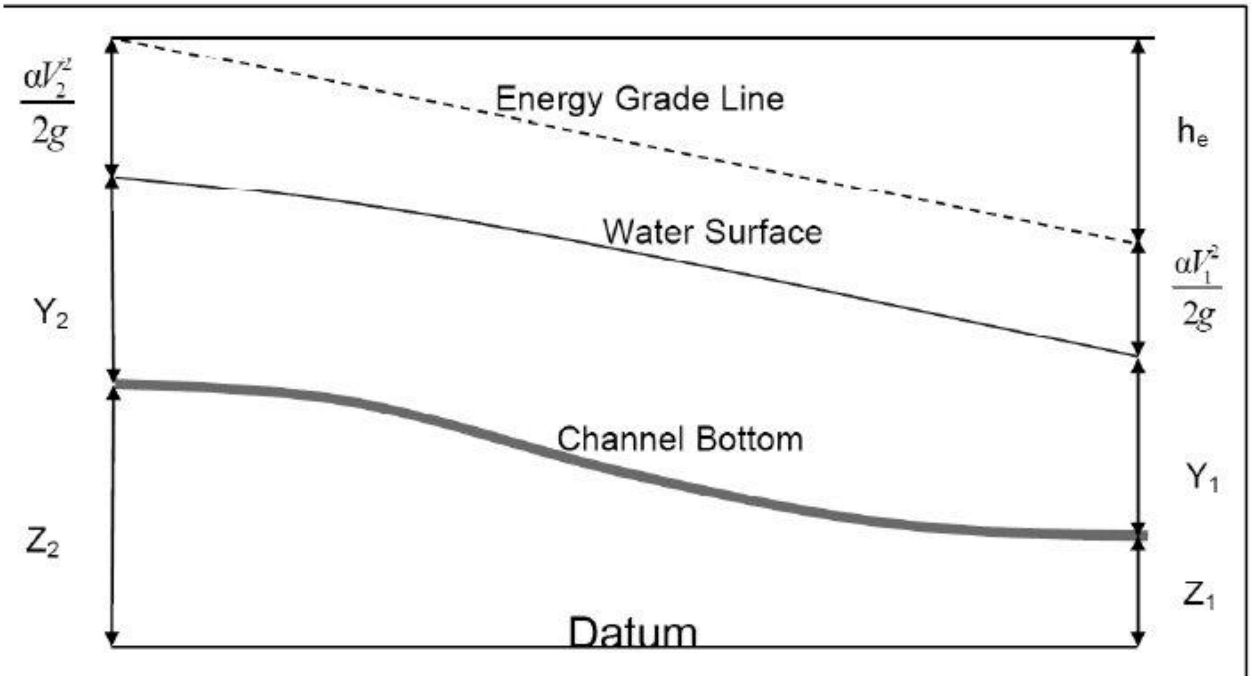


Figure 4: Representation of the terms in the energy equation for a schematic river reach (Source: USACE, 2010b)

The term *he* calculates as

$$h_e = LS_f + C\left|\frac{a_2V_2^2}{2g} - \frac{a_1V_1^2}{2g}\right| \tag{4-3}$$

where: *L* = reach length between cross-sections

Sf = friction slope between the two sections

C = expansion or contraction loss coefficient

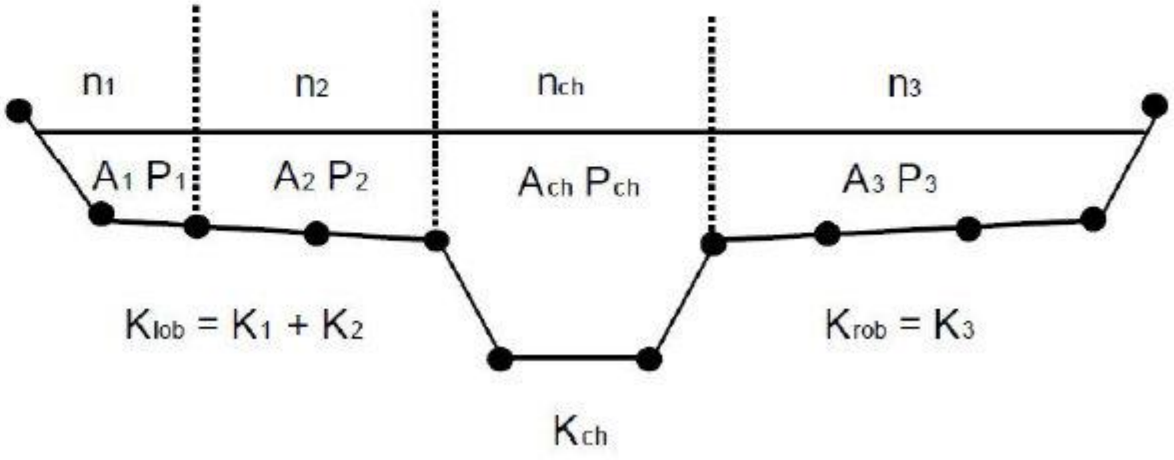
The second term of this equation represents energy losses by contraction or expansion of the river width from one cross-section to the next, the first term accounts for friction losses due to the roughness of the channel bed. The expression *Sf* calculates as

$$S_f = \left(\frac{Q}{K}\right)^2 \tag{4-4}$$

with *Q* being the discharge in the channel, and *K* representing the conveyance, which expresses a measure of the capacity of water transport through the cross-section (GRAF, 1998). The conveyance *K* is a function of the Manning's roughness value (*n*), the flow area of the cross-section *A* and its hydraulic radius *R*, which is the ratio between area *A* and wetted perimeter. It is calculated as

$$K = \frac{1.486}{n} A R^{\frac{2}{3}} \qquad (4\text{-}5)$$

The conveyance is calculated for several subdivisions along the cross-section, with breakpoints between divisions at the verticals where Manning's n values change (Fig. 7). Usually these changes occur at least at the transition from the banks to the main channel, but it is also possible to 24 implement further changes of roughness values within the channel or along the banks. Therefore also the friction slope *Sf* is calculated for every subdivision separately, and its weighted mean is calculated according to the discharge in every subdivision. In HEC-RAS this is achieved by weighting the reach lengths *L* of every subdivision with the discharge, rather than weighting the friction slope itself (USACE, 2010b).



The model calculates values for water surface elevation and flow velocity from downstream to upstream cross-sections for subcritical flow with Froude numbers smaller 1 using Equations 4-2 and 4-3. For the lowermost cross-section the water surface elevation for the given steady discharge (normal depth) has to be defined by the user as a boundary condition. The computational procedure for the calculation of flow velocities and water surface elevations has to be iterative, as both parameters are unknown at the same time, and due to a lack of definite boundary conditions within the formulas a solution using a set of linearized equations is not applicable. Therefore the model algorithm bases the calculation of the conveyance and velocity head on a preliminary randomly assumed water surface. With these values the calculation of *Sf* and the solution of Equation 4-3 are possible. With the obtained value of *he* it is then possible to solve Equation 4-2 for a calculated water elevation. This water surface is then compared with the water surface height that was assumed in the first step. As long as the difference in these water surface values exceeds a certain error value, the described steps are repeated with systematically adapted preliminary water surface heights, until a good fit of assumed and calculated water elevation is achieved (USACE, 2010b).

For the calculation of critical and supercritical flow conditions the application of the principle of energy conservation based on a gravitational head as described above is not feasible anymore. Supercritical flow occurs usually at bridges and weirs, and is characterized by inertial forces dominating the hydraulic conditions, rather than gravitational forces. Supercritical flow occurs if

$$V \geq \sqrt{gL} \qquad \textbf{(4-6)}$$

with *V* being the flow velocity, *g* representing gravitational acceleration and *L* defining the characteristic length, a measure representing a characteristic water depth based on the channel 25 geometry (for calculation see CHOW, 1959). The ratio between flow velocity and the root term is also known as Froude number with supercritical flows occurring at values ≥ 1 (CHOW, 1959). For supercritical flow, but also at stream junctions, weirs and bridges HEC-RAS uses a momentum based approach for the calculation of flow hydraulics, based on Newton’s second law of motion. This law states that the sum of all forces (□) attacking a point of mass (*m*) induces a change in momentum for the mass point which is proportional to the acceleration (□) in the resulting direction:

$$\sum \overrightarrow{F_x} = m \cdot \vec{a} \qquad \textbf{(4-7)}$$

With the product of the discharge *Q*, the specific weight of water □ and the change in velocity between cross-sections in flow direction Δ□□ , also representing a force, the momentum balance can be written as

$$P_2 - P_1 + W_x - F_f = Q\rho V_x \tag{4-8}$$

with: Px = Hydrologic pressure forces at locations 1 and 2
Wx = Force due to the weight of the water in x-direction (flow direction)
Ff = Force due to external friction losses from 2 to 1

After the application of hydraulic principles of hydrostatic pressure and the shear stress law for friction losses the functional form of this equation, as it is also used by HEC-RAS comes to

$$\frac{Q_2^2\beta_2}{gA_2} + A_2\bar{Y}_2 + \left(\frac{A_1 + A_2}{2}\right)LS_0 - \left(\frac{A_1 + A_2}{2}\right)L\bar{S}_f = \frac{Q_1^2\beta_1}{gA_1} + A_1\bar{Y}_1 \tag{4-9}$$

where: β_x = Momentum coefficient (due to varying velocity distribution in irregular channels)
Y_x = Depth from water surface to the centroid of the cross-sectional area
A_x = Cross-section area
L = Distance between cross-sections 1 and 2 along the flow gradient (x-axis)
S_0 = slope of the channel bed
S_f = friction slope between the cross-sections

The detailed and commented derivation of this form of the momentum equation can be obtained from USACE (2010b)

4.2 Unsteady Flow Simulation

The unsteady flow component of HEC-RAS will be used in this thesis for the main analysis of the discharge behavior at the river sections concerning the conditions of the desired output variables of streamflow. However, the disquisition of the theory of unsteady flow hydraulics is very complex and also mathematically challenging, when elaborated in detail. Therefore it cannot be described in the framework of this thesis at length, but will rather be discussed in a basic and most comprehensible way. For further reference, an elaborate, yet understandable, introduction in unsteady flow hydraulics is given by GRAF (1998). The implementation of the theory into the model HEC-RAS is documented extensively by USACE (2010b). The explanations and equations given in this chapter are therefore also predominantly based on these references.

Unsteady flow calculations are based on both, the conservation of mass (continuity), and the conservation of momentum. The continuity principle states that the change of the amount of an incompressible fluid must always equal the difference between incoming and outflowing fluid during a given time interval *dt* and for a given river section *dx*. This yields

$$\frac{dQ}{dx} = -\frac{dA}{dt} \qquad (4\text{-}10)$$

with *dQ* being the net amount of discharge into the control volume and *dA/dt* representing the net increase in storage over the time interval *dt*. In HEC-RAS the channel and the floodplains are considered separate for unsteady flow calculation. Therefore lateral water flows between these systems are possible and have to be considered. With this addition the full continuity equation, as it is used by the model, can be written as:

$$\frac{dQ}{dx} + \frac{dA}{dt} \pm q_l = 0 \qquad (4\text{-}11)$$

The term *ql* represents the lateral inflow per unit length of the control volume *dx* into the system, and accounts hereby for the connection of the channel and floodplain systems in HEC-RAS.
The second principle for unsteady flow simulations is the conservation of momentum, as it is expressed by Newton's second law of motion (see Equation 4-7). For the mathematic expression in HEC-RAS the principle of the conservation of momentum is formulated as follows: 'The net rate of momentum (momentum flux) entering the volume plus the sum of all external forces acting on the volume is equal to the rate of accumulation of momentum' (USACE, 2010b). This interpretation is expressed mathematically with the term

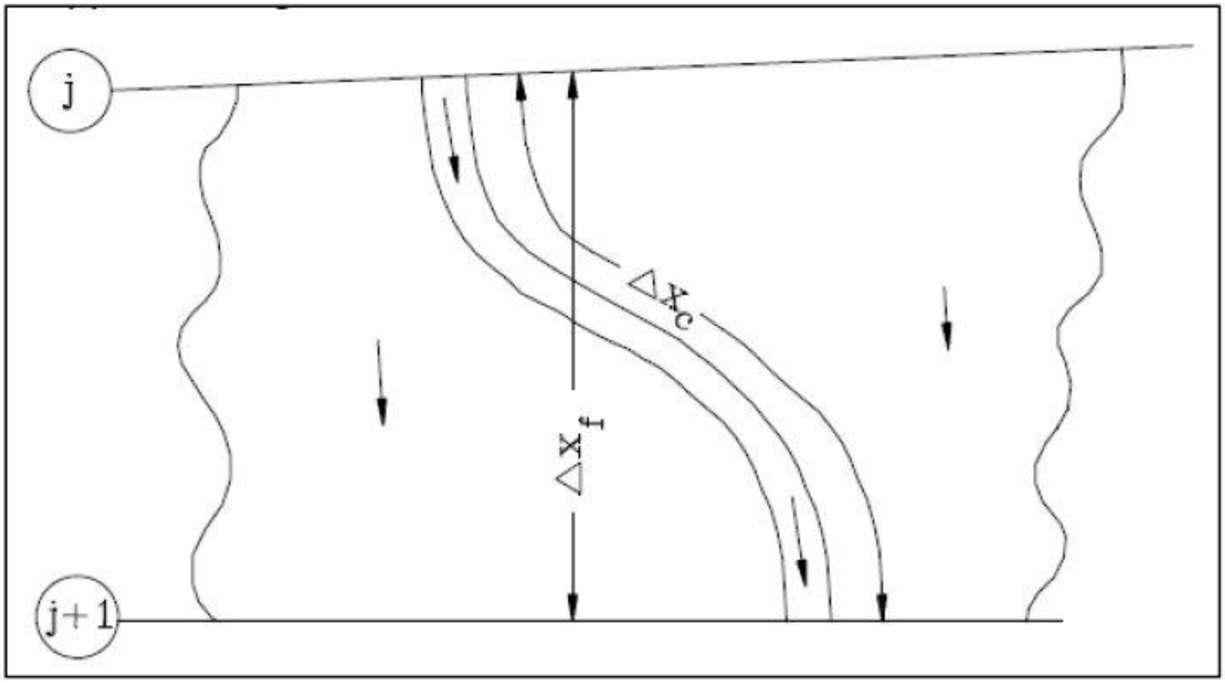
$$\underbrace{\rho \Delta x \frac{dQ}{dt}}_{1} = \underbrace{-\rho \frac{dQV}{dx} \Delta x}_{2} - \underbrace{\rho g A \frac{dh}{dx} \Delta x}_{3} - \underbrace{\rho g A \frac{dz_0}{dx} \Delta x}_{4} - \underbrace{\rho g A S_f \Delta x}_{5} \tag{4-12}$$

where ρ = fluid density
V = flow velocity
g = gravitational acceleration
A = cross-sectional area
h = water height
z_0 = datum elevation
S_f = friction slope

The term #*1* describes the rate of accumulation of momentum; the term #*2* expresses the net rate of momentum (momentum flux) that enters the system. The pressure force induced to the water volume by the river bed is denoted by the term #3, followed by the gravitational force momentum 27 denoted by term #4. The last part of equation 4-12 represents the friction force which drags the water volume at the river bed and bank boundaries. The detailed derivation of all the terms of Equation 4-12 can be obtained from USACE (2010b). With $z0 + h = z$ and dz/dx being the slope of the water surface, the final form of the momentum equation can be simplified and written as:

$$\frac{dQ}{dt} + \frac{dQV}{dx} + gA\left(\frac{dz}{dx} + S_f\right) = 0 \tag{4-13}$$

The interaction between the main channel and the floodplain is an important factor for unsteady inundation modelling, and was therefore also addressed in HEC-RAS.



Usually the flow path of the floodplain area is shorter than the one of the main channel (see Fig. 8). This problem was addressed by FREAD (1976) as well as SMITH (1978) by assuming two separate channels for floodplain (index *f*) and main stream (index *c*) and implementing the equations of motion 4-11 and 4-13 for each of them separately. This approach is also being followed in HEC-RAS. A discharge (*Q*) splitting between floodplain and main channel according to conveyance *K* was selected, to make the exchange of momentum between floodplain and main channel at every cross-section negligible (USACE, 2010b). With

$$Q_c = \phi Q \qquad (4\text{-}14)$$

And

$$\phi = \frac{K_c}{K_c + K_f} \qquad (4\text{-}15)$$

the equations of motion can be written as

$$\frac{dA}{dt} + \frac{d(\phi Q)}{dx_c} + \frac{d[(1-\phi)Q]}{dx_f} = 0 \qquad (4\text{-}16)$$

And

$$\frac{dQ}{dt} + \frac{d\left(\frac{\phi^2 Q^2}{A_c}\right)}{dx_c} + \frac{d\left(\frac{(1-\phi)^2 Q^2}{A_f}\right)}{dx_f} + gA_c\left(\frac{dz}{dx_c} + S_{fc}\right) + gA_f\left(\frac{dz}{dx_f} + S_{ff}\right) = 0 \qquad (4\text{-}17)$$

The solution of these partial differential equations in HEC-RAS is achieved using an implicit finite difference approach. The objective of such an approach is the transformation of the continuous time, space and parameter derivatives of the functions into discrete grid cells of infinitesimal size (HILDEBRAND, 1968). Most of the times a finite approach is the most feasible way to be able to solve partial differential equations numerically. Furthermore a discrete solution eases the implementation in programming code during the model development. For the implementation in HEC-RAS, all terms of the Equations 4-16 and 4-17 were considered separately and transformed into a finite scheme.

The Hydraulic Reference Manual of HEC-RAS (USACE, 2010b) provides tables with the transformation results of all terms of the motion equations, considering the derivatives in time, in space and of the function values. Additionally two additional sources of momentum are introduced in the finite scheme, accounting on the one hand for forces that are induced on the water volume by weirs, bridges or other in-stream structures, on the other hand considering the lateral influx of momentum at stream junctions. These additions allow for assessment of the influence of in-stream structures, but also the analysis of whole river networks in the unsteady flow module of HEC-RAS. For a successful application of the unsteady flow module furthermore a boundary condition at the upstream and at the downstream end of every reach is necessary. The upstream boundary condition must be a flow or stage hydrograph, yielding discharge over time. The downstream boundary condition can either be provided also by a flow hydrograph (only recommended for the analysis of single flood events), a stage hydrograph yielding water level over time, a rating curve between stage and flow or a normal depth, expressed as the friction slope of the downstream cross-section.

4.3 Sediment Transport

The sediment transport routine of HEC-RAS will be used in this study mainly to assess the sediment discharge. Furthermore the attempt will be made to show changes in the grain size distribution at cross-sections due to the in-stream sediment dynamics over time. The sediment transport module cannot account for the influence of in-stream structures like bridges and weirs on the sediment dynamics. Moreover just the channel volume itself is being considered as the space where all processes are happening (USACE, 2010b).

The basic assumption for sediment transport in HEC-RAS is the hydrodynamic principle of continuity for sediment particles which was first postulated by EXNER (1925). This principle states that the difference between inflowing and outgoing sediment load in a control volume is proportional to the change in river bed elevation, as processes like deposition or erosion occur. The equation describing this process can be formulated as follows (GRAF, 1984):

$$\frac{d\eta}{dt} = -a_E \frac{d\bar{u}}{dx} \qquad \text{(4-18)}$$

The parameter ⍰ represents the elevation of the channel over a datum. The cross-sectional average velocity is given by the parameter □□, and the term *ae* represents the Exner erosion coefficient, giving an indication on the packaging density of the sediment. This equation can be rearranged in the form of a continuity equation for the solid phase, as it is also used in HEC-RAS. For the derivation see GRAF, 1998:

$$(1-\lambda_p)B\frac{d\eta}{dt} = -\frac{dQ_s}{dx} \qquad \text{(4-19)}$$

where λ_p = porosity of the active layer
B = channel width
Q_s = transported sediment load

The sediment continuity Equation 4-19 is solved for every control volume assigned to one crosssection in HEC-RAS. While the inflowing sediment is only determined by the sediment load coming from the upstream control volume, the outgoing sediment load is a function of the transport capacity of the water for the given hydrological conditions (USACE, 2010b). The capacity for transport furthermore depends on the bed grain size distribution within the control volume. As a comprehensive approach for the determination of the sediment transport capacity over all grain size classes that occur in a given control volume is not developed yet, HEC-RAS calculates the transport potential for every occurring grain size class separately. With the actual distribution of grain sizes in the volume the capacity for transport is evaluated afterwards. For the transport potential evaluation numerous approaches have been developed, yielding good results for a wide range of different hydrodynamic and sediment conditions. HEC-RAS provides the choice between seven different transport potential calculation approaches, which are discussed concerning applicability and calculation methodology in the Hydraulic Reference Manual (USACE, 2010b). All of these approaches though focus, with one exception, on the transport dynamics from sand sizes up to coarser material.

This is due to the fact, that the fall velocity of smaller particles is usually too slow, or easily affected 30 by minor turbulences in the stream, which makes their behavior hard to model on a river stream scale. Furthermore these particles show cohesion properties induced by electrostatic and electrochemical processes which usually have to be considered in the modelling process. The transport potential is calculated for each occurring grain size class separately, and then transformed into the transport capacity under the consideration of the percentages of every of these classes in the control volume. Therefore the transport capacity is calculated as (USACE, 2010b)

$$T_c = \sum_{j=1}^{n} \beta_j T_j \qquad (4\text{-}20)$$

where: T_c = transport capacity

β_j = percentage of grain size class j of the total active layer compound

T_j = transport potential for grain size class j

The transport capacity defines the possible amount of sediment which leaves the control volume, based on the grain size distribution and the hydrological conditions within the stream. If the outgoing sediment load exceeds the incoming amount, erosion happens within the control volume, and deposition occurs when the transport capacity is lower than the incoming amount of sediment. For the mobile bed calculation the change in bed elevation is then further assessed using the Exner Equation 4-18. Yet not all the sediment with a potential to deposition or erosion according to excess or deficit in the sediment balance, also participates in these processes. There are three limiting factors (after USACE, 2010b): The temporal deposition limiter which draws the fall velocity of particles of different grain sizes towards the flow velocity, and therefore depicts the residence time in the control volume. This information limits the amount of sediment, which is actually deposited per time step. The second factor is the erosion temporal limiter which has to be applied due to the fact that it is under real conditions hardly possible to erode an unlimited amount of material in a given time step. The erosion limiter is an exponential function, yielding an entrainment coefficient *Ce* which is then multiplied with the computed sediment deficit. The third limiter has to be set up due to sorting and armoring effects within the river bed, impeding bed erosion further. Armoring is the process of erosion of fine material, leaving coarser material at the active layer surface behind, preventing underlying finer material from erosion. The algorithms for modelling these processes in HEC-RAS are quite complex, and will not be discussed in further detail here. They can be obtained in the Hydraulic Reference Manual though for detailed study (USACE, 2010b).

The calculation of sediment dynamics in HEC-RAS is based on quasi-unsteady flow. This flow representation assumes steady flow values for a defined time step with changing flow conditions only between two time steps. Furthermore HEC-RAS uses three computational time steps for sediment modelling (after USACE, 2010b):

Flow Duration: This time step is the coarsest of the three time steps. In this step flow and sediment loads are assumed constant (quasi-unsteady flow)

Computational Increment: The bed geometry and hydrodynamics are updated after every of these time steps, though the driving factors flow and sediment load remain the same over several increments during the flow duration.

Bed Mixing Time Step: In this time step the computations for sediment deposition and erosion are executed, which changes the composition of the active layer for every time step. With the change in the composition also the sediment transport capacity changes, even though the hydrodynamics, and therefore the transport potential remain constant.

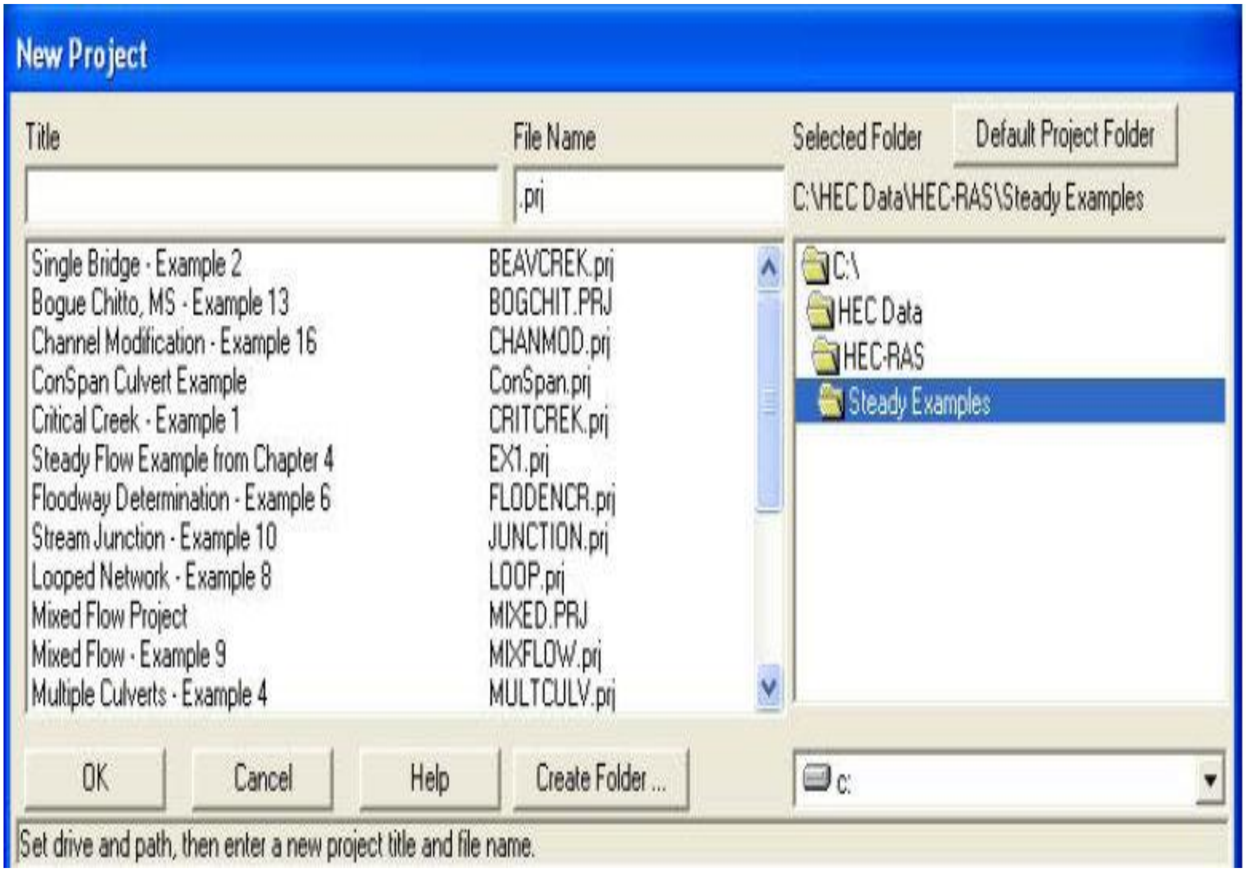
These algorithms for steady and unsteady flow as well as sediment movement serve as the foundation for the HEC-RAS modelling in this thesis and are further regarded during the model setup for the ten river sections within the investigated catchment in China

5. Model Setup and Application

5.1 HEC-RAS Modeling Procedure

Our first target is to analyze the steady flow using HEC-RAS.

First of all, we started a new project by clicking the new project button and gave it a name. We also selected the directory to work in.As our target is to conduct Steady Flow Analysis that’s why our steps were according to that goal.



File Name: .prj

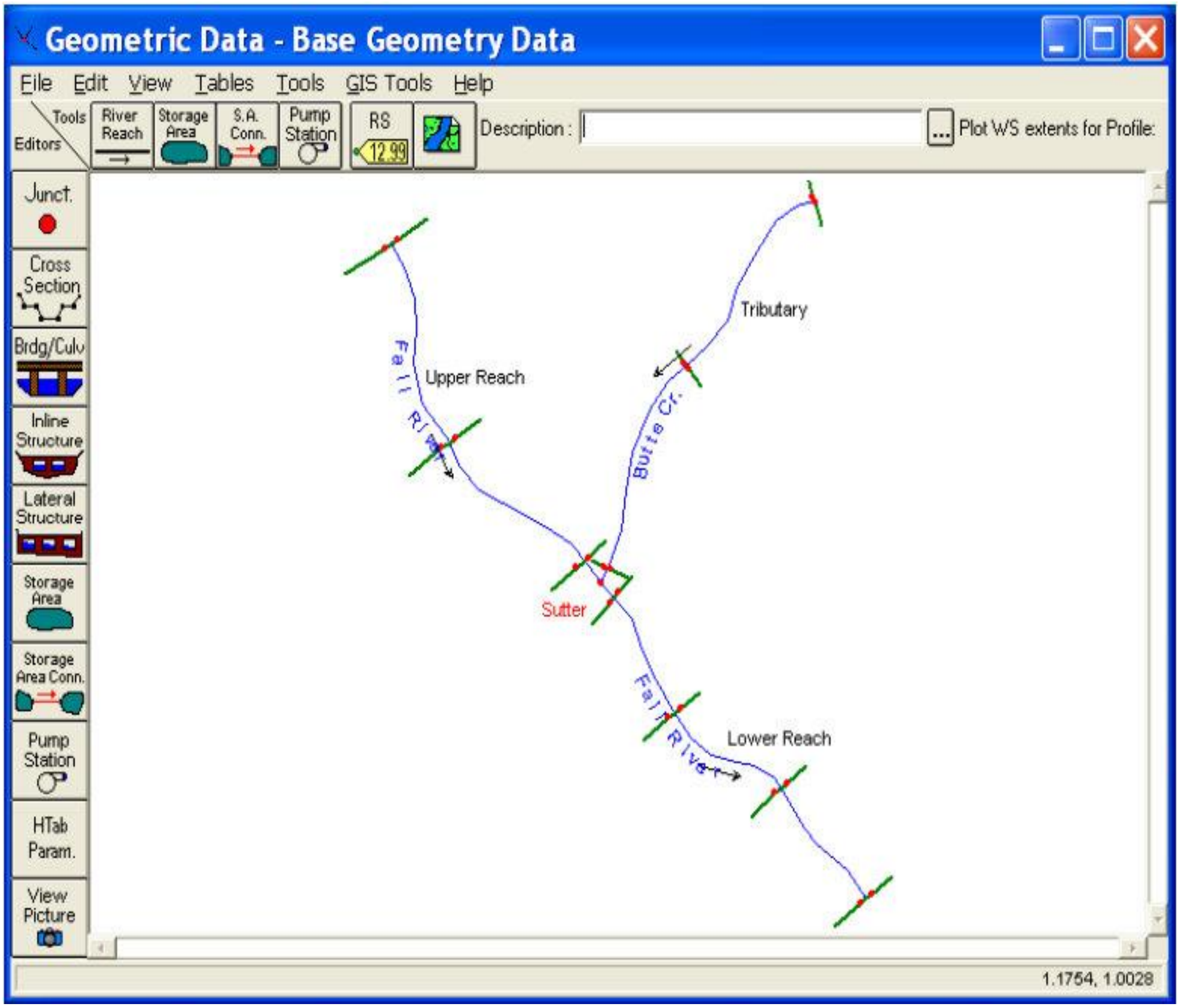
Selected Folder: C:\HEC Data\HEC-RAS\Steady Examples

C:\
HEC Data
HEC-RAS
Steady Examples

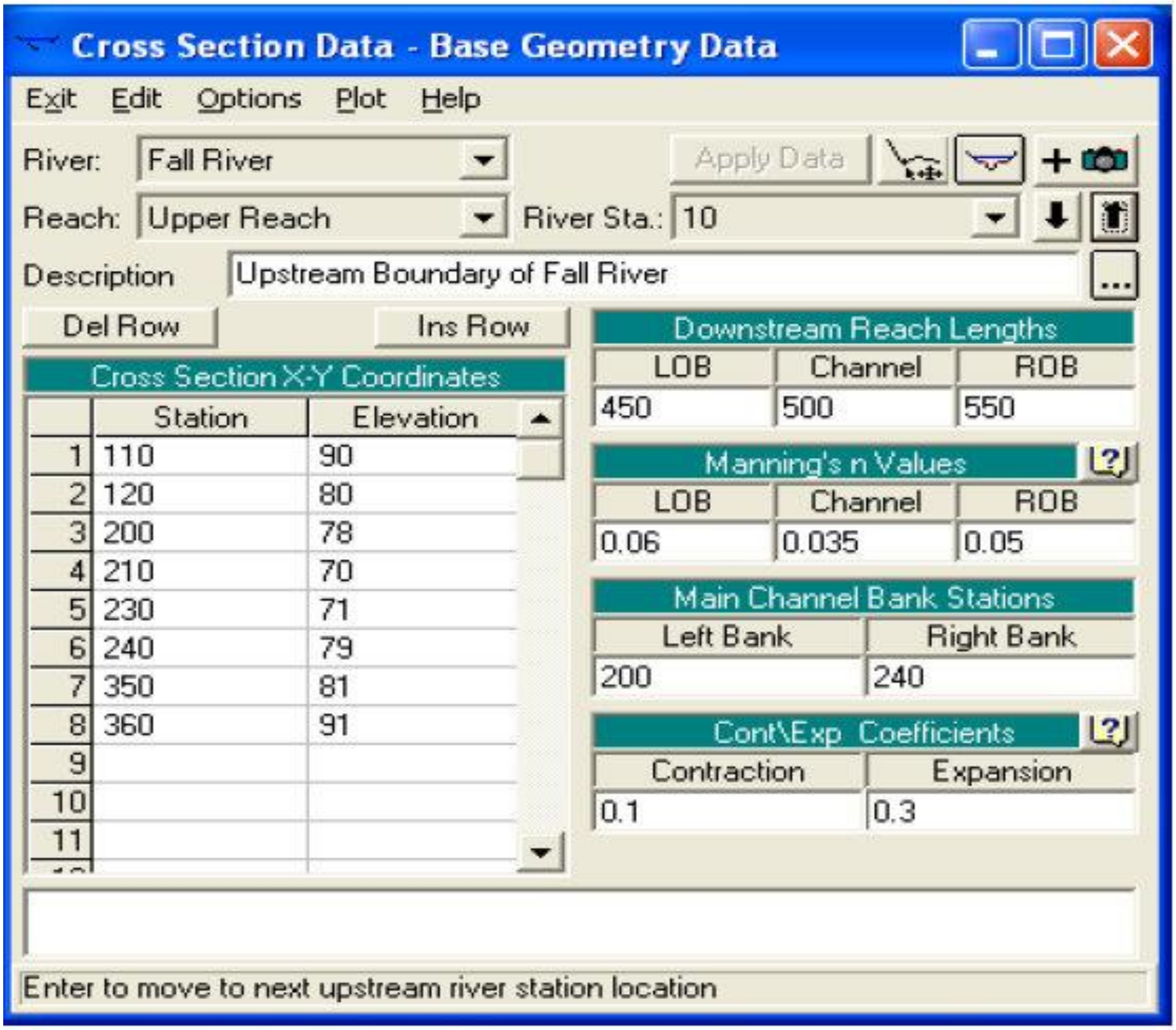
Single Bridge - Example 2	BEAVCREK.prj
Bogue Chitto, MS - Example 13	BOGCHIT.PRJ
Channel Modification - Example 16	CHANMOD.prj
ConSpan Culvert Example	ConSpan.prj
Critical Creek - Example 1	CRITCREK.prj
Steady Flow Example from Chapter 4	EX1.prj
Floodway Determination - Example 6	FLODENCR.prj
Stream Junction - Example 10	JUNCTION.prj
Looped Network - Example 8	LOOP.prj
Mixed Flow Project	MIXED.PRJ
Mixed Flow - Example 9	MIXFLOW.prj
Multiple Culverts - Example 4	MULTCULV.prj

Set drive and path, then enter a new project title and file name.

At the second stage, we had to enter the geometric data by clicking in the Edit option of HEC-RAS. We entered the river name, reach name, river station and other details in the geometric data option.



Before entering the geometric data, we had drawn the schematic of the river and after that entered the Cross section and hydraulic structure data of that section.



River: Fall River

Reach: Upper Reach

River Sta.: 10

Description: Upstream Boundary of Fall River

Cross Section X-Y Coordinates

	Station	Elevation
1	110	90
2	120	80
3	200	78
4	210	70
5	230	71
6	240	79
7	350	81
8	360	91
9		
10		
11		

Downstream Reach Lengths

LOB	Channel	ROB
450	500	550

Manning's n Values

LOB	Channel	ROB
0.06	0.035	0.05

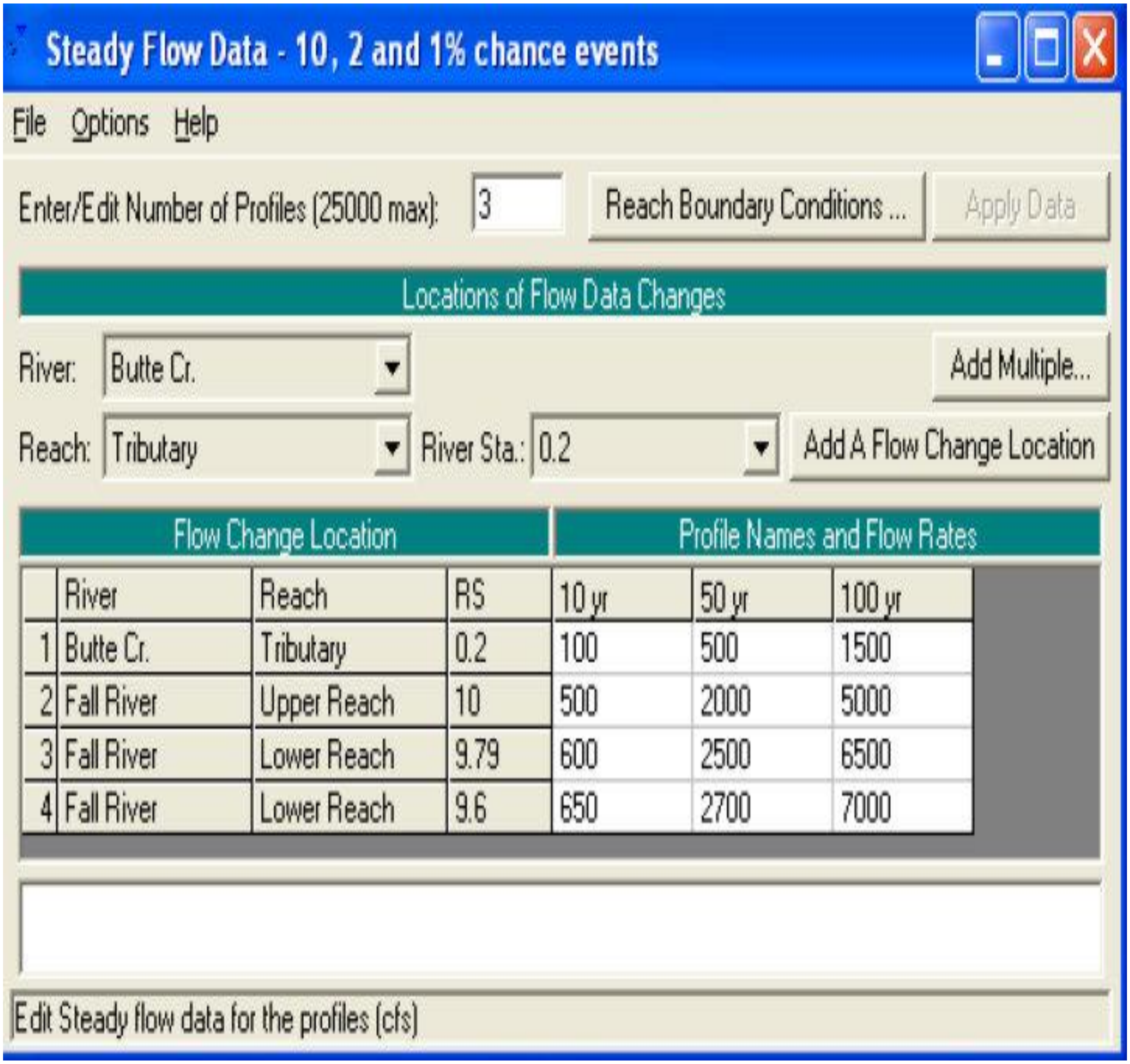
Main Channel Bank Stations

Left Bank	Right Bank
200	240

Cont\Exp Coefficients

Contraction	Expansion
0.1	0.3

At our third stage, we entered the flow data and boundary conditions. By clicking on the EDIT menu we entered those values. Boundary conditions were required only to perform calculations. If a subcritical flow analysis is going to be performed , then only the downstream boundary conditions are required. Boundary condition data entry were bring by clicking REACH BOUNDARY CONDITIONS. After entering all the data we saved the file in the hard disk.



Enter/Edit Number of Profiles (25000 max): 3

River: Butte Cr.

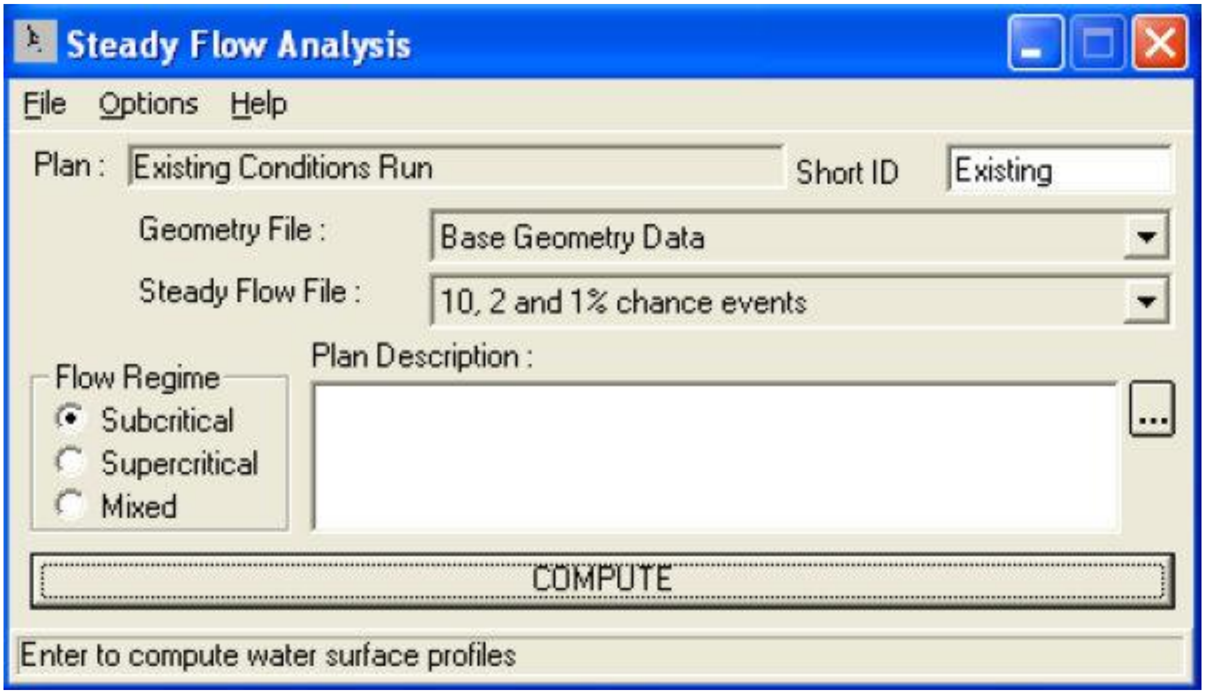
Reach: Tributary

River Sta.: 0.2

	Flow Change Location			Profile Names and Flow Rates		
	River	Reach	RS	10 yr	50 yr	100 yr
1	Butte Cr.	Tributary	0.2	100	500	1500
2	Fall River	Upper Reach	10	500	2000	5000
3	Fall River	Lower Reach	9.79	600	2500	6500
4	Fall River	Lower Reach	9.6	650	2700	7000

Edit Steady flow data for the profiles (cfs)

At the final stage, we conducted the hydraulic computations. As we’re conducting Steady Flow Analysis, that’s why we had to run the Steady Flow Analysis option.
The simulation manager window has been shown below:



Plan : Existing Conditions Run

Short ID Existing

Geometry File : Base Geometry Data

Steady Flow File : 10, 2 and 1% chance events

Flow Regime

● Subcritical

○ Supercritical

○ Mixed

Plan Description :

Enter to compute water surface profiles

That’s how we conducted Steady Flow Analysis using one-D HEC-RAS model.

Geomorphology and Hydrology of the Jamuna River.

The river Jamuna is highly dynamic and chaotic in nature. The rapid migrations of channels and frequent development of sandbars at the Jamuna Bridge site are creating problem to understand the river morphology.

The Jamuna is the name given to the braided river downstream of the Old Brahmaputra distributary and is one of three large sand-bed rivers that cross the low-lying deltaic floodplain of Bangladesh. The Jamuna river rises in the Tibetan plateau, and 93% of its catchment lies outside Bangladesh. At 2740 km from its source and 220 km from the northern borders of Bangladesh, the Jamuna joins first the Ganges (thereafter becoming the `Padma') and then the Meghna, eventually discharging into the Bay of Bengal. The Jamuna is extremely dynamic, with bank erosion rates up to 1 km per year, bed scour depths of up to 40 m and annual sediment transport of up to 2000 x 10^6 tons, this being the third highest alluvial sediment load in the world. The Jamuna braid belt is approximately 10 km wide and has a channel pattern that is a combination of braided and anatomizing, because it contains a number of islands that are vegetated and stable and only inundated during high-magnitude floods. At the coarsest scale, the channel pattern resembles a series of interconnected `island-node-island' units with bank erosion focused at the outer bends of highly sinuous first-order channels.

Braided reaches of the Jamuna River contain many different types and sizes of bars, where a bar is defined as a bedform whose length is of the same order or greater than the channel width and whose height is comparable with the mean depth of the generating flow (ASCE,1966). Bars in the Jamuna are macroforms and megaforms in the hierarchical bedform classification of Jackson (1975) and Church & Jones (1982). One of the most common bar types in the Jamuna is the mid-channel bar (terminology of Ashworth, 1996), which is usually associated with flow divergence immediately downstream of a confluence or node of flow convergence (Klaassen et al., 1993; Thorne et al., 1993; Mosselman et al., 1995), but can also develop in highly sinuous reaches by chute cut-off of the inner point bar at high flow (cf.Bridge et al., 1986; Ashmore, 1991; Richardson et al., 1996). The occurrence and morphology of mid-channel bars in the Jamuna is strongly stage dependent, although bars can also become emergent without a change in flow stage or discharge. Mid-channel bars in the Jamuna are analogous to the ‘cross-channel bars' and `sand flats' described by Cant & Walker (1978) and have planforms similar to the ‘unit' or ‘longitudinal' bars described in gravel-bed rivers.

A range of micro- and mesoscale bedforms (terminology after Jackson, 1975) is present in the Jamuna, including ripples, dunes and upper-stageplane beds. The term ‘dune’ is used here to encompass the bedforms previously described as megaripples in the Jamuna, which are dynamically analogous to dunes and scale with flow depth. Recent work suggests that the transition from dunes to upper-stage plane beds at high flow in the Jamuna may not be as common as suggested in other studies of large sand-bed rivers. Over 40% of the bed of the Jamuna is occupied by dunes at any flow stage, and this figure can rise to 100% during the highest discharges.

Dune morphology is often three-dimensional with well-developed scour troughs and spurs between adjacent crest lines. Average dune height and wavelength, measured for three different reaches on the Jamuna during low, rising, high and falling stages during the 1994 and 1995 flood season, were 1 m and 37 m, respectively, although dunes up to 6 m in height have been recorded in the deepest thalwegs at high flow stages.

Water and sediment discharge in the Jamuna is dominated by the annual monsoon that usually begins in April, with a steeply rising hydrograph that peaks in late July/early August and drops to a low in February (Figure). The 27-year daily discharge record from Bahadurabad shows a mean annual peak discharge of approximately 69 000 m^3 s^{-1} (bank full discharge at Bahadurabad is difficult to estimate but is approximately 48 000 m^3 s^{-1}; with a maximum of approximately 100 000 m^3 s^{-1} recorded during severe flooding in 1988. Estimates of the total sediment load in the Jamuna range between 500 and 725 x 10^6 tons per year, the majority of which is transported as suspended load.

6. Analysis and Discussion of the Model Result

6.1 Analysis of Input

Cross Section

Equipment

- Tape measure (long and waterproof)
- Meter ruler (ranging poles can also be used)
- Waders
- Data collection sheets

Methodology

Channel width

Stretch a tape measure taut across the river at 90o to the channel. The start and finish points of the tape will depend on whether you are investigating the river in its existing state (see 1) or wish to take into account the conditions when in flood (see 2)

1. To measure current water level, keep the tape about 20cm above the water level and measure to point where the dry bank meets the water (observe from straight above)
2. To measure the bank-full width - measure to the full height of the bank and width of the river (where the gradient of the bank and vegetation suggest maximum capacity, above which the river would burst its banks and flood)

River depth

Use a meter ruler or ranging pole and take measurements at regular 30cm to 50cm intervals (depending on the channel size).

Figure two: Measuring river depth. Photo copyright Amy Hatchwell).

Wetted perimeter

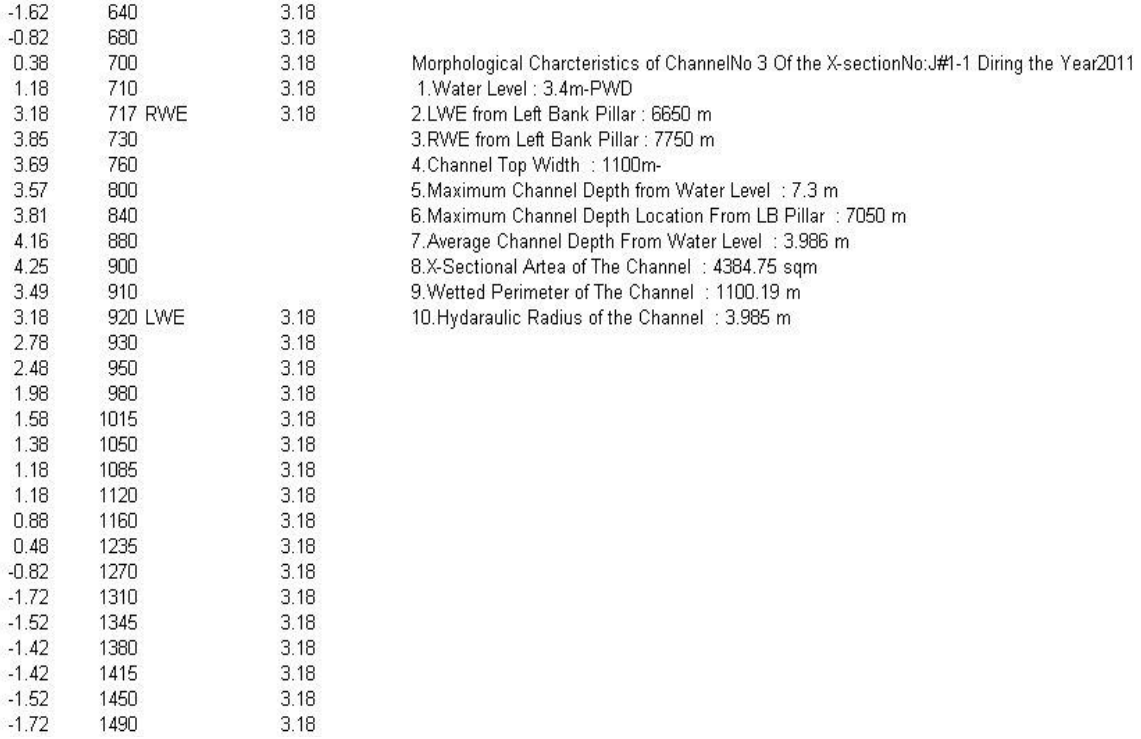
The wetted perimeter of a river refers to that part of the channel that is in contact with water. It represents the friction that slows down the river velocity, so the longer the wetted perimeter, the more friction between channel and water. Wetted perimeter can be measured using a heavy chain, rope or measure tape, which should be stretched across the river bed from one bank to the other. This can be hard to do, especially in larger channels or where the bed is very rough. Fast flowing water conditions can also be problematic. Wetted perimeter is often better calculated from the graphed results of the profile.

Considerations and possible limitations

- A soft river bed can affect values. Ensure that the ruler just touches the bed
- A strong current or bow wave created by the ruler can give inaccurate depth readings. Ensure narrow edge faces upstream to reduce resistance.

6.2 Analysis of HEC-RAS Output values

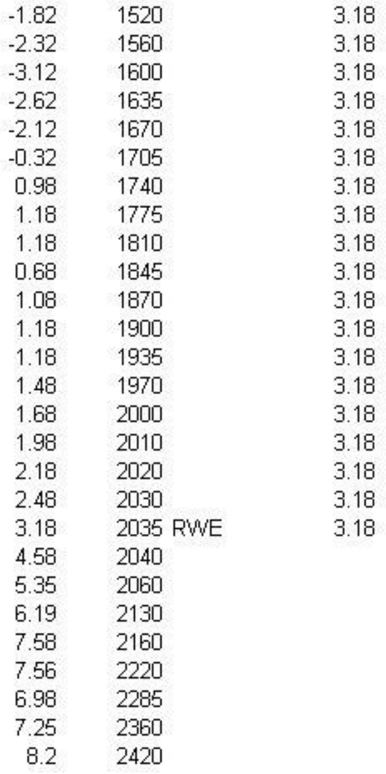
Data for Section No: J#1-1 during the Year 2011



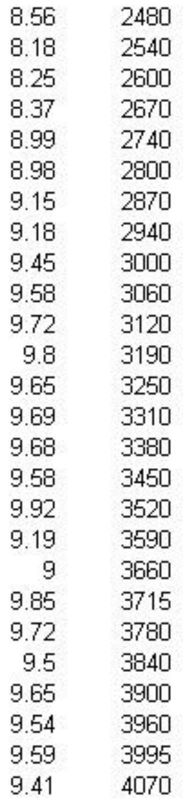
-1.62	640	3.18
-0.82	680	3.18
0.38	700	3.18
1.18	710	3.18
3.18	717 RWE	3.18
3.85	730	
3.69	760	
3.57	800	
3.81	840	
4.16	880	
4.25	900	
3.49	910	
3.18	920 LWE	3.18
2.78	930	3.18
2.48	950	3.18
1.98	980	3.18
1.58	1015	3.18
1.38	1050	3.18
1.18	1085	3.18
1.18	1120	3.18
0.88	1160	3.18
0.48	1235	3.18
-0.82	1270	3.18
-1.72	1310	3.18
-1.52	1345	3.18
-1.42	1380	3.18
-1.42	1415	3.18
-1.52	1450	3.18
-1.72	1490	3.18

Morphological Charcteristics of ChannelNo 3 Of the X-sectionNo:J#1-1 Diring the Year2011
1.Water Level : 3.4m-PWD
2.LWE from Left Bank Pillar : 6650 m
3.RWE from Left Bank Pillar : 7750 m
4.Channel Top Width : 1100m-
5.Maximum Channel Depth from Water Level : 7.3 m
6.Maximum Channel Depth Location From LB Pillar : 7050 m
7.Average Channel Depth From Water Level : 3.986 m
8.X-Sectional Artea of The Channel : 4384.75 sqm
9.Wetted Perimeter of The Channel : 1100.19 m
10.Hydaraulic Radius of the Channel : 3.985 m

<u>RL</u> <u>Distance</u> <u>GL of wooden peg- 1at L/B</u>

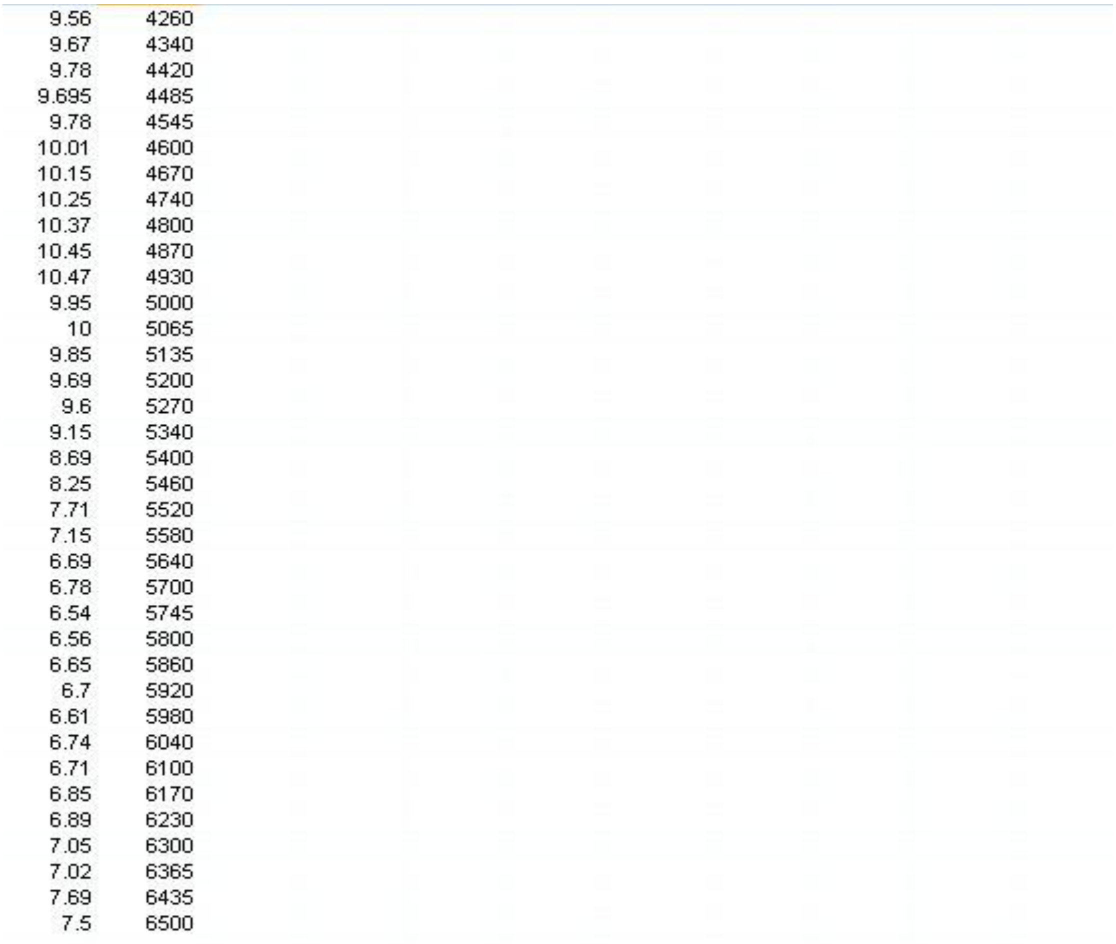


-1.82	1520		3.18
-2.32	1560		3.18
-3.12	1600		3.18
-2.62	1635		3.18
-2.12	1670		3.18
-0.32	1705		3.18
0.98	1740		3.18
1.18	1775		3.18
1.18	1810		3.18
0.68	1845		3.18
1.08	1870		3.18
1.18	1900		3.18
1.18	1935		3.18
1.48	1970		3.18
1.68	2000		3.18
1.98	2010		3.18
2.18	2020		3.18
2.48	2030		3.18
3.18	2035	RWE	3.18
4.58	2040		
5.35	2060		
6.19	2130		
7.58	2160		
7.56	2220		
6.98	2285		
7.25	2360		
8.2	2420		



8.56	2480
8.18	2540
8.25	2600
8.37	2670
8.99	2740
8.98	2800
9.15	2870
9.18	2940
9.45	3000
9.58	3060
9.72	3120
9.8	3190
9.65	3250
9.69	3310
9.68	3380
9.58	3450
9.92	3520
9.19	3590
9	3660
9.85	3715
9.72	3780
9.5	3840
9.65	3900
9.54	3960
9.59	3995
9.41	4070

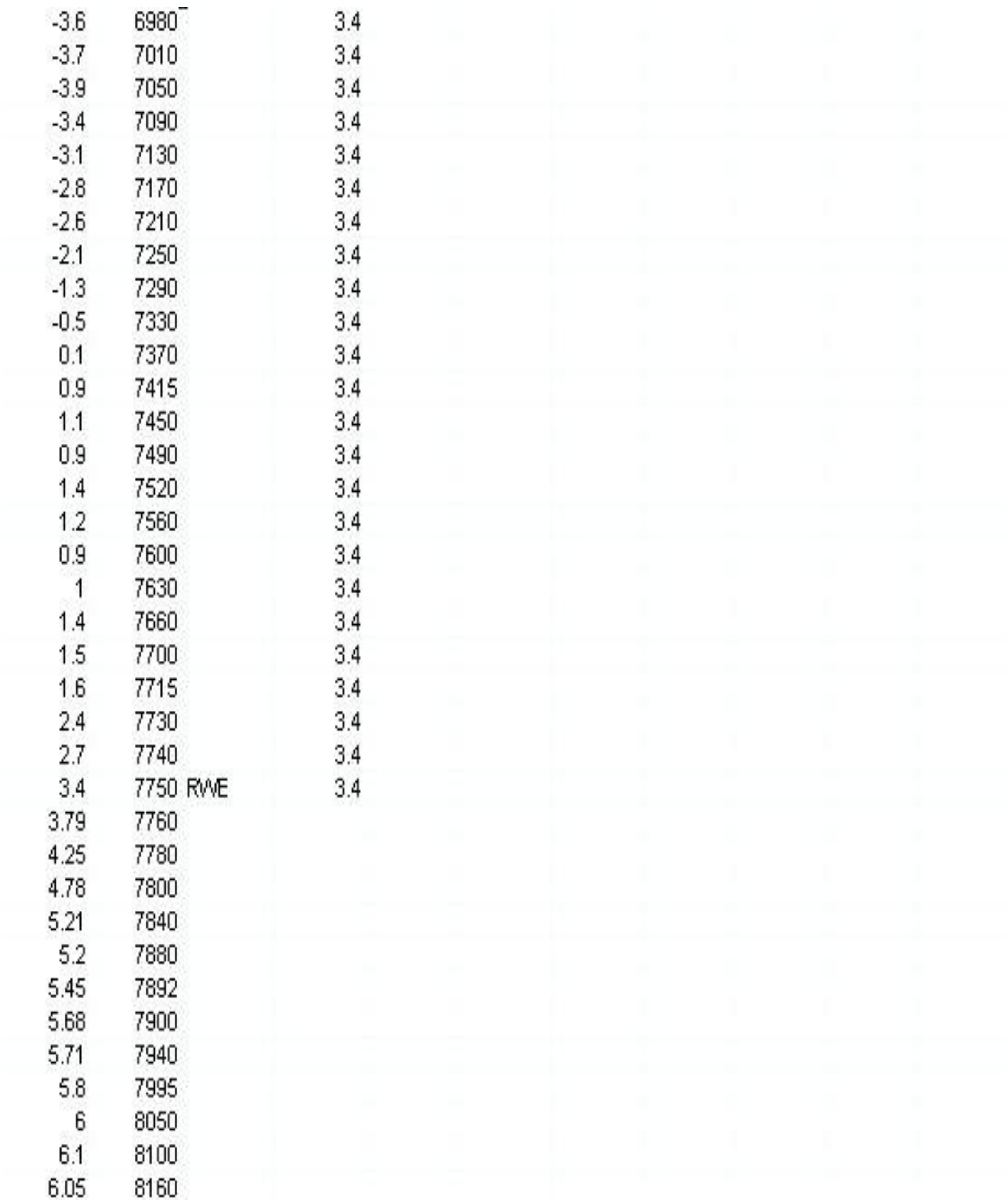
RL Distance GL of wooden peg- 1at L/B



9.56	4260
9.67	4340
9.78	4420
9.695	4485
9.78	4545
10.01	4600
10.15	4670
10.25	4740
10.37	4800
10.45	4870
10.47	4930
9.95	5000
10	5065
9.85	5135
9.69	5200
9.6	5270
9.15	5340
8.69	5400
8.25	5460
7.71	5520
7.15	5580
6.69	5640
6.78	5700
6.54	5745
6.56	5800
6.65	5860
6.7	5920
6.61	5980
6.74	6040
6.71	6100
6.85	6170
6.89	6230
7.05	6300
7.02	6365
7.69	6435
7.5	6500

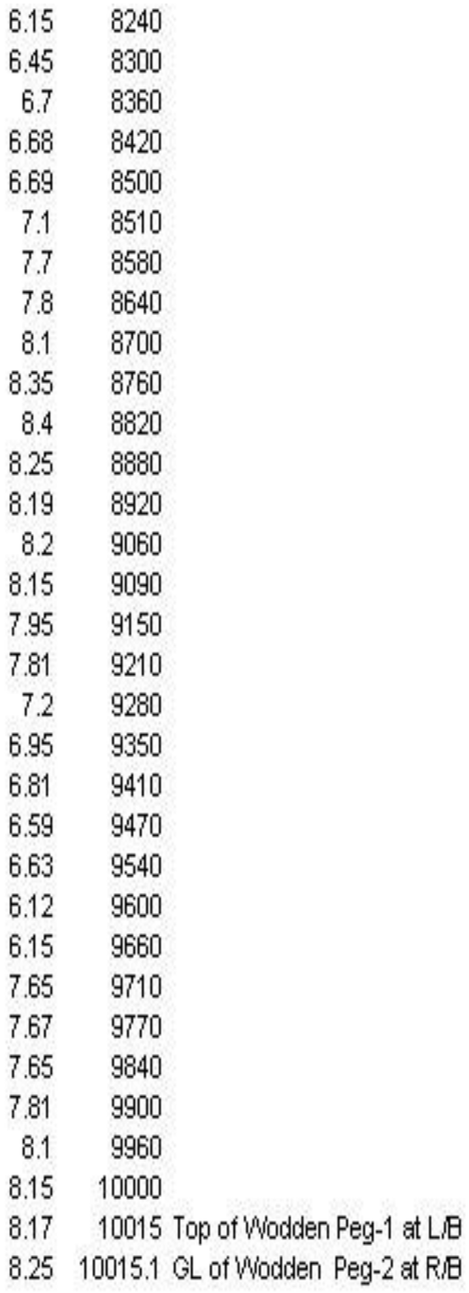
7.02	6365		
7.69	6435		
7.5	6500		
7.63	6560		
7.45	6600		
7.35	6620		
7.21	6635		
5.65	6642		
3.4	6650	LWE	3.4
3	6660		3.4
2.4	6680		3.4
1.6	6710		3.4
0.9	6750		3.4
0.2	6790		3.4
-1.1	6830		3.4
-1.6	6870		3.4
-1.9	6910		3.4
-3.1	6940		3.4

RL Distance GL of wooden peg- 1at L/B

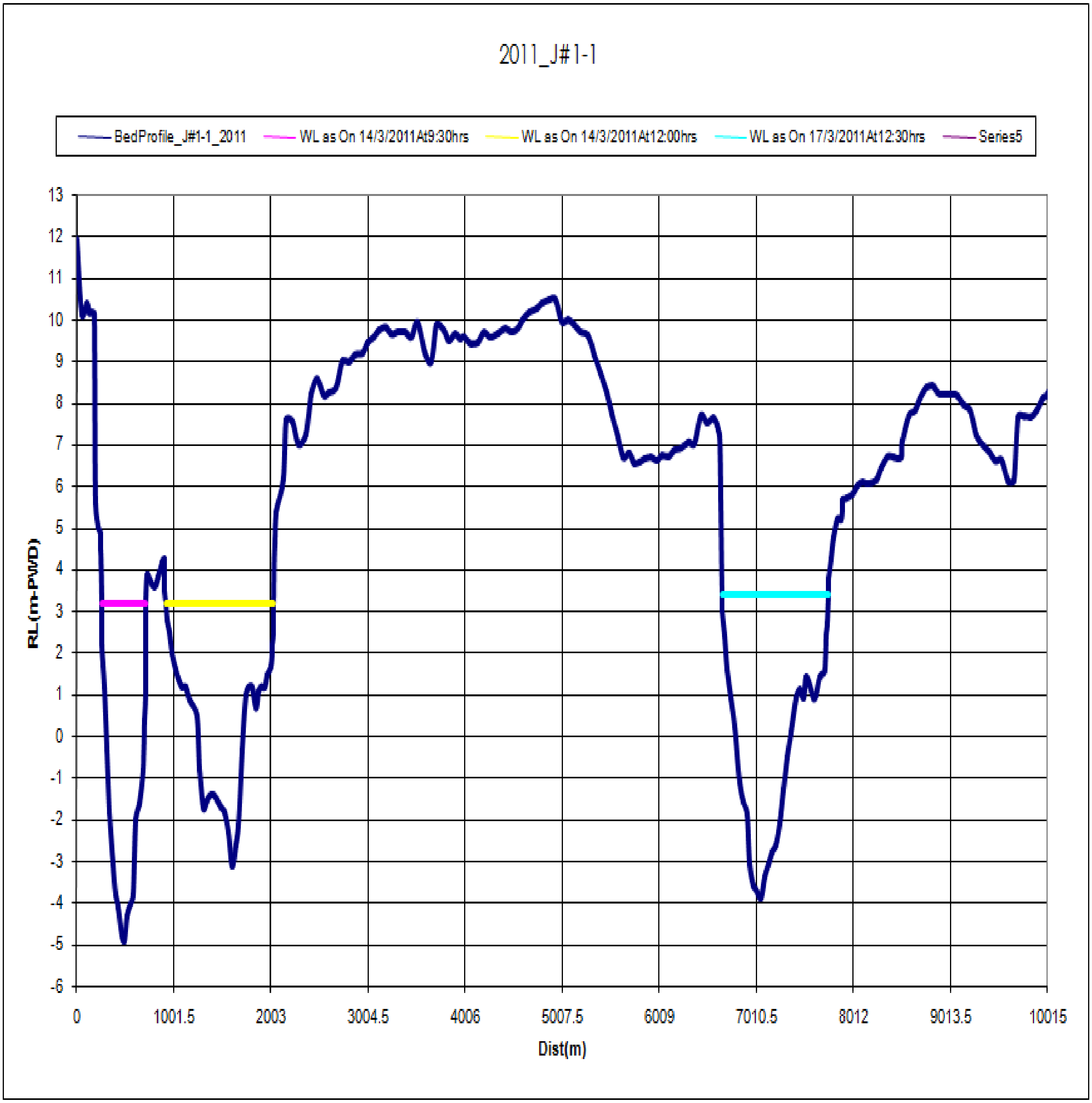


-3.6	6980		3.4
-3.7	7010		3.4
-3.9	7050		3.4
-3.4	7090		3.4
-3.1	7130		3.4
-2.8	7170		3.4
-2.6	7210		3.4
-2.1	7250		3.4
-1.3	7290		3.4
-0.5	7330		3.4
0.1	7370		3.4
0.9	7415		3.4
1.1	7450		3.4
0.9	7490		3.4
1.4	7520		3.4
1.2	7560		3.4
0.9	7600		3.4
1	7630		3.4
1.4	7660		3.4
1.5	7700		3.4
1.6	7715		3.4
2.4	7730		3.4
2.7	7740		3.4
3.4	7750	RWE	3.4
3.79	7760		
4.25	7780		
4.78	7800		
5.21	7840		
5.2	7880		
5.45	7892		
5.68	7900		
5.71	7940		
5.8	7995		
6	8050		
6.1	8100		
6.05	8160		

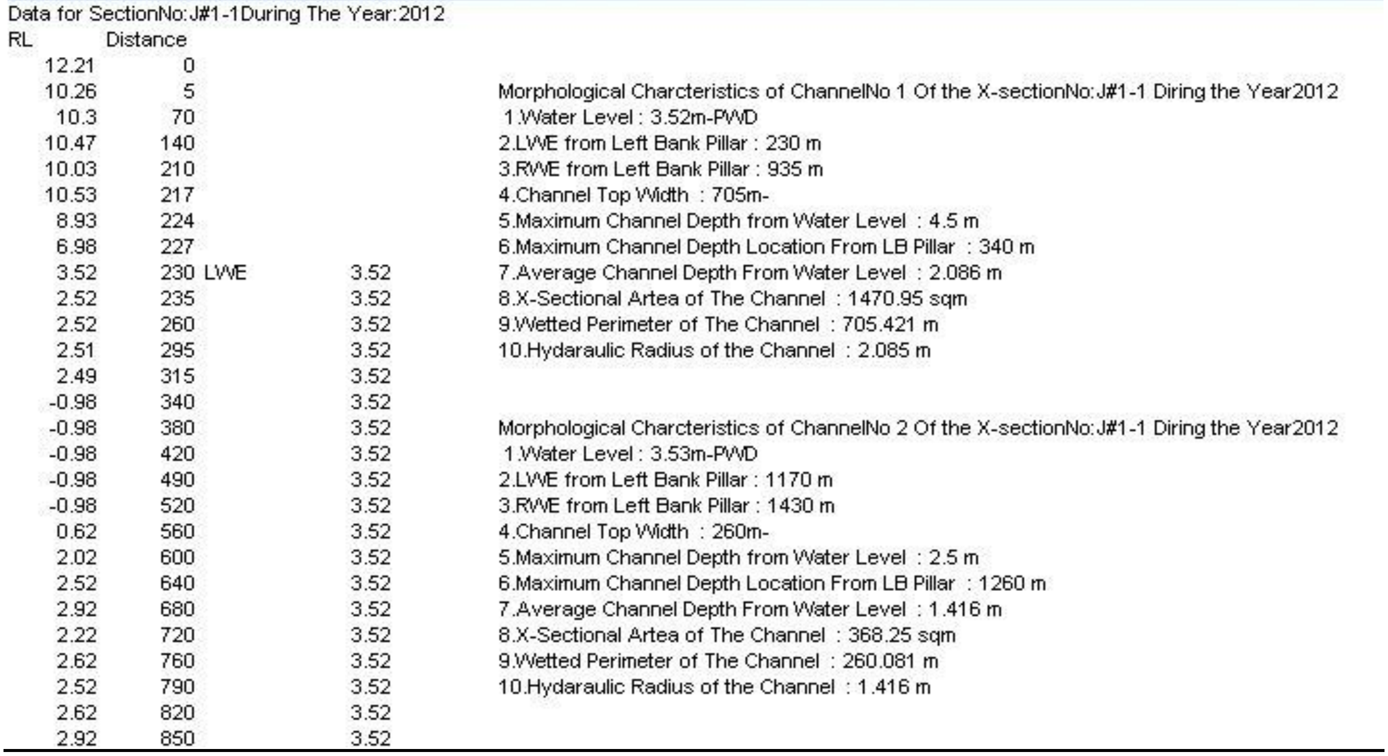
RL Distance



6.15	8240	
6.45	8300	
6.7	8360	
6.68	8420	
6.69	8500	
7.1	8510	
7.7	8580	
7.8	8640	
8.1	8700	
8.35	8760	
8.4	8820	
8.25	8880	
8.19	8920	
8.2	9060	
8.15	9090	
7.95	9150	
7.81	9210	
7.2	9280	
6.95	9350	
6.81	9410	
6.59	9470	
6.63	9540	
6.12	9600	
6.15	9660	
7.65	9710	
7.67	9770	
7.65	9840	
7.81	9900	
8.1	9960	
8.15	10000	
8.17	10015	Top of Wodden Peg-1 at L/B
8.25	10015.1	GL of Wodden Peg-2 at R/B

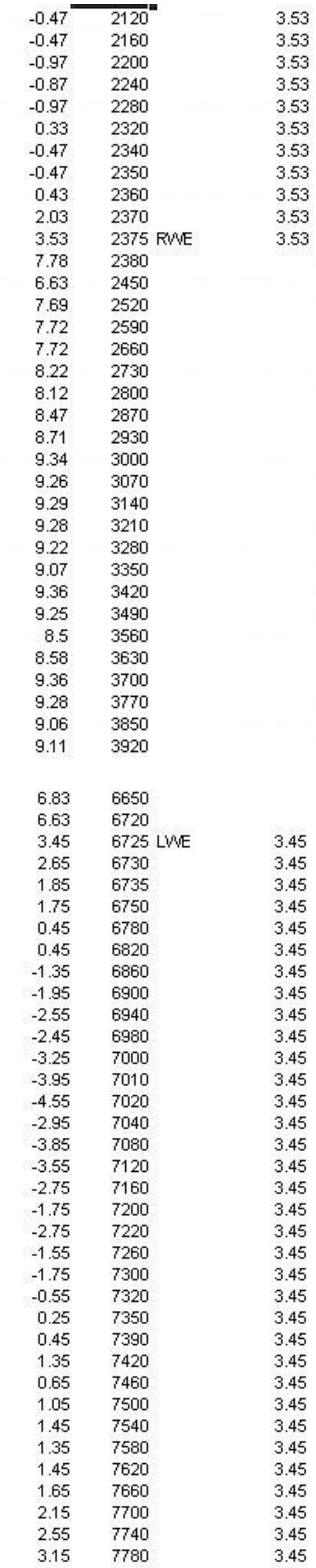

2011_J#1-1
BedProfile_J#1-1_2011
WL as On 14/3/2011At9:30hrs
WL as On 14/3/2011At12:00hrs
WL as On 17/3/2011At12:30hrs
Series5
RL(m-PWD)
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
1001.5
2003
3004.5
4006
5007.5
6009
7010.5
8012
9013.5
10015
Dist(m)

Data for Section No: J#1-1 during the Year 2012

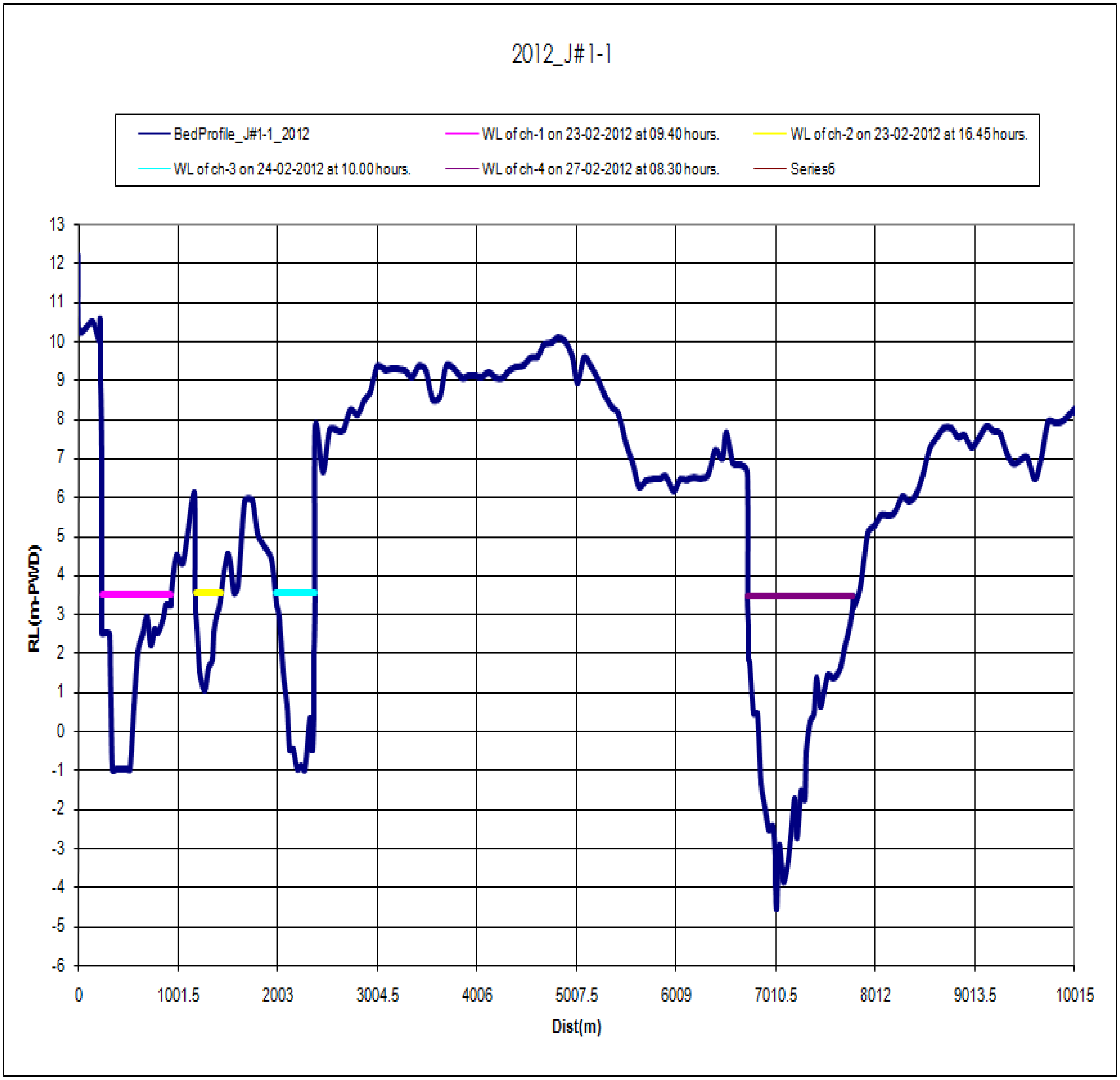


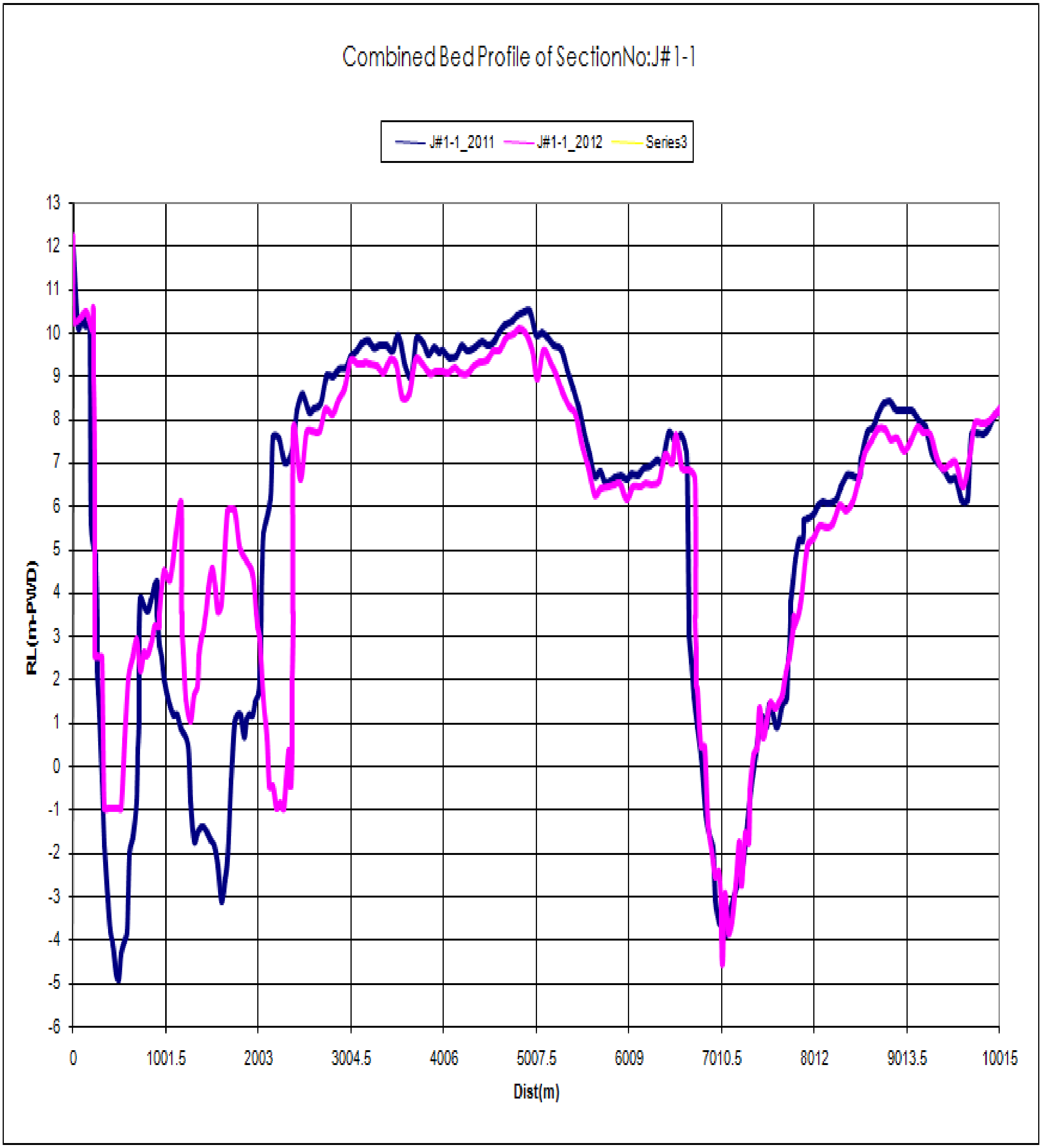
```
Data for SectionNo:J#1-1During The Year:2012
RL          Distance
    12.21          0
    10.26          5                          Morphological Charcteristics of ChannelNo 1 Of the X-sectionNo:J#1-1 Diring the Year2012
     10.3         70                           1.Water Level : 3.52m-PWD
    10.47        140                          2.LWE from Left Bank Pillar : 230 m
    10.03        210                          3.RWE from Left Bank Pillar : 935 m
    10.53        217                          4.Channel Top Width  : 705m-
     8.93        224                          5.Maximum Channel Depth from Water Level  : 4.5 m
     6.98        227                          6.Maximum Channel Depth Location From LB Pillar  : 340 m
     3.52        230 LWE            3.52      7.Average Channel Depth From Water Level  : 2.086 m
     2.52        235                3.52      8.X-Sectional Artea of The Channel  : 1470.95 sqm
     2.52        260                3.52      9.Wetted Perimeter of The Channel  : 705.421 m
     2.51        295                3.52      10.Hydaraulic Radius of the Channel  : 2.085 m
     2.49        315                3.52
    -0.98        340                3.52
    -0.98        380                3.52      Morphological Charcteristics of ChannelNo 2 Of the X-sectionNo:J#1-1 Diring the Year2012
    -0.98        420                3.52       1.Water Level : 3.53m-PWD
    -0.98        490                3.52      2.LWE from Left Bank Pillar : 1170 m
    -0.98        520                3.52      3.RWE from Left Bank Pillar : 1430 m
     0.62        560                3.52      4.Channel Top Width  : 260m-
     2.02        600                3.52      5.Maximum Channel Depth from Water Level  : 2.5 m
     2.52        640                3.52      6.Maximum Channel Depth Location From LB Pillar  : 1260 m
     2.92        680                3.52      7.Average Channel Depth From Water Level  : 1.416 m
     2.22        720                3.52      8.X-Sectional Artea of The Channel  : 368.25 sqm
     2.62        760                3.52      9.Wetted Perimeter of The Channel  : 260.081 m
     2.52        790                3.52      10.Hydaraulic Radius of the Channel  : 1.416 m
     2.62        820                3.52
     2.92        850                3.52
```

```
     2.62        820                3.52
     2.92        850                3.52
     3.22        880                3.52      Morphological Charcteristics of ChannelNo 3 Of the X-sectionNo:J#1-1 Diring the Year2012
     3.22        930                3.52       1.Water Level : 3.53m-PWD
     3.52        935 RWE            3.52      2.LWE from Left Bank Pillar : 1980 m
      4.5        980                          3.RWE from Left Bank Pillar : 2375 m
      4.3       1050                          4.Channel Top Width  : 395m-
      6.1       1160                          5.Maximum Channel Depth from Water Level  : 4.5 m
     3.53       1170 LWE            3.53      6.Maximum Channel Depth Location From LB Pillar  : 2200 m
     3.03       1175                3.53      7.Average Channel Depth From Water Level  : 3.236 m
     2.63       1190                3.53      8.X-Sectional Artea of The Channel  : 1278.25 sqm
     1.53       1220                3.53      9.Wetted Perimeter of The Channel  : 395.49 m
     1.03       1260                3.53      10.Hydaraulic Radius of the Channel  : 3.232 m
     1.63       1300                3.53
     1.83       1340                3.53
     2.53       1360                3.53      Morphological Charcteristics of ChannelNo 4 Of the X-sectionNo:J#1-1 Diring the Year2012
     2.93       1380                3.53       1.Water Level : 3.45m-PWD
     3.13       1410                3.53      2.LWE from Left Bank Pillar : 6725 m
     3.33       1425                3.53      3.RWE from Left Bank Pillar : 7785 m
     3.53       1430 RWE            3.53      4.Channel Top Width  : 1060m-
     4.08       1460                          5.Maximum Channel Depth from Water Level  : 8 m
     4.55       1500                          6.Maximum Channel Depth Location From LB Pillar  : 7020 m
      4.3       1530                          7.Average Channel Depth From Water Level  : 3.889 m
     3.55       1560                          8.X-Sectional Artea of The Channel  : 4122 sqm
     3.74       1600                          9.Wetted Perimeter of The Channel  : 1060.493 m
     5.87       1670                          10.Hydaraulic Radius of the Channel  : 3.887 m
      5.9       1740
     5.06       1800
     4.73       1870
     4.41       1940
     3.53       1980 LWE            3.53
     3.23       1990                3.53
     2.93       2010                3.53
     1.53       2050                3.53
     0.63       2090                3.53
```

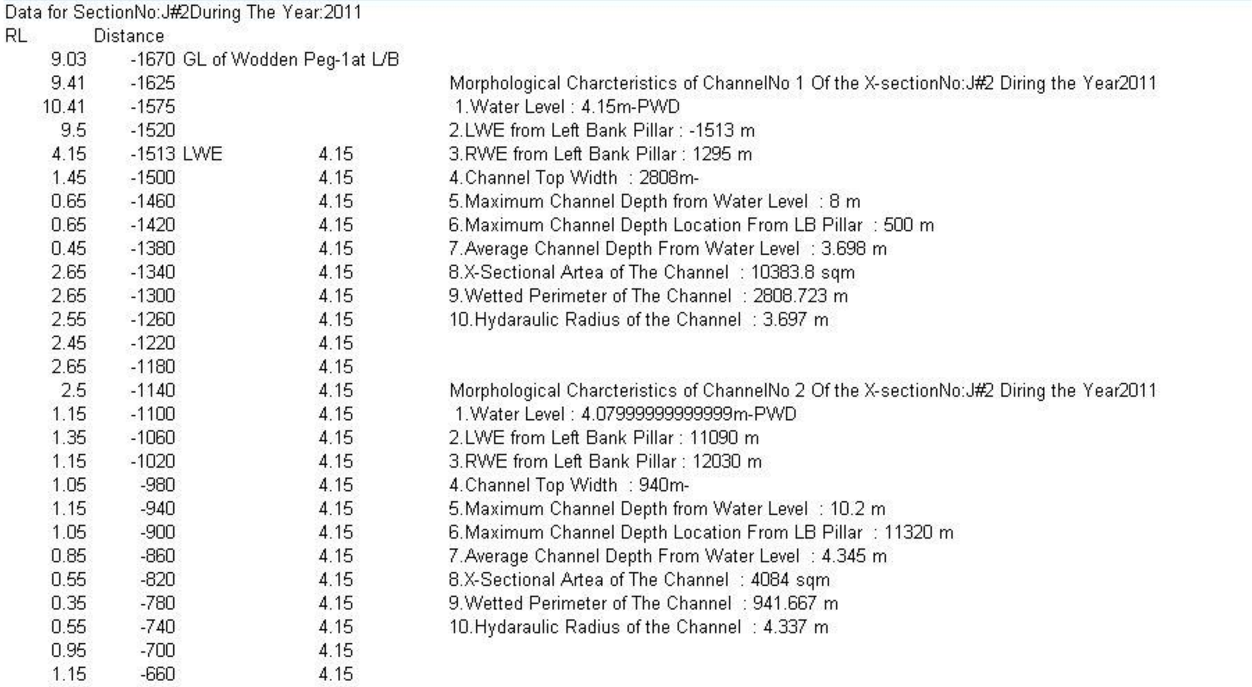


RL	Distance		GL of wooden peg- 1at L/B
-0.47	2120		3.53
-0.47	2160		3.53
-0.97	2200		3.53
-0.87	2240		3.53
-0.97	2280		3.53
0.33	2320		3.53
-0.47	2340		3.53
-0.47	2350		3.53
0.43	2360		3.53
2.03	2370		3.53
3.53	2375	RWE	3.53
7.78	2380		
6.63	2450		
7.69	2520		
7.72	2590		
7.72	2660		
8.22	2730		
8.12	2800		
8.47	2870		
8.71	2930		
9.34	3000		
9.26	3070		
9.29	3140		
9.28	3210		
9.22	3280		
9.07	3350		
9.36	3420		
9.25	3490		
8.5	3560		
8.58	3630		
9.36	3700		
9.28	3770		
9.06	3850		
9.11	3920		
6.83	6650		
6.63	6720		
3.45	6725	LWE	3.45
2.65	6730		3.45
1.85	6735		3.45
1.75	6750		3.45
0.45	6780		3.45
0.45	6820		3.45
-1.35	6860		3.45
-1.95	6900		3.45
-2.55	6940		3.45
-2.45	6980		3.45
-3.25	7000		3.45
-3.95	7010		3.45
-4.55	7020		3.45
-2.95	7040		3.45
-3.85	7080		3.45
-3.55	7120		3.45
-2.75	7160		3.45
-1.75	7200		3.45
-2.75	7220		3.45
-1.55	7260		3.45
-1.75	7300		3.45
-0.55	7320		3.45
0.25	7350		3.45
0.45	7390		3.45
1.35	7420		3.45
0.65	7460		3.45
1.05	7500		3.45
1.45	7540		3.45
1.35	7580		3.45
1.45	7620		3.45
1.65	7660		3.45
2.15	7700		3.45
2.55	7740		3.45
3.15	7780		3.45


2012_J#1-1
BedProfile_J#1-1_2012
WL of ch-1 on 23-02-2012 at 09.40 hours.
WL of ch-2 on 23-02-2012 at 16.45 hours.
WL of ch-3 on 24-02-2012 at 10.00 hours.
WL of ch-4 on 27-02-2012 at 08.30 hours.
Series6
RL(m-PWD)
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
1001.5
2003
3004.5
4006
5007.5
6009
7010.5
8012
9013.5
10015
Dist(m)


Combined Bed Profile of SectionNo:J#1-1
J#1-1_2011
J#1-1_2012
Series3
RL(m-PWD)
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
1001.5
2003
3004.5
4006
5007.5
6009
7010.5
8012
9013.5
10015
Dist(m)

Data for Section No: J#2 during the Year 2011

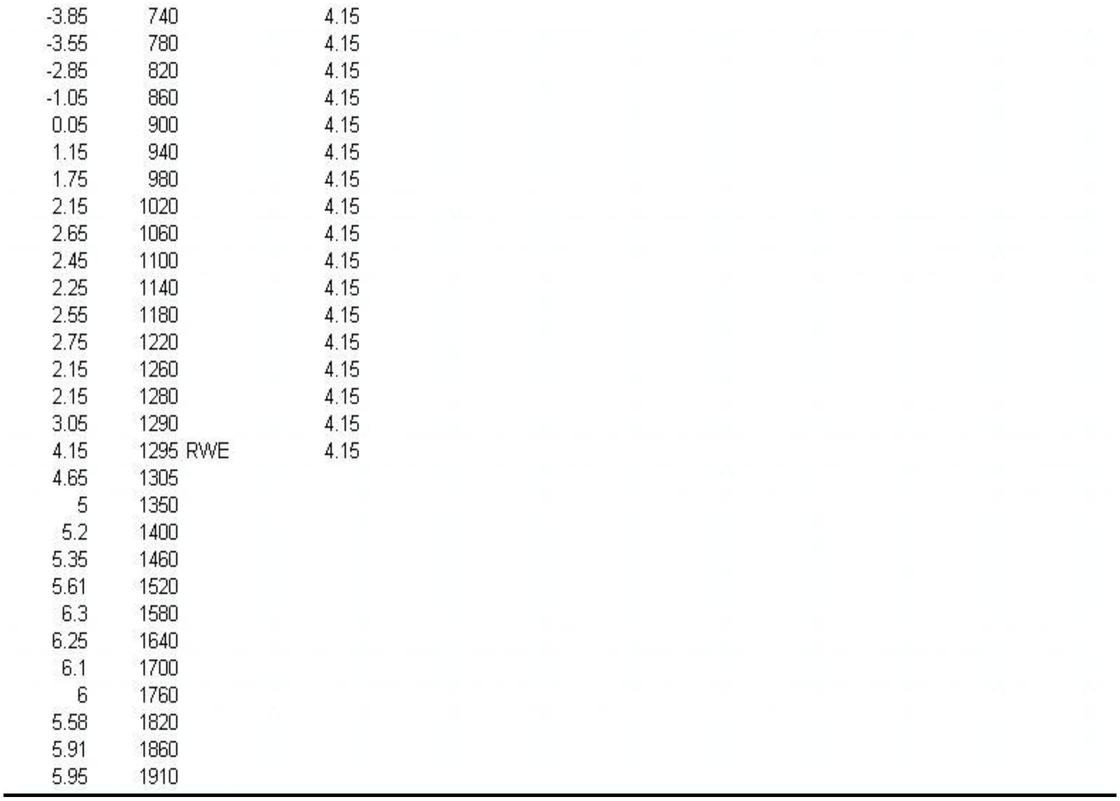


Data for SectionNo:J#2During The Year:2011

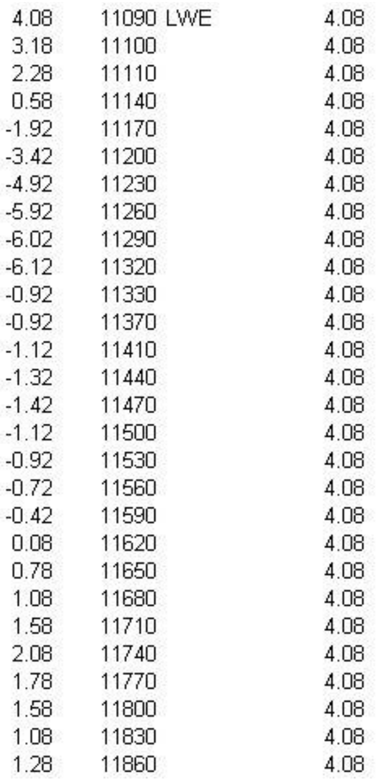
RL	Distance		
9.03	-1670	GL of Wodden Peg-1at L/B	
9.41	-1625		
10.41	-1575		
9.5	-1520		
4.15	-1513	LWE	4.15
1.45	-1500		4.15
0.65	-1460		4.15
0.65	-1420		4.15
0.45	-1380		4.15
2.65	-1340		4.15
2.65	-1300		4.15
2.55	-1260		4.15
2.45	-1220		4.15
2.65	-1180		4.15
2.5	-1140		4.15
1.15	-1100		4.15
1.35	-1060		4.15
1.15	-1020		4.15
1.05	-980		4.15
1.15	-940		4.15
1.05	-900		4.15
0.85	-860		4.15
0.55	-820		4.15
0.35	-780		4.15
0.55	-740		4.15
0.95	-700		4.15
1.15	-660		4.15

Morphological Charcteristics of ChannelNo 1 Of the X-sectionNo:J#2 Diring the Year2011
1.Water Level : 4.15m-PWD
2.LWE from Left Bank Pillar : -1513 m
3.RWE from Left Bank Pillar : 1295 m
4.Channel Top Width : 2808m-
5.Maximum Channel Depth from Water Level : 8 m
6.Maximum Channel Depth Location From LB Pillar : 500 m
7.Average Channel Depth From Water Level : 3.698 m
8.X-Sectional Artea of The Channel : 10383.8 sqm
9.Wetted Perimeter of The Channel : 2808.723 m
10.Hydaraulic Radius of the Channel : 3.697 m

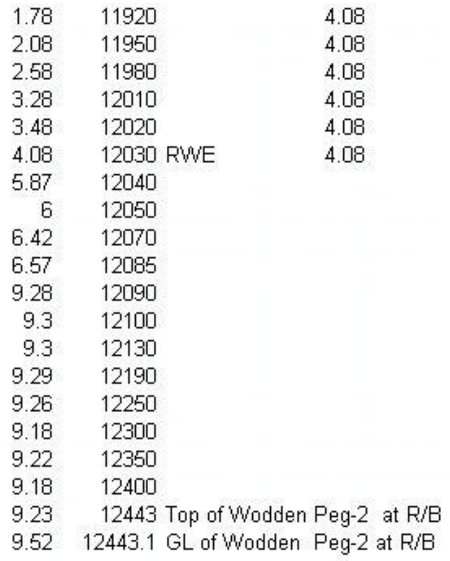
Morphological Charcteristics of ChannelNo 2 Of the X-sectionNo:J#2 Diring the Year2011
1.Water Level : 4.07999999999999m-PWD
2.LWE from Left Bank Pillar : 11090 m
3.RWE from Left Bank Pillar : 12030 m
4.Channel Top Width : 940m-
5.Maximum Channel Depth from Water Level : 10.2 m
6.Maximum Channel Depth Location From LB Pillar : 11320 m
7.Average Channel Depth From Water Level : 4.345 m
8.X-Sectional Artea of The Channel : 4084 sqm
9.Wetted Perimeter of The Channel : 941.667 m
10.Hydaraulic Radius of the Channel : 4.337 m



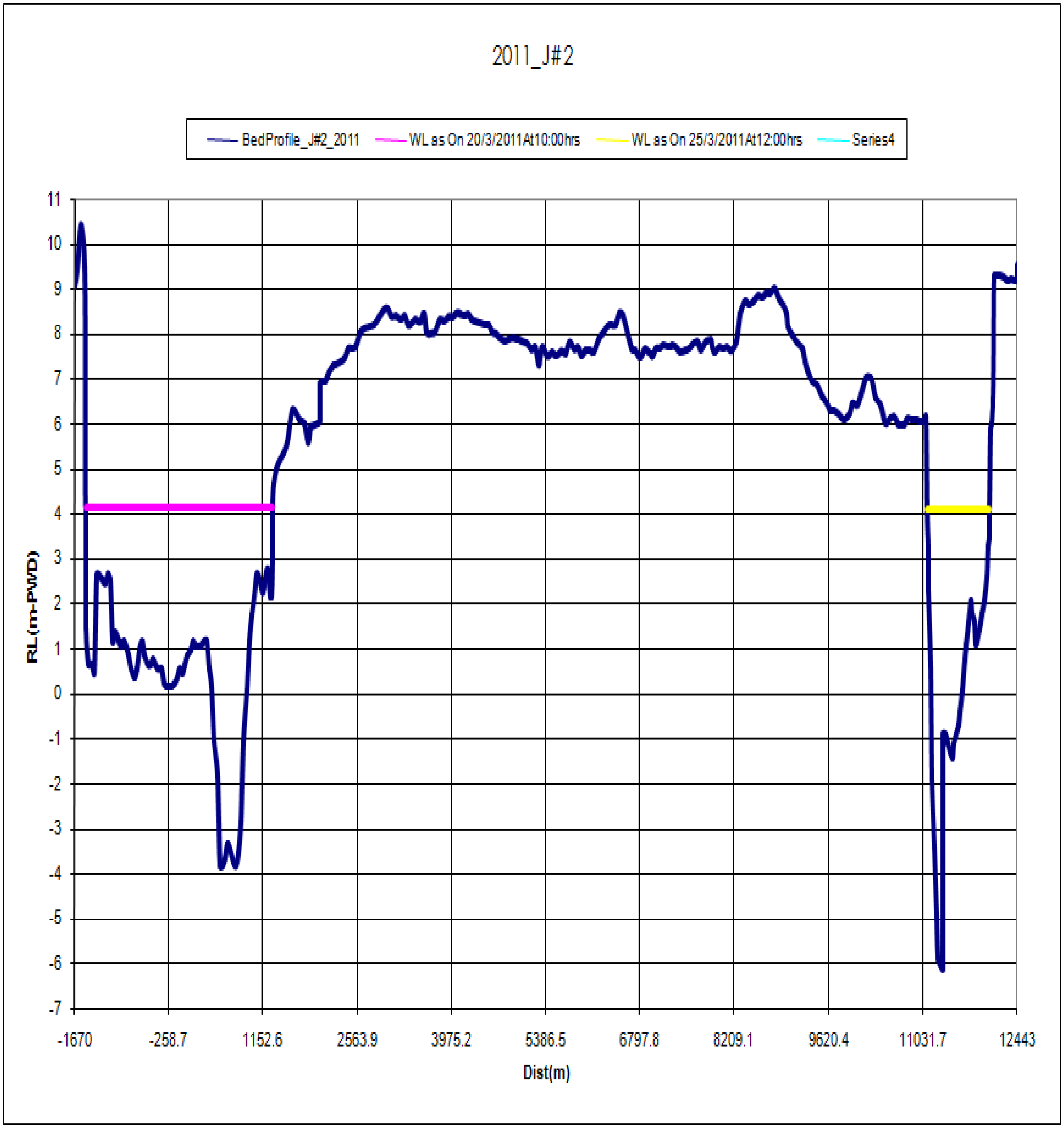
-3.85	740		4.15
-3.55	780		4.15
-2.85	820		4.15
-1.05	860		4.15
0.05	900		4.15
1.15	940		4.15
1.75	980		4.15
2.15	1020		4.15
2.65	1060		4.15
2.45	1100		4.15
2.25	1140		4.15
2.55	1180		4.15
2.75	1220		4.15
2.15	1260		4.15
2.15	1280		4.15
3.05	1290		4.15
4.15	1295	RWE	4.15
4.65	1305		
5	1350		
5.2	1400		
5.35	1460		
5.61	1520		
6.3	1580		
6.25	1640		
6.1	1700		
6	1760		
5.58	1820		
5.91	1860		
5.95	1910		



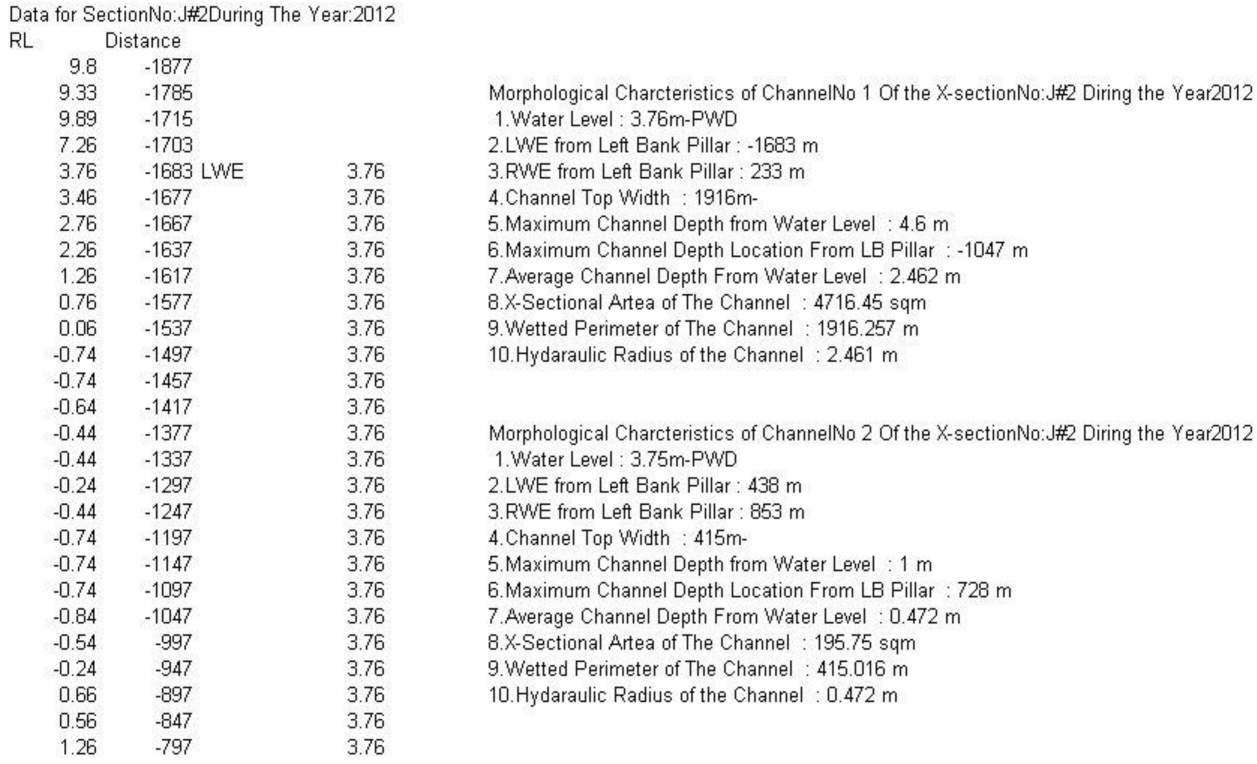
RL	Distance	GL of wooden peg-1 at L/B
4.08	11090 LWE	4.08
3.18	11100	4.08
2.28	11110	4.08
0.58	11140	4.08
-1.92	11170	4.08
-3.42	11200	4.08
-4.92	11230	4.08
-5.92	11260	4.08
-6.02	11290	4.08
-6.12	11320	4.08
-0.92	11330	4.08
-0.92	11370	4.08
-1.12	11410	4.08
-1.32	11440	4.08
-1.42	11470	4.08
-1.12	11500	4.08
-0.92	11530	4.08
-0.72	11560	4.08
-0.42	11590	4.08
0.08	11620	4.08
0.78	11650	4.08
1.08	11680	4.08
1.58	11710	4.08
2.08	11740	4.08
1.78	11770	4.08
1.58	11800	4.08
1.08	11830	4.08
1.28	11860	4.08



1.78	11920	4.08
2.08	11950	4.08
2.58	11980	4.08
3.28	12010	4.08
3.48	12020	4.08
4.08	12030 RWE	4.08
5.87	12040	
6	12050	
6.42	12070	
6.57	12085	
9.28	12090	
9.3	12100	
9.3	12130	
9.29	12190	
9.26	12250	
9.18	12300	
9.22	12350	
9.18	12400	
9.23	12443 Top of Wodden Peg-2 at R/B	
9.52	12443.1 GL of Wodden Peg-2 at R/B	


2011_J#2
BedProfile_J#2_2011
WL as On 20/3/2011At10:00hrs
WL as On 25/3/2011At12:00hrs
Series4
RL(m-PWD)
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-1670
-258.7
1152.6
2563.9
3975.2
5386.5
6797.8
8209.1
9620.4
11031.7
12443
Dist(m)

Data for Section No: J#2 During the Year 2012

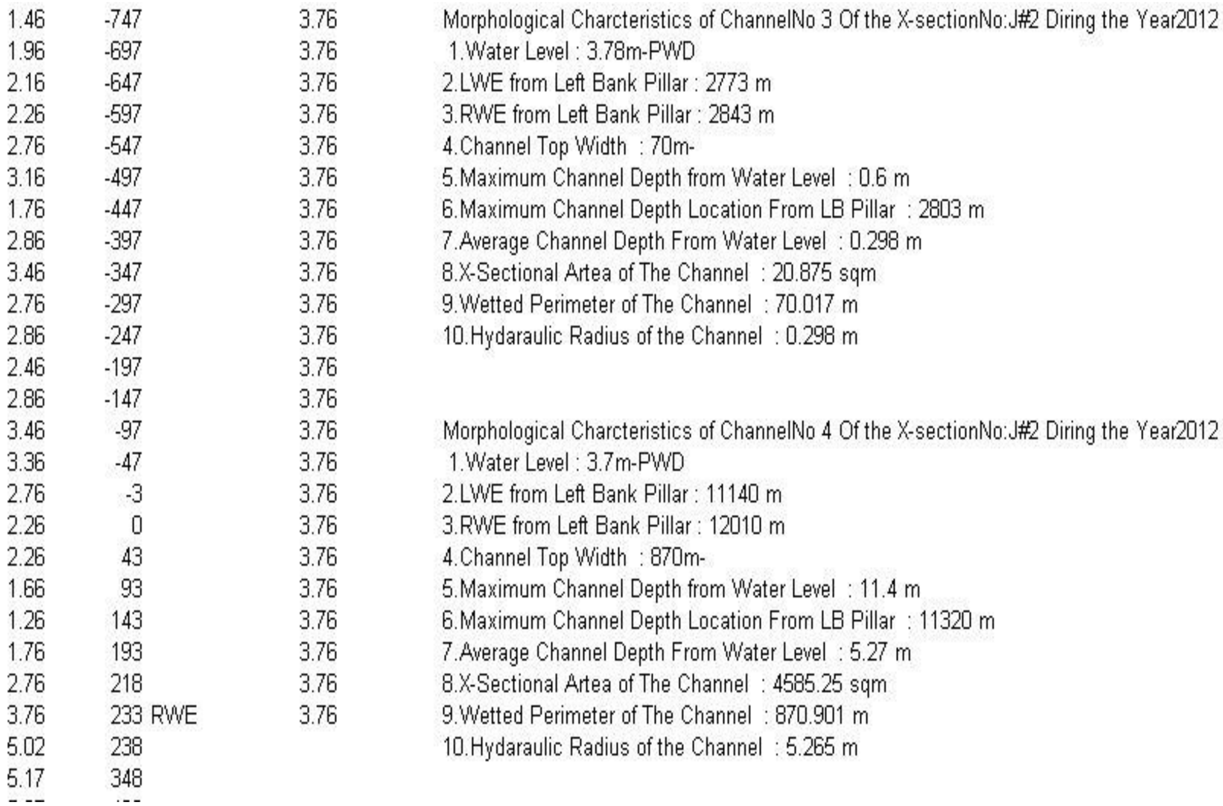


Data for SectionNo:J#2During The Year:2012

RL	Distance	
9.8	-1877	
9.33	-1785	
9.89	-1715	
7.26	-1703	
3.76	-1683 LWE	3.76
3.46	-1677	3.76
2.76	-1667	3.76
2.26	-1637	3.76
1.26	-1617	3.76
0.76	-1577	3.76
0.06	-1537	3.76
-0.74	-1497	3.76
-0.74	-1457	3.76
-0.64	-1417	3.76
-0.44	-1377	3.76
-0.44	-1337	3.76
-0.24	-1297	3.76
-0.44	-1247	3.76
-0.74	-1197	3.76
-0.74	-1147	3.76
-0.74	-1097	3.76
-0.84	-1047	3.76
-0.54	-997	3.76
-0.24	-947	3.76
0.66	-897	3.76
0.56	-847	3.76
1.26	-797	3.76

Morphological Charcteristics of ChannelNo 1 Of the X-sectionNo:J#2 Diring the Year2012
1.Water Level : 3.76m-PWD
2.LWE from Left Bank Pillar : -1683 m
3.RWE from Left Bank Pillar : 233 m
4.Channel Top Width : 1916m-
5.Maximum Channel Depth from Water Level : 4.6 m
6.Maximum Channel Depth Location From LB Pillar : -1047 m
7.Average Channel Depth From Water Level : 2.462 m
8.X-Sectional Artea of The Channel : 4716.45 sqm
9.Wetted Perimeter of The Channel : 1916.257 m
10.Hydaraulic Radius of the Channel : 2.461 m

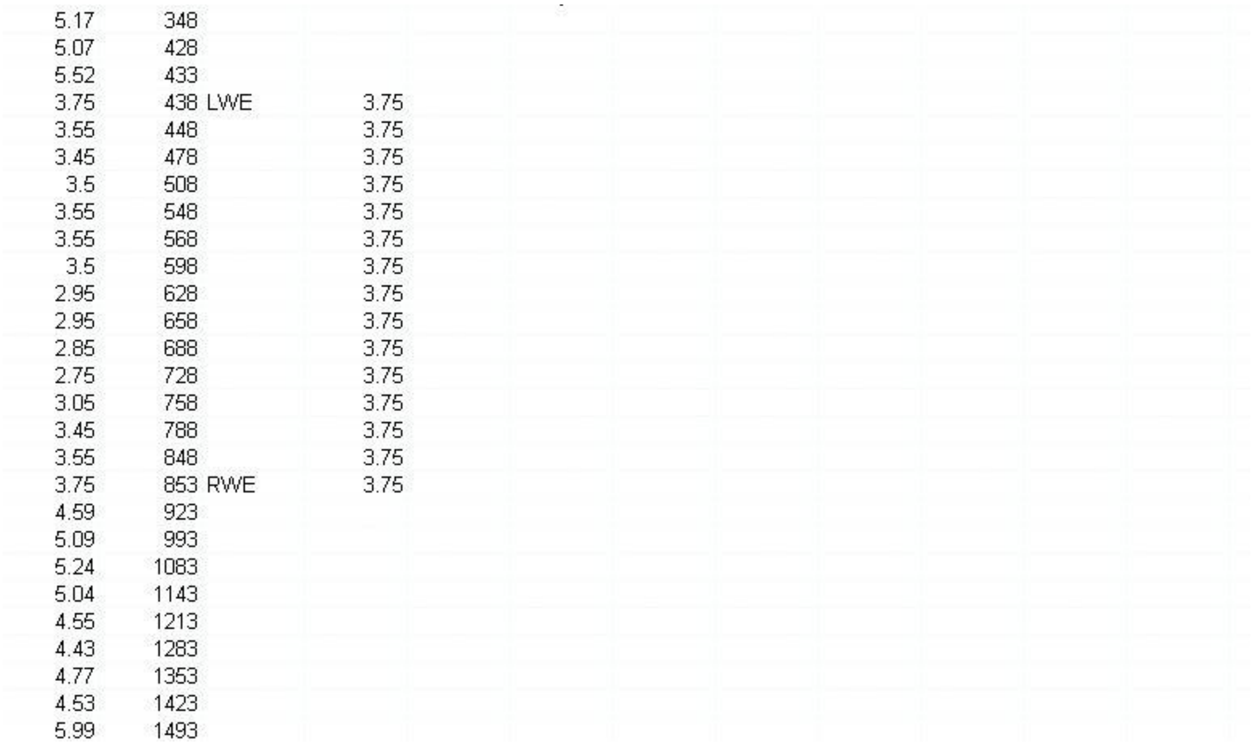
Morphological Charcteristics of ChannelNo 2 Of the X-sectionNo:J#2 Diring the Year2012
1.Water Level : 3.75m-PWD
2.LWE from Left Bank Pillar : 438 m
3.RWE from Left Bank Pillar : 853 m
4.Channel Top Width : 415m-
5.Maximum Channel Depth from Water Level : 1 m
6.Maximum Channel Depth Location From LB Pillar : 728 m
7.Average Channel Depth From Water Level : 0.472 m
8.X-Sectional Artea of The Channel : 195.75 sqm
9.Wetted Perimeter of The Channel : 415.016 m
10.Hydaraulic Radius of the Channel : 0.472 m



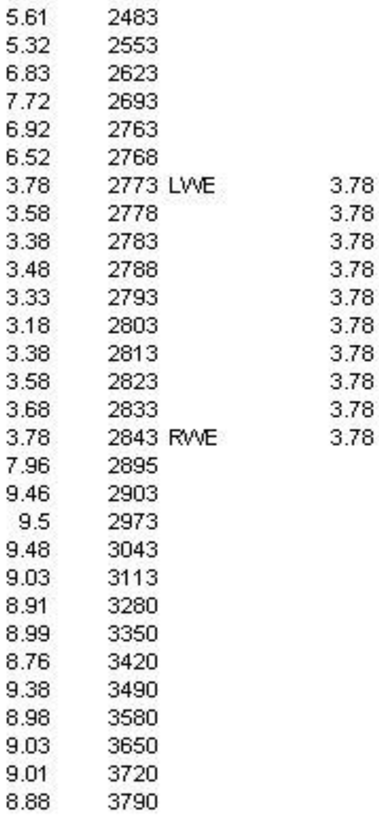
1.46	-747	3.76
1.96	-697	3.76
2.16	-647	3.76
2.26	-597	3.76
2.76	-547	3.76
3.16	-497	3.76
1.76	-447	3.76
2.86	-397	3.76
3.46	-347	3.76
2.76	-297	3.76
2.86	-247	3.76
2.46	-197	3.76
2.86	-147	3.76
3.46	-97	3.76
3.36	-47	3.76
2.76	-3	3.76
2.26	0	3.76
2.26	43	3.76
1.66	93	3.76
1.26	143	3.76
1.76	193	3.76
2.76	218	3.76
3.76	233 RWE	3.76
5.02	238	
5.17	348	

Morphological Charcteristics of ChannelNo 3 Of the X-sectionNo:J#2 Diring the Year2012
1.Water Level : 3.78m-PWD
2.LWE from Left Bank Pillar : 2773 m
3.RWE from Left Bank Pillar : 2843 m
4.Channel Top Width : 70m-
5.Maximum Channel Depth from Water Level : 0.6 m
6.Maximum Channel Depth Location From LB Pillar : 2803 m
7.Average Channel Depth From Water Level : 0.298 m
8.X-Sectional Artea of The Channel : 20.875 sqm
9.Wetted Perimeter of The Channel : 70.017 m
10.Hydaraulic Radius of the Channel : 0.298 m

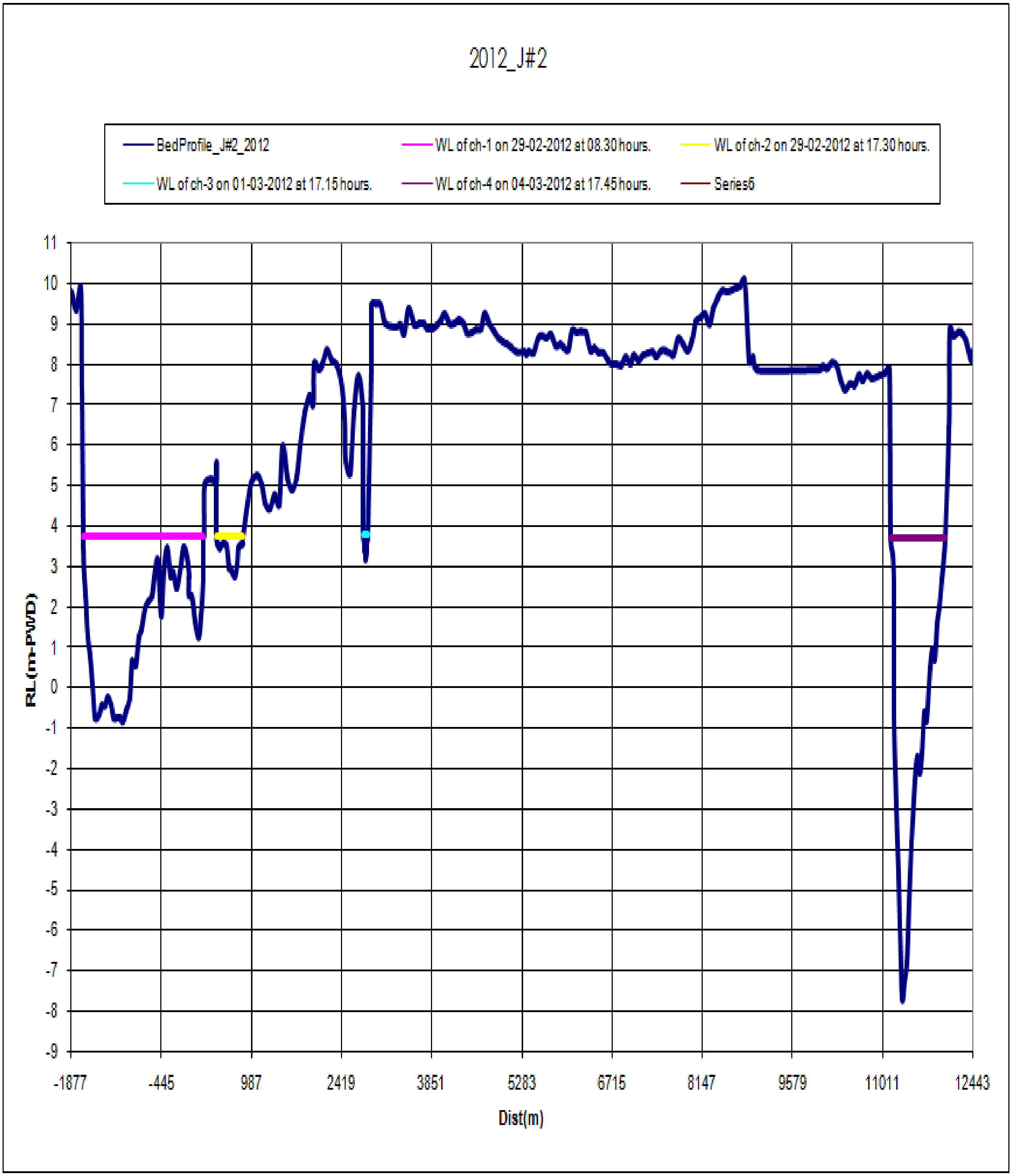
Morphological Charcteristics of ChannelNo 4 Of the X-sectionNo:J#2 Diring the Year2012
1.Water Level : 3.7m-PWD
2.LWE from Left Bank Pillar : 11140 m
3.RWE from Left Bank Pillar : 12010 m
4.Channel Top Width : 870m-
5.Maximum Channel Depth from Water Level : 11.4 m
6.Maximum Channel Depth Location From LB Pillar : 11320 m
7.Average Channel Depth From Water Level : 5.27 m
8.X-Sectional Artea of The Channel : 4585.25 sqm
9.Wetted Perimeter of The Channel : 870.901 m
10.Hydaraulic Radius of the Channel : 5.265 m

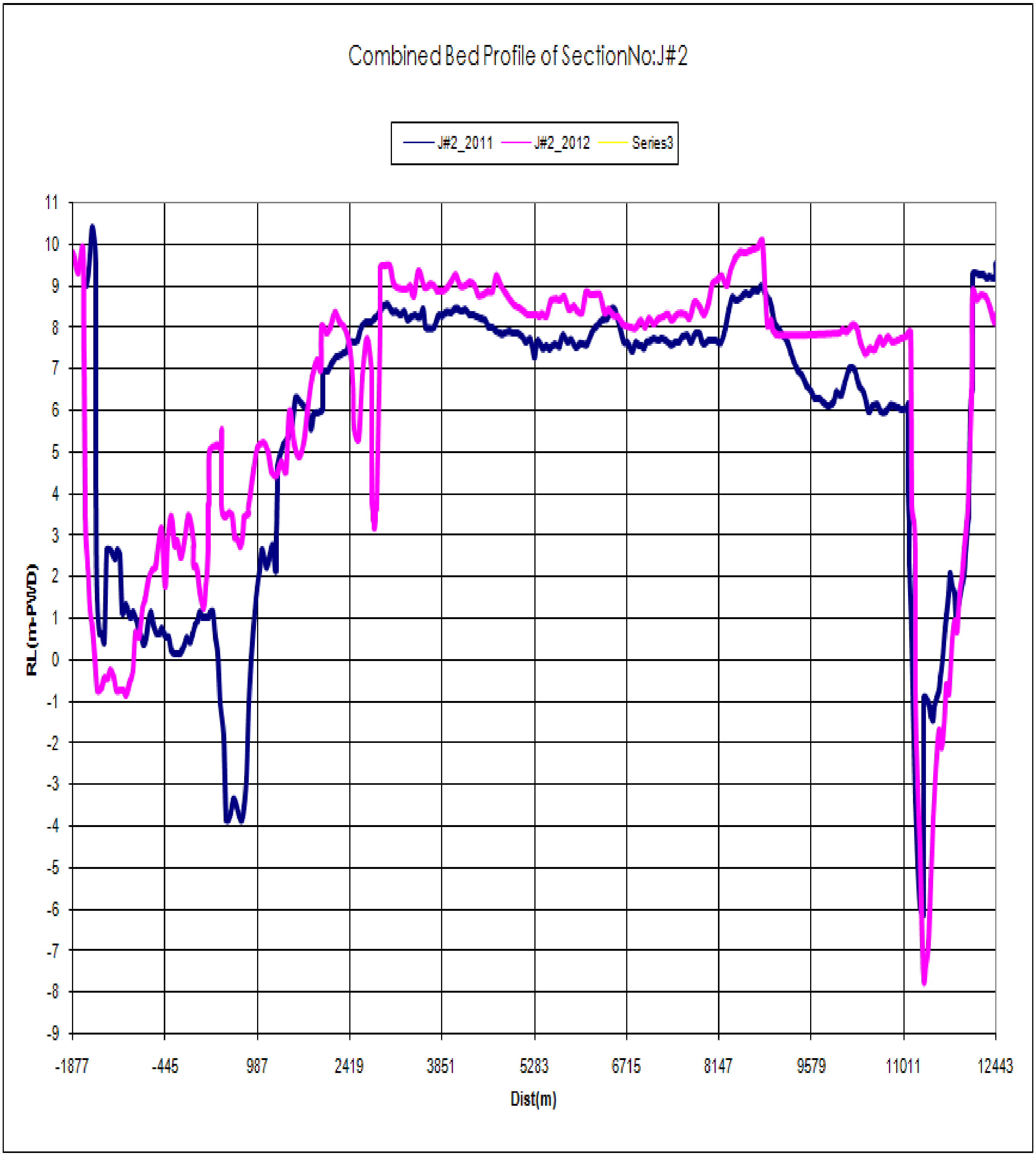


RL	Distance	GL of wooden peg-1 at L/B
5.17	348	
5.07	428	
5.52	433	
3.75	438 LWE	3.75
3.55	448	3.75
3.45	478	3.75
3.5	508	3.75
3.55	548	3.75
3.55	568	3.75
3.5	598	3.75
2.95	628	3.75
2.95	658	3.75
2.85	688	3.75
2.75	728	3.75
3.05	758	3.75
3.45	788	3.75
3.55	848	3.75
3.75	853 RWE	3.75
4.59	923	
5.09	993	
5.24	1083	
5.04	1143	
4.55	1213	
4.43	1283	
4.77	1353	
4.53	1423	
5.99	1493	



5.61	2483	
5.32	2553	
6.83	2623	
7.72	2693	
6.92	2763	
6.52	2768	
3.78	2773 LWE	3.78
3.58	2778	3.78
3.38	2783	3.78
3.48	2788	3.78
3.33	2793	3.78
3.18	2803	3.78
3.38	2813	3.78
3.58	2823	3.78
3.68	2833	3.78
3.78	2843 RWE	3.78
7.96	2895	
9.46	2903	
9.5	2973	
9.48	3043	
9.03	3113	
8.91	3280	
8.99	3350	
8.76	3420	
9.38	3490	
8.98	3580	
9.03	3650	
9.01	3720	
8.88	3790	


2012_J#2
BedProfile_J#2_2012
WL of ch-1 on 29-02-2012 at 08.30 hours.
WL of ch-2 on 29-02-2012 at 17.30 hours.
WL of ch-3 on 01-03-2012 at 17.15 hours.
WL of ch-4 on 04-03-2012 at 17.45 hours.
Series6
RL(m-PWD)
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-1877
-445
987
2419
3851
5283
6715
8147
9579
11011
12443
Dist(m)


Combined Bed Profile of SectionNo:J#2
J#2_2011
J#2_2012
Series3
RL(m-PWD)
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-1877
-445
987
2419
3851
5283
6715
8147
9579
11011
12443
Dist(m)

7. Conclusion and Recommendation:

7.1 Conclusions

From this study the following conclusion can be drawn:

(1) It is observed that after conducting simulation using HEC-RAS, the water bed profile is different in different distance and RL.

(2) It is clear from the study that the morphological characteristics of the river cross section played the vital role in determining the variance in bed profile.

We've successfully simulated seventeen river section to conduct the water flow analysis. By simulating the upstream and downstream flow of Jamuna river for particular years, we can easily assume the elevation of water levels for the upcoming years. This analysis looks promising for further going analysis. We can use this process for simulating further cross section of Jamuna river. Also it can be conducted for other braided rivers.

7.2 Recommendations

We conducted this simulation only for braided type rivers. But this simulation should also be tested in other types of rivers. Besides, we used one dimensional HEC-RAS modeling for the simulation. Other types of software may give some different values. So, simulation should be conducted by using other types of software also.

8. References

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HEC-RAS - Hydrologic Engineering Center, www.hec.usace.army.mil/software/hec-ras/