APPLICATION OF HEC-RAS AT THE DOWNSTREAM OF A TAIL RACE CHANNEL OF MAITHON HYDEL STATION

A thesis submitted towards partial fulfilment of
the requirements for the degree of

Master of Engineering in
Water Resources and Hydraulic Engineering
Course affiliated to Faculty of Engineering &Technology
Jadavpur University

Submitted by

SUBHAJYOTI CHAKRABORTI

EXAMINATION ROLL NO.: M4WRE19011

Under the guidance of

Prof. (Dr.) PANKAJ KUMARROY
Professor
School Of Water Resources Engineering,
Jadavpur University
&
Dr GOURAB BANERJEE
Assistant Professor
School Of Water Resources Engineering,
Jadavpur University

School of Water Resources Engineering
M.E.(Water Resources & Hydraulic Engineering)
Course affiliated to Faculty of Engineering and Technology
Jadavpur University
Kolkata-700032
India
2019

M.E. (Water Resources & Hydraulic Engineering) Course affiliated to

Faculty of Engineering and Technology Jadavpur University Kolkata, India

CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled **"Application Of HEC-RAS At The Downstream Of A Tail Race Channel Of Maithon Hydel Station"** is bonafide work carried out by **SUBHAJYOTI CHAKRABORTI** under our supervision and guidance for partial fulfilment of the requirement for Post Graduate Degree of Master of Engineering in Water Resources & Hydraulic Engineering during the academic session 2018-2019.

THESIS ADVISOR	**THESIS ADVISOR**
Prof. (Dr.) Pankaj Kumar Roy	**Dr. Gourab Banerjee**
Professor	**Assistant Professor**
School of Water Resources Engineering	**School of Water Resources Engineering**
Jadavpur University, Kolkata- 700032	**Jadavpur University, Kolkata- 700032**

DIRECTOR
Prof. (Dr.) Asis Mazumdar
School of Water Resources Engineering
Jadavpur University, Kolkata- 700032

DEAN

Prof. (Dr.) Pankaj Kumar Roy
Faculty of Interdisciplinary Studies, Law & Management Jadavpur University, Kolkata-700032

M.E. (Water Resources & Hydraulic Engineering) Course Affiliated to
FacultyofEngineeringandTechnologyJadavpurUniversityKolkata,India

CERTIFICATE OF APPROVAL **

This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactorily to warranty its acceptance as a pre-requisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for purpose for which it has been submitted.

Committee

Final Examination
for the evaluation of the thesis

**** Only in case the thesis is approved.**

Declaration of Originality and Compliance of Academic Ethics

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as a part of my Master of Water Resources & Hydraulic Engineering degree during academic session 2018-2019.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by this rules and conduct, I have fully cited and referred all material and results that are not original to this work.

Name: **SUBHAJYOTI CHAKRABORTI**

Roll Number: **M4WRE19011**

Thesis Title: **Application Of HEC-RAS At The Downstream Of A Tail Race Channel Of Maithon Hydel Station**

Signature:

Date:

ACKNOWLEDGEMENT

I express my sincere gratitude to my Thesis Advisor **Prof. (Dr.) Pankaj Kumar Roy,** Professor of School of Water Resources Engineering, Jadavpur University **& Dr. Gourab Banerjee,** Assistant Professor of School of Water Resources Engineering, Jadavpur University under whose valuable guidance this work has been carried out. It would have been impossible to carry out this thesis work with confidence without his wholehearted involvement, advice, support and constant encouragement throughout. He has not only helped me to complete my thesis work but also have given valuable advice to proceed further in my life.

I also express my sincere gratitude to all the faculty members **Prof. (Dr.) Asis Mazumdar, Director, Prof. (Dr.) Arunabha Majumder,** Emeritus Professor of School of Water Resources Engineering, Jadavpur University**, Dr. Subhasis Das ,** Assistant Professor of School of Water Resources Engineering, Jadavpur University **& Dr. Rajib Das ,** Assistant Professor of School of Water Resources Engineering, Jadavpur University for their valuable suggestion.

Thanks are also due to all staff of School of Water Resources Engineering and the Regional Centre, NAEB, Jadavpur University for their help and support.

I would also like to thank Damodar Valley Corporation (DVC) and its officials for their constant help and assistance.

I would also like to thank **Miss Swetasree Nag** and **Miss Sudipa Halder,** Junior Research Fellow of School of water resources Engineering ,Jadavpur University & my fellow batch mates and classmates for their constant help and encouragement during my thesis.

But not the least ,I thank Almighty God ,my loving mother **Smita Chakraborti** and father **Dr Subrata Chakraborti** and all other family members and friends for their consistent help ,moral support, mental strength and inspiration during the study.

Date : May, 2019

Place : Jadavpur University,

Kolkata

SUBHAJYOTI CHAKRABORTI

(Roll No. -M4WRE19011)

Abstract

Water is the precious gift by the nature has now become limited, especially for drinking water need due to increasing population and pollution. Such situation arise the need to manage and conserve it more efficiently and judiciously. Dams are needed to effectively use the water in various useful purposes. In this study, an attempt was made to develop a hydrologic model with help of advance software HECRAS to get an over view of the hydrological condition of the downstream of a Tail race channel of Maithon Hydel station. Q-GIS software is used to get the involvement of the catchment area for the flow calculation of the various points of the river Barakar. Digital Elevation Model (DEM) is used to identify the change in the topographical scenario throughout the study area .Finally from the satellite images of the Google Earth of the river system schematic is adapted for the model generation .Detail analysis of the sites is carried out from the data of the site visits and the data obtained from survey report. Due to high discharge in rainy season low lying areas such as tails race of the downstream side of the Maithon dam affected by the floods and cased massive soil erosion and scouring which will also effect impact on stability of the dam. To prevent this hazards sustainable stable channel design is needed. In this present thesis work an attempt had been made to know the stable channel dimension with help of HEC-RAS software. The simulated results from HEC-RAS will provide important information's related to natural disaster. In addition, it reduces the uncertainty for flood inundation mapping under future dam releases. The collected data were used to generate the output by the software model and for flow calculation. The present study revealed that the flow rates of 65 m^3/s ,130 m^3/s and 200 m^3/s is carried out and it can be concluded that the tail race cross section is sufficient to carry the above-mentioned discharges. Outcome of model quantify that the average velocity of downstream section is 1.75 m/s which is quite more than the normal river velocity so bed material with boulder pitching needs to be addressed in the downstream channel to avoid scouring and erosion at bed level. The results are also depicted in the form of cross section outputs, profile outputs, XYZ perspective plots, general profile plots ,water surface profiles, rating curves which are useful for predicting flood mitigation measures.

LIST OF TABLES

LIST OF MAPS

LIST OF GRAPHS

LIST OF PHOTOGRAPHS

LIST OF FIGURES

TABLE OF CONTENTS

CHAPTER :-1

CHAPTER:- 2

CHAPTER:- 3

Chapter :- 4

Chapter :-5

CHAPTER :-6

Chapter :- 7

Chapter :- 8

Chapter :- 9

1. INTRODUCTION

1.1 . GENERAL BACKGROUND

Water is one of the most important elements for living being on earth. It solves the various purposes such as biological need, domestic , agricultural and industrial requirement of water. Water availability in India mainly obtained from precipitation, surface water and groundwater storage. India experiences an average precipitation of 1,170 millimetres per year, or about 4,000 cubic kilometres of rains annually or about 1,720 cubic metres of fresh water per person every year. Some 80 percent of its area experiences rains of 750 millimetres or more a year. However, this rain is not uniform in time or geography. Most of the rains occur during its monsoon seasons (June to September), with the north east and north receiving far more rains than India's west and south. Other than rains, the melting of snow over the Himalayas after winter season feeds the northern rivers to varying degrees. The southern rivers, however experience more flow variability over the year. For the Himalayan basin, this leads to flooding in some months and water scarcity in others. Despite extensive river system, safe clean drinking water as well as irrigation water supplies for sustainable agriculture are in shortage across India, in part because it has, as yet, harnessed a small fraction of its available and recoverable surface water resource. India harnessed 761 cubic kilometres (20 percent) of its water resources in 2010, part of which came from unsustainable use of groundwater. Of the water it withdrew from its rivers and groundwater wells, India dedicated about 688 cubic kilometres to irrigation, 56 cubic kilometres to municipal and drinking water applications and 17 cubic kilometres to industry.Vast area of India is under tropical climate which is conducive throughout the year for agriculture due to favourable warm and sunny conditions provided perennial water supply is available to cater to the high rate of evapotranspiration from the cultivated land. Though the overall water resources are adequate to meet all the requirements of the country, the water supply gaps due to temporal and spatial distribution of water resources are to be bridged by interlinking the rivers of India.The total water resources going waste to the sea are nearly 1200 billion cubic meters after sparing moderate environmental / salt export water requirements of all rivers. Food security in India is possible by achieving water security first which in turn is possible with energy security to supply the electricity for the required water pumping as part of its rivers interlinking. Water resources including rivers, lakes or fresh water wetlands are known as surface water resources. Precipitation is the natural recharging source for the surface water resources and it also maintain the hydrological cycle. Rivers are the major source of water in India. The utilizable annual surface water in rivers of the country is 690 km^3. Human activities like artificial dams, reservoirs are also included in the same category and have capacity to increase utilization of the water.

Large dams and development are interrelated, and this acquaintance may be implemented in an integrated way to boost up the economy of backward region using mainly the water, mineral, and power resources. Development has been defined as a dynamic process of growth, expansion, or realization of potential, bringing regional resources into full productive use (Husain 2011). Regional development emphasizes on re-organizing the space for its comprehensive development with a view to providing ideal living conditions to all human communities in all regions of human occupancy not in isolation from each other but in integration with each other (Chandna 2008). In India, one of the earliest outcomes of comprehensive regional planning was enacted as the multipurpose river valley project, constructing large dams on major rivers (focusing on flood mitigation, irrigation and hydropower). Importantly, the first river valley project of India was jointly implemented in Damodar

River Basin (DRB) by the states of Jharkhand (then Bihar) and West Bengal under the great leadership of first Prime Minster, Pandit Jawaharlal Nehru. The most significant geographical aspect of this developmental program is the modification of natural spatial unit, i.e., drainage basin, which is the fundamental unit of geomorphic and hydrological study. Under the Damodar Valley Multipurpose Project (DVMP), the vast resources (water, minerals, coals, forest, and alluvial soils) of DRB are not only to be envisioned in their entirety but also to be developed in an integrated way where the water, land, and people are simultaneously bounded in a seamless web (Krik 1950; Saha 1979). The large-scale modification of river basin is enacted by the fluvial engineering structures, including dams, barrages, weirs, sluices, canals, and embankments, to regulate stream flow and to use water resource in productive ways (Mishra 2001). However, river basins are considered an important repository of neo-tectonic, hydrological, climatic, and anthropogenic changes because the fluvial system is the most sensitive elements of the earth’s surface, and any shift in environmental conditions instigates a rapid response from the fluvial system (Sridhar 2008; SinghviandKale 2009). So the construction of dams and other structures on the river demolishes its previous natural entity and compels the fluvial system to enter into a new phase of equilibrium with changing aggradation and degradation processes.

Flood inundation mapping and Hydraulic modelling are performed to provide important informations from the flood event including the water surface elevations and level of inundation within the study area. A hydraulic simulation model is a mathematical representation of the physical hydraulic processes that occur during a flood event. Such processes can be described by Conservation of Mass, Conservation of Momentum, and Conservation of Energy equations posed in either one, two or three dimensions. As one might expect, as the dimensionality of the problem increases the complexity associated with solving the problem also increases. As a result, many different simplifications and assumptions have been made to create models capable of providing suitable accuracy without requiring a large amount of computing power or input data. A river system is a combination of the main river channel and adjacent floodplain areas. When the water surface elevations of a waterway during a flood event exceed the depth of the main channel, then the flow expands into floodplains. In 1D hydraulic modelling, the flow is assumed to move in the longitudinal direction only, that is, downstream. The terrain in a1D model is represented as a system of cross-sections and the results are an estimate of the average velocity and water depth at each cross section. The use of hydraulics models as decision support has become essential to better describe and knowledge the flow characteristics, particularly the water surface profiles. However, the choice must be made by identifying parsimonious model structure which provides good predictive power and represents the real behaviour of the hydraulic system. This representation passes by the estimation of the most important hydraulic parameters of flow such as water surface, Froude number, water flow velocity, slope etc. In this paper, we focus on the Barakar river basin located downstream of the tail race of Maithon Dam.

The hydraulic engineer’s inevitable task in hydraulic design practices includes the computation of water surface profiles for an open channel. The computation is carried out for (a) the discharge in a channel with sub-critical or super-critical flow (b) determination of back water effect of a proposed hydraulic structure like dam, barrage, weir bridge etc. and to design canals and transition zones (c)tracing of upstream flood levels with the channel improvement (d) establishing water surface profiles for levee design (e) establishing flooded area limits for flood insurance studies (f) determination of water surface elevation for flood plain management (g) determination of areas inundated by various flood discharges for the assessment of damages (h) providing a reasonable initial condition from which an unsteady simulation can be started (i) determination of the safe and optimum operation of control structures and so on.

An open channel is a conduit in which a liquid flows with a free surface. Open channel flow may be either steady or unsteady. Steady flow in open channel is said to occur when the flow properties such as the discharge at a section do not changes with time. If the change in flow condition with respect to time is a major, concern, then the open channel flow should be treated as unsteady. In most of the open channel problems it is necessary to study the flow behaviour under steady conditions. Steady flowing an open channel system is termed as steady uniform flow when the depth is the same at every section of the channel. On the other hand, the flow is termed as steady varied flow when the depth of flow changes along the length of channel. Steady uniform flow is the fundamental type of flow treated in open channel hydraulics. Varied flow also may be either gradually or rapidly varying. In rapidly varying flow, the depth of flow changes abruptly over a comparatively short distance. Hydraulic jumps and the hydraulic drops are the examples of rapidly varied flows.

Flow dynamics understanding in a river system is an essential step to the water needs agreement .This representation documentations by the assessment essential factors of flow like water surface, Froude number, velocity of water flow. In this paper, we focus on the river Barakar basin.
When the various parameters at any point do not change with time, this flow is called Steady flow. Unsteady (non-steady) is the flow in which changes with time do occur as discussed earlier. In practice, steady flow is the exception rather than the rule, but here in the following case it is supposed that the flow is steady .Steady Flow Analysis for downstream tail race using HEC-RAS Program is conducted in the given study.HEC-RAS 5.0, 2016 program is an applied software package for simulation of river network in steady and unsteady flow regime which is based on hydraulic routing. This program is commonly mentioned in hydraulic systems analysis.

HEC-RAS model based on hydraulic routing is selected to describe the hydraulic behaviour of this river basin by performing steady flow calculations in order to generate water surface profiles for different discharges. This software is widely recommended in analysis of hydraulic systems because it provides useful information for water management and planning. This model is very little demanding in data, it is very easy to provide results. The application of the model on the tail race of the downstream of Maithon dam gives satisfactory results. It allows identifying the high and low flow characteristics areas such as water surface profiles, water surface elevation, flow velocity, top width, slopes, surface, volume, elevation of energy grade line , wetted perimeterandareas of the large and narrow width have been located .It also allows view the hydraulic parameters including water surface profiles evolution along the river reach. These results also indicate that HEC-RAS model is suitable for investigation and simulation of hydraulic flows in river network of Baraka river cross-section.
The Hydrologic Engineering Center's (HEC) River Analysis System (HEC-RAS) software allows you to perform one-dimensional steady flow, one and two-dimensional unsteady flow calculations, sediment transport/mobile bed computations, and water temperature/water quality modelling. HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking environment. The system is comprised of a graphical user interface (GUI), separate analysis components, data storage and management capabilities, graphics and reporting facilities. The user interacts with HEC-RAS through a graphical user interface (GUI). The main focus in the design of the interface was to make it easy to use the software, while still maintaining a high level of efficiency for the user. The interface provides the functions such as Filemanagement, Data entry/editing and GIS

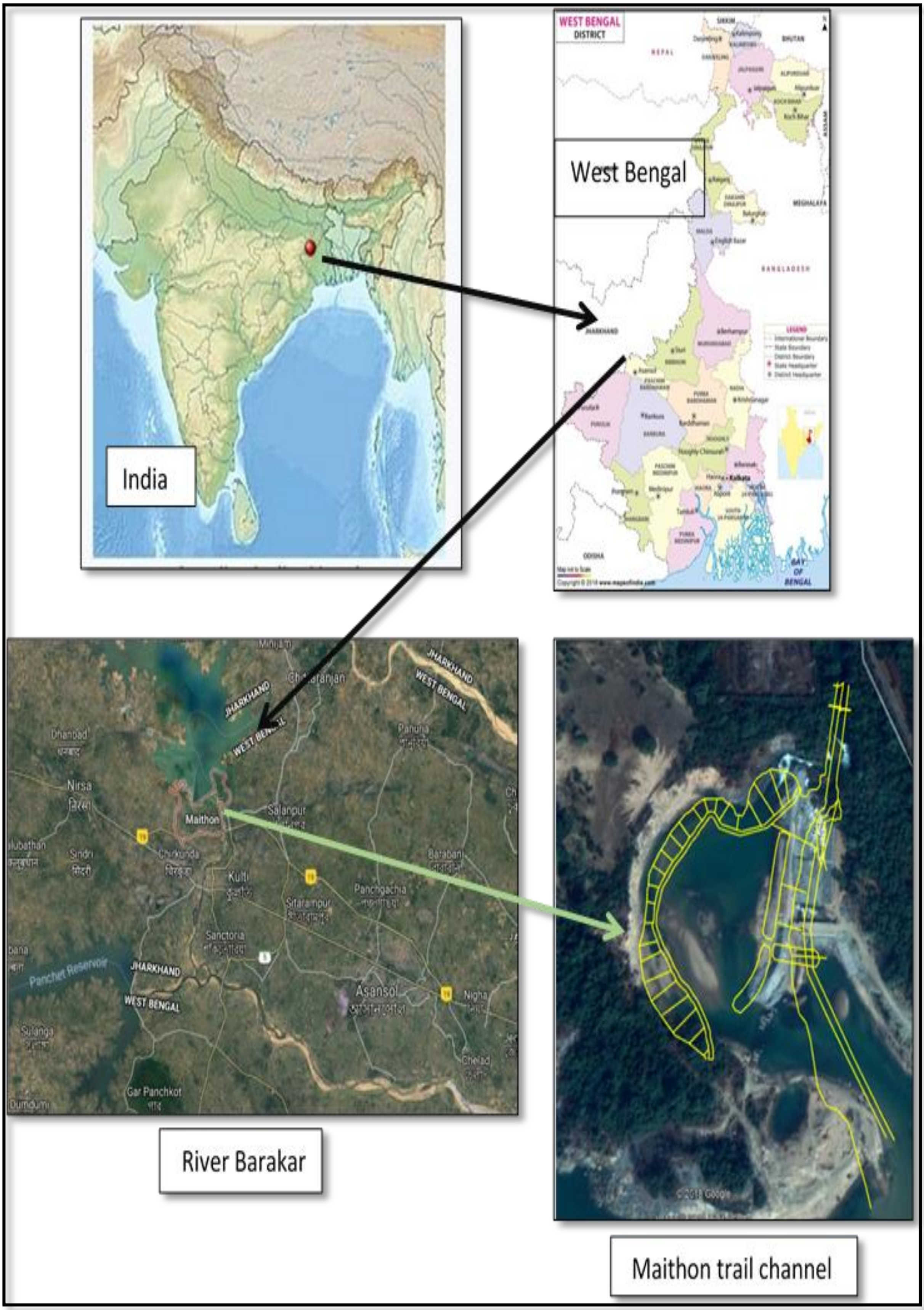
datainterfaces,Riveranalyses,Tabulation and graphical displays of input and outputdata,Inundation mapping and animations of water propagation,Reportingfacilities,On-linehelp.

In this given study the river Barakar of the tail race of Maithon dam is considered for the steady flow analysis. It is proposed by DVC that that the downstream culvert structure will be destroyed and the new river path will be constructed considering the full stretch of river and reducing the reduce level of river to 94m as specified. The reduce level will be reduced by dredging and excavation. There is a upstream adverse slope through which water is pumped and subsequently after the slope there is two wall which reduce the velocity of river and after that the river goes down to reduce level of 94 mother steady flow analysis is carried out due constant discharge of 65 m^3/s ,130 m^3/s and 200 m^3/s is released from the pumping station.Whereas main emphasis is given to the maximum discharge of 200 m^3/s. Accordingly the hydraulic analysis is carried out.

1.2 THE STUDY AREA

The Study Area is located 48 km from Dhanbad, at a place called Maithon, which is in the state of Jharkhand. It is 15,712 ft. (4,789 m) long and 165 ft. (50 m) high. This dam was specially designed for control of flood of the region and generates 60,000 kW of electric power. There is an underground power station the first of its kind in the whole of South East Asia. The dam is constructed on the Barakar River. The lake is spread over 65 square kilometres and the study area is mainly downstream of Maithon dam on one of its tail race .The flow initially is uniform and further downstream is non uniform in nature. PS locations have been identified, discharge data, water level maps were collected from the records of DVC, in-situ soil samples were collected through slim boring survey. In chapter 3 the general characteristics and features pertinent to the place are illustrated. These characteristics include the location, climatic conditions, land use, topography and drainage pattern.

Figure 1.1 : Picture of Maithon Dam



Map 1.1 : Location of study Area

1.3.OBJECTIVE OF THE STUDY

The objective of this study are to develop hydraulic calculation model at the downstream of a Tail race channel of Maithon Hydel station using the software- HEC-RAS, evaluation of the flow pattern through steady flow analysis at a stretch in tail race channel in river Barakar. Identification of the flood affected area of the study region and to develop flood reduction plan. To develop the various profile plots such as cross sections, water surface profile, general profile plot, rating curves, X-Y-Z perspective plot to have the clear view of the future condition after implementing the proposed change of river course.

1.4 SCOPE OF WORK

The purpose of this research work is to outline the procedure engaged in using the software HECRAS incomputing the steady flow analysis of the considered river system for generating profiles of water surface. The application of the modelling software is efficient to manage a full network of channels, adentritic or a single river reach. The steady flow is used for carrying out supercritical subcritical and mixed flow regime of profile of water surface .The overall aim of the study is to integrate and develop a river analysis system including dam in the study area. Key feature to achieve the research objectives are given below.

1. HECRAS software for steady flow analysis of the river model.

2. Satellite images using Google Earth for determination of theelevations,latitude, and longitude of several points.

3. Use of DEM & QGIS for having the idea of the catchment area involvement.

4. Data of cross section,discharge, slope and soil properties given by Damodar Valley Corporation.

1.5 OUTLINE OF THE THESIS

The thesis consists of seven chapters .chapter 1 describes the overview of the research study, chapter 2 contains literature review .Chapter 3 describes the study area and its characteristics. Chapter 4 reveals the relevance of numerical model and working principle of HECRAS in determining the results. Chapter 5 illustrates the research methodology .Chapter 7 presents data analysis and result.Finally in chapter 8 the summary of the research study describes in conclusions and recommendations .References are given at the end of the dissertations.

2. LITERATURE REVIEW

The following studied have been carried out in previous years in HECRAS using different parameter methodology and parameter estimation. The main purpose of this literature review is to take guidance from their earlier studies.

Kayuun, T.S. et al.(2018) made a two dimensional steady analysis on the Northern of Tigris River between Al- Muthana Bridge and Sarai gauging station in Baghdad city in Iraq**.** Using the HEC RAS version 5.03 software. The unsteady analysis is carried out to simulate the result and make use of the field measured data and use the result for calibration and verification purpose. The flow velocities and water elevation is computed based on the predetermined flow rate of flooding scenario of 3050 m^3/s. The result are used to determine the inundation mapping for the region from (1930- 2004), using relevant data. The effect of increase in flow on roughness coefficient is obtained from rating curve. The roughness coefficient is increasing rapidly for low discharge and less steeper for medium and high discharge .In this analysis two dimensional analysis is carried out for peak flow to find the velocity and the water surface elevation .Hence the maximum and minimum water level is obtained as 37m and 35m respectively. The predicted water elevation at Sarai gauging station is compared with the measured water level and found acceptable. The average velocity computed is quite satisfactory.

Omran, Z.A.et al.(2018) used the HECRAS program for analysis of study area Shatt Al Hilla for 51.100 km length of it for each 100 m long. The model simulation with field survey for Shatt Al-Hilla were verified with different table and graph and the results is obtained in the form of various parameter like velocity ,slope, discharge etc. The HECRAS is used to carry out steady and unsteady flow analysis. The water surface level increase with increase in discharge accordingly the velocity changes with change in cross sections. The results shows velocity increase in the center of the Al-Hilla city from the beginning of the study area. High probability of embankment erosion may cause frequent shifting of bends. The river has a risk of cumulative sedimentation load .This is mainly due to slow velocity of river for both high discharge i.e. 170m3/sand low discharge .i.e. 70m3/s which is used for the analysis.

Sathe, N. J. et al. (2018) had used the HECRAS software for the hydraulic jump simulation over ogee spillway. The model is simulating to locate the position of hydraulic jump and the corresponding water surface level profile. Computed results are compared with the experimental results. The comparison shows the HECRAS output gives satisfactory result in determining the location of hydraulic jump .the range of Froude Number is acceptable. The hydraulic jump is well merged with the stilling basin. The hydraulic jump forms at the toe of spillway and further moves downstream with increase in discharge. The water surface profile the hydraulic jump gets submerged at the toe of the spillway. Flow characteristic given by HECRAS shows good result. Thus the result is satisfactorily in agreement with experimental result for hydraulic jump formation over ogee spillway.

Shamkhi, M.S. et al. (2018), used HEC RAS for calibration purpose of manning`s n value of Tigris river reach. Data is collected from 2006-2017 eight data sets for two parameters stage and discharge .The study is carried out in downstream of Kut barrage reach. The results give average value of manning`s value n .The study is conducted because no study is conducted in this reach for calibration purposes. The range of water surface level of (+10.300 to +12.511) and flow discharge range of (202.7 - 355.280) m^3/secare obtained for the given study.

Shayannejad, M.et al. (2018) carried out the unsteady flow analysis in open channel. The characteristics and finite difference method is used as the basis in HECRAS unsteady flow analysis. The cross section data, boundary conditions, initial discharge is used for analysis. The surface profile, flowhydrograph, flow velocity distribution is obtained as the result. In this process the energy and duration equations are decided for steady, slowly diverse flow by the Newton–Raphson procedure.

Alzahrani, A.S. (2017) made comparison on analysis of one-dimensional and two dimensional analysis of HECRAS software in determination of water level and flood inundation. The two modelsare tested in the Great Miami and bear creek. The flood inundation map is obtained and compared with the measured inundation extent. The study illustrates the academic basis for modelling floodplain flow based on the two-dimensional analysis. The study also helps to get the suitable manning`s value n for the two dimensional analysis. The two-dimensional analysis is more reliable for storage area inclusion as already such information is present in the two dimensional models itself. The two dimensional modelling is done by terrain map/model with projection coordinate system, creating the computational mesh, providing a flow inputs and exit stage, exploring a land cover with a spatial bed roughness, setting a turbulence, running Simulation and Validation the results.Thetwodimensional model reduce time consumption and effort as compared to onedimensional model.

Peck, W.W. (2017) used HECRAS for hydraulic design of bridges .The study is carried out nine bridge location of Louisiana, Mississippi, and Alabama**.** Factors affecting are examined such as location of transitional length, interference due inappropriate boundary conditions, effect of bridge calculation due to high current, effect of bridge calculation due to low current, effect of cross section interpolation. Comparison is done between observed and computed value. The calculated water level is much lower than observed value s because energy losses due to contraction and expansion are not taken into account. Interpolating cross sections give more detailed water elevation ascompared portions of reach not containing cross section. Interpolation does affect significantly in case of rapidly varied flow. Inappropriateselection of boundary values affects upstream water elevation.

Ahmad, H.F. et al (2016) described the application of HEC RAS on prediction of flood of river Jhelum .The data of peak flood is used to predict the expected future flood .This will help the insurers, policymakers, engineers to make necessary steps. The model outputs predicted overflow at maximum locations under the study area for 50 years and above return period. The main objective of the study is to find the water surface elevation above the bed level. The main focus is to use HECRAS software in simulating the water surface profile of the river Jhelum which is most responsible for the flood in Kashmir. The one dimensional HECRAS model is used for computation of results. The analysis suggests that most area of the study area is to get inundated for 50 years and 100 years flood. The left bank area is more susceptible to flood than the right bank area.

Maharjan, L.B. et al. (2016) had made a comparative study between 1D and 2D flow analysis and to find the best among the two. The analysis are done on both prismatic and non-prismatic channel.1D analysis is used for prismatic channel expect at bends which require 2D analysis. For non-prismaticchannel 2D analysis give precise water surface elevation. Prismatic channel give similar result for 1d and 2d analysis .but for non-prismatic channel 1d and 2d analysis for a given discharge .The water level near dam ,bridges and various hydraulic structure can be obtained by this software. The sediment transport and scouring of bed materials can be stimulated by this model. According to the outcome of these study both steady and unsteady flow can be carried out for flow near dam and hydraulic structures .flow floe near hydraulic structures two dimensional analysis should be carried out 1d and 2d unsteady for analysis should be carried for both prismatic and non-prismatic channel.

ShahiriParsa, A.S. et al (2016) in this study, one-dimensional model Hydrologic Engineering Centers—River Analysis System and two-dimensional model CCHE2D were used to simulate the flood zoning in the Sungai Maka district in Kelantan state, Malaysia. The two model HECRAS AND CCHE2D are used to match the result of the most section. The floodplain zoning maps is useful in choosing the most significant factors that can affect any area of flood return periods are volume and surface runoff to the upstream of the river or flood conditions and its physical characteristics (such as surface morphology). Geometry of rivers is also important, as they are used for hydraulic calculations and studies on riverbeds to estimate the flow characteristics of a particular interval on a river; the adaptation of boundary condition is required.

Hussien, H.(2015) in the study uses HECRAS software for constructing one dimensional hydrodynamic model and to measure the water quality parameters. The study is conducted on the Dubai Creek to understand the process effecting of creek .The result shows increase in algae concentrations in the Creek Mouth station to Sanctuary station and increase in nutrient in the sewage treatment plant outfall station. The Dissolve Oxygen is maximum at the creek station and minimum at the Wharfagestation.The model validation by carrying out the sensitivity analysis on hydrodynamic and water quality parameters. This study on water quality parameter is investigated and effect of combination of various quality parameter is assessed. Further studies are done for obtaining the distribution of pollution in Dubai creek region.

Serede, I.J. et al. (2015) had conducted the study on theMwea irrigation system ,Kenya. The HECRAS model is used to estimate the error and determine the canal capacity potential.The HECRAS model is used for calibration and validation of discharge, gate opening and water levels. The statistical and graphical methods are used for determining the canal capacity. The result shows the increase in hydraulic resistance led to decrease in canal capacity potential. This study is to improve the management and operation of the irrigation system for effective and efficient water supply for the farmers. Calibration and immediate installation of measuring device immediate downstream of the off takes. Research on the canal construction is to check whether the construction is as par the original design and the test model validity is maintained. The seepage and evaporation losses are obtained by other technique which the HECRAS model cannot account for. The model estimate the potential bank overflow at specific discharge and to dredge at required location to keep the stretch free from siltation and keep the water level well below the bank level.

Traore, V.B. et al (2015) used HEC-RAS to find the hydraulic characteristics of the river. The Arc GIS is used to find the bathymetry of the selected region .The region between the confluence dam and Kounkane threshold is taken as the river reach for the given study. The region is divided into 24 cross sections and the cross sections geometry is created by HEC RAS software. The analysis is used to find the flow velocity, depth, slope and other parameters. The results show most of the hydraulic parameters decreases from upstream to downstream. These helps decisions makers to take optimum decision for the management of water for irrigation in the Anambe river region. The HECRAS model is used to compute the flow characteristics of the study area to know the hydraulic behaviour of the river. This helps to find the high and low flow characteristics of the area such as flow depth, flow volume and their spatial evolution along the river reach.

Mehta,D.J .et al (2014) had conducted study on flood prone areas of Surat city near river Tapi.The hydraulic model was used to carry out uniform flow computations and to evaluate the flood conveyance performance. The main objective is to find the cross section output for various past flood events, to find the self-adequacy of the existing cross section at different discharge and to ensure safe conveyance of discharge by constructing retaining wall and embankments .With the increase of slope the velocity increases and hence the discharge capacity of the river increase .The capacity of river Tapi is to be increased so as to decrease the possibility of flood in future in the city of Surat. From the analysis it had been found that the West and Southwest Surat is highly prone to flood whereas the East of Surat is least prone. The cross section where the water overflows necessary precautions in the form of retaining wall and embankments should be taken

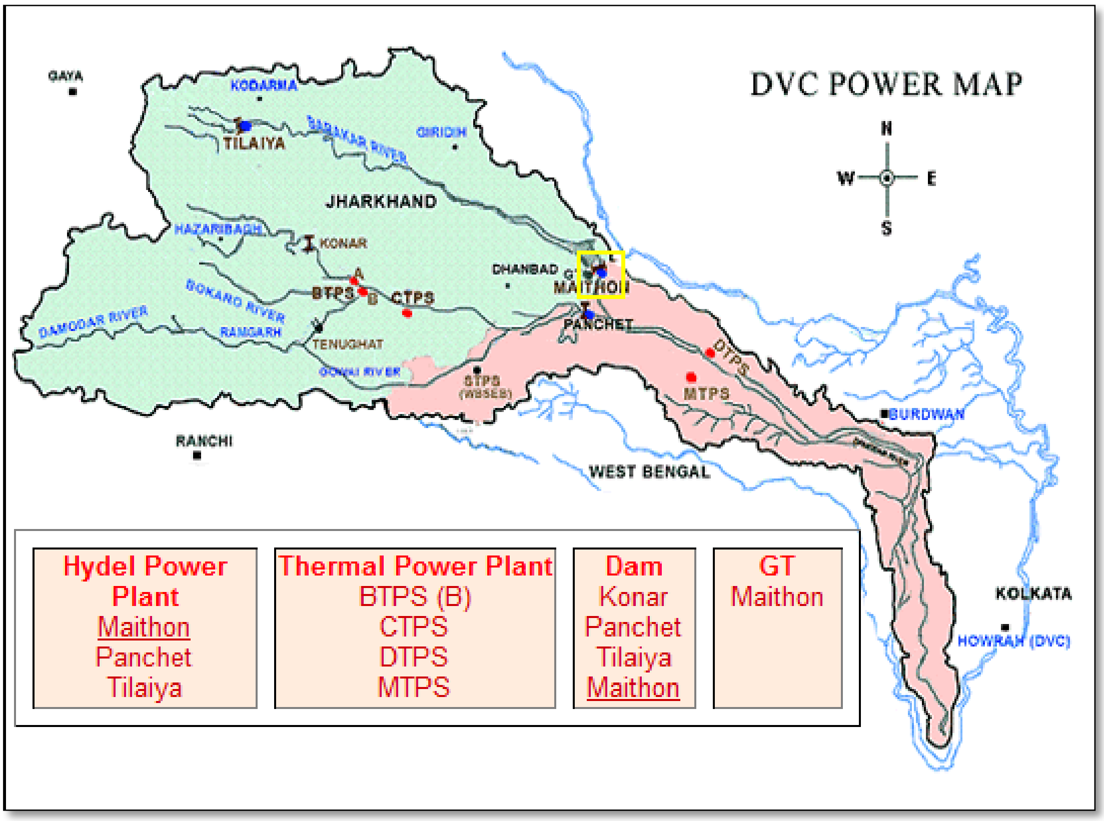
Tahmasbinejad, H. et al. (2012) in the present study conducted test in the Karun River region, south west Iran. This area is the domain of frequent occurrence of severe flash flooding. The two model used in this study is HEC HMS and HEC RAS .HEC HMS is used to obtain overland flow and channel runoff from the precipitation of the given area and HEC RAS is to carry out hydraulic modelling of the unsteady flow of the river system obtained from the flood hydrograph which is obtained as the output of the HECHMS. The study of this area can be used as a prototype to carry out the model applications in other areas. This study can be used as the hydrological tool for the further future study in the area. The simulated data is compared with Athe water storage data of several storm event data. The main objective of the modelling is to create a database so that the computation made by municipal office in river training work hydraulic work converge at appoint and same assumptions is taken for roughness coefficient and hydrological data so that constant updating of the data takes place.

Kasper, K.E. et al (2005) used hydraulic model to calculate the flow depth and energy losses in a river system and are defined as the 1 d 2d and 3d models.HEC RAS in 1D model Is used to find out the calculations for steady and unsteady flow in rapid varied and gradually varied flow. The meander bend s where the velocity in one direction is not significant and the velocity in other two direction is significant the HECRAS 1D model is used.HECRAS is often used to find the 3d velocity profile with and without bend weirs research is to be conducted to fin the accuracy of HECRAS.In this present study the spiral and secondary currents is found out as the minor losses in the mender bends. the spiral and secondary currents is quite significant in amount in energy losses and to be measured accurately tom determine the total losses in meander bends .In this present study only manning`s n and contraction and expansion coefficients is used to measure the losses .The Bend way weirs has limited options .In the future there is a scope to extend the study to other structures like bridges, weiroptions, block structures etc.

Shelley,J.carried out a study in the Turtle Creek lake region. One dimensional unsteady analysis and sediment model analysis carried in the study area. HEC RAS model was used to evaluate the technical feasibility and effectiveness of altering the reservoir operations to decrease sediment trapping efficiency. This model used new features of RULES editor and unsteady flow analysis of the HECRAS 5.0 beta version. This model is used for sedimentation analysis and to find the variation of sediment accumulation for various reservoir operational procedures in large reservoirs. The results found out mainly preliminary for the calculation s for all the early stages. The analysis used the HECRAS 5.0 model for mobile bed model for modelling and calculating the sediment load for the Turtle Creek lake region. Additional measures for model stability had to be taken for producing stable hydraulic model.

3. DESCRIPTION OF STUDY AREA

The Study Area is located at latitude 23°47′13.06″ north and longitude 86°49′01.44″East on river Barakar at Maithon in District Dhanbad in the state of Jharkhand. It is in the Lower Ganga basin. The catchment area up to Maithon Dam has been estimated as6388.69 km², using SRTM DEM. The height of the dam is 56.08 m. The dam has a total length of 4426.76 m comprising 4064.35 m long earthen embankment and 362.41 m long concrete overflow section. The river forms the boundary between West Bengal and Jharkhand in that area. The dam was inaugurated on 27 September 1957. The dam (both concrete and earthen) is 4,860 meters long and the concrete dam is 43.89 meters high above the river bed level. The reservoir has a live storage capacity of 441.64 Mm³ and a gross storage capacity of 1,093.54 Mm³. The project was constructed between 1951 and1957. The spillway has been designed to pass a maximum discharge 13,592 m3/s. As per criteria specified in BIS 11223-1985, the dam qualifies for a large dam and should therefore be designed to safely pass Probable Maximum Flood (PMF).The unique feature of Maithon is that the hydel power station is located underground in the left bank of the river (on the West Bengal side) and is the first of its kind in India. The Power Station has a total generating capacity of 60 MW with three units of 20 MW each. About 13 kilometres downstream from Maithon , the Barakar joins the Damodar at Dishergarh. Maithon Dam is 48 kilometres from Dhanbad and around 25 kilometres from Asansol.



Map 3.1 : Location of Maithon Dam

Fig 3.1:Maithon Dam

Photograph 3.1: Tail race channel of Maithon Hydel Power Station

Photograph 3.2: Discharge out let of the Maithon Hydel Power Station

3.1 NATURAL PROFILE OF THE STUDY AREA

3.1.1 Climatology

Moderate winters and hot and humid summers characterize the climate of the area. The meanannual rainfalls in different catchments of the Damodar valley are Barakar 126cm, Damodar127.2cm and lower valley 132.9cm. The 82% of the mean annual rainfall occurs during the four monsoon months from June to September. The mean daily temperature varies from 40^0C in summer to below 20 ^{0}C in winters. The rainfall in this area during the monsoon season is mainly due to the passage of depressions and lows over and near the area.

3.1.2 Pedology

The reservoir is located on the Chhotanagpur Gneissic Terrain. Gneiss and amphibolite are the major rocks in the catchment area. These rocks are highly jointed. Basic intrusive and their metamorphic equivalents are also common. Gondwana rocks comprising sandstone and shale are encountered one km south of the dam .The country rock is sporadically exposed in the catchment area and is usually covered by loamy soil and the soil is subject to considerable water erosion leading to moderate loss of top soil. The climate of the area is hot sub humid. The tripartite water resources around the Maithon reservoir comprise portion of the Barakar River, the reservoir water and the subsurface water.

Photograph 3.3: Forests and Rocky terrain of the study area

Photograph 3.4: Rocky terrain of the study area

3.1.3 Land use pattern

Land pattern mainly consists of hilly areas, forests etc. The major changes of the land use land cover of the river basin include increase in the build-up area and agricultural land and reduction of the vegetation cover. The hydrological impact of such changes in land use land cover is manifested in the increase of minimum discharge and the fluctuation of the wet season discharge are the result of the land use changes over the studied period from 1992 to 2011. The reduction of vegetation cover increases the surface flow during the rainy season that leads to fluctuation in the wet season discharge. The reduction of the vegetation cover and increase of barren lands leads to the soil erosion in the catchment area and reservoir sedimentation started increasing from the last decade of the late 20th century. The land use changes also modify the river morphology, such as changes in planform, sinuosity ratio and braid-channel ratio. The related changes in bed form include width, length and area of the mid-channel bars, point bars etc. The rainfall, tectonic activity and human activities play a role in the modification of sediment supply and thus affect the aggradation and degradation processes of the river. The current pace of changes can lead to further modification in future which can be a cause for concern regarding the fluvial health of Barakar river system.

Photograph 3.5: Forest and hilly terrain of the study area

Photograph 3.6: Hilly and rocky areas

3.1.4 Drainage pattern

The main tributaries of Barakar River apparently follow major lineaments. Satellite imagery of the area reveals 3 sets of major lineaments, trending N-S 278 S. Study area showing the Maithon reservoir, litho-boundaries and lineament trends (bold lines). TI-T4 is tributaries showing distinct course changes (continuous line for the present and broken line for the past flows.) Changes in the Stream Courses around Maithon Reservoir Fig. 3.2. The streams flow over a nearly flat topography but displays numerous high angle bends controlled by the lineaments. Located at Dhanbad may throw further light on the tectonic regime of the area. The satellite imagery shows abrupt beginning and disappearance of several first to third order streams. One such stream T (Fig. 3.2) flows perennially north of the Kalyaneswari temple along the NE-SW lineament trend. In course of field checking, an attempt was made to identify its source. After tracing about 2 km upstream, it was observed that considerable leakage from the reservoir contributed to the flow in TI. Subsequent examination of the top sheet of the area, surveyed during 1923-'27 (pre-dam period) indicates that TI was in existence ahead of the dam construction. The perennial source of Tj is, therefore, independent of the reservoir leakage. Streams like T~ with perennial to quasi perennial flow abound in this area. Lineament controlled drainage pattern and absence of any visible source of perennial flow strongly suggest existence of a complex network of surface and subsurface water flows. Field checks revealed ubiquitous occurrence of gaping joint planes that appears to form an interlaced network of high transmissivity in this area allowing confinement and substantial downward movement of influent water from the Barakar River.

Fig3.2 : Area showing Maithon reservoir, litho boundaries and lineaments (bold lines)

3.1.5 Geomorphology

The Barakar River is the main tributary of the Damodar River in eastern India. Originating near Padma in Hazaribagh district of Jharkhand it flows for 225 km across the northern part of the Chotanagpur Plateau, mostly in a west to east direction, before joining the Damodar near Dishergarh in the Bardhhaman district of West Bengal .It has a catchment area of 6,987 km^2 and the main tributaries Barsoti and Usri join the Barakar from the south and north respectively. The studied section consists of the Hazaribagh plateau, the dissected uplands of plateau fringe and the aggradation plain of Jharkhand and West Bengal .In the upstream region, the Barakar River flows over rugged topography in the gneissic areas with prominent narrow incised valley. In the upstream reach of the Maithon and Tilaiya Dam, aggradation process predominates, with relatively wide valley. In the downstream reach the water flow is regulated by the dam, where the river flows over degraded bedrock surfaces. At the confluence point, where sandstones are exposed as bed rock several potholes have formed with maximum diameter of 2 meters, indicating high energy condition at this point. In the plateau fringe and adjoining plain area soil erosion is prominent with rates above 3.5 t ha/yr. Land use change from forested to agricultural land is also prominent. The main types of soil that are present in the area are alfisol and inceptisol. The elevation of this area varies from 150 to 400 m and the average annual rainfall of the region ranges from 1300–1400 mm/yr. This region is rich in minerals and mining activities are predominant in the region. In the river, sand mining occurs in the downstream areas, especially in the downstream area of Maithon dam.

3.1.6 DVC water management plan

Damodar Valley Water Resources Projects are the first multipurpose project of its kind in the post independent India. This project came into existence with the primary objective of flood control along with the overall development of the valley area for supplying water for irrigation, municipal and industrial purposes, hydel power generation etc. It is the second biggest river valley project in the world after the Tennessee Valley Project of USA.

The primary objectives of the DVC are flood control, irrigation and generation and distribution of power. The other objectives are as follows:

(1) The supply of adequate water for industrial and domestic purposes
(2) Promotion and control of navigation in the Damodar River and its tributaries and channels
(3) Promotion of afforestation and control of soil erosion in the Deodar valley
(4) Promotion of public health
(5) Promotion of recreation
(6) Fish enhancement

The primary objective of the Damodar Valley Corporation (DVC) was to utilize the water resources of the most problematic river ‘Damodar’ – the sorrow of eastern India – by flood control, irrigation and navigation benefits and power generation. A series of dams have been constructed on the river Damodar and its tributary, the Barakar. However, repeated devastating floods in the lower Bengal basin during the recent years have led to the question of usefulness of these dams. There is a steady growth of population in the vicinity of the reservoir since its construction. The human activities greatly reduce the vegetation cover and the top soil consequently... Apparently, the situation is an inevitable outcome of population explosion, and a detailed examination of land use indicates that the reservoir is under serious threat of pollution and increased sedimentation. The Barakar is the major tributary of the Damodar. The DVC constructed the Maithon reservoir on Barakar during the post-independence period. The Maithon reservoir and its adjoining areas (lat. 23°46′–23°56′N, long. 86°45′–86°54′E) were selected for the present study. The area is situated at the border of West Bengal and Jharkhand. The changes in land use and land cover in the river basin drives long-term modifications in the river hydrology, sedimentology and morphology. The Barakar River is the principal tributary of the Damodar.

DVC has a network of five dams - Tilaiya and Maithon on river Barakar, Panchet on river Damodar and Konar on river Konar. Besides, Durgapur barrage and canal network, handed over to Government of West Bengal in 1964, remained a part of the total system of water management. Four multipurposedams were constructed during the period 1948 to 1959.These are Maithon Dam, Panchet Dam, Tilaiya Dam Konar Dam and Tenughat Dam.

A barrage on river Damodar was constructed in 1955 at Durgapur for supply of irrigation water to the districts of Burdwan, Bankura & Hoogly. It has an irrigation potential of 3.64 lakh ha.3, 42,000 ha under Kharif crop. 22,267 ha under Rabi crop.30,000 ha of land in the upper valley is being irrigated, every year by lift irrigation with the water available from about 8400 check dams constructed by DVC.

3.2 CONTOUR MAP OF THE STUDY AREA

Steep slope are visible along the right bank of the catchment area which is highly susceptible to bank erosion and a management structure is highly recommended. Gentle slope is visible along the left bank.

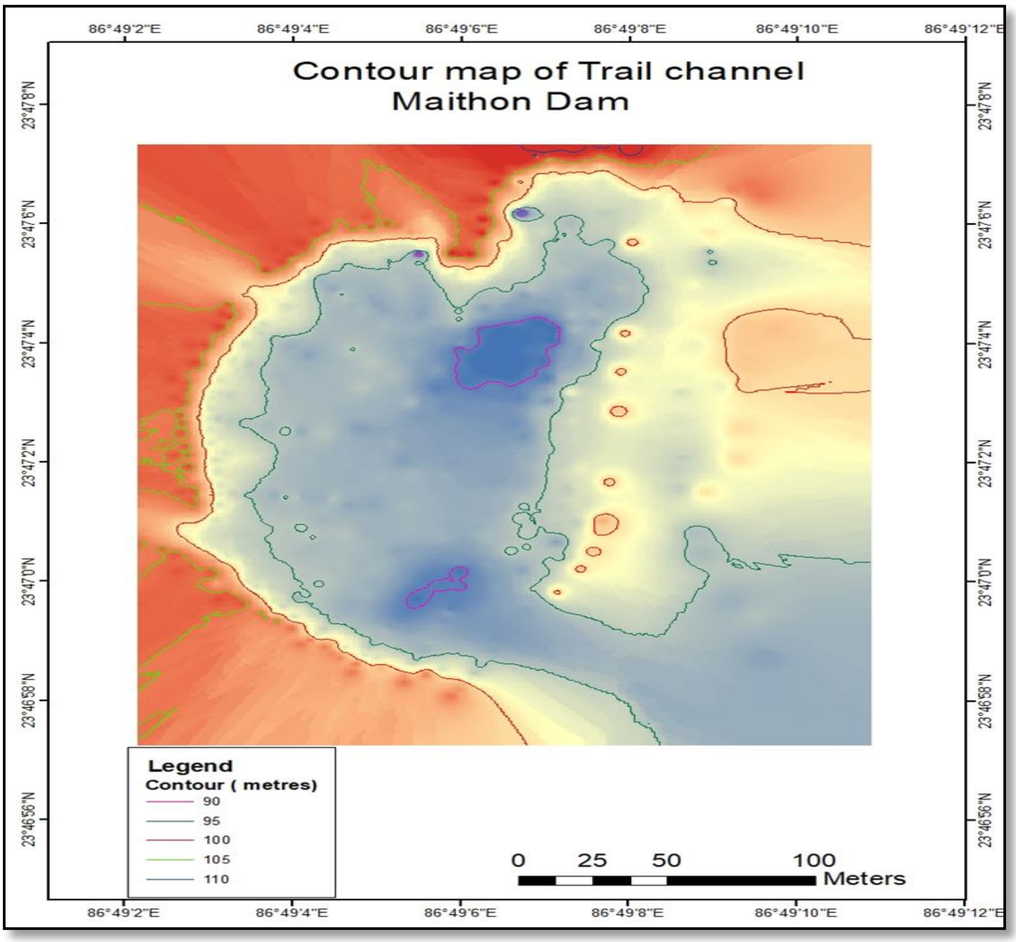


Fig 3.3: Contour map of study area

3.3 ELEVATION AND TOPOGRAPHY OF THE STUDY AREA:

The elevation of the region varies between 113 meters to 86 meters. The general slope is from west to east. The flow direction is also from west to east.

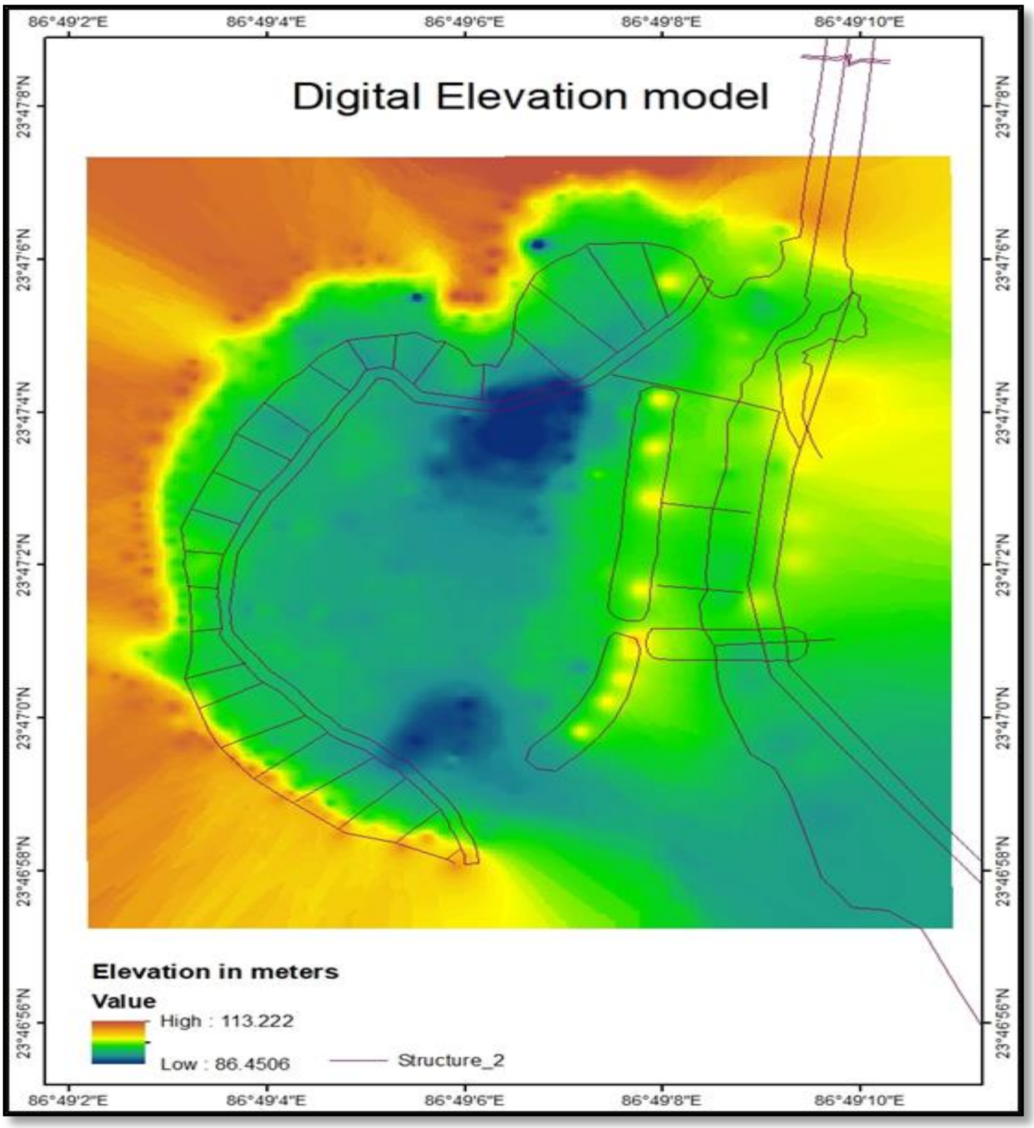


Fig 3.4 :Digital Elevation Model of the study area

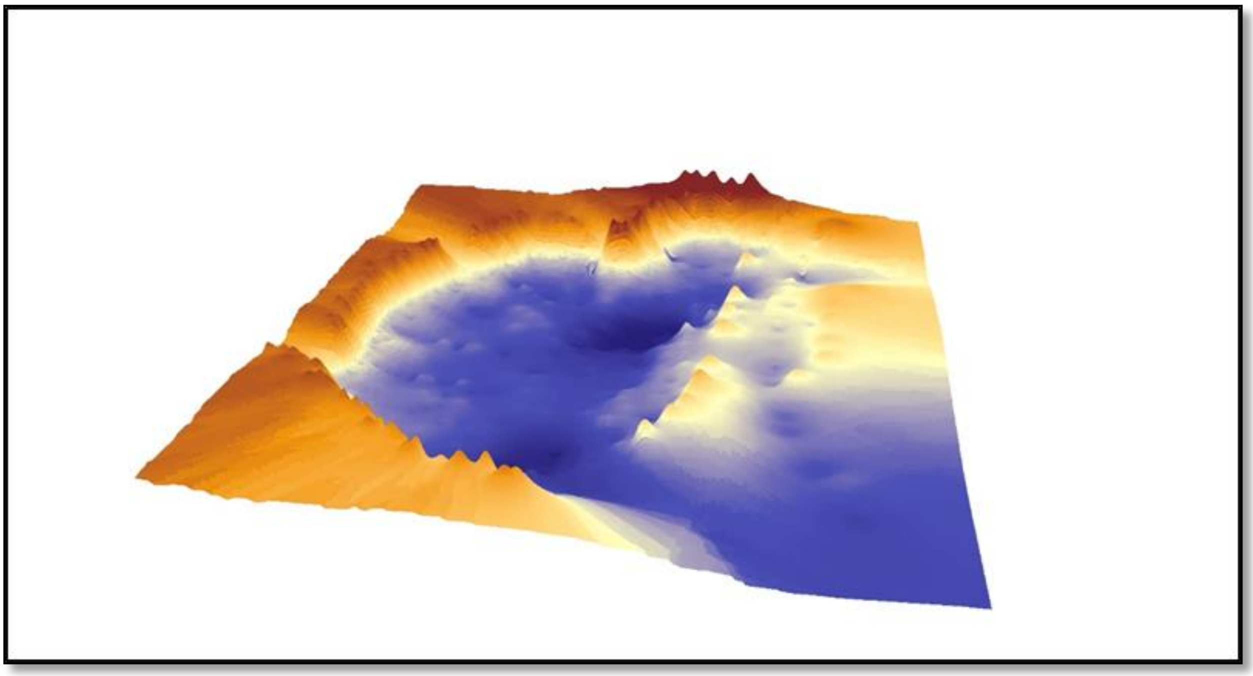


Fig 3.5 : 3D View of the study area

3.4 SURFACE WATER SCENARIO

The water level has been acquired from different location in the study area and has been interpolated. The water level is higher near the source of the trail channel. The water level varied from 94.33 meters to 96.585 meters

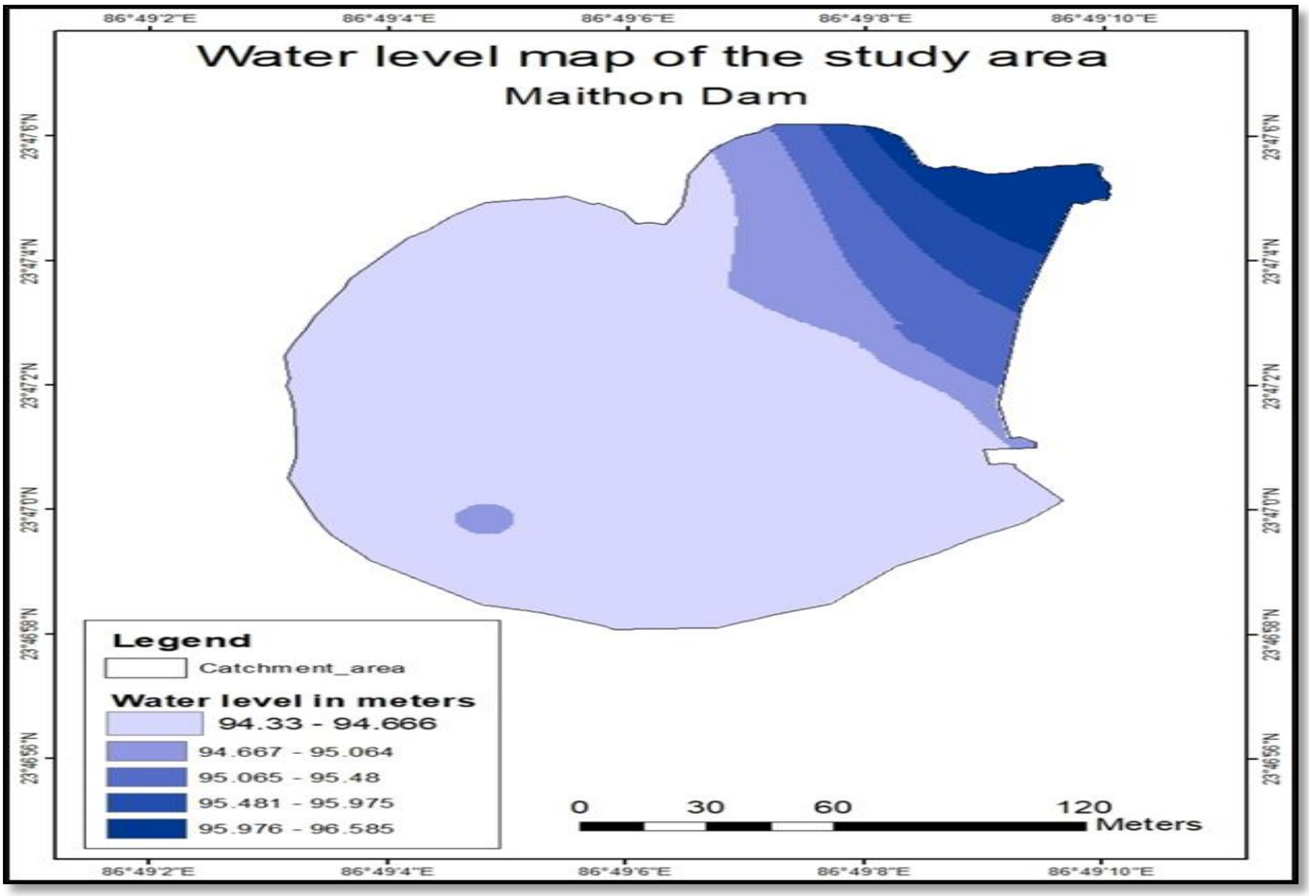


Fig 3.6: Water level map of the study area

4. CHAPTER : METHODOLOGY

The working procedure is divided into Literature Review, Data collection, Data Analysis Output and Result Analysis and Conclusion & Recommendation Pictorial view stated in Fig 4.1 is describing all points raised to understand the entire process.

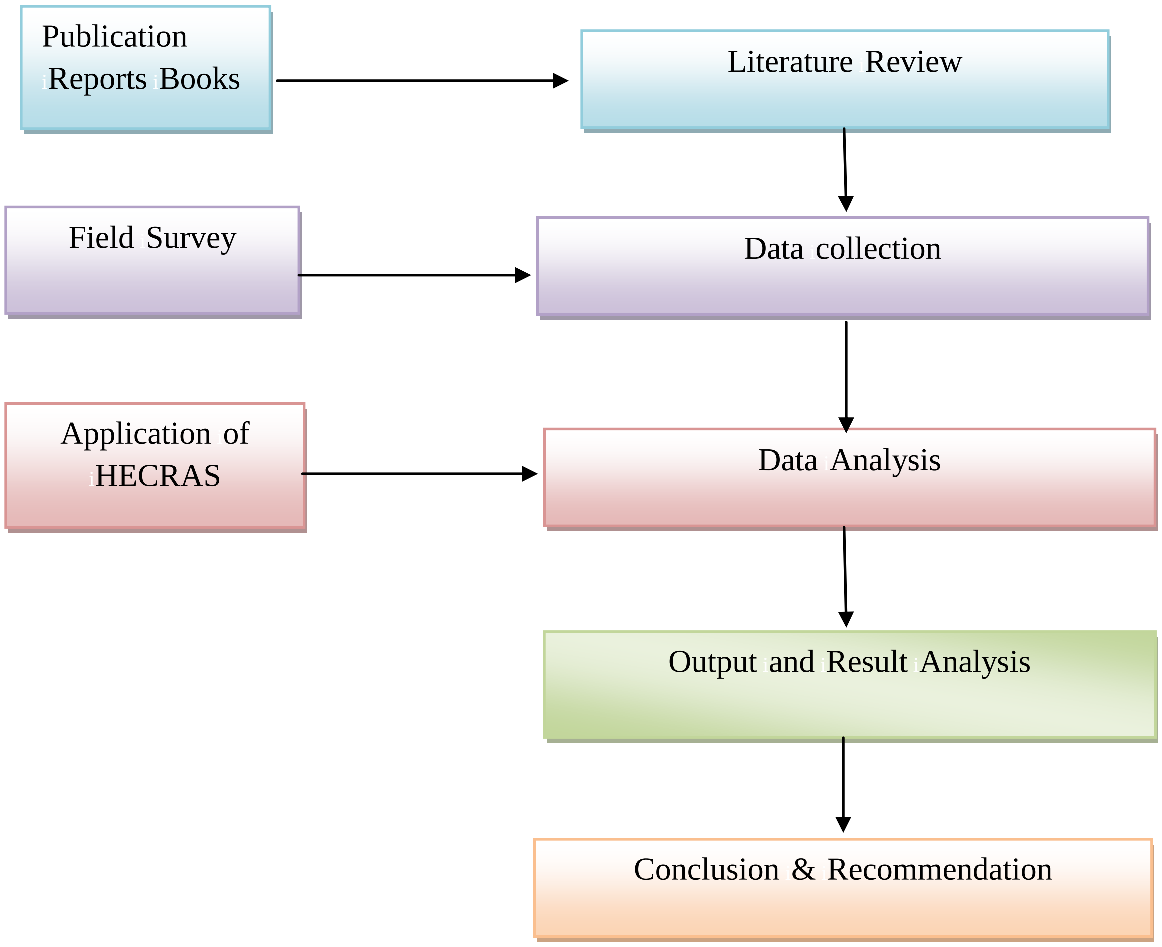


Fig 4.1 :Flow chart of Methodology

In this chapter ,methodologies by which the various objectives of the study is obtained is mentioned and discussed .The process of hydrologic modelling is shown with the help of flowchart as shown in Fig 4.2.The detail description of methodolgy is discussed below.

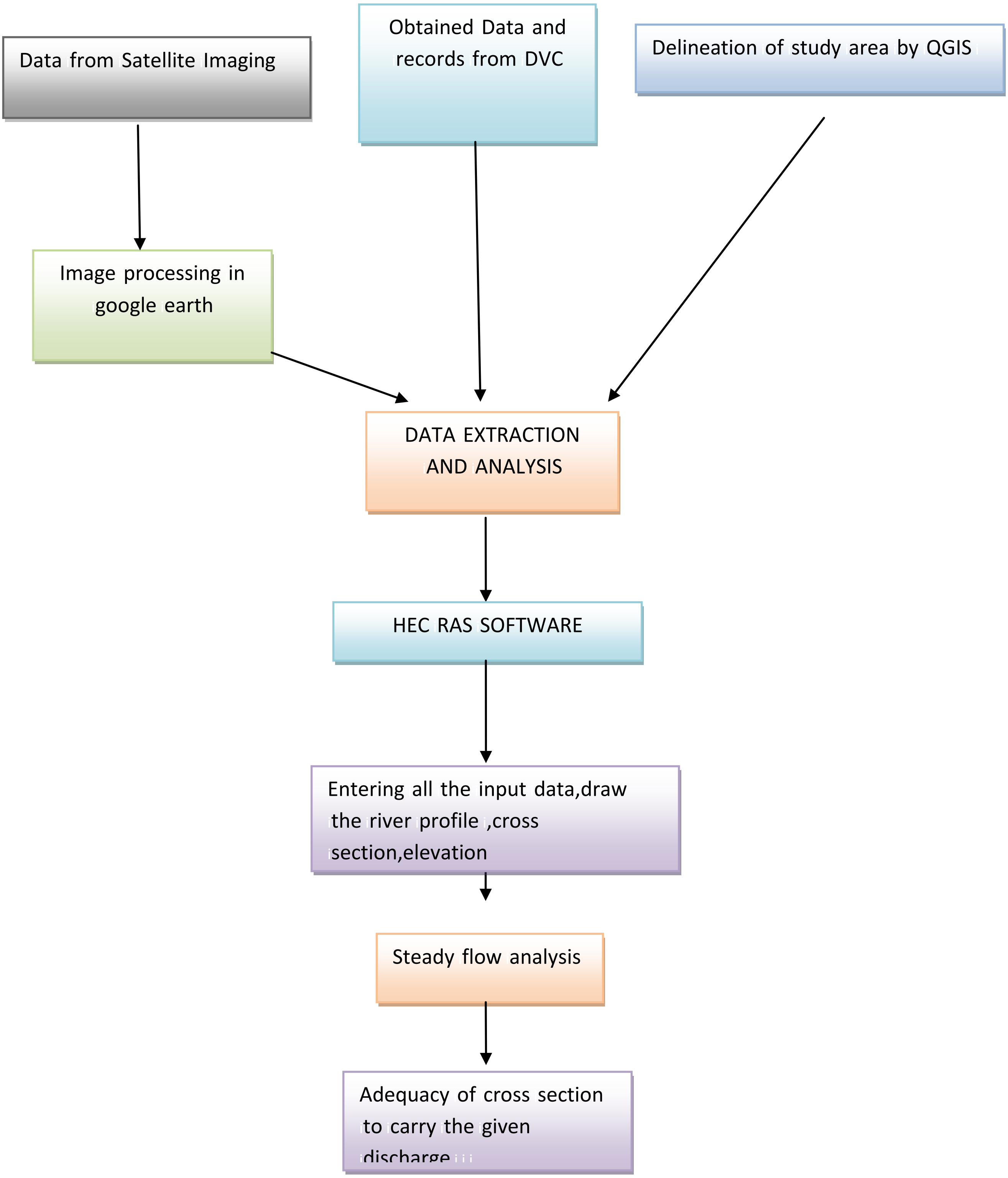


Fig 4.2 :Flow chart of Hydrological modelling

4.1 COLLECTION OF SATELLITE IMAGES AND DATA FROM GOOGLE EARTH.

Firstly the study area is identified by Google Earth.The path is identified The Barakar river profile is drawn .The cross section has been drawn with the help of line tool in Google Earth.The cross section is numbered accordingly.

Fig 4.3 : Google Earth image of the Maithon Dam tail race region

4.2 DATA COLLECTION FROMDAMODAR VALLEY CORPORATION

The data and records such as cross section , reduce level of bed ,properties of soil,study map information regarding the gabion structure , bed side slope etc.

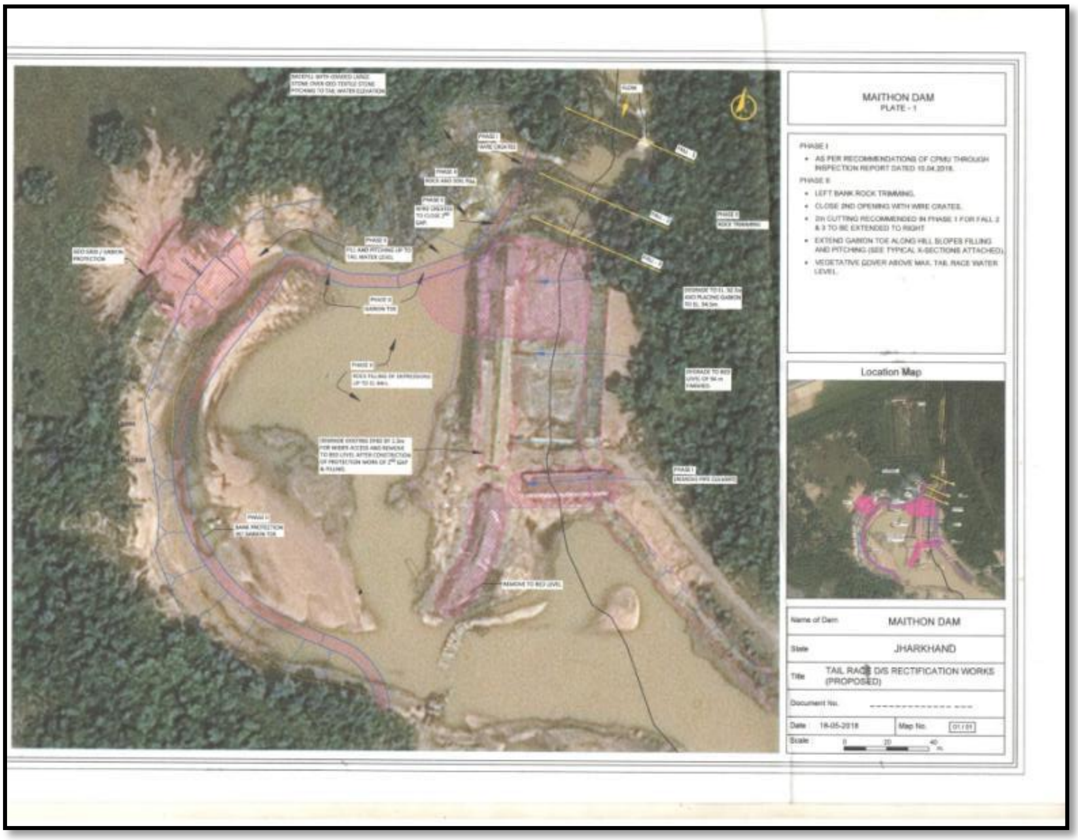


Fig 4.4 :Proposed Plan of Downstream region of Maithon Tail Race channel

4.3 DELINEATION OF STUDY AREA BY ArcGIS

The bed level map has been prepared using the GIS software in the same way the DEM has been prepared (Fig 4.5). The bed level has been acquired from different location in the study area and has been interpolated. The bed level is higher near the source of the trail channel.

Fig 4.5 :Delineation of study area by ArcGIS

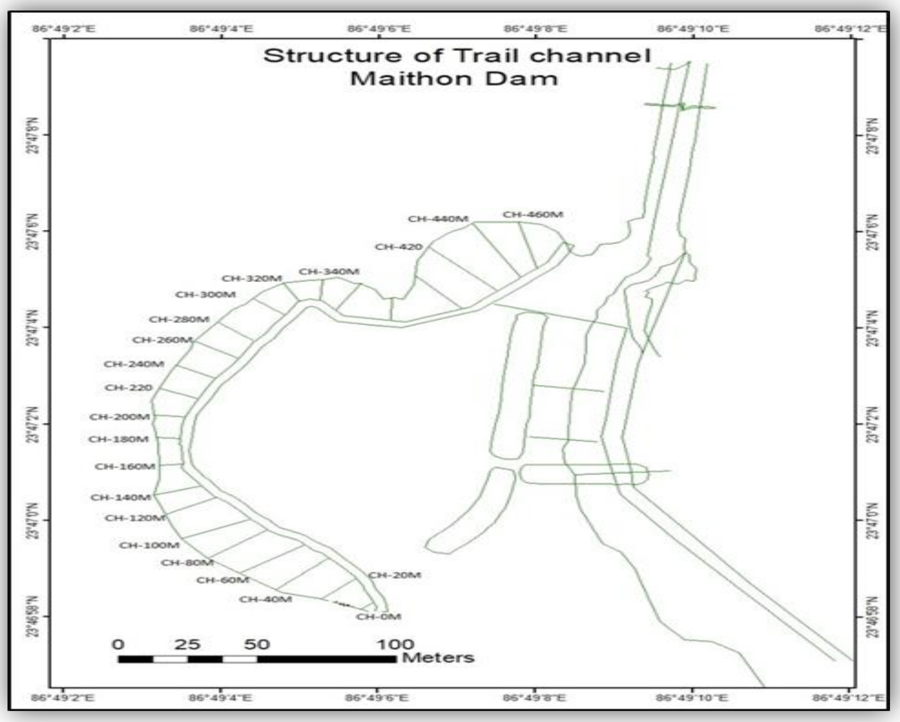


Fig 4.6:Base map of the study area

4.4 HECRAS MODELLING

Hydraulic Analysis of floods can be carried out using HECRAS (developed by U.S. Army Corps of Engineers) version .Initially ,HECRAS could only used for steady ,gradually flow modelling. The steady flow model is capable of modelling subcritical, super critical and mixed flow regime water surface profiles. A peak discharge is applied in all the obtained cross section to find the maximum water elevation of the cross section. It is also used to find the velocity of the cross section so as to check the velocity is within the permissible limit.

Final step is in corporating all the data and inputs in HECRAS and develop a model of river system.

HECRAS utilises the Standard Step Method having the following utility ,

1. Iterative computations of water surface elevation between two known cross sections.
2. Steady flow.
3. Does not require uniform cross section.
4. Requires known channel cross sections along the reach.
5. Computations of energy equation section by section.
6. Control section .

a) Super critical flow : evaluate from upstream to downstream.
b) Sub critical flow : evaluate from downstream to upstream.

The cross section view , the water surface profile ,the rating curve ,X-Y-Z perspective plot and velocity vs. chainage table is obtained as the result after steady flow analysis in HECRAS software.

5. THEORETICAL CONCEPT OF HYDROLOGICAL MODELLING

5.1 GRADUALLY VARIED FLOW

The flow in an open-channel is termed as gradually varied flow (GVF) when the depth of flow varies gradually with longitudinal distance. Such flows are encountered both on upstream and downstream sides of control sections. Analysis and computation of gradually varied flow profiles in open-channels are important from the point of view of safe and optimal design and operation of any hydraulic structure.

Basic Assumptions in GVF Analysis :

1.The gradually varied flow to be discussed here considers only steady flows. This implies that flow characteristics do not change with time and pressure distribution is hydrostatic over the channel section.

2. The head loss in a reach may be computed using an equation applicable to uniform flow having the same velocity and hydraulic mean radius of the section. This implies that the slope of energy grade line may be evaluated using a uniform flow formula such as Manning equation and Chezy equation, with the corresponding roughness coefficient applicable primarily for uniform flow.

3. Channel bottom slope is small. This implies that the depth of flow measured vertically is same as depth of flow measured perpendicular to channel bottom.

4. There is no air entrainment.

5. The velocity distribution in the channel section is invariant. This implies that the energy correction factor, α , is a constant and does not vary with distance.

6. The resistance coefficient is not a function of flow characteristics or depth of flow. It does not vary with distance.

7. Channel is prismatic.

.

5.2 COMPUTATION OF GRADUALLY VARIED FLOW

The computation of gradually-varied flow profiles involves basically the solution of dynamic equation of gradually varied flow. The main objective of computation is to determine the shape of flow profile.

Broadly classified, there are three methods of computation; namely:

1.The graphical-integration method,

2.The direct-integration method,

3.Step method

5.2.1 The Standard-Step Method

In this method, the depth is calculated from distance. This method is applicable to both non prismatic and prismatic channels. It is a trial and error process.

Y_2 is assumed and H_2 is computed using the formula $H_2= Z_2+Y_2+V^2/2g$

$$H_2' = H_1 + h_f = H_1 + \frac{1}{2}\left(S_{f1} + S_{f2}\right)\Delta x$$

is computed .Where

$$h_f = \frac{1}{2}\bar{S}_f \Delta x$$

$H_2 = H`_2$ is compared and If $H_2 = H`_2$ then assumed y_2 is ok. Else another value of y_2 is assumed.

The initial estimate can be improved by the amount $\Delta y_2 = \dfrac{H_e}{1 - Fr_2^2 + \dfrac{3}{2}\dfrac{s_{e_2}}{R_2}\Delta x}$ of

Where $H_e = H - H`$

For natural rivers, instead of depth y, it is preferable to use the height h of the water level above some fixed datum. This height, h=z+y, is known as the STAGE. Hence total head at a section can be written as:

$$H = y + z + \alpha\frac{V^2}{2g} = h + \alpha\frac{V^2}{2g}$$

5.2.2 Step Method-Divided Channels

- Let us consider a channel cross section which is divided into distinct regions having distinct flow characteristics.
- The most common example of this situation is the one shown in Fig 6.1 below, the case of overbank flow, when the flow over the berms has a different depths and the surface possible a different roughness, from those existing in the main channel.

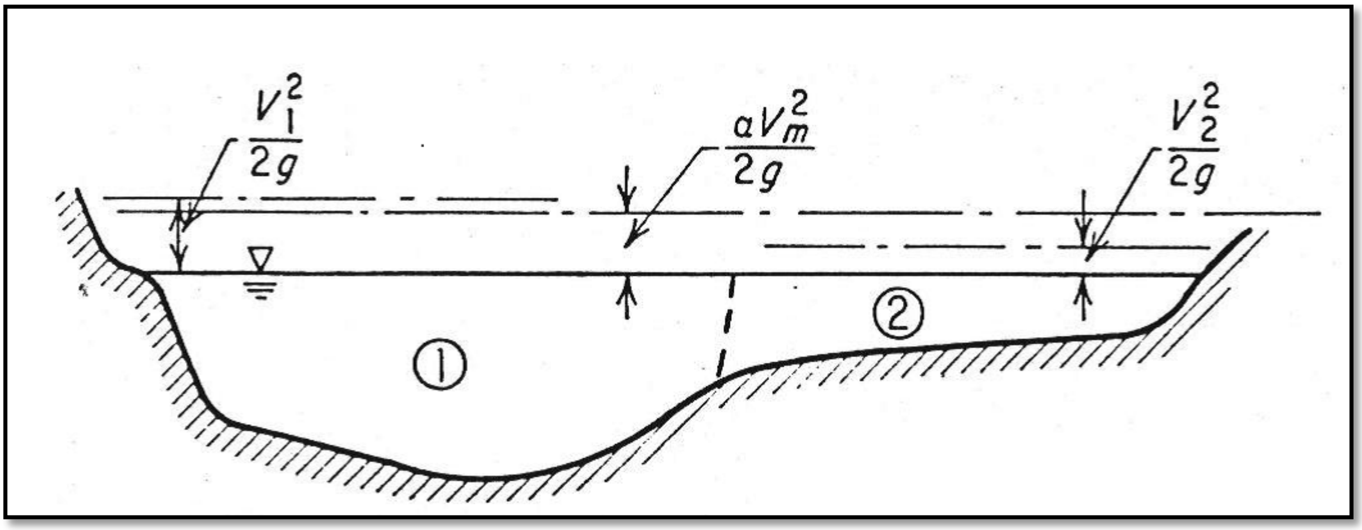


Fig 5.1 :Example of overbank flow and the use of a coefficient to define a mean velocity head

- If the channel is straight the water-surface level will remain substantially constant over the whole section of flow, since the hydrostatic pressure must remain constant along any horizontal line drawn across the section.
- However, the distinct regions of flow shown in Figure will almost certainly have different velocities and velocity heads; the problem then is to define a total head H applicable to the entire cross section.

- The solution is to use the energy coefficient, α; the total head line then extends across the whole water surface, a distance of above it, as shown in Fig.5.1. This total head line, and any head losses deduced from it, are assumed to be applicable to the section as a whole, and also to each of the individual subsections.

- The algebra required is conveniently handled by the use of the conveyance K. The energy coefficient , α, is defined by the equation

$$\alpha = \frac{\sum\left(\upsilon_1^3 A_1\right)}{\upsilon_m^3 \sum A_1} = \frac{\left(\sum A_1\right)^2}{\left(\sum Q_1\right)^3} \sum\left(\frac{Q_1^3}{A_1^2}\right)$$

- Where subscripts 1, 2, 3,… indicate the distinct subsections of the flow

Now since we are assuming that the same value of friction slope S_f applies to each subsection, it follows from the definition of the conveyance K , that

$$\frac{Q_1}{K_1} = \frac{Q_2}{K_2} = \frac{Q_3}{K_3} = \ldots \frac{Q_n}{K_n} = \frac{\sum Q_1}{\sum K_1}$$

And therefore that

$$\alpha = \frac{\left(\sum A_1\right)^2}{\left(\sum K_1\right)^3} \sum\left(\frac{K_1^3}{A_1^2}\right)$$

Since each element of Eq. (2) is equal to $(S_f)1/2$, it follows that

$$S_f = \left(\frac{\sum Q_1}{\sum K_1}\right)^2 = \frac{Q^2}{\left(\sum K_1\right)^2}$$

Where Q is the total flow.

Thus α and S_f, the two factors which are of critical importance in the tabulation, can be calculated without explicitly evaluating the discharges etc. The values of K which are to be inserted in Equations are obtained from the Manning equation as

$K = (1/n)\, R_h^{2/3} A$

This information is used for carrying out hit and trial method of standard step method describe is previous section.

5.2.3 Conveyance Calculation:

From Manning Equation

$Q = (1/n)\, R_h^{2/3} A S_F^{1/2}$
$K = (1/n)\, R_h^{2/3} A$
$Q = K S_F^{1/2}$

Q = flow

n = Manning’s coefficient

A = cross sectional area

R_h = hydraulic radius

S_f = friction slope

K = conveyance

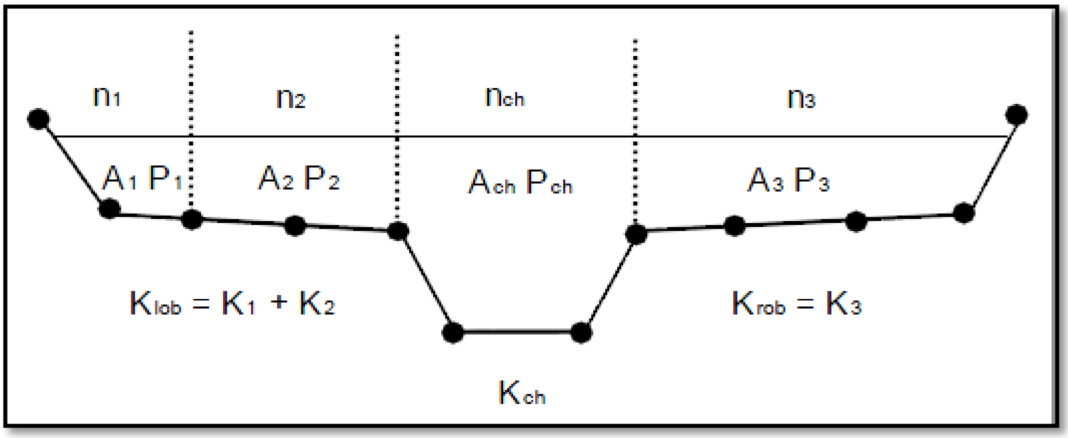


Fig 5.2 : Cross section divided into sub sections

5.3 STEADY FLOW WATER SURFACE PROFILES

HEC-RAS is currently capable of performing one-dimensional water surface profile calculations for steady gradually varied flow in natural or constructed channels. Subcritical, supercritical, and mixed flow regime water surface profiles can be calculated. Topics discussed in this section include: equations for basic profile calculations; cross section subdivision for conveyance calculations; composite Manning's n for the main channel; velocity weighting coefficient alpha; friction loss evaluation; contraction and expansion losses; computational procedure; critical depth determination; applications of the momentum equation; and limitations of the steady flow model. Fig 5.3 depicts the terms of the energy equation representation

5.3.1 Equations for Basic Profile Calculations

Water surface profiles are computed from one cross section to the next by solving the Energy equation with an iterative procedure called the standard step method. The Energy equation is written as follows:

$$Z_2 + Y_2 + \frac{a_2 V^2}{2g} = Z_2 + Y_2 + \frac{a_2 V^2}{2g} + he$$

Z_1 , Z_2 = Elevation of the main channel inverts
Y_1 , Y_2 = Depth of water st cross sections
V_1 , V_2 = Average velocities
a_1 , a_2 = Velocity weighing coefficients
g = Gravitational acceleration
h_e = Energy head loss

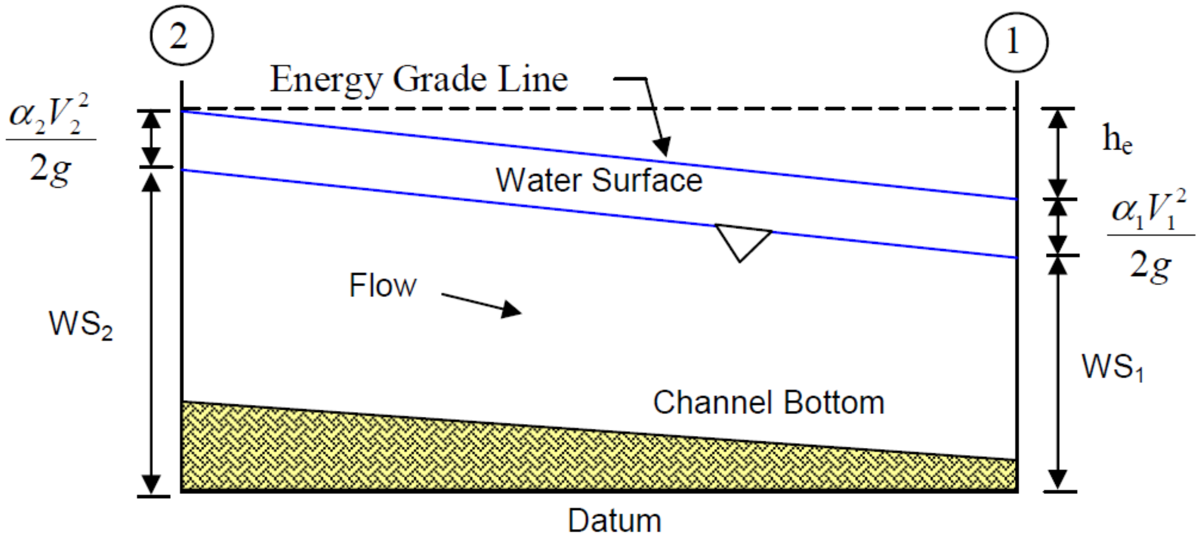


Fig 5.3: Representation of terms in energy equation

5.3.2 Energy Loss, h_e

Energy loss mainly divided into friction losses and other losses **.**

Friction losses

The transverse distribution of flow of the river is divided into strips having similar hydraulic properties in the direction of flow. Each cross section is sub divided into portions that are referred to as subsections as shown in Fig 5.2. Friction loss is calculated as shown below:

$$h_f = \left(\frac{Q}{K^1}\right)^2$$

$$\text{Where, } K^1 = \sum_{j=1}^{J} \left[\frac{1.49}{n_j}\right] \frac{\frac{(A_2 + A_1)}{2}\left[\frac{R_2 + R_1}{2}\right]_j^{1/2}}{L_j^{1/2}}$$

The energy loss term h_e in above equation is composed of friction loss h_f and form loss h_o. Only contraction and expansion losses are considered in the geometric form loss term. To approximate

$h_e = h_f + h_o$

A_1, A_2 = downstream and upstream area, respectively of the cross sectional flow normal to the flow direction

J = total number of subsections

L_j = length of the j^{th} strip between subsections

N = Manning's roughness coefficient

Q = water discharge

R_1, R_2 = downstream and upstream hydraulic radius

Other losses

Energy losses due following equation due to contractions and expansions by are computed by

$$h_0 = C_L \left| \frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g} \right|$$

Where, C_L = loss coefficient for contraction and expansion. If the quantity within the absolute value notation is negative, flow is contracting,

C_L is the coefficient for contraction; if is positive, flow is expanding and C_L is the coefficient of expansion.

In the standard step method for water surface profile computations, calculations proceed from the downstream to upstream based upon the reach's downstream boundary conditions and starting water surface elevation.

Friction loss is calculated with the help of Manning Equation & Contraction/Expansion loss is obtained with the help of loss coefficient

$he = LS_f + [(\alpha_1 V_1^2/2g) - (\alpha_2 V_2^2/2g)]$

L = reach length

A = cross sectional area

C = contraction/expansion coefficient

α = velocity weighing coefficient

S_f = friction slope

h_e = head loss

g = gravitational acceleration

V = flow velocity

5.4 HEC-RAS HYDRAULICS

HEC-RAS is a one-dimensional steady flow hydraulic model designed to aid hydraulic engineers in channel flow analysis and floodplain determination. The results of the model can be applied in floodplain management and flood insurance studies. If you recall from hydraulics, steady flow describes conditions in which depth and velocity at a given channel location do not change with time. Gradually varied flow is characterized by minor changes in water depth and velocity from cross-section to cross-section. The primary procedure used by HEC-RAS to compute water surface profiles assumes a steady, gradually varied flow scenario, and is called the direct step method. The basic computational procedure is based on an iterative solution of the energy equation: ,

$$H = Z + Y + \frac{\alpha V^2}{2g}$$

which states that the total energy at any given location along the stream is the sum of potential energy (Z + Y) and kinetic energy ($V^2/2g$). The change in energy between two cross-sections is called head loss (h_L). The energy equation parameters are illustrated in the following Fig 6.4

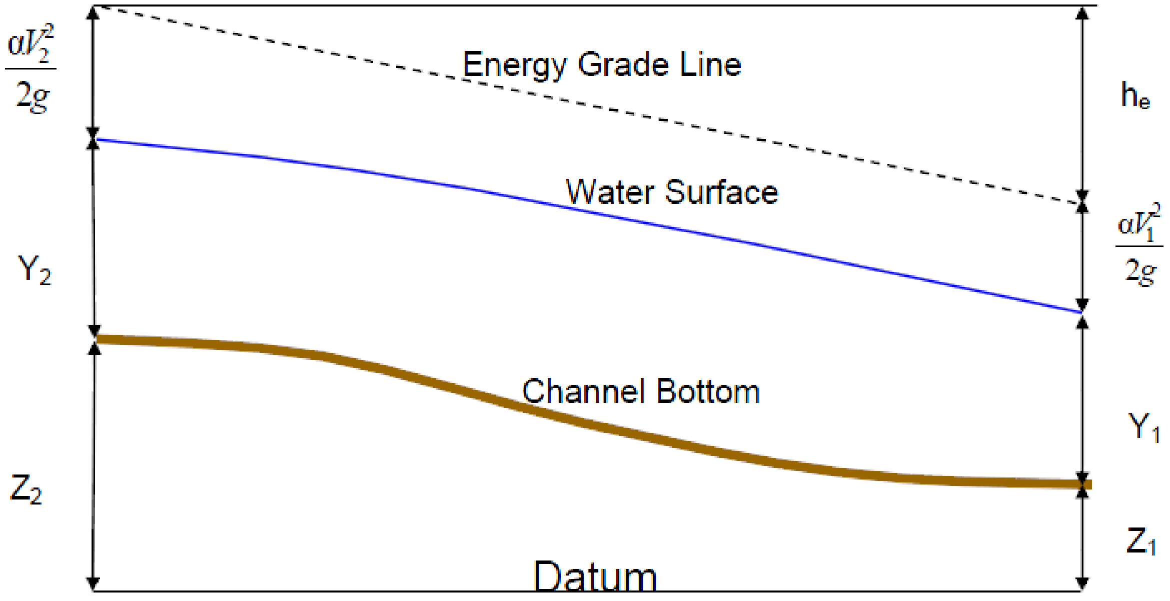


Fig 5.4 : Total Energy Grade Line diagram

Given the flow and water surface elevation at one cross-section, the goal of the direct step method is to compute the water surface elevation at the adjacent cross-section. Whether the computations proceed from upstream to downstream or vice versa, depend on the flow regime. The dimensionless Froude number (Fr) is used to characterize flow regime, where:

- Fr < 1 denotes Subcritical flow
- Fr > 1 denotes Supercritical flow
- Fr = 1 denotes Critical flow

For a subcritical flow scenario, which is very common in natural and man-made channels, direct step computations would begin at the downstream end of the reach, and progress upstream between adjacent cross-sections. For supercritical flow, the computations would begin at the upstream end of the reach and proceed downstream

5.4.1 Standard Step Computations

- Initial water surface (WS) elevation at 2 is assumed
- Based on assumed Water Surface elevation, determine the corresponding total conveyance and velocity head
- With values from step 2, $Sf$is computed and solution for h_e is done.
- With values from steps 2 and 3, 1D energy equation is used for obtaining new WS elevation at 2
- WS elevations of step 1 and step 4is compared. The process is iterated until values agree to within 0.003 m or to user-defined tolerance.

The program is constrained by a maximum number of iterations (default = 20) .If max iterations is reach before balanced WS is achieved, then critical depth is calculated. Then check if error of minimum error WS is within predefined tolerance If within predefined error tolerance and at the correct side of critical depth, then minimum error WS will be used and set a warning message Or else critical depth will be used and a warning message is set. While both are not valid solutions, minimum error WS is better than critical depth .

Common sources of error are inadequate number of cross sections (reach length too long) ,Bad cross section data ,Wrong boundary condition specified i.e. subcritical ,supercritical and critical .

6. APPLICATION OF HEC RAS

6.1 PURPOSE OF HECRAS

The Hydrologic Engineering Centre (HEC) in California developed the River Analysis System (RAS) to aid hydraulic engineers in channel flow analysis and floodplain determination. It includes numerous data entry capabilities, hydraulic analysis components, data storage and management capabilities, and graphing and reporting capabilities. The basic computational procedure of HEC-RAS for steady flow is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction and contraction / expansion. The momentum equation may be used in situations where the water surface profile is rapidly varied. These situations include hydraulic jumps, hydraulics of bridges, and evaluating profiles at river confluences. For unsteady flow, HEC-RAS solves the full, dynamic, 1-D Saint Venant Equation using an implicit, finite difference method. The unsteady flow equation solver was adapted from Dr. Robert L. Barkau’s UNET package. HEC-RAS is equipped to model a network of channels, a dendritic system or a single river reach. Certain simplifications must be made in order to model some complex flow situations using the HEC-RAS one-dimensional approach. It is capable of modelling subcritical, supercritical, and mixed flow regime flow along with the effects of dam, bridges, culverts, weirs, and structures. Different steps of HEC-RAS model simulation in current study discussed below.

6.2 GENERAL CAPABILITIES OF HEC RAS

a) User Interface

The main focus in the design of the interface was to make it easy to use the software, while still maintaining a high level of efficiency for the user. The interface provides for the following functions:

- File management
- Data entry/editing and GIS data interfaces
- River analyses
- Tabulation and graphical displays of input and output data
- Inundation mapping and animations of water propagation
- Reporting facilities
- On-line help

b) Data Storage and Management

Data storage is accomplished through the use of "flat" files (ASCII and binary), the HEC-DSS (Data Storage System), and HDF5 (Hierarchical Data Format, version 5). User input data are stored in flat files under separate categories of project, plan, geometry, steady flow, unsteady flow, quasi-steady flow, sediment data, and water quality information.

Output data is predominantly stored in separate binary files (HEC and HDF5). Data can be transferred between HEC-RAS and other programs by utilizing the HEC-DSS.Data management is accomplished through the user interface. A single filename is entered for the project being developed. Once the project filename is entered, all other files are automatically created and named by the interface as needed. The interface provides for renaming, moving, and deletion of files on a project-by-project basis.

c) Graphics and Reporting

Graphics include X-Y plots of the river system schematic, cross- sections, profiles, rating curves, hydrographs, and inundation mapping. A three-dimensional plot of multiple cross-sections is also provided. Inundation mapping is accomplished in the HEC-RAS Mapper portion of the software. Inundation maps can also be animated, and contain multiple background layers (terrain, aerial photography, etc.…).Tabular output is available. Pre-defined tables can be selected or own customized tables can be developed. All graphical and tabular output can be displayed on the screen, sent directly to a printer (or plotter), or passed through the Windows Clipboard to other software, such as a word-processor or spreadsheet.

6.3 PROGRAM CAPABILITIES OF HEC-RAS

1. Steady Flow Water Surface Profiles.

This component of the modelling system is intended for calculating water surface profiles for steady gradually varied flow.

2. Unsteady Flow Simulation:

This component of the HEC-RAS modeling system is capable of simulating one-dimensional; two-dimensional; and combined one/two-dimensional unsteady flow through a full network of open channels, floodplains, and alluvial fans. The unsteady flow component can be used to performed subcritical, supercritical, and mixed flow regime (subcritical, supercritical, hydraulic jumps, and drawdowns) calculations in the unsteady flow computations module.

3. Sediment Transport/Movable Boundary Computations:

This component of the modeling system is intended for the simulation of one-dimensional sediment transport/movable boundary calculations resulting from scour and deposition over moderate to long time periods

4. Water Quality Analysis:

This component of the modeling system is intended to allow the user to perform riverine water quality analyses. The current version of HEC-RAS can perform detailed temperature analysis and transport of a limited number of water quality constituents (Algae, Dissolved Oxygen, Carbonaceous Biological Oxygen Demand, Dissolved Orthophosphate, Dissolved Organic Phosphorus, Dissolved Ammonium Nitrate, Dissolved Nitrite Nitrogen, Dissolved

Nitrate Nitrogen, and Dissolved Organic Nitrogen).

To start the HECRAS Software by Double clicking on the HECRAS icon of the window .It can also be started from start menu by selecting program then HEC and then HECRAS**.**

Fig 6.1: HECRAS 5.0 Icon on windows

These are the following options which will appear to execute the model.

a) File:

This option is used for file management. Options available under the File menu include: New Project; Open Project; Save Project; Save Project As; Rename Project: Delete Project; Project Summary etc. In addition, the most recently opened projects will be listed at the bottom of the File menu, which allows the user to quickly open a project that was recently worked on.

b) Edit:

This option is used for entering and editing data. Data are categorized into six types: Geometric Data; Steady Flow Data; Quasi- Unsteady Flow; Unsteady Flow Data; Sediment Data; and Water Quality Data.

c)Run:

This option is used to perform the hydraulic calculations. The options under this menu item include: Steady Flow Analysis; Unsteady Flow Analysis; Sediment Analysis; Water Quality Analysis; Hydraulic Design Functions; and Run Multiple Plans.

d)View:

This option contains a set of tools that provide for graphical and tabular displays of the model output. The View menu item currently includes: Cross Sections; Water Surface Profiles; General Profile Plot; Rating Curves; X-Y-Z Perspective Plots; Stage and Flow Hydrographs; Hydraulic Properties Plots; Detailed Output Tables; Profile Summary Tables.

e)Options:

This menu item allows the user to change Program Setup options; set Default Parameters; establish the Default Units System (U.S. Customary or Metric); Convert Project Units (U.S. Customary to Metric, or Metric to U.S. Customary);

f)Help:

This option allows the user to get on-line help for HEC-RAS; display the HEC-RAS manuals (User’s manual, Hydraulic Reference Manual); install example projects; How to customize the Help menu; go to the HEC-RAS web page; go to an online guide for selecting Manning’s n values; view the terms and conditions of use statement; and display the current version information about HEC-RAS.

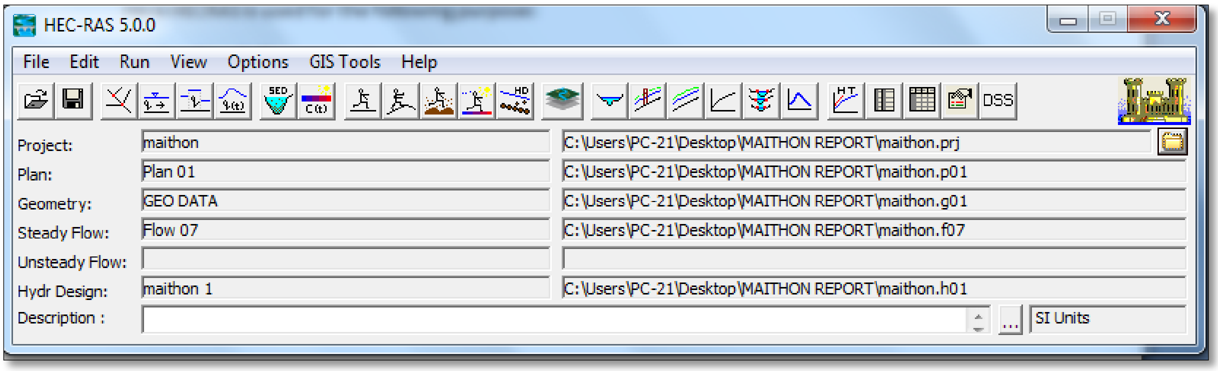
6.4 STEPS IN DEVELOPING A HYDRAULIC MODEL WITH HEC-RAS:

There are six main steps in creating a hydraulic model with HEC-RAS

1. Starting a new project
2. Drawing the Schematic of the River System
3. Entering Cross section data
4. Entering flow data and boundary conditions
5. Performing the hydraulic calculations
6. Viewing and printing results

6.4.1. Starting a New Project

The first step in developing an HEC-RAS application is to start a new project. The *File*menu on the main window is clicked and New Project is selected. The *New Project*window should appear first, the drive is set and the directory desired to work in. Next the project title and filename is entered. Once the information is entered, theOKbuttonis pressed to have the data accepted.



Project: maithon C:\Users\PC-21\Desktop\MAITHON REPORT\maithon.prj
Plan: Plan 01 C:\Users\PC-21\Desktop\MAITHON REPORT\maithon.p01
Geometry: GEO DATA C:\Users\PC-21\Desktop\MAITHON REPORT\maithon.g01
Steady Flow: Flow 07 C:\Users\PC-21\Desktop\MAITHON REPORT\maithon.f07
Unsteady Flow:
Hydr Design: maithon 1 C:\Users\PC-21\Desktop\MAITHON REPORT\maithon.h01
Description :

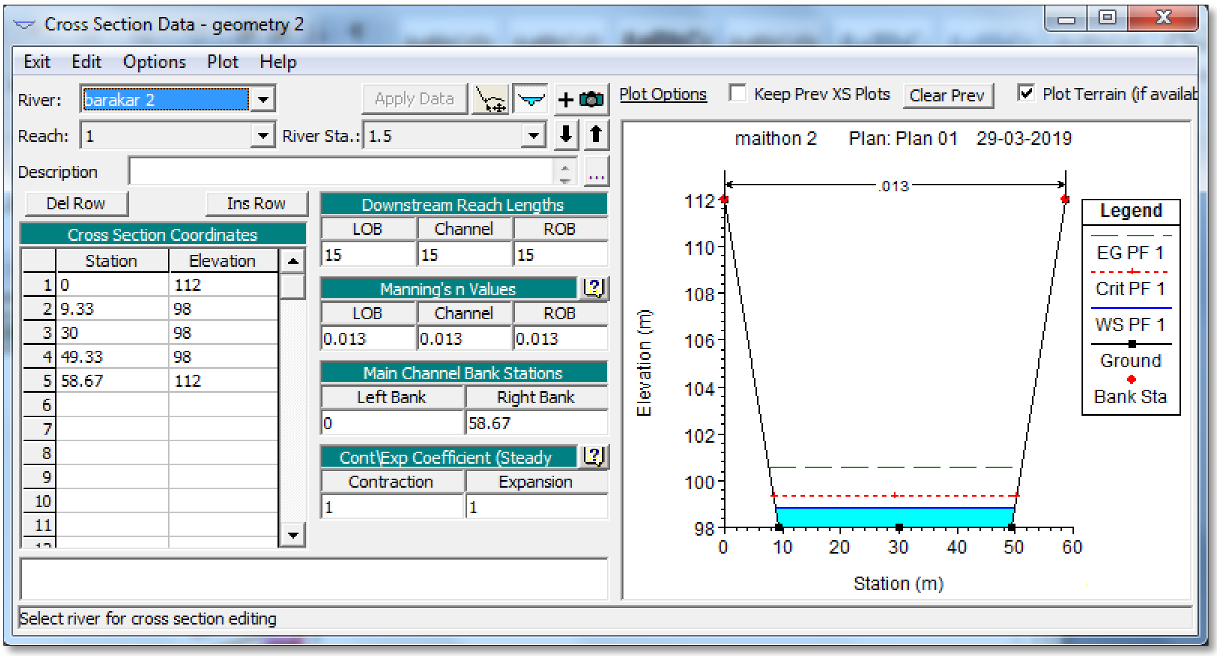
Fig 6.2:The HECRAS Main Window with Example

6.4.2. Drawing the Schematic of the River System

By Clicking the *River Reach* button on the geometric data window. The mouse pointer is moved over to the drawing area and the pointer is placed at the location in which the first reach is desired to draw. The left mouse button is pressed once to start drawing the reach. By moving the mouse pointer and continuing to press the left mouse button to add additional points to the line segment. To end the drawing of the reach, the left mouse button is double clicked and the last point of the reach will be placed at the current mouse pointer location. All reaches must be drawn from upstream to downstream (in the positive flow direction), because the program assumes this to be true. Once the reach is drawn, the interface will prompt to enter an identifier for the *River* name and the *Reach* name. In this case study, the river name is given as Barakar2 River.

6.4.3. Entering The Cross Sectional Data

In this step cross sectional data is entered .First the river reach is selected .Then the Options Menu is clicked and *Add new cross section* is selected. Then the River station identifier box appear .Cross section is plotted from upstream to downstream and proper description is entered in each cross section. The apply button is pressed after entering all cross sectional data such as station vs elevation ,Manning`s value, downstream reach length etc. The data is saved in hard disk by going to geometric data window.



Cross Section Data - geometry 2

River: barakar 2
Reach: 1
River Sta.: 1.5
Description:

Cross Section Coordinates

	Station	Elevation
1	0	112
2	9.33	98
3	30	98
4	49.33	98
5	58.67	112
6		
7		
8		
9		
10		
11		

Downstream Reach Lengths

LOB	Channel	ROB
15	15	15

Manning's n Values

LOB	Channel	ROB
0.013	0.013	0.013

Main Channel Bank Stations

Left Bank	Right Bank
0	58.67

Cont\Exp Coefficient (Steady

Contraction	Expansion
1	1

☐ Keep Prev XS Plots
☑ Plot Terrain (if availab

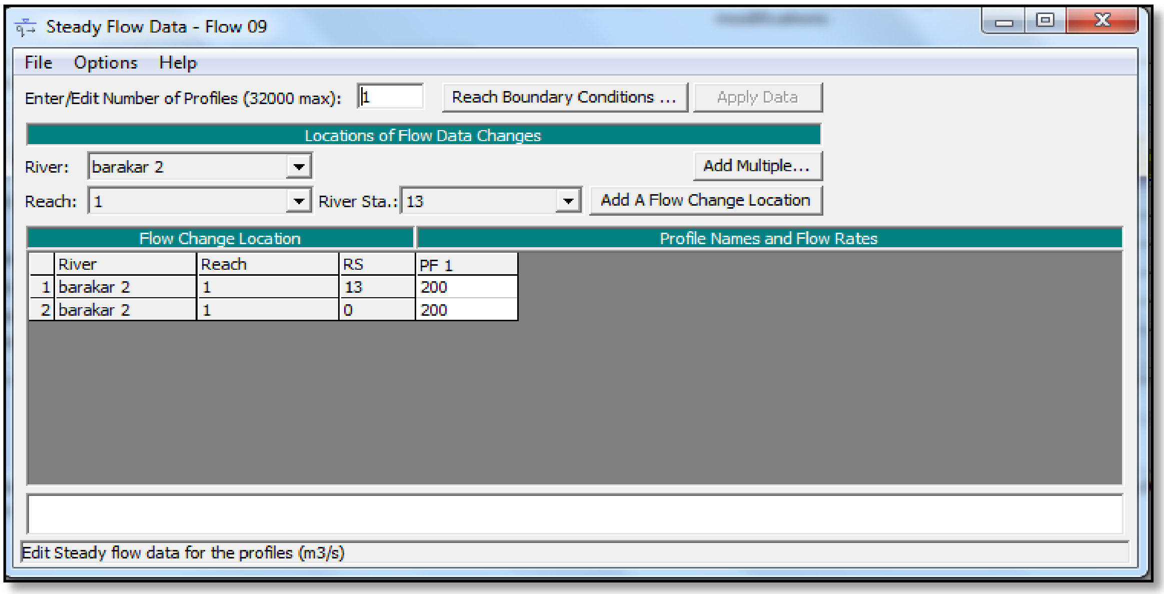
Select river for cross section editing

Fig 6.3 : The Cross Section Data Editor with example

6.4.4. Entering Flow Data And Boundary Conditions

In the next step the required data is entered to perform the water profile calculations. . In a supercritical flow analysis is going to be performed, then only the upstream boundary conditions are required. The Boundary Conditions data entry form can be brought up by pressing the *Reach Boundary Conditions* button from the Steady Flow Data entry form. The boundary conditions is available in the form four options 1. Known water surface elevations 2.Critical depth 3. Normal depth 4.Rating curve .Once all of the steady flow data and boundary conditions are entered, the data is saved in the hard disk. This can be accomplished by selecting *Save Flow Data As* from the *File* option on the Steady Flow

Data menu bar. Flow data is saved in a separate file. A title is entered for the flow data, the filename is automatically assigned.



Enter/Edit Number of Profiles (32000 max): 1

River: barakar 2

Reach: 1

River Sta.: 13

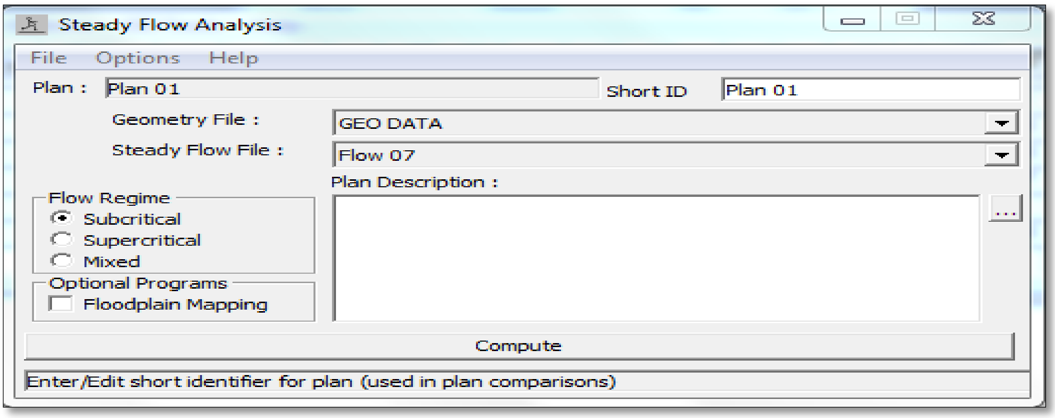
	River	Reach	RS	PF 1
1	barakar 2	1	13	200
2	barakar 2	1	0	200

Edit Steady flow data for the profiles (m3/s)

Fig 6.4 :Steady Flow Data window

6.4.5. Performing The Hydraulic Calculations

Once all of the geometric data and flow data are entered. The hydraulic calculations are ready to be perform . As stated previously, there are five types of calculations that can be performed in the current version of HEC-RAS: Steady Flow Analysis, Unsteady Flow Analysis, Sediment Transport/Mobile Boundary Modeling, Water Quality Analyses, and Hydraulic Design Functions. Any of the available hydraulic analyses can be selected from the *Run*menu bar option on the HEC-RAS main window. The steady flow analysis is performed in the present study. Once a Plan Title and Short Identifier (Short ID) have been entered, a *Flow Regime* an be selected for which the model will perform calculations. Subcritical, Supercritical, or Mixed flow regime calculations are available. Once a Plan is selected and then set all of the calculation options, the steady flow calculations can be performed by pressing the *Compute* button at the bottom of the Steady Flow Analysis window. When this button is pressed, the HEC-RAS system packages up all the data for the selected plan and writes it to a run file. The system then runs the steady flow model and passes it the name of the run file. This process is executed in a separate window.



Plan : Plan 01
Short ID: Plan 01

Geometry File : GEO DATA

Steady Flow File : Flow 07

Flow Regime
● Subcritical
○ Supercritical
○ Mixed

Optional Programs
☐ Floodplain Mapping

Enter/Edit short identifier for plan (used in plan comparisons)

Fig 6.5 :Steady Flow Analysis window

6.4.6.Viewing Graphical and Tabular Results

Once all of the computations has finished ,the results can be viewed. Several output features are available under the **View** option from the main window. These options include:

a) Cross section plots:

This help us to view cross section at various locations along the river reach.

b) Water surface profile plot:

It shows the water surface depth for each discharge in the longitudinal direction.

c) General profile plots :

It shows the plot of the velocity vs main channel downstream distance for each discharge.

d) Rating curve plots :

It provide the graphs between water surface level (stage) vs discharge at each cross section.

e) X-Y-Z perspective plots:

It plots water surface level w.r.t bank stations points for a particular discharge.

f) Hydrograph plots :

It provides the plot between discharge and time.

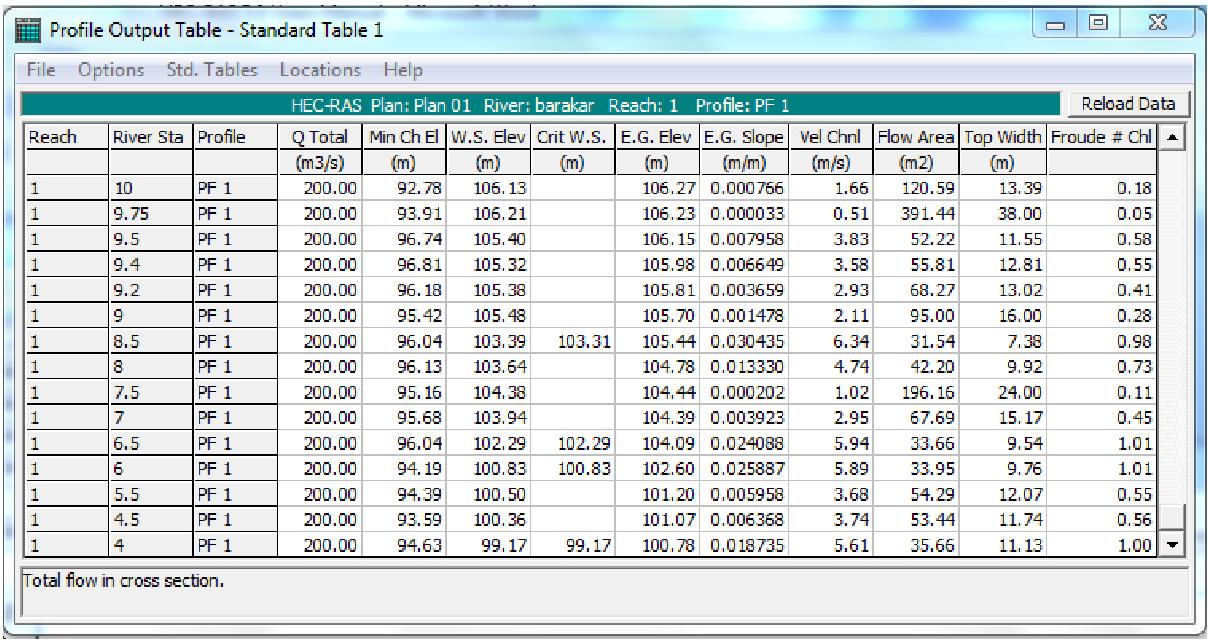
g) Hydraulic property tables(if unsteady flow simulation was performed)

h) Tabular output at specific locations(Detailed Output Tables) :

Detailed output tables show hydraulic information at a single location, for a single profile.

f) Tabular output for many locations(Profile Summary Tables):

Profile summary tables are used to show a number of hydraulic variables for several cross sections.

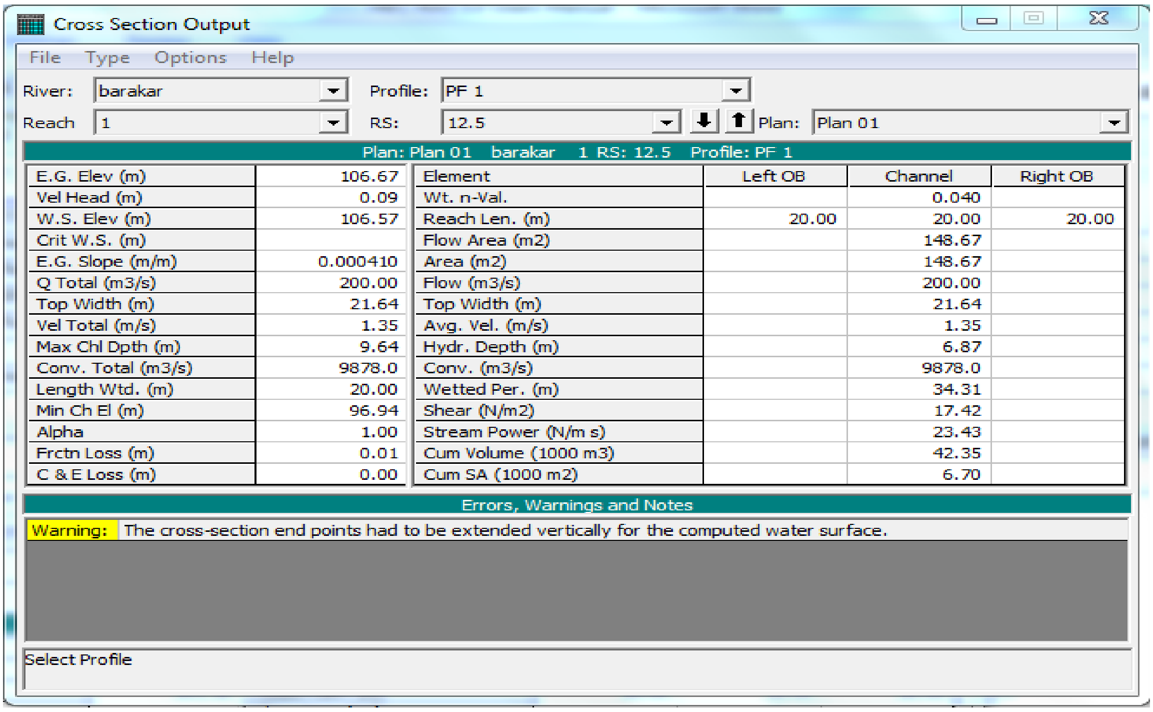


HEC-RAS Plan: Plan 01 River: barakar Reach: 1 Profile: PF 1

Reach	River Sta	Profile	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
1	10	PF 1	200.00	92.78	106.13		106.27	0.000766	1.66	120.59	13.39	0.18
1	9.75	PF 1	200.00	93.91	106.21		106.23	0.000033	0.51	391.44	38.00	0.05
1	9.5	PF 1	200.00	96.74	105.40		106.15	0.007958	3.83	52.22	11.55	0.58
1	9.4	PF 1	200.00	96.81	105.32		105.98	0.006649	3.58	55.81	12.81	0.55
1	9.2	PF 1	200.00	96.18	105.38		105.81	0.003659	2.93	68.27	13.02	0.41
1	9	PF 1	200.00	95.42	105.48		105.70	0.001478	2.11	95.00	16.00	0.28
1	8.5	PF 1	200.00	96.04	103.39	103.31	105.44	0.030435	6.34	31.54	7.38	0.98
1	8	PF 1	200.00	96.13	103.64		104.78	0.013330	4.74	42.20	9.92	0.73
1	7.5	PF 1	200.00	95.16	104.38		104.44	0.000202	1.02	196.16	24.00	0.11
1	7	PF 1	200.00	95.68	103.94		104.39	0.003923	2.95	67.69	15.17	0.45
1	6.5	PF 1	200.00	96.04	102.29	102.29	104.09	0.024088	5.94	33.66	9.54	1.01
1	6	PF 1	200.00	94.19	100.83	100.83	102.60	0.025887	5.89	33.95	9.76	1.01
1	5.5	PF 1	200.00	94.39	100.50		101.20	0.005958	3.68	54.29	12.07	0.55
1	4.5	PF 1	200.00	93.59	100.36		101.07	0.006368	3.74	53.44	11.74	0.56
1	4	PF 1	200.00	94.63	99.17	99.17	100.78	0.018735	5.61	35.66	11.13	1.00

Total flow in cross section.

Fig 6.6 : Profile Output Table With Example



River: barakar

Profile: PF 1

Reach 1

RS: 12.5

Plan: Plan 01

Plan: Plan 01 barakar 1 RS: 12.5 Profile: PF 1

E.G. Elev (m)	106.67
Vel Head (m)	0.09
W.S. Elev (m)	106.57
Crit W.S. (m)	
E.G. Slope (m/m)	0.000410
Q Total (m3/s)	200.00
Top Width (m)	21.64
Vel Total (m/s)	1.35
Max Chl Dpth (m)	9.64
Conv. Total (m3/s)	9878.0
Length Wtd. (m)	20.00
Min Ch El (m)	96.94
Alpha	1.00
Frctn Loss (m)	0.01
C & E Loss (m)	0.00

Element	Left OB	Channel	Right OB
Wt. n-Val.		0.040	
Reach Len. (m)	20.00	20.00	20.00
Flow Area (m2)		148.67	
Area (m2)		148.67	
Flow (m3/s)		200.00	
Top Width (m)		21.64	
Avg. Vel. (m/s)		1.35	
Hydr. Depth (m)		6.87	
Conv. (m3/s)		9878.0	
Wetted Per. (m)		34.31	
Shear (N/m2)		17.42	
Stream Power (N/m s)		23.43	
Cum Volume (1000 m3)		42.35	
Cum SA (1000 m2)		6.70	

Errors, Warnings and Notes

Warning: The cross-section end points had to be extended vertically for the computed water surface.

Select Profile

Fig 6.7 :Cross section output table with Example

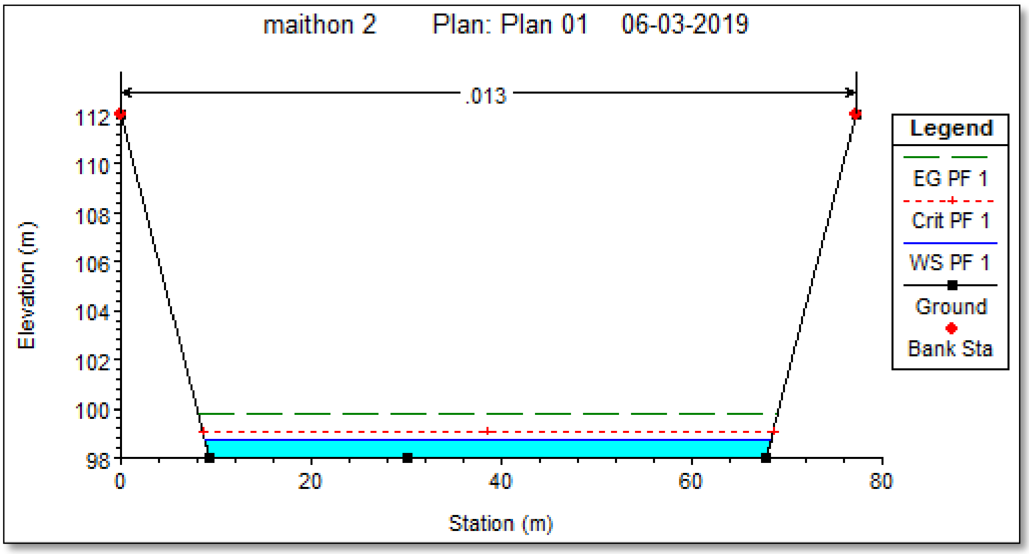


Fig 6.8 : Cross Section Plot

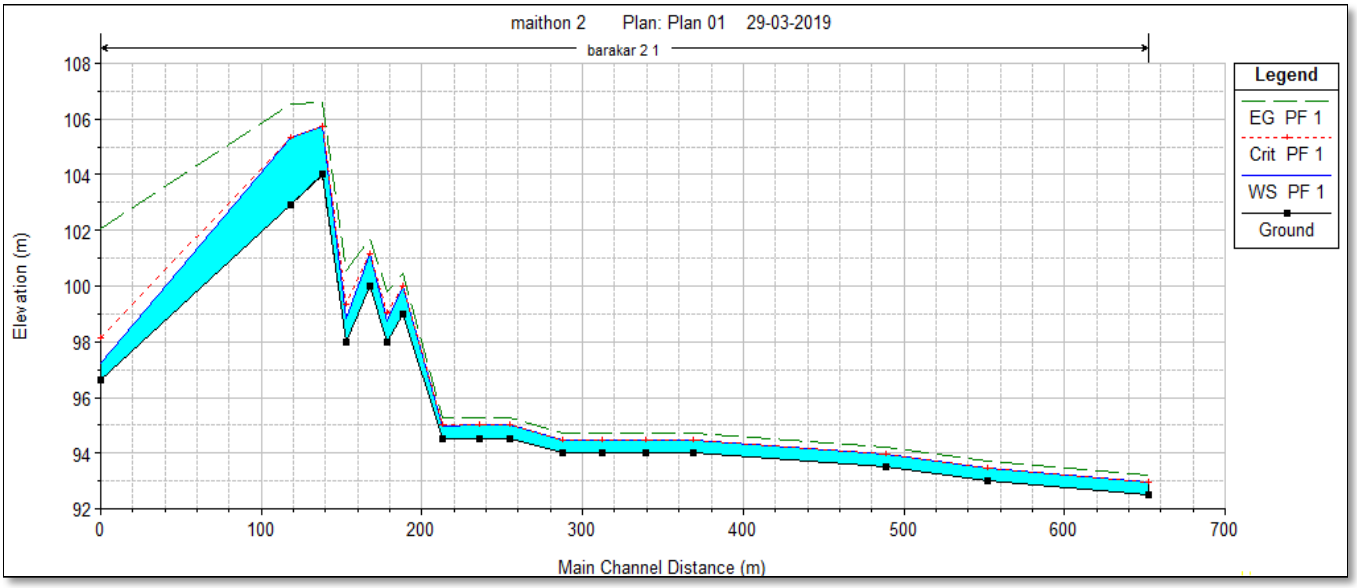


Fig 6.9 : Profile Plot

6.4.7. Printing Graphics and Tables

All of the plots and tables can be sent directly to a printer/plotter or passed through the Windows clipboard to another program (e.g., a word processor). The printer or plotter that gets used is based on what currently have been selected as the default printer for Windows. The default printer settings(e.g., portrait to landscape) before printing occurs may be changed.

a) Sending Graphics Directly to the Printer

b) Sending Graphics to the Windows Clipboard

c) Sending Tables to the Windows Clipboard

6.4.8. Exiting the Program

Before the HEC-RAS software is exited ,all the data is saved. This can be accomplished easily by selecting *Save Project* from the *File* menu on the HEC-RAS main window. Any data (geometric, flow, and plan data) that have not been saved will automatically be saved .To exit the HEC-RAS software, *Exit* is selected from the *File* menu of the HEC-RAS main window.

6.5 ADVANTAGES AND DISADVANTAGES OF HECRAS

Advantages

a) HEC-RAS helps in modelling water flowing through systems of open channels and computing water surface profiles.

b) HEC-RAS finds particular commercial application in floodplain management and flood insurance studies to evaluate floodway encroachments.

c) Some of the additional uses are: bridge and culvert design and analysis, levee studies, and channel modification studies.

d) It can be used for dam breach analysis, though other modeling methods are presently more widely accepted for this purpose.

Disadvantages

a) Users may find numerical instability problems during unsteady analysis.

b) Problems of instability especially in steep and/or highly dynamic rivers and streams.

7. DATA ANALYSIS AND RESULTS

Throughout the Barakar river the flow is gradually varied (steady) flow. From the HECRAS Output of all the cross sections it can be interpreted that the water level will be well below both the banks of the cross section under steady (gradually varied)flow of discharge 200m^3/s. Following figure presents computed section using HEC-RAS software and given discharge.

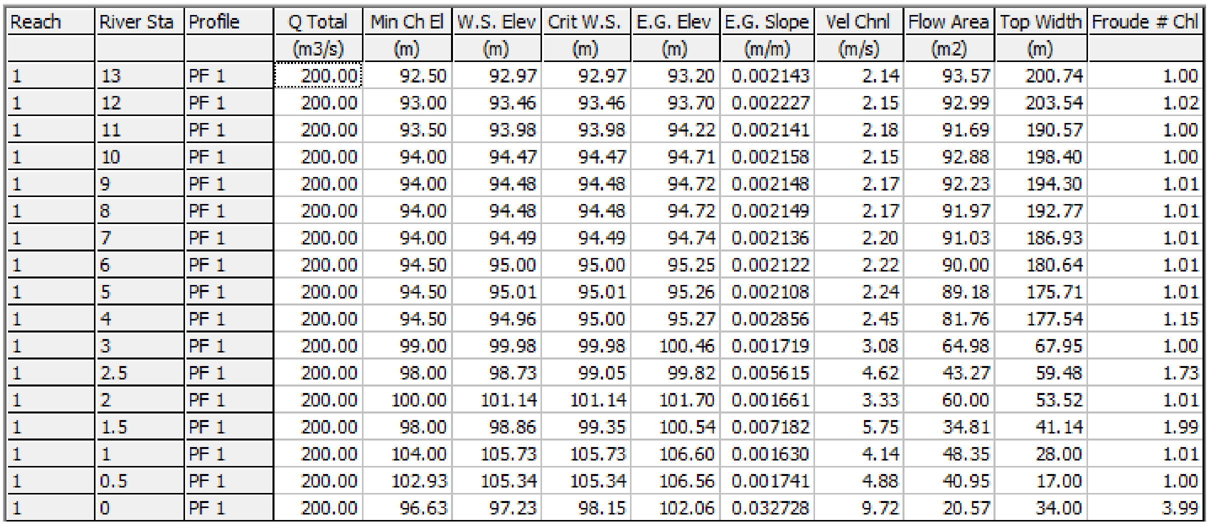
The hydrological modelling for the present river in study was performed using the USACE Hydrologic Engineering Centre’s River Analysis System (HEC-RAS) version 5.0 for performing one dimensional steady flow analysis. By giving the parameters at their respective cross-sectional locations without leaving any class unattended the model then became ready to run to simulate the desired results. The model was run for one dimensional steady flow water surface profile computations for river Barakar. The energy equation, using the standard step method, solved the steady flow, while Manning’s equation and contraction/expansion coefficients determined head losses as mentioned in previous sections.

The flow in the channel as given as 200 m^3/s, 130 m^3/s and 65 m^3/s has been considered for steady flow analysis. When these values are given as input at all the 17 cross-sections the output obtained is as shown in following figure.

7.1 PROFILE OUTPUT

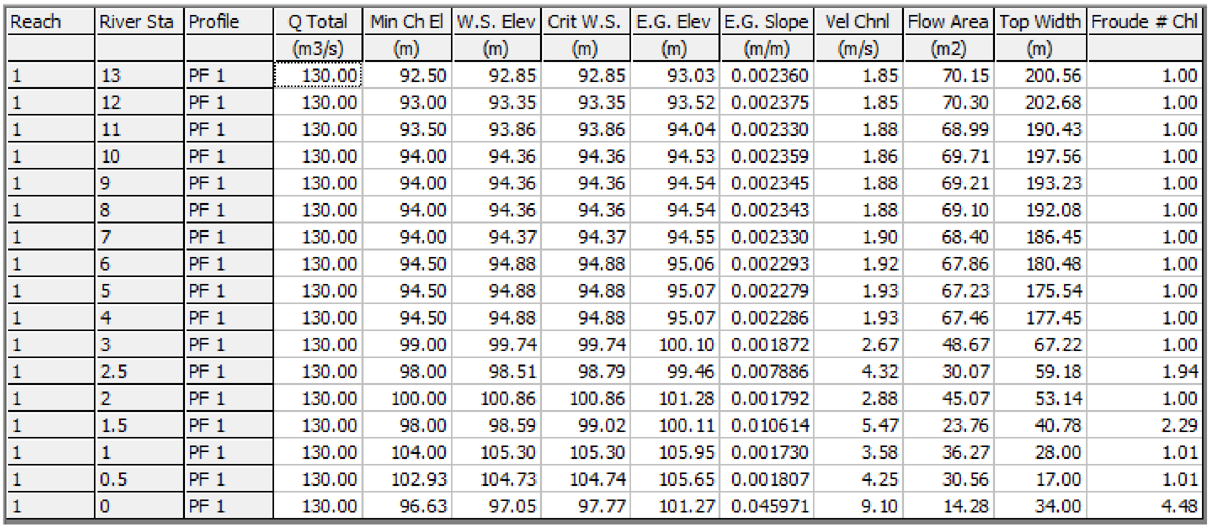
The output of the HECRAS software for discharge of 200 m^3/s , 130 m^3/s and 65 m^3/s is shown in tabular form in Table 7.5 , Table 7.6 and Table 7.7.

Table7.1 :Profile output table for 200 m^3/s discharge



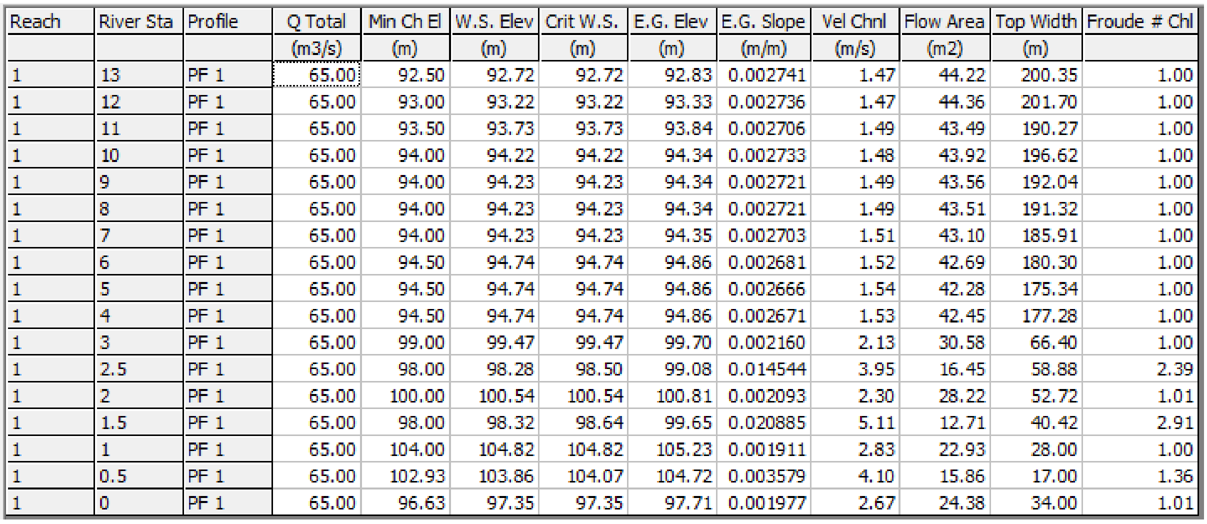
Reach	River Sta	Profile	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
1	13	PF 1	200.00	92.50	92.97	92.97	93.20	0.002143	2.14	93.57	200.74	1.00
1	12	PF 1	200.00	93.00	93.46	93.46	93.70	0.002227	2.15	92.99	203.54	1.02
1	11	PF 1	200.00	93.50	93.98	93.98	94.22	0.002141	2.18	91.69	190.57	1.00
1	10	PF 1	200.00	94.00	94.47	94.47	94.71	0.002158	2.15	92.88	198.40	1.00
1	9	PF 1	200.00	94.00	94.48	94.48	94.72	0.002148	2.17	92.23	194.30	1.01
1	8	PF 1	200.00	94.00	94.48	94.48	94.72	0.002149	2.17	91.97	192.77	1.01
1	7	PF 1	200.00	94.00	94.49	94.49	94.74	0.002136	2.20	91.03	186.93	1.01
1	6	PF 1	200.00	94.50	95.00	95.00	95.25	0.002122	2.22	90.00	180.64	1.01
1	5	PF 1	200.00	94.50	95.01	95.01	95.26	0.002108	2.24	89.18	175.71	1.01
1	4	PF 1	200.00	94.50	94.96	95.00	95.27	0.002856	2.45	81.76	177.54	1.15
1	3	PF 1	200.00	99.00	99.98	99.98	100.46	0.001719	3.08	64.98	67.95	1.00
1	2.5	PF 1	200.00	98.00	98.73	99.05	99.82	0.005615	4.62	43.27	59.48	1.73
1	2	PF 1	200.00	100.00	101.14	101.14	101.70	0.001661	3.33	60.00	53.52	1.01
1	1.5	PF 1	200.00	98.00	98.86	99.35	100.54	0.007182	5.75	34.81	41.14	1.99
1	1	PF 1	200.00	104.00	105.73	105.73	106.60	0.001630	4.14	48.35	28.00	1.01
1	0.5	PF 1	200.00	102.93	105.34	105.34	106.56	0.001741	4.88	40.95	17.00	1.00
1	0	PF 1	200.00	96.63	97.23	98.15	102.06	0.032728	9.72	20.57	34.00	3.99

Table7.2 :Profile output table for 130 m^3/s discharge



Reach	River Sta	Profile	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
1	13	PF 1	130.00	92.50	92.85	92.85	93.03	0.002360	1.85	70.15	200.56	1.00
1	12	PF 1	130.00	93.00	93.35	93.35	93.52	0.002375	1.85	70.30	202.68	1.00
1	11	PF 1	130.00	93.50	93.86	93.86	94.04	0.002330	1.88	68.99	190.43	1.00
1	10	PF 1	130.00	94.00	94.36	94.36	94.53	0.002359	1.86	69.71	197.56	1.00
1	9	PF 1	130.00	94.00	94.36	94.36	94.54	0.002345	1.88	69.21	193.23	1.00
1	8	PF 1	130.00	94.00	94.36	94.36	94.54	0.002343	1.88	69.10	192.08	1.00
1	7	PF 1	130.00	94.00	94.37	94.37	94.55	0.002330	1.90	68.40	186.45	1.00
1	6	PF 1	130.00	94.50	94.88	94.88	95.06	0.002293	1.92	67.86	180.48	1.00
1	5	PF 1	130.00	94.50	94.88	94.88	95.07	0.002279	1.93	67.23	175.54	1.00
1	4	PF 1	130.00	94.50	94.88	94.88	95.07	0.002286	1.93	67.46	177.45	1.00
1	3	PF 1	130.00	99.00	99.74	99.74	100.10	0.001872	2.67	48.67	67.22	1.00
1	2.5	PF 1	130.00	98.00	98.51	98.79	99.46	0.007886	4.32	30.07	59.18	1.94
1	2	PF 1	130.00	100.00	100.86	100.86	101.28	0.001792	2.88	45.07	53.14	1.00
1	1.5	PF 1	130.00	98.00	98.59	99.02	100.11	0.010614	5.47	23.76	40.78	2.29
1	1	PF 1	130.00	104.00	105.30	105.30	105.95	0.001730	3.58	36.27	28.00	1.01
1	0.5	PF 1	130.00	102.93	104.73	104.74	105.65	0.001807	4.25	30.56	17.00	1.01
1	0	PF 1	130.00	96.63	97.05	97.77	101.27	0.045971	9.10	14.28	34.00	4.48

Table7.3 :Profile output table for 65 m^3/s discharge



Reach	River Sta	Profile	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
1	13	PF 1	65.00	92.50	92.72	92.72	92.83	0.002741	1.47	44.22	200.35	1.00
1	12	PF 1	65.00	93.00	93.22	93.22	93.33	0.002736	1.47	44.36	201.70	1.00
1	11	PF 1	65.00	93.50	93.73	93.73	93.84	0.002706	1.49	43.49	190.27	1.00
1	10	PF 1	65.00	94.00	94.22	94.22	94.34	0.002733	1.48	43.92	196.62	1.00
1	9	PF 1	65.00	94.00	94.23	94.23	94.34	0.002721	1.49	43.56	192.04	1.00
1	8	PF 1	65.00	94.00	94.23	94.23	94.34	0.002721	1.49	43.51	191.32	1.00
1	7	PF 1	65.00	94.00	94.23	94.23	94.35	0.002703	1.51	43.10	185.91	1.00
1	6	PF 1	65.00	94.50	94.74	94.74	94.86	0.002681	1.52	42.69	180.30	1.00
1	5	PF 1	65.00	94.50	94.74	94.74	94.86	0.002666	1.54	42.28	175.34	1.00
1	4	PF 1	65.00	94.50	94.74	94.74	94.86	0.002671	1.53	42.45	177.28	1.00
1	3	PF 1	65.00	99.00	99.47	99.47	99.70	0.002160	2.13	30.58	66.40	1.00
1	2.5	PF 1	65.00	98.00	98.28	98.50	99.08	0.014544	3.95	16.45	58.88	2.39
1	2	PF 1	65.00	100.00	100.54	100.54	100.81	0.002093	2.30	28.22	52.72	1.01
1	1.5	PF 1	65.00	98.00	98.32	98.64	99.65	0.020885	5.11	12.71	40.42	2.91
1	1	PF 1	65.00	104.00	104.82	104.82	105.23	0.001911	2.83	22.93	28.00	1.00
1	0.5	PF 1	65.00	102.93	103.86	104.07	104.72	0.003579	4.10	15.86	17.00	1.36
1	0	PF 1	65.00	96.63	97.35	97.35	97.71	0.001977	2.67	24.38	34.00	1.01

7.2 CROSS SECTION OUTPUT

At cross-section from 0-0` to 13-13` for flow of 200 m^3/s the cross-section is sufficient to carry flow. The figure of the cross sections for maximum given discharge of 200m^3/s is shown below

The cross section output is calculated for maximum discharge only so as to obtain the maximum water level possible in the given cross sections of the river. From the output it is clear that the water level is well below the bank levels. So no possibility of flood in the given study region even for maximum discharge allowed. The cross section output is shown in Fig 7.1, Fig 7.2, Fig 7.3,Fig 7.4 and Fig 7.5.

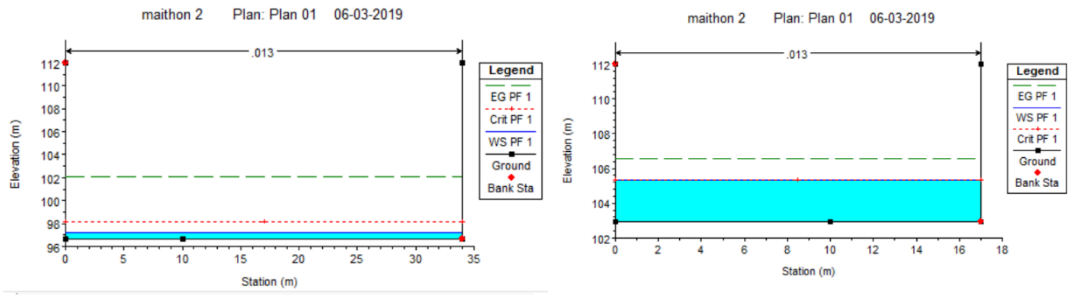


Fig 7.1(a) water elevation at cross section 0-0`

Fig 7.1(b) water elevation at cross section 0.5-0.5'`

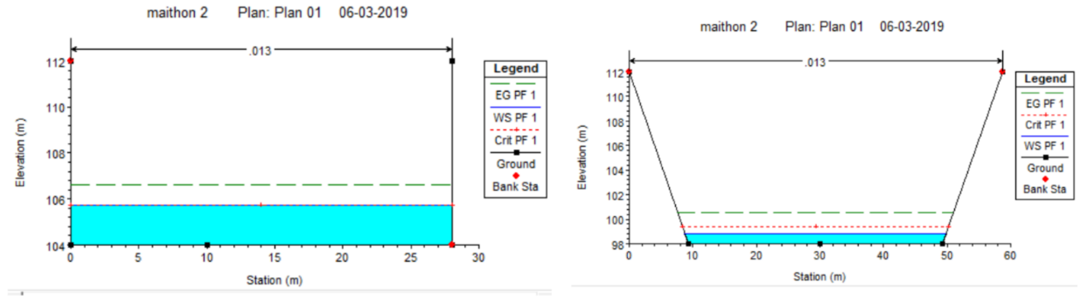


Fig 7.1 (c) water elevation at cross section 1-1`

Figure 7.1(d) water elevation at cross section 1.5-1.5`

Fig 7.1 : Water elevation from cross section 0-0` to 1.5`-1.5`for 200 m^3/s discharge

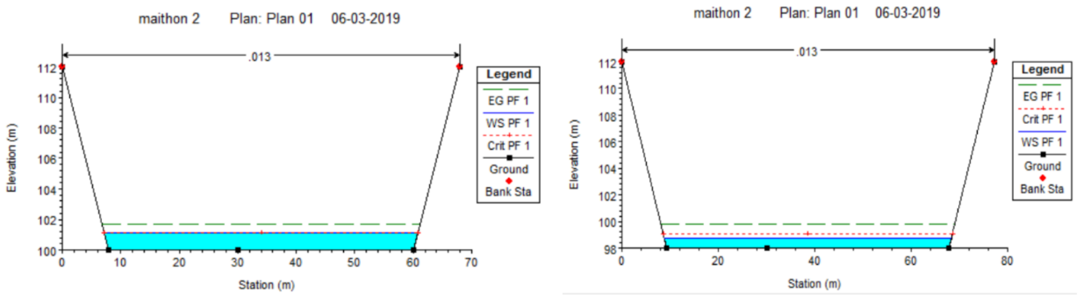


Fig 7.2 (a) water elevation at cross section 2-2`

Fig 7.2 (b) water elevation at cross section 2.5-2.5`

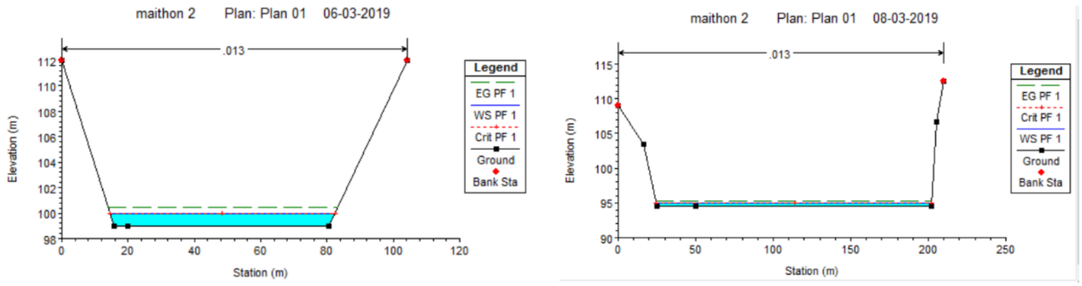


Fig 7.2 (c) water elevation at cross section 3-3`

Fig 7.2 (d) water elevation at cross section 4-4`

Fig 7.2 : Water elevation from cross section 2-2` to 4`-4` for 200 m^3/s discharge

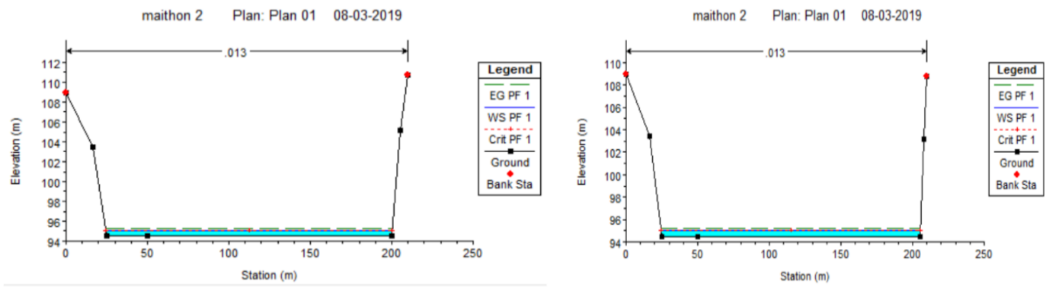


Fig 7.3(a) water elevation at cross section 5-5`

Fig 7.3(b) water elevation at cross section 6-6`

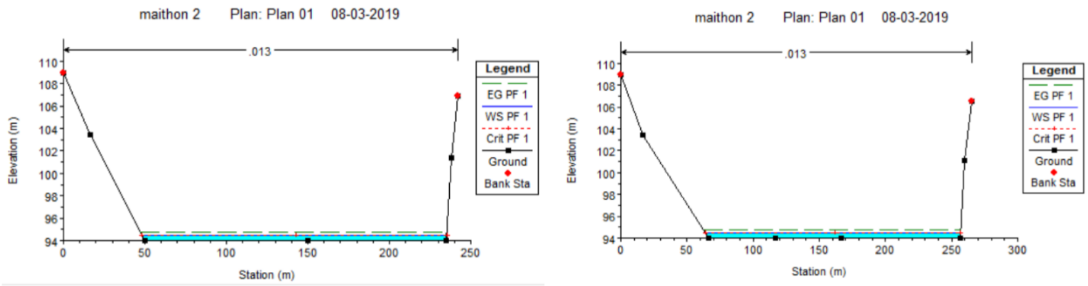


Fig 7.3 (c) water elevation at cross section 7-7`

Fig 7.3(d) water elevation at cross section 8-8`

Fig 7.3 : Water elevation from cross section 5-5` to 8-8` for 200 m^3/s discharge

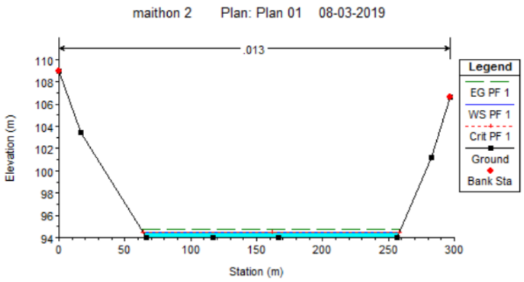


Fig 7.4(a) water elevation at cross section 9-9`

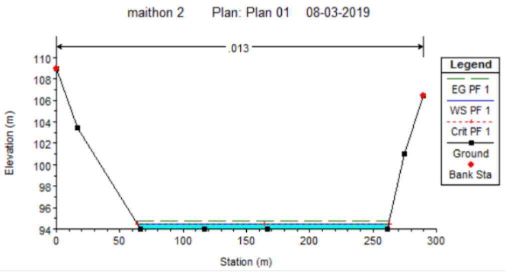


Fig 7.4(b) water elevation at cross section 10-10`

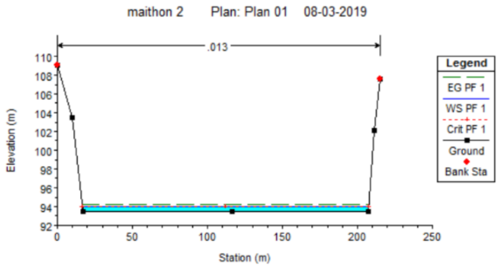


Fig 7.4(c) water elevation at cross section 11-11`

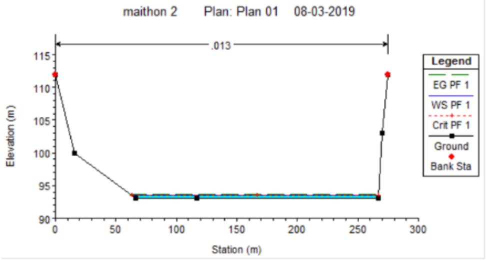


Fig 7.4(d) water elevation at cross section 12-12`

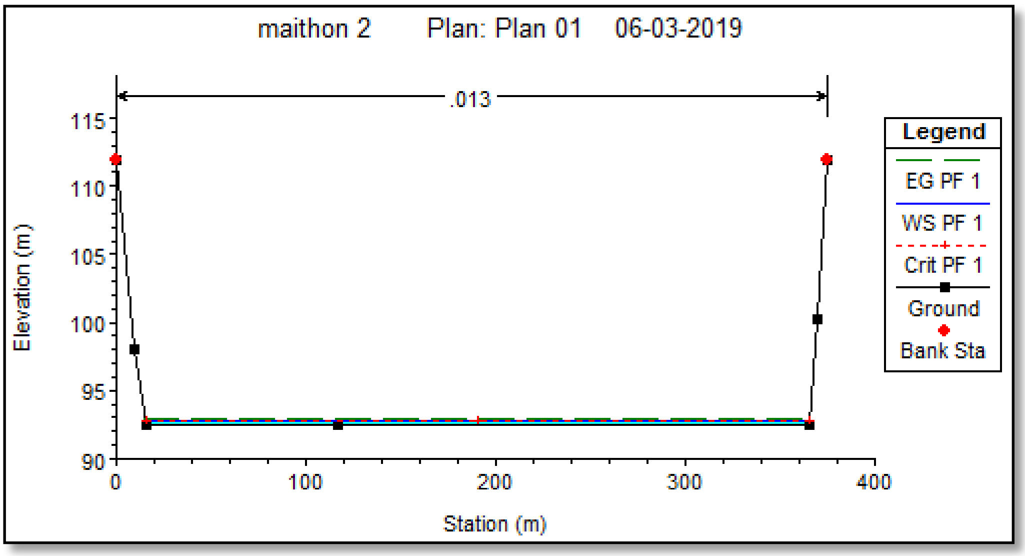


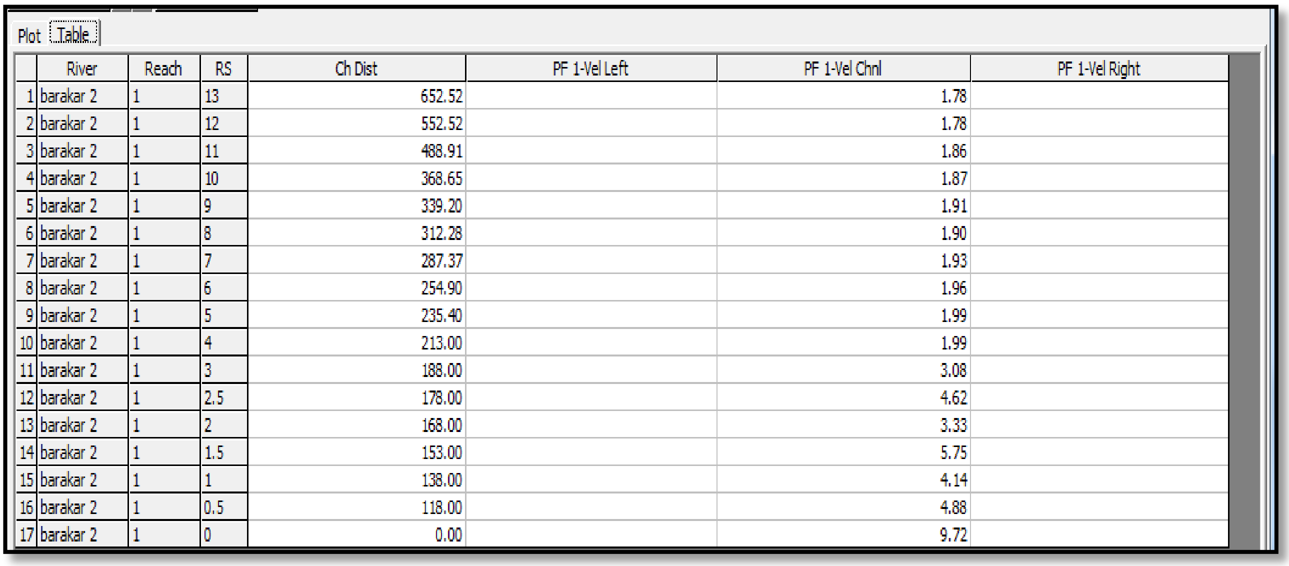
Fig7.4 (e) : Water elevation from cross section 13-13`

Fig7.4 : Water elevation from cross section 9-9` to 13-13` for 200 m^3/s discharge

By using this analysis, one can easily predict the water elevation for given discharge of 200m^3/s in the surrounding area of study reach and accordingly measure can be taken up in the form of bank protection like levees, bunds, by raising the level of gabions, stone pitches , embankment and scour protection. In this paper, the present study is used to check sufficiency of all the cross-sections of Barakar river from tail race of Maithon dam to carry specified magnitude of discharge.

From cross section 0-0` to 13-13` the average velocity of the river has been found to be range between 1.78 and 9.72 m/s .for 200m^3/s discharge which is depicted in the given figure.

Table7.4 :velocity vs channel distance table for 200 m^3/s discharge



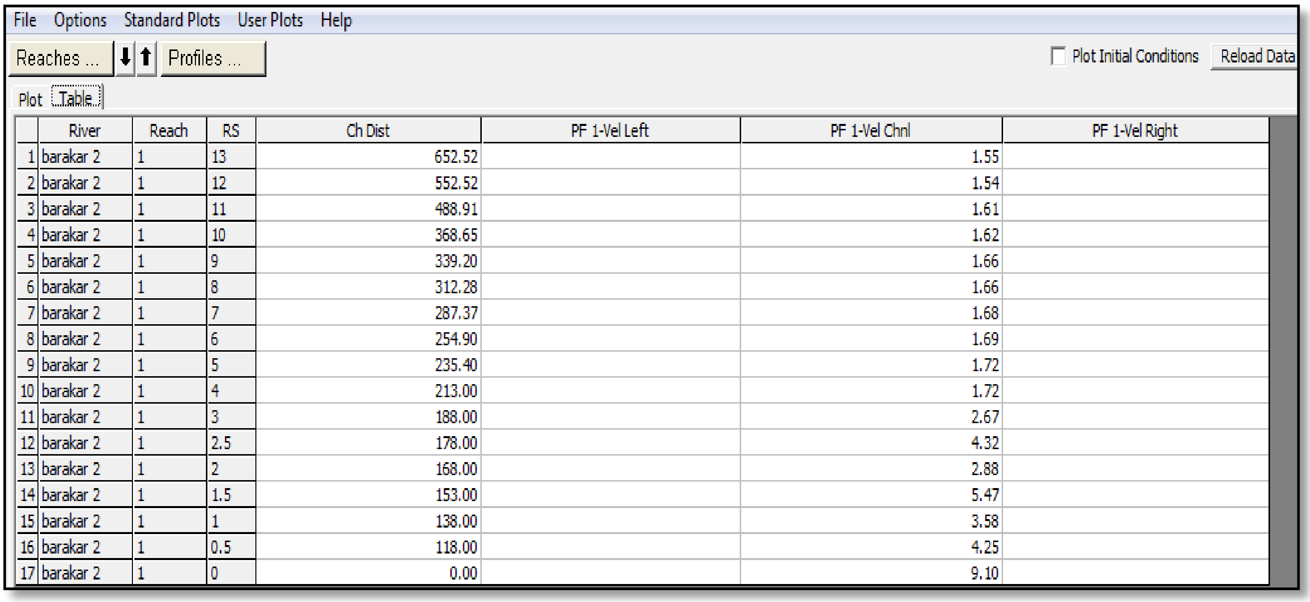
	River	Reach	RS	Ch Dist	PF 1-Vel Left	PF 1-Vel Chnl	PF 1-Vel Right
1	barakar 2	1	13	652.52		1.78	
2	barakar 2	1	12	552.52		1.78	
3	barakar 2	1	11	488.91		1.86	
4	barakar 2	1	10	368.65		1.87	
5	barakar 2	1	9	339.20		1.91	
6	barakar 2	1	8	312.28		1.90	
7	barakar 2	1	7	287.37		1.93	
8	barakar 2	1	6	254.90		1.96	
9	barakar 2	1	5	235.40		1.99	
10	barakar 2	1	4	213.00		1.99	
11	barakar 2	1	3	188.00		3.08	
12	barakar 2	1	2.5	178.00		4.62	
13	barakar 2	1	2	168.00		3.33	
14	barakar 2	1	1.5	153.00		5.75	
15	barakar 2	1	1	138.00		4.14	
16	barakar 2	1	0.5	118.00		4.88	
17	barakar 2	1	0	0.00		9.72	

The velocity curve shows a sudden rise in velocity in two wall region because this rise in velocity helps the water to rise above the wall section .The upstream velocity is also high due to less width in the upstream sections. In the downstream of wall section the velocity decreases below 2 m/s which is due to increase in river width in the downstream region. But due to the downstream river velocity is quite high above the 1 m/s range hence there is a possibility of scour .Hence necessary precaution by using the bed material in the form of boulder pitching to avoid the erosion and scouring at bed level.

From cross section 0-0` to 13-13` the average velocity of the river has been found ranging between 1.22 m/s and 2.67 m/s. for 65 m3/s discharge which is depicted in the given Table 7.6. It is also observed that the velocities at section 0-0` are received a quiet higher value which may due to sudden change in bed level for all three discharges. Model output also shown that the average stage ranging between 92.82 m and 105.73 m for considering the highest discharge of 200 m^3/s is observed based other input parameters collected using

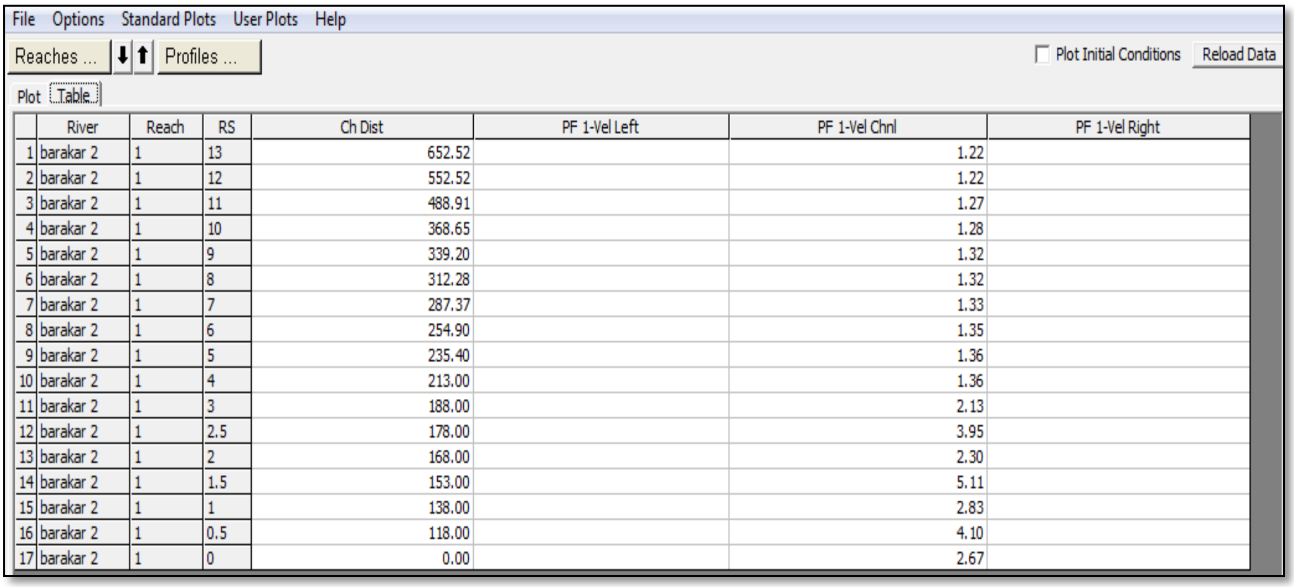
DEM Google elevation of Arc GIS software and the same calculations have been made for other two discharges 65 m^3/s and 130 m^3/s reflected in Table 7.5 and Table 7.6.

Table7.5 :velocity vs channel distance table for 130 m^3/s discharge



	River	Reach	RS	Ch Dist	PF 1-Vel Left	PF 1-Vel Chnl	PF 1-Vel Right
1	barakar 2	1	13	652.52		1.55	
2	barakar 2	1	12	552.52		1.54	
3	barakar 2	1	11	488.91		1.61	
4	barakar 2	1	10	368.65		1.62	
5	barakar 2	1	9	339.20		1.66	
6	barakar 2	1	8	312.28		1.66	
7	barakar 2	1	7	287.37		1.68	
8	barakar 2	1	6	254.90		1.69	
9	barakar 2	1	5	235.40		1.72	
10	barakar 2	1	4	213.00		1.72	
11	barakar 2	1	3	188.00		2.67	
12	barakar 2	1	2.5	178.00		4.32	
13	barakar 2	1	2	168.00		2.88	
14	barakar 2	1	1.5	153.00		5.47	
15	barakar 2	1	1	138.00		3.58	
16	barakar 2	1	0.5	118.00		4.25	
17	barakar 2	1	0	0.00		9.10	

Table7.6 :velocity vs channel distance table for 65 m^3/s discharge



	River	Reach	RS	Ch Dist	PF 1-Vel Left	PF 1-Vel Chnl	PF 1-Vel Right
1	barakar 2	1	13	652.52		1.22	
2	barakar 2	1	12	552.52		1.22	
3	barakar 2	1	11	488.91		1.27	
4	barakar 2	1	10	368.65		1.28	
5	barakar 2	1	9	339.20		1.32	
6	barakar 2	1	8	312.28		1.32	
7	barakar 2	1	7	287.37		1.33	
8	barakar 2	1	6	254.90		1.35	
9	barakar 2	1	5	235.40		1.36	
10	barakar 2	1	4	213.00		1.36	
11	barakar 2	1	3	188.00		2.13	
12	barakar 2	1	2.5	178.00		3.95	
13	barakar 2	1	2	168.00		2.30	
14	barakar 2	1	1.5	153.00		5.11	
15	barakar 2	1	1	138.00		2.83	
16	barakar 2	1	0.5	118.00		4.10	
17	barakar 2	1	0	0.00		2.67	

7.3 XYZ PERSPECTIVE PLOT

The XYZ Perspective plot output of the HECRAS software for discharge of 200 m^3/s , 130 m^3/s and 65 m^3/s is shown in tabular form in Fig 7.5 , Fig 7.6 and Fig 7.7.

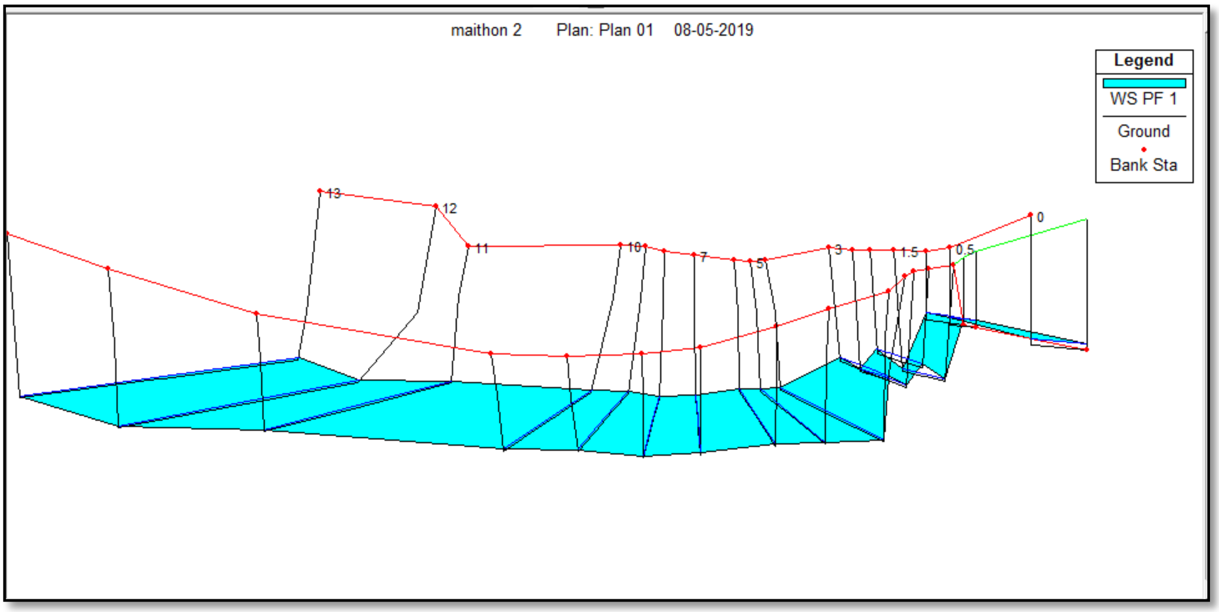


Fig7.5 : XYZ Perspective plot for 65 m^3/s

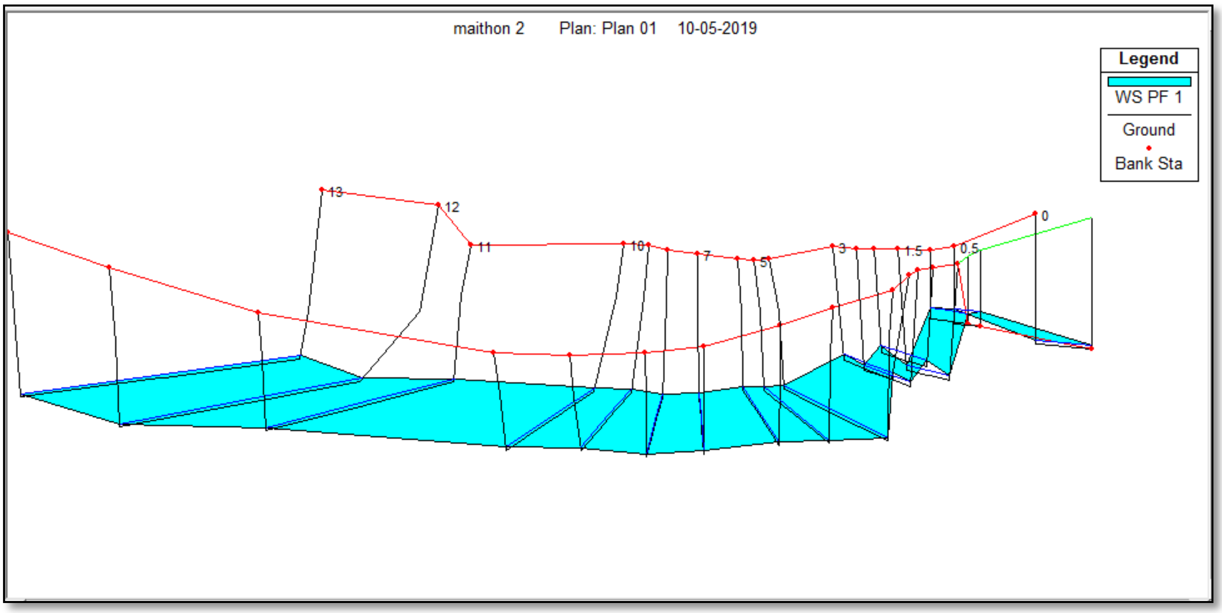


Fig 7.6 : XYZ Perspective plot for 130 m^3/s

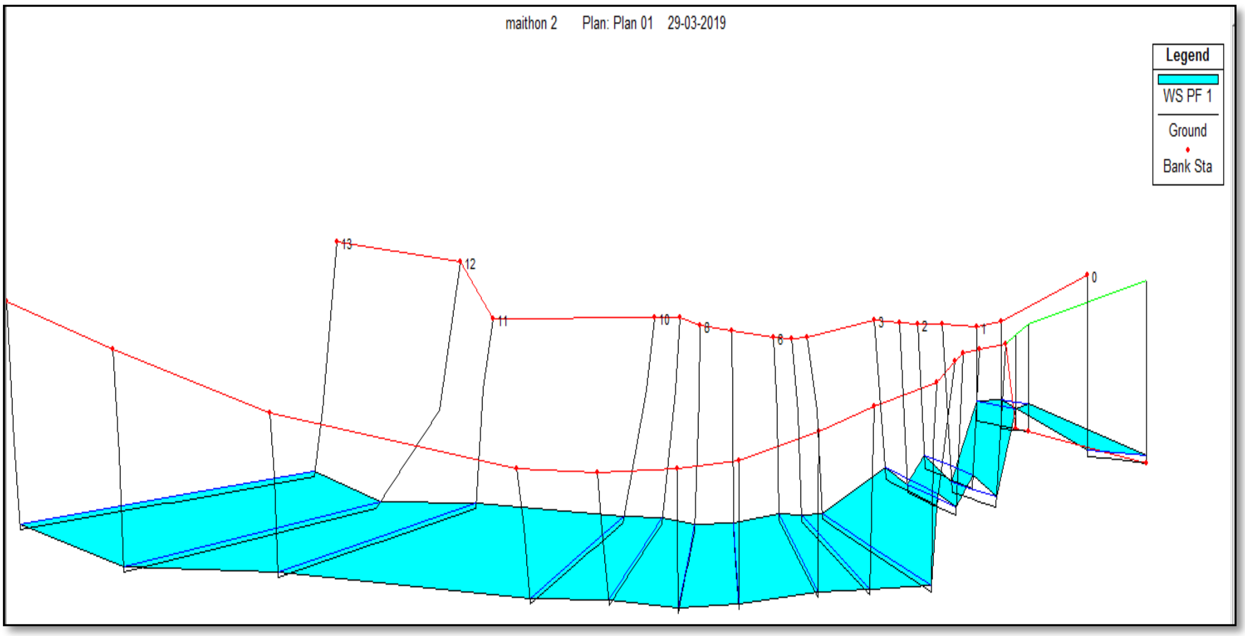


Fig7.7 : XYZ Perspective plot for 200 m^3/s

Table7.7 : Stage at all cross section for various discharge in Tabular form

DISCHARGE(m^3/s)	65	130	200
CROSS SECTION	STAGE (m)	STAGE (m)	STAGE (m)
13-13`	92.65	92.74	92.82
12-12`	93.15	93.24	93.32
11-11`	93.67	93.76	93.85
10-10`	94.17	94.27	94.36
9-9`	94.18	94.28	94.37
8-8`	94.18	94.28	94.37
7-7`	94.18	94.29	94.38
6-6`	94.69	94.79	94.89
5-5`	94.69	94.8	94.9
4-4`	94.69	94.8	94.9
3-3`	99.47	99.74	99.98
2.5-2.5`	98.28	98.51	98.73
2-2`	100.54	100.86	101.14
1.5-1.5`	98.32	98.59	98.86
1-1`	104.82	105.3	105.73
0.5-0.5`	103.86	104.73	105.34
0-0`	97.35	97.05	97.23

7.4 RATING CURVE

Rating curve is the plot between stage of the water level vs discharge of flow of the channel.

At cross section from section 13-13` to 0-0` for discharge varying as 65m^3/s , 130 m^3/s and 200 m^3/s ,the required rating curve for Table 7.7 which is obtained are shown in Fig 7.8,Fig 7.9,Fig 7.10 , Fig 7.11 and Fig 7.12.

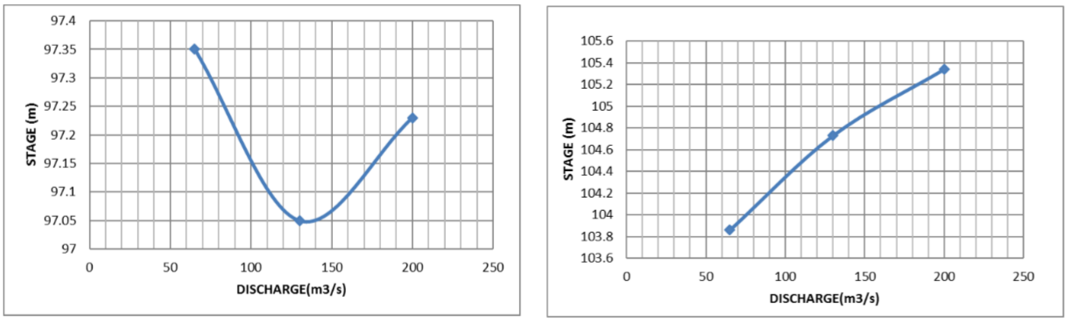


Figure 7.8(a) Rating Curve of Cross-section 0-0'

Figure 7.8(b) Rating Curve of Cross-section 0.5-0.5'

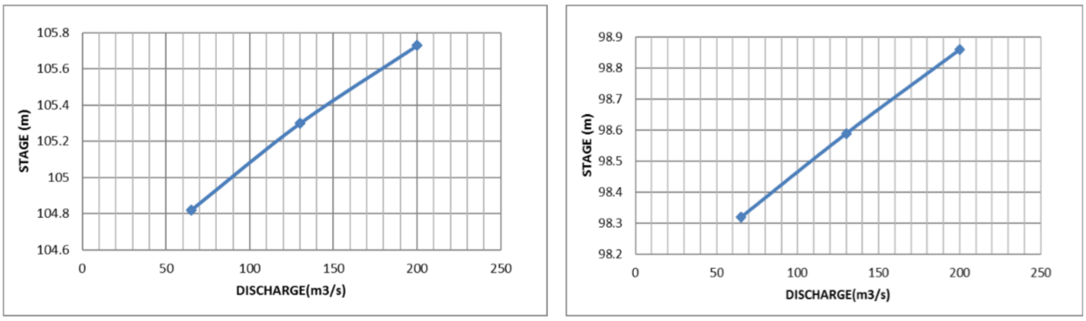


Figure 7.8(c) Rating Curve of Cross-section 1-1'

Figure 7.8(d) Rating Curve of Cross-section 1.5-1.5'

Fig 7.8 : Rating curve from cross section 0-0` to 1.5-1.5`

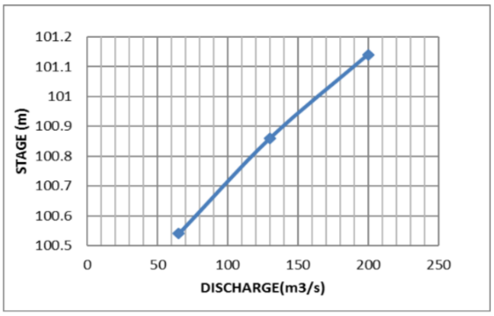


Figure 7.9(a) Rating Curve of Cross-section 2-2’

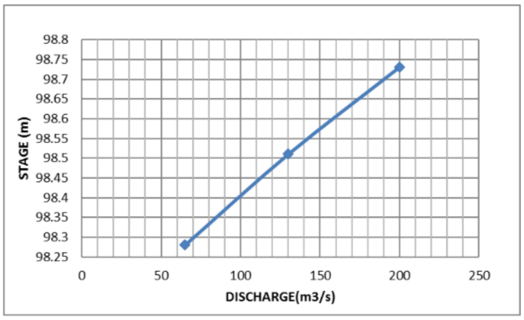


Figure 7.9(b) Rating Curve of Cross-section 2.5-2.5’

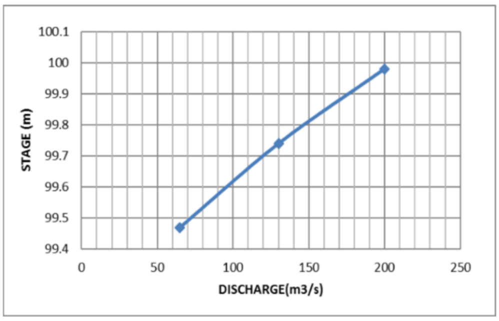


Figure 7.9(c) Rating Curve of Cross-section 3-3’

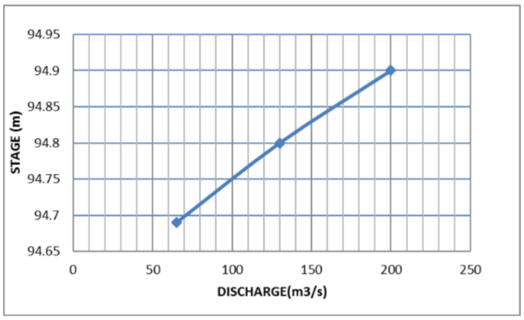


Figure 7.9(d) Rating Curve of Cross-section 4-4’

Fig 7.9 : Rating curve from cross section 2-2` to 4-4`

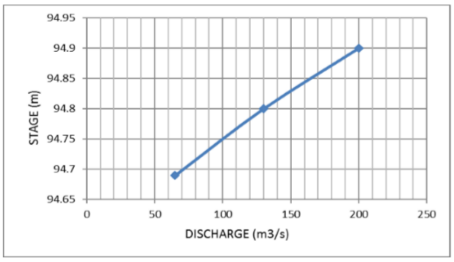


Fig 7.10(a) Rating Curve of Cross-section 5-5’

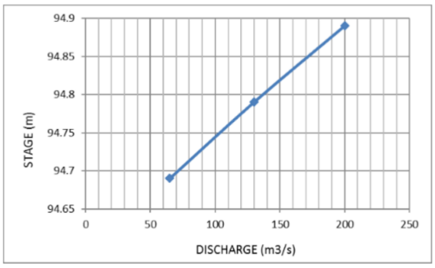


Figure 7.10(b) Rating Curve of Cross-section 6-6’

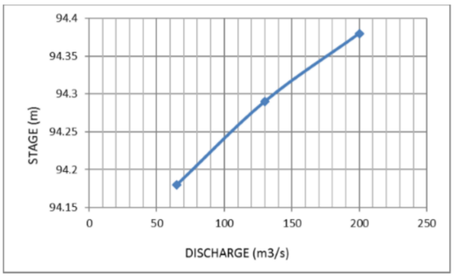


Figure 7.10(c) Rating Curve of Cross-section 7-7’

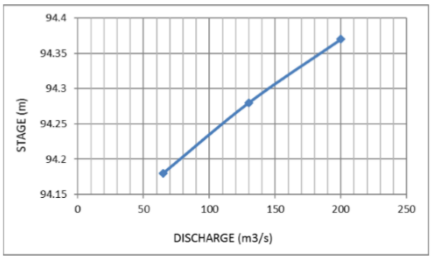


Figure 7.10(d) Rating Curve of Cross-section 8-8’

Fig 7.10 : Rating curve from cross section 5-5` to 8-8`

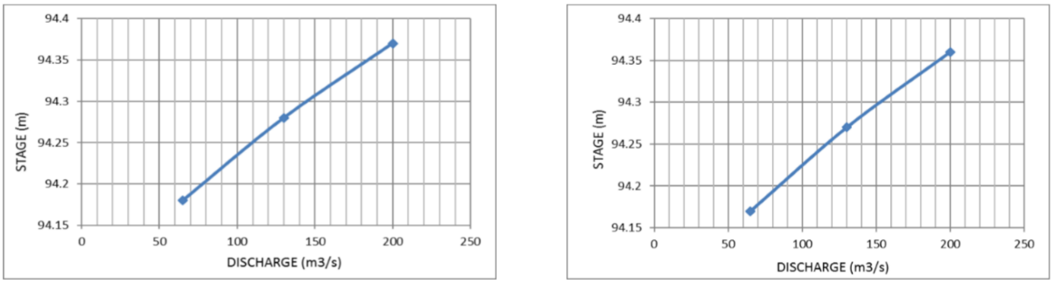


Figure 7.11(a) Rating Curve of Cross-section 9-9’

Figure 7.11(b) Rating Curve of Cross-section 10-10’

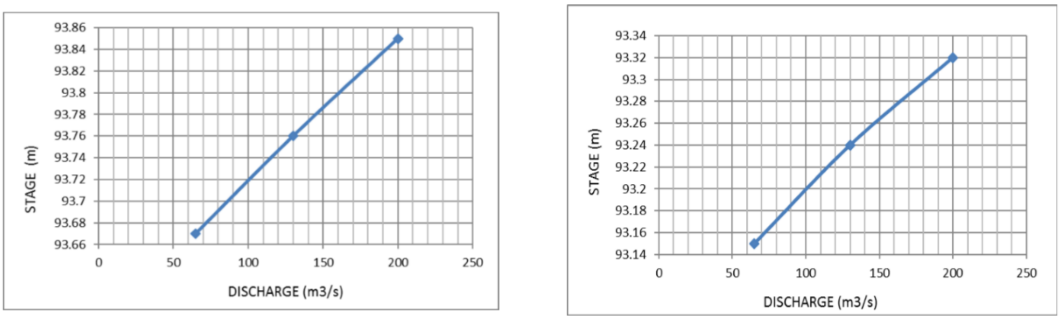


Figure 7.11(c) Rating Curve of Cross-section 11-11’

Figure 7.11(d) Rating Curve of Cross-section 12-12’

Fig 7.11 : Rating curve from cross section 9-9` to 12-12`

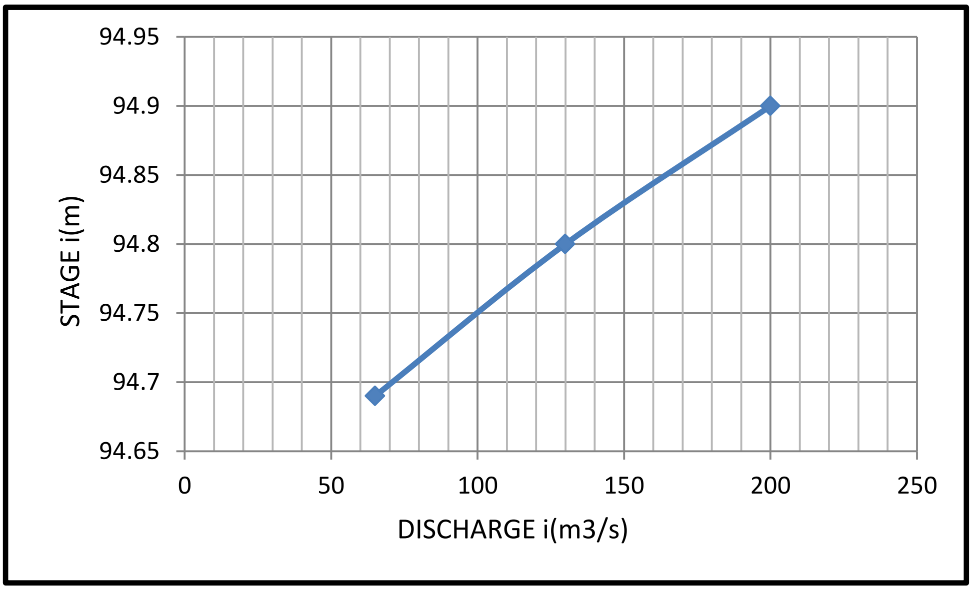


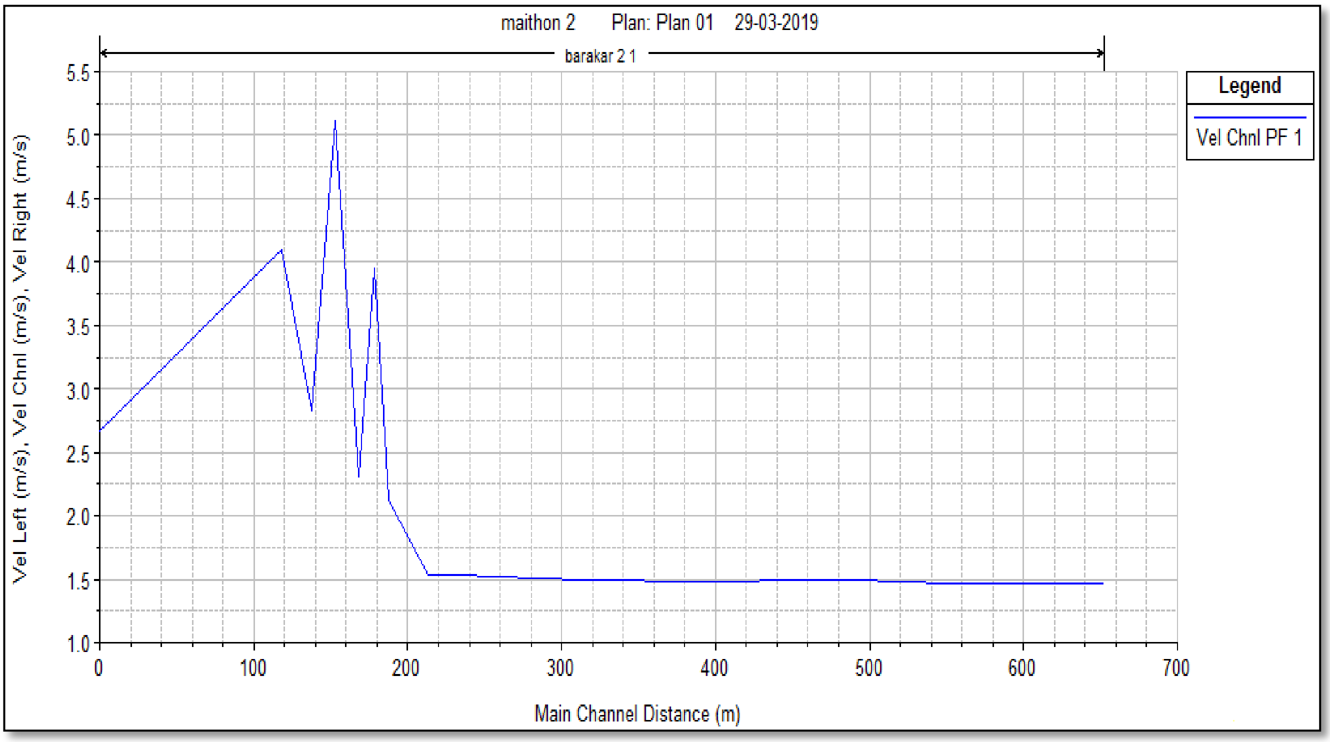
Fig 7.12 : Rating curve from cross section 13-13`

7.5 GENERAL PROFILE PLOT

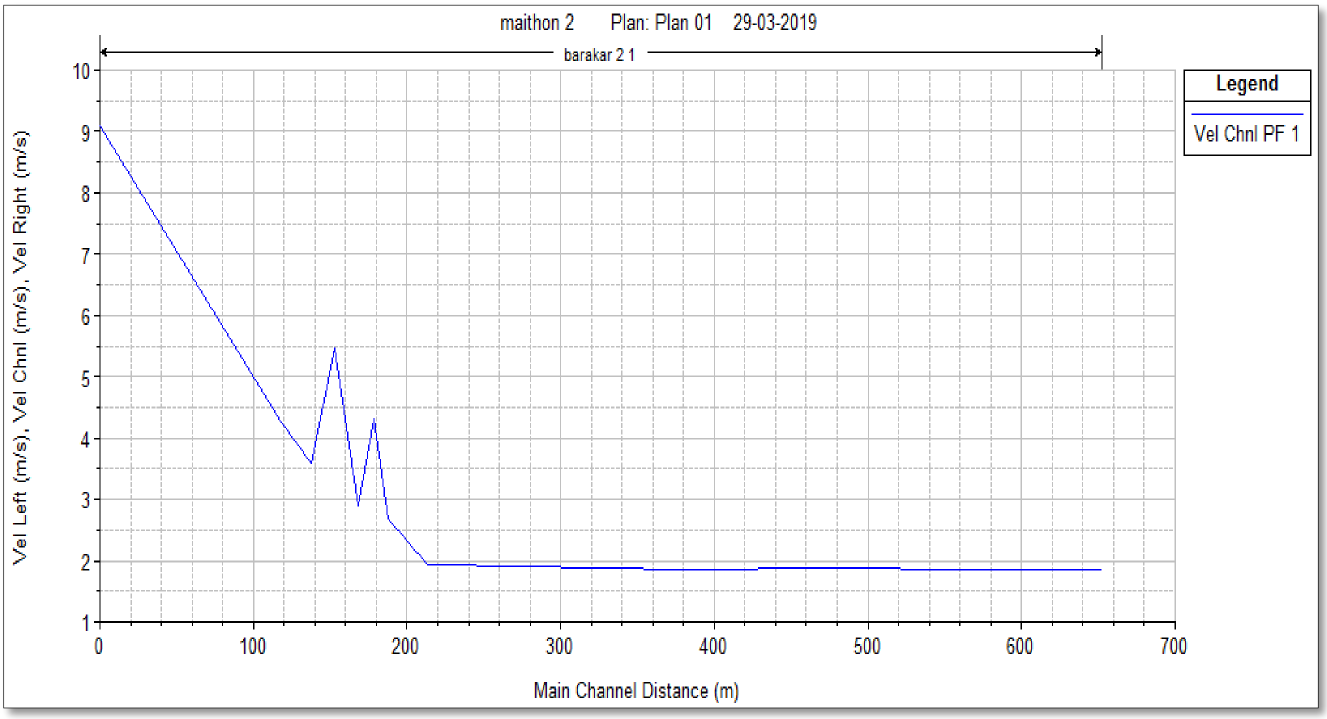
The velocity of the upstream sections for low discharge 65 m^3/s shows less velocity in the upstream of adverse slope. This may be due to this range of discharge is unable to produce high velocity which is required.

The velocity profiles curve of all the 17 cross sections for 65 m^3/s, 130 m^3/s and 200m^3/s are shown below. The average velocity of the river has been found to be range between 1.78 and 9.72 m/s for the discharge of 200 m^3/s.

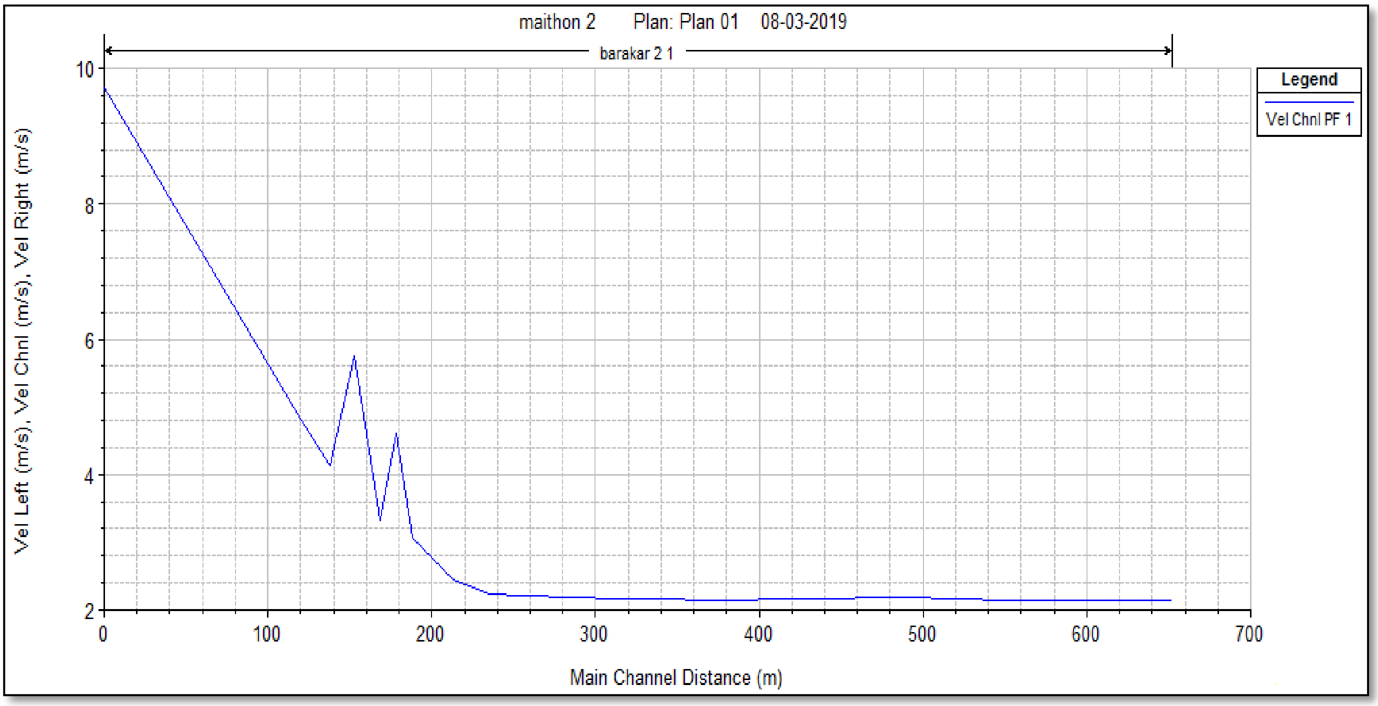
The velocity curve shows a sudden rise in velocity at immediate cross section of downstream of the two walls. This due to increase in velocity head due significant change in elevation difference .Also in the downstream end there is huge drop of velocity due increase in width at the downstream end .The velocity decrease to velocity of 1.78 m/s which is much less than the upstream velocity of 9.72 m/s .The huge velocity at the upstream of adverse slope is due to the huge velocity head required to carry the water up the adverse slope .The large velocity causes scouring .Hence necessary precaution has to be taken at the high velocity areas. Thus there is mild slope downstream from intermediate constant reduce level of 94m. This similar trend is observed for lesser discharge of 130 and 65 m^3/s. These similar trends can be observed from the following velocity vs main channel distance for discharge of 130 m^3/s and 65 m^3/s shown in Graph 7.2 and Fig 7.3.



Graph 7.1 : General Profile Plot for Discharge 65 m^3/s



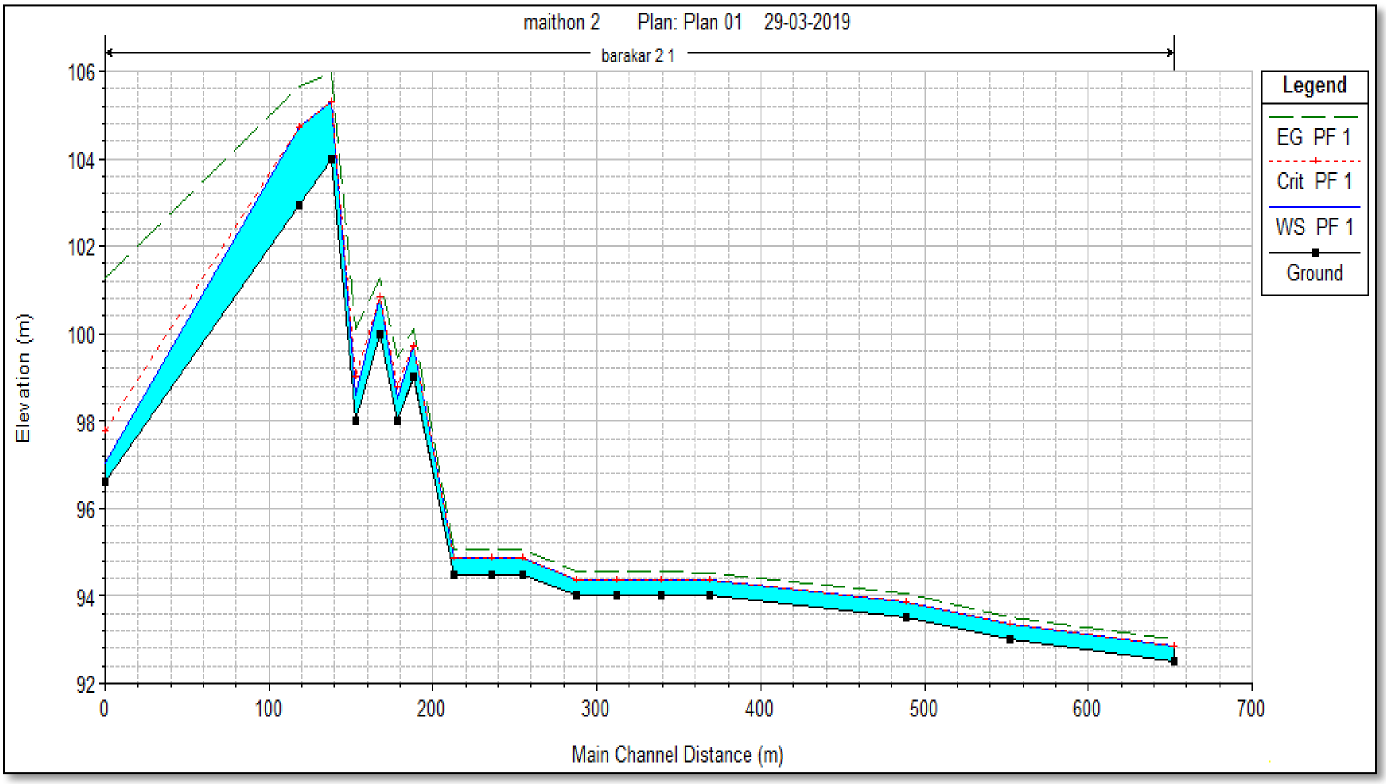
Graph 7.2 : General Profile Plot for Discharge 130 m^3/s



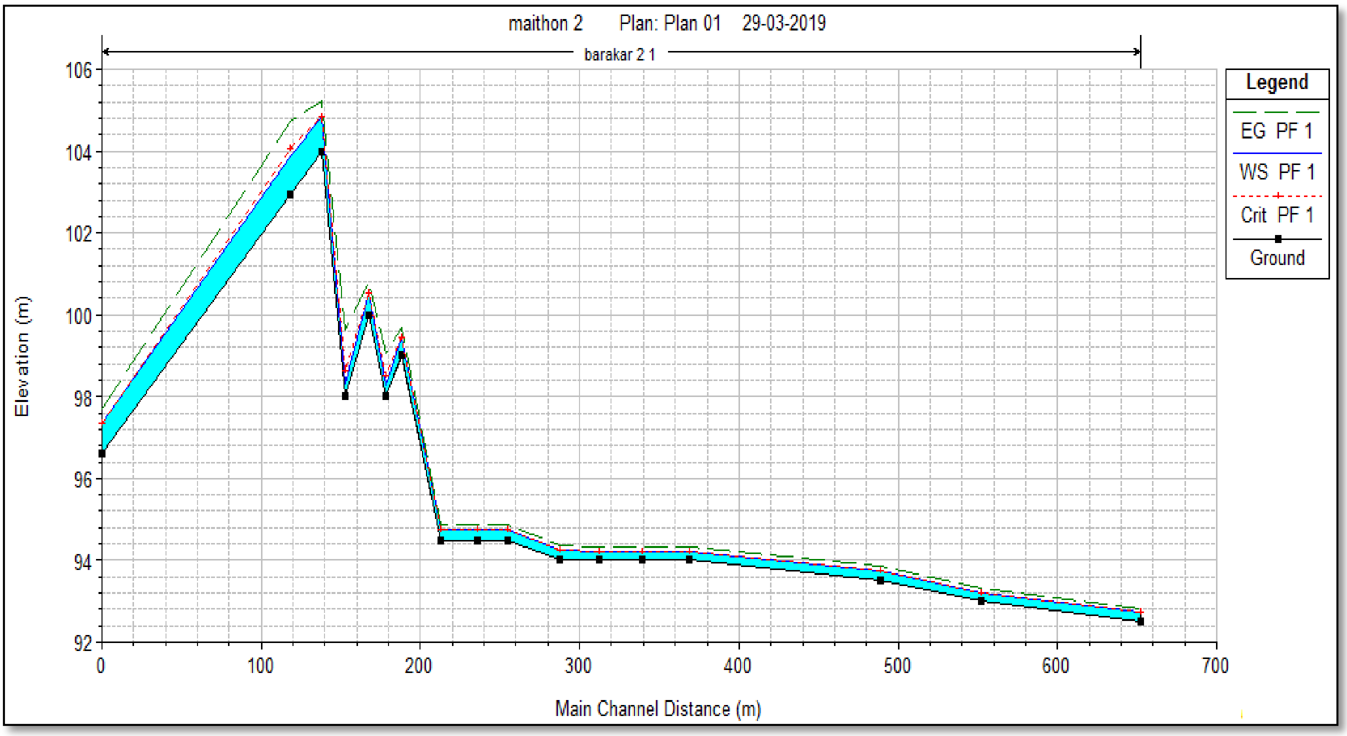
Graph 7.3 : General Profile Plot for Discharge 200 m^3/s

7.6 WATER SURFACE PROFILE

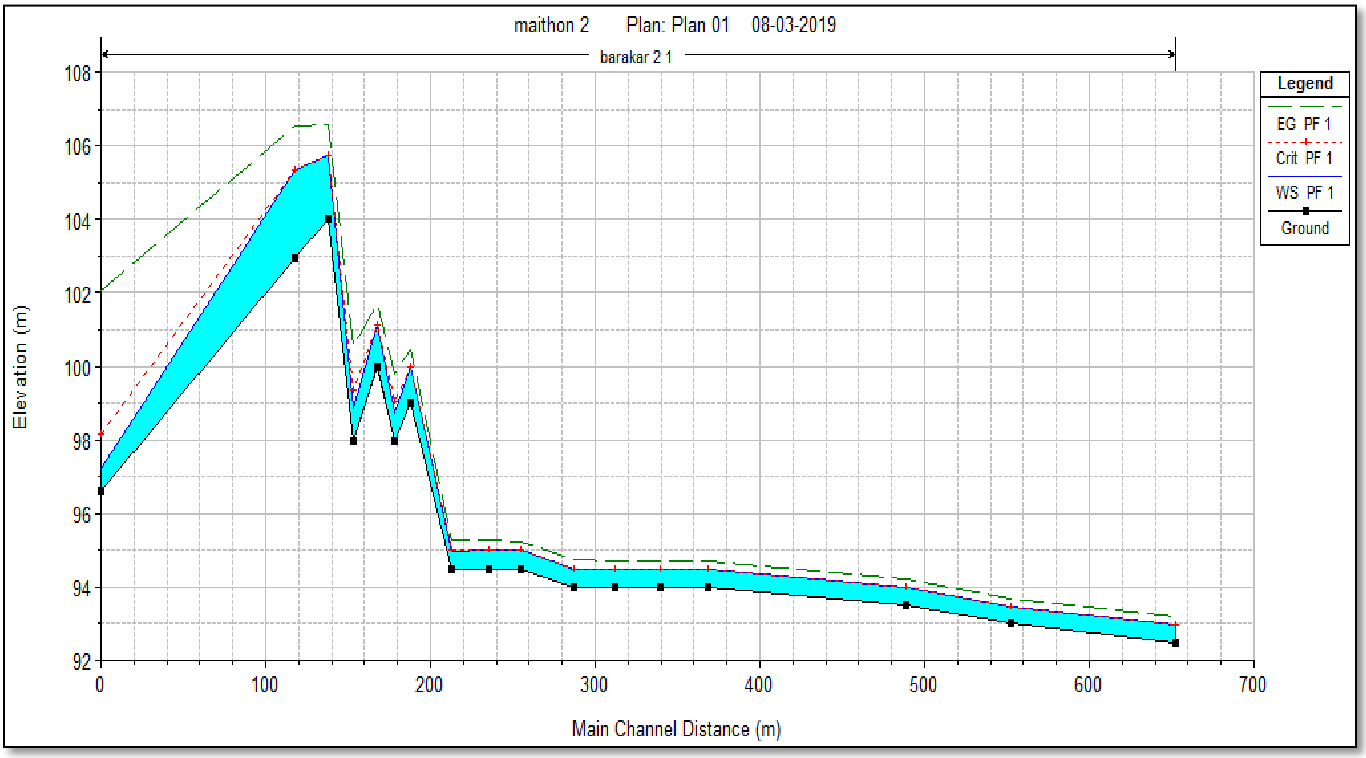
The output for water surface profile of the HECRAS software for discharge of 65 m^3/s , 130 m^3/s and 200 m^3/s is shown in graphic form in Graph 7.4 , Graph 7.5 and Graph 7.6. This helps us to obtain the water level at various chainage points or main channel distance from upstream to downstream.



Graph 7.4 : Water surface profile for 65 m^3/s discharge



Graph 7.5 : Water surface profile for 130 m^3/s discharge



Graph 7.6 : Water surface profile for 200 m^3/s discharge

8. CONCLUSION AND RECOMMENDATIONS

- The downstream cross section of the study area has water level well below the bank level by keeping the bed level at 94 m even at high discharge of 200 m^3/s. These results have been obtained with the help of HEC-RAS software.

- As the slope of river increases downstream, the velocity of water decreases. The width of bank of study reach has increased considerably in downstream region.

- The bed level from cross section 6-6` to 10-10`is taken as 94 m and from 4-4` to 6-6` marked in figures given in the report is taken as 94.5 m.

- The bed level from 0-0` to 3-3` is taken from DEM software.

- The results are obtained for three specific discharge of 200 m^3/s,130 m^3/s and 65 m^3/s.

- From the rating curve at various section the stage for various discharges can be obtained at every cross sections.

- From the cross sectional view the water level for maximum discharge of 200 m^3/s can be obtained.

- Hence the given stretch of river is safe and the cross section is adequate to carry the discharge of 200 m^3/s.

- The results shows that the average velocity ranging between 1.78 m/s and 9.72 m/s has been found at different locations. The maximum velocity of 9.72 m/s is observed at cross section 0-0` (downstream of hydel power tunnel) whereas the minimum velocity of 1.78 m/s is observed at section 12-12` and 13-13` which is little bit higher for 200 m^3/s discharge.

- There two walls for energy dissipation at two different R.L. 104 m and 100m where velocities are found to be 4.88 m/s and 5.75 m/s and depth of water surface elevation ranged between 0.32 m and 2.41 m is found in sections 0.5-0.5` and 1.5-1.5`.

- Since the average velocity of downstream section is found to be 1.75 m/s which is quite more than the normal river velocity so bed material with boulder pitching needs to be addressed in the downstream channel to avoid scouring and erosion at bed level.

9. REFERENCES

1. U.S. Army Corps of Engineers ,Hydrologic Engineering Center ,HECRAS User`s Manual v 5.0, February 2016.

2. Mehta D.J., Ramani & M Joshi M.(2014). *Application of 1-D HEC-RAS model in design of channels.* International Journal of Innovative Research in Advanced Engineering (IJIRAE).Volume 1 Issue 7, ISSN: 2349-2163.

3. Ahmad H.F.,Alam A.,Bhat M.S.& Ahmad S.(2016). *One Dimensional Steady Flow Analysis Using HECRAS– A case of River Jhelum, Jammu and Kashmir*. European Scientific Journal November 2016 edition .Vol.12, No.32, ISSN: 1857 – 7881 (Print).

4. Traore V.B., SoussouSambou S., HyacintheSambou H. &Diaw A.T.(2015) . *Steady flow simulation in Anambe river basin using HEC-RAS.* International Journal of Development Research. Vol. 5 Issue, 07, pp. 4968-4979, ISSN: 2230-9926.

5. Omran Z .A., NarimanYahya Othman N .A.& Saleh Z.A.(2018*).Steady flow analysis for Shatt Al- Hilla using HEC-RAS program.* International Journal of Civil Engineering and Technology (IJCIET) . Volume 9, Issue 6, pp. 525–533, ISSN Print: 0976-6308.

6. Shelley J. *Unsteady flow and sediment modelling in a large reservoir using HEC-RAS 5.0.*
U.S. Army Corps of Engineers, Kansas City District.

7. Kayyun T.S. &DagherD.H .(2018*). 2D-Unsteady Flow within a Reach in Tigris River International Journal of Scientific & Engineering Research.* Volume 9, Issue 5, 2246 ISSN 2229-5518 .

8. Hussien H.(2015).*Water quality modelling of Dubai creek using HEC-RAS*-A Thesis Presented to the Faculty of the American University of Sharjah College of Engineering in Partial Fulfillmentof the Requirements for the Degree of Master of Science in Civil Engineering Sharjah, United Arab Emirates.

9. Shamkhi M.S.&AttabZ.S.(2018).*Estimation of Manning's Roughness Coefficient for Tigris River by Using HEC-RAS model*. Wasit journal of Engineering Sciences. Volume 6, Issue 3.

10.Shayannejad M., Ostad-Ali-Askari K., Eslamian S., Singh VP & Dalezios N.R..(2018). *Analyzing of Flow in Open Channels Networks Using HEC-RAS.* Journal of Ecology & Natural Resources. ISSN: 2578-4994 .

11.Maharjan L.B. &Shakya N.M.(2016).*Comparative study of one dimensional and two dimensional steady surface flow analysis* .Journal of Advanced College of Engineering and Management, Vol. 2.

12. Kasper K.E., Christopher I. Thornton C.I, Abt C.I. , Robeson M D., & Watson C.C.(2005). *Accuracy of HEC-RAS to calculate flow depths and total energy loss with and without bendway weirs in a meander bend.*

13. Peck W.W. (2001). *Evaluation of Alternatives For Hydraulic Design of Bridges With HEC-RAS.* University of Tennessee, Knoxville.

14.Alzahrani, A.S.(2017*).Application of two-dimensional hydraulic modelling in Riverine systems using HEC-RAS* .The School of Engineering of the University of Dayton.

15. Sengupta S. &ChatterjeeA.(2000).*Changes In The Stream Courses Around Maithon Reservoir, Eastern India: Observations Using Remote Sensing Data*. Journal of the Indian Society of Remote Sensing, Vol. 28, No. 4.

16. SeredeI.J.,Mutua B.M. &Raude J.M.(2015).*Hydraulic Analysis of Irrigation Canals using HEC-RAS Model: A Case Study of Mwea Irrigation Scheme, Kenya.* International Journal of Engineering Research & Technology (IJERT)ISSN: 2278-0181Vol. 4 Issue 09.

17. Sathe N. J., Surve A. V,Hinge G. A. & Aswar D. S. (2018).*Study of end weir using HEC-RAS of Gunjwani dam spillway.* International Journal of Innovations in Engineering Research and Technology[IJIERT] ISSN: 2394-3696 VOLUME 5, ISSUE 6.

18. ShahiriParsaA., Noori M.& HeydariMandRashidi M.(2016*). Floodplain Zoning Simulation by Using HEC-RAS and CCHE2D Models in the Sungai Maka River*.Air, Soil and Water Research 2016:9 55–62 doi:10.4137/ASWR.S36089.

19. Tahmasbinejad H ., Feyzolahpour M ., Mumipour M . & Zakerhoseni F.(2012).*Rainfall runoff Simulation and Modelling of Kruna River Using HECRAS AND HECHMS Models Izeh District ,Iran* .Journal of Applied Sciences 12 (18) : 1900-1908,2012, ISSN 1812-5654.