FLOOD MAPPING OF PAGLADIA RIVER AT NALBARI, ASSAM

A dissertation submitted in
Partial Fulfilment of the Requirement for the Award of the Degree of

MASTERS OF TECHNOLOGY
In
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DECLARATION

I hereby declare that the work presented in the dissertation "FLOOD MAPPING OF PAGLADIA RIVER AT NALBARI, ASSAM" in partial fulfillment of the requirement for the award of the degree of "MASTER OF TECHNOLOGY" in Civil Engineering (with specialization in Water Resource Engineering), submitted in the Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati – 13 under Assam Science & Technology University,is a real record of my work carried out in the said college for under the supervision of Dr. Pulendra Dutta, Assistant Professor, Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati – 13.

Do hereby declare that this project report is solemnly done by me and is my effort and that no part of it has been plagiarized without citation.

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ABSTRACT

Assam is very prone to river bank erosion and flood because of various hydro-meteorological and topographical characteristics. Pagladia, the main river of Nalbari district results extensive flooding and bank erosion and also considered as a problematic river in the history of Assam. That's why it is important to study the flow pattern of this river. In this present work, a study has been done along the river Pagladia which focuses on the calculation of surface water elevations, velocity and flood inundation depths on downstream area of NH-27 in Nalbari for different number of discharges and also includes determination of flood inundation area for a discharge of 100-year return period. Hence, it will stimulate the critical situation of flood and its impact on Pagladia River basin on downstream side. Hydrologic Engineering Centres' River Analysis System (HEC-RAS) model of given study area was prepared.

The calibrated performance has been used to simulate the level of water in river at different cross-sections. The purpose is to give a hand to policy makers, planners and insurers, to develop a strong strategy for the development of flood mitigation measures and plans to minimize the losses associated with the disaster in the study area.

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CHAPTER-1

INTRODUCTION

1.1 PROLOGUE

River flooding has a reputation for being one of nature's most catastrophic wonders, especially in urban areas. One of the most catastrophic characteristic threats that can result in the loss of life, property, and money is flooding. As a result, it is crucial to conduct an efficient analysis and create an open surge risk architecture that gives priority to the effects of mitigation. Flooding is the process of submerging a region by a sudden surge in water brought on by snowmelt, intense precipitation concentrated in the top part of a basin and also within its lower part, or by the failure of a dam, putting people's lives and property in the affected area at risk. It might be a regular occurrence for a stream. Eighty percent of the precipitation falls between June and September, during the monsoon season. These, together with the rivers' low carrying capacity, are to blame for flooding, backed-up drainage systems, and erosion of riverbanks. It occurs when excessive or ongoing precipitation exceeds the ability of the soil to absorb water and the stream channel to transport it. This results in a stream overflowing its banks and flooding nearby land. Despite the fact that floods frequently occur in monsoon-affected areas, many places still require surge danger maps in order to prevent or lessen the damage. Therefore, it is essential to create and advance predictive models and observational tools, as well as to set up regulatory frameworks and contingency plans.

It has been a while since the globe has given much thought to stream surge chance assessment. However, it has been found that a variety of surge relief measures, the management of floodplains, and the use of science and knowledge can all reduce flood damages. There are two types of management strategies to lessen flood damage: non-structural strategies and structural strategies. Damming, trenching, diverting stream flooding, and other physical flood relief structure constructions are all applications of structural flood administration. The non-structural surge administration strategy involves lessening surge's negative effects without building any actual structures. The first and most important step in optimising the surrounding areas is to foresee flood risks in streams and establish their boundaries. The waterway zoning maps are unquestionably among the most important and crucial pieces of information needed when designing projects with attention, and they should be taken into account periodically for project operational improvement. It is important to provide the maps in the first place since the canal zoning maps enable valuable data, such as the depth and zone of flood protection in flood zones.

Only if technical tools like flood modelling are adopted can relief measures be capable of being developed. One of the designing tools that provides precise information about the flood profile is flood modelling. The factors that control the flood are precipitation, runoff, catchment characteristics, and return period. Floodplain studies provide water surface profiles and maps of the floodplain to help plan land use in flood-prone areas. Studies of floodplains often include the analysis of significant surges that are used to calibrate models and establish with certainty that the model can generate notable water surface heights seen during actual surge events. Hydrological modelling can be difficult, especially in areas with little information, and hydrologic models need to be well calibrated in order to be a disentangled depiction of the real situation.

In order to accurately predict the stream size and water levels along the reach, a good waterway flood demonstration requires a sufficient description of the waterway channel and floodplain geometry, as well as an exact portrayal of the show parameters. Computer models are essential to these investigations because they help in determining the water surface profiles related to various flow conditions. In order to identify floodplains, the computed water surface elevations are frequently manually drawn on paper maps. In both GIS and non-GIS environments, computer programme tools have been developed and improved to extract spatial details that are important for hydraulic models from geographic information sources. Through these models, we are able to learn about the effects of earlier human activity on the stream's structure and study the significant effects of changing arrive usage on the waterway's performance through time. This spatial and temporal information may be a crucial input for surge management and formative planning. These softwires, which provide a large range of options for modelling water-powered structures, have been successfully applied in regions similar to medium mountains and have been the topic of some general distributions and proposal work.

Due to unique hydro-meteorological and physical features of the basin in which it is located, the Nalbari area of Assam is particularly prone to river bank disintegration and flooding. Due to frequent and severe floods, as well as bank disintegration, Pagladia River, the primary river of the Nalbari region, has long been regarded as a challenging river in Assamese history. Therefore, it is crucial to comprehend the appropriate techniques that the residents would have employed to reduce and defend against river bank erosion and flooding, as well as to recommend some relevant solutions.

ArcMap is a programme that is widely used in conjunction with HEC-RAS. In this study, the waterway release, channel, floodplain shape, and channel resistance are crucial inputs to HEC-RAS. A stream flow could be depicted using a different arrangement of the HEC-RAS hydraulic model. Using GIS techniques, it is simple to create flood visualisations that could be helpful for surge relief and organising the basin for conducting various types of studies, such as developing flood forecasts and flood immersion models, examining various surge control options, attending to the social impacts of small dam evacuations, and developing a framework for surge advance indication. This study uses these tools to emphasise the study area's vulnerability to flooding as a result of urbanisation and unusual precipitation events and evaluates the viability of employing wetlands as a mitigation option. In this study, HEC-RAS are used to show how to properly examine and entertain hydraulic streams in the water system layout of the Waterway system. This is often the main justification for using it in this investigation.

1.2 OBJECTIVES OF THE STUDY

Since the degree of the immersion is dependent on the terrain and changes over time, it is unclear how to estimate flood extents. When there is a bank of full stream depth during a flood event, water is no longer contained solely inside the main stream channel and spills onto nearby flood plains. These factors make preparing a flood forecast highly difficult and time-consuming. For the purpose of assessing the potential flood dangers brought on by floods, numerical modelling of the Nalbari-Brahmaputra Reach of the Pagladia River in the Nalbari district has been undertaken in this work. The stakeholders in the management of water resources would benefit from the study's findings.

The numerical analysis programme HEC-RAS (Hydrologic Engineering Centre- River Analysis System) provides the finer details of flood profiles. The computer programme is very easy to use and has accurate calibration. A GIS and HEC-RAS strategy for river modelling facilities is presented in this work. The method establishes a connection between the HEC-RAS hydraulic simulation and ArcView GIS, enabling improved showcase and evaluation of the research area's floodplain data. The goal of the study is to use ArcMap, HEC-HMS and HEC-RAS to create a floodplain map for the Nalbari town area of the Nalbari district utilising rainfall data and discharge data obtained from the Nalbari Sub-division of Lower Assam Investigation Division, Water Resource Department, Assam.

CHAPTER 2

LITERATURE REVIEW

The exploration of the literature on the subject has been done and several publications have been reviewed. These literature reviews show how well-known this subject and its scholarly background are. The primary goal of this project is floodplain modelling using hydraulic models. To defend the riverbank against flooding, many researchers employed a variety of strategies and methodologies. This chapter provides an overview of earlier studies that addressed floodplain modelling using hydrodynamic models.

Xixi Wang et al. (2010) used a 1-D hydrodynamic model to predict the design discharge for an ungauged overflow-receiving watershed. The goal of this study is to calculate the maximum overflow rate from the Red River of the North (RRN) into the Hartsville Coulee during the record flooding that occurred in 1997. This model, known as HEC-RAS, provides the maximum overflow rate, which can be used in conjunction with estimates from the USGS and the USACE that were based on field reconnaissance and Manning's equation.

This study appears that the HEC-RAS dynamic show can be utilized to plan to assess the release of flood receiving watersheds that channels out from the streams. There's a extend inside which the values can be utilized to plan discharge for that specific channel.

Prafulkumar V. Timbadiya et al. (2011) has done a study on Calibration of HEC-RAS Model on Prediction of Flood for Lower Tapi River, India. Through simulation of surges using HEC-RAS for the years 1998 and 2003, together with images of canal reaches taken during the field visit of the lower Tapi Stream, it has been demonstrated the necessity of various channel roughness coefficient Manning's 'n' values along the waterway. The surge for the year 2006 in the river has been replicated using the calibrated model in terms of channel roughness. By recording the flood peaks of observed and simulated surges and computing the root mean square error (RMSE) for the intermediate gauging stations on the lower Tapi Stream, it has been possible to access the execution of the calibrated HEC-RAS-based model.

A value of n = 0.035 up to Kakrapar weir and n = 0.025 downstream of Kakrapar weir might be suitable for recreation of future flood in the lower Tapi Stream, according to simulation of the previously described surge for various values of Manning's unpleasantness coefficient along the river reach. In order to advance the results, a two-dimensional hydrodynamic model of the lower Tapi River, including its flood plain region, is necessary.

Sudha Yerramilli (2012) has done a Hybrid Approach of Integrating HEC-RAS and GIS towards the Identification and Assessment of Flood Risk Vulnerability in the City of Jackson, MS. To reveal the vulnerability of the current foundation of the area whose formative codes are tied to a 100-year magnitude flood event, a 200-year size flood occasion that the research area experienced in 1979 was replicated. The outcomes demonstrated the effectiveness of the developed half-breed approach in illustrating the surge condition, visualising the geographical degree, and assessing the location's helplessness. The City of Jackson is exposed to an increased risk due to its key transportation corridors (I-55, Highway 80) and other essential infrastructure being affected by surge waters, according to the defencelessness appraisal from the 1979 surge event simulated by the HEC-RAS model.

Arc GIS and the HEC-RAS 1-D flood simulation model work together to show how well they can simulate flood events and spatially represent how vulnerable a location is to a risk occurrence in terms of the depth and size of the inundation. The HEC-RAS rebuilt water level depth at Pearl Stream at Jackson coordinated with the only immersion depth data at that time with just 4.75% of under estimation. The majority of I-55 and Highway 80, two of the state's main thoroughfares, are expected to be under water, causing the paralysis of the capital city of Mississippi.

Darshan J. Mehta et al. (2014) made a study on the use of the 1D HEC-RAS model in the design of canals in Surat city. Surat city and the surrounding districts are particularly impacted by river Tapi surges. Since a long time back, the city has seen countless floods. The years 1883, 1884, 1942, 1944, 1945, 1949, 1959, 1968, 1994, 1998, 2002, 2006, 2007, and 2012 all had significant floods. In this investigation, the necessity for surge entryways on the storm channels is moreover assessed relying on the HEC-RAS water surface elevation computation for distinct surge releases. Existing storm routes are not stamped as it were. The recommendations are done based on this study are either to extend height of bank or develop a holding wall at certain areas along the study reach.

The study area is heavily impacted by the surge, so it is important to develop a surge reducing plan for the study area that will help to prevent a major calamity in the near future. It is strongly advised to increase the carrying capacity of the Tapi stream in order to reduce the surge in the Surat city's surrounding area in light of previous surge events. According to the analysis of the surge event of 2006, the West and South West zones are most likely to flood, whilst the East zone is least likely. In a dangerous flood occurrence in 2006, Surat city was submerged to a degree of 90–95 percent.

Azaz khan I.Pathan et al. (2015) conducted a study on River Flood Modeling Using GIS, HEC-GeoRAS, and HECRAS for the Purna River, Navsari District, Gujrat, India. In this study, the GIS data was first imported and then exported to the HEC-RAS, which prepared the output of the HEC-RAS and carried out the steady stream inquiry and hydraulic design evaluation. Additionally, HEC-RAS will provide the height of the water's surface elevation after receiving the slope and top release of a given cross region. By providing Bank, Surge divider, and other tools, we are able to predict the surge from this work.

The study demonstrates the value of combining ArcGIS and HECRAS to assess flooding at various cross segments and predict the probability of flooding at particular cross segments that will provide the water surface elevation after applying top discharge so that future opportunities lie in forming bank close rivers and preparing floodplain mapping of streams as well as creating surge hazard outline for Navsari area under changing scenarios.

Somaiyeh Khaleghi et al. (2015) has done a study on the integrated use of HEC-RAS, GIS, and RS for flood risk assessment in the Lighvan Chai River. GIS and the HEC-RAS model were used to determine the surge inclined area with different return times throughout the 16 km length of the Lighvan Chai Stream, and satellite images were used to extract land use changes over the last 10 years (2000–2010).

The outcomes of Lighvan Chai surge zoning appear that the proportion of overflowed zone by 25-year to the flooded area by 200-year return period is proportionate to 67%. This issue shows that roughly 67% of the total area of flooding is caused by 25-year or less. According to the study of the Lighvan basin, the percentages of thick pasture, desert land, and irrigated farming have decreased by 44%, 54.3%, and 0.5%, respectively. In any case, the private region, the fragile field, and the rained cultivating have all increased by, respectively, 88.9%, 45.5%, and 38.6%. Thus, flooding causes damage to productive rural areas and private range in the studied region.

Vieux Boukhaly Traore et al. (2015) has done a steady flow simulation in Anambe river basin using HEC-RAS. The river reach that was selected is situated between the Kounkane threshold and the confluence dam. We divided the canal reach into 24 cross sections that are perpendicular to the stream course and are numbered from 1 to 24 using a LANDSTAT image of this area. Bathymetry is extracted using the ArcGIS computer application for each cross segment. Hec-ras calculates the flow characteristics for each stream flow. The high and low stream characteristics zones have been located.

The majority of these stream parameters decrease from upstream to downstream, according to the analysis of the results. However, it is crucial to understand the limitations of the 1D HEC-RAS models. This method assumes that the flow is channelled even though the typical flow is three-dimensional. Additional research employing a 3D methodology is necessary to more fully understand the stream in this waterway basin.

Ahmad Shahiri Parsa et al. (2016) as done a study on Floodplain Zoning Simulation by Using HEC-RAS and CCHE2D Models in the Sungai Maka River. The purpose of this study is to focus on the investigation of HEC-RAS and CCHE2D in order to assess and anticipate the surge profundity and spatial degree of flood in the Sungai Maka floodplain. This will help the decision-makers, particularly the involved government's division, and developers make an appropriate arrangement for future advancement.

CCHE is a 2D model, while HEC-RAS is one of the 1D dynamic models. According to the results, the meander's portion of the stream exhibits a 6% contrast between the 1D and 2D models.

Hakim Farooq Ahmad et al. (2016) has done a study the application of HEC RAS Model using 1D steady flow analysis for flood studies in the river Jhelum in Kashmir valley. The HEC-RAS model used peak flood records to determine the resulting anticipated flood levels.

The first focus of the investigation was on assessing the suitability of the HEC-RAS model for simulating the water surface profiles of the Jhelum River, which is the waterway most responsible for flooding the whole Kashmir valley. The results obtained from the use of one-dimensional steady flow analysis using the HEC RAS model sows that the area under study was found to get inundated to a greater extent for 100- year & 50-year floods and the left bank of the river is more vulnerable to get inundated than the right bank.

Thaileng Thol et al. (2016) has done a flood study of a river reach in Cambodia using HEC-RAS. The Lower Mekong Stream in Cambodia, which is 50 km long, was chosen to represent the surge pattern from 2000 to 2013. An outline of a ten-year return period flood was too set up. The investigation is based primarily on the observed information of water level of 8 years, 18 river cross-sections and digital elevation model (30 m x 30 m). DEM is in a low resolution hence it cannot detail each height changing; fewer cross sections cannot make accurate stream bathymetries such as expansion and compression.

The yields for the flood research from 2000 to 2013 and the 10-year return period flood included the stream as well as flood depth and degree. The total affected areas on both sides of this 50 km-long stream, excluding the river area, which is approximately 4600 ha, were increased from 1,400 to 7,400 ha and consisted of various arrive uses, including residential, rice field, and mechanical zone, while the surge profundity ranged from zero to almost 10 m on both sides of the stream.

Awu John et al. (2017) has done a case study of Oyun River, Nigeria where flood inundation simulations were done using HEC-RAS. The study location is around 20 kilometres from Kwara State's capital, Ilorin. In this study, an advance enquiry about the plan was received. A Digital Elevation (DEM) of the Oyun Stream Basin was used to create RAS Layers, stream layers centerlines, stream way centerlines, major channel banks, and cross-section cut-lines in Hec-GeoRAS. Using the RAS Layers, the HEC-RAS demonstration revealed the hydraulic parameters of an open channel stream moving downstream and mapped the flood immersion zone.

The water surface profile that was created using the findings from the Hec-Ras investigation revealed that the surge inundation area covered a range of 11.217 m2 inside the Oyun Waterway reach, while the depth of the immersion area varied from 0.6 m to 2.8 m, separately. It was also agreed that the results of this study will provide governments and other organisations with extensive data for better planning and decision-making regarding surge control and mitigation.

Usman Khalil et al. (2017) has done a floodplain mapping for Chashma –Taunsa Reach, Indus River. Using HEC-RAS, ArcGIS, and its extension HecGeoRas as tools, surge hydraulic demonstrating and floodplain mapping have been carried out in this work to have a baseline assessment of flood vulnerability and to offer foresight for emergency ready arrangements.

Unsteady flow from Chashma-Taunsa reach of Indus Waterway has been well calibrated and validated, which appear a great base for the generation of surge immersion maps for the study reach. Simulated flood inundation depths, Flood area simulated maximum depth for 25 year and 500-year flood for 2010 flood were also found out. Based on recurrence analysis, it is determined that the 2010 flood in Chashma and Taunsa had a 180-year and 300-year return period, respectively.

Sania Modak et al. (2017) have reviewed a Flood Control and Prediction of Flood Using HECRAS. Due to flooding during the rainy season, Surat city is severely affected. The main problem in Surat is flood. Flooding happens in Tapti Stream during a rainstorm, affecting many ranges. Surge is responsible for property and live misfortunes. The development computing approach known as HEC-RAS provides surge notifications for managing water streams and computing the water surface profile. Various 1D hydrodynamics models are employed to determine the surge occasion. Cross-sections were omitted from the lower Tapti River's Auto-Cad record.

Daily discharge data for the Tapi bowl from 1995 to 2005 is provided by the Central Water Commission, and flood data is provided by Flood Cell Surat. To help with the analysis of steady and unsteady streams, the following data was gathered: Index Plans, Toposheets, and AutoCAD maps of the respective reaches. The State Water Data Center in Gandhinagar provided the Discharge VS Water Surface Levels (Elevation) data.

Prabeer Kumar Parhi (2018) has done a Flood Management in Mahanadi Basin using HEC-RAS. In this study, the return period is calculated using the peak flood levels at several sites along the Mahanadi River reach between the Hirakud dam and Naraj, the river's delta head. The analysis was done using surges from the past 25 years because it is considered that these surges are the most critical and fall under changing climatic conditions.

This study came to the conclusion that the left and right banks of the river's existing embankments system are insufficient to protect the low-lying portions of the Mahanadi delta from flooding and to withstand floods of 25 years return period. As an alternative to moderate floods channel, clearance may be taken up to decrease the ruin of surges in the deltaic locales of Mahanadi Stream.

Sivasankkar Selvanathan et al. (2019) has done a GIS mapping algorithms for floodway modelling. Infringement investigation techniques are the foundation of floodway modelling with HECRAS. The Stream Morphing, Normal Remove, and Buffer Floodway calculations were assessed for their capabilities and insufficiencies with respects to floodway mapping. It was discovered that the Buffer Floodway approach, which is based on the TIN crossing point, produces a smooth floodway boundary and significantly decreases manual smoothing and alteration by a modeller.

The specified buffer floodway algorithm's success depends on the information being properly pre-processed. The preferred buffer floodway computation has some drawbacks. In any case, it should be highlighted that the final output from the calculation provides a really nice floodway border for the modellers to manually fine-tune (after post-processing). The building blocks used to determine the floodway border are shaped by the TINs. ArcGIS's spatial and cartographic capabilities are effectively used by the buffer floodway computation to produce smoothed floodway boundaries between modelled cross-sections.

Selman Ogras et al. (2020) as done a case Study on Tigris River. The flood analysis using HEC-RAS is done. Between the historical Ten-Eyed Bridge and the Diyarbakr-Silvan Highway, the floodplain was examined. Using the AutoCAD Civil 3D programme, the 1/1000 maps of the study zone were digitalized, and cross sections were created using the location's digital elevation models. The HEC-RAS software was used to characterise the obtained cross segments, and it was decided to conduct a one-dimensional floodplain investigation of the Tigris Waterway and determine the hydraulic properties of the surge bed and the water surface profiles of the discharge of (25, 50, 100, and 500) cumecs flood recurring.

This section of the route narrows as a result of the Sadi Bridge's inadequate span at the beginning of our study. The situation will become clearer when taking into account the University Bridge clearance (almost 400 m) on the same course. Since it is not possible to intervene within the historic Ten-Eyed Bridge due to its inadequate capacity, it is possible to construct a tunnel connected to the Tigris Stream on the edges of Mount Krklar and extracting flooding waters to prevent potential damages.

Pallavi H et al. (2021) as done a study on Analysis of Steady Flow using HEC-RAS and GIS Techniques. An endeavor has been made to analyze the flood inundation boundary of the downstream of T.Narsipura, discharge gaging station for an extent of 37.78 km which is located within the upper Cauvery basin, Karnataka with an integrated approach of ARC-GIS and HEC-RAS. The data products such as SRTM DEM information and the discharge information are of Central Water Commission (CWC), Bengaluru for 21years (1998-2018). Steady flow investigation is carried out utilizing HEC-RAS to distinguish the change in flooding design.

Due to excessive flow from the Kabini and KRS reservoirs in 2018, there was an unprecedented flood situation that blocked off over 30 villages at T. Narsipura and the lower lying of the Kabini stream. Additionally, the research area is located in a zone that is surge inclined. The study made it abundantly evident that the HEC-RAS model and remotely sensed data (DEM) are essential for geospatial analysis of the hydrologic cycle, including inundation mapping, watershed mapping, and depicting flood plains.

CHAPTER 3

STUDY AREA AND MATERIALS

3.1 STUDY AREA

The study region is located along the mighty Brahmaputra River's north bank. River Pagladia is one of the major tributaries in the northern bank of the mighty Brahmaputra River system. The Pagladia, as its name implies, has been a chronic source of trouble due to its frequent changing of flow course. It originates from foothill of Bhutan and passes through Baksa and Nalbari district in the state of Assam in Indian Territory and ultimately joins with the river Brahmaputra in the village Lawpara in Nalbari district of Assam. This river consists of a number of important tributaries like Mutunga, Dimla, Nona and Chulkhona. This entire river system drains an area of 1, 674 Sq. km and this area lies between longitudes 91° 20 ′ E and 91°42′ and latitudes 26°14′ N and 26°59′ N. Out of the total catchments of 1,674 square km, the catchments area within Indian Territory is 1,251 square km and the remaining 423 sq. km lies in Bhutan. The hilly catchment area of the sub-basin is 465 sq km; out of which an area of 423 square km is in Bhutan and the rest 42 square km in Indian Territory.

The discharge data is collected from the Nalbari Sub-division of Lower Assam Investigation Division, Water Resource Department, Assam.

3.2 ABOUT PAGLADIA RIVER

The Pagladia River is a northern bank tributary of the Brahmaputra River in the Indian state of Assam. The Pagladia River originates in the Bhutan hills and flows through Baksa District and Nalbari district before its confluence with the Brahmaputra River. After traversing through the Bhutan territory, it enters the Nalbari district of Assam near Chowki. The river flows in a north southerly direction up to Bijalighat and then it flows in a south westerly direction up to its confluence near Lowpara village. The total length of the river is 196.80 km. Out of which it flows for a length of 19 km in the hill of the Bhutan territory and the rest 177.8 km through the Nalbari and Baksa district of Assam. The Mutanga River is one of the left bank tributaries of Pagladia River. It originates from the Bhutan hills and covers a length of about 30 km. It joins the river Pagladia on left bank at 28.5 km below Chowki and 0.75 km upstream to Thalkuchi village. Another tributary named Darranga originating from the Bhutan hills joins Mutanga on its right bank near Barkajuli, approximately 6 km upstream of the confluence of Mutunga with Pagladia.

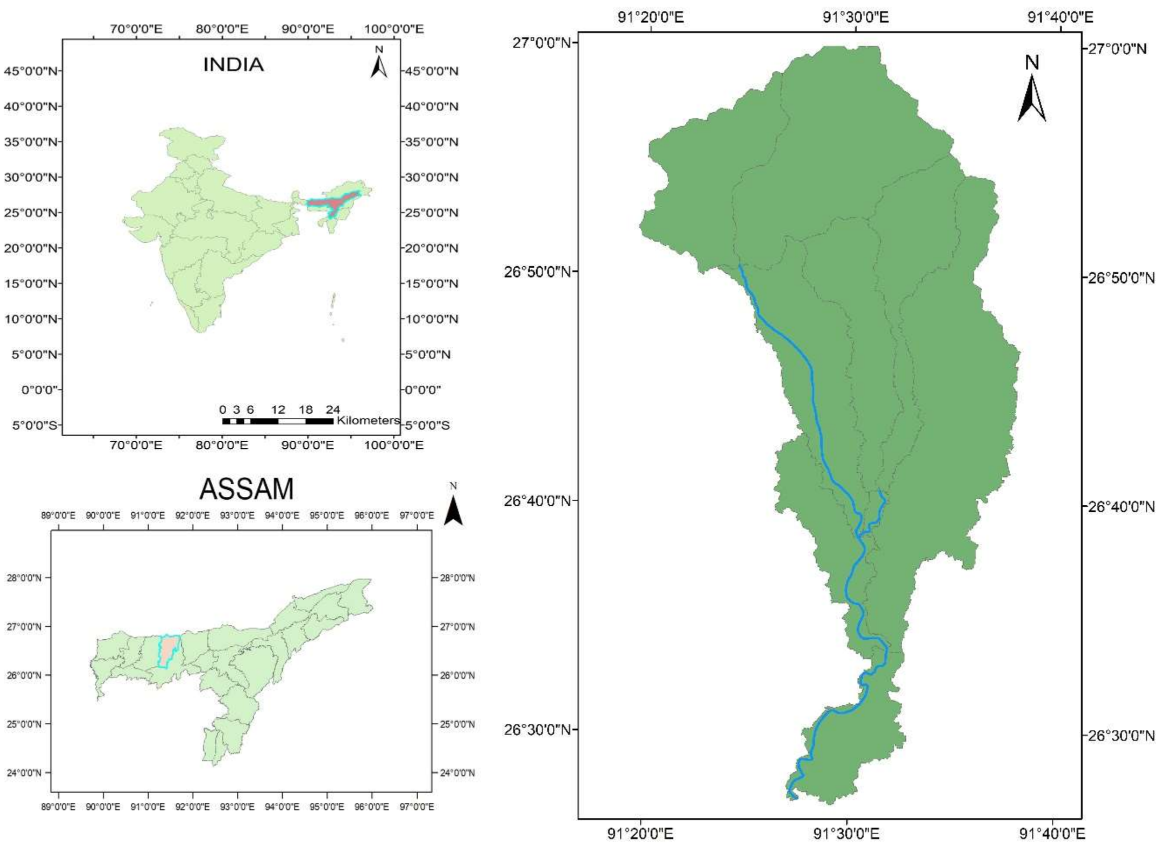


Fig 3.1: Pagladia river basin map

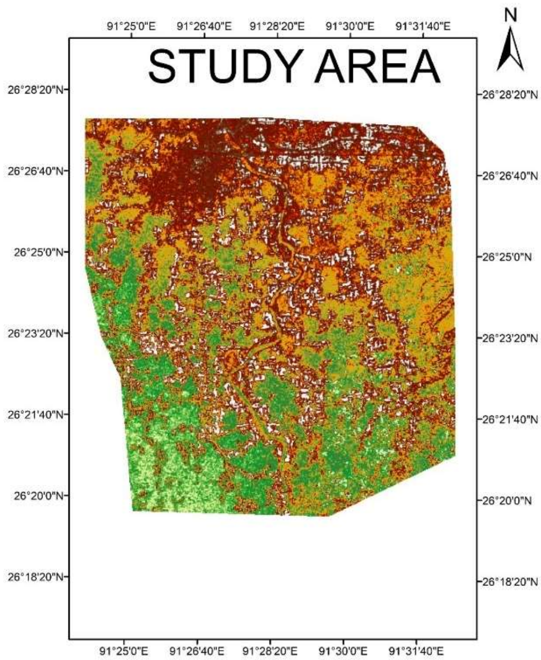


Fig 3.2: Study area

Pagladia River is perennial, very shallow, and is characteristically known for flash floods and high discharge rates. This River during its course shows great seasonal variations in its water content throughout the year. As the river originates from the mountains of Bhutan, during rainy season the river swells up and increases its boundary significantly inundating the nearby shores and has high water current. Pagladia is primarily a rain feed river, so during winter season when there is no rainfall, the river shrinks and confined to a stream of few metres at breath.

3.3 MATERIALS

3.3.1 Google Earth Pro: We can make extremely detailed maps with this geospatial desktop application, which is free. All users now have access to high-quality, high-resolution aerial photographs and ground photographs thanks to Google Earth Pro. Google Earth Pro offers a variety of tools and layers for exploring our green globe in addition to the aerial view of the earth. In conclusion we can say that Google Earth Pro is a capable and expert application that is easily accessible in the market. The study area is chosen, and the river centre lines are established and exported to ArcGIS for further use.

3.3.2 ArcMap: It is a geographic information system (GIS) which utilises maps and geographic data maintained by the Environmental Systems Research Institute (ESRI). Additionally, it can be used for making and using maps, gathering geographic data, evaluating information that has been mapped, sharing and discovering geographic information, utilising maps and geographic data in a variety of applications, and maintaining geographic data in a database. In this study, the river basin is identified using ArcGIS, and a basin map identifying solely the study region is identified using a DEM that was acquired using "USGS Earth Explorer."

3.3.3 HEC-HMS:

HEC-HMS (Hydrologic Engineering Center's Hydrologic Modelling System) is a software developed by the Hydrologic Engineering Center (HEC) of the United States Army Corps of Engineers. It is a powerful and widely used tool for hydrological modelling, specifically designed for simulating the hydrologic processes within a watershed. HEC-HMS is used by engineers, hydrologists, and researchers to analyse and predict the behaviour of watersheds and river systems under various hydrological conditions.

HEC-HMS allows users to simulate various hydrological processes, including rainfall, runoff, evapotranspiration, snowmelt, and more. The software provides a comprehensive platform for building watershed models and assessing the impact of different factors on the water cycle.

3.3.4 HEC-RAS:

HEC-RAS is a hydraulic model created by the Hydrologic Engineering Centre. This software is developed by U.S Federal Government resources and is therefore in the public domain. The primary model of HEC-RAS was created in 1990 and evolved from a steady flow model called HEC-2, first created in 1966. As computer capabilities moved forward, the HEC-2 computer program was changed over to the windows-based HEC-RAS computer program to assist water powered displaying with a graphical user interface (GUI). The HEC-RAS programme is a coordinated framework designed for interactive use in a multitasking environment. The system includes a graphical user interface, independent investigative components, information capacity and administrative capabilities, visuals, and reporting tools. It is open for use, copying, distribution, and redistribution. However, it is desired that HEC receive the proper credit for any future uses of this work. The Momentum equation is used in circumstance where the water surface profile is rapidly varied and Energy equation is only valid for gradually varied. These conditions take into account computations for mixed flow regimes (such as hydraulic jumps), the hydraulics of bridges, and profiling at stream confluences (stream intersections).

Forecasts of areas likely to be submerged by a specific flood can be effectively improved and streamlined using HEC-RAS models. Initially, the HEC-RAS model was used to compute water surface profiles for a 1D steady state flow. The modeller now has the choice of using the steady flow or the unstable flow option. The HEC-RAS model also offers a number of capabilities in addition to the unsteady and steady flow options, including modelling of open channel systems and single streams (with both unsteady and steady flow options), analysis of bridges, weirs, and culverts (with both unsteady and steady stream options), visualisation of capacity zones, route failures at dams, tunnels, pumping stations, and levees (with the unsteady flow option only), and management of subcritical, super critical and mixed flow administrations (steady flow option only). The stream geometry was imported from ArcGIS to HEC-RAS for this study, and it will now be used to consider the stream characteristics for steady conditions, such as finding discharge at different cross sections of the river, velocity of the river at different areas, etc., which can help with flood mapping.

3.4 DATA COLLECTED

3.4.1 Rainfall Data

The rainfall data of Nalbari area from 2006 to 2021 is collected from Nalbari Sub-division of "Lower Assam Investigation Division, Water Resource Department" are shown in table 3.1

Table3.1: Rainfall data of Nalbari area from 2006 to 2021 collected from Nalbari Sub-division of Lower Assam Investigation Division, Water Resource Department

Year	Maximum Daily Rainfall (mm)
2006	134
2007	104
2008	119
2009	73
2010	115.4
2011	77
2012	136
2013	74
2014	127
2015	138
2016	88.6
2017	139.8
2018	113.2
2019	177.2
2020	179.4
2021	118

3.4.2 Discharge Data

The discharge data of Pagladia River from 1992 to 2017 collected from Nalbari Sub-division of "Lower Assam Investigation Division, Water Resource Department" are shown in table 3.2

Table3.2: Discharge data of Pagladia River from 1992 to 2017 collected from Nalbari Sub-division of Lower Assam Investigation Division, Water Resource Department

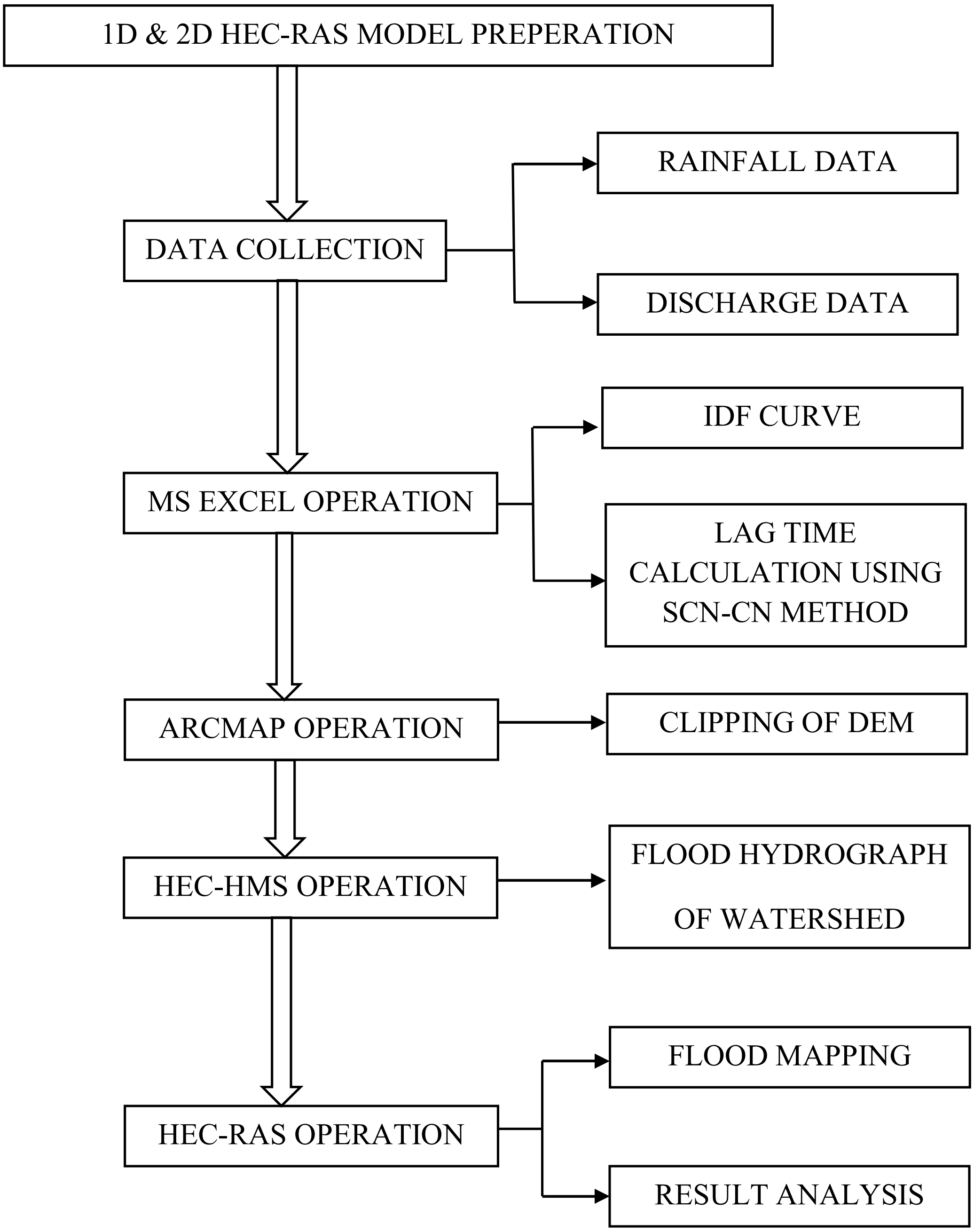
Year	Date corresponding to maximum discharge	Maximum discharge(m^3/s)	Date corresponding to minimum discharge	Minimum discharge(m^3/s)
1992	15-Jul	509	01-Apr	4
1993	21-Jul	658.41	27-Dec	6
1994	22-Jun	346	31-Mar	4
1995	NA	NA	NA	NA
1996	13-Jul	536	01-May	4
1997	17-Jun	558	30-Mar	12
1998	12-Jun	501	12-Dec	4
1999	24-Jun	200	11-Apr	3
2000	NA	NA	NA	NA
2001	NA	NA	NA	NA
2002	NA	NA	NA	NA
2003	NA	NA	NA	NA
2004	08-Jul	673	18-Mar	12
2005	20-Jul	426	20-Mar	13
2006	13-Jun	299	04-Apr	8
2007	27-Jul	315	12-Feb	14
2008	31-Aug	353	03-Mar	12
2009	02-Jul	243	22-Mar	13
2010	28-Jun	189	19-Mar	9
2011	17-Sep	132.37	30-Dec	9.79
2012	27-Jun	316.35	05-Apr	2.78
2013	07-Sep	195.84	11-Apr	0.86
2014	23-Sep	243.07	27-Apr	1.14
2015	31-Aug	329.55	23-Mar	2.86
2016	27-Jul	240.8	22-Mar	8.05
2017	12-Aug	335.39	27-Mar	12.19

CHAPTER 4

METHODOLOGY

4.1 INTRODUCTION

The methodology used for preparation and assessment of model is illustrated through the following flow chart.



4.2 OPERATIONS IN GOOGLE EARTH PRO

By using Google Earth Pro software, the study area is selected and the centre line of the river and both the left and right banks are also selected.

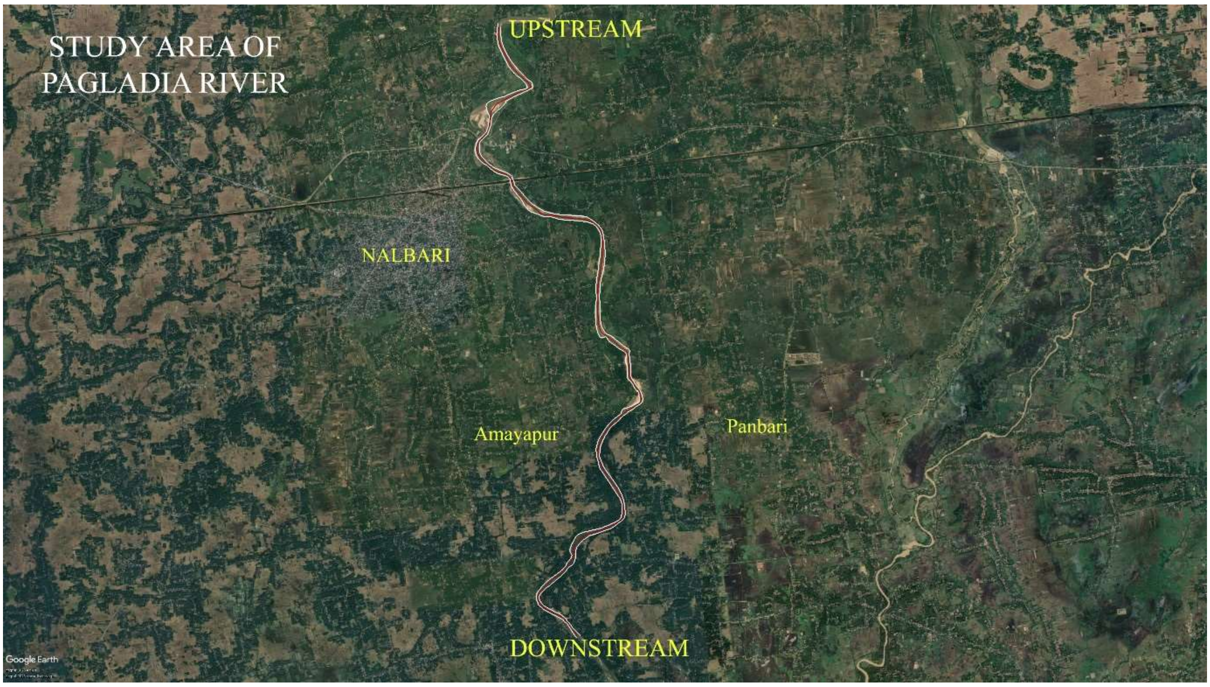


Fig 4.1: Centre line and bank line of Pagladia River in Google Earth Pro

4.3 OPERATIONS IN ARCMAP

1. Firstly, the DEM is downloaded from USGS earth explorer. The downloaded DEM is imported to the ArcMap using the add data feature of the software.

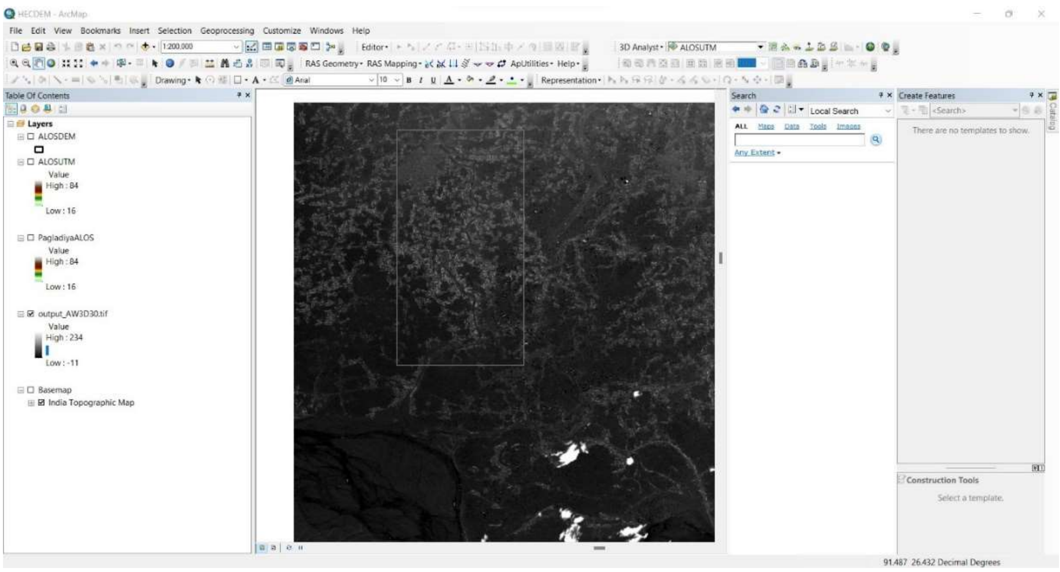


Fig 4.2: Importing DEM to ArcMap

2. To clip a DEM in ArcMap, we have followed these following steps.

A. First, we open ArcMap and add the DEM layer that we want to clip.

B. Add the layer that you want to use as the clip feature. This can be a polygon, a shape file, or any other feature layer.

C. Make sure that the two layers have the same projection.

D. Click on the "Geoprocessing" menu and select "Clip."

E. In the Clip tool dialog box, select the input raster layer (the DEM layer) and the clip feature layer.

F. Choose the output raster location and name, and make sure that the "Use Input Features for Clipping Geometry" option is selected.

G. Click OK to run the tool.

H. Once the clip operation is completed, you will have a new clipped DEM layer.

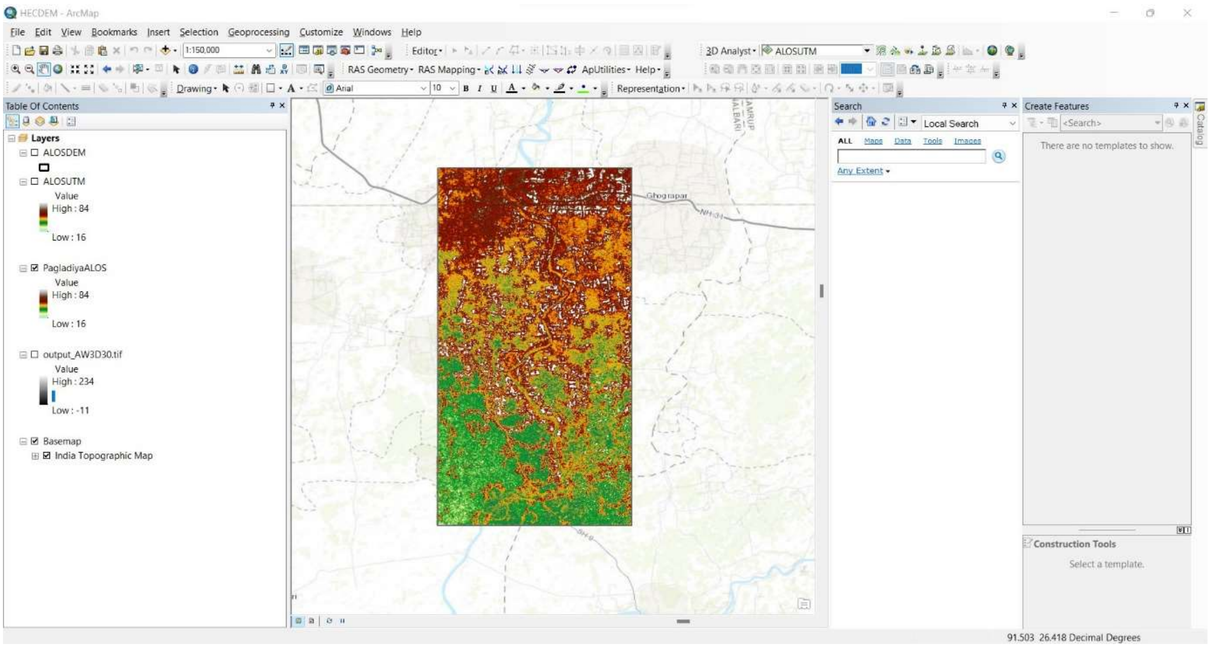


Fig 4.3: Clipped DEM

3. The clipped DEM is now given a suitable projection based on the location of the river. In the present study WGS 1984 having a UTM Zone 46 is used.

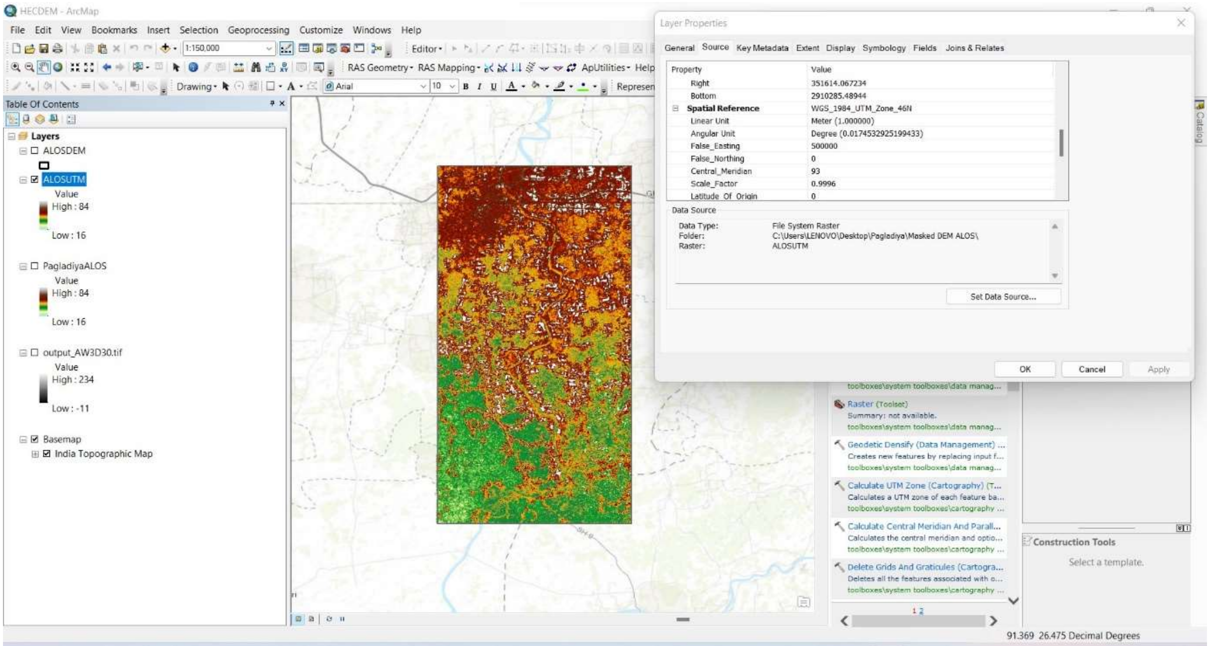


Fig 4.4: Assigned projections to the DEM

4.4 LAND USE AND LAND COVER

Land use and land cover are terms used in geography and environmental studies to describe the way land is utilized by humans and the type of natural and artificial features that cover the Earth's surface.

1. **Land Use**: This refers to the human activities and purposes that land is designated for. It includes various categories such as residential, commercial, industrial, agricultural, recreational, and more. Land use helps us understand how different areas are developed and utilized based on societal and economic needs.

2. **Land Cover**: This term describes the physical and biological material found on the Earth's surface, including both natural and artificial elements. Examples of land cover categories are forests, grasslands, water bodies, urban areas, barren land, and more. Land cover data helps us understand the extent of various types of surfaces on the planet.

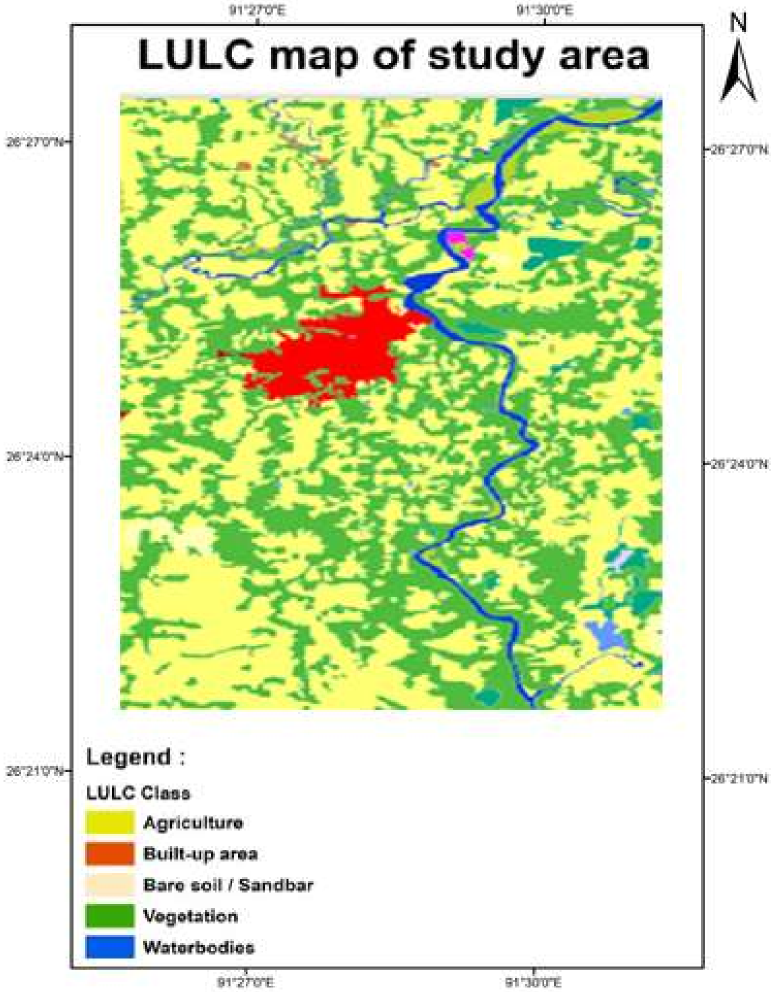


Fig 4.5: Land use and land cover map of Study area

4.5 OPERATIONS IN MS EXCEL

4.5.1 Gumbel Method of Flood Frequency analysis:

The 2D hydrodynamic simulation provides information on hydraulic parameters such as water surface elevation, velocity, and flow depth at a different location in the computational domain. The flood frequency analysis is done by using Gumbel's method for the annual peak streamflow data for a period of 2006-2021, to calculate the discharges at three different return periods, mainly 25 years, 50 years, and 100 years. It is also known as the Generalized Extreme Value distribution method. The discharge corresponding to the above-mentioned return periods are calculated using frequency analysis. The observed data is fitted to Gumbel's distribution and the discharge is calculated using the general equation of frequency analysis, given by

$$x_T = x + K_T \times S$$

Where,

x_T = Design intensity for a particular duration and a particular return period

x = Mean of the annual maximum for a particular duration

S = Standard Deviation of the annual maximum for a particular duration

K_T = Frequency factor

Extreme value type I (EV-I) distribution, also known as Gumbel's distribution, is a limiting probability distribution which is used to model the maximum or minimum values from a sample of independent, identically distributed random variables, as the size of the sample increases. Frequency factor (K_T) is determined by the standard equation derived from Gumbel's distribution function as,

$$K_T = -\frac{\sqrt{6}}{\pi}\{0.5772 + \ln(\ln(\frac{T}{T-1}))\}$$

The K_T values are a function of return period only as can be observed from the above equation. The K_T for the return periods is calculated as mentioned in Table 2.1.

Table 4.1 Frequency factor (K_T) values for different return periods

	2 YEAR	10 YEAR	25 YEAR	50 YEAR	75 YEAR	100 YEAR
Y_T	0.366512921	2.250367327	3.198534261	3.901938658	4.310784111	4.600149227
K_T	-0.15479	1.5031	2.33753	2.95656	3.31636	3.57102

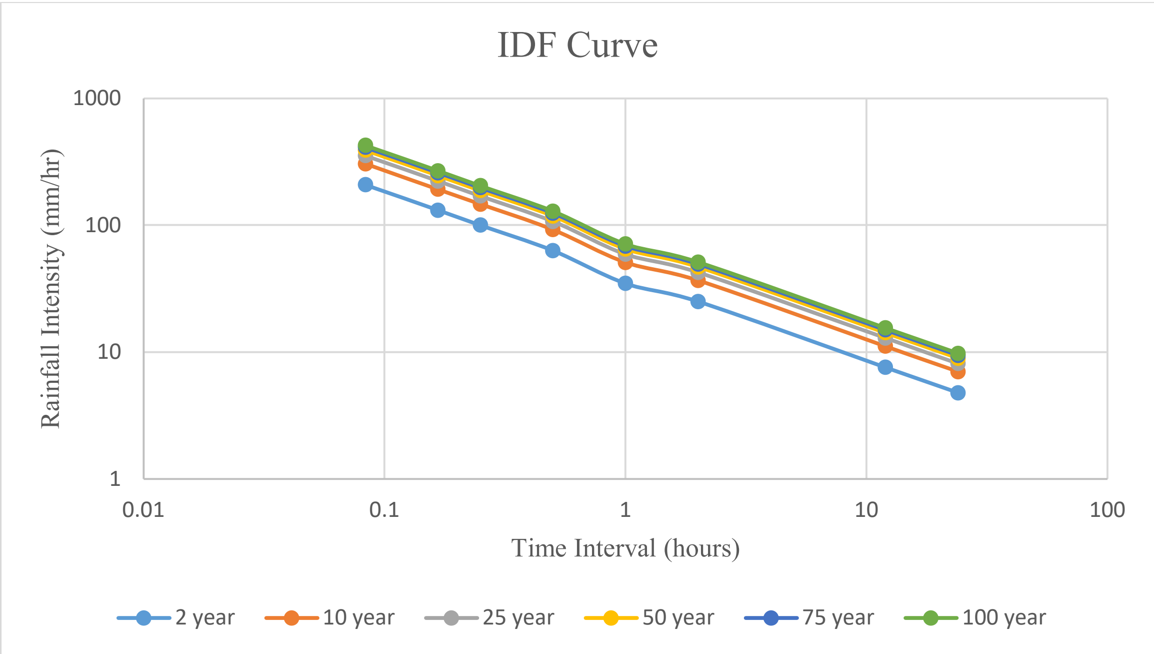
1. 

Fig 4.6: IDF Curve for various return period

Table 4.2: Gumbel Distribution

		PRECIPITATION							
Year	Maximum Rainfall (mm)	5 min	10 min	15 min	30 min	60 min	120 min	720 min	1440 min
2006	134	20.2912	25.5653	29.2649	36.8715	40.5824	58.5299	106.3559	134
2007	104	15.7484	19.8417	22.7131	28.6167	31.4968	45.4262	82.5449	104
2008	119	18.0198	22.7035	25.9890	32.7441	36.0396	51.9780	94.4504	119
2009	73	11.0542	13.9274	15.9428	20.0867	22.1083	31.8857	57.9401	73
2010	115.4	17.4746	22.0167	25.2028	31.7535	34.9493	50.4056	91.5930	115.4
2011	77	11.6599	14.6905	16.8164	21.1874	23.3197	33.6328	61.1149	77
2012	136	20.5940	25.9469	29.7017	37.4218	41.1881	59.4035	107.9433	136
2013	74	11.2056	14.1181	16.1612	20.3619	22.4112	32.3225	58.7338	74
2014	127	19.2312	24.2298	27.7362	34.9454	38.4624	55.4724	100.8000	127
2015	138	20.8969	26.3284	30.1385	37.9722	41.7938	60.2771	109.5307	138
2016	88.6	13.4164	16.9036	19.3498	24.3792	26.8328	38.6996	70.3219	88.6
2017	139.8	21.1695	26.6718	30.5316	38.4675	42.3389	61.0633	110.9593	139.8
2018	113.2	17.1415	21.5969	24.7223	31.1482	34.2830	49.4447	89.8469	113.2
2019	177.2	26.8328	33.8072	38.6996	48.7585	53.6656	77.3992	140.6437	177.2
2020	179.4	27.1660	34.2270	39.1801	49.3638	54.3319	78.3602	142.3899	179.4
2021	118	17.8684	22.5127	25.7706	32.4690	35.7367	51.5412	93.6567	118

Mean	18.1106	22.8180	26.1201	32.9092	36.2213	52.2401	94.9266	119.6000
Standard deviation	4.8682	6.1335	7.0211	8.8460	9.7363	14.0422	25.5164	32.1487

Table 4.3: Rainfall intensity for different return period

Time (hr)	Time (min)	Mean	Standard deviation	2 YEARS		10 YEARS		25 YEARS		50 YEARS		75 YEARS		100 YEARS	
				Rainfall (mm)	Rainfall (mm/hr)	Rainfall (mm)	Rainfall (mm/hr)	Rainfall (mm)	Rainfall (mm/hr)	Rainfall (mm)	Rainfall (mm/hr)	Rainfall (mm)	Rainfall (mm/hr)	Rainfall (mm)	Rainfall (mm/hr)
0.0833	5	18.1106	4.8682	17.36	208.29	25.43	305.14	29.49	353.88	32.50	390.04	34.26	411.06	35.49	425.94
0.1667	10	22.818	6.1335	21.87	131.21	32.04	192.22	37.16	222.93	40.95	245.71	43.16	258.95	44.72	268.33
0.25	15	26.1201	7.0211	25.03	100.13	36.67	146.69	42.53	170.13	46.88	187.51	49.40	197.62	51.19	204.77
0.5	30	32.9092	8.8460	31.54	63.08	46.21	92.41	53.59	107.17	59.06	118.13	62.25	124.49	64.50	129.00
1	60	36.2213	9.7363	34.71	34.71	50.86	50.86	58.98	58.98	65.01	65.01	68.51	68.51	70.99	70.99
2	120	52.2401	14.0422	50.07	25.03	73.35	36.67	85.06	42.53	93.76	46.88	98.81	49.40	102.39	51.19
12	720	94.9266	25.5164	90.98	7.58	133.28	11.11	154.57	12.88	170.37	14.20	179.55	14.96	186.05	15.50
24	1440	119.6	32.1487	114.62	4.78	167.92	7.00	194.75	8.11	214.65	8.94	226.22	9.43	234.40	9.77

4.5.2 Lag Time calculation: Lag time is calculated for different sub-basins using Curve Number Method.

Table 4.4: Lag Time Calculation

Sub-basins	Hydraulic Length (l) m	Average Basin Slope (S) (m/m)	Average Basin Slope (Y)%	Curve Number (CN)	S=[(1000/CN)-10] (inch)	Lag Time (L) (hour)	Lag Time (L) (min)
Sub-1	18525.15	0.0418696	4.18695	84.6	1.82	3.57	214.12
Sub-2	26804.76	0.5584182	55.8418	80	2.50	1.53	91.65
Sub-3	20396.41	0.5937154	59.3715	80	2.50	1.19	71.43
Sub-4	27022.27	0.2243553	22.4355	82.12	2.18	2.27	136.00
Sub-5	33024.51	0.3678606	36.7860	81.86	2.22	2.10	125.76
Sub-6	6191.5	0.0444935	4.44935	80	2.50	1.68	100.54
Sub-7	48820.02	0.1101065	11.0106	83.52	1.97	4.96	297.45
Sub-8	25173.23	0.0440994	4.40994	84.85	1.79	4.41	264.33
Sub-9	28938.45	0.1470652	14.7065	83.97	1.91	2.78	166.81

Formula used in Lag Time calculation:

T_c= 1.67L

$$L=\frac{l^{0.8}(S+1)^{0.7}}{1900Y^{0.5}}$$

where,

L= Lag time (Hrs)

l=Hydraulic Length

S= (1000/CN) – 10

CN = Curve Number

4.6 OPERATIONS IN HEC-HMS

Developing a flood study model with HEC-HMS (Hydrologic Engineering Center's Hydrologic Modeling System) involves several steps to simulate rainfall-runoff processes and analyze the resulting hydrographs. HEC-HMS is commonly used for hydrologic modeling to estimate streamflow in watersheds. Here's a general outline of the process:

1. Data Collection and Preparation:
    - Obtain topographic data: You will need Digital Elevation Models (DEMs) or other elevation data to define the watershed boundaries and flow directions. (Source: USGS SRTM 30m resolution)
    - Gather meteorological data: Obtain rainfall data, such as observed precipitation records or design storm data for various return periods. (Source: Water Resource Department)
    - Acquire land use and soil data: Collect information on land cover types and soil properties within the watershed.
    - Land Cover Source: Bhuvan-Thematic Services of the National Remote Sensing Centre (NRSC), Indian Space Research Organization (ISRO).
2. Set Up the Project:
    - Launch HEC-HMS: Open the HEC-HMS software and create a new project.
    - Define the watershed: Digitize or import the watershed boundary based on the topographic data.
    - Divide the watershed into sub-basins: Define sub-basins within the main watershed based on hydrologic characteristics and flow patterns.

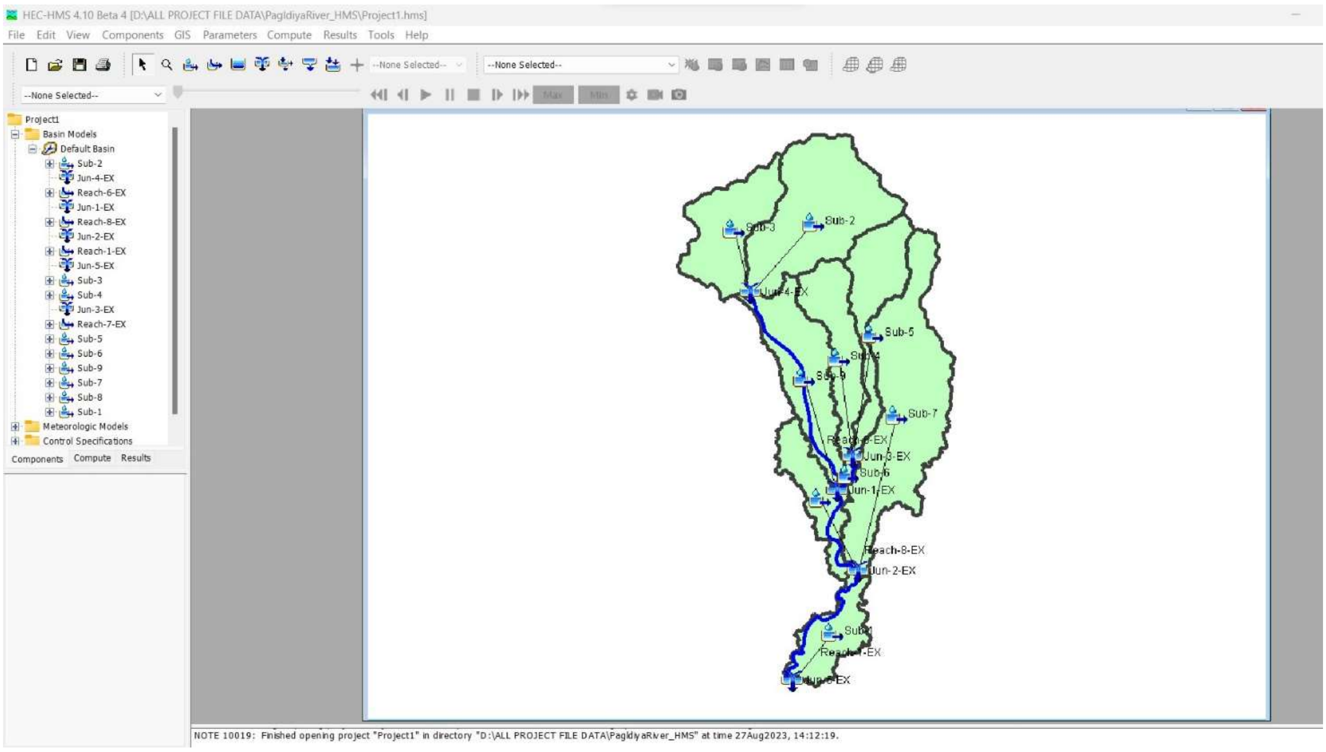


Fig 4.7: HEC-HMS interface showing sub-basins and junctions

3. Hydrologic Model Setup:
    - Select a hydrologic method: Choose an appropriate hydrologic method, such as SCS-CN (Soil Conservation Service Curve Number) or SCS Unit Hydrograph, to estimate runoff.
    - Assign land use and soil data: Assign the appropriate land use and soil data to each HRU.
    - Set up rainfall data: Input the rainfall data for the simulation period, including rainfall depths and durations.
4. Model Calibration and Parameters:
    - Calibrate the model: Adjust the model parameters (e.g., CN values, time to peak, lag time) to match observed streamflow data from gauged locations within the watershed.
    - Validate the model: Verify the model's performance by comparing simulated results with independent observed data.
5. Run the Simulation:
    - Configure simulation settings: Set the simulation duration and time step, as well as any other relevant simulation parameters.
    - Initiate the simulation: Run the HEC-HMS model to compute the rainfall-runoff process for the selected events or storm periods.
6. Post-Processing and Analysis:
    - Review the results: Analyze the output hydrographs generated by HEC-HMS for each sub-basin or outlet point in the watershed.
    - Assess flood characteristics: Examine the peak flow rates, hydrograph shapes, and other relevant parameters to understand the hydrologic response.
7. Communicate Findings:
    - Prepare reports and summaries: Document the modeling process, input data, calibration results, and conclusions.
    - Share the results: Communicate the findings and hydrograph outputs with relevant stakeholders, such as government agencies, communities, or decision-makers.

4.7 OPERATIONS IN HEC-RAS (1 DIMENSIONAL MODELLING)

The following are the general steps for performing a one-dimensional (1D) hydraulic modelling using HEC-RAS:

A. Create a new project in HEC-RAS: Launch the HEC-RAS program and create a new project. Select the SI units of measurement. We then digitize the river centre line, and specify the river reach that we want to model. The DEM which is saved using ArcMAP is imported in HEC-RAS using the RAS Mapper feature of software.

A. Assigning Projection: Projection file is downloaded from spatialreference.org and applied in the terrain model.

B. Define the geometry of the river: The RAS Mapper of HEC-RAS allows us to define cross-sections, banks, and floodplains for our river. After defining the cross-sections, we can set the channel shape, bank stations, and the floodplain geometry.

C. Define the boundary conditions: You need to specify the upstream and downstream boundary conditions for our model, including the flow rate, water surface elevation, and boundary geometry.

D. Assigning roughness values: We need to specify the Manning's n values (0.035) for each cross-section to define the channel roughness. The Manning's n values can be assigned based on the channel material, vegetation, or other factors that influence the channel roughness.

E. Run the HEC-RAS model: After setting up the geometry, boundary conditions, and roughness values, you can run the model to calculate the water surface elevation, velocity, and other hydraulic parameters for each cross-section. The HEC-RAS model uses the Saint Venant equations to simulate the hydraulic behaviour of the river.

   HEC-RAS model use the energy equation to compute a water solution based on given discharge.

$$Z_2 + Y_2 + \alpha_2 \frac{V_2^2}{2g} = Z_1 + Y_1 + \alpha_1 \frac{V_1^2}{2g} + h_e$$

   Where, Z_1 and Z_2 are the elevation of the main channel invert, Y_1 and Y_2 are depth of water at cross section, V_1 and V_2 are average velocities, α_1 and α_2 are the velocity weighting coefficient, g and h_e are gravitational acceleration and head loss respectively. The head loss between two cross sections is comprised of friction losses and contraction or expansion losses.

F. Review the results: After running the HEC-RAS model, we can review the results to ensure that they are reasonable and make any necessary adjustments to the model inputs or parameters. We can visualize the results using graphs, tables, and maps.

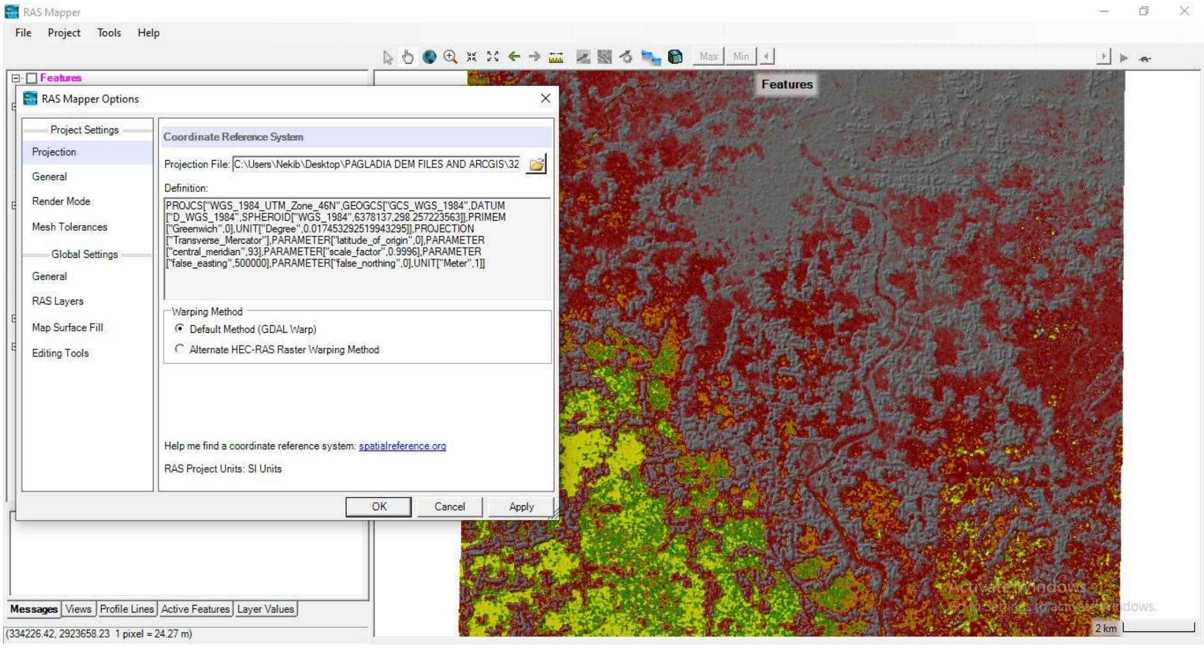


Fig 4.8: Applying projection to the terrain in RAS Mapper

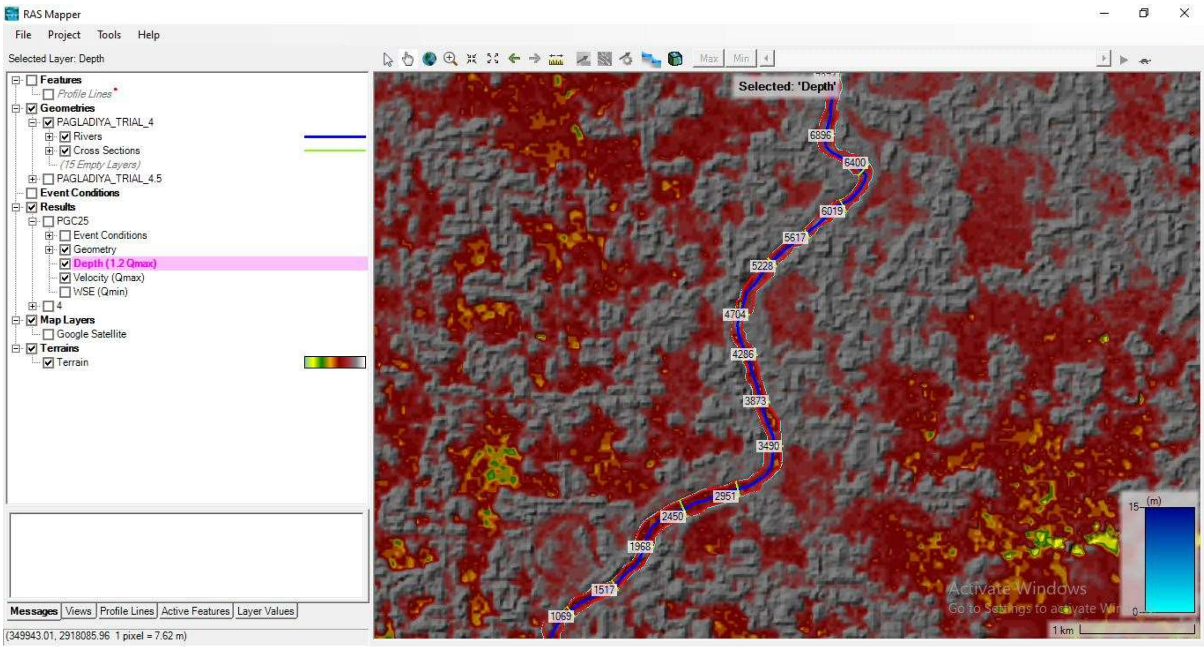


Fig 4.9: Marking bank lines, flow paths and cross sections in the RAS Mapper

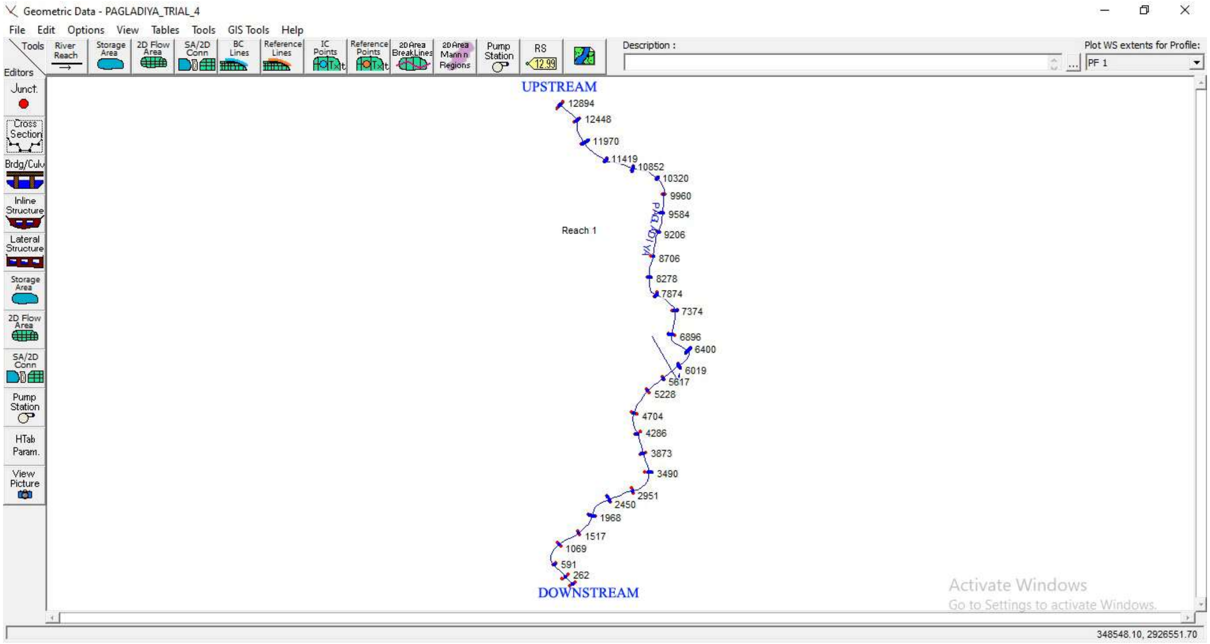
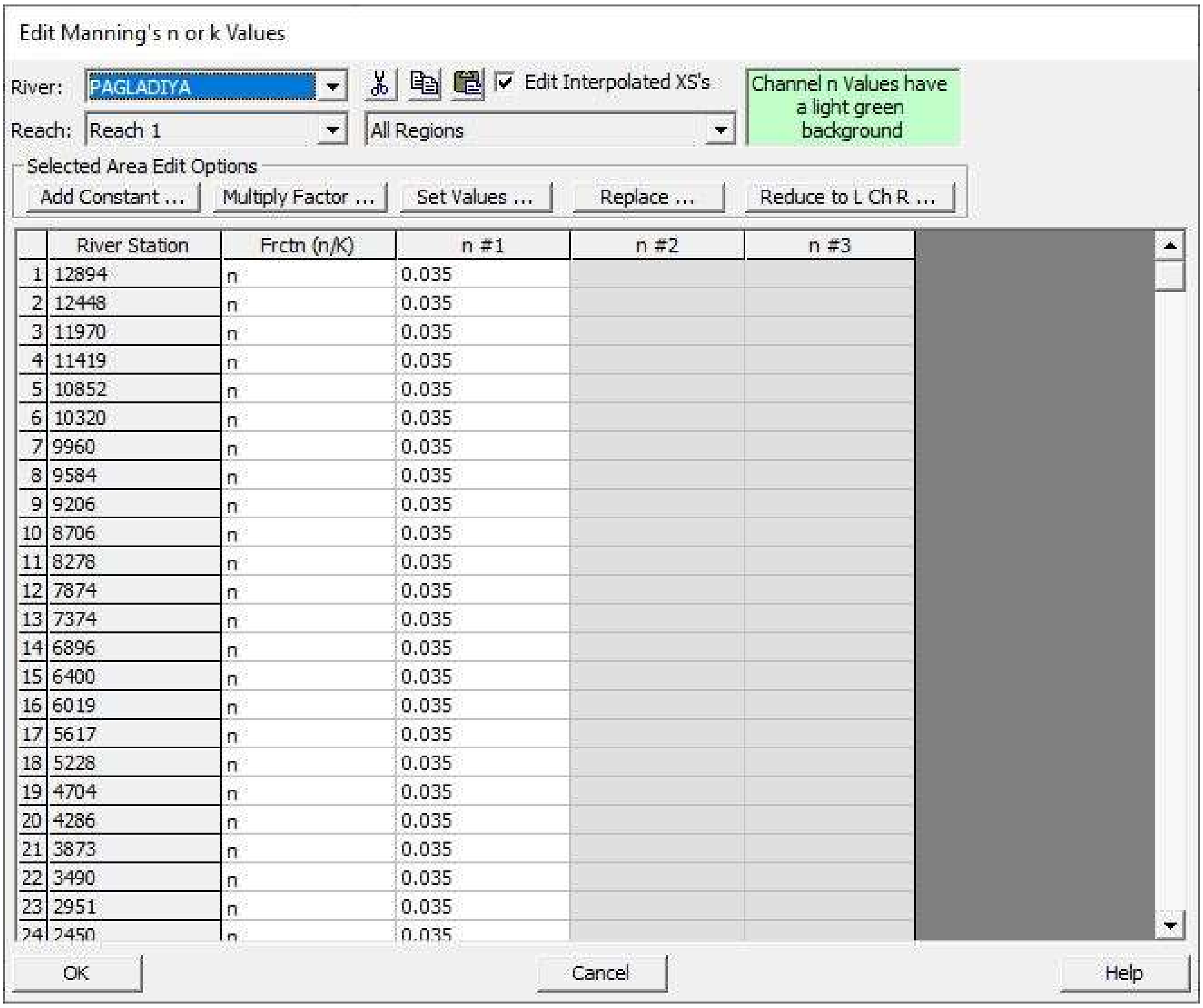


Fig 4.10: Cross section window of HEC-RAS



	River Station	Frctn (n/K)	n #1	n #2	n #3
1	12894	n	0.035		
2	12448	n	0.035		
3	11970	n	0.035		
4	11419	n	0.035		
5	10852	n	0.035		
6	10320	n	0.035		
7	9960	n	0.035		
8	9584	n	0.035		
9	9206	n	0.035		
10	8706	n	0.035		
11	8278	n	0.035		
12	7874	n	0.035		
13	7374	n	0.035		
14	6896	n	0.035		
15	6400	n	0.035		
16	6019	n	0.035		
17	5617	n	0.035		
18	5228	n	0.035		
19	4704	n	0.035		
20	4286	n	0.035		
21	3873	n	0.035		
22	3490	n	0.035		
23	2951	n	0.035		
24	2450	n	0.035		

Fig 4.11: Applying Manning's n value for the flow

STEDY FLOW ANALYSIS

At first, we analyse the results for steady flow of the river. For that the steady flow option is selected. Five discharge values are selected which will appears in different names as Q_{min}, Q_{max}, Q_{avg}, 1.1Q_{max} and 1.2Q_{max}.

Table 4.5: Discharge data considered for study

Minimum Discharge (m^3/s)	Maximum Discharge (m^3/s)	Average Discharge (m^3/s)	1.1 times maximum discharge (m^3/s)	1.2 times maximum discharge (m^3/s)
0.86	673	361.894	740.3	807.6

In table 3.1, three discharge values are selected for this study i.e.Q_{min},Q_{max}, Q_{avg} and two values are selected as 10% and 20% of maximum discharge value of the available data from 1992 to 2017.

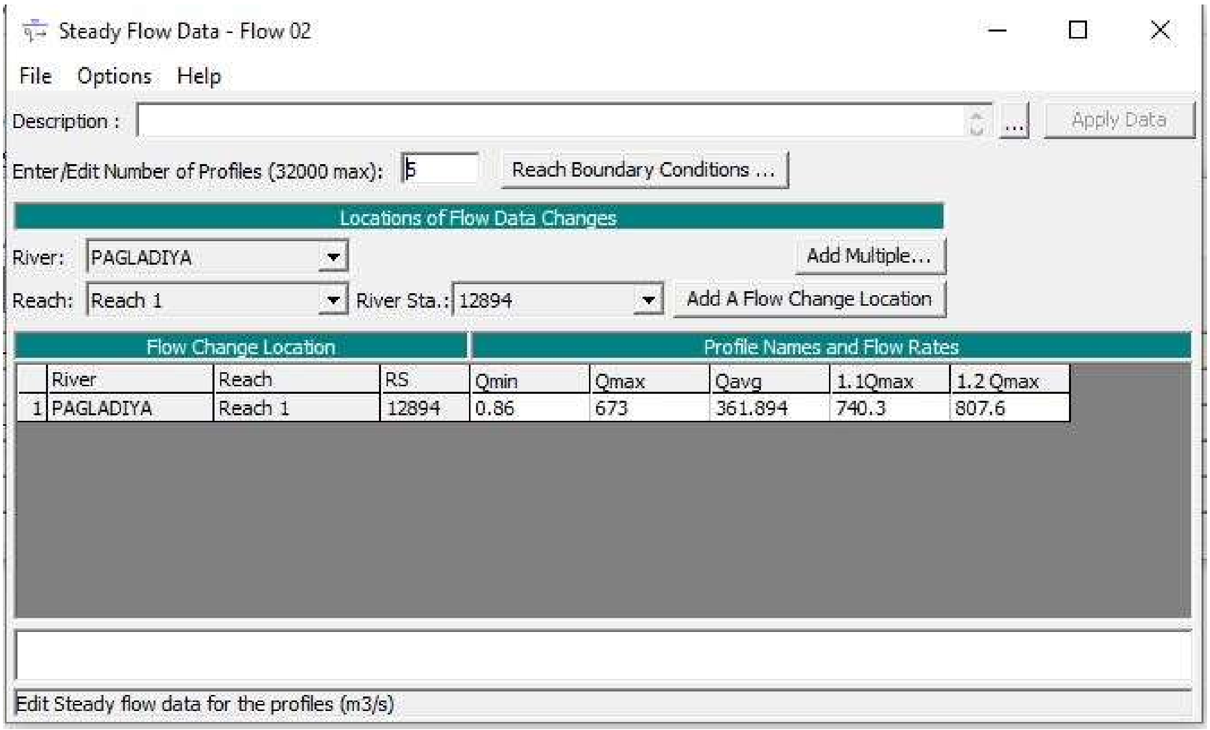


Fig 4.12: Entering Steady Flow Data

After saving the steady flow data the final step is to run the steady flow analysis where the flow regime is selected as mixed and then we compute the flow analysis.

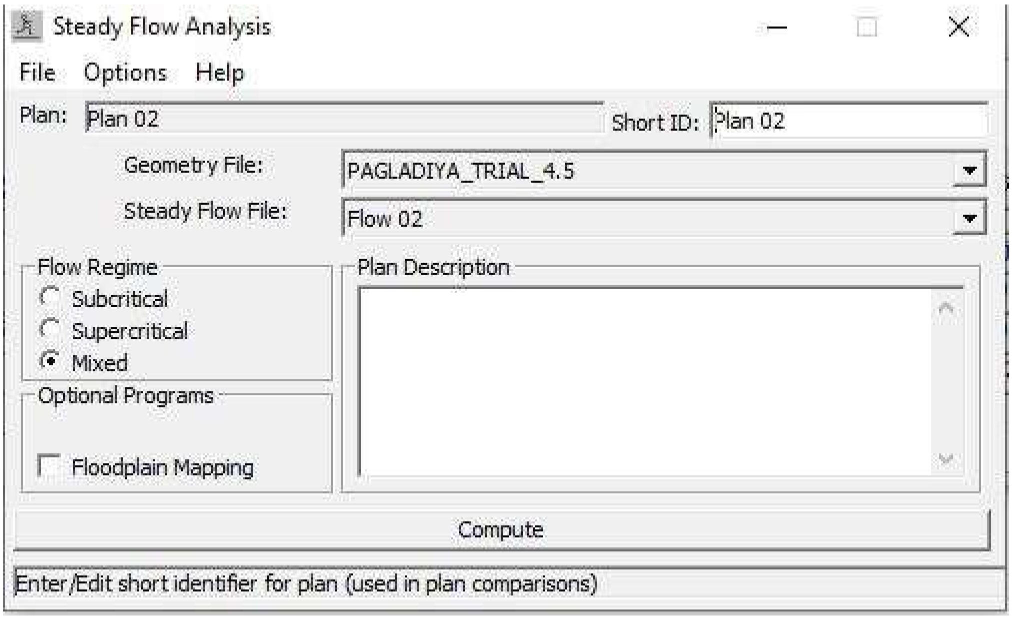


Fig 4.13: Computation of Steady flow analysis

After successful run of Steady flow, various results are obtained. The results of Upstream and Downstream sections are shown below.

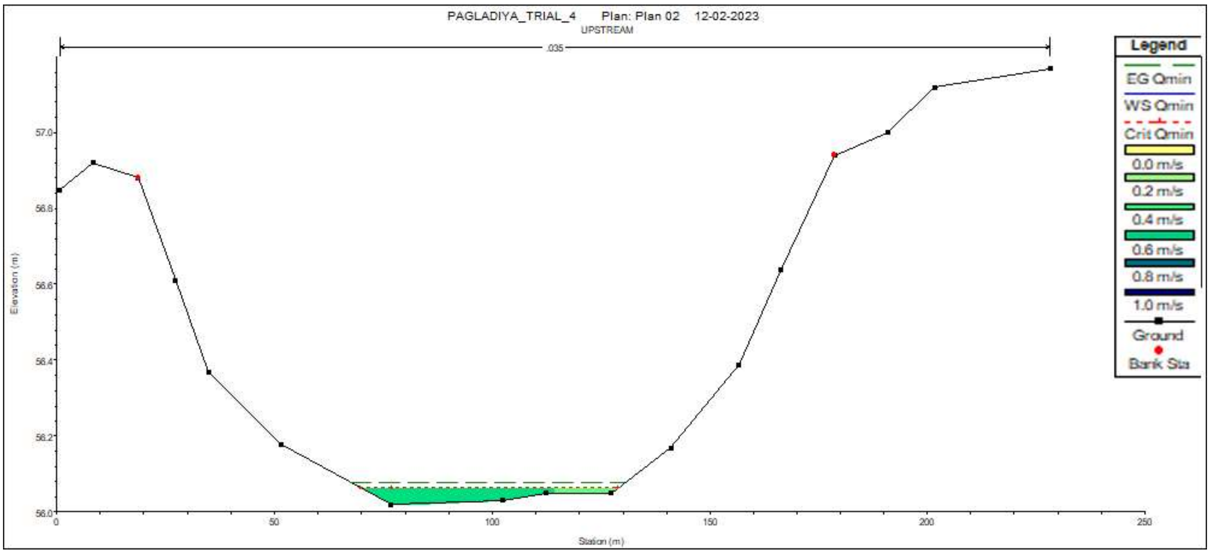


Fig 4.14: Elevation depth graph at upstream section for Q_{min}

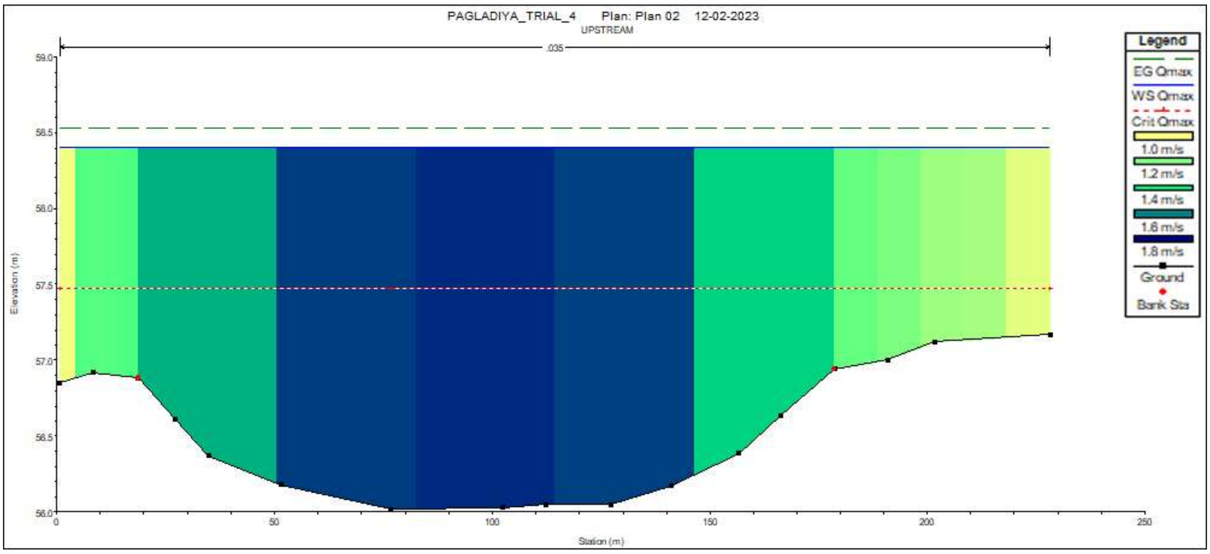


Fig 4.15: Elevation depth graph at upstream section for Q_{max}

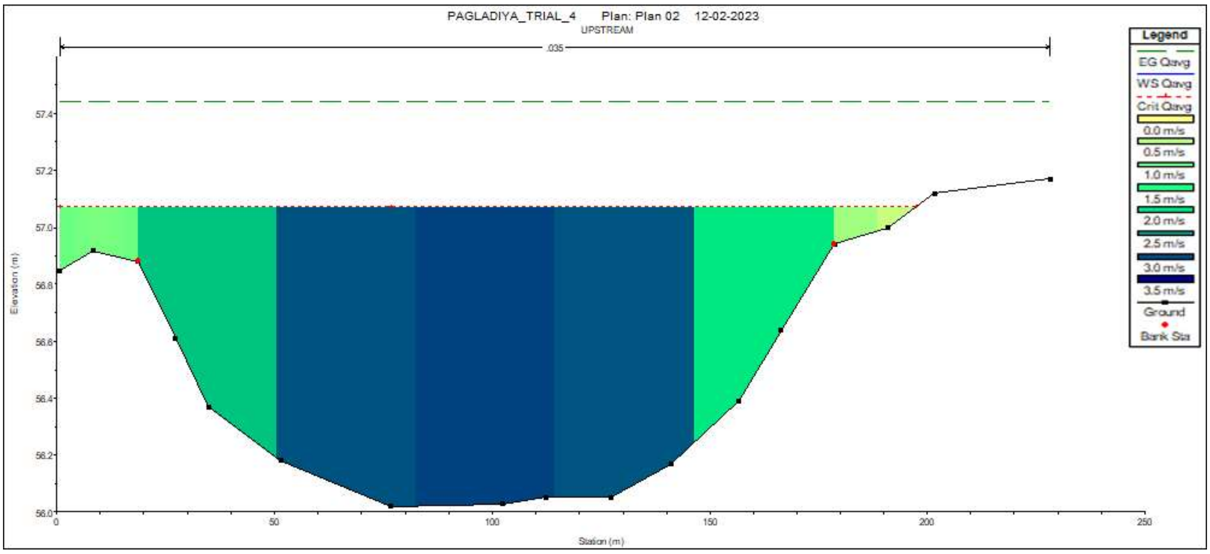


Fig 4.16: Elevation depth graph at upstream section for Q_{avg}

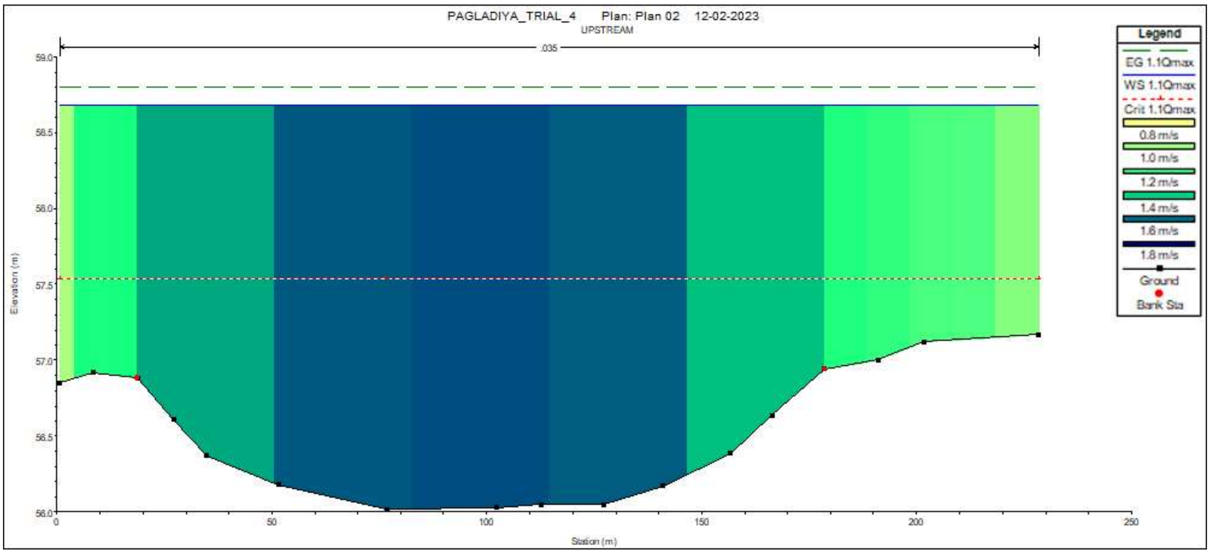


Fig 4.17: Elevation depth graph at upstream section for 1.1 times Q_{max}

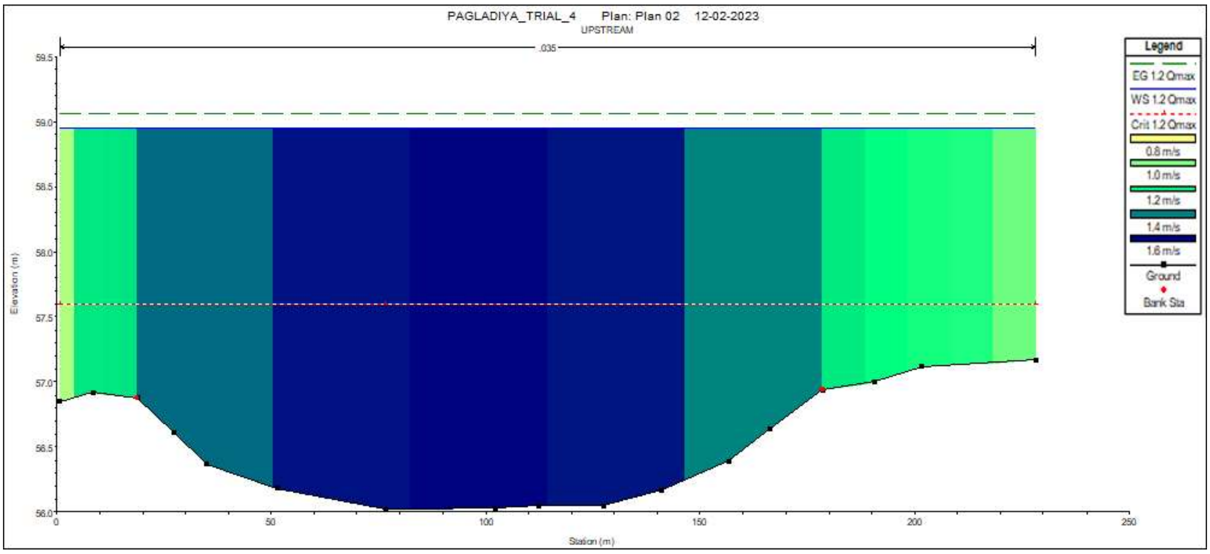


Fig 4.18: Elevation depth graph at upstream section for 1.2 times Q_{max}

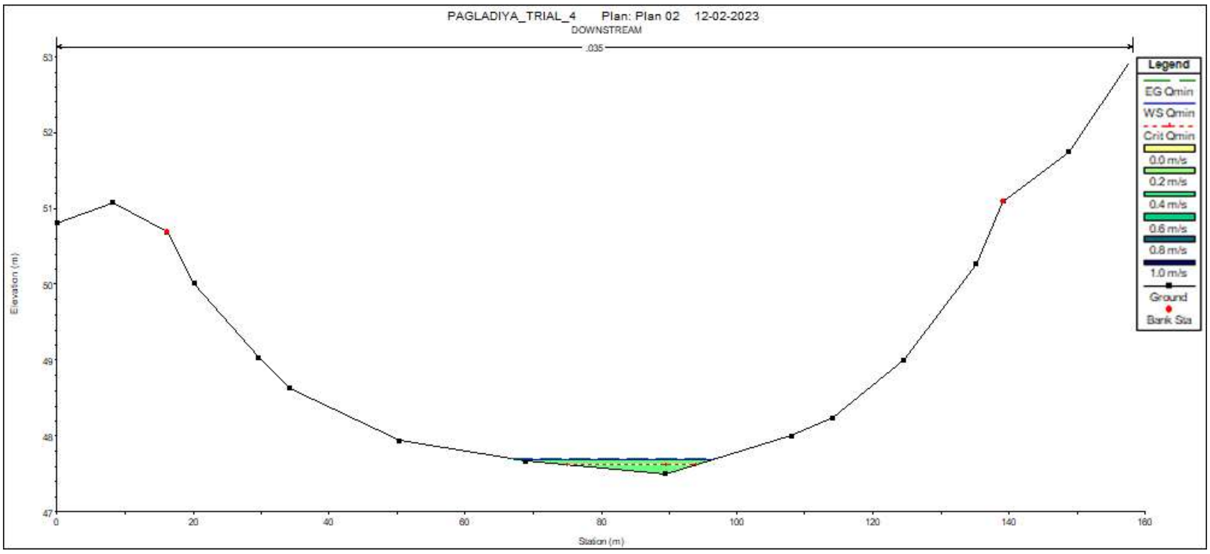


Fig 4.19: Elevation depth graph at downstream section for Q_{min}

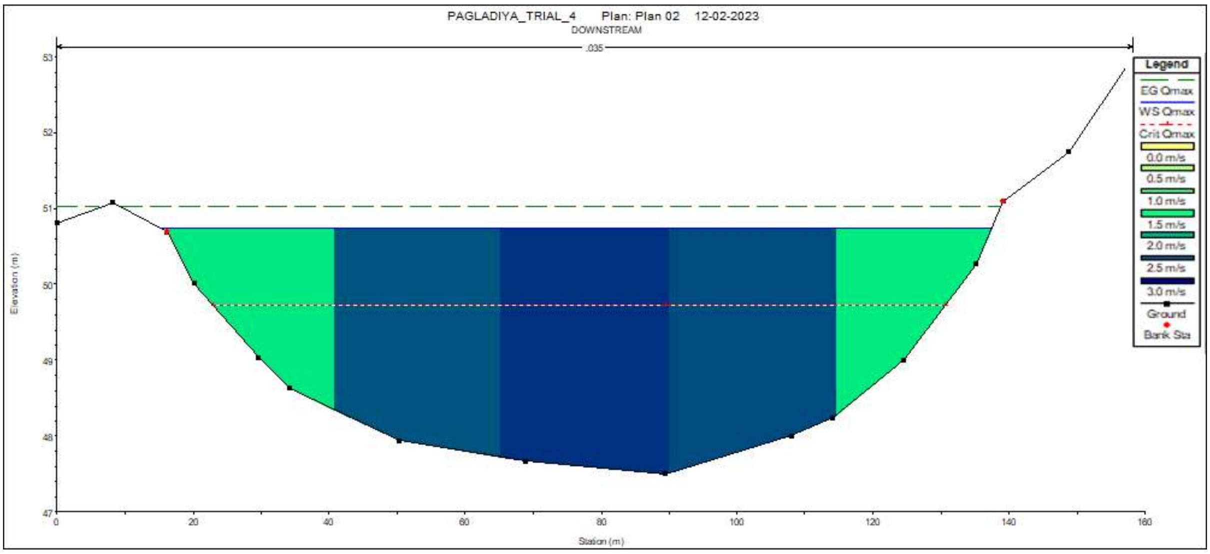


Fig 4.20: Elevation depth graph at downstream section for Q_{max}

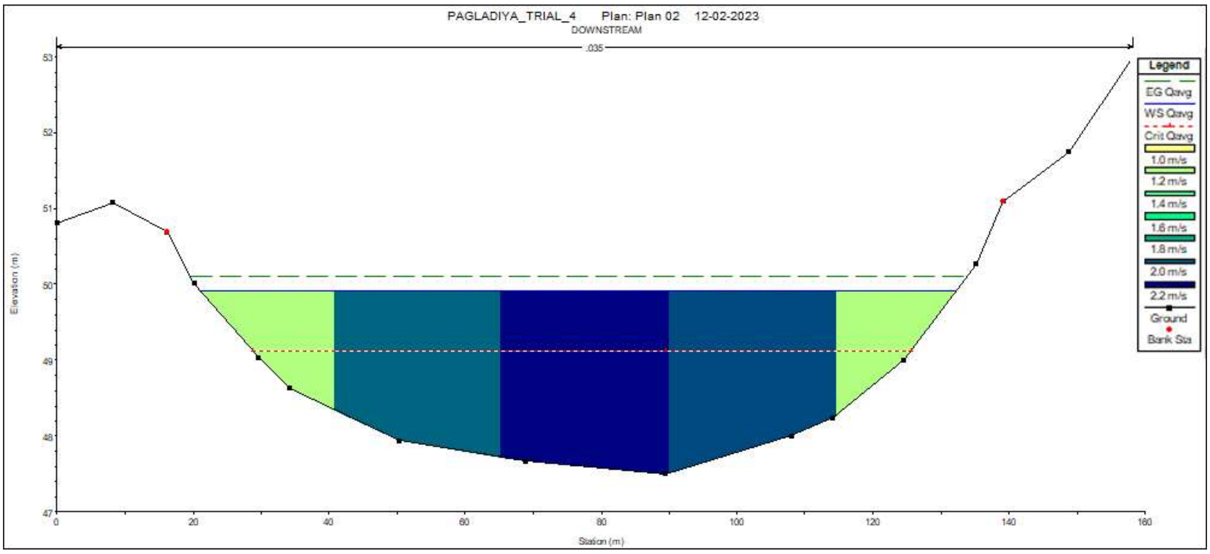


Fig 4.21: Elevation depth graph at downstream section for Q_{avg}

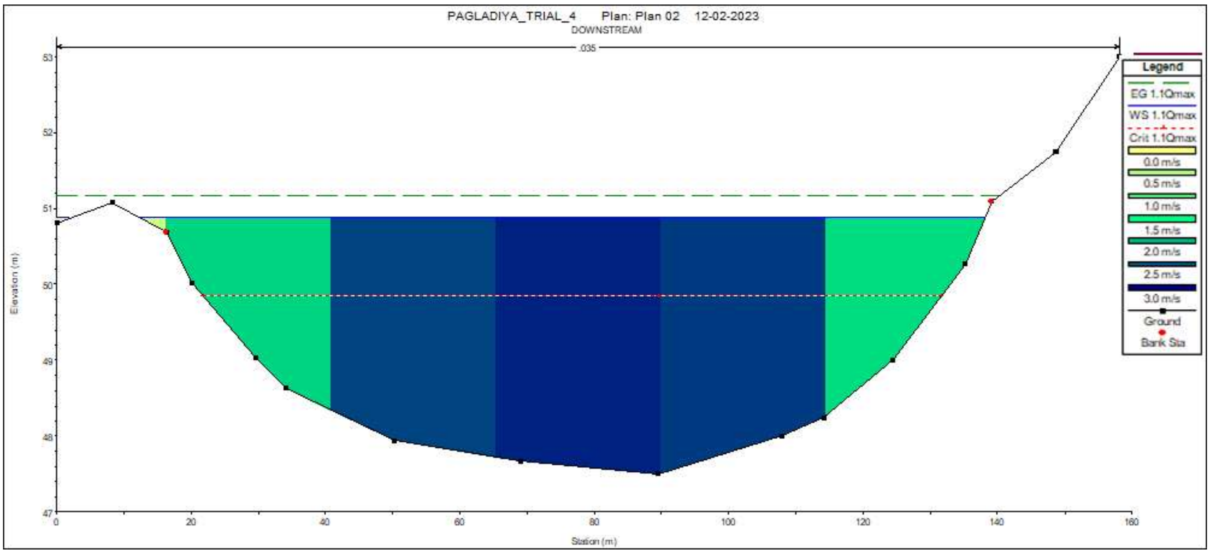


Fig 4.22: Elevation depth graph at downstream section for 1.1 times Q_{max}

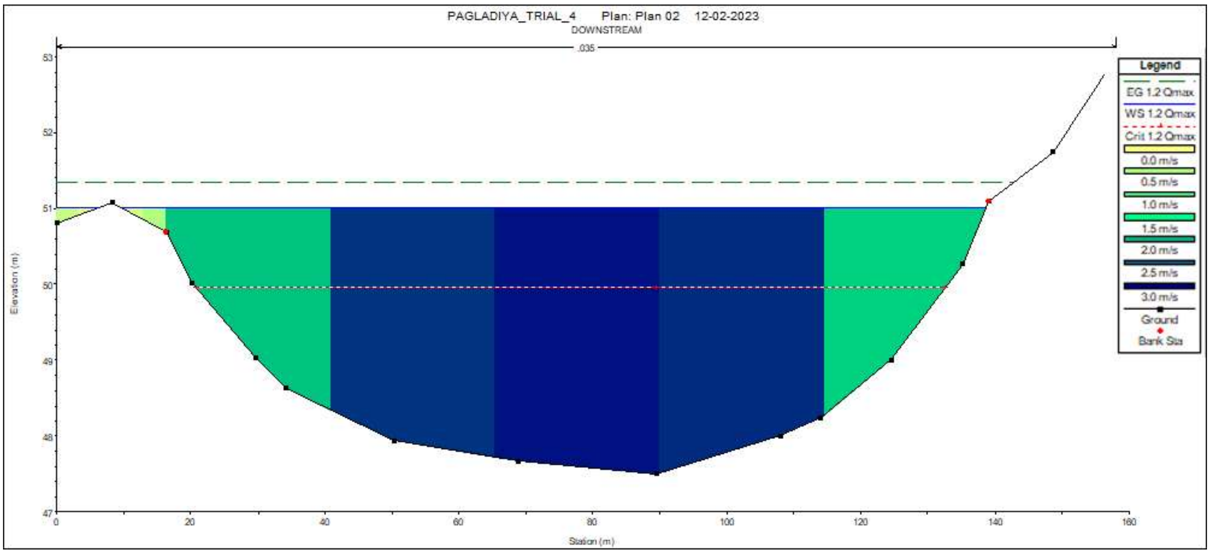


Fig 4.23: Elevation depth graph at downstream section for 1.2 times Q_{max}

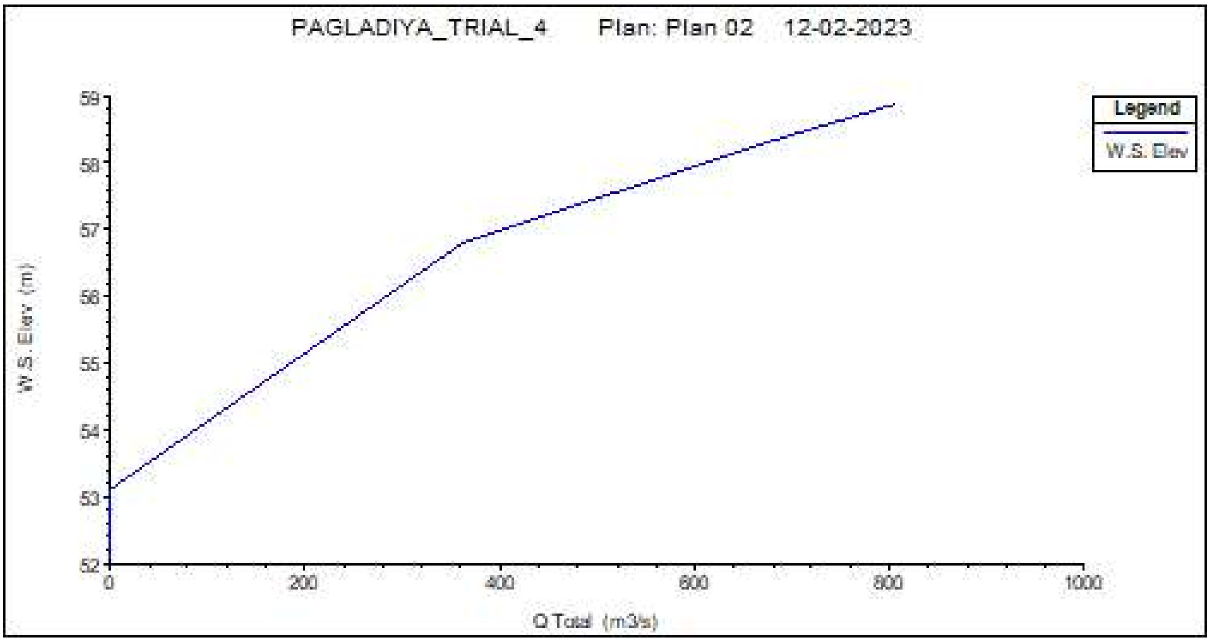


Fig 4.24: Rating curve of Upstream

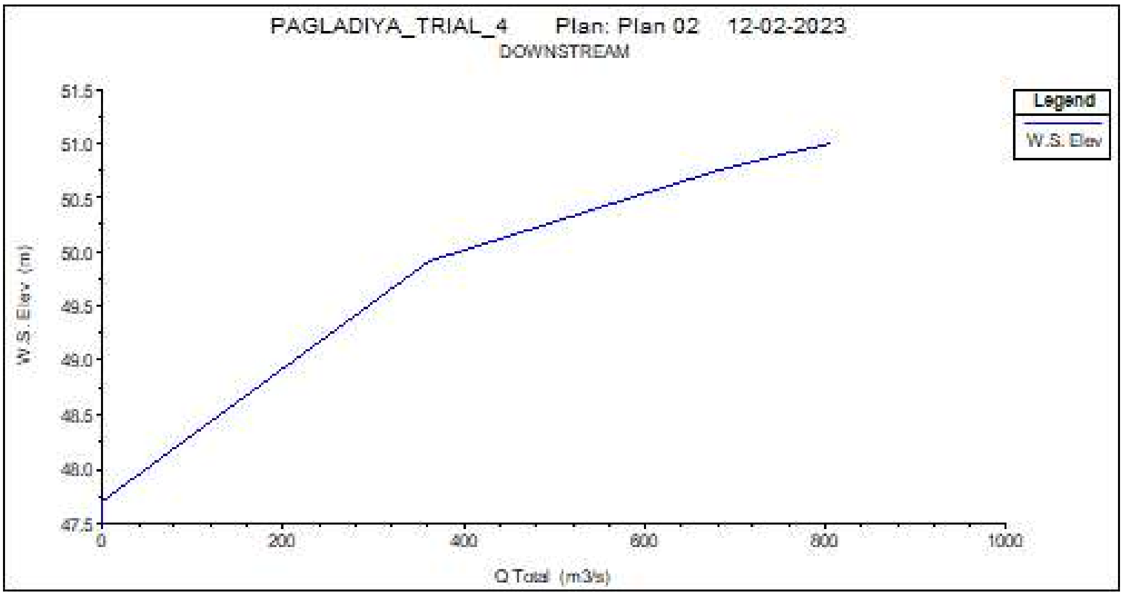


Fig 4.25: Rating curve of Downstream

4.8 OPERATIONS IN HEC-RAS (TWO-DIMENSIONAL MODELLING)

The 2D modelling capability of HEC-RAS allows for more accurate representation of complex hydraulic conditions, such as flow patterns, water levels, and velocities. Here's a step-by-step guide to performing a HEC-RAS 2D modelling analysis:

1. **Project Setup:**
   - Launch HEC-RAS and create a new project.

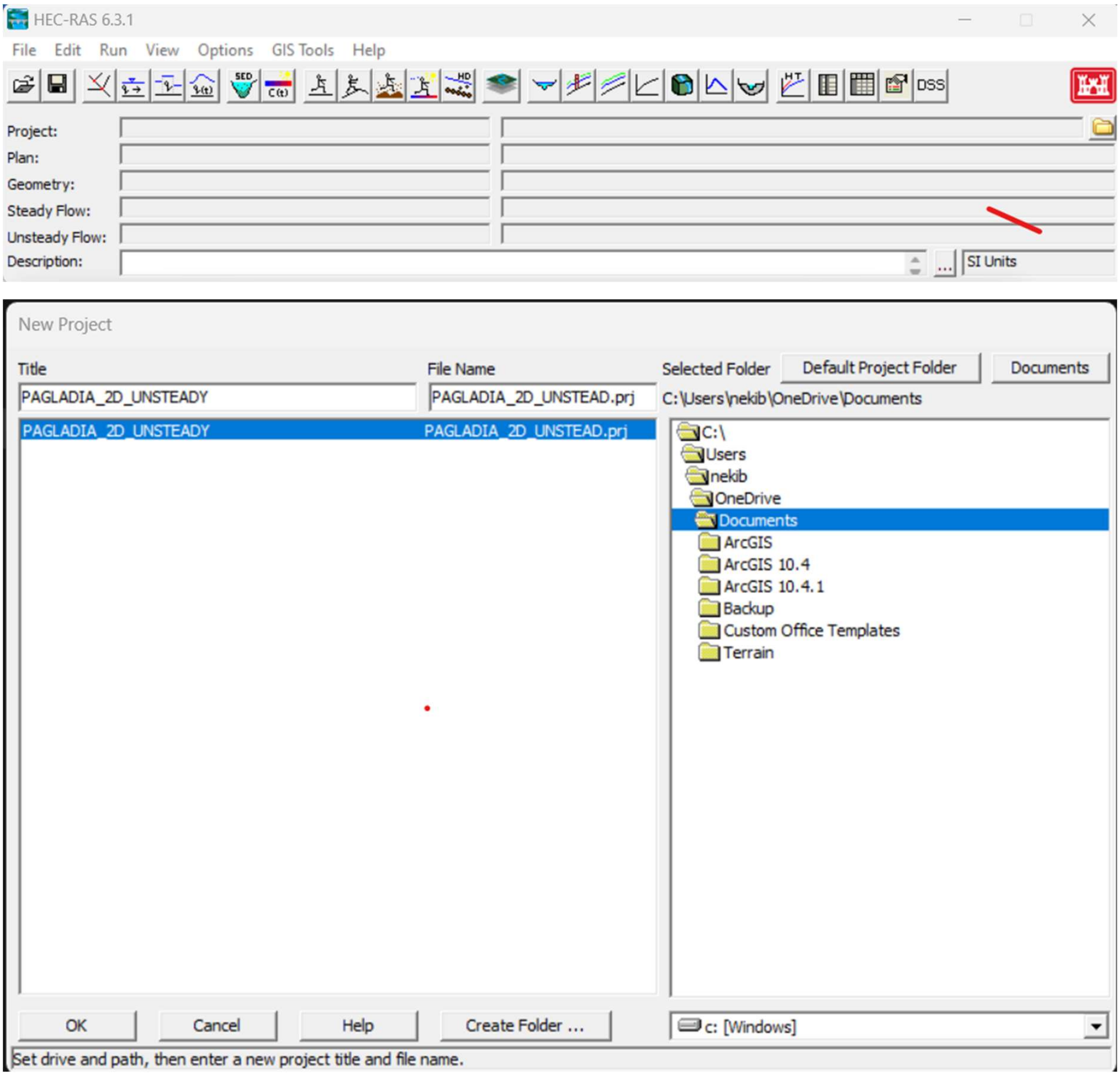


Fig 4.26: Creating a new project

   - Define the project's geographical location and coordinate system.

- Set up a 2D modelling analysis by selecting the "2D Flow Area" option.

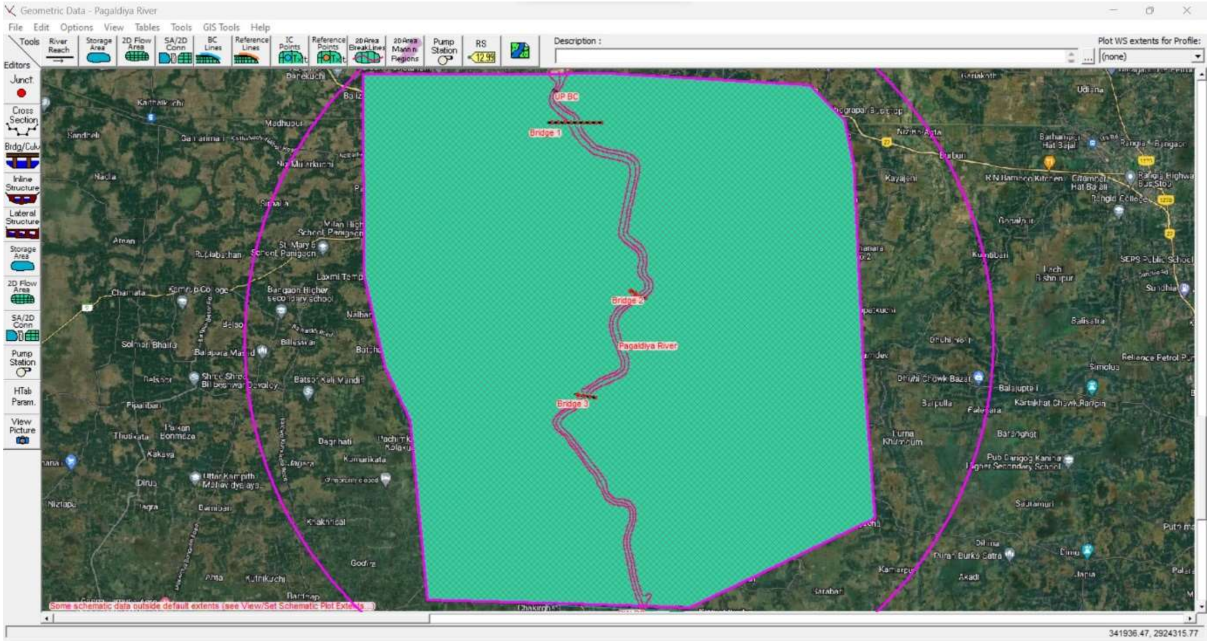


Fig 4.27: Setting up of 2D Flow Area

2. Define Geometry:

- Import or create a terrain elevation dataset (e.g., Digital Elevation Model or DEM) that represents the topography of the study area.
- Define cross sections and banks to create the geometry of the river or channel.

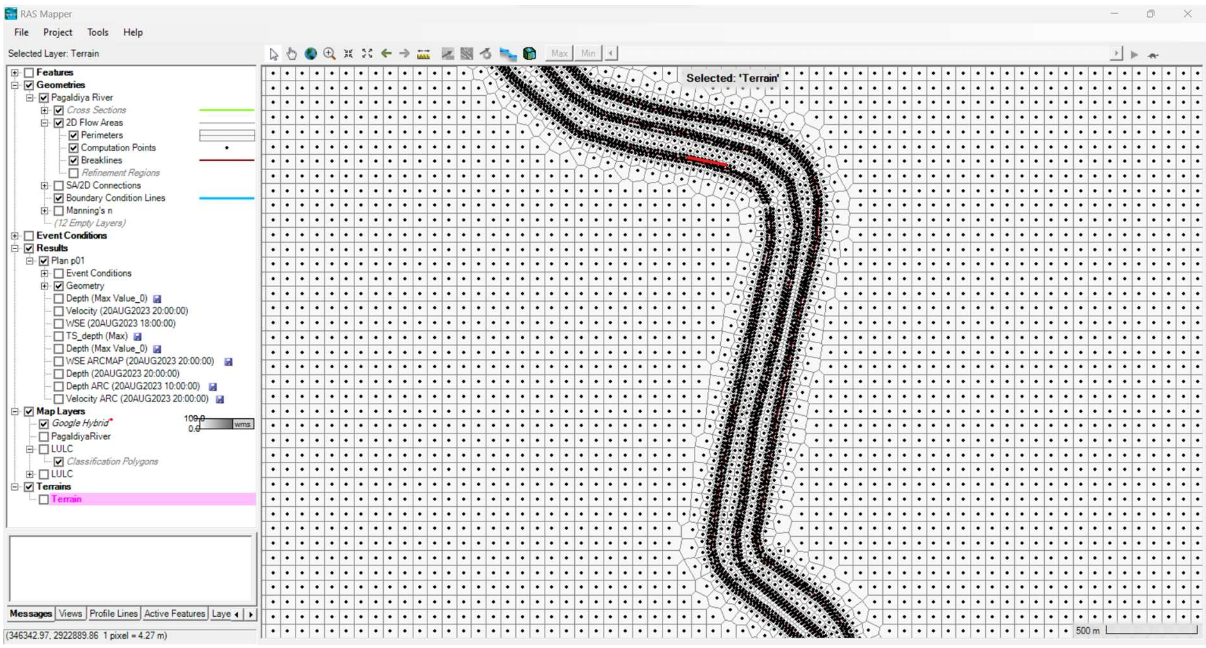


Fig 4.28: Defining the Left and Right Over Banks

3. **Define Hydraulic Structures:**
   - Add any structures that impact the flow, such as bridges, culverts, weirs, and levees.
   - Specify the characteristics of these structures, including dimensions, openings, and flow behaviour.

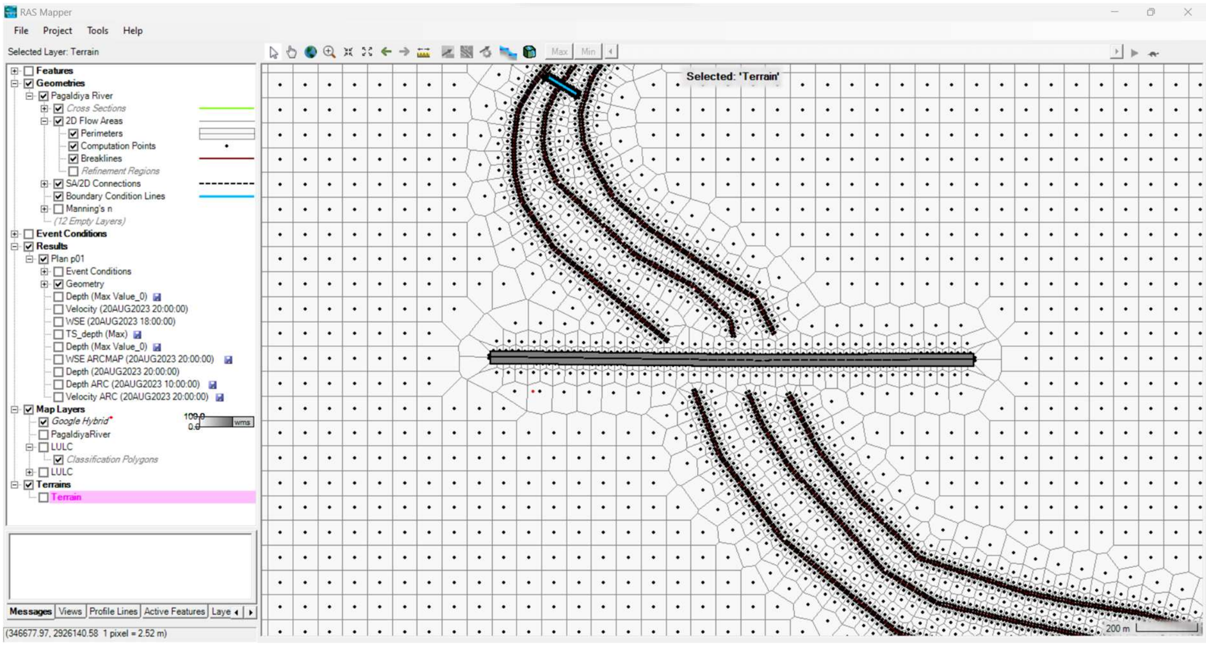


Fig 4.29: Setting up of Bridge

4. **Define Boundary Conditions:**
   - Set up upstream and downstream boundary conditions by specifying water levels, discharges, or hydrographs.
   - Define lateral boundary conditions if the model area is adjacent to other water bodies.

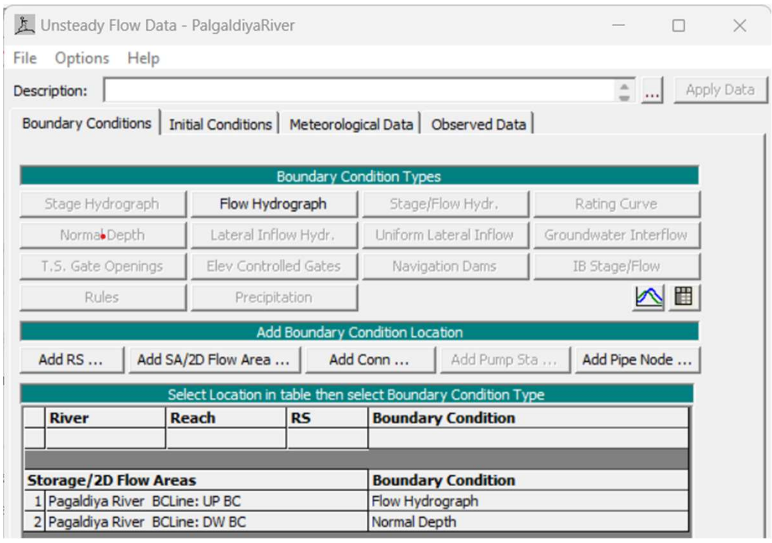


Fig 4.30: Defining Boundary Conditions

5. **Define Initial Conditions:**
   - Specify the initial water surface elevations within the modelling domain.
   - This step is crucial to provide a starting point for the analysis.
6. **Mesh Generation:**
   - Create a mesh or grid that discretizes the 2D modelling area.
   - HEC-RAS uses this mesh to solve the governing equations for flow.
7. **Define Roughness Coefficients:**
   - Assign Manning's roughness coefficients to different land use or surface types within the modelling area.
   - These coefficients influence the flow resistance and velocity distribution.

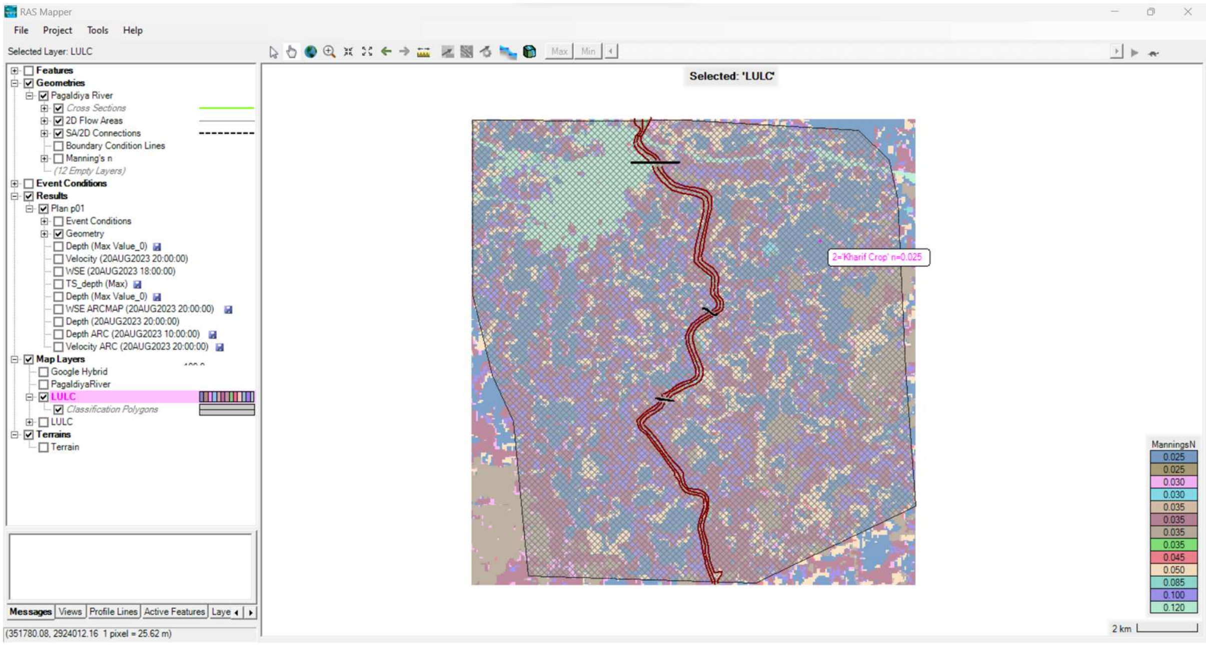


Fig 4.31: LULC Map in HEC-RAS

8. **Run the Simulation:**
   - Configure the simulation settings, such as time step, simulation duration, and numerical solver options.
   - Initiate the simulation and let HEC-RAS solve the 2D flow equations iteratively over time.

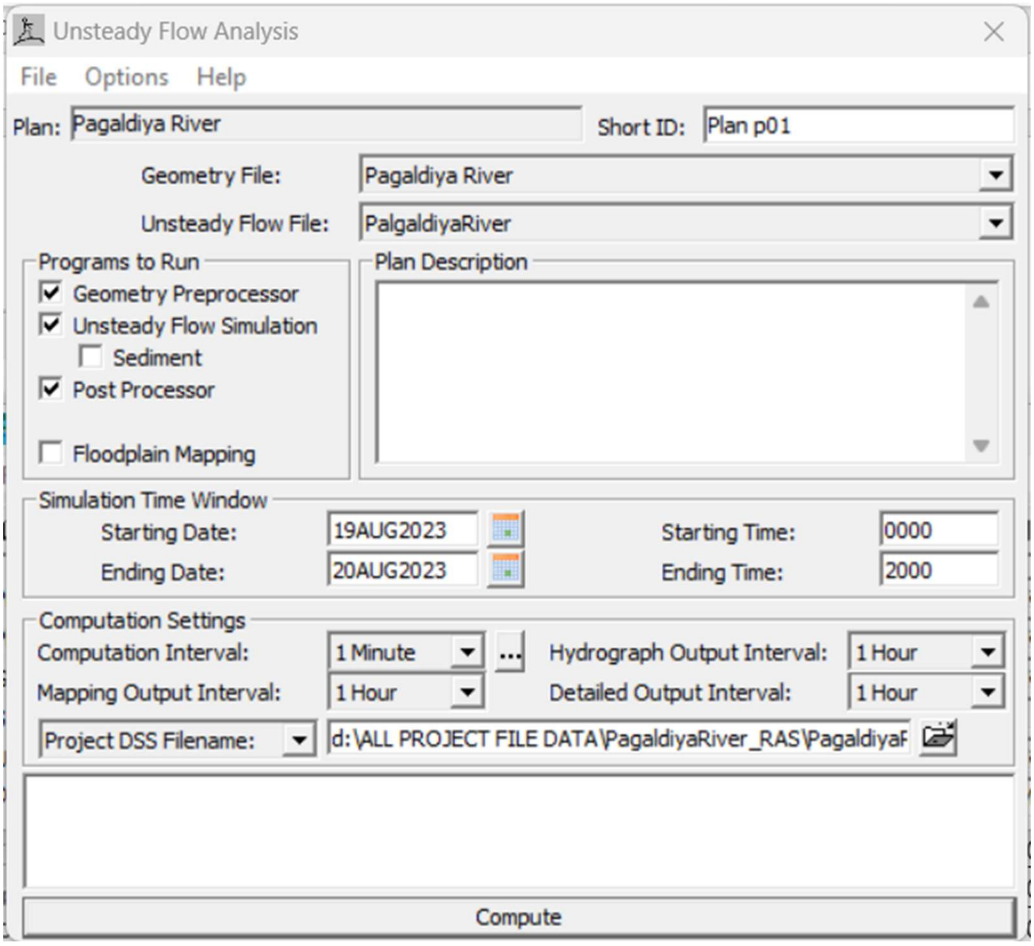


Fig 4.32: Simulation Run

9. Visualization and Analysis:

- Monitor the simulation progress and check for any convergence issues.
- Visualize results through water surface elevation plots, flow velocity vectors, inundation maps, and other relevant outputs.

10. Post-Processing and Interpretation:

- Analyse the simulation results to understand flow patterns, water levels, velocities, and potential flood extents.
- Extract key information for decision-making and reporting.

11. Model Calibration (Optional):

- Compare the simulation results with available observed data to validate the model's accuracy.
- Adjust parameters like roughness coefficients or boundary conditions to improve the model's match with reality.

Chapter 5

RESULTS AND DISCUSSION

5.1 RESULTS FROM HEC-HMS

Time series plot at 5-minute interval of 2 days is obtained from HEC-HMS

Table 5.1: Table showing the time series results for HEC-HMS

Date	Time	Inflow from Reach-1-EX (m3/s)	Inflow from Sub-1 (m3/s)	Outflow (m3/s)
19-Aug-23	00:00	0	0	0
19-Aug-23	00:05	0	0	0
19-Aug-23	00:10	0	0	0
19-Aug-23	00:15	0	0	0
19-Aug-23	00:20	0	0	0
19-Aug-23	00:25	0	0	0
19-Aug-23	00:30	0	0	0
19-Aug-23	00:35	0	0	0
19-Aug-23	00:40	0	0	0
19-Aug-23	00:45	0	0	0
19-Aug-23	00:50	0	0	0
19-Aug-23	00:55	0	0	0
19-Aug-23	01:00	0	0	0
19-Aug-23	01:05	0	0	0
19-Aug-23	01:10	0	0	0
19-Aug-23	01:15	0	0	0
19-Aug-23	01:20	0	0	0
19-Aug-23	01:25	0	0	0
19-Aug-23	01:30	0	0	0
19-Aug-23	01:35	0	0	0
19-Aug-23	01:40	0	0	0
19-Aug-23	01:45	0	0	0
19-Aug-23	01:50	0	0	0
19-Aug-23	01:55	0	0	0
19-Aug-23	02:00	0	0	0
19-Aug-23	02:05	0	0	0
19-Aug-23	02:10	0	0	0
				Continued in Appendix I

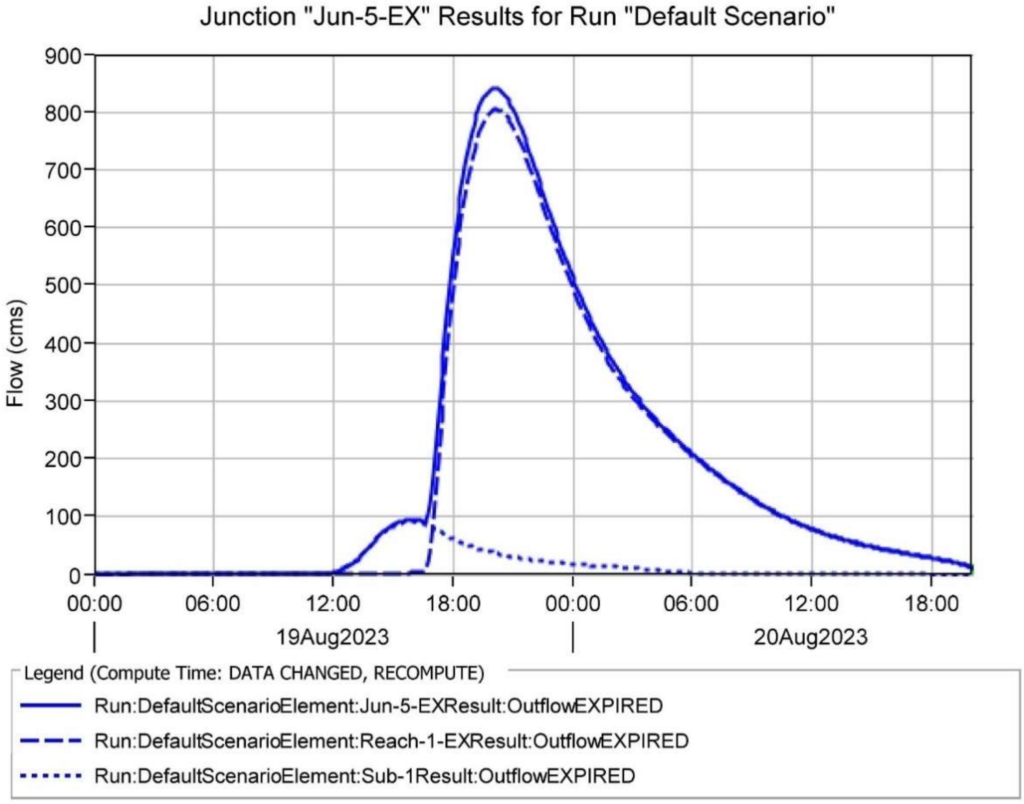


Fig 5.1: Hydrograph of downstream obtained from HEC-HMS

5.2 RESULTS FROM HEC RAS (1D MODEL):

After providing all the input parameters to the software for the computation, various outputs in terms of the table and the graphs are obtained such as the value of ground elevation, velocity head, water surface elevation, total velocity, max channel depth, losses, average velocity, wetted perimeter, etc. The rating curve is also determined i.e. graph between water surface height and discharge at the given surge at a given cross area. This gives the approximate idea about the water level at different release values.

The profile output table of steady flow analysis is shown below.

Table 5.2: Profile output table for steady flow analysis for Q_{avg} profile

Reach	***River Station***	***Profile***	***Q Total***	***Minimum Channel Elevation***	***Water Surface Elevation***	***Critical Water Surface***	***Energy Gradient Elevation***	***Energy Gradient Slope***	***Velocity Of Channel***	***Flow Area***	***Top Width***	***Froude No of the Channel***
			(m3/s)	***(m)***	***(m)***	***(m)***	***(m)***	***(m/m)***	***(m/s)***	***(m2)***	***(m)***	
Reach 1	12894	Qavg	361.89	56.02	57.07	57.07	57.44	0.011637	2.71	136.69	196.73	0.95
Reach 1	12448	Qavg	361.89	52.11	56.8	53.7	56.84	0.000147	0.8	461.11	140.46	0.14
Reach 1	11970	Qavg	361.89	51	56.79		56.8	0.000028	0.45	839.48	172.9	0.06
Reach 1	11419	Qavg	361.89	51.56	56.75		56.78	0.000088	0.74	517.76	123.4	0.11
Reach 1	10852	Qavg	361.89	51	56.71		56.73	0.000058	0.64	594.61	128.1	0.09
Reach 1	10320	Qavg	361.89	52.32	56.59		56.67	0.00033	1.32	294.05	75.8	0.21
Reach 1	9960	Qavg	361.89	52.78	55.87		56.32	0.005238	3.08	122.94	72.48	0.73
Reach 1	9584	Qavg	361.89	48	56.08		56.11	0.000068	0.81	479.27	84.4	0.1
Reach 1	9206	Qavg	361.89	51.44	56		56.07	0.000266	1.2	327.78	88.1	0.19
Reach 1	8706	Qavg	361.89	50.06	55.43		55.76	0.001877	2.6	145.88	52.96	0.47
Reach 1	8278	Qavg	361.89	50	55.49		55.53	0.000134	0.95	405.68	91.6	0.14
Reach 1	7874	Qavg	361.89	49	55.45		55.48	0.000098	0.77	492.12	120.6	0.12
Reach 1	7374	Qavg	361.89	49.74	55.4		55.43	0.000105	0.78	485.69	125.96	0.12
Reach 1	6896	Qavg	361.89	52	55.33		55.36	0.000179	0.81	460.85	157.5	0.15
Reach 1	6400	Qavg	361.89	51	55.27		55.3	0.0001	0.69	542	148.5	0.11

Reach	***River Station***	***Profile***	***Q Total***	***Minimum Channel Elevation***	***Water Surface Elevation***	***Critical Water Surface***	***Energy Gradient Elevation***	***Energy Gradient Slope***	***Velocity Of Channel***	***Flow Area***	***Top Width***	***Froude No of the Channel***
Reach 1	5617	Qavg	361.89	51.91	54.97		55.13	0.00111	1.85	208.38	88.1	0.36
Reach 1	5228	Qavg	361.89	51	54.28		54.5	0.00253	2.1	177.75	112.14	0.5
Reach 1	4704	Qavg	361.89	49.73	53.98		54.04	0.000373	1.11	336.96	137.93	0.21
Reach 1	4286	Qavg	361.89	49	53.86		53.91	0.000258	0.94	391.02	138.45	0.18
Reach 1	3873	Qavg	361.89	49.38	53.77		53.81	0.000206	0.92	399.47	124.32	0.16
Reach 1	3490	Qavg	361.89	49.27	53.72		53.75	0.000126	0.74	511.93	159.6	0.13
Reach 1	2951	Qavg	361.89	50	53.6		53.64	0.000294	0.99	382.5	145	0.19
Reach 1	2450	Qavg	361.89	50	53.51		53.54	0.000148	0.76	496.19	164.5	0.13
Reach 1	1968	Qavg	361.89	48.31	53.46		53.48	0.000083	0.63	587.53	176.34	0.1
Reach 1	1517	Qavg	361.89	50	53.09		53.35	0.002292	2.28	163.6	84.98	0.5
Reach 1	1069	Qavg	361.89	49.44	52.17		52.37	0.002021	2.02	181.41	99.44	0.46
Reach 1	591	Qavg	361.89	48	51.39		51.58	0.001378	1.93	191.68	88.63	0.39
Reach 1	262	Qavg	361.89	48.23	50.43		50.79	0.004899	2.64	137.05	90.16	0.68
Reach 1	59	Qavg	361.89	47.5	49.91	49.13	50.1	0.00218	1.91	189.84	110.97	0.47

Continued in Appendix II

5.3 RESULTS FROM HEC-RAS 2D MODELLING

2D HEC-RAS Map provides us these following datas.

- **Water Surface Profiles**: The most fundamental result is the water surface profile, which shows how the water level changes along the length of the river or channel.
- **Flood Extent Map**s: HEC-RAS 2D modelling allows us to generate floodplain maps that illustrate the extent of flooding for various water levels. These maps can be useful for emergency planning, land-use decisions, and risk assessment.
- **Velocity and Flow Distribution:** The model can provide information about flow velocity and direction across the study area. This can be important for assessing the potential for erosion, sediment transport, and habitat changes.
- **Inundation Depth:** HEC-RAS can calculate the depth of inundation at various locations within the floodplain. This information is useful for understanding the potential impact of a flood event on structures and infrastructure.
- **Animation:** Some visualization tools within HEC-RAS allow you to create animations of the simulated flow, which can be useful for presentations and conveying the results to stakeholders.

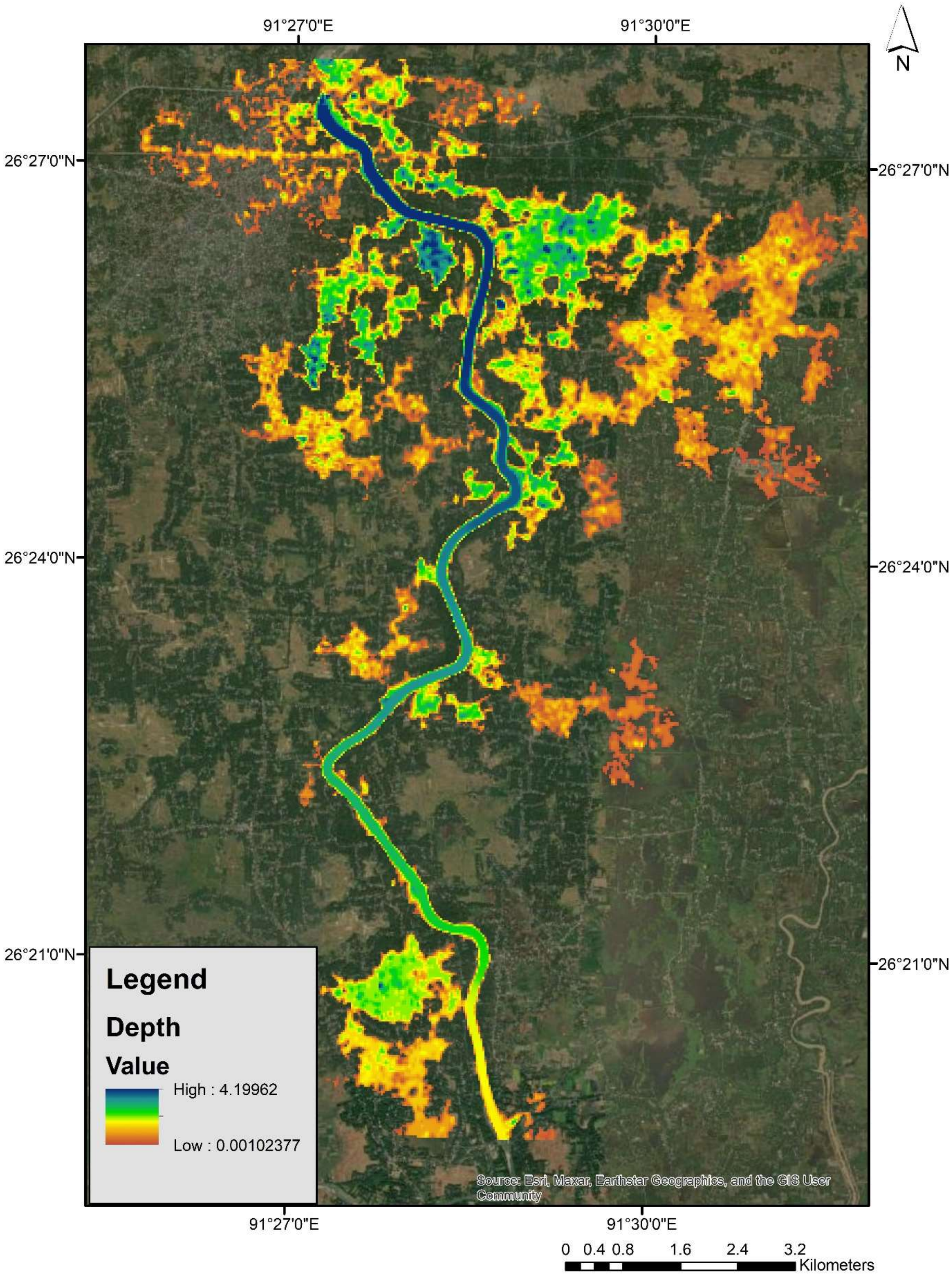


Fig 5.2: Flood inundation depth without Embankment

From the model it is clearly seen that due to 100-year return period flood, a part of Nalbari town gets inundated. In our study area the maximum depth of inundation is found out to be 4.19m.

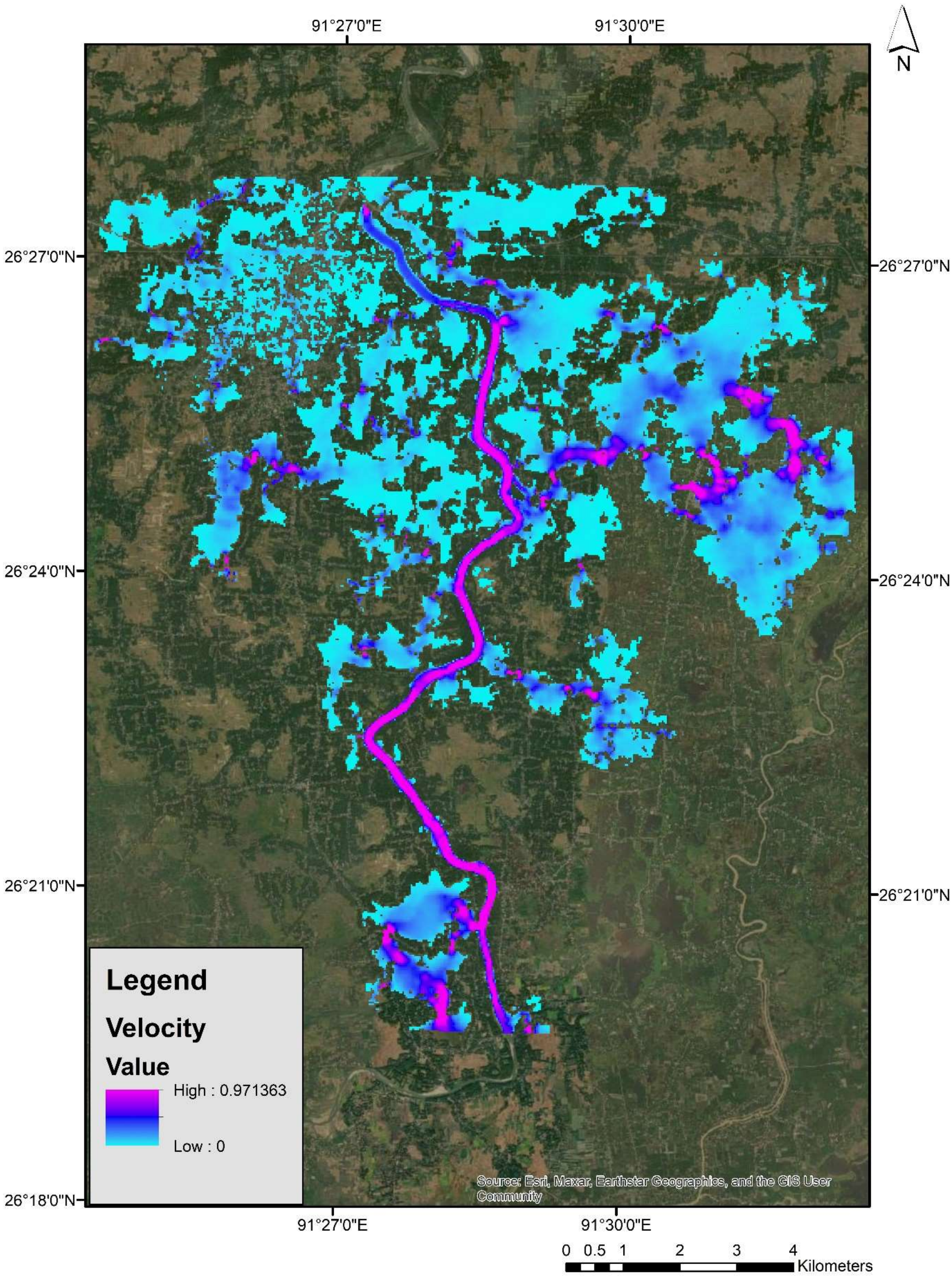


Fig 5.3: Velocity in different section in Study area

In this HEC-RAS model, the maximum velocity reached in our study area is 0.97m/s.

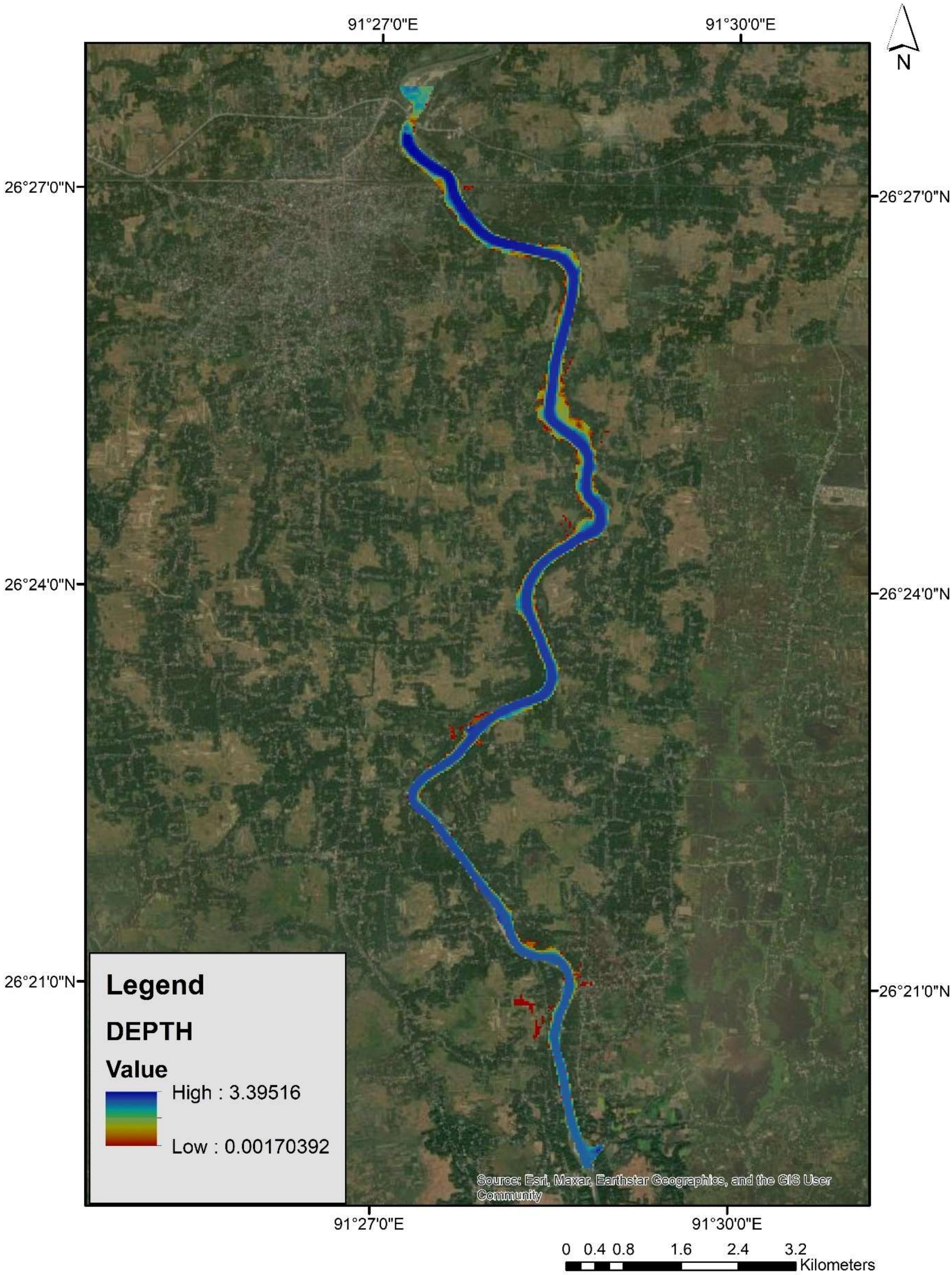


Fig 5.4: Depth Profile with Embankment

In this present figure, it is seen that after providing embankments, flood in contained in the channel only.

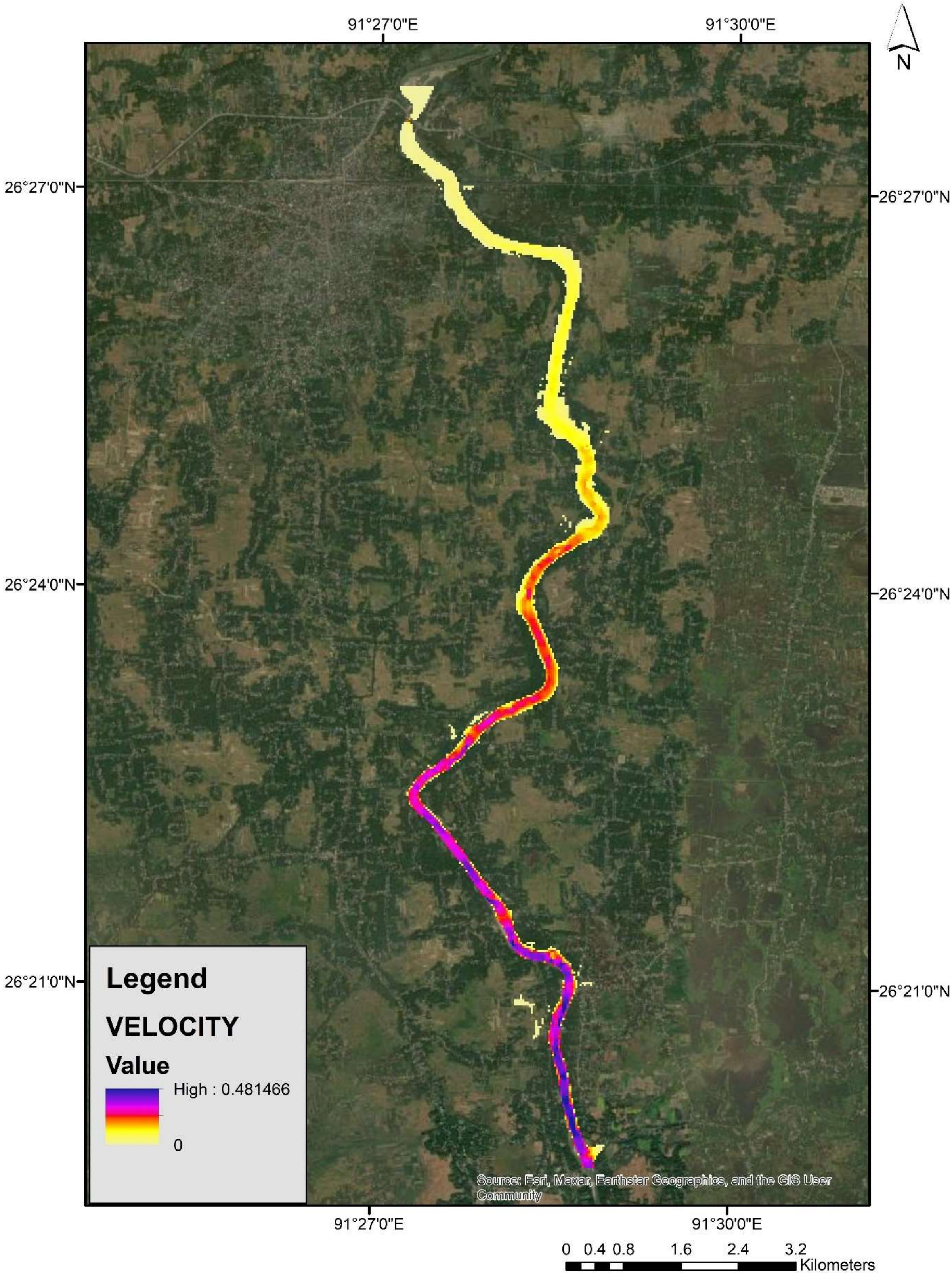


Fig 5.5: Velocity in different section in Study area after providing embankment

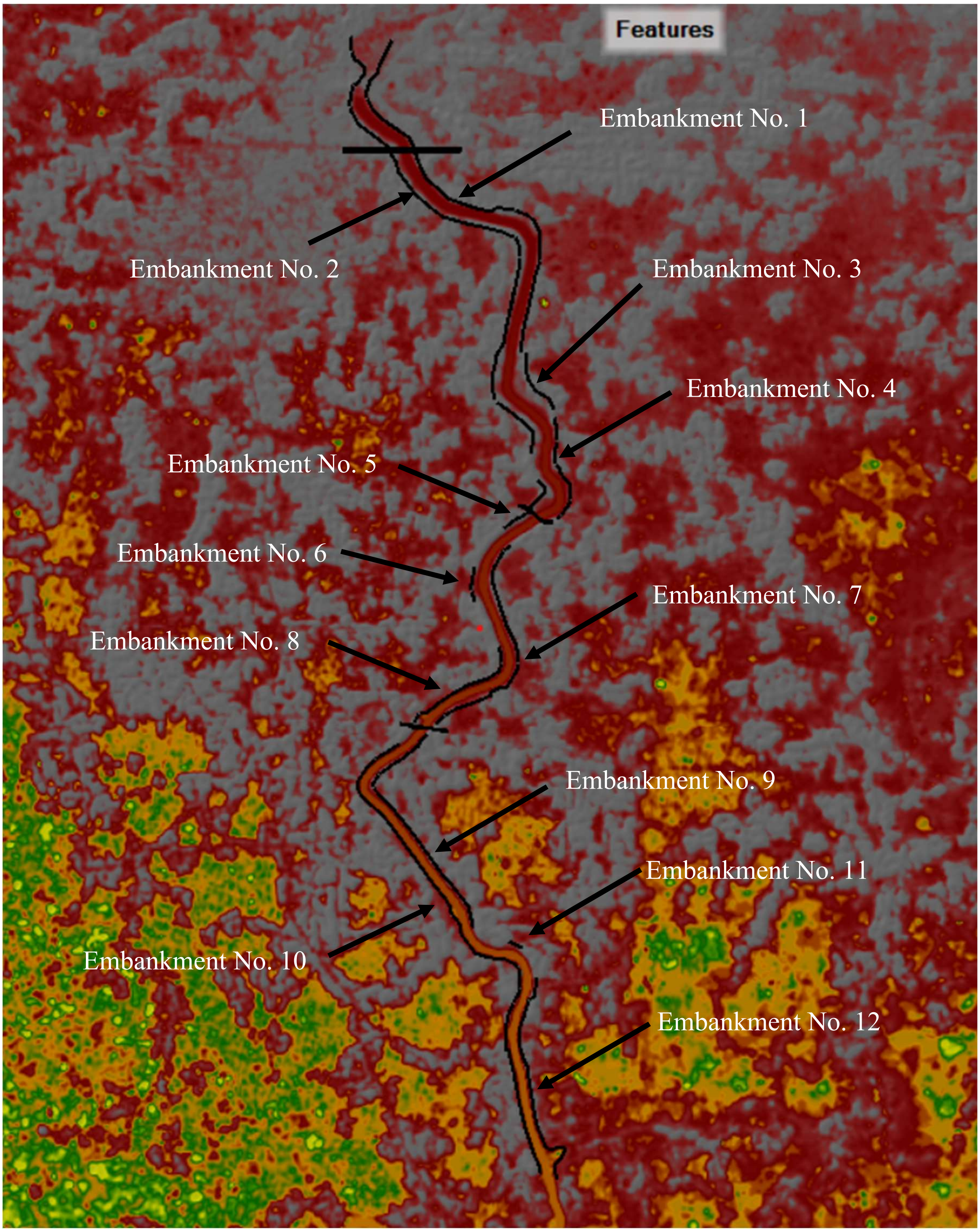


Fig 5.6: Probable suggested locations of embankments

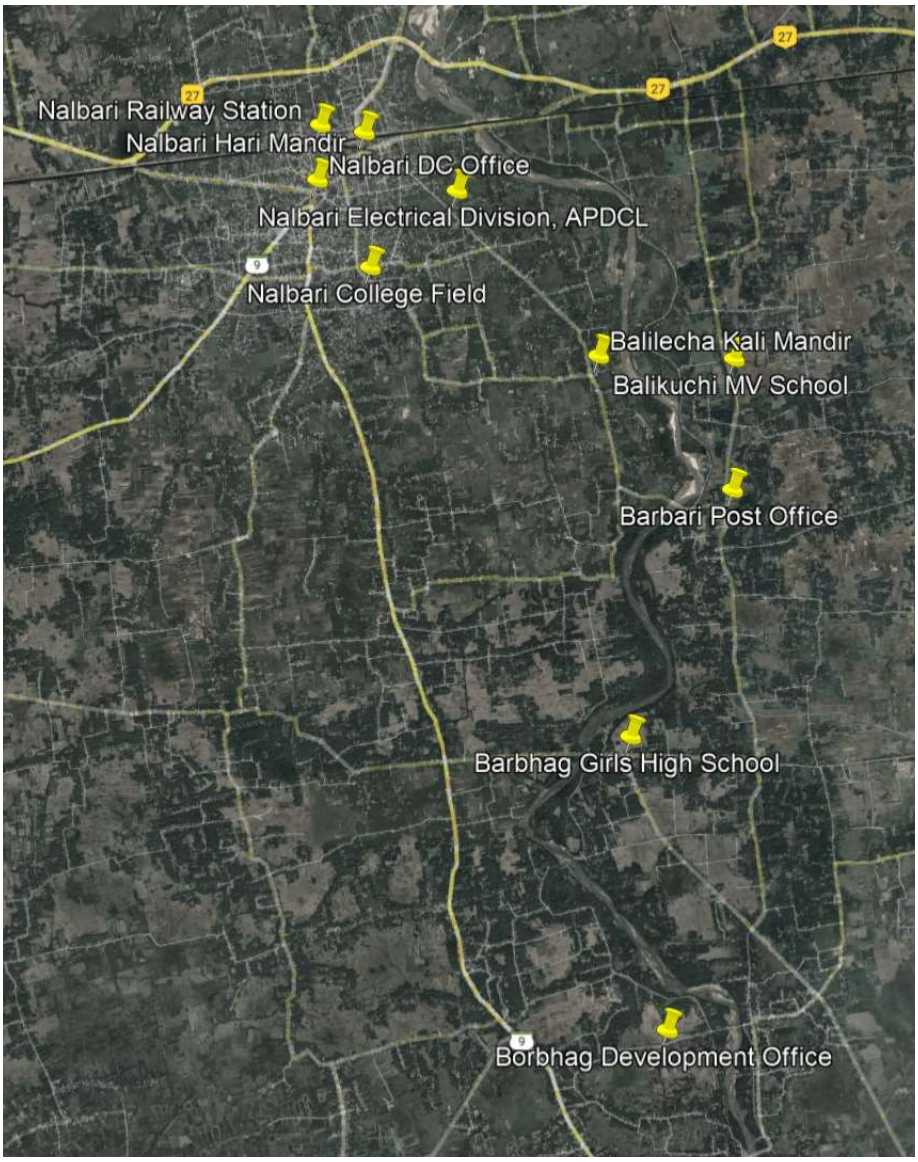


Fig 5.7: Some prominent points in my study area

Table 5.3: coordinates of Various Prominent Locations

Prominent Points	Coordinates	Flood Inundation Depth (m)
Nalbari Electrical Division, APDCL	Latitude: 26°26'31.17"N Longitude: 91°27'18.30"E	0.54
Nalbari Railway Station	Latitude: 26°27'3.76"N Longitude: 91°26'21.87"E	0.50

Prominent Points	Coordinates	Flood Inundation Depth (m)
Nalbari Hari Mandir	Latitude: 26°26'58.74"N Longitude: 91°26'40.70"E	0
Balilecha Kali Mandir	Latitude: 26°25'19.39"N Longitude: 91°28'11.53"E	0.17
Balikuchi MV School	Latitude: 26°25'11.69"N Longitude: 91°29'10.61"E	0.18
Barbari Post Office	Latitude: 26°24'20.53"N Longitude: 91°29'2.76"E	0.51
Nalbari College Field	Latitude: 26°26'5.16"N Longitude: 91°26'36.34"E	0.91
Barbhag Girls High School	Latitude: 26°22'49.23"N Longitude: 91°28'5.15"E	0.24
Borbhag Development Office	Latitude: 26°20'53.90"N Longitude: 91°28'5.49"E	0.44

Chapter 6

CONCLUSION

River Pagladia is one of the major tributaries in the northern bank of the mighty Brahmaputra River system. The Pagladia, as its name implies, has been a chronic source of trouble due to its frequent changing of flow course. The movement of the river into the land due to erosion resulted in the breaching of existing embankments, which is perceived as a threat to the mainland. So, it is essential to examine the Pagladia river’s flood susceptibility.

The numerical analysis programme HEC-RAS (Hydrologic Engineering Centre- River Analysis System) provides the finer details of flood profiles. To study the flood map in the area a 1D & 2D model has been prepared using HEC-RAS Software which will allow to have a better visualization of the flooding scenario of the river.

In this present study, from the HEC-HMS model we have obtained a flood hydrograph of 48 hours for 100-year return period having a peak discharge of 841 cubic meter per second. This flood hydrograph is used to build two 2D model, one with embankment and another without embankment in HEC-RAS from which we obtained various results like water surface elevation, inundation depth and velocity at different locations in our study area. From these two models we found that out of the total 19338.508 hectares study area, 3972 hectares land gets inundated. Hence to protect the area from flooding we can provide embankment of height up to 5.4m so that flood water does not overtop the bank.

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APPENDIX I

Table 5.1: Table showing the time series results for HEC-HMS

Date	Time	Inflow from Reach-1-EX (m3/s)	Inflow from Sub-1 (m3/s)	Outflow (m3/s)
19-Aug-23	02:15	0	0	0
19-Aug-23	02:20	0	0	0
19-Aug-23	02:25	0	0	0
19-Aug-23	02:30	0	0	0
19-Aug-23	02:35	0	0	0
19-Aug-23	02:40	0	0	0
19-Aug-23	02:45	0	0	0
19-Aug-23	02:50	0	0	0
19-Aug-23	02:55	0	0	0
19-Aug-23	03:00	0	0	0
19-Aug-23	03:05	0	0	0
19-Aug-23	03:10	0	0	0
19-Aug-23	03:15	0	0	0
19-Aug-23	03:20	0	0	0
19-Aug-23	03:25	0	0	0
19-Aug-23	03:30	0	0	0
19-Aug-23	03:35	0	0	0
19-Aug-23	03:40	0	0	0
19-Aug-23	03:45	0	0	0
19-Aug-23	03:50	0	0	0
19-Aug-23	03:55	0	0	0
19-Aug-23	04:00	0	0	0
19-Aug-23	04:05	0	0	0
19-Aug-23	04:10	0	0	0
19-Aug-23	04:15	0	0	0
19-Aug-23	04:20	0	0	0
19-Aug-23	04:25	0	0	0
19-Aug-23	04:30	0	0	0
19-Aug-23	04:35	0	0	0
19-Aug-23	04:40	0	0	0
19-Aug-23	04:45	0	0	0
19-Aug-23	04:50	0	0	0
19-Aug-23	04:55	0	0	0
19-Aug-23	05:00	0	0	0
19-Aug-23	05:05	0	0	0
19-Aug-23	05:10	0	0	0

Date	Time	Inflow from Reach-1-EX (m3/s)	Inflow from Sub-1 (m3/s)	Outflow (m3/s)
19-Aug-23	05:20	0	0	0
19-Aug-23	05:25	0	0	0
19-Aug-23	05:35	0	0	0
19-Aug-23	05:40	0	0	0
19-Aug-23	05:45	0	0	0
19-Aug-23	05:50	0	0	0
19-Aug-23	05:55	0	0	0
19-Aug-23	06:00	0	0	0
19-Aug-23	06:05	0	0	0
19-Aug-23	06:10	0	0	0
19-Aug-23	06:15	0	0	0
19-Aug-23	06:20	0	0	0
19-Aug-23	06:25	0	0	0
19-Aug-23	06:30	0	0	0
19-Aug-23	06:35	0	0	0
19-Aug-23	06:40	0	0	0
19-Aug-23	06:45	0	0	0
19-Aug-23	06:50	0	0	0
19-Aug-23	06:55	0	0	0
19-Aug-23	07:00	0	0	0
19-Aug-23	07:05	0	0	0
19-Aug-23	07:10	0	0	0
19-Aug-23	07:15	0	0	0
19-Aug-23	07:20	0	0	0
19-Aug-23	07:25	0	0	0
19-Aug-23	07:30	0	0	0
19-Aug-23	07:35	0	0	0
19-Aug-23	07:40	0	0	0
19-Aug-23	07:45	0	0	0
19-Aug-23	07:50	0	0	0
19-Aug-23	07:55	0	0	0
19-Aug-23	08:00	0	0	0
19-Aug-23	08:05	0	0	0
19-Aug-23	08:10	0	0	0
19-Aug-23	08:15	0	0	0
19-Aug-23	08:20	0	0	0
19-Aug-23	08:25	0	0	0
19-Aug-23	08:30	0	0	0.1
19-Aug-23	08:35	0	0	0.1
19-Aug-23	08:40	0	0	0.1
19-Aug-23	08:45	0	0	0.1

Date	Time	Inflow from Reach-1-EX (m3/s)	Inflow from Sub-1 (m3/s)	Outflow (m3/s)
19-Aug-23	08:55	0.1	0	0.1
19-Aug-23	09:05	0.1	0	0.1
19-Aug-23	09:10	0.1	0	0.1
19-Aug-23	09:15	0.1	0	0.1
19-Aug-23	09:20	0.1	0	0.1
19-Aug-23	09:25	0.1	0.1	0.1
19-Aug-23	09:30	0.1	0.1	0.2
19-Aug-23	09:35	0.1	0.1	0.2
19-Aug-23	09:40	0.1	0.1	0.2
19-Aug-23	09:45	0.1	0.1	0.2
19-Aug-23	09:50	0.1	0.1	0.2
19-Aug-23	09:55	0.1	0.1	0.3
19-Aug-23	10:00	0.1	0.2	0.3
19-Aug-23	10:05	0.1	0.2	0.3
19-Aug-23	10:10	0.1	0.2	0.3
19-Aug-23	10:15	0.1	0.2	0.4
19-Aug-23	10:20	0.1	0.3	0.4
19-Aug-23	10:25	0.1	0.3	0.5
19-Aug-23	10:30	0.1	0.4	0.5
19-Aug-23	10:35	0.2	0.4	0.6
19-Aug-23	10:40	0.2	0.5	0.6
19-Aug-23	10:45	0.2	0.5	0.7
19-Aug-23	10:50	0.2	0.6	0.8
19-Aug-23	10:55	0.2	0.7	0.9
19-Aug-23	11:00	0.2	0.8	0.9
19-Aug-23	11:05	0.2	0.9	1
19-Aug-23	11:10	0.2	1	1.2
19-Aug-23	11:15	0.2	1.1	1.3
19-Aug-23	11:20	0.2	1.2	1.4
19-Aug-23	11:25	0.2	1.3	1.5
19-Aug-23	11:30	0.2	1.5	1.7
19-Aug-23	11:35	0.2	1.7	1.9
19-Aug-23	11:40	0.2	1.9	2.1
19-Aug-23	11:45	0.2	2.1	2.3
19-Aug-23	11:50	0.2	2.5	2.7
19-Aug-23	11:55	0.2	2.9	3.1
19-Aug-23	12:00	0.2	3.5	3.8
19-Aug-23	12:05	0.2	4.2	4.5
19-Aug-23	12:10	0.2	5.1	5.3
19-Aug-23	12:15	0.2	6.1	6.3
19-Aug-23	12:20	0.2	7.3	7.5

Date	Time	Inflow from Reach-1-EX (m3/s)	Inflow from Sub-1 (m3/s)	Outflow (m3/s)
19-Aug-23	12:35	0.3	11.5	11.7
19-Aug-23	12:40	0.3	13.1	13.3
19-Aug-23	12:45	0.3	14.7	15
19-Aug-23	12:50	0.3	16.5	16.8
19-Aug-23	12:55	0.3	18.4	18.7
19-Aug-23	13:00	0.3	20.5	20.8
19-Aug-23	13:05	0.3	22.6	23
19-Aug-23	13:10	0.3	24.9	25.3
19-Aug-23	13:15	0.4	27.4	27.8
19-Aug-23	13:20	0.4	30	30.4
19-Aug-23	13:25	0.4	32.8	33.2
19-Aug-23	13:30	0.4	35.7	36.1
19-Aug-23	13:35	0.5	38.7	39.2
19-Aug-23	13:40	0.5	41.9	42.4
19-Aug-23	13:45	0.5	45.2	45.7
19-Aug-23	13:50	0.5	48.6	49.1
19-Aug-23	13:55	0.6	51.9	52.5
19-Aug-23	14:00	0.6	55.3	55.9
19-Aug-23	14:05	0.7	58.5	59.2
19-Aug-23	14:10	0.7	61.6	62.4
19-Aug-23	14:15	0.8	64.6	65.4
19-Aug-23	14:20	0.8	67.5	68.3
19-Aug-23	14:25	0.9	70.2	71.1
19-Aug-23	14:30	1	72.7	73.7
19-Aug-23	14:35	1.1	75.1	76.1
19-Aug-23	14:40	1.1	77.3	78.5
19-Aug-23	14:45	1.2	79.4	80.6
19-Aug-23	14:50	1.3	81.2	82.6
19-Aug-23	14:55	1.4	82.9	84.4
19-Aug-23	15:00	1.5	84.4	86
19-Aug-23	15:05	1.7	85.7	87.4
19-Aug-23	15:10	1.8	86.9	88.6
19-Aug-23	15:15	1.9	87.8	89.7
19-Aug-23	15:20	2.1	88.6	90.7
19-Aug-23	15:25	2.2	89.4	91.6
19-Aug-23	15:30	2.4	90	92.4
19-Aug-23	15:35	2.6	90.5	93.1
19-Aug-23	15:40	2.7	90.9	93.7
19-Aug-23	15:45	2.9	91.1	94.1
19-Aug-23	15:50	3.2	91.1	94.3
19-Aug-23	15:55	3.4	91	94.3

Date	Time	Inflow from Reach-1-EX (m3/s)	Inflow from Sub-1 (m3/s)	Outflow (m3/s)
19-Aug-23	16:05	3.9	90.1	94
19-Aug-23	16:10	4.2	89.6	93.7
19-Aug-23	16:15	4.5	88.9	93.4
19-Aug-23	16:20	4.9	88.3	93.1
19-Aug-23	16:25	5.3	87.5	92.8
19-Aug-23	16:30	5.9	86.7	92.6
19-Aug-23	16:35	7	85.9	92.8
19-Aug-23	16:40	9.9	84.9	94.8
19-Aug-23	16:45	19.7	83.9	103.6
19-Aug-23	16:50	37.6	82.8	120.4
19-Aug-23	16:55	62.3	81.6	143.9
19-Aug-23	17:00	92.2	80.3	172.5
19-Aug-23	17:05	125.5	79	204.4
19-Aug-23	17:10	160.9	77.5	238.3
19-Aug-23	17:15	197.3	75.9	273.2
19-Aug-23	17:20	234.1	74.2	308.3
19-Aug-23	17:25	270.6	72.5	343.1
19-Aug-23	17:30	306.5	70.7	377.2
19-Aug-23	17:35	341.4	69	410.4
19-Aug-23	17:40	375.1	67.3	442.4
19-Aug-23	17:45	407.6	65.6	473.2
19-Aug-23	17:50	438.6	64	502.6
19-Aug-23	17:55	468.2	62.5	530.7
19-Aug-23	18:00	496.3	61.1	557.4
19-Aug-23	18:05	522.9	59.7	582.7
19-Aug-23	18:10	548.1	58.5	606.6
19-Aug-23	18:15	571.8	57.2	629.1
19-Aug-23	18:20	594.2	56	650.2
19-Aug-23	18:25	615.2	54.8	670
19-Aug-23	18:30	634.8	53.7	688.5
19-Aug-23	18:35	653.2	52.6	705.7
19-Aug-23	18:40	670.3	51.5	721.7
19-Aug-23	18:45	686.2	50.4	736.6
19-Aug-23	18:50	700.9	49.4	750.3
19-Aug-23	18:55	714.6	48.4	762.9
19-Aug-23	19:00	727.1	47.4	774.5
19-Aug-23	19:05	738.6	46.5	785
19-Aug-23	19:10	749	45.6	794.6
19-Aug-23	19:15	758.4	44.7	803.2
19-Aug-23	19:20	766.9	43.9	810.8
19-Aug-23	19:25	774.5	43.1	817.5

Date	Time	Inflow from Reach-1-EX (m3/s)	Inflow from Sub-1 (m3/s)	Outflow (m3/s)
19-Aug-23	19:35	786.8	41.5	828.3
19-Aug-23	19:40	791.7	40.7	832.5
19-Aug-23	19:45	795.7	40	835.7
19-Aug-23	19:50	799	39.3	838.2
19-Aug-23	19:55	801.4	38.5	839.9
19-Aug-23	20:00	803.1	37.8	840.9
19-Aug-23	20:05	804	37.1	841.1
19-Aug-23	20:10	804.2	36.4	840.6
19-Aug-23	20:15	803.8	35.7	839.5
19-Aug-23	20:20	802.6	35	837.7
19-Aug-23	20:25	800.9	34.4	835.3
19-Aug-23	20:30	798.5	33.8	832.3
19-Aug-23	20:35	795.6	33.1	828.8
19-Aug-23	20:40	792.2	32.6	824.7
19-Aug-23	20:45	788.2	32	820.2
19-Aug-23	20:50	783.8	31.5	815.2
19-Aug-23	20:55	778.9	30.9	809.8
19-Aug-23	21:00	773.6	30.4	804
19-Aug-23	21:05	767.9	29.9	797.8
19-Aug-23	21:10	761.9	29.4	791.3
19-Aug-23	21:15	755.5	28.9	784.4
19-Aug-23	21:20	748.8	28.4	777.3
19-Aug-23	21:25	741.9	28	769.9
19-Aug-23	21:30	734.7	27.5	762.2
19-Aug-23	21:35	727.3	27.1	754.4
19-Aug-23	21:40	719.7	26.6	746.3
19-Aug-23	21:45	711.9	26.2	738.1
19-Aug-23	21:50	703.9	25.8	729.7
19-Aug-23	21:55	695.9	25.4	721.3
19-Aug-23	22:00	687.7	25	712.7
19-Aug-23	22:05	679.5	24.6	704
19-Aug-23	22:10	671.1	24.2	695.3
19-Aug-23	22:15	662.7	23.8	686.6
19-Aug-23	22:20	654.3	23.5	677.8
19-Aug-23	22:25	645.9	23.1	669
19-Aug-23	22:30	637.4	22.8	660.2
19-Aug-23	22:35	629	22.4	651.4
19-Aug-23	22:40	620.5	22.1	642.6
19-Aug-23	22:45	612.1	21.8	633.9
19-Aug-23	22:50	603.8	21.5	625.2
19-Aug-23	22:55	595.4	21.2	616.6

Date	Time	Inflow from Reach-1-EX (m3/s)	Inflow from Sub-1 (m3/s)	Outflow (m3/s)
19-Aug-23	23:05	579	20.6	599.6
19-Aug-23	23:10	570.8	20.3	591.2
19-Aug-23	23:15	562.8	20.1	582.9
19-Aug-23	23:20	554.8	19.8	574.6
19-Aug-23	23:25	546.9	19.6	566.5
19-Aug-23	23:30	539.1	19.3	558.5
19-Aug-23	23:35	531.4	19.1	550.5
19-Aug-23	23:40	523.9	18.8	542.7
19-Aug-23	23:45	516.4	18.6	535
19-Aug-23	23:50	509	18.4	527.3
19-Aug-23	23:55	501.7	18.2	519.8
20-Aug-23	00:00	494.5	18	512.5
20-Aug-23	00:05	487.4	17.7	505.2
20-Aug-23	00:10	480.5	17.5	498
20-Aug-23	00:15	473.7	17.3	491
20-Aug-23	00:20	466.9	17.2	484.1
20-Aug-23	00:25	460.3	17	477.3
20-Aug-23	00:30	453.8	16.8	470.6
20-Aug-23	00:35	447.4	16.6	464
20-Aug-23	00:40	441.1	16.4	457.5
20-Aug-23	00:45	434.9	16.2	451.2
20-Aug-23	00:50	428.9	16	444.9
20-Aug-23	00:55	422.9	15.8	438.8
20-Aug-23	01:00	417.1	15.7	432.7
20-Aug-23	01:05	411.3	15.5	426.8
20-Aug-23	01:10	405.7	15.3	421
20-Aug-23	01:15	400.2	15.1	415.3
20-Aug-23	01:20	394.8	14.9	409.7
20-Aug-23	01:25	389.5	14.7	404.2
20-Aug-23	01:30	384.2	14.5	398.8
20-Aug-23	01:35	379.1	14.3	393.5
20-Aug-23	01:40	374.1	14.2	388.3
20-Aug-23	01:45	369.2	14	383.1
20-Aug-23	01:50	364.4	13.7	378.1
20-Aug-23	01:55	359.6	13.5	373.2
20-Aug-23	02:00	355	13.3	368.3
20-Aug-23	02:05	350.5	13.1	363.6
20-Aug-23	02:10	346	12.9	358.9
20-Aug-23	02:15	341.6	12.6	354.3
20-Aug-23	02:20	337.4	12.4	349.8
20-Aug-23	02:25	333.2	12.2	345.3

Date	Time	Inflow from Reach-1-EX (m3/s)	Inflow from Sub-1 (m3/s)	Outflow (m3/s)
20-Aug-23	02:35	325	11.7	336.7
20-Aug-23	02:40	321.1	11.4	332.5
20-Aug-23	02:45	317.2	11.2	328.3
20-Aug-23	02:50	313.4	10.9	324.3
20-Aug-23	02:55	309.6	10.7	320.3
20-Aug-23	03:00	306	10.4	316.4
20-Aug-23	03:05	302.4	10.1	312.5
20-Aug-23	03:10	298.8	9.9	308.7
20-Aug-23	03:15	295.4	9.6	305
20-Aug-23	03:20	292	9.4	301.3
20-Aug-23	03:25	288.6	9.1	297.7
20-Aug-23	03:30	285.3	8.8	294.2
20-Aug-23	03:35	282.1	8.6	290.7
20-Aug-23	03:40	278.9	8.3	287.3
20-Aug-23	03:45	275.8	8.1	283.9
20-Aug-23	03:50	272.7	7.8	280.6
20-Aug-23	03:55	269.7	7.6	277.3
20-Aug-23	04:00	266.7	7.4	274.1
20-Aug-23	04:05	263.8	7.1	270.9
20-Aug-23	04:10	260.9	6.9	267.8
20-Aug-23	04:15	258	6.6	264.7
20-Aug-23	04:20	255.2	6.4	261.6
20-Aug-23	04:25	252.5	6.2	258.6
20-Aug-23	04:30	249.7	6	255.7
20-Aug-23	04:35	247	5.8	252.8
20-Aug-23	04:40	244.3	5.5	249.9
20-Aug-23	04:45	241.7	5.3	247
20-Aug-23	04:50	239.1	5.1	244.2
20-Aug-23	04:55	236.5	4.9	241.4
20-Aug-23	05:00	234	4.7	238.7
20-Aug-23	05:05	231.4	4.5	236
20-Aug-23	05:10	228.9	4.4	233.3
20-Aug-23	05:15	226.4	4.2	230.6
20-Aug-23	05:20	224	4	228
20-Aug-23	05:25	221.5	3.8	225.4
20-Aug-23	05:30	219.1	3.7	222.8
20-Aug-23	05:35	216.7	3.5	220.2
20-Aug-23	05:40	214.3	3.4	217.7
20-Aug-23	05:45	211.9	3.2	215.2
20-Aug-23	05:50	209.6	3.1	212.7
20-Aug-23	05:55	207.2	3	210.2

Date	Time	Inflow from Reach-1-EX (m3/s)	Inflow from Sub-1 (m3/s)	Outflow (m3/s)
20-Aug-23	06:05	202.6	2.8	205.3
20-Aug-23	06:10	200.3	2.6	202.9
20-Aug-23	06:15	198	2.5	200.5
20-Aug-23	06:20	195.7	2.4	198.1
20-Aug-23	06:25	193.4	2.4	195.8
20-Aug-23	06:30	191.2	2.3	193.4
20-Aug-23	06:35	188.9	2.2	191.1
20-Aug-23	06:40	186.7	2.1	188.8
20-Aug-23	06:45	184.5	2	186.5
20-Aug-23	06:50	182.3	1.9	184.2
20-Aug-23	06:55	180.1	1.9	181.9
20-Aug-23	07:00	177.9	1.8	179.7
20-Aug-23	07:05	175.7	1.7	177.5
20-Aug-23	07:10	173.6	1.7	175.2
20-Aug-23	07:15	171.4	1.6	173
20-Aug-23	07:20	169.3	1.5	170.8
20-Aug-23	07:25	167.2	1.5	168.7
20-Aug-23	07:30	165.1	1.4	166.5
20-Aug-23	07:35	163	1.4	164.4
20-Aug-23	07:40	160.9	1.3	162.2
20-Aug-23	07:45	158.8	1.3	160.1
20-Aug-23	07:50	156.8	1.2	158
20-Aug-23	07:55	154.8	1.2	155.9
20-Aug-23	08:00	152.7	1.1	153.9
20-Aug-23	08:05	150.7	1.1	151.8
20-Aug-23	08:10	148.7	1	149.8
20-Aug-23	08:15	146.8	1	147.8
20-Aug-23	08:20	144.8	1	145.8
20-Aug-23	08:25	142.9	0.9	143.8
20-Aug-23	08:30	141	0.9	141.9
20-Aug-23	08:35	139.1	0.9	139.9
20-Aug-23	08:40	137.2	0.8	138
20-Aug-23	08:45	135.3	0.8	136.1
20-Aug-23	08:50	133.5	0.8	134.2
20-Aug-23	08:55	131.6	0.7	132.4
20-Aug-23	09:00	129.8	0.7	130.5
20-Aug-23	09:05	128	0.7	128.7
20-Aug-23	09:10	126.3	0.7	126.9
20-Aug-23	09:15	124.5	0.6	125.1
20-Aug-23	09:20	122.8	0.6	123.4
20-Aug-23	09:25	121.1	0.6	121.6

Date	Time	Inflow from Reach-1-EX (m3/s)	Inflow from Sub-1 (m3/s)	Outflow (m3/s)
20-Aug-23	09:35	117.7	0.5	118.2
20-Aug-23	09:40	116	0.5	116.6
20-Aug-23	09:45	114.4	0.5	114.9
20-Aug-23	09:50	112.8	0.5	113.3
20-Aug-23	09:55	111.2	0.5	111.7
20-Aug-23	10:00	109.6	0.4	110.1
20-Aug-23	10:05	108.1	0.4	108.5
20-Aug-23	10:10	106.6	0.4	107
20-Aug-23	10:15	105	0.4	105.4
20-Aug-23	10:20	103.6	0.4	103.9
20-Aug-23	10:25	102.1	0.4	102.5
20-Aug-23	10:30	100.6	0.3	101
20-Aug-23	10:35	99.2	0.3	99.5
20-Aug-23	10:40	97.8	0.3	98.1
20-Aug-23	10:45	96.4	0.3	96.7
20-Aug-23	10:50	95.1	0.3	95.4
20-Aug-23	10:55	93.7	0.3	94
20-Aug-23	11:00	92.4	0.3	92.7
20-Aug-23	11:05	91.1	0.3	91.3
20-Aug-23	11:10	89.8	0.3	90
20-Aug-23	11:15	88.5	0.2	88.8
20-Aug-23	11:20	87.3	0.2	87.5
20-Aug-23	11:25	86	0.2	86.3
20-Aug-23	11:30	84.8	0.2	85.1
20-Aug-23	11:35	83.6	0.2	83.9
20-Aug-23	11:40	82.5	0.2	82.7
20-Aug-23	11:45	81.3	0.2	81.5
20-Aug-23	11:50	80.2	0.2	80.4
20-Aug-23	11:55	79.1	0.2	79.2
20-Aug-23	12:00	78	0.2	78.1
20-Aug-23	12:05	76.9	0.2	77
20-Aug-23	12:10	75.8	0.2	76
20-Aug-23	12:15	74.8	0.1	74.9
20-Aug-23	12:20	73.7	0.1	73.9
20-Aug-23	12:25	72.7	0.1	72.9
20-Aug-23	12:30	71.7	0.1	71.8
20-Aug-23	12:35	70.7	0.1	70.9
20-Aug-23	12:40	69.8	0.1	69.9
20-Aug-23	12:45	68.8	0.1	68.9
20-Aug-23	12:50	67.9	0.1	68
20-Aug-23	12:55	66.9	0.1	67.1

Date	Time	Inflow from Reach-1-EX (m3/s)	Inflow from Sub-1 (m3/s)	Outflow (m3/s)
20-Aug-23	13:05	65.1	0.1	65.2
20-Aug-23	13:10	64.3	0.1	64.3
20-Aug-23	13:15	63.4	0.1	63.5
20-Aug-23	13:20	62.5	0.1	62.6
20-Aug-23	13:25	61.7	0.1	61.8
20-Aug-23	13:30	60.9	0.1	60.9
20-Aug-23	13:35	60	0.1	60.1
20-Aug-23	13:40	59.2	0.1	59.3
20-Aug-23	13:45	58.4	0.1	58.5
20-Aug-23	13:50	57.7	0.1	57.7
20-Aug-23	13:55	56.9	0.1	57
20-Aug-23	14:00	56.1	0.1	56.2
20-Aug-23	14:05	55.4	0.1	55.4
20-Aug-23	14:10	54.6	0.1	54.7
20-Aug-23	14:15	53.9	0	54
20-Aug-23	14:20	53.2	0	53.2
20-Aug-23	14:25	52.5	0	52.5
20-Aug-23	14:30	51.8	0	51.8
20-Aug-23	14:35	51.1	0	51.1
20-Aug-23	14:40	50.4	0	50.5
20-Aug-23	14:45	49.8	0	49.8
20-Aug-23	14:50	49.1	0	49.1
20-Aug-23	14:55	48.4	0	48.5
20-Aug-23	15:00	47.8	0	47.8
20-Aug-23	15:05	47.2	0	47.2
20-Aug-23	15:10	46.5	0	46.6
20-Aug-23	15:15	45.9	0	45.9
20-Aug-23	15:20	45.3	0	45.3
20-Aug-23	15:25	44.7	0	44.7
20-Aug-23	15:30	44.1	0	44.1
20-Aug-23	15:35	43.5	0	43.5
20-Aug-23	15:40	42.9	0	42.9
20-Aug-23	15:45	42.3	0	42.4
20-Aug-23	15:50	41.8	0	41.8
20-Aug-23	15:55	41.2	0	41.2
20-Aug-23	16:00	40.6	0	40.7
20-Aug-23	16:05	40.1	0	40.1
20-Aug-23	16:10	39.5	0	39.5
20-Aug-23	16:15	39	0	39
20-Aug-23	16:20	38.5	0	38.5
20-Aug-23	16:25	37.9	0	37.9

Date	Time	Inflow from Reach-1-EX (m3/s)	Inflow from Sub-1 (m3/s)	Outflow (m3/s)
20-Aug-23	16:35	36.9	0	36.9
20-Aug-23	16:40	36.4	0	36.4
20-Aug-23	16:45	35.8	0	35.9
20-Aug-23	16:50	35.3	0	35.3
20-Aug-23	16:55	34.8	0	34.8
20-Aug-23	17:00	34.3	0	34.3
20-Aug-23	17:05	33.8	0	33.8
20-Aug-23	17:10	33.3	0	33.3
20-Aug-23	17:15	32.8	0	32.8
20-Aug-23	17:20	32.3	0	32.3
20-Aug-23	17:25	31.8	0	31.9
20-Aug-23	17:30	31.4	0	31.4
20-Aug-23	17:35	30.9	0	30.9
20-Aug-23	17:40	30.4	0	30.4
20-Aug-23	17:45	29.9	0	29.9
20-Aug-23	17:50	29.4	0	29.4
20-Aug-23	17:55	28.9	0	28.9
20-Aug-23	18:00	28.4	0	28.4
20-Aug-23	18:05	27.9	0	27.9
20-Aug-23	18:10	27.4	0	27.4
20-Aug-23	18:15	26.9	0	26.9
20-Aug-23	18:20	26.4	0	26.4
20-Aug-23	18:25	25.9	0	25.9
20-Aug-23	18:30	25.4	0	25.4
20-Aug-23	18:35	24.9	0	24.9
20-Aug-23	18:40	24.4	0	24.4
20-Aug-23	18:45	23.8	0	23.8
20-Aug-23	18:50	23.3	0	23.3
20-Aug-23	18:55	22.7	0	22.7
20-Aug-23	19:00	22.1	0	22.1
20-Aug-23	19:05	21.5	0	21.5
20-Aug-23	19:10	20.9	0	20.9
20-Aug-23	19:15	20.2	0	20.2
20-Aug-23	19:20	19.5	0	19.5
20-Aug-23	19:25	18.8	0	18.8
20-Aug-23	19:30	18	0	18
20-Aug-23	19:35	17.1	0	17.1
20-Aug-23	19:40	16.1	0	16.1
20-Aug-23	19:45	14.9	0	14.9
20-Aug-23	19:50	13.6	0	13.6
20-Aug-23	19:55	12.2	0	12.2
20-Aug-23	20:00	10.6	0	10.6

APPENDIX II

Table 5.4: Profile output table for steady flow analysis for Q_{min} profile

Reach	*River Station*	*Profile*	*Q Total*	*Minimum Channel Elevation*	*Water Surface Elevation*	*Critical Water Surface*	*Energy Gradient Elevation*	*Energy Gradient Slope*	*Velocity Of Channel*	*Flow Area*	*Top Width*	*Froude No, of the Channel*
			(m3/s)	*(m)*	*(m)*	*(m)*	*(m)*	*(m/m)*	*(m/s)*	*(m2)*	*(m)*	
Reach 1	12894	Qmin	0.86	56.02	56.06	56.06	56.08	0.04333	0.54	1.6	59.14	1.04
Reach 1	12448	Qmin	0.86	52.11	53.12	52.17	53.12	0	0.02	56.37	80.92	0.01
Reach 1	11970	Qmin	0.86	51	53.12		53.12	0	0	207.92	160.2	0
Reach 1	11419	Qmin	0.86	51.56	53.12		53.12	0	0.01	88.95	91.92	0
Reach 1	10852	Qmin	0.86	51	53.12		53.12	0	0.01	151.01	111.02	0
Reach 1	10320	Qmin	0.86	52.32	53.12		53.12	0.000002	0.03	32.28	63.59	0.01
Reach 1	9960	Qmin	0.86	52.78	53.04	53.04	53.11	0.024284	1.14	0.75	5.79	1.01
Reach 1	9584	Qmin	0.86	48	52.15	48.27	52.15	0	0.01	159.39	71.46	0
Reach 1	9206	Qmin	0.86	51.44	52.15		52.15	0.000009	0.05	18.02	42.71	0.02
Reach 1	8706	Qmin	0.86	50.06	52.15		52.15	0.000002	0.04	23.12	21.53	0.01
Reach 1	8278	Qmin	0.86	50	52.15		52.15	0	0.01	109.8	72.39	0
Reach 1	7874	Qmin	0.86	49	52.15		52.15	0	0.01	125.9	80.8	0

Reach	*River Station*	*Profile*	*Q Total*	*Minimum Channel Elevation*	*Water Surface Elevation*	*Critical Water Surface*	*Energy Gradient Elevation*	*Energy Gradient Slope*	*Velocity Of Channel*	*Flow Area*	*Top Width*	*Froude No, of the Channel*
			(m3/s)	*(m)*	*(m)*	*(m)*	*(m)*	*(m/m)*	*(m/s)*	*(m2)*	*(m)*	
Reach 1	6400	Qmin	0.86	51	52.15		52.15	0	0.01	81.26	131.93	0
Reach 1	6019	Qmin	0.86	50.55	52.15		52.15	0	0.01	104.5	107.56	0
Reach 1	5617	Qmin	0.86	51.91	52.14		52.15	0.000849	0.22	3.91	28.87	0.19
Reach 1	5228	Qmin	0.86	51	51.14	51.14	51.18	0.028416	0.9	0.96	11.93	1.01
Reach 1	4704	Qmin	0.86	49.73	50.36	49.93	50.36	0.000061	0.1	8.35	26.51	0.06
Reach 1	4286	Qmin	0.86	49	50.36		50.36	0.000001	0.02	34.67	47.54	0.01
Reach 1	3873	Qmin	0.86	49.38	50.36		50.36	0.000001	0.02	43.94	72.48	0.01
Reach 1	3490	Qmin	0.86	49.27	50.36		50.36	0.000001	0.02	45.89	75.33	0.01
Reach 1	2951	Qmin	0.86	50	50.35		50.36	0.000256	0.15	5.8	31.44	0.11
Reach 1	2450	Qmin	0.86	50	50.34		50.34	0.000013	0.04	20.52	78.33	0.03
Reach 1	1968	Qmin	0.86	48.31	50.34		50.34	0	0.01	124.28	120.3	0
Reach 1	1517	Qmin	0.86	50	50.34	50.16	50.34	0.000504	0.22	3.93	19.64	0.16
Reach 1	1069	Qmin	0.86	49.44	49.59	49.59	49.63	0.029198	0.88	0.98	12.93	1.01
Reach 1	591	Qmin	0.86	48	48.44	48.12	48.44	0.000046	0.08	10.14	34.88	0.05

Reach 1	262	Qmin	0.86	48.23	48.38		48.38	0.005946	0.4	2.16	28.13	0.46
Reach 1	59	Qmin	0.86	47.5	47.69	47.62	47.7	0.00218	0.29	2.97	29.46	0.29

Table 5.5: Profile output table for steady flow analysis for Q_{max} profile

Reach	***River Station***	***Profile***	***Q Total***	***Minimum Channel Elevation***	***Water Surface Elevation***	***Critical Water Surface***	***Energy Gradient Elevation***	***Energy Gradient Slope***	***Velocity Of Channel***	***Flow Area***	***Top Width***	***Froude No of the Channel***
			(m3/s)	***(m)***	***(m)***	***(m)***	***(m)***	***(m/m)***	***(m/s)***	***(m2)***	***(m)***	
Reach 1	12894	Qmax	673	56.02	58.4	57.47	58.53	0.001178	1.64	437.29	227.64	0.36
Reach 1	12448	Qmax	673	52.11	58.31		58.36	0.000153	1.02	672.04	140.46	0.15
Reach 1	11970	Qmax	673	51	58.29		58.31	0.000041	0.64	1099.03	172.9	0.08
Reach 1	11419	Qmax	673	51.56	58.23		58.28	0.000116	1.02	699.99	123.4	0.13
Reach 1	10852	Qmax	673	51	58.18		58.22	0.000083	0.9	782.15	128.1	0.11
Reach 1	10320	Qmax	673	52.32	57.97		58.12	0.000429	1.83	398.88	75.8	0.25
Reach 1	9960	Qmax	673	52.78	57.43		57.8	0.002121	2.79	253.64	92.7	0.51
Reach 1	9584	Qmax	673	48	57.53		57.6	0.000116	1.2	601.33	84.4	0.14
Reach 1	9206	Qmax	673	51.44	57.41		57.52	0.00033	1.62	451.55	88.1	0.22
Reach 1	8706	Qmax	673	50.06	56.61		57.13	0.002289	3.31	211.82	58.73	0.54

Reach	*River Station*	*Profile*	*Q Total*	*Minimum Channel Elevation*	*Water Surface Elevation*	*Critical Water Surface*	*Energy Gradient Elevation*	*Energy Gradient Slope*	*Velocity Of Channel*	*Flow Area*	*Top Width*	*Froude No of the Channel*
			(m3/s)	*(m)*	*(m)*	*(m)*	*(m)*	*(m/m)*	*(m/s)*	*(m2)*	*(m)*	
Reach 1	7374	Qmax	673	49.74	56.57		56.63	0.000157	1.12	633.3	126	0.15
Reach 1	6896	Qmax	673	52	56.49		56.54	0.00021	1.08	642.67	157.5	0.17
Reach 1	6400	Qmax	673	51	56.41		56.45	0.000142	0.98	710.58	148.5	0.14
Reach 1	6019	Qmax	673	50.55	56.33		56.39	0.00018	1.14	618.32	126.6	0.16
Reach 1	5617	Qmax	673	51.91	55.94		56.22	0.001283	2.43	295.53	90.8	0.41
Reach 1	5228	Qmax	673	51	55.4		55.66	0.001572	2.3	305.67	114.3	0.43
Reach 1	4704	Qmax	673	49.73	55.15		55.25	0.000378	1.4	503.75	144.2	0.22
Reach 1	4286	Qmax	673	49	55.03		55.11	0.000289	1.24	556.12	143.9	0.2
Reach 1	3873	Qmax	673	49.38	54.91		54.99	0.000264	1.27	545.64	131.45	0.19
Reach 1	3490	Qmax	673	49.27	54.85		54.9	0.000164	1.01	693.12	159.6	0.15
Reach 1	2951	Qmax	673	50	54.7		54.78	0.000328	1.29	542.27	145	0.21
Reach 1	2450	Qmax	673	50	54.6		54.65	0.000187	1.03	675.21	164.5	0.16

Reach 1	1968	Qmax	673	48.31	54.53		54.57	0.00012	0.9	777.87	178.4	0.13
Reach 1	1517	Qmax	673	50	53.98		54.39	0.002481	2.88	241.32	89.62	0.54
Reach 1	1069	Qmax	673	49.44	53.12		53.42	0.001799	2.47	282.66	113	0.46
Reach 1	591	Qmax	673	48	52.26		52.6	0.001645	2.58	270.26	90.91	0.45
Reach 1	262	Qmax	673	48.23	51.2		51.72	0.004769	3.19	211.13	102.55	0.71
Reach 1	59	Qmax	673	47.5	50.73	49.74	51.01	0.002181	2.36	285.39	121.98	0.49

Table 5.6: Profile output table for steady flow analysis for 1.1 Q_{max} profile

Reach	***River Station***	***Profile***	***Q Total***	***Minimum Channel Elevation***	***Water Surface Elevation***	***Critical Water Surface***	***Energy Gradient Elevation***	***Energy Gradient Slope***	***Velocity Of Channel***	***Flow Area***	***Top Width***	***Froude No of the Channel***
			(m3/s)	***(m)***	***(m)***	***(m)***	***(m)***	***(m/m)***	***(m/s)***	***(m2)***	***(m)***	
Reach 1	12894	1.1Qmax	740.3	56.02	58.68	57.54	58.8	0.000915	1.56	501.4	227.64	0.32
Reach 1	12448	1.1Qmax	740.3	52.11	58.59		58.64	0.000154	1.07	711.42	140.46	0.15
Reach 1	11970	1.1Qmax	740.3	51	58.58		58.6	0.000043	0.67	1147.53	172.9	0.08
Reach 1	11419	1.1Qmax	740.3	51.56	58.5		58.56	0.00012	1.07	734.03	123.4	0.14
Reach 1	10852	1.1Qmax	740.3	51	58.45		58.5	0.000087	0.95	817.23	128.1	0.12

Reach	*River Station*	*Profile*	*Q Total*	*Minimum Channel Elevation*	*Water Surface Elevation*	*Critical Water Surface*	*Energy Gradient Elevation*	*Energy Gradient Slope*	*Velocity Of Channel*	*Flow Area*	*Top Width*	*Froude No of the Channel*
			(m3/s)	*(m)*	*(m)*	*(m)*	*(m)*	*(m/m)*	*(m/s)*	*(m2)*	*(m)*	
Reach 1	9584	1.1Qmax	740.3	48	57.8		57.87	0.000125	1.28	623.81	84.4	0.14
Reach 1	9206	1.1Qmax	740.3	51.44	57.66		57.79	0.000341	1.7	474.36	88.1	0.23
Reach 1	8706	1.1Qmax	740.3	50.06	56.83		57.39	0.0023	3.43	224.83	59.7	0.55
Reach 1	8278	1.1Qmax	740.3	50	56.93		57.03	0.000228	1.47	537.5	91.6	0.19
Reach 1	7874	1.1Qmax	740.3	49	56.87		56.94	0.000157	1.17	663.87	120.6	0.15
Reach 1	7374	1.1Qmax	740.3	49.74	56.79		56.86	0.000165	1.18	661.39	126	0.16
Reach 1	6896	1.1Qmax	740.3	52	56.71		56.77	0.000214	1.13	677.43	157.5	0.17
Reach 1	6400	1.1Qmax	740.3	51	56.63		56.68	0.000149	1.04	742.94	148.5	0.15
Reach 1	6019	1.1Qmax	740.3	50.55	56.54		56.61	0.000189	1.2	645.25	126.6	0.17
Reach 1	5617	1.1Qmax	740.3	51.91	56.13		56.43	0.001296	2.53	312.75	90.8	0.41
Reach 1	5228	1.1Qmax	740.3	51	55.61		55.87	0.001494	2.35	329.46	114.3	0.43
Reach 1	4704	1.1Qmax	740.3	49.73	55.37		55.47	0.000379	1.45	534.87	144.2	0.23

Reach	***River Station***	***Profile***	***Q Total***	***Minimum Channel Elevation***	***Water Surface Elevation***	***Critical Water Surface***	***Energy Gradient Elevation***	***Energy Gradient Slope***	***Velocity Of Channel***	***Flow Area***	***Top Width***	***Froude No of the Channel***
			(m3/s)	***(m)***	***(m)***	***(m)***	***(m)***	***(m/m)***	***(m/s)***	***(m2)***	***(m)***	
Reach 1	3490	1.1Qmax	740.3	49.27	55.06		55.12	0.00017	1.06	726.5	159.6	0.15
Reach 1	2951	1.1Qmax	740.3	50	54.9		54.99	0.000334	1.35	571.73	145	0.21
Reach 1	2450	1.1Qmax	740.3	50	54.8		54.85	0.000194	1.08	708.29	164.5	0.16
Reach 1	1968	1.1Qmax	740.3	48.31	54.73		54.78	0.000126	0.95	813.31	178.4	0.13
Reach 1	1517	1.1Qmax	740.3	50	54.15		54.58	0.00251	2.98	256.12	90.46	0.55
Reach 1	1069	1.1Qmax	740.3	49.44	53.29		53.61	0.00177	2.55	302.66	114.79	0.46
Reach 1	591	1.1Qmax	740.3	48	52.42		52.78	0.001698	2.7	284.37	91.27	0.46
Reach 1	262	1.1Qmax	740.3	48.23	51.33		51.88	0.004772	3.29	225.05	104.31	0.72
Reach 1	59	1.1Qmax	740.3	47.5	50.87	49.85	51.18	0.002184	2.45	303.1	127.53	0.5

Table 5.7: Profile output table for steady flow analysis for 1.2 Q_{max} profile

Reach	***River Station***	***Profile***	***Q Total***	***Minimum Channel Elevation***	***Water Surface Elevation***	***Critical Water Surface***	***Energy Gradient Elevation***	***Energy Gradient Slope***	***Velocity Of Channel***	***Flow Area***	***Top Width***	***Froude No of the Channel***
			(m3/s)	***(m)***	***(m)***	***(m)***	***(m)***	***(m/m)***	***(m/s)***	***(m2)***	***(m)***	
Reach 1	12894	1.2 Qmax	807.6	56.02	58.95	57.6	59.06	0.000747	1.52	562.85	227.64	0.29
Reach 1	12448	1.2 Qmax	807.6	52.11	58.86		58.92	0.000155	1.1	749.32	140.46	0.15
Reach 1	11970	1.2 Qmax	807.6	51	58.85		58.87	0.000044	0.7	1194.22	172.9	0.08
Reach 1	11419	1.2 Qmax	807.6	51.56	58.77		58.83	0.000124	1.12	766.78	123.4	0.14
Reach 1	10852	1.2 Qmax	807.6	51	58.72		58.76	0.000091	1	850.99	128.1	0.12
Reach 1	10320	1.2 Qmax	807.6	52.32	58.47		58.66	0.00046	2.01	437.19	75.8	0.26
Reach 1	9960	1.2 Qmax	807.6	52.78	57.97		58.35	0.001745	2.82	303.7	92.7	0.47
Reach 1	9584	1.2 Qmax	807.6	48	58.05		58.14	0.000133	1.35	645.34	84.4	0.15
Reach 1	9206	1.2 Qmax	807.6	51.44	57.91		58.05	0.000352	1.77	496.21	88.1	0.23
Reach 1	8706	1.2 Qmax	807.6	50.06	57.04		57.64	0.002298	3.54	237.47	60.63	0.55
Reach 1	8278	1.2 Qmax	807.6	50	57.15		57.26	0.000241	1.55	557.64	91.6	0.19
Reach 1	7874	1.2 Qmax	807.6	49	57.09		57.17	0.000165	1.23	690.25	120.6	0.16

Reach	*River Station*	*Profile*	*Q Total*	*Minimum Channel Elevation*	*Water Surface Elevation*	*Critical Water Surface*	*Energy Gradient Elevation*	*Energy Gradient Slope*	*Velocity Of Channel*	*Flow Area*	*Top Width*	*Froude No of the Channel*
			(m3/s)	*(m)*	*(m)*	*(m)*	*(m)*	*(m/m)*	*(m/s)*	*(m2)*	*(m)*	
Reach 1	7374	1.2 Qmax	807.6	49.74	57.01		57.08	0.000173	1.24	688.47	126	0.16
Reach 1	6896	1.2 Qmax	807.6	52	56.92		56.99	0.000217	1.18	710.99	157.5	0.17
Reach 1	6400	1.2 Qmax	807.6	51	56.84		56.89	0.000155	1.09	774.2	148.5	0.15
Reach 1	6019	1.2 Qmax	807.6	50.55	56.75		56.82	0.000198	1.26	671.28	126.6	0.17
Reach 1	5617	1.2 Qmax	807.6	51.91	56.31		56.63	0.001307	2.62	329.43	90.8	0.42
Reach 1	5228	1.2 Qmax	807.6	51	55.81		56.09	0.001433	2.4	352.27	114.3	0.42
Reach 1	4704	1.2 Qmax	807.6	49.73	55.58		55.69	0.00038	1.5	564.64	144.2	0.23
Reach 1	4286	1.2 Qmax	807.6	49	55.45		55.54	0.000299	1.35	616.51	143.9	0.2
Reach 1	3873	1.2 Qmax	807.6	49.38	55.32		55.42	0.000282	1.39	600.21	134.01	0.2
Reach 1	3490	1.2 Qmax	807.6	49.27	55.26		55.32	0.000176	1.11	758.46	159.6	0.16
Reach 1	2951	1.2 Qmax	807.6	50	55.1		55.19	0.00034	1.4	599.93	145	0.21
Reach 1	2450	1.2 Qmax	807.6	50	54.99		55.05	0.0002	1.13	739.98	164.5	0.17
Reach 1	1968	1.2 Qmax	807.6	48.31	54.92		54.97	0.000132	0.99	847.27	178.4	0.14

Reach	*River Station*	*Profile*	*Q Total*	*Minimum Channel Elevation*	*Water Surface Elevation*	*Critical Water Surface*	*Energy Gradient Elevation*	*Energy Gradient Slope*	*Velocity Of Channel*	*Flow Area*	*Top Width*	*Froude No of the Channel*
			(m3/s)	*(m)*	*(m)*	*(m)*	*(m)*	*(m/m)*	*(m/s)*	*(m2)*	*(m)*	
Reach 1	1517	1.2 Qmax	807.6	50	54.3		54.77	0.002537	3.08	270.42	91.27	0.55
Reach 1	1069	1.2 Qmax	807.6	49.44	53.46		53.8	0.001744	2.62	322.14	116.1	0.46
Reach 1	591	1.2 Qmax	807.6	48	52.57		52.96	0.001748	2.82	297.81	91.61	0.47
Reach 1	262	1.2 Qmax	807.6	48.23	51.46		52.05	0.004772	3.38	238.66	106	0.72
Reach 1	59	1.2 Qmax	807.6	47.5	51.01	49.96	51.34	0.002183	2.53	321.23	135.23	0.5