1D / 2D FLOOD MODELLING OF RIVER INDUS: GUDDU – SUKKUR REACH

By

Muhammad Faisal Arif
(NUST201362917MSCEE15313F)

A Thesis submitted in partial fulfillment of
the requirements for the degree of

Master of Science
in
Water Resources Engineering and Management

DEPARTMENT OF WATER RESOURCES ENGINEERING AND MANAGEMENT
NUST INSTITUTE OF CIVIL ENGINEERING
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY
SECTOR H-12, ISLAMABAD, PAKISTAN

(2017)

This is to certify that the

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Associate Professor Dr. Sajjad Haider

NUST Institute of Civil Engineering (NICE)

School of Civil & Environmental Engineering (SCEE)

National University of Sciences & Technology, Islamabad

DEDICATED TO

MY FAMILY

ACKNOWLEDGEMENTS

I am thankful to Almighty Allah, the most merciful, the most beneficent for His boundless blessings due to which am able to complete the research.

I am grateful to the NICE for providing me all the facilities and necessary help required for successful completion of my research work. I also appreciate entire staff and faculty of NICE for their support.

I feel indebted to my research supervisor Dr Sajjad Haider for his encouragement, guidance and support throughout the course of my research and without which I would not have completed it. My appreciation also goes to my committee members for their encouragement and constant support.

I am also grateful to all the students of MS WRE&M 13 for their support and sharing with me their experience and knowledge of working with different software's and field experience. I acknowledge contribution of Lt Col Fawad, who has given me his valuable time out of his very committed schedule for discussion on GIS aspects of research.

(Muhammad Faisal Arif)

ABSTRACT

Floods are one of the worst natural hazards being face by mankind, bring infrastructure devastation and are also responsible for loss of human life. Pakistan, since its creation, has faced the challenge of floods. However, not much has been done in field of numerical modeling and predicting the flood extent / behavior. Basing on availability of good quality topographical data (10m DEM) and hydrological data the reach of Guddu- Sukkur is selected for modeling. In this study an attempt has been made to simulate the major flood event of 2010. Moreover, for the first time an effort is made to resolve a Tori Bund dispute scientifically (a controversy whether the Flood Protection Bund (FPB) i.e. Tori Bund was breached to safeguard interest of local feudal or the bund was overtopped). A 10m Digital Elevation Model (DEM) of the area with +0.5m vertical accuracy is used.

The topographic data is used to construct river geometry using ArcGIS and HEC-GeoRAS. 1D steady model using HEC-RAS is run to simulate the flood. A tool in ArcGIS is also used to graphical represent the flood plain delineation including visualization of overtopping of the bund. Unsteady flow 1D & 2D models are run using Basic Simulation Environment (BASEMENT). The recorded water surface elevation (obtained from irrigation department) was then used to calibrate the model and in the course of this research, three GIS software namely ArcGIS, Global Mapper and Quantum GIS, three water resource software's namely BASEMENT, HEC-RAS & Geo HAC-RAS and two processers' i.e. BASEmesh and SMS10 are used.

2010 flood simulation on modeled reach of Guddu-Sukkur shows reduced height of bunds verses WSE particularly the downstream of mid reach. The methodology presented in study can be used to simulate flood events for other reaches / river provided that topographic and hydrological data is available.

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ABBREVIATION

1D	One-dimensional
2D	Two-dimensional
ArcGIS	Aeronautical Reconnaissance Coverage Geographic Information System
BUA	Built up Area
BASEMENT	Basic Simulation Environment
DEM	Digital Elevation Model
DTM	Digital Terrain Model
FPB	Flood Protection Bund
FEWS	Flood Early Warning System
FFC	Flood Forecasting Commission
FFD	Flood Forecasting Division
GeoRAS	Geographic River Analysis System
GIS	Geographic Information System
HEC-RAS	Hydrologic Engineering Center River Analysis System
IRI	Irrigation Research Institute
LiDAR	Light Detection and Ranging
NDMA	National Disaster Management Authority
NED	National Elevation Dataset
PMD	Pakistan Meteorological Department
RMSE	Root Mean Squared Error
RS	Remote Sensing
SMS	Surface Water Modeling System
SRTM	Shuttle Radar Topography Mission
WAPDA	Water and Power Development Authority
WSE	Water Surface Elevation

LIST OF NOTATIONS

Cumecs	-	Cubic meter per second
Cusecs	-	Cubic feet per second
Km	-	Kilometer
M	-	Meter
m / m	-	meter per meter
m^3 / sec	-	meter cube per second
MAF	-	Million Acre Feet
%	-	Percentage
&	-	And

Chapter 1

INTRODUCTION

1.1 General

World over floods are the most destructive natural hazards which not only affect social but also the economic foundation of the population and cause more death than any other phenomenon. Occurrence of floods is increasing in many countries of the world. Due to climate change and recent floods events in different countries, there is a need to come out with more specific flood risk management plans. Flood forecasting methods depend mainly on the quality and collected data related to hydrology and the hydrological yield of the corresponding area under study (Bashir et al. 2010). Apart from negative impact, floods have positive impacts as well. Water resource people consider floods as one of important natural occurrence for good of local ecosystem. The flood occurrence should be understood with the aim to have better preparations which will lessen or prevent flood damage.

Pakistan is under constant threat of major floods. In last about five years, country has faced three major floods. Damage to life and properties may have less if the capacity building of local and disaster management authorities has been undertaken. Pakistan possesses significant topographic layout and the peculiar climate of the country results in large spatial as well as temporal variations. The mountains in the country add to the wide variation in the climate of places located at the same latitudinal belts. Impacts of climate change have become evident, the frequency and intensity of severe precipitation events, mostly occurring in monsoon season have increased as recorded during the last few decades. The occurrence of extreme events depicts a shift in the climate in Pakistan that may be attributed to climate change. Owing to complex topography, Northern half of Pakistan is very sensitive to the changes in precipitation (PMD, 2012). Analysis of past drought events depicts that there is well above monsoon rainfall in Pakistan after every drought period. Sixteen drought events during last fifty years ended in wet monsoon season over Pakistan. It is highly important to investigate the climate change impact on spatial and temporal rainfall characteristics. It is suggested that based on the expected changes flood models be employed to prepare flood hazard maps for timely rescue and relief operations.

1.2 Pakistan Water Resources

Pakistan resources mainly consist of the Indus River including its tributaries. It brings in about 138 million acre feet (MAF) of flow per annum (Kahlown et al. 2003). The major branch of River Indus is 1800 miles (2900 km) long from the Himalayas to Arabian Sea. 360,000 square mile is covered by the basin. (Mantell et al. 1976)

1.2.1 River System of Pakistan

The total area of Pakistan, measuring 7, 96,095 square kilometer, is divided into three major hydrological units, namely Indus River Basin, Closed Basin of Kharan Desert and Makran Coastal Basin. Details of these basins are given at **Annexure-D**.

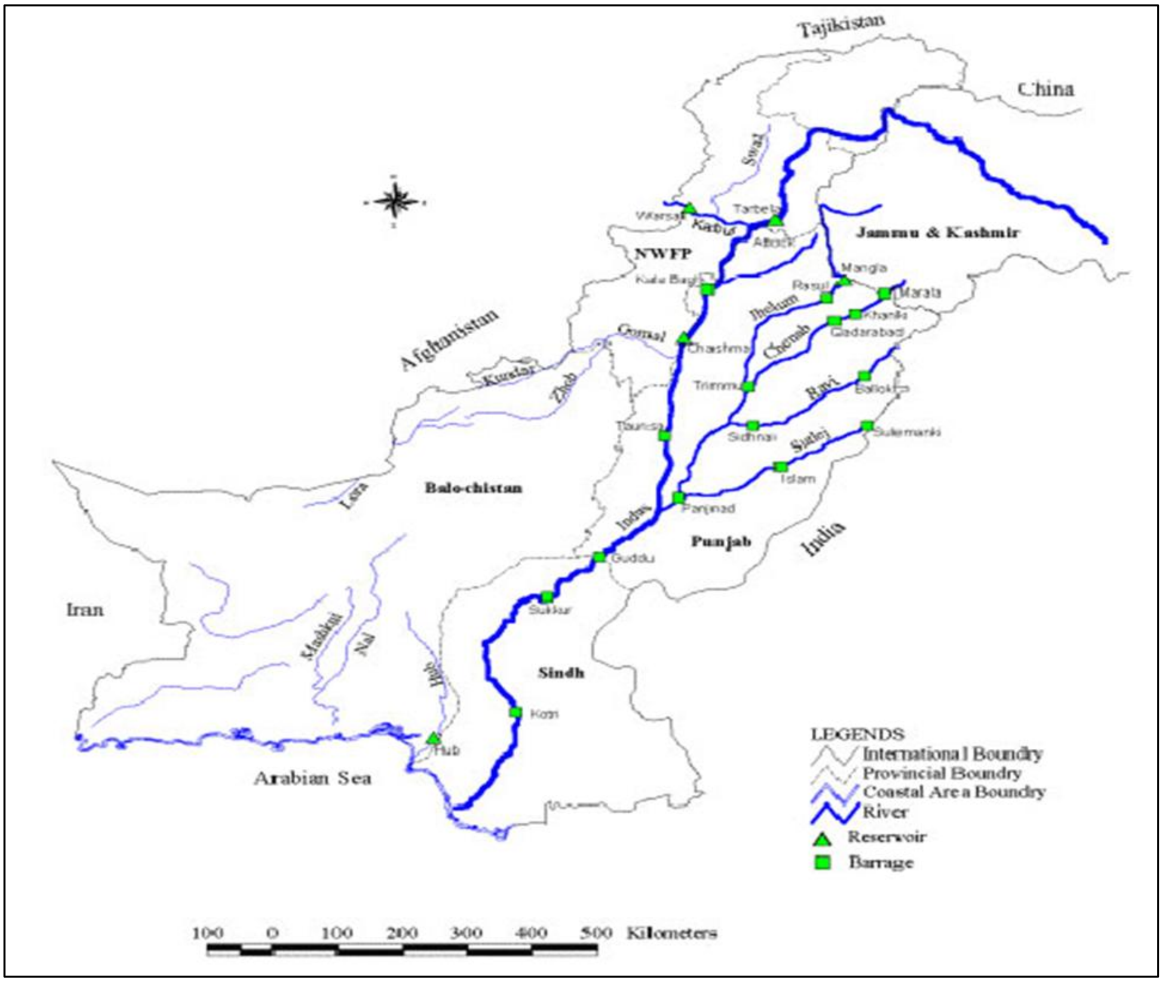


Figure 1.1: River System of Pakistan

1.2.2 Catchment Areas

Indus and its tributaries upper reaches are mainly in India, some part of Tibet and also in Chinese territories. Considerable volume of water runs down the tributaries of these rivers after major Heavy rainfall / snowmelt event in catchment areas, which pass through the vast flood plains of Pakistan before finally falling into the Arabian Sea. Catchment areas of major rivers are given at **Annexure-E**.

1.3 Floods in Pakistan

Monsoon incursions, sudden and abnormal releases by India towards Pakistan are major causes of floods in Pakistan (UNSECO 2012). Country has faced high floods in 1950, 1956, 1957, 1958,1963,1965,1973, 1976, 1988, 1992 and 2010, apart from number of low floods in isolated pockets. 2010 floods is considered as one of the extreme flood.

1.3.1 Classification of Floods

Floods are classified into five different levels as far as Pakistan is concerned, shown in table 1.1 (UNSECO 2012)

Table 1.1: Classification of Flood

S/no.	Classification	Details
1	Low Flood	When the river is flowing within the actual channel with chances to spread over river island / belas.
2	Medium Flood	In medium flood, river flows is partly inundating river islands / belas but below half of its maximum flood level.
3	High Flood	When the level of river is almost fully submerging islands/belas and flowing up to high banks/bunds but without encroaching on the free board.
4	Very High Flood	When the water level of river flows is between high banks / bunds.
5	Exceptionally High Flood	When there is imminent danger of overtopping/breaching or a breach has actually occurred or high bank areas become inundated.

1.3.2 Flood Limits

Flood limits are also categorized as per its intensity as Low, Medium, High, Very High and Exceptionally High. The heavy rainfall in the catchments can produce exceptionally high flood peaks. Flood limits for various control structure are given at **Annexure-F**.

1.4 Floods - 2010

Pakistan is very much prone to disaster due to natural hazards including extreme floods, as the history tells us. However, 2010 floods were extremely severe when it comes to record breaking rainfall, spatial extent and water level recorded at various location of Indus River. It results in over 1500 deaths and over 15 million people were displaced / lost their homes (NASA.Org). Floods 2010 began in 3rd week of July following heavy monsoon rains. The main reason was the confluence of 'westerly' weather system with the 'seasonal' monsoon system emanating from Arabian Sea (UNSECO.org). River flows exceeded the record of last 100 years as the phenomena were coupled with global warming and change in climate. Area of more than 130,000 square km was affected and about 20 million people had to face adverse effect of flood. Floods have damaged very important crops over an area of 4.386 million acres. Huge damage occurred to infrastructure like communications, public services, power network and irrigation network.

1.4.1 Flood at Guddu - Sukkur Barrages

First wave of Exceptionally High Flood peaks of 11, 48,000 cusecs passed Guddu Barrage between 8-9 August 2010 (Annual Flood Report, FFC, 2010). Flow of 11, 31,000 cusecs passed Sukkur Barrage between 9-11 August 2010. Due to immense pressure, 16 miles long Marginal Bund of Guddu Barrage was breached at five locations (a breach in Sindhh and another four in Punjab). Due to immense pressure, Tori Bund downstream Guddu Barrage was breached on 06 August 2010, inundating several villages along right bank of River Indus. In order to save Jacobabad city, 3-4 cuts were made at Jacobabad bypass due to which flood water entered Baluchistan. Flood water crossed over Indus Highway, due to which roads between Shikarpur-Jacobabad, Jacobabad–Sibbi and Shikarpur to Kandhkot were cut off. Second wave of Exceptionally

High Flood again passed through Guddu and Sukkur barrages between 14-17 Augusts. The discharge on these locations was 10, 76,000 and 10, 25,000 cusecs, respectively.

1.4.2 Tori Bund Breach

Water pressure caused breaches in Tori Bund in first week of August. Mass evacuation of residents carried out from Kashmore and Jacobabad districts as these were submerged by flood water. Water released after breach of Tori bund also inundated areas in other districts including, Shikarpur, Larkana, Qamber-Shahdadkot, Dadu. The general population / resident blamed the government for making intentional breaches in Tori Bund to safe land of influential people of the area. The irrigation department claimed that said that cut was not deliberate but was due to water overtopping Tori Bund and later the pressure of water caused breaches. The controversy was investigated through judicial commission, which mainly relied on statements of the locals. No scientific research has been made to justify the claim of local authorities.

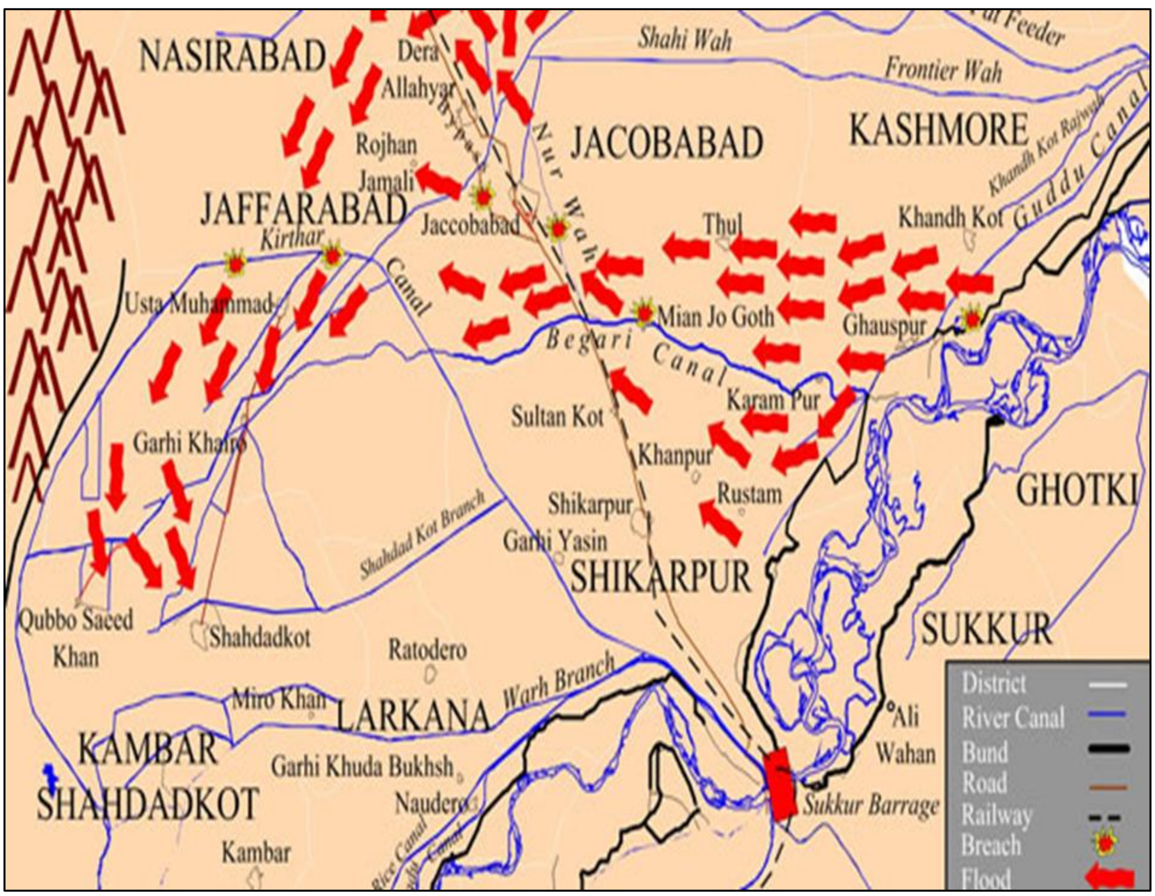


Figure 1.2 : Tori Bund Breach

1.5 Research Overview

Conventional means of modeling i.e. physical modeling is being practiced in Pakistan sine long. Research centre has been established at Nandipur to study the different effects on physical models. Off late, numerical modeling is also being practiced and numbers of studies have been carried out. The major limitation has been availability of topographical data to construct the river geometry. The physical survey to obtain topographical is both resource intensive and time consuming. The advent of Geographical Information System (GIS) and availability of satellite imagery has brought revolution in field of modeling. A good quality Digital Elevation Model (DEM) is essential to predict accurately through a model. GIS and water resource software are used in this research to replicate the flood event of 2010 between two control structures i.e. Guddu Barrage and Sukkur Barrage. Moreover, an endeavor has been made to scientifically investigate the controversy pertaining to Tori Bund breach.

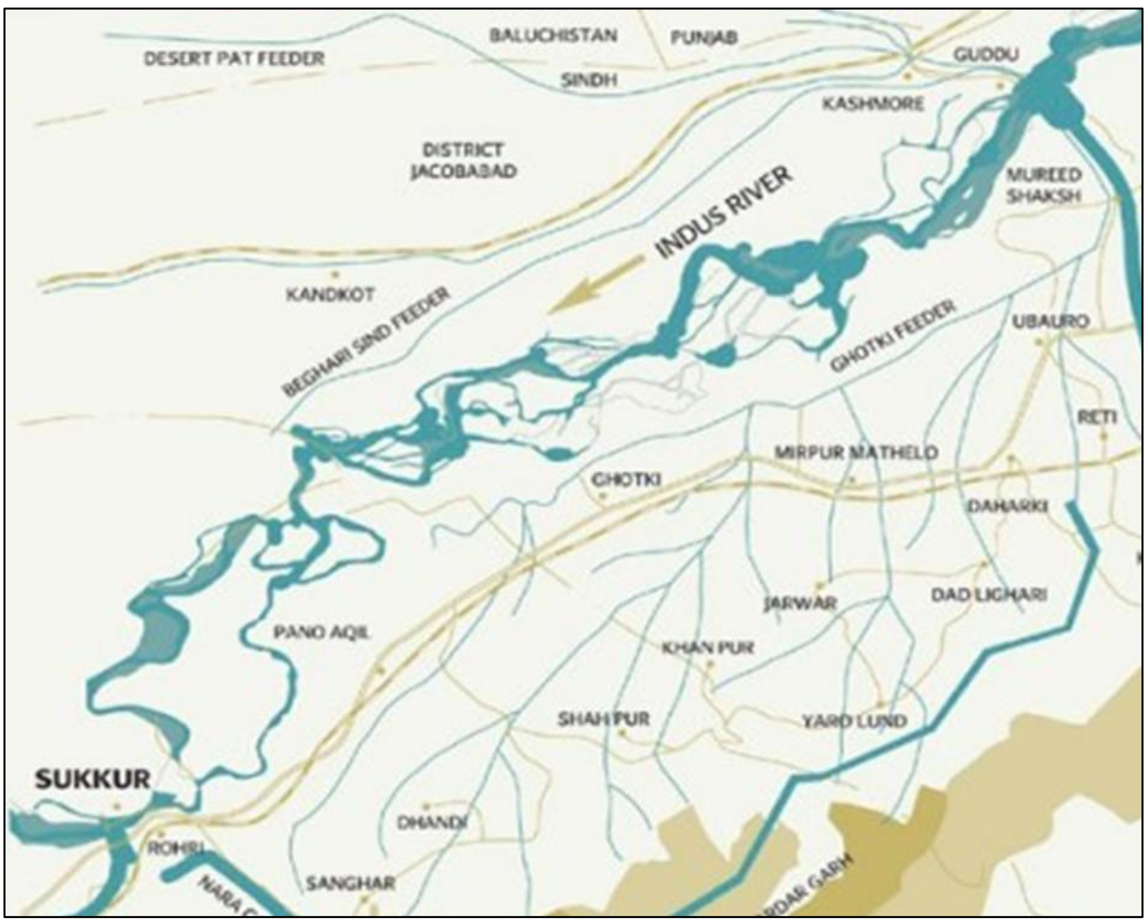


Figure 1.3: River Indus (Guddu – Sukkur Reach)

1.6 Research Objectives

1) To create river geometry by using GIS based topographical data.
2) To model Guddu - Sukkur Reach of River Indus and simulate flood event of 2010.
3) To ascertain whether Tori Bund was breached or overtopped during 2010 flood.
4) Simulations of 1D / 2D model.
5) To check applicability of the model to simulate flood events for other reaches / river.

1.7 Research Significance

Floods are common occurrence in Pakistan and responsible for huge losses. The major cause of losses is unplanned breaches in the bunds or breach due to overtopping is an important issue. Based on the model developed in this study it will be possible to adjust the heights of protective bunds according to maximum discharge values. Model prepared for this reach can be used on any other reach of any river if the topographical data is available for that particular reach. An endeavor is also made to settle the controversy of Tori Bund incident, which will provide a guideline to safeguard against such incidents in future.

1.8 Thesis Layout

This thesis contains total of five chapters. Introductory discussion including the research objective/overview discussed in 1st Chapter. Different models and case studies deliberated upon in Literature review. In 3rd Chapter, method and procedures are discussed. Discussion on results obtained through different models has been discussed in 4th Chapter. Finally, certain conclusions are drawn and corresponding recommendations given in last Chapter.

Chapter 2

LITRATURE REVIEW

2.1 Types of Models

Before actually constructing a prototype or to study the impact of change of various variables, a model is constructed. The model helps predict the various conditions and suggests most appropriate and economical design. Before advent of powerful computing techniques using computers, physical models were prepared involving lot of time and resources. Now a days, analytical and numerical models are being preferred.

2.1.1 Physical Model

A physical hydraulic model is used to find or confirm solutions for engineering problems and represents a real prototype. Physical model study is vital for planning and for design of hydraulic structures. These physical model studies are quite expensive, and are time consuming / resources intensive. (Chaudhry 2008). Pakistan has an institute for studying the physical models at Nandipur known as Irrigation Research Institute (IRI) Nandipur. Studies have been undertaken at this research institute.

2.1.2 Numerical Model

Numerical models are actually mathematical models that use employ numerical time-stepping procedure to obtain the models behavior over a period of time. Models are also probabilistic artificial intelligence and deterministic. The mathematical solution obtained is represented by a table and/or graph. In the past, the utility of numerical-simulation modeling was often limited as numerical methods and computer capacity were deficient. Today, for the most part, advances in numerical methods, computer technology, and hydrologic instrumentation have enabled model engineers to produce models that are more nearly formulated on pure hydraulic considerations and have a greater potential to provide more comprehensive flow information (Horritt et al. 2002).

2.1.3 Analytical Model

These are also mathematical models that in which the solution to the equations used to describe change in a system can be shown as a mathematical analytic function. In analytical models, the geometry is simple and boundary conditions are known thus giving us theoretically exact answer. In numerical models the solutions are approximate.

2.2 Hydraulic Modeling and Inundation Mapping

Hydraulic modeling / flood inundation mapping are used to predict required information from a flood event. This information includes the extent of inundation and water surface elevations at specific points. A hydraulic model is actually a depiction of the processes that happens during a flood event. Different simplifications and assumptions made to create models and representing compound channel flow are often point of debate. A compound channel is a combination of the main river channel along with floodplain areas. When the flow exceeds the height of the main channel during a flood event, the flow spreads into the flatter floodplains. Generally, large flows are often simulated using one-dimensional or two-dimensional models with assumption of a steady-state. Momentum exchange, storage areas in the floodplain, formation of turbulent eddies / shear layers between the main channel flows are few flow processes in compound channel (Bates et al. 2000).

2.2.1 GIS and Hydraulic Modeling

The computers become primary source of data for decision making in hydraulic analysis. Since so much of water resources is associated with earth's surface processes / connection to the topography, computer-based methodology known as the geographic information system (GIS) is the answer in the evaluation of different phenomenon.

GIS Data collection includes ground surveys, digitization of existing maps, aerial photography, satellite imaging data, or combinations of all these. GIS connects land use / cover data to topographic data and properties related to geographic places including description of soils, land use, ground cover, ground water conditions, as well as man-made systems on or below the land surface. The characteristic that differentiates a GIS from general computer mapping or drawing systems is the link to the information data base.

Digital Elevation Model (DEM) is a raster dataset containing information about the topography of a region and is used as a prerequisite to hydraulic modeling. For hydraulic modeling purposes, DEMs are used to determine the active channel cross sectional elevations, water surface elevations and flood extents. Resolution and accuracy are the two main properties of a DEM that affect hydraulic and hydrologic modeling results. The spatial resolution of a DEM refers to the area covered on the ground surface by a single cell which suggests that a higher resolution DEM has more number of cells per unit area and thus represents the topography more accurately as compared to a coarser resolution DEM (ESRI, 2014). Resolutions of DEMs can affect the parameters and attributes derived from them and influence models associated with them. The vertical accuracy of a DEM is the probability distribution of digital elevation values measured with respect to the true value. It is measured by the amount of linear error in elevation (ESRI, 2014b). The accuracy of a DEM directly influences the hydraulic modeling results (Casas et al. 2006; Fisher & Tate 2006). Thus, DEM resolution and accuracy have a significant impact on water surface elevations and flood extents. DEMs obtained from LiDAR data have a high resolution and accuracy and are used extensively for hydraulic modeling purposes (Cook & Merwade 2009; Rayburg et al. 2009). The water surface elevations and flood maps obtained on using LiDAR data are more accurate than the other widely used DEMs present in the world (Charlton et al. 2003).

2.2.2 One Dimensional and Two Dimensional Models

Water is assumed to be flowing in the longitudinal direction in one-dimensional hydraulic modeling. Terrain is represented in 1D model as a sequence of cross-sections. It simulates flow to estimate the average velocity and water depth at each cross-section. 1D finite difference solutions of the full Saint-Venant Equations is mostly used approach for modeling fluvial hydraulics. The Saint Venant Equations are based on conservation equations of mass and momentum for a control volume.

Water moves in both directions in two-dimensional models, i.e. the longitudinal and lateral direction. It is assumed that velocity is negligible in the vertical direction. Through a finite element mesh, these models represent the terrain as a continuous surface. Widely available software such as MIKE11 and HEC-RAS use the general form of the section-averaged Navier-Stokes equations.

2.3 Effects of Topography on Hydraulic Models

Because of high resolution elevation data received from LiDAR, it is now possible to develop high quality/ accurate floodplain maps. Recent studies on subject conducted have shown that topography is one of the most essential parameters in any type of flood inundation modeling (Marks et al. 2000).

2.4 Effects of Geometry on Hydraulic Models

Cross-section for 1D models as well as mesh resolution for 2D models, is very important factor in floodplain mapping when it comes to Hydraulic model geometry.

2.5 Flood Modeling in Pakistan

2.5.1 Flood Early Warning System

NESPAK and Pakistan Meteorological Department collaborated with Netherlands Delft Hydraulics to develop FEWS (Flood Early Warning System). FEWS Model uses two major analysis procedures to carry out estimate of flood wave propagation in the Indus River System. It contains following two modules

1. SAMO (Sacramento): Rainfall-Runoff Model

2. SOBEK: Hydraulic Model

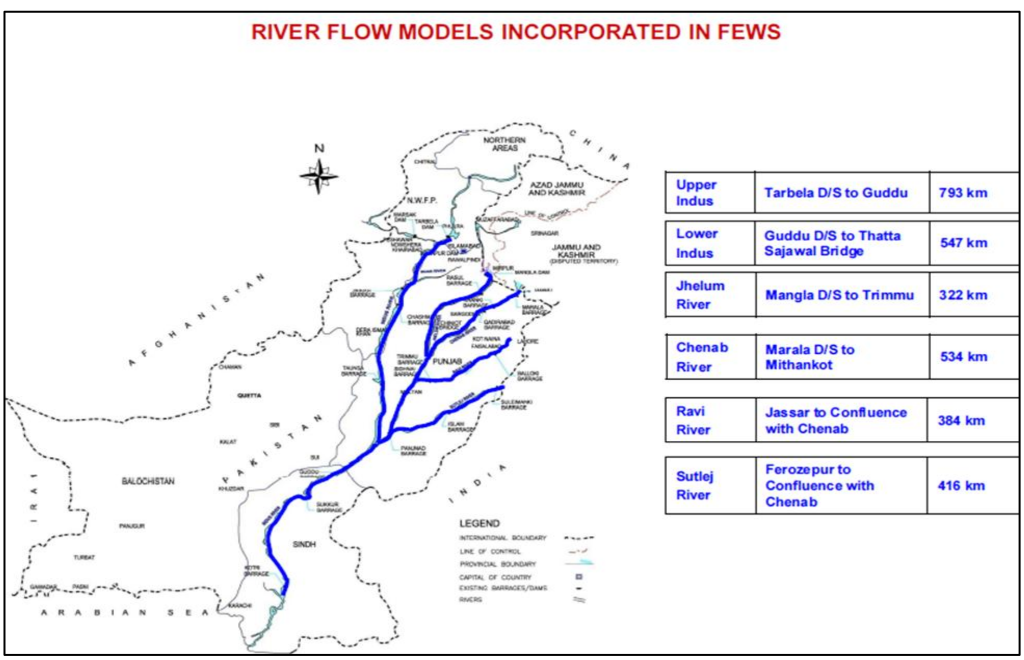


Figure 2.1: River Flow Models Incorporated in FEWS

2.5.2 Independent Studies

Although flood modeling has been taken up recently in the country, numbers of studies / researches have been carried out. Flood Inundation Modeling for Nullah Lai Stream was carried to study the flash flooding case of Nallah Lai (Umer 2015). 2D Saint Venant Equation model for the flood propagation in the channel and over the adjacent land surfaces of Nullah Lai was used to recommend suitable measures for flood mitigation in Lai stream. Previous studies on Lai used 1D modeling. The research showed the potential of the 2D hydraulic simulation to predict the flooding extent and the wave propagation, highlighting its role in the rescue and relief efforts for the urban population living in flood-prone basins.

A study for Swat River was carried out to predict flood hazard areas in the Swat river basin (Irfan et al. 2014). A 30 M DEM is used to create river geometry and then HEC-RAS was used to simulate the flood as 1 D steady model. The research study has demonstrated integration of GIS technology with computer based flood modeling technique to identify high risk of flood inundation areas for disaster risk management. A similar study using 30 M DEM has been carried for Soan River (Malik et al. 2012). The study concluded that the Flood inundation maps indicate that structures previously constructed are effective against 100 year flood, right bank is safe but some areas on the left bank are still under risk of inundation. Both the studies used DEM as topographical source, it was concluded from these studies that it is mandatory to use high resolution DEM to predict the flood more accurately.

Chapter 3

MATERIALS AND METHODS

3.1 General

Hydraulic modeling of River Indus (Guddu – Sukkur reach) has been carried out using the GIS and hydraulic software. Hydrological data was obtained through different departments / sources in the form of discharge values, whereas, topographic data is mainly extracted from DEM of the area. Geometry of the river was constructed using available GIS software as a good quality; high resolution DEM of the area is available. Geometry includes river cross sections (1D analysis) generated mainly through ArcGIS and mesh generation (2D analysis) accomplished using SMS 10. The necessary geometric corrections are made in HEC-RAS. Later on the geometry is exported to BASEMENT using different plug in.

As a first step the simulation is run in HEC-RAS (steady flow analysis) for different discharge values using geometric file prepared in ArcGIS. The graphical representation is obtained in HEC-RAS showing Water Surface Elevation (WSE) along the Flood Protection Bunds (FPB). Same is also depicted through HEC-GeoRAS in ArcGIS (flood plain delineation). A similar 1D / 2D analysis is carried out using BASEMENT (unsteady flow analysis) to ascertain WSE along the FPB.

3.2 The Study Area

River Indus originates in Tibetan plateau (north of Pakistan) and flow through Pakistan in southerly direction along the entire length of the country to fall into the Arabian Sea near the port city of Karachi (South of Pakistan). The reach selected is in the southern part where the ground becomes flatter and river meanders considerably. The reach is located in between two control structures namely Guddu Barrage and Sukkur Barrage. The reach is 160 km long and 20-25 km wide. A system of Levees and FPB enclose the reach on either side. The flood plains are mostly cultivated and have considerable vegetation, the broad distribution of land use is as under:-

Table 3.1: Land Use / Land Cover

Land Cover Type	**Area Percentage**
Built up Area	2%
River	17%
Flood Plain	65%
Forest / Vegetation	15%

3.2.1 Flood Protection Bunds

In a system of levees, different names have been assigned to bunds due to their proximity with a particular village e.g. Tori Bund. The river flows between these bunds (left and right protective bunds). The height of these bunds varies from 5 - 15 m and is made of compacted earth having sand contents. Number of minor bunds / loop bunds have also been constructed to give added protection against flood.

3.2.2 River Plain

There is a huge river plain, which exists between both left and right protection bund. Number of buildup areas have been made, crops are being cultivated and large vegetation exists as river plain comes under water during high flooding only.

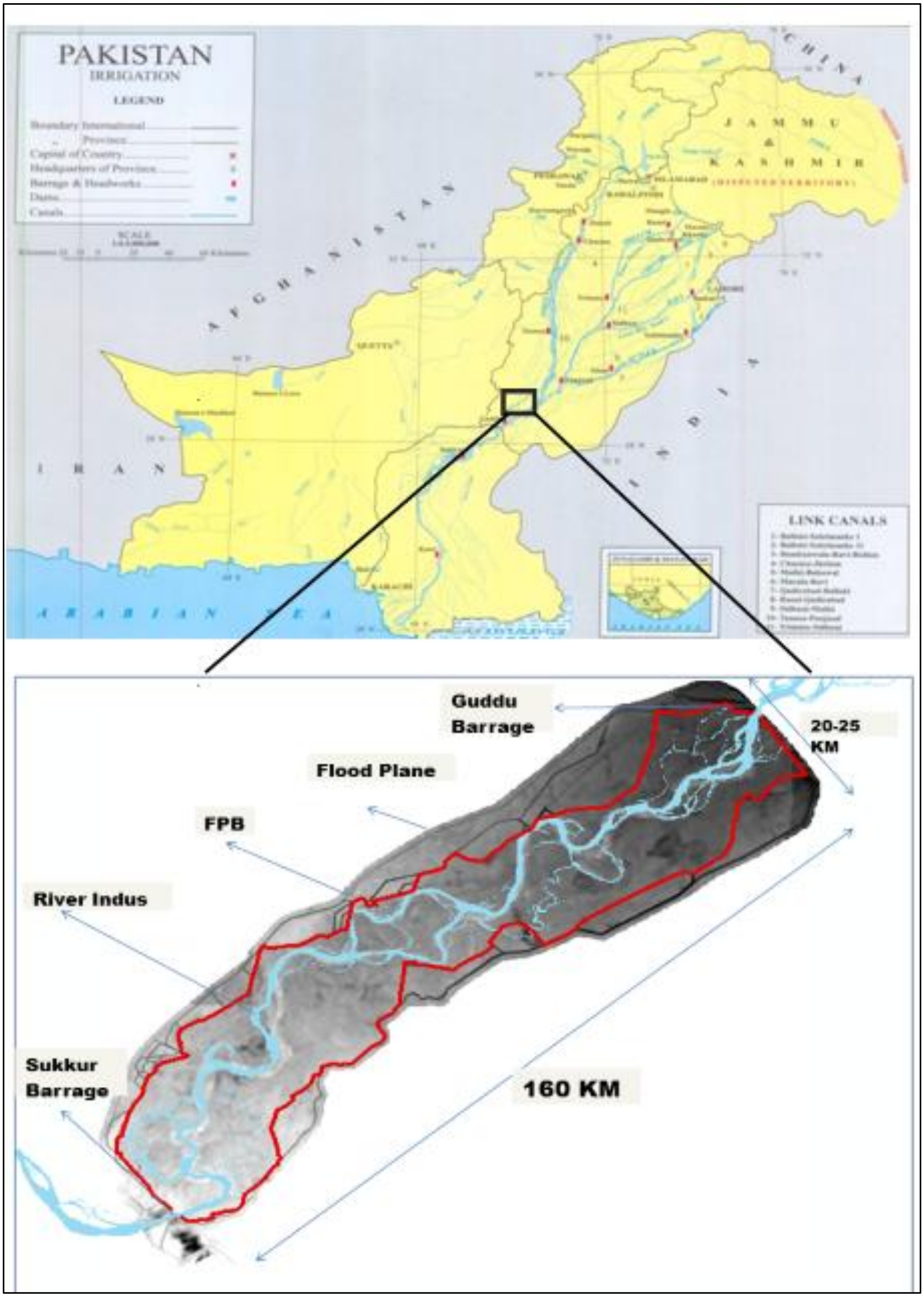


Figure 3.1: Study Area

3.3 Data Collection

3.3.1 Topographical Data

Topographical data was acquired as a DEM. The acquired DEM is having resolution of 10m and vertical accuracy of ±0.5 m and used for constructing the geometry of the river. It also has Land Cover / Land use data, which enable the correct selection of Manning 'n' value. Properties of DEM are given below:

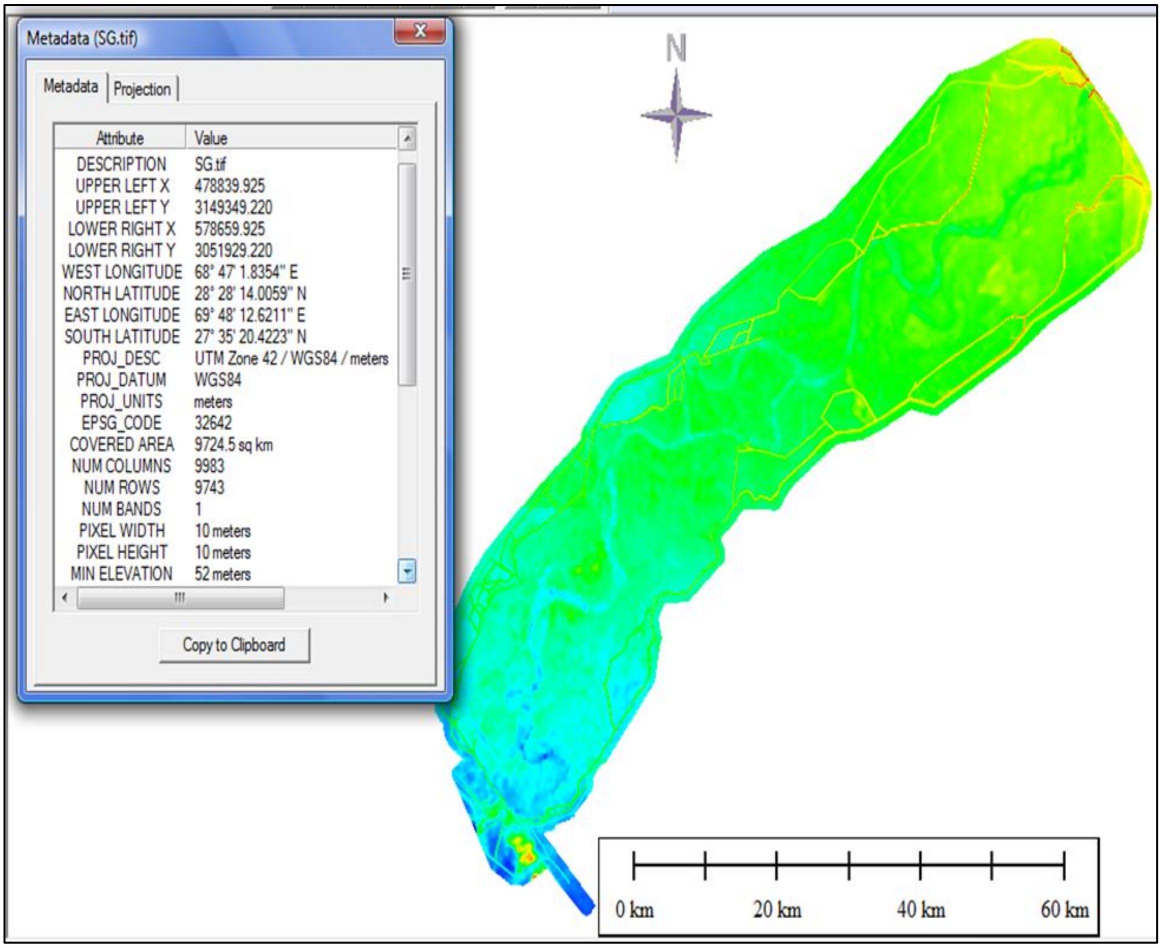


Figure 3.2: DEM Properties

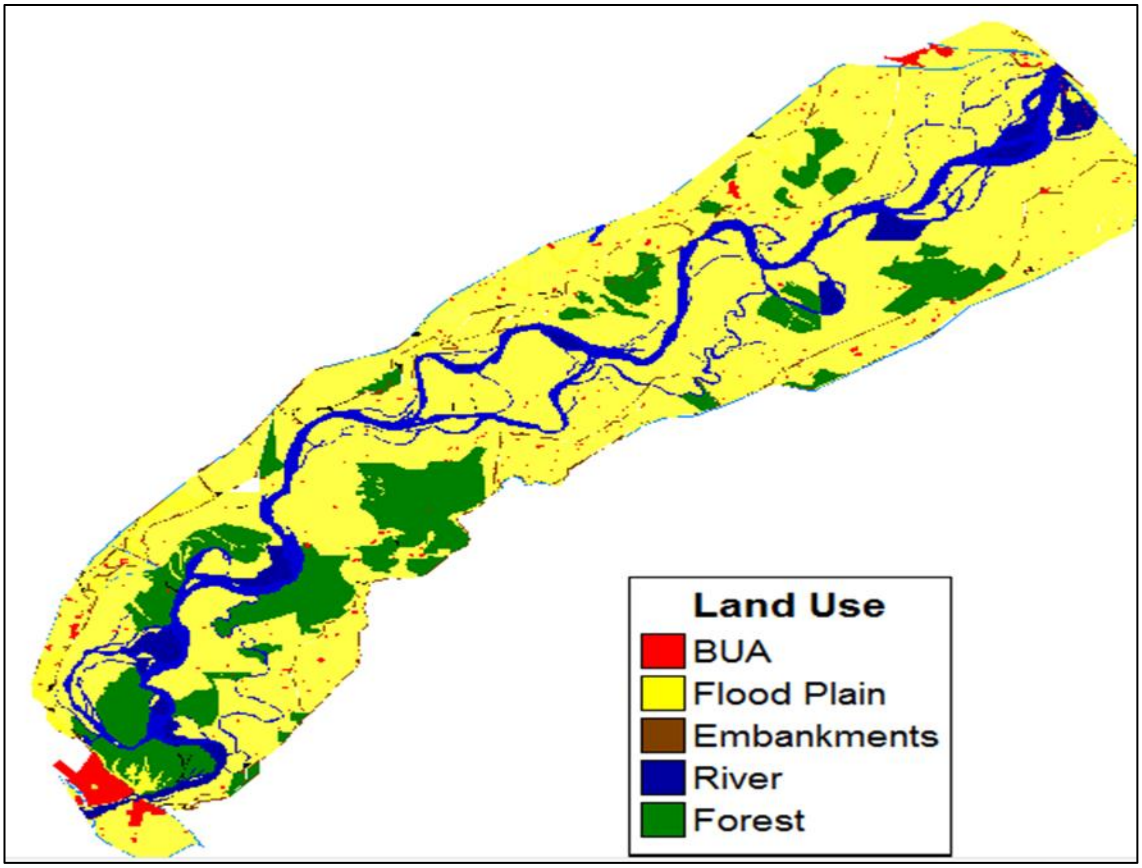


Figure 3.3: Land Use

3.3.2 Hydrological Data

Hydrological Data is obtained in the form of discharge values during 2010 flood at control structures i.e. Guddu and Sukkur Barrage. The recorded WSE along the FPB are also obtained to calibrate the model and to compare results. The record of discharge and WSE are attached as **Annexure-G**. The data clearly shows value of peak discharge of 11, 48,000 cusec on 9 Aug 2010, which caused the breach of Tori Bund and the resultant havoc.

3.3.3 Data Sources

The data has been collected from multiple sources, details of which are given in the following table:-

Table 3.2 : Data Acquisition

Data	**Data Form**	**Acquiring Agency**
Topographic Data	Digital Elevation Model (DEM)	NESPAK
Hydrological Data	Discharge – Guddu Barrage	Sindh Irrigation Deptt
Land Use / Land Cover	Digital Elevation Model	NESPAK
Data of Flood Event 2010	Water Surface Elevation (WSE)	Sindh Irrigation Deptt

3.4 Data Integration in GIS

ArcGIS is the program mainly used to integrate the data in GIS environment. The river geometry is constructed using DEM. The first step in the process is to digitize the DEM. The major layers created using HEC-GeoRAS plugin (RAS Geometry) are Stream Centre line i.e. main river channel, Levees alignment i.e. FPBs and cross-sections . The digitized layers are then integrated to form the river geometry, required for the model development.

3.4.1 Cross-Section Generation

The area is almost flat as the elevation difference from Guddu to Sukkur (160 km reach) is about 15 m, hence cross section are taken at about 2-3 km difference. The cross sections are taken between protective bunds. In the process of digitization, a Manning 'n' table is also generated using Land use / Land cover. User has to give only 'n' values for type of land once. The program automatically generates values for every cross section. Each cross section has 15-20 'n' values depending upon the type of land encountered in a cross section. After completing the digitization, the geometry file is ready to be exported to the HEC-RAS for further processing.

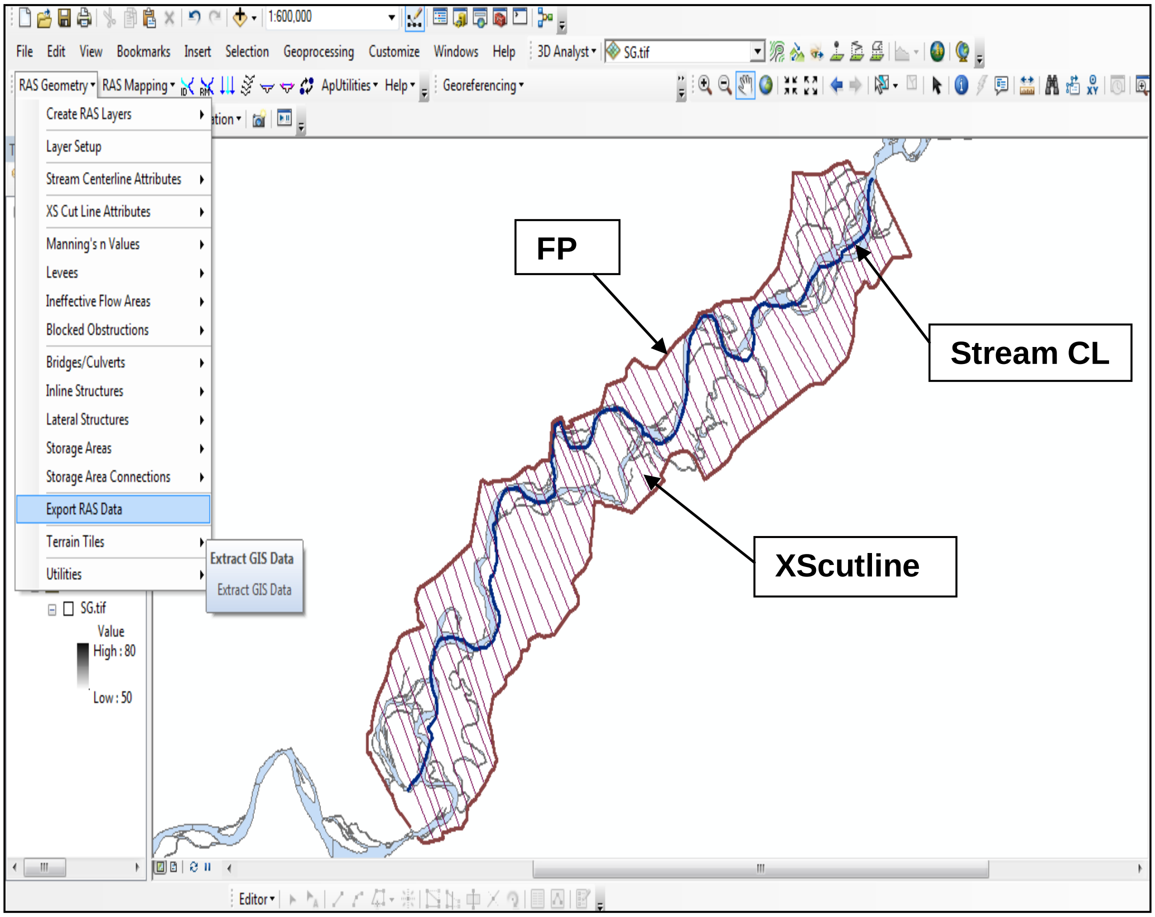


Figure 3.4 : Digitization of DEM

3.4.2 2D Mesh Generation

The mesh is generated using two different program i.e. BASEmesh plugin of QGIS and SMS 11.2 program. Both the meshes are then compared and the more refined mesh is selected for model simulation. BASEmesh is a plugin to the free and open source geographic information system (GIS) software Quantum GIS (QGIS). The plugin is a tool for creating computational meshes, based on the advanced mesh generator TRIANGLE. Furthermore, features for loading and editing existing meshes are provided. The cross sectional data generated in ArcGIS is exported to QGIS. Using this data and BASEmesh plugin a mesh is generated and then further refined using tools in QGIS.

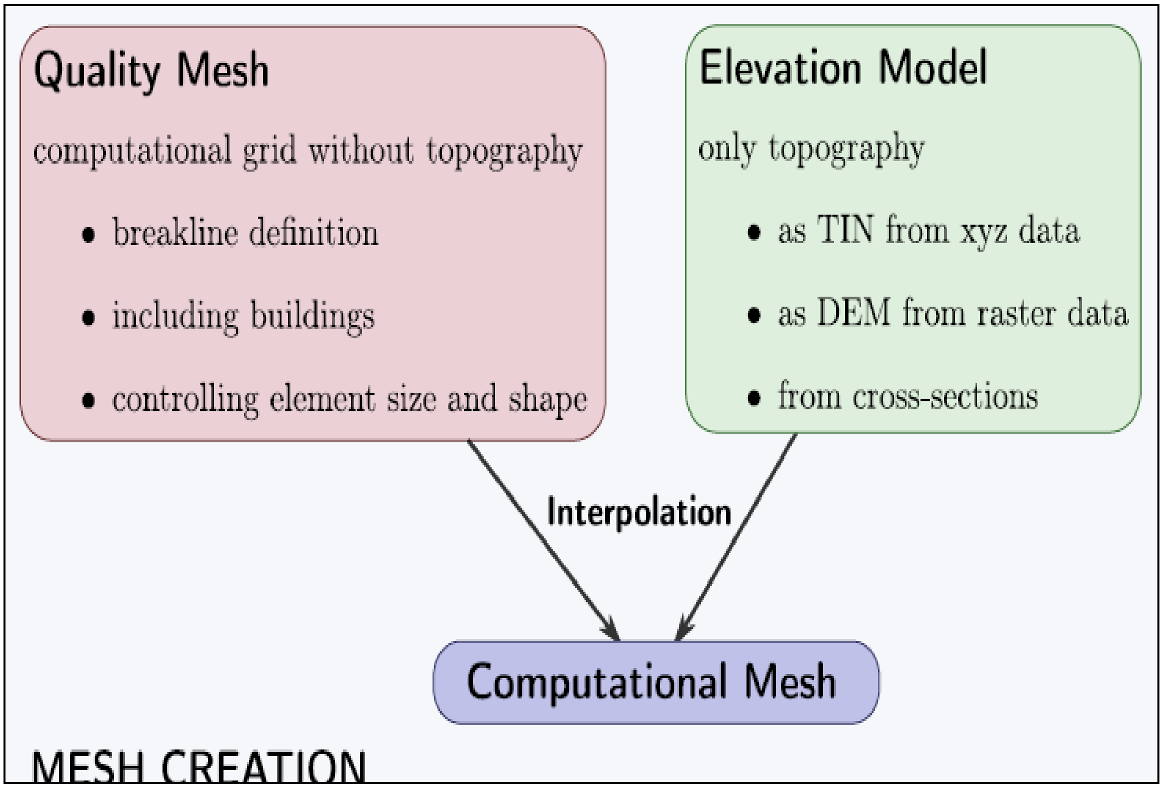


Figure 3.5: Mesh Generation in BASEmesh

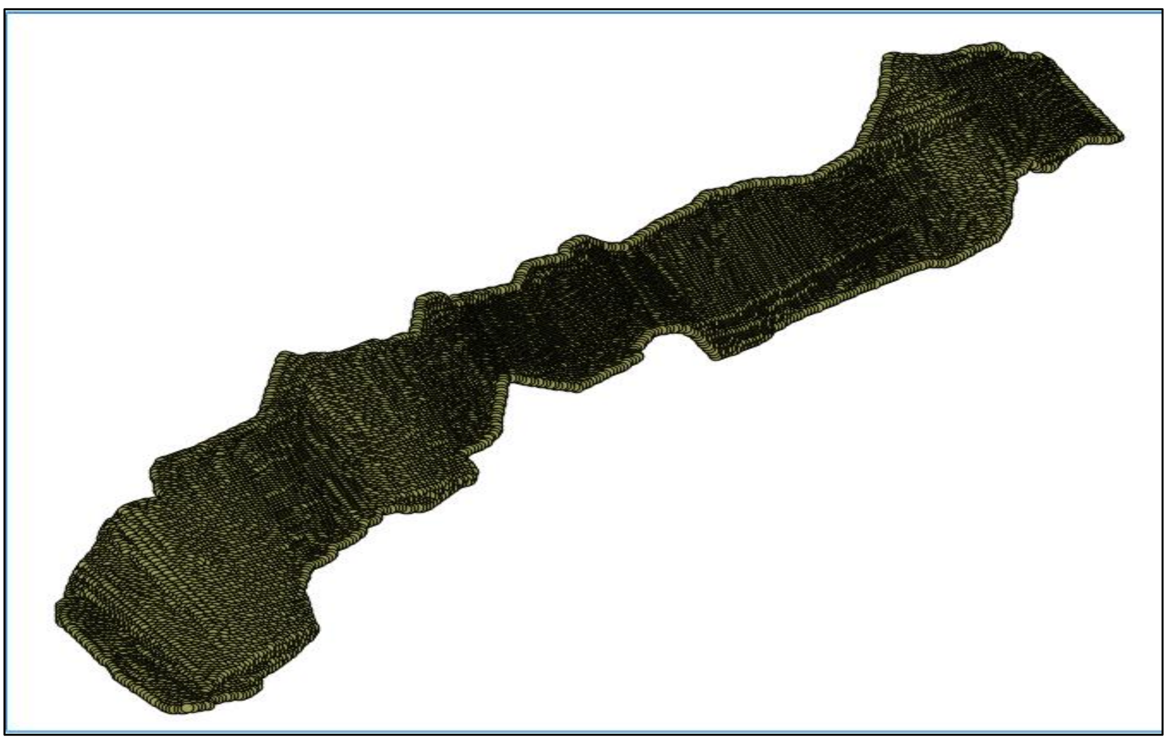


Figure 3.6: Mesh Generation using BASEmesh

For generation of mesh in SMS 11.2, elevation data extracted from DEM is loaded in the software and after giving necessary break lines, the mesh is generated. The software has advance technique to refine the mesh and remove any unwanted / small elements.

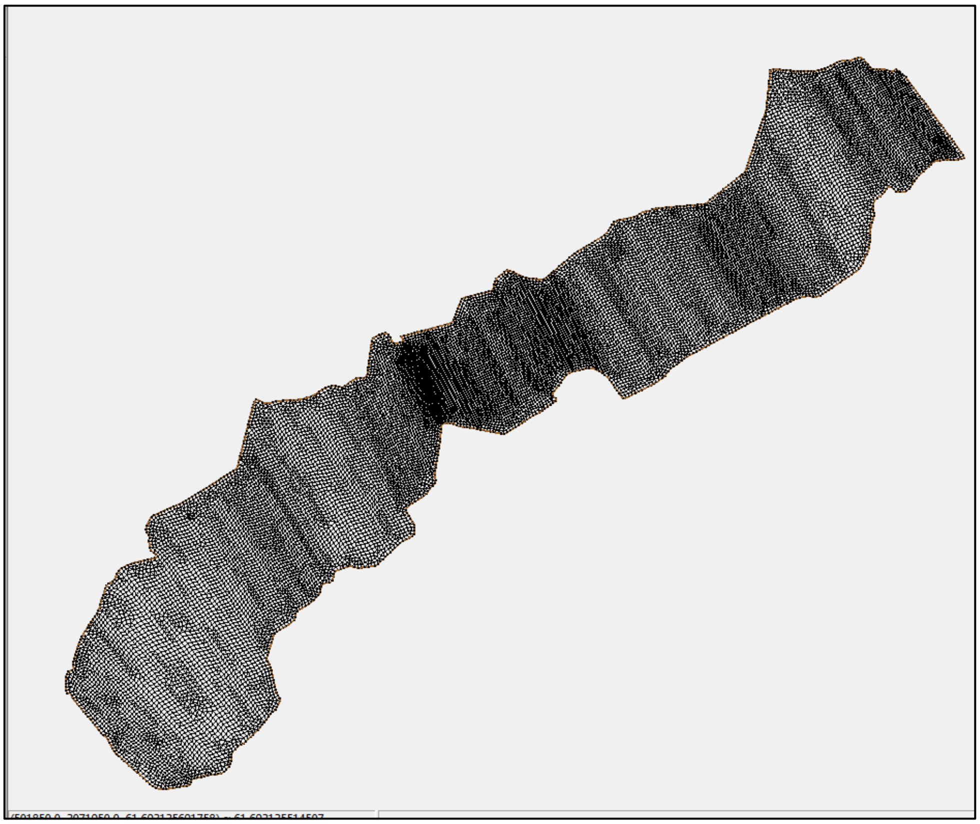


Figure 3.7: Mesh Generation in SMS 11.2

3.5 Selection of Roughness Coefficient

3.5.1 Manning ‘n’ for 1D analysis

Selection of values of ‘n’ for different Land Use is extremely important for accurately predicting the flow. Basing on the standard values of ‘n’ for different materials, previous studies (Limerinos et al. 1970 & Arcement et al.1989) and expert opinion, three set of ‘n’ values are made to be used. Manning value is the variable used during the calibration of the model. The best suited set of values will be selected as final value. The values are added as table while preparing geometry in ArcGIS, which automatically generates values for each cross section as shown in **Annexure-I**. Three set of Manning 'n' (converted to stickler 'k' for BASEMENT; n=1/ k) used as under:-

Table 3.3: Set of 'n' Values

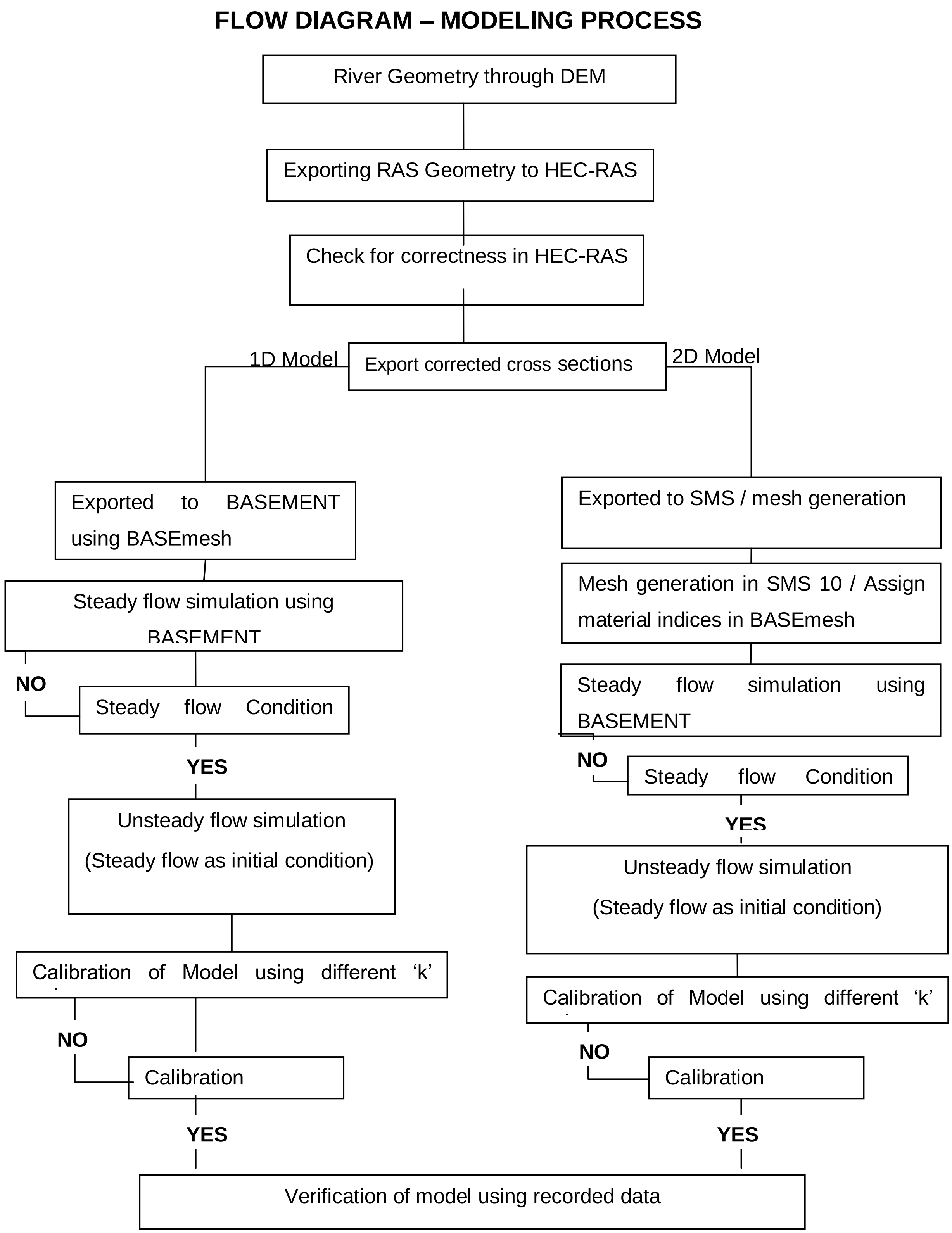
Land Cover Type	Manning set 1	Manning Set 2	Manning Set 3
Built up Area	0.02	0.02	0.018
River	0.030	0.04	0.035
Flood Plain	0.055	0.065	0.06
Forest	0.15	0.15	0.15

3.5.2 Material indices for 2D Mesh

As 'n' values are being used in cross sectional data, material indices are used to cater for friction in mesh generation. Material indices are attribute used in BASEMENT to distinguish between different materials which can be used to define friction, soil composition etc. The MATID attribute is used to set material indices for each element within the mesh, BASEMENT uses these indices to set up zones with different characteristics in the mesh, e.g. to set different friction values in the river bed and in the flood plain of the domain. In this case only two material indices are used; one was the friction value for the river bed and other for the flood plain.

3.6 Model Development

3.6.1 Modeling Process



3.6.2 HEC-RAS Model & Inundation Mapping

For development of model in HEC-RAS the GIS2RAS file is exported to HEC-RAS from ArcGIS. The file contains all the geometric data along with the values of 'n' for each cross section. As a first step each cross section is checked for any error or if a cross section is drastically different from other cross sections due to digitizing error. It is also beneficial to reduce number of points by using the tool of cross section point filter so as to ease out the computational time. On the average each cross section has 1200 - 1500 points (due to high resolution DEM), which are reduced to 100 - 200 points.

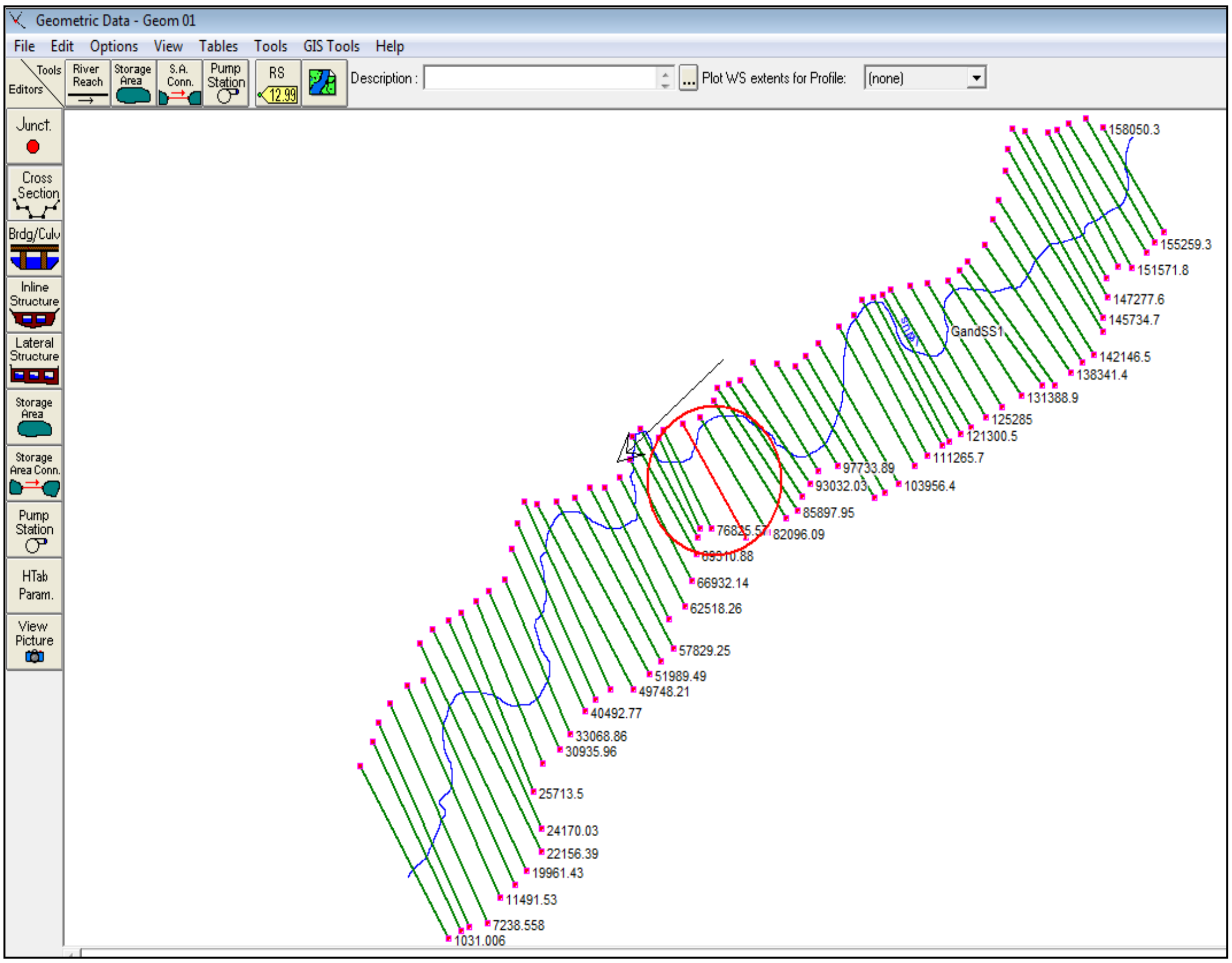


Figure 3.9 : Cross Sections in HEC- RAS

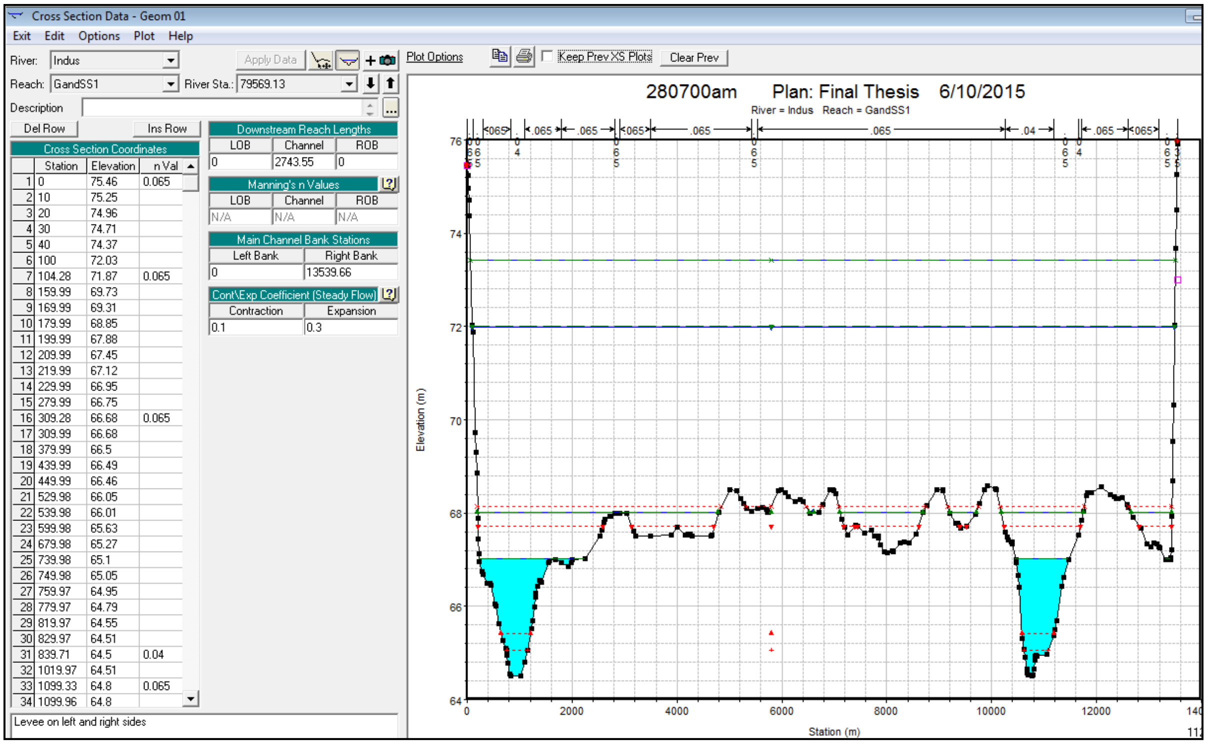


Figure 3.10: Cross Section in HEC-RAS

After correcting each cross section, the manning 'n' table is checked for errors. Again it's the HEC-RAS limitation that it can assign 20 values of 'n' in cross section and the correction are made accordingly. Once geometry is finalized, the flow data is added and up to 25000 profiles (different discharge values) can be generated using HEC-RAS. The option is available to run steady or unsteady analysis. After entering the required input the model is ready to run the simulation. In this study, a steady flow analysis is carried out for the discharge values of 1500 cumecs, 20000 cumes and 32530 cumecs (peak discharge in 2010 flood).

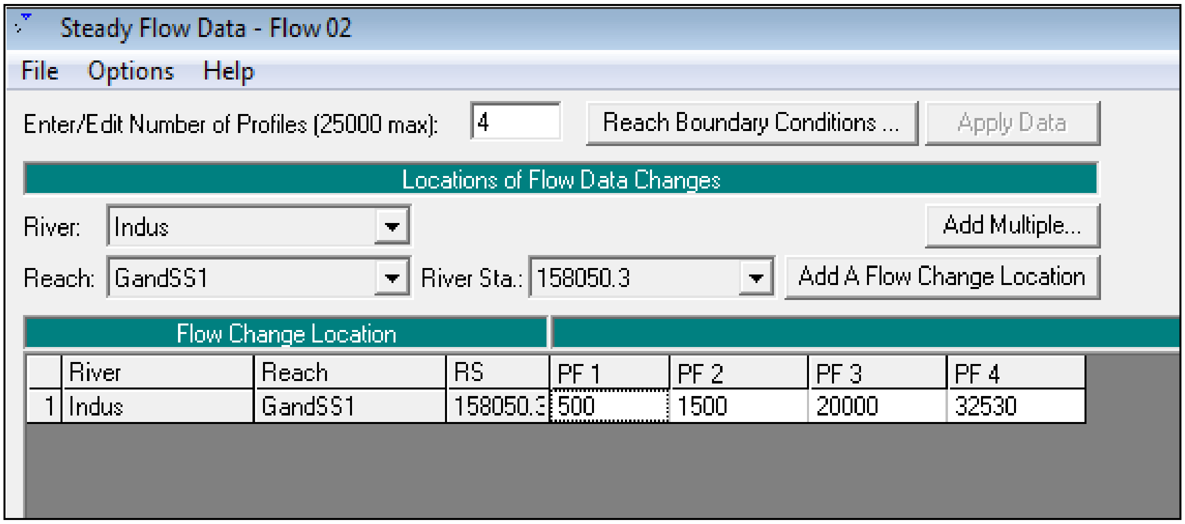


Figure 3.11 : Flow Data in HEC-RAS

3.6.3 BASEMENT Model

Topographical data required for BASEMENT 1D model is mainly the river cross sections. The program has the capability to import the cross sections from HEC-RAS. The geometric data exported from ArcGIS to HEC-RAS is further exported to BASEchain using the pre-processor BASEmesh.

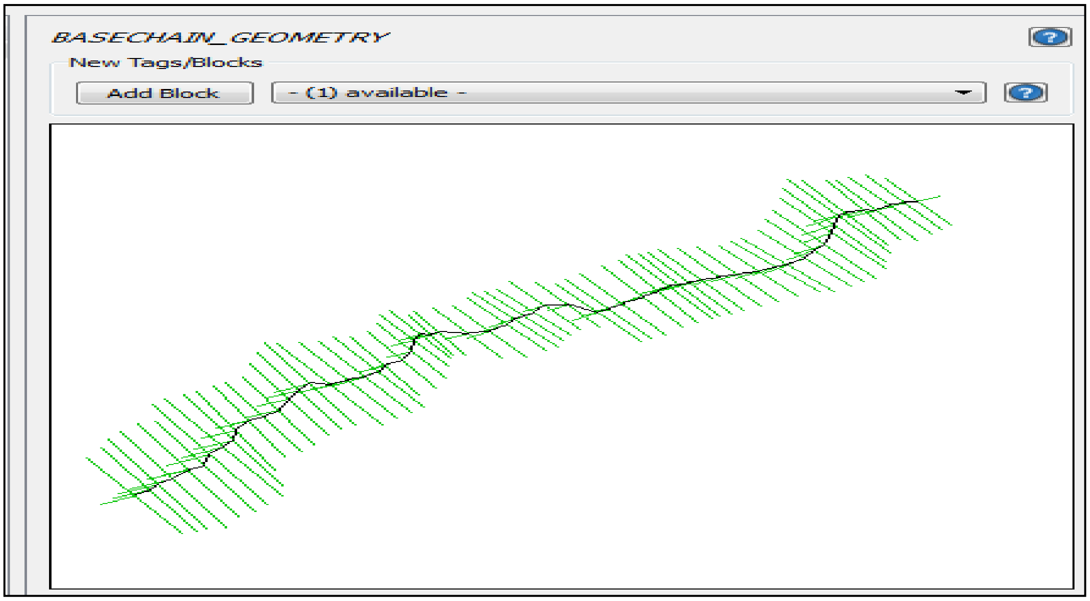


Figure 3. 12: Geometry in BASEchain

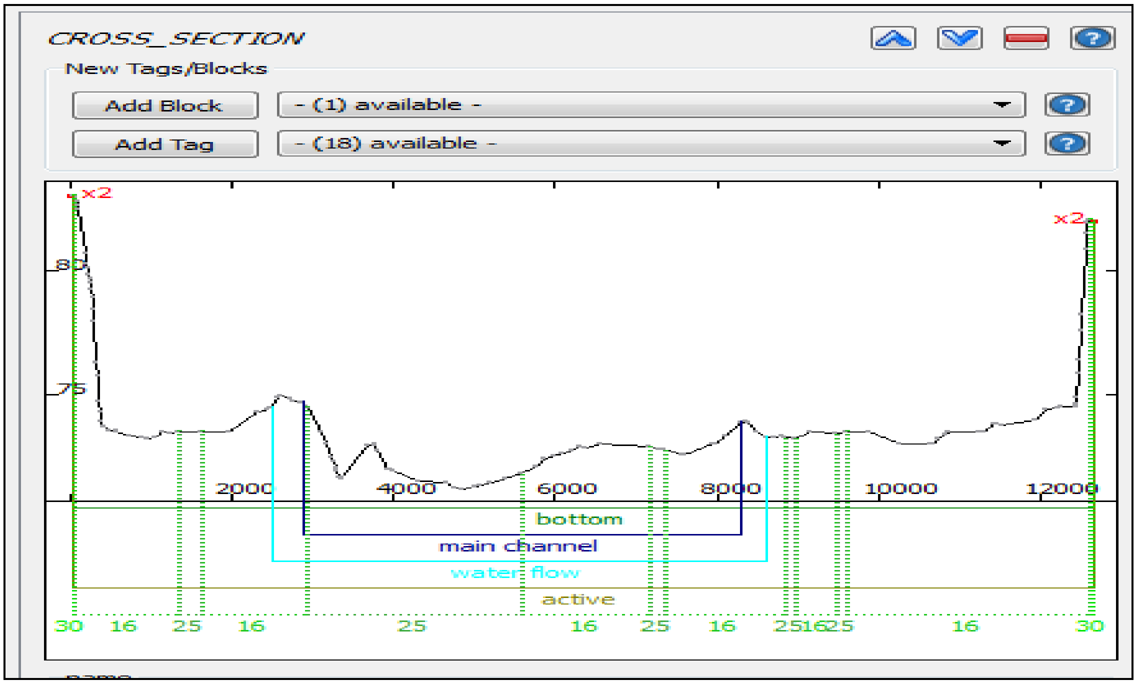


Figure 3.13: Typical Cross Section in BASEchain

The Stickler 'k' values (converted from 'n') are also exported along with each cross section. Main channel and water flow area for each cross section is also described since the cross section includes whole of the area between the two banks. This is achieved through DEM, which precisely indicates the main channel.

Apart from geometry, input structure of BASEMENT requires to specify whether it's 1D (BASE chain) or 2D simulation (BASE plane). The other inputs or "tag / blocks" required are the physical properties, hydraulics, and time step and output mode. Physical properties includes gravity, viscosity and rho fluid. Hydraulics includes the friction, input boundary and output boundary conditions. The friction given as 'k' values, the input boundary condition as hydrograph and output boundary as hq relation. The hydrograph is given as text file and mainly consists of inflow hydrograph. Initial condition is taken as dry. Output time step and output mode is also specified. Another tag "special output" also exist if output of simulation desired in form of WSE (Water Surface Elevation), discharge and velocity etc. The screenshot blow describes the various tags / blocks:-

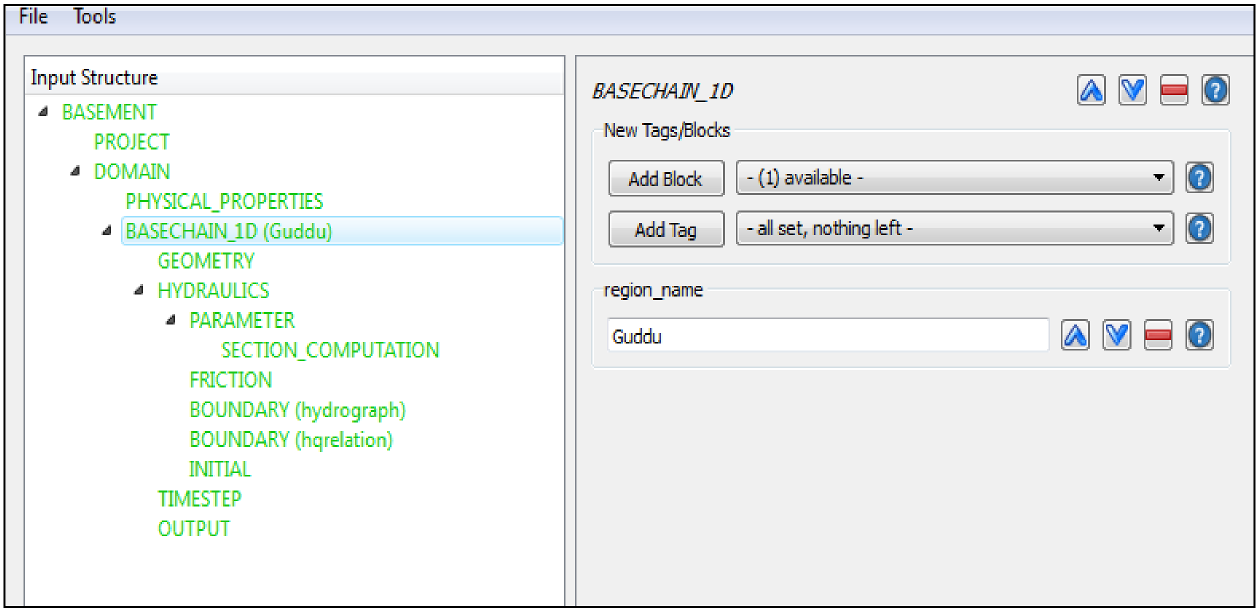


Figure 3.14: Tags / Blocks in BASEchain

For 2D simulation in BASEplane, all the "tags / blocks" are required to be as in BASE chain as explained above. However, geometry is in the form of inflow / outflow strings. These are the inflow and out flow 'nodes' obtained from the 2D mesh.

Chapter 4

RESULTS AND DISCUSSION

4.1 Model Simulation

4.1.1 HEC-RAS Model Simulation / Inundation Mapping

The model setup, as described in the previous chapter, required discharge values for a simulation. A steady flow analysis is carried out at discharge value of 500 cumecs, 1500 cumecs, 20000 cumecs and peak discharge of 2010 flood through Guddu Barrage i.e. 32530 cumecs. On running the steady flow analysis, simulation for each profile (discharge) is run sequentially and results can be viewed in the form of water surface profile for each cross section, a general profile plot, x-y prospective plot and rating curve. Since this study focuses on the overtopping of bunds, a general profile plot is obtained. The same values are plotted on excel graph as well.

For inundation mapping through HEC Geo-RAS, all the profiles are exported back to ArcGIS and again the simulation are run using ”Flood delineation” tool in HEC Geo-RAS. The results are depicted graphically on DEM.

4.1.2 1D BASEMENT (BASEchain) Model Simulation

On the completion of model setup (described in last chapter) two simulation are run. The first simulation, with a discharge of 10000 cumecs, has the aim to create a steady flow as initial condition. For steady flow, in output data of the last time step, the discharges between the cross sections correspond to the steady inflow discharge of 10000 m^3/s at all edges. Once the steady state has been reached the ‘.dat’ file, which contains the result of last time step, is used for subsequent simulations. Now the simulation is run for flood hydrograph of 2010 flood event with maximum discharge of 32500 m^3/s (11, 48,000 cusecs) and using different sets of ‘k’ values. The results are available for calibration as text file.

4.1.3 2D BASEMENT (BASEplane) Model Simulation

After completing the setup, simulation was run on BASEplane and the output option given was SMS 10 format. The output can be obtained in the form of depth, WSE, maximum WSE and velocity etc. Here the WSE output was obtained to compare it with existing data.

4.2 Model Calibration

For calibration of any hydraulic model, the basic variable is Manning roughness co-efficient ’n’. Since value of ‘n’ has been exported along with geometric data, it is possible to run simulation for different ‘n’ values (‘k’ values for BASEMENT). Water level data recorded by Sindh Irrigation Department at peak discharge from Guddu Barrage i.e. 11, 48,000 cusecs was plotted against the L-sections of a portion of FPB and used to calibrate the model. Breaching of Tori Bund is also kept in mind while calibrating the model. Comparing the results of simulation (with different n/k values) with recorded value gives the calibrated model for that portion. Simulations are then run for entire reach using particular set of values. Using different set of ‘n’ values (given in table 3); the plot of water level computed by model are attached as **Annexure-H**. Manning ‘n’ set 2 produces the closest results when compared with recorded values. For the 2D model, material indices are used as per ‘n’ values of set 2.

4.3 Model Verification / Results

4.3.1 HEC-RAS Model Result & Inundation Mapping

The results of simulation in HEC-RAS can be seen as profile plot and for this research can reveal the points of overtopping of bund. The general profile / water surface elevation for different discharge values is as under:-

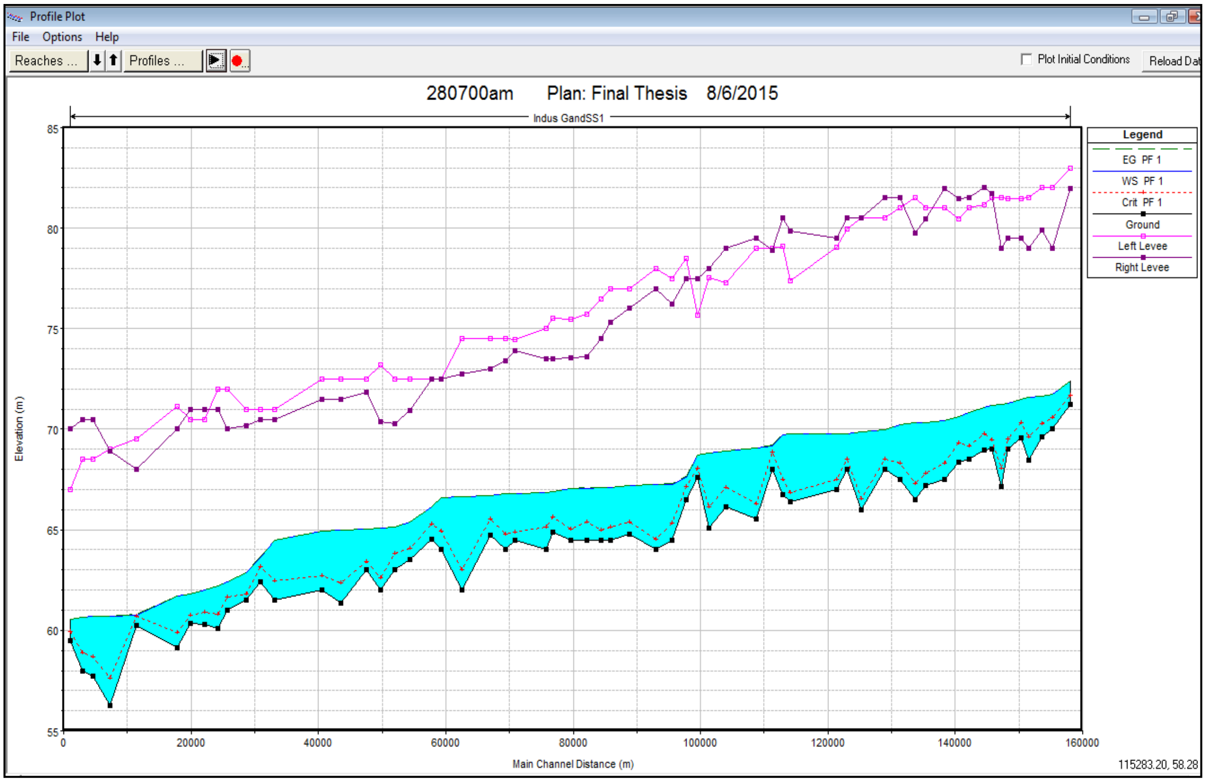


Figure 4.1: WSE at 500 cumecs

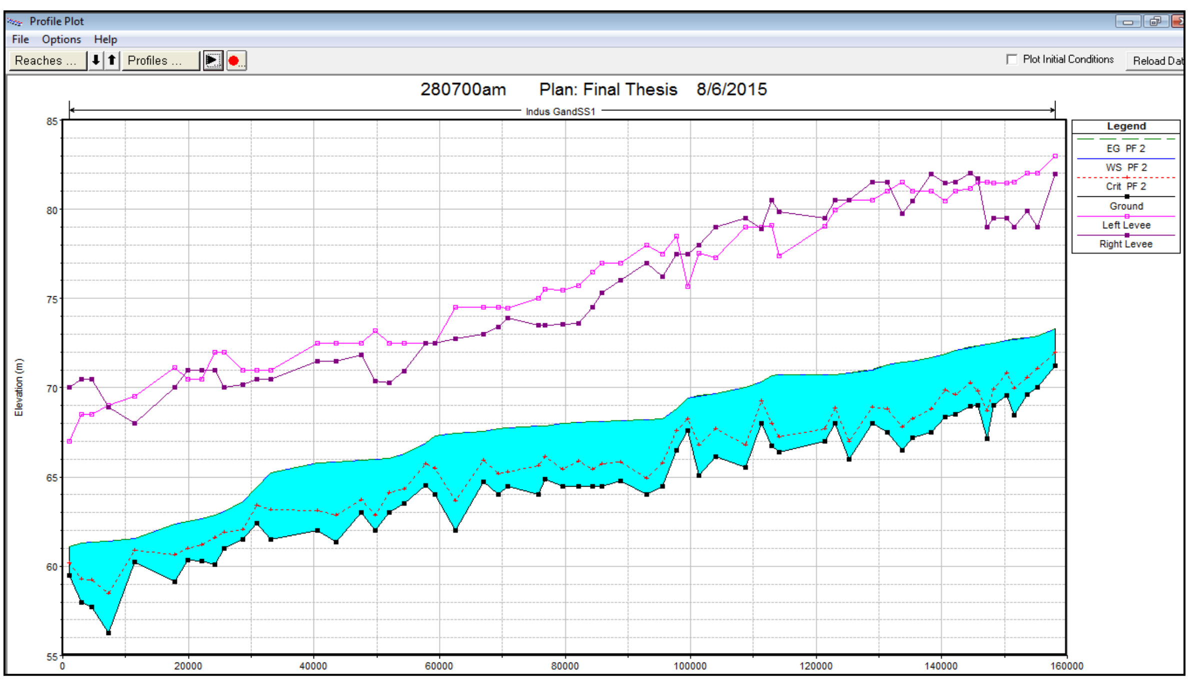


Figure 4.2: WSE at 1500 cumecs

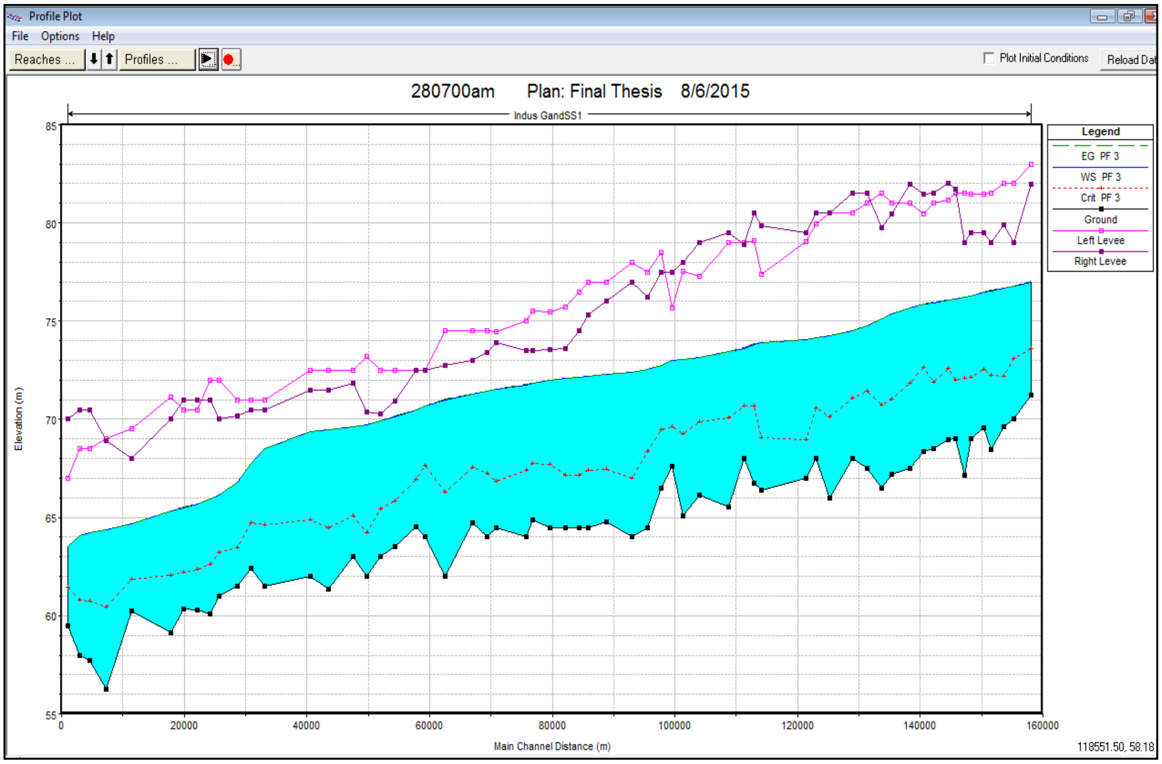


Figure 4.3: WSE at 20000 cumecs

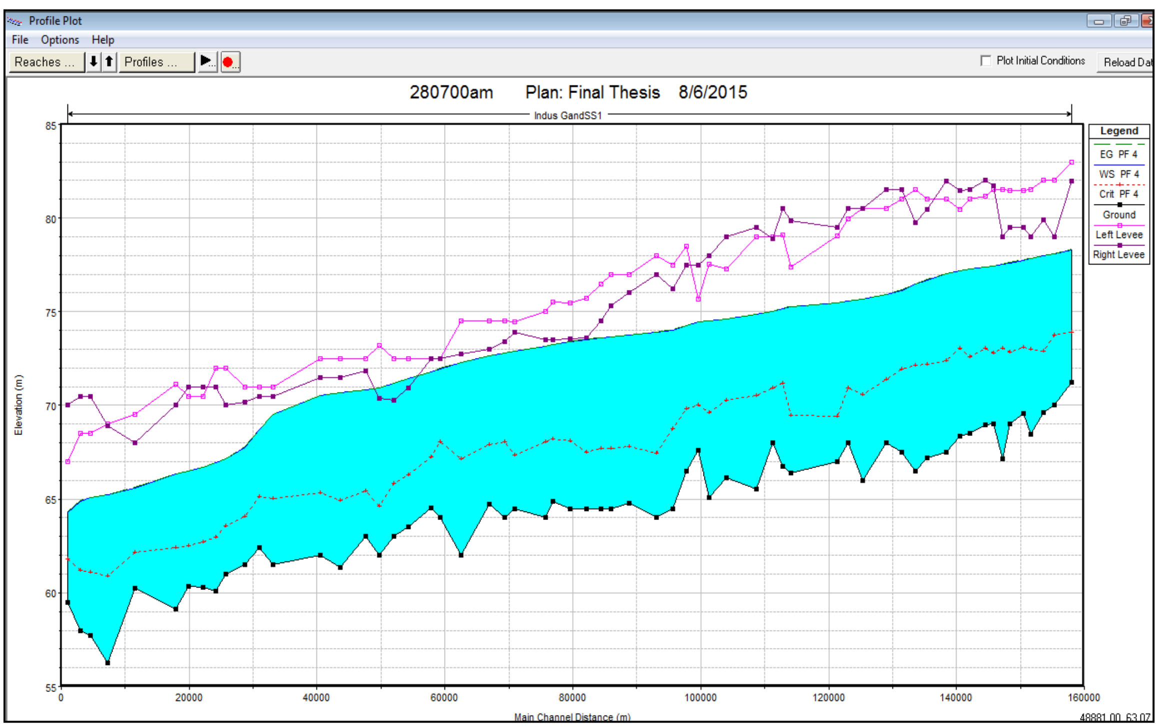


Figure 4.4: WSE at 32530 cumecs (Peak of 2010 Flood)

The results of HEC-RAS show that the bund is being overtopped at Tori, which is true as per ground condition **(Annexure-I)**. It also shows a threaten point upstream of Tori and had the discharge is what was experienced in 1976 (12, 00,000 cusecs) the overtopping would have also occurred at that point as well.

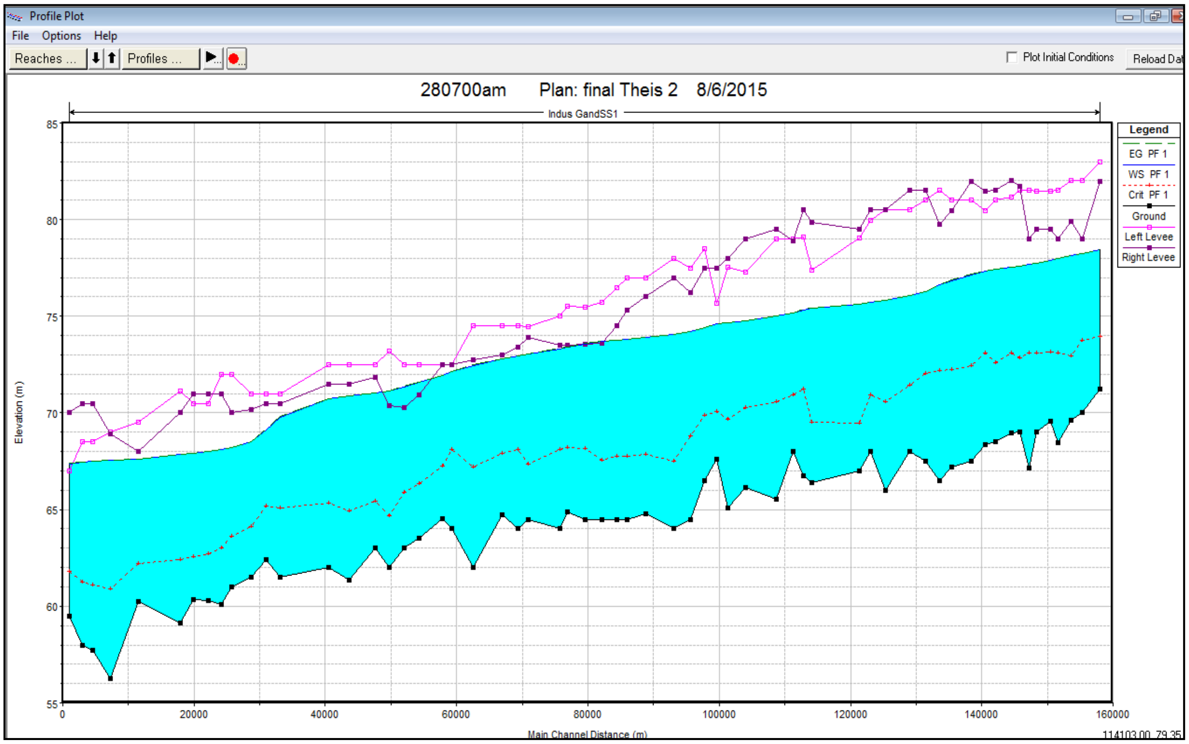


Figure 4.5: WSE at 33980 cumecs (Peak of 1976 Flood)

The inundation mapping in ArcGIS shows the water surface imposed over the map.

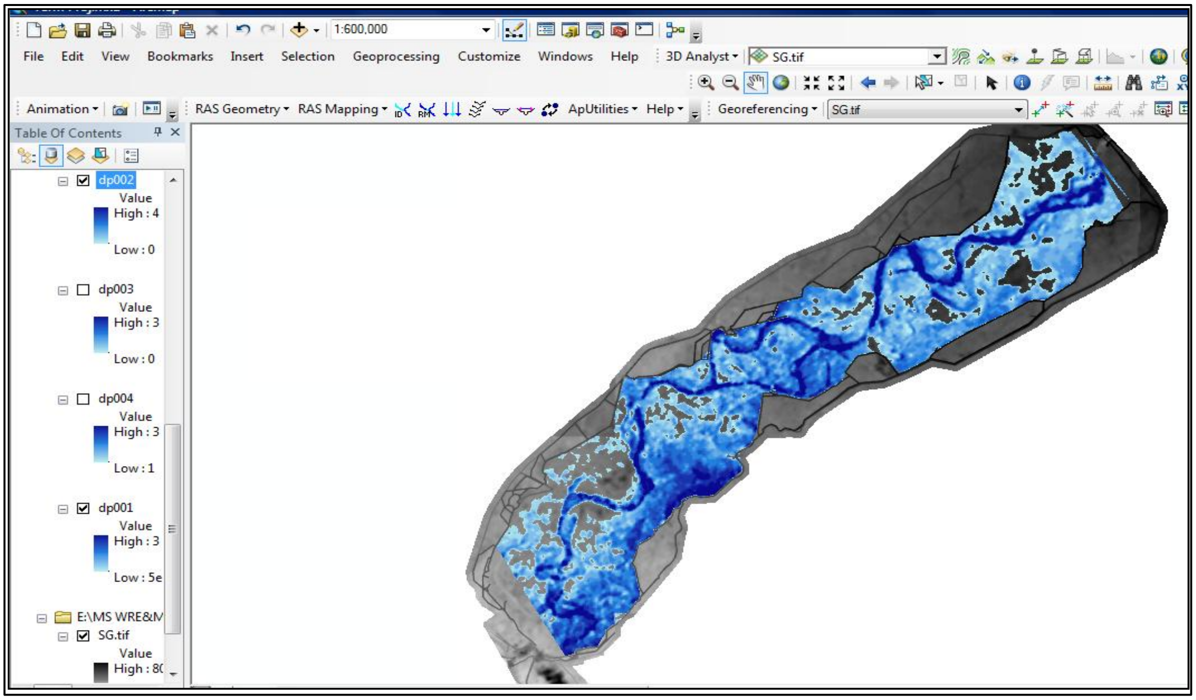


Figure 4.6: Inundation Mapping (1500 cumecs)

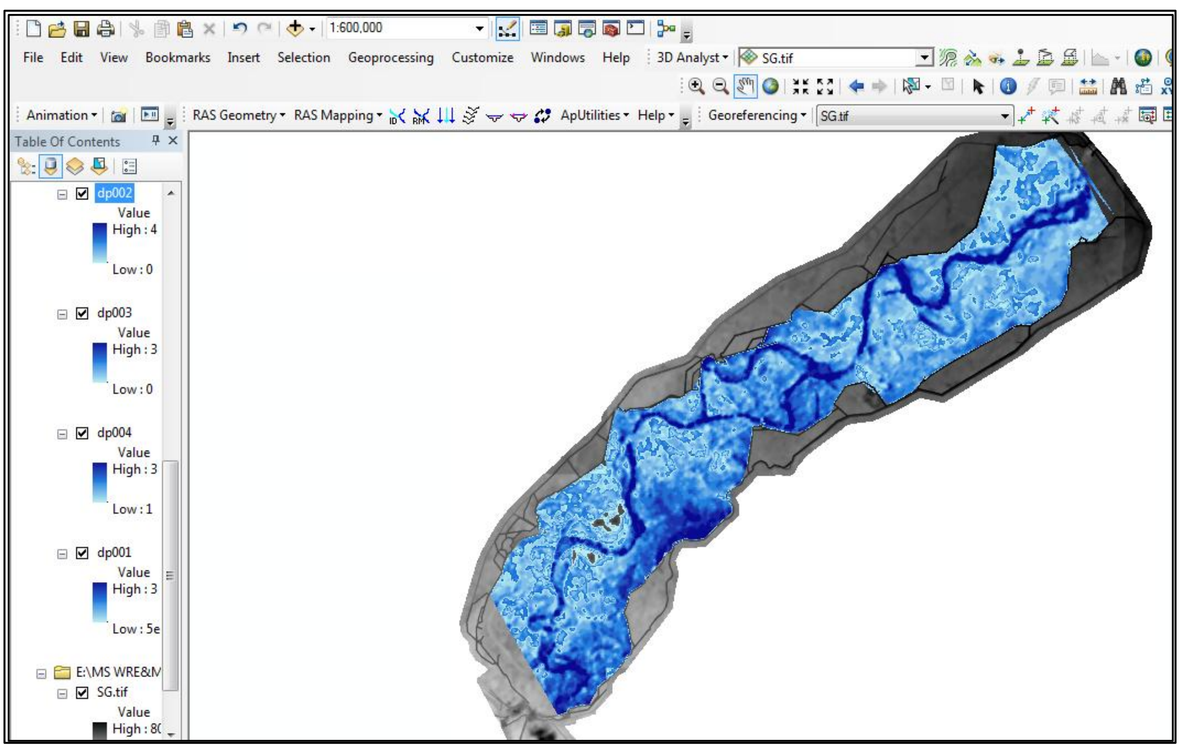


Figure 4.7: Inundation Mapping (32500 cumecs)

The values of WSE obtained from simulation from HEC-RAS are plotted on the excel sheet along with the values of bund height and recorded WSE elevation obtained from Sindh Irrigation Department. The graphical representation is given below:-.

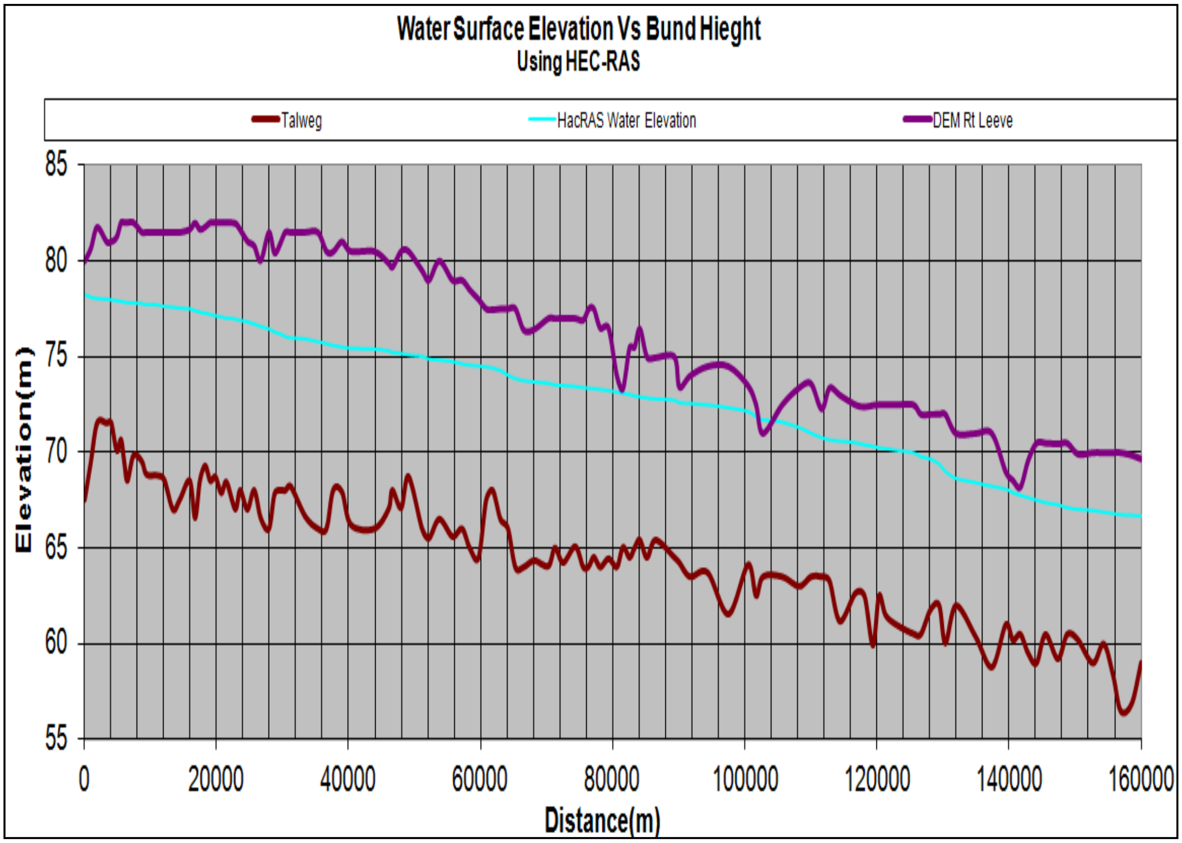


Figure 4.8: Water Surface Elevation Vs Bund Heights

4.3.2 1D BASEMENT Model Result

BASEMENT result, are generated in the form of table, which gives not only the WSE but also gives energy head, velocity etc. at each cross section. To obtain the desired results for comparison, WSE is plotted against the profile of FPB. The graphical representation is given below. The result clearly shows that the overtopping of the bund occurred due to less height of the bund.

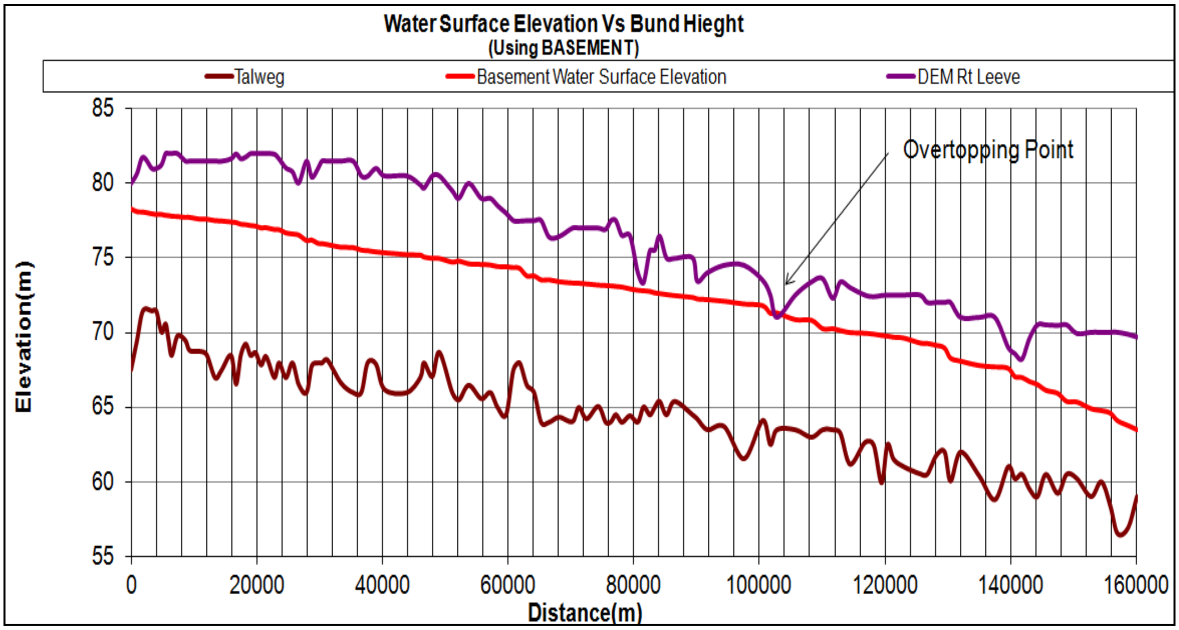


Figure 4.9: Water Surface Elevation Vs Bund Heights

4.3.3 2D BASEMENT Model Result

While generating the results form BASEplane, option is available to obtain the desired output. The study, since WSE is being used as variable to compare results, same has been taken as output after simulation. The results are shown below:-

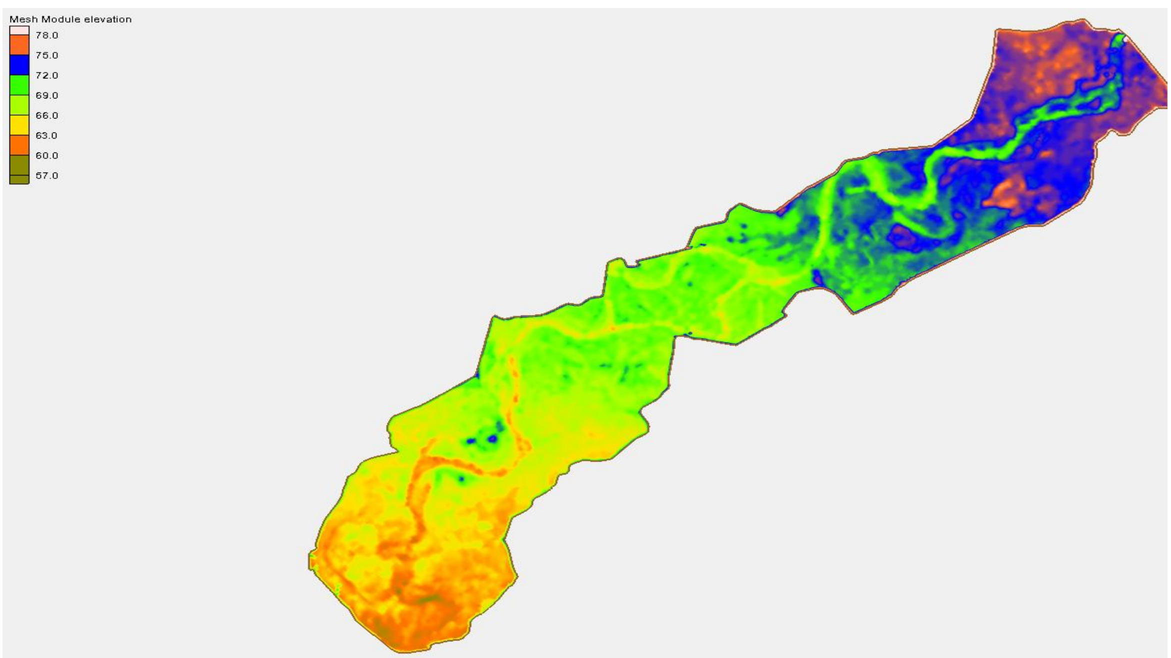


Figure 4.10: Bathymetery

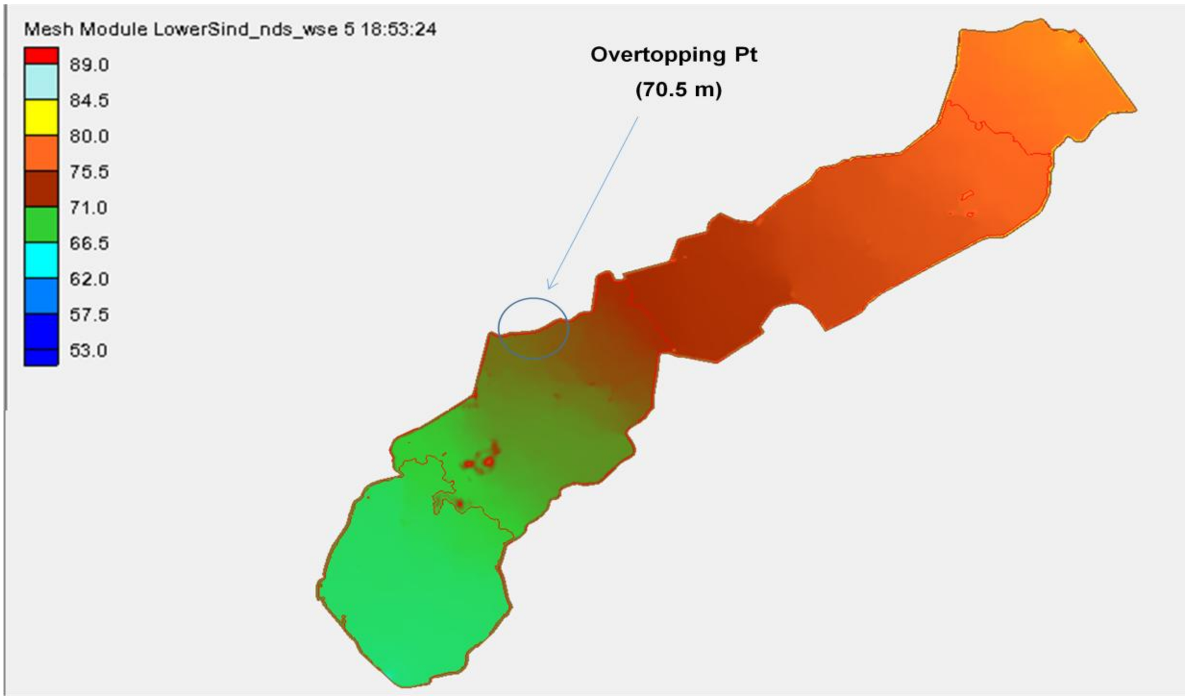


Figure 4.11: Water Surface Elevation (at 32530 cumecs)

4.4 Factual Position of Tori Bund Incident

Number of inquiries were held to ascertain the factual position of the incident including a Commission comprising of retired judges and Judicial Commission ordered by the Supreme Court. The commission mainly relied on statements of locals and irrigation officials. However, no scientific evidence was brought forward. Basing on gathered statements commission concluded that height of bunds in area are not being maintained as per Sindh Government Standing Order and Procedures (SOPs) and hence the caused breaching of the bund. Now, using the available data, it has been proved that breaching actually occurred due to overtopping.

During the course of research a neutral official from organization carrying out the relief operation was asked to deliberate on issue. The official happens to be on the spot when actual overtopping of the bund started and carried put rescue of the persons taking refuge on the said portion of bund. As per his account, due to less height of bund in that particular portion the water started flowing over the bund and soon the complete portion of bund was submerged in water. The point made above amply proves the result of the study.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- A good resolution DEM (10m), digitized and integrated through GIS software, can be used with fair accuracy to construct river geometry.
- 2010 flood simulation on the modeled reach of Guddu-Sukkur shows reduced height of bunds Versus WSE particularly the downstream of mid reach.
- Tori bund was probably overtopped due to reduced height and was not intentionally breached.
- 1D Modeling is more efficient / accurate for river / flood plain enclosed between bunds. 2D model can be utilized for large areas and generation of hazard maps.
- The methodology presented in this study can be used to simulate flood events for other reaches / river provided that topographic and hydrological data is available.

5.2 Recommendations

- Good resolution digital data may be acquired for carrying out the research in field of Water resources planning and management. LiDAR may be procured at national level to facilitate data availability.
- Height of various protective bunds and location of old breaching section may be revised based on scientific assessment carried out through river modeling.
- More research studies may be carried out on FEWS by students to modify the framework provided by the system as per our national requirements.
- Present study may be expanded by modelling the water flow extent after the breach (2D model), this will help in preparation of flood hazard maps.

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ANNEXURE-A

Major Causes of Floods in Indus Basin Rivers

River Indus:

Indus and other snow fed rivers are also likely to experience flooding due to heat wave in early summer. This phenomenon occurred in June 2005 and was followed by early monsoon rains that caused wide spread flooding in KPK. Floods in upper Indus generally result from heavy precipitation in hilly catchment of lower Himalayas and Hindukush which have limited valley storage. Superimposed upon significant snowmelt base flow, these conditions cause very heavy floods (UNSECO.Org). Lower Indus receives combined flows of Upper Indus and its left, and right bank tributaries. Floods in this reach may occur from July-October. The river can be in high flood for a period exceeding one month.

River Jhelum:

The intense rainfall in the catchments can produce exceptionally high flood peaks. The 33280 square km catchment of Jhelum River has produced three recorded floods in excess of 28000 m^3/sec in the last 75 years, with the latest in September 1992. The estimated Probable Maximum Flood (PMF) for the river varies between 48000 to 70000 m^3/sec at the recording station. Major catchment area of River Jhelum above Mangla is between 4000-12000 feet above Mean Sea Level. This results in early snow-melt runoff from February, reaching its peak in early June. High floods in the river, however, result from heavy rainfall in catchment area during the monsoon season of July to September. Though, Mangla Dam (with estimated live storage capacity of 4.54 MAF) being an irrigation replacement project does not have any storage specifically allocated to flood control, yet during early part of its filling, till about early August, it can significantly help in flood regulation (UNSECO.Org).

River Chenab:

Floods in Chenab generally result from heavy precipitation in the hilly catchment areas in lower Himalayas with limited valley storage. Snow melt flow reach peak in early July. This, however, is not a significant factor contributing to high floods during August and September. Manipulation of hydropower projects by India with significant storage on River Chenab can also result in a flood like situation for a certain period of time affecting significant area adjoining the river course.

River Ravi:

Flooding in Ravi generally results from excessive rainfall in the mountainous catchments in India and sub-mountainous areas draining into lower river reaches within Pakistan. Snow melt makes no significant contribution to flood peaks in Ravi. The snow melt flows normally occur in the spring, falling off before the monsoon rains begin in June/ July.

River Beas / Sutlej:

Floods in Beas and Sutlej result from intensive rainfall in catchment areas within India. Occurrence and severity of floods in this river is greatly altered by the construction of upstream dams (Pong Dam on Beas and Bhakra Dam on Sutlej) in India during 1963-1977. However, when these reservoirs are full, some late monsoon rains can still bring down large flood flows into Pakistan.

ANNEXURE-B

Flood Management in Pakistan

Flood season in Pakistan extends from June 15 to October 15 (4 months). Flood management during this period generally covers preparation of flood forecasts and warnings including their dissemination to public and concerned agencies. It covers maintenance and operation of various flood protection/ control/ regulating works and management of on-line reservoirs (Tarbela, Chashma and Mangla) and whenever required it also include evacuation of affected people and relief measures.

Institutional Arrangement for Flood Management

Flood management is a multi-functional process involving various federal and provincial departments. In this, the Federal Flood Commission (FFC), is the lead federal agency in providing necessary institutional framework to supplement provincial flood management measures. The Commission has revised flood management policy of the country through two major projects, Flood Protection Section Project (FPSP) I and II. Number of organizations, as listed below, are responsible for issuing alerts / warnings (Flood Management by FFC, 2012) and implement preventive measures including evacuations:-

1. Flood Forecasting Division (FFD)
2. National Disaster Management Authority (NDMA)
3. Provincial Irrigation and Drainage Authority
4. WAPDA
5. Provincial Relief Department
6. Pakistan Army
7. Emergency Relief Cell

8. Civil Defense Organization

Role of Different Departments

Flood Forecasting Division (FFD). FFD, a subsidiary of PMD, plays a central role in flood forecasting and warning. The department obtains hydro meteorological data from various national and international sources including satellite data to prepare flood forecasts, which are disseminated to various flood management and relief organizations.

National Disaster Management Authority (NDMA). NDMA was raised in the aftermath of Earthquake 2005 and has a constitutional cover. The body has been assigned following roles:-

1. Lay down guidelines for preparing disaster management plans by all concerned.
2. Provide necessary technical assistance to provincial governments for preparation of disaster management plans in line with laid down guidelines.
3. Coordinate response in the event of disaster.
4. Promote general education and awareness in relation to disaster management.
5. Lay down guidelines for concerned ministries and provincial governments regarding measures in response to any threatening disaster situation or disaster.
6. For any specific purpose or for general assistance, requisition of services of any person(s) and such person(s) shall be a co-opted member and exercise such power as conferred upon him by authority in writing.

Provincial Irrigation and Drainage Authority. The authority plays a prominent role in flood management through planning, design, construction and maintenance of flood protection works. It also undertakes flow measurements at specific rivers and irrigation canal sites.

WAPDA:

The authority is custodian of Tarbela and Mangla dams and undertakes day to day reservoir management for irrigation flow releases. It helps FFD through provision of rainfall data from telemetric rain gauge stations and flood data at various locations in Indus River system.

Provincial Relief Department:

These are headed by Relief Commissioners who coordinate relief efforts during and after floods. The Commissioners also undertakes flood preparation actions such as inspection of flood protection measures and establishment of flood warning and flood relief centres at local government level.

Pakistan Army:

Army carries out relief and rescue missions during flood emergency, when requisitioned in 'Aid of Civil Power'. It also mobilizes necessary resources for immediate restoration of infrastructure including protective embankments during and after floods.

Emergency Relief Cell:

Emergency Relief Cell is established in Cabinet Division of Federal Government. The relief cell plans for major disasters including floods by stockpiling basic life necessities required by the population affected by flooding.

Civil Defense Organization:

This organization assists local administration / Army in rescue, evacuation and relief efforts and provides manpower for flood management training in rescue and relief work.

In addition, Provincial Health, Agriculture, Livestock, Food, Communication, Works, Planning and Development departments play an important role in flood management.

ANNEXURE-C

GIS Software

It is a Geographic Information System (GIS) for working with maps and geographic information. It is used for: creating and using maps; compiling geographic data; analyzing mapped information; sharing and discovering geographic information; using maps and geographic information in a range of applications; and managing geographic information in a database. The system provides an infrastructure for making maps and geographic information available throughout an organization, across a community, and openly on the Web.

QGIS:

QGIS (previously known as "Quantum GIS") is a cross platform free and open-source desktop geographic information system (GIS) application that provides data viewing, editing, and analysis capabilities. Similar to other software GIS systems QGIS allows users to create maps with many layers using different map projections. Maps can be assembled in different formats and for different uses. QGIS allows maps to be composed of raster or vector layers.

Global Mapper:

Global Mapper is a geographic information system (GIS) software package currently developed by Blue Marble Geographic's that runs on Microsoft Windows. The GIS software competes with ESRI, GeoMedia, Manifold System, and MapInfo GIS products. Global Mapper handles both vector, raster, and elevation data, and provides viewing, conversion, and other general GIS features.

Modeling Software

HEC-RAS:

HEC-RAS is a computer program that models the hydraulics of water flow through natural rivers and other channels. The program is one-dimensional, meaning that there is no direct modeling of the hydraulic effect of cross section shape changes, bends, and other two- and three-dimensional aspects of flow. The program was developed by the US

Department of Defense, Army Corps of Engineers in order to manage the rivers, harbors, and other public works under their jurisdiction; it has found wide acceptance by many others since its public release in 1995. The Hydrologic Engineering Center (HEC) in Davis, California developed the River Analysis System (RAS) to aid hydraulic engineers in channel flow analysis and floodplain determination. It includes numerous data entry capabilities, hydraulic analysis components, data storage and management capabilities, and graphing and reporting capabilities. The basic computational procedure of HEC-RAS for steady flow is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction and contraction / expansion. The momentum equation may be used in situations where the water surface profile is rapidly varied. For unsteady flow, HEC-RAS solves the full, dynamic, 1-D Saint Venant Equation using an implicit, finite difference method.

BASEMENT:

Basic Simulation Environment provide a flexible and functional environment for numerical simulation of rivers and sediment transport involved. Typical employment include simulation of flow behavior under steady and unsteady conditions (1D & 2D, 3D under const.) and simulation of sediment transport / erosion. 1D module is based on the Saint Venant Equations (SVE) for unsteady one dimensional flow. Spatial Discretization used is finite volume. The flow conditions at a channel cross section can be defined by two flow variables. Therefore, two of the three conservation laws are needed to analyze a flow situation. 2D module is based on the 2D Saint Venant Equations (SVE) for unsteady two dimensional flow. Spatial Discretization used is finite volume.

ANNEXURE -D

HYDROLOGICAL UNITS – PAKISTAN

Hydrological Units	Physiographic Area	Principal Rivers & Tributary Relationship	Geographical Area in Square Miles
Indus River Basin	Mountain basins of the North & West of the Indus Plains plus Kachhi Plains, desert area of the Sindhh and the Rann of Kutch	Indus Siran Kabul Kunhar (Chitral) Swat Panjkora Haro, Soan Kohat, Kurram Gomal, Zhob Panjnad, Chenab Jhelum, Sutlej, Ravi , Bias	216,700
Kharan Desert (Closed) Basin	Mountain Basins of the Quetta area & basins tributary to the dry lakes (Haouni Lora, Haouni Mashkel and others) of the Kharan Desert Area	Nari, Bolan & others Kachhi plain streams Pishin Lora Baddo Rakhshan Mashkel and many small streams	46,400

Makran Coastal Basin	Numerous individual coastal basins extending 200 miles or more into the interior	Malir,Hub,Porali' Kud,Hingol,Nal Mashkai Dasht Nihing Kech	47,300
Total Area -- Pakistan			310,400

ANNEXURE-E

DETAILS OF THE INDUS CATCHMENT AREA (SQUARE MILES)

Location	Rivers						
	Indus	**Jhelum**	**Chenab**	**Ravi**	**Sutlej**	**Beas**	**Total Area**
Region-wise							
Pakistan	77125	5122	12209	11333	11232	--	117021
India	--	--	--	987	9091	1797	11875
Sub Total	77125	5122	12209	12320	20323	1797	128896
Uplands & Hills							
Pakistan	80953	5066	1260	--	--	--	87279
India	--	--	1735	3421	3047	5922	14125
Jammu & Kashmir	47298	11171	10831	--	--	--	69300
China	18067	--	--	--	17853	--	35900
Afghanistan	29200	--	--	--	--	--	29200
Sub Total	175513	16237	13826	3421	20885	5922	235804
Total Area	252638	21359	26035	15741	41208	7719	364700
Country-Wise							
Pakistan	158078	10188	13469	11333	11232	--	204300
India	--	--	1735	4408	12138	7719	26000

Jammu & Kashmir	47298	11171	10831	--	--	--	69300
Afghanistan	29200	--	--	--	--	--	29200
Tibet(China)	18062	--	--	--	17838	--	35900

ANNEXURE-F

FLOOD LIMITS

Sr.	Rivers	Site	Low	Medium	High	Very High	Exceptionally High
a.	**Indus**						
		Tarbela Down stream	2.50	3.75	5.00	6.50	8.00
		Attock Bridge	2.50	3.75	5.00	6.50	8.00
		Kalabagh Barrage	2.50	3.75	5.00	6.50	8.00
		Chashma Barrage	2.50	3.75	5.00	6.50	8.00
		Taunsa Barrage	2.50	3.75	5.00	6.50	8.00
		Guddu Barrage	2.00	3.50	5.00	7.00	9.00
		Sukkur Barrage	2.00	3.50	5.00	7.00	9.00
		Kotri Barrage	2.00	3.00	4.50	6.50	8.00
b.	**Jhelum**						
		Kohala	1.00	1.50	2.00	3.00	4.00
		Mangla Head/Works	0.75	1.10	1.50	2.25	3.00
		Rasul Barrage	0.75	1.10	1.50	2.25	3.00
c.	**Chenab**						

		Marala Barrage	1.00	1.50	2.00	4.00	6.00
		Qadirabad Barrage	1.00	1.50	2.00	4.00	6.00
		Trimmu Barrage	1.50	2.00	3.00	4.50	6.00
		Punjnad Head/Works	1.50	2.00	3.00	4.50	6.00
e.	**Ravi**						
		Jassar Bridge	0.50	0.75	1.00	1.50	2.00
		Shahdara Bridge	0.40	0.65	0.90	1.35	1.80
		Balloki Head/Works	0.40	0.65	0.90	1.35	1.80
		Sidhnai Head/Works	0.30	0.46	0.50	0.90	1.30
f.	**Sutlaj**						
		Suleimanki Head/Works	0.50	0.80	1.20	1.75	2.25
		Islam Head/Works	0.50	0.80	1.20	1.75	2.25

ANNEXURE-G

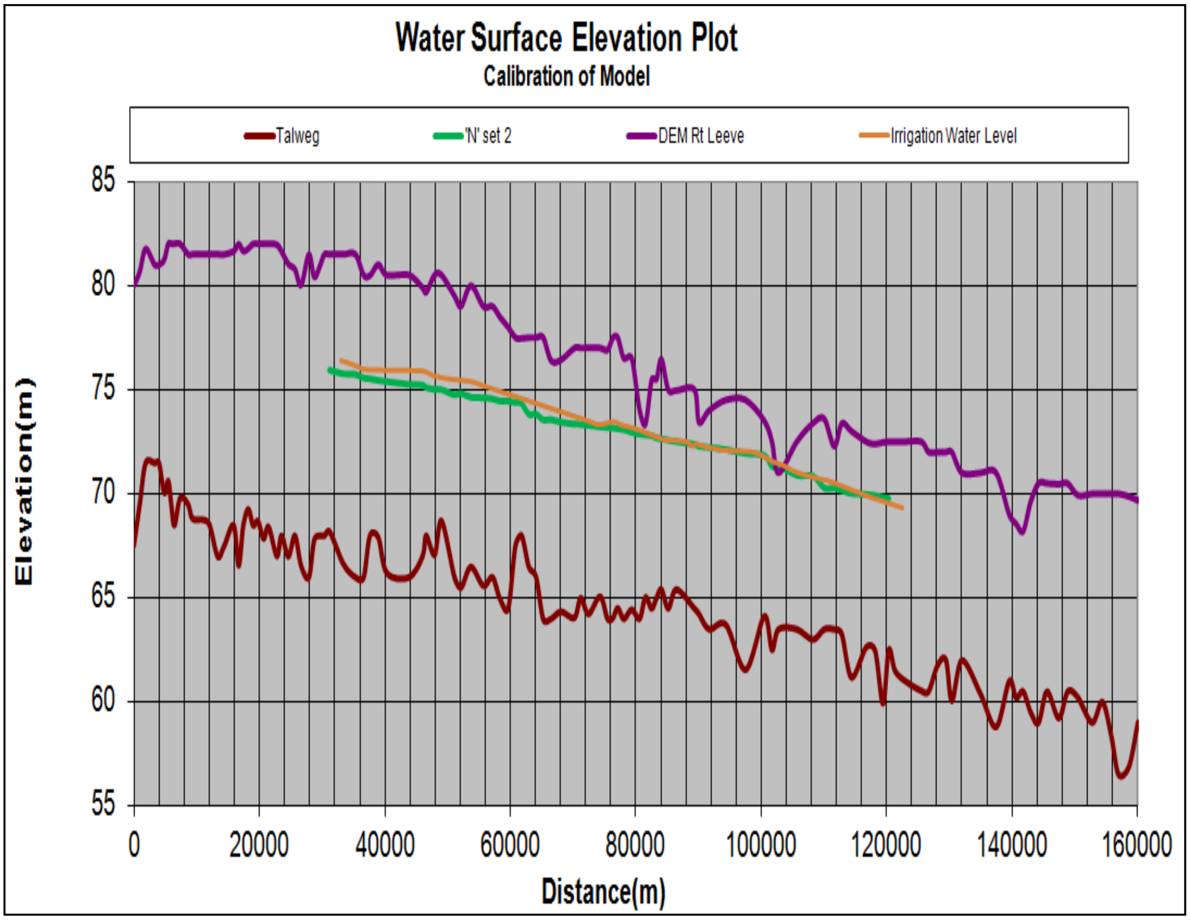
Water Level Recorded by Sindh Irrigation Department at Peak Discharge from Guddu Barrage (11, 48, 0000 Cusecs)

Distance from Tori (m)	Right Levee Name	Left Levee Name	Recorded Water Levels 2010 Floods (m)
0	Tori	OGDC	69.28963415
1960.90922			69.48826571
3827.319427			69.67929505
5656.402646			69.86405772
11334.58912			70.54434029
12201.54911			70.63191522
13296.75526			70.69604514
15981.32621			70.91879649
17526.06541			71.08471669
18490.13047			71.2617783
19623.98863			71.40574389
20771.56279			71.52662809
21346.62469	Gora Ghat		71.62696398
22207.27564			71.77712898
24144.72954			71.99433953
27323.30271			72.04268293
28843.79349			72.07211059
30485.2805			72.17762786
31752.59038			72.2606327
32969.29743		LM Bund	72.3706767
33431.08833			72.2606327
34382.8535	Ghora Ghat		72.46997483
35017.79729			72.50262695
36058.59114		Rawnti Bund	72.53908175
37210.7623			72.57061347
38177.96614			72.58837728
42056.59496	Kacha Kharif		73.05012622

44061.76388			73.22783308
44756.77887			73.27889207
45231.11382			73.34016591
46042.93367			73.45199094
48324.98555			73.29951365
49794.22767			73.45062583
50383.99465			73.51021104
50849.44069			73.55722752
Distance from Tori (m)			Recorded Water Levels 2010 Floods (m)
51523.46385			73.62531316
52158.01994			73.68941209
52775.01804			73.75173742
53366.83814			73.81197277
53997.22303			73.87680813
54308.37507			73.90881025
55003.15022			73.97985833
59462.16705		Dilwaro Bund	74.43332939
60515.97711			74.53977876
61204.01311			74.6092799
61881.2153			74.67768668
62519.28121			74.74214015
63370.71628	Kacha Kharif		74.82814685
63910.20041			74.8826422
64409.32533			74.93306071
65092.78843			75.00209992
65655.61048			75.05895272
66773.46359			75.17187132
68936.54748		Machka Bund	75.39037267
72454.92413			75.50812214
73386.92417			75.56803252
74165.19406			75.61806089
74669.33203			75.65046764

75106.99313			75.71223819
75709.21911			75.80072276
76621.83421			75.89441791
85469.99843			75.951833
86531.42722			76.051829
87079.35917			76.135892
87812.80002		Ghotki Bund	76.22256
88461.57508			76.295881
89535.14014			76.390243

ANNEXURE-H



Water Surface Elevation Plot
Calibration of Model
Talweg
'N' set 2
DEM Rt Leeve
Irrigation Water Level
85
80
75
70
65
60
55
Elevation(m)
0
20000
40000
60000
80000
100000
120000
140000
160000
Distance(m)

ANNEXURE-I

Manning ‘n’ Table in exported from ArcGIS

Edit Manning's n or k Values

River: Indus | Edit Interpolated XS's | Channel n Values have a light green background

Reach: GandSS1 | All Regions

Selected Area Edit Options: Add Constant ... | Multiply Factor ... | Set Values ... | Replace ... | Reduce to L Ch R ...

	River Station	'rctn (n/K	n #1	n #2	n #3	n #4	n #5	n #6	n #7	n #8	n #9	n #10	n #11	n #12	n #13	n #14	n #15	n #16	n #17	n #18
1	158050.3	n	0.035	0.065	0.04	0.065	0.065	0.04	0.065	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.065	0.035		
2	155259.3	n	0.035	0.065	0.065	0.065	0.065	0.065	0.04	0.065	0.04	0.065	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04
3	153538.1	n	0.065	0.065	0.02	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.065	0.065	0.065	0.04
4	151571.8	n	0.035	0.065	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.065	0.02	0.065
5	150414	n	0.035	0.065	0.02	0.065	0.02	0.065	0.02	0.065	0.02	0.065	0.065	0.065	0.065	0.04	0.065	0.04	0.065	0.04
6	148333.1	n	0.035	0.065	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.065	0.065	0.065	0.065	0.065
7	147277.6	n	0.065	0.065	0.065	0.065	0.065	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.065	0.065	0.04	0.065
8	145734.7	n	0.035	0.065	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.065	0.065	0.065	0.065	0.04	0.065	0.065	0.065	0.02
9	144492	n	0.065	0.065	0.065	0.065	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.065	0.065	0.065	0.02	0.065	0.065	0.04
10	142146.5	n	0.035	0.15	0.065	0.065	0.065	0.02	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.04	0.065	0.04
11	140480.8	n	0.15	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.04	0.065	0.04	0.065	0.065	0.04	0.065	0.065	0.065
12	138341.4	n	0.15	0.065	0.15	0.065	0.065	0.15	0.065	0.065	0.065	0.065	0.065	0.065	0.04	0.065	0.04	0.065	0.04	0.065
13	135397.1	n	0.035	0.15	0.065	0.15	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.04	0.065	0.04	0.065
14	133640.7	n	0.035	0.065	0.15	0.065	0.15	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.04	0.065	0.04	0.065	0.065	0.065
15	131388.9	n	0.15	0.065	0.15	0.065	0.065	0.065	0.065	0.065	0.065	0.04	0.065	0.04	0.065	0.035				
16	128995.4	n	0.035	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.04	0.04	0.065	0.035
17	125285	n	0.035	0.065	0.065	0.065	0.04	0.065	0.04	0.065	0.065	0.04	0.065	0.065	0.04	0.065	0.065	0.035		
18	123006.9	n	0.035	0.065	0.065	0.065	0.04	0.065	0.15	0.15	0.065	0.065	0.04	0.065	0.065	0.04	0.065	0.04	0.065	0.065
19	121300.5	n	0.065	0.035	0.065	0.065	0.065	0.065	0.065	0.15	0.15	0.04	0.15	0.065	0.04	0.065	0.04	0.065	0.065	0.04
20	114134.3	n	0.065	0.035	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.15	0.065	0.15	0.065	0.15	0.04	0.04	0.04	0.04
21	112857.8	n	0.035	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.15	0.065	0.15	0.065	0.04	0.065	0.04	0.065	0.04	0.04
22	111265.7	n	0.035	0.065	0.065	0.065	0.065	0.065	0.04	0.065	0.065	0.065	0.065	0.065	0.065	0.04	0.065	0.065	0.04	0.035
23	108759.7	n	0.035	0.065	0.02	0.065	0.02	0.065	0.04	0.065	0.065	0.065	0.02	0.065	0.04	0.065	0.065	0.065	0.065	0.065
24	103956.4	n	0.065	0.035	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065
25	101320.5	n	0.065	0.035	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.065	0.065	0.065	0.065
26	99569.59	n	0.065	0.035	0.04	0.02	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.065	0.04	0.065	0.065	0.065	0.065
27	97733.89	n	0.035	0.065	0.04	0.065	0.065	0.04	0.065	0.065	0.065	0.065	0.15	0.065	0.15	0.15	0.065	0.035		
28	95575.13	n	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.065	0.065	0.065	0.15	0.065	0.15	0.065
29	93032.03	n	0.035	0.065	0.04	0.065	0.065	0.04	0.065	0.065	0.065	0.065	0.15	0.065	0.02	0.065	0.065	0.035		
30	88800.93	n	0.035	0.065	0.065	0.04	0.065	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.065	0.15	0.065	0.065	0.065	0.065
31	85897.95	n	0.035	0.065	0.02	0.065	0.065	0.065	0.065	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065
32	84444.2	n	0.035	0.065	0.065	0.065	0.065	0.065	0.04	0.065	0.04	0.065	0.065	0.04	0.065	0.065	0.065	0.065	0.065	0.04
33	82096.09	n	0.035	0.065	0.065	0.065	0.065	0.04	0.065	0.065	0.04	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.04	0.065
34	79569.13	n	0.065	0.065	0.065	0.04	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.04	0.065	0.04	0.065	0.065	0.065	0.035
35	76825.57	n	0.035	0.065	0.035	0.065	0.04	0.065	0.04	0.065	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.065
36	75796.15	n	0.035	0.065	0.04	0.065	0.065	0.02	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.035		
37	70891.8	n	0.035	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.065	0.04	0.035						