FLOOD INUNDATION MAPPING - A CASE STUDY

A DISSERTATION

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By

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CANDIDATE'S DECLARATION

I hereby certify that work being presented in the Dissertation entitled "FLOOD INUNDATION MAPPING – A CASE STUYDY" is in partial fulfilment of the requirement for the award of the Degree of Master of Technology and submitted to the Department of Water Resources Development and Management (WRD&M), Indian Institute of Technology Roorkee. This is an authentic record of my own work carried out during the period from July 2007 to June 2008 under the supervision and guidance of Dr. S. K. Mishra, Associate Professor, WRD&M, IIT Roorkee, Uttrakhand, India.

The matter presented in this dissertation has not been submitted by me for the award of any other degree.

Dated: 29th June, 2008
WRD&M, IIT, Roorkee

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CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

A flood inundation map project needs geographic data from traditional aerial mapping for terrain modeling and map presentation and cross-section data for hydraulic calculations. The hydrologic analysis is needed for determination of discharges or water levels that correspond to the final flood inundation maps. Finally, hydraulic analysis facilitates computation of water surface profiles for flood discharges of different return periods. The water surface profiles are used for depiction of flood inundation maps.

The objective of this dissertation work is to present a case study of Godavari River in the 143 km upstream reach of Polavaram dam site for the preparation of flood inundation map. The popular one-dimensional hydraulic model named HEC-RAS model is used for hydraulic analysis. The input data requires sufficient number of cross-sections wide enough and spaced closely to represent the floodplain and these are derived from SRTM 90M digital elevation model data through Remote Sensing and GIS. Steady flow data constitute 50,100 and 500 yrs. return period floods from frequency analysis. Inundated areas are determined using Geographical Information System (GIS).

HEC-RAS is an integrated system of software designed for interactive use in a multi-tasking environment. HEC-RAS has the ability to import three dimensional (3D) river schematic and cross section data created in a GIS. While the HEC-RAS software only utilizes two-dimensional data during the computation; the three dimensional information is used in the program for display purpose only. After completion of hydraulic analysis, the computed water surface profiles can be exported back to the GIS system for development and display of a flood inundation mapping.

A triangular irregular network (TIN) is generated from the available elevation data. The terrain TIN is then transformed into a regular grid with grid size 15-20 meters. In the same way, a TIN is generated between the cross sections. The cross sections have water elevations that represent 50, 100 and 500 years return periods. Different TINs are then transformed into water surface grid with same definition as the terrain grid. The

inundated areas are identified by subtracting the land surface grid from the water surface grid, resulting in positive values in inundated areas. The final product is smoothed polygons representing inundated areas with a specified return period.

Flood inundation mapping is an important component of the non-structural measures. The results of the study suggest that cross-sections generated using Remote Sensing and GIS data, coupled with little manipulations, are in close agreement with the cross-sections observed at limited number of sites in the considered study reach of Godavari basin. The flood values derived from frequency analysis, using Gumbel distribution, for 50, 100 and 500 years return periods comes out to be 97604, 98948 and 96259 cumec, respectively. The inundated areas computed using HEC-RAS for these return period floods are of the order of 10.8, 11.65 13.69 sq. km., respectively. A sensitivity analysis of FRL reveals the existence of a power relationship between FRL and the corresponding inundated area.

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CHAPTER 1

FLOOD INUNDATION MAPPING

1.1. INTRODUCTION

Floods are probably the most recurring, widespread, disastrous and frequent natural hazards of the world. India is one of the worst flood-affected countries, being second in the world after Bangladesh and accounts for one-fifth of global death count due to floods. About 40 million hectares or nearly 1/8th of India's geographical area is flood-prone. Providing absolute protection to all flood prone areas for all magnitudes of floods of different probabilities of occurrence is neither practically possible nor economically viable. Hence a practical approach in flood management is to provide a reasonable degree of protection against flood damage at economic costs. In this scenario, the regulation of flood hazard areas coupled with enactment and enforcement of flood hazard zoning could prevent damage of life and property from flooding in short term as well as in long term. Flood management and control are necessary not only because floods impose a curse on the society, but the optimal exploitation of the land and proper management and control of water resources are of vital importance for bringing prosperity in the predominantly agricultural-based economy of this diversely populated country. Flood management activities can be broadly classified into four major groups:

(i) Attempts to modify the flood.

(ii) Attempts to modify the susceptibility to flood damage.

(iii) Attempts to modify the loss burden.

(iv) Bearing the loss.

Attempts to modify the flood involves flood protection by means of physical measures such as construction of embankments, construction of detention reservoir, channel improvements etc. Each of the above measures aims to protect an area rather than a particular property and normally involves high capital cost. Attempts to modify the "damage susceptibility" involve actions designed to reduce the vulnerability of property and other developmental activities in the flood plains to the flood hazard. Attempts to "modify the loss burden" consist of actions to modify the incidence of losses, by spreading them over a large segment of the community. "Bearing the loss" means "living with floods."

All these measures of flood management can be classified as below:

- Structural measures
- Non – structural measures

Broadly, all measures taken up under the activity of "Modifying the flood" which are mostly in the nature of physical measures are being treated as "Structural Measures", while those under three activities mentioned above are grouped as "Non-structural measures". Non-structural measures are broadly grouped into the following: Flood plain zoning, flood proofing, flood forecasting & warning, disaster preparedness & response planning, disaster relief, flood fighting, and flood insurance.

Flood plain zoning

The basic concept of flood plain management is to regulate the land use in the flood plains in order to restrict the damage due to floods, while deriving maximum benefits from the same. This is done by determining the locations and the extent of areas likely to be affected by floods of different magnitudes/frequencies and to develop those areas in such a fashion that the resulting damage is minimum in case the floods do occur.

Flood proofing

Flood proofing measures help greatly in the mitigation of distress and provide immediate relief to the population in flood prone areas. The techniques adopted consist of providing raised platforms for shelter for men and cattle and raising the public utility installation above flood levels.

Flood forecasting and warning

Flood forecasting enables forewarning as to when the river is going to use its flood plains, to what extent and for how long. With reliable advance information/warning about impending floods, loss of human lives and movable properties and human miseries can be reduced to a considerable extent. People and cattle can be shifted to safer places. Similarly, valuable movable properties can be removed to safer places beyond the area to be inundated.

Disaster preparedness and response planning

The subject is dealt at two levels, State level and Central level. Plans are made in advance for disaster mitigation, warning, emergency operations rehabilitation and recovery.

Flood fighting

The subject requires advance planning of preparedness to fight floods. Flood fighting measures normally involve evacuation of flood victims, air dropping of food packets, supply of food and fodder and other essential commodities, release of emergency funds to local bodies, restoration of roads/rail links, power supplies, water supply etc.

Flood disaster relief

Government of India releases funds from National Fund for Calamity Relief (NFCR), and Calamity Relief Fund (CRF) after proper assessment of disaster.

Flood Insurance

Flood insurance is advantageous both to the public and the government. It provides a mechanism for spreading the loss over the large number of individuals. The development of Flood Hazard Maps for zoning and insurance programs is part of these non-structural components. Flood Hazard Mapping is a vital component for appropriate land use planning in flood-prone areas. It creates easily-read, rapidly-accessible charts and maps which facilitates the administrators and planners to identify areas of risk and prioritize their mitigation / response efforts. The main target groups are municipalities and county officials, who are responsible for land use planning and emergency planning at local, county levels respectively. The flood inundation map represents a tool to achieve: improved land use planning with respect to flood hazards and improved flood warning and emergency preparedness.

1.1.1 IMPROVED LAND USE PLANNING WITH RESPECT TO FLOOD HAZARDS

A sensible use of flood prone areas is regarded as the best way of keeping the damage potential at a reasonable level. Improvement in land use planning with respect to risk of flooding is among the most important measures to achieve this goal.

1.1.2. IMPROVED FLOOD WARNING AND EMERGENCY PREPAREDNESS

The maps will be useful in emergency planning and action connected to flood situations. The basis data and model results from the mapping will make quantitative flood forecasting possible, i.e. forecasting of water levels locally, flood inundation maps can be generated related to the forecasted flood levels, allowing quick assessment of the potential impacts of a given flood. The maps will simplify rescue operations such as evacuation and give background information when setting priorities to other actions. Thus,

"Flood inundation maps present the area prone to flooding at one or more floods with given return periods." Flood Hazard Mapping is a vital component for appropriate land use planning in flood-prone areas. It creates easily-read, rapidly-accessible charts and maps which facilitates the administrators and planners to identify areas of risk and prioritize their mitigation/ response efforts.

1.2. PRODUCTION METHOD

The maps are produced digitally, to make the users able to make their own presentations in combination with other information, using their own tools. High accuracy mapping is chosen, in order to make the users able to use the results in land use planning without further analyses. Land surface is represented by a DEM (Digital Elevation Model) based on detailed elevation data and the river bed is represented by surveyed cross sections. Expected accuracy of the DEM is +/- 30 cm.

Through flood frequency analyses and hydraulic simulations water levels for 10, 20, 50, 100, 200 and 500 years floods are calculated. Expected accuracy of the computed water levels is +/- 30 cm. Inundated areas are determined using Geographical Information System (GIS). Historic events related to other known hazards in the river system, such as ice jams, ice run, erosion, debris flows etc. are identified based on information from local informers and archives, without trying to relate the events to statistical probability. The final results from each river reach are delivered to the users both as a report with paper maps and as digital data. The presentation is standardized at scale 1:15000 with cross sections, levees etc marked. Water levels for all computed floods are presented both in a table and in a graph (longitudinal profile)

1.3. FLOOD INUNDATION MAP

• Map presentation: Inundated areas in blue. Areas without direct connection to the river (behind levees, culverts etc) are marked with a particular shade.

• Base map data: detailed digital maps (scale 1:1000), cross sections surveyed by consultants.

We can conclude that flood inundation map represents effective tools to achieve:

• Improved land use planning with respect to flood hazards in accordance to the new standards.

• Improved flood warning and emergency preparedness. The maps will be useful in emergency planning and action connected to flood situations. The underlying data will make quantitative flood forecasting possible, i.e. forecasting of water levels locally. Flood inundation maps can, by the use of GIS, be generated related to the forecasted flood levels, allowing quick assessment of the potential impacts of a given flood. In addition, such maps will simplify rescue operations such as evacuation, and give background information when setting priorities to other actions.

• Improved flood protection plans. The maps show clearly which areas that are vulnerable. Vertical dimension of flood dikes can be taken directly from the tables. It is easy to calculate the benefit of a construction project.

1.4 OBJECTIVES

The objective of this dissertation work is to present literature review, methodology and a case study of Godavari River for the preparation of flood inundation map as follow:

(i) To obtain cross-sections of Godavari river in u/s of Polavaram dam site at various locations through processing of SRTM 90M Digital Elevation Database of study area using various GIS and Remote Sensing software.

(ii) To reconstruct the river cross-sections and derive longitudinal bed profile based on available hydraulic data.

(iii)To test the validity of derived/computed cross-sections with the actually observed limited cross-sections.

(iv) Flood frequency analysis for determination of flood discharges for various return periods.

(v) To prepare Flood Inundation Map for the study area.

(vi)To carry out a sensitivity analysis.

1.5 ORGANIZATION OF THESIS

The study is organized in the following chapters:

Chapter 2 : It provides a brief review of literature with respect to GIS and HEC-RAS model.

Chapter 3 : It describes the model features and capabilities, simulation approach, Assumptions and limitations and mathematical formulation of HEC-RAS Model.

Chapter 4 : It presents the description of the upstream of Polavaram Dam site area (Godavari River Basin) and data availability.

Chapter 5 : It describes the data processing including creation of cross-sections on 90m DEM (SRTM) of study area and data bases with brief of software used.

Chapter 6 : It describes the methodology adopted for preparation of Flood Inundation Map.

Chapter 7 : It summarizes and concludes the study.

CHAPTER 2

REVIEW OF LITERATURE

2.1 COUPLING METHODS

Given the spatial nature of flood plain management components, a Geographical Information System (GIS) based flood information system is desirable. Coupling methods for integrating GIS and engineering models have been explored since late 1980s as part of the GIS community's efforts to improve the analytical capabilities of GIS (Sui and Maggio, 1999). In spite of this effort, it has been stated that GIS is limited in its ability to perform any kind of engineering modeling (Yang and Tsai, 2000) and can only provide for data storage, management, inventory, and mapping functionalities. In flood studies, GIS has normally been used to display the resulting flood boundaries under different formats like vector, raster, and TIN (Azagra et al.1999). The static "nature" of GIS has been recognized as a large constraint through strong statements in the literature. "Until GIS has explicit time variation in its data structures, its role will largely be limited to an input data provider, output display, and mapping device" (Maidment, 1993). Thus, for many years it has been believed that GIS can only contribute to environmental modeling by adding the benefits of its capabilities for handling and storing massive spatially distributed data which is then given a format (via Export Utilities) for the input of a given model or imported after a model simulation is executed for visualization and spatial analysis. In other words, a pure pre- and post-processor functionality has been attributed to GIS. Different approaches have been used so far to integrate GIS with hydrologic modeling. In general, these approaches can be grouped into four categories: Embedding GIS in hydrological modeling, embedding hydrological modeling in GIS, loose coupling, and tight coupling. Each coupling approach is conceptually shown in Fig. 2.1.

Developers of almost every environmental model have realized not only the relevance and need of high-level spatial visualization of their outputs but also the need to generate output formats readable by commercial GIS software. As a consequence,

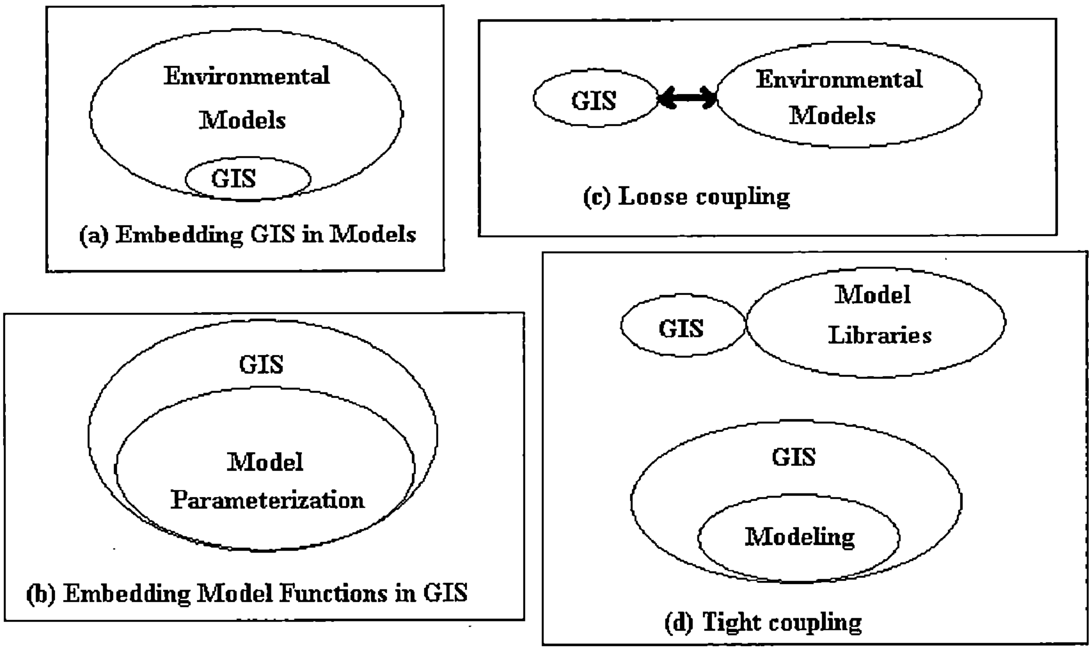


Fig. 2.1 Integration of GIS and Environmental Models

many models have introduced "Export to GIS" capabilities to improve visualization and enhance data sharing properties. Therefore, under the first approach (Fig. 2.1a); GIS functionalities are embedded in pre-existing modeling systems. This might be termed the conventional GIS post- processing approach in which the classical role of GIS as a georeferenced mapping tool is implemented. Under this scheme, GIS is considered as a mapping tool and is conceptually irrelevant to the fundamentals of hydrological modeling (Sui and Maggio, 1999).

Under the second approach (Fig. 2.1b) and restricted by the static nature (time invariance) of existing GIS, some type of hydrological modeling functions have been added as add-ins or extensions to the most common GIS software packages. These "modeling" capabilities are usually intended for model configuration and parameterization and normally take advantage of spatial analyst extensions to generate hydrologic related data sets that are used as input for many of the industry standard modeling systems. Some commercial GIS packages have embedded some type of modeling capability in its systems. The Arc Hydro data model and associated toolset for water resources in Arc GIS (Maidment, 2002) and the hydrologic functions in the Raster GIS GRASS (GRASS, 1993) are some examples of this approach.

The loose coupling approach (Fig. 2.1c) tries to communicate between a standard GIS package and Hydrologic and Hydraulic (H&H) modeling systems via a data exchange framework. Data exchange is normally done through generation of model-specific ASCII or binary data formats that the next system in the workflow can assimilate. Thus, data are transferred and exchanged between models and GIS, with each system having its own way of looking at the data. Data conversion between models and GIS is normally tedious and error prone. Recognizing this fact, standard data exchange formats are now being developed that will facilitate data exchange in more generic and comprehensive forms using generic and self-described formats, such as XML (Djokic, 1995). Under this scheme, some kind of communication/integration between standard systems is envisioned but ways to centrally handle this integration were not available until recently with new GIS and Information Technology (IT) developments. Under the loose integration approach each external application (including GIS) remains as an independent system that is executed through its own interface after the previous application has produced its output and some data exchange process is executed to enable the next application to use it as its input. In other words, there is no central system accessing the components and the integration depends only on flows of reformatted data from one application to the other. Many GIS pre- and post-processors have been developed to interface with the industry standard environmental models; some examples are the Watershed Modeling System (Nelson, 2000), the Watershed Analyst, HEC-GeoHMS (USACE, 2000b), HEC-GeoRAS (Djokic et al., 1992, Ackerman et al., 1999, USACE, 2002a), CRWR-PrePro (Olivera and Maidment, 2000) etc., which generate the needed files for specific model configuration and set up. Attempts to synthesize several available GIS-based tools for digital floodplain analysis have also been undertaken (Anderson, 2000).

The Tight coupling approach (Fig. 2.1d) promotes the "GIS modeling dream" in which the customization environment of a standard GIS software package is used to develop a complete hydrologic, hydraulic, or environmental system fully inside the GIS hosting environment. By this approach, a user can develop his/her own modeling libraries inside the GIS system. To support this approach, not only a well-defined interface to the GIS data structures is needed but also a time varying character of the GIS system that meets inherent storage demands is required. Under this approach the environmental models are executed directly from inside the GIS system either by calling the modeling libraries on demand or by directly having model constructs in the GIS structure. Under the partial tight integration each application is still independent of each other but centrally managed from a single application that can perform calls to execute the external applications as required by the workflow. Many believe this approach is best due to the incorporation of proven and benchmarked proprietary modeling systems that are already widely used and accepted by the engineering community. Partially tight integrations of ArcGIS with hydrologic libraries like HEC LibHydro have been developed to capitalize on pre-processing and visualization capabilities of GIS (Whiteaker, 2003). A recent fully tight integration for the TOPMODEL hydrological model and GIS (AVTOP) was reported (Huang and Jiang, 2002) in which an already existing stand-alone model was re-developed within the GIS environment by means of the macro language Avenue of ArcView 3.x. The previous survey of GIS-based integrating approaches expose several ways of exploiting the GIS benefits in modeling exercises. In order to streamline and automate the generation of flood inundation maps a tight coupling approach (Fig. 2.1d) is needed in which stand-alone engineering models are either externally executed from a central framework or fully re-developed inside the GIS framework. A fully tight integration (Fig. 2.1d Lower) in which all the needed stand-alone models are re-developed within the GIS environment is currently possible only for simplified conceptual models. Conceptual models do not have a physically-based definition that relies in solutions of partial differential equations which are still difficult to formulate and solve inside a GIS environment. A partially tight integration (Fig. 2.1d Upper) that utilizes stand-alone applications and centrally managed from a GIS-based application is selected in this research as the most suitable method to accomplish the proposed modeling integration. This selected approach allows the incorporation of proven and benchmarked proprietary modeling systems that are already widely used and accepted by the engineering community and regulating agencies in flood studies. The selected partially tight integration provides a framework to centrally handle the modeling integration via new GIS and IT developments. The central system externally accesses the interrelated components and the integration depends on flows of reformatted data that is automatically relayed from one application to the other.

2.2 GIS-BASED FLOODPLAIN MANAGEMENT

Given that river and floodplain aspects of floodplain management have a spatial component, a GIS-based approach is suitable to manipulate and visualize the spatial distribution of flood project components. Traditionally, GIS overlay functionalities and computational engines have been used in automated floodplain delineation systems. Several automated GIS-based flood plain delineation systems have been developed to support flood damage assessment components (Noman, et al., 2001). Some of the most well-known systems are: Arc/Info MIKE11-GIS, Arc/Info Floodplain delineation, ArcView MIKE11-GIS, Watershed Modeling System, flood mapping functionalities in FLOODWAVE, and the HEC-GeoRAS post-processing delineation. In contrast with the abundant systems for automated floodplain delineation, GIS-based flood damage assessment systems have not proliferated. By the end of the 1980s, many countries started to experience a worsening trend in recurrent flood problems mostly attributed to urban and land use developments that substantially change runoff characteristics and drainage configurations. Some of the attempts to address the increasing pattern of severe flood occurrences by means of GIS- integrated systems are summarized below to provide a conceptual framework for the present research.

To formulate appropriate floodplain management strategies in the form of basin management plans, the government of Hong Kong started to develop in 1990 a system for flood risk assessment (Brimicombe and Bartlett, 1996). The proposed flood risk assessment system was based on the transfer of GIS-based parameterization to stand alone hydrologic/hydraulic modeling systems whose output is passed back to GIS for output visualization and reporting. The spatial extent of flood was superimposed to land use configurations to define flood hazard maps as the main foundation for a spatial decision support system. Even though GIS-based, the system does not represent a true integration of GIS and modeling with central execution of all the involved processes. This system achieves integration by means of data exchange only and not by means of a central and unified execution of chained systems representing the modeling workflow of processes and data.

An early attempt to integrate "industry standard" hydraulic numerical modeling and geographic information systems was done through the ArcView GIS software (Muller and Rungoe, 1995). An interface between the 1-D numerical hydraulic model of the Danish Hydraulic Institute, MIKE 11 and Arc View 3.x was developed, the MIKE11-GIS ArcView interface. MIKE 11 was coupled with Arc View to generate 2D and 3D water level and flood inundation maps. The system allows for rapid generation of inundation boundaries for different flood scenarios, including scenarios with or without flood protection measures. It provided a systematic protocol for locating the inundated land under alternative mitigation strategies. The system allows for making multiple runs and testing a number of scenarios efficiently. Almost simultaneously with the previous approach in 1996, the Delft Hydraulics Research Institute developed a flood hazard assessment model for the river Meuse case study in south Netherlands as a direct response to the flooding events of December 1993 (Jonge et al., 1996). Recognizing the fact that the important river related aspects of flooding and managing floods (safety, agriculture, industry, etc.) all have a spatial component, the GIS package ARC/INFO was selected at the time as the central framework to develop the model (Tineke De et al., 1996).

GIS-based flood hazard assessment schemes have been proposed by several researchers. A flood impact assessment system based on land use was developed using ARC/INFO and its customization language AML (Arc Macro Language) (Boyle et al., 1998). The GIS interface included hydraulic simulations, generic damage curves, and simulation functions or alternative plan evaluations. This method does not have explicit consideration of uncertainties and the floodplain modeling phase starts at the hydraulic level. A GIS-based flood information system for the Chia-I County in Taiwan has also been reported (Yang and Tsai, 2000). This system encompasses three main components: floodplain modeling, flood damage, and flood information support. The floodplain modeling method uses modeling cells defined by irregular polygons associated with the main channel and to the floodplains. The cell boundaries are defined by high ground corresponding to stream banks, levees, roads, etc. and the land use within each modeling cell is considered to be homogeneous. The downside of this system is the lack of hydrologic simulations based on the design storms defined for flood damage calculations. More recently, a flood warning and response system that employs aerial photography, terrain elevation data, channel geometry, demographic and structural data, and transportation systems with a hydraulic HEC-RAS model has been implemented to create an automated flood mapping application using the Geographic Information Systems, ArcGIS, for the Susquehanna River in Pennsylvania (Ackerman, 2004).

Out of the above reported GIS-based systems, only the Hong Kong (Brimicombe and Bartlett, 1996) and the Taiwanese (Yang and Tsai, 2000) approaches included some type of hydrologic and hydraulic integration to support floodplain delineation and flood damage evaluations. The MIKE11-GIS ArcView interface configures an integration scheme with the 1D hydraulic model of the Danish Hydraulic Institute, the Susquehanna flood warning system represents integration with just the HEC-RAS hydraulic component. All the reported GIS-based Flood Information Systems described above, except for the Susquehanna system, use some level of aggregation for the floodplain infrastructure inventory. The system for Taiwan defines modeling cells with homogeneous land use in it configuring a damage aggregation at the cell level. The case study for Ontario directly divides the floodplain into four types of land uses (residential, commercial, industrial, and open space) without aggregating them at the modeling cell level. Once a property is classified in one of this four land use categories they are all treated the same way in terms of flood damage calculations.

Thus, there are two levels of aggregation, the land use level (for flood damage calculation purposes) and the modeling cell level (to simplify hydraulic calculations) which includes the first one also. By having the second level of aggregation for hydraulic reasons the system does not account for land use variations within each modeling cell which represents an important limitation for the flood damage assessment component and its very spatial nature. The aggregation of floodplain inventories into coarse land uses allows for the use of case specific flood depth-damage curves obtained for each land use through field studies and floodplain inventories and representing one of the three basic functions (as described in section 2.1) needed to perform the traditional economic evaluation for flood damage assessments. These empirical depth- damage curves are normally developed by a property survey of the floodplain and by individual or aggregated estimates of depth versus damage for each land use category in the floodplain. The HEC-FDA system provides for a somewhat less aggregated approach to evaluate the depth-damage relationship. In it, each structure is given a particular depth-damage assessment based on a more detail definition of the properties' first floor and ground levels. Specification of first floor stages and beginning damage depth stages for each property in the inventory allow for a more realistic approach. However, the depth-damage relationship is aggregated at each damage index location station and the effect of a given depth at the index location relies on very good quality field surveys and evaluations. This approach even though more realistic relies on very hard to get depth-damage relationships that can quickly become obsolete given the dynamic nature of floodplains regularly affected by new regulations, alleviation plans, and changing land use configurations. So, even though the HEC-FDA provides a distributed approach for definition of depth-damage curves (based on a distributed structure inventory) it aggregates the spatial inventory of the floodplain into reach index locations configuring a lumped damage assessment methodology. By defining the three basic functions at damage reach index locations a supposedly uniform floodplain section gets aggregated to each index location station. Through this approach any changes on the floodplain configuration are difficult to introduce and will imply a new definition of the basic functions. As part of this research, an alternative approach for flood damage assessment is sketched that takes full advantage of the distributed strength of GIS to obtain the depth-damage relationship at each structure based on the current depth at that spatial location as given by the integrated floodplain delineation process (The Map2Map application). By doing this, a more realistic assessment is expected that may keep up with the dynamic development of the floodplains without having to redefine the aggregated depth-damage curves at the land use, modeling cell, or index location level.

2.3 FLOOD MITIGATION PLAN EVALUATION AND SIZING

After the floodplain has been simulated and the flood inundation extent delineated under a given floodplain and hydrologic configuration, some framework is normally used to evaluate a proposed set of flood management plans. To accomplish a flood plan evaluation flood maps are normally generated based on GIS overlay analysis. In GIS-based systems the flood maps are then used for flood damage calculation processes based on three basic functional relationships for hydrology (flood-frequency curve), hydraulics (rating curve), and economics (stage-damage curve). The evaluation process of a flood alleviation project follows a standard simulation algorithm based on standard and approved hydrologic and hydraulic software. Normally, the simulation of local projects composed of levees or similar structures allows one to determine if the proposed structure protects against a given design flow event as required by Central/State or local regulations. In particular, the levee certification process was traditionally driven by protection criteria against river stage associated with the 1% chance flood (100 yr flood event) plus 3 feet of freeboard. This conventional approach based on flood frequency analysis was abandoned in the early 1990's when the Corps of Engineers adopted risk analysis techniques that replace the aforementioned "1% event plus freeboard standard".

Besides having to consider the set of components that make up an optimal solution some authors have tried to answer the question of optimal size of already selected projects. Multiple criteria can be used to define the "optimal" flood control solution. One alternative is represented by the economic efficiency of the project. The optimal sizing of flood damage reduction plans based on economic efficiency has been addressed by a combination of a simulation and an optimization models. Methods for optimal sizing of flood damage reduction plans based on economic efficiency have been reported (Wurbs, 1996). The method searches for an optimum mitigation plan that may include non-structural measures. In these optimization approaches, the objective function is normally represented by the minimization of the total system cost and decision variables are represented by the size of the structural components of the system. To develop a flood impact analysis system, flood related information describing the spatial distribution of the floodplain is needed. GIS layers containing an inventory of damage sensitive facilities that belong to some category of land used (residential, educational, industrial, commercial, etc.) are obtained. Each of these damage sensitive components must have an associated database that provides the attributes on which damage estimates can be calculated using economic methods such as benefit-cost analysis.

2.4 PROPOSED CONTRIBUTIONS TO KNOWLEDGE

The idea of model integration has been described under various statements as "bringing the models together", "watershed in a box", or "Regional Watershed Modeling System". As mentioned before, attempts to accomplish this modeling integration have been reported in the literature which follows a step-wise approach in which the data is passed from one modeling program to another in a manual fashion favoring a time consuming and error-prone workflow that is functional but not very productive nor efficient. The GIS-based character of the reported attempts is represented only by the transfer of GIS-computed parameterizations to stand-alone modeling systems whose output is passed back to GIS for visualization purposes only. Thus, this step-wise integration based only on pre- and post-processing data exchange does not represent a true integration of the involved modeling systems.

Process analysis/models represented by stand-alone simulation models may synergistically employ the output of another simulation model and thus be sequentially linked. To achieve the linkage, geographically oriented data models can be used to spatially associate the exchange of information from one process model to another. Once all the needed integrating elements are developed, a workflow model (here in a GIS environment called ModelBuilder) can be used to empower a seamless end-to-end integration as the gluing platform that prevents the conventional step-wise approach. The true geographically-driven integration proposed in this research empowers a spatial linkage of all the necessary flow exchange points (hydrograph entry points) via a connection based on ModelCodes. For HEC-HMS the HMSCode is represented by the name of the hydrologic elements entering a runoff hydrograph to the stream network and geographically represented in GIS. For HEC-RAS a RASCode constructed with the union of the StreamID, ReachID, and Station is proposed to establish the connection between GIS and HEC-RAS. This connection makes possible the transfer of information (runoff hydrographs) from HEC-HMS elements to HEC-RAS cross sections via a geographic framework represented by the Arc Hydro data model for water resources. None of the reported systems (out of only two that include the hydrologic end) allow for readily incorporating rainfall inputs of various natures and forms like historic, real-time, forecasted, and design storm events. The modular character of the proposed integration allows code reuse of common elements and straight forward incorporation of new components to account for several rain map formats potentially used to drive the system. By having this flexibility, it is possible to drive the integrated system with diverse rain maps to generate multipurpose flood maps. The proposed integration system herein relies on pre-existing modeling systems that might be fully generated for a given study area by means of Interface Data Models in charge of storing and generating a complete GIS-based model configuration above the traditional and just-geometric pre-processing setups.

2.5 HEC-RAS - (Version-4.0, 2006)

This is the latest version developed by US Army Corps of Engineers at Hydrologic Engineering Center. This is Next Generation of hydrologic engineering software which encompasses several aspects of hydrologic engineering including river hydraulics; reservoir system simulation; flood damage analysis; and real time river forecasting for reservoir operations. The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities. The HEC-RAS system will ultimately contain three one dimensional hydraulic analysis components (i) Steady flow water surface profile (ii) Unsteady flow simulations (iii) movable boundary sediment transport computations. Apart from this software contains several hydraulic design features. This is capable of importing GIS data or HEC-2 data (Brunner, 2002; HEC-RAS Manual, 2006). It is an integrated system of software, designed for interactive use in a multi-tasking environment. The system is comprised of a graphical user interface, separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities. HEC-RAS has the ability to import three dimensional (3D) river schematic and cross section data created in a GIS. While the HEC-RAS software only utilizes two dimensional data during the computation; the three dimensional information is used in the program for display purpose. After completion of hydraulic analysis, the computed water surface profiles can be exported back to the GIS system for development and display of a flood inundation mapping. The HEC-RAS system will ultimately contain three one-dimensional hydraulic analysis components for:

- Steady flow water surface profile computations

• Unsteady flow simulation

• Movable boundary sediment transport computations

A key element is that all three components will use a common geometric data representation and common geometric and hydraulic computation routines. In addition to the three hydraulic analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed (HEC-RAS Manual, 2006). The review of existing models indicates that several models are available with different features. All the models use St. Venant's equations and have different sediment predictors, energy slope relations and distribution of aggradation/degradation equations. A natural river has many complexities due to its size, flow variations, concentration of sediment and its properties, engineering works carried out on the river and other geographical, meteorological, social factors. Due to these reasons, no model can claim to have considered all the factors. Therefore, the models cannot have universal applicability. Hence, for modelling a particular river one should be very careful to choose a model, which is applicable according to the characteristics of that river. HEC-RAS (version 4.0) is latest in the family of the existing models for sediment transport & mobile bed modeling, and therefore, in this dissertation it has been employed for flood inundation mapping.

2.5.1 MODELLING SYSTEMS IN HEC-RAS

HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking, multi-user network environment. The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities. The system contains three one-dimensional hydraulic analysis components for: (1) steady flow water surface profile computations; (2) unsteady flow simulation; and (3) movable boundary sediment transport computations. A key element is that all three components use a common geometric data representation and common geometric and hydraulic computation routines. In addition to the three hydraulic analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed (Brunner, 2002; Warner, 2002).

2.5.2 HYDRAULIC CAPABILITIES

HEC-RAS is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. The following is a description of the major hydraulic capabilities of HEC-RAS.

Steady Flow Water Surface Profiles: This component of the modeling system is intended for calculating water surface profiles for steady gradually varied flow. The system can handle a single river reach, a dendritic system, or a full network of channels. The steady flow component is capable of modeling subcritical, supercritical, and mixed flow regimes water surface profiles. The basic computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations (i.e., hydraulic jumps), hydraulics of bridges, and evaluating profiles at river confluences (stream junctions). The effects of various obstructions such as bridges, culverts, weirs, spillways and other structures in the flood plain may be considered in the computations. The steady flow system is designed for application in flood plain management and flood insurance studies to evaluate floodway encroachments. Also, capabilities are available for assessing the change in water surface profiles due to channel improvements and levees.

Unsteady Flow Simulation: This component of the HEC-RAS modeling system is capable of simulating one-dimensional unsteady flow through a full network of open channels. The unsteady flow equation solver was adapted from Robert L. Barkau's UNET model (HEC, 2004). This unsteady flow component was developed primarily for sub-critical flow regime calculations. The hydraulic calculations for cross-sections, bridges, culverts, and other hydraulic structures that were developed for the steady flow component were incorporated into the unsteady flow module. Additionally, the unsteady flow component has the ability to model storage areas and hydraulic connections between storage areas as well as between stream reaches.

Sediment Transport/Movable Boundary Computations: This component of the modeling system is intended for simulation of one-dimensional sediment transport/movable boundary calculations resulting from scour and deposition over moderate time periods (typically years, although applications to single flood events will be possible).

The sediment transport potential is computed by grain size fraction, thereby allowing the simulation of hydraulic sorting and armoring. Major features include the ability to model a full network of streams, channel dredging, various levee and encroachment alternatives, and the use of several different equations for the computation of sediment transport.

The model will be designed to simulate long-term trends of scour and deposition in a stream channel that might result from modifying the frequency and duration of the water discharge and stage, or modifying the channel geometry. This system can be used to evaluate deposition in reservoirs, design channel contractions required to maintain navigation depths, predict the influence of dredging on the rate of deposition, estimate maximum possible scour during large flood events, and evaluate sedimentation in fixed channels (Brunner, 2002 ; Warner 2002; Manual HEC-RAS,2006).

2.5.3 THEORITICAL BASIS FOR ONE- DIMENSIONAL FLOW CALCULATION

HEC-RAS is currently capable of performing one-dimensional water surface profile calculations for steady gradually varied flow in natural or constructed channels. Subcritical, supercritical, and mixed flow regime water surface profiles can be calculated.

Equations for Basic Profile Calculations

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

$$Y_2 + Z_2 + \frac{\alpha_2 V_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \qquad (2.1)$$

where: Y_1 , Y_2 = depth of water at cross sections; Z_1 , Z_2 = elevation of the main channel inverts; V_1, V_2 = average velocities (total discharge/total flow area); α_1, α_2 = velocity weighting coefficients; g = gravitational acceleration; h_e = energy head loss. A diagram showing the terms of the energy equation is shown in Fig. 2.2.

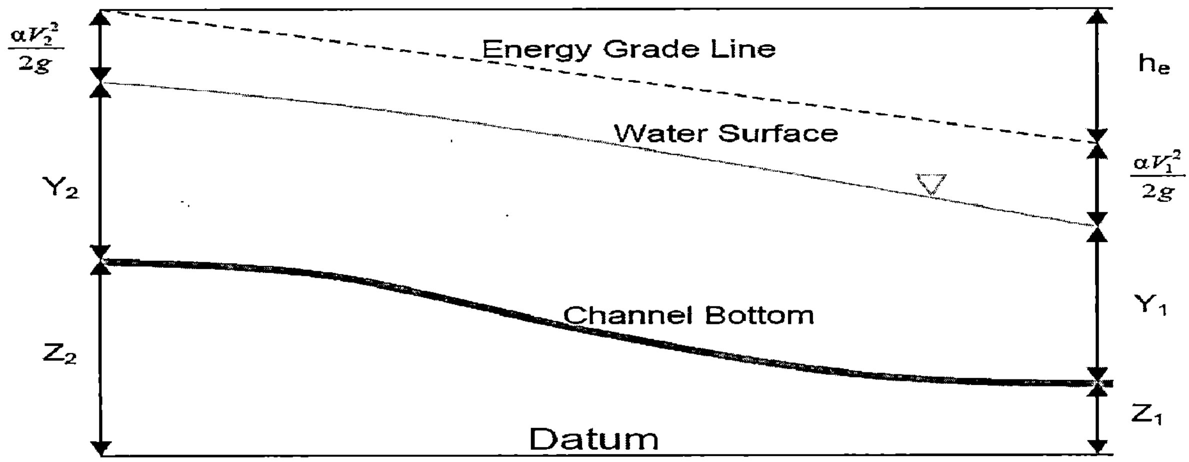


Fig. 2.2 Representations of Terms in the Energy Equation

The energy head loss (h_e) between two cross sections is comprised of friction losses and contraction or expansion losses. The equation for the energy head loss is as follows:

$$h_e = L\overline{S_f} + C\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right| \tag{2.2}$$

The distance weighted reach length, L, is calculated as:

$$L = \frac{L_{lob}\overline{Q_{lob}} + L_{ch}\overline{Q_{ch}} + L_{rob}\overline{Q_{rob}}}{\overline{Q_{lob}} + \overline{Q_{ch}} + \overline{Q_{rob}}} \tag{2.3}$$

where: L_{lob}, L_{ch} and L_{rob} = cross section reach lengths specified for flow in the left overbank, main channel, and right overbank, respectively ; $\overline{Q_{lob}}$, $\overline{Q_{ch}}$ and $\overline{Q_{rob}}$ = arithmetic average of the flows between sections for the left overbank, main channel, and right overbank, respectively

Cross Section Subdivision for Conveyance Calculations

The determination of total conveyance and the velocity coefficient for a cross section requires that flow be subdivided into units for which the velocity is uniformly distributed. The approach used in HEC-RAS is to subdivide flow in the overbank areas using the input cross section n-value break points (locations where n-values change) as the basis for subdivision. Conveyance is calculated within each subdivision from the following form of Manning's equation (based on English units):

$$Q = KS_f^{1/2} \tag{2.4}$$

$$K = \frac{1.486}{n} AR^{2/3} \tag{2.5}$$

where K = conveyance for subdivision; n = Manning's roughness coefficient for subdivision; A = flow area for subdivision; R = hydraulic radius for subdivision (area / wetted perimeter)

The program sums up all the incremental conveyances in the overbanks to obtain a conveyance for the left overbank and the right overbank. The main channel conveyance is normally computed as a single conveyance element. The total conveyance for the cross section is obtained by summing the three subdivision conveyances (left, channel, and right). In general, it is felt that the HECRAS default method is more commensurate with the Manning equation and the concept of separate flow elements (Brunner, 2002).

Composite Manning's n for the Main Channel

Flow in the main channel is not subdivided, except when the roughness coefficient is changed within the channel area. HEC-RAS tests the applicability of subdivision of roughness within the main channel portion of a cross section, and if it is not applicable, the program will compute a single composite n value for the entire main channel. The program determines if the main channel portion of the cross section can be subdivided or if a composite main channel n value is utilized. The computed composite n_c should be checked for reasonableness. The computed value is the composite main channel n- value in the output and summary tables.

Evaluation of the Mean Kinetic Energy Head

Because the HEC-RAS software is a one-dimensional water surface profiles program, only a single water surface and therefore a single mean energy is computed at each cross section. For a given water surface elevation, the mean energy is obtained by computing a flow weighted energy from the three subsections of a cross section (left overbank, main channel, and right overbank). Fig. 2.3 shows how the mean energy would be obtained for a cross section with a main channel and a right overbank (no left overbank area).

V_1 = mean velocity for sub area 1, V_2 = mean velocity for sub area 2

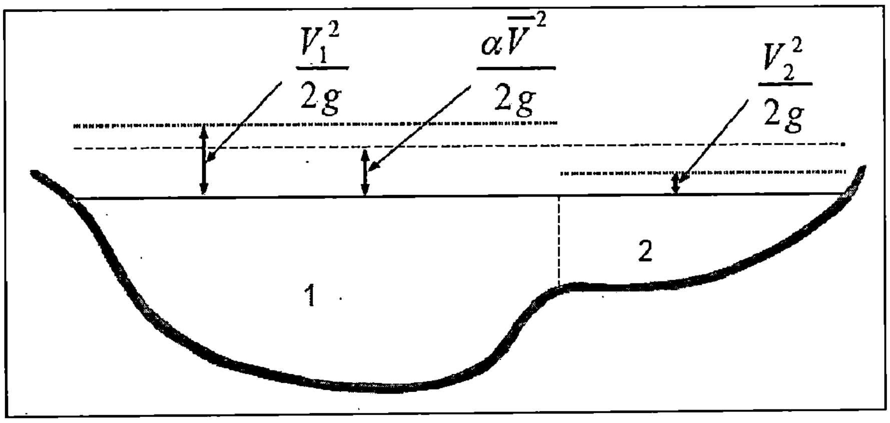


Fig. 2.3 Example of How Mean Energy is obtained

To compute the mean kinetic energy it is necessary to obtain the velocity head weighting coefficient α.. α is calculated as follows:

Mean Kinetic Energy Head = Discharge-Weighted Velocity Head

$$\alpha \frac{\overline{V^2}}{2g} = \frac{Q_1 \frac{V_1^2}{2g} + Q_2 \frac{V_2^2}{2g}}{Q_1 + Q_2} \qquad \alpha = \frac{2g\left[Q_1 \frac{V_1^2}{2g} + Q_2 \frac{V_2^2}{2g}\right]}{(Q_1 + Q_2)\overline{V^2}}$$

$$\alpha = \frac{\left[Q_1 V_1^2 + Q_2 V_2^2\right]}{(Q_1 + Q_2)\overline{V^2}}$$

In general:

$$\alpha = \frac{\left[Q_1 V_1^2 + Q_2 V_2^2 + \dots\dots + Q_N V_N^2\right]}{Q\overline{V^2}} \tag{2.6}$$

The velocity coefficient, α, is computed based on the conveyance in the three flow elements: left overbank, right overbank, and channel. It can also be written in terms of conveyance and area as in the following equation:

$$\alpha = \frac{(A_t)^2 \left[\frac{K_{lob}^3}{A_{lob}^2} + \frac{K_{ch}^3}{A_{ch}^2} + \frac{K_{rob}^3}{A_{rob}^2}\right]}{K_t^3} \tag{2.7}$$

where: A_t = total flow area of cross section; A_{lob}, A_{ch}, A_{rob} = flow areas of left overbank, main channel and right overbank, respectively; K_t = total conveyance of cross section; K_{lob}, K_{ch}, K_{rob} = conveyances of left overbank, main channel and right overbank, respectively.

Friction Loss Evaluation

Friction loss is evaluated in HEC-RAS as the product of S_f and L Eq. (2.2), where S_f is the representative friction slope for a reach and L is defined by Eq. (2.3). The friction slope (Slope of the energy grade line) at each cross section is computed from Manning's equation as follows:

$$S_f = \left[\frac{Q}{K}\right]^2 \tag{2.8}$$

Alternative expressions for the representative reach friction slope (S_f) in HEC-RAS are as follows:

Average Conveyance Equation

$$\overline{S_f} = \left[\frac{Q_1+Q_2}{K_1+K_2}\right]^2 \tag{2.9}$$

Average Friction Slope Equation

$$\overline{S_f} = \frac{S_{f1}+S_{f2}}{2} \tag{2.10}$$

Geometric Mean Friction Slope Equation

$$\overline{S_f} = \sqrt{S_{f1}\times S_{f2}} \tag{2.11}$$

Harmonic Mean Friction Slope Equation

$$\overline{S_f} = \frac{2(S_{f1}\times S_{f2})}{S_{f1}+S_{f2}} \tag{2.12}$$

Eq. (2.12) is the "default" equation used by the program; that is, it is used automatically unless a different equation is requested by input. The program also contains an option to select equations, depending on flow regime and profile type (e.g., S_1, M_1, etc)

Contraction and Expansion Loss Evaluation

Contraction and expansion losses in HEC-RAS are evaluated by the following equation:

$$h_{ce} = C\left|\frac{\alpha_1 V_1^2}{2g} + \frac{\alpha_2 V_2^2}{2g}\right| \tag{2.22}$$

where C = the contraction or expansion coefficient

The program assumes that a contraction is occurring whenever the velocity head downstream is greater than the velocity head upstream. Likewise, when the velocity head upstream is greater than the velocity head downstream, the program assumes that a flow expansion is occurring.

Steady Flow Program Limitations

The following assumptions are implicit in the analytical expressions used in the current version of the program:

1. Flow is steady.
2. Flow is gradually varied. (Except at hydraulic structures such as: bridges; culverts; and weirs. At these locations, where the flow can be rapidly varied, the momentum equation or other empirical equations are used.)
3. Flow is one dimensional (i.e., velocity components in directions other than the direction of flow are not accounted for).
4. River channels have "small" slopes; say less than 1:10.

Flow is assumed to be steady because time-dependent terms are not included in the energy equation Eq. (2.1). Flow is assumed to be gradually varied because Eq. (2.1) is based on the premise that a hydrostatic pressure distribution exists at each cross section. At locations where the flow is rapidly varied, the program switches to the momentum equation or other empirical equations. Flow is assumed to be one-dimensional because Eq. (2.2) is based on the premise that the total energy head is the same for all points in a cross section. Small channel slopes are assumed because the pressure head, which is a component of Y in Eq. (2.1), is represented by the water depth measured vertically.

The program has the capability to deal with movable boundaries (i.e., sediment transport) and requires that energy losses be definable with the terms contained in Eq. (2.2).

Uniform Flow Computations

For preliminary channel sizing and analysis for a given cross section, a uniform flow editor is available in HEC-RAS. The uniform flow editor solves the steady-state, Manning's equation for uniform flow. The five parameters that make up the Manning's equation are channel depth, width, slope, discharge, and roughness:

$$Q = f(A, R, S, n) \tag{2.14}$$

where Q = Discharge; A = Cross sectional area; R = Hydraulic radius; S = Energy slope, n = Manning's n value

When an irregularly shaped cross section is subdivided into a number of sub areas, a unique solution for depth can be found. And further, when a regular trapezoidal shaped section is used, a unique solution for the bottom width of the channel can be found if the channel side slopes are provided. The dependant variables A and R can then be expressed in the Manning equation in terms of depth, width and side slope as follows:

$$Q = f(Y, W, z, S, n) \quad (2.15)$$

where Y = Depth; W= Bottom width; z = Channel side slope

By providing four of five parameters, HEC-RAS will solve the fifth for a given cross section. When solving for width, some normalization must be applied to a cross section to obtain a unique solution, therefore a trapezoidal or compound trapezoidal section with up to three templates must be used for this situation.

Cross Section Subdivision for Conveyance Calculations

In the uniform flow computations, the HEC-RAS default Conveyance Subdivision Method is used to determine total conveyance. Sub areas are broken up by roughness value break points and then each sub area's conveyance is calculated using Manning's equation. Conveyances are then combined for the left overbank, the right overbank, and the main channel and then further summed to obtain the total cross section conveyance.

Bed Roughness Functions

Because Manning's n values are typically used in HEC-RAS, the uniform flow feature allows for the use of a number of different roughness equations to solve for n. HEC-RAS allows the user to apply any of these equations at any area within a cross section; however, the applicability of each equation should be noted prior to selection. Manning equation method, one n value or a range of n values is prescribed across the cross section and then the Manning's equation is used to solve for the desired parameter.

CHAPTER 3

METHODOLOGY

This chapter provides a description of the technical activities based on the technical guidelines in the handbook. Commons for all activities are that the work is to be carried out by a qualified person and verified by a qualified person. The guidelines should ensure project quality assurance through internal verification of data, models and results.

3.1 GUIDELINES FOR COLLECTING GEOGRAPHIC DATA

The objective of these guidelines is to specify what geographic data is needed in the preparation of Flood Inundation Map project and the quality of these data. The flood inundation map project needs geographic data from traditional aerial mapping for terrain modeling and map presentation and cross-section data obtained from surveying to hydraulic calculations. The effective flow parts of cross sections shall be mapped by field surveying. Before surveying the cross sections are planned based on map (1:5000) and existing water surface profiles. The cross sections are finally determined after a field study, described and plotted on a detailed map. A hydraulic competent person carries out this work. A consulting agency carries out the final surveying. Actual survey methods are sounding, ADCP, echo sounder or measurements with dipstick. Along one cross section, the survey can measure polar, but relatively between the start point and other points the horizontal and vertical accuracy should be within 10 cm. The survey is based on the same horizontal and vertical datum that is used in the map project. The cross sections are marked with bolts that later are basis for measurements of calibration water level. The survey report and data formats are specified into details. After surveying the profiles must be controlled with respect to position, direction distances and codes.

3.2 HYDROLOGIC ANALYSIS

The hydrologic analysis is needed to get discharges or water levels that correspond to the final flood inundation maps. The analysis is defined together with the person that carries out the hydraulic analysis who in detail knows the extent of the project needed for hydraulic analysis. Within one catchment all inundation projects are treated in one hydrologic analysis. Basis data for the analysis is long term water stage observation series from hydrometric stations and catchment characteristics. If there is lack of hydrometric stations, nearby stations with similar catchment characteristics are used in the analysis. If the stretch within one project is expected to have flood-dampening effect, a hydrograph should be constructed. The hydrologic analysis starts with definition of which points along the river where the hydraulic analysis shall be carried out and discharge information needed. Catchment characteristics are calculated for these points together with characteristics for the hydrometric stations. Thereafter the frequency analysis is carried out for the hydrometric station. The frequency analysis is based on 24-hour mean but is later scaled to culmination value. The results from the hydrometric stations are then scaled to the earlier defined points for hydraulic calculations, mainly relatively to the catchment area. The final results are discharges that represent culmination at 10, 20 50, 100, 200 and 500 years return period. At river confluence the relative corresponding discharge in the tributary river are determined while there is flood in main river and reverse. Historical flood events often have local observations of water levels. If possible, .the discharges for these events are calculated in order to calibrate the model. The guidelines give advises for use of distribution function based on series length. Series shorter than 10 years may only be used to determinate mean flood, Q_m.

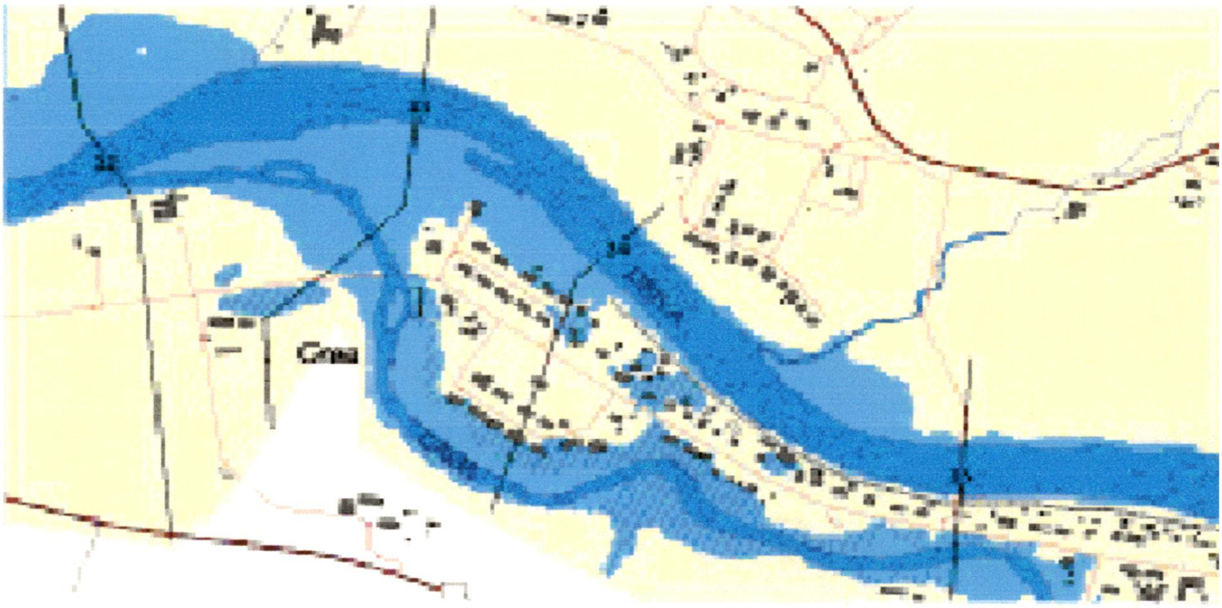
3.3 HYDRAULIC ANALYSIS

The objective of the guidelines is to specify demands for input data, model and model set-up and documentation of the activity. Water surface profiles are calculated in one of the hydraulic simulation programs MIKE 11 or HEC-RAS. If a hydrograph is needed because of dampening effects, MIKE 11 must be used. Use of other models needs documentation. The river cross-sections are collected as for determined cross section localities on the basis of changes in slope, roughness or contraction. These changes are mapped at the same time, as cross sections localities are determined. A hydraulic analysis starts by calculating distances between the profiles. This may be done in an integrated hydraulic-GIS system or at a GIS system alone. The analyst must approve that the distances are correct with respect to effective flow distances. Lengthening of cross sections from terrain model is done at the same time. When cross sections are imported to the hydraulic model, codes will indicate which parts of the cross section are active and less active. The relative roughness factors across and between cross sections should be set before calibration starts. The analyst must be careful not to overestimate the flood plain as effective flow area. Bridges are implemented as culverts or bridges unless the loss trough bridges just are loss due to contraction or expansion that can be handled otherwise. It is specified how bridges are measured in field. Rivers along flood plains have mainly sub-critical flow. It is manly trough bridges that the flow may turn supercritical. The models are therefore calibrated from lower end upstream. If classic critical profiles as a dam-weir exist, it will be used as lower boundary condition with known discharge curve. The highest flood observations are often the most important, but as a general rule the calibration starts for the lower flood marks. As a minimum the model should be calibrated at a mean flood event. This flood normally covers the river channel give and gives good advice of Manning's M or n. The calibrated water profile should be within +/-15 cm. Unrealistic Manning's n or M values are not to be used. Municipalities collect calibration data as water stage observations within the project period. Upstream boundary condition is the discharge hydrograph. Downstream boundary is depending on the locality and available calibration data. Normally a Q/h curve is used, either explicitly specified or as an assumption about flow condition (critical or normal depth). If good calibration data exist downstream, the need for additional cross sections downstream decrease. At sea level mean spring tide is used as standard boundary conditions for all discharges. So far we have not been able to correlate sea level with flood events. At the moment only extreme values at some ports along the coast exist. Finally the model is run with discharges representing the different return periods. Expected accuracy of the computed water profiles is +/- 30 cm if the calibration has been successful. The results from the hydraulic simulations are water levels in each cross section that is delivered to flood inundation analyst in a specified format.

3.4 FLOOD INUNDATION ANALYSIS

A TIN is generated from all available elevation data. Basis data are contours and situation data carrying level information as for instance roads, rivers, water and dikes. These map data have expected vertical accuracy +/- 30 cm. The terrain TIN is then transformed into a regular grid with grid size 5-10 meters. In the same way a TIN is generated between the cross sections. The cross sections have water elevations that represent 10, 20, 50, 100, 200 and 500 years return periods. The different TINs are then transformed into water surface grid with same definition as the terrain grid. The inundated areas are identified by subtracting the land surface grid from the water surface grid, resulting in positive values in inundated areas. The final product is smoothed polygons representing inundated areas with a specified return period. The municipalities receive these polygons beside complete maps and a report. The maps are produced digitally, to make the users able to make their own presentations in combination with other information, using their own tools. The main users, the local municipalities get a draft of the map before final production. It is important that they are involved in the process and identify themselves with the product. The final results from each river reach are delivered to the users both as a report with paper maps and as digital data. The presentation is standardized at scale 1:15000 with cross sections, levees etc. marked. Water levels for all computed floods are presented both in a table and in a graph (longitudinal profile). Fig. 3.1 shows standard presentation of an inundated area by flood. The inundated areas are presented with blue color. Areas isolated from the river by natural or man-made levees are given a particular signature, since these areas have a different probability for flooding compared to the areas in direct connection to the river.

FLOOD INUNDATION MAP



- Map presentation: Inundated areas in blue.
  Areas without direct connection to the river (behind levees, culverts etc.)
  are marked with diagonal shape
- Base map: Digital maps (scale 1:1000), cross sections surveyed by cosultants

Fig. 3.1 Flood inundation map

CHAPTER 4

STUDY AREA AND DATA AVAILABILITY

4.1 GENERAL

In this study, one of the flood prone river of India i.e. Godavari flowing through Andhra Pradesh state has been selected for flood inundation mapping based on 50 years,100 years and 500 years return period floods. The river Godavari is the second largest river in the country and the largest in Southern India. It is roughly triangular in shape and the main river itself runs practically along the base of the triangle. The Godavari basin receives major part of its rainfall during the Southwest monsoon period. The other rainy seasons are not so well defined and well spread as the South-West monsoon season. They contribute about 16% of the total annual rainfall in the Godavari basin. The annual rainfall of Godavari basin varies from 3000 mm to 600 mm. The Godavari River has a drainage area of 313,000 km^2 that includes more that one state. It flows for a total length of about 1465 km in a general South-Eastern direction through the States of Maharashtra and Andhra Pradesh before joining the Bay of Bengal. The major tributaries joining the Godavari are the Pravara, the Purna, the Manjra, the Maner, the Pranhita, the Penganga, the Wardha, the Wainganga, the Indravati and the Sabari. Fig.4.1 shows location of Polavaram dam with upstream river plane area under consideration.

Since the Godavari river brings more water than can be used at the moment one of the main reasons for constructing Polavaram Dam is not to let the water flow into the Indian Ocean. 644 tmcft (18 billion m3) is currently not being utilised from the Godavari and the Andhra Pradesh government wants a part of this water to be captured by Polavaram Dam together with other major projects on the river like Dummagudem and Inchampalli. The Dam will be constructed at a level of 150 feet (47metres) and raise the water along the river stretch upstream in Godavari and several of its tributaries. The submersion will stretch for more than along the Sabari River, a tributary to Godavari, up to the borders of Orissa and Chhattisgarh. The dam created by the barrage close to Polavaram village will flood areas 145 km along the Godavari river valley up to Dummugudem, the proposed site for another major irrigation project. Submersion will also spread along the Sabari and Sileru rivers that are tributaries to the Godavari across the borders north to Chhattisgarh and Orissa.

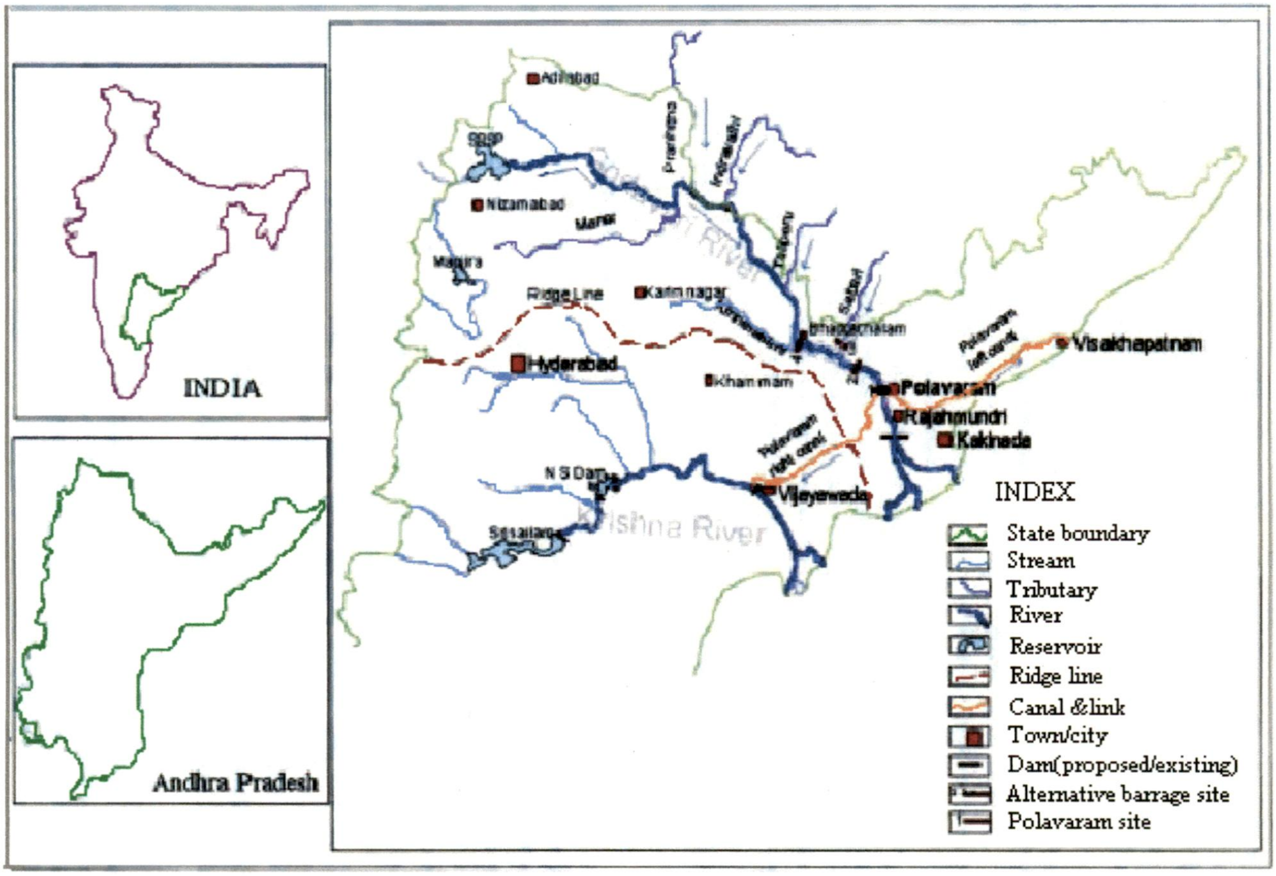


Fig. 4.1 Location of the study area

4.2 TOPOGRAPHY AND GEOGRAPHIC LOCATION

The Godavari basin Fig. 4.1 is bounded on the North by the Satmala Hills, the Ajanta Range and the Mahadeo Hills, on the South and East by the Eastern Ghats and on the West by the Western Ghats. The Godavari basin lies between the Latitude 16° 16′ N and 23° 43′ N and Longitudes 73° 26′ E and 83° 07′ E. It rises in the Sahyadri hills at an altitude of about 1067m near Triambakeswar in the Nasik district of Maharashtra State and flows across the Deccan plateau from the Western Ghats to Eastern Ghats. Rising in the Western Ghats about 80 km from the shore of the Arabian sea. The Godavari basin extends over an area of 312813 sq. km, which is nearly 10% of the total geographical area of the country. The basin comprises areas in the States of Maharashtra, Madhya Pradesh, Chhattisgarh, Andhra Pradesh, Karnataka and Orissa. The percentages of areas of basin the state of Maharashtra, Madhya Pradesh, Andhra Pradesh, Karnataka and Orissa are 48.6, 20.9, 23.4, 1.4, 5.7 respectively (NWDA 1991).

HYDRAULIC DATA: For the study of Flood Inundation Mapping in the area the Hydraulic Data available are :

(i) Index Map of Godavari Basin (Fig 4.2)

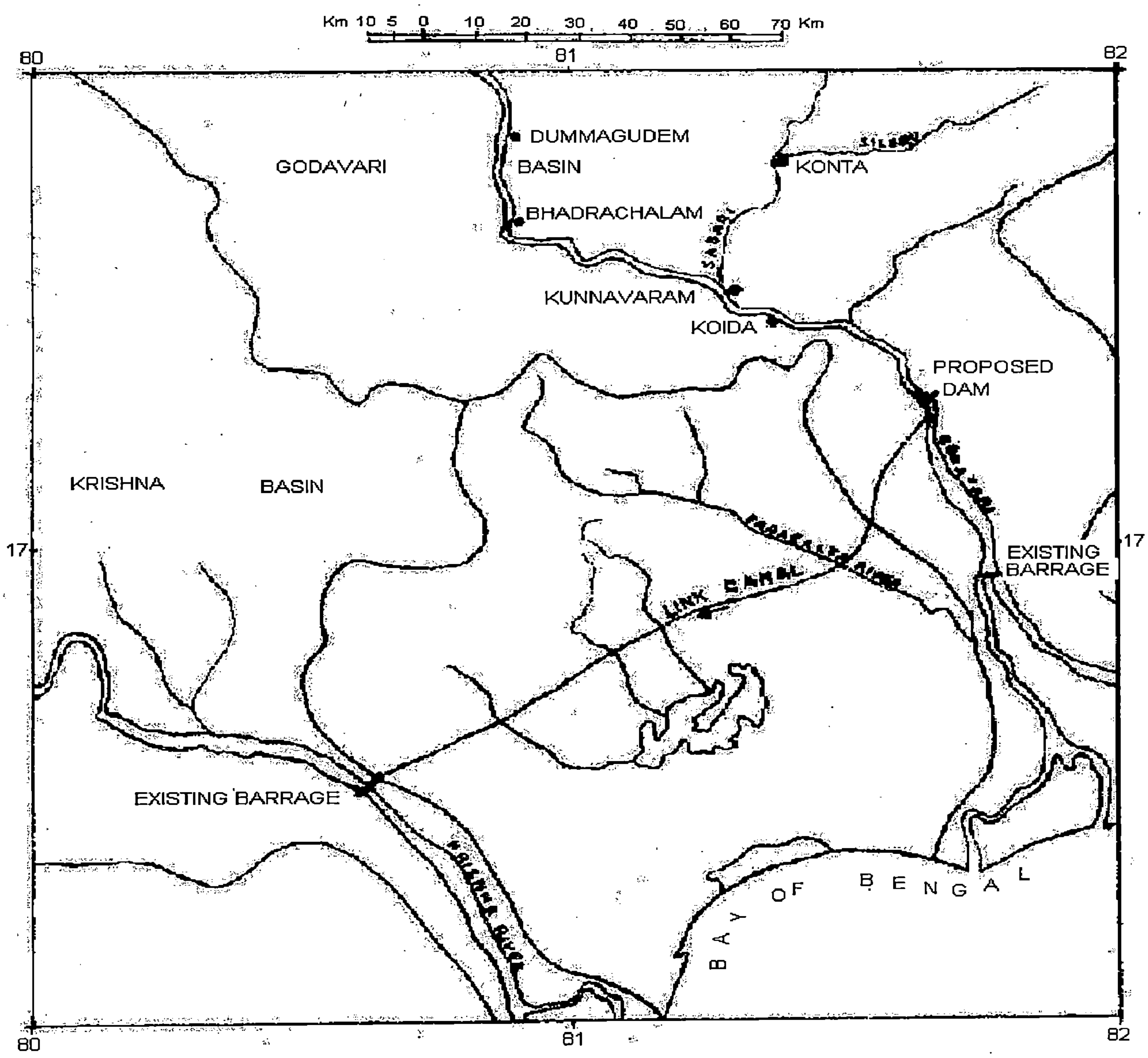


Fig. 4.2 Index map of Godavari Basin

(ii) Peak flood recorded at existing anicut for the period from 1881–1975 (Table 4.1)

Table 4.1 Peak Flood Recorded at Existing Anicut for the Period from 1881 - 1975

SL. NO.	YEAR	HEADH (feet)	DISCHARGE (lakh cusecs)	SL. NO.	YEAR	HEAD H (feet)	DISCHARGE (lakh cusecs)
1	1881	5.75	5.48	49	1929	10.5	8.44
2	1882	13.25	15.9	50	1930	13	9.72
3	1883	13.4	16.13	51	1931	11.1	9.54
4	1884	14	17.05	52	1932	13.7	9.33
5	1885	10	11.1	53	1933	13.9	10.2
6	1886	16.15	20.46	54	1934	14.4	10.29
7	1887	15.15	18.86	55	1935	9.5	8.08
8	1888	7.25	7.37	56	1936	12.4	10.75
9	1889	11.5	13.27	57	1937	10.4	7.85
10	1890	10.5	11.82	58	1938	12.5	10.11
11	1891	16.25	20.62	59	1939	11.2	8.96
12	1892	12.25	14.38	60	1940	15.8	17.91
13	1893	14.25	17.44	61	1941	8.1	6.26
14	1894	10.85	12.32	62	1942	17.9	21.08
15	1895	9.35	10.19	63	1943	8	7.25
16	1896	13.05	15.59	64	1944	16.2	20.82
17	1897	9.35	10.19	65	1945	13.3	11.64
18	1898	9	9.71	66	1946	14	12.24
19	1899	2.4	1.8	67	1947	12.5	10.93
20	1900	15.75	19.82	68	1948	8.2	6.57
21	1901	7	7.05	69	1949	12.8	10.57
22	1902	5	4.59	70	1950	8.2	4.58
23	1903	12.73	15.14	71	1951	12.8	9.82
24	1904	5.5	5.87	72	1952	6.5	5.36
25	1905	7.3	7.95	73	1953	19.5	30.12
26	1906	11.7	10.78	74	1954	12.9	10.85
27	1907	15.25	12.28	75	1955	14.6	15.03
28	1908	11.9	10.36	76	1956	15.3	15.71
29	1909	8.8	9.01	77	1957	16.1	17.46
30	1910	11.1	9.65	78	1958	17.7	24
31	1911	12.5	11.44	79	1959	18.8	27.8
32	1912	14.25	11.86	80	1960	12.1	9.89
33	1913	11.6	9.69	81	1961	13.5	11.85
34	1914	12.5	11.41	82	1962	16.4	17.59
35	1915	10.75	10.66	83	1963	12.4	10.13
36	1916	9.45	9.15	84	1964	11.2	8.93
37	1917	11.6	9.36	85	1965	8.3	5.92
38	1918	8.9	7.18	86	1966	17.4	22.1
39	1919	7.22	6.78	87	1967	12	9.82
40	1920	5.4	5.28	88	1968	7.3	5.77
41	1921	13.9	9.98	89	1969	12.4	12.6
42	1922	10.3	8.24	90	1970	16.2	20.03
43	1923	6.4	5.55	91	1971	7.2	5.26
44	1924	7.4	6.29	92	1972	10.3	7.75
45	1925	10.6	7.96	93	1973	11.2	8.9
46	1926	11.8	9.33	94	1974	7.7	5.77
47	1927	10.5	8.45	95	1975	12.9	11.83
48	1928	8.6	7.25				

(iii) Cross – Sections for three sites viz. Koida, Bhadrachalam, Dummagudem

(Tables 4.2 - 4.4)

Table 4.2 Cross-Section of Godavari at R.D. 40.75Km(Koida)

SL. NO.	DISTANCE (METER)	ELEVATION (METER)	SL. NO.	DISTANCE (METER)	ELEVATION (METER)
1	740.00	45.00	38	740.00	40.00
2	760.00	40.00	39	760.00	40.00
3	780.00	38.50	40	780.00	40.00
4	800.00	38.20	41	800.00	38.00
5	820.00	38.00	42	820.00	30.00
6	840.00	38.00	43	840.00	20.80
7	860.00	38.10	44	860.00	19.80
8	880.00	38.20	45	880.00	20.00
9	900.00	38.40	46	900.00	20.00
10	920.00	38.50	47	920.00	19.90
11	940.00	38.60	48	940.00	20.00
12	960.00	38.80	49	960.00	19.60
13	980.00	39.00	50	980.00	19.00
14	1000.00	39.00	51	1000.00	18.60
15	1020.00	39.00	52	1020.00	17.80
16	1040.00	39.00	53	1040.00	17.00
17	1060.00	39.00	54	1060.00	16.50
18	1080.00	39.00	55	1080.00	15.60
19	1100.00	39.00	56	1100.00	15.00
20	1120.00	39.00	57	1120.00	14.60
21	1140.00	39.00	58	1140.00	14.00
22	1160.00	39.00	59	1160.00	13.60
23	1180.00	39.50	60	1180.00	13.60
24	1200.00	39.50	61	1200.00	12.00
25	1220.00	39.00	62	1220.00	11.00
26	1240.00	38.60	63	1240.00	8.00
27	1260.00	38.80	64	1260.00	7.00
28	1280.00	39.00	65	1280.00	7.00
29	1300.00	39.00	66	1300.00	6.80
30	1320.00	39.00	67	1320.00	6.00
31	1340.00	39.00	68	1340.00	3.00
32	1360.00	39.80	69	1360.00	4.90
33	1380.00	39.40	70	1380.00	6.50
34	1400.00	39.40	71	1400.00	10.00
35	1420.00	39.60	72	1420.00	24.80
36	1440.00	40.00	73	1440.00	25.00
37	1460.00	40.00	74	1460.00	40.00

Table 4.3 Cross-Section of Godavari at R.D. 118.685Km (Bhadrachalam)

SL. NO.	DISTANCE (METER)	ELEVATION (METER)	SL. NO.	DISTANCE (METER)	ELEVATION (METER)
1.00	0.00	53.00	33.00	800.00	33.00
2.00	25.00	45.50	34.00	825.00	33.00
3.00	50.00	44.00	35.00	850.00	33.00
4.00	75.00	40.00	36.00	875.00	33.10
5.00	100.00	38.90	37.00	900.00	33.20
6.00	125.00	33.00	38.00	925.00	33.40
7.00	150.00	32.00	39.00	950.00	33.50
8.00	175.00	30.00	40.00	975.00	33.30
9.00	200.00	29.60	41.00	1000.00	33.00
10.00	225.00	31.00	42.00	1025.00	32.20
11.00	250.00	31.00	43.00	1050.00	32.10
12.00	275.00	30.00	44.00	1075.00	32.00
13.00	300.00	31.80	45.00	1100.00	33.00
14.00	325.00	31.00	46.00	1125.00	33.50
15.00	350.00	30.00	47.00	1150.00	35.00
16.00	375.00	29.50	48.00	1175.00	36.00
17.00	400.00	29.70	49.00	1200.00	45.60
18.00	425.00	28.00	50.00	1225.00	46.90
19.00	450.00	28.30	51.00	1250.00	47.10
20.00	475.00	30.20	52.00	1275.00	48.00
21.00	500.00	29.90	53.00	1300.00	48.00
22.00	525.00	32.00	54.00	1325.00	47.20
23.00	550.00	32.60	55.00	1350.00	47.00
24.00	575.00	31.80	56.00	1375.00	46.80
25.00	600.00	31.80	57.00	1400.00	46.00
26.00	625.00	32.60	58.00	1425.00	45.80
27.00	650.00	32.60	59.00	1450.00	45.50
28.00	675.00	31.00	60.00	1475.00	46.00
29.00	700.00	31.50	61.00	1500.00	46.20
30.00	725.00	32.50	62.00	1525.00	46.40
31.00	750.00	32.60	63.00	1550.00	46.60
32.00	775.00	33.00			

Table 4.4 Cross-Section of Godavari at R.D. 143.115Km (Dummagudem)

SL. NO.	DISTANCE (METER)	ELEVATION (METER)	SL. NO.	DISTANCE (METER)	ELEVATION (METER)
1.00	0.00	57.00	31.00	750.00	43.00
2.00	25.00	60.20	32.00	775.00	43.00
3.00	50.00	51.90	33.00	800.00	43.00
4.00	75.00	49.40	34.00	825.00	42.00
5.00	100.00	45.60	35.00	850.00	43.00
6.00	125.00	43.70	36.00	875.00	43.00
7.00	150.00	43.50	37.00	900.00	42.00
8.00	175.00	43.30	38.00	925.00	42.00
9.00	200.00	43.00	39.00	952.00	42.00
10.00	225.00	41.50	40.00	975.00	42.90
11.00	250.00	41.70	41.00	1000.00	43.00
12.00	275.00	42.00	42.00	1025.00	42.80
13.00	300.00	43.00	43.00	1050.00	43.30
14.00	325.00	42.00	44.00	1075.00	43.90
15.00	350.00	42.00	45.00	1100.00	43.80
16.00	375.00	42.00	46.00	1125.00	43.70
17.00	400.00	43.00	47.00	1150.00	43.60
18.00	425.00	42.40	48.00	1175.00	43.60
19.00	450.00	43.00	49.00	1200.00	43.50
20.00	475.00	43.00	50.00	1225.00	43.50
21.00	500.00	44.00	51.00	1250.00	43.60
22.00	525.00	44.00	52.00	1275.00	43.80
23.00	550.00	44.00	53.00	1300.00	43.60
24.00	575.00	44.00	54.00	1325.00	46.00
25.00	600.00	44.00	55.00	1350.00	45.10
26.00	625.00	44.00	56.00	1375.00	44.80
27.00	650.00	44.00	57.00	1400.00	45.00
28.00	675.00	44.00	58.00	1425.00	47.30
29.00	700.00	44.00	59.00	1450.00	48.00
30.00	725.00	44.00	60.00	1475.00	52.00

(iv) Longitudinal – section of Godavari River upstream of Polavaram dam-site. It has been given in Table A1 (Appendix – A)

(v) Cross – section of bore whole chart at Polavaram dam-site given in Figs.A1 and A2 (Appendix – A).

All the above data have been taken from the Project Report of M. Tech. (WRD) 49th batch 2005 of WRD&M, IIT Roorkee.

(viii) SRTM 90M Digital Elevation Database

The SRTM digital elevation data, originally produced by NASA, is a major breakthrough in digital mapping of the world, and provides a major advance in the accessibility of high quality elevation data for large portions of the tropics and other areas of the developing world. The SRTM dataset provides a recent snapshot of the Earth's land surface. The SRTM 90m DEM's have a resolution of 90m at the equator, and are provided in mosaiced 5 deg x 5 deg tiles for easy download and use. The DEM files have been mosaicked into a seamless global coverage in geographic coordinate system - WGS84 datum. These files are available for download in both Arc-Info ASCII format, and as GeoTiff, for easy use in most GIS and Remote Sensing software applications. The earth science community regularly uses products like SRTM data for hydrologic and geologic investigations. Elevation data are used for various applications, most notably the production of topographic maps and three-dimensional visualizations of the Earth's surface. Hence, SRTM 90m DEM's for Latitude 16° 16′ N and 23° 43′ N and Longitudes 73° 26′ E and 83° 07′ E is downloaded from http://srtm.csi.cgiar.org/ site in Tiff format.

CHAPTER 5

DATA PROCESSING

5.1 GENERAL

HEC-RAS is a computer program for modeling water flowing through systems of open channels and computing water surface profiles. It can be used in the GIS programme, ArcView (with 3-D analyst and spatial analyst extensions). ArcView can create a DTM. Similarly GEO-RAS can be used to create cross sections and other geometrical data for use in HEC-RAS and can be used to export water surface data from HEC-RAS back into ArcView to create flood maps with depths and extents of flooding. To create HEC-RAS database the interface needs two types of information about the study area. These are map themes and database files.

A. Map Themes: It requires the following data/material:

(i) Digital Elevation Model

Digital Elevation Model (DEM) is sampled array of elevations (Z) that is regularly spaced in the X & Y directions. DEM of the study area has been taken from SRTM 90M Digital elevation database in TIFF. Tag Image File Format (TIFF) serves as an interface to several scanners and graphic arts packages. It supports black-and-white, grayscale, pseudo color, and true color images, all of which can be stored in a compressed or uncompressed format. By default, ArcView looks for TIFF images when they have these file extensions: .tif; .tff; .tiff

(ii) Image Data

EMAGINE (.img) files are produced using the IMAGINE image processing software created by ERDAS. To use IMAGINE images with ArcView we must first load the

IMAGINE image extension. By default, ArcView looks for IMAGINE images when they have these file extensions: .img.

(iii) **ArcView shapefiles**

ArcView shape files are a simple, non-topological format for storing the geometric location and attribute information of geographic features. A shape file is one of the spatial data formats that one can work with in ArcView. The shape file format defines the geometry and attributes of geographically-referenced features in as many as five files with specific file extensions i.e. .shp, .shx, .dbf, .sbn and sbx. that should be stored in the same project workspace.

(iv) TIN

With the 3D Analyst, surface themes can be created and used for analysis. Triangulated Irregular Networks (TINs) surface models gives the power and flexibility needed to solve a wide variety of surface modeling tasks including contouring, profiling, color hillshade mapping, and more.

B. Database files :

(i) Peak flood data table.

(ii) Observed cross-section and Longitudinal-section data table.

(iii) Computed cross section data table.

(iv) Stage discharge data table.

(v) Sediment data table.

5.2 SOFTWARE USED

To prepare the above required input information following software is used:

Sl. No.	Layer	Layer Format	Source	File type	Software used
1	Dem	Raster	Satellite Imagery	Tiff	ERDAS IMAGINE 8.5
2	Image	Raster	Satellite Imagery	img	ERDAS IMAGINER 8.5
3	Image	Point	Satellite Imagery	shp	ERDAS IMAGINE 8.5 & ELWIS 3.0
4	Tin	Point	Shapefile	shp	ArcView GIS 3.2
5	Centre line, River banks. Cross-sections	Point	Shapefile	dbf	ArcView GIS 3.3 & Geo-RAS
6	Centre line, River banks. Cross-sections	Point	RAS import	sdf	HEC-RAS Version 4.0

5.3 MAP THEMES

5.3.1 DIGITAL ELEVATION MODEL

SRTM 90m DEM's data for the study area comes to the Viewer window of ERDAS IMAGINE 8.5 as a raster data when searched for (.tif) extension file. In ERDAS IMAGINE, file name extensions identify the file type. When data are imported into ERDAS IMAGINE from TIFF, they are converted to the ERDAS IMAGINE file format and stored in image file with (.img) extension for further processing.

5.3.2 IMAGE DATA

Since the map represents a very large area, we concentrate on study area i.e. area of interest (AOI). In the main window of ERDAS IMAGINE we go for .img file in Viewer and select AOI and do reprojection. ERDAS IMAGINE reprojection converts latitude and longitude to UTM WGS84 where UTM is a coordinates grid system and WGS84 is the datum for GPS readings. The study area falls in north 44 UTM zone. Following details are requiring to be given:

Projection type - UTM Spheroid name - WGS84 Datum name - WGS84
UTM zone - 44 North or south - North

Here we note down the image information by clicking "Top raster layer" from sub menu of Viewer window as: Width, Height, Upper Left X, Lower Right X, Upper Left Y, Lower Right Y and Pixel. Then after saving geometric model it is exported in "Generic Binary" data form through clicking Import on main ERDAS IMAGINE window.

Now we use Integrated Land and Water Information System (ILWIS) which is another Geographic Information System (GIS) with image processing capability. As a GIS package, ILWIS allows to input, manage, analyze and present geographical data. From the data we can generate information on the spatial and temporal patterns and processes on the earth surface. In ILWIS, most spatial operations are performed on raster maps. When using satellite images, we already have raster maps. Pixels in a satellite image almost have values ranging from 0 to 255. In ILWIS, satellite images have domain Image. A domain defines the values, classes or identifiers that can be stored in a map or column. Hence with the available image information we first open ILWIS and from file click import and find out the exported file from ERDAS IMAGINE in general raster format. We create Coordinate system, Geo-reference, Domain, and then Segment map. Now we can draw centre line, river banks and cross sections etc. with edit option. After completing all operations we go for vectorize option by selecting raster map where raster to point option is selected and exported. Fig. 5.1 shows a geo-referenced. Raster map with given coordinate system and domain in ILWIS.

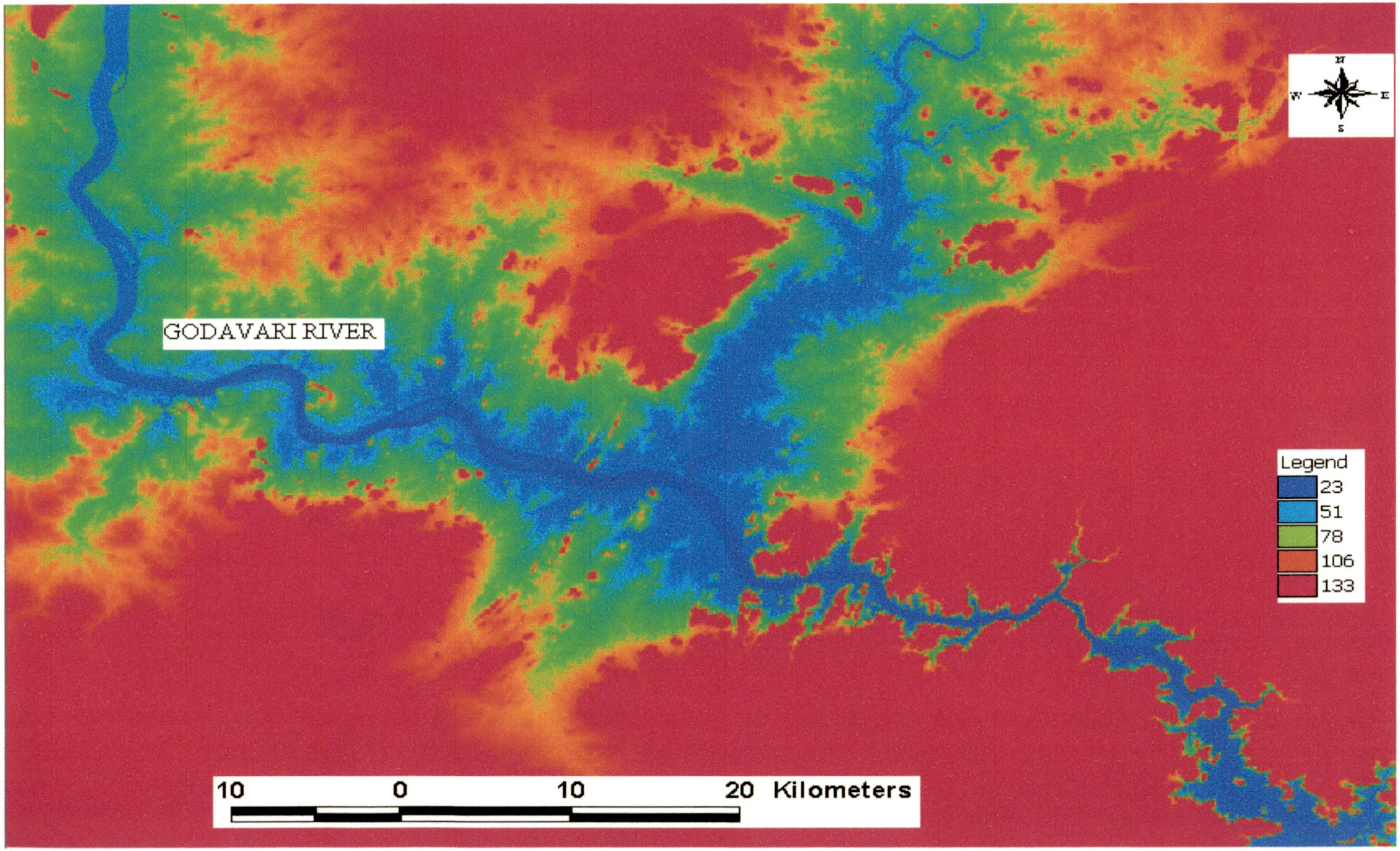


Fig. 5.1 Raster image of study area in ILWIS

5.3.3 ARCVIEW SHAPEFILE

ArcView is a powerful, easy-to-use tool which brings geographic information to our desktop. ArcView gives us the power to visualize, explore, query and analyze data spatially. It has the extension of 3D analyst and HEC-GeoRAS 3.1.1. The file exported from ILWIS is in the form of shapefile. By opening ArcView we go for import in file menu through proper selection of source data. All the required shape files i.e. raster map, centre line, river banks cross-sections are stored here for further processing.

5.3.4 TIN

A TIN theme represents one or more geographic layers, usually at least a surface layer, where space is partitioned into a set of non-overlapping triangles. Attribute and geometry information is stored for the points, lines, and faces that comprise each triangle. This information is used for display, query, and analysis purposes. The shape file of raster map exported from ILWIS is opened in ArcView and selected by clicking left mouse button. Now from main menu bar Surface menu is selected, where option 'create TIN from feature'comes. By clicking this TIN is created. Fig 5.2 shows the created TIN of the study area. There are numbers of tool to make corrections in any of the shape file. Before exporting from ArcView pre-RAS process is done from main menu. All the processes are under pre-RAS is done sequentially. Under theme setup centerline completion, centerline topology, length/stations and centerline elevation are completed. Cross-section attributing is done for stream/reach names, stationing bank station and reach length and cross-section elevations. Lastly, RAS GIS Import file is generated in which header export; centerline export and cross-section export are done to have ultimately geometric data for use in HEC-RAS.

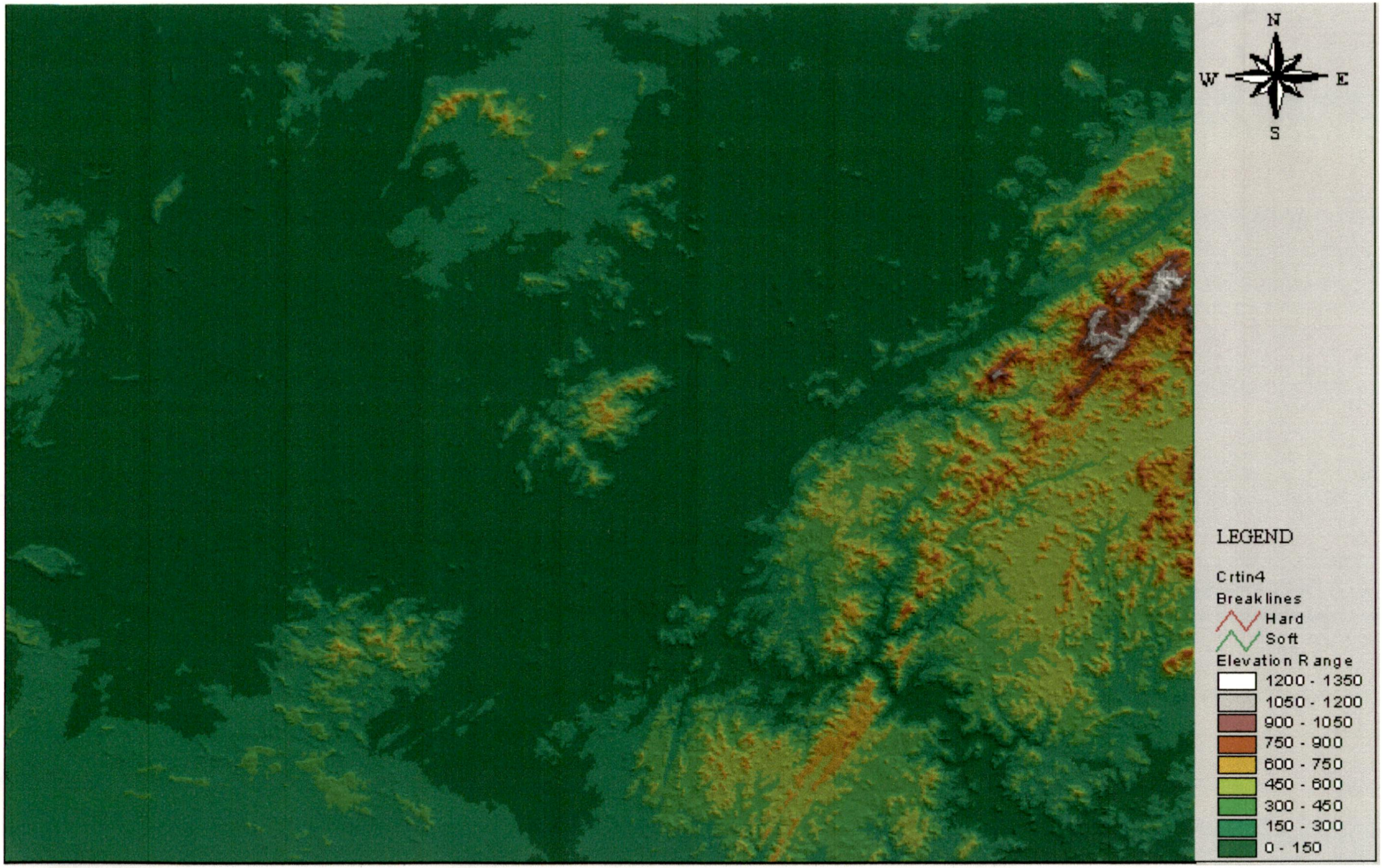


Fig. 5.2 Created TIN of the study area

5.4 DATABASE

Following databases were processed and prepared as per HEC-RAS (version 4.0).

5.4.1 PEAK DISCHARGE DATA TABLE

Peak flood available for the period from 1881 to 1975 at existing anicut are used for the assessment of various return period by flood frequency analysis.

5.4.1.1 FLOOD FREQUENCY ANALYSIS

The objective of flood frequency analysis is to relate the magnitude of extreme flood events to their frequency of occurrence through the use of probability distribution. Though U.S. Weather Resources Council recommends testing of outliers before carrying out the flood frequency analysis, because of lack of additional information to confirm the outliers, this part of analysis is not done.

Chow (1951) has shown that most frequency distribution functions applicable in hydraulic studies can be expressed by the following equation known as the general equation of hydrologic frequency analysis.

$$X_t = \overline{X} + K_T * \sigma$$

where, X_t = value of variate X of a random hydraulic series with return period T,

X = mass of variate

σ = standard deviation of variate

K_T = frequency factor which depends upon the return period T and assumed frequency distribution. Some of the commonly used frequency distribution functions for the prediction of extreme flood values are:-

(i) Gumbel distribution

(ii) Log-Pearson Type III Distribution

(iii) Log-Normal Distribution

(iv) Normal Distribution

Normal Distribution can not be used for flood frequency analysis as flood event can not be negative. So this distribution is not discussed here.

LOG NORMAL DISTRIBUTION

This is based on the Log-Normal probability law and assumes that the flood values are such that their natural logarithms are normally distributed. For this distribution the frequency factor K_T is equal to normal variate. The value of Z corresponding to an exceedence probability of P (=1/T) can be calculated by finding the value of intermediate variable W,

$$W = \{\ln(\frac{1}{p^2})\}^{1/2} \qquad (0<p \leq 0.5)$$

Then Z can be calculated using the approximation

$$Z = W - \frac{2.515517 + 0.802853W + 0.010328W^2}{1 + 1.432788W + 0.189269W^2 + 0.001308W^3}$$

Using the above formula annual maximum discharge of various return- periods can be found.

GUMBEL DISTRIBUTION

This extreme value distribution was introduced by Gumbel (1941) and is commonly known as Gumbel distribution. It is one of the most widely used probability distribution functions for extreme value in hydrologic and meteorological studies for prediction of floods peaks, maximum rainfall and maximum wind speed.

Here, $\overline{X}$ = mean of variate, S_y = standard deviation, C_s = coefficient of skewness

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

This gives the K_T values for different return periods (T) which are used for calculating flood discharges using

$$X_t = \overline{X} + K_T S_y$$

LOG - PEARSON TYPE III DISTRIBUTION

For this distribution, first annual floods are transformed to logarithmic values Y= log(X) and then we find the mean, standard deviation and skewness coefficient of the logarithms to get the value of K_T for the desired recurrence interval. The flood magnitude Q for the desired recurrence interval is now estimated from

$$\text{Log}(Q) = \overline{Y} + K_T S_y$$

where, $K_T = f(T, C_s)$ is a function of both the recurrence interval and skewness. When $C_s = 0$, the frequency factor is equal to the standard normal variable Z. In other conditions frequency factor K_T is computed by the following expression given by Kite (1977)

$$K_T = Z + (Z^2+1)K + \frac{1}{3}(Z^3-6Z)K^2 - (Z^2-1)K^3 + ZK^4 + \frac{1}{3}K^5$$

where, $K = C_s / 6$

The annual peak flood data from 1881 to 1975 are used for calculation of various parameters essential in different distribution systems for flood frequency analyses are shown in the Table 5.1 below. In the table head and corresponding discharges for all 95 years have been given. In the next column discharges are converted from lakh cusec to cumec and the last column records the logarithmic value of discharges which are essential for Log-Normal Distribution and Log-Pearson Type III Disribution. In the bottom three rows of table Mean, Standard Deviation and Skewness have been calculated.

Table 5.1 Peak Flood Recorded at Existing Anicut for the Period from 1881 – 1975

YEAR	HEAD H (feet)	X=DISCHARGE Q (lakh cusecs)	HEAD H (meter)	DISCHARGE Q (cumecs)=X	Y=LOG(Q)
1881	5.75	5.48	1.8	15518.2	4.2
1882	13.25	15.9	4.0	45025.4	4.7
1883	13.4	16.13	4.1	45676.7	4.7
1884	14	17.05	4.3	48282.0	4.7
1885	10	11.1	3.0	31432.8	4.5
1886	16.15	20.46	4.9	57938.4	4.8
1887	15.15	18.86	4.6	53407.5	4.7
1888	7.25	7.37	2.2	20870.3	4.3
1889	11.5	13.27	3.5	37577.8	4.6
1890	10.5	11.82	3.2	33471.7	4.5
1891	16.25	20.62	5.0	58391.5	4.8
1892	12.25	14.38	3.7	40721.1	4.6
1893	14.25	17.44	4.3	49386.4	4.7
1894	10.85	12.32	3.3	34887.6	4.5
1895	9.35	10.19	2.8	28855.9	4.5
1896	13.05	15.59	4.0	44147.6	4.6
1897	9.35	10.19	2.8	28855.9	4.5
1898	9	9.71	2.7	27496.7	4.4
1899	2.4	1.8	0.7	5097.2	3.7
1900	15.75	19.82	4.8	56126.0	4.7
1901	7	7.05	2.1	19964.1	4.3
1902	5	4.59	1.5	12997.9	4.1
1903	12.73	15.14	3.9	42873.3	4.6
1904	5.5	5.87	1.7	16622.6	4.2
1905	7.3	7.95	2.2	22512.7	4.4
1906	11.7	10.78	3.6	30526.7	4.5
1907	15.25	12.28	4.6	34774.4	4.5
1908	11.9	10.36	3.6	29337.3	4.5
1909	8.8	9.01	2.7	25514.4	4.4
1910	11.1	9.65	3.4	27326.8	4.4
1911	12.5	11.44	3.8	32395.7	4.5
1912	14.25	11.86	4.3	33585.0	4.5
1913	11.6	9.69	3.5	27440.0	4.4
1914	12.5	11.41	3.8	32310.7	4.5
1915	10.75	10.66	3.3	30186.9	4.5
1916	9.45	9.15	2.9	25910.9	4.4
1917	11.6	9.36	3.5	26505.5	4.4
1918	8.9	7.18	2.7	20332.2	4.3
1919	7.22	6.78	2.2	19199.5	4.3
1920	5.4	5.28	1.6	14951.8	4.2
1921	13.9	9.98	4.2	28261.2	4.5
1922	10.3	8.24	3.1	23333.9	4.4
1923	6.4	5.55	2.0	15716.4	4.2
1924	7.4	6.29	2.3	17811.9	4.3
1925	10.6	7.96	3.2	22541.0	4.4
1926	11.8	9.33	3.6	26420.6	4.4
1927	10.5	8.45	3.2	23928.6	4.4

YEAR	HEAD H (feet)	X=DISCHARGE Q (lakh cusecs)	HEAD H (meter)	DISCHARGE Q (cumecs)=X	Y=LOG(Q)
1928	8.6	7.25	2.6	20530.5	4.3
1929	10.5	8.44	3.2	23900.3	4.4
1930	13	9.72	4.0	27525.0	4.4
1931	11.1	9.54	3.4	27015.3	4.4
1932	13.7	9.33	4.2	26420.6	4.4
1933	13.9	10.2	4.2	28884.2	4.5
1934	14.4	10.29	4.4	29139.1	4.5
1935	9.5	8.08	2.9	22880.8	4.4
1936	12.4	10.75	3.8	30441.7	4.5
1937	10.4	7.85	3.2	22229.5	4.3
1938	12.5	10.11	3.8	28629.4	4.5
1939	11.2	8.96	3.4	25372.8	4.4
1940	15.8	17.91	4.8	50717.3	4.7
1941	8.1	6.26	2.5	17727.0	4.2
1942	17.9	21.08	5.5	59694.1	4.8
1943	8	7.25	2.4	20530.5	4.3
1944	16.2	20.82	4.9	58957.8	4.8
1945	13.3	11.64	4.1	32962.0	4.5
1946	14	12.24	4.3	34661.1	4.5
1947	12.5	10.93	3.8	30951.4	4.5
1948	8.2	6.57	2.5	18604.8	4.3
1949	12.8	10.57	3.9	29932.0	4.5
1950	8.2	4.58	2.5	12969.6	4.1
1951	12.8	9.82	3.9	27808.2	4.4
1952	6.5	5.36	2.0	15178.4	4.2
1953	19.5	30.12	5.9	85293.5	4.9
1954	12.9	10.85	3.9	30724.9	4.5
1955	14.6	15.03	4.5	42561.8	4.6
1956	15.3	15.71	4.7	44487.4	4.6
1957	16.1	17.46	4.9	49443.0	4.7
1958	17.7	24	5.4	67962.9	4.8
1959	18.8	27.8	5.7	78723.7	4.9
1960	12.1	9.89	3.7	28006.4	4.4
1961	13.5	11.85	4.1	33556.7	4.5
1962	16.4	17.59	5.0	49811.2	4.7
1963	12.4	10.13	3.8	28686.0	4.5
1964	11.2	8.93	3.4	25287.9	4.4
1965	8.3	5.92	2.5	16764.2	4.2
1966	17.4	22.1	5.3	62582.5	4.8
1967	12	9.82	3.7	27808.2	4.4
1968	7.3	5.77	2.2	16339.4	4.2
1969	12.4	12.6	3.8	35680.5	4.6
1970	16.2	20.03	4.9	56720.7	4.8
1971	7.2	5.26	2.2	14895.2	4.2
1972	10.3	7.75	3.1	21946.4	4.3
1973	11.2	8.9	3.4	25202.9	4.4
1974	7.7	5.77	2.3	16339.4	4.2
1975	12.9	11.83	3.9	33500.1	4.5
Mean	11.58	11.38	3.53	32236.18	4.47
Std. dev.	3.39	5.25	1.03	14874.28	0.20
Skewness	-0.09	1.22	-0.09	1.22	-0.30

Now for various the recurrence intervals of 50, 100, 200, 300, 400 and 500 years, frequency factors are calculated from the above discussed formula for all three distributions and flood magnitude Q are calculated which are shown in the table below:

Recurrence Interval (years)	Flood Discharge Through Different Frequency Distributions(cumec)		
	Log-Normal	Log-Pearson Type III	Gumbel
50	74212	65806	70795
100	84000	72516	78892
200	94065	79059	86960
300	100130	82833	91672
400	104479	85467	95013
500	107907	87573	97604

RELIABILITY ANALYSIS

The reliability of the result of frequency analysis depends on how well the probabilistic model applies to the given set of hydrologic data. To this end, confidence limits are presented.

CONFIDENCE LIMIT

Statistical estimates are often produced in an interval within which the true value can reasonably expected to lie. The size of confidence interval depends on the confidence level α is given by

$$\alpha = (1-\beta)/2$$

For estimating the event magnitude for return period, upper limit $Y^{U}_{T,\alpha}$ and lower limit $Y^{L}_{T,\alpha}$ may be specified by adjustment of the frequency factor equation:

$$Y^{U}_{T,\alpha} = \overline{Y} + S_y K^{U}_{T,\alpha}$$

$$Y^{L}_{T,\alpha} = \overline{Y} + S_y K^{L}_{T,\alpha}$$

where $K^{U}_{T,\alpha}$ and $K^{U}_{T,\alpha}$ are upper and lower confidence limit factors which can be determined for normally distributed data using non-central t-distribution (Kendell and Stuart, 1967). The same factors are used to construct the approximate confidence limit for Log-Pearson Type III distribution. The approximate values for these factors are given by following formula:

$$K^{U}_{T,\alpha} = \frac{K_T + \sqrt{K_T^{2} - ab}}{a}$$

$$K^{L}_{T,\alpha} = \frac{K_T - \sqrt{K_T^{2} - ab}}{a}$$

where $a = 1 - \frac{Z_\alpha^{2}}{2(n-1)}$ and $b = K_T^{2} - \frac{Z_\alpha^{2}}{n}$ in which n = no. of peak annual flood values.

LOG-PEARSON TYPE III DISTRIBUTION

Reliability analysis of Log- Pearson Type III distribution is done using the above mentioned method, for 90% confidence limit

$$\alpha = (1-\beta)/2 = 0.05$$

From table, required value of $Z\alpha = 1.645$ (Statistical t-table with right tail probability)

$$a = 0.98561 \quad \text{and } b = 6.3178$$

Now considering 90% confidence limit and a recurrence interval of 500 years, frequency factor $K^{U}_{500,0.05} = 2.90667$

Confidence limit for upper limit

$Y^{U}_{500,0.05} = 5.0337$ and corresponding discharge $X_U = 108068$ cumecs

Similarly for lower limit

$Y^{L}_{500,0.05} = 4.89537$ and corresponding discharge $X_L = 78591$ cumecs

STANDARD ERROR

The standard error of estimate S_e is a measure of the standard deviation of event magnitude computed from samples about the true event magnitude. Formulas for the standard error of estimate for the Normal and Extreme Value Type I (Gumbel) Distribution are:

Normal Distribution

$$S_e = \frac{S*(2+Z^2)^{1/2}}{n}$$

Extreme Value Type I (Gumbel) Distribution

$$S_e = \frac{1}{n}(1+1.1396K_T + 1.1000K_T{}^2)^{1/2}S$$

where S is the standard deviation of original sample. Standard Error can be used to construct confidence limits in a similar manner for Log-Normal Distribution and Gumbel Distribution.

LOG NORMAL DISTRIBUTION

For T = 500 years W = 3.52551 and Z = 2.87851 = K_T

From Table 5.1

S = 0.20 n = 95, then $S_e = 0.064898$

For 90% confidence limit, $\alpha = 0.05$ $Z\alpha = 1.645$

Upper limit, $Y^{U}_{500,0.05} = 5.13491$ and corresponding discharge $X_U = 136429$cumecs

Similarly Lower limit, $Y^{L}_{500,0.05} = 4.92132$ and corresponding discharge X_L =83443cumecs

GUMBEL DISTRIBUTION

For T = 500 years, $K_T = 4.392721$ and for 90% confidence limit, $\alpha = 0.05$ $Z\alpha = 1.645$

From Table 5.1 Standard deviation (S) = 14874.28 and n =95 and

Standard error $S_e = 817.36972_\alpha$

Upper limit, $^{U}X_{T,\alpha} = X_t + S_e\ Z\alpha$

$$^{U}X_{500,0.05} = 98948\text{cumec}$$

Lower limit, $^{L}X_{T,\alpha} = X_t - S_e\ Z\alpha$

$$^{L}X_{500,0.05} = 96259\text{cumec}$$

Hence we can summarize the findings of various distributions with consideration of standard error for 500 year return periods in following table:

Table 5.2 500 years returns period flood computed from different distributions

Distribution	Flood Discharge (cumecs)		
	500 Years Return Period	Upper Limit	Lower Limit
Gumbel's Distribution	97604	98948	96259
Log-Normal Distribution	107907	110662	105218
Log-Pearson Type III Distribution	87573	103846	76258

When we examine the result shown in the above table, it can be seen that the Gumbel Distribution has given better result because more the difference between upper and lower limit of discharges taking care of standard error lesser are the reliability to the true event magnitude. With least difference of upper and lower limit of discharges Gumbel Distribution will give the best fit values of flood discharge. Hence its discharges 70795, 78892 and 97604 cumec for return period 50, 100 and 500 years respectively will be used for simulation in HEC-RAS for creating flood inundation maps.

5.4.2 OBSERVED CROSS-SECTION AND LONGITUDINAL SECTION DATA TABLE

There are only three observed cross-sections and a longitudinal-section available for use in HEC-RAS. These are at Koida(40.75Km), Bhadrachalam(118.685Km), Dummagudem (143.115Km). These cross-sections are used as the guide lines for computing several cross-sections in between. Similarly L-section is used for verification and modification of deepest bed levels of computed various cross-sections.

5.4.3 COMPUTED CROSS-SECTION DATA TABLE

In HEC-RAS (Version 4.0) while importing the geometric data and then plotting various cross sections and viewing the longitudinal bed profile it was observed that the deepest portion of bed was having same elevations for a long distance. It was due to the presence of water in thalweg Raster image that could not represent the actual bed levels but elevation of water level. Therefore, all cross-sections were recomputed in thalweg as per the bed levels in the available observed longitudinal-section. Observed longitudinal bed profile data has been given in Table A1 of the Appendix A. Table 5.2 shows the computed longitudinal bed profile data. A total 143.11 km length upstream of the dam site of Godavari River was considered for flood inundation and a total 121 cross sections were plotted while intermediate distances cross sections were interpolated suitably on the basis of observed longitudinal bed profile data. Fig. 5.1 shows the longitudinal bed profile and X-Y-Z perspective plot of cross sections of Godavari River has been shown in Fig.5.2.

Table 5.3 Longitudinal Bed Profile Data

Sl. No.	Distance in Km	Bed level in metre	Sl. No.	Distance in Km	Bed level in metre	Sl. No.	Distance in Km	Bed level in metre
1	0	2.99	42	59.05	14.13	83	103.05	26.92
2	0.96	7.48	43	60.01	15.26	84	104.07	26.29
3	1.97	8.5	44	60.99	16.39	85	105.13	25.75
4	2.25	9.94	45	62.03	16.68	86	106.11	21.72
5	3.97	5.82	46	64.18	17.16	87	107.08	21.84
6	5.04	0.98	47	65.16	18.03	88	108.05	24.53
7	6.02	-2.77	48	66.10	18.86	89	109.08	27.40
8	7.03	-4.39	49	67.73	19.76	90	110.11	28.38
9	7.99	-5.99	50	68.16	19.15	91	111.06	28.56
10	9.00	-4.54	51	69.18	18.30	92	112.10	27.39
11	10.03	-0.40	52	71.12	19.58	93	113.04	28.47
12	11.00	8.5	53	72.15	21.67	94	115.05	26.61
13	13.06	-5.99	54	73.15	21.67	95	116.04	30.65
14	15.03	9.56	55	74.12	23.26	96	117.11	29.71
15	16.02	7.42	56	75.09	24.57	97	118.	28.84
16	17.04	4.77	57	76.15	24.63	98	119.05	33.39
17	18.03	2.17	58	77.12	24.93	99	120.08	34.20
18	19.02	-0.39	59	78.14	25.25	100	121.13	34.59
19	20.02	-3.39	60	79.18	25.60	101	122.08	34.36
20	21.00	-7.94	61	80.11	24.84	102	123.12	34.66
21	22.05	-4.23	62	81.13	23.27	103	125.05	35.11
22	23.02	-0.13	63	82.05	23.07	104	126.09	38.91
23	24.05	0.79	64	83.11	21.11	105	127.12	36.48
24	28.03	-5.99	65	84.15	20.22	106	128.10	36.22
25	32.05	5.81	66	85.14	19.39	107	129.07	37.54
26	36.01	-6.09	67	86.09	21.18	108	130.12	37.53
27	40.75	2.99	68	87.13	22.45	109	131.14	31.59
28	41.02	5.81	69	88.09	22.88	110	132.12	31.40
29	43.04	8.35	70	89.15	26.30	111	133.12	35.25
30	43.98	5.63	71	90.09	22.95	112	134.41	38.17
31	45.04	3.51	72	91.07	18.50	113	135.68	37.97
32	46.03	4.62	73	92.09	18.70	114	136.55	36.91
33	47.04	5.75	74	93.07	19.55	115	137.11	40.11
34	48.03	7.23	75	95.12	19.22	116	138.11	42.17
35	49.02	9.97	76	96.08	19.81	117	139.09	40.96
36	52.03	15.52	77	97.10	20.44	118	140.06	41.70
37	53.01	16.05	78	98.09	28.84	119	141.12	42.16
38	55.01	9.01	79	99.07	21.64	120	142.15	42.16
39	55.99	13.27	80	100.07	24.47	121	143..11	42.17
40	57.02	13.40	81	101.07	24.47			
41	57.99	12.92	82	102.06	26.23			

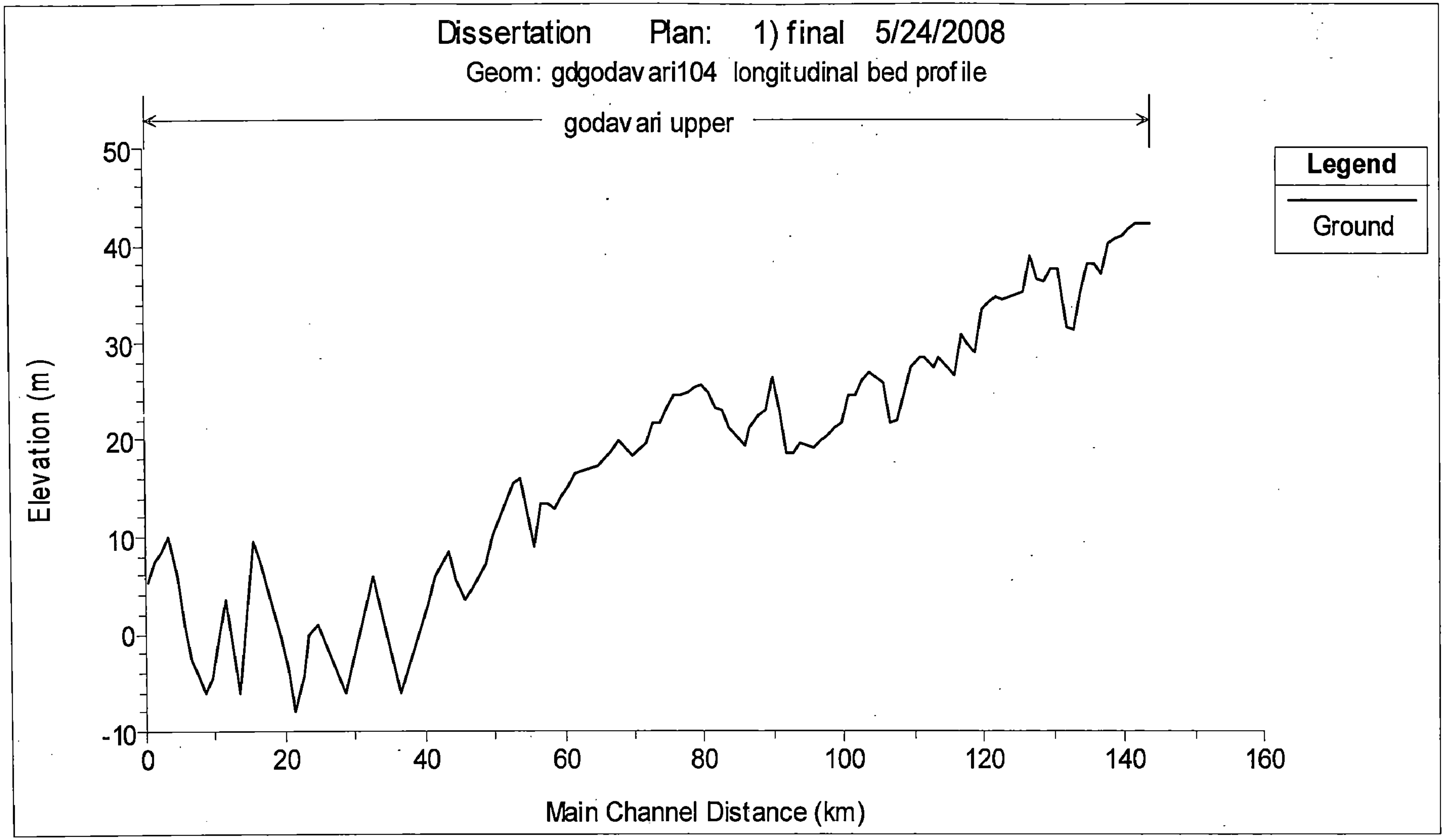


Fig. 5.3 Longitudinal bed profile of Godavari River in study area

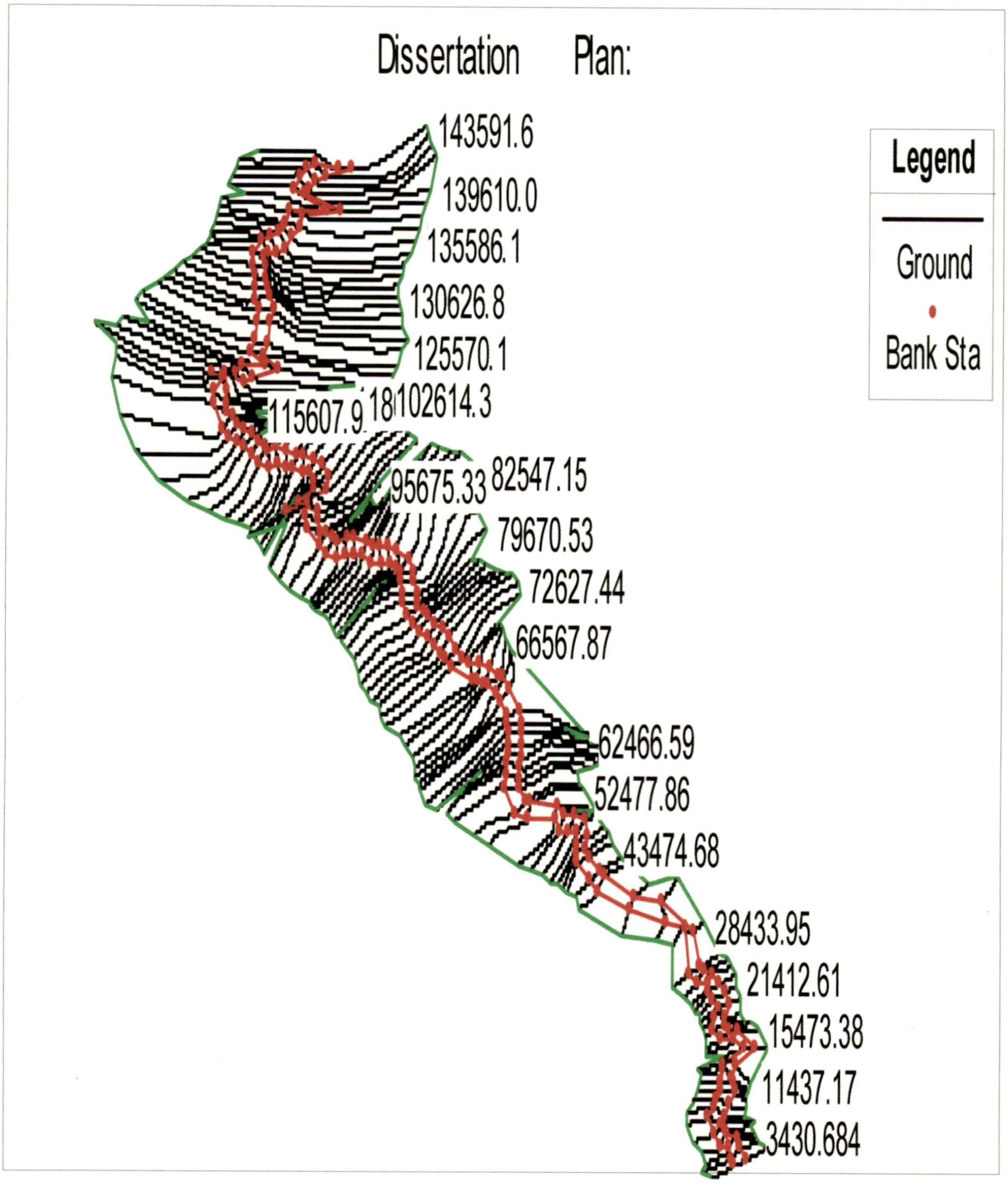


Fig. 5.4 X-Y-Z Perspective plot of cross sections of Godavari River for the study area

5.5 PERFORMANCE EVALUATION

Since there was not the actual representation of cross-sections in deepest bed level due to presence of water all the cross sections are computed and modified as per the available observed l-section and three cross-sections. All these computed cross-sections should be near the best fit of the actually observed cross-sections. There are number of methods for checking the extent of match between computed and observed data. For example, Root Mean Square Error Method, Nash Sutcliffe Co-efficient Method etc. Here we have used Nash Sutcliffe Co-efficient method.

The **Nash-Sutcliffe model efficiency coefficient** is used to assess the predictive power of hydrological models. It is defined as:

$$E = 1 - \frac{\sum_{1}^{N}(Y_0 - Y_p)^2}{\sum_{1}^{N}(Y_0 - \overline{Y_0})^2}$$

where Y_0 = Observed Deepest Level, Y_p = Predicted or computed deepest level.

The Nash-Sutcliffe efficiencies can range from -∞ to 1. An efficiency of 1 (*E*=1) corresponds to a perfect match of modeled bed levels (computed) to the observed data. An efficiency of 0 (*E*=0) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero (-∞<*E*<0) occurs when the observed mean is a better predictor than the model. Essentially, the closer the model efficiency is to 1, the more accurate the model is. It should be noted that Nash-Sutcliffe efficiencies can also be used to quantitatively describe the accuracy of model outputs other than bed levels. This method can be used to describe the predictive accuracy of other models as long as there is observed data to compare the model results. For example, Nash-Sutcliffe efficiencies have been reported in scientific literature for model simulations of discharge, and water quality constituents such as sediment, nitrogen, and phosphorus loadings. The validation of the prediction of bed profile has been observed to be quite encouraging when measured with Nash-Sutcliffe (E) coefficients. Since the only two sets of the data pattern were available for the validation of the predicted values of the designed parameter the correlation between the observed and predicted data for the total reach is found to be close to unity. Hence, the Nash-Sutcliffe coefficient is used as the measure of the goodness of fit.

The computed cross-sections are compared with the available observed limited number of cross-sections. All the cross sections downstream of 44.42 Km are compared with observed cross-section at Koida (40.75 Km), cross-sections upstream of 44.42 Km up to 119.59 Km are compared with the observed cross-section at Bhadrachalam (118.63 Km) and rest cross-sections up to 143.11 Km are compared with the observed cross-section at Dummagudem (143.115Km) based on similar bed profile features of the available limited cross-sections. Table 5.3 shows the validity test of computed cross-sections with actually observed limited cross-sections using Nash-Sutcliffe Co-efficient. Nash-Sutcliffe Co-efficient (E) for Koida, Bhadrachlam and Dummagudem came to be 0.61, 0.71 and 0.47 respectively. The overall value of the N. S. Co-efficient varies in the range from 0.35 to 0.86 and thus giving more or less a less than satisfactory to satisfactory representation of the observed cross-sections.

Table 5.4 Testing the Validity of Computed Cross-Sections with Observed Limited Cross–Section

SL. NO.	RIVER STATION IN (KM)	COMPARISON OF CROSS-SECTIONS AT KM		NASH-SUTCLIFFE COEFFICIENT
		OBSERVED C/S	COMPUTED C/S	
		KOIDA		
1	0.465	40.75	0.465	0.64
2	1.43	40.75	1.43	0.53
3	2.44	40.75	2.44	0.63
4	3.43	40.75	3.43	0.86
5	4.41	40.75	4.41	0.73
6	5.48	40.75	5.48	0.44
7	6.46	40.75	6.46	0.35
8	7.45	40.75	7.45	0.37
9	8.42	40.75	8.42	0.49
10	9.42	40.75	9.42	0.66
11	10.46	40.75	10.46	0.71
12	11.44	40.75	11.44	0.62
13	13.46	40.75	13.46	0.37
14	15.47	40.75	15.47	0.38
15	16.45	40.75	16.45	0.87
16	17.46	40.75	17.46	0.44
17	18.45	40.75	18.45	0.49
18	19.43	40.75	19.43	0.39
19	20.43	40.75	20.43	0.57
20	21.41	40.75	21.41	0.35
21	22.69	40.75	22.69	0.49
22	23.42	40.75	23.42	0.81
23	24.44	40.75	24.44	0.47
24	28.43	40.75	28.43	0.32
25	32.49	40.75	32.49	0.55
26	36.44	40.75	36.44	0.56
27	**40.75**	**40.75**	**40.45**	**0.61**
28	41.45	40.75	41.45	0.66
29	43.47	40.75	43.47	0.73

SL. NO.	RIVER STATION IN (KM)	COMPARISON OF CROSS-SECTIONS AT KM		NASH-SUTCLIFFE COEFFICIENT
		OBSERVED C/S	COMPUTED C/S	
BHADRACHALAM				
30	44.42	118.685	44.42	0.52
31	45.47	118.685	45.47	0.55
32	46.46	118.685	46.46	0.35
33	47.47	118.685	47.47	0.68
34	48.47	118.685	48.47	0.59
35	49.47	118.685	49.47	0.36
36	52.48	118.685	52.48	0.44
37	53.44	118.685	53.44	0.39
38	55.46	118.685	55.46	0.35
39	56.44	118.685	56.44	0.41
40	57.46	118.685	57.46	0.35
41	58.44	118.685	58.44	0.65
42	59.49	118.685	59.49	0.40
43	60.46	118.685	60.46	0.37
44	61.43	118.685	61.43	0.43
45	62.47	118.685	62.47	0.73
46	64.65	118.685	64.65	0.66
47	65.63	118.685	65.63	0.78
48	66.57	118.685	66.57	0.39
49	67.59	118.685	67.59	0.81
50	68.64	118.685	68.64	0.77
51	69.68	118.685	69.68	0.59
52	71.60	118.685	71.60	0.37
53	72.63	118.685	72.63	0.61
54	73.64	118.685	73.64	0.76
55	74.61	118.685	74.61	0.41
56	75.58	118.685	75.58	0.49
57	76.64	118.685	76.64	0.35
58	77.62	118.685	77.62	0.39
59	78.62	118.685	78.62	0.37
60	79.67	118.685	79.67	0.48
61	80.60	118.685	80.60	0.84
62	81.62	118.685	81.62	0.73

SL. NO.	RIVER STATION IN (KM)	COMPARISON OF CROSS-SECTIONS		NASH-SUTCLIFFE COEFFICIENT
		OBSERVED C/S	COMPUTED C/S	
BHADRACHALAM				
63	82.55	118.685	82.55	0.58
64	83.61	118.685	83.61	0.61
65	84.67	118.685	84.67	0.73
66	85.67	118.685	85.67	0.39
67	86.62	118.685	86.62	0.42
68	87.65	118.685	87.65	0.44
69	88.62	118.685	88.62	0.38
70	89.69	118.685	89.69	0.59
71	90.64	118.685	90.64	0.63
72	91.61	118.685	91.61	0.77
73	92.63	118.685	92.63	0.51
74	93.61	118.685	93.61	0.54
75	95.67	118.685	95.67	0.75
76	96.63	118.685	96.63	0.62
77	97.66	118.685	97.66	0.44
78	98.65	118.685	98.65	0.35
79	99.63	118.685	99.63	0.38
80	100.61	118.685	100.61	0.81
81	101.61	118.685	101.61	0.71
82	102.61	118.685	102.61	0.74
83	103.61	118.685	103.61	0.79
84	104.61	118.685	104.61	0.43
85	105.68	118.685	105.68	0.82
86	106.66	118.685	106.66	0.35
87	107.62	118.685	107.62	0.37
88	108.59	118.685	108.59	0.35
89	109.62	118.685	109.62	0.83
90	110.64	118.685	110.64	0.76
91	111.60	118.685	111.60	0.47
92	112.64	118.685	112.64	0.39
93	113.57	118.685	113.57	0.37
94	115.61	118.685	115.61	0.39
95	116.60	118.685	116.60	0.38

SL. NO.	RIVER STATION IN (KM)	COMPARISON OF CROSS-SECTIONS		NASH-SUTCLIFFE COEFFICIENT
		OBSERVED C/S	COMPUTED C/S	
96	117.65	118.685	117.65	0.43
97	**118.68**	**118.685**	**118.68**	**0.71**
		DUMMAGUDEM		
98	119.59	143.59	119.59	0.37
99	120.61	143.59	120.61	0.39
100	121.65	143.59	121.65	0.74
101	122.6	143.59	122.6	0.39
102	123.64	143.59	123.64	0.36
103	125.57	143.59	125.57	0.36
104	126.61	143.59	126.61	0.46
105	127.63	143.59	127.63	0.36
106	128.61	143.59	128.61	0.37
107	129.58	143.59	129.58	0.51
108	130.63	143.59	130.63	0.39
109	131.64	143.59	131.64	0.44
110	132.66	143.59	132.66	0.68
111	133.64	143.59	133.64	0.36
112	134.67	143.59	134.67	0.41
113	135.59	143.59	135.59	0.41
114	137.62	143.59	137.62	0.39
115	138.62	143.59	138.62	0.47
116	139.61	143.59	139.61	0.35
117	140.58	143.59	140.58	0.38
118	141.65	143.59	141.65	0.41
119	142.67	143.59	142.67	0.38
120	**143.11**	**143.115**	**143.11**	**0.47**

A graphical representation of comparison of computed cross-sections at 40.75 Km, 118.68Km and 143.11Km as sample with observed cross-sections at Koida, Bhadrachalam and Dummagudem have been shown in Figs. 5.3 - 5.4 together with their cross-sections data in Tables 5.4 – 5.6 respectively.

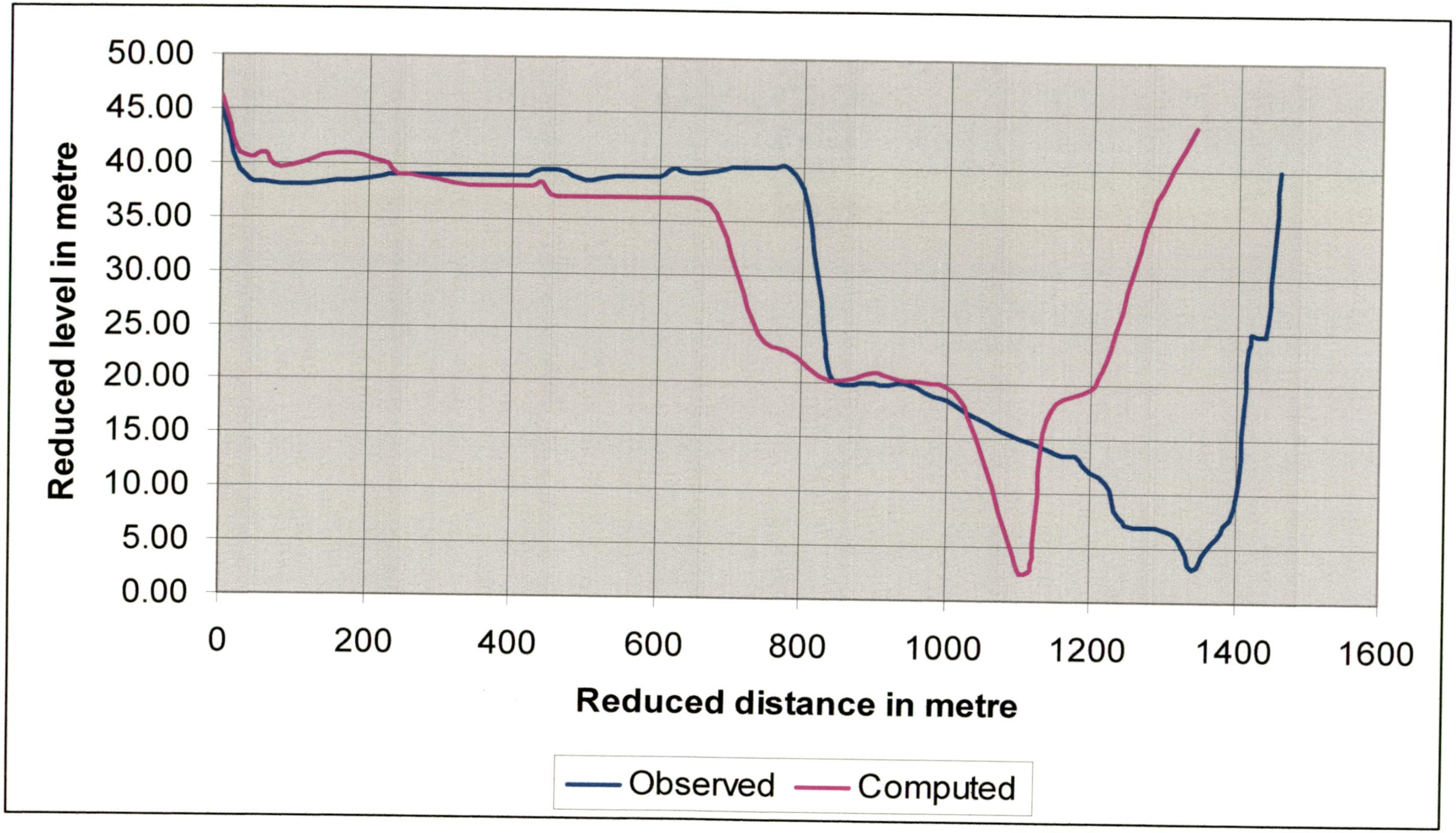


Fig. 5.5 Computed and observed cross-section at Koida

Table 5.5 Comparison of cross-section at Koida of Godavari River

OBSERVED CROSS-SECTION			OBSERVED CROSS-SECTION		
SL. NO.	DISTANCE (METER)	ELEVATION (METER)	SL. NO.	DISTANCE (METER)	ELEVATION (METER)
1	0	45.00	55	1080	15.60
2	20	40.00	56	1100	15.00
3	40	38.50	57	1120	14.60
4	60	38.20	58	1140	14.00
5	80	38.00	59	1160	13.60
6	100	38.00	60	1180	13.60
7	120	38.10	61	1200	12.00
8	140	38.20	62	1220	11.00
9	160	38.40	63	1240	8.00
10	180	38.50	64	1260	7.00
11	200	38.60	65	1280	7.00
12	220	38.80	66	1300	6.80
13	240	39.00	67	1320	6.00
14	260	39.00	68	1340	3.00
15	280	39.00	69.	1360	4.90
16	300	39.00	70	1380	6.50
17	320	39.00	71	1400	10.00
18	340	39.00	72	1420	24.80
19	360	39.00	73	1440	25.00
20	380	39.00	74	1460	40.00
21	400	39.00	COMPUETD CROSS-SECTION		
22	420	39.00	SL. NO.	DISTANCE (METER)	ELEVATION (METER)
23	440	39.50	1	0	46.20
24	460	39.50	2	20	41.36
25	480	39.00	3	40	40.56
26	500	38.60	4	60	41.00
27	520	38.80	5	80	39.60
28	540	39.00	6	160	41.00
29	560	39.00	7	220	40.11
30	580	39.00	8	240	38.90
31	600	39.00	9	260	39.00
32	620	39.80	10	340	38.00
33	640	39.40	11	420	38.00
34	660	39.40	12	440	38.50
35	680	39.60	13	460	37.00
36	700	40.00	14	540	37.00
37	720	40.00	15	600	37.12
38	740	40.00	16	620	37.09
39	760	40.00	17	640	37.08
40	780	40.00	18	680	35.8
41	800	38.00	19	740	24.56
42	820	30.00	20	780	22.93
43	840	20.80	21	840	20.27
44	860	19.80	22	900	21.00
45	880	20.00	23	920	20.71
46	900	20.00	24	940	20.22
47	920	19.90	25	1020	18.60
48	940	20.00	26	1100	2.99
49	960	19.60	27	1120	2.99
50	980	19.00	28	1140	17.03
51	1000	18.60	29	1200	19.76
52	1020	17.80	30	1220	22.31
53	1040	17.00	31	1280	35.87
54	1060	16.50	32	1340	44.10

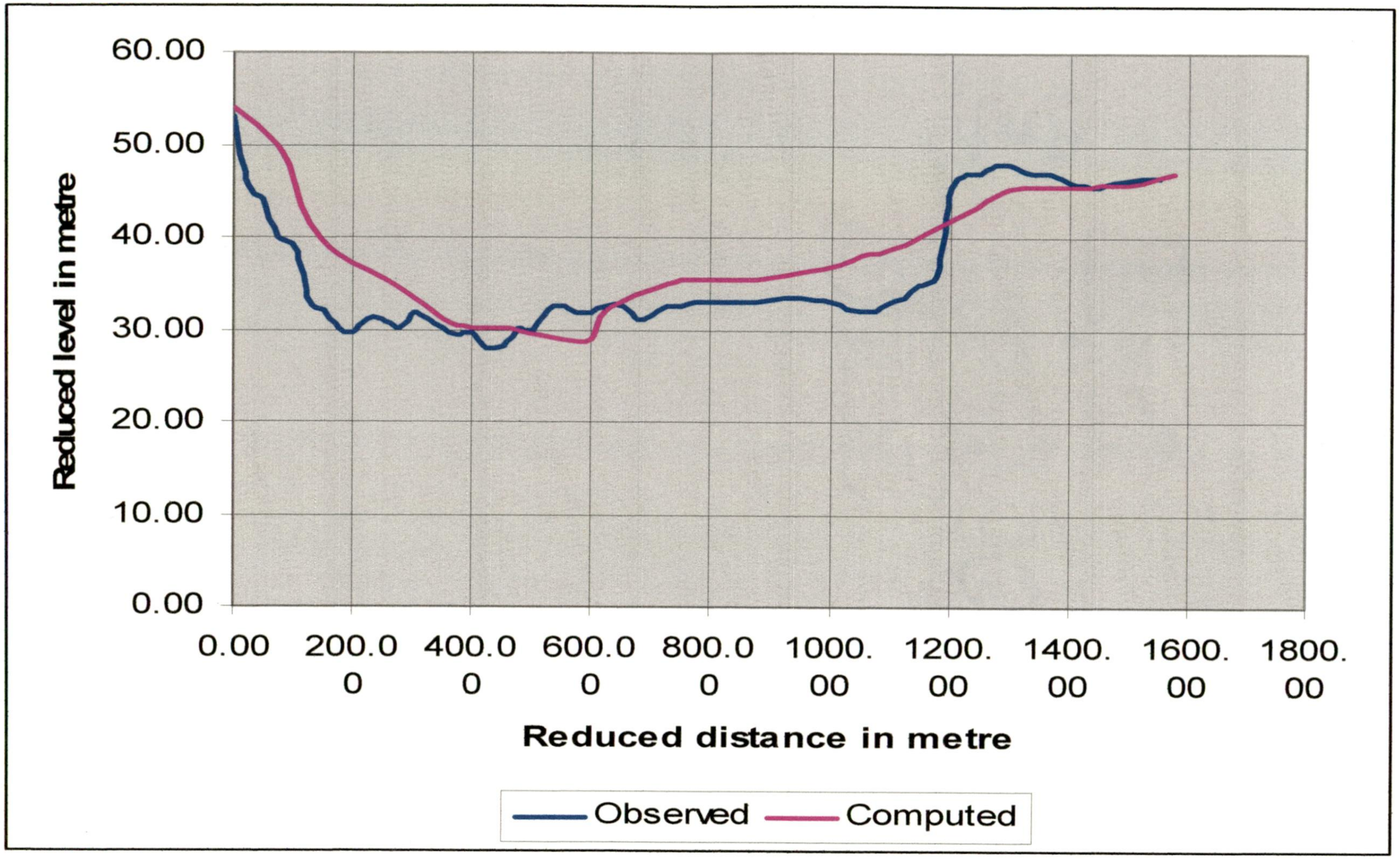


Fig. 5.6 Computed and observed cross-section at Bhadrachalam

Table 5.6 Comparison of cross-section at Bhadrachalam of Godavari River

OBSERVED CROSS-SECTION			OBSERVED CROSS-SECTION		
SL. NO.	DISTANCE (METER)	ELEVATION (METER)	SL. NO.	DISTANCE (METER)	ELEVATION (METER)
1	0	53.00	49	1200	45.60
2	25	45.50	50	1225	46.90
3	50	44.00	51	1250	47.10
4	75	40.00	52	1275	48.00
5	100	38.90	53	1300	48.00
6	125	33.00	54	1325	47.20
7	150	32.00	55	1350	47.00
8	175	30.00	56	1375	46.80
9	200	29.60	57	1400	46.00
10	225	31.00	58	1425	45.80
11	250	31.00	59	1450	45.50
12	275	30.00	60	1475	46.00
13	300	31.80	61	1500	46.20
14	325	31.00	62	1525	46.40
15	350	30.00	63	1550	46.60
16	375	29.50	COMPUETD CROSS-SECTION		
17	400	29.70	SL. NO.	DISTANCE (METER)	ELEVATION (METER)
18	425	28.00	1	0	54.00
19	450	28.30	2	75	49.80
20	475	30.20	3	100	48.66
21	500	29.90	4	125	46.36
22	525	32.00	5	175	42.19
23	550	32.60	6	275	38.49
24	575	31.80	7	350	38.69
25	600	31.80	8	375	37.49
26	625	32.60	9	425	36.83
27	650	32.60	10	450	36.08
28	675	31.00	11	475	36.12
29	700	31.50	12	550	28.84
30	725	32.50	13	600	28.95
31	750	32.60	14	625	37.00
32	775	33.00	15	725	37.00
33	800	33.00	16	750	37.35
34	825	33.00	17	825	40.61
35	850	33.00	18	875	40.81
36	875	33.10	19	925	39.85
37	900	33.20	20	1000	41.82
38	925	33.40	21	1025	41.75
39	950	33.50	22	1050	42.83
40	975	33.30	23	1125	44.17
41	1000	33.00	24	1275	44.67
42	1025	32.20	25	1300	44.54
43	1050	32.10	26	1325	43.48
44	1075	32.00	27	1350	43.00
45	1100	33.00	28	1400	43.41
46	1125	33.50	29	1475	45.74
47	1150	35.00	30	1525	46.06
48	1175	36.00	31	1575	47.00

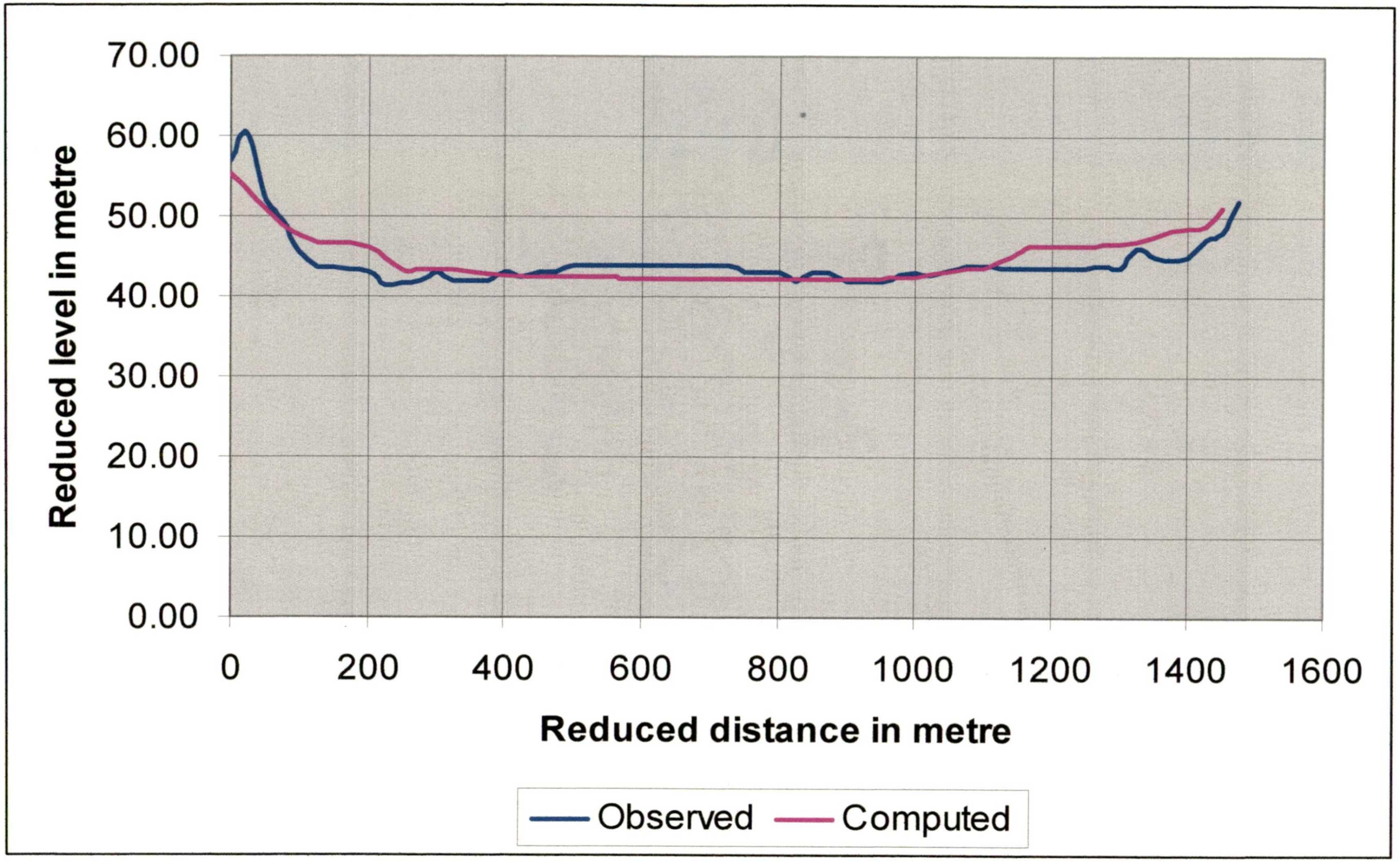


Fig. 5.7 Computed and observed cross-section at Dummagudem

Table 5.7 Comparison of cross-section at Dummagudem of Godavari River

OBSERVED CROSS-SECTION			OBSERVED CROSS-SECTION		
SL. NO.	DISTANCE (METER)	ELEVATION (METER)	SL. NO.	DISTANCE (METER)	ELEVATION (METER)
1	0	57.00	50	1225	43.50
2	25	60.20	51	1250	43.60
3	50	51.90	52	1275	43.80
4	75	49.40	53	1300	43.60
5	100	45.60	54	1325	46.00
6	125	43.70	55	1350	45.10
7	150	43.50	56	1375	44.80
8	175	43.30	57	1400	45.00
9	200	43.00	58	1425	47.30
10	225	41.50	59	1450	48.00
11	250	41.70	60	1475	52.00
12	275	42.00	COMPUETD CROSS-SECTION		
13	300	43.00	SL. NO.	DISTANCE (METER)	ELEVATION (METER)
14	325	42.00	1	0	51.20
15	350	42.00	2	75	48.90
16	375	42.00	3	125	46.80
17	400	43.00	4	150	46.80
18	425	42.40	5	200	46.20
19	450	43.00	6	250	43.25
20	475	43.00	7	275	43.20
21	500	44.00	8	325	43.20
22	525	44.00	9	375	42.90
23	550	44.00	10	425	42.60
24	575	44.00	11	475	42.50
25	600	44.00	12	500	42.40
26	625	44.00	13	550	42.40
27	650	44.00	14	575	42.19
28	675	44.00	15	650	42.18
29	700	44.00	16	675	42.18
30	725	44.00	17	725	42.18
31	750	43.00	18	750	42.17
32	775	43.00	19	825	42.19
33	800	43.00	20	850	42.19
34	825	42.00	21	900	42.19
35	850	43.00	22	925	42.22
36	875	43.00	23	950	42.26
37	900	42.00	24	975	42.40
38	925	42.00	25	1000	42.40
39	952	42.00	26	1075	43.50
40	975	42.90	27	1100	43.50
41	1000	43.00	28	1150	45.60
42	1025	42.80	29	1175	46.30
43	1050	43.30	30	1250	46.30
44	1075	43.90	31	1275	46.80
45	1100	43.80	32	1325	46.90
46	1125	43.70	33	1375	48.20
47	1150	43.60	34	1425	49.00
48	1175	43.60	35	1450	51.11
49	1200	43.50			

CHAPTER 6

RESULTS AND DISCSSION

Using the detailed instructions available for setting up of HEC-RAS model (HEC-RAS Version 4.0), the model is setup for Database of Godavari river project's study area discussed in chapters 4 & 5. In the following paragraphs details for setting-up of model, sensitivity analysis and discussion are presented.

6.1 HEC-RAS MODEL SETUP

All the required map themes such as stream centre line, flow path centre line(optional), main channel banks(optional) and cross-section cut lines, levees and database sets are prepared as discussed in chapter 5.The Geometric data are imported in GIS format for further analysis.

6.2 HYDRAULIC ANALYSIS

To compute the water surface profile for the development and display of Flood Inundation Map hydraulic analysis is performed. Hydraulic analysis requires geometric data and steady flow data.

6.2.1 GEOMETRIC DATA

In geometric data 121 cross-sections upstream of proposed dam site have been studied for simulation. Manning's roughness co-efficient, expansion co-efficient, contraction co-efficient along with the coordinates (elevation and station) of the cross section points constitutes the geometric data. As per the project of Mekh Nath Sharma M. tech. WRD 49^{TH} batch 2005, the roughness co-efficient of 0.04 for the left and right over bank and 0.035 for the main channel have been taken. Similarly expansion and contraction co-efficients of 0.3 and 0.1 respectively have been used in simulation.

6.2.2 STEADY FLOW DATA

In the present study three flood discharges viz. 50, 100 and 500 years return period discharge (Chapter 5) have been taken for study of Flood Inundation Mapping. These are:

Q_{50} = 70795Cumec

Q_{100} = 78892Cumec

Q_{500} = 97604Cumec

The hydraulic computation starts from the downstream boundary towards the upstream boundary of the study reach. Here we provide downstream boundary condition as spillway rating curve. The length of spillway is given as 830m in the "Cross-section and bore well details of Dam site" in the project report. The normal reservoir level is taken as 45.72m (150ft) which is to be cleared by Central Water Commission as expeditiously as possible. The spillway discharge rating curve is given by:

$$Q = C_d * (L - 0.20 H) * H^{3/2}$$

where C_d = coefficient of discharge that depends on the following factors:

(i) Depth of approach,

(ii) Relation of the actual crest shape to the ideal nappe shape,

(iii)Upstream face slope,

(iv)Downstream apron interface and,

(v) Downstream submergence.

The maximum coefficient of discharge is 2.21 if not affected by the other hydraulic parameters like submergence, velocity of approach etc. Therefore taking Cd = 2.21, and L = 830m

$$Q = 2.21 * (830 - 0.2 * H) * H^{3/2}$$

This gives the relationship between Q and H which can be used as spillway rating curve (Downstream boundary condition) as given below

Discharge (cumec)	H in metre (NRL + h1)
0	45.72
100	45.864
500	46.14
1500	46.594
2000	46.779
2500	46.949
4500	47.539
6000	47.924
10000	48.819
20000	50.641
35000	52.869
70000	57.076
100000	60.131

6.2.3 STEADY FLOW ANALYSIS

Using the above data, the water surface profiles are determined. The detailed profile output table and corresponding waters surface profiles are given in tables using all the geometric and steady flow data the program is executed for all three profiles which finally produces the water surface profiles. The water surface profiles and their corresponding detailed profile output tables are given in Figs. 6.1-6.3 and Tables 6.1-6.3 respectively.

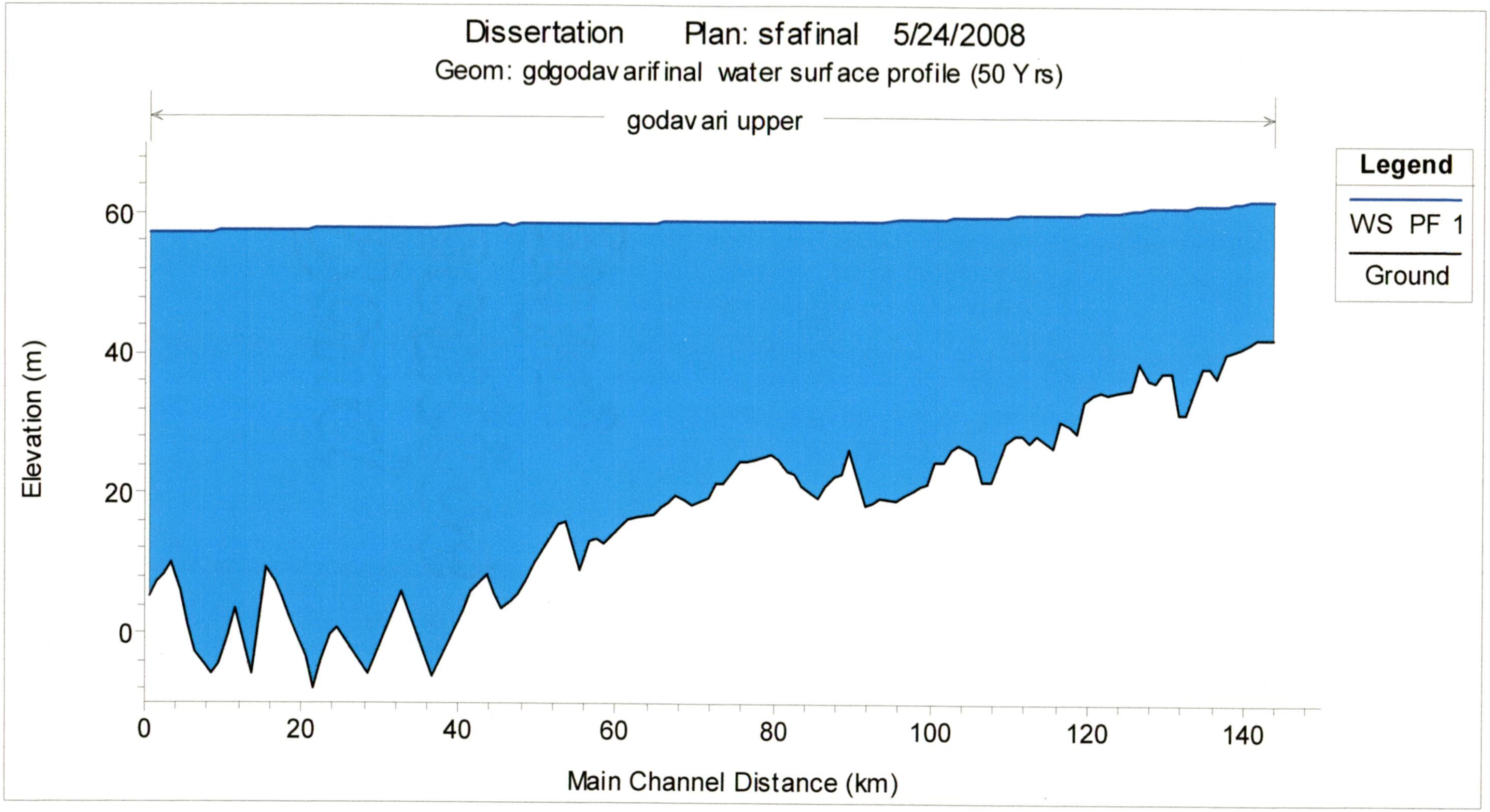


Fig. 6.1 Water Surface Profile of 50 Yrs. Return Period Flood

Table 6.1 Water Surface Profile Output Table for 50 Yrs. Return Period Flood

River Sta	Profile	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
143110.6	50 Yrs	70795	42.17	62.21	62.45	0.00014	2.33	40450.42	5675.99	0.18
142670.8	50 Yrs	70795	42.16	62.14	62.31	0.00011	2.03	50682.75	8408.62	0.15
141653.2	50 Yrs	70795	42.16	61.98	62.18	0.00014	2.21	45968.8	7010.72	0.17
140583.8	50 Yrs	70795	41.7	61.88	62.05	0.00010	1.98	46335.87	5633.77	0.15
139610	50 Yrs	70795	40.96	61.76	61.94	0.00012	2.12	45216.3	5522.53	0.16
138622.1	50 Yrs	70795	40.55	61.55	61.8	0.00016	2.36	36841.21	3826.01	0.18
137624	50 Yrs	70795	40.11	61.42	61.64	0.00014	2.28	41261.62	5602.22	0.17
136570.6	50 Yrs	70795	36.91	61.37	61.51	0.00008	1.86	54506.07	7154.42	0.13
135586.1	50 Yrs	70795	37.97	61.31	61.44	0.00007	1.76	58248.13	7187.24	0.12
134673.1	50 Yrs	70795	38.17	61.28	61.37	0.00005	1.52	70403.01	9092.16	0.11
133642.9	50 Yrs	70795	35.25	61.19	61.31	0.00006	1.69	56596.21	6806.75	0.12
132660.6	50 Yrs	70795	31.4	61.11	61.25	0.00007	1.82	52820.42	6881.08	0.12
131641.6	50 Yrs	70795	31.59	61.03	61.18	0.00009	1.91	53480.95	7510.28	0.14
130626.8	50 Yrs	70795	37.53	61.02	61.09	0.00006	1.51	75082.07	10569.38	0.11
129578	50 Yrs	70795	37.54	60.96	61.03	0.00005	1.52	77831.62	10794.23	0.11
128611.5	50 Yrs	70795	36.22	60.88	60.97	0.00006	1.62	66814.56	8556.57	0.11
127628.9	50 Yrs	70795	36.48	60.82	60.92	0.00006	1.61	64734.51	7634.68	0.11
126611.1	50 Yrs	70795	38.91	60.78	60.85	0.00005	1.4	68807.16	6110.84	0.11
125570.1	50 Yrs	70795	35.11	60.65	60.78	0.00008	1.79	49459.98	5413.66	0.13
123638.4	50 Yrs	70795	34.66	60.41	60.6	0.00010	2.07	44151.63	5166.25	0.15
122604	50 Yrs	70795	34.36	60.29	60.49	0.00011	2.13	43010.59	5041.38	0.16
121651.4	50 Yrs	70795	34.59	60.34	60.39	0.00003	1.24	84611.85	8955.84	0.09
120613.9	50 Yrs	70795	34.2	60.26	60.35	0.00006	1.54	72104.58	9686.63	0.11
119592.6	50 Yrs	70795	33.39	60.26	60.3	0.00003	1.14	96983.82	9507.36	0.08
118680.1	50 Yrs	70795	28.84	60.08	60.24	0.00010	1.97	47713.78	6001.63	0.14
117651.7	50 Yrs	70795	29.71	60.04	60.15	0.00006	1.69	57820.43	7331.48	0.12
116595.9	50 Yrs	70795	30.65	60	60.08	0.00005	1.47	69488.7	9482.42	0.1
115607.9	50 Yrs	70795	26.61	60	60.04	0.00002	1.09	102277.8	10059.64	0.07
113576.4	50 Yrs	70795	28.47	59.97	60	0.00002	0.85	122295.5	10611.96	0.06
112640.4	50 Yrs	70795	27.39	59.92	59.98	0.00003	1.23	94197.1	12339.67	0.08
111602.8	50 Yrs	70795	28.56	59.85	59.94	0.00004	1.52	63818.17	5260.27	0.1
110645.8	50 Yrs	70795	28.38	59.85	59.89	0.00002	1.13	94594.41	9348.4	0.08
109620	50 Yrs	70795	27.4	59.77	59.86	0.00003	1.44	64500.51	5229.6	0.09
108593.1	50 Yrs	70795	24.53	59.75	59.82	0.00003	1.33	69591.49	4529.04	0.08
107624.3	50 Yrs	70795	21.84	59.75	59.8	0.00002	1.15	87033.54	6506.21	0.07
106661.1	50 Yrs	70795	21.72	59.67	59.76	0.00004	1.5	63121.08	5489.35	0.1
105681.3	50 Yrs	70795	25.75	59.57	59.71	0.00006	1.79	50205.56	4952.27	0.12
104611.3	50 Yrs	70795	26.29	59.53	59.64	0.00005	1.63	59404.38	5773.39	0.11
103606.8	50 Yrs	70795	26.92	59.48	59.59	0.00005	1.59	58872.31	5329.25	0.11
102614.3	50 Yrs	70795	26.23	59.46	59.54	0.00004	1.46	68510.78	6197.63	0.1
101614.4	50 Yrs	70795	24.47	59.41	59.49	0.00004	1.49	67163.05	6430.42	0.1
100611.4	50 Yrs	70795	24.47	59.4	59.45	0.00003	1.19	89802.79	8403.61	0.08
99626.55	50 Yrs	70795	21.64	59.29	59.4	0.00006	1.65	53871.16	4358.82	0.12
98653.43	50 Yrs	70795	21.04	59.24	59.34	0.00006	1.58	62164.59	6862.81	0.11
97660.4	50 Yrs	70795	20.44	59.18	59.28	0.00006	1.62	63611.13	7606.99	0.12
96635.14	50 Yrs	70795	19.81	59.2	59.23	0.00002	1.06	110380.5	12898.7	0.07
95675.33	50 Yrs	70795	19.22	59.2	59.21	0.00001	0.75	155089	13619.69	0.05
93610.99	50 Yrs	70795	19.55	59.07	59.17	0.00005	1.59	62501.63	6123.82	0.11
92632.39	50 Yrs	70795	18.7	59.06	59.12	0.00003	1.26	78622.28	6720.98	0.09
91610.36	50 Yrs	70795	18.5	59.06	59.09	0.00002	0.94	113740.1	9003.45	0.06
90637.52	50 Yrs	70795	22.95	59.04	59.07	0.00002	1	102204.8	8500.53	0.07
89691.11	50 Yrs	70795	26.3	59.02	59.05	0.00002	0.98	100742.1	8611.06	0.07
88624.52	50 Yrs	70795	22.88	59	59.03	0.00001	0.94	116909.4	9568.29	0.06
87653.28	50 Yrs	70795	22.45	58.97	59.01	0.00002	1.11	94456.25	8759.39	0.07
86624.56	50 Yrs	70795	21.18	58.97	58.99	0.00002	0.92	113023.7	9327.31	0.06
85673.69	50 Yrs	70795	19.39	58.96	58.98	0.00001	0.83	141263.7	14254.57	0.05
84672.95	50 Yrs	70795	20.22	58.95	58.97	0.00001	0.64	167747.7	11881.97	0.04
83606.27	50 Yrs	70795	21.11	58.93	58.95	0.00001	0.85	130687.8	11185.75	0.05

River Sta	Profile	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
82547.15	50 Yrs	70795	23.07	58.91	58.94	0.00002	0.99	107060.9	8165.78	0.06
81621.99	50 Yrs	70795	23.27	58.89	58.92	0.00002	1.05	100169.7	9037.53	0.07
80601.74	50 Yrs	70795	24.84	58.85	58.9	0.00002	1.14	82888.7	5928.74	0.07
79670.53	50 Yrs	70795	25.6	58.84	58.88	0.00002	1.08	91223.58	6918.61	0.07
78623.9	50 Yrs	70795	25.25	58.82	58.87	0.00002	1.07	99936.46	8730.23	0.06
77617.42	50 Yrs	70795	24.93	58.83	58.85	0.00001	0.75	145284.8	10200.19	0.05
76643.37	50 Yrs	70795	24.63	58.82	58.84	0.00001	0.77	136554.6	9401.23	0.05
75587.15	50 Yrs	70795	24.57	58.82	58.83	0.00001	0.68	157235.1	10387.06	0.04
74610.04	50 Yrs	70795	23.26	58.81	58.82	0.00001	0.73	156355.4	11719.47	0.04
73641.34	50 Yrs	70795	21.67	58.8	58.82	0.00001	0.66	175555.3	12980.16	0.04
72627.44	50 Yrs	70795	21.67	58.8	58.81	0.00001	0.7	162713.2	11713.75	0.04
71604.56	50 Yrs	70795	19.58	58.78	58.8	0.00001	0.86	120832	8657.74	0.05
69681.33	50 Yrs	70795	18.3	58.76	58.79	0.00001	0.86	124404.3	9191.14	0.05
68639.97	50 Yrs	70795	19.15	58.76	58.78	0.00001	0.71	168214.7	12662.28	0.04
67587.65	50 Yrs	70795	19.76	58.75	58.77	0.00001	0.81	129735	8983.66	0.05
66567.87	50 Yrs	70795	18.86	58.75	58.76	0.00001	0.68	172097.3	12934.25	0.04
65630.24	50 Yrs	70795	18.03	58.75	58.75	0.00000	0.51	231858.7	16224.54	0.03
64648.94	50 Yrs	70795	17.16	58.74	58.75	0.00000	0.47	229161.4	13180.26	0.03
62466.59	50 Yrs	70795	16.68	58.73	58.74	0.00000	0.55	205760.5	14342.76	0.03
61433.35	50 Yrs	70795	16.39	58.73	58.74	0.00000	0.52	213874.7	13426.98	0.03
60457.13	50 Yrs	70795	15.26	58.73	58.74	0.00000	0.55	203142.6	12331.97	0.03
59490.47	50 Yrs	70795	14.13	58.72	58.73	0.00000	0.63	164937.4	8563.94	0.03
58440.84	50 Yrs	70795	12.92	58.7	58.73	0.00001	0.76	119509.3	5290.24	0.04
57464.92	50 Yrs	70795	13.4	58.7	58.72	0.00001	0.66	154716.6	9031.59	0.04
56444.54	50 Yrs	70795	13.27	58.67	58.71	0.00001	0.98	104889	6923.78	0.06
55456.8	50 Yrs	70795	9.01	58.65	58.69	0.00001	1.01	89174.65	4489.1	0.05
53445.18	50 Yrs	70795	16.05	58.54	58.65	0.00003	1.52	50045.96	2323.16	0.09
52477.86	50 Yrs	70795	15.52	58.55	58.61	0.00002	1.25	68390.87	3761.54	0.07
49470.09	50 Yrs	70795	9.97	58.55	58.56	0.00001	0.74	135402.9	7421.9	0.04
48466.75	50 Yrs	70795	7.23	58.51	58.55	0.00001	0.99	84724.84	3432.71	0.05
47473.31	50 Yrs	70795	5.75	58.45	58.54	0.00002	1.33	56622.03	2236.92	0.07
46459.41	50 Yrs	70795	4.62	58.37	58.5	0.00004	1.61	44856.56	1888.87	0.1
45468.78	50 Yrs	70795	3.51	58.41	58.46	0.00001	1.04	83399.98	3892.23	0.06
44420.23	50 Yrs	70795	5.63	58.34	58.43	0.00003	1.44	53687.98	2199.2	0.09
43474.68	50 Yrs	70795	8.35	58.29	58.4	0.00003	1.49	47830.42	1621.58	0.09
41455.85	50 Yrs	70795	5.81	58.27	58.34	0.00002	1.22	64318.7	2480.64	0.07
40750.81	50 Yrs	70795	2.99	58.13	58.3	0.00005	1.84	38751.81	1539.18	0.11
36436.82	50 Yrs	70795	-6.09	58	58.13	0.00003	1.59	45022.93	1518.82	0.09
32488.61	50 Yrs	70795	5.81	57.94	58.01	0.00002	1.24	63494.95	2477.61	0.07
28433.95	50 Yrs	70795	-5.99	57.83	57.93	0.00002	1.37	52515.35	1624.56	0.07
24437.75	50 Yrs	70795	0.79	57.8	57.85	0.00001	1.08	77499.58	2881.13	0.06
23425.59	50 Yrs	70795	-0.13	57.8	57.84	0.00001	0.94	90983.45	3545.52	0.05
22468.17	50 Yrs	70795	-4.23	57.8	57.83	0.00001	0.89	98840.61	4122.29	0.05
21412.61	50 Yrs	70795	-7.94	57.77	57.82	0.00001	1.04	78140.28	2650.86	0.05
20433.19	50 Yrs	70795	-3.39	57.67	57.79	0.00003	1.57	45305.04	1432.54	0.09
19428.69	50 Yrs	70795	-0.39	57.66	57.76	0.00002	1.41	50616.14	1442.81	0.07
18455.88	50 Yrs	70795	2.17	57.65	57.74	0.00002	1.33	56317.21	2010.93	0.07
17463.76	50 Yrs	70795	4.77	57.59	57.71	0.00003	1.56	46645.6	1623.78	0.09
16447.4	50 Yrs	70795	7.42	57.6	57.67	0.00002	1.26	64444.09	2590.83	0.07
15473.38	50 Yrs	70795	9.56	57.43	57.62	0.00007	1.98	37810.23	1731.94	0.13
13466.13	50 Yrs	70795	-5.99	57.43	57.53	0.00002	1.39	51860.84	1622.34	0.08
11437.17	50 Yrs	70795	3.49	57.44	57.48	0.00001	1.01	80419.36	3120.24	0.06
10464.47	50 Yrs	70795	-0.4	57.41	57.47	0.00001	1.1	74320.64	3016.89	0.06
9419.675	50 Yrs	70795	-4.54	57.39	57.45	0.00001	1.14	70199.37	2473.93	0.06
8420.585	50 Yrs	70795	-5.99	57.33	57.43	0.00002	1.4	51701.07	1621.79	0.08
7455.965	50 Yrs	70795	-4.39	57.36	57.4	0.00001	1.02	82747.5	3124.13	0.05
6462.75	50 Yrs	70795	-2.77	57.36	57.38	0.00001	0.9	106296.5	4973.46	0.05
5487.018	50 Yrs	70795	0.98	57.35	57.38	0.00001	0.78	115458.1	4558.22	0.04
4413.234	50 Yrs	70795	5.82	57.35	57.37	0.00001	0.72	121325.3	4383.79	0.04
3430.684	50 Yrs	70795	9.94	57.33	57.36	0.00001	0.89	92710.07	3448.82	0.05
2443.8	50 Yrs	70795	8.5	57.3:	57.35	0.00001	1.03	80064.86	3384.68	0.06
1430.336	50 Yrs	70795	7.48	57.23	57.33	0.00002	1.39	53872.43	1899.72	0.08
465.512	50 Yrs	70795	5.23	57.16	57.29	0.00004	1.64	43601.48	1520.39	0.1

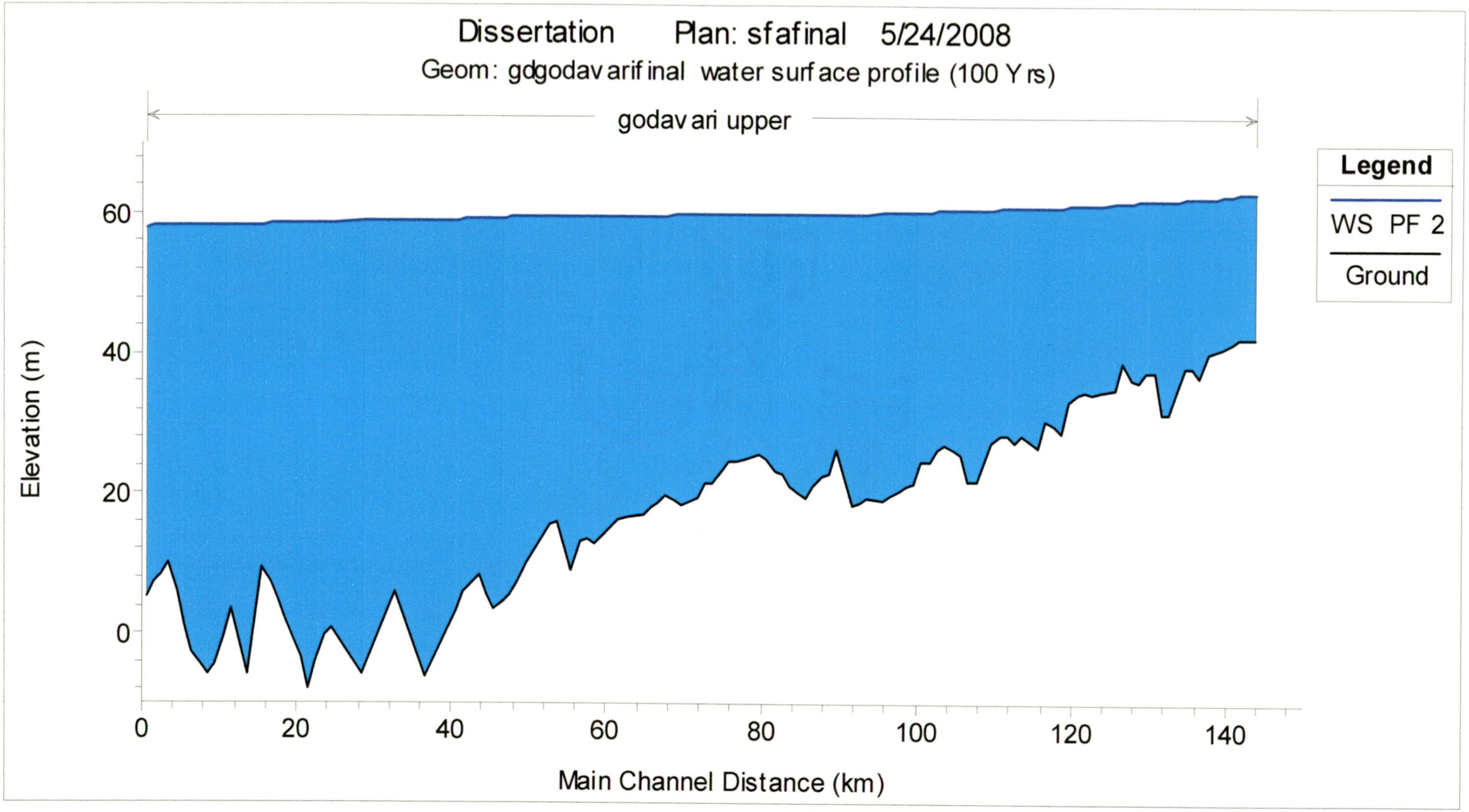


Fig. 6.2 Water Surface Profile of 100 Yrs. Return Period flood

Table 6.2 Water Surface Profile Output Table for 100 Yrs. Return Period Flood

River Sta	Profile	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
143591.6	100 Yrs	78892	42.17	63.15	63.39	0.00014	2.36	46004.02	6060.6	0.17
142670.8	100 Yrs	78892	42.16	63.1	63.26	0.00010	2.01	58951.36	8848.82	0.15
141653.2	100 Yrs	78892	42.16	62.95	63.14	0.00013	2.19	53001.35	7522.72	0.17
140583.8	100 Yrs	78892	41.7	62.85	63.02	0.00010	2.03	51999.42	6028.16	0.15
139610	100 Yrs	78892	40.96	62.73	62.92	0.00011	2.14	50711.65	5700.87	0.16
138622.1	100 Yrs	78892	40.55	62.53	62.78	0.00016	2.41	40688.88	4051.94	0.18
137624	100 Yrs	78892	40.11	62.41	62.63	0.00013	2.3	47032.23	6196.59	0.17
136570.6	100 Yrs	78892	36.91	62.36	62.5	0.00007	1.87	61777.87	7468.14	0.13
135586.1	100 Yrs	78892	37.97	62.31	62.43	0.00007	1.78	65629.67	7634.25	0.12
134673.1	100 Yrs	78892	38.17	62.28	62.37	0.00005	1.52	79805.17	9790.74	0.1
133642.9	100 Yrs	78892	35.25	62.18	62.31	0.00006	1.77	63787.76	7783.59	0.12
132660.6	100 Yrs	78892	31.4	62.1	62.25	0.00007	1.86	60066.62	7649.72	0.12
131641.6	100 Yrs	78892	31.59	62.03	62.18	0.00008	1.91	61274.99	8032.3	0.13
130626.8	100 Yrs	78892	37.53	62.02	62.09	0.00005	1.52	86181.71	11574.71	0.11
129578	100 Yrs	78892	37.54	61.97	62.04	0.00005	1.51	89242.7	11671.97	0.11
128611.5	100 Yrs	78892	36.22	61.89	61.99	0.00005	1.62	75852.8	9351.34	0.11
127628.9	100 Yrs	78892	36.48	61.84	61.94	0.00005	1.64	72669.75	8080.06	0.11
126611.1	100 Yrs	78892	38.91	61.8	61.87	0.00005	1.42	75025.1	6152.48	0.1
125570.1	100 Yrs	78892	35.11	61.67	61.8	0.00008	1.84	55187.47	5949.5	0.13
123638.4	100 Yrs	78892	34.66	61.42	61.62	0.00010	2.12	49673.46	5899.36	0.15
122604	100 Yrs	78892	34.36	61.31	61.51	0.00011	2.16	48494.48	5648.14	0.15
121651.4	100 Yrs	78892	34.59	61.36	61.41	0.00003	1.27	94237.78	9810.83	0.09
120613.9	100 Yrs	78892	34.2	61.29	61.37	0.00005	1.53	82554.23	10461	0.11
119592.6	100 Yrs	78892	33.39	61.29	61.33	0.00003	1.16	106930.9	9697.28	0.08
118634.1	100 Yrs	78892	28.84	61.11	61.28	0.00009	1.99	54334.1	6917.1	0.14
117651.7	100 Yrs	78892	29.71	61.07	61.19	0.00006	1.76	66295.35	8777.81	0.12
116595.9	100 Yrs	78892	30.65	61.03	61.12	0.00004	1.49	80294.83	11236.57	0.1
115607.9	100 Yrs	78892	26.61	61.03	61.08	0.00002	1.11	112840	10542.75	0.07
113576.4	100 Yrs	78892	28.47	61.01	61.03	0.00002	0.87	133675.2	11490.52	0.06
112640.4	100 Yrs	78892	27.39	60.96	61.01	0.00002	1.23	107472.1	13042.35	0.08
111602.8	100 Yrs	78892	28.56	60.88	60.98	0.00004	1.57	69279.05	5280.98	0.1
110645.8	100 Yrs	78892	28.38	60.89	60.93	0.00002	1.15	104629.5	9871.88	0.07
109620	100 Yrs	78892	27.4	60.8	60.9	0.00004	1.5	69945.97	5310.95	0.09
108593.1	100 Yrs	78892	24.53	60.78	60.86	0.00003	1.39	74277.84	4551.18	0.08
107624.3	100 Yrs	78892	21.84	60.78	60.83	0.00002	1.19	93774.79	6533.43	0.07
106661.1	100 Yrs	78892	21.72	60.7	60.8	0.00004	1.55	68878.67	5661.02	0.1
105681.3	100 Yrs	78892	25.75	60.59	60.75	0.00006	1.86	55641	5592.33	0.12
104611.3	100 Yrs	78892	26.29	60.56	60.67	0.00005	1.68	65425.25	5922.96	0.11
103606.8	100 Yrs	78892	26.92	60.51	60.62	0.00005	1.64	64479.55	5557.63	0.11
102614.3	100 Yrs	78892	26.23	60.49	60.57	0.00004	1.49	74978.91	6356.43	0.1
101614.4	100 Yrs	78892	24.47	60.44	60.53	0.00004	1.52	73831.96	6520.3	0.1
100611.4	100 Yrs	78892	24.47	60.43	60.48	0.00003	1.21	98588.59	8541.4	0.08
99626.55	100 Yrs	78892	21.64	60.32	60.44	0.00006	1.71	58562.95	4874.22	0.12
98653.43	100 Yrs	78892	21.04	60.28	60.38	0.00005	1.62	69566.75	7567.87	0.11
97660.4	100 Yrs	78892	20.44	60.22	60.32	0.00006	1.62	71811.79	8207.98	0.11
96635.14	100 Yrs	78892	19.81	60.23	60.27	0.00002	1.07	124012.2	13360.58	0.07
95675.33	100 Yrs	78892	19.22	60.23	60.25	0.00001	0.77	169344	13873.17	0.05
93610.99	100 Yrs	78892	19.55	60.11	60.21	0.00005	1.62	69071.3	6521.72	0.11
92632.39	100 Yrs	78892	18.7	60.1	60.16	0.00003	1.29	85715.77	6891.97	0.09
91610.36	100 Yrs	78892	18.5	60.1	60.13	0.00002	0.97	123168.8	9134.11	0.06
90637.52	100 Yrs	78892	22.95	60.08	60.11	0.00002	1.03	111128.4	8638.94	0.07
89691.11	100 Yrs	78892	26.3	60.06	60.09	0.00002	1.01	109934.8	9047.38	0.07
88624.52	100 Yrs	78892	22.88	60.04	60.07	0.00001	0.96	126905.7	9655.96	0.06
87653.28	100 Yrs	78892	22.45	60.01	60.06	0.00002	1.17	104142.2	9526.43	0.07
86624.56	100 Yrs	78892	21.18	60.01	60.03	0.00002	0.94	122844.3	9549.19	0.06
85673.69	100 Yrs	78892	19.39	60	60.02	0.00001	0.83	156293.2	14625.45	0.05
84672.95	100 Yrs	78892	20.22	59.99	60.01	0.00001	0.66	180178.5	12045.54	0.04
83606.27	100 Yrs	78892	21.11	59.97	59.99	0.00001	0.87	142624.6	11781.07	0.05

River Sta	Profile	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
82547.15	100 Yrs	78892	23.07	59.95	59.98	0.00002	1.02	115595.3	8271.08	0.06
81621.99	100 Yrs	78892	23.27	59.92	59.96	0.00002	1.09	109779.2	9502.01	0.07
80601.74	100 Yrs	78892	24.84	59.89	59.94	0.00002	1.19	89131.07	6117.99	0.07
79670.53	100 Yrs	78892	25.6	59.87	59.92	0.00002	1.16	98517.11	7186.58	0.07
78623.9	100 Yrs	78892	25.25	59.86	59.9	0.00002	1.1	109101.7	9055.26	0.07
77617.42	100 Yrs	78892	24.93	59.87	59.88	0.00001	0.78	155901.5	10307.38	0.05
76643.37	100 Yrs	78892	24.63	59.85	59.88	0.00001	0.82	146601	9947.58	0.05
75587.15	100 Yrs	78892	24.57	59.85	59.87	0.00001	0.71	168046.3	10528.29	0.04
74610.04	100 Yrs	78892	23.26	59.84	59.86	0.00001	0.76	168670.8	12008.7	0.04
73641.34	100 Yrs	78892	21.67	59.84	59.85	0.00001	0.7	189350	13708.03	0.04
72627.44	100 Yrs	78892	21.67	59.83	59.85	0.00001	0.74	175214.6	12345.87	0.04
71604.56	100 Yrs	78892	19.58	59.81	59.84	0.00001	0.9	129973.8	9055.71	0.05
69681.33	100 Yrs	78892	18.3	59.79	59.82	0.00001	0.9	134301.8	9954.9	0.05
68639.97	100 Yrs	78892	19.15	59.79	59.81	0.00001	0.74	181422.3	12935.8	0.04
67587.65	100 Yrs	78892	19.76	59.78	59.8	0.00001	0.84	139227	9446.02	0.05
66567.87	100 Yrs	78892	18.86	59.78	59.79	0.00001	0.7	185548.5	13169.27	0.04
65630.24	100 Yrs	78892	18.03	59.78	59.78	0.00000	0.53	248626.7	16291.81	0.03
64648.94	100 Yrs	78892	17.16	59.77	59.78	0.00000	0.49	243119.1	13990.3	0.03
62466.59	100 Yrs	78892	16.68	59.77	59.77	0.00000	0.57	220711.1	14694	0.03
61433.35	100 Yrs	78892	16.39	59.76	59.77	0.00000	0.54	227744.4	13491.16	0.03
60457.13	100 Yrs	78892	15.26	59.76	59.77	0.00000	0.58	216084.2	12760.93	0.03
59490.47	100 Yrs	78892	14.13	59.75	59.76	0.00001	0.66	173764.9	8589.39	0.04
58440.84	100 Yrs	78892	12.92	59.73	59.76	0.00001	0.81	125073.8	5679.3	0.04
57464.92	100 Yrs	78892	13.4	59.73	59.75	0.00001	0.69	164007.8	9045.5	0.04
56444.54	100 Yrs	78892	13.27	59.7	59.74	0.00001	1.02	112035.4	7007.07	0.06
55456.8	100 Yrs	78892	9.01	59.67	59.72	0.00001	1.09	93800.81	4560.53	0.06
53445.18	100 Yrs	78892	16.05	59.55	59.67	0.00004	1.63	52415.38	2384.29	0.1
52477.86	100 Yrs	78892	15.52	59.56	59.63	0.00002	1.32	72249.05	3875.93	0.08
49470.09	100 Yrs	78892	9.97	59.56	59.58	0.00001	0.78	142959.2	7495.48	0.04
48466.75	100 Yrs	78892	7.23	59.52	59.57	0.00001	1.07	88195.2	3464.77	0.06
47473.31	100 Yrs	78892	5.75	59.44	59.55	0.00002	1.43	58912.36	2354.33	0.08
46459.41	100 Yrs	78892	4.62	59.36	59.51	0.00004	1.73	46733.27	1914.43	0.1
45468.78	100 Yrs	78892	3.51	59.41	59.46	0.00002	1.11	87302	3954.22	0.06
44420.23	100 Yrs	78892	5.63	59.32	59.43	0.00003	1.54	55859.3	2214.41	0.09
43474.68	100 Yrs	78892	8.35	59.26	59.4	0.00003	1.61	49415.91	1629.28	0.09
41455.85	100 Yrs	78892	5.81	59.25	59.33	0.00002	1.31	66744.53	2489.88	0.07
40448.81	100 Yrs	78892	2.99	59.09	59.28	0.00006	1.97	40228.88	1554.5	0.12
36436.82	100 Yrs	78892	-6.09	58.94	59.09	0.00004	1.71	46453.37	1524.29	0.1
32488.61	100 Yrs	78892	5.81	58.88	58.96	0.00002	1.33	65818.52	2486.36	0.08
28433.95	100 Yrs	78892	-5.99	58.75	58.87	0.00002	1.49	54013.51	1639.16	0.08
24437.75	100 Yrs	78892	0.79	58.72	58.78	0.00001	1.16	80147.39	2887.3	0.06
23425.59	100 Yrs	78892	-0.13	58.72	58.76	0.00001	1.02	94257.16	3585.25	0.05
22468.17	100 Yrs	78892	-4.23	58.72	58.75	0.00001	0.95	102634.9	4142.47	0.05
21412.61	100 Yrs	78892	-7.94	58.68	58.74	0.00001	1.13	80565.01	2660.02	0.06
20433.19	100 Yrs	78892	-3.39	58.56	58.71	0.00003	1.7	46588.96	1434.73	0.09
19428.69	100 Yrs	78892	-0.39	58.55	58.67	0.00002	1.54	51908.89	1447.26	0.08
18455.88	100 Yrs	78892	2.17	58.55	58.65	0.00002	1.45	58128.05	2038.05	0.08
17463.76	100 Yrs	78892	4.77	58.47	58.62	0.00004	1.69	48085.17	1630.92	0.1
16447.4	100 Yrs	78892	7.42	58.49	58.57	0.00002	1.36	66750.55	2599.88	0.08
15473.38	100 Yrs	78892	9.56	58.3	58.52	0.00007	2.13	39315.58	1747.73	0.13
13466.13	100 Yrs	78892	-5.99	58.29	58.41	0.00002	1.51	53265.3	1627.11	0.08
11437.17	100 Yrs	78892	3.49	58.3	58.35	0.00001	1.09	83135.78	3141.99	0.06
10464.47	100 Yrs	78892	-0.4	58.28	58.34	0.00002	1.19	76946.5	3059.75	0.06
9419.675	100 Yrs	78892	-4.54	58.25	58.32	0.00002	1.23	72331.91	2480	0.06
8420.585	100 Yrs	78892	-5.99	58.18	58.3	0.00003	1.52	53081.7	1626.49	0.08
7455.965	100 Yrs	78892	-4.39	58.21	58.26	0.00001	1.1	85424.84	3135.16	0.06
6462.75	100 Yrs	78892	-2.77	58.21	58.25	0.00001	0.96	110564.7	4992.39	0.05
5487.018	100 Yrs	78892	0.98	58.21	58.23	0.00001	0.84	119366.8	4574.52	0.04
4413.234	100 Yrs	78892	5.82	58.2	58.23	0.00001	0.77	125080.6	4396.49	0.04
3430.684	100 Yrs	78892	9.94	58.18	58.22	0.00001	0.96	95657.69	3468.81	0.05
2443.8	100 Yrs	78892	8.5	58.15	58.2	0.00002	1.12	82959.47	3434.29	0.06
1430.336	100 Yrs	78892	7.48	58.07	58.18	0.00003	1.51	55464.66	1906.53	0.08
465.512	100 Yrs	78892	5.23	57.98	58.14	0.00004	1.78	44856.7	1524.22	0.1

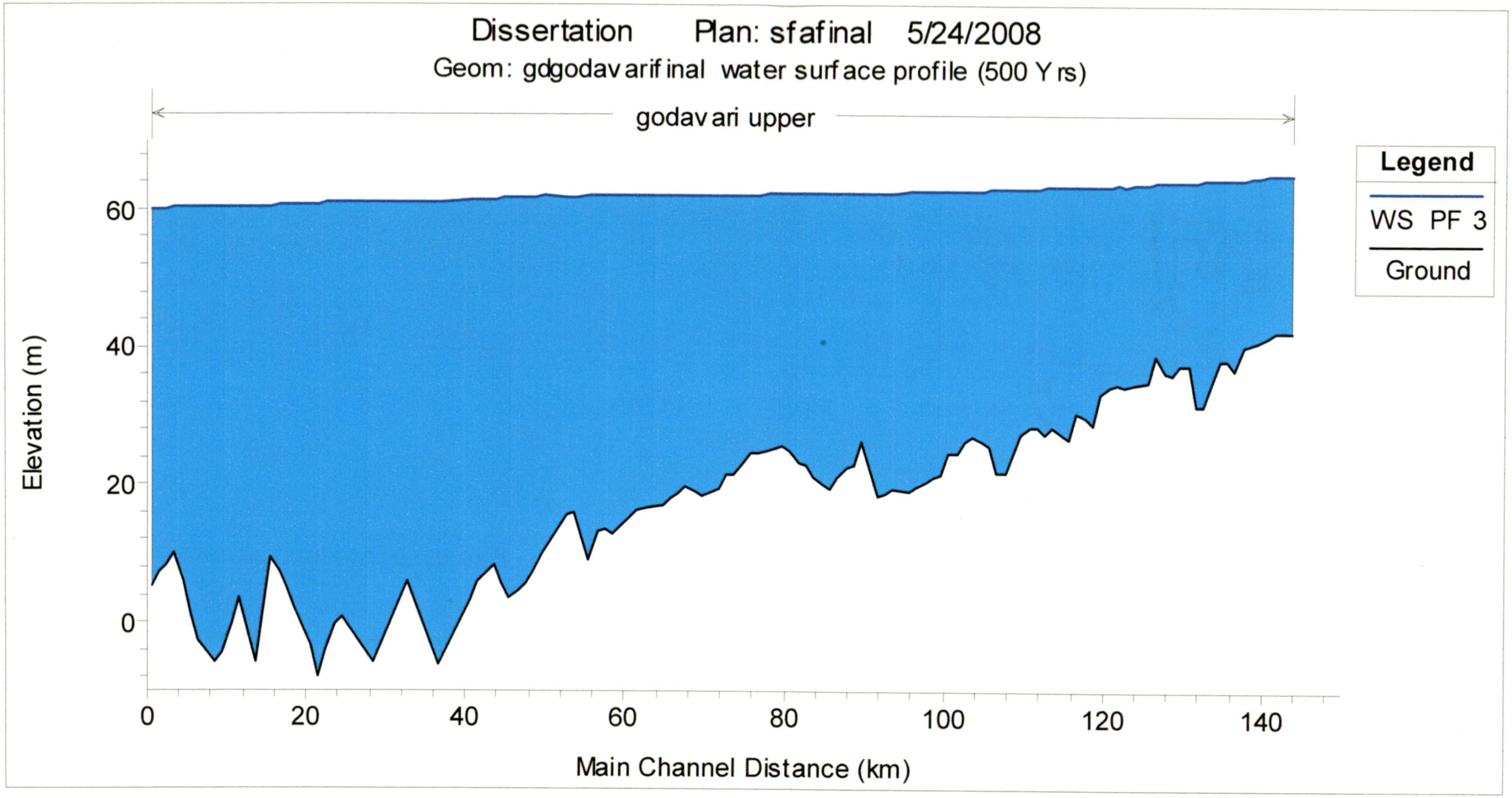


Fig. 6.3 Water Surface Profile of 500 Yrs. Return Period Flood

Table 6.3 Water Surface Profile Output Table for 500 Yrs. Return Period Flood

River Sta	Profile	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
143591.6	500 Yrs.	97604	42.17	65.25	65.47	0.00012	2.38	59678.3	7091.18	0.17
142670.8	500 Yrs.	97604	42.16	65.22	65.35	0.00008	1.97	78902.54	10085.06	0.14
141653.2	500 Yrs.	97604	42.16	65.09	65.26	0.00010	2.12	69729.59	7999.3	0.15
140583.8	500 Yrs.	97604	41.7	64.98	65.15	0.00009	2.07	66129.36	7067.01	0.14
139610	500 Yrs.	97604	40.96	64.88	65.06	0.00010	2.17	63384.95	6291.88	0.15
138622.1	500 Yrs.	97604	40.55	64.67	64.93	0.00014	2.5	50271.46	5106.49	0.18
137624	500 Yrs.	97604	40.11	64.59	64.79	0.00012	2.29	63020.56	8381.62	0.16
136570.6	500 Yrs.	97604	36.91	64.55	64.68	0.00007	1.88	79255.3	8616.59	0.12
135586.1	500 Yrs.	97604	37.97	64.5	64.61	0.00006	1.81	84527.73	9477.74	0.12
134673.1	500 Yrs.	97604	38.17	64.48	64.56	0.00004	1.51	102033.1	10499.58	0.1
133642.9	500 Yrs.	97604	35.25	64.38	64.51	0.00005	1.8	83006.8	9841.78	0.11
132660.6	500 Yrs.	97604	31.4	64.3	64.45	0.00006	1.92	78406.94	9074.67	0.12
131641.6	500 Yrs.	97604	31.59	64.26	64.38	0.00007	1.88	81709.84	10649.5	0.13
130626.8	500 Yrs.	97604	37.53	64.25	64.31	0.00004	1.49	114922	13832.79	0.1
129578	500 Yrs.	97604	37.54	64.21	64.27	0.00004	1.45	117221.2	13335.04	0.1
128611.5	500 Yrs.	97604	36.22	64.13	64.22	0.00005	1.64	98825.71	11523.55	0.11
127628.9	500 Yrs.	97604	36.48	64.08	64.18	0.00005	1.64	91696.97	8744.23	0.11
126611.1	500 Yrs.	97604	38.91	64.04	64.12	0.00005	1.47	89495.16	6811.3	0.1
125570.1	500 Yrs.	97604	35.11	63.89	64.05	0.00008	2.04	69321.24	6638.07	0.14
123638.4	500 Yrs.	97604	34.66	63.68	63.87	0.00009	2.16	65589.27	7590.38	0.14
122604	500 Yrs.	97604	34.36	63.59	63.78	0.00010	2.19	62645.36	7077.04	0.15
121651.4	500 Yrs.	97604	34.59	63.64	63.69	0.00003	1.3	118401.6	11562.92	0.08
120613.9	500 Yrs.	97604	34.2	63.58	63.65	0.00004	1.47	107387.3	11284.47	0.1
119592.6	500 Yrs.	97604	33.39	63.58	63.62	0.00002	1.17	130226.7	11036.84	0.08
118634.1	500 Yrs.	97604	28.84	63.42	63.57	0.00008	1.99	72251.45	8460.98	0.14
117651.7	500 Yrs.	97604	29.71	63.38	63.49	0.00006	1.78	88990.55	11042.28	0.12
116595.9	500 Yrs.	97604	30.65	63.35	63.43	0.00004	1.49	111482.8	15280.72	0.1
115607.9	500 Yrs.	97604	26.61	63.35	63.39	0.00002	1.12	138445.6	11369.08	0.07
113576.4	500 Yrs.	97604	28.47	63.33	63.35	0.00002	0.93	162455.9	13348.03	0.06
112640.4	500 Yrs.	97604	27.39	63.29	63.33	0.00002	1.21	138448	13655.86	0.07
111602.8	500 Yrs.	97604	28.56	63.2	63.3	0.00004	1.65	81564.27	5335.95	0.1
110645.8	500 Yrs.	97604	28.38	63.21	63.25	0.00002	1.18	128455.3	10467.26	0.07
109620	500 Yrs.	97604	27.4	63.12	63.22	0.00004	1.6	82482.66	5551.5	0.09
108593.1	500 Yrs.	97604	24.53	63.09	63.18	0.00003	1.51	84953.53	4693.44	0.09
107624.3	500 Yrs.	97604	21.84	63.09	63.15	0.00002	1.26	108962.1	6597.17	0.07
106661.1	500 Yrs.	97604	21.72	63.02	63.12	0.00004	1.64	82459.34	6077.04	0.1
105681.3	500 Yrs.	97604	25.75	62.9	63.06	0.00006	1.97	69459.87	6327.11	0.12
104611.3	500 Yrs.	97604	26.29	62.88	62.99	0.00005	1.74	79504.04	6219.89	0.11
103606.8	500 Yrs.	97604	26.92	62.83	62.94	0.00005	1.73	78288.98	6425.36	0.11
102614.3	500 Yrs.	97604	26.23	62.81	62.89	0.00004	1.54	90456.87	6960.61	0.1
101614.4	500 Yrs.	97604	24.47	62.76	62.85	0.00004	1.57	89347.47	6816.43	0.1
100611.4	500 Yrs.	97604	24.47	62.76	62.81	0.00002	1.23	118593.9	8724.91	0.08
99626.55	500 Yrs.	97604	21.64	62.64	62.77	0.00006	1.82	71540.46	6177.26	0.12
98653.43	500 Yrs.	97604	21.04	62.61	62.7	0.00005	1.64	89027.52	9164.77	0.11
97660.4	500 Yrs.	97604	20.44	62.56	62.65	0.00005	1.61	93654.37	10515.55	0.11
96635.14	500 Yrs.	97604	19.81	62.58	62.61	0.00002	1.06	156608.9	14413.36	0.07
95675.33	500 Yrs.	97604	19.22	62.57	62.59	0.00001	0.79	202531.8	14393.97	0.05
93610.99	500 Yrs.	97604	19.55	62.45	62.55	0.00005	1.67	85545.66	7307.22	0.11
92632.39	500 Yrs.	97604	18.7	62.45	62.51	0.00003	1.34	102179.7	7229.03	0.08
91610.36	500 Yrs.	97604	18.5	62.45	62.48	0.00002	1	144723.6	9244.57	0.06
90637.52	500 Yrs.	97604	22.95	62.43	62.46	0.00002	1.06	131802	9127.96	0.07
89691.11	500 Yrs.	97604	26.3	62.41	62.44	0.00002	1.04	132124	9803.78	0.07
88624.52	500 Yrs.	97604	22.88	62.39	62.42	0.00001	1.01	149860.1	9898.78	0.06
87653.28	500 Yrs.	97604	22.45	62.36	62.41	0.00002	1.21	128084.9	11010.25	0.07
86624.56	500 Yrs.	97604	21.18	62.36	62.39	0.00002	0.98	147020.9	10793.64	0.06
85673.69	500 Yrs.	97604	19.39	62.35	62.37	0.00001	0.83	192036.2	15708.13	0.05
84672.95	500 Yrs.	97604	20.22	62.35	62.36	0.00001	0.7	209029	12436.95	0.04
83606.27	500 Yrs.	97604	21.11	62.32	62.35	0.00001	0.9	172469.2	13396.01	0.05

River Sta	Profile	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
82547.15	500 Yrs.	97604	23.07	62.3	62.33	0.00002	1.07	135316.1	8469.56	0.06
81621.99	500 Yrs.	97604	23.27	62.28	62.32	0.00002	1.13	133415.1	10589.34	0.07
80601.74	500 Yrs.	97604	24.84	62.24	62.3	0.00002	1.28	105279.3	7828.69	0.08
79670.53	500 Yrs.	97604	25.6	62.22	62.27	0.00002	1.25	116969.4	8638.28	0.07
78623.9	500 Yrs.	97604	25.25	62.21	62.25	0.00002	1.15	131344.5	9865.01	0.07
77617.42	500 Yrs.	97604	24.93	62.22	62.24	0.00001	0.82	180319.2	10468.76	0.05
76643.37	500 Yrs.	97604	24.63	62.2	62.23	0.00001	0.88	170482.5	10574.07	0.05
75587.15	500 Yrs.	97604	24.57	62.2	62.22	0.00001	0.77	193182	10953.15	0.04
74610.04	500 Yrs.	97604	23.26	62.19	62.21	0.00001	0.8	197778.1	12749.45	0.04
73641.34	500 Yrs.	97604	21.67	62.19	62.2	0.00001	0.74	223015.3	14889.12	0.04
72627.44	500 Yrs.	97604	21.67	62.18	62.2	0.00001	0.78	206042.1	13694.95	0.04
71604.56	500 Yrs.	97604	19.58	62.15	62.19	0.00001	0.98	152354	10221.05	0.05
69681.33	500 Yrs.	97604	18.3	62.14	62.17	0.00001	0.96	159663.3	11637.4	0.05
68639.97	500 Yrs.	97604	19.15	62.14	62.16	0.00001	0.77	212495.9	13426.2	0.04
67587.65	500 Yrs.	97604	19.76	62.12	62.15	0.00001	0.91	162594.3	10390.6	0.05
66567.87	500 Yrs.	97604	18.86	62.12	62.14	0.00001	0.75	217184.7	13783.73	0.04
65630.24	500 Yrs.	97604	18.03	62.12	62.13	0.00000	0.56	287091	16528.29	0.03
64648.94	500 Yrs.	97604	17.16	62.12	62.13	0.00000	0.53	277704.4	15628.37	0.03
62466.59	500 Yrs.	97604	16.68	62.11	62.12	0.00000	0.62	256245.3	15503.48	0.03
61433.35	500 Yrs.	97604	16.39	62.11	62.12	0.00000	0.58	259629.5	13820.97	0.03
60457.13	500 Yrs.	97604	15.26	62.1	62.11	0.00000	0.63	246540.8	13167.85	0.03
59490.47	500 Yrs.	97604	14.13	62.09	62.11	0.00001	0.72	193954.2	8644.17	0.04
58440.84	500 Yrs.	97604	12.92	62.07	62.1	0.00001	0.91	138710.7	5948.18	0.05
57464.92	500 Yrs.	97604	13.4	62.07	62.09	0.00001	0.75	185211.1	9073.91	0.04
56444.54	500 Yrs.	97604	13.27	62.03	62.08	0.00001	1.11	128703.2	7407.42	0.06
55456.8	500 Yrs.	97604	9.01	62	62.06	0.00001	1.21	104502.5	4625.66	0.06
53445.18	500 Yrs.	97604	16.05	61.84	62.01	0.00004	1.84	58050.01	2521.42	0.1
52477.86	500 Yrs.	97604	15.52	61.86	61.95	0.00003	1.48	81484.56	4129.39	0.08
49470.09	500 Yrs.	97604	9.97	61.87	61.89	0.00001	0.85	160354.3	7559.94	0.05
48466.75	500 Yrs.	97604	7.23	61.82	61.88	0.00001	1.21	96254.18	3546.08	0.06
47473.31	500 Yrs.	97604	5.75	61.72	61.85	0.00003	1.65	64399.49	2467.9	0.08
46459.41	500 Yrs.	97604	4.62	61.62	61.81	0.00005	1.97	51189.88	2060.3	0.11
45468.78	500 Yrs.	97604	3.51	61.68	61.75	0.00002	1.26	96448.26	4089.86	0.07
44420.23	500 Yrs.	97604	5.63	61.57	61.71	0.00004	1.75	60881.52	2247.03	0.1
43474.68	500 Yrs.	97604	8.35	61.49	61.67	0.00004	1.86	53066.65	1642.92	0.1
41455.85	500 Yrs.	97604	5.81	61.48	61.59	0.00003	1.5	72330.41	2511.03	0.08
40448.81	500 Yrs.	97604	2.99	61.27	61.53	0.00007	2.26	43653.58	1577.12	0.13
36436.82	500 Yrs.	97604	-6.09	61.1	61.3	0.00004	1.98	49753.89	1536.84	0.11
32488.61	500 Yrs.	97604	5.81	61.03	61.13	0.00003	1.52	71189.12	2506.73	0.08
28433.95	500 Yrs.	97604	-5.99	60.87	61.02	0.00003	1.74	57549.4	1706.25	0.09
24437.75	500 Yrs.	97604	0.79	60.83	60.91	0.00002	1.33	86261.97	2901.51	0.07
23425.59	500 Yrs.	97604	-0.13	60.83	60.89	0.00001	1.17	101941.8	3683.42	0.06
22468.17	500 Yrs.	97604	-4.23	60.83	60.88	0.00001	1.08	111434.9	4174.83	0.06
21412.61	500 Yrs.	97604	-7.94	60.78	60.86	0.00002	1.31	86183.39	2692.86	0.07
20433.19	500 Yrs.	97604	-3.39	60.62	60.82	0.00004	1.98	49549.69	1439.77	0.11
19428.69	500 Yrs.	97604	-0.39	60.61	60.78	0.00003	1.8	54897.96	1457.5	0.09
18455.88	500 Yrs.	97604	2.17	60.6	60.74	0.00003	1.68	62389.01	2100.46	0.09
17463.76	500 Yrs.	97604	4.77	60.51	60.7	0.00004	1.95	51423.28	1645.67	0.11
16447.4	500 Yrs.	97604	7.42	60.54	60.64	0.00003	1.55	72095.29	2620.74	0.08
15473.38	500 Yrs.	97604	9.56	60.3	60.58	0.00009	2.43	42840.28	1784.15	0.15
13466.13	500 Yrs.	97604	-5.99	60.29	60.45	0.00003	1.77	56567.9	1687.89	0.09
11437.17	500 Yrs.	97604	3.49	60.31	60.37	0.00002	1.26	89495.64	3225.94	0.07
10464.47	500 Yrs.	97604	-0.4	60.27	60.35	0.00002	1.37	83150.99	3154.9	0.07
9419.675	500 Yrs.	97604	-4.54	60.24	60.33	0.00002	1.43	77276.4	2494.02	0.07
8420.585	500 Yrs.	97604	-5.99	60.14	60.3	0.00003	1.77	56323.79	1683.3	0.09
7455.965	500 Yrs.	97604	-4.39	60.19	60.25	0.00002	1.27	91647.02	3163.8	0.07
6462.75	500 Yrs.	97604	-2.77	60.19	60.23	0.00001	1.09	120486.2	5034.53	0.06
5487.018	500 Yrs.	97604	0.98	60.19	60.22	0.00001	0.97	128465.4	4637.53	0.05
4413.234	500 Yrs.	97604	5.82	60.18	60.21	0.00001	0.89	133793.6	4417.87	0.05
3430.684	500 Yrs.	97604	9.94	60.15	60.2	0.00001	1.11	102533.8	3514.99	0.06
2443.8	500 Yrs.	97604	8.5	60.11	60.18	0.00002	1.28	89792.56	3511.78	0.07
1430.336	500 Yrs.	97604	7.48	60	60.15	0.00003	1.75	59166.19	1922.27	0.09
465.512	500 Yrs.	97604	5.23	59.89	60.1	0.00005	2.07	47769.33	1532.8	0.12

6.3 PREPARATION OF FLOOD INUNDATION MAP

After performing steady flow analysis water surface profile data are exported from HEC-RAS to process into GIS data sets. HEC-GeoRAS is an ArcView GIS extension specifically designed to process geospatial data for use with the HEC-RAS. For importing HEC-RAS results into the GIS, the RAS-GIS export file is selected and the terrain TIN is used for flood plain delineation. The post-processing of RAS results creates GIS Themes for inundation analysis. All GIS Themes developed during RAS post-processing are based on the content of the RAS GIS Export data and the terrain TIN. The HEC-GeoRAS creates the preliminary data sets as follows:

- Stream network shape
- Cross-section cut-lines shape
- Bounding polygon shape for each water surface profile
- Main channel bank shape
- Velocity point shape for each water surface profile
- Storage area polygon shape

These datasets are created without user input for use in generating inundation and velocity data sets. First we created water surface TIN based on the water surface elevation at each cross-section and the bounding polygon data specified in the RAS GIS. Now floodplain delineation was performed by rasterization of water surface TIN. The floodplain is delineated where the water surface elevations are higher than the terrain elevation or the edge of the water surface grid was limited by the bounding polygon. Figs. 6.4-6.6 show floodplain with Terrain contours for different profiles. The used profiles are 50, 100 and 500 Yrs. return period floods. Since the Terrain Tin is very detailed hence it is not appropriate to use for a background. Because extremely large TIN data sets take much longer time to display on the screen, line themes (contours) of 10 meter intervals have been used for quick display. Figs. 6.7-6.9 show floodplain delineation in bounding polygon for different profiles. Bounding polygon shows the absolute boundaries of the flood plain. It limits the edge of the water surface to the end of the cross-sections, levees and bridges and culvert openings. Here it has been tried to capture the entire extent of flood plain through wide enough and closely spaced cross-sections. Fig. 6.10-6.12 show water depth grid for different profiles. The floodplain delineation procedure converts the water surface TIN and Terrain TIN to grids with the same cell size and origin. This results in creation of depth grid where it finds water surface grid higher than the terrain grid. The depth grid is finally converted to the floodplain polygon. Using the depth grid with a color gradient allows us to quickly identify the areas flooded to greater (or lesser) depths which can be seen through legends of these figures. The water depths at various locations in an interesting area can be found easily.

In brief, the area likely to be inundated due to different floods is given in Table 6.4

Table 6.4 Area Inundated due to Various Floods

RETURN PERIODS	DISCHARGE IN CUMEC	AREA INUNDATED IN SQ. KM.
50 YRS.	70795	10.8
100 YRS.	78892	11.65
500 YRS.	97604	13.69

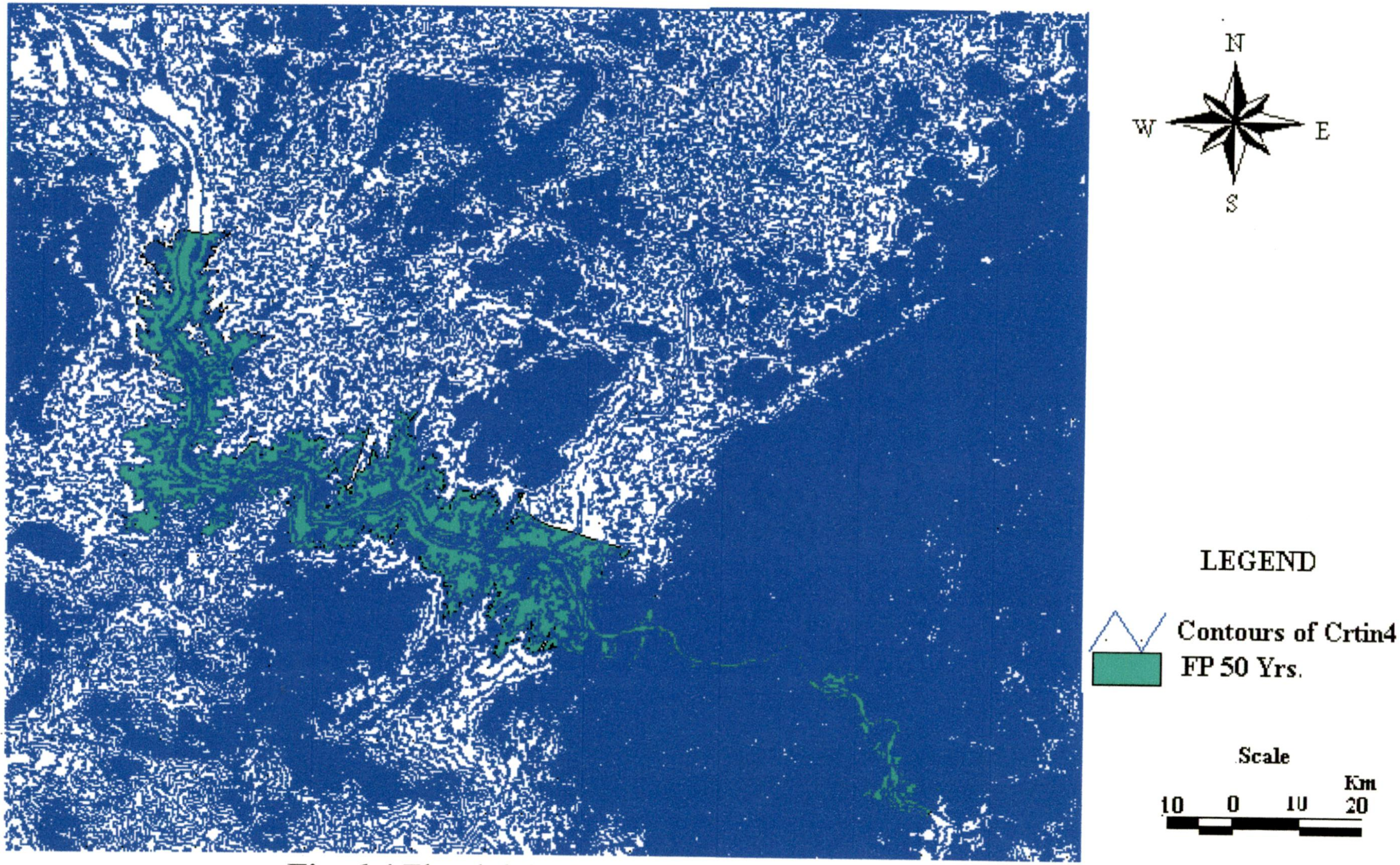


Fig. 6.4 Floodplain for 50 Yrs. profile with terrain contours

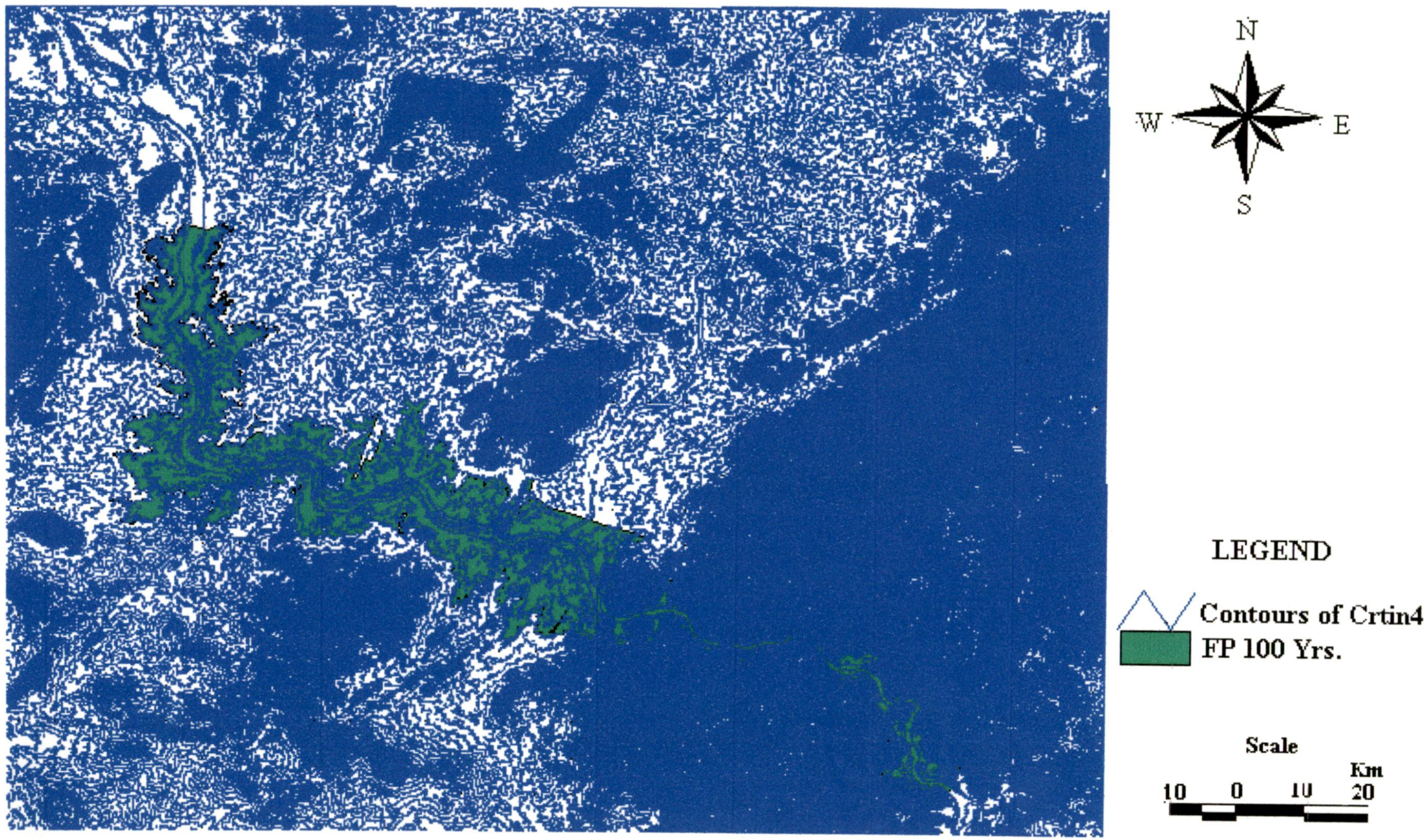


Fig. 6.5 Floodplain for 100 Yrs. profile with terrain contours

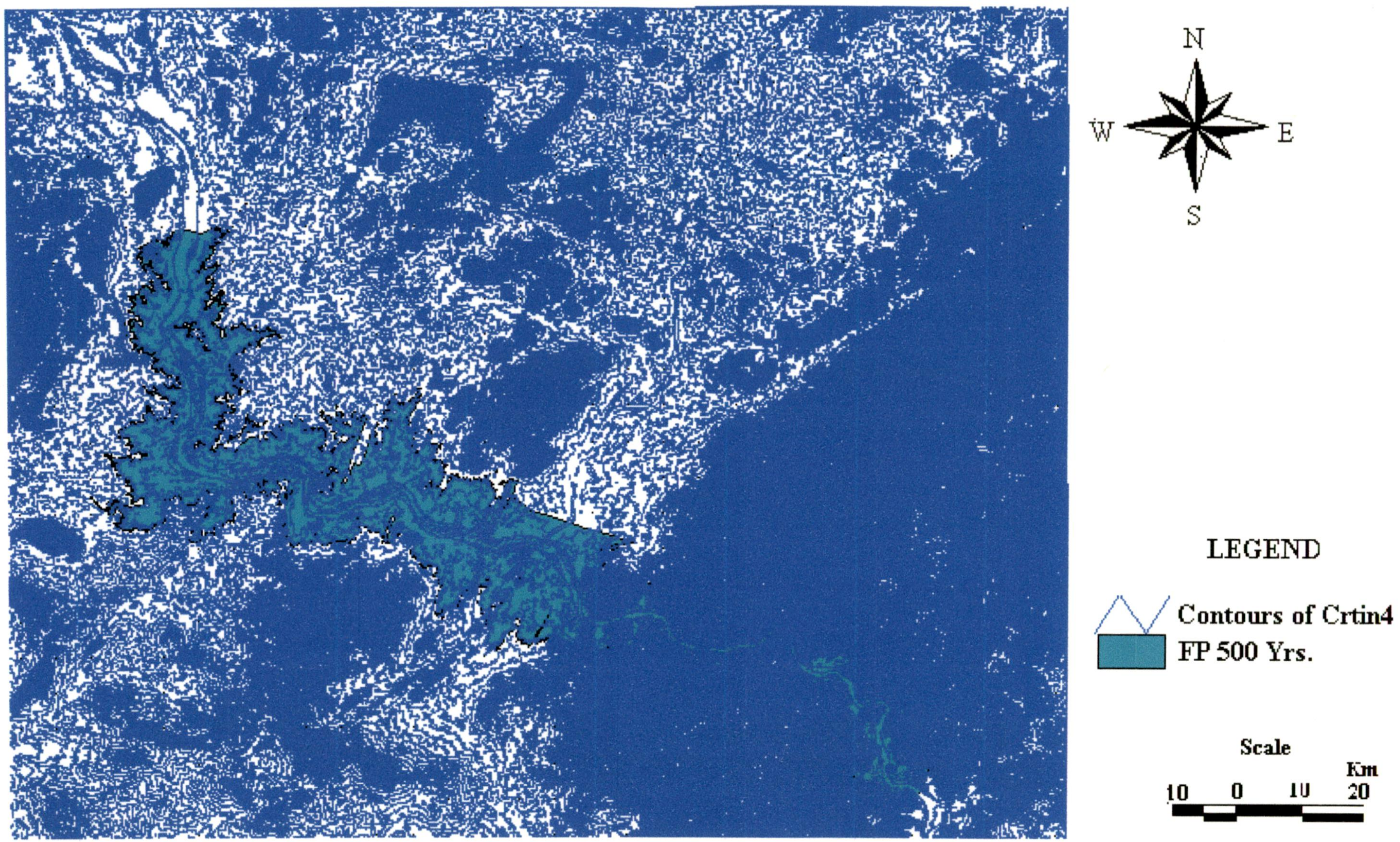


Fig. 6.6 Floodplain for 500 Yrs. profile with terrain contours

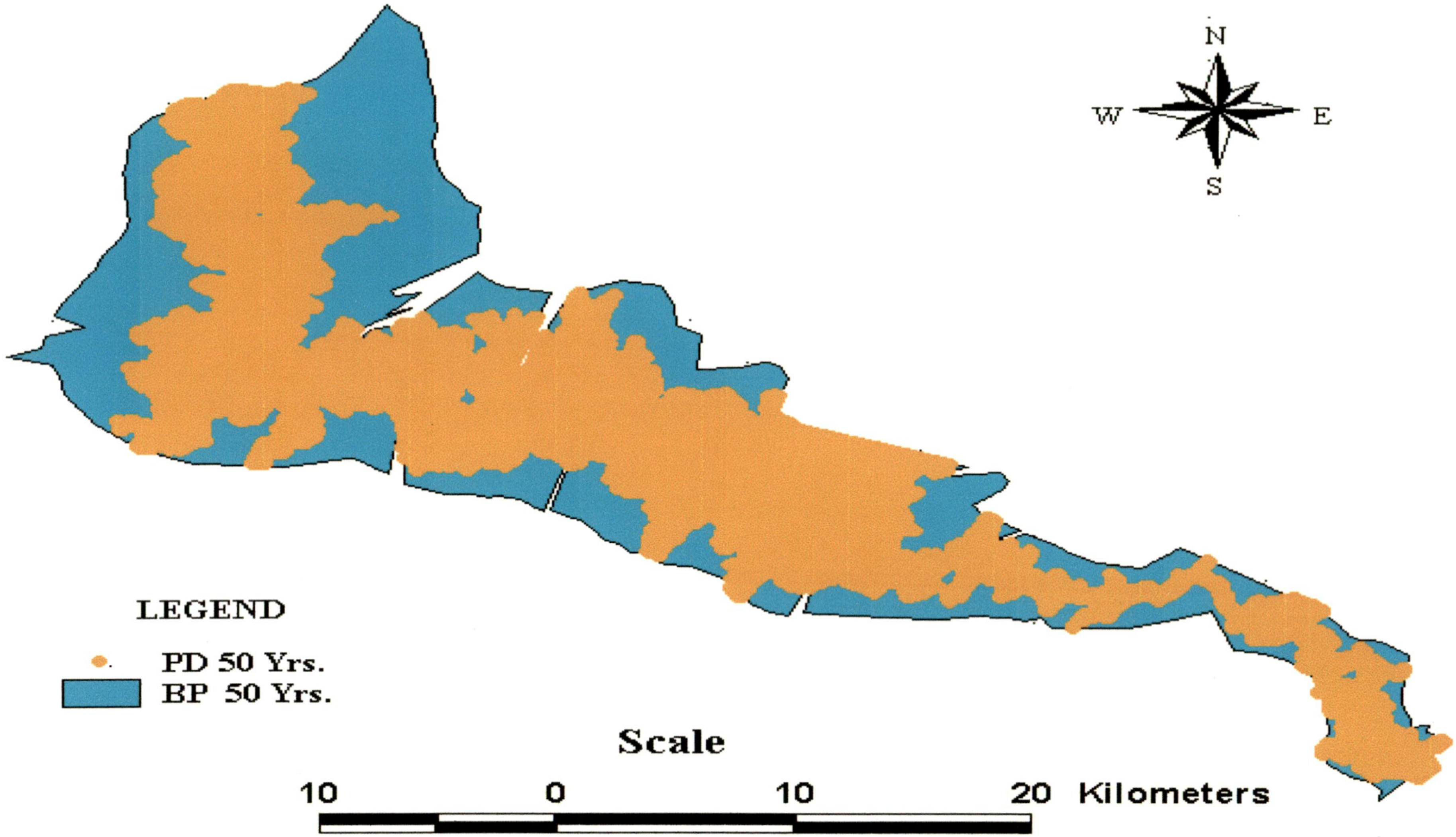


Fig. 6.7 Floodplain delineation for 50 Yrs. profile with bounding polygon

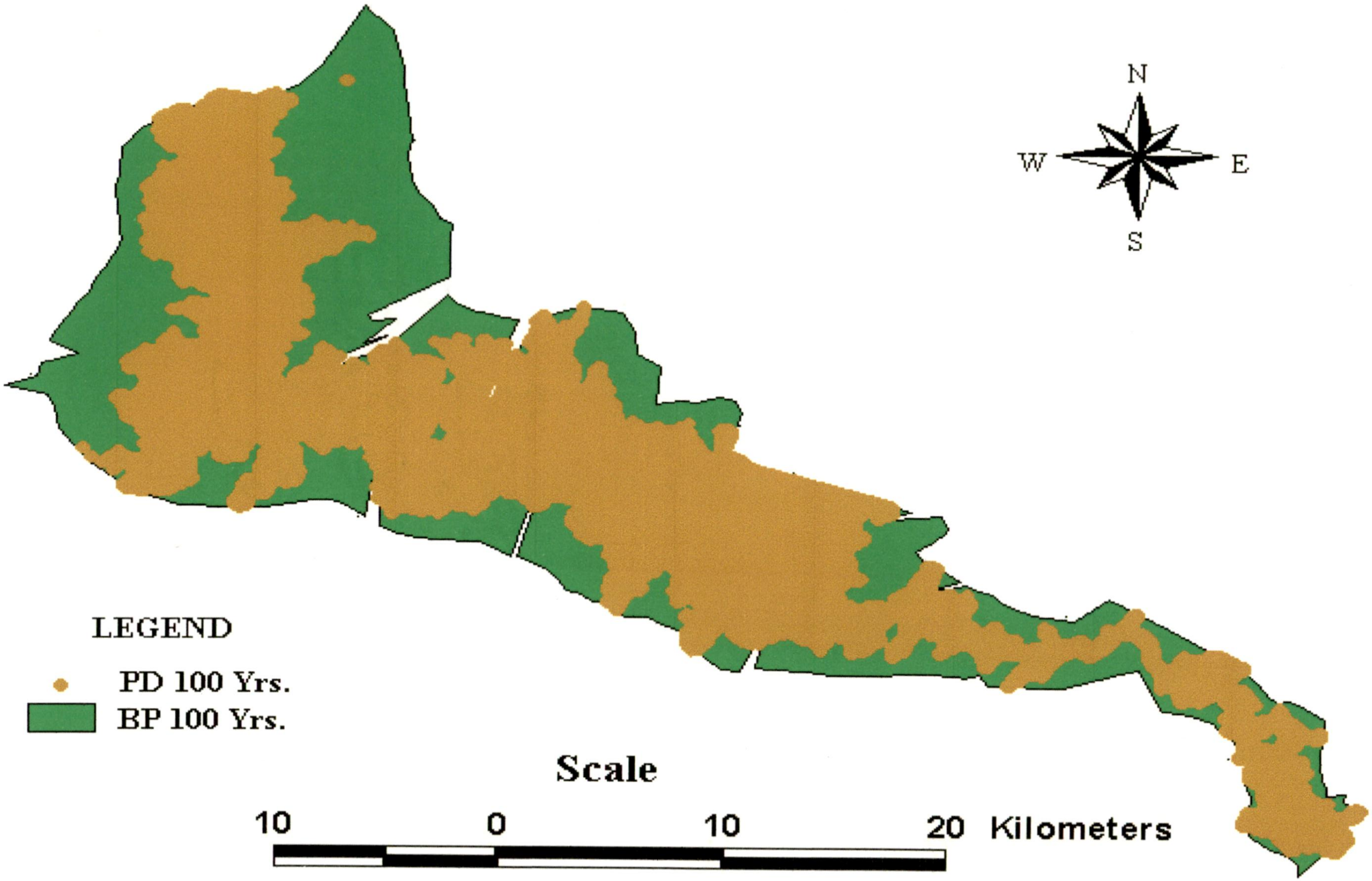


Fig. 6.8 Floodplain delineation for 100 Yrs. profile with bounding polygon

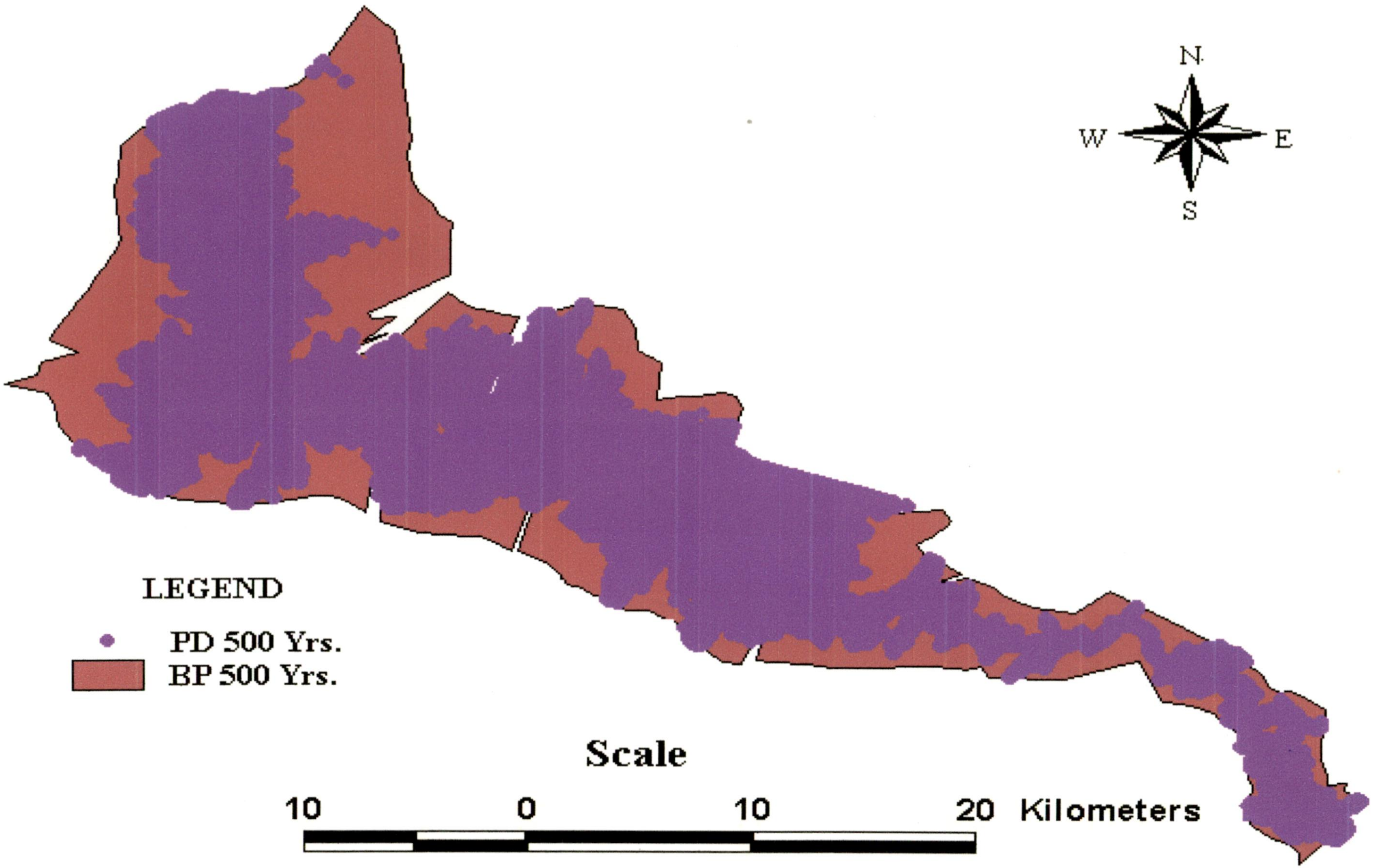


Fig. 6.9 Floodplain delineation for 500 Yrs. profile with bounding polygon

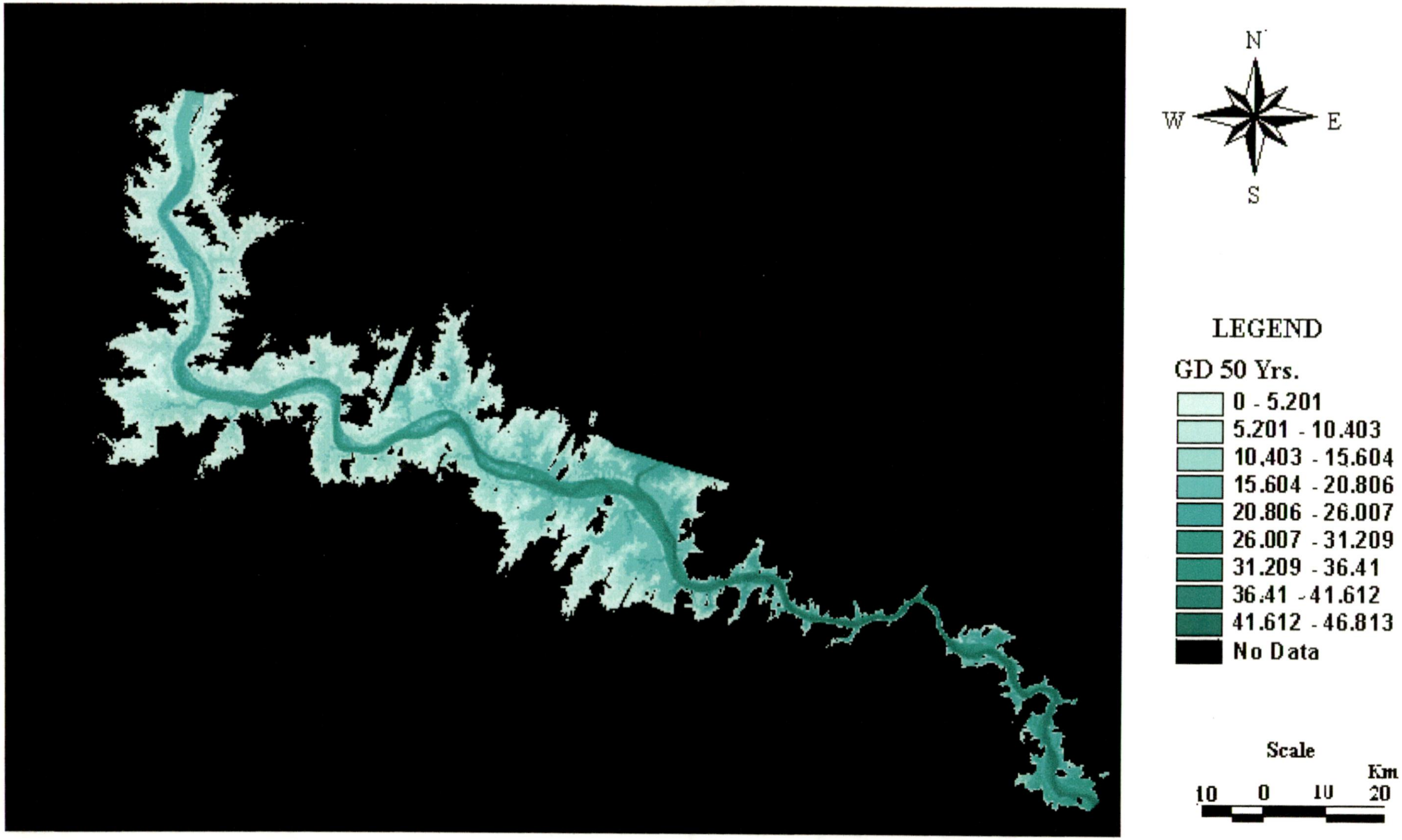


Fig. 6.10 Depth grid for 50 Yrs profile with identify results for water depth

Fig. 6.11 Depth grid for 100 Yrs profile with identify results for water depth

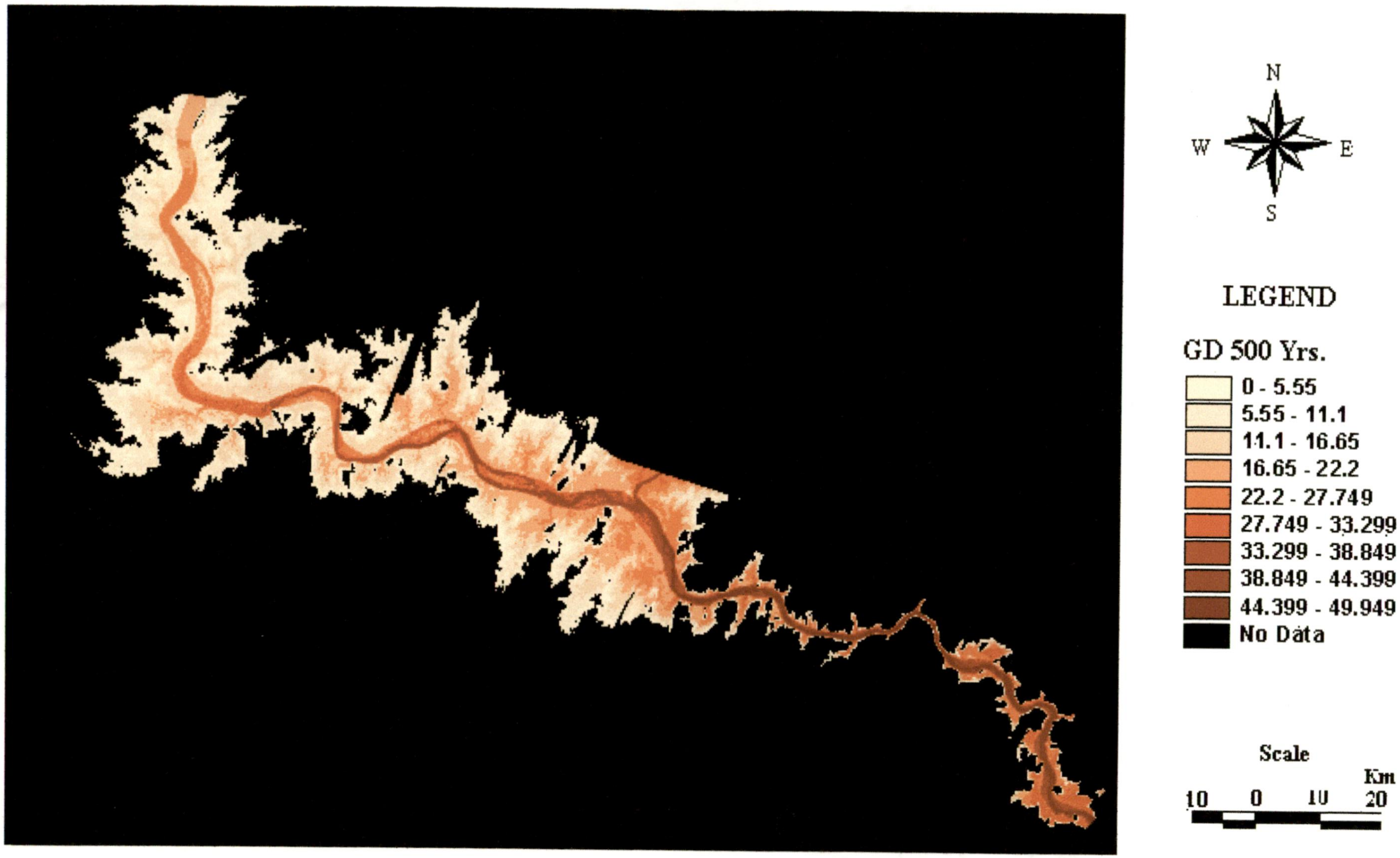


Fig. 6.12 Depth grid for 500 Yrs profile with identify results for water depth

6.4 SENSITIVITY ANALYSIS

Sensitivity Analysis (SA) is the study of how the variation (uncertainty) in the outcomes of a mathematical model can be apportioned, qualitatively or quantitatively, to different sources of variation in the input of a model. In other words it is a procedure to determine the sensitivity of the outcomes of an alternative to changes in its parameters. If a small change in a parameter results in relatively large changes in the outcomes, the outcomes are said to be sensitive to that parameter and parameter has to be determined very accurately or that the alternative has to be redesigned for low sensitivity. Sensitivity analysis can be done as a tool to ensure the quality of the modeling/assessment. Sensitivity Analysis is popular in financial applications, risk analysis, signal processing, neural networks and any area where models are developed. Sensitivity analysis can also be used in model-based policy assessment studies

Sensitivity analysis can be used to determine:

- The model resemblance with the process under study
- The quality of model definition
- Factors that mostly contribute to the output variability
- The region in the space of input factors for which the model variation is maximum
- Optimal - or instability - regions within the space of factors for use in a subsequent calibration study
- Interactions between factors

Regarding this study there are various parameters like Manning's roughness, Bed slope, Discharge, Width of spillway, Spillway rating curve etc. which can be considered for the Sensitivity Analysis. Since main focus in this study was given on flood inundation hence with fixed length of spillway (Fig A2 of Appendix A), Spillway rating curve is chosen for Sensitivity Analysis. The Free Reservoir Level (FRL) is taken 45.72m (150ft.) to be cleared by the Central Water Commission based on various agreements reached between the neighboring States for sharing Godavari Waters and for construction of the Polavaram Project.

By increasing and decreasing the spillway rating curve by 20% and 30% in the following equation

$$Q = 2.21 * (830 - 0.2 * H) * H^{3/2},$$

the spillway rating curves are prepared and given in Table 6.5

Table 6.5 Computation of Spillway Rating Curve at Varying FRL

Discharge (cumec)	H in metre (NRL + h1)	20% increase	20% decrease	30% increase	30% decrease
0	45.72	54.864	36.576	59.436	32.004
100	45.864	55.008	36.720	59.580	32.184
500	46.14	55.284	36.996	59.856	32.424
1500	46.594	55.738	37.450	60.310	32.878
2000	46.779	55.923	37.635	60.495	33.063
2500	46.949	56.093	37.805	60.665	33.233
4500	47.539	56.683	38.395	61.255	33.823
6000	47.924	57.068	38.780	61.640	34.208
10000	48.819	57.963	39.675	62.535	35.103
20000	50.641	59.785	41.497	64.357	36.925
35000	52.869	62.013	43.725	66.585	39.153
70000	57.076	66.755	48.467	71.327	43.895
100000	60.131	69.275	50.987	73.847	46.415

Now HEC-RAS is run with the same geometric data and steady flow data for two profiles Q_{100} = 78892Cumec Q_{500} = 97604Cumec with the boundary conditions given in the above table of spillway rating curve, Steady flow analysis are performed each time under different Plans. Flow Areas of each cross-section are obtained for both the return period floods applying different spillway rating curves as boundary condition. All the computed flow areas are tabulated as area of submergence (total flow area) for different spillway rating curves as given in Table B1 of Appendix B. From Table B1 of Appendix B, computed total submerged area for 100 and 500 yrs. return period floods at various spillway rating curves as boundary condition are taken out and given in Table 6.6 in sq. km. for further analysis.

Table 6.6 Computation of Submergence Area for 100 & 500 YRS. Return Period Floods

FRL (M)	AREA SUBMERGED IN SQ.M	
	Q_{100} = 78892Cumec	Q_{500} = 97604Cumec
32.00	6.62	8.08
36.58	7.65	9.20
45.72	11.88	13.65
54.86	19.57	21.64
59.44	24.54	26.71

Now a relationship is developed between Free Reservoir Level (FRL) and Area of Submergence due to different magnitude of floods at different spillway rating curves. Fig. 6.13 shows the graph between FRL and Area Submerged based on above data and its outcomes has been mentioned in 'Discussion of Results'.

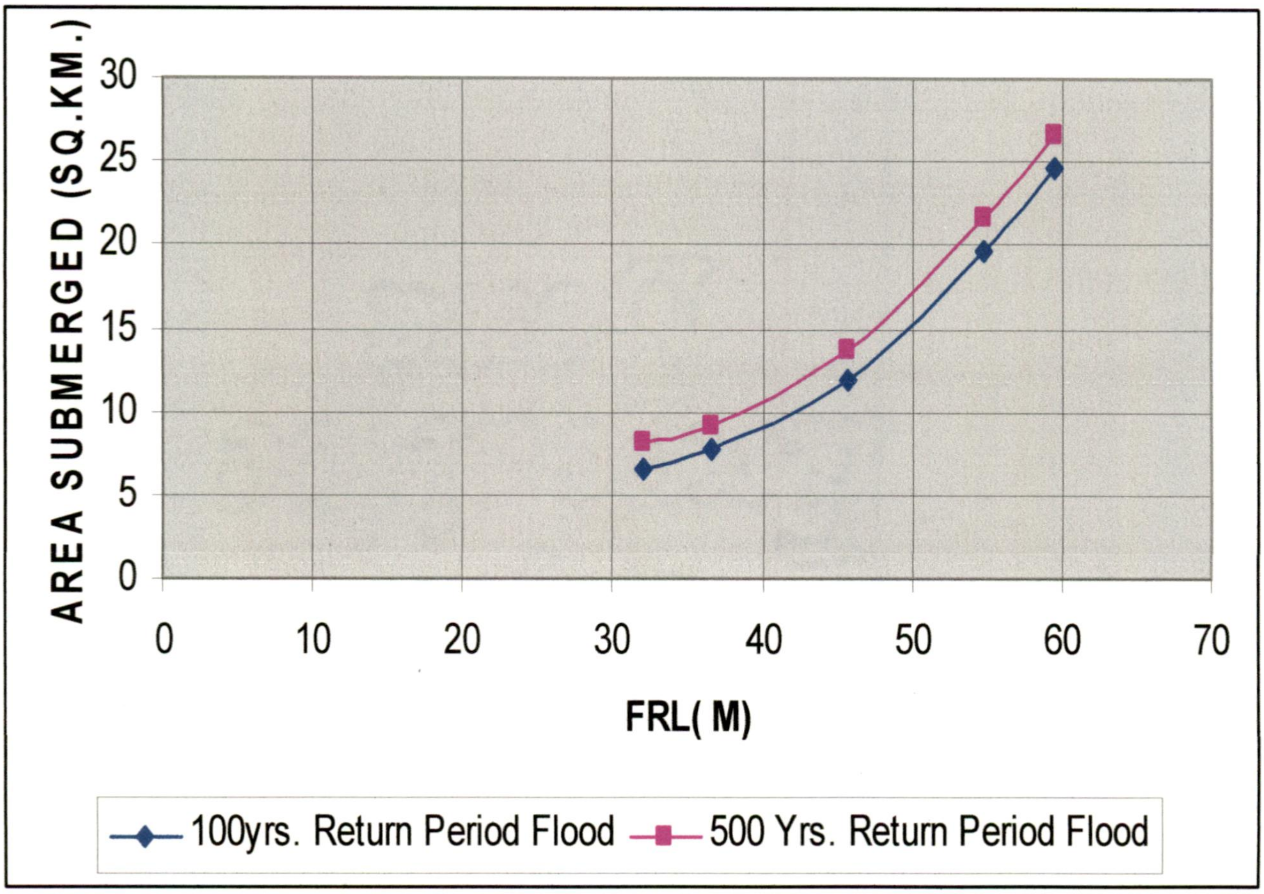


Fig. 6.13 FRL versus Area Submerged

6.5 DISCUSSION OF RESULTS

To obtain a Flood Inundation Map first of all the annual peak flood data from 1881-1975 at existing G & D site of Godavari River are utilized in flood frequency analysis for prediction of extreme flood values. The flood frequency analysis is carried out using Gumbel, Log-Pearson Type III and Log-Normal distributions. The observed data are fitted to these distributions using the frequency factor. The flood discharges for 50, 100, and 500 years return periods are calculated. For the reliability of the results Standard Error and Confidence Limit are taken into consideration. Estimated peak floods are produced in an interval within which the true value can reasonably be expected to lie. The upper limit and lower limit of flood discharge computed by Gumbel's Distribution has the least difference as compared with other distributions. Therefore computed flood discharges of 97604, 98948 and 96259 cumec for 50, 100, and 500 years return periods respectively by Gumbel' Distribution have been used for production of Flood Inundation Map.

There are three observed cross-sections only in between 143 km long Godavari river and nothing was known about the river plain. To prepare a Flood Inundation Map of the area, sufficient number. of cross-sections spaced closely and wide enough are required to represent the floodplain. This forms the geometric data to carry out steady flow analysis to have water surface profile on HEC-RAS. Since there is no toposheet available for the study area, the SRTM digital elevation data of 90m resolution is used for creation of centre line, river banks and various cross-sections. The SRTM digital elevation data are produced by NASA and available in mosaicked 5 deg x 5 deg tiles for easy download and use. The SRTM dataset provides a recent snapshot of the Earth's land surface. The SRTM digital elevation data for Latitude 16° 16′ N and 23° 43′ N and Longitudes 73° 26′ E and 83° 07′ E is downloaded and modified on 8th Feb'2008. ERDAS IMAGINE gives various information about map, projection, statistics, and layer of the raster image. A long exercise has been done on raster image data using ERDAS IMAGINE, ILWIS, ArcView GIS and HEC-GeoRAS to develop the geometric data file. ERDAS IMAGINE reprojection converts latitude and longitude to UTM WGS84 where UTM is a coordinates grid system and WGS84 is the datum for GPS readings. The study area falls in north 44 UTM zone. Using ILWIS it is easy to identify the water feature clearly that helps to draw centre line, river banks and cross sections. Raster map is converted to point which constitutes the shape of the study area as well as shape of centre line, river banks and cross-sections in ILWIS before export to ArcView GIS. In arcView GIS lots of work are performed. TIN of the study area is constructed and attributes regarding stream/reach names, stationing, bank stations, reach lengths are provided here. Centre line and cross-sections elevation are also processed through preRAS in ArcView GIS. With all details including elevations of various cross-sections, geometric data in GIS format are available for use in HEC-RAS.

While importing the geometric data in HEC-RAS and viewing cross-section plotting of all 121 cross-sections, it is found that elevations in thalweg are same for quite a long distance. It means the deepest bed level of the river is not seen due to presence of water in thalweg and elevations shown in water portion actually are water surface elevation and not the actual bed of the river. Hence the elevations of water surface are modified to give bed levels through interpolation of observed longitudinal-section of the river. Now the longitudinal bed profile of the river is corrected as per the available data but still some cross-sections were having some discrepancies. Since we have only three actually observed cross-sections at 40.75, 118.685 and 143.115 Km. these are used for modification of all the cross-sections. The Nash-Sutcliffe model efficiency coefficient is then used to assess the predictive power of the approach used as it compares the computed data with observed ones. The cross sections downstream of 44.42 Km are compared with observed cross-section at Koida (40.75 Km), cross-sections upstream of 44.42 Km up to 119.59 Km are compared with the observed cross-section at Bhadrachalam (118.63 Km) and rest cross-sections up to 143.11 Km are compared with the observed cross-section at Dummagudem (143.115Km) based on similar bed profile features of the available limited cross-sections. Nash-Sutcliffe Co-efficient (E) for Koida, Bhadrachlam and Dummagudem came to be 0.61, 0.71 and 0.47 respectively. The overall value of the N. S. Co-efficient varies in the range from 0.35 to 0.86 and thus giving more or less a good representation of the observed cross-sections. A graphical representation of comparison of computed cross-sections at 40.75 Km, 118.68Km and 143.11Km as sample with observed cross-sections at Koida, Bhadrachalam and Dummagudem have been shown in Figs. 5.3 - 5.4

Since the Full Reservoir Level (FRL) was fixed as 45.72m (150 ft.), the area inundated for 78892 Cumec and 97604 Cumec Discharge came as 11877595 Sq.m and 13648454 Sq.m respectively. It is obvious from the graph or tabular data that by increase and decrease of Reservoir level by 20% and 30% inundation area is increased 1.65 and 2.06 times and 0.64 and 0.56 times respectively for 78892 Cumec Flood Discharge. Similarly by increase and decrease of Reservoir level by 20% and 30% inundation area is increased 1.58 and 1.95 times and 0.67 and 0.59 times respectively for 97604 Cumec Flood Discharge. Hence decreasing of reservoir level although showed lesser inundated area but it may not fulfill the water requirement for irrigation, hydro-power, flood mitigation etc. On the other hand increase of reservoir level had a drastic increase in inundation area affecting neighboring States Chattisgarh and Orrisa as well as reduction in water to downstream area. Therefore, FRL of Polavaram Dam at 45.72m from M.S.L. is found justified.

Steady flow analysis is performed on HEC-RAS using the geometric data and steady flow data (50, 100, 500yrs.return period floods) to obtain water surface profile at each cross-section. These output are exported to ArcView GIS where with the use of HEC geoRAS extension Flood Inundation Maps are created. Figs. 6.4-6.6 show floodplain with Terrain contours, Figs 6.7-6.9 show floodplain delineation in bounding polygon and Figs. 6.10-6.12 show water depth grid for different profiles. Bounding polygon shows the absolute boundaries of the flood plain. Use of the depth grid with a color gradient, the areas flooded can be quickly identified to greater (or lesser) depths. The water depths at various locations in an interesting area can be found easily by clicking which comes immediately as attributes.

6.6 LIMITATIONS OF THE STUDY

1) There will be a contribution to the discharge from two tributaries that joins the river Godavari between Bhadrachalam and Koida. But because of lack of data same

discharge was used throughout the reach of the river for simulation. Hence some error in water surface profile would be observed in river reach upstream of Bhadrachalam.

2) As simulation by HEC-RAS was limited to fixed condition (Bed and banks were assumed to be fixed) of river only, it could not depict the actual scenario of water surface profiles. In actual case there would be deposition and scour of river bed leading to corresponding change in bed and water surface profile.

3) Selection of an appropriate value of Manning's n is very significant to the accuracy of the computed water surface profiles. Manning's n value should be calibrated whenever observed water surface profile information (gauge data, as well as high water mark) is available.

4) Flood plain delineation performed on ArcView GIS with HEC-geoRAS extension could be examined very closely so that it could be hydraulically correct. Flood plain delineation process in GeoRAS could be done iteratively to refine the hydraulic model in HEC-RAS.

5) This should be a part of Non-sructural measures of flood management to reduce short and long term damages. Using the method investigated in this dissertation could lead to a significant saving of time and resources versus the conventional paper delineation.

6) The lesson learned from this dissertation can be applied to a larger area encompassing the entire Godavari River Basin and other river basins of the country.

7) Many floodplains have become outdated and this allows for easier revision. Flood plain maps can be updated more frequently due to changing hydrologic and hydraulic conditions and the output should be used to any of the following area: floodplain management, flood insurance determination, economic impact analysis, flood warning systems and hydraulic design.

CHAPTER 7

CONCLUSIONS AND SCOPE FOR FUTURE STUDY

7.1 CONCLUSION

Developed by US Army Corps of Engineers at Hydrologic Engineering centre (HEC), the HEC-RAS software allows one to perform one-dimensional steady flow, unsteady slow calculations. The present study endeavored to create a flood inundation map in the 143 km upstream reach of Polavaram dam on Godavari River. The salient observations of the study are summarized as follows:

1. The Flood Inundation Mapping forms to be an important component of non-structural measures and the data generated by Remote Sensing and GIS can be useful in hydraulic analysis.
2. Cross-sections generated using Remote Sensing and GIS data, coupled with little manipulations, are in close agreement with those observed at limited number of sites in the considered study reach of Godavari river.
3. The 50, 100 and 500 years return period floods generated using Gumbel Distribution were 97604, 98948 and 96259 cumec, respectively, and these were seen to lie in the middle of those derived from Log-Normal and Log-Pearson Type III distributions.
4. The inundated areas computed using HEC-RAS for the above 50, 100 and 500 yrs. return period floods were of the order of 10.8, 11.65 13.69 sq. km, respectively.
5. The sensitivity analysis of FRL revealed inundated areas to increase with increase in FRL, and vice-versa, following the power relationship.

7.2 SCOPE OF FUTRE STUDY

- In the present study sediment analysis has not been done due to non availability of sediment data and flood hydrograph. Water surface profile with proper consideration of sediment can be obtained on HEC-RAS to create more accurate Flood Inundation Map.

- Flood Inundation Map can be created taking consideration of morphological changes of the Godavari River in 2-D hydrodynamic module.
- In future work, connection of the HEC-RAS stream channel data and DEM data would allow creation of a continuous terrain surface model where 3D visualization of a flood could be visualized.

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APPENDIX "A"

Table A1 Longitudinal Section of River Godavari at U/S of Dam Site

SL. NO.	DISTANCE (km)	DEEPEST BED LEVEL (m)	WATER LEVEL (m)	REMARKS	SL. NO.	DISTANCE (km)	DEEPEST BED LEVEL (m)	WATER LEVEL (m)	REMARKS
1	0.0	2.0			48	100.7	22.3	53.4	
2	0.8	7.4			49	103.0	22.9	53.5	
3	1.5	7.5			50	103.7	26.7	53.6	
4	2.3	8.0	28.9	Dam Site	51	106.0	25.6	53.8	
5	3.6	10.6	29.9		52	107.0	20.0	53.9	
6	6.0	2.3	31.1		53	109.8	28.0	54.1	
7	8.9	-2.0	31.1		54	110.5	28.4	54.1	
8	13.5	-6.7	34.3		55	111.8	28.6	54.3	
9	15.8	11.7	35.8		56	112.7	27.3	54.3	
10	20.3	9.3	36.5		57	113.5	28.6	54.3	
11	21.8	-2.6	36.9		58	115.7	30.6	54.5	
12	22.5	-9.5	38.5		59	116.5	30.8	54.3	
13	24.0	3.1	39.3		60	118.7	28.6	54.9	Bhadrachalam
14	27.0	-12.8	40.1		61	119.1	33.2		
15	27.8	4.2	41.5		62	119.9	33.3		
16	30.0	11.1	41.9		63	120.6	34.2		
17	31.5	9.5	41.9		64	121.4	34.8		
18	33.8	-12.3	40.5		65	122.1	34.3		
19	39.3	0.4	43.7		66	122.9	34.4		
20	40.8	4.1	44.3	Koida	67	123.6	34.6		
21	43.0	9.7	45.8		68	124.4	35.5		
22	45.3	3.3	46.9		69	125.1	35.4		
23	48.3	6.6	48.0		70	125.9	34.9		
24	53.5	16.1	49.8		71	126.6	36.2		
25	55.8	8.0	49.1		72	127.4	35.9		
26	57.3	13.6	50.2		73	128.1	34.3		
27	59.2	12.6	50.3		74	128.9	37.1		
28	61.7	16.7	50.4		75	129.6	37.6		
29	64.0	16.6	50.8		76	130.4	37.8		
30	67.7	19.9	50.9	Kunnvaram	77	131.1	37.1		

31	70.7	16.6	50.9		78	131.9	29.2		
32	72.2	21.8	50.9		79	132.6	31.4		
33	73.7	21.5	50.9		80	133.4	34.0		
34	75.2	24.6	51.0		81	134.1	37.4		
35	76.7	24.6	51.1		82	134.9	38.4		
36	79.7	25.6	51.1		83	135.6	38.0		
37	82.7	22.9	51.2		84	136.4	39.6		
38	83.2	21.5	51.3		85	137.1	39.7		
39	85.7	19.3	51.3		86	137.9	40.3		
40	86.5	19.9	51.6		87	138.6	40.6		
41	87.8	22.7			88	139.4	40.4		
42	88.7	22.9	51.7		89	140.1	42.2		
43	89.5	26.5			90	140.9	41.4		
44	90.0	26.0			91	141.6	42.1		
45	91.7	17.9	51.7		92	142.4	42.8		
46	94.7	20.5	52.1		93	143.1	41.2		Dummagudem
47	95.5	19.1	51.7						

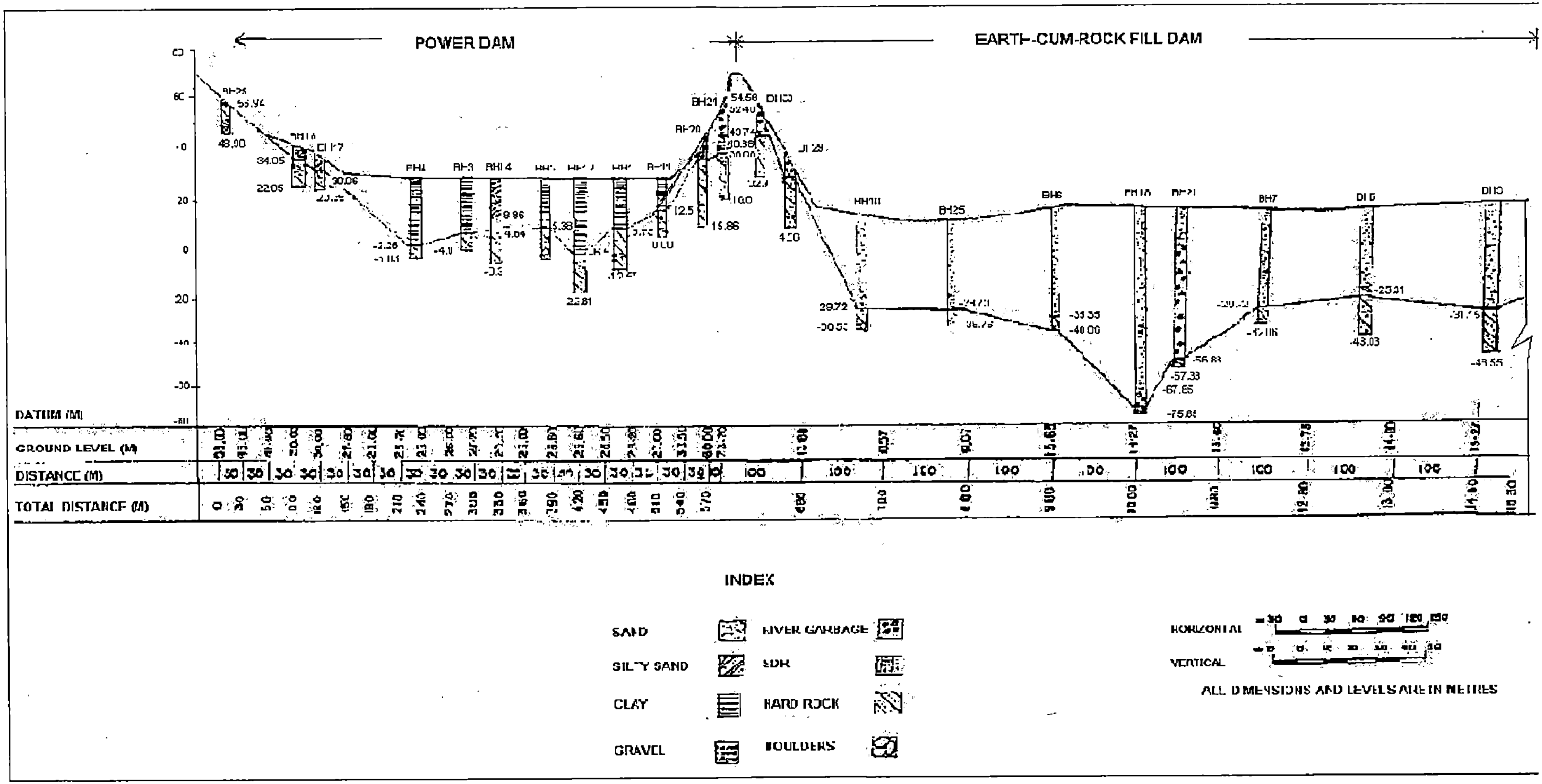

Fig. A1 Cross-Section and Bore Well Details of Polavaram Dam Site

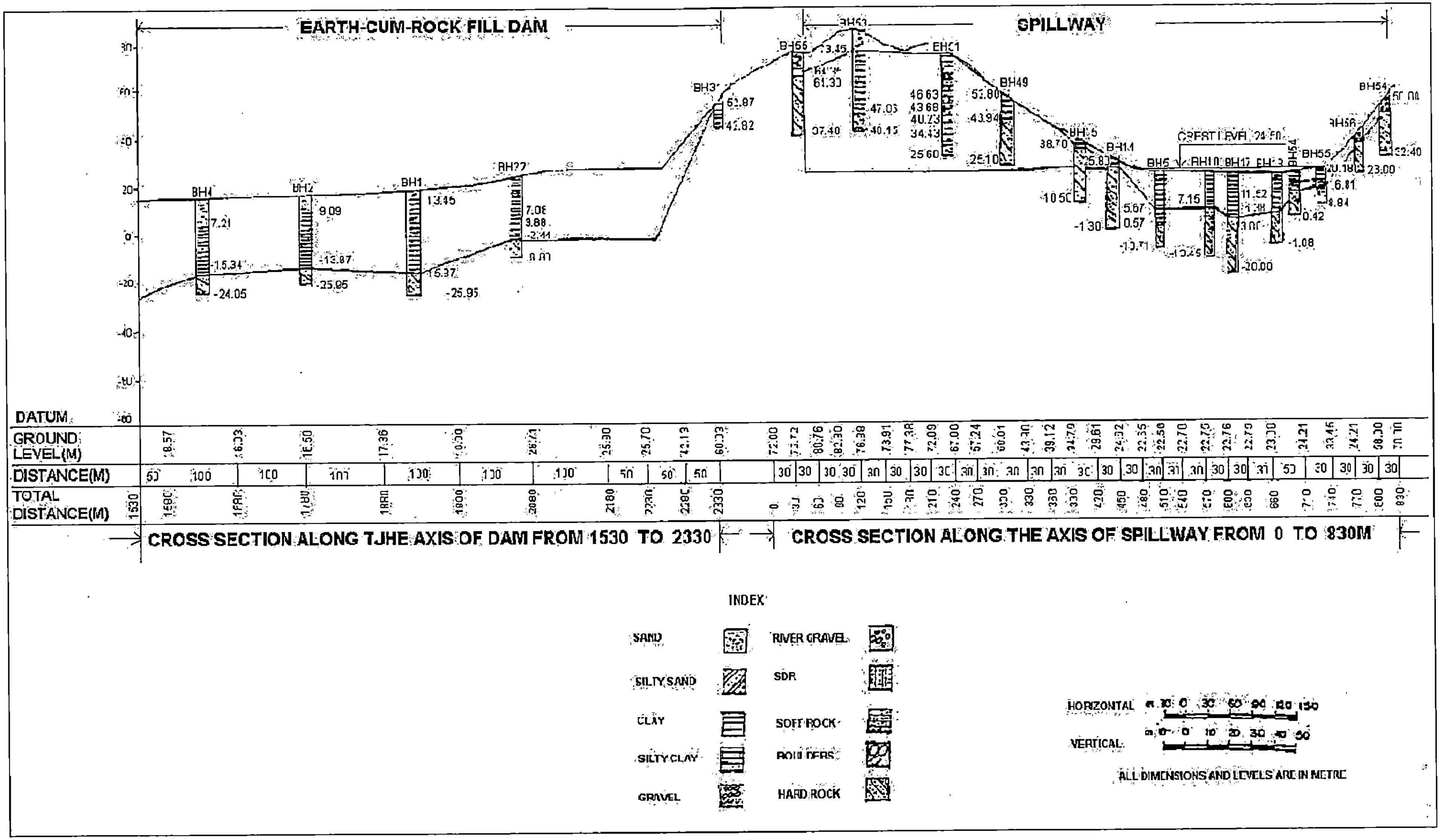

Fig. A2 Cross-Section and Bore Well Details of Polavaram Dam Site

APPENDIX "B"

TABLE B1 Submerged Area at Different spillway Rating Curves

RIVER STATION	FLOW AREA FOR 100 YRS. RETURN PERIOD FLOOD (SQ. M.) AT					FLOW AREA FOR 500 YRS. RETURN PERIOD FLOOD (SQ. M) AT				
	SPILLWAY RATING CURVE (45.72M)	20% INCREASE (54.86M)	20% DECREASE (36.58 M)	30% INCREASE (59.44M)	30% DECREASE (32M)	SPILLWAY RATING CURVE (45.72M)	20% INCREASE (54.86M)	20% DECREASE (36.58M)	30% INCREASE (59.44M)	30% DECREASE (32M)
143591.6	46555	89727	36690	131423	35777	59127	107955	46595	153956	45236
142670.8	59775	119890	44793	168924	43548	78105	142415	59592	193406	57536
141653.2	53701	103658	40317	147811	39060	69076	123039	52910	171226	51038
140583.8	52584	97137	41525	135228	40485	65540	113777	51553	156516	49998
139610	51281	90593	39958	122867	38829	62848	104523	49896	141582	48325
138622.1	41111	80698	32863	124975	32039	49821	100071	39566	147263	38373
137624	47708	104034	34991	152517	33742	62250	125629	44820	175472	42938
136570.6	62596	118705	45767	165306	43976	78457	138860	58783	188572	56340
135586.1	66482	130913	49259	179846	47424	83636	153221	62286	202160	59742
134673.1	80903	152001	58983	207643	56721	101039	176982	75354	234180	72107
133642.9	64683	132008	47975	183185	46396	82056	155173	59881	206495	57315
132660.6	60962	124042	44001	173038	42405	77513	145621	55641	197018	52998
131641.6	62239	136615	43208	193758	41304	80642	162295	56111	219742	53148
130626.8	87584	180884	59695	244772	56685	113525	209683	78681	274318	74431
129578	90665	181548	61156	245802	57908	115856	210379	81001	275034	76526
128611.5	77020	161156	53498	224868	50960	97627	189231	68767	254868	65104
127628.9	73690	138630	51926	194043	49462	90775	162556	66089	222603	62760
126611.1	75806	123342	58034	159757	55824	88776	138927	69684	178377	66969
125570.1	55967	107438	41044	151941	39733	68594	126381	49588	173453	47096
123638.4	50503	105739	34099	149321	32246	64705	123341	43019	171946	40355
122604	49302	108350	32489	158547	30551	61811	129615	41217	182192	38440
121651.4	95629	183577	66344	249409	63011	117051	211625	81880	281000	77008
120613.9	84068	167867	50396	228647	46294	106042	193493	68285	258076	62595
119592.6	108334	190231	75114	247208	70794	128915	214564	93169	274264	87483
118634.1	55387	126585	34490	182265	32094	71202	150384	44216	209148	40723
117651.7	67629	171609	42523	255374	40078	87669	207884	53236	293076	48989
116595.9	82039	201708	47936	287131	44442	109586	238821	63001	325695	57130
115607.9	114460	199199	75642	251475	69986	137037	221905	95038	274390	88057
113576.4	135454	237774	94529	305171	88749	160793	267243	114490	334754	107242
112640.4	109500	211709	63851	272571	58731	136727	238538	84314	298667	76226
111602.8	70111	110535	48599	134655	45416	80884	121073	59006	144934	54974
110645.8	106190	185261	69099	233045	63887	127119	206083	86148	253720	79346
109620	70795	115569	49010	146550	45699	81766	128564	59230	161118	55141
	75006	112278	55847	139566	52721	84345	123195	64898	153059	61277
	94823	144952	67110	175968	62616	108105	157907	80210	190391	74944
	69801	118562	47262	148704	43971	81660	131327	56911	162253	52704
	56577	107915	36474	142478	33995	68610	122329	44252	157477	40646
	66420	115748	41380	147956	37786	78661	129084	51674	162647	46802
	65422	120806	42904	161506	39427	77410	137681	51757	179253	47565
	76064	134446	47319	173065	42557	89500	150895	59362	189843	53503

RIVER STATION	FLOW AREA FOR 100 YRS. RETURN PERIOD FLOOD (SQ. M.) AT					FLOW AREA FOR 500 YRS. RETURN PERIOD FLOOD (SQ. M) AT				
	SPILLWAY RATING CURVE (45.72M)	20% INCREASE (54.86M)	20% DECREASE (36.58 M)	30% INCREASE (59.44M)	30% DECREASE (32M)	SPILLWAY RATING CURVE (45.72M)	20% INCREASE (54.86M)	20% DECREASE (36.58M)	30% INCREASE (59.44M)	30% DECREASE (32M)
101614.4	74954	131032	45224	168701	40446	88401	146417	57122	186477	51078
100611.4	100060	171419	60323	218187	53573	117380	190954	76532	239582	68319
99626.55	59430	117950	38066	169526	34185	70663	139498	46354	191297	41896
98653.43	70921	149581	39760	204406	34678	87714	171440	50525	230174	44340
97660.4	73306	162034	37552	219265	32123	92128	186206	49428	243368	42156
96635.14	126427	246369	65084	324801	55905	154515	279229	85917	358616	72913
95675.33	171848	287537	103533	352536	90884	200440	315203	128439	379737	113403
93610.99	70286	129234	37105	163008	30860	84458	143343	49084	177324	41190
92632.39	86995	147139	50841	182112	42923	101103	161855	63970	196717	55400
91610.36	124863	199789	74348	240878	63176	143345	217194	93306	257798	80895
90637.52	112739	188024	64505	233004	53412	130438	206845	82397	251782	70443
89691.11	111637	191791	65426	237515	55601	130652	211147	81593	256275	70528
88624.52	128721	211092	76760	260509	66087	148373	231624	94655	281161	82178
87653.28	105951	201104	59971	259527	50339	126420	225696	75131	283610	64443
86624.56	124666	223277	70039	295571	57355	145384	253164	89641	326544	75697
85673.69	159077	290694	83234	368230	68779	189651	323207	107239	400407	89758
84672.95	182469	288704	111829	351548	93985	207138	315115	137544	377489	119192
83606.27	145776	259545	82668	322864	68905	171755	286247	103822	348784	88325
82547.15	117182	190356	68375	237469	56156	134017	209356	85639	258458	72869
81621.99	115167	212988	61734	273313	50902	136560	237707	78951	299681	65834
80601.74	90323	166725	55945	223700	47530	104089	188851	67342	250436	58589
79670.53	99922	172054	60695	213702	51633	115635	189292	73293	232647	63450
78623.9	110879	195830	59125	247022	48422	129817	217074	75745	268426	62310
77617.42	157913	248644	96260	300848	80163	178698	270405	117207	322436	100794
76643.37	148547	240372	90511	293444	75244	168844	262369	110392	315772	94706
75587.15	170104	267003	106548	329216	89427	191485	292702	127992	355100	111045
74610.04	171024	280022	97909	345518	80229	195795	306382	122994	374874	102783
73641.34	192042	320973	113909	400858	94377	220700	354084	140074	433875	119069
72627.44	177653	299880	105902	375549	87999	203908	331171	129544	407159	110356
71604.56	131761	227335	80299	297225	67712	150760	255306	96786	327765	83337
69681.33	136284	237018	81753	297441	68171	157849	261635	98905	323458	84729
68639.97	183978	299261	105179	364119	87415	210389	326133	131006	390753	109328
67587.65	141399	234434	85488	290764	70194	161591	257475	103848	314583	88535
66567.87	188161	302921	106833	366010	84557	215013	329071	133988	391969	111255
65630.24	251853	389387	149530	462425	122242	284491	419920	183270	491924	154968
64648.94	245901	379916	160903	453772	137491	275250	410784	189477	483596	165543
62466.59	223633	363856	135687	452051	113739	253800	400092	163766	488680	139999
[illegible]433.35	230423	349990	143177	419820	117709	257449	378685	173110	449289	147878
[illegible].13	218623	329885	139114	396817	116342	244459	357033	165750	425191	143230
[illegible]	175473	251601	118749	302418	101471	192586	271871	138367	325455	121722

RIVER STATION	FLOW AREA FOR 100 YRS. RETURN PERIOD FLOOD (SQ. M.) AT					FLOW AREA FOR 500 YRS. RETURN PERIOD FLOOD (SQ. M) AT				
	SPILLWAY RATING CURVE (45.72M)	20% INCREASE (54.86M)	20% DECREASE (36.58 M)	30% INCREASE (59.44M)	30% DECREASE (32M)	SPILLWAY RATING CURVE (45.72M)	20% INCREASE (54.86M)	20% DECREASE (36.58M)	30% INCREASE (59.44M)	30% DECREASE (32M)
58440.84	126212	177837	91916	207713	81501	137769	189947	103572	220887	93616
57464.92	165810	241216	106032	281201	89207	183772	257856	126328	297321	108849
56444.54	113440	179029	71905	218064	60926	127540	194781	84602	234569	73478
55456.8	94716	133528	65804	154507	57945	103763	142167	75157	163033	66896
53445.18	52900	74981	37979	87964	33822	57642	80163	42473	93303	38268
52477.86	73039	108878	49094	129817	42933	80816	117335	56166	138408	49517
49470.09	144484	208590	96405	243085	82409	159127	222656	111029	257192	97251
48466.75	88903	119295	65419	136194	58026	95677	126086	72872	143072	65734
47473.31	59396	81347	45097	94362	41147	63995	86517	49210	99679	45159
46459.41	47130	66055	34096	77721	30206	50850	70567	37970	82571	33973
45468.78	88119	123636	61291	143046	52869	95774	131406	69397	150720	61153
44420.23	56320	75606	40764	86177	35737	60507	79683	45387	90397	40482
43474.68	49756	63944	38159	71680	34321	52792	66941	41570	74706	37865
41455.85	67266	88894	49357	100382	43451	71909	93399	54583	104835	48805
40448.81	40559	54629	29519	62791	25713	43384	57714	32542	65979	28891
36436.82	46782	60270	35191	67364	30992	49486	62946	38206	70019	34148
32488.61	66360	88480	47122	100088	40151	70748	92845	51938	104436	45058
28433.95	54375	69934	41499	78419	36618	57246	73046	44585	81589	39820
24437.75	80786	106556	57615	119910	48550	85741	111489	63096	124830	54299
23425.59	95052	128194	67698	145825	57883	101281	134689	73887	152363	64024
22468.17	103553	140585	70786	159675	58395	110685	147649	78380	166696	66133
21412.61	81156	105798	59788	118986	51427	85699	110620	64739	123878	56588
20433.19	46910	59767	35150	66372	30429	49288	62146	37764	68744	33165
19428.69	52233	65314	40432	72125	35731	54632	67753	43028	74630	38432
18455.88	58586	77788	42935	88127	37021	62006	81478	46258	91905	40327
17463.76	48454	63328	34992	71080	29532	51121	66078	37831	73864	32463
16447.4	67338	90985	45776	103201	36957	71613	95354	50332	107584	41646
15473.38	39718	56285	25199	65090	19273	42505	59337	27855	68233	21846
13466.13	53640	69548	39638	78129	33537	56251	72514	42296	81186	36200
11437.17	83861	114292	57043	130472	45265	88888	119960	62084	136174	50317
10464.47	77655	107599	52853	124265	42820	82555	113334	57242	130291	46967
9419.675	72906	96000	51370	109349	42267	76803	100568	55218	114154	46007
8420.585	53460	69449	39186	78055	32756	56003	72377	41722	81082	35254
7455.965	86154	115115	59097	129861	47261	91044	120216	63857	134997	51866
6462.75	111727	157936	68595	181620	50793	119526	166126	75976	189912	57498
5487.018	120432	163138	80313	185468	62198	127581	170815	87447	193354	69154
4413.234	126105	166528	87237	187081	69136	132950	173639	94204	194243	76114
3430.684	96468	129077	66364	146053	52518	101862	134904	71586	151997	57730
2443.8	83765	116291	54992	133179	42586	89118	122067	59676	139113	47060
1430.336	68269	94257	43725	107850	32595	72507	98856	47730	112614	36282
465.512	110606	156006	68254	179399	48786	118001	164019	75274	187503	55303
TOTAL	**11877595**	**19566183**	**7653681**	**24535747**	**6625363**	**13648454**	**21636092**	**9197323**	**26714875**	**8077253**