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Government of the People's Republic of Bangladesh
Bangladesh Water Development Board

River Training Studies of The Brahmaputra River

Report on Model Studies

Volume 3

Comprising

Part 7 1-D Numerical Hydrodynamic Modelling of the Brahmaputra River

Part 8 1-D Numerical Morphological Modelling of the Brahmaputra River

March 1993

Sir William Halcrow & Partners Ltd.

in association with

Danish Hydraulic Institute
Engineering & Planning Consultants Ltd.
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HALCROW

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RIVER TRAINING STUDIES OF THE BRAHMAPUTRA RIVER

REPORT ON MODEL STUDIES

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Part 7

1-D Numerical Hydrodynamic Modelling of the Brahmaputra River

RIVER TRAINING STUDIES OF THE BRAHMAPUTRA RIVER

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PART 7 - 1-D HYDRODYNAMIC MODELLING

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1. INTRODUCTION

1.1 Background

BRTS has carried out 1-D hydrodynamic modelling using the 'MIKE 11' numerical modelling system developed by the Danish Hydraulics Institute. MIKE 11 is a general purpose open channel modelling system which includes a hydrodynamic core model to simulate unsteady but unidirectional flows, and a sediment transport module which can calculate sediment movement on a reach-by-reach basis.

Two separate models have been used by BRTS: the one to investigate flows and levels in the Brahmaputra River and the second to determine the consequences of over-bank flooding occurring as a result of breaches in the Brahmaputra Right Embankment (BRE).

MIKE 11 is currently being used by the Surface Water Modelling Centre of the Master Planning Organization for the Bangladesh Surface Water Modelling Programme for construction of their general and regional surface water models for use on projects under the Flood Action Plan. The technical capabilities of MIKE 11 are described in the Working Paper on 2-D Modelling (BRTS, December 1990).

1.2 Scope of the Modelling Programme

A detailed description of the models, their capability/verification and preliminary findings at the end of 1991 were reported in Annex 2 of the Second Interim Report. Reference should be made to this report for further information, although a detailed summary of this work is given in Section 2.

During the first two months of 1992 the BRTS hydrodynamic modelling programme was completed, with further runs of the Brahmaputra River model being used to determine design water levels along the river and to carry out a sensitivity analysis of maximum water levels for a range of engineering schemes.

In accordance with FAP-25 recommendations the BRTS version of the 1-D model for the Brahmaputra River was run for the period 1965-89 using corrected boundary conditions and simulation outputs from FAP-25 Model Run 5; the output from this simulation was compared with gauging stations records to check that the model performed satisfactorily for the full year period. In general the comparison between observed and modelled water levels for the 25 years (1965-89) were found to be to an equivalent standard as for the period 1988/89 for which it was calibrated. Close coordination was maintained with FAP-25 throughout this period to ensure consistency of approach and compatibility of output.

Output from the 25 year simulation was further analysed to derive design water levels, velocities and the corresponding confidence limits for specified return periods at priority locations along Brahmaputra River.

Two additional 25 year model runs were made to simulate future conditions following the implementation of engineering works associated with the construction of the Jamuna Bridge and left bank confinement as proposed by FAP-3. Outputs from these two simulations were also analysed to derive design water levels and velocities of specified return periods at the key locations under these conditions.

Twelve model runs were also carried out using the 1988 flood event boundary conditions, in order to determine the sensitivity of maximum water levels in the Brahmaputra to different BRE set-back distances with and without the Jamuna Bridge and under different degrees of confinement of the river. Two additional runs based on the 1988 event were made with two different Jamuna Bridge lengths to quantify the sensitivity of river water levels to the degree of local constriction.

The additional runs carried out during the period January to March 1992 are summarised in Table 1.1.

2. SUMMARY OF WORK LEADING TO THE SECOND INTERIM REPORT

2.1 Setting up 1-D Model of the Brahmaputra River

2.1.1 Model Description

BRTS created two versions of the model to represent the Brahmaputra River: the main more detailed model, which was based on the 1986/87 cross-sections and the second verification model based on the 1988/89 cross-sections for which there were fewer cross sections available.

The Brahmaputra River model was built within the overall structure of the SWMC General Model (GM1) (See Figure 2.1). The Brahmaputra channel was represented by cross-sections at approximately 4 km intervals compared with 6 to 15 km in the General Model. This decrease in the interval between successive cross-sections allowed a more accurate description of flood water profiles along the Brahmaputra than was possible using the General Model. It also reduced the influence of an individual cross section on water levels, which was particularly relevant given the high degree of variability in cross section properties. The extent and boundaries of the BRTS 1-D model are illustrated in the schematic shown in Figure 2.1. Table 2.1 details the locations of each boundary condition shown in this figure.

The advantage of building the BRTS model within the overall structure of the SWMC General Model was that the structure automatically provided the downstream boundary conditions for the Brahmaputra and its distributaries. GM1 extends well downstream of the river channels of interest to BRTS and also models flow across the left-bank floodplain using a quasi-two dimensional network of channels and floodplain cells.

The Brahmaputra is represented in the model as a single compound channel, bounded by the braid belt of the river, and constructed on the basis of cross-section survey data. This approach provided satisfactory representation of conveyance at the high flows of relevance to this study as demonstrated by the test carried out by BRTS for a 45 km reach of the Brahmaputra between Chandanbaisa and Sirajganj and reported on in the First Interim Report.

To verify the model a second version of the model was built using the 1988/89 cross sections on which the same hydraulic roughness to stage relationship at each cross section has been used as in the calibration.

2.1.2 Data Requirements

The following types of data were used in the construction of the 1-D hydrodynamic model:

- river channel and flood plain cross sections
- measured discharges
- observed water levels
- field measurements in Test Area 1 and 2

Data sources have been described in the BRTS Inception Report.

Topographic Data

BWDB Morphology Division annually measure cross-sections across the Brahmaputra, usually at a spacing of 8 km but during 1986/87 this interval was reduced to approximately 2 km. The annual cross-section survey of the river is referenced from permanent pillars situated on either the right or left bank and the section line traverses across the river on a fixed compass bearing.

The location of the cross-sections relative to eastings and northings was not determined to an adequate standard at the start of the study, and so a survey programme was implemented.

The main objectives of the 1-D modelling were: (a) to carry out comparative runs to assess the potential impact of future changes to the river, such as the effects of confinement (b) to provide design water levels with confidence limits for the design of short-term works and to check the adequacy of the existing BRE crest levels (c) to provide boundary conditions for the North West out-of-bank model and the 2-D model and physical modelling.

For this purpose the date of the cross-section data was less important than the spacing between the cross-sections and so it was agreed that the cross-sections surveyed in 1986/87 would be used, as an extensive survey programme during that year had collected sections at approximately 2 km intervals. The more recent 1988/89 cross-sections, which were surveyed at approximately 8 km interval were used for verification of the model, as described in Section 3.8.

As part of the morphological studies BRTS collected approximately 700 cross section surveys covering the period 1965-1990, which have been digitised by BRTS and entered into a database.

Discharge Measurements

The only site at which discharges are regularly measured on the Brahmaputra-Jamuna is at Bahadurabad Transit (Gauge no 46.9.L). Uninterrupted data was available for the water years 1986-89 which covered the periods used for calibrating and verifying the 1-D hydrodynamic model.

Daily discharges at Bahadurabad are published by BWDB, for observed daily water levels. They are determined via a rating curve for Bahadurabad Transit which is constructed at the end of each flood season.

Water Levels

Water levels on the Brahmaputra are measured daily by BWDB at eighteen sites.

2.1.3 Survey Work

To set up the model so that it could be considered to be satisfactorily representative of the river two key items of data were verified on site.

- Location of survey cross sections
- Location of Water Level gauge sites.

Position of Survey Cross Sections

To establish a satisfactorily representative 1-D hydrodynamic model of the Brahmaputra River the reference position of the river cross-sections needed to be defined in terms of eastings and northings. Each of the cross sections surveyed by BWDB have a permanent pillar situated on the left or right bank which is used as a starting reference point whenever a cross section is to be surveyed. The bearing of the survey traverse relative to grid north remains the same each year and so establishing the position of the permanent pillars defines the location of the crossing.

As described in Annex 1 of the Second Interim Report, the locations of the pillars were determined by a site survey. The positions of the survey cross sections were recorded on a set of 1:50,000 plans and are as shown on Figure 2.2.

Water Level Gauge Sites

All the gauge sites used in the calibration of the model were visited and the correct easting and northing established.

GPS position fixing equipment became available from May 1991 and was used to establish these locations to within an accuracy of ± 100 m. Prior to this time the gauge sites were fixed by referencing the gauge to an item on site which could be located on aerial photographs; for instance the corners of buildings. Using this information it was possible to refer to the photographs and the BRTS 1:50,000 base plans to fix the position of the gauge site to within ± 100 m. The grid coordinates of the gauge sites are shown on Table 2.2.

Quality Control Procedures

Data received with the General Model (GM1) such as river cross-sections, catchment runoff (NAM results), discharge time series and observed water levels, had already been through certain quality control procedures implemented by SWMC.

Further quality control checks were carried out by BRTS on this data and the additional cross-section data in the BRTS models. These included:-

- Visual checks on the cross-section raw data file that the file agreed with the graphical plots contained in the BWDB survey record books

- A check that all cross-sections were entered in the database with the lateral offset distance increasing from left to right thus ensuring the correct definition of right and left bank top levels on each cross-section.

- A check that effective bank top levels were correctly identified - in the case of the right bank this was the crest of the BRE, and on the left bank a flood embankment (where one exists) or the natural floodplain level.

- In cases where the BRE did not appear on the cross-section, the right bank floodplain was extended at a representative elevation for the distance up to the BRE, and the crest elevation of the BRE was then marked on the cross-section.

- Checking the location of gauges and certain river cross-sections as described in section 2.3.2.

- Screening and appraisal of the historic discharge data at Bahadurabad. (Discussed in the hydrology Annex of the First Interim Report).

- Screening and appraisal of the observed water level data along the Brahmaputra. (see Hydrology Annex of First Interim Report).

FAP-25 have also undertaken detailed reviews of the water level and discharge data at Bahadurabad and the other gauge sites being referenced by BRTS.

2.1.4 Schematization

As described in the First Interim Report the river network was represented as a composite channel network. Runs carried out in February 1991 using a network schematization of a typical major anabranch system indicated that for a 1-D model it was reasonable to use this approach; the 1988 flood water levels simulated by the network representation, at Kazipur, mid way down the test reach, were compared with those generated by representing this reach as a compound channel. In both cases, the simulated water levels matched the observed 1988 levels during the flood season (mid May to mid October) equally well.

The above test showed that although differential low flow levels in individual anabranches may be modelled more accurately using a network of anabranch channels, this more detailed schematization made no significant difference to the results at the high flows which were of concern to the work being carried out by BRTS.

2.1.5 Boundary Conditions

Figure 2.1 and Table 2.1 show the schematic for the model including the location of the HT (Head-Time boundary) and QT (Flow-Time boundary) boundary conditions.

During calibration and verification the model was run using boundary conditions for the two flood seasons 1988/89 and 1989/90, although for the application run used to consider breaches in the BRE, boundary data was required for the full period 1986 to 1990.

2.1.6 Re-calibration

The model containing the 1986/87 cross-section data was initially calibrated during March 1991, although at that time it was recognized that final calibration could not take place until completion of the survey work. Following completion of the site survey the correct position of the morphological cross-sections used in the 1-D model were established.

The calibration of the 1-D hydrodynamic model was completed after carrying out fine adjustment of the roughness coefficients. A rational approach to the calibration procedure was taken with the "n" or "N" profile at each cross section taken to vary linearly with stage from a roughness value at the low flow condition up to a second value at bankfull; during the calibration runs only these two values were adjusted. Given the high degree of variability between sections it was considered inappropriate to have a more complex variation in roughness values and this is consistent with the approach taken by other FAP studies.

Resistance factors N ($=^1/_n$) used for the Brahmaputra varied within the range 31-50 at bankfull conditions and 20-40 at low flows (Table 2.3). The model performance was compared against the 1988 observed water levels at Chilmari, Bahadurabad (T), Mathurapara, Kazipur, Sirajganj, Mathura and Teota and produced a good fit for the gauge sites on the right bank. The match at Bahadurabad , the only station on the left bank, was less good, however, with the model predicting a higher level than that recorded at the station. The mis-match can be explained in terms of a combination of three factors:-

- over-estimation of the input boundary flow, (i.e. errors in flow gauging)
- datum inconsistency between bench marks on the left and right banks,
- local datum transfer error at Bahadurabad

To investigate the sensitivity of the river network to a variation in flow the model was run with up to 20% less flow; this indicated that a reduction in flow of approximately 15% would be sufficient to result in a good match between the modelled and observed levels at Bahadurabad. This flow adjustment was within the estimated confidence limits for the gauging at Bahadurabad (see First Interim Report).

2.1.7 Verification

The verification of the BRTS model was carried out using the 1988/89 cross-section data which covered the Brahmaputra at a spacing of approximately 8 km.

To verify the BRTS model the roughness values used were the same as in calibration model at the same level. The model was then run using the hydrographic input data for the year 1989/90.

Comparison of the observed and modelled water levels at Chilmari, Mathurapara, Kazipur, Sirajganj and Mathura gauge sites were made because of availability of 1989-90 water level data. The model performance was good at Kazipur and Sirajganj. However as reported earlier (Second Interim Report, Annex 2) the model performance was not as good at Chilmari, Mathurapara and Mathura. As Mathura is within the backwater influence of the Ganges, the water level at Mathura was dominated by the Ganges and not by the roughness coefficients chosen during the calibration of the Brahmaputra River. At the other two gauge sites the likely cause for the less satisfactory performance of the model was the large variability in two sets of cross-section data surveyed in 1986-87 and 1988-89; when calibrating the model the roughness coefficients chosen for use in the model also effectively took into account how well the chosen cross sections represented each reach. As the verification model used a different set of cross sections, at a large spacing of 8 km, a poorer match would have been expected than for the calibration model. Given these factors and also the potential errors in gauge readings the differences were considered to be within expected limits and the verification of the model was considered satisfactory for the purposes of the BRTS study.

2.2 Setting up 1-D Model of the Right Bank Flood Plain

2.2.1 Background

The economic assessment of alternative strategies for providing flood protection to the right bank flood plain is given in Annex 6 of the Second Interim Report. To determine the extent, timing and duration of inundation due to breaches in the BRE, BRTS, in conjunction with FAP-2, used the Brahmaputra River model and an out of bank version of the North West Regional (NWR) model.

SWMC initially set up and calibrated a series of disconnected sub-models which were brought together by FAP-2 to form the NWR pilot model. A "cut-down" version of this model, covering the area of interest to the BRTS study, was used as the core of the model to study flooding to the west of the BRE. As the pilot model was an in-bank model the first task for BRTS staff was to include floodplain details from data being prepared by SWMC.

2.2.2 Model Description

<u>The River Network</u>

The in-bank model used in the study was a "cut-down" version of pilot model developed by SWMC and FAP-2 which includes the major river channels of the North-West region. The model includes part of the Ghagot, Karatoya and Baral river network and the full length of the Bangali and Ichamati with a link channel located upstream of Gaibandha connecting the Ghagot with the Karatoya. To this model BRTS added flood plain data so that the model could simulate flooded areas. Figure 2.3 shows the model schematic.

The cross-section data used in the model were those prepared by SWMC in a series of sub-models which were later brought together by FAP-2 as the pilot model. This model has been upgraded by SWMC to include additional cross sections and floodplain information. The pilot model was considered adequate for this purpose however as the output from the model was primarily for use in the economic analysis which was more concerned with the change in flooded area due to breaches rather than absolute values.

To represent various breach scenarios (described in more detail in Section 2.4) a series of link channels were established between the respective breach sites and the channel network. When a breach occurs in the BRE the flood wave moves downstream and, depending on local topography, causes flooding both in the vicinity of the breach and, after entry into the Ghagot-Karatoya-Bangali system, additional flooding further downstream. There can also be limited flooding upstream of the breach site within the backwater influence of the raised water levels. The links between the breach sites and the river network were approximated as wide shallow channels; this was considered to be a reasonable representation of the overland flow observed to occur in practice and noted during a site visit in September/October 1991 (Section 2.2). Flow velocities recorded during the breach runs (Section 2.4) also confirmed that although local scour may occur at the breach site in hydraulic terms the conveyance of the channel is correctly represented as a wide channel based upon existing topography.

NAM Catchments

The North West model included 20 sub-catchments as defined by SWMC/FAP-2 covering the Ghagot-Karatoya-Bangali system. The runoff contributions from these catchments were previously generated by SWMC/FAP-2 using the MIKE 11 NAM model. BRTS received the computed inflow hydrographs from FAP-2 and used these as direct inputs to the hydrodynamic model. In some cases the inflow is at a point node and in others it is represented as a distributed inflow.

2.2.3 Data Requirements

Channel Topography of the Ghagot-Karatoya-Bangali System

The channel cross-section data used in the model were compiled by SWMC from a variety of sources. Most of the topographic survey work was undertaken by BWDB either as part of a routine programme to collect data on the rivers or for specific projects.

The link channel used to investigate the various breach scenarios was detailed as a wide shallow channel connecting the breach location with the Ghagot-Karatoya-Bangali system. The level data used to represent the channel was derived either from field visits or from 4 inch and 8 inch to the mile topographic maps which contain spot heights and contour levels.

Flood Plain Topography

The pilot model received by BRTS did not include river flood plains. SWMC however compiled flood-plain data for inclusion in the updated North West model. Stage-area curves were prepared for each of the flood cells attached to the nodes included in the model. To determine the stage-area relationship, spot levels on the flood plain were taken from the 1 km grid of spot levels derived by MPO and the information then processed by a program written by SWMC.

Boundary Data

The flow and head boundary data used in the model covering the years 1986 - 1990 were those used in the calibration of the pilot model and were provided by FAP-2. Inflow data included records from gauge sites and hydrographs derived from running the NAM model.

1986-89 boundary water levels at the BRE breach sites were simulated by running the Brahmaputra River model for the same time period and outputing the level data at the nodes adjacent to the breach site.

2.2.4 Flood Cell Definition

SWMC determined stage-area relationships for the flood cells considering each flood cell to be part of the respective cross-section contained in the North West model. The flood cell definition was prepared using the schematization of the upgraded model which contained additional cross-sections to those used in the pilot model.

To determine the floodplain levels to be attached to each cross-section the appropriate stage-area curve for the section was chosen and converted to a stage-width plot by dividing by the cell length. The stage-width profile could then be added to the in-bank cross-section data to represent the floodplain for that section.

Inevitably when producing an average floodplain profile the start of the floodplain does not exactly coincide with the levels of the edge of the in-bank cross section. It should, therefore, be expected that some minor adjustment of the levels would be necessary to eliminate unrealistic steps in the composite section. In practice, however, it was found that a number of areas within the model had a mismatch which was far too large and the reason for this anomaly needed to be investigated. Two checks were carried out to verify the floodplain stage-area curves:-

- The stage-area characteristics of a number of the flood cells were cross-checked against 8 inch/mile maps. By using the spot heights a stage-area curve for each flood cell was constructed and compared with the stage-area curve received from SWMC. In each case the curve matched well indicating agreement.

- Stage-area curves for all flood cells used in the model were also plotted on a common graph and these showed an internal consistency.

Both FAP-2 and SWMC indicated that there appeared to be persistent problems with the accuracy of bench marks used to tie the cross-sections into Public Works Datum (PWD) and so it seemed more likely that the mismatch was a datum error with the survey of the cross-sections.

2.2.5 Site Survey of Flooded Area

As part of BRE inventory survey the location and extent of breaches in the BRE along the length of the Brahmaputra were identified on the ground. During August 1991 a separate field visit was carried out by BRTS staff in conjunction with FAP-2 to identify the nature, cause and magnitude of flooding.

Since retired embankments had not been constructed in the reach of the embankment between Sariakandi and Sirajganj at the time of the survey, the survey activities concentrated within this reach as the extent of flooding could still be observed. During the field survey the location of breaches in this reach and the inter-connections with the Bangali/Ichamati river were identified. A qualitative assessment was also made of the damage caused by flow through the breaches to the strip of land between the Brahmaputra and the Bangali/Ichamati. Additional information was collected on the impact that the flooding had on agricultural practices by interviewing local residents and also through observation.

Breaches in the BRE at Mathurapara and Simla were visited and the alignment of the channels connecting the Brahmaputra with the Bangali/Ichamati were defined by using the GPS position fixing system. The hydraulic geometry and discharge of the link channel were estimated in the field.

Interviews carried out at Mathurapara indicated that the BRE is breached during most years. At this time the Bangali river at this point was approximately 2.5 km away from the breach site and there were at least two well defined shallow channels connecting the Brahmaputra with the Bangali river. The estimated flow through the link channel was about 1200 m^3/s.

2.2.6 Calibration

Preliminary Calibration

The preliminary calibration of the sub-models which comprised the pilot in-bank model was carried out at the SWMC. This calibration of the hydrodynamic model was for the 1990 flood season for which data had been collected specifically by SWMC while the calibration of the NAM model was for the period from 1986 to 1990. SWMC's preliminary calibration used a hydraulic resistance coefficient which varied with flow depth. FAP-2 later modified the SWMC preliminary calibration by using a constant roughness coefficient on the basis that field data were not sufficiently reliable for a more sophisticated allocation of roughness coefficients.

At some sites the water level predictions by the in-bank model were incorrect throughout the year, with the model simulations lying consistently above or below the observations. Another likely source of error, therefore, which seemed to be confirmed by BRTS observation that the cross-sections levels were not in agreement with floodplain data, was that there is an error in the datum referenced by the cross-section surveys.

Modified Calibration

Once BRTS had included the floodplain in the model it was re-run to check the calibration of the model during the 1990 flood season.

It is likely that the datum referenced at the gauge sites was the same as that picked up when surveying the cross-sections used in the model. As detailed in Section 2.2.4 the cross sections were adjusted in the out of bank model to agree with the floodplain data. It was to be expected, therefore, that the observed and modelled stage hydrographs would differ by an amount of the same order of magnitude as these shifts in datum.

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Although the modelled against observed levels differed substantially, the shape of the stage hydrograph in each case compared reasonably well indicating that if the change in cross-section datum was taken into account then the match could be considered reasonable.

The application of the model by BRTS was to compare differences in flooded areas at the master planning level. The model was considered to be adequate for this purpose.

2.3 Application of 1-D Model of the Brahmaputra River

2.3.1 Objectives and Approach

The hydrodynamic model of the Brahmaputra River was used by BRTS to investigate flows and levels in the river and, in conjunction with the NWR model, to determine the consequences of the BRE being breached at different locations.

Steady state runs of the model were used to determine boundary conditions for the 2-D and Physical modelling. Output from a 25 year (1964-1989) run of the SWMC GM1 model, which was carried out by FAP-25 (Run 2), was also analysed to determine the "construction window" which can be expected for the different activities involved in undertaking construction work at the sites selected for implementation of river bank protection measures in the short term, (Phase 1).

2.3.2 Determination of Construction Windows at Phase 1 Locations

Background

A key consideration to the contractor when preparing his method of work, and therefore of primary consideration when costing the tender submission will be the "construction window" that can be expected for the various activities involved in undertaking the work. The window will be determined by the number of days during which water levels and velocities are below set limits; for instance it would be impracticable to lay geotextile fabric under water when current velocities exceed 1.5 m/s.

The sites selected for early implementation (Phase 1) are as follows:

- Fulcharighat
- Sariakandi
- Mathurapara
- Kazipur
- Sirajganj
- Betil

Of these, three, Sariakandi, Mathurapara and Sirajganj, have been included in the River Bank Protection Project as Priority Works.

Methodology

The 1-D hydrodynamic model of the Brahmaputra River prepared by SWMC was used by FAP-25 to simulate the water levels and average current velocities at each cross section for the period 1965-1990, excluding the 1971/72 season; during this period there were records of the flow and head boundary conditions required for input to the model. BRTS used the output from the model to carry out a statistical analysis from which to establish the probability of either the water level or current velocity remaining below a prescribed limit for different durations for the Phase 1 sites.

The data from the MIKE 11 model run was analysed within a dBase IV file structure using programs written specifically for the purpose. To export the data from MIKE 11 the output data was transferred as a text file and imported into a database file structured to contain fields for time, water level and flow. Unfortunately average velocities were not saved during the MIKE 11 run. It was, however, possible to derive this information from an analysis of water level, flow data and cross-sectional data as described at the end of this section.

A program was written to analyse the water level and flow data at sections which either directly corresponded to, or were adjacent to, a Phase 1 location.

Figure 2.4 illustrates the steps involved in the analysis of the data to determine the likelihood of a construction window of specified duration occurring in a typical year. The steps included in the analysis were:

- export data from MIKE 11 as a text file.

- Create database files of suitable structure to contain MIKE 11 data. One file contained information on water levels at the specified sections and a separate file contained details on flows

- Import data from the text file exported from MIKE 11.

- Step through the file for each location and determine the duration of the construction window below a series of levels for each year. Output the data to a separate database file

- Re-order the data so that the years appear in ascending order of the duration of construction window.

- Taking the 25 years water level record as being representative of levels in the river the probability of each duration being exceeded was then calculated, the probability of exceedance was determined as:

  First year 100 %
  Second year 96 %
  (100 - 1 x 100/25)
  Third year
  (100 - 2 x 100/25) 92 % ..... etc.

- Plot for each node the family of curves which show the probability of a construction window.

The average velocity at each time step was determined by computing the flow and cross section area at each time step. The stage-area relationship was known at each cross-section and so it was possible to

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determine the cross-sectional area at a given water level. This in conjunction with the flow occurring at the same time step gave the average flow velocity.

A stage against flow plot for each of the sites showed that, other than for Betil where there is a backwater influence from the Ganges River, there is a practically constant rating curve at each of the sites. Given this unique relationship between stage and flow it was therefore possible to attribute an average velocity which corresponded to each of the stages shown on the plots.

Results

The results of this analysis have been recorded as a series of cumulative probability plots at each site. Curves for Sariakandi and Sirajganj are presented in Figure 2.5. Included on the plots is the average velocity which corresponds to each water level.

The velocities which occur adjacent to the construction works will be greater that the average velocity at that point in the river. The ratio of near bank velocity to average velocity estimated as part of the physical modelling programme (see Draft Final Report Section 4.6) has been applied to obtain representative values for the sites. The average velocities derived from this work are based upon only one year of cross section data and so may not represent the worst case that can occur at a particular site.

2.3.3 Boundary Conditions To Investigate Breaching of BRE

To determine the extent, timing and inundation of flooding as a consequence of breaching of the BRE an out of bank version of the North West Regional (NWR) model was run (Section 2.4) using Head-Time (HT) boundary conditions generated by runs of the BRTS model of the Brahmaputra River.

Flow and boundary conditions for the Brahmaputra River Model, covering the years 1986-89, were collected from SWMC and FAP-2 and used as input data to the model. This was then run for the full period with stage-time outputs generated at the nodes adjacent to each site for use as HT boundary conditions in the NWR model.

2.3.4 Investigation of the Effect of the Jamuna Bridge Construction

Methodology

The effect on water levels and morphology in the Brahmaputra from the proposed construction of the Jamuna Bridge have been investigated using both the 2-D morphology modelling system and the 1-D hydrodynamic model. The 2-D model has been used to estimate local changes in water level and scour which will take place in the vicinity of the bridge while the 1-D model was used to provide boundary conditions for the 2-D model and to determine the extent of the backwater influence.

The alignment of the proposed Jamuna Bridge and the position of the guide bunds were taken by reference to the JMBA report. The upstream and downstream edge of the guide bunds are located at BRTS chainage

168.50 km and 170.75 km and the distance between the guide bunds are 5.25 and 4.50 km at the upstream and downstream ends.

To represent the constriction due to the construction of the bridge new cross-sections were generated at chainages 168.50 and 170.75 km using the existing sections modified to allow for the reduced width. These modified cross-sections were included in the cross-section data base of the calibrated model with the channel roughness coefficients set to have the same distribution relative to stage as in the parent cross-sections.

Once the cross-section database was created the model was used to simulate 1988 flood conditions in the Brahmaputra using the 1988 boundary conditions both with and without the closure of the upper off-take channel of the Dhaleswari near Bhuapur.

Results

Simulated 1988 maximum flood levels with and without the proposed Jamuna Bridge are shown graphically in Figure 2.6, which illustrates the backwater effect of the bridge. Approximately 2.0 km upstream of the Bridge the maximum water level with the bridge in place is approximately 0.3 m higher than without the bridge. The backwater effect of the bridge reaches to Mathurapara but is less than 0.05 m upstream of Chandanbaisa.

Average maximum simulated velocities with and without the bridge were compared and it was found that the maximum average velocity at the bridge section could be 2.24 m/s which is an increase of 0.8 m/s.

The simulated 1988 peak flow passing through the upper Dhaleswari off-take channel near Bhuapur increased from 2,600 m3/s to 3,250 m3/s after construction of the proposed bridge. Closure of the off-take channel would have only a minor effect on flood levels in the Brahmaputra.

2.4 Application of 1-D Model of the Right Bank Flood Plain

2.4.1 Objectives

The objectives of the 1-D hydrodynamic model of the right bank flood plain were to determine the impact on the area of flooding due to breaches occurring at different locations in the BRE. The change in flooded area due to breaching was used in the economic analysis, reported in Annex 6 of the Second Interim Report.

2.4.2 Approach

A large number of breach scenarios could occur in the BRE with the magnitude of flooding depending primarily on breach location and the local topography. It is possible, however, to divide the area into zones with similar conditions for which a single breach is representative. In choosing these zones consideration was given to:

- topography
- proximity of significant rivers to the breach
- Breach history

The drainage behind the BRE changes from a pattern which is towards the Brahmaputra in the north to one which drains away from the river in the south and this has a major influence on flood flows.

The over-riding cause of BRE failure is due to erosion from the Brahmaputra River itself. Six "typical" breach locations were chosen to represent areas with a similar risk of attack from the Brahmaputra River and also similar consequences of failure as described in Section 2.4.3.

As part of the BRE walk-over survey the location of breaches in the BRE were identified and records of breaches in the BRE were collected from different BWDB sub-divisions.

Alignment of link channels connecting the breach locations with the Ghagot-Karatoya-Bangali system were determined from old 1:50,000, 4 inch and 8 inch to a mile maps, SPOT imagery, aerial photographs and field surveys. Link channel cross-sections were either measured at the field or estimated from the map information.

To determine the influence of each breach site on flooding the model was firstly run with the BRE intact as a "base case" and then for each breach scenario. The flooded area for each breach was compared to the base case to determine the incremental change. A final run with all 6 breach sites was also run to illustrate the effect of minimal protection from the BRE.

Boundary water levels for each of the breach sites for the period 1986-89 were simulated by using the BRTS 1-D calibration model for the Brahmaputra.

Breaching in the BRE generally occurs during the period June-October and can cause severe damage to field crops. It is also known from agronomic studies that flooding of less than 10 days duration does not severely affect the crop production.

Having run the model the output was post-processed, using a program written by BRTS staff, to determine the average 10-day water level at each node. This data was then used to derive the 10-day average flooded area by reference to the stage-area curve for each cell. A comparison of the time-flooded area tables for each breach scenario and the "base-case" gave the increase in flooded area due to each breach.

2.4.3 Selection of Breach Locations

Existing breach locations in the BRE were identified during the BRE walk-over survey in the period May 1990 - April 1991. Also, history on the retirements of the BRE were collected from various O & M Sub-divisions of BWDB. Based on this information and considering the topography, drainage pattern, morphology and erosion potential of the Brahmaputra right bank the BRE within the study area was divided into eight zones. Only six zones were modelled because the topography of two zones is such that flood flow would not normally enter the Bangali/Ichamati river system.

2.4.4 Modelling of Breaches

Once the breach sites were selected the topographical data for each link channel was collected and stored in the cross-section data base of MIKE 11. A separate river data file including the link channel was created for each breach site and the system file was stored for each site.

1986-89 boundary conditions for the six breach sites were stored in the boundary data base of MIKE 11 and a separate boundary system file was created for each breach site. Individual simulations were made for each breach site with time step of 30 minutes and results were stored at 48 time steps.

A composite breach simulation was made assuming all six breaches in the BRE to occur simultaneously. The time step and storing of results were kept the same as the individual breach simulation.

2.4.5 Results

Maximum simulated flows through the breaches were compared for the period 1986-89 for the six sites Fulchari, Mathurapara, Kazipur, Simla, Sirajganj and Betil. This gave a good range of conditions varying from the virtually direct connection between Brahmaputra and Bangali at Sariakandi/ Mathurapara (Figure 2.7) and the substantial overland distance traversed by flows through a breach in the vicinity of Fulchari. The significance of the breach in terms of the distance upstream was also clearly shown with the increased flood inundation depth and duration due to the breach at Betil being almost negligible in comparison to that due to breaches further north.

As expected, the highest inflow into the North-West river system was due to a breach in the BRE at Mathurapara. This was because the breach site was located only 2.8 km from the Bangali river and there was a well defined channel linking the Brahmaputra and the Bangali. Moreover, in response to the differential hydraulic head between the Brahmaputra and the Bangali the likelihood of a very wide breach developing in the BRE could not be discounted. The peak flow of 1,500 m^3/s under the 1988 flood condition compared with the estimated flow observed during 1991 of 1,200 m^3/s indicated that the model was giving reasonable values.

The second highest inflow to the Ghagot-Karatoya-Bangali was simulated in 1988 through the breach at Kazipur, about 1350 m^3/s. At the other end of the range flow through a breach at Betil was 475 m^3/s. The outfall of the link channel connecting the breach site at Betil and the Bangali was under backwater influence of the Brahmaputra and so the differential head was less than further north. Flows for the other locations are given in Table 2.4.

In general, the maximum inflows through the six locations were broadly consistent in terms of the topography, location and length of existing link channels and the hydraulic head between the Brahmaputra and the Ghagot-Karatoya-Bangali system. The resulting water levels were post-processed to derive maximum flooded area at each cell location for each breach scenario.

Breaches occurred in 1988 and channels were not eroded at that time. Analysis of the model results indicated that the maximum average velocities through the link channels were generally very low and did not exceed 0.2 m/s. This confirms that little erosion would take place other than in the locality of the breach site and that therefore the simulation of a wide shallow channel was a reasonable approximation to what occurs in practice.

3. 25 YEAR RUNS OF BRAHMAPUTRA RIVER MODEL

3.1 Objective and Approach

In the context of BRTS specific objectives to be fulfilled by the 25 year runs were as follows:

- to produce water levels and velocities for design of river training works with and without the proposed Jamuna Bridge and Brahmaputra left bank confinement by FAP-3.

- to determine effect of confinement of the Brahmaputra by the JMB and the FAP-3 Brahmaputra left bank proposal.

- to estimate the range of variation in char inundation because of the confinement schemes.

As recommended by FAP-25, design water levels for future development schemes were derived from statistical analysis of simulated water levels using 25 years of historical hydrographical data (1965-89). As discussed in section 1.2, three 25 year simulations were made using the BRTS 1-D model for the Brahmaputra River. The first 25 year model run with the current BRE location and left bank condition was made after final calibration and verification had been completed to the standards set by FAP-25.

3.2 Setting Up the Model

3.2.1 General

Setting up of the 1-D hydrodynamic model has been described in Section 2.1.

3.2.2 FAP-25 Modifications

The FAP-25 version of the SWMC General Model and the BRTS 1-D model of the Brahmaputra River use common inflow boundaries in model simulations, which are as follows:

- Teesta inflow represented by daily discharge at Kaunia

- Brahmaputra inflow represented by daily discharge at Bahadurabad Transit with a lead time of 8 hours.

As BWDB usually apply a systematic shift correction which tends to amplify measurement errors in the process of generating mean daily discharge data for Bahadurabad Transit and Hardinge Bridge, FAP-25 collected measured discharge data for the 25 year period of the two stations and computed revised annual rating curves. These revised rating curves were applied by FAP-25 to derive revised daily discharge time series from measured (BWDB) and corrected (FAP-25) daily water levels for the two stations.

Inflow time series data for the 25 year period of the rivers Teesta and Brahmaputra were collected by BRTS from FAP-25. Also collected from FAP-25 were the simulated outputs from their Run 5 as shown in Table

3.1.

3.2.3 Modifications to the Brahmaputra River Model

FAP-25 found that by the representation of the Teesta as a flow/time boundary it was possible to run the base model of Brahmaputra River with a time step of 2 hour, without loss of quality.

This provided a considerable improvement in model performance and a similar approach was followed for this study.

In order to run the base model for a 25 year period with daily time series boundary data it is necessary to split the 25 year simulation into more than two sub-groups. FAP-25 ran the model for the 25 year simulation in 5 year blocks. As MIKE 11 cannot run simulations in batches, once a simulation for one 5 year block is complete it is necessary to set up the model for the next 5 year block. In doing so it usually takes a long time to complete a simulation for the full 25 year period. In addition handling of time series output for various analyses becomes cumbersome and time consuming. Moreover, storing of results of the full hydrological year (ie 1st April - 31st March) requires more available blank space in the magnetic media. Considering all these limitations and fulfilling overall objectives of BRTS 25 year model runs, 15 May - 15 November boundary time series data of each year except 1971 (for which boundary time series data is not available) were joined together in some relative time scale to provide daily time series data continuously at the model boundaries of the Brahmaputra River. This approach allowed completion of each 25 years simulation in one set up of model run. Moreover, handling and processing of time series data are more efficient with this approach.

Besides the Brahmaputra River there are many rivers used in the model for which storing of simulation results are not relevant to BRTS. Even in the case of the Brahmaputra River it is not usually necessary to store simulated results at each node of the river. MIKE 11 supports storing of simulated water level and discharge at pre-selected nodes of the river network used in a simulation. This facility makes it possible to curtail the size of the simulation results file when it becomes necessary. Pre-selection of sections for the Brahmaputra was done in such a way that the pre-selected sections uniformly covered the entire length of the river within the BRTS study limits. Reference gauging stations located outside the study limits but used in the calibration of the model were also selected for storing of results. Table 3.2 shows the sections selected for storing of simulated water level and discharge.

The pre-selection facility in MIKE 11 for storing of simulated velocity at selected sections is not as effective as that for water level/ discharge and accordingly all the three 25 year simulations were made without storing of simulated velocity.

Water level, discharge and stage area characteristics for each selected section for each 25 year simulation are stored in separate data bases. A program was then developed using dBase III to create a further data base for each 25 year run and compute and store velocity time series data for each selected section. Thus for each of the 25 year runs there are separate data bases which contain simulated water level, discharge and velocity time series data for the 25 year period (ie 185 x 24 = 4,440 records). Analysis of results for each 25 year simulation option can be done very efficiently after extracting the required data from the data base.

3.3 Calibration Check

As recommended by FAP-25, estimation of design parameters for future development schemes should be derived from statistical analyses of simulated parameters for the 25 year period (1965-89). To meet project objectives BRTS required design water levels and velocities along the right bank of Brahmaputra River at locations where the BRE was seriously threatened. It was therefore necessary to check that the 1-D model reliably represented extreme hydraulic conditions (ie. floods) for the 25-year period along the Brahmaputra right bank.

Simulation results from the 25-year model run using the existing BRE location and the current Brahmaputra left bank condition were compared with BWDB observed annual peak water levels at the reference gauging stations used by BRTS for calibration of their 1-D model. Brahmaputra comparison stations include Chilmari, Bahadurabad Transit, Mathurapara, Kazipur, Sirajganj, Mathura and Teota. Except for Bahadurabad Transit and Teota, all gauges are located on the Brahmaputra right bank. Teota is located near the Brahmaputra Ganges confluence at Aricha and hence is directly influenced by Ganges flow.

As shown in Figures 3.1 to 3.4 and Table 3.3 the average variance between 25-year observed and modelled annual peak water levels at the Brahmaputra right bank reference gauging stations is generally satisfactory. Average departures for the 25-year period at these stations lie within 0.10 m.

However model performance for the 25-year period is less good at the gauging stations located on the Brahmaputra left bank. This could arise from various combinations of datum and flow gauging errors.

During the calibration check of model performance for the 25-year period it was found that the observations at Bahadurabad Transit were inconsistent with observations from the other gauging stations; if Bahadurabad alone were considered then a much smoother channel would be required to bring the modelled water levels in line with observations; in fact a channel roughness set to the practical upper limit of Manning's n=0.02 would not be adequate to make observed and modelled values agree. The mis-match between observed and simulated water levels at Bahadurabad Transit can arise from a complex combination of three factors:

- mis-match between Brahmaputra left and right bank SOB bench marks
- incorrect transfer of levels from SOB bench mark to the gauge
- over-estimation of the Brahmaputra input boundary flow

Preliminary findings of FAP-18 indicate a potential difference of approximately 20 cm between Brahmaputra left and right bank SOB bench marks.

Inaccuracy resulting from incorrect transfer of levels from SOB bench mark to the gauge site is somewhat difficult to quantify as the location of the gauge at Bahadurabad is not fixed. The gauge has to be frequently shifted along or across the river to cover the entire range of variation of the stage hydrograph.

To investigate the sensitivity of the river network to a variation in flow at Bahadurabad, the model was run with up to 20% less Brahmaputra inflow; this indicated that a reduction in flow of approximately 15% would be sufficient to result in good match between the modelled and observed levels at Bahadurabad Transit.

On an average the model underestimated annual peak water level at Teota by 0.47 m for the 25-year period. Poor performance of the model at Teota can be explained by the discrepancy between Brahmaputra left and right bank datum levels plus any local datum error. To check this, model performance for the 25-year period was checked at Baruria Transit (Padma 7.5 km). The model performance at Baruria was found to be almost the same as reported by FAP-25 (Ref. Run 5). This indicates that there may be room for improving model performance at Teota by updating the calibration of Padma River but this falls outside the scope of the BRTS.

Chilmari, Bahadurabad, Kazipur, Sirajganj and Mathura are common Brahmaputra calibration stations of BRTS and FAP-25. In general, the average difference between observed and simulated annual peak water levels at Brahmaputra right bank gauging stations using the BRTS Brahmaputra 1-D River Model are lower than those reported by FAP-25 (Flood Hydrology Study, Main Report, June 1992). However the range of variation between observed and simulated annual peak flood levels at these gauging sites is usually higher than FAP-25 estimates. The higher range of variation in model performance in simulating annual peak flood levels could occur because of the approach followed in calibrating the model. The channel roughness values as used in FAP-25 - GM were chosen primarily to "shoe horn" the modelled water levels to agree with observed; this often led to an unrealistically large variation across a section and between adjacent sections; as the FAP-25 - GM Brahmaputra sections are at a larger spacing, each section had a greater impact on water levels than in the case of the BRTS model which has closer spaced sections. Moreover, a rational approach to the calibration procedure was followed by BRTS with the "n" or "N" (1/n) profile at each cross-section taken to vary linearly with stage from a roughness value at the low flow condition up to a second value at bankfull. Roughness beyond this level was assumed to remain fixed.

3.4 The Model Runs

In order to simulate water level and velocity in the Brahmaputra under different scenarios it was necessary to develop specific models to serve the purpose. For the three selected 25 year simulations three models were constructed. A base model was created first as described below:

(a) <u>Base Model</u>

The base model used for the 25 year simulation runs was the calibration model for the Brahmaputra River. The calibration model uses the 61 Brahmaputra cross-sections surveyed by BWDB in

1986/87. The river network used in the base model is exactly same as the calibration model except for the representation of the Teesta in the model. In order to achieve practicable run times for the 25 year run it was necessary to use longer time steps than is permissible for the calibration model. The modification that was adopted with this objective was to represent the Teesta, which is relatively steep and consequently requires a relatively short time step, as a lateral inflow to the Brahmaputra.

To confirm that this modification did not adversely affect the performance of the model a comparison was made using the 1988 flood event. It was found that there was no significant difference between the flows and levels predicted at various locations along the length of the river.

(b) Jamuna Multi-purpose Bridge (JMB)

The alignment of the proposed Jamuna Bridge and the position of the guide bunds were obtained from the JMBA design report (1988). The location of the upstream and downstream edges of the guide bunds are located at BRTS chainages 168.50 km and 170.75 km.

To represent the constriction caused by the bridge, new cross-sections were generated at chainages 168.50 and 170.75 km using existing sections JS-6 and J-6-1 with the overall width limited to allow for the reduced width. The effective bridge widths, excluding piers, which have been simulated are 4,608 m, (JMB design report) 3,600 m and 5,600 m. In each case the Northern Dhaleswari off-take at Bhuapur (ARD5) was assumed to be closed off (Figure 3.5).

The modified cross-sections have channel roughness coefficients which have the same distribution relative to stage as the parent cross-sections.

(c) Addition of Brahmaputra Left Bank Confinement in Accordance with the FAP-3 Proposal

The FAP-3 proposal for an extension of the Brahmaputra left bank flood embankment that was considered includes a partly existing embankment from the Old Brahmaputra to the Dhaleswari off-take (Figure 3.6), thereafter following the left bank of the Dhaleswari up to the Kaliganga Dhaleswari bifurcation point at Kalitola. The main Brahmaputra flood plain spillage channel (ARJAM) and its four linkage channels to the Brahmaputra at nodes ADR3, ARD4, ARD5 and ARD6 are cut off by the embankment and no longer carry flow.

3.5 Analysis of Results

3.5.1 Water Level

As recommended by FAP-25 log-normal distribution was fitted to the annual maximum water levels simulated in each 25 year run. Parameters of the distribution were estimated by the method of modified maximum likelihood as adopted by FAP-25. Fitting by this distribution is generally satisfactory.

Tables 3.4 to 3.6 show the maximum simulated water levels for each year from 1965/66 to 1989/90 at selected chainages along the Brahmaputra for the existing condition (BRE only), the BRE with Jamuna Bridge (4608 m), and BRE, Jamuna Bridge and Left Embankment as proposed by FAP-3. Table 3.7 shows maximum water levels at the same chainages for different return periods, for the same three sets of conditions, obtained by analysing the simulated annual maximum water levels for the 25 year period.

Figures 3.7 to 3.12 illustrate the impact on water level, for different return periods, as a result of constructing the Jamuna Bridge (4,608 m water opening) and thereafter the extension of the left bank flood embankment as proposed by FAP-3.

The impact of Jamuna Bridge construction is most marked over the 20 km immediately upstream, for example at Sirajganj, 6 km upstream, where the water level is increased by 43 cm for a 100 year return period. At Sariakandi, 55 km upstream of the bridge, the effect has virtually disappeared. Extension of the left bank flood embankment would have a greater effect, extending over the whole study reach, though diminishing to minimal at the confluence with the Teesta. Again, the effect is most conspicuous in the Sirajganj area, with a rise of 70 cm above the "with Jamuna Bridge" water level for a 100 year return period.

3.5.2 Velocity

EV1/GEV distribution was fitted to annual maximum velocity series simulated in each 25 year run at each selected locations. Parameters of EV1/GEV distribution were estimated by the method of probability weighted moments. EV1 satisfactorily fitted sample data of all selected sections except Ch. 205.15 km.

Tables 3.8 to 3.11 give the same details for velocity as tables 3.4 to 3.7 referred to in Section 3.5.1 above do for water level.

Figures 3.13 to 3.18 provide a similar comparison of the impact on mean velocity at representative cross sections, from which the effect of the reduction in area of the left bank flood plain available for flood attenuation can be seen in the relatively high flow which results downstream.

3.5.3 Frequency of Char Inundation

A similar analysis to that used for the computation of construction windows was used to investigate the frequency of inundation of chars for different depths and durations, both for the present situation and after the construction of a local constriction to the channel such as the Jamuna Bridge. The results for two locations, Kazipur and Sirajganj are illustrated in Figure 3.19. As would be expected, the impact at Kazipur is relatively minor. It should be emphasised that these changes represent the condition immediately after construction and before bed adjustment in the vicinity of the bridge has taken place; after one, or at most two seasons, the impact will be much reduced.

4. WATER LEVEL SENSITIVITY ANALYSIS

4.1 Objectives

A sensitivity analysis of Brahmaputra water levels attributable to various river engineering schemes is required for the evaluation of the impact of varying levels of intervention.

As noted in section 1.2, fourteen model runs were made using the 1988 flood event boundary condition to establish the sensitivity of water levels in the Brahmaputra to different BRE set-back distances with and without Jamuna bridge and for different degrees of confinement of the Brahmaputra. Combinations of these conditions that were simulated are presented in matrix form in Table 4.1.

The principal issues investigated were:

- sensitivity of Brahmaputra water level and velocity to BRE set-back distance under different degrees of confinement of the Brahmaputra left bank.

- sensitivity of water level and velocity distribution in the Brahmaputra to the width of the constriction to be created by the proposed Jamuna bridge, also with different degrees of confinement of the Brahmaputra left bank.

4.2 Approach

In order to simulate 1988 water level and velocity in the Brahmaputra River under these diverse project scenarios it was necessary to develop fourteen individual models. The base model developed for the 25 year run was used as the base model for 1988 runs.

The other models were then created by modifying the base model to reflect the proposed engineering schemes. These models can be classified into four distinct groups, as described in Section 4.3 below.

The same boundary data as described in Section 3.2.2 was used for all simulations. As such, 1988 boundary data used in the 25 year runs and the 1988 series of simulations are exactly the same. Moreover, the timestep and simulation periods for the sensitivity runs are the same as the 25 year model runs. As the size of result files for sensitivity runs are relatively small, water levels and velocities for all Brahmaputra models are stored for each simulation.

4.3 Runs of Model

(a) Jamuna Multi-Purpose Bridge (JMB)

The alignment of the proposed Jamuna bridge and the position of the guide bunds were obtained from the JMBA design report (1988). The location of the upstream and downstream edges of the guide bunds are located at BRTS chainages 168.50 km and 170.75 km respectively.

To represent the constriction caused by the bridge, new cross-sections were generated at chainages 168.50 and 170.75 km using existing sections JS-6 and J-6-1 with the overall width limited to allow for the reduced width after construction. The effective overall bridge spans, excluding piers, which have been simulated, are 4,608 m, (JMB design report) 3,600 m and 5,600 m. In each case the Northern Dhaleswari off-take at Bhuapur (ARD5) was assumed to be closed off (Figure 3.5).

The modified cross-sections have channel roughness coefficients which have the same distribution relative to stage as the parent cross-sections.

(b) Addition of Brahmaputra Left Bank Confinement in Accordance with the FAP-3 Proposals

The FAP-3 proposal for an extension of the Brahmaputra left bank flood embankment that was considered includes a partly existing embankment from the Old Brahmaputra to the Dhaleswari off-take (Figure 3.6), thereafter following the left bank of the Dhaleswari up to the Kaliganga-Dhaleswari bifurcation point at Kalitola. The main Brahmaputra flood plain spillage channel (ARJAM) and its four linkage channels to the Brahmaputra at nodes ARD3, ARD4, ARD5 and ARD6 are cut off by the embankment and no longer carry flow.

(c) Fully Confined Brahmaputra Left Bank

This extreme case was simulated to provide bounding values for impact quantification purposes. It is not envisaged that such confinement would ever take place in practice. In addition to a complete flood embankment, it was assumed that both the Old Brahmaputra and Dhaleswari were fully closed off (Figure 4.1).

(d) Variation in BRE Set-back Distance

The location of the BRE as represented in the calibration model was moved landward by first 2 km and then 4 km to assess the sensitivity of water levels and velocities to the set-back distance.

4.4 Results

Table 4.2 shows the percentage of the 1988 Brahmaputra inflow spilled through the left bank distributaries under the various project options listed in Table 4.1

Old Brahmaputra and Dhaleswari are the major left bank distributaries of the Brahmaputra. During flood significant flow is spilled through these two channels. Besides these two major distributaries there are a number of minor spilling channels in the left bank along the whole length of Brahmaputra River. Simulation studies show that as much as 34% of the 1988 Brahmaputra flood flow was spilled through the left bank distributary channels and, out of this 34%, half of the flow was conveyed by the minor spilling channels along the left bank.

Different Brahmaputra left bank confinement options include closure of some of the minor spilling channels to alleviate flooding on the left bank flood plain. The JMB proposal includes the closure of the northern Dhaleswari off-take at Bhuapur.

The maximum 1988 water levels simulated for the different engineering schemes listed in Table 4.1 are shown for all the BRTS 1-D model sections in Table 4.3. For easy reference, the maximum 1988 water levels for selected key chainages, including the Teesta confluence, Manas Regulator, the "short term" works locations and Jamuna Bridge (see also Table 3.11) are shown in Table 4.4. The water levels for these key chainages are shown graphically in Figures 4.2 to 4.7.

The effects of the various engineering schemes on the water level profile along the river are illustrated in Figures 4.8 to 4.11, which show the change in peak water level for the simulated 1988 event as compared with the base case representing the present conditions. The increase in upstream water levels resulting from the construction of Jamuna Bridge is evident in all four figures, the narrower the span the higher the levels (Figure 4.11). The reduction in water levels according to setback distance of the BRE is shown in Figures 4.8 to 4.10 and the increase in levels shown in Figures 4.9 and 4.10 indicates the very significant effect which would result from confinement of the left bank.

Tables 4.5 and 4.6 show the simulated 1988 maximum mean velocities for the different engineering schemes, at all the BRT 1-D model sections and at selected key chainages, respectively. The maximum mean velocities for the latter are shown in Figures 4.12 to 4.17.

Figures 4.18 to 4.21 show the increase in maximum mean velocity over the base case for all engineering schemes which include the Jamuna Bridge, and the velocity at the bridge site is seen to increase significantly with decreasing bridge width in Figure 4.21.

5. DESIGN WATER LEVELS

5.1 Objective

The objective of this part of the 1-D hydrodynamic model study is to assess the peak water levels at locations selected for river bank protection measures for the design return period, in this case 100 years.

Further, it is necessary to assess the degree of confidence which can be attributed to the peak levels so obtained, and to express this in terms of margin of error, or freeboard.

For construction purposes, it is important to establish low water levels as these will govern the construction methods to be adopted.

5.2 Approach

The standard hydrological design event is one with a 100 year return period. The definition of such an event has been derived by the Flood Modelling and Management Study (FAP-25) based on the data derived from a 25 year simulation using the MIKE 11 General Model. A closely similar approach was followed using the BRTS Jamuna model, which is a refinement of the General Model, to derive the design water levels at the priority locations with specified confidence limits shown in Table 5.1 (see also Section 5.3 below).

For the purposes of designing the Phase 1 Priority Works, it has been assumed that the Jamuna Bridge will be built and water levels modified accordingly. The levels selected correspond to Run-4 for the 100 year return period column of Table 3.7. No direct provision has been made for the possible construction of a left bank flood embankment because of the uncertainty as to its final layout and therefore its influence on water levels; however this possibility has not been ignored and the works have been designed to facilitate modification to accommodate such an increase in water levels when the need arises.

Low Water Level is defined as the lowest annual river level with a 50 percent probability of occurrence, corresponding to a simulated discharge of 2 year return period. For practical purposes the water level of greater relevance is that which will not be exceeded for a specific degree of probability over a reasonable construction period. For the design of the works this level has been taken as LWL+2m, which corresponds approximately to a 50 percent probability of exceedance within a 160 day window. In practice this means that there is a 50 percent probability that work can be carried out in the dry above that level over a continuous period of 160 days.

5.3 Confidence Limits

A key consideration when using predicted water levels from the mathematical model is to identify the confidence limits which should be applied to the levels and the additional safety margin to be added to the design freeboard of a flood embankment.

As a means of rationalising the assessment of potential errors, those data errors which influence the water levels predicted by the model at a site have been identified under five main headings as detailed in Table 5.1 Each of the six priority locations is considered separately:-

- Cross-section Data

  The main source of error which can occur is during the transfer of levels from the nearest Survey of Bangladesh (SOB) bench mark to the bench mark pillars which are referenced each year when carrying out the cross-section survey. The confidence limits shown on Table 3.6 have been determined by the distance of the SOB bench mark from the locality of the site. In the table the value for "likely" confidence limits is based upon second order levelling accuracy while those for "possible" confidence limits are based upon third order levelling.

  Other errors due to misalignment of the section, local survey errors and variability of cross-section are likely to apply only to individual cross-sections which would only have a minimal effect on predicted water levels.

- Water Level Gauges

  The errors which can occur at the gauge sites can result in the model being calibrated to incorrect levels:-

  - o The first three items shown on Table 5.1, "missing data", "static water level" or "reading error" are usually identifiable and screening the data should have eliminated these sources of error.

  - o Gauge levels are transferred from the nearest SOB bench mark and the confidence limits are based upon the traverse distance.

  - o Gauges are periodically moved as the water levels change and at this time two types of error can occur; a) the level of the gauge staff is incorrectly levelled. b) the gauge is relocated upstream or downstream of its recorded location. If there is a significant error this can usually be picked up as a step in the recorded level plot which is not reflected at adjacent gauge sites.

  - o Cross flows can result in differential water levels of 30cm under extreme crossover conditions. Inspection of each of the gauge sites referenced for calibration of the 1-D model shows that this flow condition is unlikely to occur at these sites.

- Assumptions in 1-D Model

  As shown in Table 5.1, a number of assumptions were made when setting up the model, each of which could influence the output from the model:-

  - o The use of constant Manning's "n" values for all seasons and the use of fixed cross-sections. This has, in practice, proved to be reasonable as shown with the 25 year run of the SWMC model carried out by FAP-25. The run showed that the modelled and observed water levels agreed reasonably well throughout the period.

- o Inflow to the model has a degree of uncertainty. It is, however, likely that the error will be partly accounted for by the use of statistical analysis of water levels from the 25 year run of the model; the process of calibrating the model will take into account any tendency for flows to be consistently under or over estimated.

- Topographic Surveys

  - o The levels used as a base for the topographic survey of each priority location may be in error either due to errors in the SOB bench marks or transfer of these levels to the sites.

Most of the potential errors listed in Table 5.1 do not lend themselves to quantification by formal statistical methods. Experience and judgement must therefore be applied in order to arrive at a reasonable assessment of the confidence limits.

In Chapter 7 of the Main Report (June 1992) of their Flood Hydrology Study, FAP-25 list the components of the safety margin to be added to design water levels as

"- a margin to account for the effects of random morphological processes, as displayed through annual shifts in rating curves;

- a margin to account for possible errors in model calibration, boundary conditions and observed water levels;

- a margin to account for probable underestimation of extreme events due to the shortness of the available record of observations;

- freeboard to account for wind set-up, wave run-up and other safety requirements."

Of these, the first three are of direct relevance to the interpretation of the 1-D hydrodynamic modelling results; the fourth has to be considered in addition in the design of embankments and structures for river bank protection. FAP-25 recommend a total safety margin on account of the first three factors above of 40 cm for a 100 year return period event. This has then to be considered within the overall safety requirements including freeboard as defined as fourth factor.

TABLES

Table 1.1: Additional Simulation Runs Using the BRTS 1-D Hydrodynamic Model of the Brahmaputra River

	Existing Left Bank	FAP-3 LB Proposed	LB Fully Confined
Current BRE Location	A + B	B	B
Current BRE Location + JMB	A1+B1+B2+B3	A1+B1	B1
BRE Set Back 2 km + JMB	B1	B1	B1
BRE Set Back 4 km + JMB	B1	B1	B1

Key

	Run Type	Contents of Result File
A	1965-89 (25 years)	Preselected storing of daily water level and discharge for the period 15 May - 15 November of each year for the adjacent to priority sites
A1	1965-89 (25 years)	Storing of results same as for 'A'. River Width at JMB = 4,608 m.
B	1988	Preselected storing of daily water level, discharge and velocity for the period 15 May - 15 November for all Brahmaputra sections.
B1	1988	Storing of results same as for 'B' River width at JMB = 4,608 m.
B2	1988	Storing of results same as for 'B' River width at JMB = 3,600 m.
B3	1988	Storing of results same as for 'B' River width at JMB = 5,600 m.

Notes:

1. Simulations with Jamuna Multipurpose Bridge (JMB) assume closure of Northern Dhaleswari off-take.
2. Simulation scenario with FAP-3 Left Bank (LB) Proposal includes embankment aligned along the Brahmaputra left bank as proposed by FAP-3 at the time of the simulation.
3. The left bank fully confined scenario is an extreme case with all Brahmaputra left bank distributaries blocked off, including the old Brahmaputra and an embankment aligned along the entire length of the Brahmaputra LB in Bangladesh.

Table 2.1: Boundary Conditions of the 1-D Hydrodynamic Model of the Brahmaputra River

Gauge Site	River	Boundary Type
Kaunia	Teesta	Inflow
Bahadurabad (T)	Brahmaputra	Inflow
Hardinge Bridge	Ganges	Inflow
Bhairab Bazar	Meghna	Inflow
Gorai Railway Bridge	Gorai	Water Level
Madaripur	Arial Khan	Water Level
Chandpur	Meghna	Water Level

Table 2.2: Grid Coordinates of the Water Level Gauges on the Brahmaputra River

Name of Gauging Station	Grid Coordinates				Remarks
	BRTS		BWDB Map		
	Latitude	Longitude	Latitude	Longitude	
Chilmari (45.5)	25°34'26"	89°41'41"	25°32'30"	89°42'35"	
Fulchari T (46.9R)	25°11'24"	89°35'56"	25°10'07"	89°37'31"	
Bahadurabad T (46.9L)	25°08'00"	89°42'30"	25°08'45"	89°41'55"	
Mathurapara (15J)	24°51'32"	89°36'10"	24°52'02"	89°38'07"	
Kazipur (49A)	24°37'18"	89°40'39"	24°40'00"	89°42'20"	
Sirajganj (49)	24°27'45"	89°43'57"	24°25'10"	89°45'15"	
Shahapur	24°18'44"	89°43'09"	-	-	
Mathura (50.3)	23°57'00"	89°39'14"	23°55'50"	89°31'30"	
Teota (50.6)	23°50'07"	89°46'59"	23°51'15"	89°48'05"	Established by BRTS

Note: BWDB Map refers to the 1: 750,000 BWDB/UNDP/UNDTCD (undated) map on Bangladesh Hydrological Network

Table 2.3: **Resistance Factors in Re-Calibrated 1-D Hydrodynamic Model of Brahmaputra River**

Cross-Section No.	Chainage (km)		Stage (m.PWD)		Resistance Factor Used (1/n)				Remarks
	BRTS	SWMC	Bank-full	1986 LWL	BRTS		SWMC		
					Bank-full	1986 LWL	Bank-full	1986 LWL	
J-17	25.00	25.00	25.1	18.2	35	20	48	29	
J-17-6	28.05		24.4	17.9	35	20			
J-16-1	31.35	34.00	24.0	17.7	35	20	48	27	
J-16-3	33.60		23.5	17.5	35	20			
Generated	36.10		23.1	17.3	35	20			Chilmari
J-16	37.10	39.40	23.4	17.2	35	20	30	25	
J-16-6	42.60		23.3	16.7	37	22			
J-15-1	44.25	46.60	21.7	16.6	38	23	27	22	
J-15-2	48.60		23.0	16.2	39	24			
J-15-3	53.15		20.2	15.8	40	25			
J-15	55.65	56.00	22.0	15.6	41	26	42	23	
J-15-6	59.10		21.7	15.3	42	27			
J-14-1	63.30	60.30	21.3	14.9	43	28	40	25	
J-14-3	67.30		20.0	14.6	45	30			
J-14	71.20	64.60	20.0	14.3	46	31	37	26	
J-14-6	75.60		19.6	13.9	47	32			
Generated	78.55		19.9	13.6	48	33			Fulchari
J-13-1	81.70	71.80	19.9	13.4	49	34	43	15	
J-13-3	83.10		18.5	13.2	50	35			
Generated	84.15		18.8	13.2	50	35			Bahadurabad
J-13	84.70	76.60	19.0	13.1	50	35	44	11	(T)
JN-4	88.00		19.0	12.9	49	35			
J-12-1	93.80		18.7	12.4	47	36			
JN-2	95.50		18.5	12.3	46	36			
J-12	100.50	91.00	18.0	11.9	45	37	37	11	
J-12-6	103.90		18.0	11.6	44	37			
J-11-1	108.90	98.20	18.0	11.3	42	37	39	20	
J-11-3	113.40		17.6	10.9	40	38			
Generated	114.55		17.5	10.8	40	38			Mathurapara
J-11	117.75	105.40	16.7	10.6	39	37	40	24	
J-11-6	122.25		16.1	10.3	37	35			
J-10-1	126.50	113.80	14.8	10.0	36	34	34	16	
J-10-3	130.50		15.5	9.8	35	33			
J-10	134.30	119.80	15.2	9.5	34	32	36	16	
J-10-6	136.80		15.3	9.3	33	31			
J-9-1	139.00	125.20	13.8	9.2	32	30	37	29	
J-9-3	141.80		14.6	9.0	31	29			
Generated	142.00		14.2	9.0	31	29			Kazipur
J-9	142.45	130.60	14.8	8.9	31	29	40	14	
J-9-6	143.45		14.0	8.8	32	29			
J-8-1	145.40	137.80	14.3	8.6	33	28	35	21	
J-8-3	147.55		14.0	8.4	35	28			
J-8	149.50	143.80	14.3	8.1	36	27	40	18	
J-8-6	151.75		13.4	7.9	37	27			
J-7-1	156.60	152.20	13.3	7.4	40	25	32	24	

Table 2.3 (Cont'd): Resistance Factors in Re-Calibrated 1-D Hydrodynamic Model of Brahmaputra River

Cross-Section No.	Chainage (km)		Stage (m.PWD)		Resistance Factor Used (1/n)				Remarks
	BRTS	SWMC	Bank-full	1986 LWL	BRTS		SWMC		
					Bank-full	1986 LWL	Bank-full	1986 LWL	
JS-3	158.50	155.80	13.2	7.1	42	25	28	18	
J-7	162.35		13.0	6.7	44	24			
JS-6	166.60	163.24	13.0	6.4	44	25	32	24	
J-6-1	170.75		13.0	6.2	45	26			
J-6-3	174.30	170.20	13.0	5.9	45	27	31	24	
J-6	177.70		13.4	5.7	46	28			
J-6-6	179.20	176.20	12.8	5.6	46	29	32	27	
J-5-1	180.60		11.7	5.5	46	29			
J-5-3	185.70	182.20	11.2	5.2	46	31	28	16	
J-5	188.20		11.7	5.0	47	31			
J-5-6	191.75	188.20	11.2	4.8	47	32	28	12	
J-4-1	195.75		10.6	4.6	48	33			
J-4-3	197.65	196.60	11.0	4.4	48	34	32	17	
J-4	201.30		10.2	4.2	48	35			
J-4-6	203.30	205.00	10.5	4.1	48	36	31	15	
J-3-1	205.15		10.2	4.0	49	36			
J-3-3	211.25	213.40	9.0	3.6	49	38	30	19	
J-3	213.20		10.0	3.4	49	38			
J-3-6	216.50		9.8	3.2	50	39			
Generated	218.90	218.20	9.0	3.1	50	40	32	14	Mathura
J-2-1	220.00	227.80	9.0	3.0	50	40	34	17	
J-2	223.20	232.60	9.1	2.9	50	40	33	32	
J-1-1	229.40	237.40	4.0	2.7	50	40	30	25	
J-1	230.75		4.8	2.7	50	40			
J-0-1	235.50		7.0	2.5	50	40			Teota
Maximum					50	40	48	32	
Minimum					31	20	27	11	

Notes:

1. Chainage 0.0 km is roughly at Noonkhawa
2. 1986 LWL refers to lowest water level profile down the Brahmaputra in 1986-87
3. SWMC calibration refers to the 06 March 1991 calibration of the Brahmaputra
4. Resistance factor is expressed as the reciprocal of Manning's 'n'.

Table 2.4: **Maximum Modelled Flow Spilled into the Ghagot-Karatoya-Bangali System through Breaches in BRE**

Breach Location	Maximum Flow Spilled (m^3/s)
Fulchari	950
Mathurapara	1,500
Kazipur	1,400
Sonali Bazar	900
South of Sirajganj	750
Betil	750

Table 3.1: Source of 1965-89 Boundary Data for 25 year Simulation Using 1-D Model of the Brahmaputra River

River	Gauging Station	Type of Boundary	Source
Brahmaputra	Bahadurabad Transit	Flow	FAP-25 (corrected and revised using BWDB measured data)
Teesta	Kaunia	Flow	FAP-25 (Data base created using BWDB data)
Ganges	Hardinge Bridge	Flow	FAP-25 (Simulation output from Run 5)
Meghna	Bhairab Bazar	Flow	FAP-25 (Simulation output from Run 5)
Gorai	Gorai Railway Bridge	Water Level	FAP-25 (Simulation output from Run 5)
Arial Khan	Madaripur	Water Level	FAP-25 (Simulations output from Run 5)
Meghna	Chandpur	Water Level	FAP-25 (Simulation output from Run 5)

Table 3.2: Pre-selected Cross-Sections for Storing Simulated Water Level and Discharge of 25 Year Model Run

River	Chainage km	Remarks
Brahmaputra	25.00	
	36.10	Chilmari water level gauge
	44.25	
	55.65	
	59.10	
	63.30	
	71.20	
	75.60	
	78.55	Fulchari water level gauge
	83.10	
	84.15	Bahadurabad Transit gauging station
	95.50	
	100.50	
	108.90	
	113.40	
	114.55	Mathurapara water level gauge
	117.75	
	126.50	
	134.30	
	136.80	
	139.00	
	142.00	Kazipur water level gauge
	145.40	
	151.75	
	156.60	
	162.35	Sirajganj water level gauge
	168.50	u/s of JMB guide bund
	170.75	d/s of JMB guide bund
	174.30	
	180.60	
	185.70	
	188.20	
	191.75	
	193.55	
	195.75	
	205.15	
	218.90	Mathura water level gauge
	229.40	
	235.50	Teota water level gauge
Padma	7.50	Baruria Transit gauging station

Table 3.3 : Difference between Recorded and Modelled (Option: Existing Condition) Annual Maximum Water Levels in Metre

Year	Gauging Stations							
	Chilmari	Bahadurabad	Mathurapara	Kazipur	Sirajganj	Mathura	Teota	Baruria
1965-66	-0.45	-0.38			-0.04	-0.25	1.38	-0.05
1966-67	-0.36	-0.85			-0.28	-0.41	0.54	-0.27
1967-68	-0.11	-0.93		-0.33	-0.40	0.13	0.45	-0.27
1968-69	0.43	-0.22		0.13	0.18	0.43	0.77	0.02
1969-70	0.54	0.20		0.37	0.39	0.40	0.46	-0.32
1970-71	-0.03	-0.34		0.25	0.02	0.55	0.67	-0.13
1972-73	0.10	-0.37		-0.14	-0.13	0.20	0.52	-0.41
1973-74	0.01	-0.35		-0.01	0.25	0.37	0.57	-0.37
1974-75	-0.31	-0.77		-0.48	-0.38	0.08	0.60	-0.63
1975-76	0.51	-0.08		-0.07	0.09	0.09	1.04	-0.40
1976-77	0.16	-0.26		-0.21	-0.36	-0.07	0.48	-0.50
1977-78	0.26	-0.23		-0.26	-0.07	-0.23	0.55	-0.63
1978-79	0.50	0.06		-0.17	0.17	-0.22	0.01	-0.80
1979-80		-0.08		-0.11	0.05	-0.33	0.38	-0.61
1980-81	-0.72	-1.08		-0.52	-0.27	-0.38	0.08	-0.86
1981-82		-0.66		-0.19	0.03	-0.30	0.25	-0.62
1982-83		-0.57	-0.53	-0.03	-0.03	-0.32	-0.03	-0.64
1983-84	0.12	-0.36	0.23	-0.14	0.16	-0.02	0.35	-0.47
1984-85	-0.08	-0.54	-0.17	-0.19	0.30	-0.26	0.16	-0.64
1985-86	0.25	-0.45	0.39	0.21	0.37	0.08	0.29	-0.32
1986-87	0.75	0.00	0.78	0.70	0.69	0.19	0.37	-0.46
1987-88	0.39	-0.83	0.15	0.22	0.33	0.18	0.48	-0.29
1988-89	-0.25	-0.88	-0.11	-0.01	0.08	-0.08	0.39	-0.54
1989-90	-0.34	-0.68	-0.06	-0.14	-0.32	0.04		-0.41
Maximum	0.75	0.20	0.78	0.70	0.69	0.55	1.38	0.02
Average	0.07	-0.44	0.09	-0.05	0.03	-0.01	0.47	-0.44
Minimum	-0.72	-1.08	-0.53	-0.52	-0.40	-0.41	-0.03	-0.86

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Table 3.4 : Annual Maximum Simulated Water Levels (m.PWD) at Selected Sections of the Brahmaputra Simulation Option : Existing BRE

Year	BRTS 1-D Model Chainage (km) for the Brahmaputra											
	44.25	63.30	75.60	84.15	113.40	136.80	151.75	162.35	170.75	180.60	185.70	205.15
1965-66	22.95	21.43	20.50	20.07	18.01	16.07	14.55	13.81	13.22	12.18	11.75	10.19
1966-67	23.41	21.84	20.90	20.46	18.38	16.43	14.89	14.15	13.56	12.54	12.11	10.70
1967-68	23.34	21.79	20.85	20.42	18.32	16.34	14.79	14.04	13.44	12.35	11.91	10.30
1968-69	22.89	21.39	20.46	20.02	17.96	16.02	14.50	13.76	13.18	12.16	11.74	10.26
1969-70	22.49	21.02	20.07	19.64	17.59	15.67	14.17	13.43	12.86	11.83	11.41	9.91
1970-71	23.46	21.90	20.97	20.54	18.45	16.49	14.94	14.20	13.60	12.55	12.12	10.61
1972-73	23.27	21.71	20.78	20.35	18.28	16.32	14.78	14.03	13.43	12.36	11.92	10.31
1973-74	23.13	21.60	20.67	20.23	18.16	16.22	14.70	13.97	13.39	12.37	11.96	10.55
1974-75	24.02	22.39	21.46	21.02	18.92	16.92	15.37	14.62	14.01	13.00	12.57	11.23
1975-76	22.56	21.07	20.12	19.68	17.64	15.73	14.24	13.51	12.95	11.97	11.58	10.28
1976-77	23.01	21.49	20.56	20.12	18.05	16.10	14.56	13.82	13.22	12.15	11.70	10.00
1977-78	23.12	21.59	20.66	20.22	18.15	16.22	14.70	13.97	13.39	12.39	11.98	10.61
1978-79	22.43	20.96	20.01	19.57	17.50	15.59	14.09	13.35	12.77	11.72	11.28	9.95
1979-80	22.73	21.23	20.30	19.86	17.80	15.88	14.36	13.62	13.04	11.99	11.55	10.10
1980-81	24.21	22.56	21.61	21.18	19.05	17.05	15.50	14.76	14.15	13.17	12.74	11.46
1981-82	23.03	21.50	20.57	20.14	18.07	16.13	14.59	13.84	13.24	12.17	11.73	10.30
1982-83	22.88	21.37	20.43	19.99	17.91	15.99	14.48	13.76	13.19	12.19	11.79	10.44
1983-84	23.24	21.67	20.72	20.29	18.23	16.29	14.76	14.03	13.45	12.44	12.03	10.76
1984-85	23.61	22.02	21.09	20.65	18.57	16.60	15.06	14.32	13.72	12.71	12.28	10.93
1985-86	22.97	21.45	20.51	20.07	17.98	16.03	14.51	13.78	13.20	12.19	11.76	10.29
1986-87	21.93	20.54	19.58	19.15	17.11	15.20	13.73	12.99	12.45	11.48	11.09	9.77
1987-88	23.49	21.91	20.97	20.54	18.47	16.51	14.97	14.24	13.64	12.62	12.20	11.01
1988-89	24.57	22.88	21.93	21.50	19.36	17.34	15.78	15.04	14.41	13.45	13.03	11.82
1989-90	23.17	21.63	20.69	20.25	18.18	16.24	14.70	13.95	13.35	12.27	11.81	10.15
Maximum	24.57	22.88	21.93	21.50	19.36	17.34	15.78	15.04	14.41	13.45	13.03	11.82
Average	23.16	21.62	20.68	20.25	18.17	16.22	14.70	13.96	13.37	12.34	11.92	10.50
Minimum	21.93	20.54	19.58	19.15	17.11	15.20	13.73	12.99	12.45	11.48	11.09	9.77

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Table 3.5 : Annual Maximum Simulated Water Levels (m.PWD) at Selected Sections of the Brahmaputra Simulation Option : Existing BRE + JMB

Year	BRTS 1-D Model Chainage (km) for the Brahmaputra											
	44.25	63.30	75.60	84.15	113.40	136.80	151.75	162.35	170.75	180.60	185.70	205.15
1965-66	22.95	21.44	20.50	20.07	18.02	16.13	14.71	14.06	13.27	12.21	11.78	10.22
1966-67	23.41	21.85	20.90	20.47	18.40	16.50	15.09	14.45	13.63	12.58	12.15	10.73
1967-68	23.34	21.79	20.86	20.42	18.34	16.40	14.98	14.33	13.50	12.39	11.94	10.34
1968-69	22.90	21.39	20.46	20.03	17.98	16.08	14.65	14.01	13.23	12.19	11.77	10.29
1969-70	22.50	21.02	20.07	19.64	17.60	15.72	14.29	13.63	12.88	11.85	11.42	9.91
1970-71	23.47	21.91	20.98	20.54	18.48	16.57	15.14	14.51	13.67	12.60	12.16	10.65
1972-73	23.27	21.72	20.79	20.36	18.30	16.40	14.96	14.32	13.49	12.40	11.96	10.35
1973-74	23.14	21.60	20.67	20.24	18.18	16.29	14.88	14.24	13.44	12.41	11.99	10.58
1974-75	24.03	22.40	21.46	21.03	18.95	17.02	15.61	14.98	14.09	13.05	12.62	11.27
1975-76	22.56	21.07	20.12	19.69	17.65	15.78	14.36	13.72	12.98	12.00	11.60	10.30
1976-77	23.01	21.49	20.56	20.13	18.07	16.16	14.72	14.07	13.27	12.18	11.73	10.01
1977-78	23.13	21.59	20.66	20.23	18.17	16.28	14.87	14.24	13.45	12.42	12.01	10.64
1978-79	22.43	20.96	20.01	19.58	17.51	15.63	14.21	13.54	12.79	11.74	11.29	9.95
1979-80	22.73	21.23	20.30	19.86	17.81	15.93	14.50	13.84	13.07	12.01	11.57	10.12
1980-81	24.21	22.56	21.62	21.18	19.08	17.15	15.75	15.14	14.24	13.22	12.79	11.50
1981-82	23.03	21.50	20.57	20.14	18.09	16.19	14.75	14.10	13.29	12.21	11.76	10.32
1982-83	22.88	21.37	20.43	20.00	17.93	16.05	14.63	14.00	13.23	12.22	11.82	10.46
1983-84	23.24	21.68	20.73	20.30	18.25	16.36	14.94	14.31	13.50	12.47	12.07	10.79
1984-85	23.61	22.02	21.09	20.66	18.60	16.69	15.27	14.64	13.79	12.75	12.33	10.97
1985-86	22.97	21.45	20.51	20.08	18.00	16.08	14.67	14.03	13.25	12.21	11.79	10.32
1986-87	21.93	20.54	19.58	19.15	17.12	15.23	13.82	13.15	12.46	11.49	11.10	9.77
1987-88	23.49	21.92	20.98	20.55	18.49	16.59	15.18	14.54	13.71	12.66	12.25	11.04
1988-89	24.58	22.89	21.94	21.51	19.39	17.45	16.05	15.45	14.52	13.51	13.09	11.87
1989-90	23.17	21.63	20.69	20.26	18.21	16.30	14.87	14.22	13.40	12.30	11.85	10.17
Maximum	24.58	22.89	21.94	21.51	19.39	17.45	16.05	15.45	14.52	13.51	13.09	11.87
Average	23.17	21.63	20.69	20.26	18.19	16.29	14.87	14.23	13.42	12.38	11.95	10.52
Minimum	21.93	20.54	19.58	19.15	17.12	15.23	13.82	13.15	12.46	11.49	11.10	9.77

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Table 3.6 : Annual Maximum Simulated Water Levels (m.PWD) at Selected Sections of the Brahmaputra Simulation Option : Existing BRE + JMB + Confined LB (FAP 3)

Year	BRTS 1-D Model Chainage (km) for the Brahmaputra											
	44.25	63.30	75.60	84.15	113.40	136.80	151.75	162.35	170.75	180.60	185.70	205.15
1965-66	22.97	21.49	20.60	20.20	18.31	16.52	15.15	14.51	13.67	12.60	12.16	10.60
1966-67	23.44	21.91	21.02	20.62	18.73	16.94	15.59	14.97	14.08	13.05	12.60	11.16
1967-68	23.37	21.85	20.97	20.56	18.65	16.82	15.46	14.82	13.93	12.82	12.36	10.75
1968-69	22.92	21.44	20.55	20.15	18.25	16.45	15.08	14.45	13.63	12.58	12.14	10.65
1969-70	22.51	21.05	20.14	19.74	17.83	16.04	14.66	14.01	13.23	12.18	11.76	10.20
1970-71	23.50	21.98	21.10	20.71	18.81	17.01	15.66	15.04	14.14	13.08	12.62	11.10
1972-73	23.30	21.78	20.90	20.51	18.62	16.81	15.44	14.80	13.92	12.84	12.38	10.77
1973-74	23.16	21.66	20.78	20.38	18.49	16.70	15.35	14.72	13.87	12.83	12.40	10.97
1974-75	24.06	22.48	21.60	21.21	19.31	17.52	16.21	15.61	14.66	13.63	13.17	11.75
1975-76	22.58	21.11	20.19	19.79	17.89	16.10	14.74	14.10	13.33	12.33	11.92	10.59
1976-77	23.03	21.55	20.66	20.25	18.35	16.53	15.17	14.52	13.67	12.57	12.10	10.33
1977-78	23.15	21.65	20.76	20.36	18.48	16.69	15.34	14.72	13.87	12.85	12.42	11.02
1978-79	22.44	20.99	20.08	19.67	17.73	15.94	14.55	13.90	13.11	12.05	11.60	10.14
1979-80	22.75	21.28	20.38	19.98	18.07	16.28	14.91	14.27	13.45	12.38	11.93	10.42
1980-81	24.25	22.64	21.76	21.37	19.46	17.69	16.38	15.79	14.84	13.82	13.38	12.01
1981-82	23.05	21.56	20.68	20.27	18.38	16.58	15.20	14.55	13.70	12.60	12.14	10.64
1982-83	22.90	21.42	20.52	20.12	18.20	16.42	15.06	14.43	13.62	12.60	12.17	10.79
1983-84	23.26	21.73	20.84	20.44	18.56	16.76	15.40	14.78	13.92	12.90	12.47	11.15
1984-85	23.64	22.09	21.22	20.83	18.94	17.14	15.81	15.19	14.29	13.26	12.81	11.40
1985-86	22.99	21.50	20.60	20.20	18.27	16.45	15.10	14.47	13.65	12.60	12.16	10.67
1986-87	21.94	20.57	19.64	19.23	17.29	15.48	14.10	13.44	12.73	11.76	11.36	9.99
1987-88	23.52	21.99	21.11	20.71	18.83	17.04	15.70	15.08	14.19	13.16	12.71	11.41
1988-89	24.62	22.98	22.09	21.71	19.81	18.03	16.74	16.15	15.17	14.15	13.71	12.39
1989-90	23.19	21.69	20.80	20.40	18.51	16.71	15.34	14.70	13.82	12.72	12.25	10.54
Maximum	24.62	22.98	22.09	21.71	19.81	18.03	16.74	16.15	15.17	14.15	13.71	12.39
Average	23.19	21.68	20.79	20.39	18.49	16.69	15.34	14.71	13.85	12.81	12.36	10.89
Minimum	21.94	20.57	19.64	19.23	17.29	15.48	14.10	13.44	12.73	11.76	11.36	9.99

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Table 3.7 : Water Level of Selected Return Periods Obtained by Analysing Simulated Annual Maximum Water Levels for the 25 Year Period

Brahmaputra 1-D Model Chainage (Km)	25 Year Model Run No.	Return Period (Year) 2	5	10	25	50	100	250	500	1000	2500	5000	10000
44.25	Run-3	23.130	23.624	23.902	24.215	24.426	24.622	24.865	25.039	25.207	25.420	25.576	25.728
	Run-4	23.133	23.628	23.907	24.220	24.432	24.629	24.873	25.048	25.216	25.430	25.587	25.740
	Run-5	23.156	23.657	23.940	24.258	24.472	24.672	24.919	25.096	25.267	25.484	25.643	25.798
63.30	Run-3	21.592	22.033	22.283	22.565	22.756	22.934	23.155	23.313	23.466	23.660	23.803	23.942
	Run-4	21.595	22.038	22.290	22.573	22.765	22.944	23.165	23.324	23.478	23.673	23.817	23.957
	Run-5	21.651	22.108	22.366	22.656	22.853	23.036	23.264	23.427	23.584	23.784	23.931	24.074
75.60	Run-3	20.657	21.098	21.346	21.622	21.808	21.980	22.193	22.345	22.491	22.676	22.812	22.943
	Run-4	20.659	21.103	21.352	21.630	21.818	21.992	22.206	22.360	22.507	22.694	22.831	22.964
	Run-5	20.764	21.227	21.486	21.776	21.970	22.151	22.373	22.532	22.684	22.878	23.019	23.156
84.15	Run-3	20.220	20.663	20.912	21.191	21.379	21.553	21.769	21.923	22.071	22.259	22.397	22.532
	Run-4	20.228	20.671	20.919	21.197	21.385	21.558	21.773	21.926	22.073	22.260	22.397	22.530
	Run-5	20.364	20.832	21.094	21.388	21.585	21.768	21.994	22.155	22.310	22.507	22.651	22.791
113.40	Run-3	18.149	18.572	18.809	19.072	19.249	19.412	19.614	19.757	19.895	20.069	20.196	20.320
	Run-4	18.169	18.597	18.836	19.109	19.281	19.446	19.649	19.794	19.932	20.108	20.236	20.361
	Run-5	18.468	18.940	19.201	19.490	19.683	19.860	20.078	20.233	20.380	20.567	20.703	20.834
136.80	Run-3	16.205	16.604	16.824	17.068	17.231	17.381	17.565	17.696	17.821	17.979	18.094	18.206
	Run-4	16.270	16.685	16.915	17.170	17.341	17.499	17.692	17.829	17.961	18.127	18.248	18.366
	Run-5	16.669	17.146	17.410	17.704	17.901	18.083	18.306	18.465	18.617	18.810	18.950	19.086
151.75	Run-3	14.674	15.058	15.273	15.513	15.674	15.824	16.008	16.139	16.265	16.425	16.542	16.655
	Run-4	14.846	15.267	15.502	15.765	15.942	16.106	16.308	16.452	16.590	16.766	16.894	17.019
	Run-5	15.309	15.806	16.085	16.397	16.607	16.801	17.042	17.213	17.378	17.588	17.741	17.890
162.35	Run-3	13.936	14.319	14.532	14.771	14.931	15.079	15.261	15.392	15.516	15.675	15.790	15.902
	Run-4	14.204	14.637	14.880	15.151	15.334	15.504	15.713	15.862	16.006	16.188	16.321	16.451
	Run-5	14.676	15.188	15.476	15.800	16.018	16.220	16.470	16.649	16.822	17.041	17.201	17.357
170.75	Run-3	13.936	14.319	14.532	14.771	14.931	15.079	15.261	15.392	15.516	15.675	15.790	15.902
	Run-4	13.399	13.788	14.006	14.250	14.414	14.566	14.754	14.889	15.018	15.181	15.301	15.418
	Run-5	13.820	14.283	14.546	14.843	15.044	15.232	15.465	15.633	15.795	16.002	16.153	16.302
180.60	Run-3	12.307	12.689	12.913	13.170	13.348	13.517	13.728	13.883	14.033	14.227	14.370	14.512
	Run-4	12.341	12.732	12.960	13.223	13.405	13.576	13.791	13.948	14.101	14.297	14.443	14.587
	Run-5	12.760	13.229	13.505	13.824	14.044	14.254	14.518	14.710	14.898	15.141	15.321	15.499
185.70	Run-3	11.878	12.259	12.485	12.747	12.930	13.103	13.323	13.484	13.641	13.844	13.996	14.146
	Run-4	11.911	12.303	12.534	12.803	12.989	13.166	13.389	13.552	13.712	13.918	14.072	14.224
	Run-5	12.311	12.777	13.054	13.378	13.605	13.820	14.094	14.295	14.492	14.748	14.939	15.129
205.15	Run-3	10.404	10.848	11.148	11.532	11.822	12.116	12.511	12.818	13.133	13.562	13.897	14.241
	Run-4	10.433	10.886	11.189	11.574	11.862	12.151	12.539	12.839	13.144	13.559	13.881	14.211
	Run-5	10.804	11.320	11.651	12.060	12.360	12.656	13.046	13.341	13.639	14.037	14.343	14.653

Notes: 25 Year Simulation Option

Run-3 - Present BRE Location + Current Brahmaputra Left Bank Condition

Run-4 - Present BRE Location + Current Brahmaputra Left Bank Condition + JMB (4,608 m)

Run-5 - Present BRE Location + FAP-3 Brahmaputra Left Bank Condition + JMB (4,608 m)

All water level in m.PWD.

Frequency analysis of water levels for different project scenarios were done by fitting a Log Normal distribution to the sample data. Parameters of the distribution were estimated by modified maximum likelihood method. This was acheived by using HYMOS software at FAP-25.

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Table 3.8 : Annual Maximum Simulated Velocities (m/s) at Selected Sections of the Brahmaputra Simulation Option : Existing BRE

Year	BRTS 1-D Model Chainage (km) for the Brahmaputra											
	44.25	63.30	75.60	84.15	113.40	136.80	151.75	162.35	170.75	180.60	185.70	205.15
1965-66	0.98	1.74	1.05	1.19	1.42	1.19	0.99	1.38	1.22	1.08	1.71	1.51
1966-67	1.02	1.77	1.08	1.23	1.44	1.21	1.01	1.40	1.24	1.11	1.77	1.62
1967-68	1.02	1.77	1.08	1.22	1.46	1.21	1.01	1.40	1.25	1.12	1.79	1.64
1968-69	0.98	1.74	1.05	1.19	1.45	1.20	0.98	1.40	1.23	1.08	1.72	1.49
1969-70	0.94	1.69	1.02	1.15	1.42	1.18	0.96	1.37	1.21	1.06	1.70	1.47
1970-71	1.02	1.77	1.08	1.23	1.43	1.21	1.01	1.39	1.23	1.10	1.73	1.52
1972-73	1.01	1.76	1.08	1.22	1.44	1.21	1.01	1.39	1.24	1.10	1.75	1.57
1973-74	1.00	1.75	1.06	1.21	1.46	1.21	1.00	1.41	1.25	1.11	1.77	1.60
1974-75	1.07	1.82	1.12	1.28	1.46	1.24	1.04	1.41	1.24	1.11	1.77	1.63
1975-76	0.95	1.71	1.02	1.16	1.42	1.18	0.96	1.35	1.19	1.03	1.62	1.32
1976-77	0.99	1.75	1.06	1.20	1.44	1.20	1.00	1.39	1.24	1.11	1.77	1.60
1977-78	1.00	1.75	1.06	1.20	1.43	1.19	0.99	1.37	1.22	1.07	1.69	1.47
1978-79	0.93	1.68	1.01	1.15	1.41	1.18	0.97	1.38	1.23	1.07	1.73	1.51
1979-80	0.96	1.72	1.03	1.17	1.42	1.18	0.98	1.39	1.22	1.08	1.73	1.53
1980-81	1.08	1.84	1.14	1.29	1.46	1.25	1.05	1.42	1.25	1.11	1.72	1.46
1981-82	0.99	1.75	1.06	1.20	1.43	1.20	0.99	1.40	1.24	1.10	1.76	1.60
1982-83	0.98	1.74	1.05	1.19	1.43	1.19	0.99	1.38	1.23	1.09	1.74	1.55
1983-84	1.01	1.77	1.08	1.22	1.45	1.21	1.00	1.38	1.22	1.07	1.68	1.44
1984-85	1.03	1.79	1.10	1.25	1.45	1.22	1.02	1.39	1.23	1.09	1.73	1.53
1985-86	0.98	1.74	1.05	1.19	1.43	1.19	0.99	1.38	1.23	1.08	1.73	1.53
1986-87	0.89	1.57	0.98	1.11	1.38	1.16	0.94	1.35	1.19	1.04	1.59	1.29
1987-88	1.03	1.79	1.10	1.24	1.45	1.22	1.01	1.39	1.23	1.10	1.74	1.53
1988-89	1.11	1.88	1.16	1.33	1.48	1.27	1.07	1.43	1.25	1.11	1.76	1.59
1989-90	1.00	1.75	1.07	1.21	1.44	1.20	1.00	1.40	1.24	1.11	1.76	1.62
Maximum	1.11	1.88	1.16	1.33	1.48	1.27	1.07	1.43	1.25	1.12	1.79	1.64
Average	1.00	1.75	1.07	1.21	1.44	1.20	1.00	1.39	1.23	1.09	1.73	1.53
Minimum	0.89	1.57	0.98	1.11	1.38	1.16	0.94	1.35	1.19	1.03	1.59	1.29

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Table 3.9 : Annual Maximum Simulated Velocities (m/s) at Selected Sections of the Brahmaputra Simulation Option : Existing BRE + JMB

Year	BRTS 1-D Model Chainage (km) for the Brahmaputra											
	44.25	63.30	75.60	84.15	113.40	136.80	151.75	162.35	170.75	180.60	185.70	205.15
1965-66	0.98	1.73	1.05	1.19	1.42	1.17	0.95	1.31	1.67	1.08	1.72	1.52
1966-67	1.02	1.77	1.08	1.23	1.43	1.19	0.96	1.32	1.76	1.11	1.77	1.62
1967-68	1.02	1.77	1.08	1.22	1.45	1.19	0.97	1.31	1.75	1.12	1.79	1.64
1968-69	0.98	1.74	1.05	1.19	1.44	1.19	0.95	1.32	1.65	1.08	1.73	1.50
1969-70	0.94	1.69	1.02	1.15	1.41	1.16	0.93	1.30	1.56	1.06	1.70	1.47
1970-71	1.02	1.77	1.08	1.23	1.42	1.19	0.96	1.31	1.78	1.10	1.74	1.53
1972-73	1.01	1.76	1.08	1.22	1.43	1.18	0.96	1.32	1.74	1.10	1.75	1.57
1973-74	1.00	1.75	1.06	1.20	1.45	1.19	0.96	1.34	1.70	1.11	1.78	1.61
1974-75	1.07	1.82	1.12	1.28	1.45	1.21	0.98	1.33	1.90	1.11	1.77	1.64
1975-76	0.95	1.71	1.02	1.16	1.42	1.16	0.93	1.30	1.56	1.03	1.62	1.33
1976-77	0.99	1.75	1.06	1.20	1.44	1.18	0.96	1.33	1.68	1.11	1.77	1.61
1977-78	1.00	1.75	1.06	1.20	1.42	1.17	0.95	1.31	1.70	1.08	1.69	1.47
1978-79	0.93	1.68	1.01	1.14	1.41	1.17	0.93	1.32	1.54	1.07	1.73	1.51
1979-80	0.96	1.72	1.03	1.17	1.42	1.17	0.94	1.32	1.62	1.08	1.73	1.53
1980-81	1.08	1.84	1.13	1.29	1.45	1.22	0.99	1.31	1.94	1.11	1.73	1.46
1981-82	0.99	1.75	1.06	1.20	1.43	1.19	0.95	1.34	1.69	1.10	1.77	1.60
1982-83	0.98	1.74	1.05	1.18	1.42	1.18	0.95	1.31	1.65	1.09	1.74	1.55
1983-84	1.01	1.76	1.08	1.22	1.44	1.19	0.96	1.32	1.72	1.07	1.68	1.44
1984-85	1.03	1.79	1.10	1.24	1.44	1.19	0.97	1.31	1.81	1.09	1.73	1.53
1985-86	0.98	1.74	1.05	1.19	1.42	1.17	0.95	1.33	1.65	1.08	1.73	1.53
1986-87	0.89	1.57	0.98	1.11	1.38	1.15	0.92	1.30	1.41	1.03	1.59	1.29
1987-88	1.03	1.79	1.09	1.24	1.44	1.20	0.97	1.31	1.78	1.10	1.74	1.53
1988-89	1.11	1.88	1.16	1.33	1.47	1.24	1.01	1.32	2.01	1.12	1.76	1.59
1989-90	1.00	1.75	1.07	1.21	1.43	1.19	0.96	1.32	1.72	1.11	1.76	1.63
Maximum	1.11	1.88	1.16	1.33	1.47	1.24	1.01	1.34	2.01	1.12	1.79	1.64
Average	1.00	1.75	1.07	1.21	1.43	1.19	0.96	1.32	1.71	1.09	1.73	1.53
Minimum	0.89	1.57	0.98	1.11	1.38	1.15	0.92	1.30	1.41	1.03	1.59	1.29

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Table 3.10 : Annual Maximum Simulated Velocities (m/s) at Selected Sections of the Brahmaputra Simulation
Option : Existing BRE + JMB + Confined LB (FAP 3)

Year	BRTS 1-D Model Chainage (km) for the Brahmaputra											
	44.25	63.30	75.60	84.15	113.40	136.80	151.75	162.35	170.75	180.60	185.70	205.15
1965-66	0.98	1.72	1.03	1.15	1.41	1.14	0.96	1.31	1.78	1.11	1.76	1.57
1966-67	1.02	1.75	1.05	1.19	1.42	1.15	0.99	1.32	1.90	1.13	1.80	1.70
1967-68	1.01	1.75	1.06	1.19	1.44	1.16	0.99	1.31	1.88	1.16	1.84	1.71
1968-69	0.98	1.73	1.03	1.15	1.44	1.16	0.96	1.33	1.76	1.11	1.76	1.56
1969-70	0.94	1.68	1.00	1.12	1.40	1.13	0.94	1.31	1.65	1.08	1.72	1.54
1970-71	1.02	1.74	1.05	1.19	1.41	1.15	0.99	1.31	1.92	1.14	1.79	1.59
1972-73	1.01	1.74	1.05	1.18	1.42	1.15	0.98	1.33	1.87	1.14	1.80	1.63
1973-74	0.99	1.74	1.04	1.17	1.44	1.16	0.98	1.34	1.82	1.14	1.81	1.69
1974-75	1.06	1.79	1.09	1.23	1.44	1.17	1.02	1.34	2.06	1.16	1.82	1.69
1975-76	0.95	1.69	1.01	1.13	1.41	1.13	0.94	1.30	1.66	1.06	1.65	1.38
1976-77	0.99	1.72	1.04	1.16	1.43	1.15	0.97	1.32	1.80	1.14	1.80	1.69
1977-78	0.99	1.72	1.04	1.17	1.40	1.13	0.97	1.31	1.82	1.11	1.74	1.53
1978-79	0.93	1.67	0.99	1.12	1.41	1.15	0.95	1.31	1.63	1.09	1.74	1.57
1979-80	0.96	1.70	1.01	1.14	1.41	1.14	0.95	1.32	1.72	1.10	1.75	1.60
1980-81	1.07	1.81	1.10	1.24	1.44	1.18	1.02	1.33	2.10	1.17	1.81	1.55
1981-82	0.99	1.72	1.03	1.16	1.43	1.16	0.97	1.33	1.81	1.13	1.80	1.67
1982-83	0.97	1.72	1.02	1.15	1.42	1.16	0.96	1.31	1.76	1.12	1.77	1.62
1983-84	1.01	1.74	1.05	1.18	1.43	1.15	0.98	1.31	1.84	1.10	1.73	1.51
1984-85	1.03	1.76	1.06	1.20	1.44	1.16	0.99	1.32	1.95	1.13	1.78	1.59
1985-86	0.98	1.72	1.03	1.16	1.40	1.14	0.96	1.33	1.76	1.10	1.75	1.60
1986-87	0.89	1.56	0.96	1.08	1.38	1.12	0.92	1.31	1.49	1.05	1.62	1.35
1987-88	1.02	1.76	1.07	1.20	1.43	1.16	0.99	1.31	1.92	1.14	1.79	1.60
1988-89	1.10	1.85	1.12	1.28	1.46	1.20	1.04	1.34	2.20	1.19	1.81	1.66
1989-90	1.00	1.73	1.04	1.17	1.42	1.15	0.98	1.32	1.85	1.14	1.81	1.69
Maximum	1.10	1.85	1.12	1.28	1.46	1.20	1.04	1.34	2.20	1.19	1.84	1.71
Average	1.00	1.73	1.04	1.17	1.42	1.15	0.98	1.32	1.83	1.12	1.77	1.60
Minimum	0.89	1.56	0.96	1.08	1.38	1.12	0.92	1.30	1.49	1.05	1.62	1.35

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Table 3.11 : Maximum Average Velocity for Different Return Periods at Selected Sections of the Brahmaputra River under Various Engineering Schemes

Brahmaputra 1-D Model Chainage (Km)	25 Year Model Run No.	Return Period (Year)							Remarks
		2	5	10	20	50	100	200	
44.25	Run-3	0.991	1.034	1.063	1.091	1.127	1.154	1.181	Downstream of
	Run-4	0.991	1.034	1.063	1.091	1.127	1.154	1.181	Teesta
	Run-5	0.988	1.029	1.057	1.083	1.117	1.143	1.168	Confluence
63.30	Run-3	1.743	1.792	1.824	1.856	1.896	1.926	1.957	Manas
	Run-4	1.742	1.791	1.824	1.855	1.896	1.926	1.957	Regulator
	Run-5	1.721	1.766	1.795	1.823	1.860	1.887	1.914	
75.60	Run-3	1.059	1.096	1.121	1.144	1.175	1.198	1.221	Fulchari
	Run-4	1.059	1.095	1.119	1.141	1.171	1.193	1.215	
	Run-5	1.035	1.066	1.087	1.107	1.133	1.152	1.172	
84.15	Run-3	1.202	1.245	1.274	1.301	1.337	1.363	1.390	
	Run-4	1.200	1.244	1.273	1.300	1.336	1.363	1.390	
	Run-5	1.164	1.202	1.228	1.252	1.283	1.307	1.330	
113.40	Run-3	1.434	1.453	1.465	1.478	1.493	1.505	1.516	Mathurapara
	Run-4	1.427	1.444	1.455	1.465	1.478	1.489	1.499	
	Run-5	1.419	1.436	1.447	1.458	1.472	1.482	1.492	
136.80	Run-3	1.200	1.222	1.236	1.250	1.268	1.281	1.294	Kazipur
	Run-4	1.182	1.199	1.211	1.222	1.236	1.247	1.258	
	Run-5	1.149	1.165	1.175	1.184	1.197	1.206	1.216	
151.75	Run-3	0.994	1.020	1.037	1.053	1.074	1.090	1.106	Simla
	Run-4	0.953	0.971	0.983	0.994	1.009	1.020	1.031	
	Run-5	0.970	0.995	1.012	1.028	1.049	1.064	1.079	
162.35	Run-3	1.386	1.404	1.415	1.426	1.440	1.451	1.462	Sirajganj
	Run-4	1.315	1.325	1.332	1.339	1.347	1.353	1.360	
	Run-5	1.318	1.328	1.335	1.342	1.351	1.357	1.364	
170.75	Run-3	1.227	1.242	1.251	1.261	1.273	1.282	1.290	Downstream edge
	Run-4	1.686	1.804	1.882	1.957	2.055	2.127	2.200	of JMB Guide
	Run-5	1.805	1.946	2.039	2.129	2.245	2.332	2.418	Bunds
180.60	Run-3	1.085	1.106	1.120	1.134	1.151	1.164	1.177	Belkuchi
	Run-4	1.085	1.107	1.122	1.136	1.154	1.168	1.181	
	Run-5	1.117	1.148	1.168	1.188	1.213	1.232	1.251	
185.70	Run-3	1.720	1.760	1.787	1.812	1.845	1.870	1.894	Betil
	Run-4	1.723	1.763	1.789	1.815	1.848	1.873	1.897	
	Run-5	1.760	1.805	1.835	1.864	1.901	1.929	1.956	
205.15	Run-3	1.542	1.601	1.621	1.634	1.643	1.647	1.650	
	Run-4	1.545	1.605	1.626	1.639	1.649	1.654	1.657	
	Run-5	1.611	1.663	1.717	1.769	1.837	1.888	1.939	

Notes: 25 Year Simulation Option:

Run-3 - Present BRE Location + Current Brahmaputra Left Bank Condition

Run-4 - Present BRE Location + Current Brahmaputra Left Bank Condition + JMB (4,608 m)

Run-5 - Present BRE Location + FAP-3 Brahmaputra Left Bank Condition + JMB (4,608 m)

All velocities are in m/s.

Table 4.1 : 1988 Model Run Index

	Existing Left Bank	FAP-3 LB Proposal	LB Fully Confined
Current BRE Location	88S01 *	88S05	88S09
Current BRE Location + JMB (4,608m)	88S02 *	88S06 *	88S10
BRE Set Back 2 km + JMB (4,608m)	88S03	88S07	88S11
BRE Set Back 4 km + JMB (4,608m)	88S04	88S08	88S12
Current BRE Location + JMB (3,600m)	88S13		
Current BRE Location + JMB (5,600m)	88S14		

* 25 Year (1965-89) simulation was also made.

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Table 4.2 : Percent of 1988 Brahmaputra inflow Spilled through LB Distributaries under Different Project Options

Distributary	Project Options											
	88S01	88S02	88S03	88S04	88S05	88S06	88S07	88S08	88S09	88S10	88S11	88S12
Old Brahmaputra	7.0%	7.0%	6.0%	6.0%	7.0%	7.0%	7.0%	6.0%	0.0%	0.0%	0.0%	0.0%
ARD3	8.0%	8.0%	7.0%	7.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ARD4	6.0%	7.0%	6.0%	6.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ARD5	3.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ARD6	1.0%	2.0%	2.0%	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Dhaleswari	9.0%	9.0%	9.0%	8.0%	11.0%	11.0%	10.0%	10.0%	0.0%	0.0%	0.0%	0.0%
Total Outflow	34.0%	33.0%	30.0%	29.0%	18.0%	18.0%	17.0%	16.0%	0.0%	0.0%	0.0%	0.0%

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Table 4.3 : Simulated 1988 Maximum Water Level with Different Engineering Schemes for Brahmaputra River

(Sheet 1 of 2)

Brahmaputra 1-D Model	Maximum Water Level (m.PWD) with Different Schemes														Remarks
Chainage (km)	88S01	88S02	88S03	88S04	88S05	88S06	88S07	88S08	88S09	88S10	88S11	88S12	88S13	88S14	
25.00	26.95	26.95	26.87	26.79	26.96	26.97	26.88	26.80	27.00	27.00	26.91	26.82	26.95	26.95	
28.05	26.38	26.38	26.30	26.24	26.40	26.40	26.32	26.25	26.44	26.44	26.35	26.28	26.38	26.38	
31.35	26.04	26.04	25.95	25.87	26.06	26.07	25.96	25.88	26.11	26.12	26.00	25.92	26.05	26.04	
33.60	25.67	25.67	25.60	25.55	25.69	25.69	25.62	25.56	25.75	25.76	25.67	25.60	25.67	25.67	
36.10	25.31	25.31	25.24	25.18	25.34	25.34	25.26	25.20	25.41	25.42	25.32	25.24	25.31	25.31	Chilmari WLG
37.10	25.20	25.20	25.13	25.07	25.23	25.24	25.15	25.09	25.31	25.32	25.21	25.14	25.21	25.20	
42.60	24.66	24.66	24.58	24.52	24.70	24.70	24.61	24.54	24.80	24.81	24.70	24.61	24.66	24.66	
44.25	24.57	24.58	24.50	24.44	24.62	24.62	24.53	24.47	24.72	24.73	24.62	24.54	24.58	24.58	
48.60	24.26	24.26	24.19	24.13	24.30	24.31	24.23	24.16	24.42	24.43	24.32	24.24	24.26	24.26	
53.15	23.93	23.93	23.85	23.79	23.98	23.99	23.90	23.83	24.12	24.13	24.01	23.92	23.93	23.93	
55.65	23.68	23.68	23.61	23.55	23.74	23.74	23.66	23.59	23.88	23.89	23.79	23.70	23.68	23.68	
59.10	23.37	23.37	23.29	23.23	23.43	23.44	23.35	23.28	23.60	23.61	23.50	23.41	23.37	23.37	
63.30	22.88	22.89	22.82	22.76	22.97	22.98	22.89	22.82	23.18	23.19	23.07	22.97	22.89	22.89	
67.30	22.40	22.40	22.32	22.25	22.51	22.52	22.42	22.34	22.77	22.79	22.65	22.54	22.40	22.40	
71.20	22.13	22.14	22.06	21.98	22.26	22.28	22.17	22.09	22.57	22.59	22.45	22.33	22.14	22.14	
75.60	21.93	21.94	21.86	21.79	22.08	22.09	21.99	21.90	22.39	22.41	22.26	22.14	21.94	21.94	
78.55	21.79	21.80	21.71	21.63	21.95	21.97	21.86	21.76	22.26	22.28	22.13	22.00	21.81	21.80	Fulchari WLG
81.70	21.63	21.64	21.54	21.46	21.80	21.82	21.71	21.61	22.12	22.14	21.98	21.85	21.64	21.64	
83.10	21.57	21.58	21.48	21.40	21.75	21.76	21.65	21.55	22.06	22.08	21.92	21.79	21.58	21.57	
84.15	21.50	21.51	21.42	21.34	21.69	21.71	21.59	21.49	22.00	22.02	21.87	21.73	21.52	21.51	B'Bad T WLG
88.00	21.20	21.21	21.13	21.05	21.42	21.44	21.33	21.23	21.73	21.76	21.61	21.48	21.22	21.21	
93.80	20.70	20.71	20.64	20.56	20.99	21.01	20.91	20.81	21.30	21.33	21.18	21.05	20.72	20.71	
95.50	20.59	20.61	20.54	20.47	20.90	20.93	20.82	20.73	21.21	21.24	21.10	20.97	20.62	20.61	
100.50	20.27	20.29	20.23	20.16	20.63	20.66	20.56	20.47	20.94	20.98	20.84	20.71	20.30	20.28	
103.90	20.02	20.05	19.98	19.92	20.40	20.43	20.33	20.24	20.71	20.76	20.62	20.49	20.06	20.04	
108.90	19.72	19.75	19.67	19.60	20.11	20.15	20.03	19.93	20.43	20.48	20.32	20.18	19.77	19.75	
113.40	19.36	19.39	19.31	19.24	19.76	19.81	19.68	19.58	20.08	20.14	19.97	19.83	19.41	19.39	
114.55	19.18	19.22	19.14	19.07	19.59	19.65	19.52	19.41	19.91	19.98	19.81	19.67	19.24	19.21	Mathurapara WLG
117.75	18.88	18.93	18.84	18.76	19.31	19.37	19.24	19.13	19.63	19.71	19.53	19.39	18.96	18.92	
122.25	18.52	18.58	18.50	18.43	18.96	19.04	18.91	18.81	19.29	19.38	19.21	19.07	18.61	18.57	
126.50	18.27	18.33	18.26	18.20	18.73	18.81	18.69	18.59	19.06	19.16	18.99	18.85	18.37	18.32	
130.50	18.00	18.08	18.01	17.95	18.49	18.58	18.46	18.37	18.81	18.93	18.76	18.63	18.12	18.07	
134.30	17.64	17.74	17.66	17.61	18.17	18.28	18.16	18.06	18.50	18.64	18.46	18.33	17.78	17.72	
136.80	17.34	17.45	17.37	17.31	17.90	18.03	17.90	17.80	18.24	18.40	18.21	18.07	17.50	17.43	
139.00	17.15	17.27	17.19	17.14	17.74	17.88	17.75	17.65	18.09	18.25	18.07	17.93	17.33	17.25	
142.00	16.78	16.93	16.86	16.81	17.43	17.59	17.47	17.37	17.78	17.97	17.79	17.65	17.01	16.91	Kazipur WLG
143.45	16.56	16.73	16.66	16.61	17.21	17.40	17.28	17.18	17.57	17.78	17.60	17.47	16.81	16.70	
145.40	16.31	16.51	16.44	16.39	16.98	17.18	17.06	16.96	17.34	17.57	17.39	17.26	16.61	16.48	

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Table 4.3 : Simulated 1988 Maximum Water Level with Different Engineering Schemes for Brahmaputra River

(Sheet 2 of 2)

Brahmaputra 1-D Model	Maximum Water Level (m.PWD) with Different Schemes														Remarks
Chainage (km)	88S01	88S02	88S03	88S04	88S05	88S06	88S07	88S08	88S09	88S10	88S11	88S12	88S13	88S14	
147.55	16.13	16.35	16.28	16.23	16.80	17.03	16.91	16.81	17.18	17.43	17.25	17.11	16.46	16.31	
149.50	15.94	16.19	16.12	16.06	16.62	16.87	16.75	16.65	17.00	17.27	17.09	16.96	16.30	16.15	
151.75	15.78	16.05	15.98	15.93	16.47	16.74	16.61	16.52	16.85	17.14	16.96	16.83	16.18	16.00	
156.60	15.48	15.80	15.73	15.69	16.20	16.50	16.38	16.29	16.59	16.91	16.73	16.61	15.95	15.75	
158.50	15.36	15.70	15.64	15.59	16.08	16.40	16.28	16.20	16.48	16.82	16.64	16.52	15.86	15.65	
162.35	15.04	15.45	15.38	15.34	15.79	16.15	16.04	15.95	16.20	16.59	16.41	16.28	15.62	15.38	Sirajganj WLG
166.60	14.66	15.12	15.06	15.02	15.39	15.82	15.72	15.64	15.82	16.26	16.10	15.98	15.32	15.04	
168.50	14.55	14.71	14.64	14.58	15.28	15.38	15.27	15.18	15.72	15.83	15.64	15.51	14.79	14.76	JMB Guide Bund (U/s)
170.75	14.41	14.52	14.44	14.38	15.15	15.17	15.04	14.94	15.60	15.61	15.41	15.27	14.51	14.54	JMB Guide Bund (D/s)
174.30	13.89	13.96	13.90	13.85	14.60	14.60	14.50	14.42	15.09	15.08	14.92	14.79	13.95	13.96	
177.70	13.61	13.67	13.62	13.57	14.33	14.33	14.22	14.15	14.86	14.86	14.68	14.55	13.66	13.67	
179.20	13.48	13.54	13.48	13.43	14.18	14.17	14.08	14.00	14.71	14.71	14.53	14.41	13.53	13.55	
180.60	13.45	13.51	13.44	13.38	14.15	14.15	14.04	13.95	14.70	14.69	14.51	14.37	13.50	13.51	
185.70	13.03	13.09	13.03	12.97	13.71	13.71	13.62	13.54	14.30	14.30	14.13	14.00	13.08	13.09	
188.20	12.89	12.95	12.88	12.81	13.57	13.57	13.47	13.38	14.19	14.19	14.01	13.87	12.94	12.95	
191.75	12.56	12.62	12.54	12.47	13.22	13.22	13.11	13.03	13.89	13.89	13.71	13.57	12.61	12.62	
193.55	12.38	12.43	12.35	12.28	13.02	13.02	12.91	12.82	13.73	13.73	13.54	13.39	12.42	12.43	
195.75	12.35	12.40	12.31	12.24	12.99	12.99	12.87	12.78	13.71	13.71	13.51	13.35	12.39	12.40	
197.65	12.24	12.29	12.21	12.13	12.87	12.87	12.76	12.66	13.58	13.58	13.39	13.23	12.28	12.29	
201.30	11.98	12.03	11.95	11.87	12.58	12.58	12.48	12.39	13.27	13.27	13.09	12.94	12.02	12.03	
203.30	11.89	11.94	11.86	11.78	12.48	12.48	12.37	12.28	13.15	13.15	12.97	12.82	11.94	11.95	
205.15	11.82	11.87	11.78	11.71	12.39	12.39	12.29	12.19	13.05	13.05	12.87	12.72	11.86	11.87	
211.25	11.73	11.78	11.68	11.59	12.28	12.28	12.16	12.05	12.92	12.92	12.72	12.56	11.77	11.78	
213.20	11.64	11.68	11.59	11.51	12.17	12.17	12.06	11.95	12.79	12.79	12.60	12.45	11.68	11.69	
216.50	11.49	11.53	11.43	11.35	12.00	12.00	11.87	11.76	12.59	12.59	12.40	12.24	11.52	11.53	
218.90	11.43	11.48	11.37	11.28	11.93	11.93	11.80	11.69	12.52	12.52	12.32	12.16	11.47	11.48	Mathura WLG
220.00	11.38	11.42	11.32	11.23	11.86	11.86	11.74	11.63	12.43	12.44	12.25	12.09	11.41	11.42	
223.20	11.17	11.21	11.11	11.03	11.62	11.62	11.51	11.40	12.14	12.15	11.98	11.83	11.20	11.21	
229.40	10.93	10.96	10.91	10.85	11.33	11.32	11.26	11.19	11.79	11.78	11.69	11.58	10.96	10.97	
230.75	10.93	10.97	10.90	10.84	11.33	11.33	11.25	11.17	11.79	11.79	11.67	11.56	10.96	10.97	
235.50	10.19	10.22	10.24	10.27	10.53	10.52	10.55	10.57	10.92	10.92	10.92	10.92	10.21	10.22	Teota WLG

File : D:\1D-MODEL\S1988\WL\88SPWL.WK1

Table 4.4 : 1988 Maximum Water Level at Selected Brahmaputra Cross-sections under Different Project Options

Model Simulation	BRTS 1-D Model Chainage (Km) of the Brahmaputra											
	44.25	63.30	75.60	84.15	113.40	136.80	151.75	162.35	170.75	180.60	185.70	205.15
88S01 *	24.57	22.88	21.93	21.50	19.36	17.34	15.78	15.04	14.41	13.45	13.03	11.82
88S02 *	24.58	22.89	21.94	21.51	19.39	17.45	16.05	15.45	14.52	13.51	13.09	11.87
88S03	24.50	22.82	21.86	21.42	19.31	17.37	15.98	15.38	14.44	13.44	13.03	11.78
88S04	24.44	22.76	21.79	21.34	19.24	17.31	15.93	15.34	14.38	13.38	12.97	11.71
88S05	24.62	22.97	22.08	21.69	19.76	17.90	16.47	15.79	15.15	14.15	13.71	12.39
88S06 *	24.62	22.98	22.09	21.71	19.81	18.03	16.74	16.15	15.17	14.15	13.71	12.39
88S07	24.53	22.89	21.99	21.59	19.68	17.90	16.61	16.04	15.04	14.04	13.62	12.29
88S08	24.47	22.82	21.90	21.49	19.58	17.80	16.52	15.95	14.94	13.95	13.54	12.19
88S09	24.72	23.18	22.39	22.00	20.08	18.24	16.85	16.20	15.60	14.70	14.30	13.05
88S10	24.73	23.19	22.41	22.02	20.14	18.40	17.14	16.59	15.61	14.69	14.30	13.05
88S11	24.62	23.07	22.26	21.87	19.97	18.21	16.96	16.41	15.41	14.51	14.13	12.87
88S12	24.54	22.97	22.14	21.73	19.83	18.07	16.83	16.28	15.27	14.37	14.00	12.72
88S13	24.58	22.89	21.94	21.52	19.41	17.50	16.18	15.62	14.51	13.50	13.08	11.86
88S14	24.58	22.89	21.94	21.51	19.39	17.43	16.00	15.38	14.54	13.51	13.09	11.87

Note : *1965-89 (25 Year) Simulation was also done.

1965-89 boundary conditions for model simulations were collected from FAP 25 (Ref. RUN 5)
All water levels are in m.PWD.

File : D:\1D-MODEL\S1988\88smwl.wk1

Table 4.5 : Simulated 1988 Maximum Average Velocity with Different Engineering Schemes for Brahmaputra River

(Sheet 1 of 2)

Brahmaputra 1-D Model Chainage (km)	Maximum Average Velocity (m/s) with Different Schemes														Remarks
	88S01	88S02	88S03	88S04	88S05	88S06	88S07	88S08	88S09	88S10	88S11	88S12	88S13	88S14	
25.00	1.553	1.553	1.470	1.404	1.550	1.550	1.468	1.402	1.543	1.543	1.461	1.397	1.553	1.553	
28.05	1.958	1.957	1.839	1.770	1.953	1.952	1.835	1.769	1.940	1.939	1.823	1.765	1.957	1.958	
31.35	1.235	1.234	1.194	1.169	1.231	1.230	1.190	1.166	1.221	1.220	1.182	1.159	1.234	1.234	
33.60	2.007	2.007	1.817	1.718	1.999	1.998	1.811	1.714	1.979	1.978	1.795	1.709	2.007	2.007	
36.10	1.615	1.615	1.558	1.516	1.607	1.606	1.551	1.513	1.587	1.585	1.533	1.508	1.615	1.615	Chilmari WLG
37.10	1.399	1.398	1.342	1.322	1.391	1.390	1.335	1.318	1.371	1.370	1.322	1.312	1.398	1.398	
42.60	1.362	1.361	1.339	1.317	1.354	1.353	1.332	1.310	1.335	1.333	1.314	1.294	1.361	1.361	
44.25	1.112	1.112	1.055	1.008	1.105	1.105	1.049	1.003	1.088	1.088	1.035	0.991	1.112	1.112	
48.60	1.482	1.481	1.437	1.402	1.471	1.470	1.427	1.392	1.445	1.443	1.403	1.371	1.481	1.481	
53.15	1.354	1.353	1.335	1.318	1.343	1.342	1.326	1.310	1.316	1.315	1.302	1.288	1.353	1.353	
55.65	1.601	1.600	1.524	1.479	1.584	1.582	1.508	1.468	1.543	1.541	1.471	1.447	1.600	1.600	
59.10	1.503	1.502	1.458	1.419	1.489	1.488	1.445	1.407	1.456	1.454	1.412	1.375	1.502	1.502	
63.30	1.883	1.881	1.817	1.773	1.853	1.850	1.788	1.751	1.783	1.779	1.723	1.714	1.880	1.882	
67.30	1.639	1.638	1.601	1.569	1.604	1.602	1.566	1.534	1.526	1.523	1.491	1.482	1.637	1.639	
71.20	1.185	1.184	1.128	1.098	1.155	1.152	1.100	1.076	1.089	1.086	1.050	1.052	1.183	1.184	
75.60	1.162	1.160	1.114	1.078	1.126	1.122	1.080	1.048	1.152	1.148	1.103	1.068	1.159	1.160	
78.55	1.182	1.180	1.185	1.195	1.140	1.137	1.144	1.158	1.160	1.156	1.159	1.164	1.178	1.180	Fulchari WLG
81.70	1.224	1.221	1.203	1.214	1.174	1.170	1.177	1.187	1.189	1.185	1.183	1.195	1.220	1.221	
83.10	1.216	1.214	1.163	1.122	1.176	1.172	1.125	1.087	1.211	1.206	1.154	1.112	1.213	1.214	
84.15	1.330	1.327	1.294	1.265	1.281	1.276	1.245	1.219	1.312	1.307	1.271	1.241	1.326	1.328	B'Bad T WLG
88.00	1.641	1.637	1.542	1.503	1.564	1.557	1.470	1.466	1.592	1.584	1.492	1.471	1.635	1.637	
93.80	1.619	1.614	1.533	1.466	1.533	1.525	1.449	1.386	1.571	1.562	1.479	1.410	1.611	1.615	
95.50	1.435	1.430	1.338	1.258	1.356	1.350	1.264	1.191	1.392	1.384	1.293	1.216	1.428	1.431	
100.50	1.337	1.331	1.259	1.210	1.240	1.232	1.169	1.125	1.263	1.254	1.188	1.142	1.328	1.332	
103.90	1.414	1.412	1.416	1.421	1.405	1.402	1.408	1.415	1.405	1.402	1.409	1.416	1.410	1.412	
108.90	1.107	1.100	1.126	1.091	1.119	1.110	1.142	1.105	1.143	1.133	1.167	1.127	1.097	1.102	
113.40	1.481	1.469	1.445	1.457	1.477	1.461	1.441	1.458	1.495	1.478	1.437	1.451	1.462	1.471	
114.55	1.706	1.703	1.703	1.703	1.677	1.675	1.675	1.675	1.676	1.673	1.673	1.906	1.701	1.704	Mathurapara WLG
117.75	1.297	1.287	1.243	1.205	1.316	1.302	1.254	1.212	1.352	1.337	1.283	1.235	1.281	1.288	
122.25	1.304	1.288	1.204	1.167	1.299	1.281	1.198	1.141	1.323	1.302	1.218	1.144	1.280	1.291	
126.50	0.948	0.937	0.893	0.859	0.951	0.937	0.895	0.861	0.973	0.958	0.914	0.879	0.931	0.939	
130.50	1.103	1.085	1.042	1.003	1.086	1.066	1.025	0.990	1.102	1.080	1.038	0.998	1.076	1.088	
134.30	1.171	1.146	1.114	1.113	1.136	1.111	1.099	1.102	1.148	1.120	1.095	1.098	1.134	1.150	
136.80	1.275	1.245	1.227	1.208	1.234	1.203	1.183	1.164	1.249	1.216	1.192	1.168	1.230	1.250	
139.00	1.006	0.983	0.929	0.893	0.983	0.960	0.907	0.873	1.001	0.976	0.922	0.886	0.972	0.987	
142.00	1.377	1.335	1.335	1.335	1.303	1.289	1.289	1.289	1.313	1.287	1.287	1.291	1.325	1.339	Kazipur WLG
143.45	1.285	1.231	1.178	1.159	1.315	1.270	1.210	1.154	1.327	1.280	1.219	1.161	1.206	1.240	
145.40	1.271	1.213	1.183	1.155	1.305	1.258	1.219	1.183	1.319	1.269	1.229	1.190	1.187	1.223	
147.55	1.072	1.020	0.972	0.937	1.104	1.062	1.007	0.968	1.116	1.073	1.018	0.978	0.997	1.029	
149.50	1.256	1.188	1.157	1.155	1.284	1.229	1.188	1.162	1.295	1.239	1.195	1.155	1.157	1.198	

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Table 4.5 : Simulated 1988 Maximum Average Velocity with Different Engineering Schemes for Brahmaputra River

(Sheet 2 of 2)

Brahmaputra 1-D Model Chainage (km)	Maximum Average Velocity (m/s) with Different Schemes														Remarks
	88S01	88S02	88S03	88S04	88S05	88S06	88S07	88S08	88S09	88S10	88S11	88S12	88S13	88S14	
151.75	1.066	1.006	0.966	0.930	1.094	1.046	1.000	0.960	1.105	1.055	1.009	0.968	0.979	1.015	
156.60	1.008	0.943	0.901	0.859	1.033	0.982	0.935	0.890	1.042	0.991	0.944	0.898	0.915	0.953	
158.50	1.104	1.031	1.031	1.032	1.117	1.055	1.033	1.033	1.121	1.059	1.030	1.033	1.001	1.042	
162.35	1.434	1.318	1.310	1.310	1.437	1.344	1.306	1.307	1.435	1.345	1.301	1.302	1.263	1.336	Sirajganj WLG
166.60	1.610	1.528	1.440	1.387	1.712	1.599	1.487	1.417	1.722	1.612	1.495	1.419	1.470	1.550	
168.50	1.445	2.612	2.658	2.696	1.520	2.780	2.830	2.874	1.517	2.821	2.883	2.930	3.294	2.138	JMB Guide Bund (u/s)
170.75	1.250	2.013	2.046	2.073	1.292	2.195	2.230	2.260	1.274	2.254	2.296	2.328	2.436	1.956	JMB Guide Bund (d/s)
174.30	2.508	2.511	2.530	2.545	2.546	2.545	2.556	2.581	2.507	2.506	2.525	2.540	2.511	2.511	
177.70	1.595	1.597	1.598	1.598	1.571	1.571	1.568	1.568	1.556	1.556	1.557	1.558	1.595	1.597	
179.20	1.471	1.485	1.432	1.402	1.625	1.624	1.535	1.479	1.628	1.627	1.526	1.462	1.483	1.486	
180.60	1.112	1.119	1.110	1.103	1.189	1.188	1.165	1.147	1.166	1.166	1.141	1.121	1.117	1.119	
185.70	1.759	1.762	1.736	1.729	1.810	1.809	1.755	1.751	1.752	1.751	1.685	1.678	1.761	1.763	
188.20	1.488	1.488	1.487	1.491	1.492	1.491	1.490	1.494	1.444	1.443	1.448	1.453	1.488	1.489	
191.75	1.764	1.770	1.782	1.790	1.815	1.814	1.816	1.817	1.716	1.715	1.723	1.731	1.768	1.771	
193.55	1.884	1.889	1.906	1.917	1.955	1.954	1.972	1.984	1.830	1.829	1.846	1.857	1.887	1.890	
195.75	1.053	1.053	1.047	1.052	1.060	1.060	1.051	1.059	1.064	1.064	1.057	1.062	1.052	1.053	
197.65	1.432	1.432	1.442	1.448	1.449	1.449	1.446	1.451	1.474	1.473	1.463	1.466	1.432	1.432	
201.30	1.927	1.931	1.940	1.956	1.966	1.964	1.967	1.981	1.985	1.983	1.976	1.989	1.929	1.932	
203.30	1.513	1.519	1.520	1.522	1.605	1.603	1.587	1.573	1.714	1.714	1.633	1.608	1.516	1.520	
205.15	1.585	1.592	1.578	1.567	1.663	1.661	1.634	1.610	1.708	1.707	1.665	1.634	1.589	1.592	
211.25	0.823	0.832	0.840	0.852	0.933	0.932	0.929	0.934	1.058	1.057	1.038	1.030	0.831	0.833	
213.20	1.517	1.522	1.531	1.539	1.582	1.581	1.583	1.583	1.628	1.626	1.609	1.608	1.520	1.522	
216.50	1.540	1.546	1.569	1.589	1.621	1.619	1.645	1.666	1.660	1.658	1.673	1.700	1.543	1.546	
218.90	1.210	1.214	1.225	1.234	1.265	1.264	1.268	1.271	1.305	1.304	1.303	1.300	1.212	1.214	Mathura WLG
220.00	1.426	1.430	1.414	1.420	1.495	1.493	1.457	1.450	1.546	1.545	1.491	1.486	1.428	1.431	
223.20	1.879	1.886	1.923	1.956	1.977	1.975	2.017	2.049	2.038	2.035	2.069	2.098	1.882	1.886	
229.40	1.276	1.299	1.059	0.908	1.387	1.401	1.137	0.973	1.575	1.588	1.286	1.093	1.295	1.300	
230.75	0.998	1.005	0.949	0.876	1.080	1.079	1.014	0.933	1.190	1.189	1.090	0.984	1.002	1.005	
235.50	3.173	3.189	2.834	2.546	3.372	3.371	2.970	2.651	3.608	3.608	3.139	2.776	3.187	3.190	Teota WLG

File : D:\1D-MODEL\S1988\88SPv.WK1

Table 4.6 : 1988 Maximum Average Velocity at Selected Brahmaputra Cross-sections under Different Project Options

Model Simulation	BRTS 1-D Model Chainage (Km) of the Brahmaputra											
	44.25	63.30	75.60	84.15	113.40	136.80	151.75	162.35	170.75	180.60	185.70	205.15
88S01 *	1.112	1.883	1.162	1.330	1.481	1.275	1.066	1.434	1.250	1.112	1.759	1.585
88S02 *	1.112	1.881	1.160	1.327	1.469	1.245	1.006	1.318	2.013	1.119	1.762	1.592
88S03	1.055	1.817	1.114	1.294	1.445	1.227	0.966	1.310	2.046	1.110	1.736	1.578
88S04	1.008	1.773	1.078	1.265	1.457	1.208	0.930	1.310	2.073	1.103	1.729	1.567
88S05	1.105	1.853	1.126	1.281	1.477	1.234	1.094	1.437	1.292	1.189	1.810	1.663
88S06 *	1.105	1.850	1.122	1.276	1.461	1.203	1.046	1.344	2.195	1.188	1.809	1.661
88S07	1.049	1.788	1.080	1.245	1.441	1.183	1.000	1.306	2.230	1.165	1.755	1.634
88S08	1.003	1.751	1.048	1.219	1.458	1.164	0.960	1.307	2.260	1.147	1.751	1.610
88S09	1.088	1.783	1.152	1.312	1.495	1.249	1.105	1.435	1.274	1.166	1.752	1.708
88S10	1.088	1.779	1.148	1.307	1.478	1.216	1.055	1.345	2.254	1.166	1.751	1.707
88S11	1.035	1.723	1.103	1.271	1.437	1.192	1.009	1.301	2.296	1.141	1.685	1.665
88S12	0.991	1.714	1.068	1.241	1.451	1.168	0.968	1.302	2.328	1.121	1.678	1.634
88S13	1.112	1.880	1.159	1.326	1.462	1.230	0.979	1.263	2.436	1.117	1.761	1.589
88S14	1.112	1.882	1.160	1.328	1.471	1.250	1.015	1.336	1.956	1.119	1.763	1.592

Note : * 1965-89 (25 Year) Simulation was also done.

1965-89 boundary conditions for model simulations were collected from FAP 25 (Ref. RUN 5)

All velocities are in m/s.

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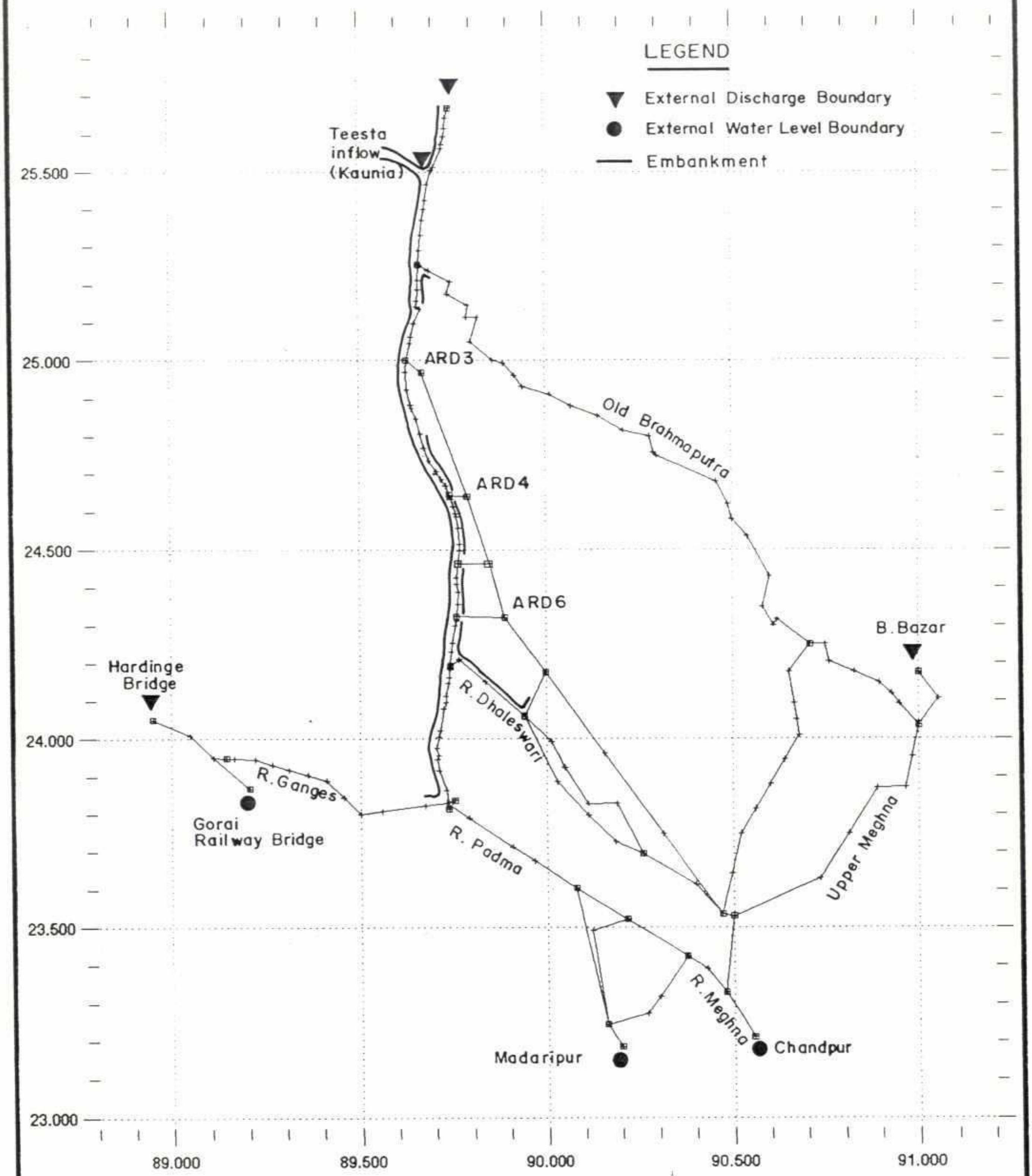
Table 5.1 Preliminary Estimate of Confidence Limits for Predicting Water Levels at Priority Sites

Potential Sources Of Error	Comment	Possible Confidence Limits Fulchari	Sariakandi	Mathurapara	Kazipur	Sirajganj	Betil	Likely Confidence Limits Fulchari	Sriakandi	Mathurapara	Kazipur	Sirajganj	Betil
Cross Section Data													
1.1 Incorrect datum	Dependent on distance to SOB BM	.02	.08	.08	.06	.06	.08	.01	.03	.03	.03	.03	.03
1.2 Location error	Only minimal local effect	.01	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00
1.3 Survey error	Only minimal local effect	.01	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00
1.4 Selection of cross section	Minimal; overall effect averaged	.01	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00
1.5 Combination		.02	.08	.08	.06	.06	.08	.01	.03	.03	.03	.03	.03
Water Level Gauge													
2.1 Missing data	Identifiable	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
2.2 Static water level	Identifiable	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
2.3 Reading error	Often Identifiable	.10	.10	.10	.10	.10	.10	.05	.05	.05	.05	.05	.05
2.4 Gauge level incorrect	Poor transfer of level from BWDB BM to gauge	.10	.10	.10	.10	.10	.10	.05	.05	.05	.05	.05	.05
2.5 Gauge sited incorrectly	Not located in recorded position	.10	.10	.10	.10	.10	.10	.02	.02	.02	.02	.02	.02
2.5 Cross flow induces a WL slope and affects WL reading	Cross flows not evident at these sites	.10	.10	.10	.10	.10	.10	.00	.00	.00	.00	.00	.00
2.7 Transfer of level to BWDB BM	Dependent on traverse distance (consider av of adj gauges)	.02	.03	.03	.03	.03	.03	.05	.08	.08	.06	.06	.08
2.8 Combination		.10	.10	.10	.10	.10	.10	.05	.08	.08	.06	.06	.08
Assumptions In 1-D Model													
3.1 Constant Mannings "n" used	Variation with depth effectively covers seasonal variation	.10	.10	.10	.10	.10	.10	.03	.03	.03	.03	.03	.03
3.2 Fixed cross sections	25 year runs indicates this is OK	.20	.20	.20	.20	.20	.20	.05	.05	.05	.05	.05	.05
3.3 Flow into model in error	Variation in inflow	.50	.45	.45	.45	.38	.32	.17	.15	.15	.15	.13	.11
3.4 Bahadurabad gauge datum inconsistent with RB sites	FAP-18 due to link left and right banks	.80	.00	.00	.00	.00	.00	.50	.00	.00	.00	.00	.00
3.5 Combination		.80	.45	.45	.45	.38	.32	.50	.15	.15	.15	.13	.11
Topographic Surveys													
4.1 SOB bench marks	Possible error in SOB bench marks	.05	.05	.05	.05	.05	.05	.02	.02	.02	.02	.02	.02
4.2 Transfer of levels	Dependent upon distance from SOB BM	.02	.08	.08	.06	.06	.08	.01	.03	.03	.03	.03	.03
4.3 Combination		.05	.08	.08	.06	.06	.08	.02	.03	.03	.03	.03	.03
Assessment Of Return Period													
5.1 Representativeness of 25 year	Sampling properties of 25 year period	.30	.30	.30	.30	.30	.30	.20	.20	.20	.20	.20	.20

Notes : BM - Bench Mark
WL - Water Level
RB - Right Bank

FIGURES

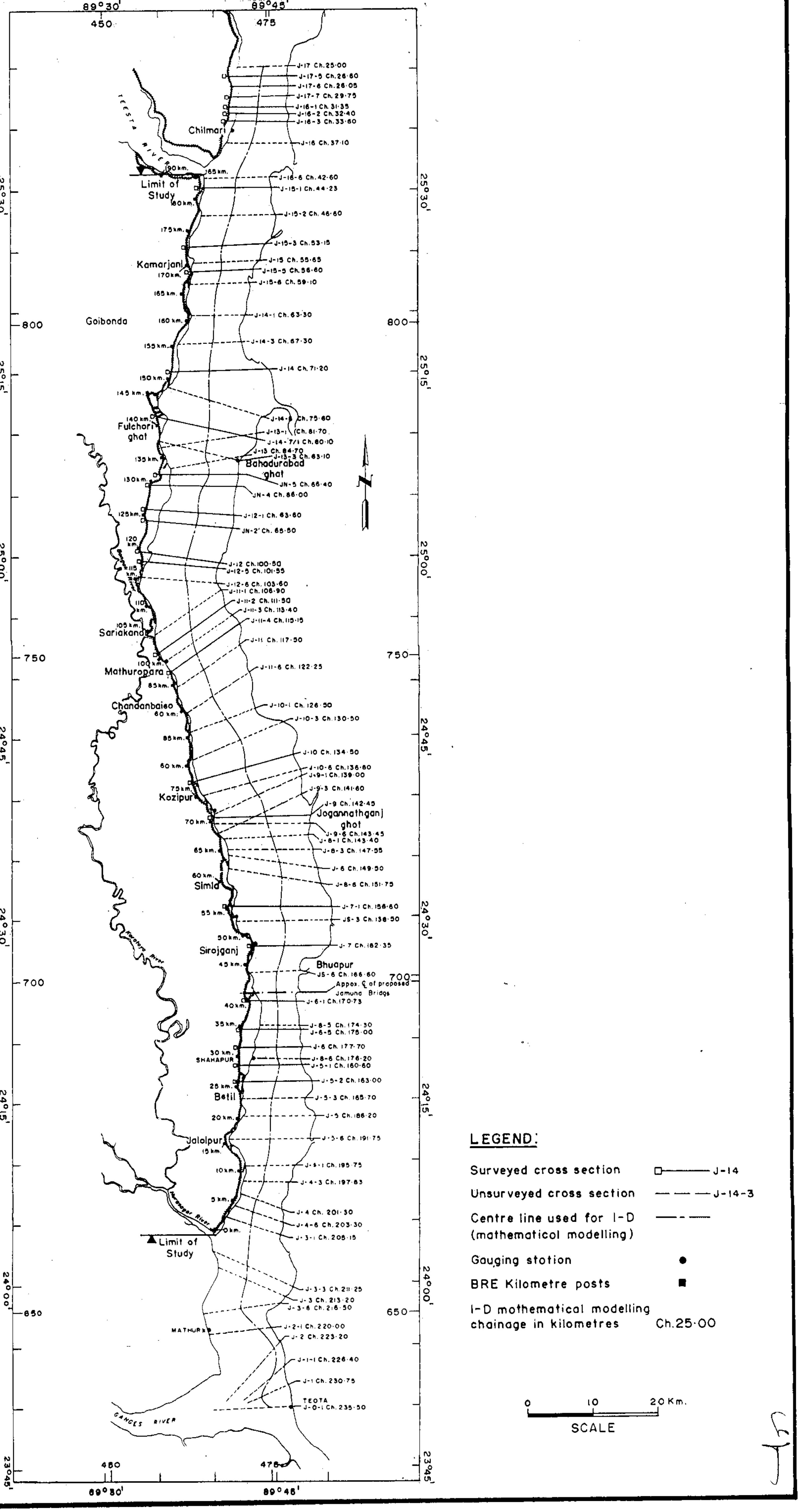


BRTS 1-D Hydrodynamic Modelling

Layout of Brahmaputra River Model:
Existing BRE and Left Bank Confinement

Vol.3 Part 7

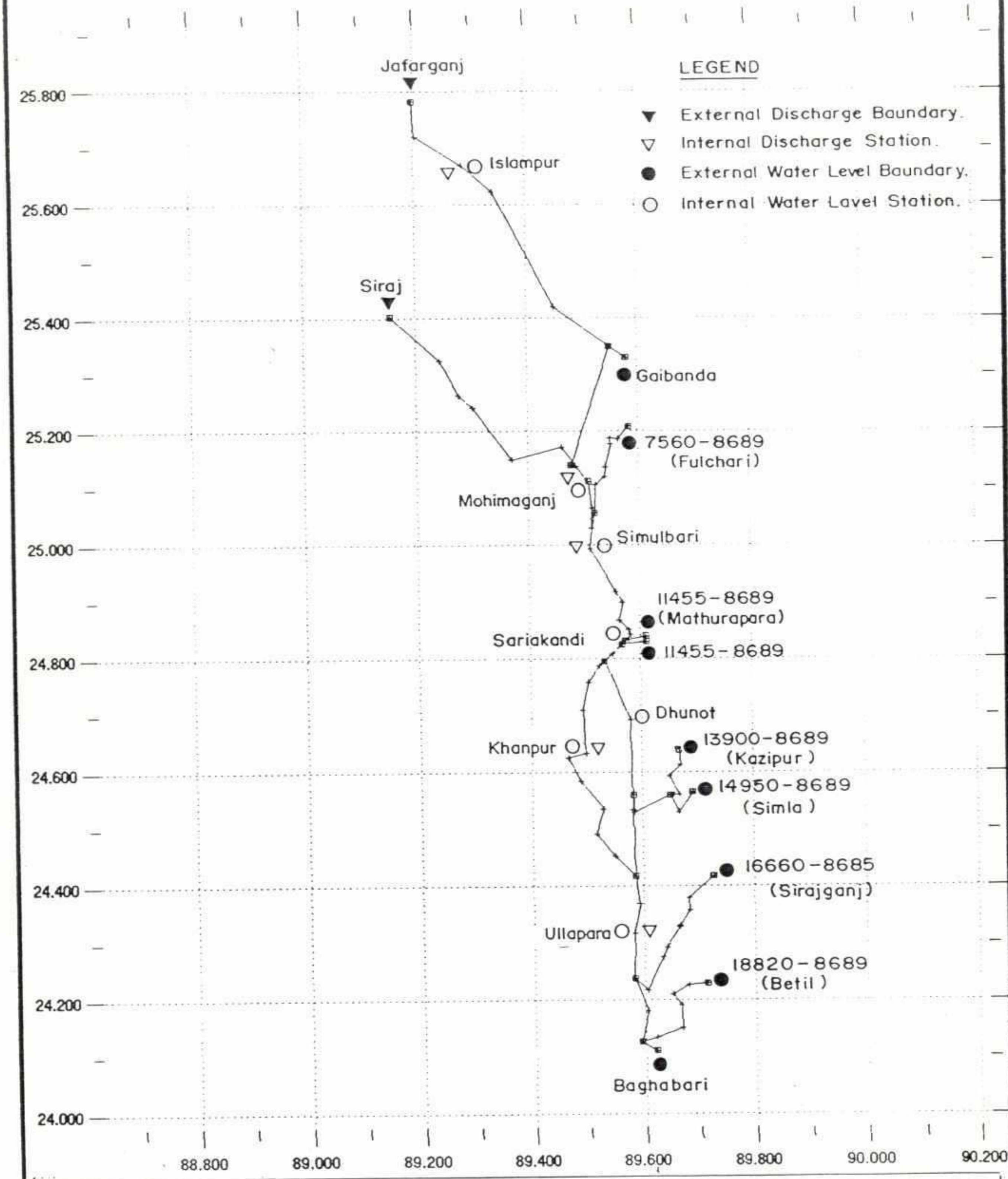
Figure 2.1



Location of Morphology Cross-Sections and Gauging Stations

Vol.3 Part 7

Figure 2.2



BRAHMAPUTRA RIVER TRAINING STUDIES
Layout of the FAP 2 Sub – Model within Which the Right Bank Model of the Brahmaputra was Built

MIKE 11

SCALE : 1 : 10000
DATA FILE : NWRM – BC2.RDF
EDITED : 16 – DEC – 1991, 17:43

Dwg no.:

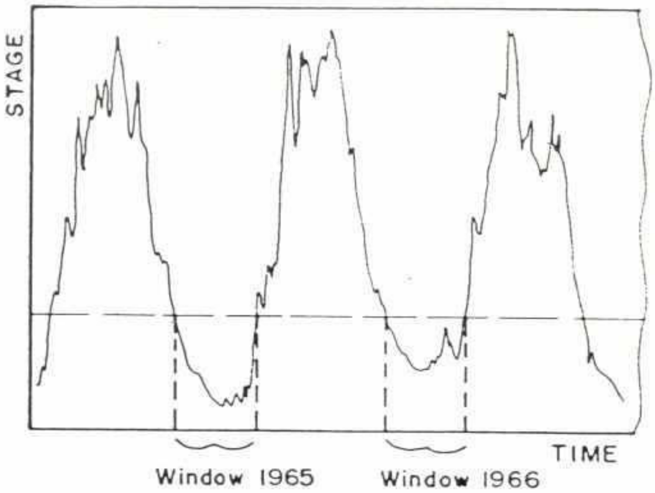
BRTS 1-D Hydrodynamic Modelling

Layout of Brahmaputra Right Bank Floodplain Model

Vol.3 Part 7

Figure 2.3

TIME	WL STAGE (m PWD)	FLOW (m^3/s)
0	10.020	4499
3600	10.190	4596
7200	10.280	4742
10800	10.320	4745

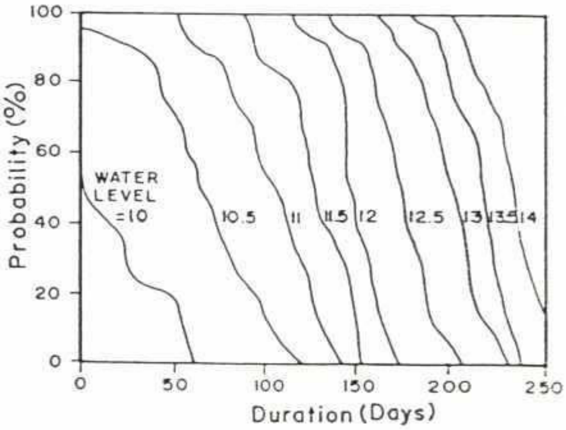


Determine Duration of Construction Window for Each Year at Various Stages

YEAR	CONSTRUCTION WINDOW (Days) STAGE (m PWD)			
	10.5	11	11.5	12
1965	94	121	140	152
1966	0	54	91	
1967	75	112	147	
1968	85	128	151	
1969	62	115	130	
1970	85	136	151	

Rank Years in Ascending Order of Construction Window Duration

YEAR	% YEARS	CONSTRUCTION WINDOW (Days) STAGE (m PWD)			
		10.5	11	11.5	12
66/67	100	0	54	91	148
88/89	96	21	61	107	
73/74	92	43	86	121	
69/70	88	62	115	130	



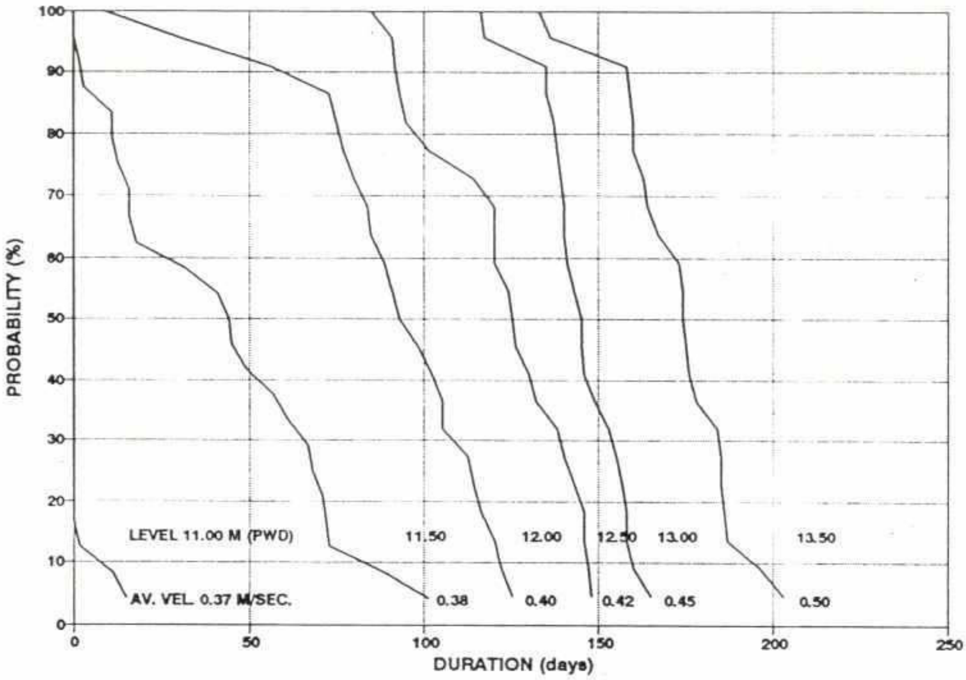
BRTS 1-D Hydrodynamic Modelling

Steps in Data Analysis to Determine Probability of Construction Window

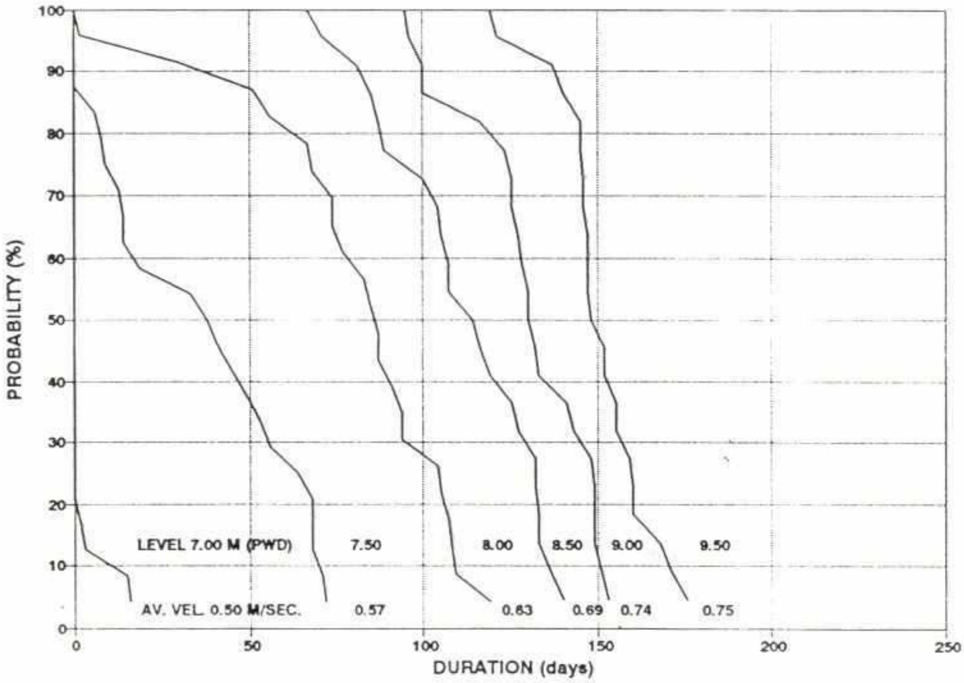
Vol.3 **Part 7**

Figure 2.4

Cross-Section J-II-I : Sariakandi



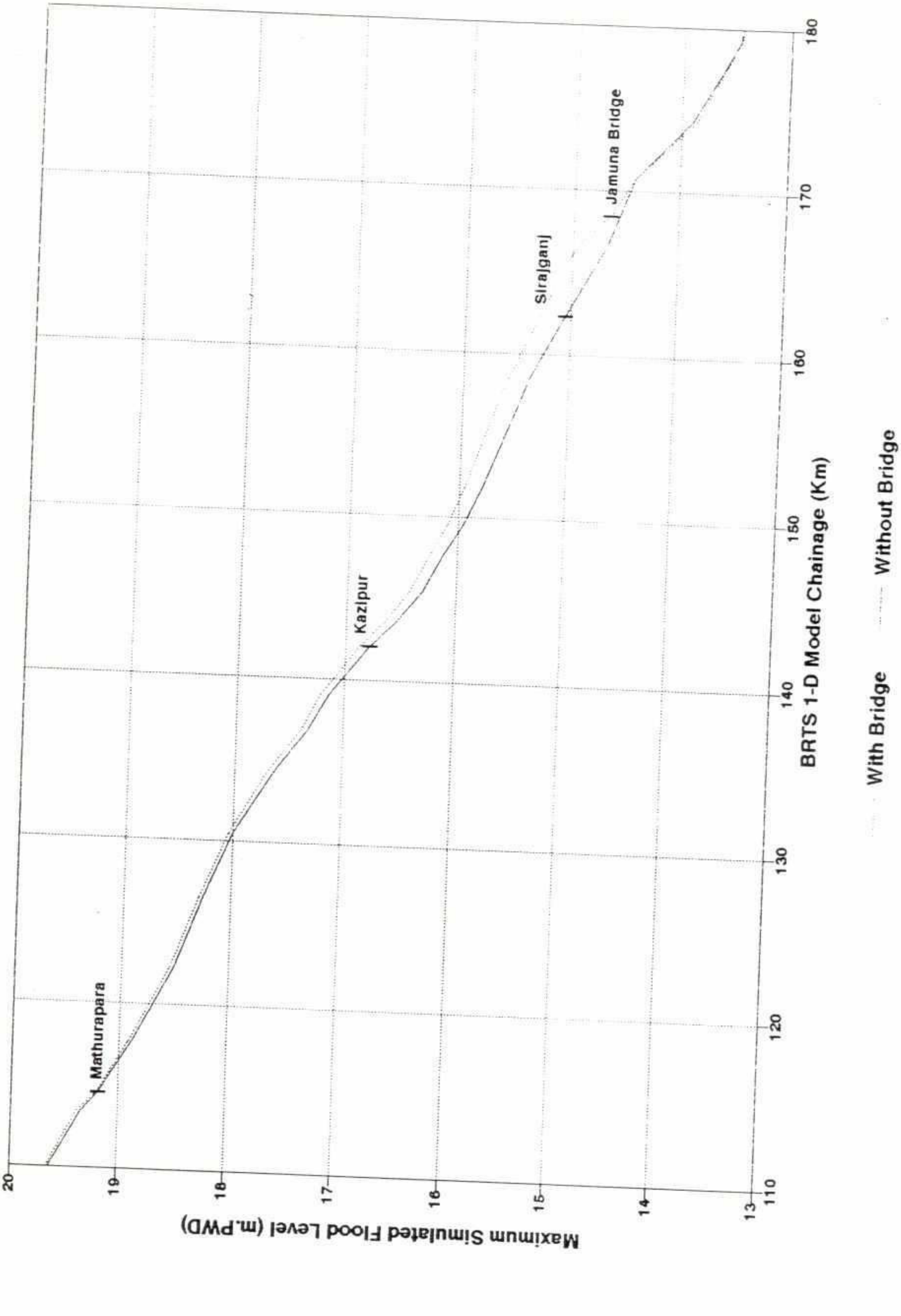
Cross-Section J-7 : Sirajganj



BRTS 1-D Hydrodynamic Modelling

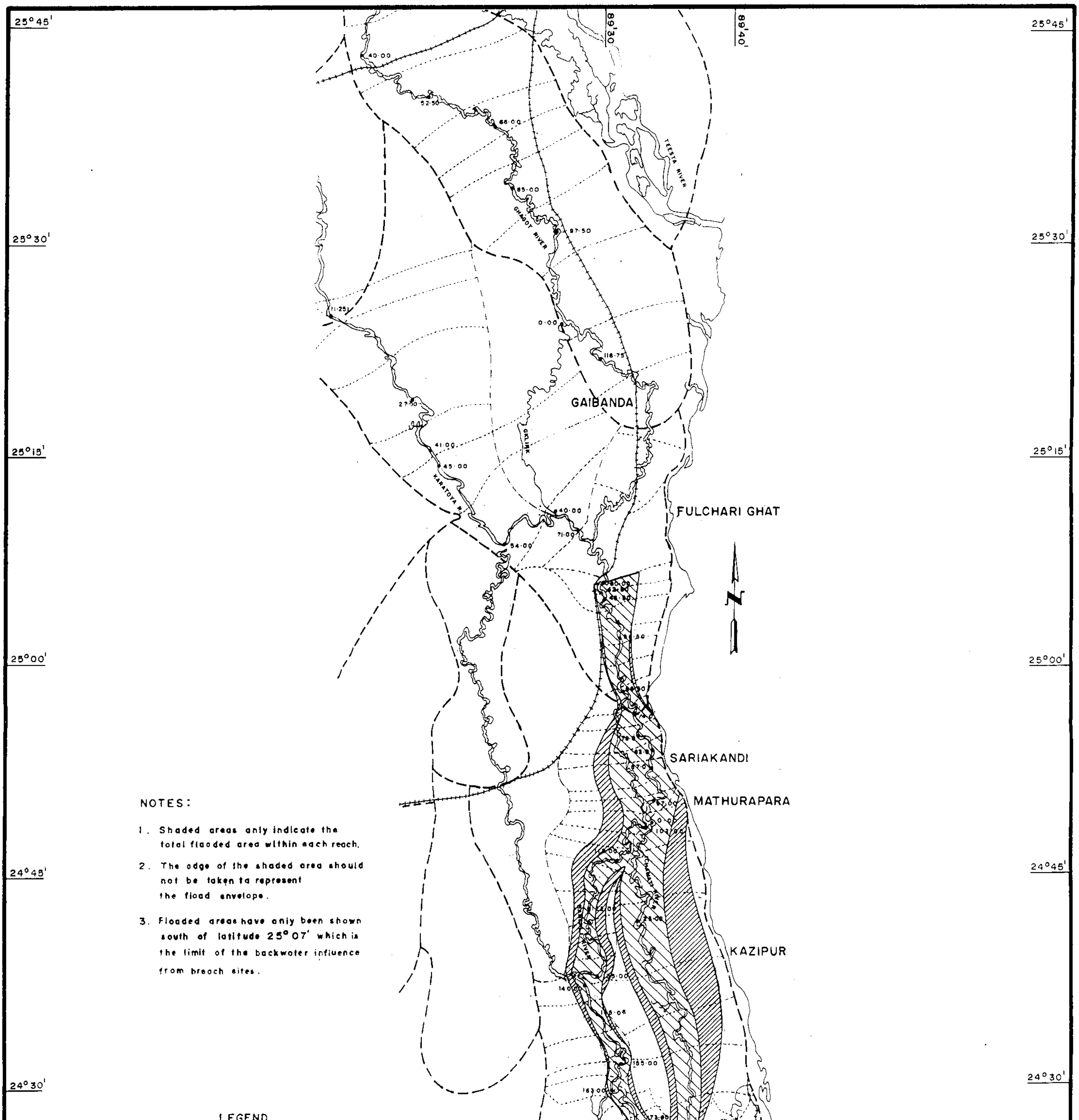
Probability of Construction Window Duration at Sariakandi and Sirajganj.	**Vol.3** **Part 7**
	Figure 2.5

92



BRTS 1-D Hydrodynamic Modelling

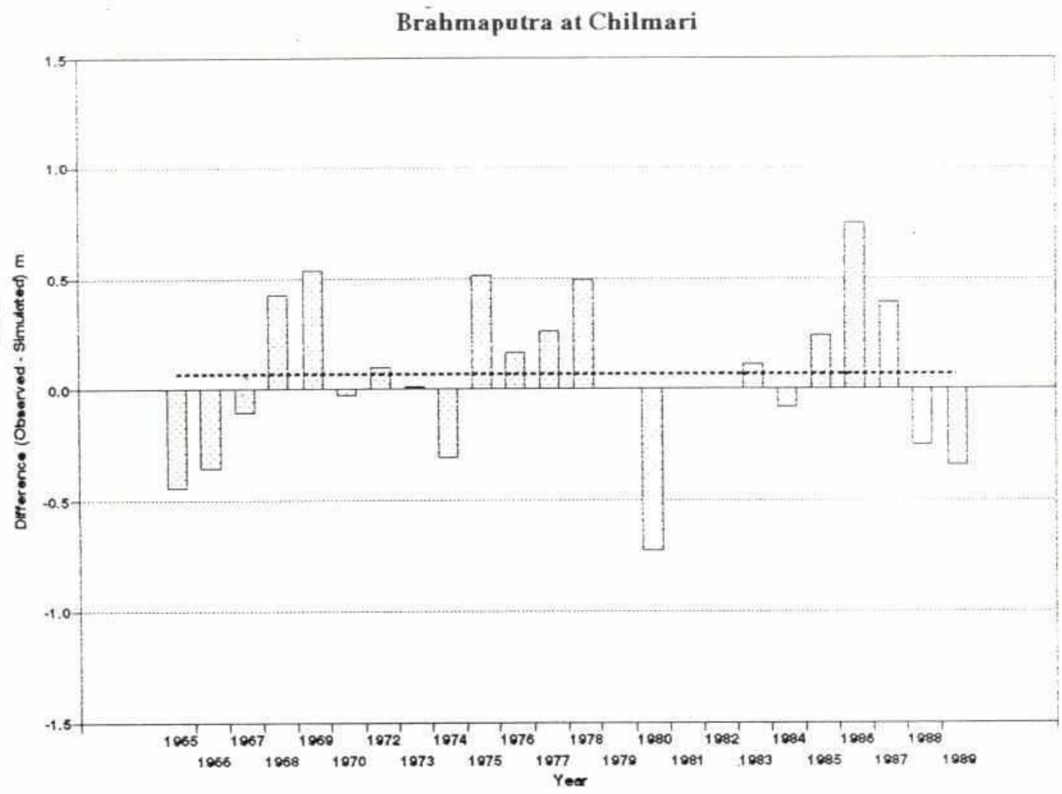
Simulated 1988 Flood Profile down the Brahmaputra with and without Jamuna Bridge	Vol.3	Part 7
	Figure 2.6	

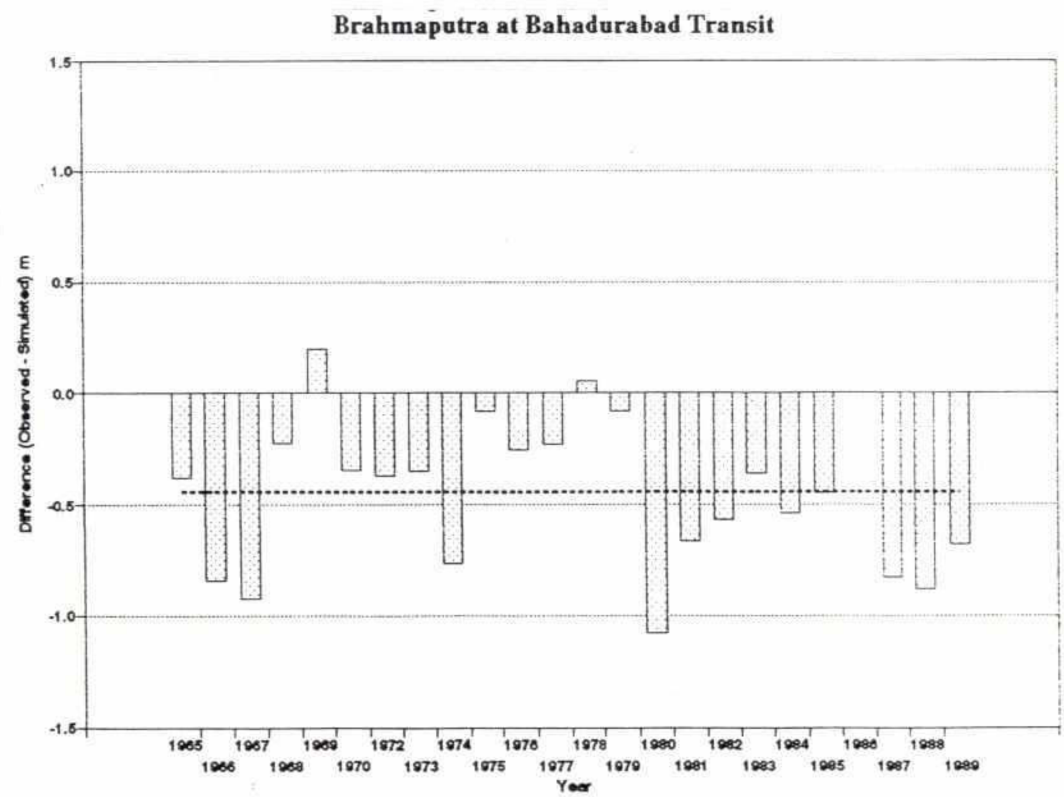


Increased Area of Flooding Due to a Breach at Mathurapara as Derived From the 1-D Model

Vol.3 Part 7

Figure 2.7

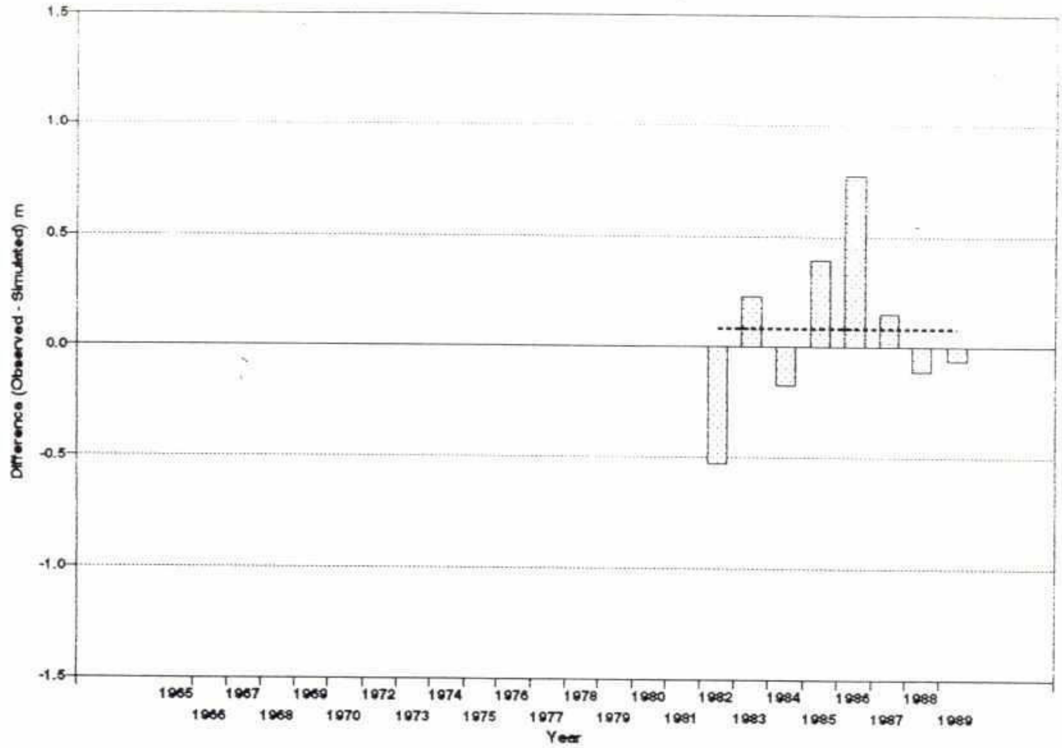




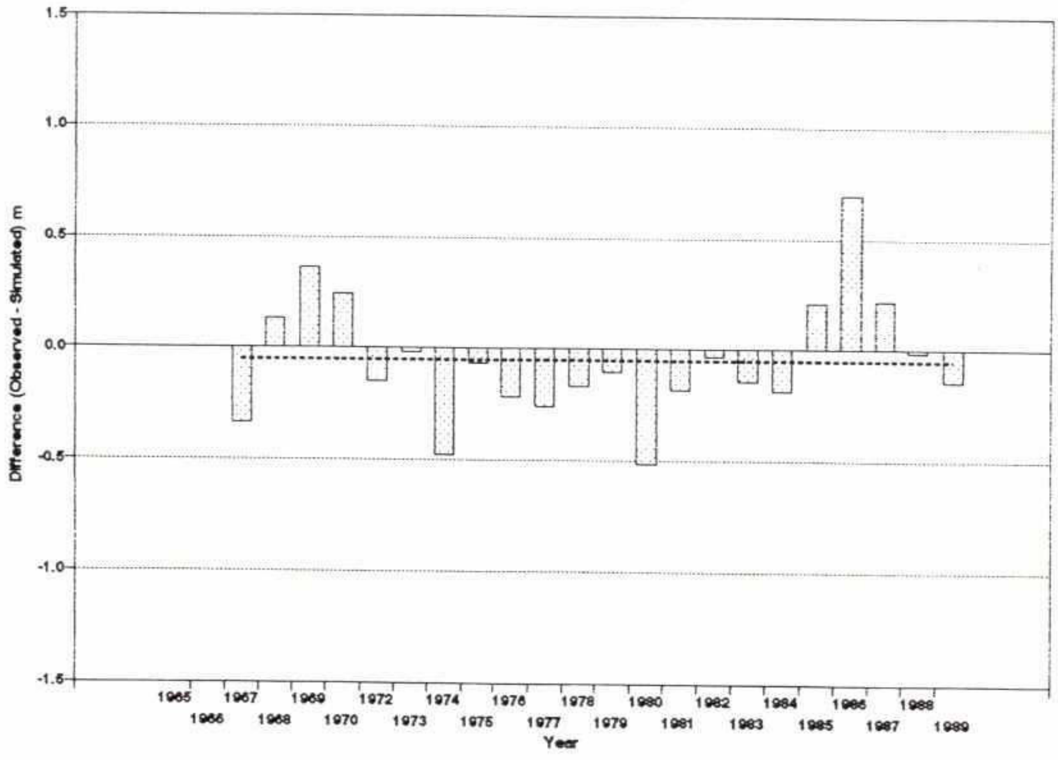
BRTS 1-D Hydrodynamic Modelling

Comparison Between Observed and Modelled Peak Water Levels at Chilmari and Bahadurabad Transit	Vol.3	Part 7
	Figure 3.1	

Brahmaputra at Mathurapara



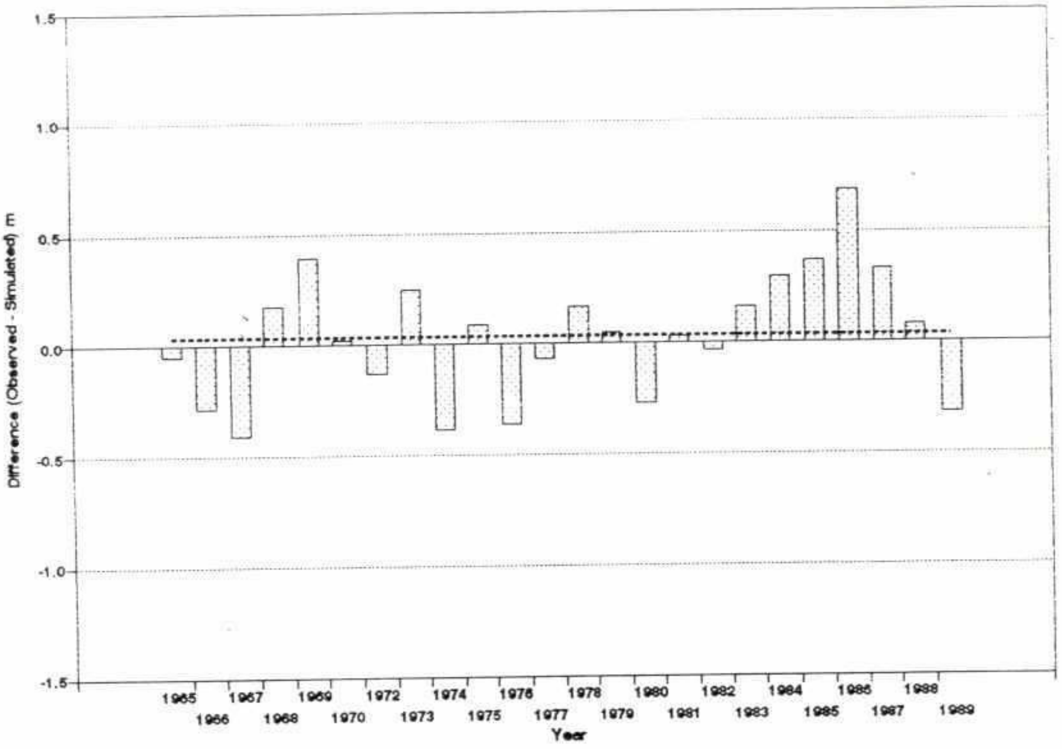
Brahmaputra at Kazipur



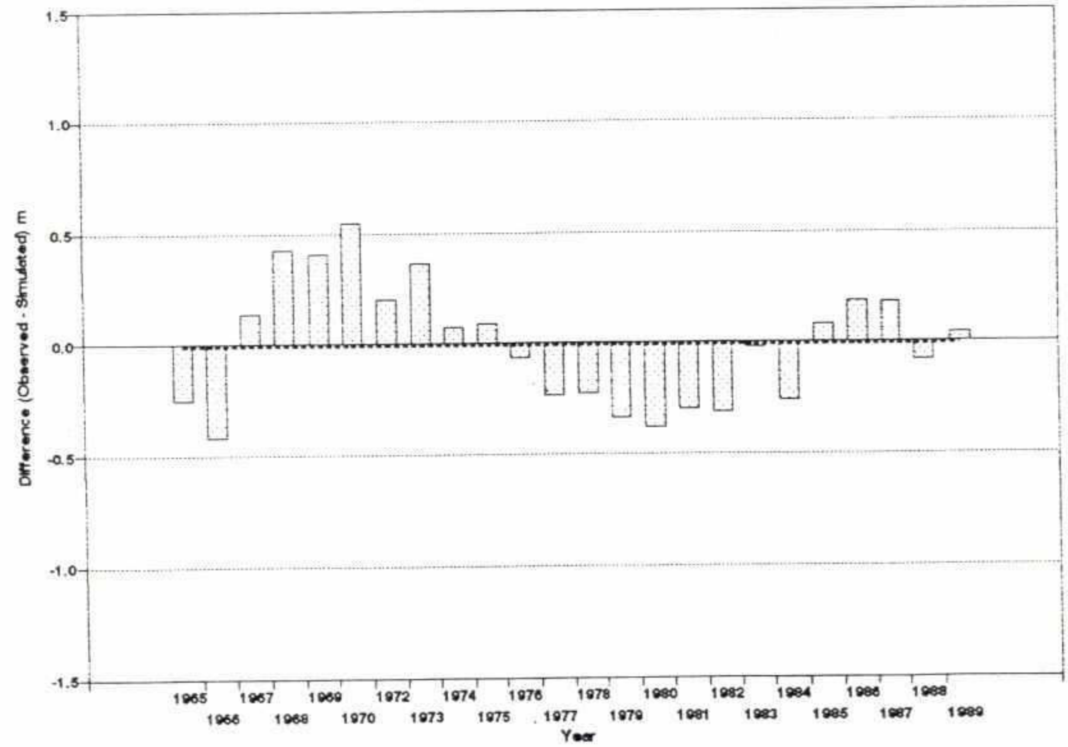
BRTS 1-D Hydrodynamic Modelling

Comparison Between Observed and Modelled Peak Water Levels at Mathurapara and Kazipur	Vol.3 Part 7
	Figure 3.2

Brahmaputra at Sirajganj

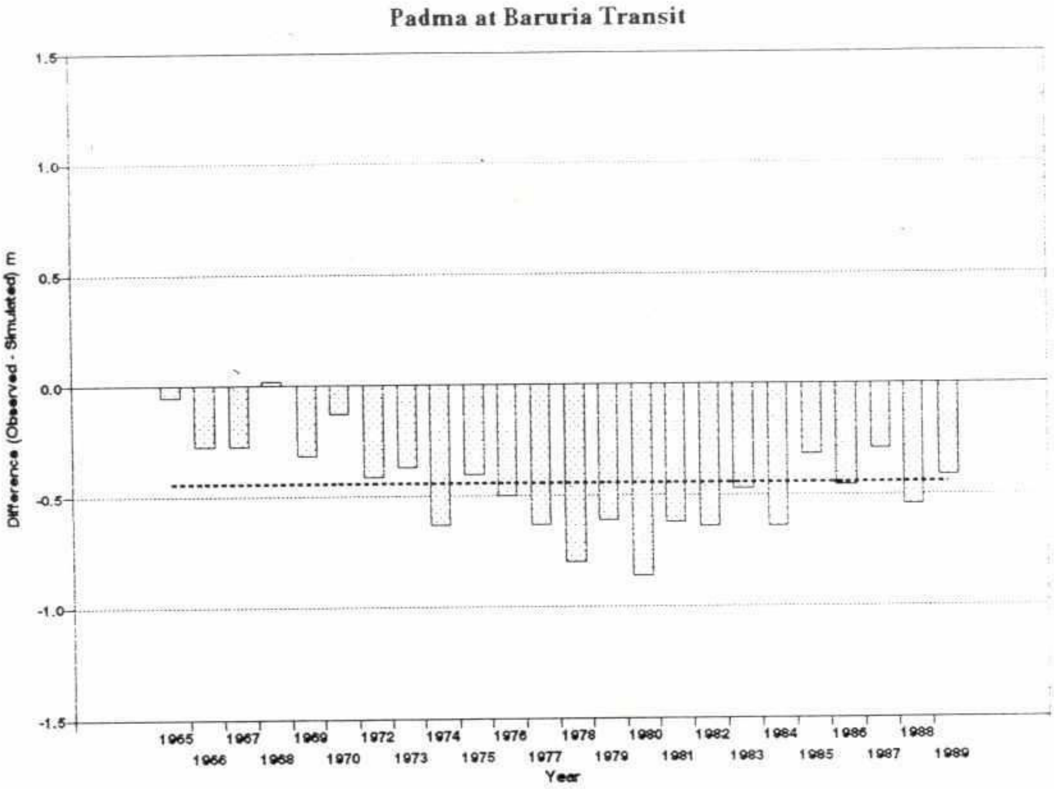


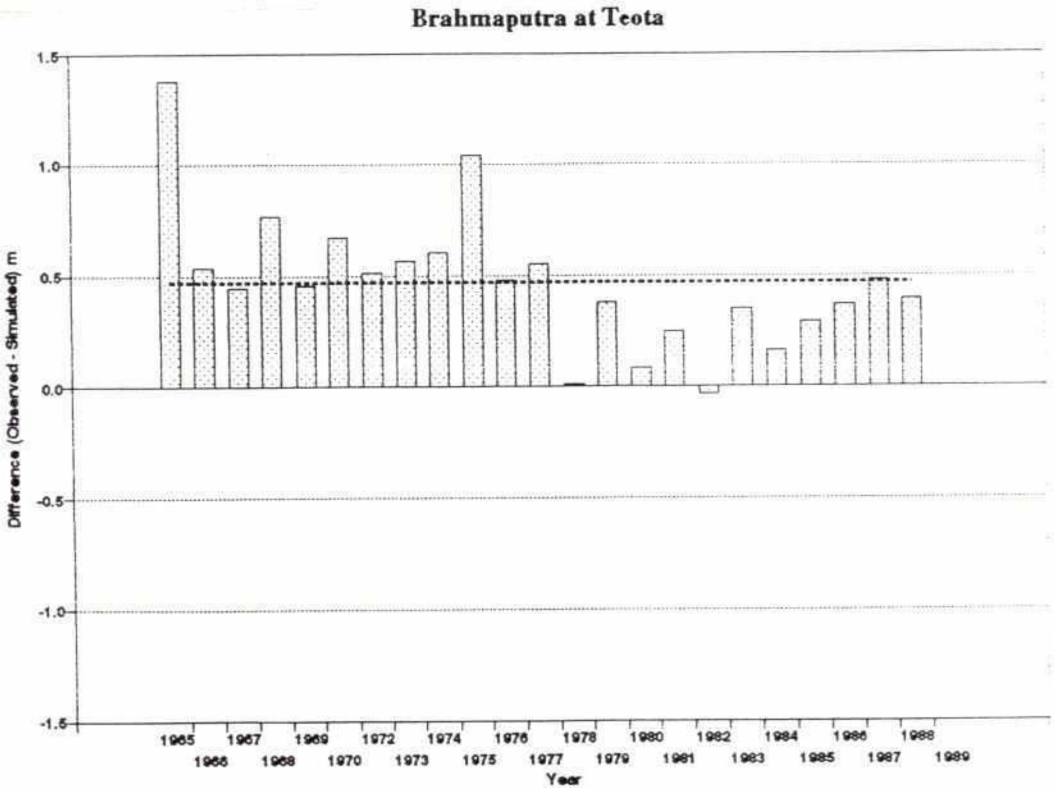
Brahmaputra at Mathura



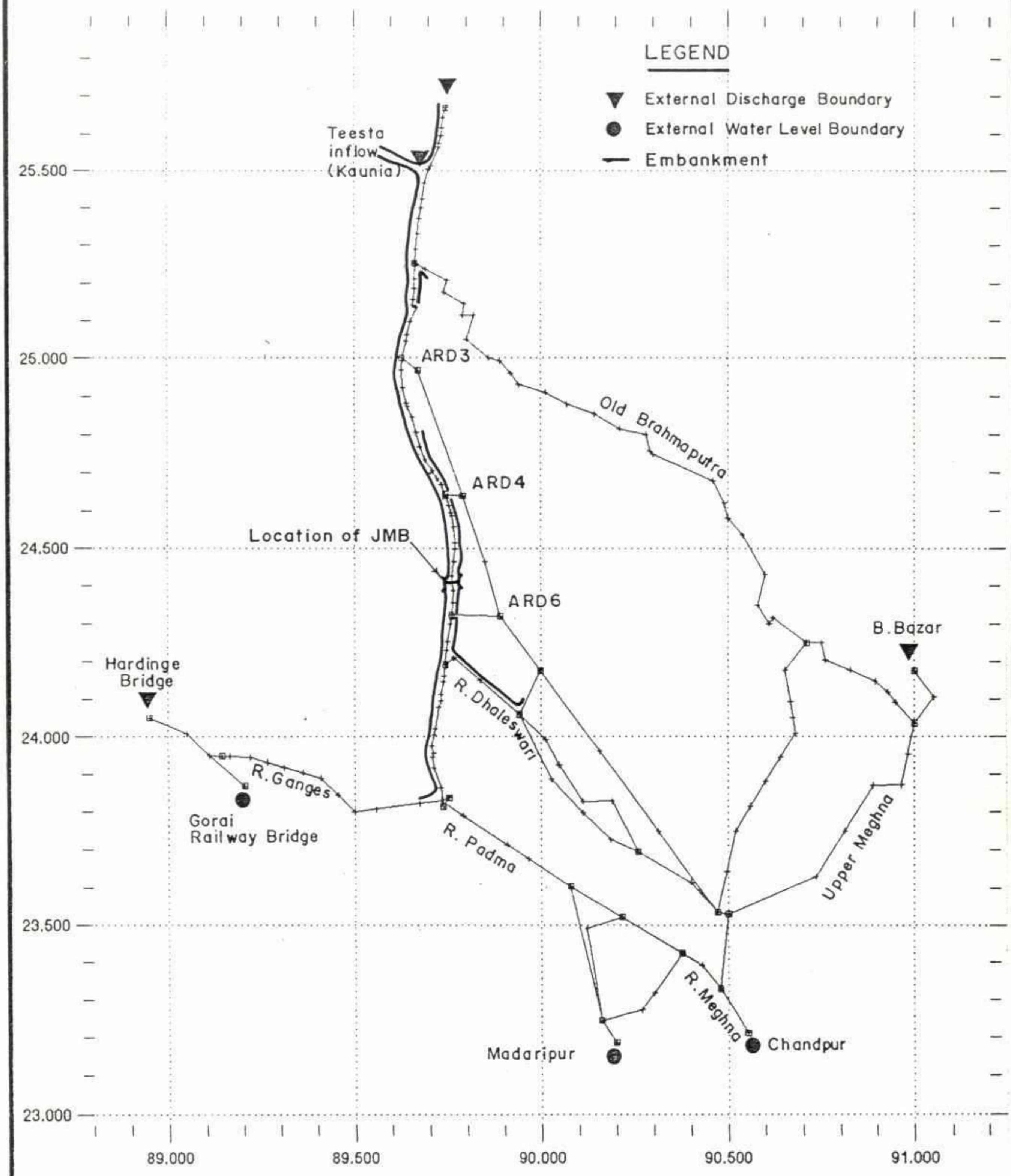
BRTS 1-D Hydrodynamic Modelling

Comparison Between Observed and Modelled Peak Water Levels at Sirajganj and Mathura	Vol.3 Part 7
	Figure 3.3





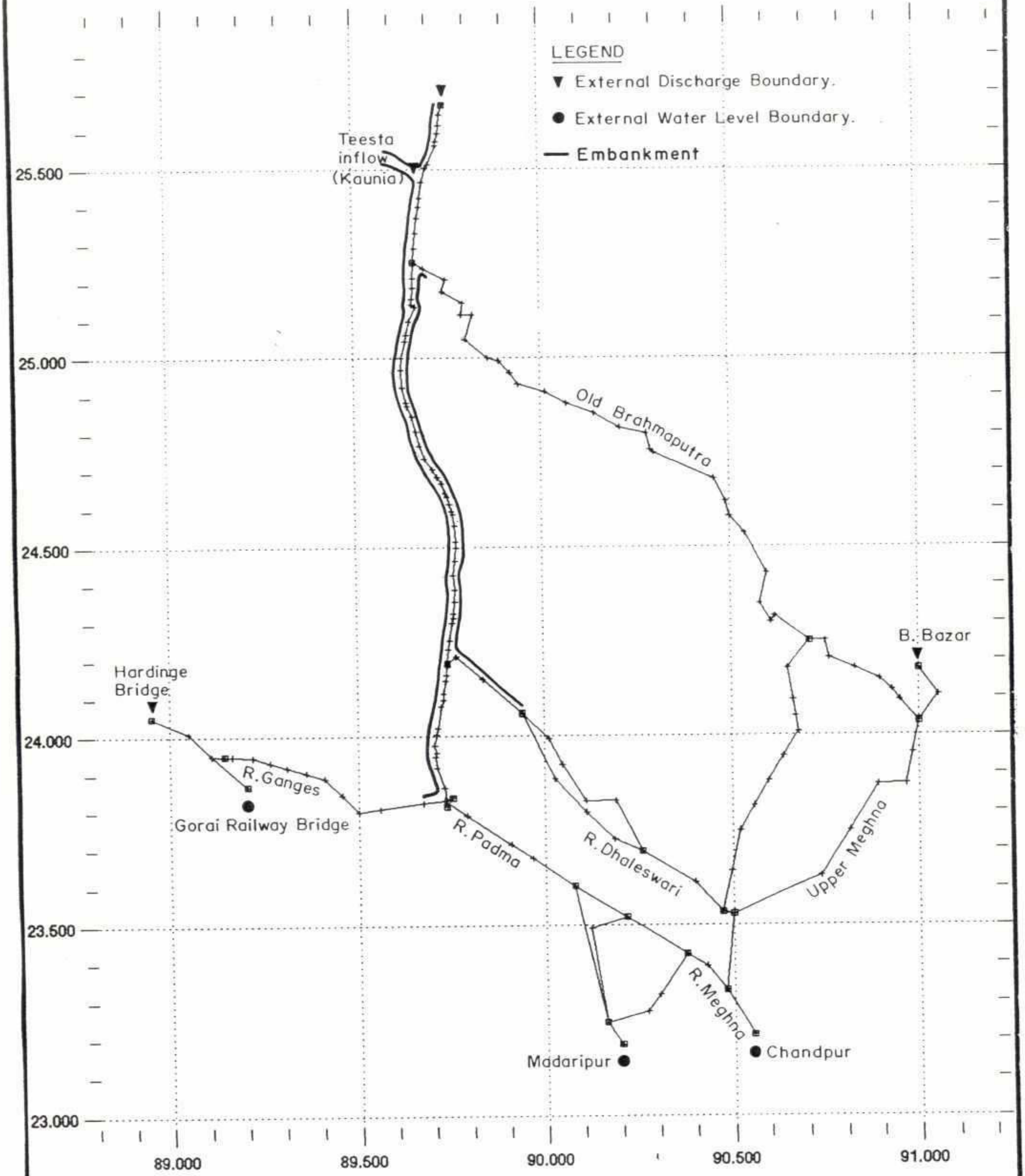
BRTS 1-D Hydrodynamic Modelling		
Comparison Between Observed and Modelled Peak Water Levels at Teota and Baruria Transit	Vol.3	Part 7
	Figure 3.4	



BRTS 1-D Hydrodynamic Modelling

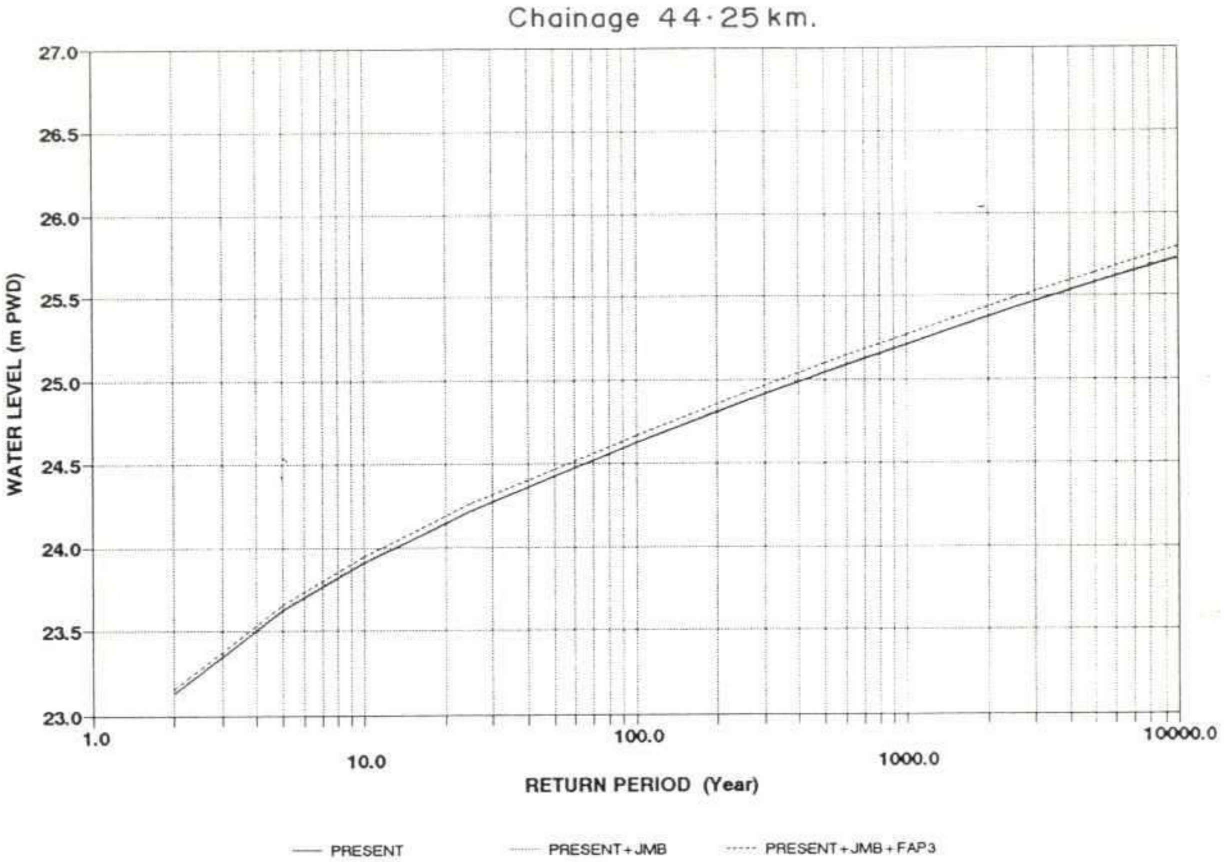
Layout of Brahmaputra River Model: Existing BRE and Left Bank Confinement +JMB	**Vol.3** **Part 7**
	Figure 3.5

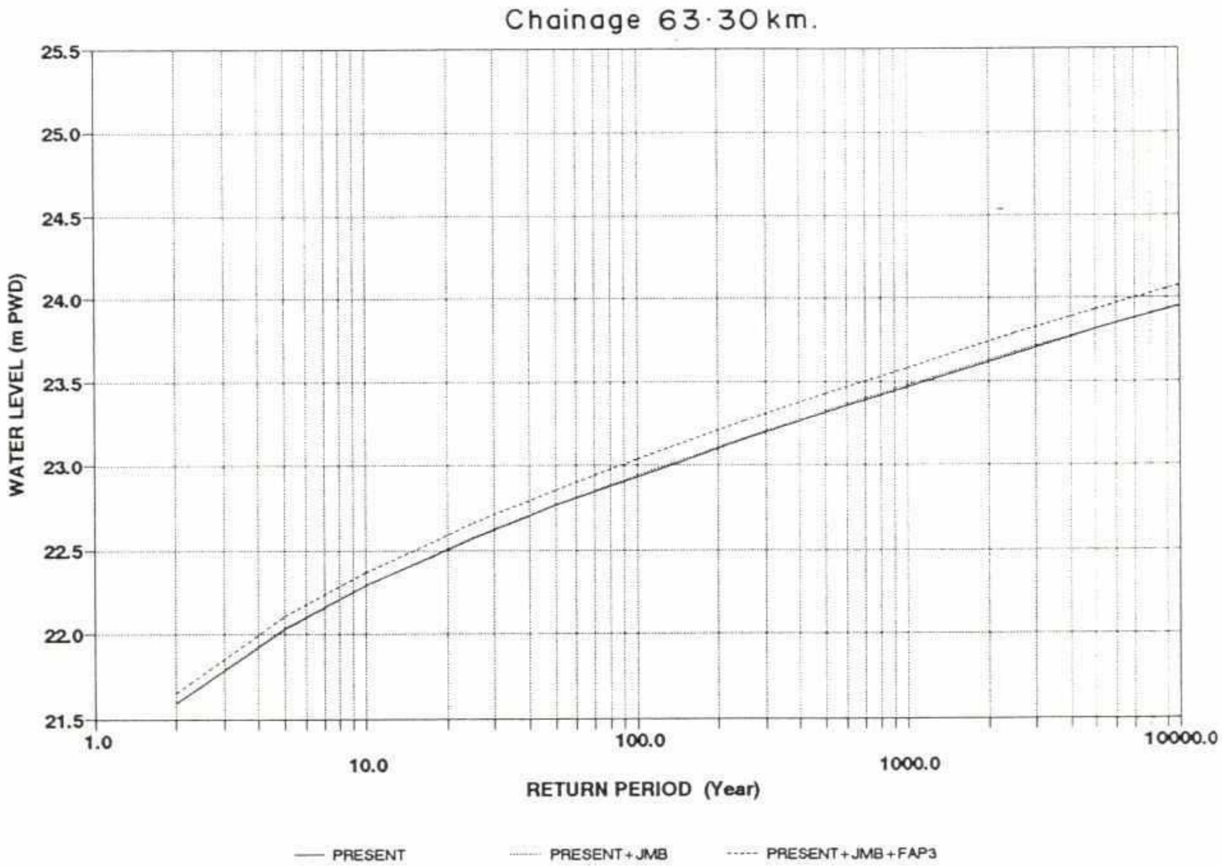
φ2



BRTS 1-D Hydrodynamic Modelling

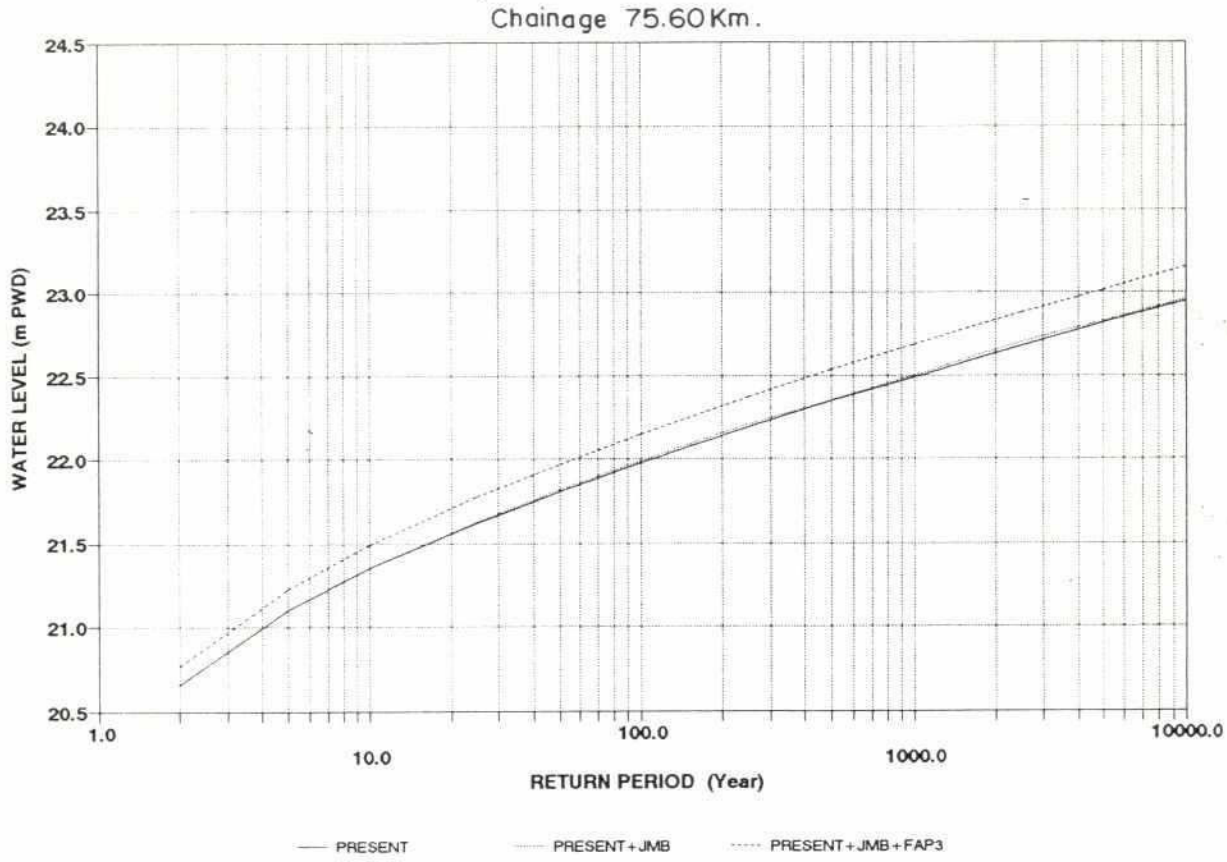
Layout of Brahmaputra River Model: Existing BRE and FAP-3 Left Bank Proposals	Vol.3 Part 7 Figure 3.6

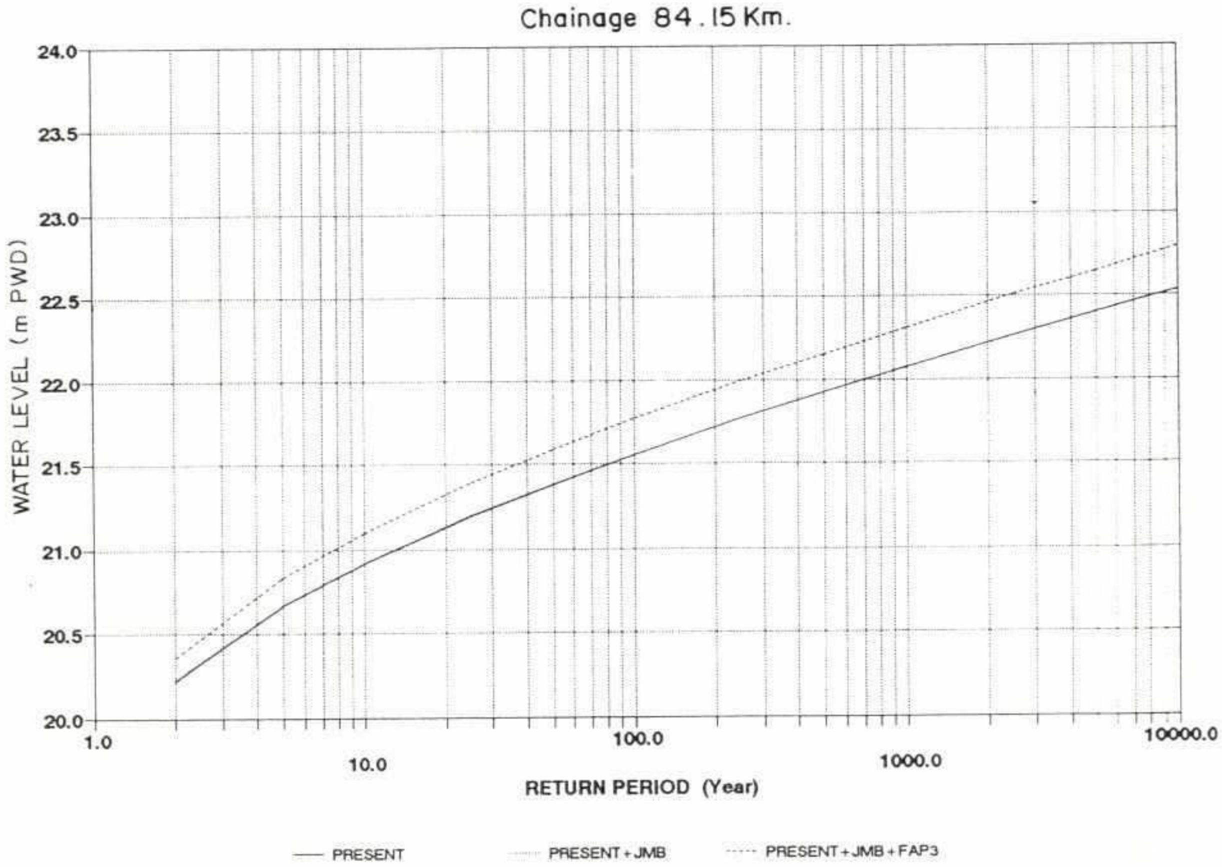




BRTS 1-D Hydrodynamic Modelling

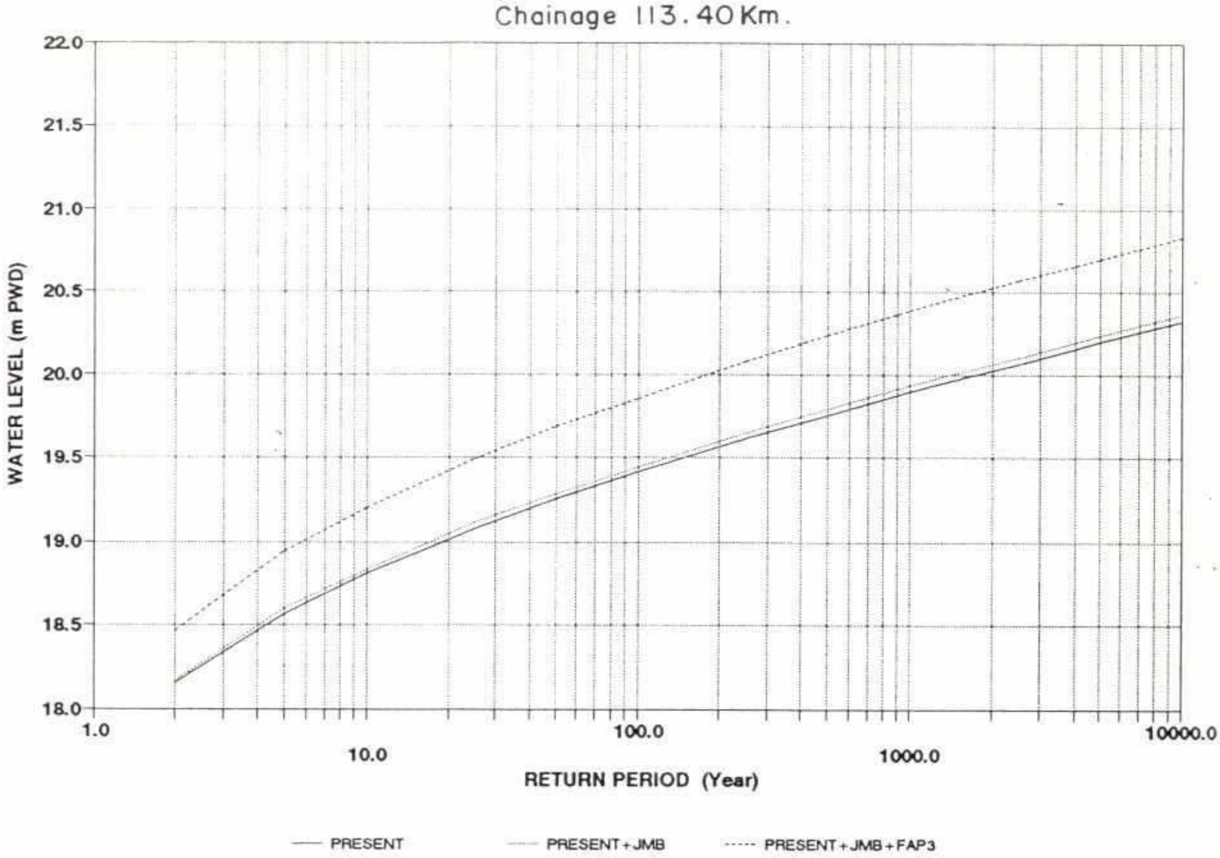
Water Level Vs. Return Period at Chainages 44.25 km and 63.30 km	Vol.3 Part 7
	Figure 3.7

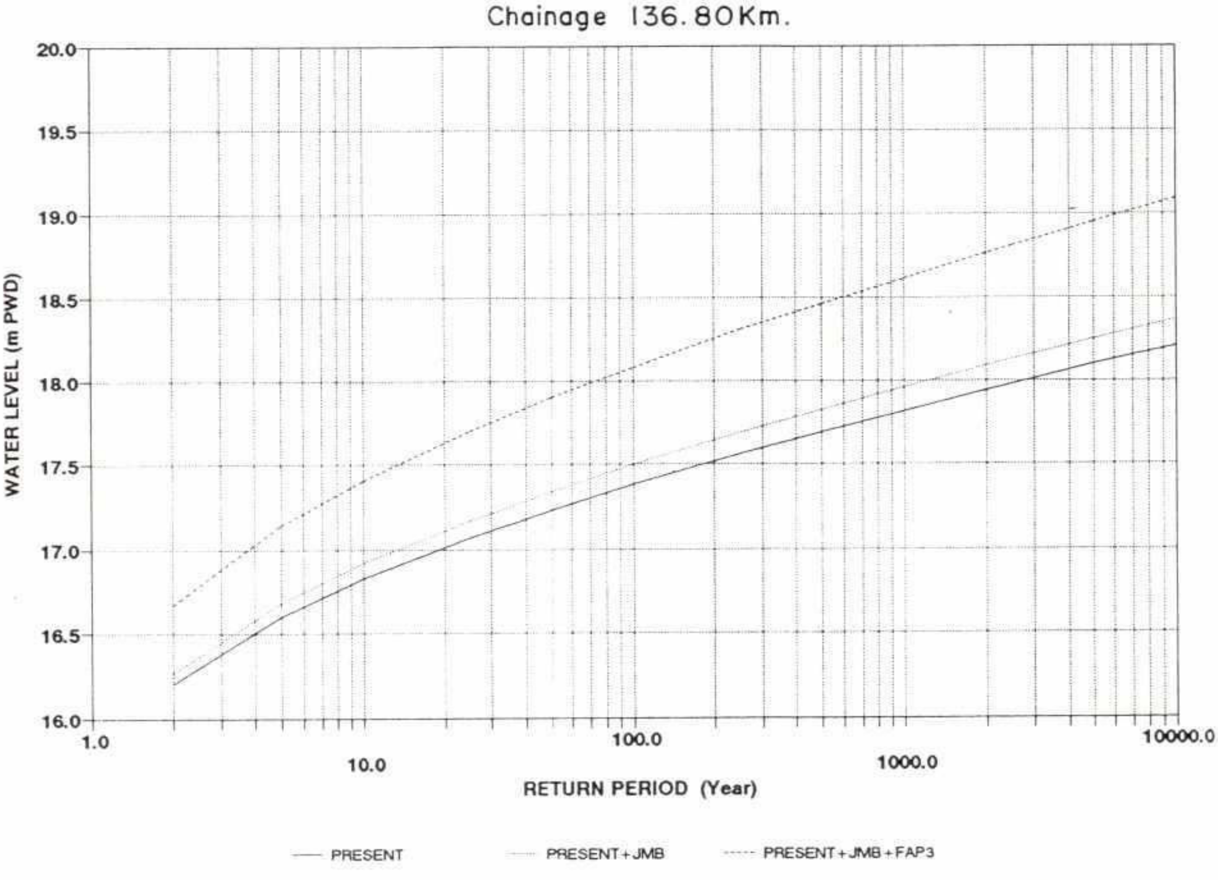




BRTS 1-D Hydrodynamic Modelling

Water Level Vs. Return Period at Chainages 75.60 km and 84.15 km	Vol.3 Part 7
	Figure 3.8





BRTS 1-D Hydrodynamic Modelling

Water Level Vs. Return Period at Chainages 113.40 km and 136.80 km	**Vol.3** **Part 7**
	Figure 3.9

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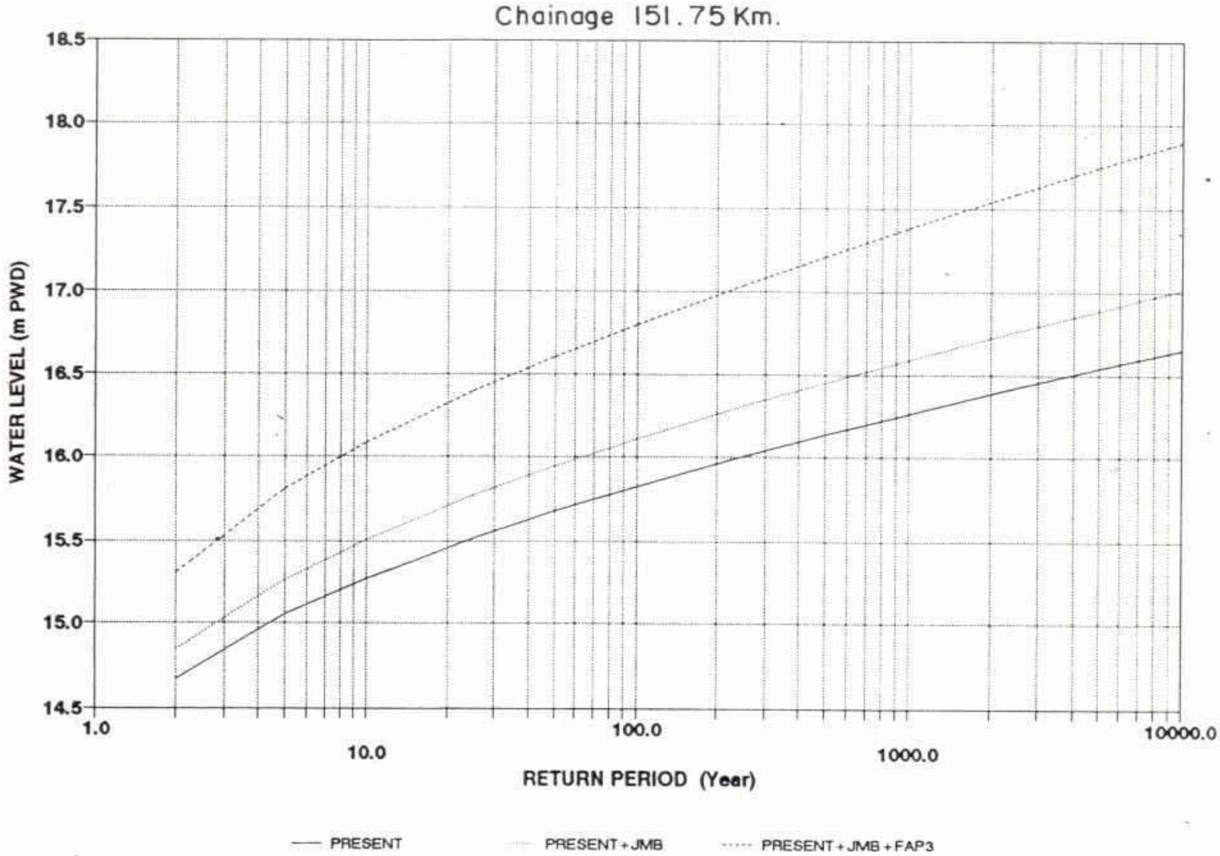
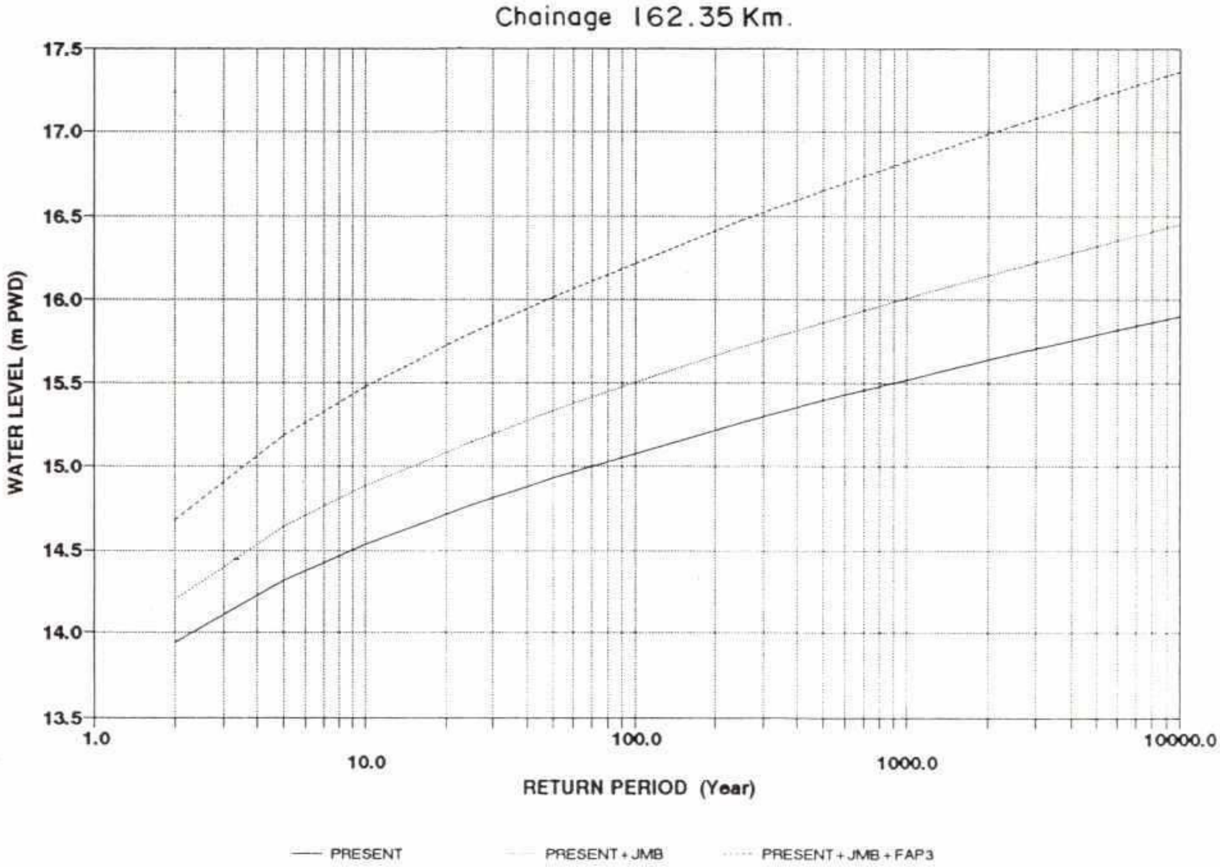


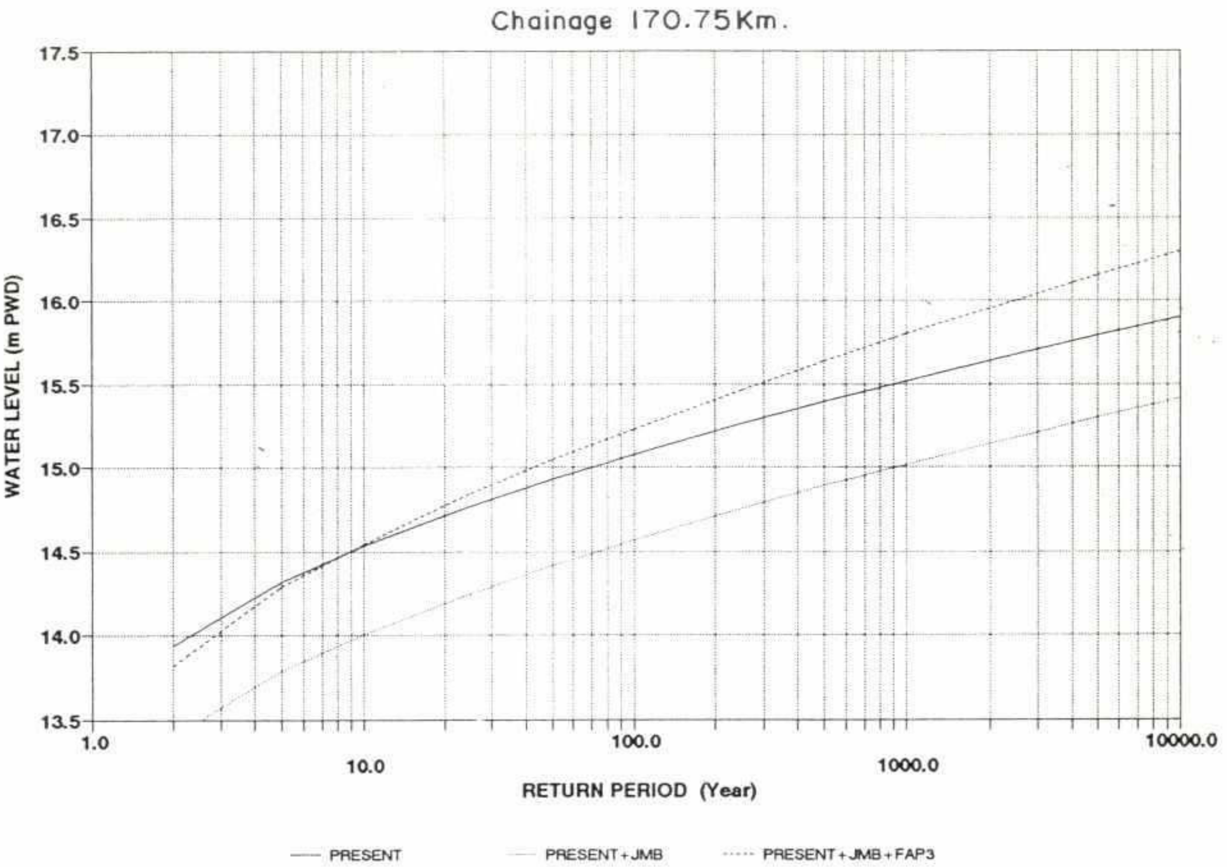


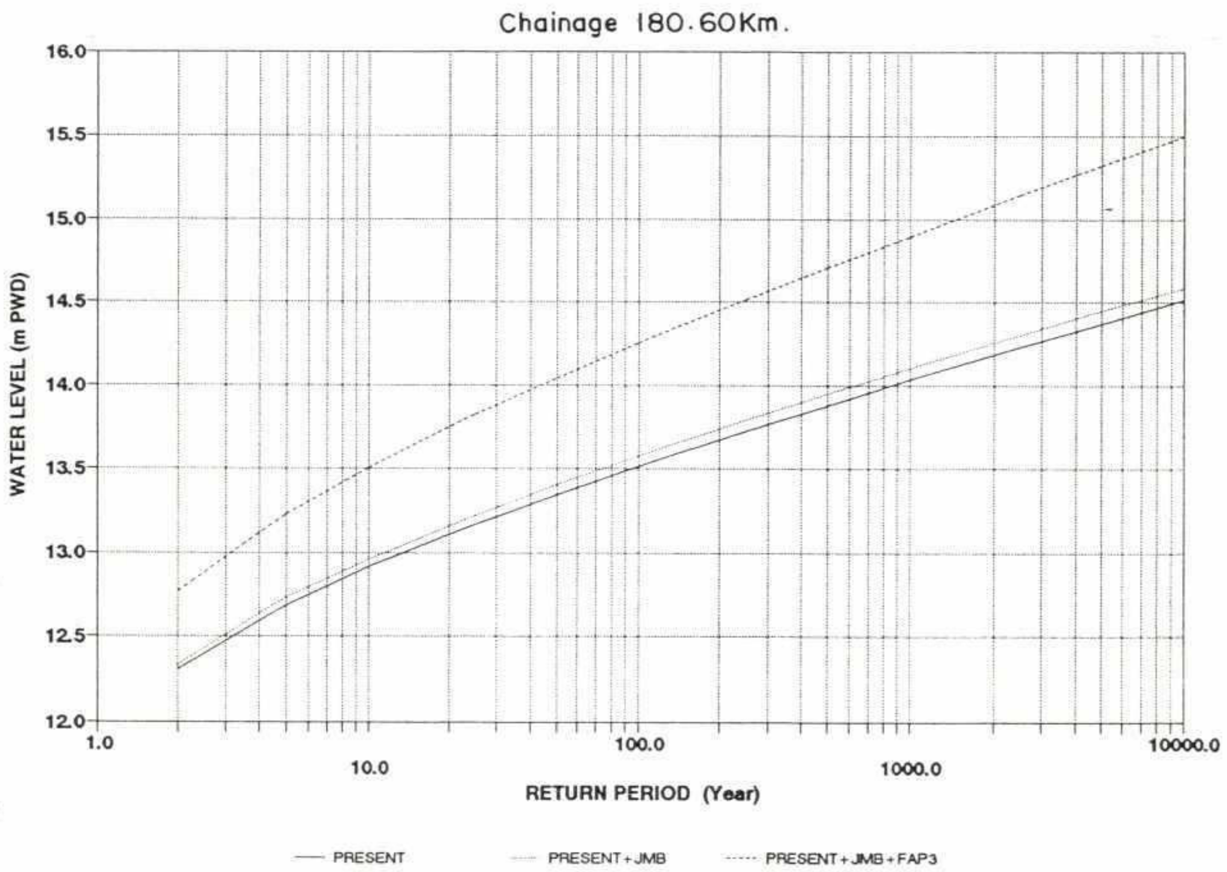
BRTS 1-D Hydrodynamic Modelling

Water Level Vs. Return Period at Chainages 151.75 km and 162.35 km

Vol.3 Part 7

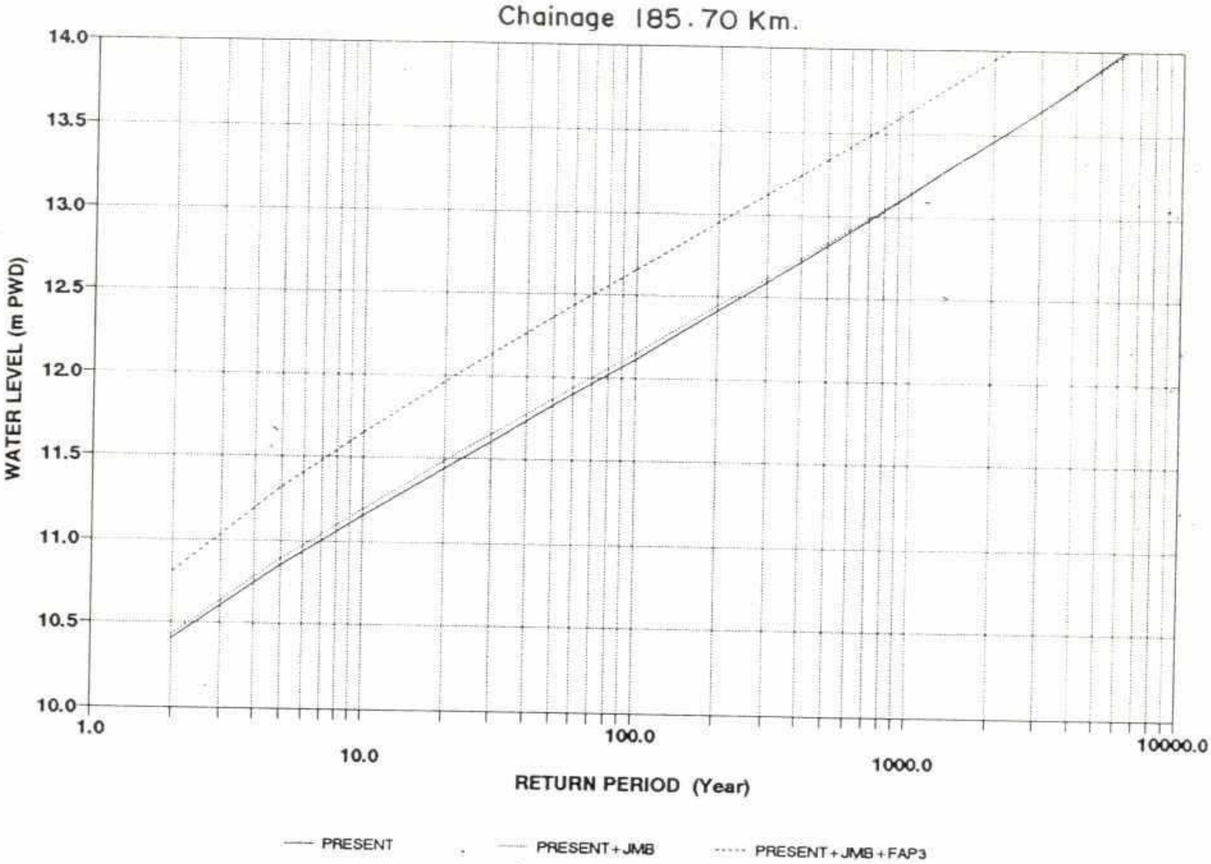
Figure 3.10

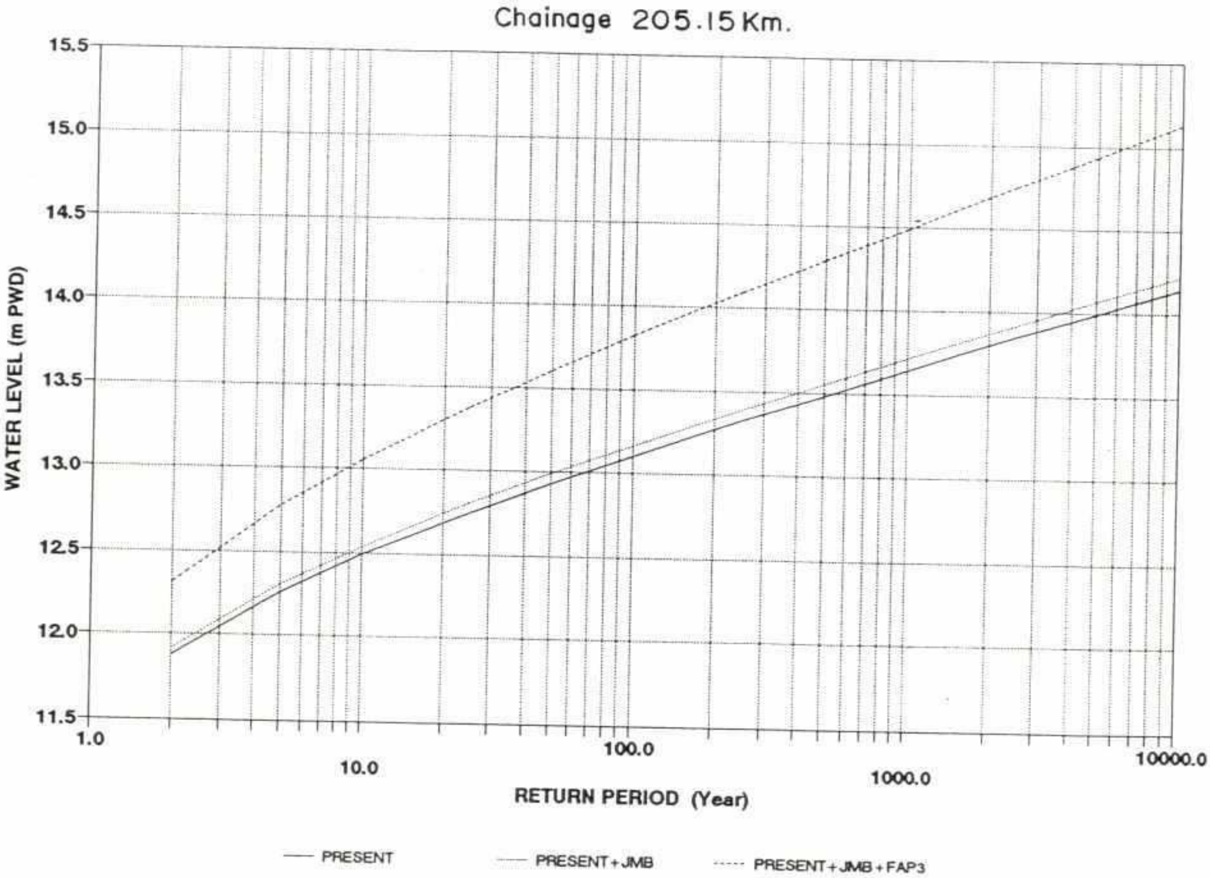




BRTS 1-D Hydrodynamic Modelling

Water Level Vs. Return Period at Chainages 170.75 km and 180.60 km	Vol.3 Part 7
	Figure 3.11

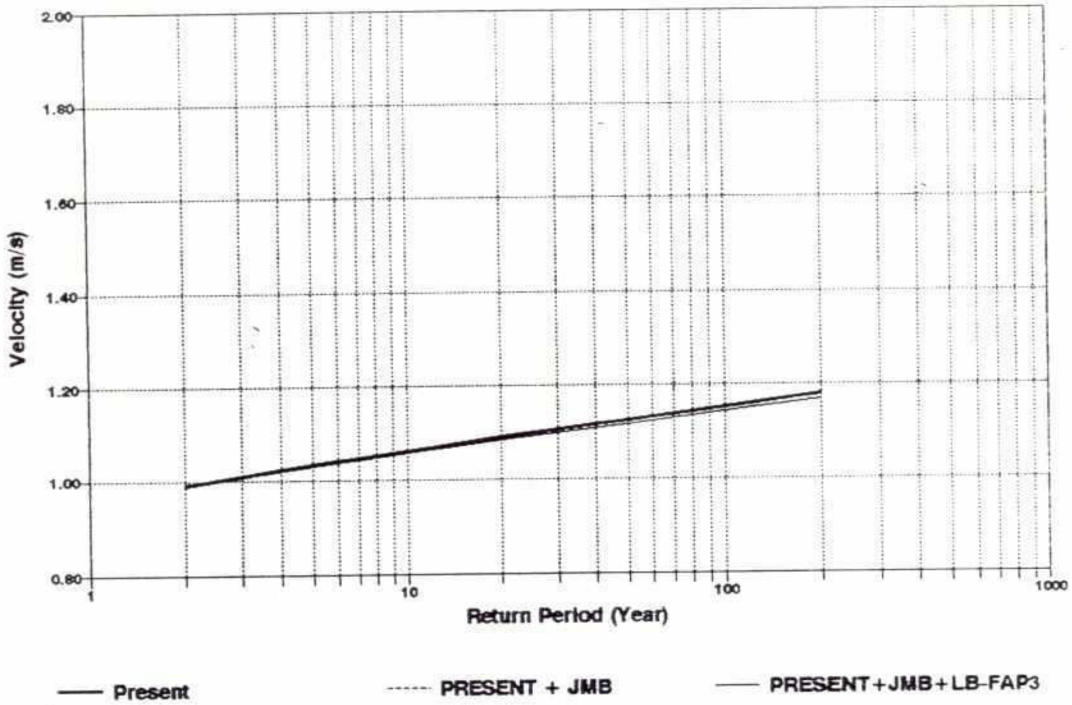




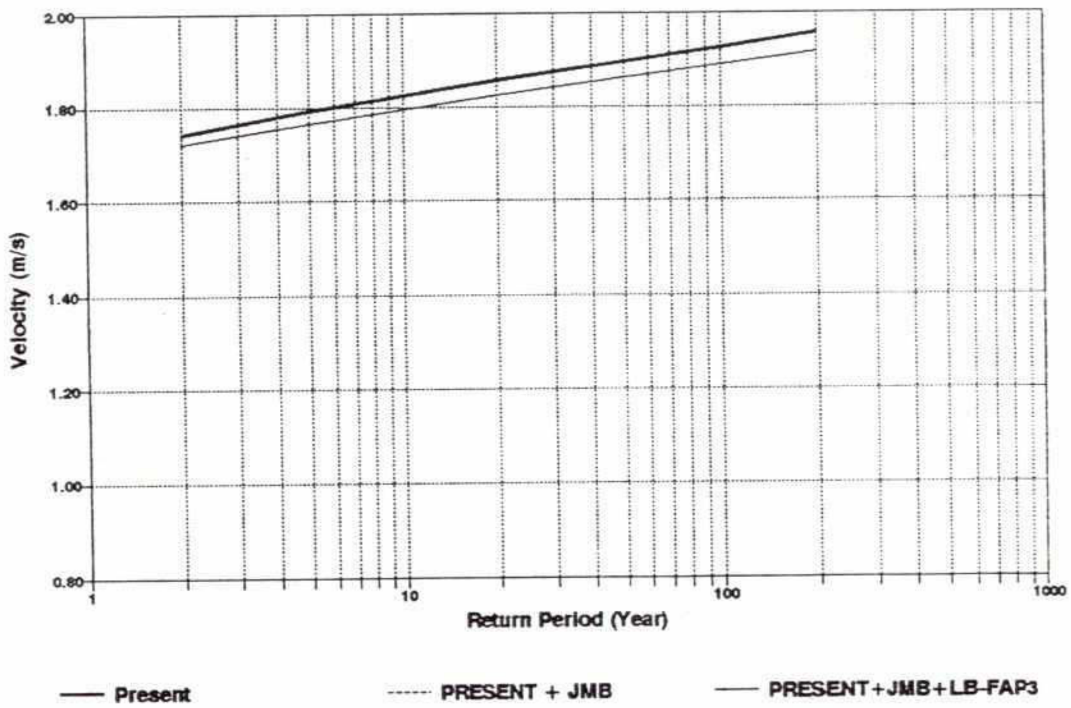
BRTS 1-D Hydrodynamic Modelling

Water Level Vs. Return Period at Chainages 185.70 km and 205.15 km	Vol.3 Part 7
	Figure 3.12

Brahmaputra at 44.25 Km

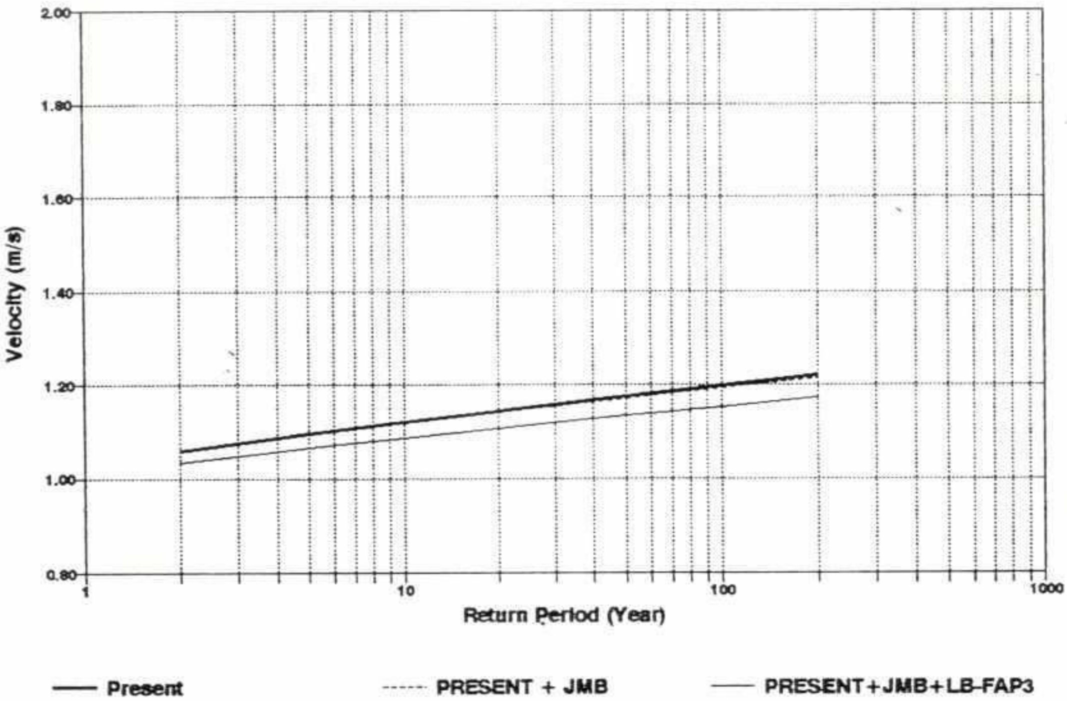


Brahmaputra at 63.30 Km

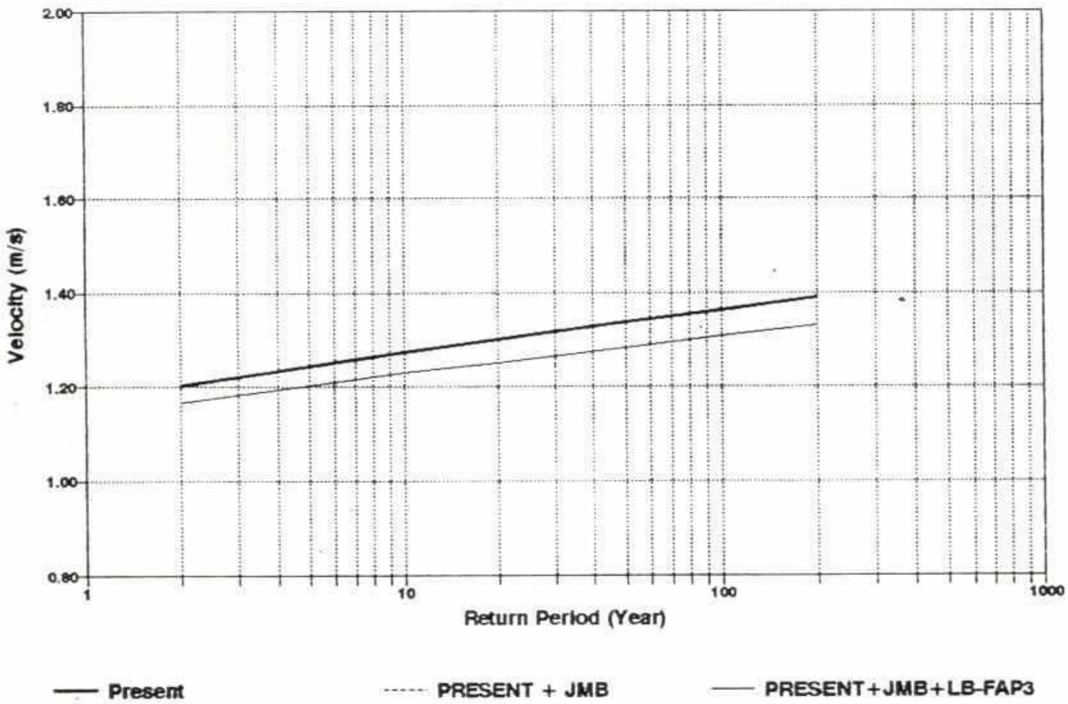


BRTS 1-D Hydrodynamic Modelling		
Maximum Mean Velocity Vs. Return Period at Chainages 44.25 km and 63.30 km	Vol.3	Part 7
	Figure 3.13	

Brahmaputra at 75.60 Km

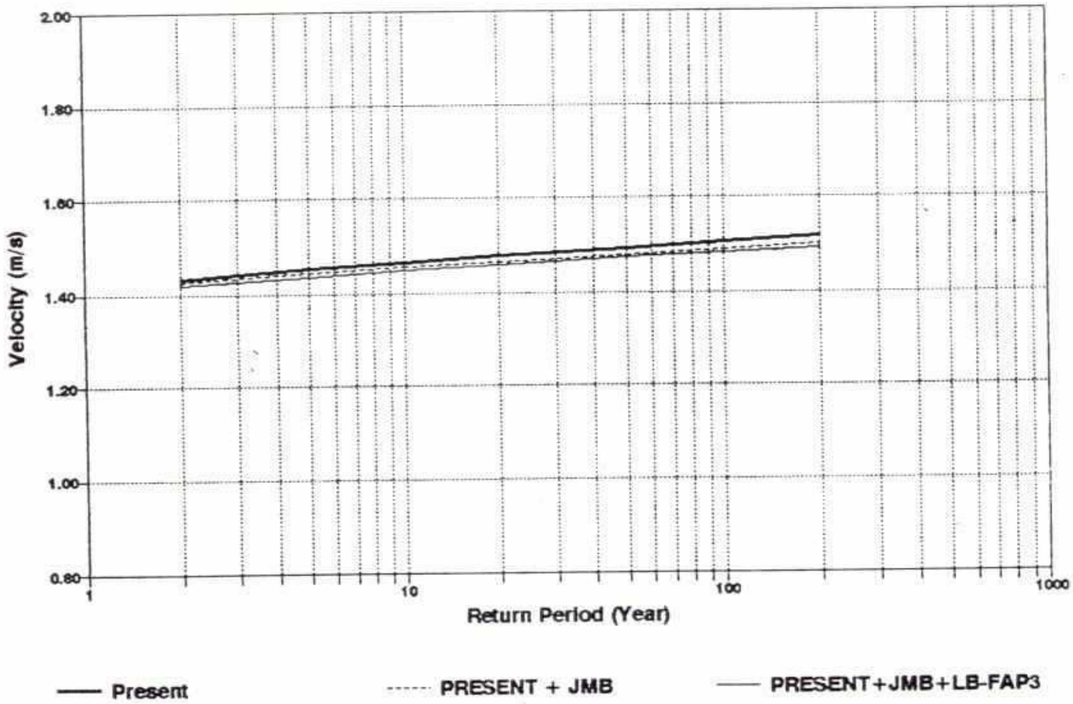


Brahmaputra at 84.15 Km

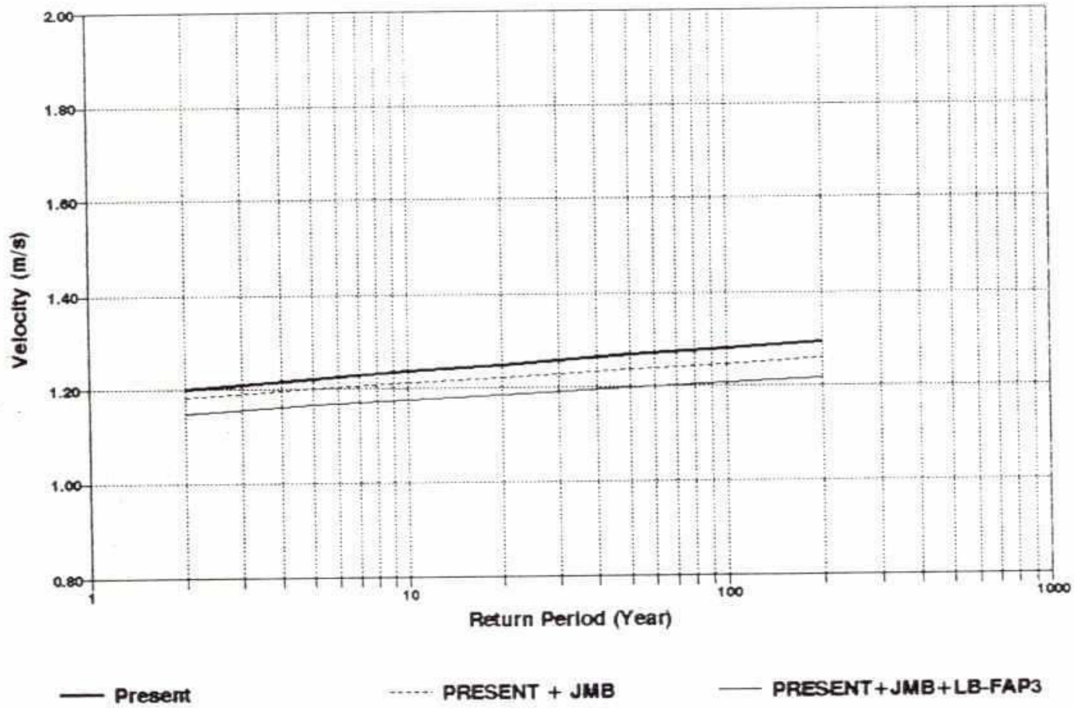


BRTS 1-D Hydrodynamic Modelling		
Maximum Mean Velocity Vs. Return Period at Chainages 75.60 and 84.15 km	Vol.3	Part 7
	Figure 3.14	

Brahmaputra at 113.40 Km



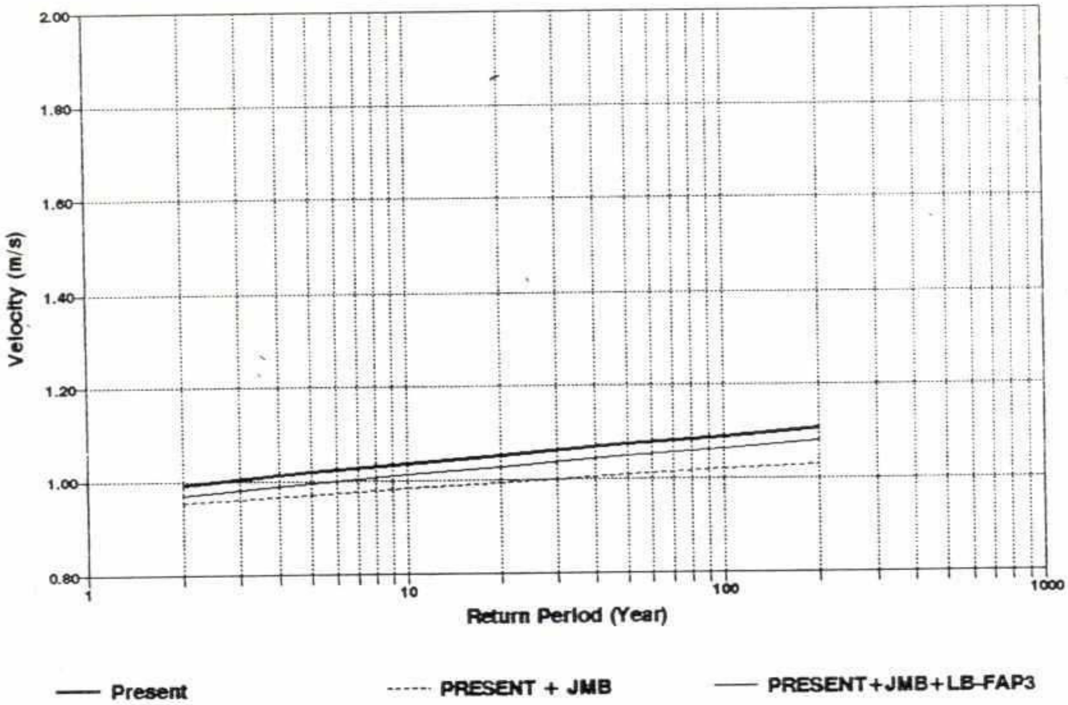
Brahmaputra at 136.80 Km



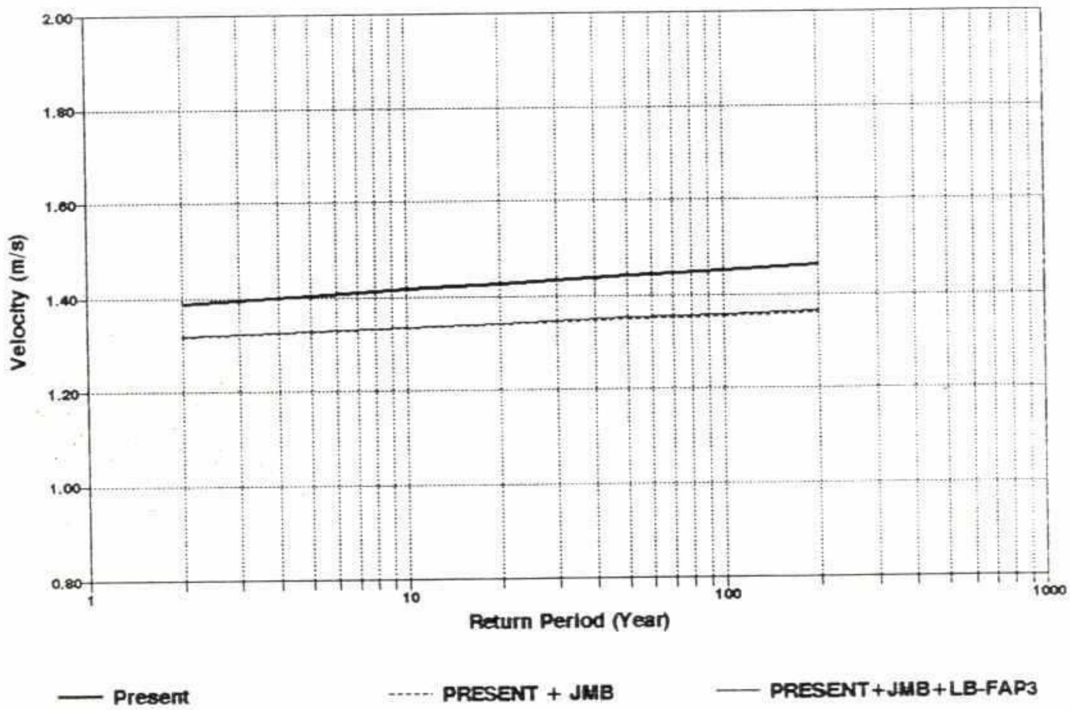
BRTS 1-D Hydrodynamic Modelling

Maximum Mean Velocity Vs. Return Period at Chainages 113.40 km and 136.80 km	Vol.3	Part 7
	Figure 3.15	

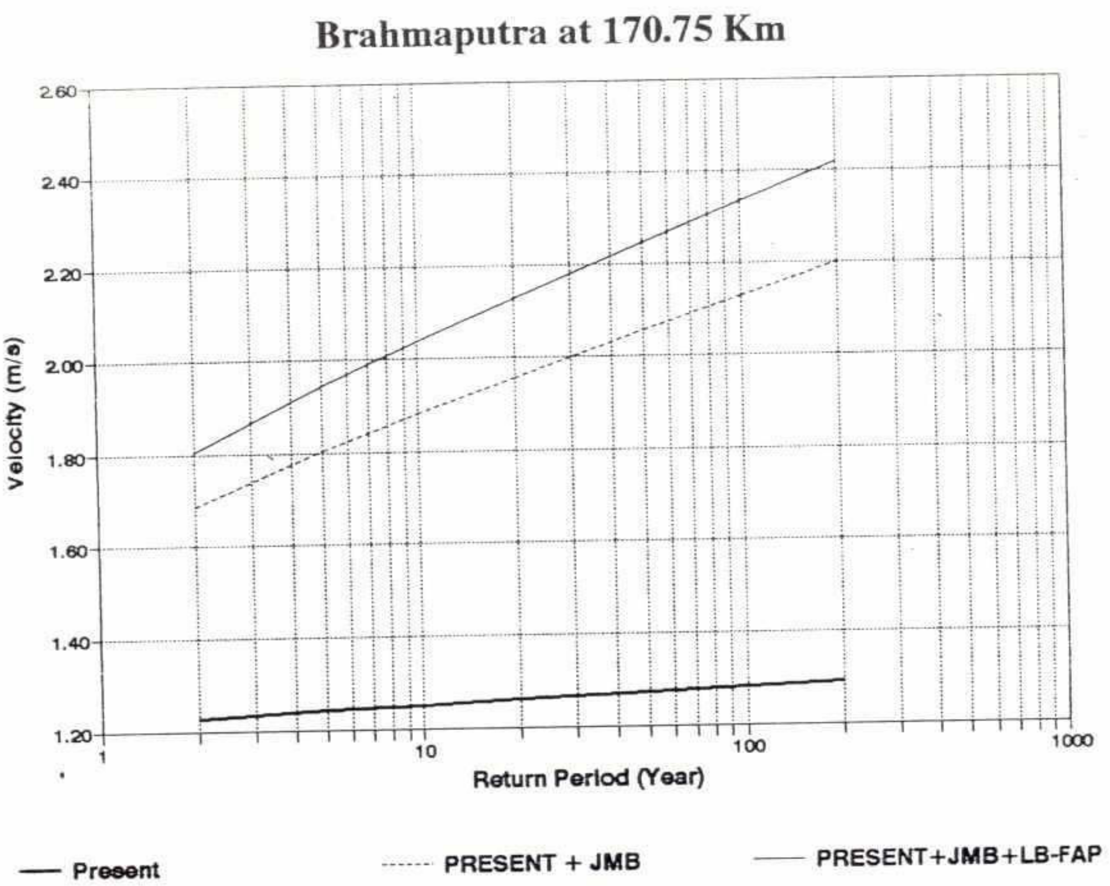
Brahmaputra at 151.75 Km

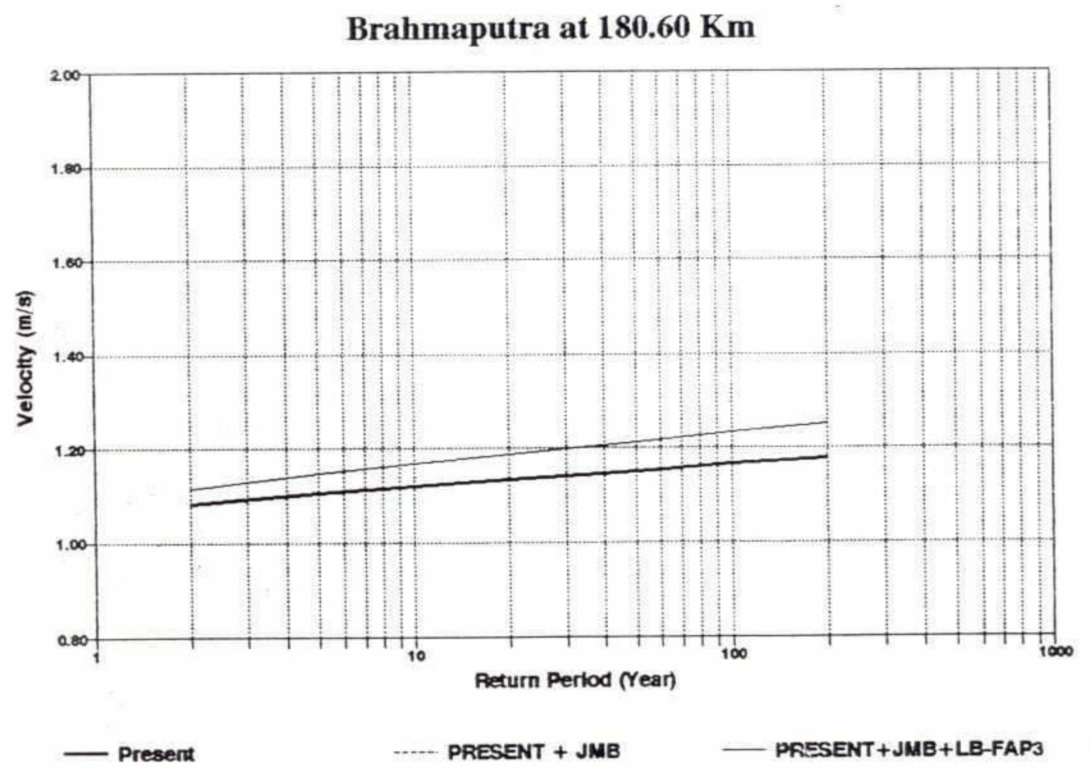


Brahmaputra at 162.35 Km



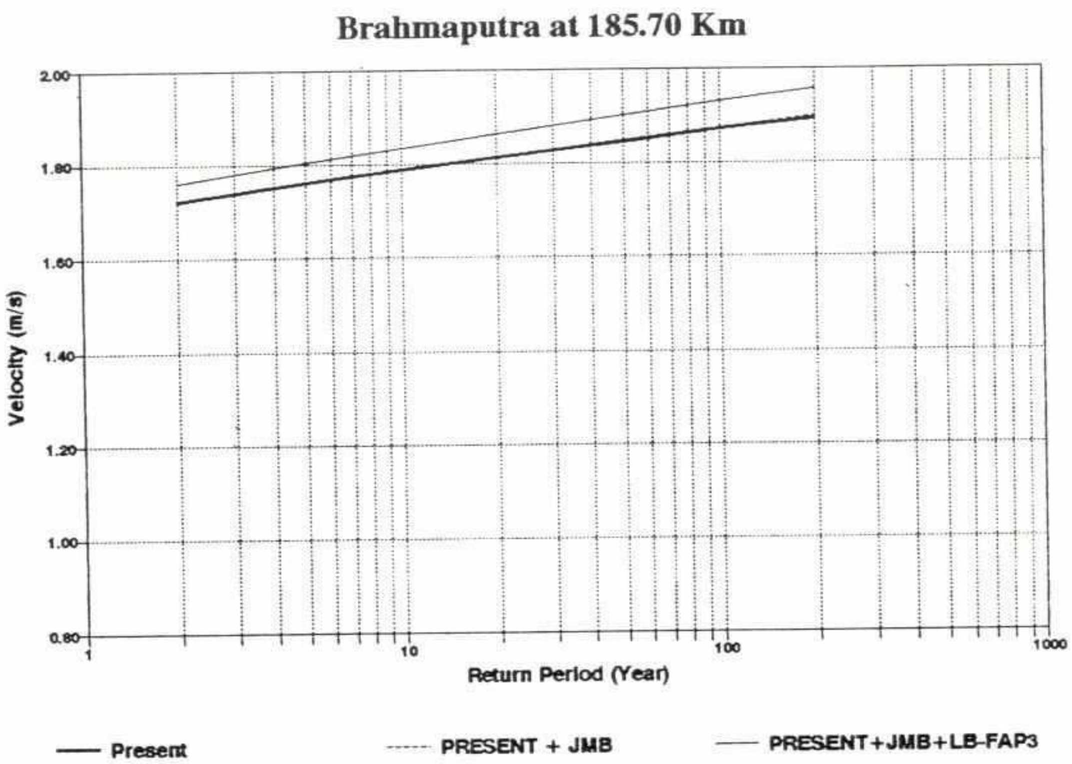
BRTS 1-D Hydrodynamic Modelling		
Maximum Mean Velocity Vs. Return Period at Chainages 151.75 km and 162.35 km	Vol.3	Part 7
	Figure 3.16	

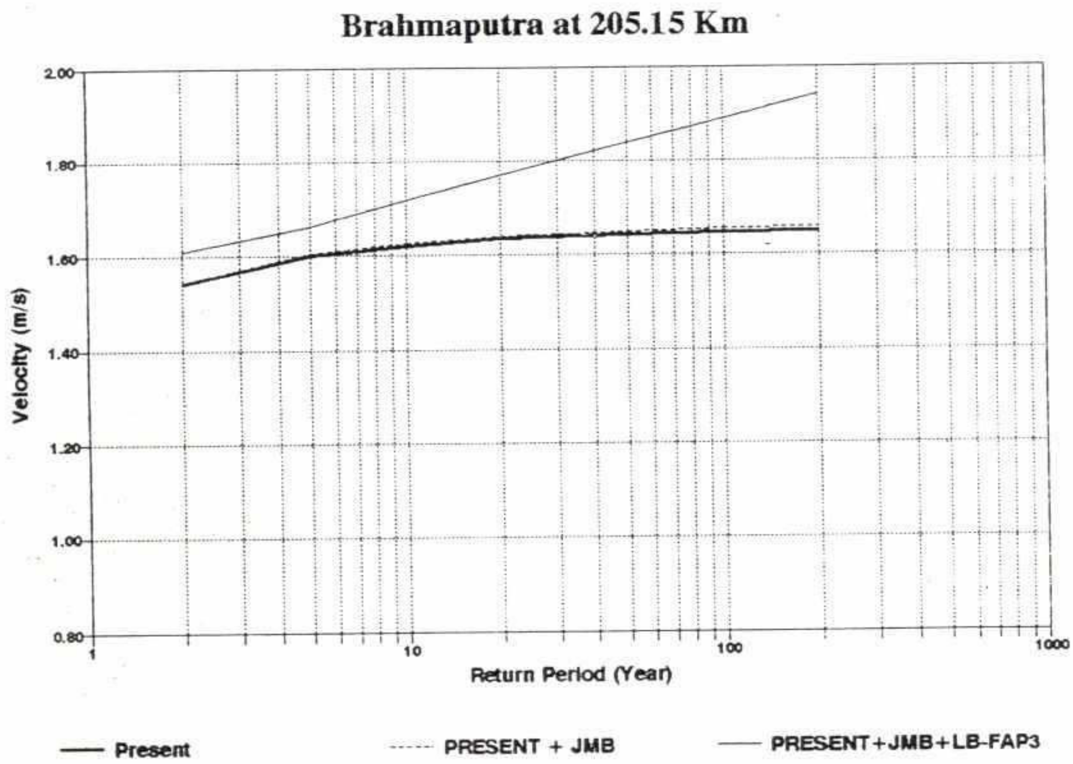




BRTS 1-D Hydrodynamic Modelling

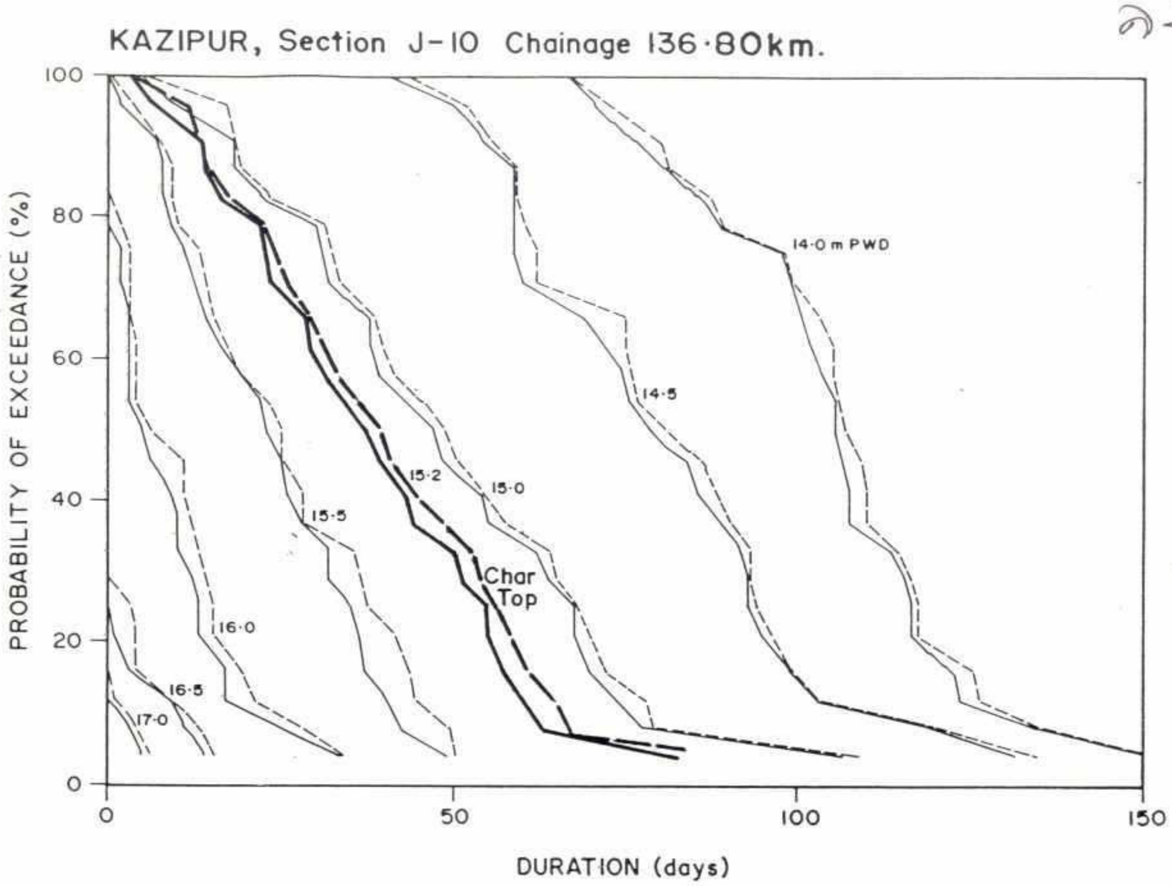
Maximum Mean Velocity Vs. Return Period at Chainages 170.75 km and 180.60 km	Vol.3 Part 7
	Figure 3.17

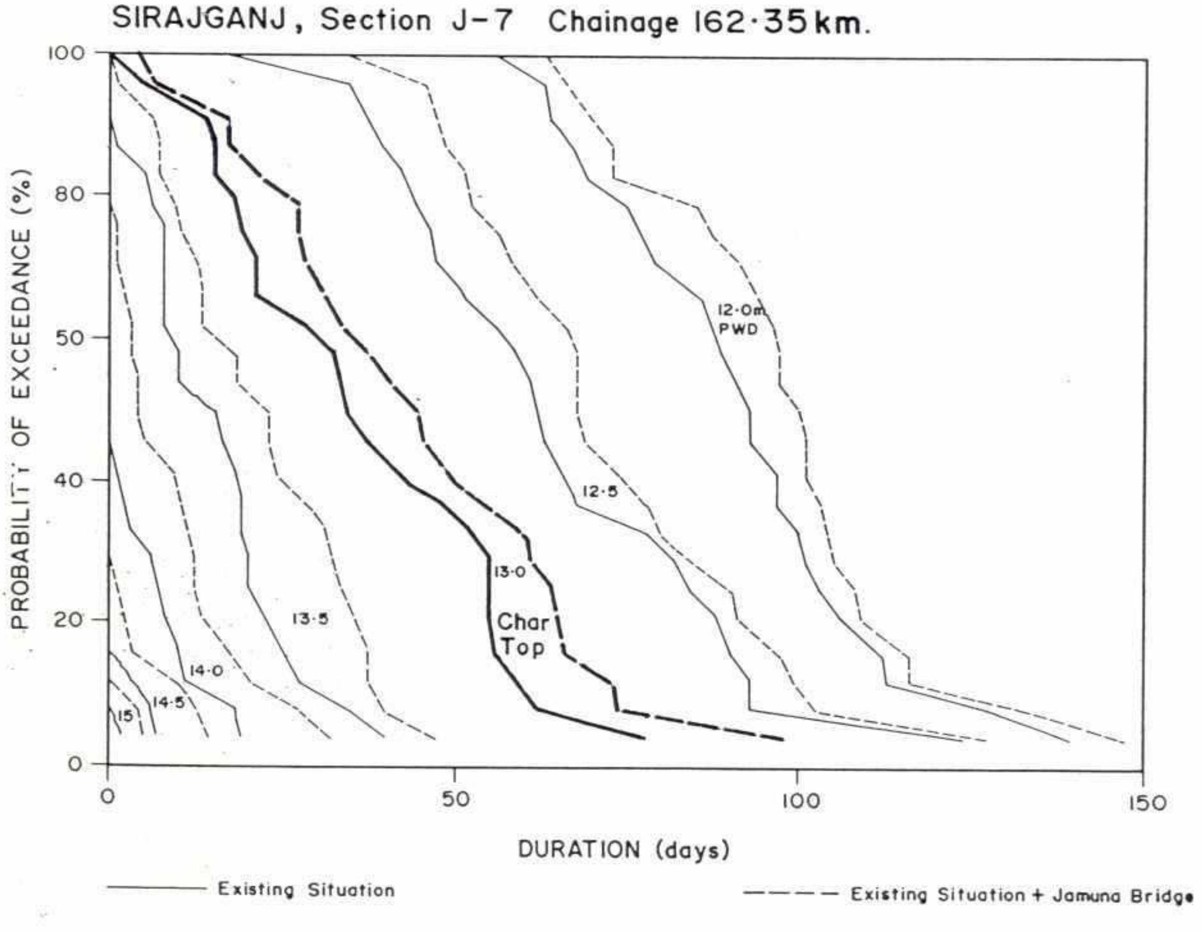




BRTS 1-D Hydrodynamic Modelling

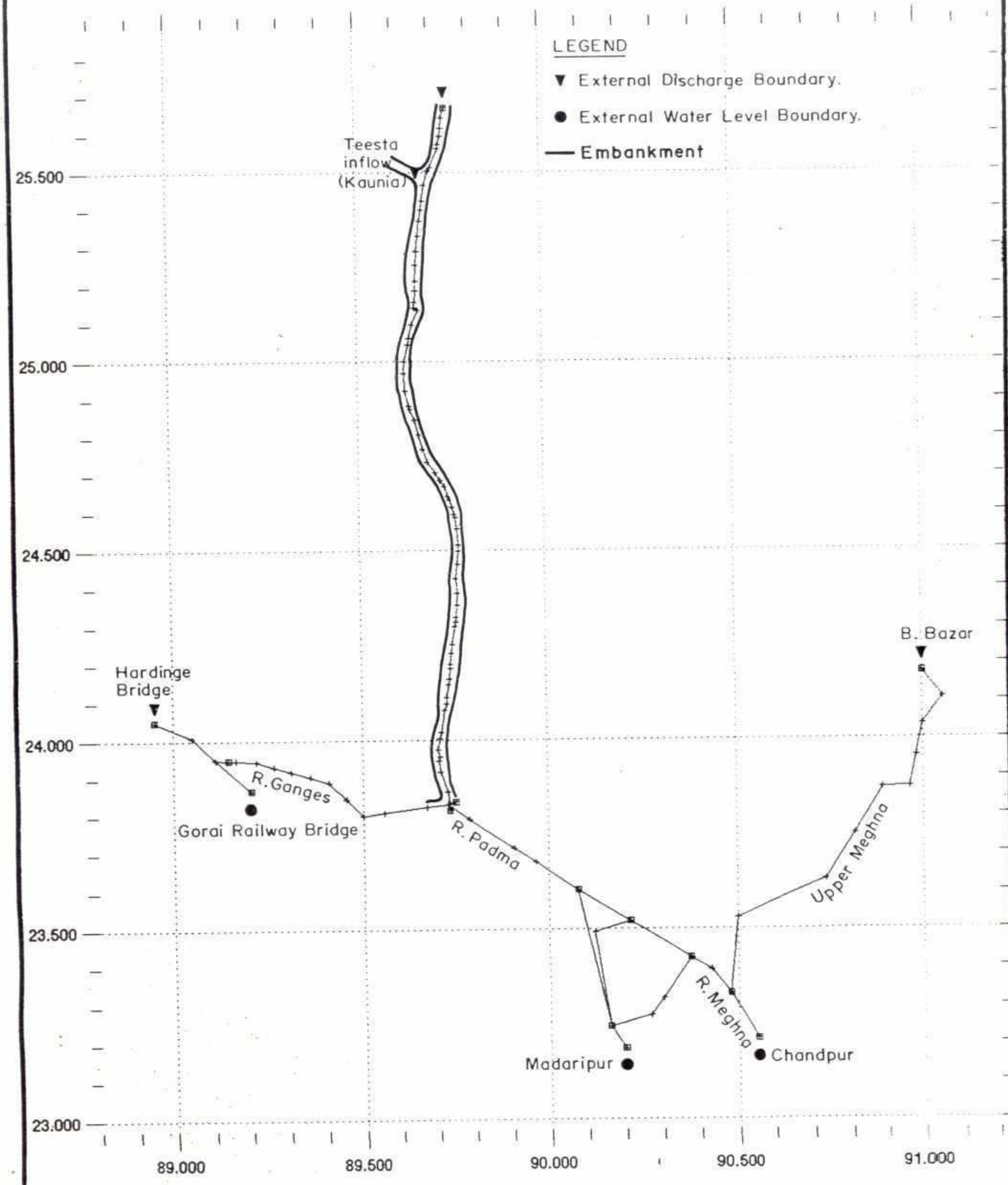
Maximum Mean Velocity Vs. Return Period at Chainages 185.70 km and 205.15 km	Vol.3 Part 7
	Figure 3.18





BRTS 1-D Hydrodynamic Modelling

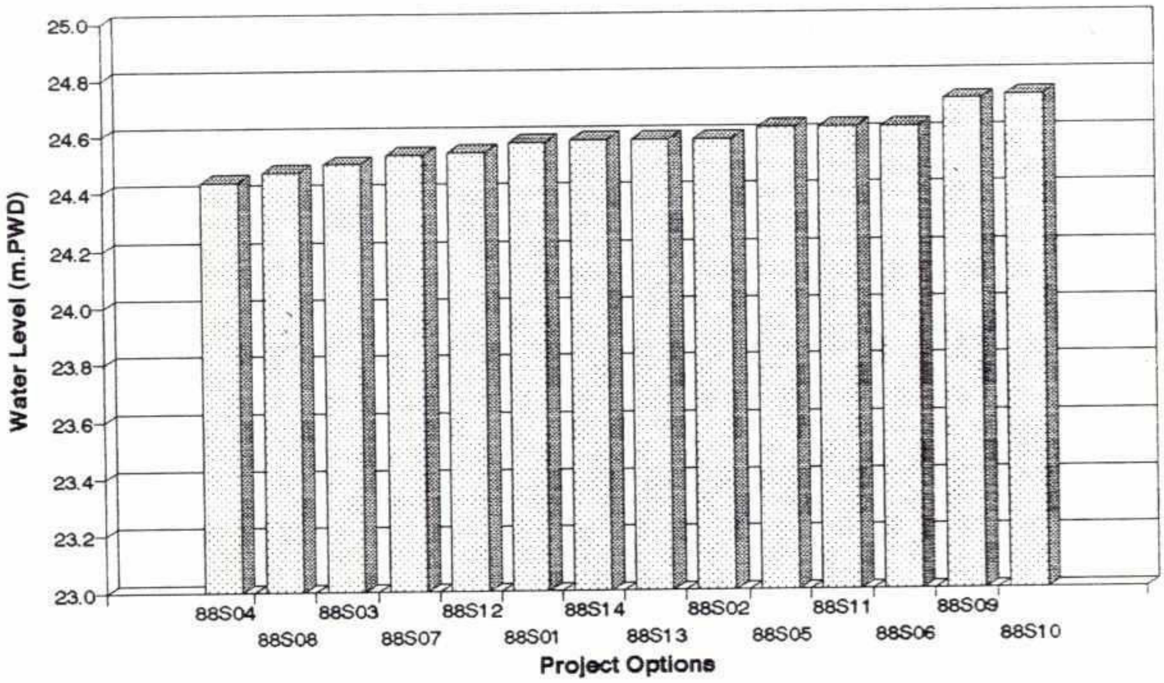
Frequency of Char Inundation with and without Construction of Jamuna Multi-Purpose Bridge	Vol.3	Part 7
	Figure 3.19	



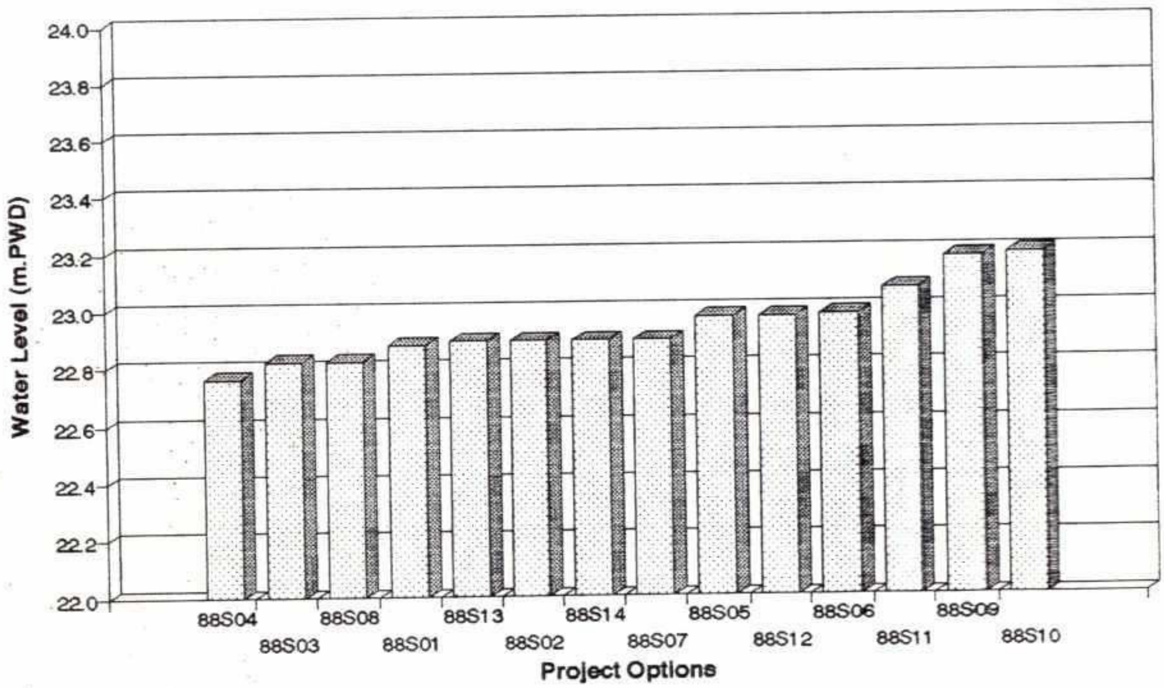
BRTS 1-D Hydrodynamic Modelling

Layout of Brahmaputra River Model: **Existing BRE and Fully Confined Left Bank**	**Vol.3** **Part 7**
	Figure 4.1

CHAINAGE 44.25 km



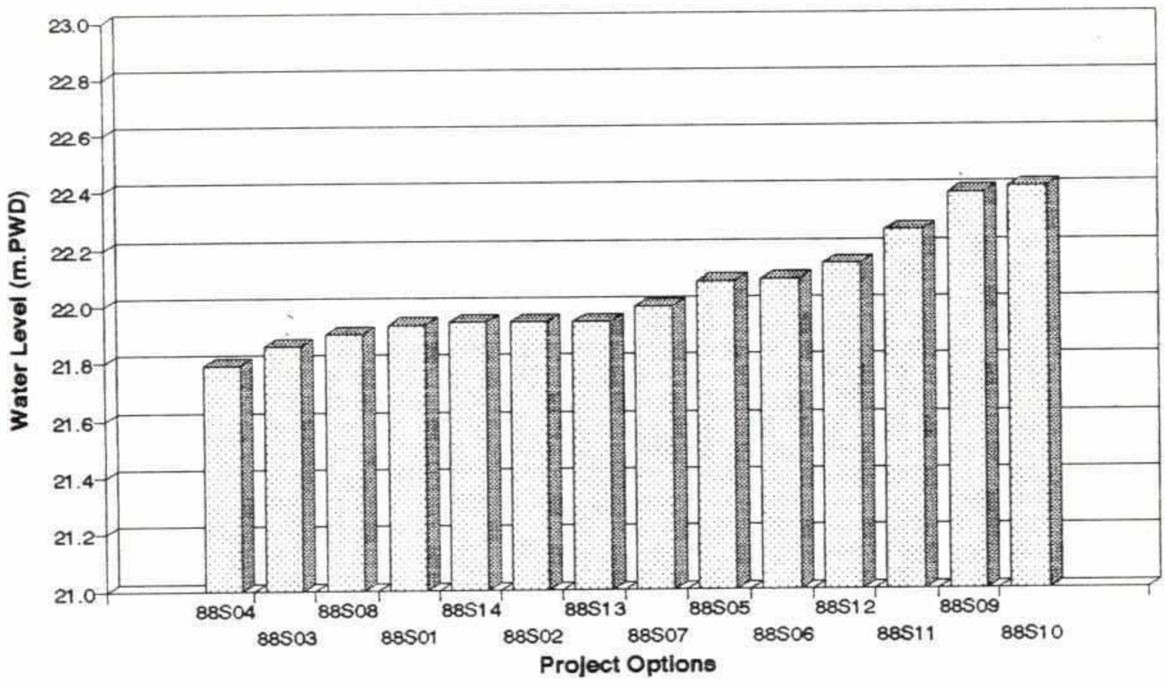
CHAINAGE 63.3 km



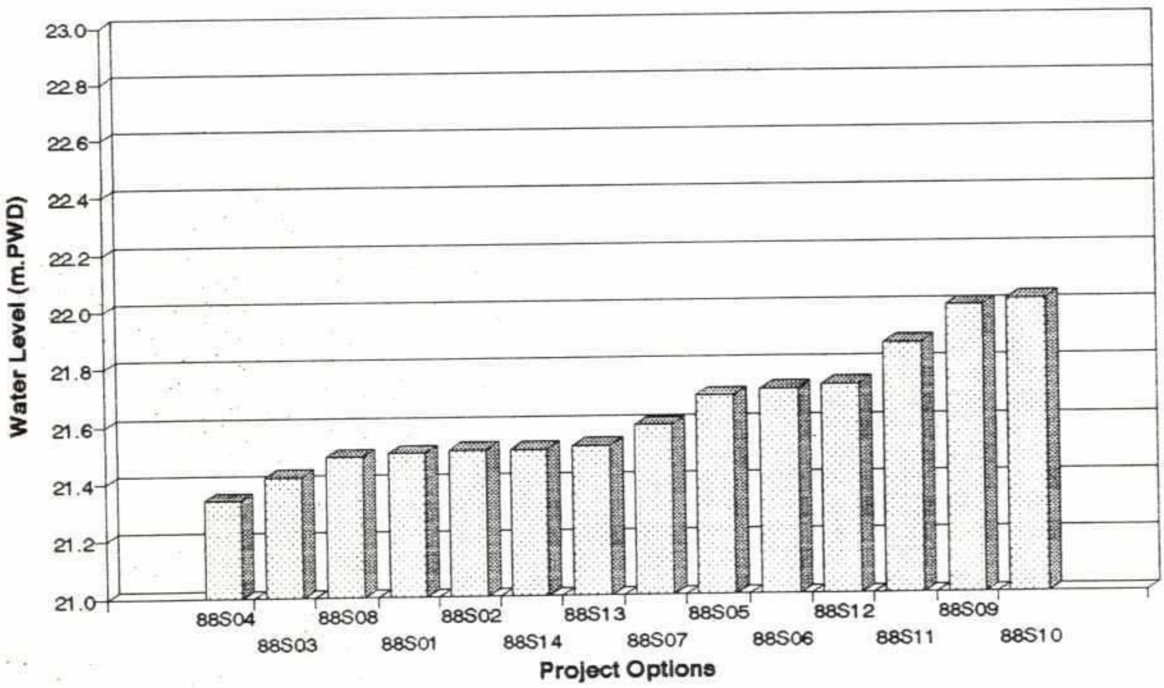
BRTS 1-D Hydrodynamic Modelling

Modelled Maximum 1988 Water Levels at Chainages 44.25 km and 63.30 km	Vol.3 Part 7
	Figure 4.2

CHAINAGE 75.6 km



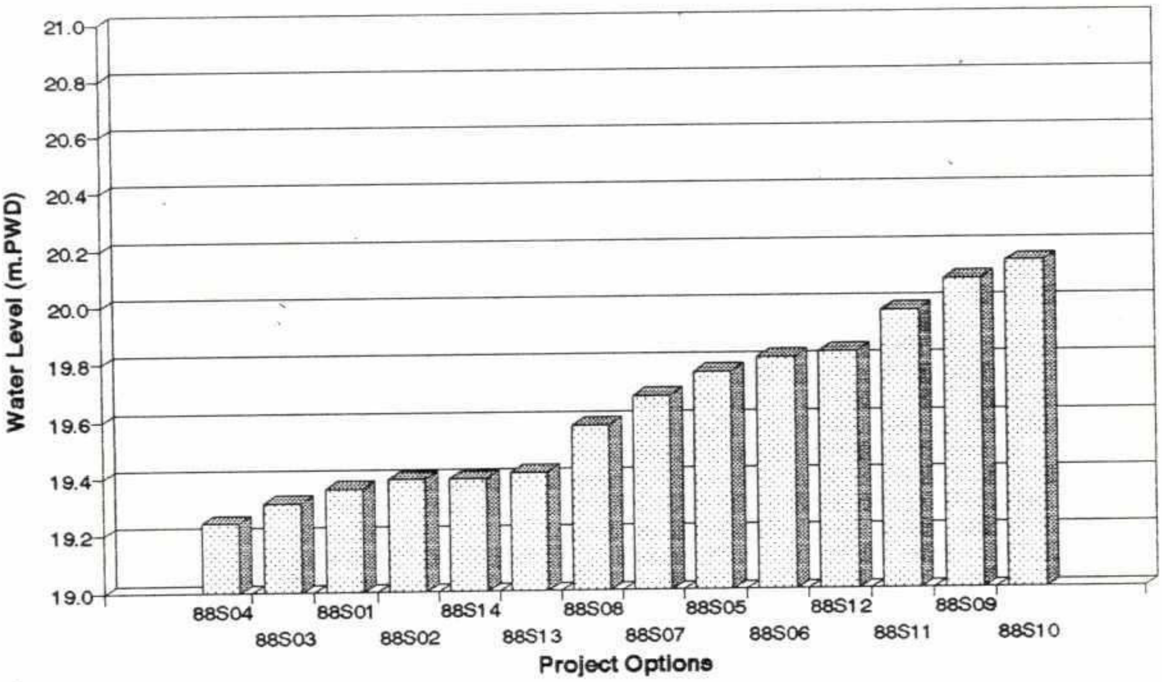
CHAINAGE 84.15 km



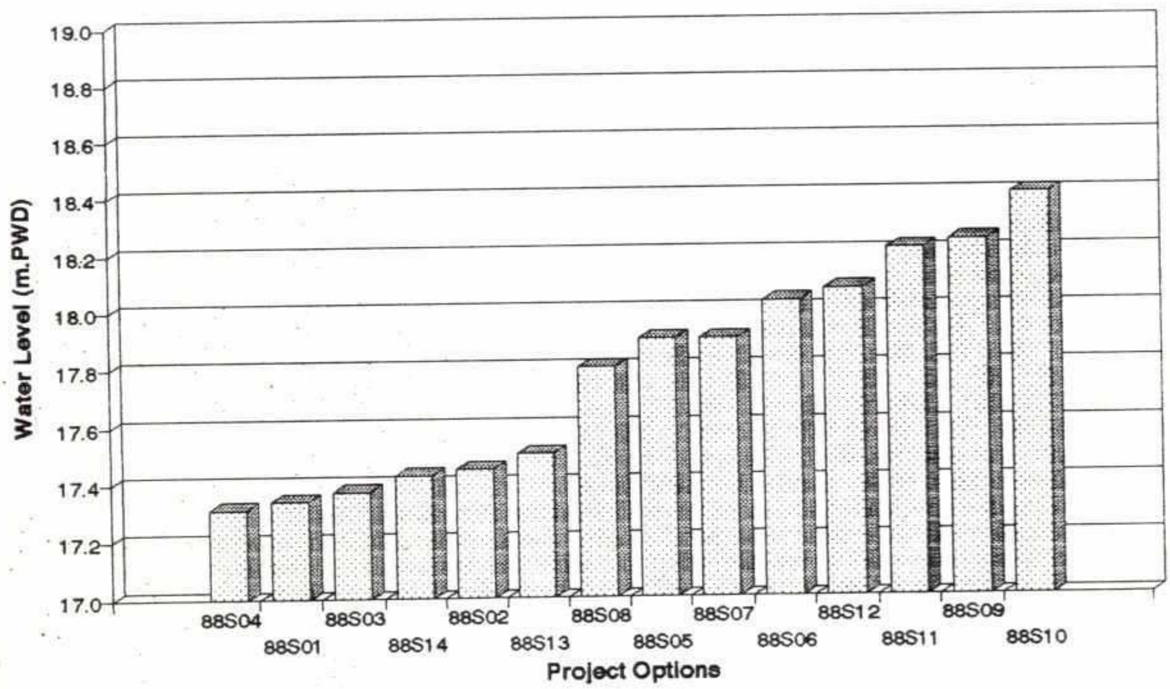
BRTS 1-D Hydrodynamic Modelling

Modelled Maximum 1988 Water levels at Chainages 75.60 km and 84.15 km	Vol.3 Part 7
	Figure 4.3

CHAINAGE 113.4 km

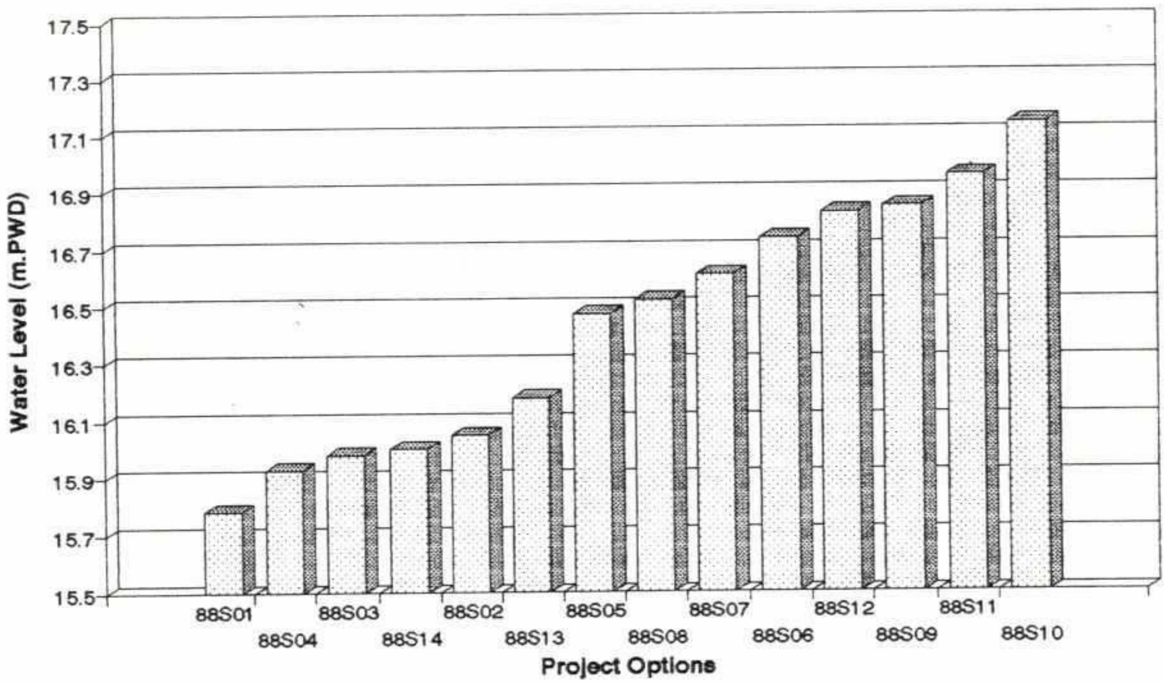


CHAINAGE 136.8 km

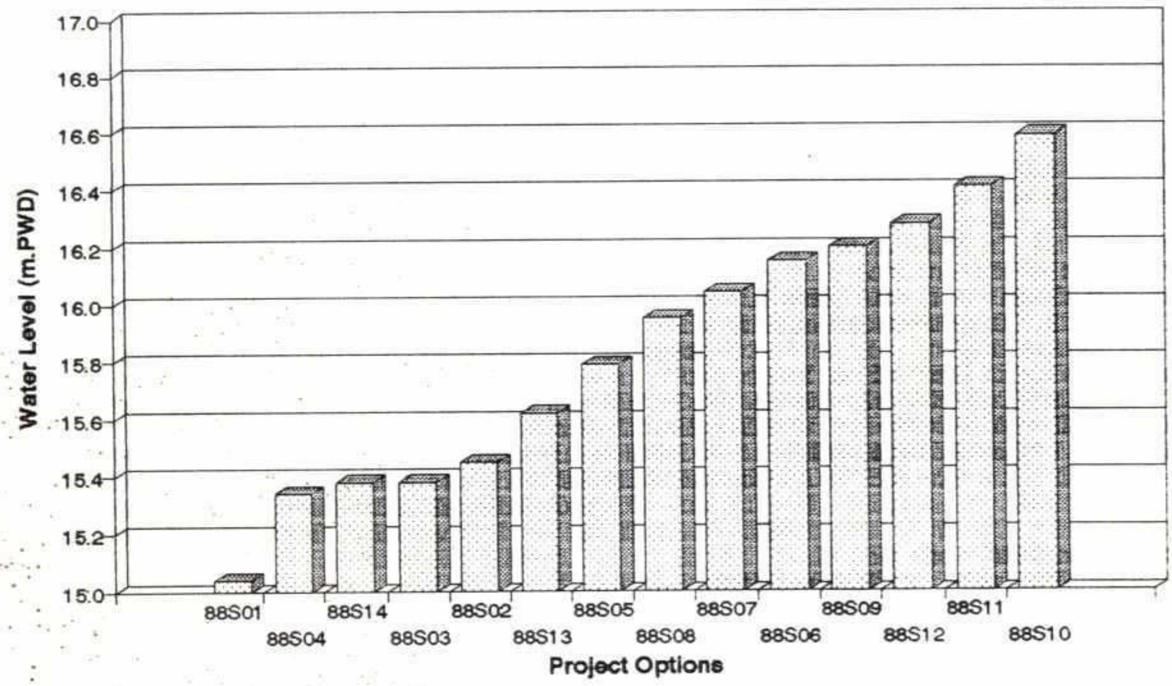


BRTS 1-D Hydrodynamic Modelling	
Modelled Maximum 1988 Water levels at Chainages 113.40 km and 136.80 km	Vol.3 Part 7 Figure 4.4

CHAINAGE 151.75 km



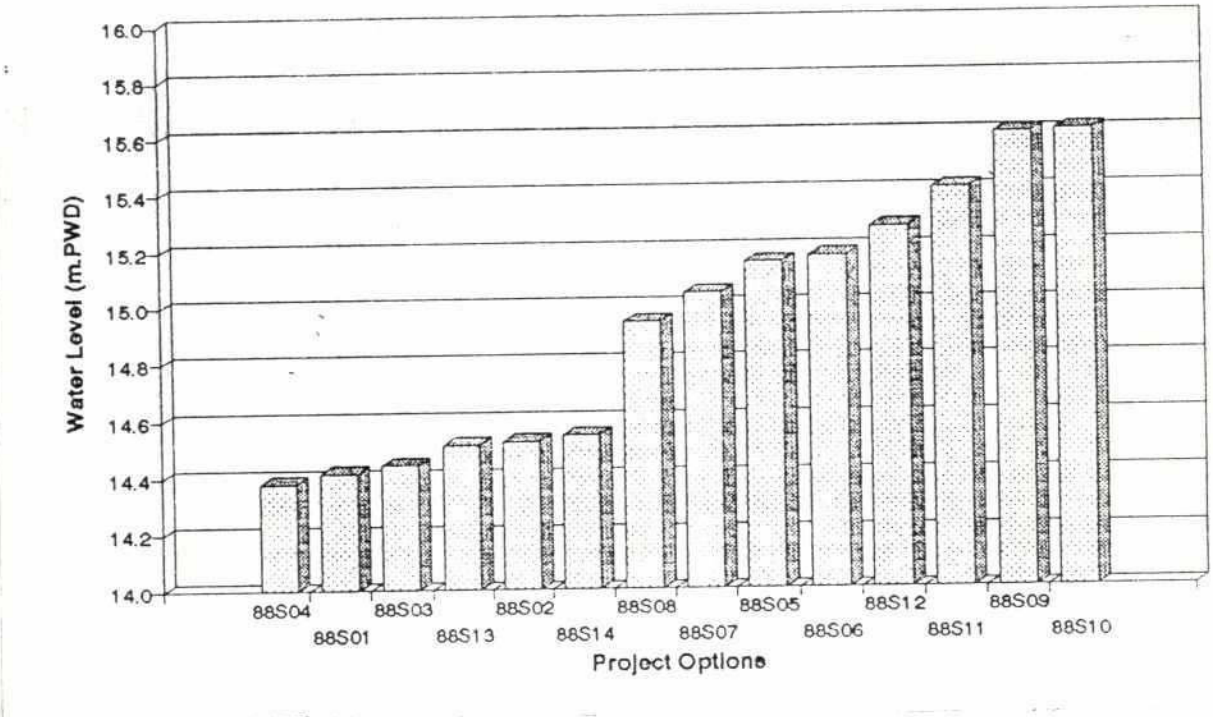
CHAINAGE 162.35 km



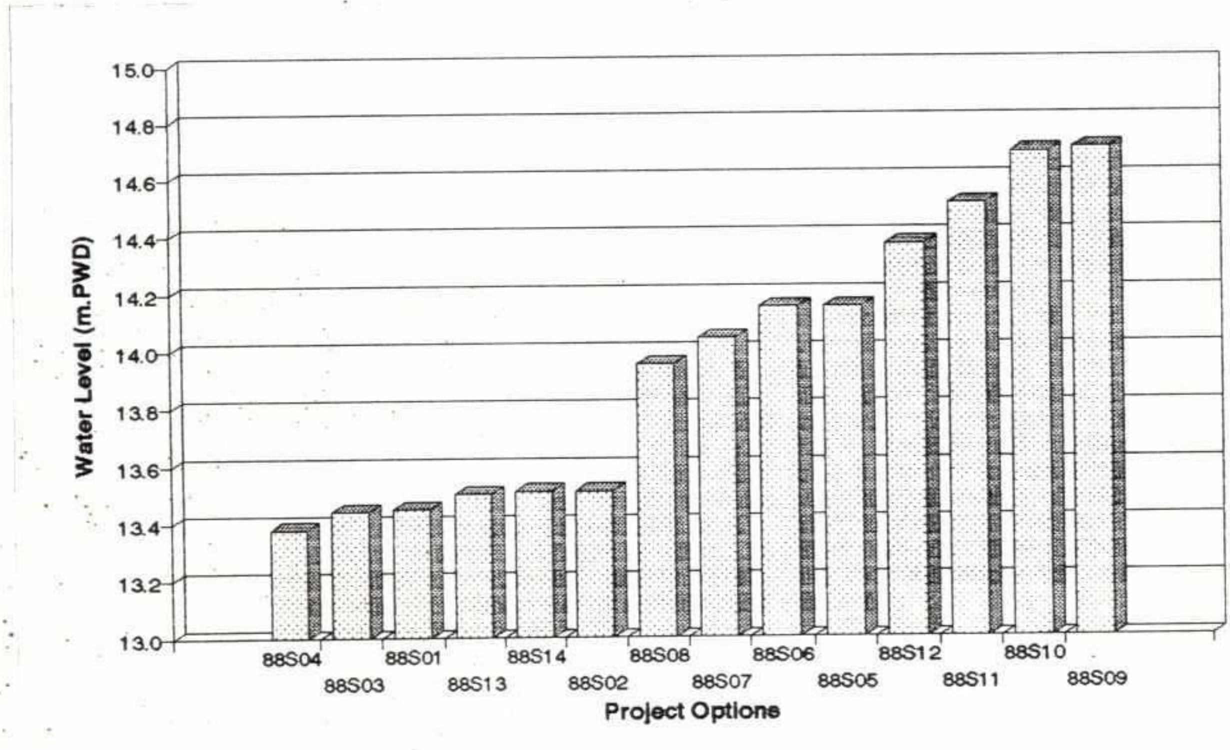
BRTS 1-D Hydrodynamic Modelling

Modelled Maximum 1988 Water levels at Chainages 151.75 km and 162.35 km	Vol.3 Part 7
	Figure 4.5

CHAINAGE 170.75 km



CHAINAGE 180.6 km

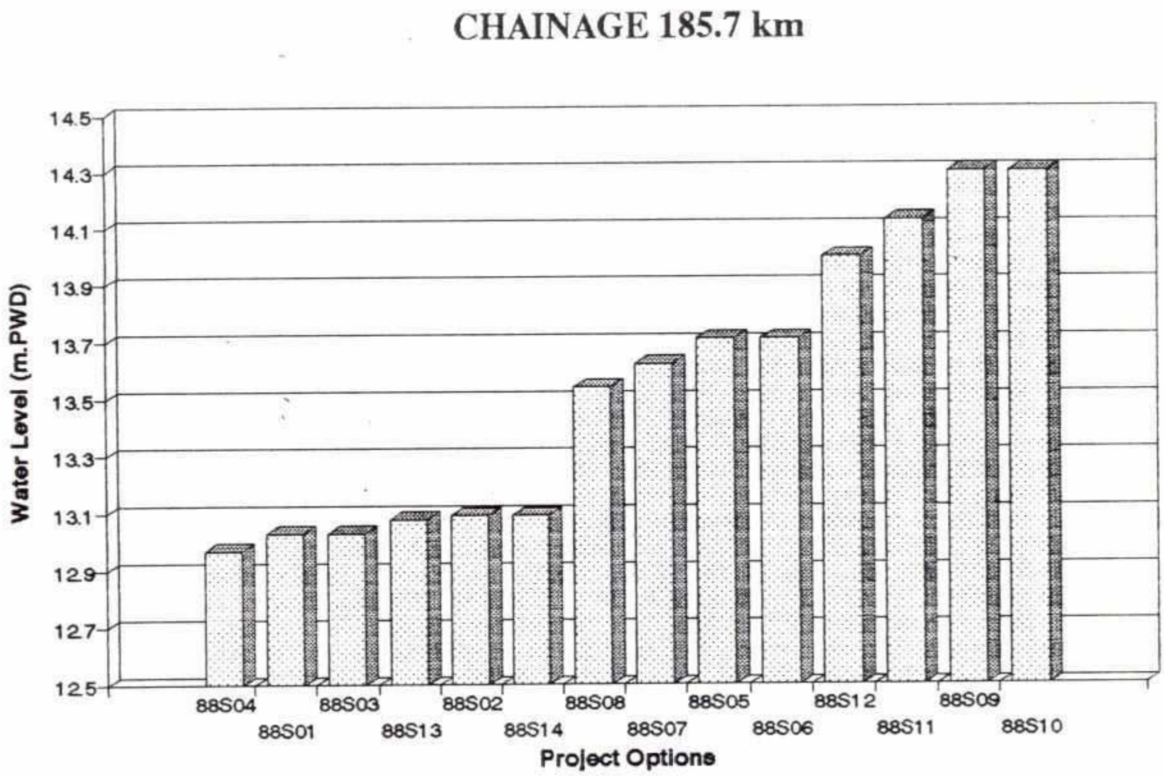


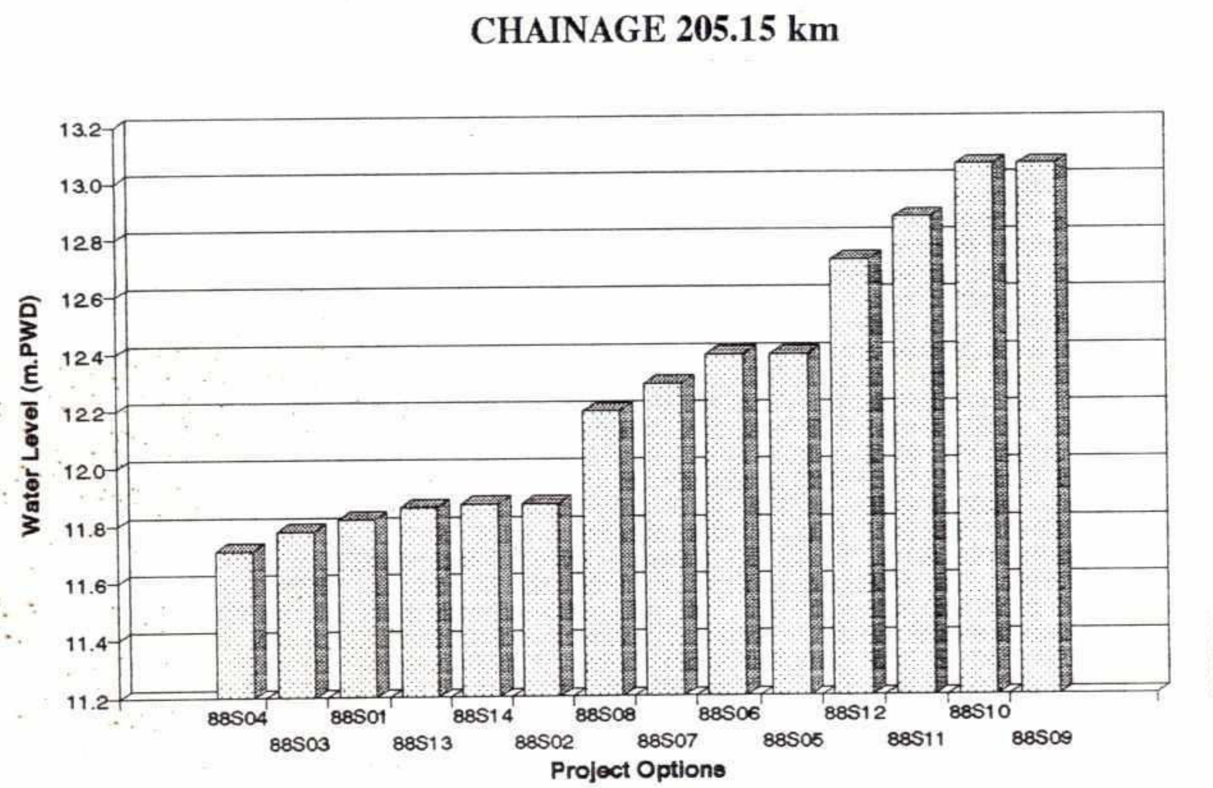
BRTS 1-D Hydrodynamic Modelling

Modelled Maximum 1988 Water levels at Chainages 170.75 km and 180.60 km

Vol.3 Part 7

Figure 4.6





BRTS 1-D Hydrodynamic Modelling

Modelled Maximum 1988 Water levels at Chainages 185.70 km and 205.15 km	Vol.3	Part 7
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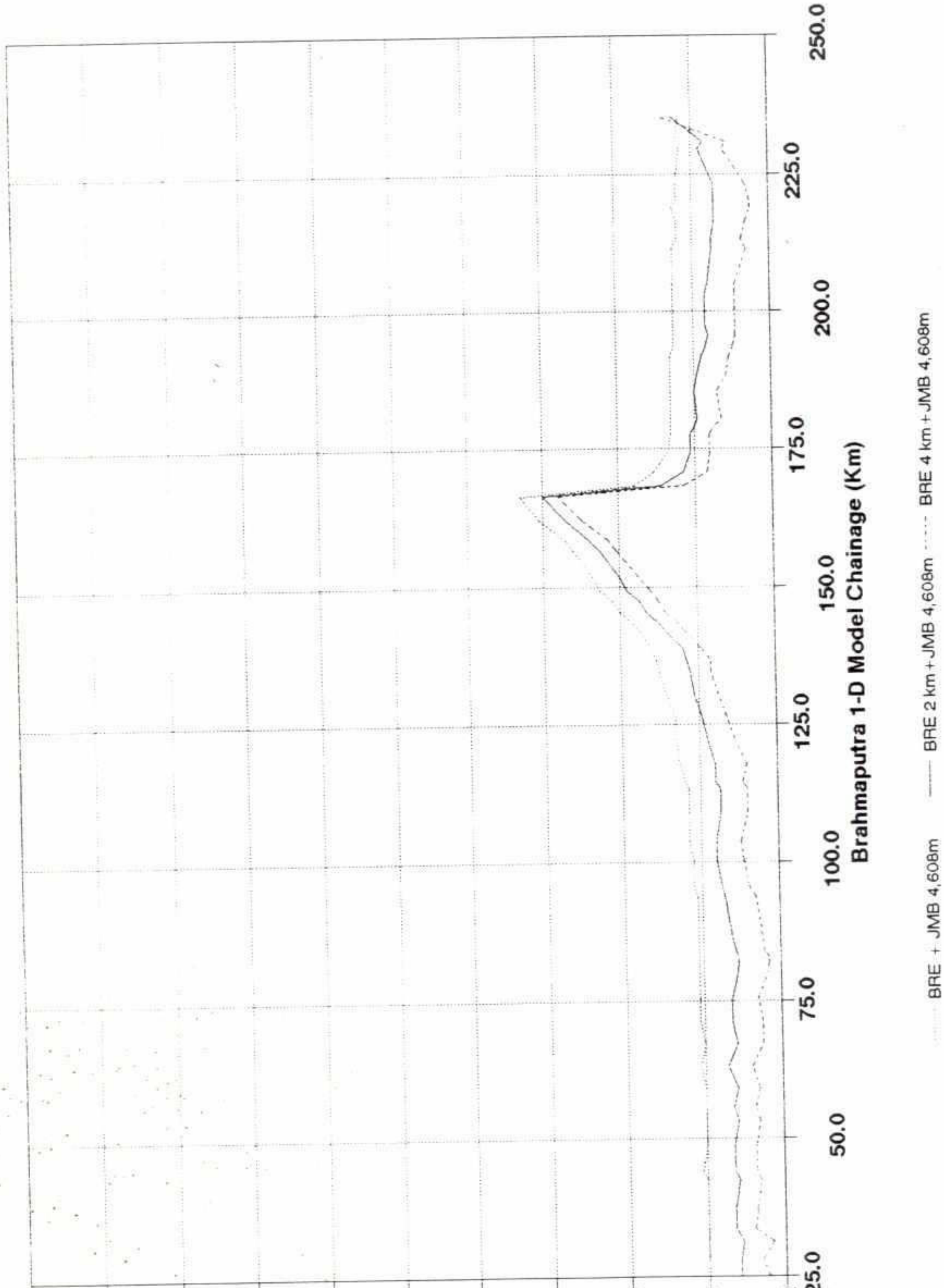
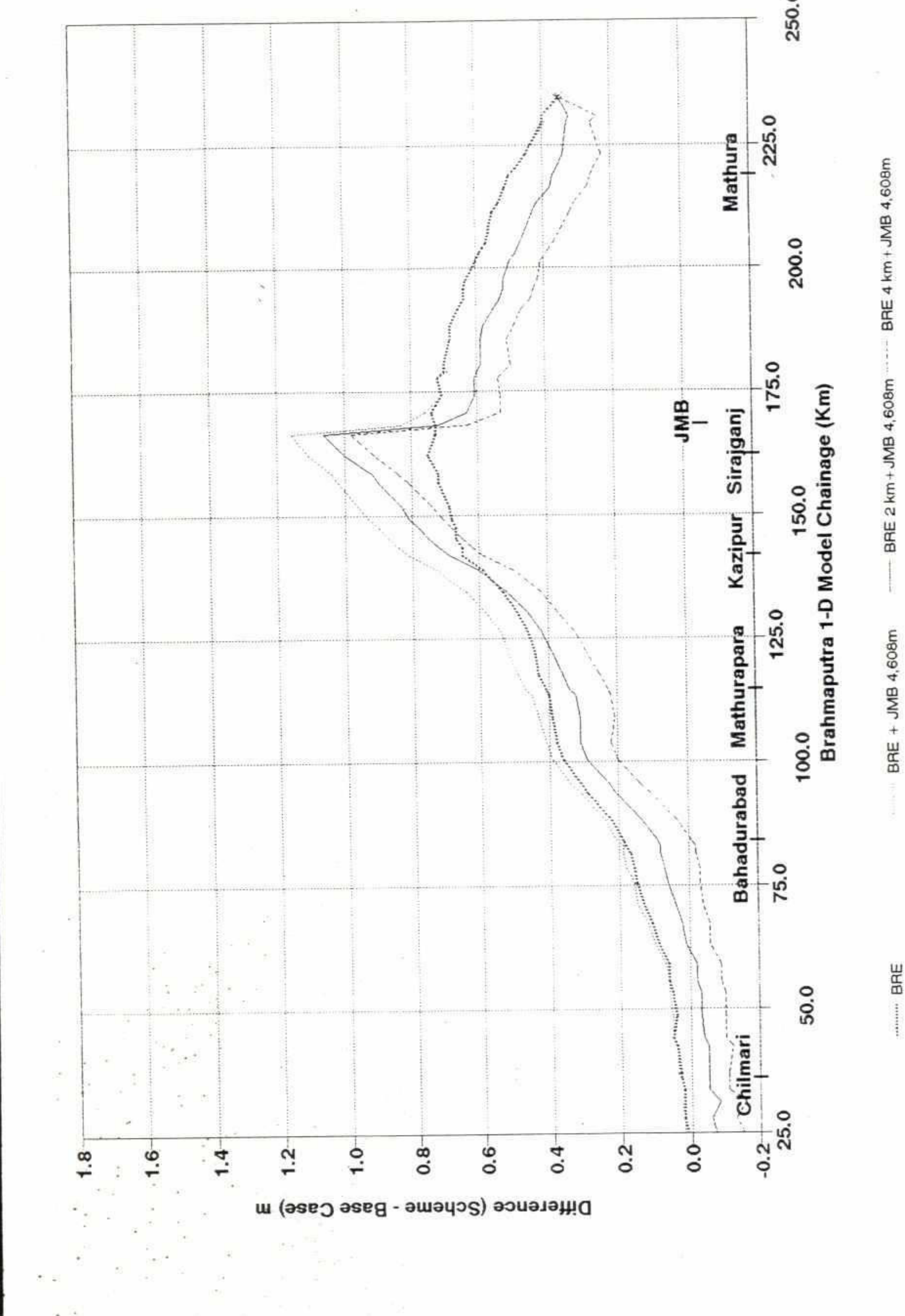


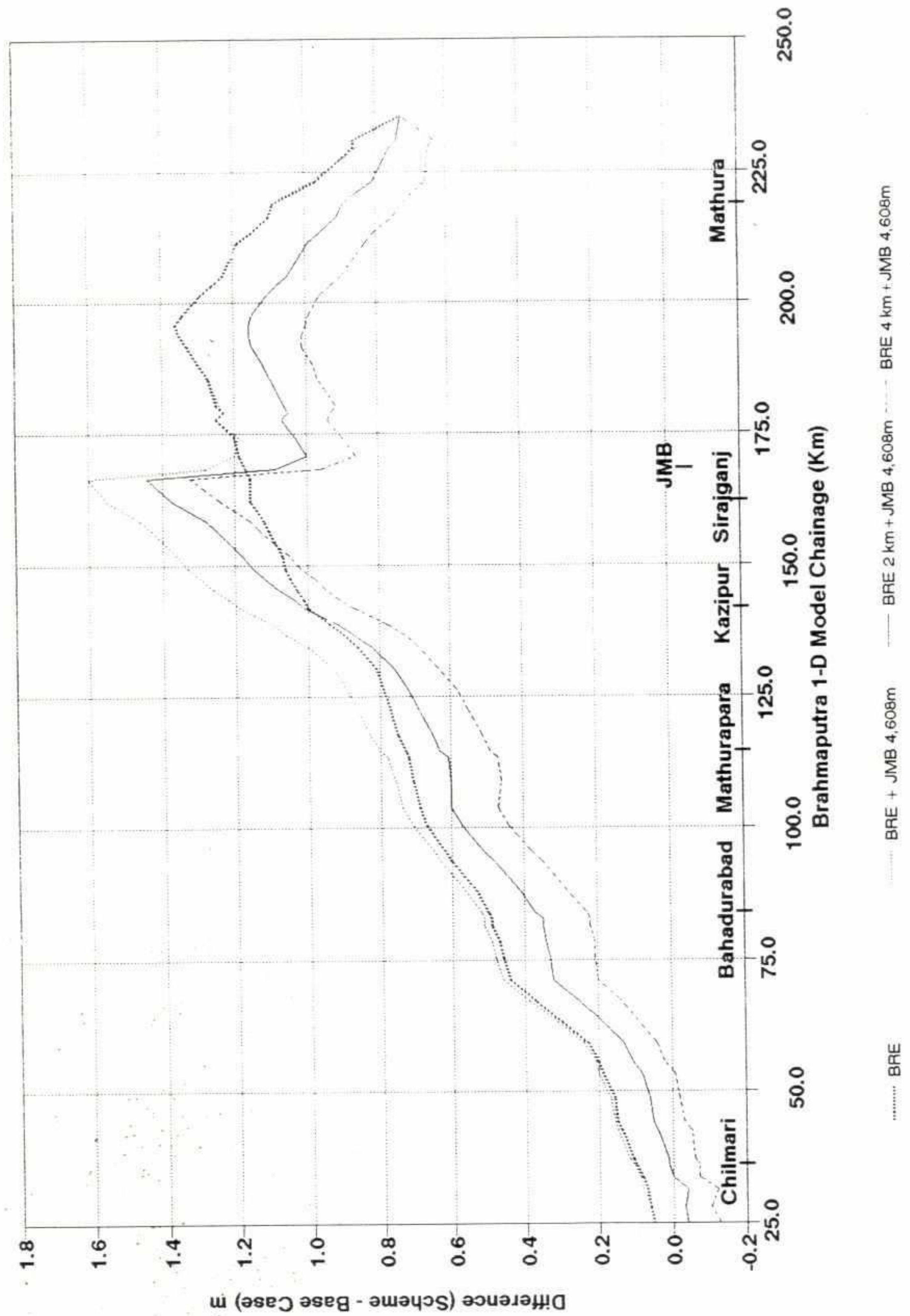
BRTS 1-D Hydrodynamic Modelling

Impact of BRE Setback Distance on 1988 Peak WL Existing Situation + JMB	Vol.3 Part 7 Figure 4.8



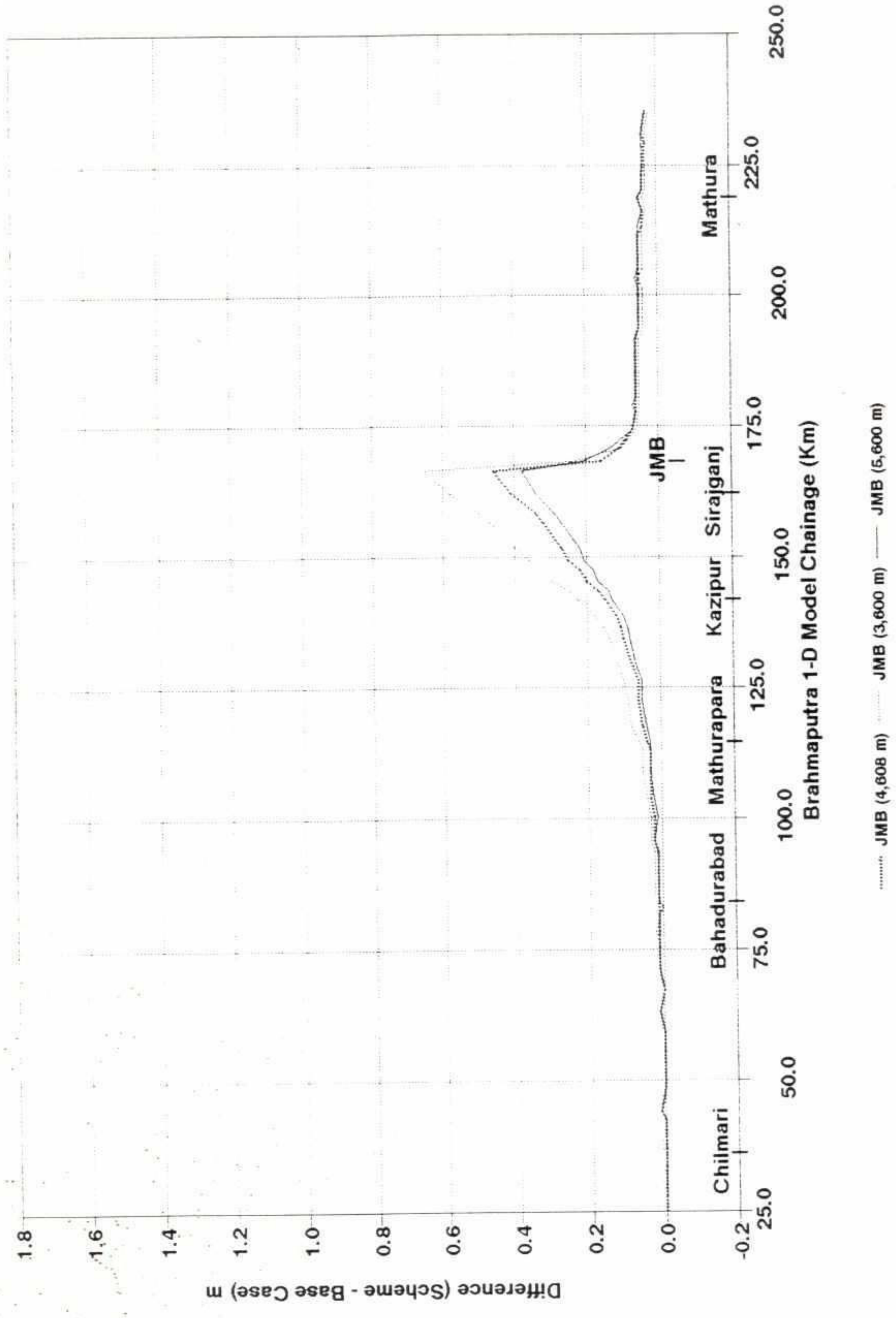
BRTS 1-D Hydrodynamic Modelling

Impact of BRE Setback Distance on 1988 Peak WL FAP-3 Left Bank Confinement + JMB	Vol.3 Part 7 Figure 4.9



BRTS 1-D Hydrodynamic Modelling

Impact of BRE Setback Distance on 1988 Peak WL Fully Confined Left Bank + JMB	Vol.3 Part 7 Figure 4.10



BRTS 1-D Hydrodynamic Modelling

Impact of Selected JMB Widths on 1988 Peak WL	Vol.3 Part 7
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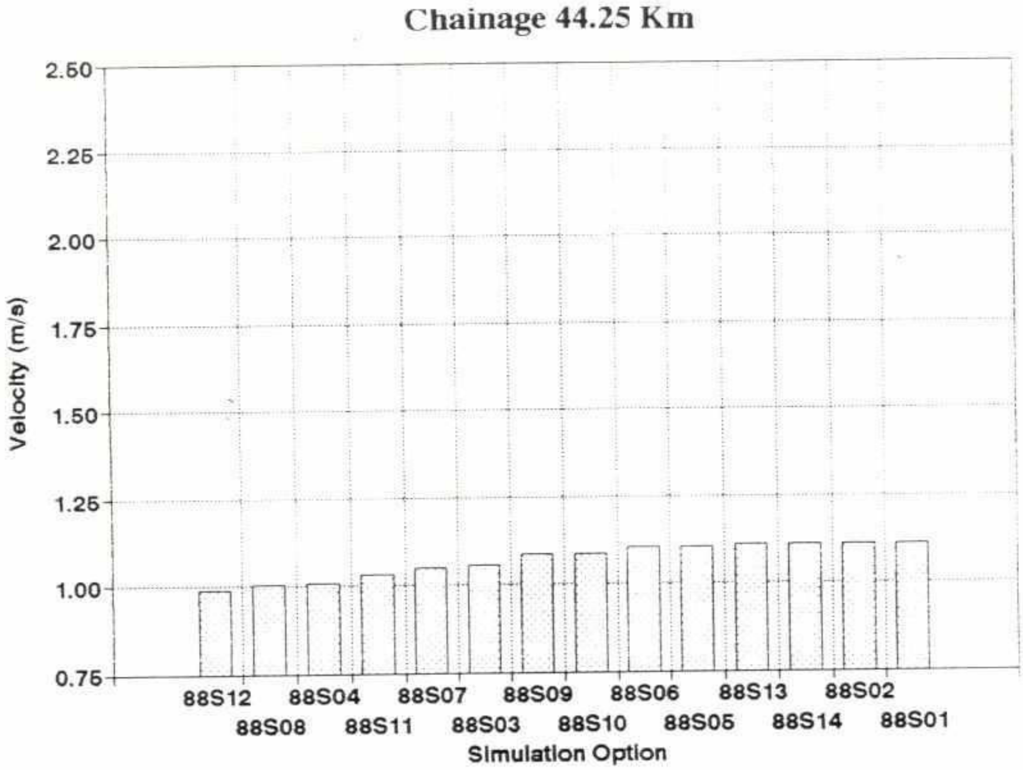

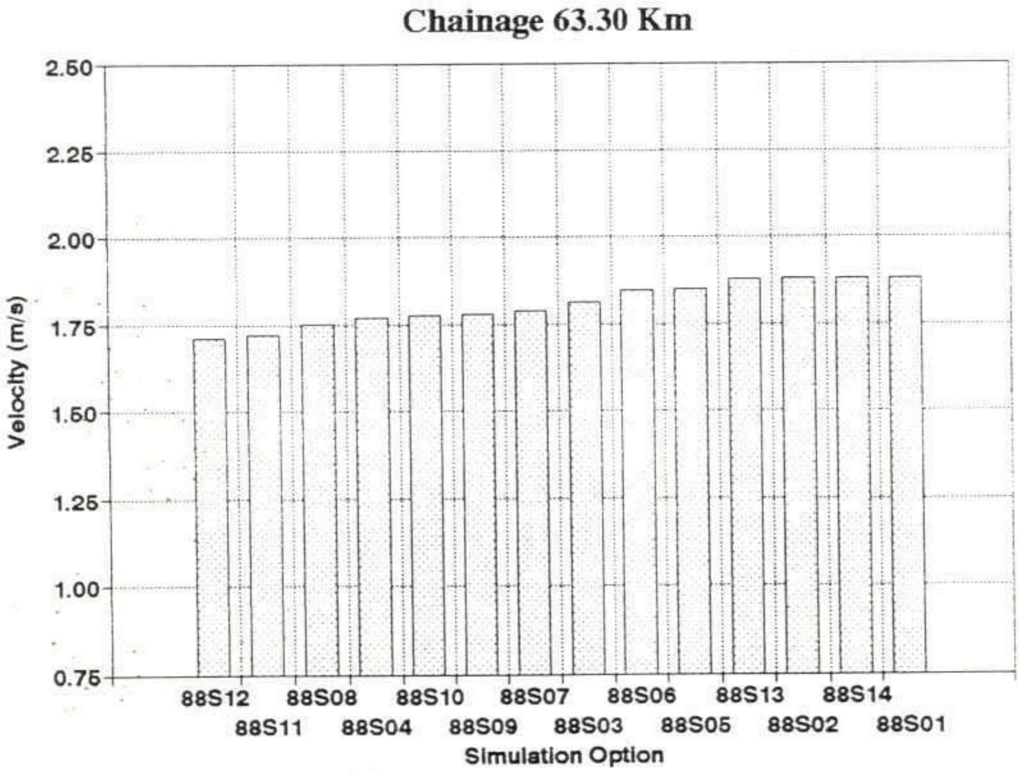

BRTS 1-D Hydrodynamic Modelling

Modelled 1988 Maximum Mean Velocity at Chainages 44.25 km and 63.30 km	Vol.3 Part 7
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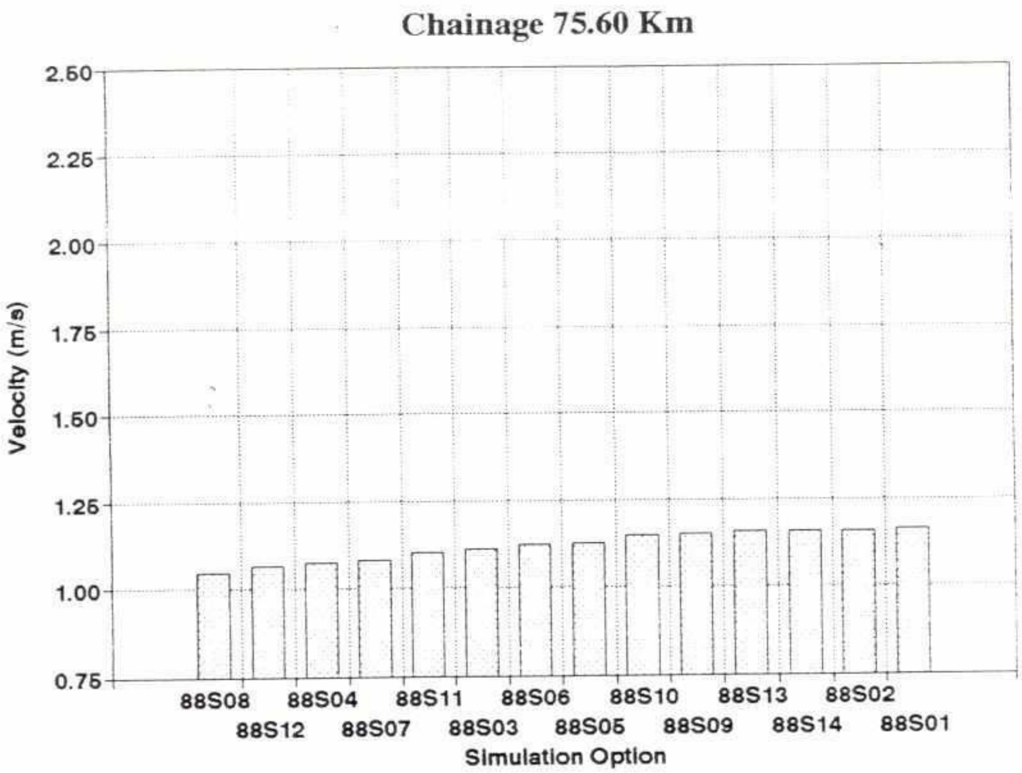

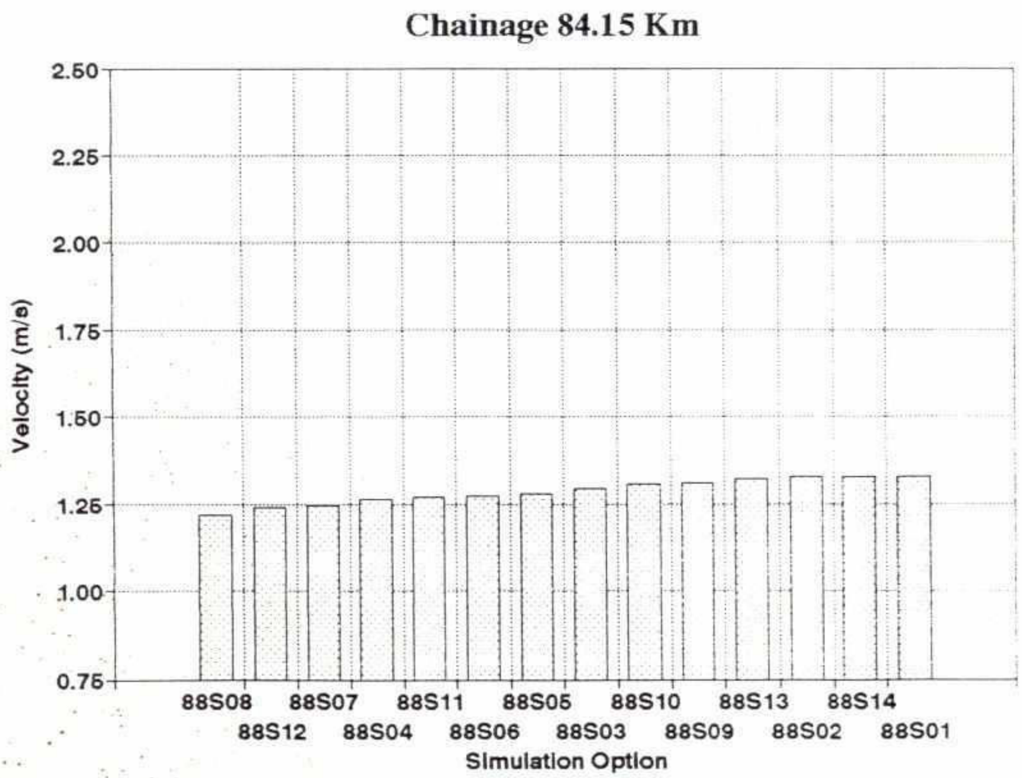

BRTS 1-D Hydrodynamic Modelling

Modelled 1988 Maximum Mean Velocity at Chainages 75.60 km and 84.15 km	Vol.3	Part 7
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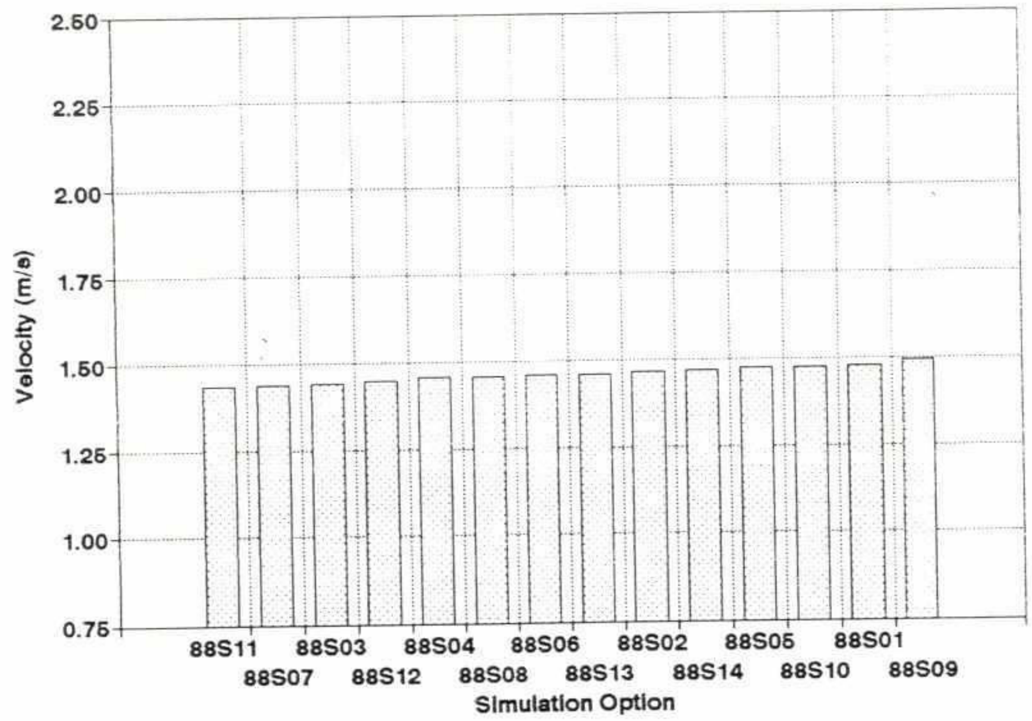
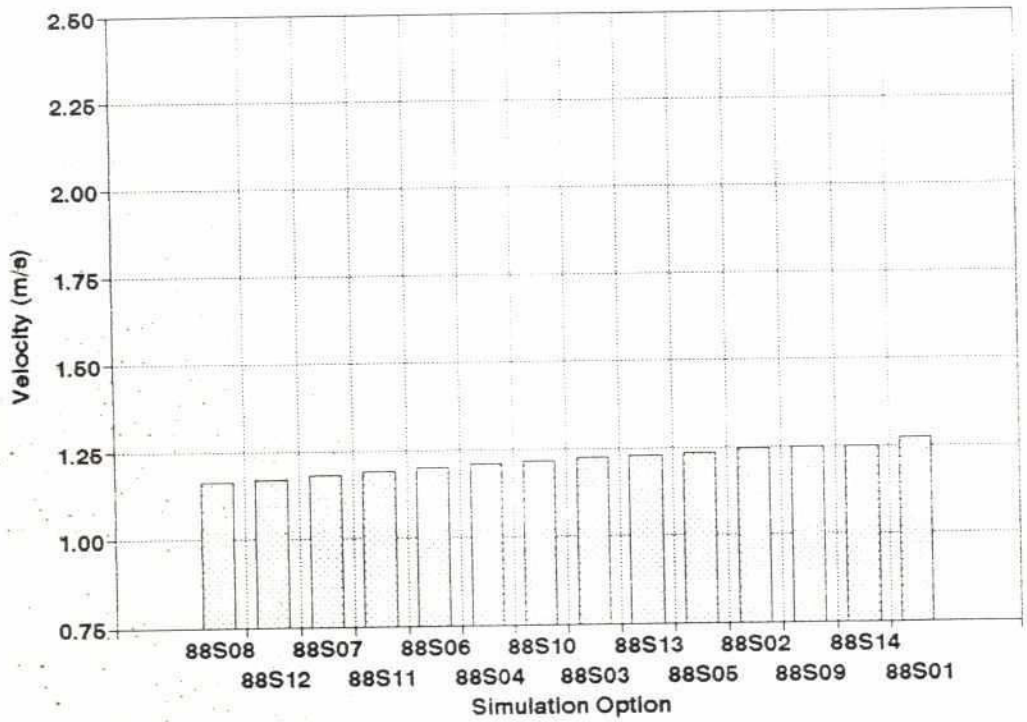
Chainage 113.40 Km



Chainage 136.80 Km



BRTS 1-D Hydrodynamic Modelling

Modelled 1988 Maximum Mean Velocity at Chainages 113.40 km and 136.80 km	Vol.3 Part 7
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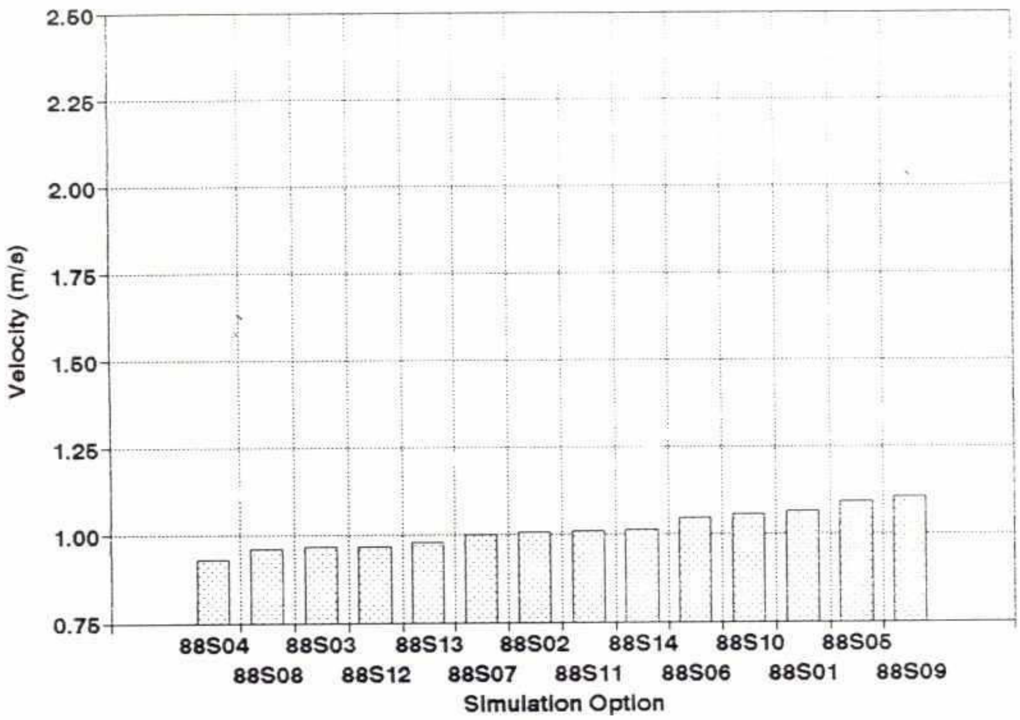
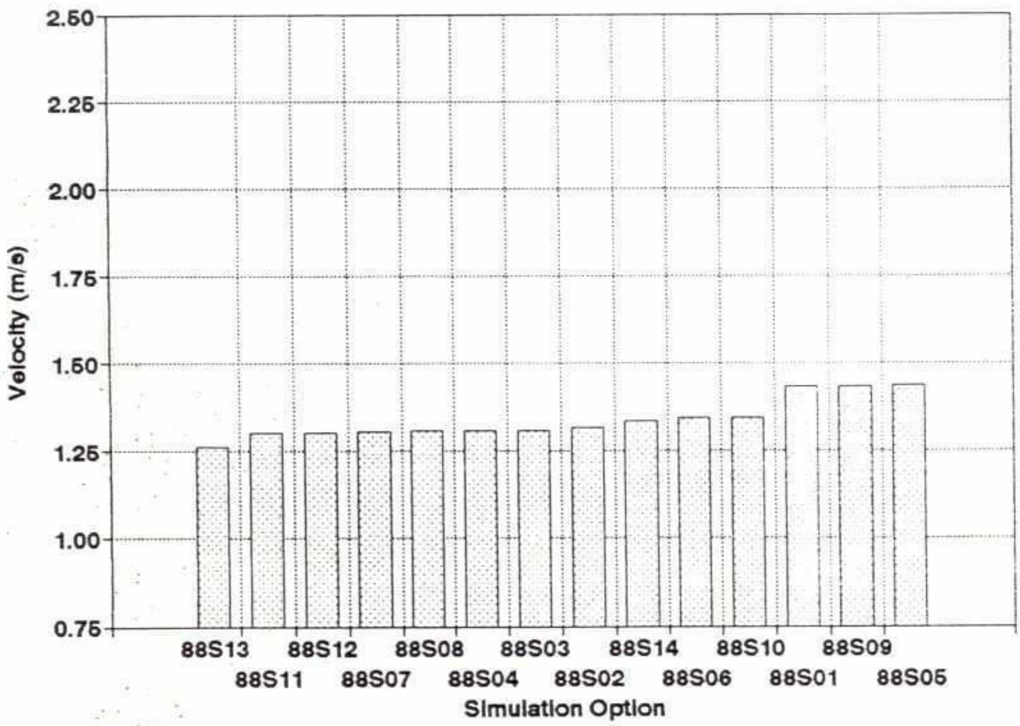
Chainage 151.75 Km



Chainage 162.35 Km



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Modelled 1988 Maximum Mean Velocity at Chainages 151.75 km and 162.35 km	Vol.3 Part 7
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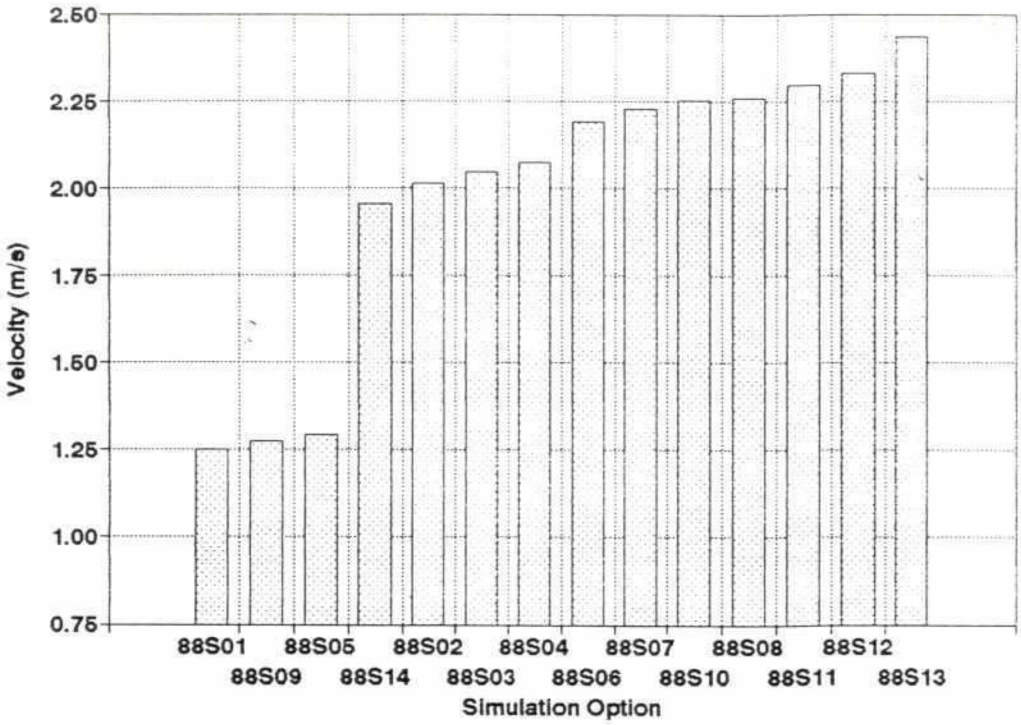
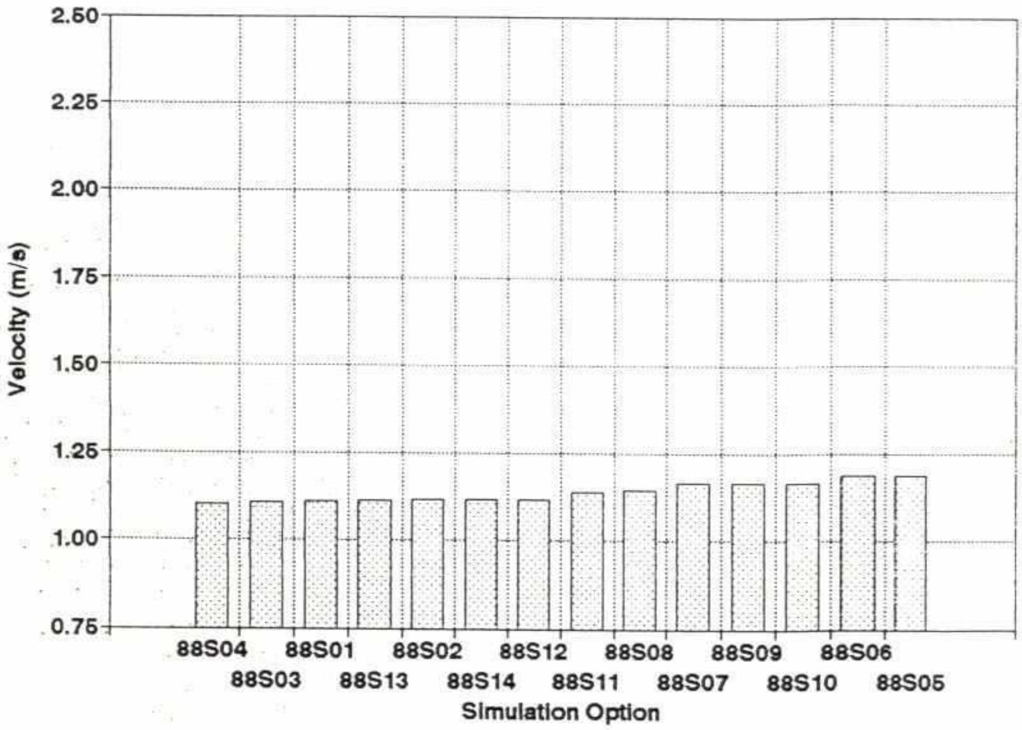
Chainage 170.75 Km



Chainage 180.60 Km



BRTS 1-D Hydrodynamic Modelling

Modelled 1988 Maximum Mean Velocity at Chainages 170.75 km and 180.60 km	Vol.3 Part 7
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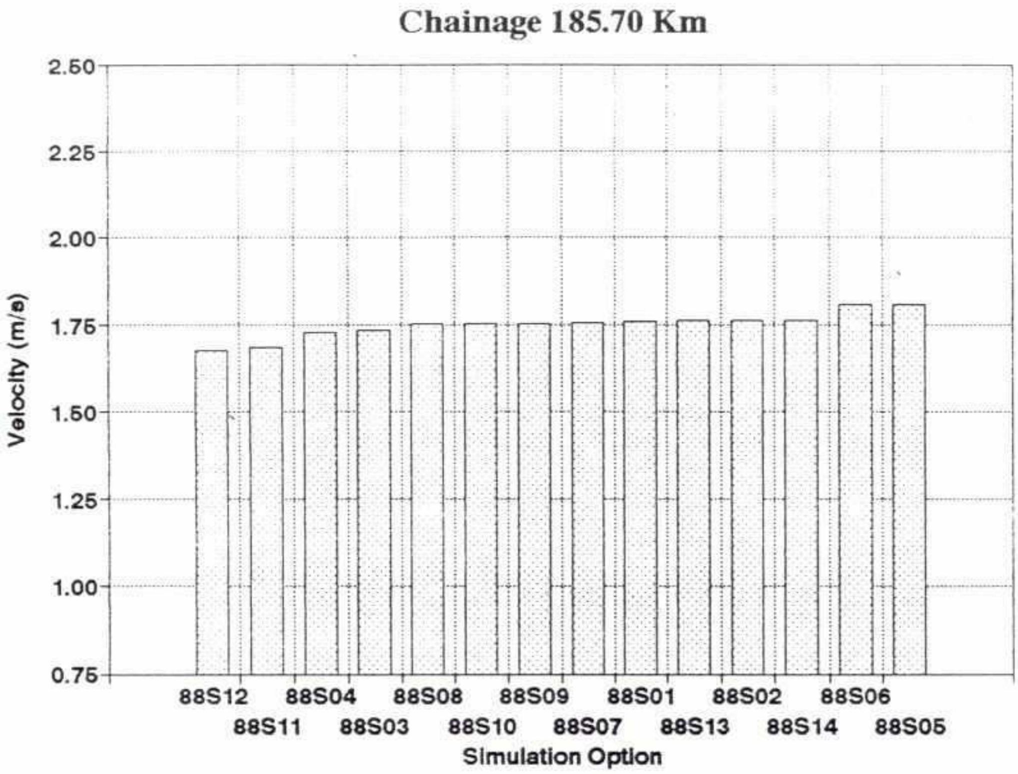

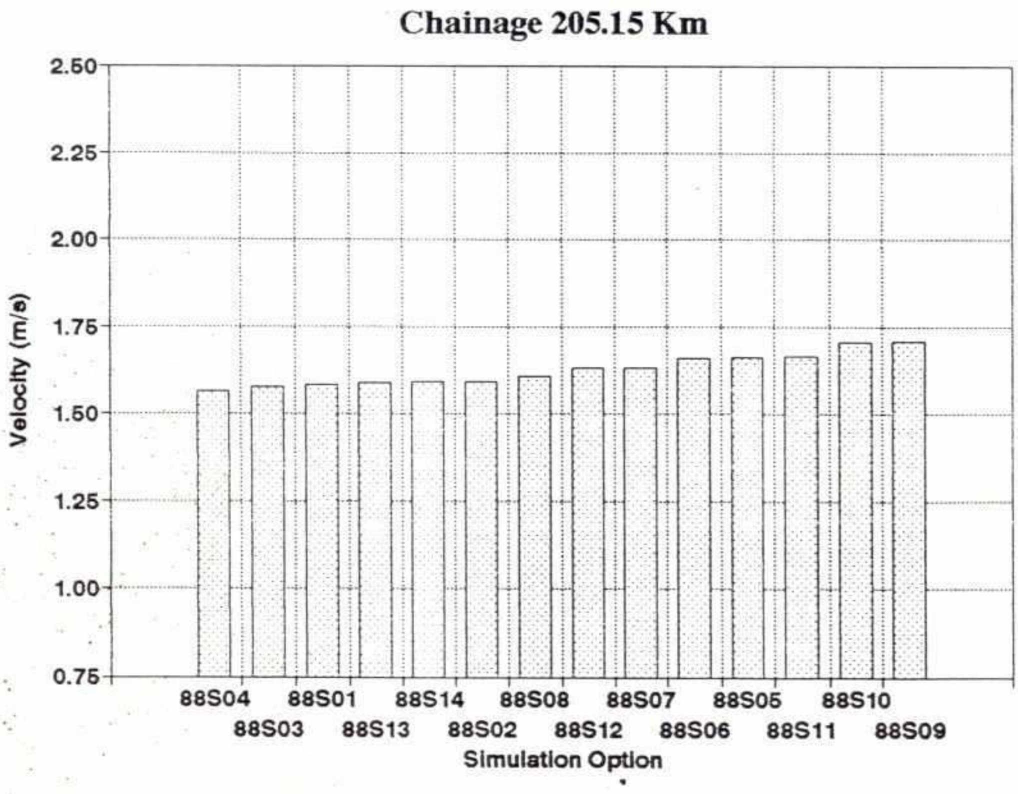

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Modelled 1988 Maximum Mean Velocity at Chainages 185.70 km and 205.15 km	Vol.3 Part 7
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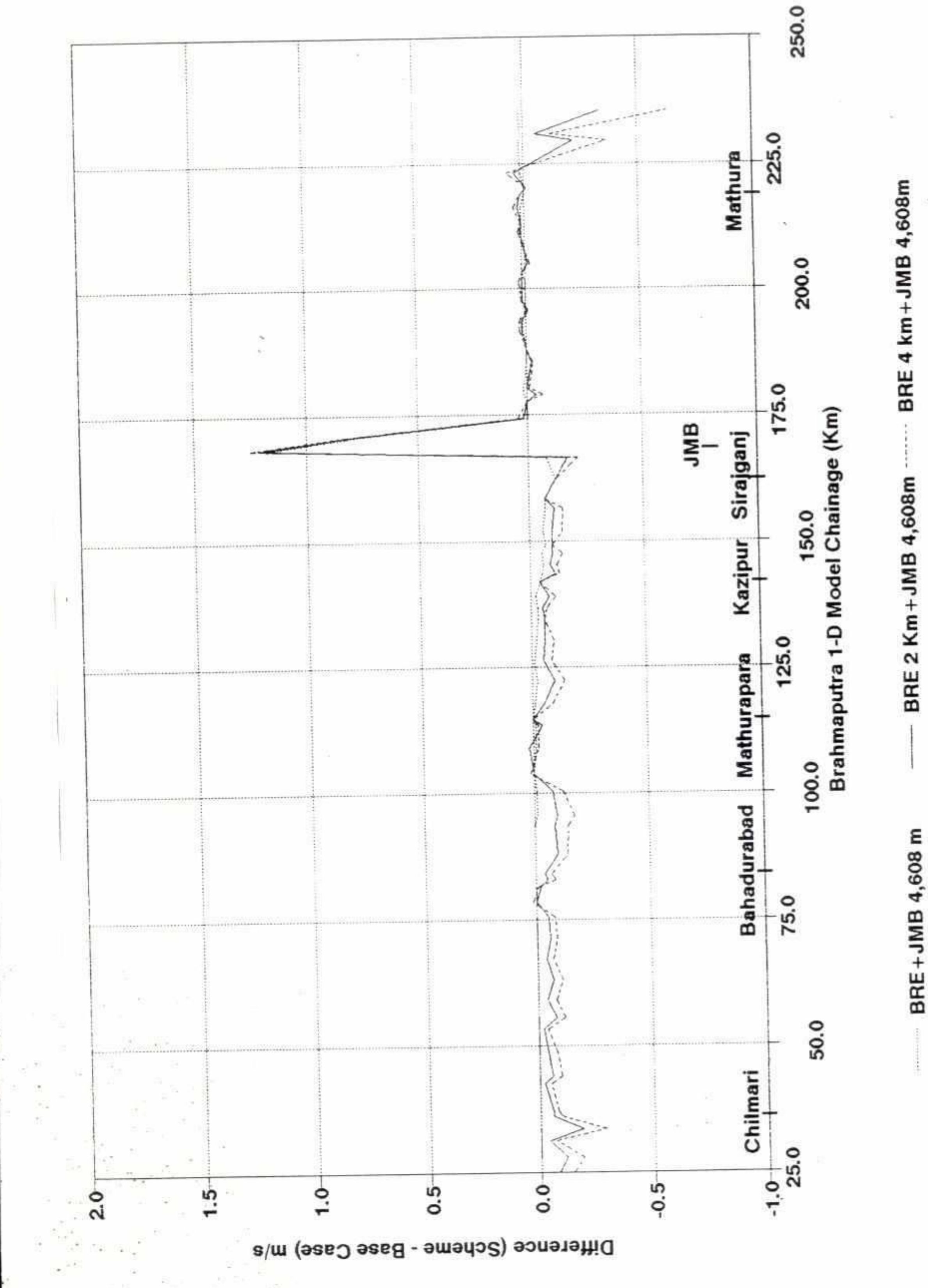
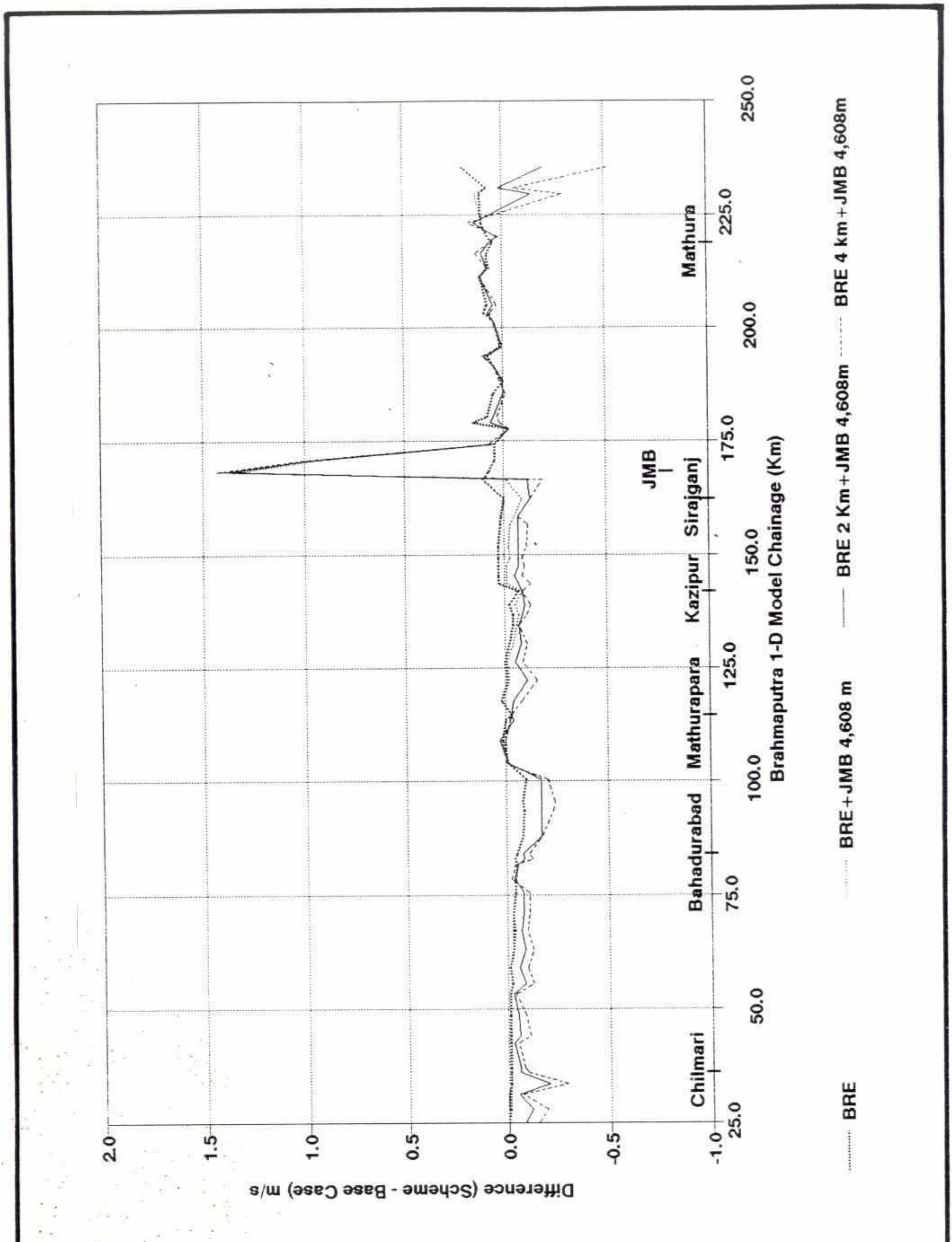


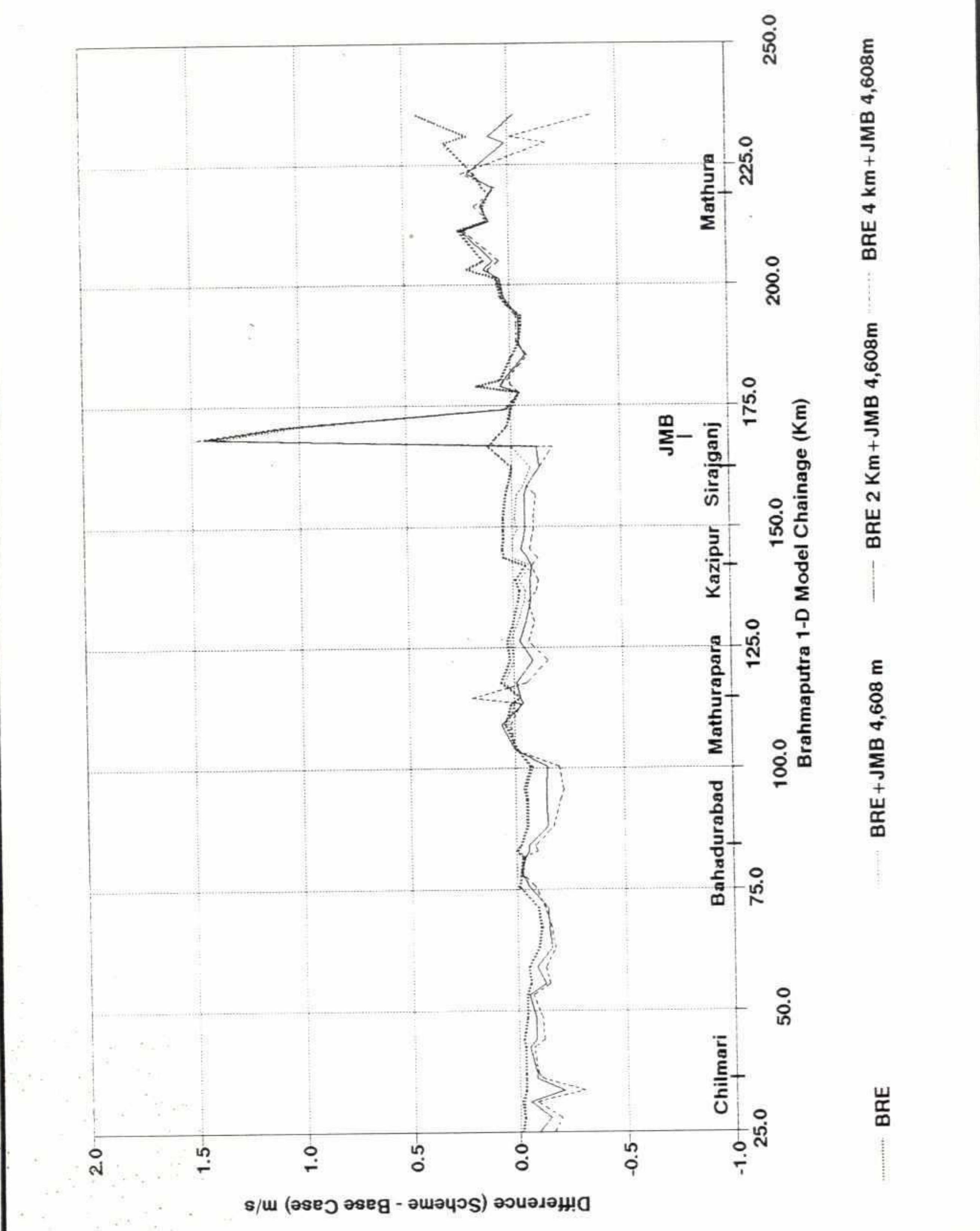
BRTS 1-D Hydrodynamic Modelling

Impact of BRE Setback Distance on Maximum Mean Velocity Existing Situation + JMB	Vol.3 Part 7 Figure 4.18



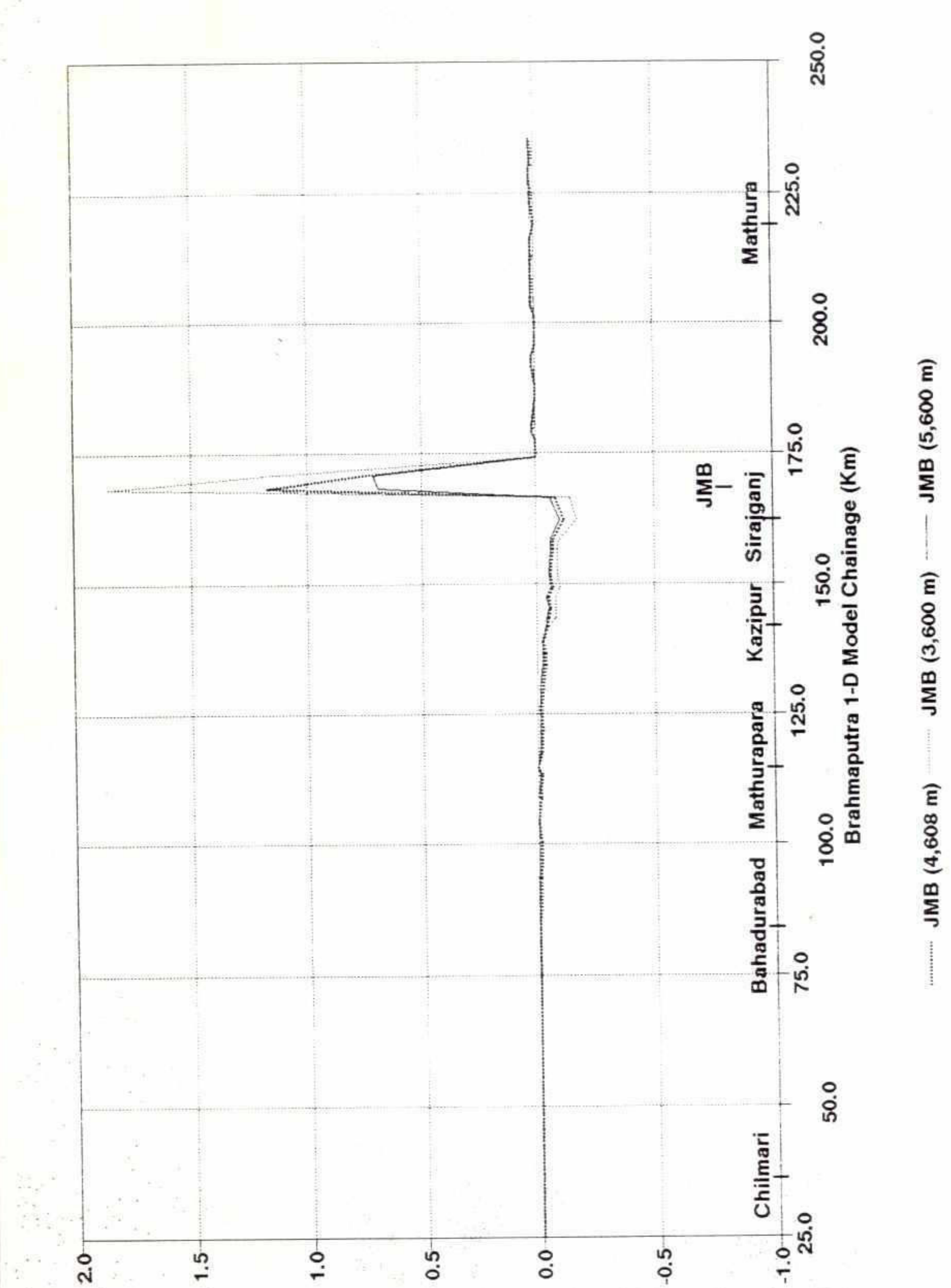
BRTS 1-D Hydrodynamic Modelling

Impact of BRE Setback Distance on Maximum Mean Velocity FAP-3 Left Bank Confinement + JMB	Vol.3 Part 7 Figure 4.19



BRTS 1-D Hydrodynamic Modelling

Impact of BRE Setback Distance on Maximum Mean Velocity Fully Confined Left Bank + JMB	Vol.3 Part 7 Figure 4.20



BRTS 1-D Hydrodynamic Modelling

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Part 8

1-D Numerical Morphological Modelling of the Brahmaputra River

HALCROW

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REPORT ON MODEL STUDIES

PART 8 - 1-D NUMERICAL MORPHOLOGICAL MODELLING OF THE BRAHMAPUTRA RIVER

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1. INTRODUCTION

1.1 Background

The Brahmaputra-Jamuna River is the largest component of the river system of Bangladesh. An earth embankment known as the Brahmaputra Right Embankment (BRE) was built during the late 1960's and early 1970's along the west bank of the Jamuna, extending some 240 km, as protection against flooding. On-going bank erosion by the river, however, has led to breaches of the BRE, with attendant crop loss and damage to buildings and infrastructure, and successive costly retirements of the BRE.

The Government of Bangladesh therefore decided to commission physical and mathematical model studies which would provide recommendations for improving the BRE to resist erosion and provide better protection against floods.

The study, which commenced in February 1990, has as its overall objective the formulation of a master plan for the long term protection of the BRE. A second objective is the design of short term (i.e., priority) measures for bank protection/stabilization at critical locations along the right bank for early implementation.

The present report deals with assessment of the long term morphological changes which could occur due to man made interventions such as the structures recommended for the master plan. The study was performed by BRTS in collaboration with SWMC using their 1-D Morphological Model.

1.2 Study Approach

The approach to the 1-D morphological modelling has been outlined in the BRTS First Interim Report. It covers four phases of activity:

1) a review of previous studies
2) the analysis of historic river cross sections and available data
3) setting up, calibrating and verifying the model
4) predictive runs

The first two phases are described in BRTS Second Interim and Draft Final Reports. The third phase has been carried out at SWMC, and is described in a separate report (SWMC,1992). The present report deals exclusively with the fourth phase.

The non-cohesive sediment transport module of MIKE 11 is used for the 1-D morphological modelling. The mathematical basis for this model, and the inherent limitations of a 1-D mathematical modelling approach, are described in the BRTS Working Paper on Mathematical Modelling. The principal limitation of the 1-D morphological modelling approach is that it is based on the assumption that the alignment and width of the river do not change during the simulation period. The effects of this limitation are discussed further in this report. The main advantage of 1-D modelling, however, is that it is feasible to simulate large scale effects, which develop on large time scales.

In Section 2 of this report the selected schematization and the calibration and verification of the model are summarized. The application simulations are described in Section 3. Finally, in Section 4 the main conclusions are summarized.

2. MORPHOLOGICAL MODEL SET UP

The one dimensional morphological model (the JGP Model) used in this study was developed by the Surface Water Modelling Centre (SWMC), comprising the Jamuna, Ganges and Padma Rivers. The schematization of the three rivers in the model was based on the results of a detailed analysis of river cross section data by SWMC. These results were later verified with BRTS data. The analysis and the theoretical basis of the schematization are described in detail in the General Model Verification Report (SWMC,1992).

2.1 Hydrodynamic Model

The three rivers are schematized with identical cross sectional shapes (except on a short reach representing the Hardinge Bridge constriction on the Ganges). Each river is represented by its own equivalent cross sectional shape and longitudinal profile derived from the cross section analysis. The variation of resistance factor with depth of flow is identical in all the cross sections in each river. The hydraulic properties of the representative cross section used in the Jamuna river are shown in Figure 2.1.

The Jamuna and Ganges were extended by 100 km into India and by 97 km upstream to Pankah respectively. This was done to reduce the effect of incompatibilities between the sediment boundary condition and the calculated sediment transport capacity at the inflow boundaries caused by bed level changes propagating upstream from an intervention in the project area.

The hydrodynamic performance of the Jamuna-Gange-Padma (JGP) model set-up with smoothed river geometry was verified for the period April 1986 to March 1989 in fixed bed mode. Main inflow boundary time series (with appropriate shifts of phase), and the lateral in and outflows were taken from the fifth 25 year simulation of the General Model carried out at SWMC for FAP25 (1992). The comparison of water levels in the Jamuna against field observations given in figures 2.2 show that the calibration is very satisfactory. A more complete set of comparisons may be found in SWMC (1992). During calibration the resistance of individual cross sections were not adjusted. The global factors used in the calibration are given in Table 2.1.

Table 2.1: Global Resistance Factors in the JGP Model

G.5.3 MULTIPLIERS FOR RESISTANCE NUMBERS IN THE JGP MODEL

Global resistance number	1.000

Branches where local resistance numbers are applicable:

River name	River chainage	Res. number
JAMUNA-EXT	0.000	0.800
JAMUNA-EXT	100.000	0.875
JAMUNA	0.000	0.875
JAMUNA	25.000	0.900
JAMUNA	84.150	0.950
JAMUNA	142.000	0.975
JAMUNA	235.400	1.000

2.2 Sediment Transport Model

The Engelund-Hansen formula was chosen for sediment transport computations essentially because the available data were not sufficiently detailed to justify the use of a more complicated formula. The large scatter observed in the field data could be ascribed at least partly to the random changes in the sediment transport capacity at any given location. Making a linear regression on a log-log plot of the observed sediment transport rate against the observed discharge was considered the most appropriate means of obtaining sediment rating curve against which to calibrate the sediment transport formula. There is a significant difference between the sediment rating curves obtained from data collected at Bahadurabad in the period 1968-70 and those collected after 1980. There is no reason to believe that the sediment transport mechanisms in the river have changed during this period. After examining the methodology currently being used in field measurements (SWMC,1991) with the original methodology published in by the EPWDA (1969) it has been concluded that the 1968-70 sediment rating curve is more reliable. This is in line with the conclusions reached by the Jamuna Bridge Study as well as BRTS.

The grain sizes from bed material samples taken from the three rivers has a great deal of seasonal and spatial variability even within a single cross section. The number of samples available, particularly in the wet season, does not have sufficient coverage to establish a single set of grain sizes to be representative of the morphological processes in the river. The fact that the Engelund-Hansen formula uses a single grain size to calculate sediment transport makes it necessary that some judgement is exercised in selecting the grain sizes to be used in the model.

The range of grain sizes (D_{50}) used in the model are shown in Table 2.2. The China-Bangladesh Joint Expert Team has suggested that the grain size decreases from 0.26 mm to 0.17 mm along the Jamuna river inside

Bangladesh, wheras the Jamuna Bridge Study used a uniform grain size of 0.18 mm in their 1-D morphological model. The JGP model assumes that the grain size decreases from 0.21 mm to 0.16 mm in the Jamuna river from the Indian border to Aricha.

The grain size gradient to be used in a model has much to do with the schematization. The Jamuna Bridge Study used a simplified approach where the Jamuna was schematized as a prismatic channel with a uniform slope without lateral in or outflows. This requires the use of a uniform grainsize if the river is to remain in long term equilibrium. This is not the case if the slope is not uniform and/or there are lateral outflows.

Exhaustive analysis of topographic data from the last 25 years have failed to establish any trend of degradation or aggradation in the Jamuna river, of a larger magnitude than the errors inherent in the data. Therefore, it is appropriate to assume that the rivers are in equilibrium and to adjust the model set up accordingly. Even if there is a small underlying trend, the model would still predict the effect of proposed schemes which would then be superimposed on the existing trend.

Table 2.2: Grain Diameters used in the Model

RIVER NAME	CHAINAGE (km)	GRAIN SIZE (mm)
JAMUNA-EXT	0.0	0.35
JAMUNA-EXT	100.0	0.21
JAMUNA	0.0	0.21
JAMUNA	65.6	0.19
JAMUNA	235.4	0.16
GANGES-EXT	0.0	0.18
GANGES-EXT	97.0	0.17
GANGES	0.0	0.17
GANGES	117.0	0.13
PADMA	0.0	0.13
PADMA	100.0	0.09

2.3 Boundary Conditions

The JGP hydrodynamic model requires the following boundary conditions.

Inflow Boundaries

1) Jamuna - Extended — Discharge time series
2) Ganges - Extended — Discharge time series

3) Teesta (lateral inflow)	Discharge time series
4) Atrai (lateral inflow)	Discharge time series

Outflow Boundaries

5) Padma (Meghna confluence)	Water level time series
6) Old Brahmaputra (lateral outflow)	Discharge time series
7) Jamuna Left Bank Spill Channels	4 Discharge time series
8) Dhaleswari (lateral out flow)	Discharge time series
9) Gorai (lateral outflow)	Discharge time series
10) Padma Right Bank Spill	Discharge time series
11) Arial Khan (lateral outflows)	2 Discharge time series

During development the model was run for the two sets of boundary conditions described below.

a) 5 Year Simulation: Discharge and water level time series were extracted from a simulation for the period April 1985 to March 1990 on the full General Model. (Run No. 5 for FAP 25). These runs were carried out for the purpose of calibrating the hydrodynamic model and the sediment transport formula. After calibration, appropriate sediment rating curves were formulated for the two main inflow boundaries on the upstream extensions of the Jamuna and the Ganges; i.e.,a relationship between water discharge and sediment transport rate (a power law) which when applied at the boundary would keep the boundary bed level reasonably stable. These sediment rating curves were used to generate sediment inflow time series for use in the morphological model runs.

b) 25 Monsoon Simulation: A set of time series boundary conditions, approximately 12.5 years long, has been constructed by BRTS by excising the dry seasons from data for the 25 years from 1965 to 1990. The time series for the hydrodynamic boundaries were extracted from a run made with the BRTS version of the General model in which the Atrai river is not included. The main sediment inflow time series were generated as described above. This set of boundaries were used to track the longer term trends in bed level changes. This set of boundaries have been repeated four times to carry out 100 year simulations.

The lateral in and outflow of sediment have been assumed to have the same concentration of sediment as in the Jamuna river. The particle grainsize gradient were adjusted until long term stability of bed levels was achieved everywhere in the system. The final grainsize distribution is shown in table 2.2.

2.4 Morphological Model Run: Baseline Simulation

A 100 monsoon simulation (4 times the same 25 monsoons) was made for the existing topography using the parameters given above. The time step used in the model runs was 4 hours. In long simulations, where the main objective was to observe the long term development of bed levels, model results were saved only once every 16 days. The bed level variations at four stations in the Jamuna river are shown in figure 2.3. It can be seen that although the net aggradation/degradation is very small, perfect stability has not been attained in the model. The bed levels are sufficiently stable, however, to enable the results of the 100 monsoon simulation to be used as a base line for comparison with model runs depicting proposed interventions in the rivers. Results pertaining to the other rivers may be found in the next General Model update report.

The sediment rating curve of the model at Bahadurabad is compared with the rating curves drawn from observed data for 1968-70 in figure 2.4. This shows good agreement. A scaling factor (a constant multiplier) of 3.35 has been used on the sediment transport rate computed by the Engelund Hansen formula. The Jamuna Bridge Study used a scaling factor of 2 in order to obtain correspondence with field measurements on a more schematized cross sectional shape (RPT/NEDECO/BCL, 1989)

3. APPLICATION

3.1 General

The 1-D morphological model has been used to predict the effect of various schemes proposed for implementation in the Jamuna River and the effect of changed boundary conditions for the river in the form of an increased sediment input to the river, for instance caused by changed land use in the catchment, and a general sea level rise due to the green house effect. In addition, the 1-D morphological model has been used to investigate the sensitivity of the river response to various degrees of artificial narrowing of the river. The following scenarios have been investigated:

1) constriction to 6000 m width
2) constriction to 5000 m width
3) constriction to 4000 m width
4) construction of Jamuna Left Embankment
5) construction of the Jamuna Multi-purpose Bridge
6) a 50 percent increase of sediment input to the river
7) a 0.5 m sea level rise

Each of these seven scenarios has been investigated in the following way:

- a 100 years morphological simulation using 25 years (1966 - 1991) records of observed water level and discharge repeated 4 times as boundary condition (see section 2.3).
- morphological simulation of the 1988 flood (close to the 1 in 100 year flood) immediately after implementation (before significant morphological changes have taken place).
- morphological simulation of the 1988 flood using the bed levels obtained from the 100 years morphological simulation (i.e. after significant morphological changes have taken place).

In addition to the 7 scenarios described above, a 100 years baseline simulation (i.e. no changes to the system) and a 1 year baseline simulation of the 1988 flood have been carried out. Thus, in total 8 100 years simulations and 15 1 year simulations have been carried out. All simulations have been carried out with time steps of four hours in the hydrodynamic model and two days in the sediment transport/bed level routine.

The results of the model simulations will be presented in the following types of plots:

- Time series of simulated bed level differences between the investigated scenarios and the baseline simulation. These plots will give an indication of the net effect of the scenario.
- Longitudinal profiles of simulated bed levels at different times. It should be noted that the raw results of the simulation are presented here, unlike in the time series presented above where the imperfection (bed level movements)

in the baseline simulation were subtracted out.

- Time series of simulated water levels for the 1988 flood for the situation before any significant bed level changes have taken place and for the conditions after the 100 years simulation. For reference the results of a similar simulations for the existing conditions (baseline simulation) are shown in the same plots.

The time series of simulated water levels for all scenarios will be presented at grid points more or less equally spaced along the Jamuna River, viz. at the upstream end of the Jamuna River (Jamuna 0.0 km), Bahadurabad (Jamuna 84.15 km), Sirajganj (Jamuna 162.35 km) and immediately upstream of the Jamuna - Ganges confluence (Jamuna 228.0 km). In addition to these grid points, the simulated bed level differences at Chilmari (Jamuna 36.10 km) will also be presented. Chilmari has been selected because this station is located upstream of the start of the constriction in scenario 1, 2 and 3.

The assumption common to the schematization of all scenarios, except for Jamuna Left Embankment and the Jamuna Bridge, is that the flow and sediment transport distributions at the offtakes from the Jamuna, Ganges and Padma have been assumed to have remained unchanged during the simulations. It is likely that this approximation only has minor influence on the results. This is supported by The Jamuna Left Bank simulations, which represent the rather extreme case where all offtakes from the Jamuna are closed.

In the following sections the selected schematizations are described in more detail, and the results presented and discussed.

3.2 Constriction of the Jamuna

The objectives of the simulations of the river response to a constriction of the width of the Jamuna are to gain insight into the sensitivity of the bed levels to very extreme interference in the river planform (as might be involved in an intensive training programme) and into the time scales on which the river response takes place. The constrictions simulated are very different from the Hard Point strategy proposed in BRTS' Long Term Master Plan. Simulation results of constrictions to 6000 m, 5000 m and 4000 m width of the river downstream of the Teesta confluence (Jamuna 48.00 km) are presented in the following.

The constrictions of the width have been represented in the model by introducing vertical walls symmetrically around the thalweg in the idealized cross sections used in the model, see Section 2. The constricted cross sections are plotted in the form of cross sectional area versus elevation in Figure 3.1. In this figure the approximate discharges at which the river actual "feels" the constriction are also indicated.

The selected approach for schematization of the constrictions is based on the assumption that the constriction takes place on the most shallow areas of the cross sections. This is a fair assumption since the time scale for lateral movements of the channels in the Jamuna is much smaller than the time scale for overall vertical movements of the mean bed level, i.e. the construction of e.g. a very long groyne into a main channel in order to constrict the width will relatively quickly cause a shift of the main channel (erosion of chars), whereas the overall bed level will respond relatively slowly to such a change.

The idealized cross sections with vertical walls that represent the constrictions in the model may not represent the actual shape of the constricted river. The river may choose a different shape as it is forced into width depth ratios more similar to meandering rivers. This is not represented in the model schematization, but is not expected to have serious effects on the model results in terms of general (averaged) bed level changes, because the cross section shape has a strong influence on the simulated sediment transport only during low flows.

The simulation results are presented in the figures 3.2 through 3.13 as summarized in Table 3.1.

Table 3.1: **Figure Numbers of Figures with Results of Simulations of Constrictions** (see Section 3.1 for details).

Width (m)	100 years Bed Level	Longitudinal Profile	1988 WL Initial	1988 WL after 100 years
6000	3.2	3.3	3.4	3.5
5000	3.6	3.7	3.8	3.9
4000	3.10	3.11	3.12	3.13

Starting from the initial conditions with low flow, with (nearly) uniform sediment transport conditions along the river, the river will not "feel" the constriction. As the discharge increases, and exceeds the value given in Figure 3.1, the river will have its original sediment transport capacity in the unconstricted sections and an increased transport capacity in the constricted cross sections due to higher flow velocities. Hence, the river will start to erode at the first constricted section (Jamuna 48.0 km). When the discharge decreases again, below the value given in Figure 3.1, the first constricted section will now have a smaller transport capacity than the supply from the upstream unconstricted sections due to the erosion taken place during the preceding high flow conditions, thus giving rise to deposition. This alternating pattern of erosion and deposition is the reason for the oscillating behavior of the bed level development seen in Figs. 3.2, 3.6 and 3.10 at Bahadurabad and Sirajganj.

The bed level variation at Jamuna 228.0 km, immediately upstream of the Jamuna - Ganges confluence is partly caused by the effect discussed above, but also by floods out of phase in Ganges and Jamuna. Generally Jamuna is flooding before Ganges. During high flow in Jamuna and low flow in Ganges the water level in the Padma is relatively low causing high velocities in the downstream reaches of the Jamuna, thus giving rise to erosion. At receding flood in the Jamuna and high flow in the Ganges the opposite takes place. In the Ganges the flow is still high causing backwater effect from the Padma in the Jamuna (low flow velocities), thus the lower reach of Jamuna will accrete.

Apart from the short term oscillations discussed above, Figure 3.2, 3.6 and 3.10 also reveals a clear trend for erosion. This trend is more pronounced the more the river is constricted. The initial mean annual sediment transport capacity in the constricted sections are larger than in the unconstricted, thus the river will erode. The constricted sections adjust to the smaller sediment supply (when compared with the increased capacity of the constricted section) by reducing the slope and increasing the water depth. This is apparent from Figure 3.3, 3.7 and 3.11 where longitudinal profiles of the bed levels are depicted. The reduction of slope causes a set down of the mean water level at Jamuna 48.0 km, which results in erosion propagating upstream in the unconstricted sections.

Equilibrium is achieved when there is no gradient in sediment transport along the river. This situation has not been reached after the 100 years simulations. This implies that the sediment transport in the downstream constricted reaches of the Jamuna is higher than in the existing condition, which causes overloading of the Padma and hence accretion in the Padma. This is illustrated in Figure 3.14, where the bed level changes in the Padma in case of a constriction of the width to 4000 m in the Jamuna is depicted. As a result the water level, and hence the bed level, increases temporarily (until an equilibrium situation is reached) in the downstream reach of the Jamuna. This trend is especially pronounced in the extreme constricted case, see Figure 3.10 and 3.13.

The initial response of the water level along the river is an increased flood water levels and nearly unchanged water levels for low flow conditions in the constricted sections and no change in the unconstricted sections as shown in Figure 3.4, 3.8 and 3.12. The long term response is quite different, see Figure 3.5, 3.9 and 3.13. In the constricted sections the low flow water level (and hence the ground water table) is significantly lower than in the existing conditions, whereas the flood water levels are nearly unchanged compared to the existing conditions. The reason for this is that the cross sections have been reduced in lateral direction but expanded, due to erosion, in vertical direction. In the unconstricted reach the water level follows the bed level, i.e. a general decrease of both low and high flow water levels. In the lower reach of the Jamuna high flow water levels are slightly higher due to the overloading of the Padma, as described above.

The averaged width of the Jamuna in the existing conditions is of the order of magnitude 13 km. A constriction of the width to 6 km, i.e. less than 50 % of the existing width only causes minor changes of the bed and water levels in the river, thus it must be concluded that the averaged bed level is relatively insensitive to changes of the width. Disregarding any possible changes of cross sectional shape the averaged bed level and water level response to a constriction of the width to 6000 m seem minor.

The simulation results also demonstrate that the time scale for changes of the averaged bed level is relatively large in the Jamuna.

3.3 Jamuna Left Embankment

Construction of an embankment along the left bank of the Jamuna has been suggested as a flood protection measure for the North Central Region (including Dhaka) and for development of agriculture in the North Central Region. Several variations of the Jamuna Left Embankment have been proposed, the most drastic involves the closure of all left bank distributaries of the Jamuna. The impact of this scheme on the conditions in the Jamuna river has been investigated with the 1-D morphological model.

The schematization of this scenario is quite straightforward, viz. all water and sediment outflows from the left bank has been removed from the model. During medium floods the combined peak outflows from the distributaries amount to about 20 percent of the flow in the Jamuna, whereas during high floods (1988 flood) it is as much as 38 percent (1988 flood).

The simulation results are presented in Figures 3.15 through 3.18 as summarized in Table 3.2.

Table 3.2: **Figures with Results of Simulations of the Jamuna Left Embankment** (see Section 3.1 for details).

Scheme	100 years Bed Level	Longitudinal Profile	1988 WL Initial	1988 WL after 100 years
JLE	3.15	3.16	3.17	3.18

In the model, the closure of the offtakes results in an approximately proportional increase of discharge and sediment transport in the lower reaches of the Jamuna. Due to the non-linear dependency of the sediment transport capacity on the flow velocity the sediment transport capacity will increase more than the sediment supply has increased. This trend becomes more pronounced in the vicinity of the Jamuna-Ganges confluence, because the Padma can easily accommodate the increased discharge without increasing its water level significantly, due to the very large conveyance in the Padma cross sections. As a consequence the Jamuna will erode in its downstream reach, as shown in Figure 3.15 and 3.16.

The increased discharge in the Jamuna will immediately after implementation of the Jamuna Left Embankment give rise to increased flood levels, as shown in Figure 3.17. As the bed level in the down stream reaches adjust to the closure of the tributaries the flood levels tend to reduce, see Figure 3.18. The water level at Jamuna 228.0 is relatively insensitive to the closure of the offtakes, because it is controlled by back water effects from the Padma, which does not react on the changes.

3.4 Jamuna Multi-purpose Bridge

The implementation of the Jamuna Multi-purpose Bridge involves an approximately triangular constriction of the width over a length of 17 km. Two options have been proposed, viz. a wide and a narrow option. The narrow option, with constriction of the width to 3500 m, will have the largest morphological impact, and is investigated with the 1-D morphological model. In addition to the narrowing of the river, it involves the closure of one of the minor distributaries from the Jamuna.

The constriction of the width has been schematized in a similar way as in the general constriction simulations described in Section 3.2. The closure of the offtake has been schematized by excluding the extraction of water and sediment from the model setup.

The simulation results are presented in the Figures 3.19 through 3.24 as summarized in Table 3.3.

Table 3.3: **Figures with Results for the Jamuna Multi-Purpose Bridge Simulations** (see Section 3.1 for details. The additional plots illustrate the conditions in the vicinity of the Bridge Axis.).

Scheme	100 years Bed Level	Longitudinal Profile	1988 WL Initial	1988 WL after 100 years	Additional Plots
JMB	3.19	3.20	3.21	3.22	3.23 3.24

The effect of the Jamuna Bridge on the bed levels of the Jamuna River is only noticeable in the vicinity of the constriction at the bridge. The small erosion seen in Figure 3.19 is caused by the closure of the offtake, and is similar to the effect discussed for the Jamuna Left Embankment in Section 3.3. At the Bridge axis constriction scour has developed as shown in Figure 3.20. During low flow the scour hole will tend to fill up, whereas it is re-eroding during high flow. This is clearly shown in Figure 3.23, where the simulated bed level variation during the 1988 flood at the Bridge Axis is depicted. Such a seasonal variation of constriction scour is well documented with data from Harding Bridge on the Ganges. The bed level at the Jamuna Bridge Axis reaches a minimum level of -1.28 m, which is 2.58 m below the existing (mean) bed level.

The erosion in the constriction during high flow causes overloading of the downstream reaches, which materialize in deposition. This is also illustrated in Figure 3.23 (Jamuna 185.40 km).

The impact of the Jamuna Bridge on water levels are minor, as shown in Figure 3.21, 3.22 and 3.24.

3.5 Increased Sediment Input

Changes in land use or in the vegetation, either due to human interference or climatic changes, in the Jamuna catchment may cause changes to the sediment load in the river. The river response to such a change has been investigated with the 1-D model, by (arbitrarily) increasing the sediment load at the upstream boundary of Jamuna-Ext. by 50 percent. The results of the simulations are presented as summarized in Table 3.4.

Table 3.4: **Figures with Results for the Increased Sediment Load Simulations** (see Section 3.1 for details).

Scenario	100 years Bed Level	Longitudinal Profile	1988 WL Initial	1988 WL after 100 years
Increased ST	3.25	3.26	no change	3.27

The river respond to the increased sediment input by increasing its slope. The effect of the increased sediment input reaches the Jamuna 0.0 after approximately 10 years. It does not appear as a steep sedimentation wave, as it would have done if a dominant discharge approach had been applied, as in the JMB 1-D morphological simulations (RPT/NEDECO/BCL, 1989). The reason for this is that the discharge variation tends to smooth the front of the sedimentation wave.

In the 100 years simulation the increase of bed level at Jamuna 0 km is close to 2 m (which is not yet the equilibrium level). This increase of bed level is also reflected in the water levels, see Figure 3.27. If the river is not forced to keep its present alignment and width, the river response would probably be quite different. The risk of a major river alignment shifts would be higher, due to the increased flood levels, and in addition the river would probably attempt to adjust its width to accommodate the increased sediment transport.

3.6 Sea Level Rise

The sea level may rise in the Bay of Bengal due to the Green House Effect during the next 50 - 100 years. The effect of a sea level rise has been modelled with the 1-D morphological model. In the model it has been schematized by raising the water level at the downstream boundary at the Padma-Meghna confluence. The sea level rise would cause backwater effects and hence sedimentation in all the rivers in the entire delta area. In a 1-D schematization this sedimentation will migrate upstream until in the end the entire modelling area has risen by an amount equal to the sea level rise. A sea level rise in the Bay of Bengal will therefore first give rise to significant changes at the Padma-Meghna confluence after some time. This delayed effect is not considered in the 1-D model simulations.

The simulation results are presented in the Figures 3.28 through 3.31 as summarized in Table 3.5.

Table 3.5: Figures with Simulation Results for Sea Level Rise
(see Section 3.1 for details).

Scenario	100 years Bed Level	Longitudinal Profile	1988 WL Initial	1988 WL after 100 years
Sea Level Rise	3.28	3.29	3.30	3.31

Jamuna is responding to the increased downstream water level by raising the bed level, starting in the lower reach. After 100 years of simulation the bed level has risen by about 0.22 m at Jamuna 228.0, which is slightly less than 50 % of the equilibrium value. The rise of bed levels are reflected directly in the simulated water levels. The time scale for the changes is quite large in the model. In reality, the time scale will be even larger, because the entire delta area will accrete provided the alignments of the rivers are not fixed.

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4. CONCLUSIONS

The one dimensional morphological model used in this study comprises the Jamuna, Ganges and Padma Rivers. The schematization of the three rivers in the model is based on representative nearly prismatic cross sections derived from an analysis of a large number of surveyed cross sections. Model simulations shows that it describes adequately the existing sediment transport and hydrodynamic conditions in the Jamuna.

The conclusions of the applications of the 1-D morphological model can be summarized as follows:

- The time scale for river response is relatively large

- The bed and water levels in the Jamuna is relatively insensitive to moderate constrictions of the width

- Very severe constrictions of the width (say to less than 5000 m width) will give significant increase of flood levels immediately after implementation. On the long term, when the river has adjusted to the constriction of the river bed will be significantly lower than in the existing conditions giving rise to a significant lowering of the low flow water levels.

- Construction of the Jamuna Left Embankment will give rise to erosion of the bed in the lower reach of Jamuna, but the effect on the water levels is modest.

- Jamuna Multi-purpose Bridge will only have local effects in the vicinity of the bridge on bed and water levels. Constriction scour will develop rapidly reducing the backwater effect from the Bridge. The depth of constriction scour will generally increase during rising stage and decrease during falling stage.

- An increased sediment input to the river will give rise to an increased slope, which especially in the upper reaches will cause a significant increase of bed and water levels.

- A rise of sea level in the Bay of Bengal will cause sedimentation in the river, which will migrate very slowly in upstream direction. A general rise of water level in the Padma - Meghna confluence of 0.5 m result in the model in 0.22 m accretion in the lower Jamuna after 100 years.

5. REFERENCES

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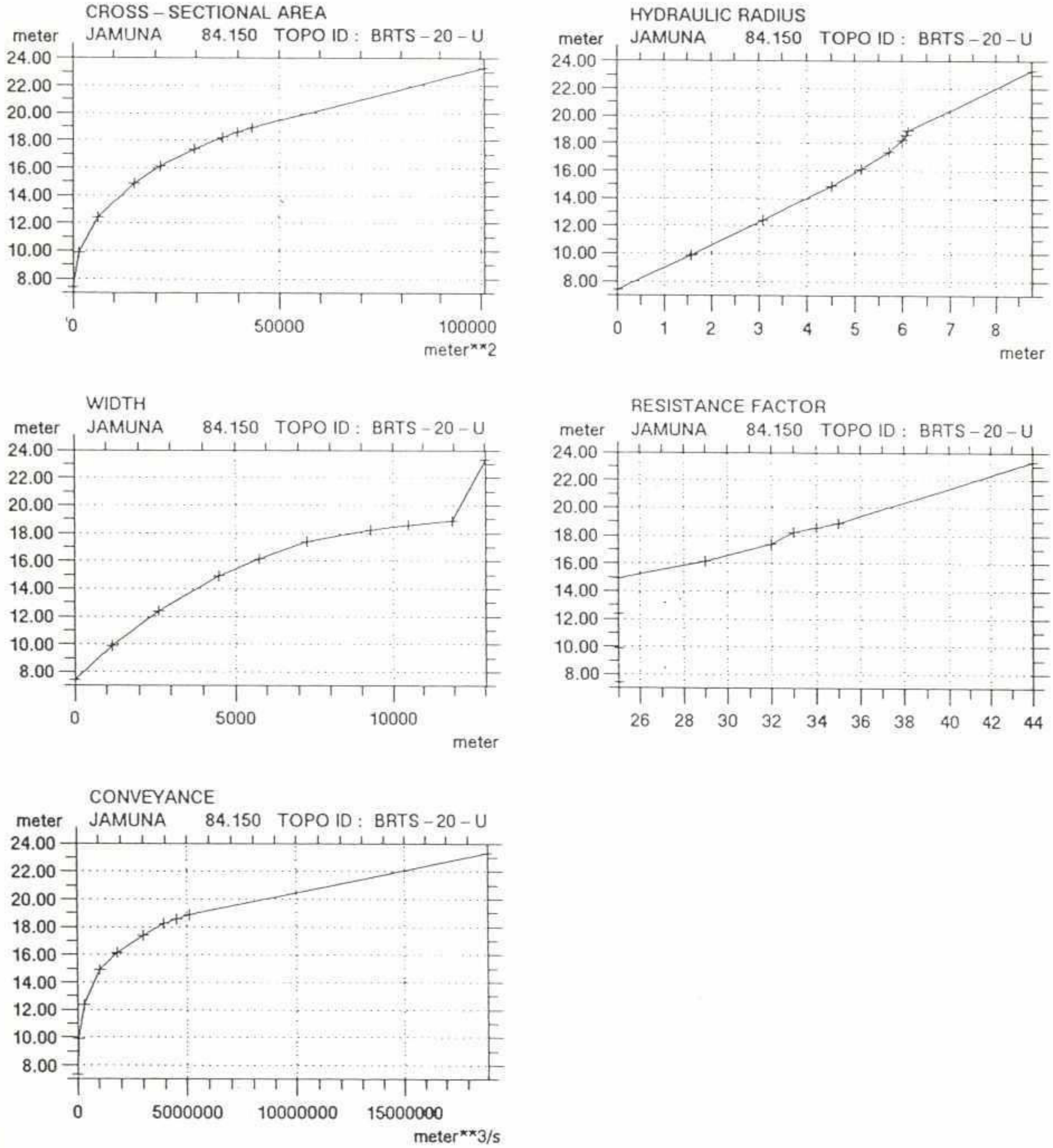
FIGURES



BRTS: 1-D MORPHOLOGICAL MODELLING

HYDRAULIC PARAMETERS OF THE SCHEMATIZED JAMUNA CROSS-SECTION

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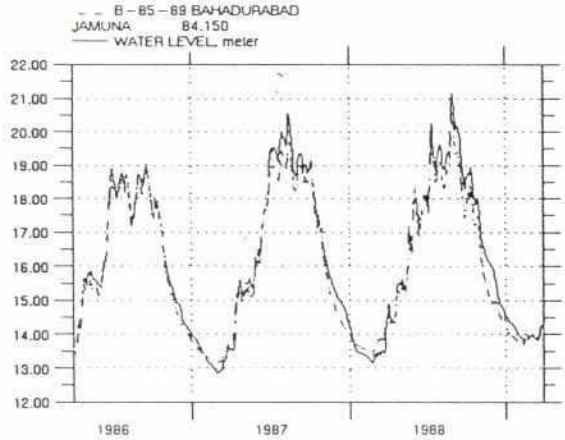
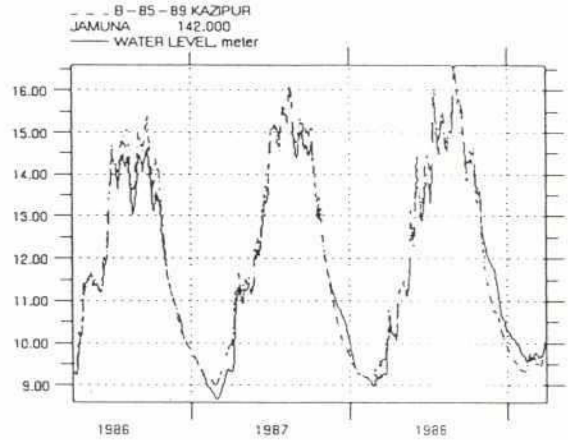
Figure 2.1



B-85-89 BAHADURABAD
JAMUNA 84.150
WATER LEVEL, meter
22.00
21.00
20.00
19.00
18.00
17.00
16.00
15.00
14.00
13.00
12.00
1986
1987
1988



B-85-89 KAZIPUR
JAMUNA 142.000
WATER LEVEL, meter
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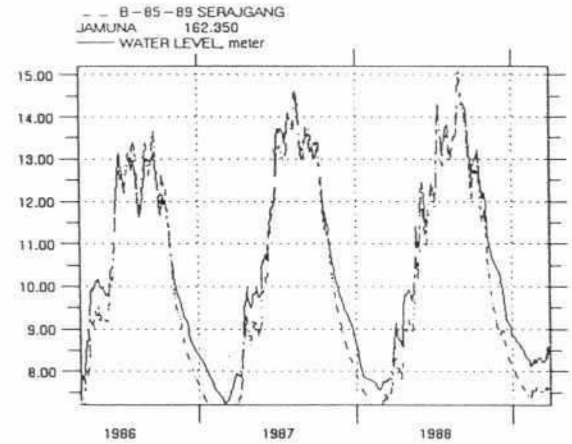
15.00
14.00
13.00
12.00
11.00
10.00
9.00
1986
1987
1988



B-85-89 SERAJGANG
JAMUNA 162.350
WATER LEVEL, meter
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13.00
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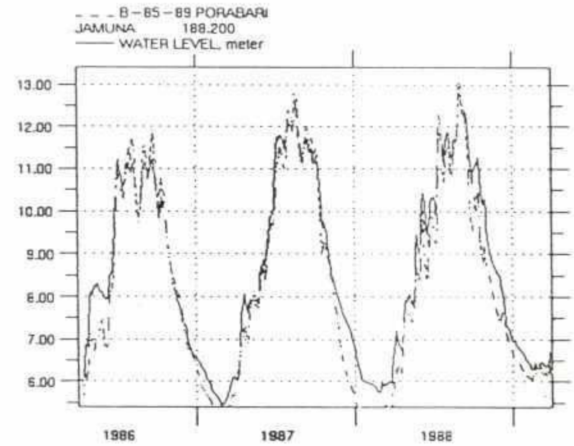
9.00
8.00
1986
1987
1988



B-85-89 PORABARI
JAMUNA 188.200
WATER LEVEL, meter
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11.00
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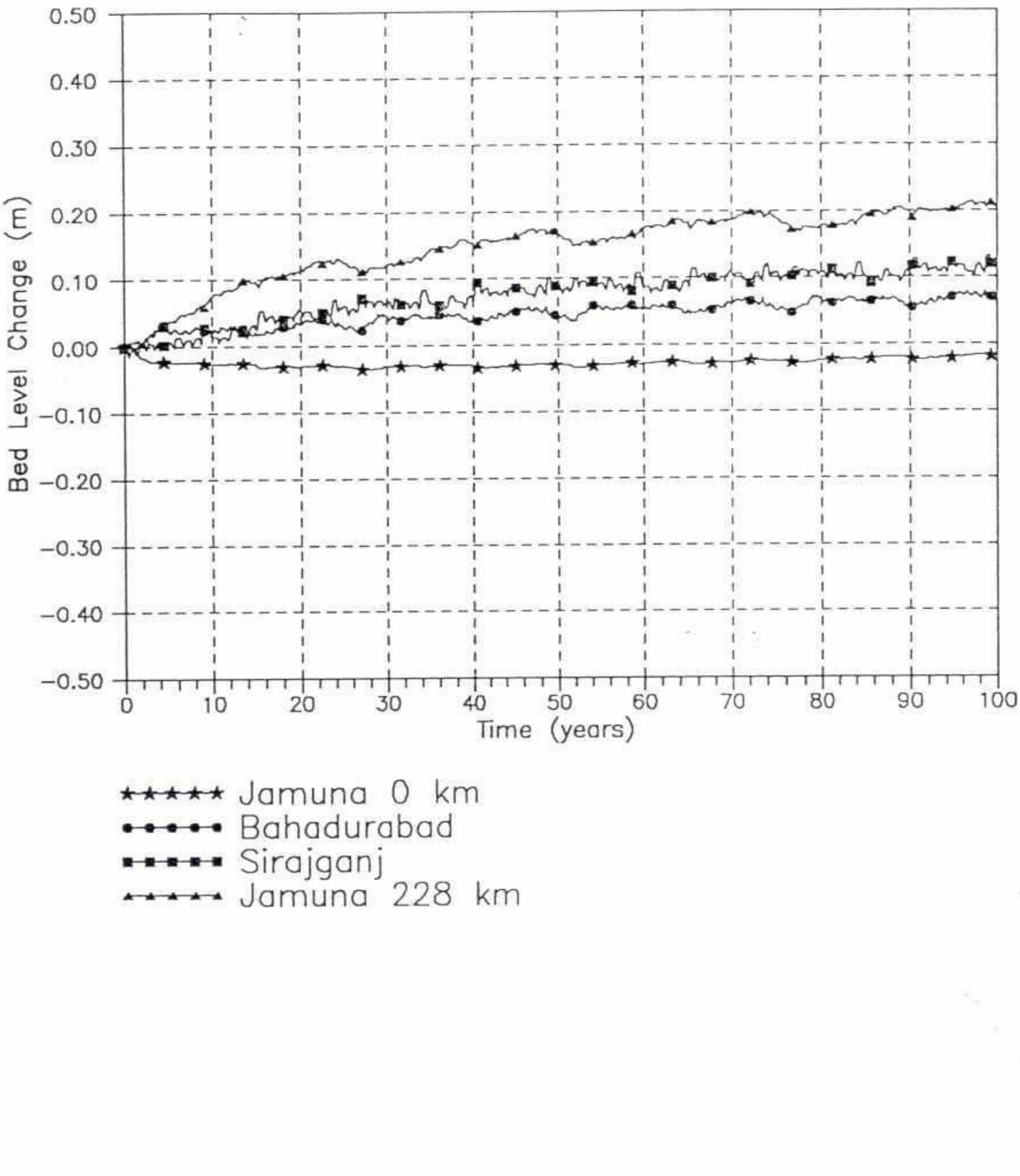
9.00
8.00
7.00
6.00
1986
1987
1988

Figure 2.2



BRTS: 1-D MORPHOLOGICAL MODELLING

BASELINE SIMULATION:
BED LEVEL CHANGE

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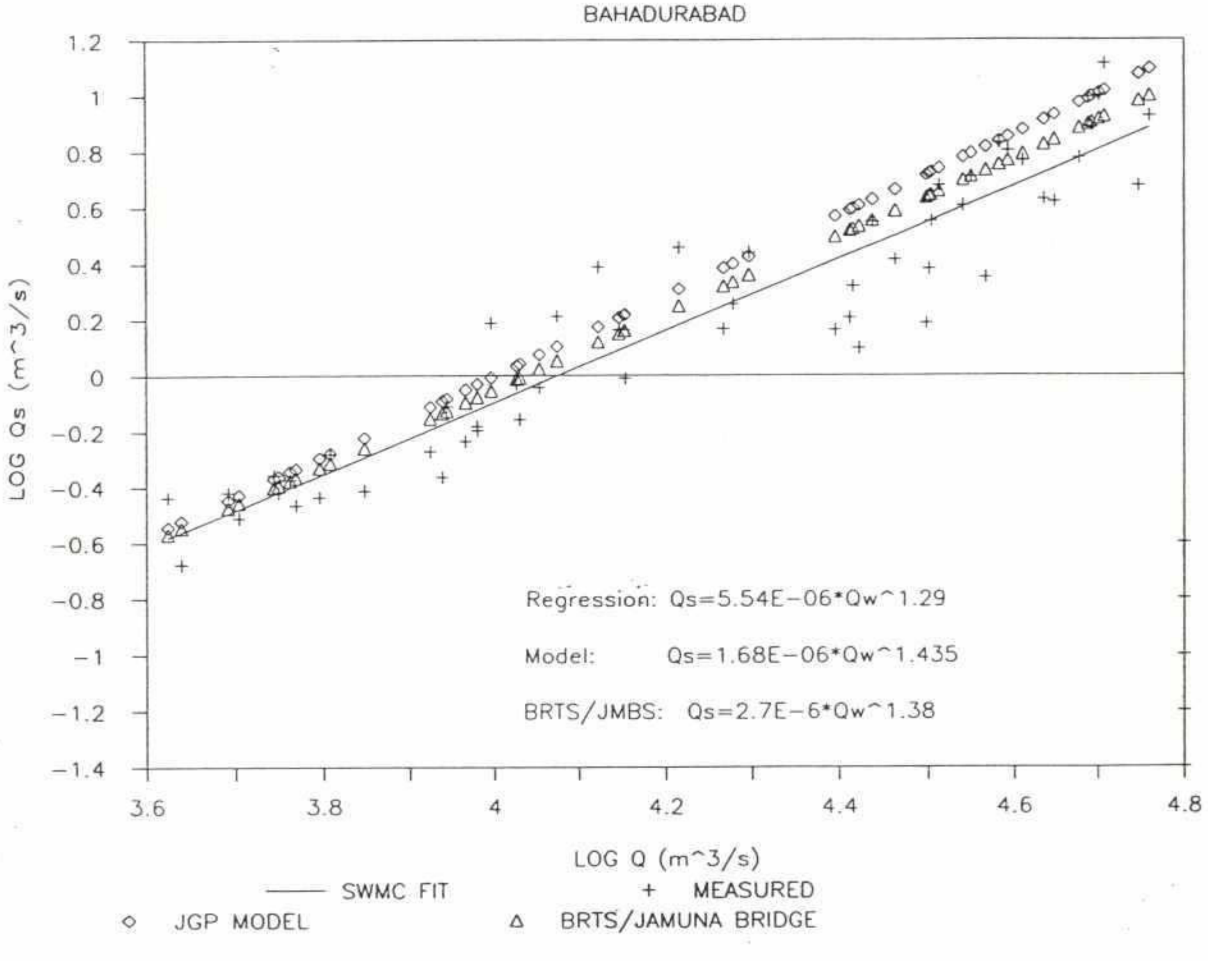
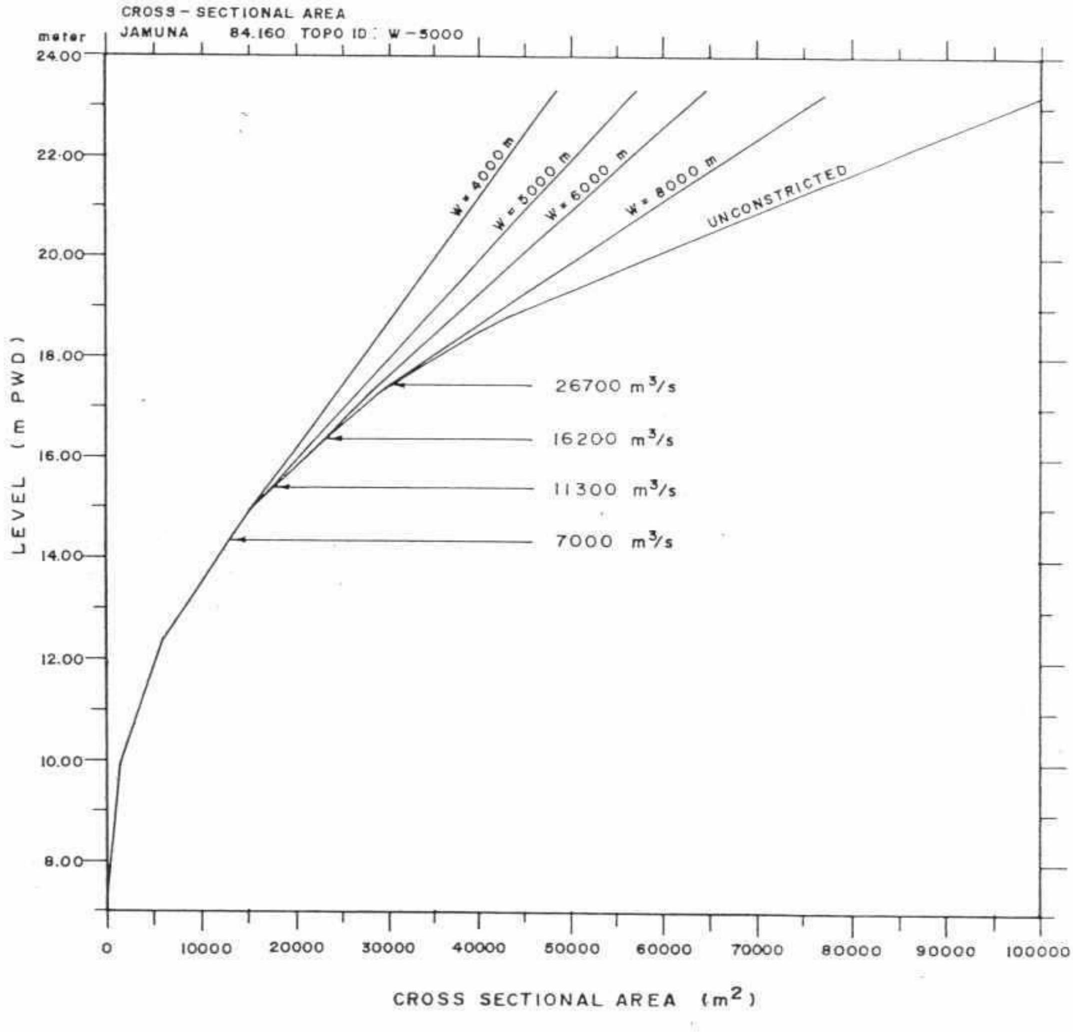
Figure 2.3



BRTS: 1-D MORPHOLOGICAL MODELLING

COMPARISON OF BAHADURABAD SEDIMENT RATING CURVES	Vol.3	Part 8
	Figure 2.4	

28D



BRTS: 1-D MORPHOLOGICAL MODELLING

CONSTRICTED CROSS SECTIONS AREA VS. ELEVATION

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Figure 3.1

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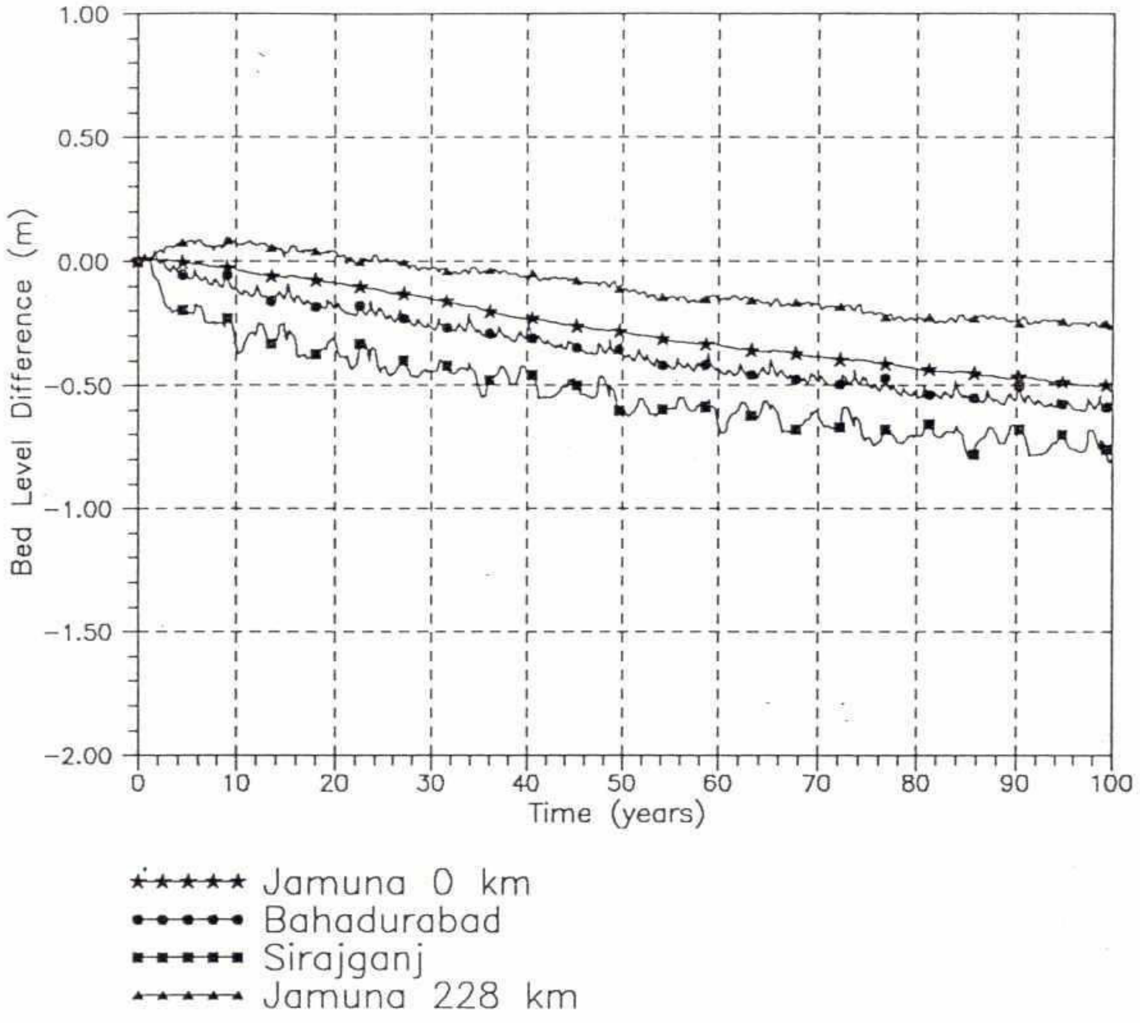
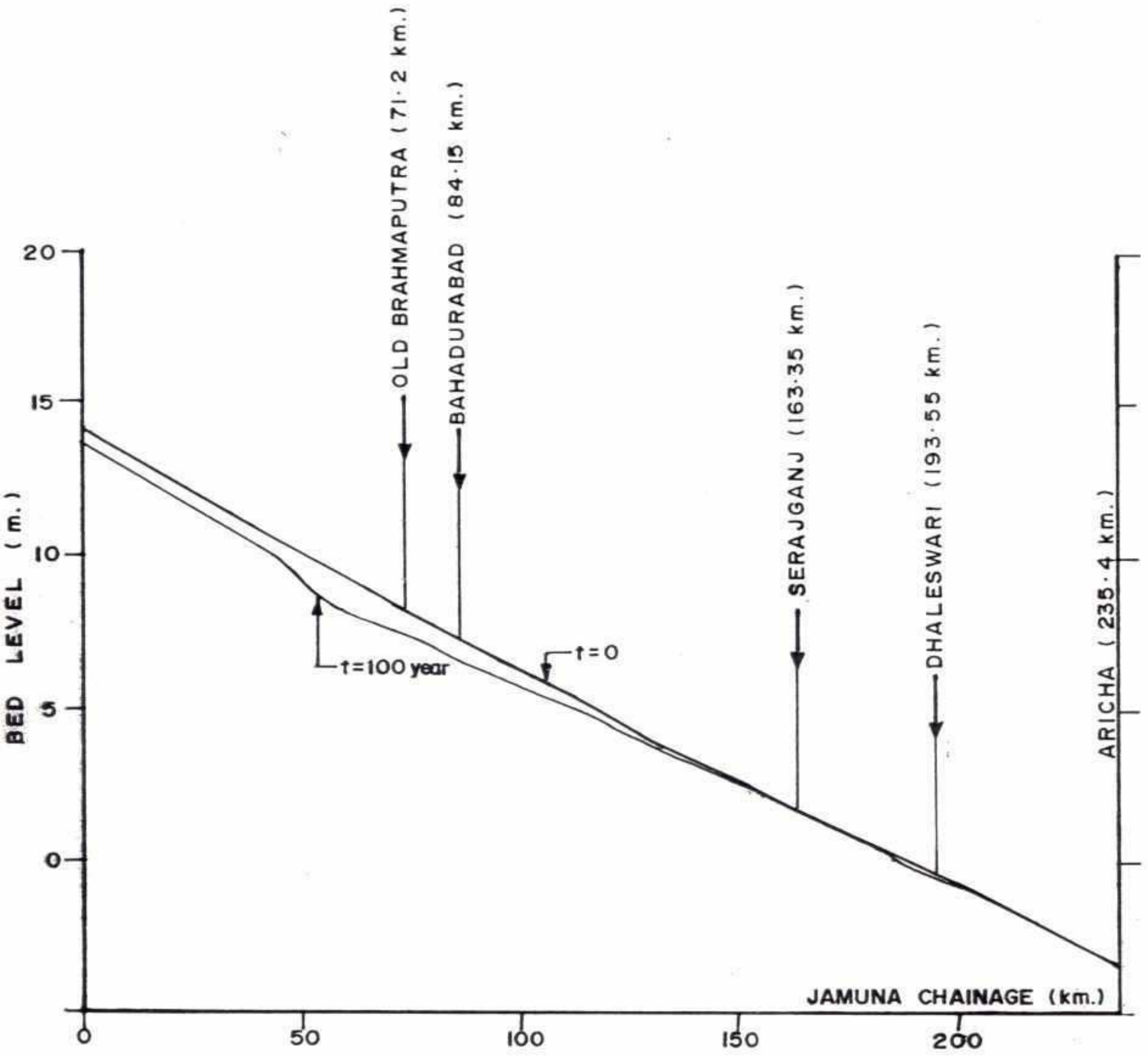


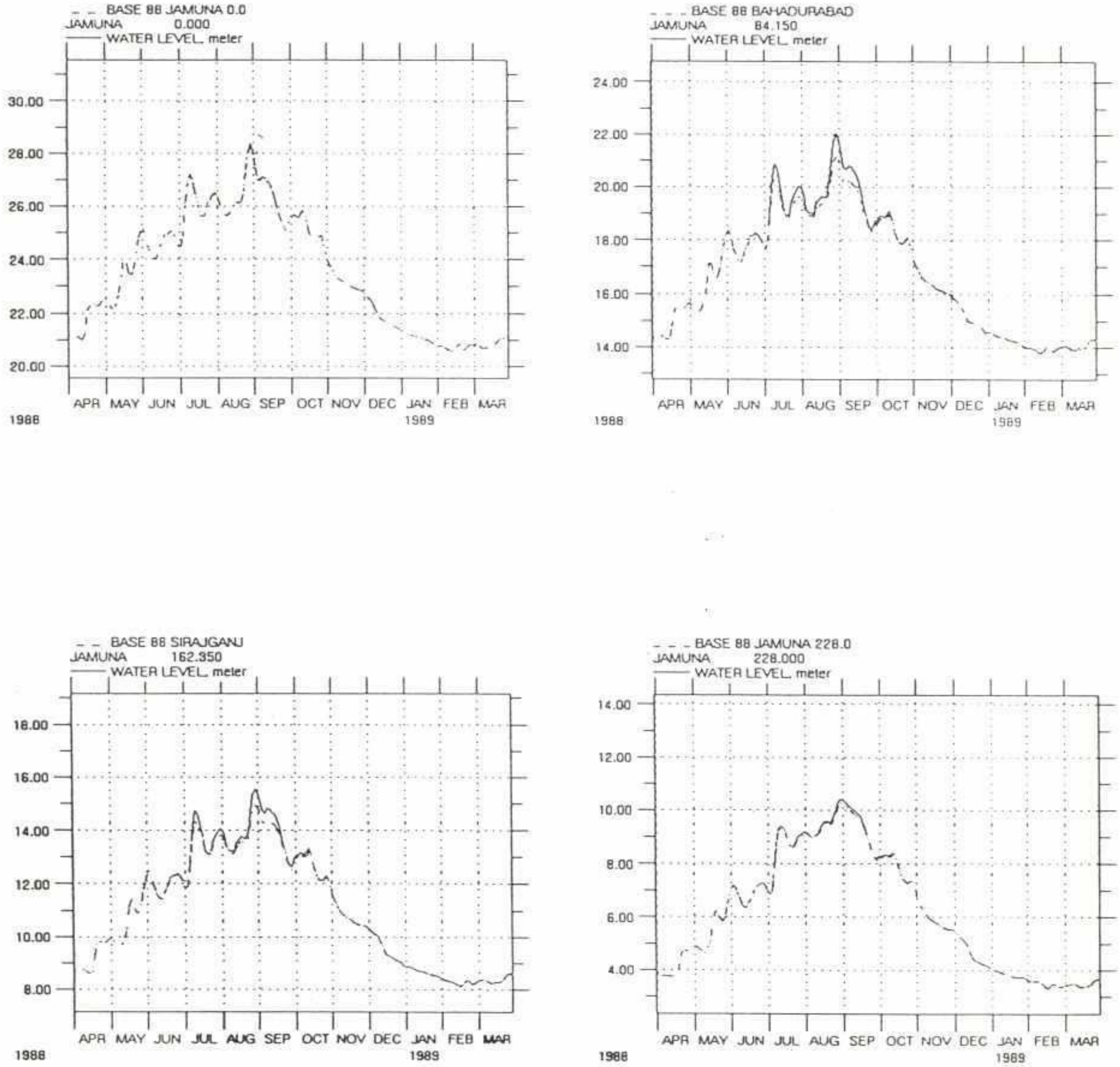
BRTS: 1-D MORPHOLOGICAL MODELLING

BED LEVEL CHANGE: **WIDTH CONSTRICTED TO 6 km**	Vol.3 Part 8 **Figure 3.2**



BRTS: 1-D MORPHOLOGICAL MODELLING

LONGITUDINAL BED PROFILES WIDTH CONSTRICTED TO 6 km	Vol.3 Part 8 Figure 3.3



BRTS: 1-D MORPHOLOGICAL MODELLING

IMMEDIATE RESPONSE TO 1988 FLOOD WIDTH CONSTRICTED TO 6 km

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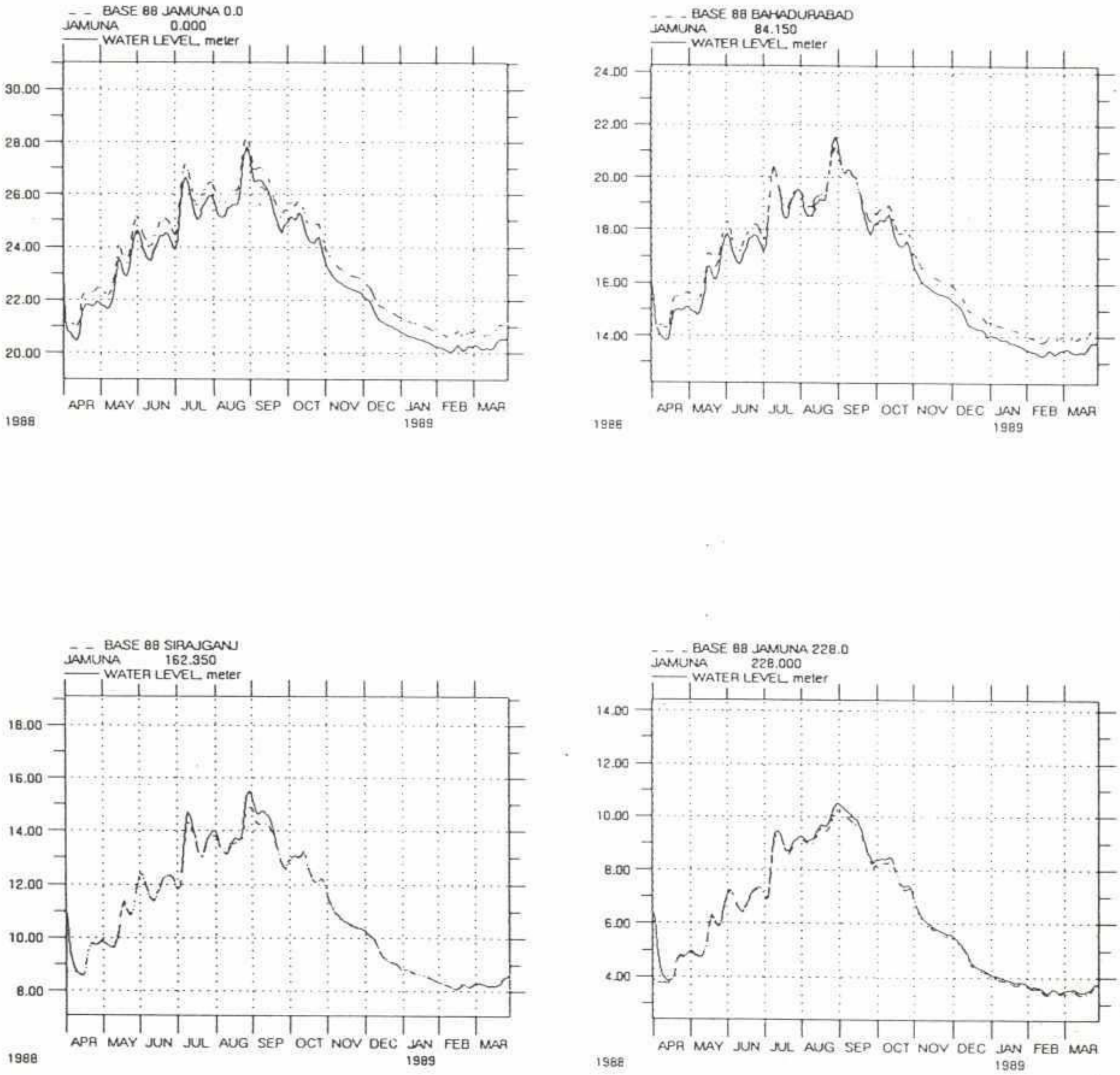
Figure 3.4



BRTS: 1-D MORPHOLOGICAL MODELLING

RESPONSE TO 1988 FLOOD AFTER 100 YEARS
WIDTH CONSTRICTED TO 6 km

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Figure 3.5

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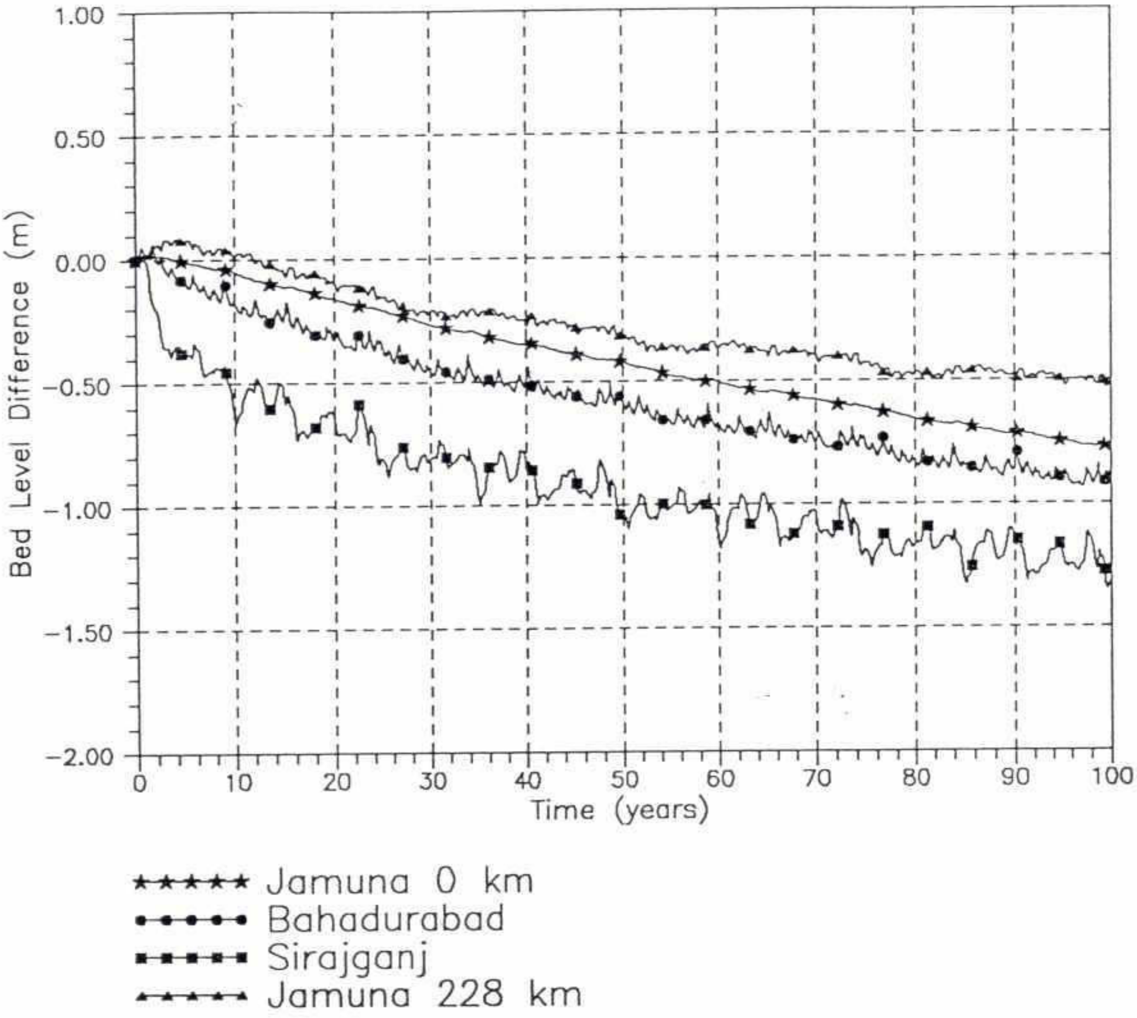

BRTS: 1-D MORPHOLOGICAL MODELLING

BED LEVEL CHANGE: WIDTH CONSTRICTED TO 5 km	Vol.3 Part 8
	Figure 3.6

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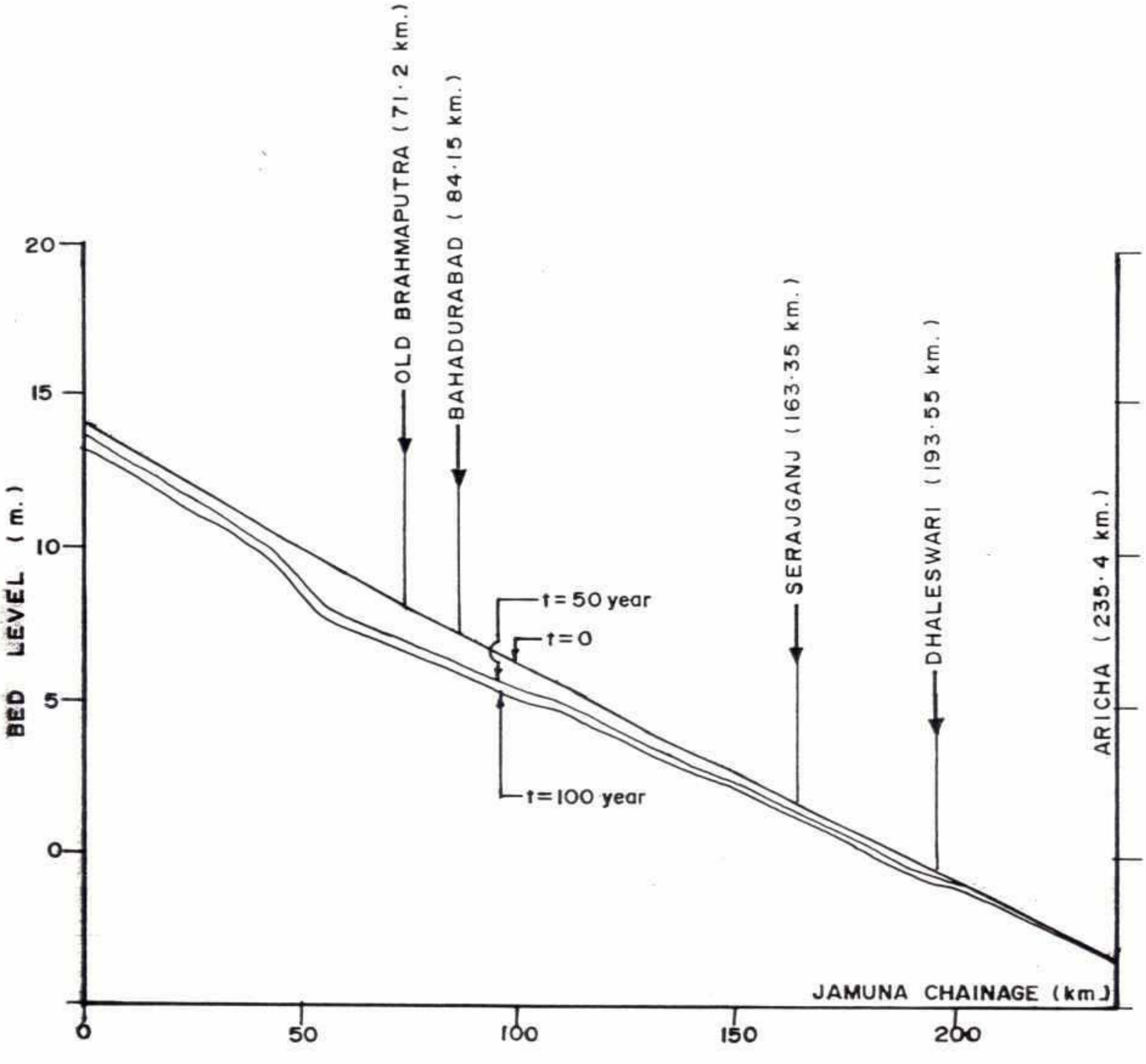
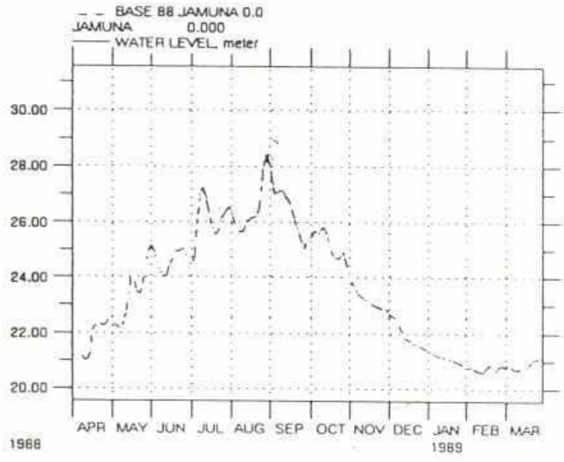
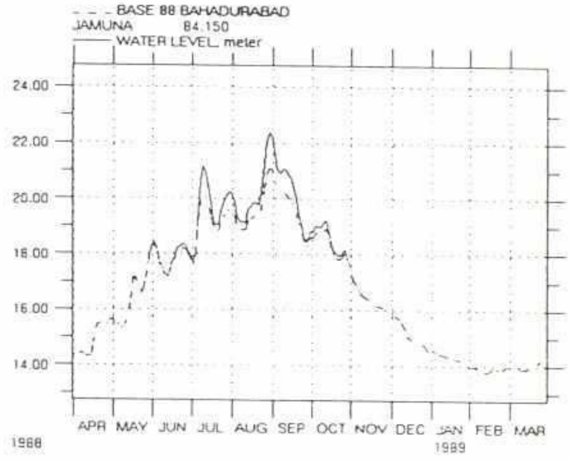
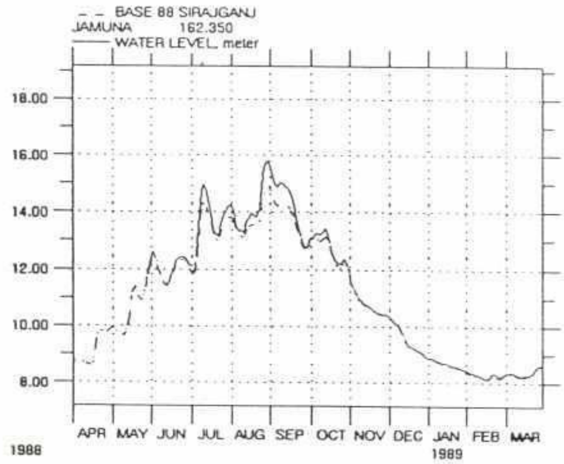


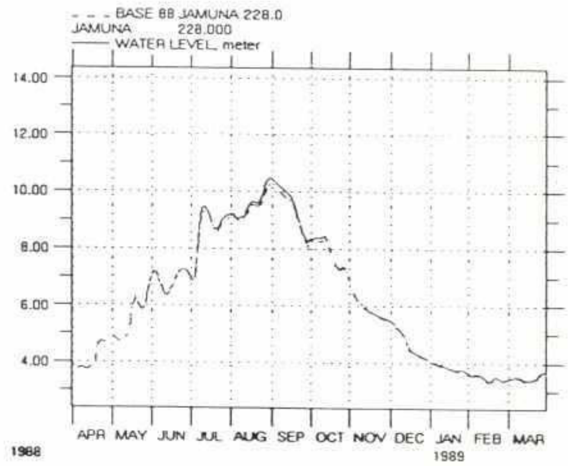
BRTS: 1-D MORPHOLOGICAL MODELLING

LONGITUDINAL BED PROFILES WIDTH CONSTRICTED TO 5 km	Vol.3 Part 8
	Figure 3.7









BRTS: 1-D MORPHOLOGICAL MODELLING

IMMEDIATE RESPONSE TO 1988 FLOOD
WIDTH CONSTRICTED TO 5 km

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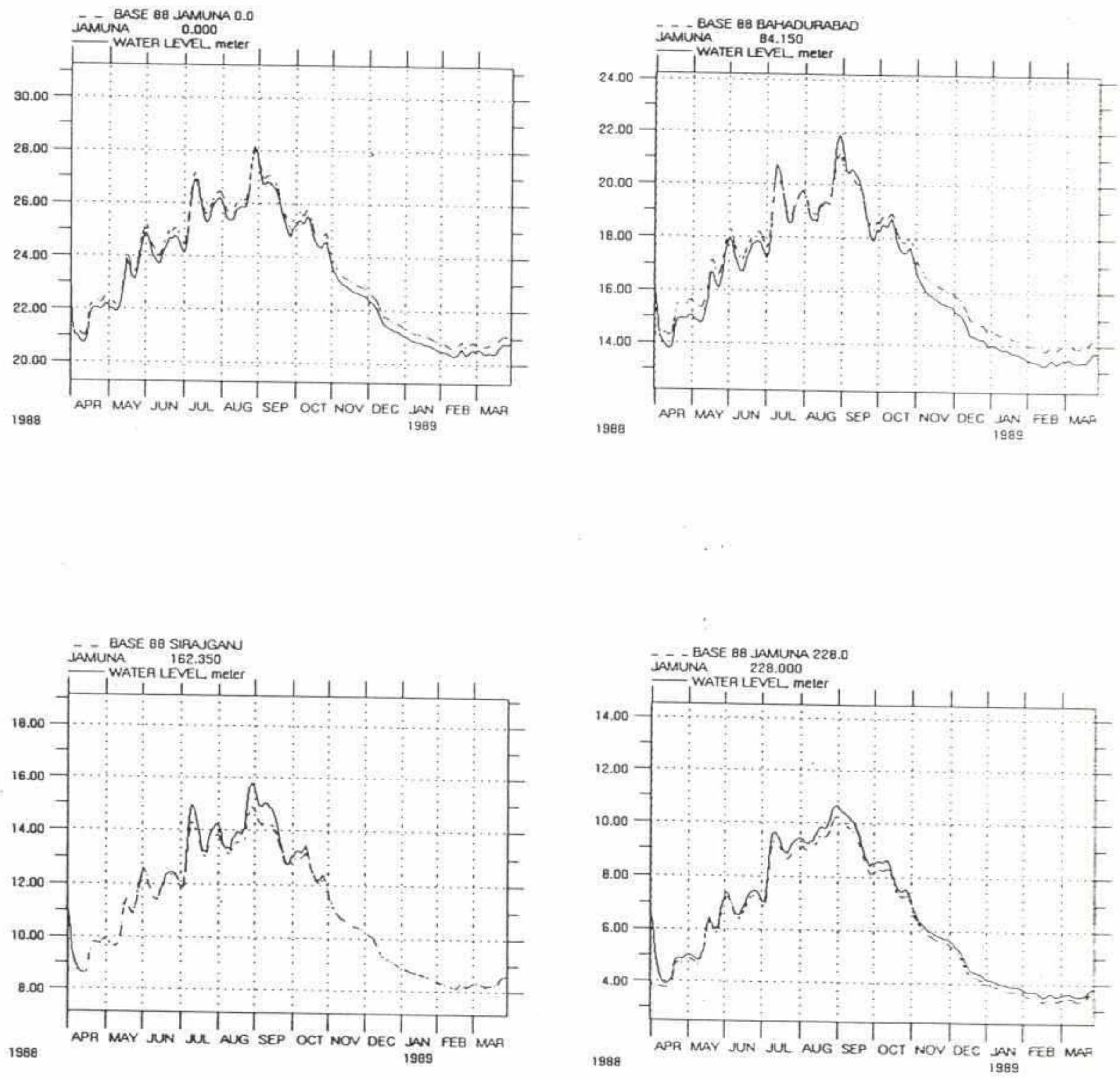
Figure 3.8



BRTS: 1-D MORPHOLOGICAL MODELLING

RESPONSE TO 1988 FLOOD AFTER 100 YEARS WIDTH CONSTRICTED TO 5 km	Vol.3 Part 8
	Figure 3.9

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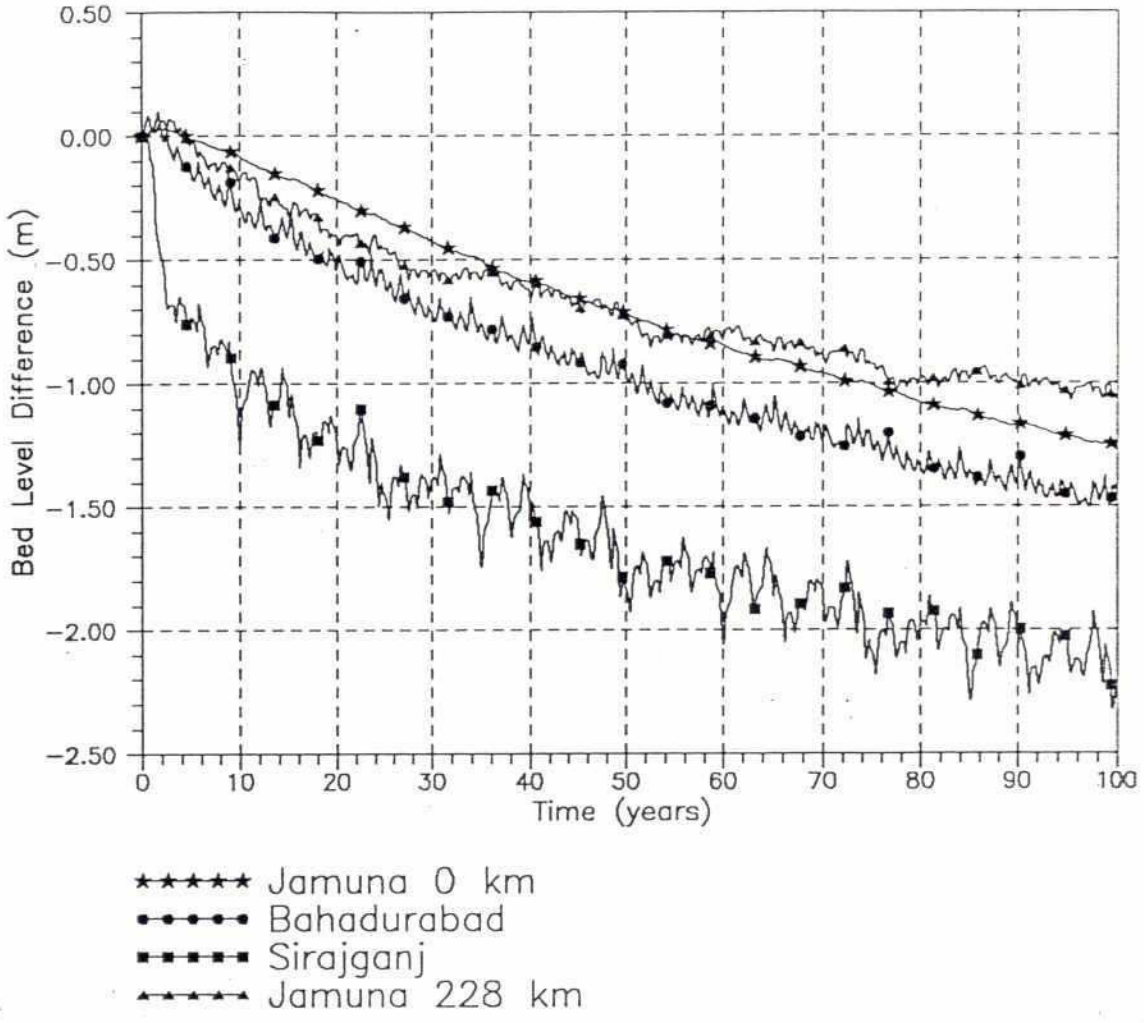

BRTS: 1-D MORPHOLOGICAL MODELLING

BED LEVEL CHANGE:
WIDTH CONSTRICTED TO 4 km

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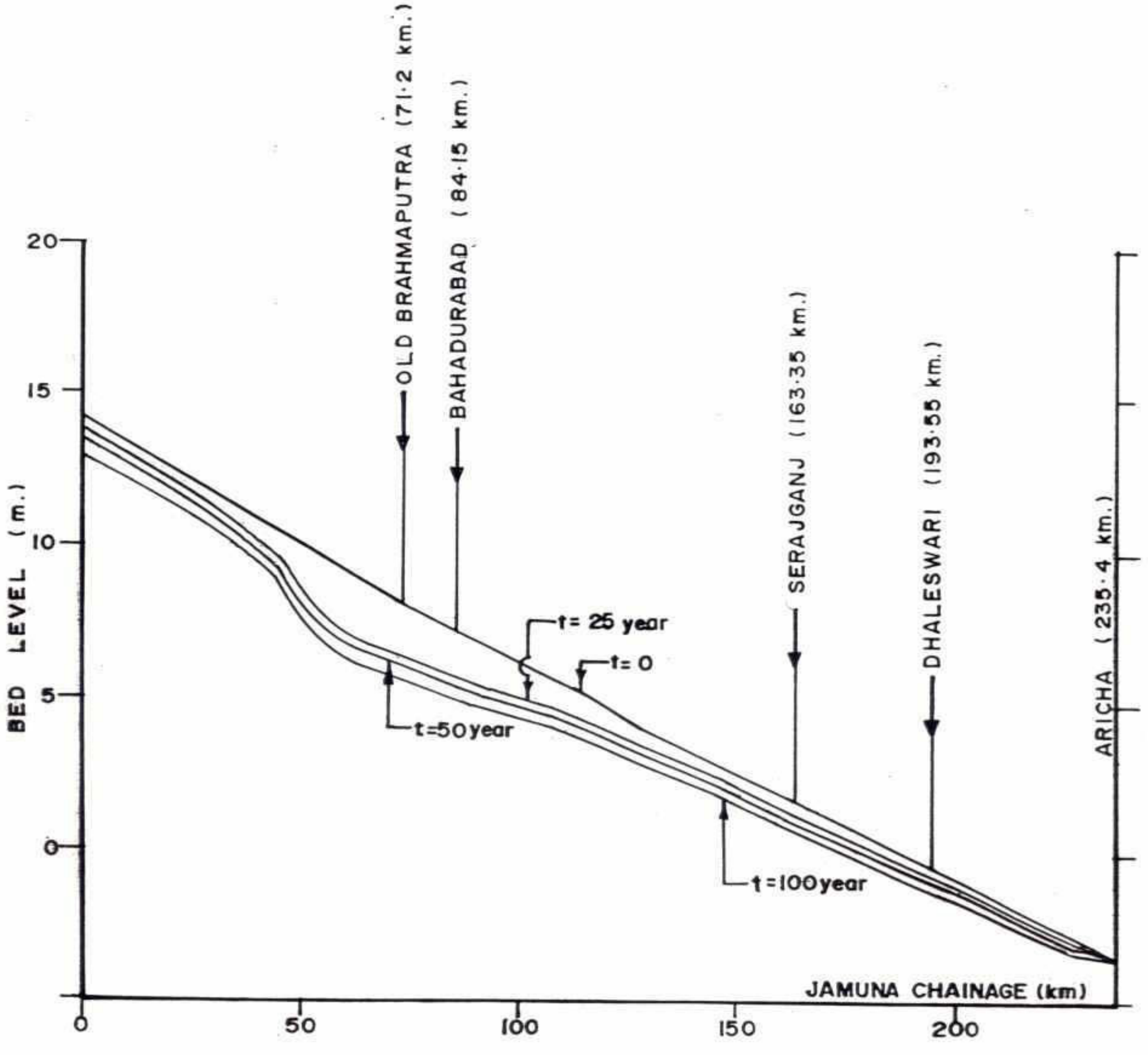
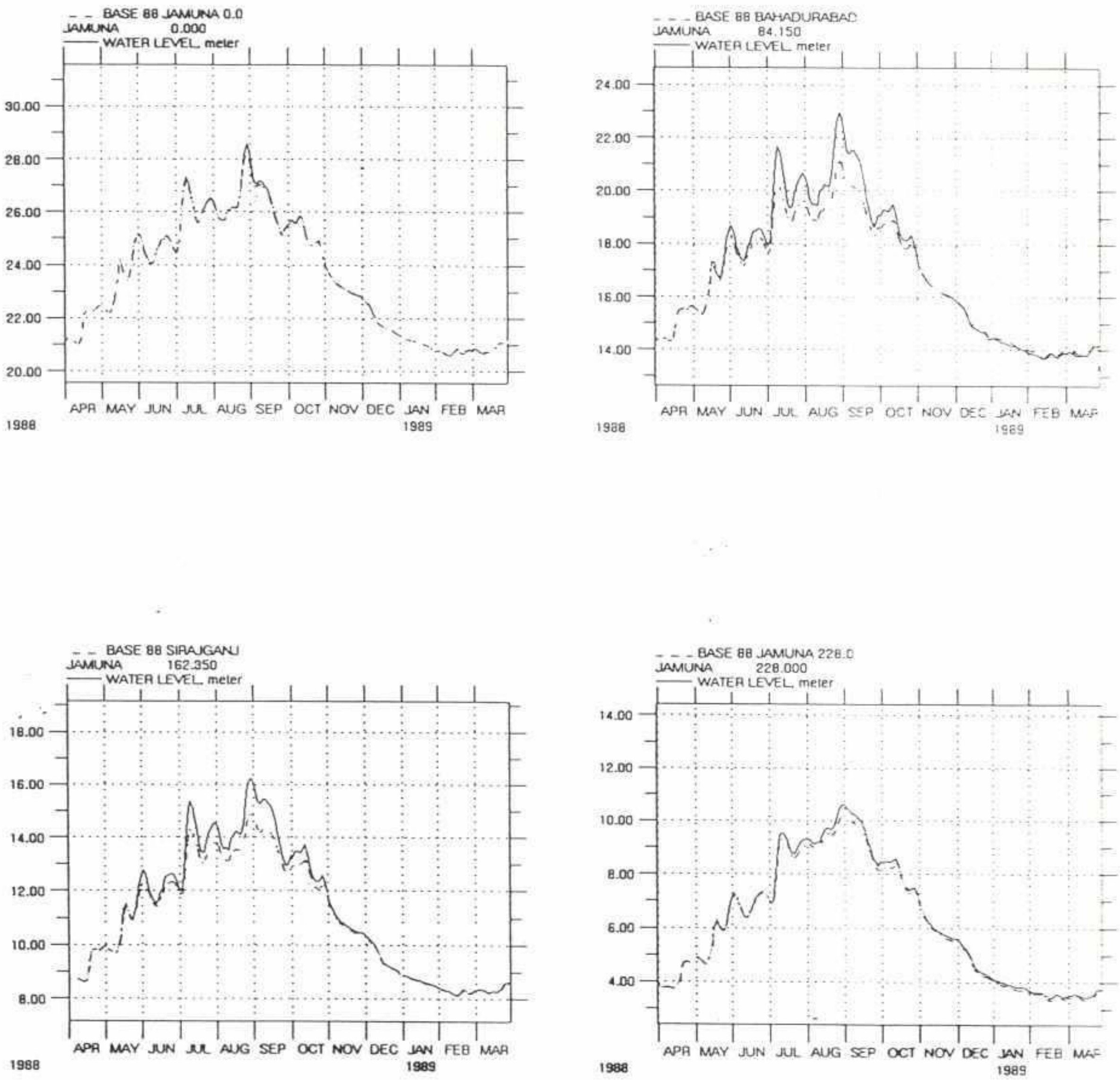
Figure 3.10	

2070



BRTS: 1-D MORPHOLOGICAL MODELLING

LONGITUDINAL BED PROFILES WIDTH CONSTRICTED TO 4 km	Vol.3	Part 8
	Figure 3.11	



BRTS: 1-D MORPHOLOGICAL MODELLING

IMMEDIATE RESPONSE TO 1988 FLOOD
WIDTH CONSTRICTED TO 4 km

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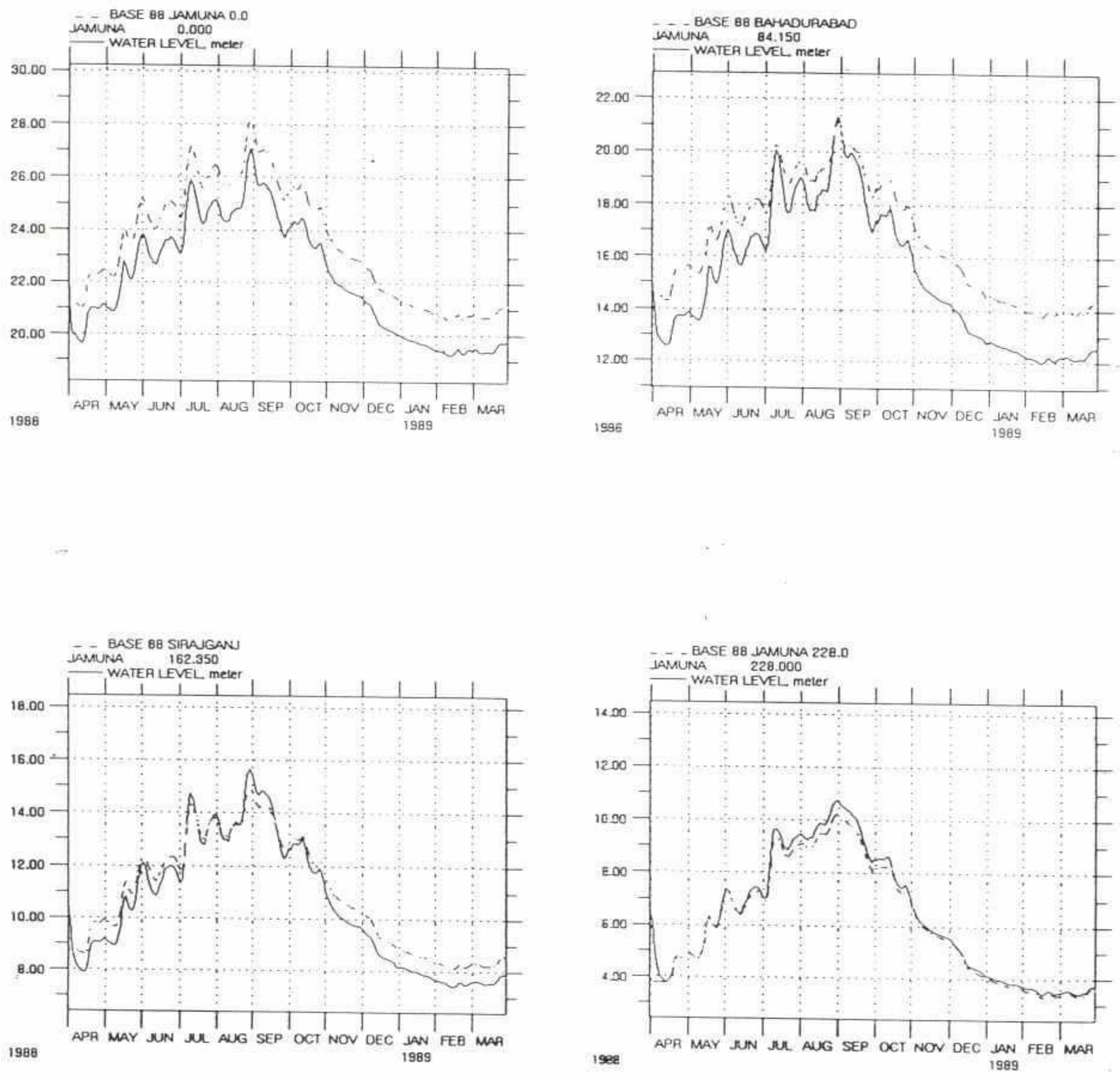
Figure 3.12



BRTS: 1-D MORPHOLOGICAL MODELLING

RESPONSE TO 1988 FLOOD AFTER 100 YEARS WIDTH CONSTRICTED TO 4 km

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Figure 3.13

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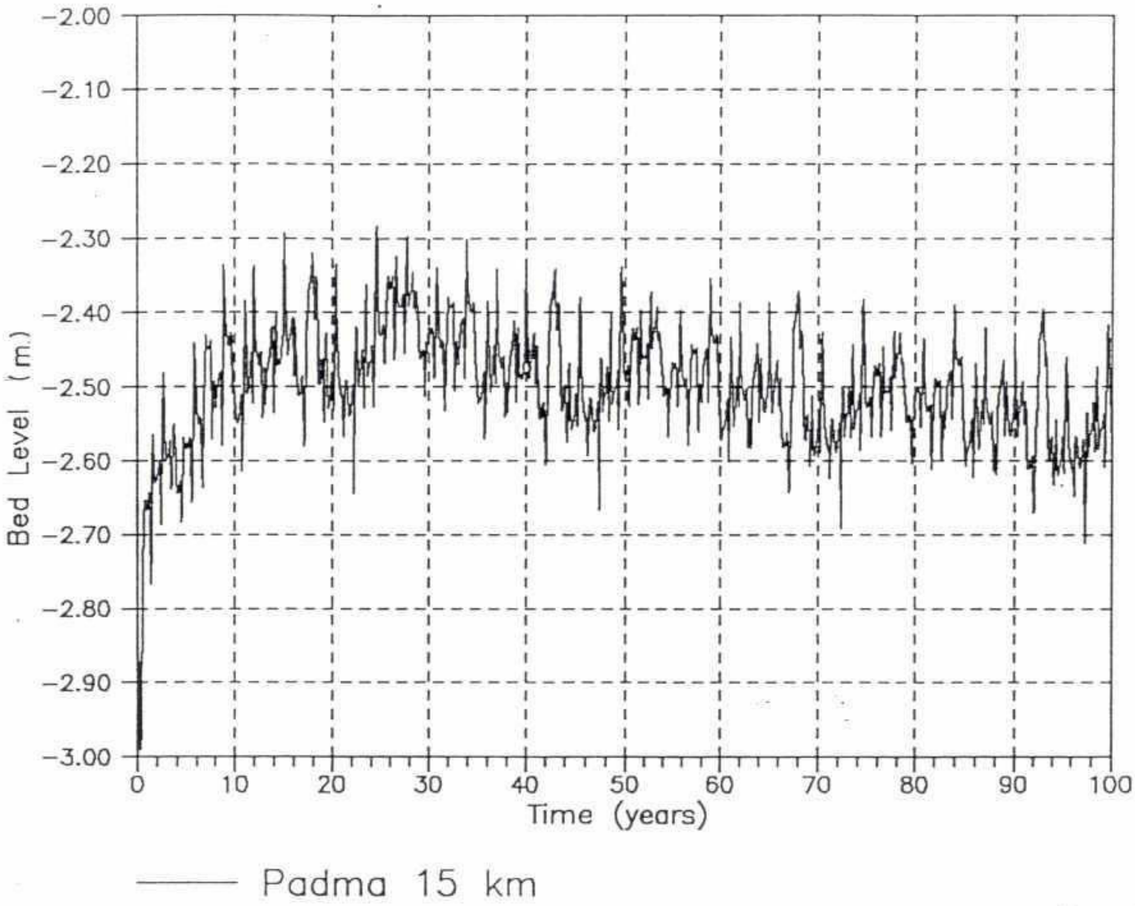
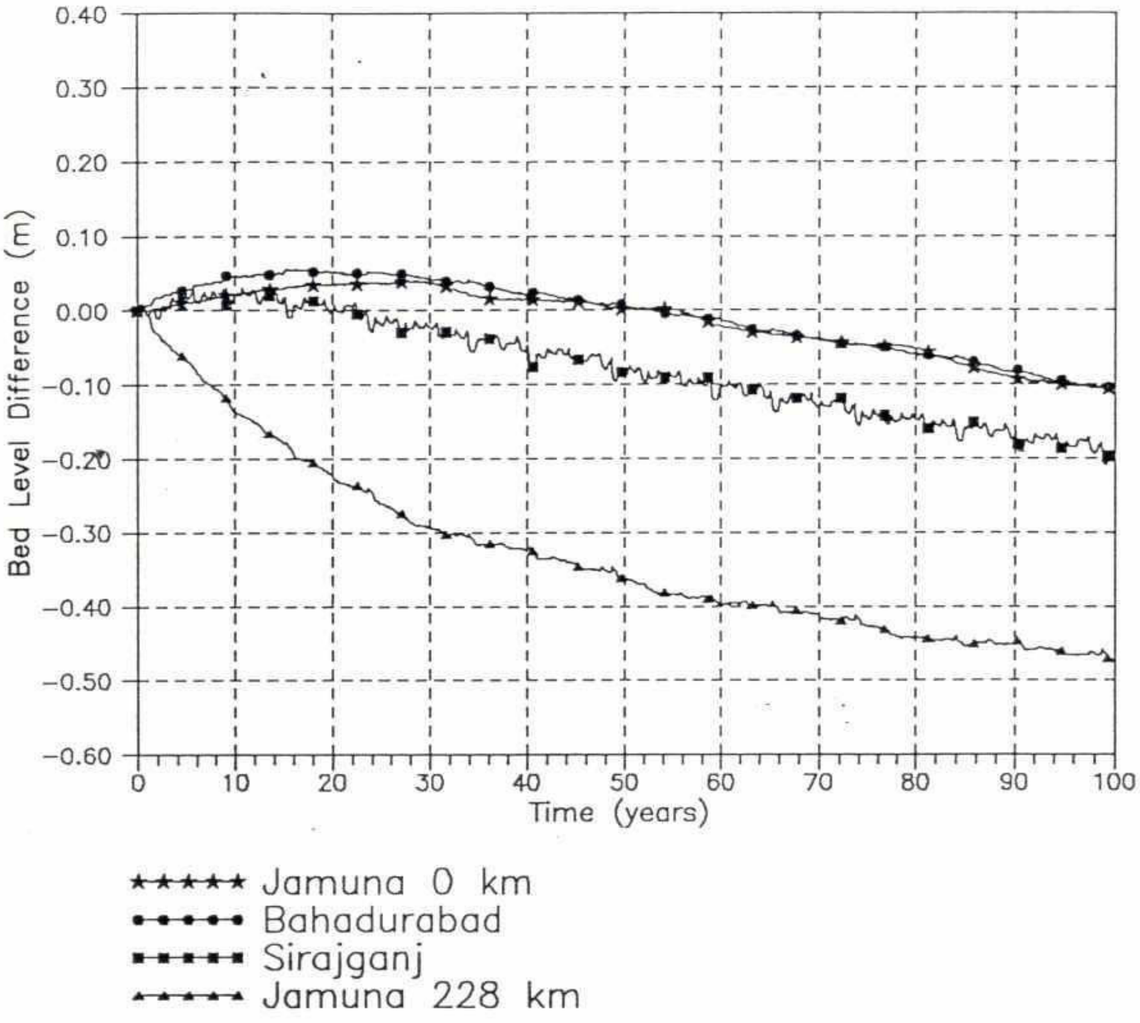


BRTS: 1-D MORPHOLOGICAL MODELLING

BED LEVEL CHANGE NEAR BARURIA **JAMUNA CONSTRICTED TO 4 km**	Vol.3 Part 8 **Figure 3.14**



BRTS: 1-D MORPHOLOGICAL MODELLING

BED LEVEL CHANGE:
JAMUNA LEFT EMBANKMENT

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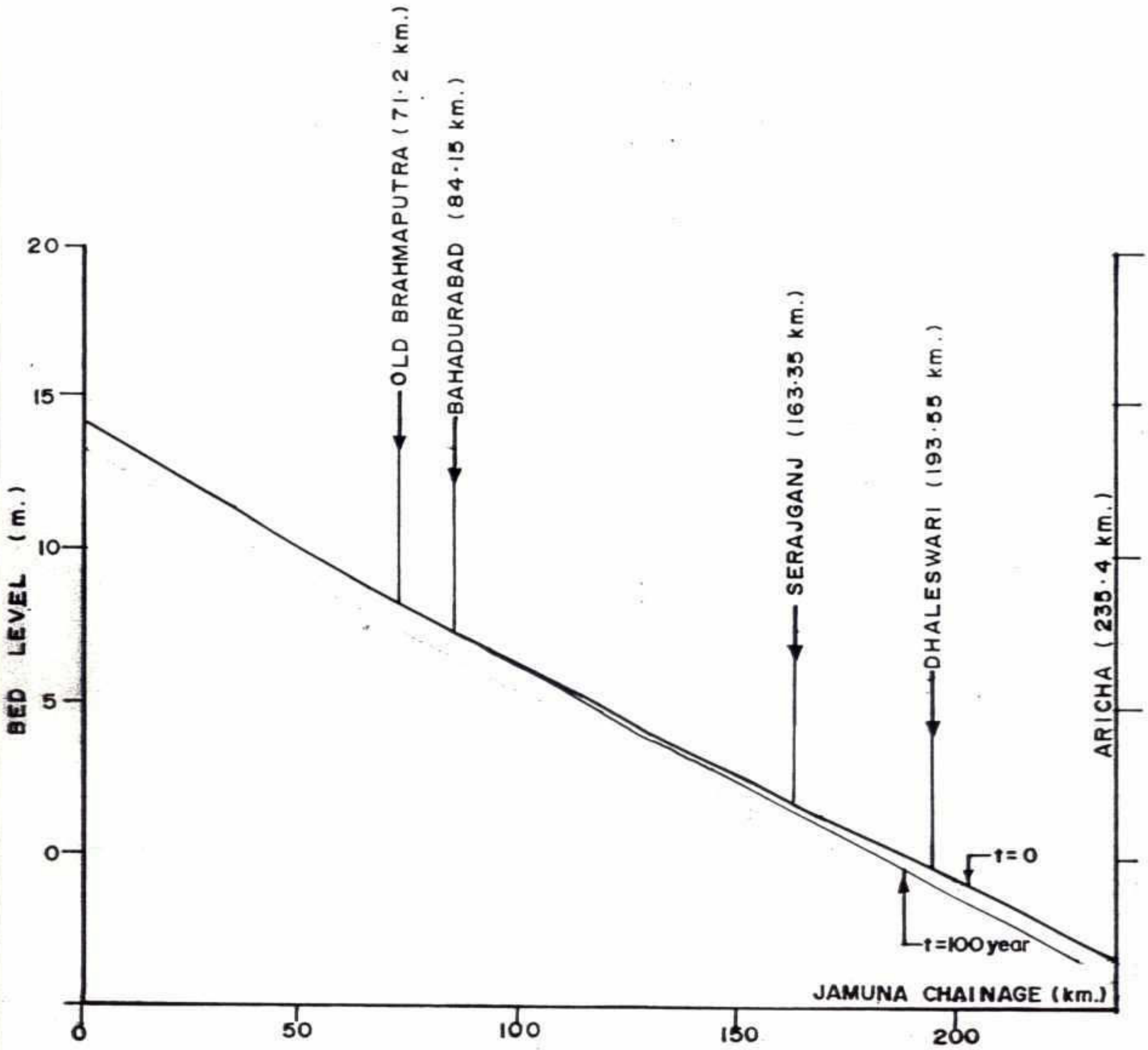
Figure 3.15



BRTS: 1-D MORPHOLOGICAL MODELLING

LONGITUDINAL BED PROFILES
JAMUNA LEFT EMBANKMENT

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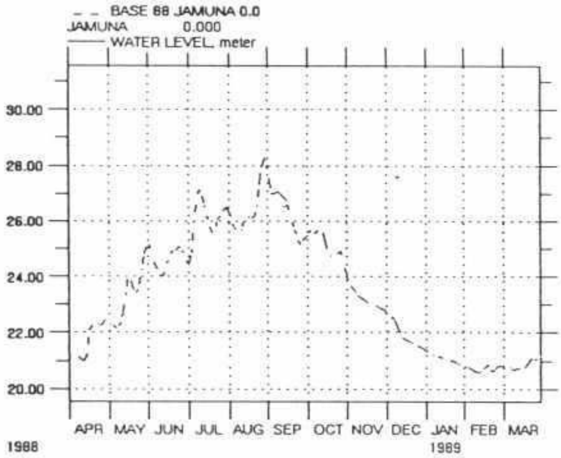
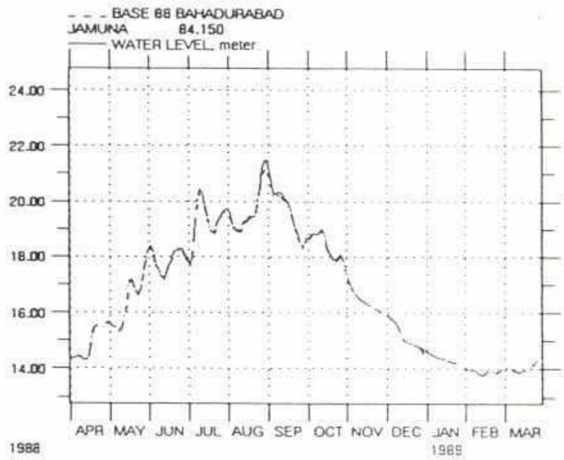
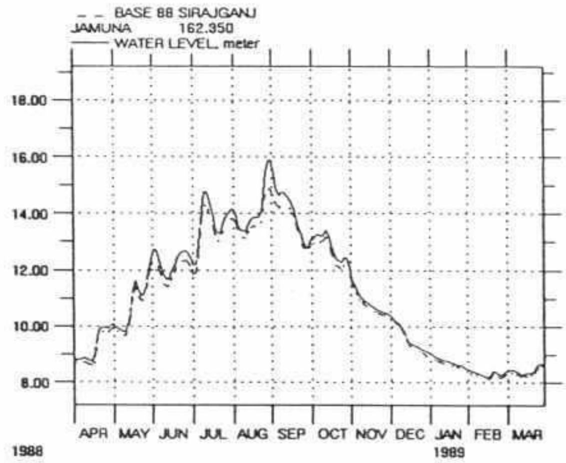
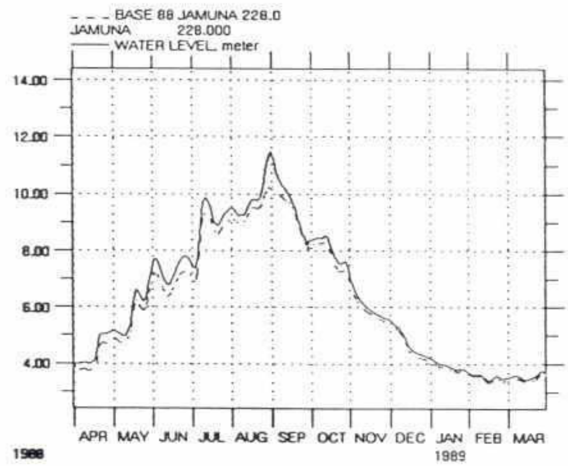
Figure 3.16









BRTS: 1-D MORPHOLOGICAL MODELLING

IMMEDIATE RESPONSE TO 1988 FLOOD
JAMUNA LEFT EMBANKMENT

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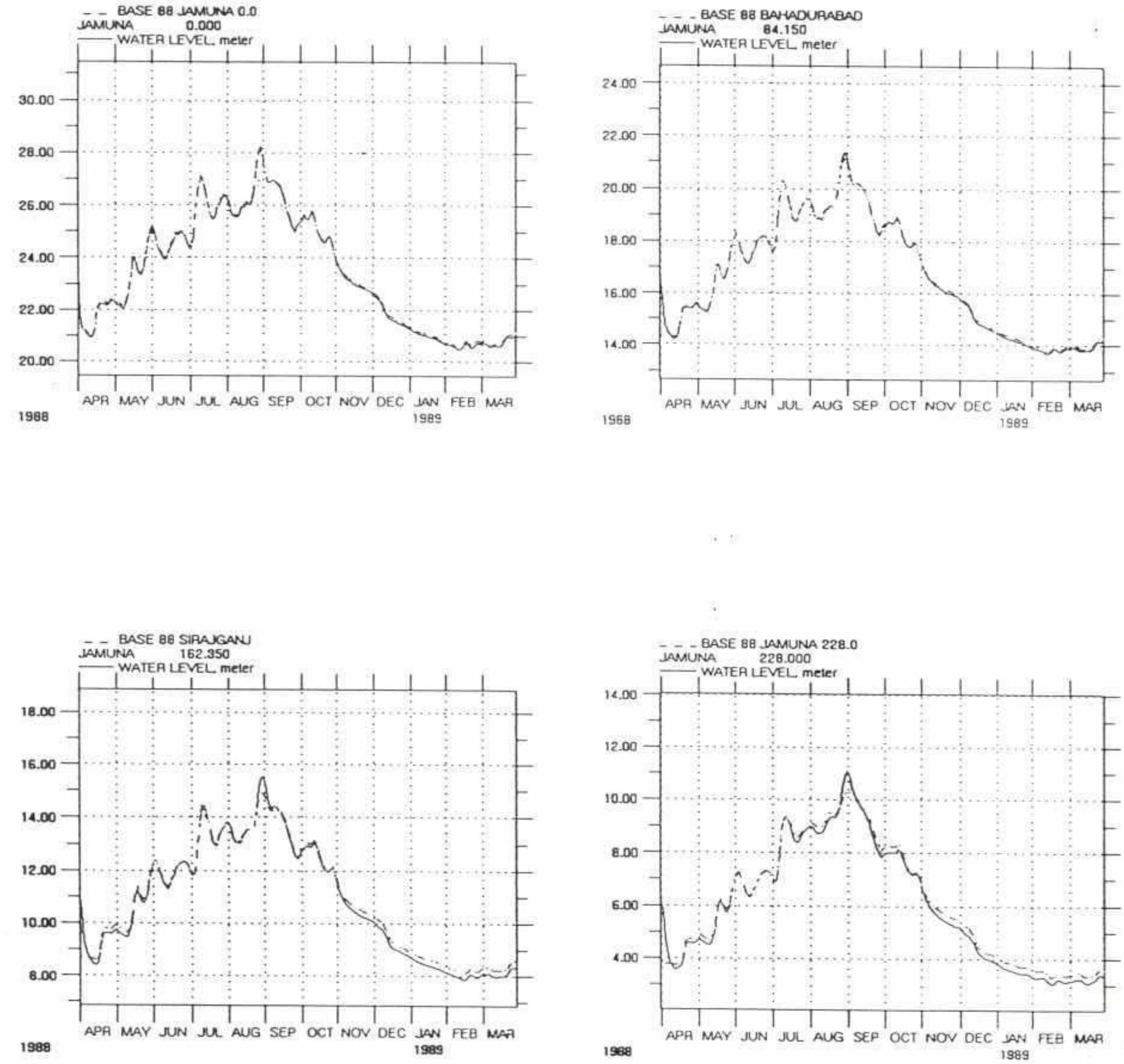
Figure 3.17



BRTS: 1-D MORPHOLOGICAL MODELLING

RESPONSE TO 1988 FLOOD AFTER 100 YEARS JAMUNA LEFT EMBANKMENT	Vol.3 Part 8
	Figure 3.18

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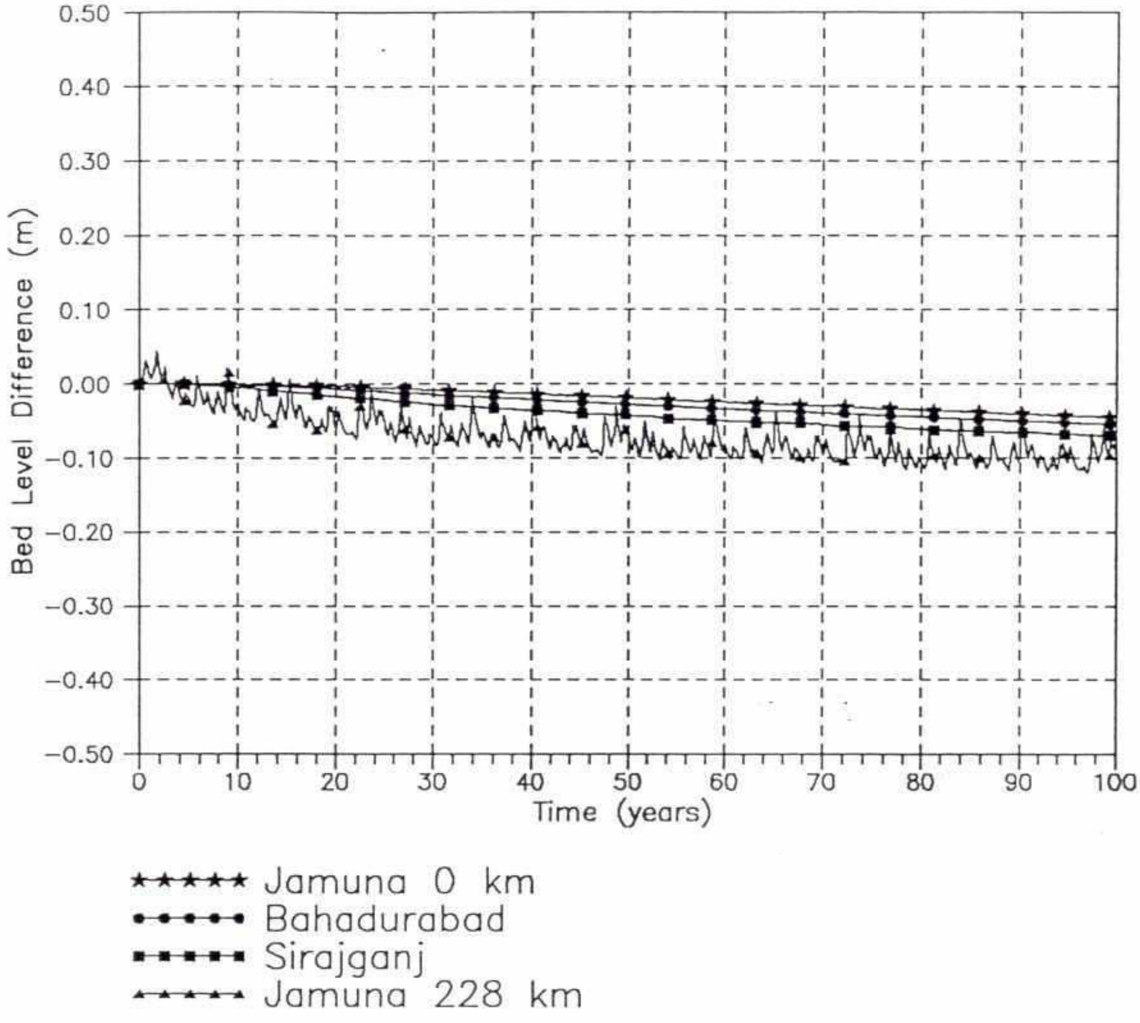

BRTS: 1-D MORPHOLOGICAL MODELLING

BED LEVEL CHANGES: **JAMUNA BRIDGE NARROW OPTION**	Vol.3 Part 8 **Figure 3.19**

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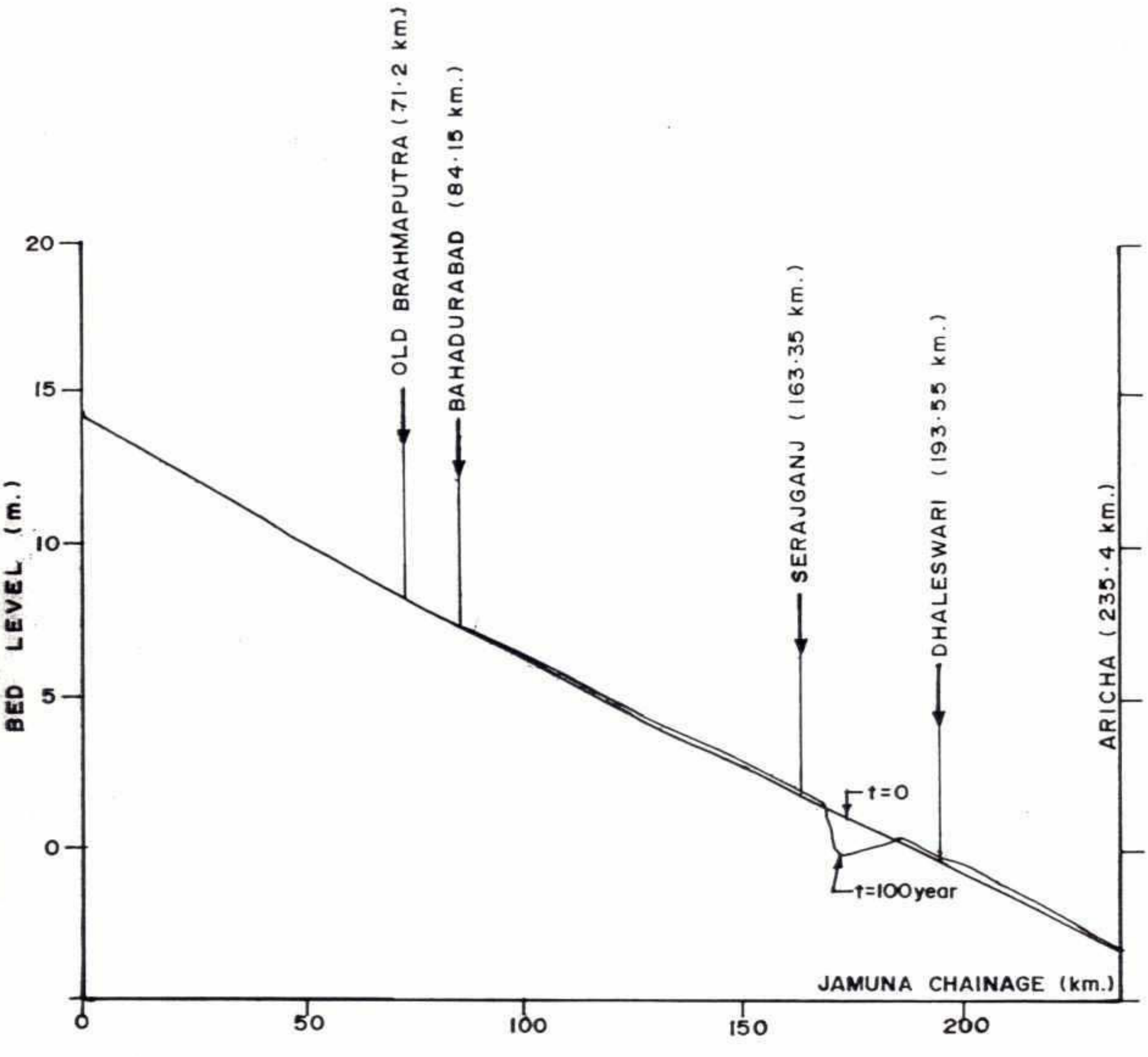
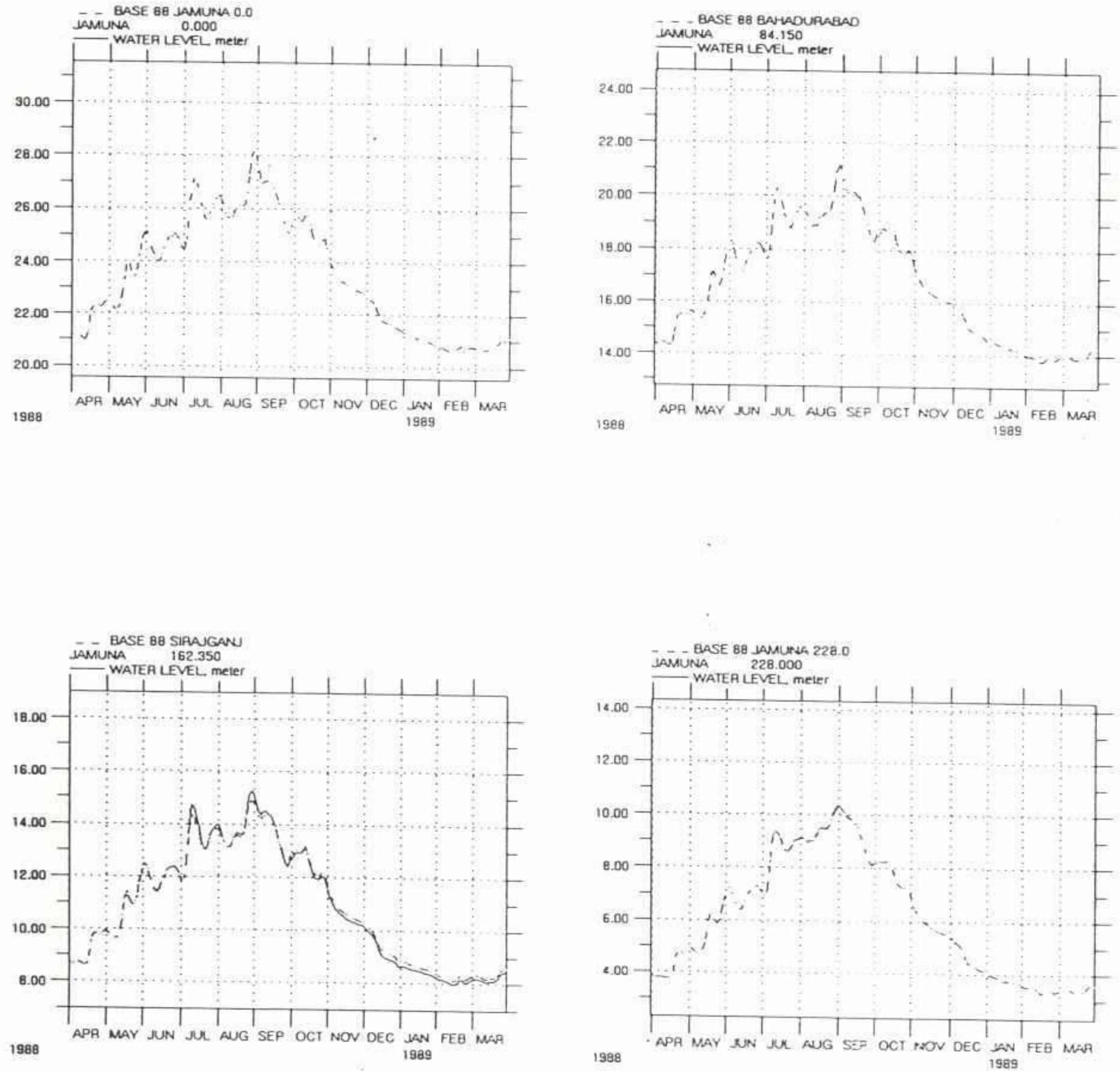


BRTS: 1-D MORPHOLOGICAL MODELLING

LONGITUDINAL BED PROFILES JAMUNA BRIDGE NARROW OPTION	Vol.3 Part 8
	Figure 3.20



BRTS: 1-D MORPHOLOGICAL MODELLING

IMMEDIATE RESPONSE TO 1988 FLOOD
JAMUNA BRIDGE NARROW OPTION

Vol.3 Part 8

Figure 3.21

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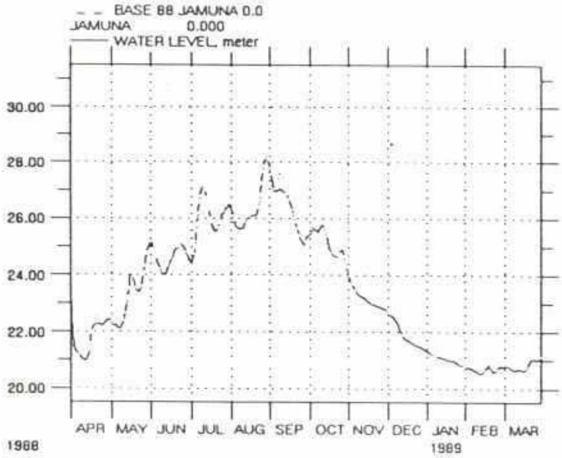
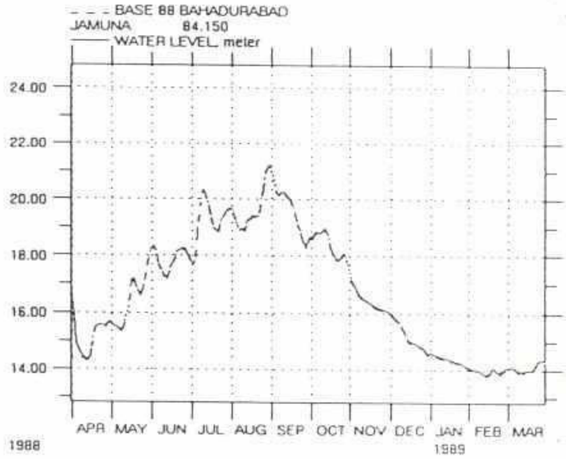
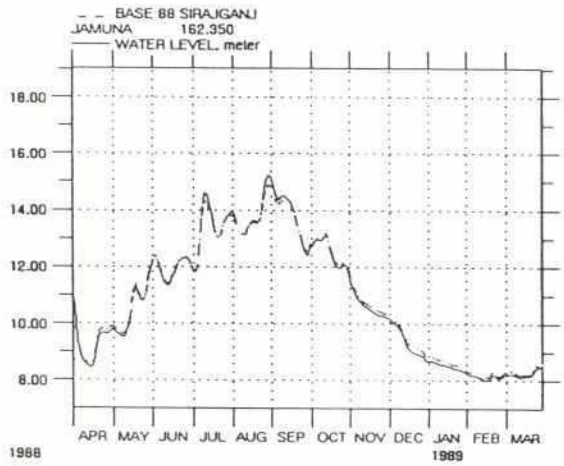
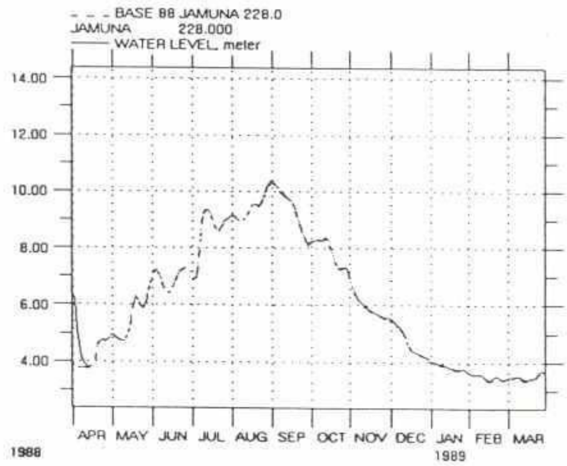






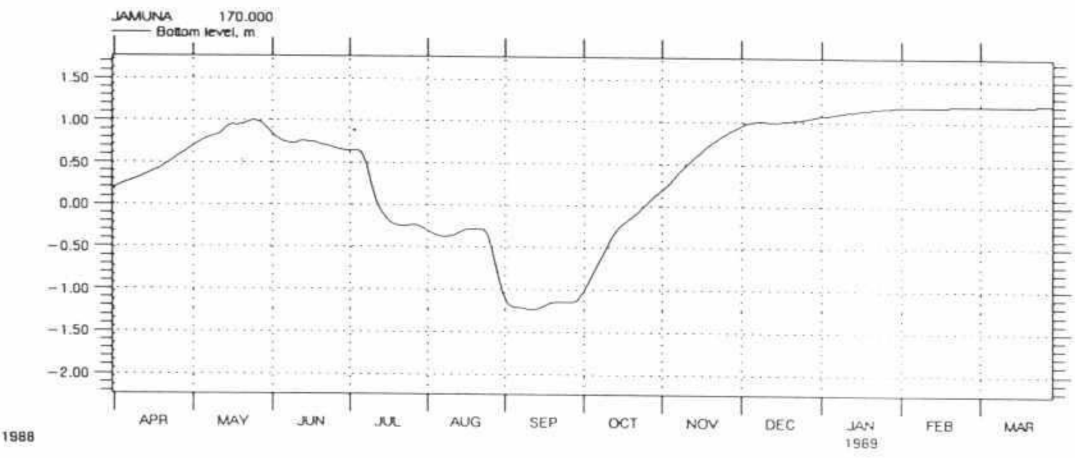


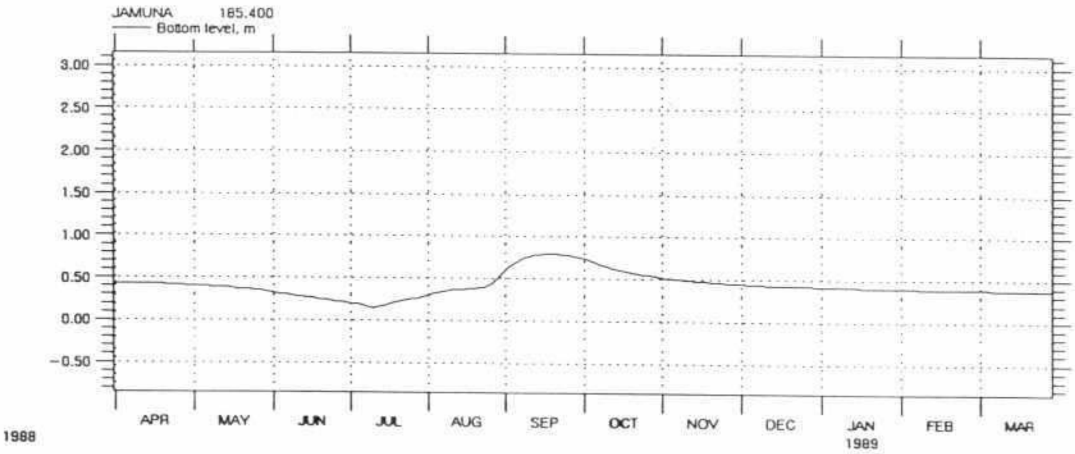
BRTS: 1-D MORPHOLOGICAL MODELLING

RESPONSE TO 1988 FLOOD AFTER 100 YEARS
JAMUNA BRIDGE NARROW OPTION

Vol.3

Figure 3.22





BRTS: 1-D MORPHOLOGICAL MODELLING

DEPOSITION DOWNSTREAM OF BRIDGE SITE JAMUNA BRIDGE NARROW OPTION	Vol.3 Part 8
	Figure 3.23

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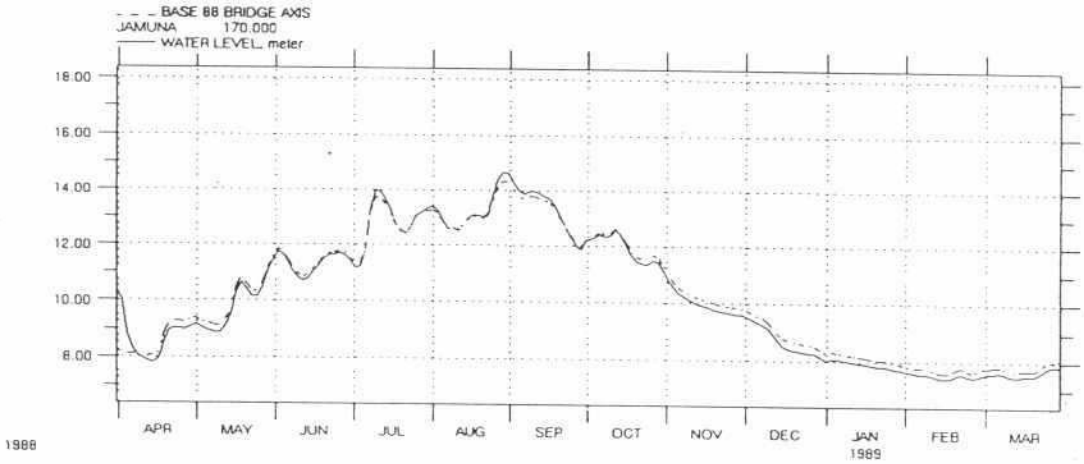
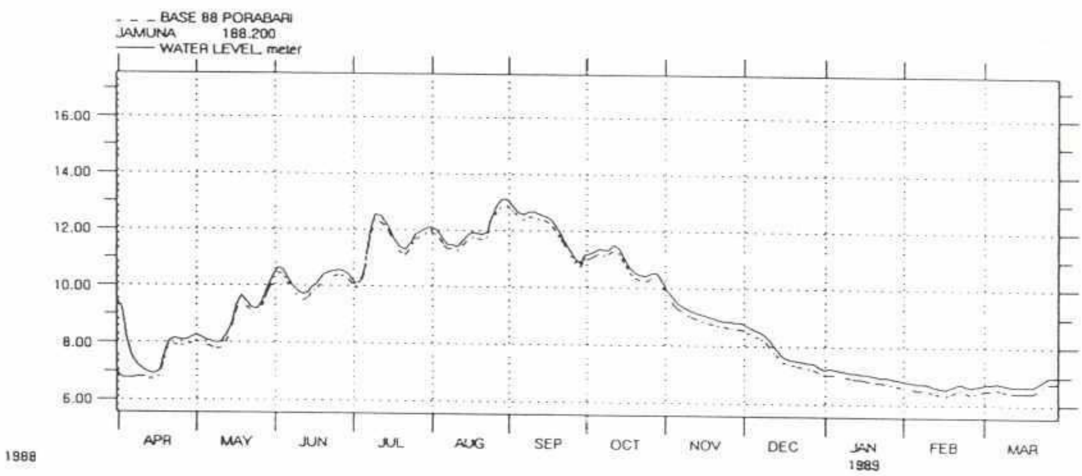


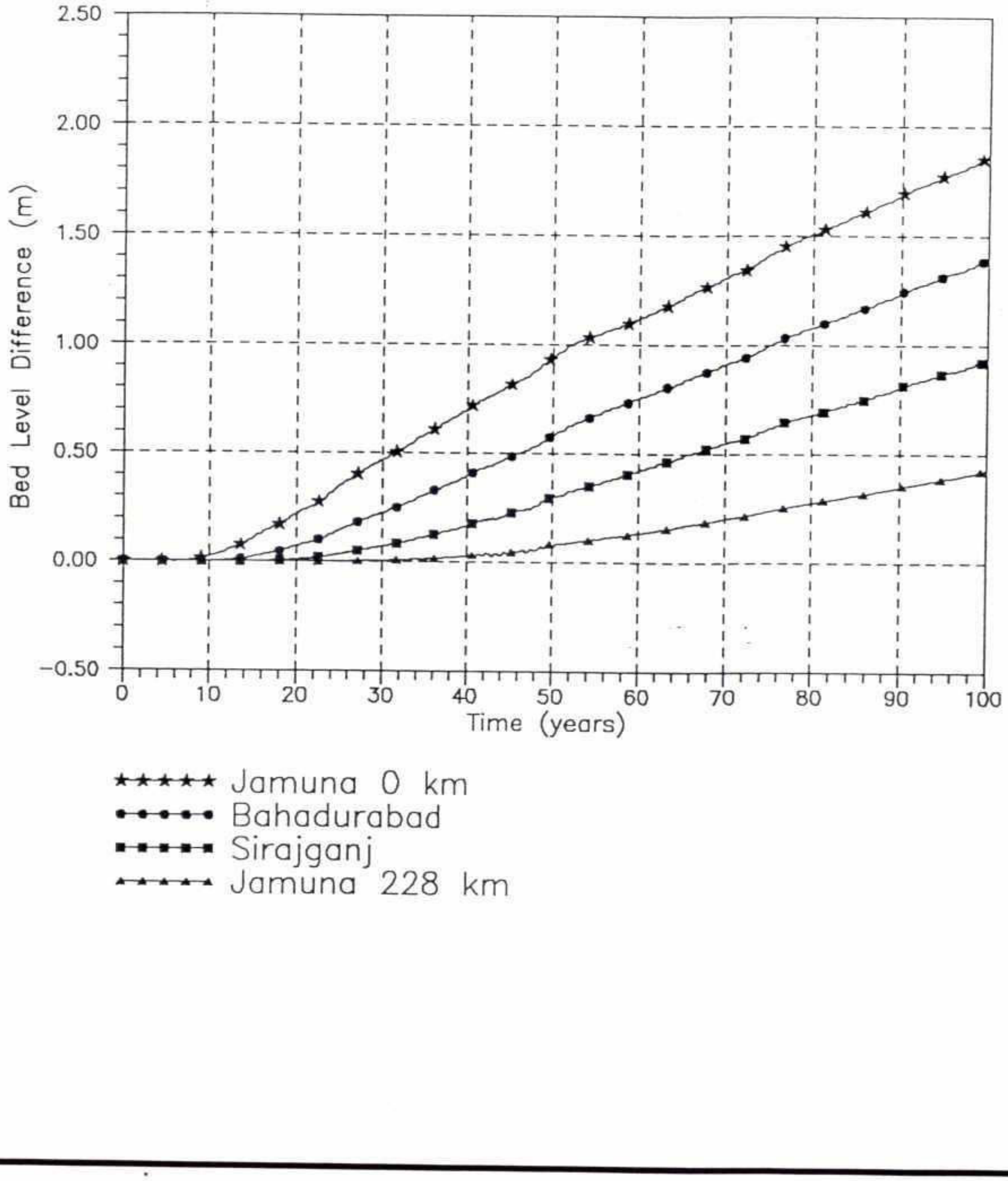


BRTS: 1-D MORPHOLOGICAL MODELLING

RESPONSE TO 1988 FLOOD AFTER 100 YEARS
JAMUNA BRIDGE NARROW OPTION

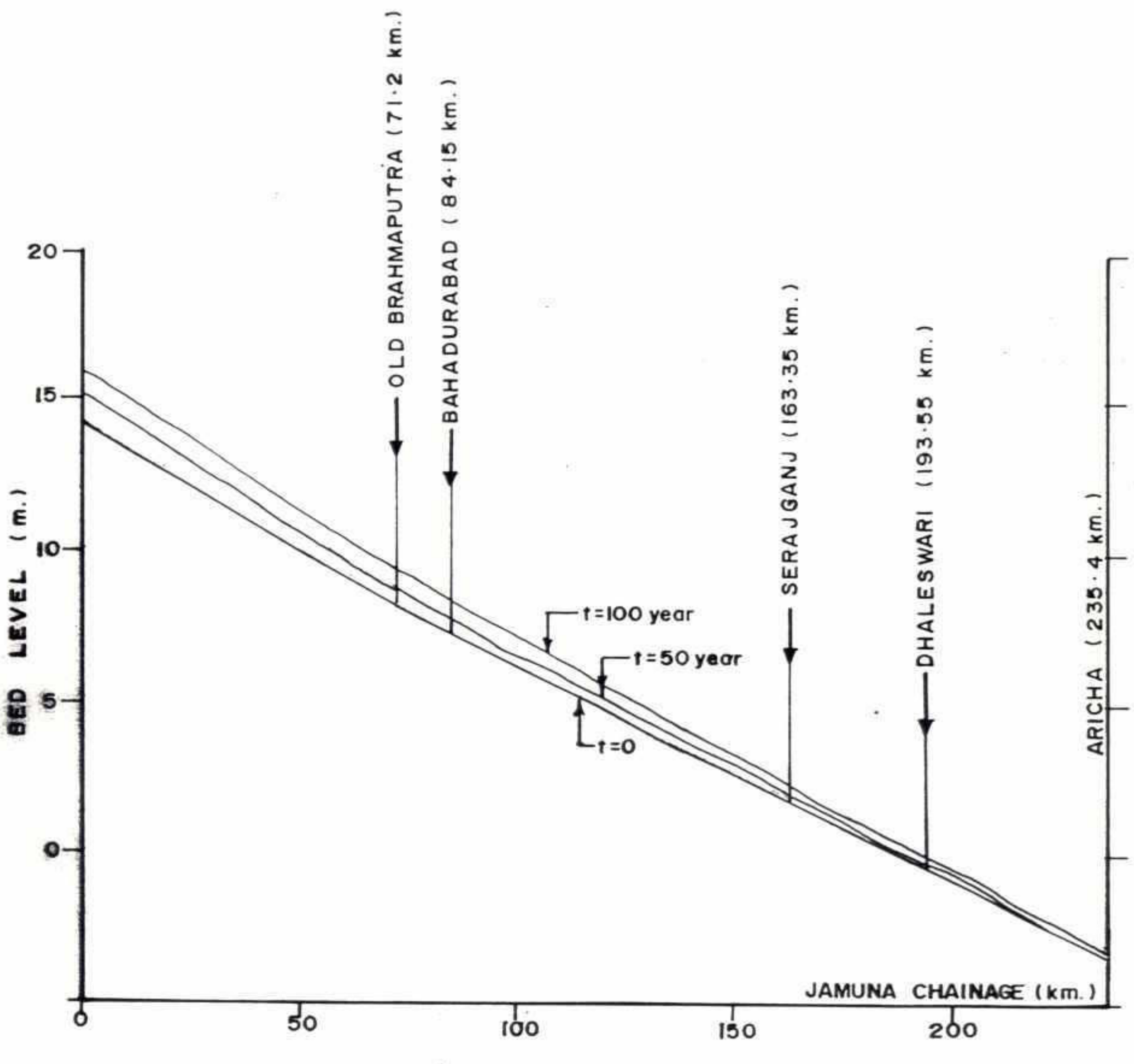
Vol.3 Part 8

Figure 3.24



BRTS: 1-D MORPHOLOGICAL MODELLING

BED LEVEL CHANGES: INCREASE SEDIMENT INPUT	Vol.3 Part 8
	Figure 3.25

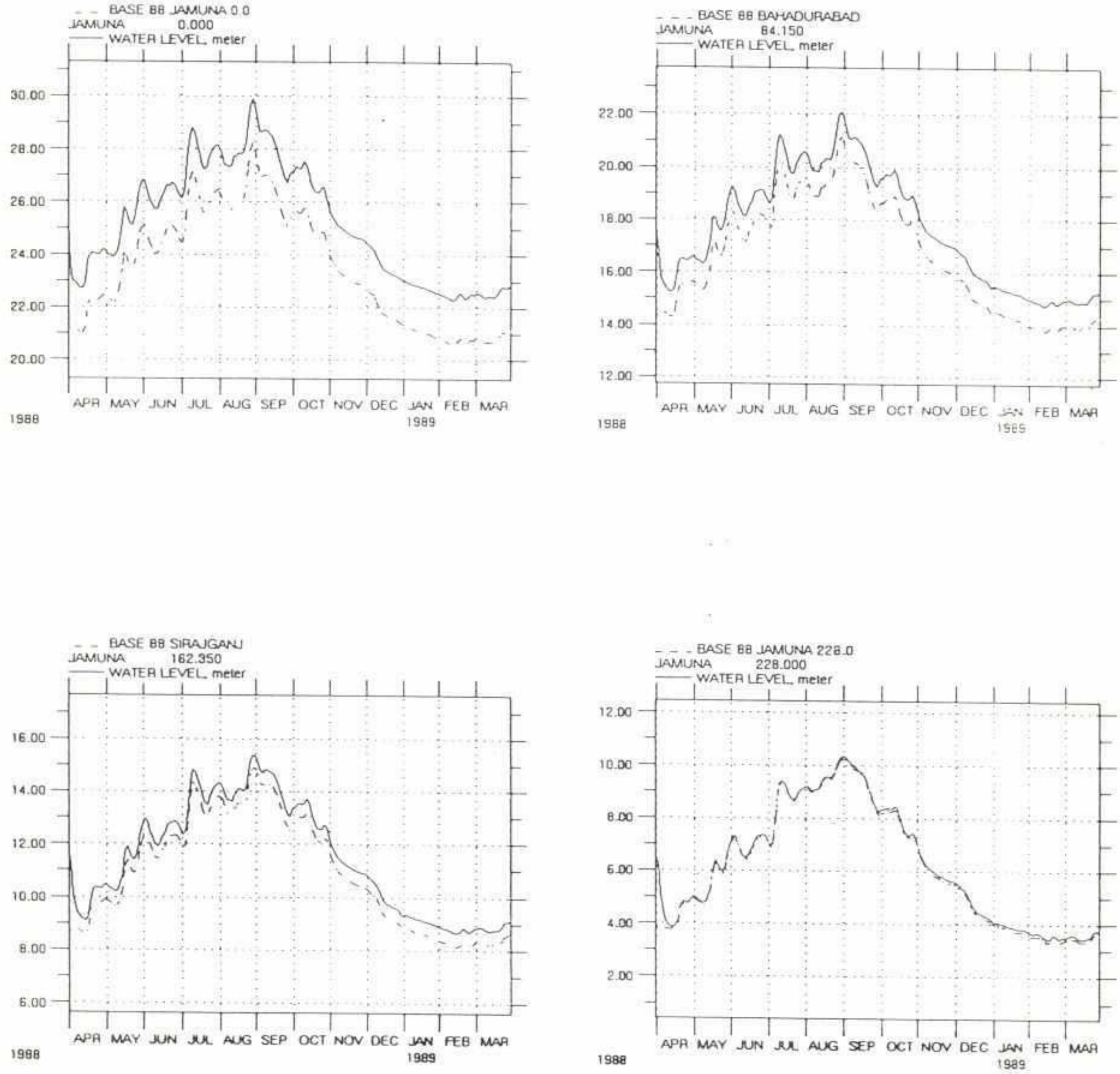


BRTS: 1-D MORPHOLOGICAL MODELLING

LONGITUDINAL BED PROFILES
INCREASED SEDIMENT INPUT

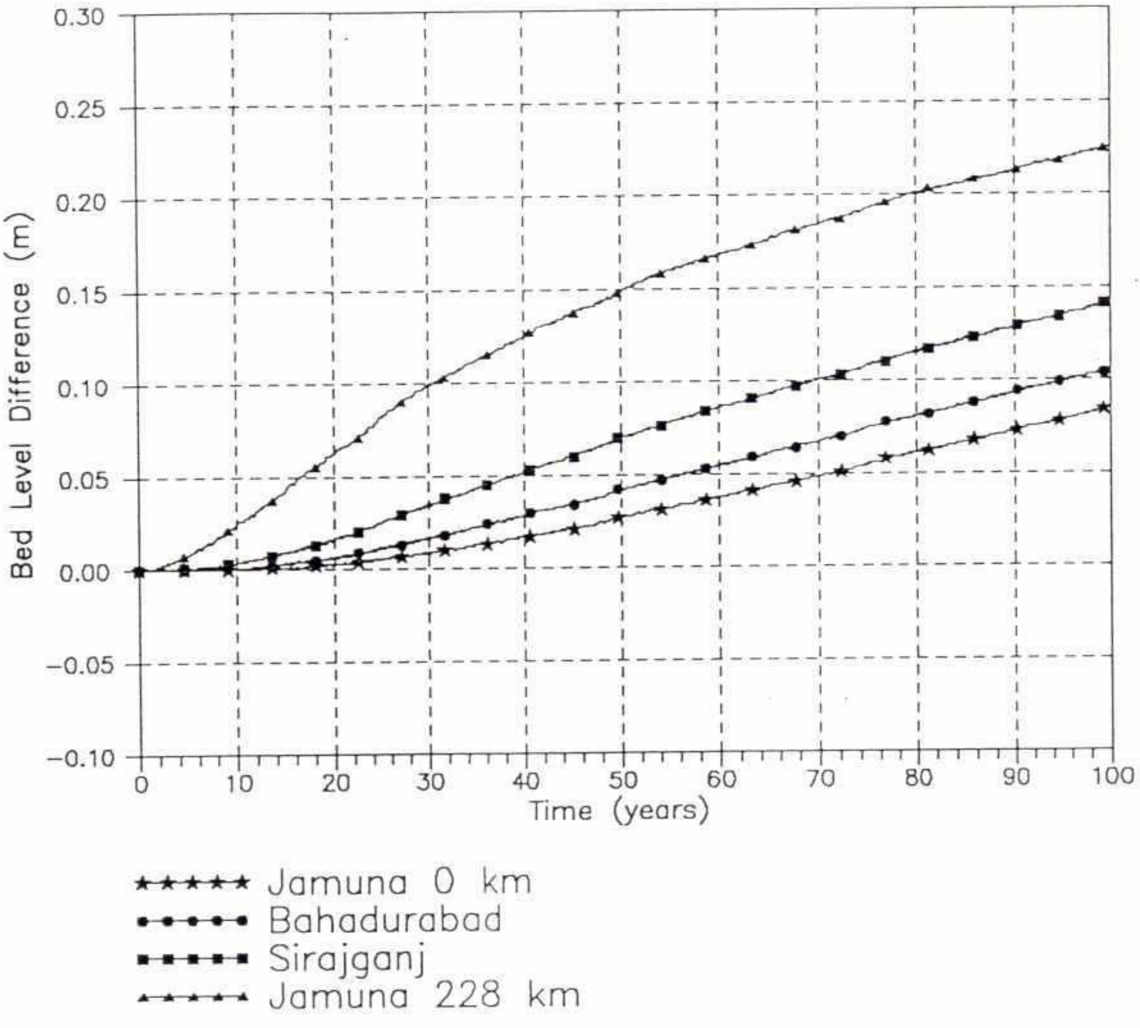
Vol.3 Part 8

Figure 3.26



BRTS: 1-D MORPHOLOGICAL MODELLING

RESPONSE TO 1988 FLOOD AFTER 100 YEARS INCREASED SEDIMENT INPUT	Vol.3 Part 8
	Figure 3.27



BRTS: 1-D MORPHOLOGICAL MODELLING

BED LEVEL CHANGES:
SEA LEVEL RISE 0.5 m

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Figure 3.28

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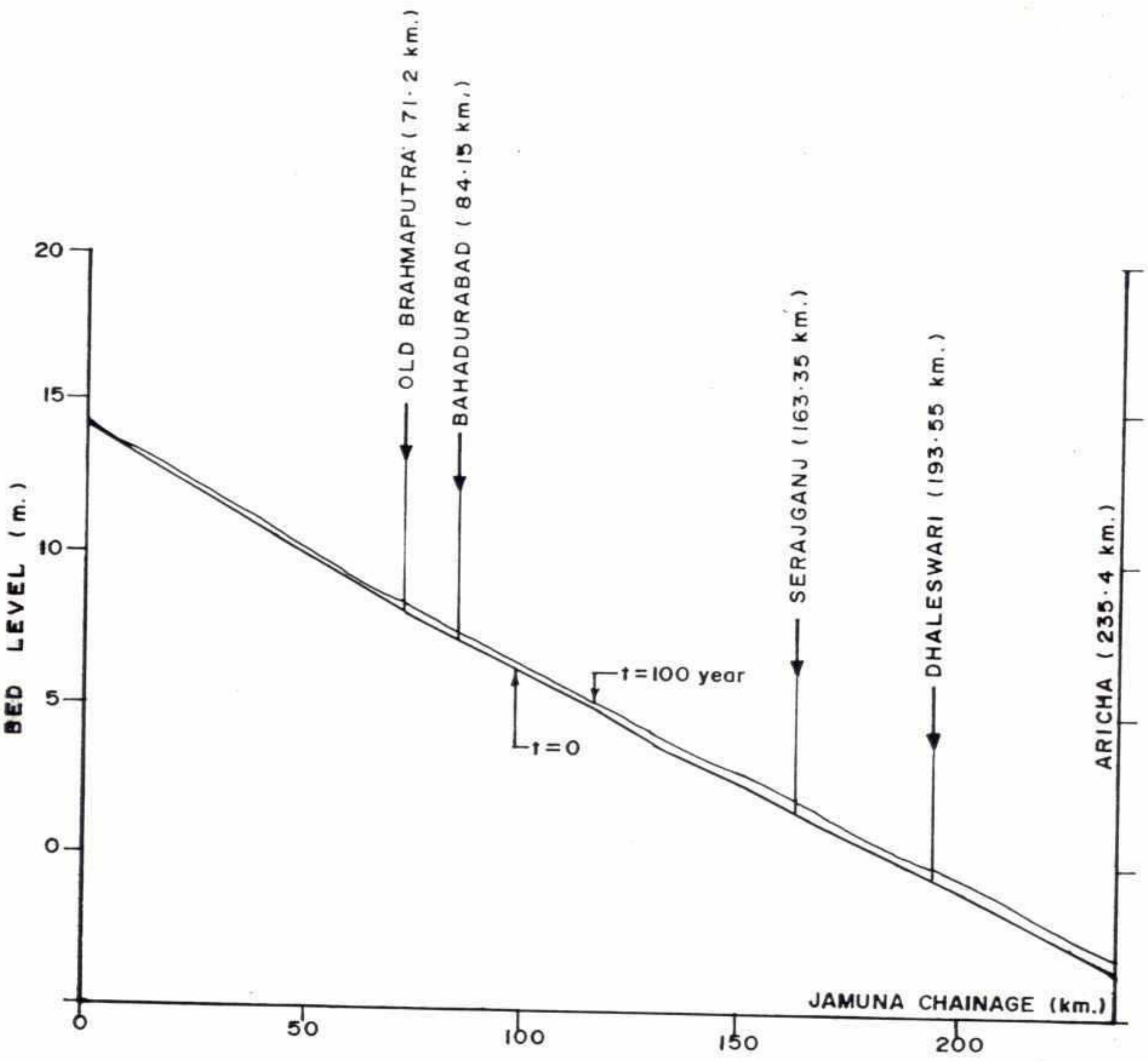
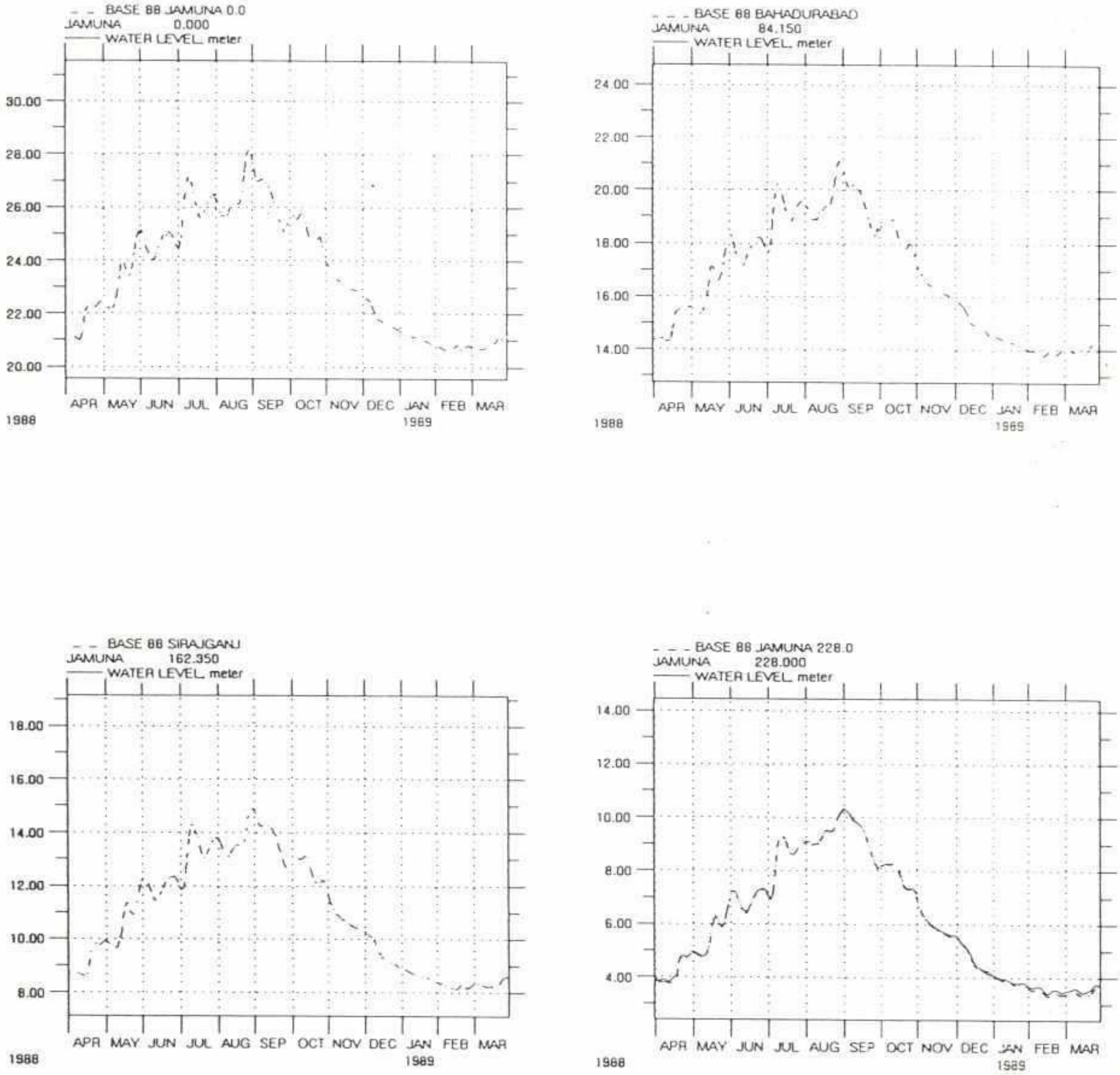


BRTS: 1-D MORPHOLOGICAL MODELLING

LONGITUDINAL BED PROFILES **SEA LEVEL RISE 0.5 m**	Vol.3 Part 8
	Figure 3.29



BRTS: 1-D MORPHOLOGICAL MODELLING

IMMEDIATE RESPONSE TO 1988 FLOOD
SEA LEVEL RISE 0.5 m

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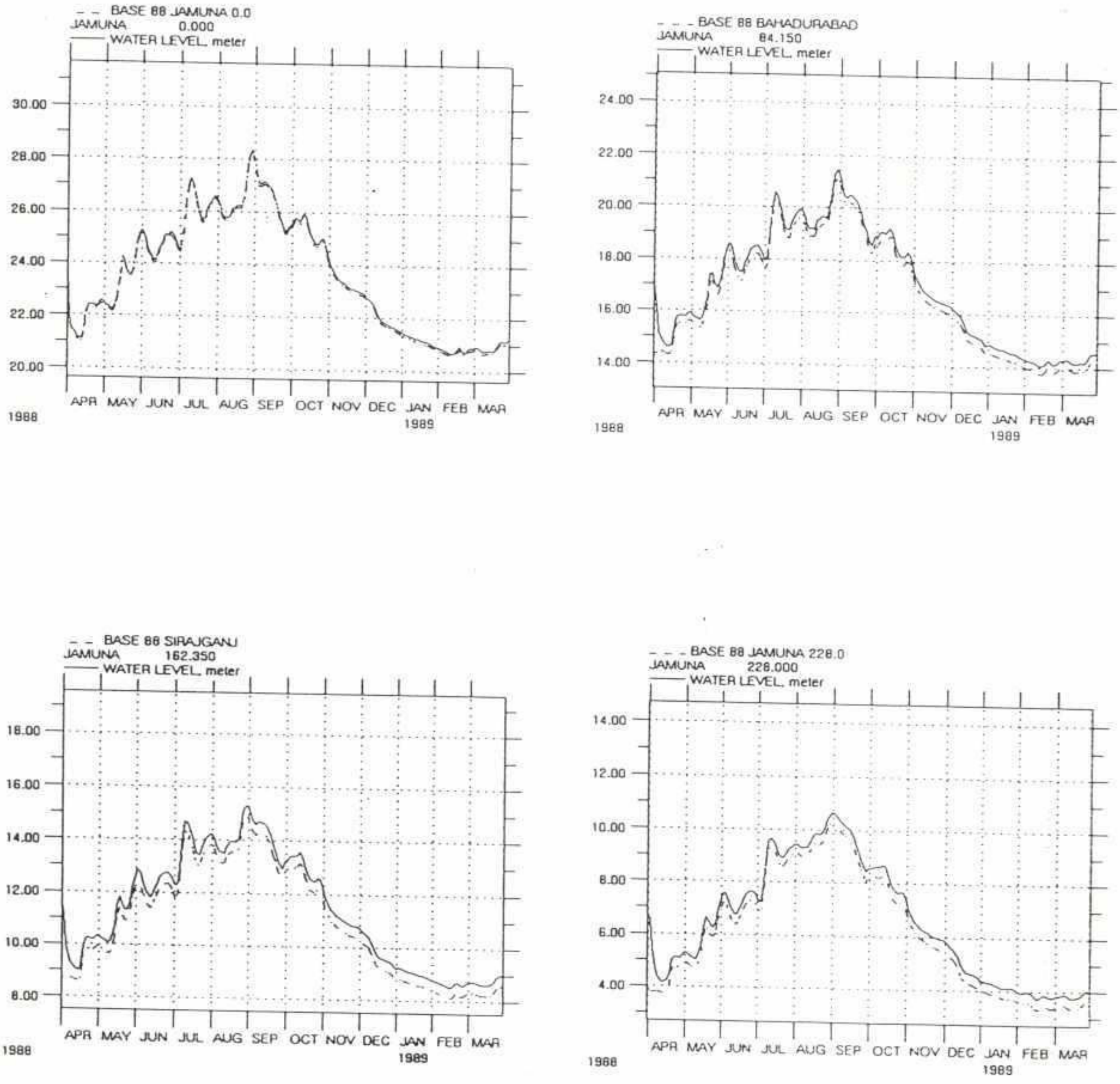
Figure 3.30



BRTS: 1-D MORPHOLOGICAL MODELLING

RESPONSE TO 1988 FLOOD AFTER 100 YEARS SEA LEVEL RISE 0.5 m	Vol.3 Part 8
	Figure 3.31