Use of morphological simulation for delineating navigation route in Ganges-Jamuna confluence

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1. Introduction

Jamuna and Ganges are the two main rivers in Bangladesh. Jamuna divides Bangladesh into eastern and western parts for a distance of 240 km from the entry at the Indian border up to the confluence with Ganges at south. Jamuna is one of the greatest rivers in the world ranking fifth in terms of discharge (Q_{avg} = 12,200 m^3/s) and eleventh in terms of drainage area (666,000 km^2) (Thorne et al. 1993). A wide variation of discharge occurs in seasons and year to year, the highest being around 100,000 m^3/s and the lowest being around 2,500 m^3/s. An average value of the dominant discharge for the Jamuna may be taken around 38,000 m^3/s (Hossain 1992). It is a well known characteristic that the river Jamuna, being a braided river, switches its numerous channels and bars in a width of about 6-18 km, in a time span of even less than a season, particularly in monsoon. Every year not only the erosion of the river banks but also the development of large bars and depositions in the main channels are posing serious problems to navigation.

Since 1997, Jamuna Bridge has linked the two parts of the country. However, as an alternative Bangladesh Inland Water Transport Authority (BIWTA) maintains a ferry service, to get access to those two parts, using the Aricha-Daulatdia-Notakhola route through confluence of the Ganges and Jamuna rivers. In recent years, the navigability in and around the confluence has been considerably reduced. Large-scale morphological changes in the Jamuna have detached the harbors from the main channel. The locations of the harbors are shifting every year, and as a result, different facilities related to commuters could not be maintained constantly. In addition, the navigation channels have to be dredged regularly in order to make the ferry service accessible, particularly during the lean period of the year. Recently, it has become an important issue to look for a sustainable measure for resolving the navigational problem at Aricha-Daulatdia-Notakhola ferry route by reducing its annual cost for dredging as well as cost for shifting the harbors.

Among the available literature the pioneering work on river morphology of the Jamuna was done in1969 by Coleman. Later a number of publications (e.g., Bristow 1987; Klaassen and Vermeer 1988a 1988b; Klaassen et al. 1988; Klaassen and van Zanten 1989; Klaassen and Masselink 1992; Thorne and Russel 1993, Hoque 1999, etc.) were made and those are mainly associated to different specific studies, related to the river engineering works (bridge, floodplain management, bank protection) or flood control.

The morphological models that are nowadays in use facilitate decision-making on selecting alternative routes, considering its sustainability for a reasonably long time in terms of keeping the channel navigable round the year, naturally or in combination of engineering interventions. Modeling as such has become an inevitable tool for obtaining a best option from a multitude of sequential simulation runs.

2. Model formulation

This study has been conducted using software based on finite element method. RMA2 and SED2D that developed by US Army Corps of Engineers for hydrodynamic and sediment transport models respectively, are used to simulate the morphology of the Jamuna near its confluence. The models have been applied under SMS (**S**urface-water **M**odeling **S**ystem) environment, which gives the pre- and post-processing options for input and output data.

The finite element mesh, finite difference grid, or cross section entities along with associated boundary conditions necessary for analysis may be specified and edited within SMS and saved to model specific files. These files are used to perform the hydrodynamic, contaminant migration, sediment transport or other desired analyses. The numerical models create solution files that contain the water surface elevations, flow velocities, contaminant concentrations, sediment concentrations or other functional data at each node, cell, or section. SMS reads this data and generates profiles and cross sectional plots, two-dimensional vector plots, drogue plots, color-shaded contour plots, time variant curve plots, and dynamic animation to enhance understanding and interpretation of numerical solutions.

The core of the modeling consists of three computational modules are described below.

2.1 Hydrodynamic module

RMA2 is a two-dimensional depth averaged finite element hydrodynamic model. It computes water surface elevations and horizontal velocity components for subcritical, free-surface flow in two-dimensional flow fields.

RMA2 computes a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows. Friction is calculated with the Manning's or Chezy's equation, and eddy viscosity coefficients are used to define turbulence characteristics. Both steady and unsteady state (dynamic) problems can be analyzed.

The generalized computer program RMA2 solves the depth-integrated equations of fluid mass and momentum conservation in two horizontal directions. The forms of the solved equations are:

$$h\frac{\partial u}{\partial t}+hu\frac{\partial u}{\partial x}+hv\frac{\partial u}{\partial y}-\frac{h}{p}\left(E_{xx}\frac{\partial^2 u}{\partial x^2}+E_{xy}\frac{\partial^2 u}{\partial y^2}\right)+gh\left(\frac{\partial a}{\partial x}+\frac{\partial h}{\partial x}\right)+\frac{gun^2}{\left(1.486h^{1/6}\right)^2}+\left(u^2+v^2\right)^{1/2}$$
$$-\zeta v_a^2\cos\psi-2h\omega v\sin\phi=0 \qquad (2.1)$$

$$h\frac{\partial v}{\partial t}+hu\frac{\partial v}{\partial x}+hv\frac{\partial v}{\partial y}-\frac{h}{p}\left(E_{yx}\frac{\partial^2 v}{\partial x^2}+E_{yy}\frac{\partial^2 v}{\partial y^2}\right)+gh\left(\frac{\partial a}{\partial y}+\frac{\partial h}{\partial y}\right)+\frac{gvn^2}{\left(1.486h^{1/6}\right)^2}+\left(u^2+v^2\right)^{1/2}$$
$$-\zeta v_a^2\cos\psi+2h\omega v\sin\phi=0 \qquad (2.2)$$

$$\frac{\partial h}{\partial t}+h\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+u\frac{\partial h}{\partial x}+v\frac{\partial h}{\partial y}=0 \qquad (2.3)$$

where, h = depth; u, v = velocities in the Cartesian directions; x, y, t = Cartesian coordinates and time; ρ = density of fluid; E = eddy viscosity coefficient; g = acceleration due to gravity; n = Manning's roughness n-value; ζ = empirical wind shear coefficient; v_a = wind speed; ψ = wind direction; ω = rate of earth's angular rotation; ϕ = local latitude.

Eqs. 2.1, 2.2 and 2.3 are solved by the FEM using the Galerkin method of weighted residuals. The elements may be one-dimensional lines, or two-dimensional quadrilaterals or triangles, and may have curved (parabolic) sides. The shape functions are quadratic for velocity and linear for depth. Integration in space is performed by Gaussian integration. Derivatives in time are replaced by a nonlinear finite difference approximation. Variables are assumed to vary over each time interval in the form:

$$f(t) = f(0) + at + bt^c \qquad t_0 + \leq t < t_0 + \Delta t \tag{2.4}$$

which is differentiated with respect to time, and cast in finite difference form. Letters a, b, and c are constants.

The solution is *fully implicit* and the set of simultaneous equations is solved by Newton-Raphson non-linear iteration. The computer code executes the solution by means of a *front-type solver*, which assembles a portion of the matrix and solves it before assembling the next portion of the matrix.

2.2 Sediment transport module

SED2D is a two-dimensional depth averaged finite element sediment model. It computes bed level changes, sediment concentrations, bed shear stress and water depth for a given period of time. It needs hydrodynamic solutions over the area from any other model. SED2D-WES can be applied to clay or sand bed sediments where flow velocities can be considered two-dimensional in the horizontal plane. It is useful for both deposition and erosion studies, and to a limited extent, for stream width studies. The program treats two categories of sediment: 1) non cohesive, which is referred to as sand herein; and 2) cohesive, which is referred to as clay.

The derivation of the basic finite element formulation is presented in Ariathurai (1974) and Ariathurai MacArthur, and Krone (1977). There are four major computations need to be performed: (a) suspended sediment concentration using convection-diffusion equation with a bed source term, (b) bed shear stress, (c) bed source quantity, and (d) bed model

The basic convection-diffusion equation is presented in Ariathurai, MacArthur, and Krone (1977),

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = \frac{\partial}{\partial x}\left(D_x\frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(D_y\frac{\partial C}{\partial y}\right) + \alpha_1 C + \alpha_2 = 0 \tag{2.5}$$

where, C = concentration, kg/m^3; T = time, sec; U = flow velocity in x-direction, m/sec; V = flow velocity in y-direction, m/sec; D = effective diffusion coefficient, m^2/sec; α_1 = a coefficient of the source term, sec^{-1}; α_2 = equilibrium concentration portion of the source term, kg/m^3/sec.

3. Model set-up

Three basic models have been developed for the present study, which are a steady model, an unsteady model and a sediment transport model. The steady model, which has to be developed first, is used to hot-start the unsteady model. Unsteady model is developed to obtain hydrodynamic solution files for sediment model and also for hydrodynamic calibration and verification processes. SED2D is an uncoupled sediment model, which requires a solution file from another model. RMA2 is used to generate the solution files for SED2D. Mesh generated under the steady model is used for all the models. Both the unsteady and sediment models are run using boundary conditions of 2001. Unsteady model is calibrated using observed water surface elevation at Aricha for 2001. Sediment model is calibrated by comparing simulated sediment rating curve with the observed curve at Baruria. Then the reach-wise simulated bathymetry has been compared with the observed bathymetry of the same period. If calibration does not show well matches with observed data, roughness and sediment size should change for hydrodynamic and sediment models respectively. Once the model is calibrated adequately, it would be ready to simulate future scenarios using envisaged boundary condition of some conceivable hydrologic years.

At first the study area has been defined using a 17th November 2000 LANDSAT image. The scanned image has been imported in the background using map module. The map module provides tools for defining the study area boundaries and features, from which a finite element mesh can be created. Mesh module is used to manipulate finite element meshes. The bathymetry is interpolated to the mesh nodes by scatter module. Once the mesh is generated, various parameters such as boundary conditions, material roughness, turbulence exchange coefficient, initial condition, wetting/drying parameters, time-step, sediment characteristics, sediment concentrations etc. are assigned using mesh module. SMS saves all the files required to run RMA2 and SED2D models. Before running the model a tool is also available to check any potential error may have in the model. The basic steps taken to develop the core model are delineated below.

3.1 Mesh generation

Steady hydrodynamic model is the core of all models. Mesh generated under this model is used for rest of the models. First the study area defined by using 17th November 2000 LANDSAT image is imported in the map module as background information. A *feature polygon* is defined as an area surrounded by three or more feature arcs.

After each polygon is assigned with their material type and mesh type, the real mesh has been generated with a total of 4185 elements and 13940 nodes. It has got four open boundaries. This mesh has been generated with their real coordinates only. The final mesh generated for the study region is showed in the Fig. 3.1.

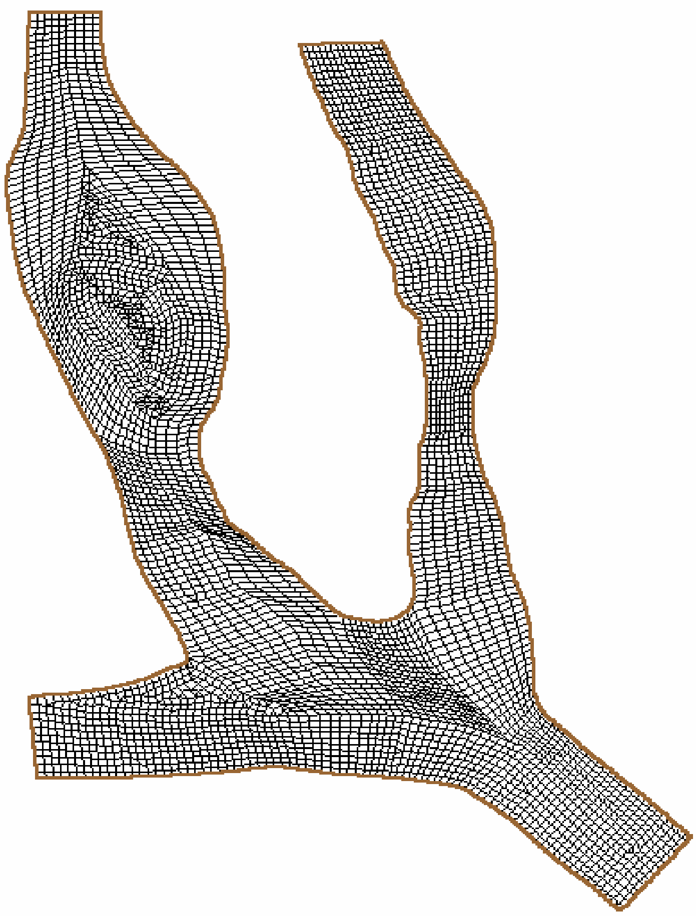


Fig.3.1 Generated mesh into the study area

3.2 Bathymetry

BIWTA lean period bathymetry charts surveyed during April 2001has been used to set-up the initial bathymetry of the model. The distribution of measured and interpolated bathymetries is shown in Figs. 3.2. Areas where data are missing, February 1999 surveyed data of BIWTA and of BWDB cross-sections as shown on to the satellite image below, have been used to fill-up the gaps.

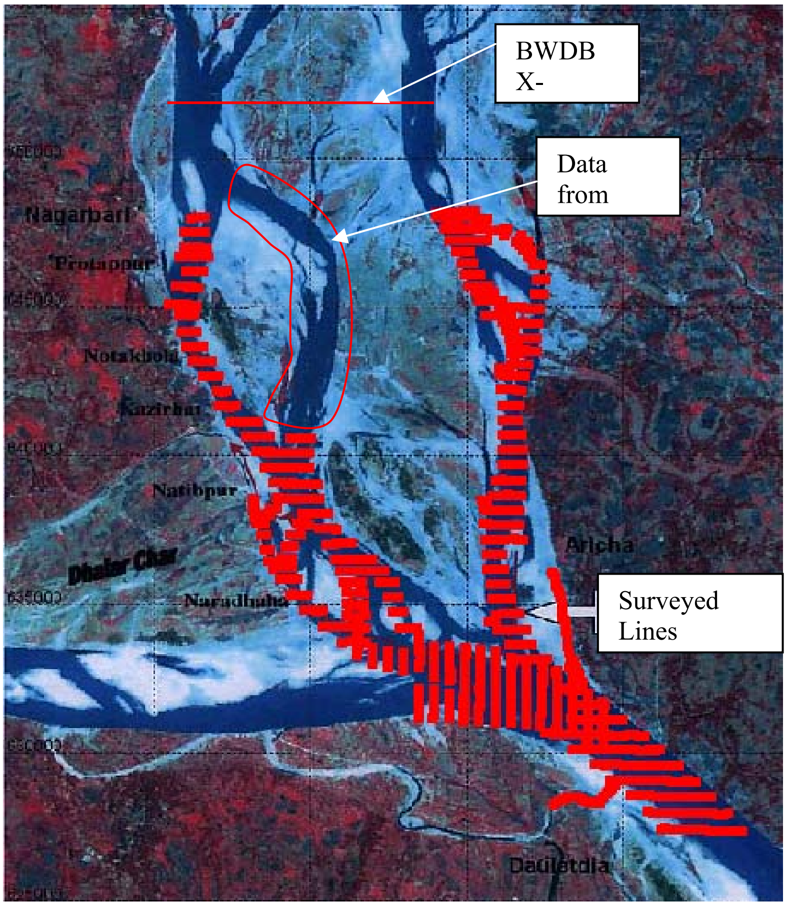


Fig. 3.2 BIWTA measured bathymetry on to the satellite image of November 2000

3.3 Boundary conditions

The rating curve at Bahadurabad has been used to generate discharge boundaries at upstream northern end. The distribution of the discharges through those two branches is generated according to their conveyance functions of the channels. Interpolated water level data from Aricha and Baruria have been applied to downstream boundary in the Padma. The discharge boundary applied to the Ganges is calculated by subtracting the discharges through Gorai Railway Bridge from the discharges through Hardinge Bridge. The discharge and water level hydrographs of monsoon, June-October 2001, as shown in Fig. 3.3 have been taken to apply into the model as boundary conditions, and subsequent calibration purposes.

3.4 Roughness parameters

For the study area initial roughness is given using Manning's roughness value. Depth varying roughness is used with the lower value of 0.025 where water depth is above 0.5 m and 0.055 is used when water depth becomes lower than 0.5 m. After calibration it has been changed to match with the observed values.

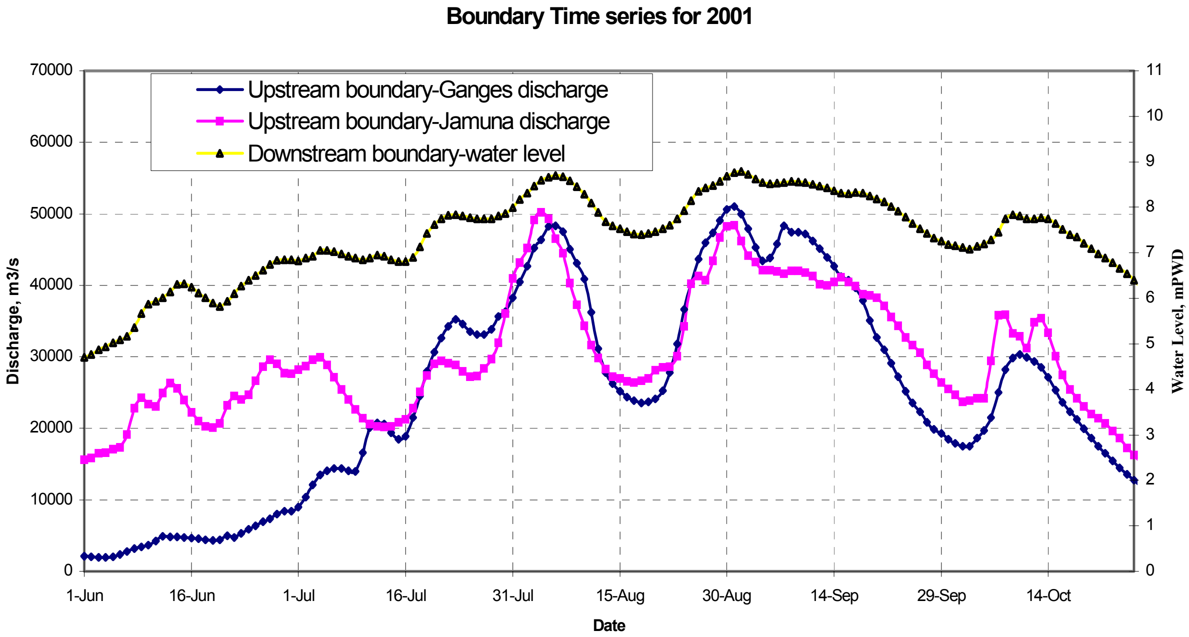


Fig. 3.3 Time series hydrographs from June to October 2001 used in the model as boundary conditions

3.5 Turbulence parameters

All forms of numerical models require some form of stabilization. The Galerkin method of weighted residuals employed by RMA2 does not include any inherent form of stabilization other than the *eddy viscosity* term. The Galerkin formulation requires a certain amount of turbulence to achieve stability and not impair the solution.

In this study turbulence by Peclet number is used to assign the eddy viscosity. Peclet number gives the better assignment as it calculates eddy viscosity after each iteration. Peclet number of 20 is used for the whole model.

3.6 Initial condition

We intend to start our simulation from 6th June 2001, the water level that has been found at 5.1 m PWD for the aforesaid time, is chosen as our desired downstream boundary. As such, 17668 m^3/s and 2062 m^3/s inflow boundary discharges have been found for combined Jamuna (eastern and western) and Ganges, respectively for the corresponding downstream 5.1 m PWD water level. But the initial water levels at nodes other than the downstream boundary are unknown at the corresponding initial boundary discharges. Therefore, it is desired to start the first run of the cold-start with an initial water level elevation of 12 m PWD, which is much higher than the maximum bed elevation found at 9 m PWD. Using revision card with 0.1 m decrease rate, the downstream boundary water surface elevation has been reduced to desired 5.1 m PWD. This cold-start for the present study has required more than 170 iterations to get into the solution for initial condition. Once the cold-start solution is obtained, it is used as a *hot-start* for other steady or unsteady models. The hot-start is a solution file used as an initial condition for subsequent unsteady model runs.

3.7 Wetting drying parameter

While elemental elimination method is used to simulate the wetting/drying phenomena, the dry depth, below which any nodes will be treated as dry, is given as 0.01 m and wetting depth, depth above which any node will become wet again, is given as 0.11 m. A tolerance of 0.1 m is provided to minimize the possibility of alternate drying and wetting of any node during iterations in the same time-step. Otherwise this will produce numerical instability. In marsh porosity method, if water level falls below the bed elevations of all the nodes of an element, a minimum flow (say 1 percent) has been set for the element to keep the element in the solution domain. This method basically has been used while the model is in the process of simulating the receding hydrograph. The third option combination method has not been used for the present study.

3.8 Steady hydrodynamic model

As mentioned above steady hydrodynamic model is used to develop hot-start file for unsteady model. For the steady model development, inflow discharges of 17668 m^3/s (western channel = 8834 m^3/s and eastern channel = 8834 m^3/s) for Jamuna and 2062 m^3/s for Ganges are taken, corresponding to downstream 5.1 m PWD water level. The steady model has used a mesh that is being developed from the satellite image of November 2000 (Fig. 3.1). The bathymetry data (Fig. 3.2) that surveyed on April 2001 by BIWTA has been applied to the mesh nodes of the model for subsequent simulation. This steady solution has been obtained through cold-start run and subsequent use of revision cards. Roughness and turbulence are assigned globally for all the nodes.

3.9 Unsteady hydrodynamic model

Unsteady model is developed for hydrodynamic simulation and also to create binary solution file for the sediment model. The same mesh and bathymetry, as applied under steady model, are in used. The time series boundary conditions for discharges and water levels are shown in Fig. 3.3. The boundary conditions show that the model has been run for monsoon season, starting from June till October 2001.

In explicit schemes time-step is restricted by stability criteria, which requires fulfillment of stringent Courant condition. But in any implicit method time-step is usually unrestricted by stability requirement, however, accuracy of the results may have an impact on selecting the time-steps. To reduce the computational time, to complete a simulation, the time-step should be as large as possible to capture the extremes of the dynamic boundary conditions and maintain numerical stability. In this study one-hour is taken as a computational interval for unsteady simulation.

Calibration has been done by comparing the computed water surface elevation with the observed water surface elevation at Aricha for 2001.

3.10 Sediment model

Once the calibration of the hydrodynamic model is complete, sediment model is ready for running using results obtained from hydrodynamic model. As described earlier SED2D is not coupled with hydrodynamic under SMS environment. So it requires velocity field of hydrodynamic solution from another model.

A new hydrodynamic solution has been initiated with the updated bathymetry for subsequent sediment run. The whole operation has been continued until the whole time period is completed. Initial suspended sediment concentrations have been generated using an arbitrary value of 0.23 ppt under the steady hydrodynamic solution file. These concentrations have been used as a hot-start for the unsteady sediment model. For inflow boundaries, time series suspended sediment loadings have been generated from the observed sediment-rating curves at Bahadurabad and Hardinge bridge stations.

3.11 Calibration and validation

Lot of uncertainties exists related to input as model geometry, boundary conditions, roughness, eddy viscosity etc., which can have momentous impact on the model solutions. Once geometry and boundary conditions have been obtained with reasonable accuracy from the field, it is common practice to set them out of preview of the calibration process. Mostly roughness and eddy viscosity are the parameters to play with to obtain an adequate match with the observed field conditions. Validation is a multi-step process of model adjustments and comparisons, leavened with careful consideration of both the model and the data. It is not a simple two-step procedure, and the term calibration should not be used.

Observed and simulated water elevations

For hydrodynamic calibration computed water surface elevations are compared with the observed water surface elevations at Aricha for June-October 2001. Calibration results showed that computed values are with in ± 0.3 m (Fig. 3.5). Roughness is adjusted during calibration to n = 0.029 when water depth is higher than 0.5 m and n = 0.045 when water depth is lower than 0.5 m. The computed water surface elevations are validated with observed water surface elevations for June-October 2002 as shown in Figs. 3.6.

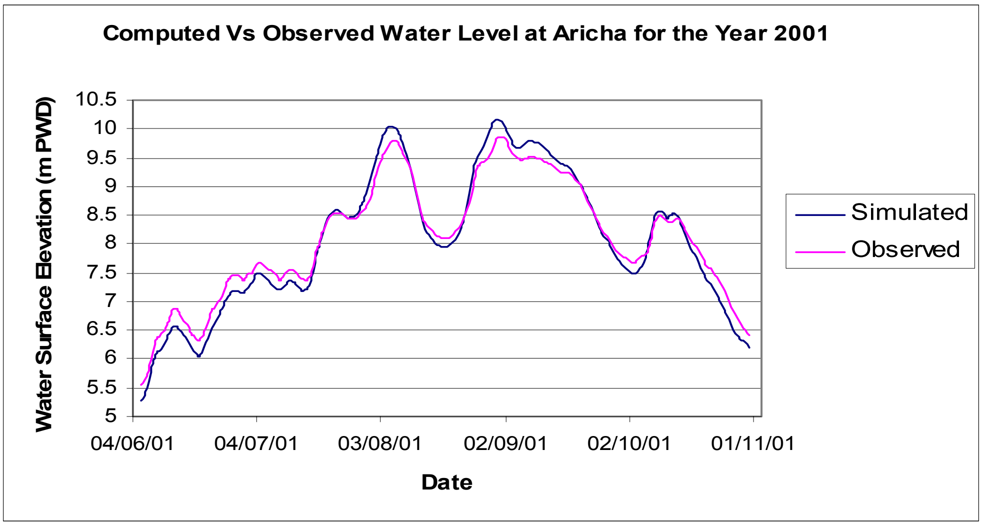


Fig. 3.5 Computed water surface elevations vs. observed water surface elevations

Observed and simulated bed elevations

For sediment model simulated bathymetry of 23rd August 2001 is compared with the observed bathymetry of 23rd August 2001. Results are presented as the bed elevations above and below 2.0 m PWD in Fig. 3.7. From the results it is found that simulated bed elevations adequately matched the observed bed elevations.

Observed and simulated sediment rating curve

A sediment rating-curve is generated from the simulation data and compared with the observed data at Baruria (FAP-24, 1996). Results have been closely matched with the observed data (Fig. 3.8).

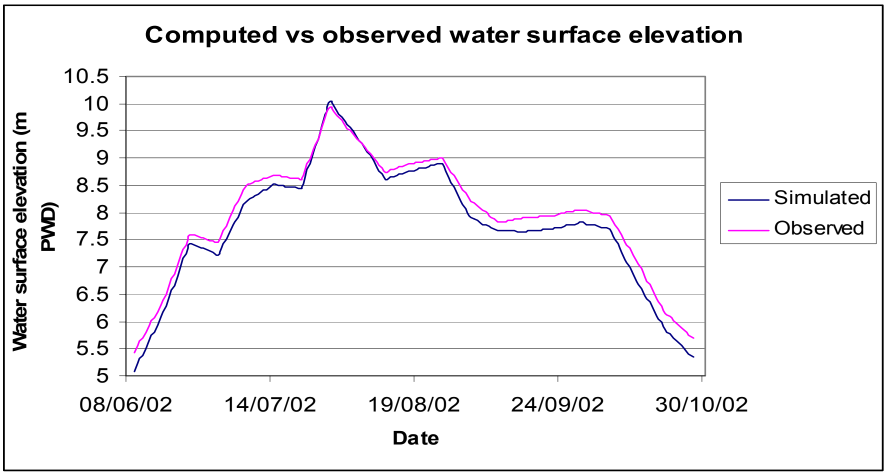
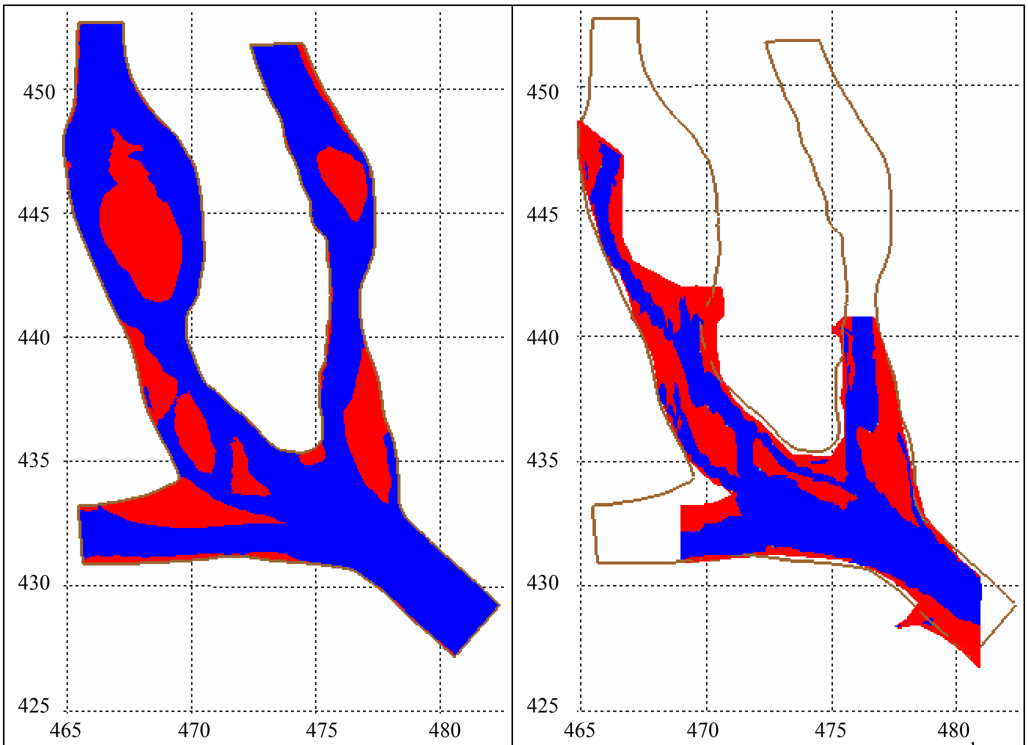


Fig. 3.6 Computed water surface vs. observed water surface elevations for 2002



(a) Simulated bathymetry of 23rd August 2001

(b) Observed bathymetry of 23rd August 2001

Fig. 3.7 Calibration of sediment model with observed bathymetry for bed elevations 2.0 m PWD below and above

River bed is assumed consisting of effective sand grain diameter of 0.15 mm. This grain size is found satisfactory during calibration for the bathymetry. A less sensitive parameter that is diffusion coefficient for suspended sediment concentration is taken as 1.5 m^2/s.

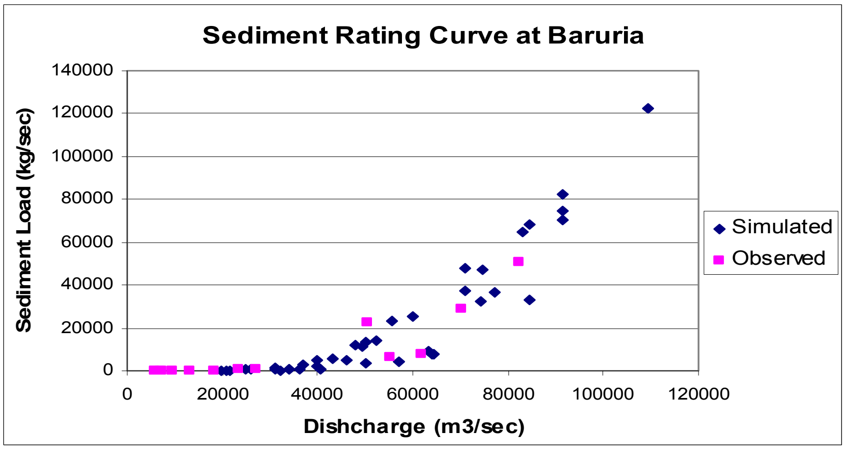


Fig. 3.8 Simulated sediment rates vs. observed rates (FAP-24) at Baruria

4. Results and Discussions

April 2001 surveyed bathymetry data in the study region are used as an initial bathymetry. The Jamuna has been divided into two anabranches in its upstream boundary. One is named as Eastern anabranch and other one as Western anabranch. The Western anabranch, near Nagarbari bifurcated into two branches; these branches are named as Branch1 and Branch2. Near Kazirhat these two branches meet again and after Natibpur there exist three channels. Main channel is the middle one (Middle channel) and others named as Left channel and Right channel as shown in Fig. 4.1.

Model gives erosion/deposition for the nodes to produce the bed level lowering or rising, however, it can not automatically shift the bank-line when a bank node gets erosion/deposition for itself. So any lowering of nodes at the bank, indicate the bank at that location is vulnerable, which is supposed to produce bank erosion and subsequent bank-line shifting. In this model vulnerable banks are identified by taking several cross-sections at different locations of the model, where the bank nodes have undergone lowering of its bed elevations. Some engineering interventions have been investigated through the calibrated and validated model, to maintain a minimum navigable depth in the channels in question.

4.1 Erosion and deposition processes

The series of figures as shown in Figs. 4.2-4.3 reveal that the two morphological years have much similar type of erosion and deposition patterns. Both erosion and deposition occur mainly in August and September of each year.

The results indicate that erosion mainly takes place in the Eastern anabranch and in the Left channel of Western anabranch. On the other hand severe deposition is taking place in the Middle and downstream of Middle channel of Western anabranch near Naradaha. This deposition is most likely due to backwater effect in the confluence. Erosion also takes place in the lower boundary of the Padma. For a clear understanding of erosion deposition patterns of different years, several cross-sections are taken from the same location of the model. The locations of those cross-sections are named as Arc1 – Arc3 as shown in Fig. 4.1

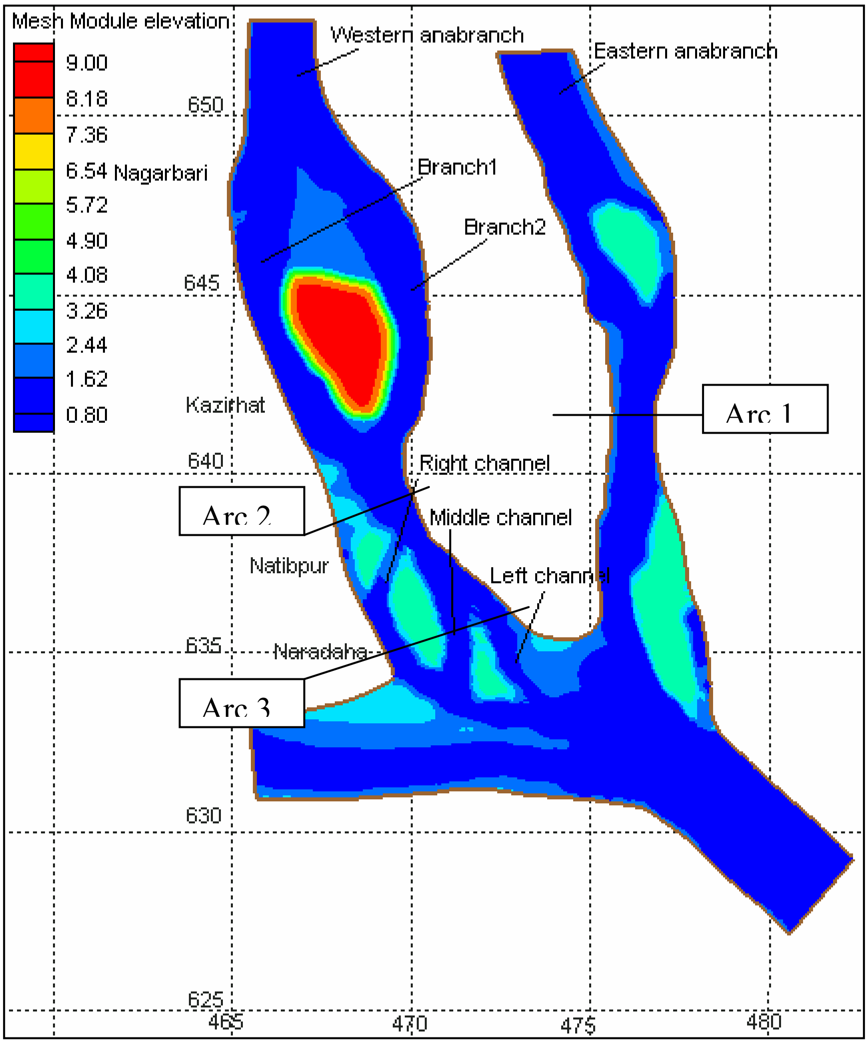


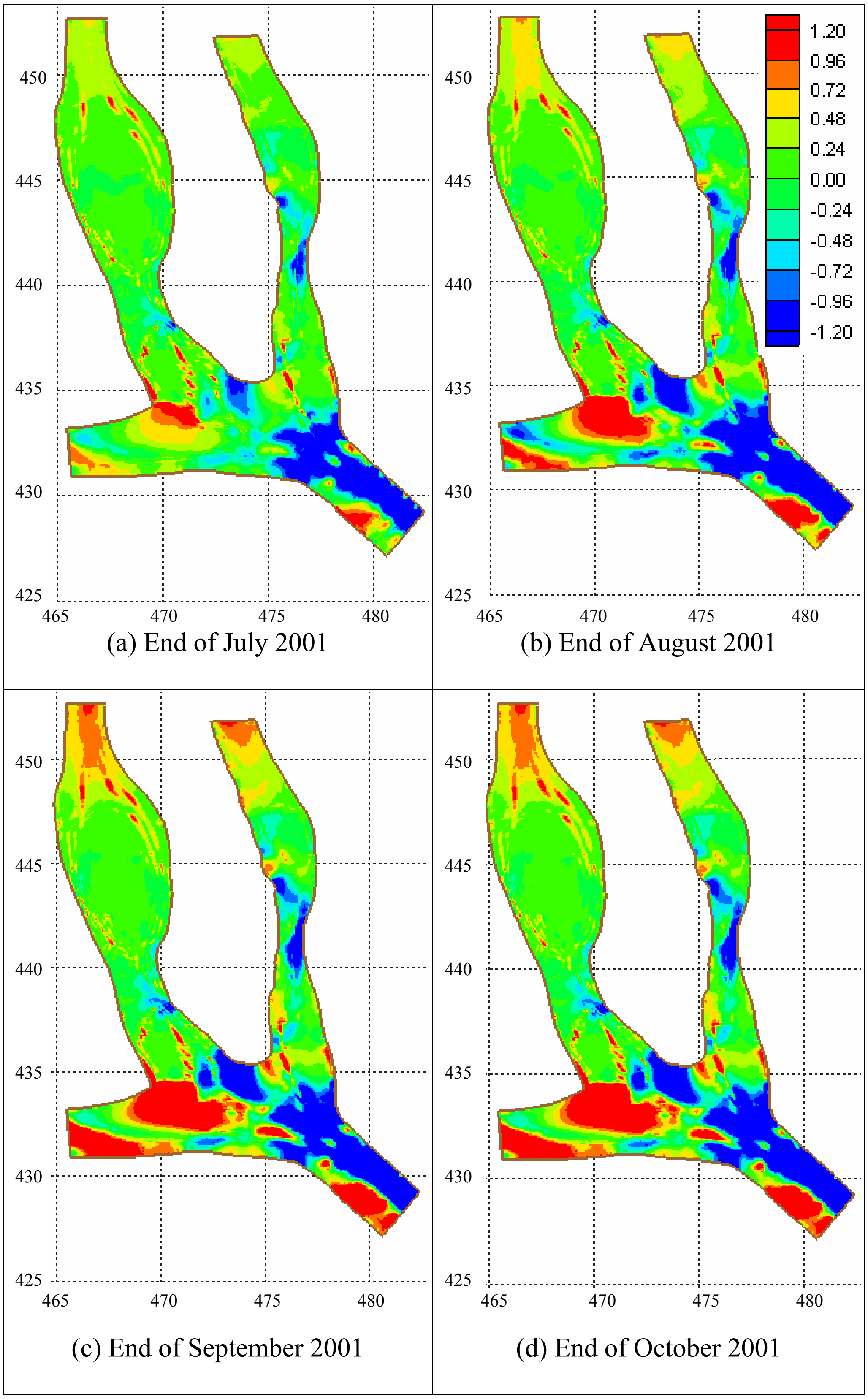
Fig. 4.1 Initial bathymetry in April 2001

In Eastern anabranch there is a small island in the upstream end of the model (Fig. 4.1). This island normally remains dry during low flows and flooded during monsoon seasons. In the beginning of the simulation, in June 2001, the main flow was passing through the left side of the island. In the subsequent years, it is clear from the

Figs. 4.2 – 4.3 that the right channel of the island has undergone severe erosion. Cross-sections superimposed at Arc1 (Fig. 4.4a) for years 2001 – 2004 indicate left bank erosion of 5.5 m. The right bank has showed a lowering of its surface by 0.6 m. So, both banks are vulnerable with erosion in this location but left bank is more affected than the right bank. Due to meandering behavior of alluvial channel, erosion is taking place at outer bank and deposition at inner bank, which has been revealed in the next reaches In Western anabranch two cross-sections have been taken to observe the erosion/deposition pattern in that channel. Near Natibpur (Arc 2, Fig. 4.4b) severe erosion of around 3 m has been found in the main channel as well as in the left bank. However, deposition in the Right channel has reduced the flow from its main channel towards its downward channels. Near Naradaha (Arc 3, Fig. 4.4c) it has been observed that erosion takes place in the Left and Middle channels whereas Right channel remains unchanged. In its course of flow, both the Left and Middle channels together enforces the main flow of the river through its left side. Just downstream of this section shows that Middle channel and downstream of Middle channel are silted up, which also divert the flow towards Left channel.

A major change has been observed at downstream of Naradaha. Huge deposition around 6-7 m has been observed in the Middle channel and in the down of the Middle channel. On the other hand, around 2 m erosion has taken place in the Left channel as well as in the left bank. This indicates that main navigation channel (Middle channel) and its downstream portion is being closed up due to heavy siltation, while the Left channel is getting open and setting opportunity for navigation towards Kazirhat.

The whole process can be rationalized as a deposition dominated progression near the confluence due to back water impact of the Ganges. Also it is striking to say that Jamuna has gone through major morphological changes immediately after 1998 flood, which is still causing all these sort of shifting until today due to instability inflicted far upstream.



(a) End of July 2001

(b) End of August 2001

(c) End of September 2001

(d) End of October 2001

Fig. 4.2 Simulated erosion/deposition for July – October 2001

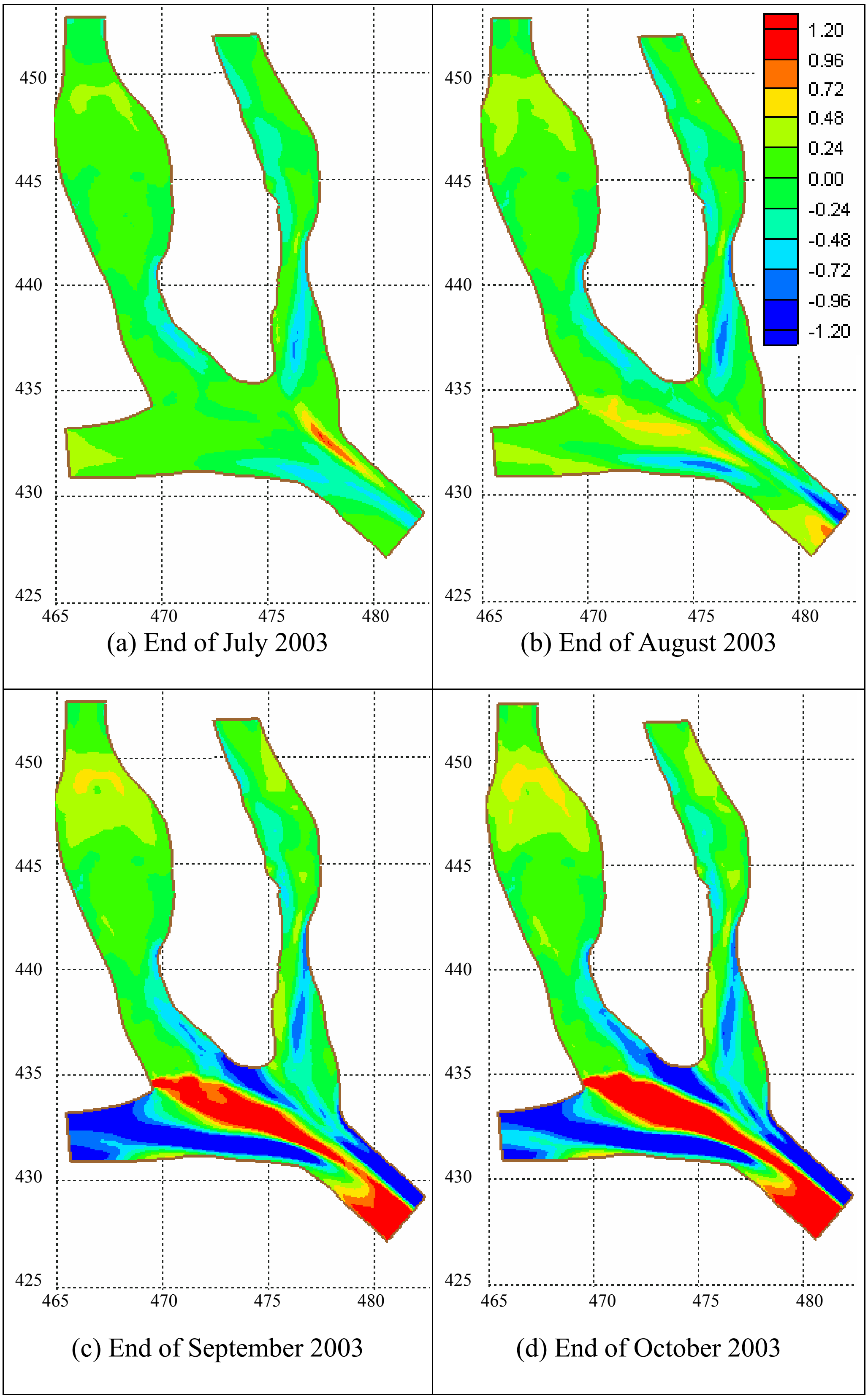
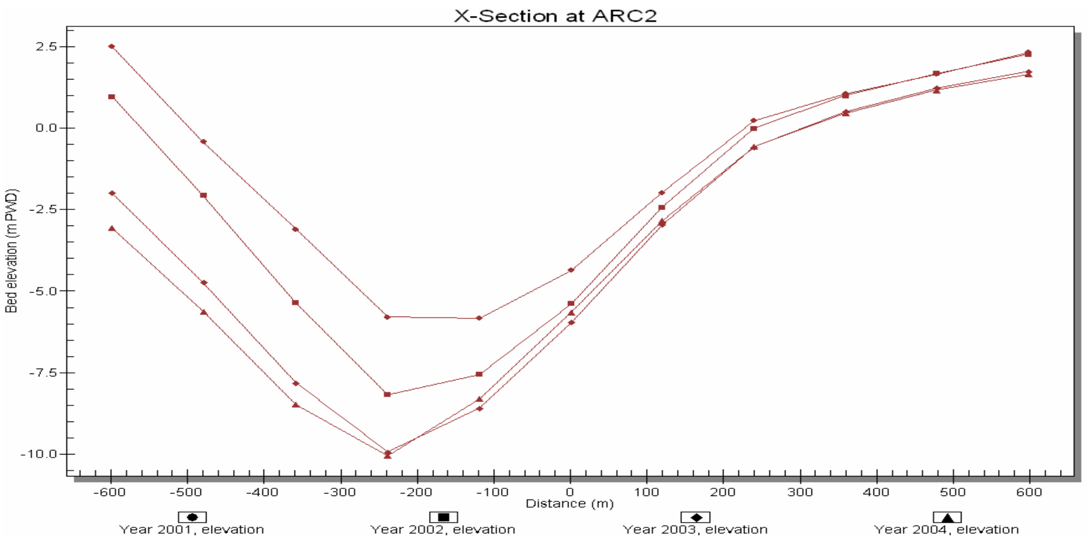
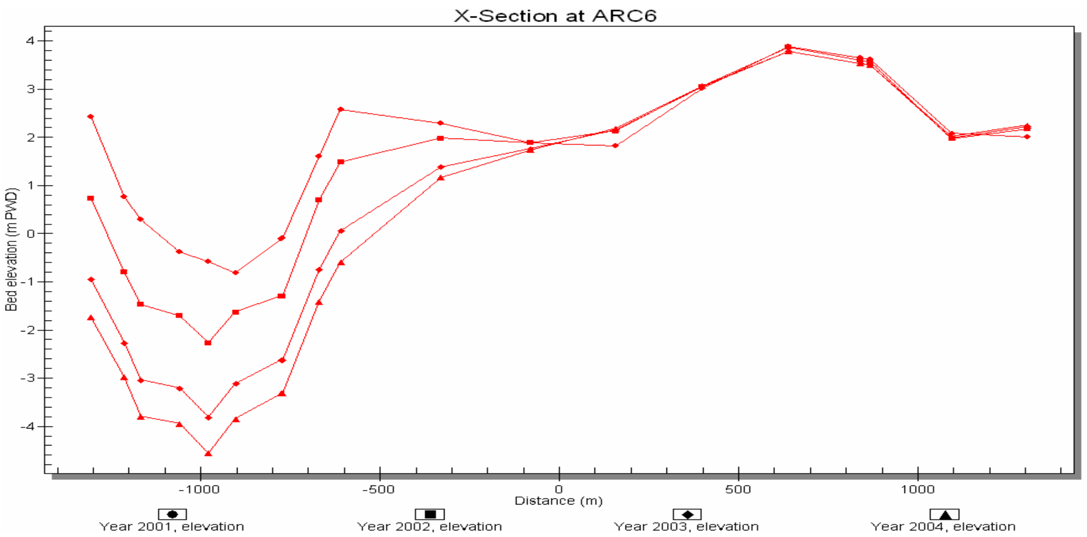


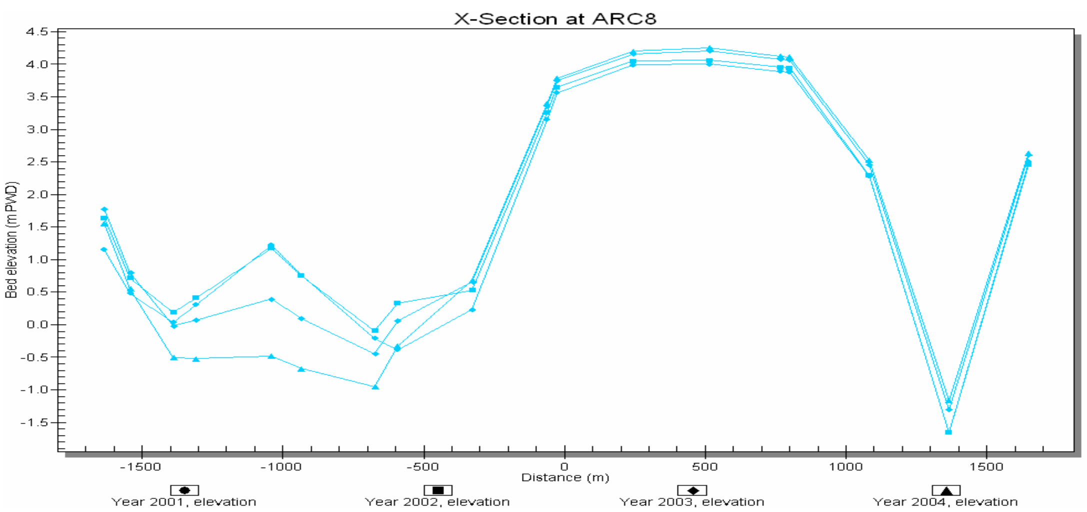
Fig. 4.3 Simulated erosion/deposition for July – October 2003



(a) Cross-section at Arc1



(b) Cross-section at Arc2



(c) Cross-section at Arc 3

Fig. 4.4 Cross-sections at different locations for 2001 to 2004

4.2 Back water impact

Investigating the velocity vectors and its magnitudes, it is clearly observed in the confluence that the velocity has been reduced drastically compared to their respective main channels. This velocity reduction in the confluence significantly diminishes their sediment transport capacity, and hence inducing deposition.

When Jamuna river has the early peak and has a larger flow than the Ganges, it is found from the velocity vectors (Fig. 4.5a) that the flow of Jamuna river thrusts the flow of Ganges further down, and as a consequence Jamuna flow velocity reduces considerably in the lower part of the confluence and induces settlement in that region.

When Ganges flows are of larger magnitudes than the flows of Jamuna, it is found from the velocity vectors of Fig.4.5b that the Ganges flow drives on to the Jamuna flow, and as a consequence Ganges velocity has been significantly reduced in the same area that has been occurred during Jamuna at its peak. This time backwater effect of Jamuna has been shifted further upward. Now settlement of Ganges sediment takes place in the upper portion of the confluence.

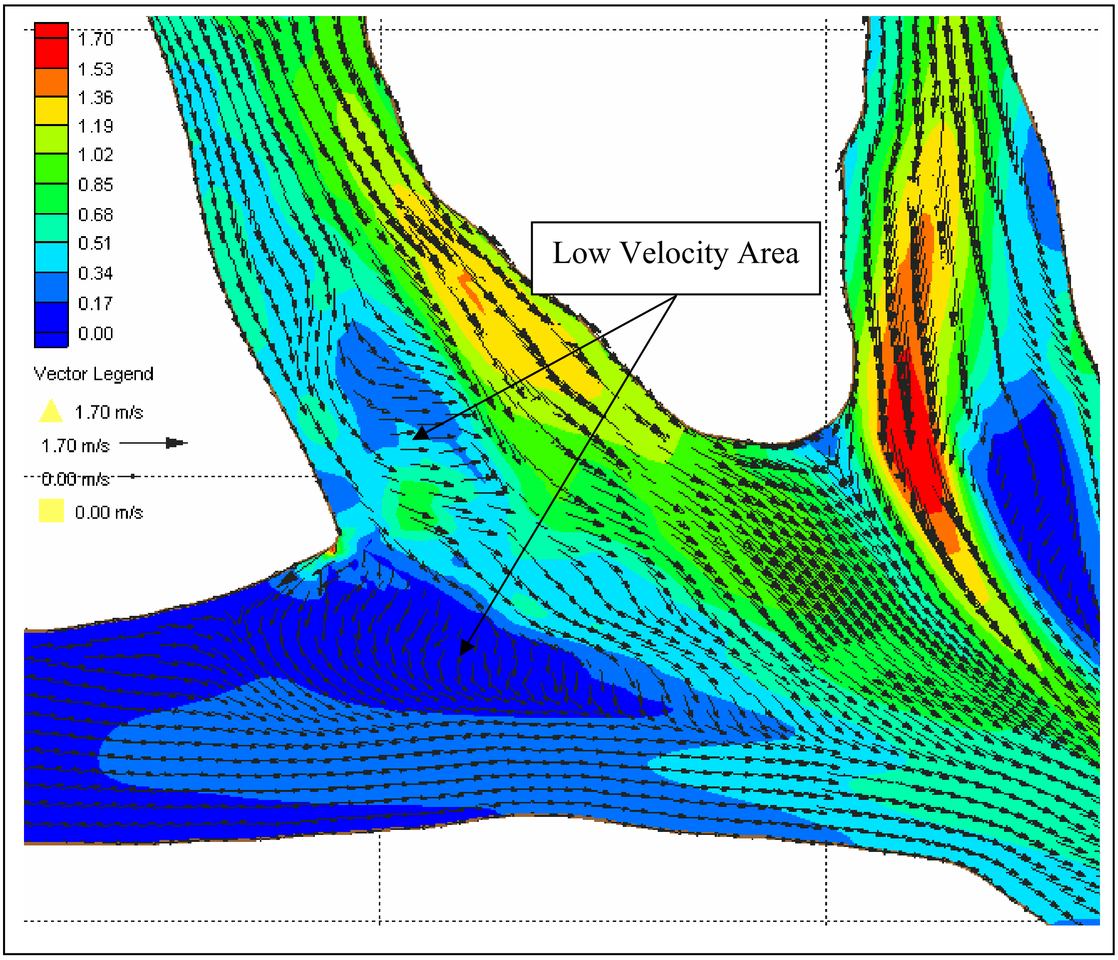


Fig.4.5a Velocity vectors in July 2003

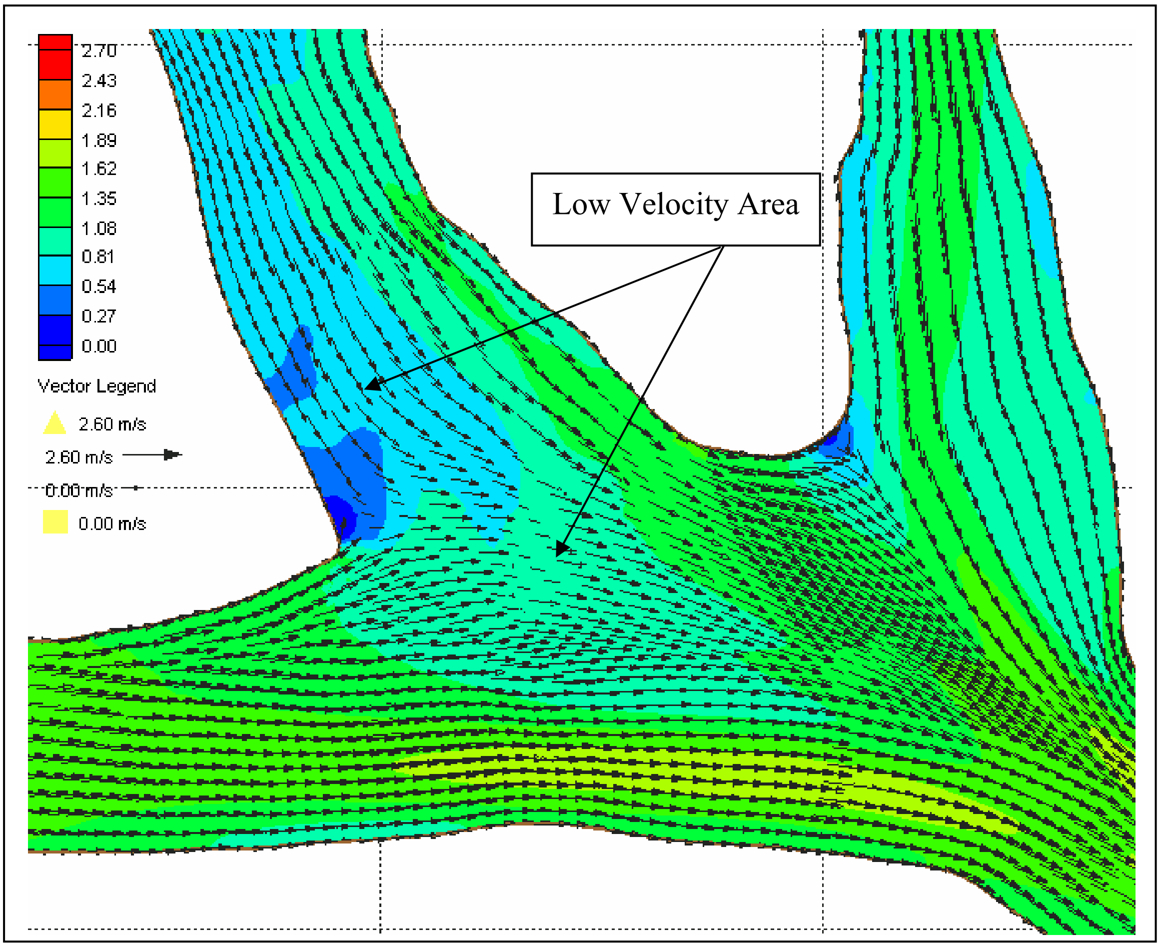


Fig. 4.5b Velocity vectors in September 2003

4.3 Plan-form changes

After three years of morphological runs, the simulated bathymetries indicate that the Middle channel, near Naradaha (Fig. 4.6), is being closed up due to heavy siltation and Left channel has been opened up due to erosion.

A similar kind of observation was being found by Hoque (1999) for 1988 flood using series of satellite images of 1973-1996. Before the devastating flood of 1988, the recent position of Western and Eastern anabranches was the location for a single channel of the Jamuna river. Hoque (1999) stated that any concurrence of Jamuna and Ganges peaks may change the plan-form radically, and this incidence has happened in both 1988 and 1998 floods.

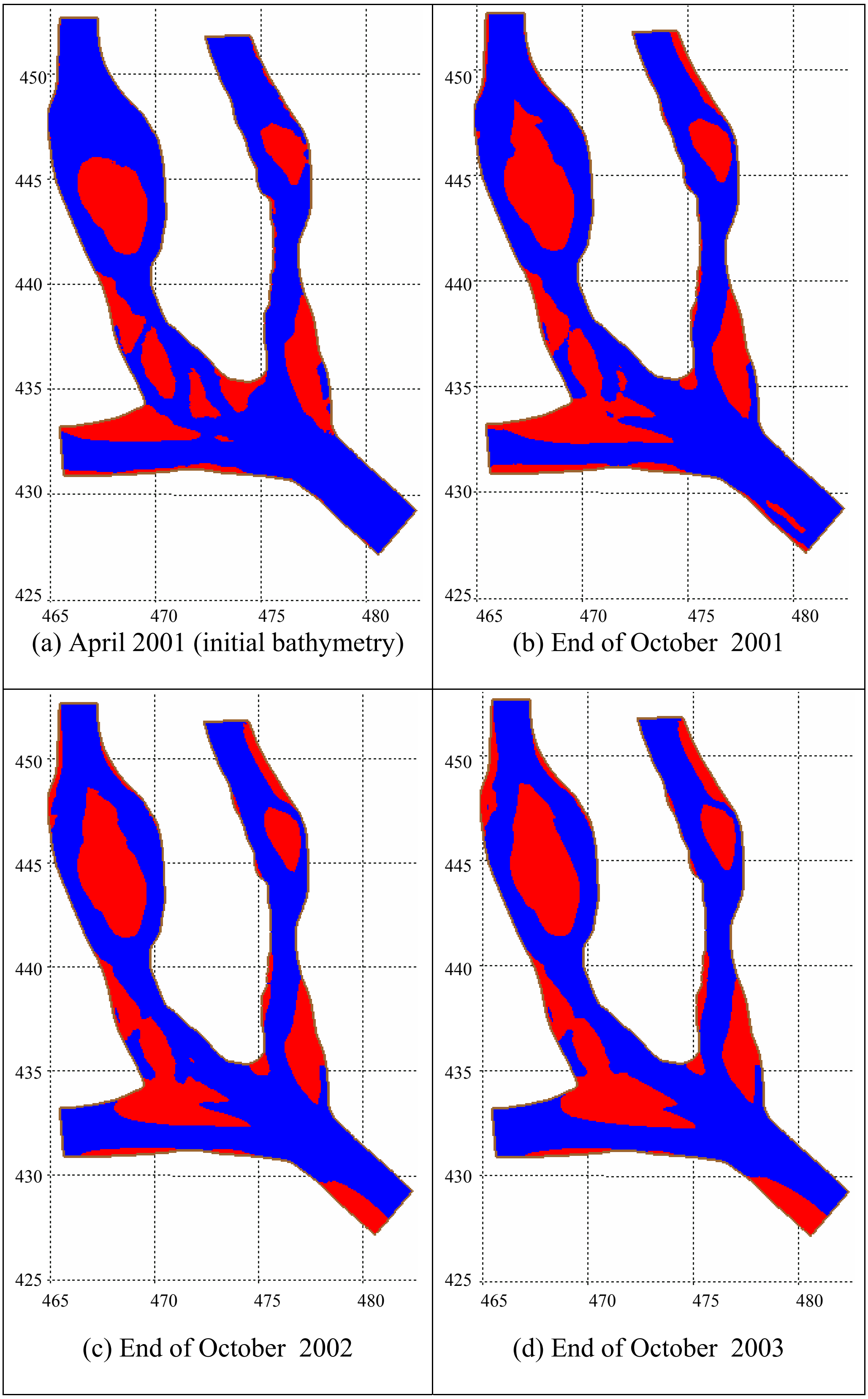


Fig. 4.6 Initial (April 2001) and simulated 2001 to 2003 bathymetries (using bed elevations 2.0 m PWD below and above)

4.4 Navigable depth

According to BIWTA the minimum depth required for a ferry is 2.3 m. Simulation runs have been given using monsoon period data (June-October) starting from 2001, up to 2003. To obtain the depths at lean periods, using lowest water levels and corresponding discharges, several steady runs have been generated for initial (April 2001) and simulated bathymetries (for October 2001, October 2002, and October 2003). Lowest water level of 2.6 m PWD at the downstream boundary has been applied for the above steady runs. The corresponding flows at Jamuna and Ganges are 4100 m^3/sec and 2110 m^3/sec, respectively. Results indicate that old route (Middle channel) near Naradaha has been blocked due to deposition and new route (Left channel) has been opened up (Fig. 4.7).

It is observed from Fig.4.8 that a deeper pocket channel exists, through out the study-period, near right bank at Naradaha. Nominal deposition has been observed as shown in Fig. 4.4b (Arc 2) for three years. It seems the location is in the leeway besides the heavy siltation region. To use that natural deep pocket as a location for ferry ghat, three possible options, as shown in Table 4.1, have been explored to find a sustainable navigable route. The amounts of capital dredging required to implement those options, as calculated from the respective 2003 simulated bathymetry, are also shown in Table 4.1.

To connect with this deep pocket, one or two channels have been dredged to formulate the options. The motivation for those options is being generated by looking into the Fig. 4.8. From the shades of 0.33 m or above depths of water as seen in Fig. 4.9, for simulated bathymetry of October 2003, it is clear that two shallow channels near Natibpur are still connected to the deep pocket. So connecting the deep pocket by means of different dredged channels has given the possible options.

The first option (Fig. 4.9a) is taken as, dredging of a channel near Naradaha to connect the lower segment of deep pocket, and second option (Fig. 4.10a) is taken as, dredging of Right channel near Natibpur to connect the upper segment of deep pocket. Scrutinizing these two options in the model runs, it is found that Option1 has shown severe deposition, whereas Option2 has shown little deposition. In a bid for further improvement, Option 3 (Fig. 4.11a) has been designed, where both upper and lower segments of the deep pocket would be connected to proposed dredged channels, along with a spur placed in the left bank near Natibpur. The options are described in next sub-articles.

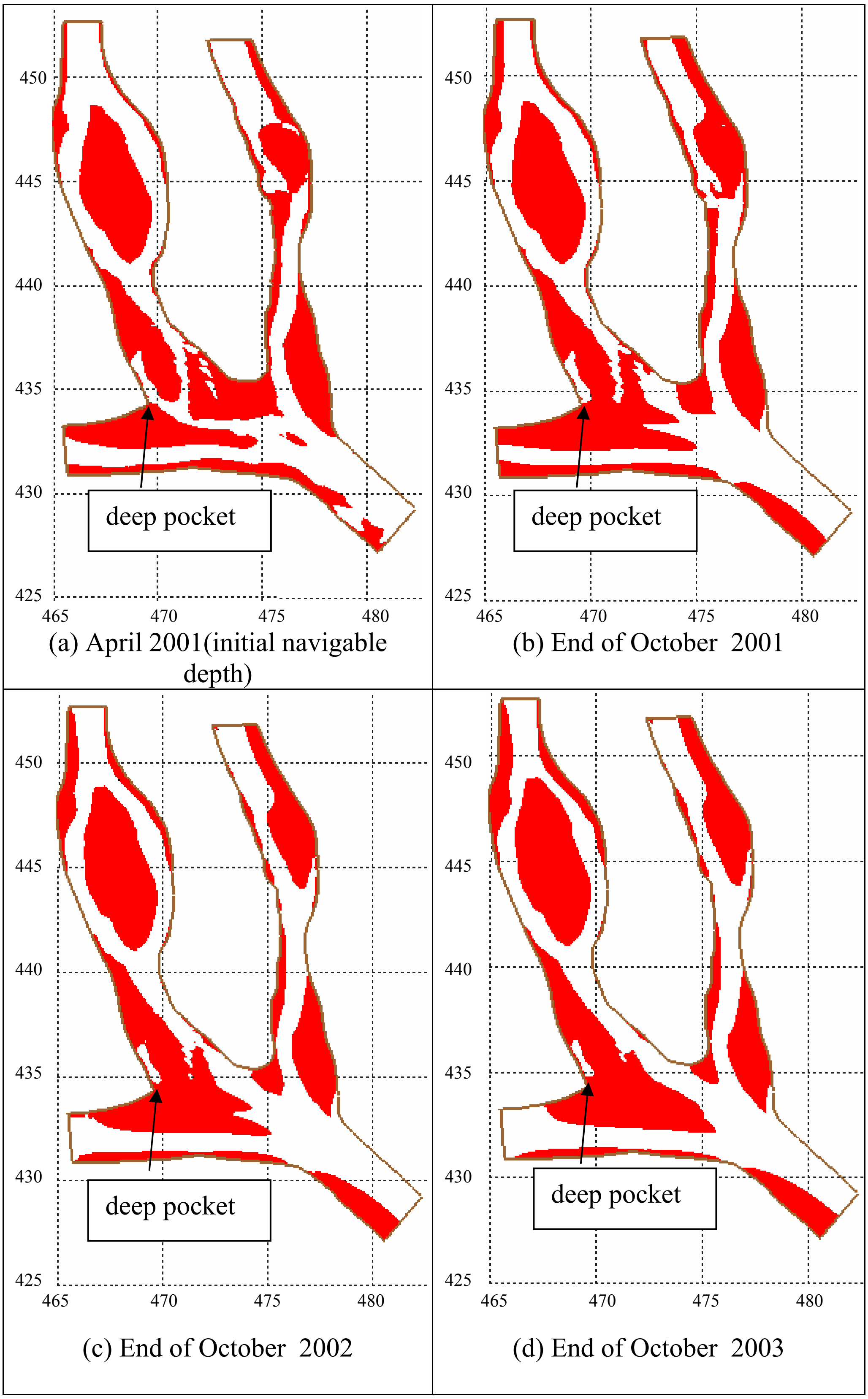


Fig. 4.7 Initial (April 2001) and simulated 2001 to 2003 navigable depths (using depths 2.3 m below and above)

Table: 4.1 Options with the amount of capital dredging and their locations

Options	Location	Intervention	Amount of dredging, Mm^3
Option 1	near Naradaha (435 Lat.)	dredging	3.57
Option 2	near Natibpur (437.5 Lat.)	dredging	0.9
Option 3	dredging in both Natibpur and Naradaha, and spur at Natibpur	dredging and spur	4.47

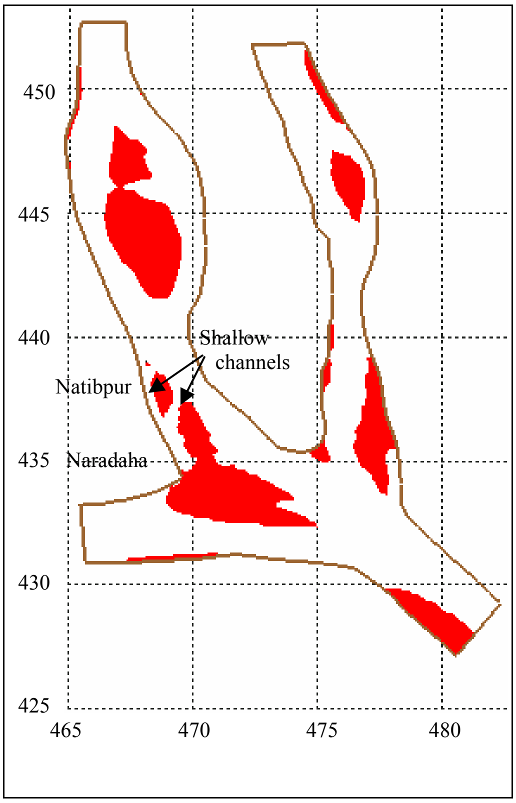


Fig. 4.8 Simulated 2003 navigable depths (using 0.33 m or above water depths)

4.4.1 Option 1: dredging downstream channel

This option is taken to connect the deeper pocket by dredging a channel in the downstream of deep pocket near Naradaha (Fig. 5.9a). Bed elevations of the nodes in question of the proposed dredged channel are lowered on to the 2003 bathymetry, to obtain the minimum navigable depth and thus the resultant bathymetry has been used to run the model for next one morphological year. After one year of simulation, navigable depths are presented in the Fig. 5.9b. It has been found that the dredged channel has been closed due to deposition. An average deposition of 3.0 m depth has been obtained in the channel. Deep pocket shows little deposition. Severe deposition that takes place near the confluence at Naradaha, results in closing of the proposed dredged channel.

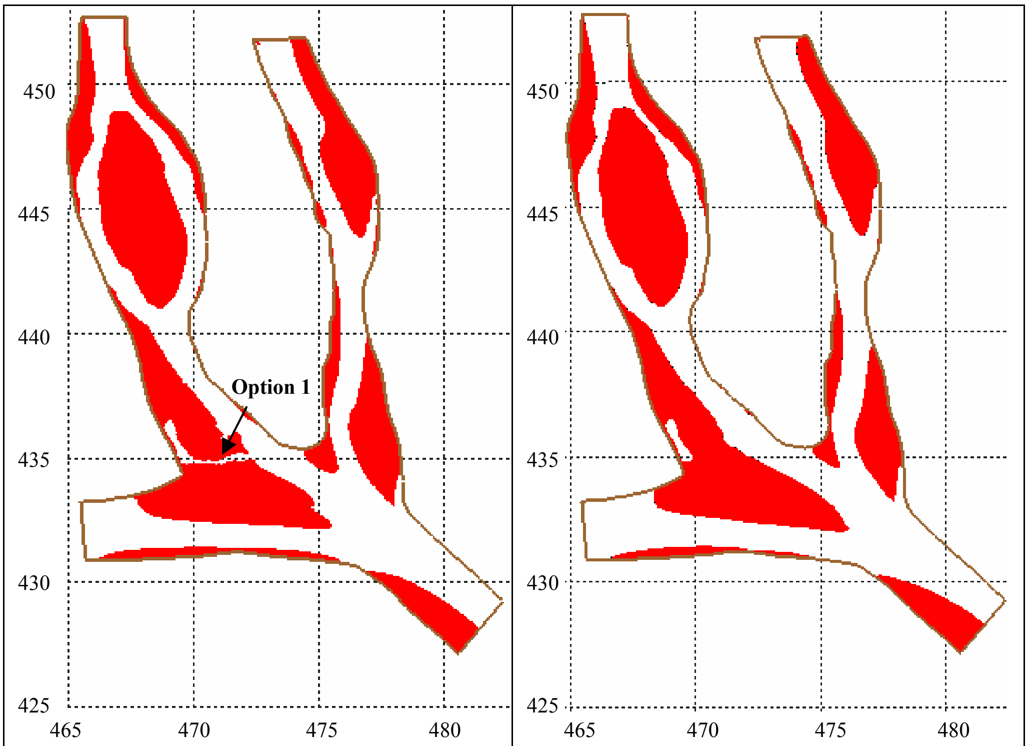


Fig. 4.9a Navigable depths on to 2003 bathymetry (using depths 2.3 m below and above)

Fig. 4.9b Navigable depths after 1-year simulation (using depths 2.0 m below and above)

4.4.2 Option 2: Dredging upstream Right channel

From three years simulations, it has been found that about 1.0 to 1.5 m deep shallow channel exists (or have a deposition of 0.6 to 0.8 m) in the Right channel of Western anabranch near Natibpur. To be connected with the deeper pocket, dredging of this shallow channel has been taken as another option. Bed elevations of the nodes in question of the channel are lowered on to the simulated 2003 bathymetry, to have a minimum navigable depth (Fig. 4.10a) and thus the resultant bathymetry has been used to run the model for next one morphological year. After one year of simulation, navigable depths are presented in the Fig. 4.10b. It has been found that the dredged channel has shown little deposition. It has been found that an average deposition of 0.35 m occurred. So a total of 0.18 Mm^3 (0.35 m×350 m width×1474 m length) volume of dredging in every year would be enough to maintain the channel as an entrance to the deep pocket.

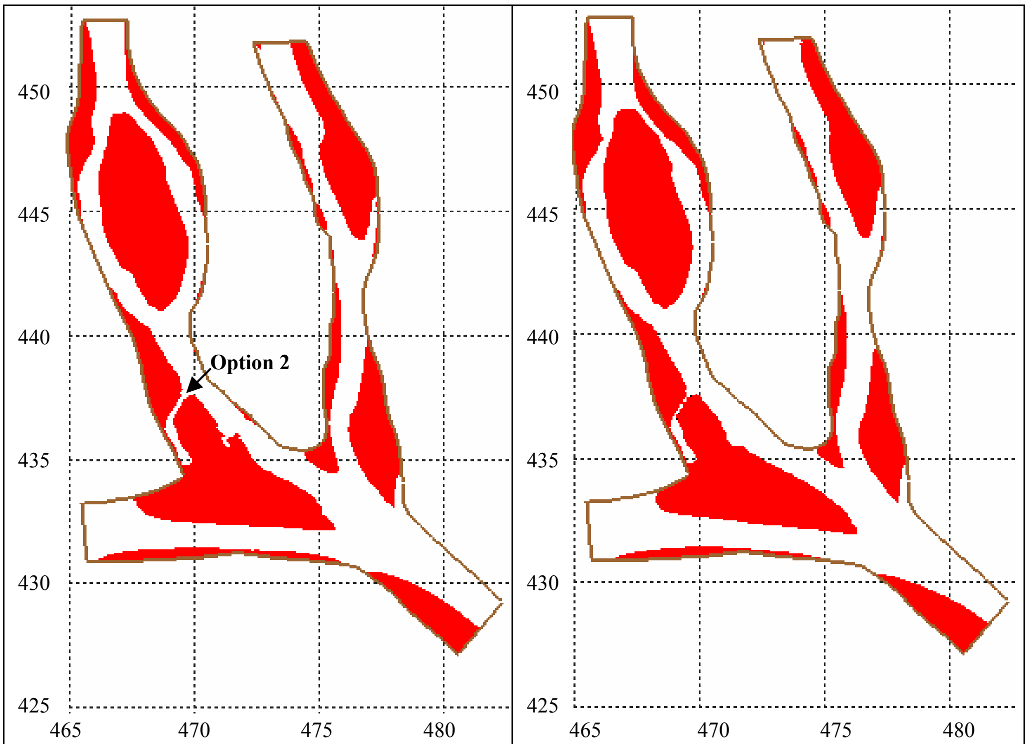


Fig. 4.10a Navigable depths on to 2003 bathymetry (using depths 2.3 m below and above)

Fig. 4.10b Navigable depths after 1-year simulation (using depths 2.0 m below and above)

4.4.3 Option 3: Dredging and spur

The spur has a width of 20 m and length of 480 m. Fig. 4.11a that shows the resultant bathymetry has been used to run the model for next one morphological year. After one year of simulation, navigable depths are presented in the Fig. 4.11b. Presence of spur induces erosion in its downstream locations starting immediately from its nose. Construction of spur has attracted more erosion at the entrance of the proposed channel. However, subsequent reaches show the opposite, around 0.45 m deposition has occurred, which is slightly more than the Option 2 deposition (average 0.35 m). The deep pocket has also shown slightly more deposition than Option 2. An average deposition of around 3.0 m has been found in the downstream proposed channel near the confluence.

Though erosion takes place at the entrance of the Right channel, part of those eroded materials have been deposited in the interior of the proposed channel, which in a way has induced higher deposition compare to Option2. Dredged downstream channel near Naradaha has disappeared, by as usual process of heavy siltation that developed due to backwater effect in the confluence. So presence of spur does not improve the situation anymore.

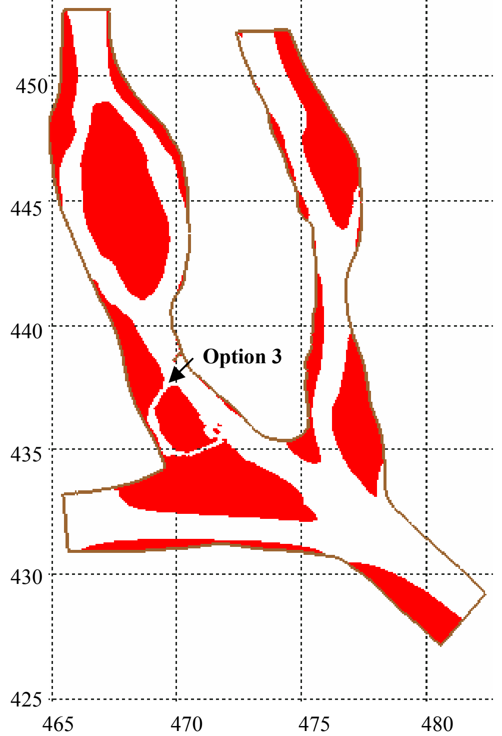


Fig. 4.11a Navigable depths on to 2003 bathymetry (using depths 2.3 m below and above)

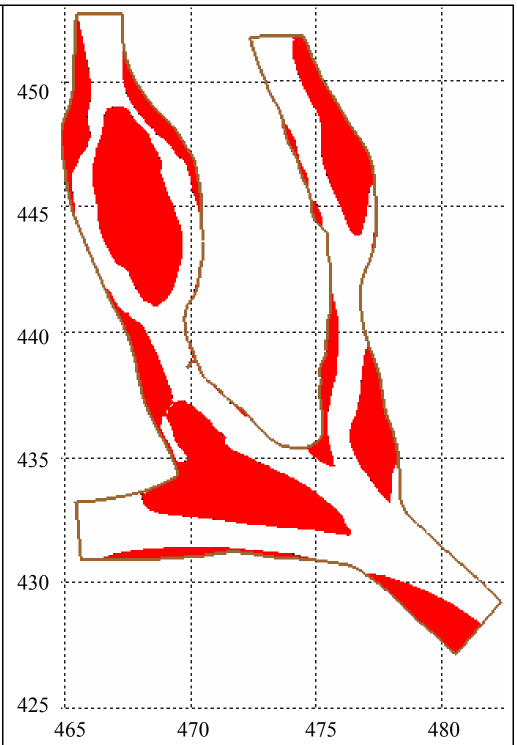


Fig. 4.11b Navigable depths after 1-year simulation (using depths 2.0 m below and above)

4.5 Location of ferry ghat

Protabpur and Kazirhat are two temporary locations for existing ferry ghats. In the past, BIWTA maintained a ferry route from Aricha to Nagorbari. This route has long been abandoned due to large-scale siltation and shifting of the western anabranch. Morphological changes have also been observed in the simulated bathymetries. A mathematical model study carried by BUET and IWM (BIWTA, 2003), suggested construction of a ferry ghat in Kazirhat. As alternatives three more locations (Khanpura, Khayerchar, and Natibpur) have been identified for possible ghat construction, however, priorities of these locations were less compared to Kazirhat. It is worthy to mention here that Khayerchar is a site, which has been favored and provisionally selected by Inter-ministerial Committee, formed in December 2002. It is about 1.0 km upstream of Naradaha, where bank elevation is around 8.0 m PWD and during monsoon the site goes under water. However, the committee in its report pointed that the crossing distances, travel time and fuel cost can be kept at minimum and greater turnouts of ferry operations may be achieved.

It was mentioned in BIWTA (2003) that Khayerchar/Naradaha site has a possibility for further siltation to discontinue the existing navigable channel in near future. A huge dredging, which is like Option 1, has been anticipated for keeping the route alive. During the time of study of BIWTA (2003), the existence of the deep pocket, as mentioned earlier, was overlooked to be connected from upstream. So this deep pocket motivates this present study to take into account the proposed dredged channel at upstream end, and explore its future sustainability. In a way, Option 2, the upstream dredged channel, has turned to be a productive option. It shows a requirement for maintenance dredging, of the order of 0.18 Mm^3, and a capital dredging of 0.9 Mm^3 has been determined to initiate the proposed option. So the new route to deep pocket is found to be 3.3 km less (Fig. 4.12) than the route followed in Kazirhat by BIWTA (2003). This site poses a new alternative compared to Kazirhat.

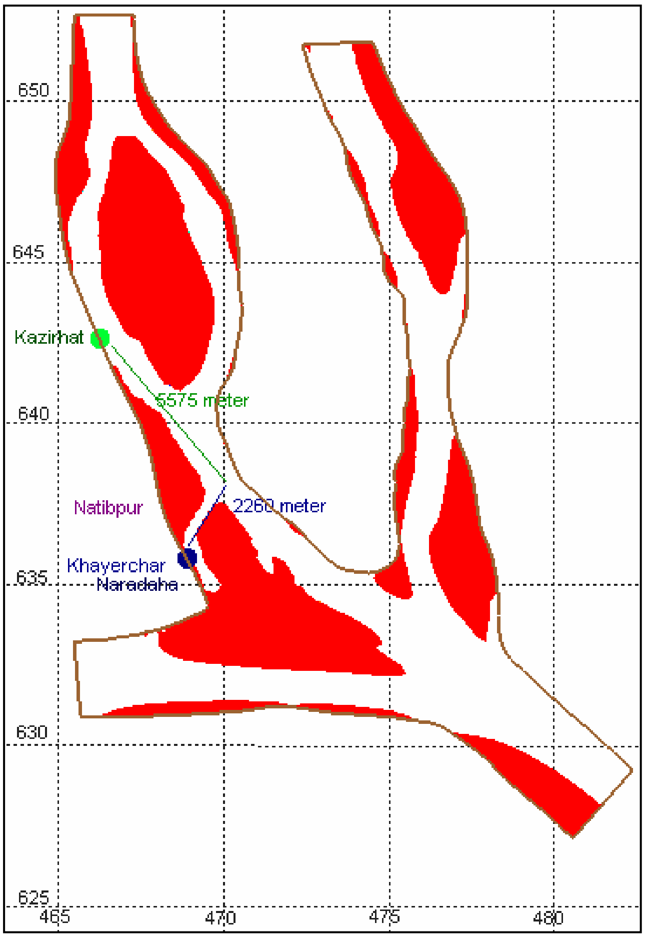


Fig. 4.12 Location of ferry ghats (contour using depths 2.3 m below and above)

5. Conclusions

Morphology of braided river is a very complex phenomenon. To study the morphological behavior of Jamuna river, two-dimensional simulations are formulated using finite element models RMA2 and SED2D under SMS environment.

The finite element mesh has been generated using LANDSAT image of 17th November 2000, and initial bed elevations for the nodes of the mesh have been composed from the scattered survey data of April 2001 by BIWTA. Once the mesh and bathymetry have been obtained, the models are ready thereby to incorporate boundary conditions, initial conditions and material properties. To simulate the morphology of the river, models have been run for monsoon, June-October of each year. It is assumed that negligible changes occur during lean seasons, and therefore these time periods have been kept out of purview of modeling. Simulations have been done for 2001-2003 for their given boundary conditions of June to October.

The summary of the findings of the present study are as follows:

1. All three years simulations have shown much similar type of erosion/deposition processes. Both erosion and deposition occur mainly in August and September of each year.
2. Erosion takes place in the outer bend of the meandering Eastern anabranch and in Western anabranch, severe deposition has been observed near the confluence due to backwater effect of Jamuna-Ganges flow. Velocity reduction in the confluence significantly diminishes their sediment transport capacity, and hence inducing deposition.
3. It is evident that the complex waterway at the confluence is further complicated by the occurrences of characteristic hydrographs from Ganges and Jamuna, that differing in strengths with time, induces different dominating phenomena to work on sediments to settle at assorted positions.
4. It has been found from the observed bathymetries of 1996-2003 that Jamuna has gone through a major transformation after 1998 flood. Its course has shifted more towards left bank particularly near confluence. This is one of the reasons for enhanced deposition in the downstream of Middle channel near Naradaha. These observations from measured data are further substantiated by the results obtained from the present simulation models.
5. Calibrated and validated model has been used to find a sustainable navigable channel. Three options have been examined using a deep pocket found near west bank of Naradaha. Option 1 is the dredging of a downstream channel connecting the lower segment of the deep pocket near Naradaha. This channel fills up with serious deposition within a season. Option 2 is the dredging of

Right channel connecting the upper segment of the deep pocket near Natibpur. This channel shows little deposition and can be maintained with yearly dredging of the order of 0.18 Mm^3. To improve further, Option 3 has been designed with a blend of Option 1 and Option 2 along with a spur in the left bank of the permanent char near Natibpur. However, the option failed to improve the situation. Lower channel again silted up within a season, and the erosion that has been initiated by the spur at the entrance of the Right channel, transport part of these sediments in the interior of the Right channel for enhanced deposition. Therefore, Option 2 has been considered for using as a navigable channel towards Khayerchar/Naradaha instead of Kazirhat proposed by BIWTA (2003).

6. The new route to deep pocket is found to be 3.3 km less than the route followed in Kazirhat. This site represents a new alternative.

References

BRTC., 2003, Hydraulic and morphological study for the selection of a site for ferry ghat alternative to Nagarbari/Notakhola, Final Report prepared by department of Water Resources Engineering, BRTC, BUET, June 2003.

Bristow, C.S., 1987, Brahmaputra River: Channel migration and deposition, proc. Conference on Fluvial Sedimentolgy.

Hauqe, N., 1999, Application of remote-sensing and GIS for monitoring fluvial processes, PhD. Thesis, Physics department, BUET.

Hossain, M.M., 1992, Total sediment load in the lower Ganges and Jamuna, Jr. Institution of Engineers, Bangladesh, vol. 20(1-2), pp. 1-8.

Klaassen, G.J., and Vermeer,K., 1988a, Channel characteristics of the braided Jamuna River, Proc. International Conference on River Regime, Wallingford, U.K., pp. 173-189.

Klassen, G.J., and Vermeer, K., 1988b, Confluence scour in a large braided rivers with fine bed material, Proc. Intrenational Conference on Fluvial Hydraulics, Budapest, Hungary, pp. 395-408.

Klaassen, G. J., and Vermeer, K., and Uddin, N., 1988, Sedimentological processes in the Jamuna (Lower Brahmaputra) River, Bangladesh, Proc. Intern. Conf. On Fluvial Hydraulics, Budapest, Hungary, pp. 381-394.

Klaassen, G.J., and Masselink, G., 1992, Planform changes of a braided river with fine sand as bed and bank material, Proc. 5th International Symp. River Sedimentation, Karlsruhe, FR Germany, pp. 459-471.

Thorne, C. R., Russel, A.P.G., and Alam, M.K., 1993, Planform pattern and channel evaluation of the Brahmaputra River, Bangladesh, in ‘Braided Rivers’J.L. Best and C.S. Bristow (eds), Geological Society of London Special Publication No. 75, ISBN 0-9003317-93-1, pp. 257-276.

Klaassen, G.J., and van Zanten, B.H.J., 1989, On cut-off ratios of curved channels, Proc. XXIIIrd IAHR Congress, Ottawa, B-121-130 pp.