Two Dimensional Numerical Modelling Support for Planning and Hydraulic Design of a Barrage in Bangladesh

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KEYWORDS
Barrage, Undersluice, Morphology, Hydraulic Design

ABSTRACT:
The Government of Bangladesh has formulated a project to bring the southwestern part of the Kurigram district under surface water irrigation. A barrage across the Dharla river is envisaged as the main structural intervention needed for intended surface water irrigation development. Two-dimensional numerical model investigation has been conducted to support planning and hydraulic design of the proposed Dharla barrage and its associated works. A 36km stretch of the Dharla has been considered for the development of a two-dimensional model using modelling software MIKE21C. The tool is particularly suited for river morphological studies and includes modules to describe flow hydrodynamics, sediment transport, alluvial resistance, scour and deposition, bank erosion and planform changes. The modules can run interactively, incorporating feedback from variations in the alluvial resistance, bed topography and bank line geometry to the flow hydrodynamics and sediment transport. The model setup consists of curvilinear computational grids with different resolutions and fixed boundaries in order to investigate various hydraulic and morphological aspects of the barrage project in base and barrage in place conditions. The initial bathymetry of the model is reproduced based on the pre-monsoon 2008 bathymetric survey data. The upstream and downstream boundaries of the model have been generated based on the recorded discharges and water levels at two gauge stations within the study reach. The model has been calibrated hydrodynamically first based on monsoon 2006 hydrological data. Morphological calibration is then made based on available field data for the same monsoon. The developed model has been applied first for establishment of baseline hydraulic and morphological conditions. Based on the model simulation results in base condition and also taking into account different relevant issues four options of layout plan for head cut, tail cut and barrage alignment have been devised. River responses to each of the four options have been tested and the most suitable option has been selected based on model results and other relevant issues in view. A trial and error approach is then followed for determining the appropriate layout of different barrage components, ancillary works and river training works starting with an initial layout plan of channel closure, canal head regulator, barrage components, guide bund, afflux bund and river training works. The subsequent layouts have been devised based on the results of hydrodynamic evaluation of previous layout. The feasible layouts are then evaluated both hydodynamically and morphologically to arrive at a fair decision regarding appropriate layout of barrage ant its ancillary works and also river training works. The performance of the selected layout under design condition has been tested with canal head regulator and main canal in place. The hydraulic design of the barrage and its ancillary works has been assessed in terms of percentage of total flow through the undersluice section, design discharge availability in the main canal with the considered head, expected afflux, maximum velocity through the barrage, velocity in the main canal for design discharge, siltation potential and need for silt excluding device etc. Based on the study findings conclusions have been drawn regarding appropriate layout of barrage and its associated works and their hydraulic design parameters.

1. INTRODUCTION

The Government of Bangladesh has formulated a project to bring the south western part of the Kurigram district under surface water irrigation for poverty alleviation and socio-economic development of this under-developed area. A barrage across the Dharla River is envisaged as the main structural intervention needed for intended surface water irrigation development. The selected location of the barrage is shown in Fig. 1. Two dimensional numerical modelling of the Dharla River has been undertaken under "Consultancy Services for Detailed Engineering Design of Kurigram Irrigation Project (South Unit)" in order to develop understanding of the physical processes of the river, planning of the barrage and associated works and assessing their hydraulic design and also assessing the effects of the barrage and river training works on river hydraulics and morphology in the upstream and downstream of the barrage in short and long-term. Incorporation of various barrage components to their dimensions in the two-dimensional model is indeed a challenging task. The hydraulics of barrage is essentially three-dimensional and thereby, cannot be accurately described through two-dimensional mathematical formulation. However, in case of gradually varied flow and relatively slow changes in river morphology two-dimensional model is capable of reproducing almost three-dimensional effects. The tool (MIKE21C) used in this study can reproduce three-dimensional effects of helical flow. The tool is also particularly suited for river morphological studies and includes modules to describe flow hydrodynamics, sediment transport, alluvial resistance, scour and deposition, bank erosion and plan form changes. The modules can run interactively, incorporating feedback from variations in the alluvial resistance, bed topography and bank line geometry to the flow hydrodynamics and sediment transport (User Guide, 2007).

Two-dimensional numerical model is developed to study the various aspects of the barrage project. In this regard four computational curvilinear grids have been generated with different resolutions mainly to cover river diversion, incorporation of barrage components to their dimensions, overcoming limitation in specifying internal boundary condition and reducing computational time. The developed model is then successfully applied for meeting different study objectives. This paper presents the outcomes of the assessment of hydraulic design of the barrage and ancillary works under different flow conditions including design discharge.

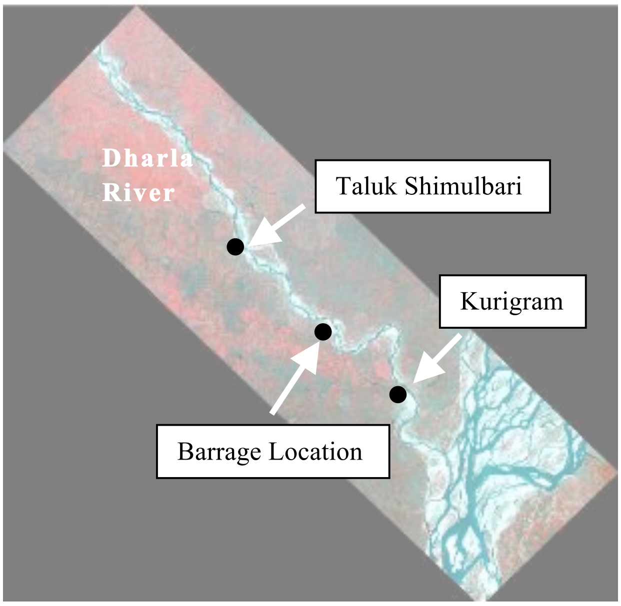

Figure 1. Location of the proposed Dharla Barrage

2. METHODOLOGY

The collected data to support the modelling work include bathymetry, historical discharge and water level, sediment and satellite imageries. The data has been utilized for model development. Several steps have been followed for development of model that include domain selection, grid generation, bathymetry preparation, calibration and validation. Different curvilinear computational grids with different resolutions and fixed boundaries have been generated according to the needs for studying different aspects of the barrage project. The generated grids appear in Fig. 2 (Final Report, 2010).

Grid 1 and grid 2 have been generated covering a computational domain of 36km whereas grid 3 covers a domain of 25km. Initial bathymetry corresponding to the three computational grids has been reproduced based on the pre monsoon 2008 bathymetric survey data. The survey data has been processed according to the requirement of bathymetry preparation using standard MIKE21C bathymetry preparation module (M21GG). The initial bathymetry corresponding to the computational grids 1 and 3 model has been shown in Fig. 3 (Final Report, 2010).

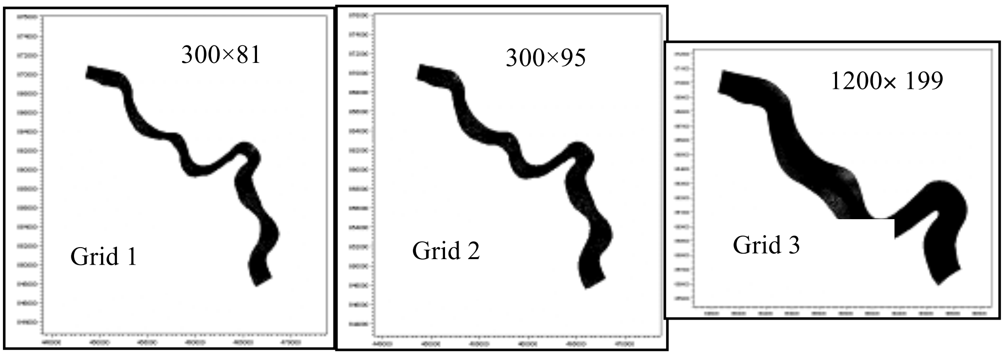

Figure 2. Generated curvilinear computational grids

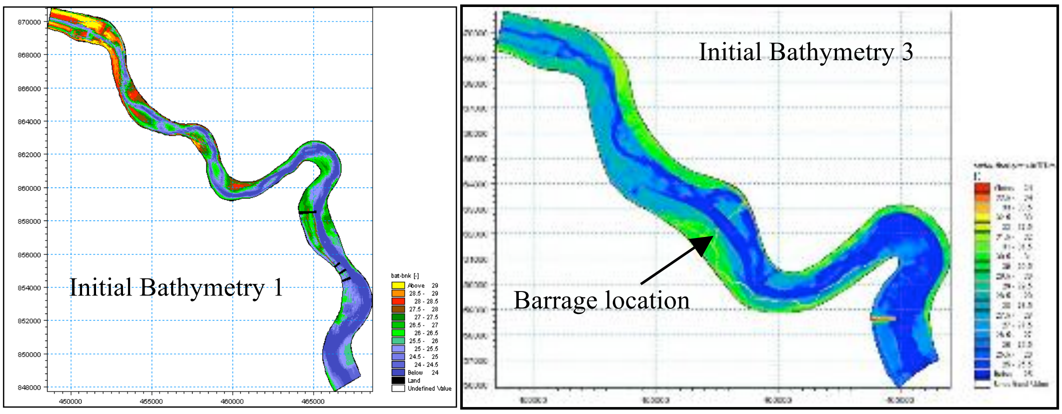

Figure 3. Prepared initial bathymetries for Grid 1 and Grid 3

The upstream boundary of the model is located somewhat upstream of Taluk Shimulbari where there is a gauge station for discharge and water level. However, there is no gauge station at the downstream boundary of the model. The water level gauge station at Kurigram is about 8km upstream of the downstream model boundary. It is, therefore, possible to determine downstream water level boundary of the model from recorded water levels at Kurigram by slope analysis. In this study boundaries have been specified as constant value and time series as necessary. Since initial assessment has been made with steady state and short-term simulations, boundaries have been generated accordingly. Steady state simulations have been made with different return period discharges and water levels. These discharges and corresponding water levels have been determined from historical record of annual maximum discharge and water level by frequency analysis using Gumbel Extreme Value Type III. On the other hand, time series boundaries have been obtained from the record of daily water levels and infrequently measured daily discharges of the Dharla River. Time series discharge boundaries are, therefore, representative of rated discharges. Inspection of available time series data shows that event in 2006, 2004 and 1968 almost corresponds to 1 in 2.33 year, 1 in 10 year and 1 in 25 year event respectively. However, no event in the record corresponds to 1 in 100 year or even 1 in 50 year event. Time series boundaries corresponding to these events have been synthesized from recorded events.

The model has been calibrated hydrodynamically first. Monsoon 2006 data has been used for calibration. Event in 2006 corresponds to an average event. During hydrodynamic calibration default values of flooding and drying depth have been specified. It is anticipated that it will cause minimum loss of computational points. Different values of eddy viscosity have been tested and finally a constant value is selected. It is found that the influence of eddy viscosity is too little in the model. Bed resistance has been specified by Chezy number. Local variations in the bed resistance have been specified using a map of resistance number. Model generated water levels at Kurigram point have been compared with measured ones at the same location in order to confirm that the model is hydrodynamically calibrated. Morphological calibration of the model has been made for the same monsoon (2006). A number of input parameters have to be specified to this end. Initial estimation of the value of different input parameters has been done based on available data and previous experience. Besides, discharge and water level, the morphological model has been calibrated against sediment transport. There is no historical record of sediment transport for the river. Under the framework of the study few measurements of sediment concentration and corresponding discharges have been conducted. These data have been compared with model generated sediment concentration and sediment transport. The alluvial resistance in the morphological model has been formulated as a function of depth as shown in Eq.1.

$$C = A.h^b \tag{1}$$

Where C is Chezy number, A is resistance coefficient, b is resistance exponent and h is water depth.

The tool used for the morphological model study facilitates inclusion of bank erosion in the continuity equation. The bank erosion model appears in Eq.2 (User Guide, 2007).

$$E_b = - \alpha \,.\, \partial z/ \partial t + \beta.\, S/h + \gamma \tag{2}$$

Where E_b is bank erosion rate in m/s, z is local bed level, S is near bank sediment transport, h is local water depth and α, β,γ are calibration coefficients specified in the model.

The above formulation has been used for simulation of bank erosion in the model. Zero bank erosion has been considered at the already protected locations. It is to be noted here that calibration of bank erosion model requires reliable historical bank erosion data. In the present study there is no such data. The validation of the model has been done for 2008 event. The validation is limited to comparison between rated and simulated discharges and observed and simulated water levels at Kurigram. No observed sediment data for this event is available for comparison. The comparison between rated and simulated discharges for 2006 event and observed and simulated water levels for 2008 event at Kurigram is shown in Fig. 4 (Final Report, 2010).

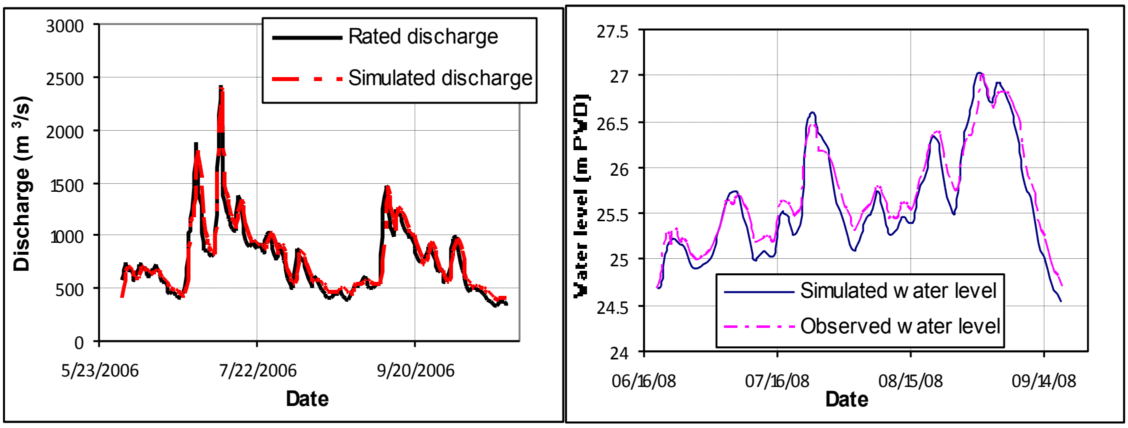

Figure 4. Comparison between rated and simulated discharges for 2006 event and between observed and simulated water levels for 2008 event at Kurigram

3. RESULTS AND DISCUSSIONS

3.1. Layout Selection

After establishment of baseline hydraulic and morphological conditions under different hydrological scenarios the model is applied for selection of appropriate layout of diversion channel, barrage and river training works through different option simulations. Fig.5 shows the selected layout of diversion channel and barrage and Fig.6 shows the selected layout of river training works. The issues considered in these selections include favorable river approach to the barrage, i.e., the streamlines are perpendicular to the barrage axis, adequate flow along the right guide bund and through the undersluice, prevention of cross flow along the barrage, optimum dimensions of the river training works etc. The structural arrangement in the finally selected layout includes barrage, guide bunds, afflux bund, groynes and approach embankment.

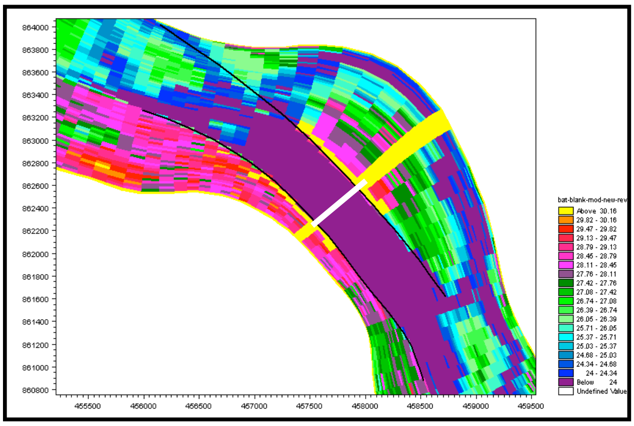

Figure 5. Selected layout of barrage and diversion channel

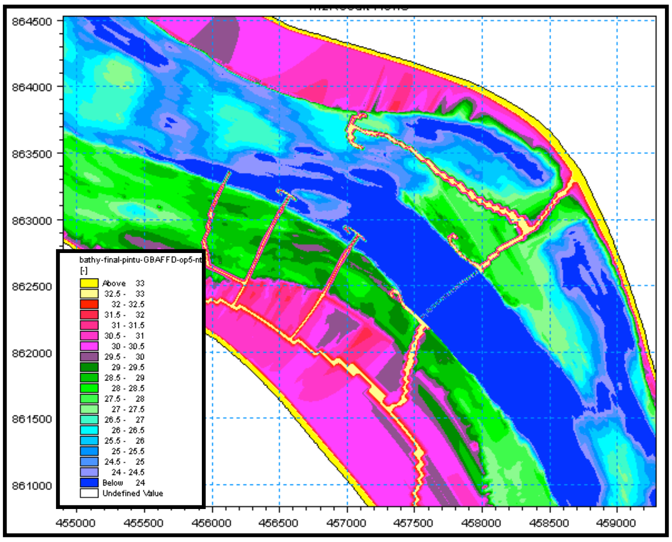

Figure 6. Selected layout plan of river training works

3.2. Assessment of Hydraulic Design

After selection of the layout of barrage and river training works the different components of the barrage, canal head regulator and main canal have been introduced in the model as per design to test their performance under different flow conditions. Based on experience, desk studies and results of modelling exercise 35 equal width (12m) bays of which 4 for undersluice section and 31 for main weir section have been considered. The length of the barrage is finalised before as 480m. The pond level is 30.2 mPWD. The design discharge of the main canal is 43.5 m^3/s and considered available head id 0.5. The orientation of the canal head regulator with barrage axis is 100^o. In order to assess hydraulic design of the barrage and ancillary works a number of tests have been conducted in both regulated and unregulated (all gates fully open) flow conditions. The velocity field near the barrage for unregulated 100 year discharge is shown in Fig.7 (Final Report, 2010). It is evident from Fig.7 that the river approach to the barrage is almost perpendicular. It is also evident that flow concentration occurs at the head of the upstream groynes and velocity distribution in the immediate upstream of the barrage does not have any noticeable skew. The maximum velocity through the barrage is of 2.7 m/s, which is found almost in the middle of the barrage.

The efficacy of the divide wall having different lengths varying from 20m to 60m has been tested for 100 year discharge. It is found that the efficacy of the divide wall increases with the increase in its length from 20m to 40m. However, the efficacy of the same somewhat decreases with an increase in its length from 40m to 60m. The value of afflux is observed to be 40cm. Fig.8 shows the effect of divide wall on local water levels.

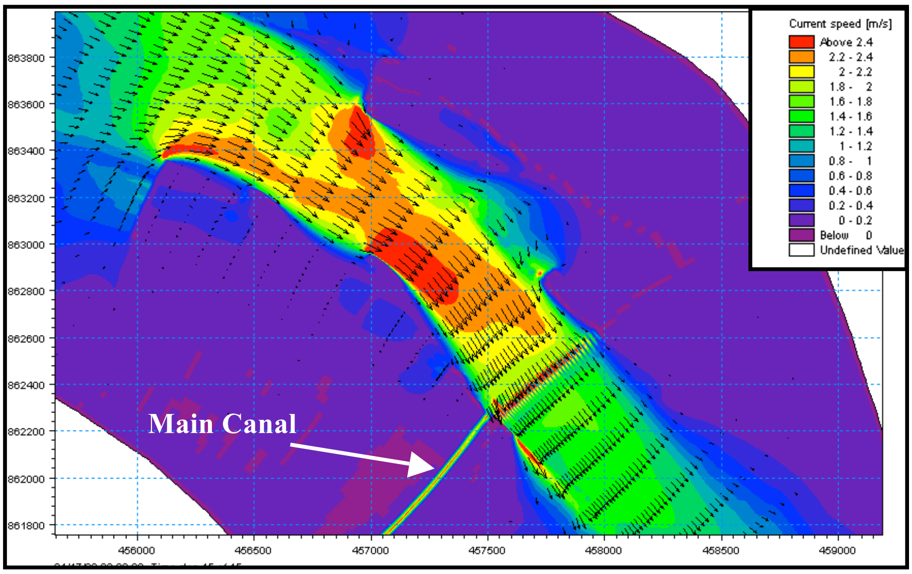

Figure 7. Velocity field near the barrage for 100 year discharge

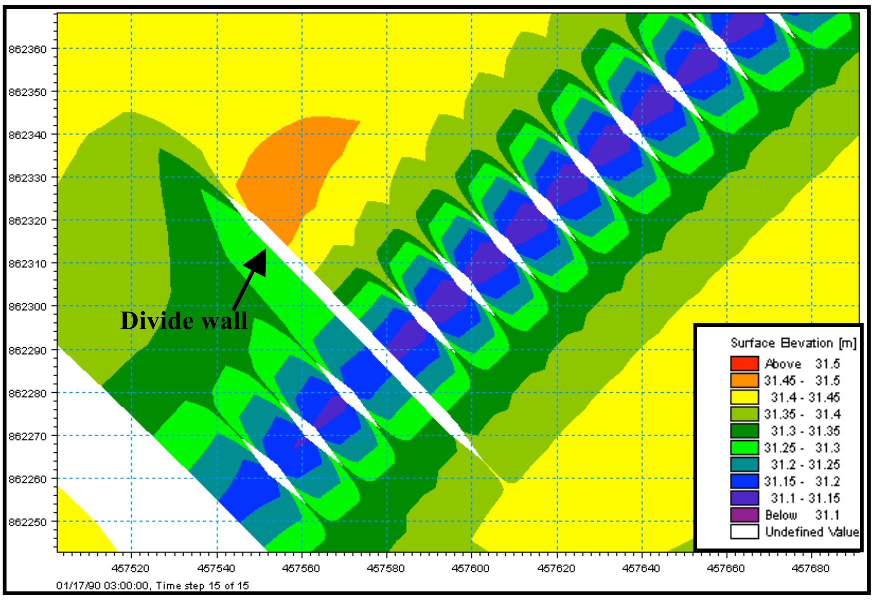

Figure 8. Effect of divide wall on local water levels under for 1 in 100 year discharge

The distribution of total discharge among main canal, undersluice section and main weir section for unregulated 25 year and 100 year discharge is shown in Table 1 (Final Report, 2010). The velocity field near the head regulator and undersluice for 100 year discharge is shown in Fig.9. It is observed that flow from the upstream smoothly approaches the head regulator with a velocity of about 1.3 m/s and 1.5 m/s for 1 in 25 year and 1 in 100 year discharge respectively. The corresponding velocity through the head regulator is found to be as 1.9 m/s and 2.65 m/s. On the other hand, the corresponding discharge through the main canal is found to be as 106 m^3/s and 163 m^3/s.

Available discharge in the main canal has been investigated under considered head (0.5m) and reservoir water level at pond level (30.2 mPWD) for different discharges ranging from 400 m^3/s to 2000 m^3/s. The downstream boundary of the main canal corresponds to full supply level (FSL) of main canal. A constant discharge of 76 m^3/s is found through the main channel for all discharges, which is higher than design discharge. The velocity through the regulator is found to be as high as 1.6 m/s. On the other hand, the approach flow velocity is found to be in the order of 0.8 m/s. Fig. 10 shows the approach flow condition at canal head regulator and undersluice under this condition for river discharges of 400 m^3/s and 2000 m^3/s.

Table 1. Distribution of Unregulated Discharges among Main Canal, Undersluice Section and Weir Section

Return Period (Year)	Percentage of total river flow		
	Main canal	Undersluice section	Main weir section
25	1.7	11.2	87.1
100	2.0	10.8	87.2

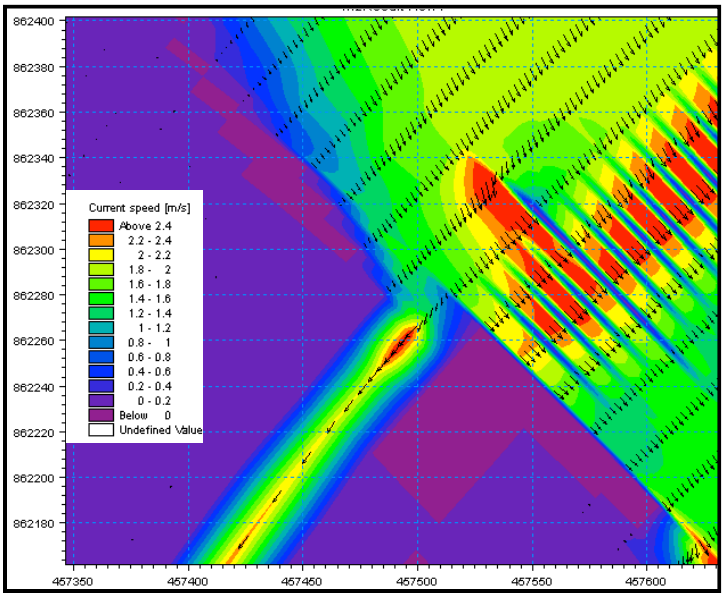

Figure 9. Velocity field near the canal head regulator and undersluice for 100 year discharge

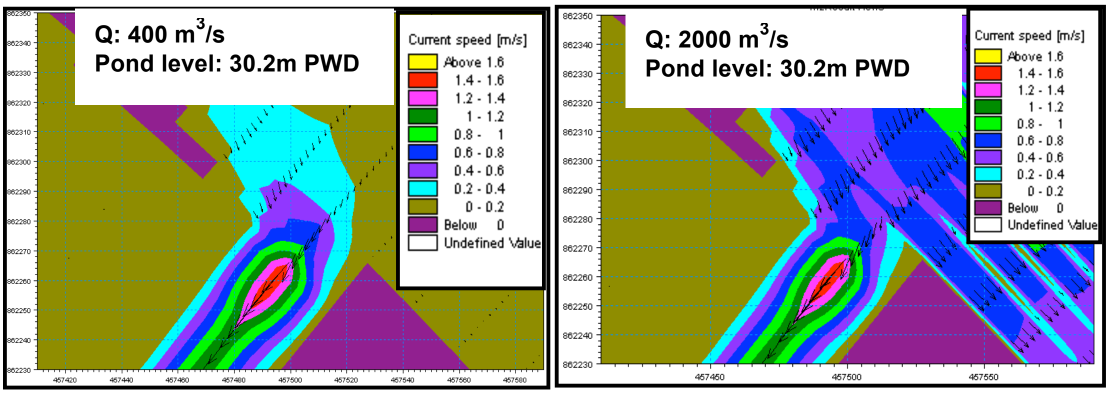

Figure 10. Approach flow condition at canal head regulator and undersluice at reservoir pond level

Morphological simulation is done with the low flow part of the hydrograph of 2006 (2.33 year event). Water level immediately upstream of the barrage corresponds to the pond level. The downstream boundary of the main canal corresponds to the design discharge of the main canal (43.5 m^3/s). Under this condition velocity field in the main canal and at head regulator is shown in Fig.11.

It is observed that the velocity through the main canal corresponding to the design discharge is 0.5 m/s. The sediment concentration in the main canal is higher than that in the main river under flow diversion condition. There is trend of sediment deposition immediately upstream of the weir section.

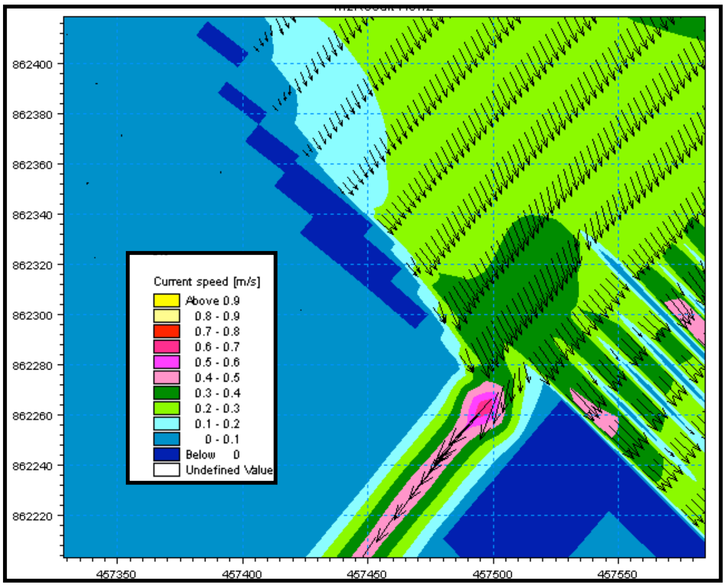

Figure 11. Velocity field in the main canal for design discharge of 43.5 m^3/s

4. CONCLUSIONS

The following conclusions have been drawn based on the study results:

- The observed afflux at barrage for design discharge is 0.4m.
- The optimum length of the divide wall is found to be as 40m.
- The orientation of the canal head regulator may be considered at an angle of 100^o with the barrage axis.
- The flow through the under sluice section as a percentage of total flow is found to be within acceptable limit.
- The design discharge of the main canal is found to be available with the considered head.
- The flow velocity in the main canal for design discharge is 0.5m/s
- There should be provision for silt excluding device. The efficacy of the silt excluder and its design may be tested by physical modelling.

ACKNOWLEDGEMENT

The authors are grateful to the Bangladesh Water Development Board (BWDB) for financial support and Development Design Consultants Ltd., Dhaka for providing necessary data, design drawings and feedback to conduct the study.

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