

Modeling and Evaluation of Equilibrium State of Morphological Predictions of the Upper Meghna River Using HEC-RAS

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ABSTRACT: Bangladesh is a riverine country having the greatest deltaic plain of the Ganges, Brahmaputra and Meghna rivers. Most of the rivers in Bangladesh are the part of these rivers. The main flow of the system discharges in the Bay of Bengal. A research was undertaken to develop a model of the Upper Meghna river to understand the morphological changes. The Upper Meghna River originates in the Shillong Plateau and foothills. It controls the flood in north east region of Bangladesh. It is a canaliform type of meandering river. It is relatively a small river having a bankful width of about 1 km. A model of Upper Meghna river basin using HEC-RAS is successfully developed in this study. The model is then used to evaluate the changes of slope and water level at different conditions. These values will help to understand the morphological changes during dry and rainy season.

KEYWORDS: Morphological changes, HEC-RAS, Upper Meghna River, Canaliform type.

I. INTRODUCTION

The Ganges-Brahmaputra-Meghna (GBM) river basin is a transboundary river basin. It encompasses approximately 1.7 million sq. km. This area is distributed between India (64 percent), China (18 percent), Nepal (9 percent), Bangladesh (7 percent) and Bhutan (3 percent) [10]. The Meghna is one of the major rivers in Bangladesh having a total length of 820 km of which 420 km flows through Bangladesh. It is an alluvial meandering river [4]. It is a transboundary river shared by India and Bangladesh. It has a total area of 82,000 Km² which covers an area equal to almost twice the size of Bhutan or Switzerland of which 47,000 Km² (57% of the total area) is located in India and 35,000 Km² (43% of the total area) is in Bangladesh [9]. The Meghna is the widest river among those that flow inside the boundaries of Bangladesh. At one point near Bhola, Meghna is 12km wide [6]. The downstream of Surma river from Ajmiriganj is often referred to as the Meghna. The Meghna has two distinct parts. The Upper Meghna from Kuliarchar to Shatnol is a comparatively small river. The Lower Meghna below Shatnol is one of the largest rivers in the world because of its wide estuary mouth. The Meghna receives Tippera Surface streams from the east and flows from the enlarged Dhaleshwari from the west [8]. The major rivers of upper meghna basin in the north-eastern region are rising rapidly while the rivers of south-eastern hilly basin are in the falling trend [11].

Based on hydrology, the basin can be divided into three regions: a) part of the basin formed by the river Barak and its two main distributaries, the Kushiyara and Surma; b) the Upper Meghna Basin, formed by the confluence of the Kushiyara and Surma in Bangladesh; and c) the Lower Meghna Basin after the Meghna meets the river Padma (formed by the confluence of the Brahmaputra and Ganges rivers [12]. The Meghna river is hydrographically referred to as Upper Meghna down to Chandpur district in Bangladesh and the associated basin is known as Upper Meghna basin.

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Vol. 9, Issue 3, March 2020

The Upper Meghna river basin has a drainage area of 70263Km² [1]. It is situated in the south of one of the rainiest regions in the world, has annual rainfall of up to 5,800 mm. It contains approximately 4,000Km² of haor areas. The peak flood flow of this river is 19,800 m³/sec and it receives a huge amount of sediment inflow (approximately 13 million tons/ year [7]). Slopes (both east and west edges) are milder and vary from 15 to 30 cm/km with a flat bottom having several kilometers width. The rivers from east and west are entering into the basin flowing over the side slopes in east-west direction. The northeast region is a tectonically active area and the rate of subsidence in this area is much higher than the deltaic plains elsewhere in the country [2]. The water levels vary approximately 4-5 meters throughout the year. This has significant impact on the shape of the river channels. The variation in water level occurs in two distinct seasons and they are dry and wet season [5].

A well-controlled system of physical and hydraulic features is maintained in water and sediment transport processes. Main objective of the study was to enhance and strengthen operational knowledge of hydraulic and morphological processes in the Upper Meghna Estuary, to find suitable slope and water level for making a stable embankment .It can help to prepare a plan with priority projects and program for flood protection, agricultural and socio-economic development for early implementation [3].

II. METHODOLOGY

The main purpose of this study is to determine the changes of slope and water level by using HEC-RAS (Hydrologic Engineering Center's River Analysis System) software for the following conditions and they are- no constriction no withdrawal, withdrawal of water, withdrawal of sediment, constriction of width. These are the equilibrium state of morphological predictions. HEC-RAS software is greatly used for modeling of water flowing through systems of open channels and computing water surface profiles. It can be used for dam breach analysis, though other modeling

methods are presently more widely accepted for this purpose. It contains several river analysis components such as steady flow water surface profile computations, one- and two-dimensional unsteady flow simulation, movable boundary sediment transport computations and water quality analysis. [9] The modeling system is used for the simulation of one-dimensional sediment transport resulting from scour and deposition over long time periods. The sediment transport is calculated by grain size fraction. The model is designed to simulate long-term trends of scour and deposition in a stream channel which is the resultant of the water discharge and stage, or changing of the channel geometry.

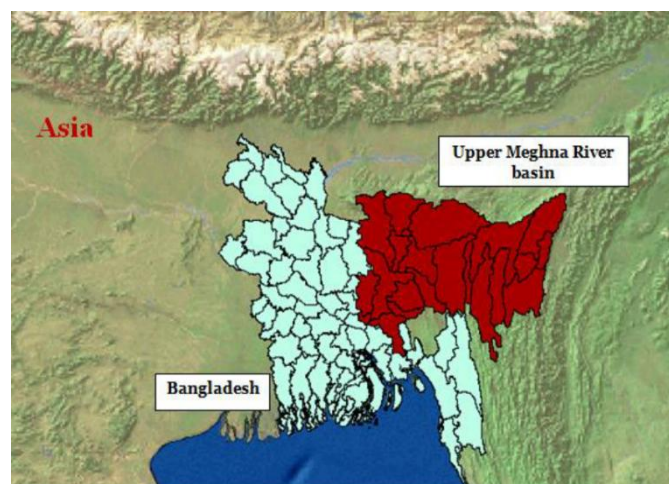


Figure 1: Upper Meghna River (Brown Colored Area) [1]

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(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 9, Issue 3, March 2020

In this study, for doing the modeling of the Upper Meghna River at first geometric data was given input. Then unsteady flow data with necessary boundary conditions was given input. The boundary conditions are flow hydrograph, stage hydrograph and lateral inflow hydrograph. Then sediment data was used at equilibrium load condition where “Yang” transport function is used. The simulation was done for 5 months (22 July, 2019 to 31 December, 2019). The output of this simulation is four equilibrium graphs showing the change of slope and water level.

III. DATA COLLECTION AND DATA ANALYSIS

Upstream flow = 25000 m³/s

Downstream water level = 10 m

Rate of withdrawal of water = 2500 m³/s

Upstream sediment transport = 6.5 m³/s

Sediment withdrawal rate = 2.5 m³/s

Width of channel = 1000 m

Width of constricted portion=750 m

Length of channel = 16000 m (As the river is too large for modeling, the section of 16000 m is taken for the sake of modeling.)

Length of constricted portion=500 m

Grain size, D₅₀ = 0.14 mm

Chezy's coefficient, C = 50

Empirical factor, b=5

Initial slope, S=0.00002

Conditions:

1. No constriction, no withdrawal
2. Withdrawal of water
3. Withdrawal of sediment
4. Constriction of width

For sediment transport,

Density of sediment = (2.65 x 1000) kg/m³
= 2650 kg/m³

Sediment load = 6.5 m³/s

= (6.5 x 2650) kg/s

= 1488240 tonnes/day

For sediment withdrawal,

Sediment load = 2.5 m³/s

= (2.5 x 2650) kg/s

= 572400 tonnes/day

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Vol. 9, Issue 3, March 2020



Figure 2: Upper Meghna River study area

Condition 1: No constriction, no withdrawal

Input of upstream flow = 25000 m³/s

Downstream water level = 10 m

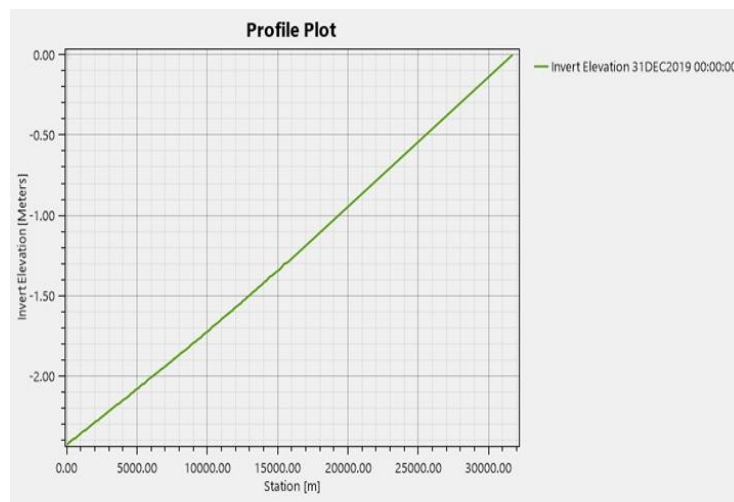


Figure 3: HEC-RAS output for no constriction and no withdrawal

From the HEC-RAS software, the equilibrium slope of the following graph is 0.000186. The figure shows a straight-line graph as it is an equilibrium graph.

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(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 9, Issue 3, March2020

Condition 2: Withdrawal of Water

For horizontal channel, $S_o = 0$. But we can take $S_o = 0.000186$ from case 1.

$$\frac{\Delta h}{h} = \frac{\Delta Q}{Q}$$

$$\text{Or, } \Delta h = \frac{2500 \times 10}{25000} = 1 \text{ m}$$

$$\frac{\Delta S}{S_o} = \frac{\Delta Q}{1 - \frac{\Delta Q}{Q}}$$

$$\text{Or, } \Delta S = \frac{\left(\frac{2500}{25000}\right)}{1 - \left(\frac{2500}{25000}\right)} * 0.000186 = 0.000021$$

From model, $\Delta h = 0.25 - (-0.875) = 1.125 \text{ m}$

$$\text{New slope from model} = \frac{1.125}{8000} = 0.00014$$

$$\Delta S = (0.000186 - 0.00014) = 0.000046$$

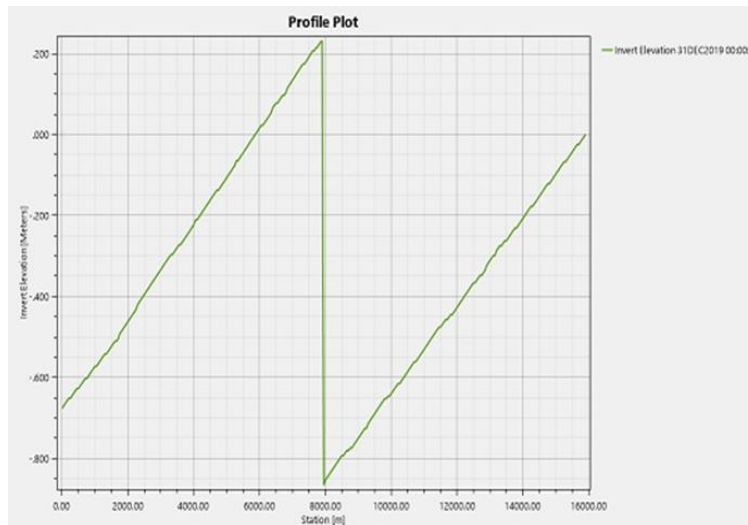


Figure 4: HEC-RAS output for withdrawal of water

From the HEC-RAS software, the equilibrium slope of the following graph is 0.000186. The figure shows the changes due to withdrawal of water.

Condition 3: Withdrawal of Sediment

For horizontal channel, $S_o = 0$. But we can take $S_o = 0.000186$ from case 1.

$$\frac{\Delta h}{h} = \left[\frac{1}{1 - \frac{\Delta Q_s}{Q_s}} \right]^{\frac{1}{b}} - 1$$

$$\text{Or, } \Delta h = \left[\frac{1}{1 - \left(\frac{2.5}{6.5}\right)} \right]^{\frac{1}{5}} - 1 * 10 = 1.02 \text{ m}$$

$$\frac{\Delta S}{S_o} = 1 - \left[1 - \left(\frac{\Delta Q_s}{Q_s}\right)^{\frac{3}{b}} \right]$$

$$\text{Or, } \Delta S = [1 - \{1 - (2.5/6.5)^{\frac{3}{5}}\}] * 0.000186 = 0.000047$$

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 9, Issue 3, March2020

From model,

$$\Delta h = -0.85 - (-0.99) = 0.14 \text{ m}$$

$$\text{New slope from model} = \frac{0.14}{8000} = 0.0000175$$

$$\Delta S = (0.000186 - 0.0000175) = 0.000168$$

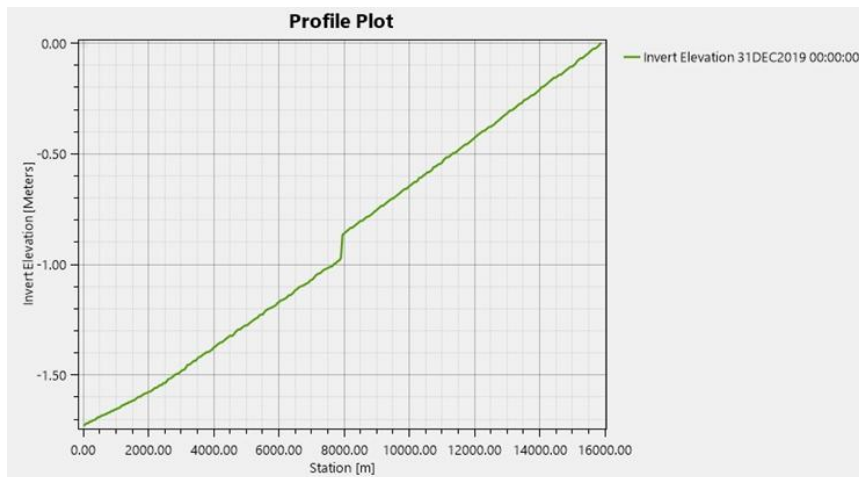


Figure 5: HEC-RAS output for withdrawal of sediment

From the HEC-RAS software, the equilibrium slope of the following graph is 0.000186. The figure shows the changes due to withdrawal of sediment.

Condition 4: Constriction of width

For horizontal channel, $S_o = 0$. But we can take $S_o = 0.000186$ from case 1.

Analytically,

$$\frac{hn}{ho} = \left[\frac{Bo}{Bn} \right]^{\frac{b-1}{b}}$$

$$\text{Or, } hn = \left[\left[\frac{1000}{750} \right]^{\frac{5-1}{5}} \right] * 10 = 12.6 \text{ m}$$

$$\Delta h = 12.6 - 10 = 2.6 \text{ m}$$

$$\frac{\Delta S}{Sn} = \left[\frac{Bn}{Bo} \right]^{\frac{b-3}{b}}$$

$$\text{Or, } \Delta S = \left[\left[\frac{750}{1000} \right]^{\frac{5-3}{5}} \right] * 0.000186 = 0.00017$$

From model,

$$\Delta h = -0.9 - (-3.26) = 2.36 \text{ m}$$

$$\Delta S = \frac{3.29 - 3.26}{500} = 0.00006$$

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Vol. 9, Issue 3, March2020

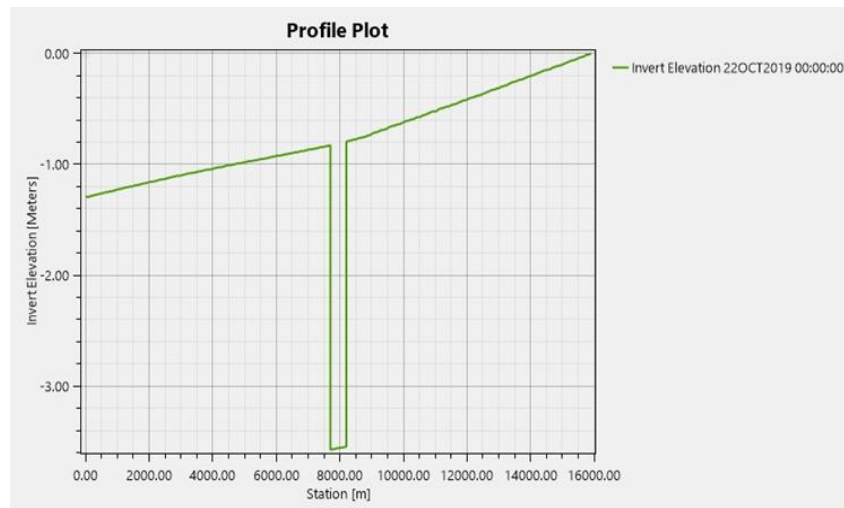


Figure 6: HEC-RAS output for constriction of width

From the HEC-RAS software, the equilibrium slope of the following graph is 0.000186. The figure shows the changes due to constriction of width of the river.

IV. RESULT AND DISCUSSION

For condition 1, equilibrium slope was found 0.000186 but the original slope of the Upper Meghna river is 0.00002. The equilibrium slope was estimated from the HEC-RAS software which is higher than the original slope. This can be possible as data was collected during high tide.

For condition 2, analytically, $\Delta h = 1$ m, $\Delta S = 0.000021$ and from model, $\Delta h = 1.125$ m, $\Delta S = 0.000046$. The output from the software is greater than the analytical solution because HEC-RAS software gives some errors due to large channel. But both values are very close to the analytical solution.

For condition 3, analytically, $\Delta h = 1.02$ m, $\Delta S = 0.000047$ and from model, $\Delta h = 0.14$ m, $\Delta S = 0.000168$. It is observed that the values from analytical solution and from model output vary a lot. The graph is also found so curvy but it should be straight line. The error occurs because HEC-RAS software takes input the sediment load. But during analytical solution, sediment load is not taken into consideration.

For condition 4, analytically, $\Delta h = 2.6$ m, $\Delta S = 0.00017$ and from model, $\Delta h = 2.36$ m, $\Delta S = 0.00006$. The values are very close for both change of slope and water level. It can be said that the solution was done with more accuracy for both analytical and software.

V. CONCLUSION

During rainy season, velocity of the river increase which leads to increase in sediment transport capacity and depth of water level. But when water is withdrawn for irrigation, industrial and domestic purpose from the section of the river, the flow of water decreases and also the velocity of the water reduces to balance the depth of water which leads to equilibrium slope. Amount of withdrawn may vary with time. When sediment is withdrawn for building purpose, the velocity increases to raise the water level high which indicated scouring. But when the section constricts, the velocity becomes almost double to initial condition for taking the whole section into an equilibrium condition. Because when velocity increases, scour occurs. For adjusting it, water level also increases to come back to the equilibrium condition.

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Vol. 9, Issue 3, March 2020

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