E-ISSN: 2707-8310
P-ISSN: 2707-8302
IJHCE 2021; 2(2): 08-17
Received: 17-04-2021
Accepted: 20-05-2021

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River morphological modelling of Brahmaputra River, Assam

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Abstract
The Brahmaputra River it is characterized by its highly braided channel pattern with creation of river bars, and it is morphologically very dynamic due to high upstream discharges and large sediment loads during the monsoon. In-order-to comprehend the morphological development of a braided river like the Brahmaputra it is essential to acquire data and information, which can be incorporated into mathematical modelling tools for numerical prediction of the morphological behaviour in the short-term and medium-term. In this study, the Palasbari-Gumi reach of the Brahmaputra River was used to develop a two-dimensional morphological model utilizing the MIKE-21C programme for prediction of erosion for planning of protection works, and morphological development at river reaches. To forecast design variables throughout the river reach, model runs were carried-out with various hydrological scenarios. For the coarse sand fraction, the predicted mean annual sediment load for the 2021 hydrological year and bankfull discharge were 257 and 314 Mt/year, respectively, while the historically recorded sediment load in the Brahmaputra was 400 Mt/year. The model predicted results show excellent similarity with ADCP velocities, design flood levels and yearly sediment load. Difference of peak model velocities with ADCP measurement is lower than 10% with majority of measured data; velocities are compared at five river sections. Predicted flood level for bankfull discharge condition were almost 98% accurate at Gumi site. This study has demonstrated how to improve the planning and execution of river training works in highly braided river like Brahmaputra by predicting morphological changes over a 2-3 year period.

Keywords: River morphology, hydrodynamics, erosion prediction MIKE 21C, and Brahmaputra River

Introduction

The recurrent floods and embankment breaching along the Brahmaputra River is partly a result of the river being morphologically active due to high upstream discharges and large sediment loads during the monsoon (Pareta, 2022) [56]. In addition, the material composition of the riverbanks and adjacent agricultural land enables weakening of the banks and soils easily during the wet season with erosion and bank collapse as a result (Pareta *et al*., 2021a) [43]. The consequence is that floodplains are eroded on seasonal basis with loss of agricultural land and settlements as a result. Because poverty is abundant in Assam the loss of vital agricultural land and property only exacerbates poverty (Pareta, 2021a) [43]. However, if proper flood and erosion management is executed then poverty can be alleviated. A fundamental understanding of the hydrologic and geomorphic behaviour of a catchment is a prerequisite for the planning of activities related to flood and erosion management (Pareta, 2021b; CEGIS, 2010) [44, 12]. Such an understanding can only be established by collecting, analyzing, and organizing various types of hydrological and physio-geographic data (Pareta, 2021c) [5].

The Brahmaputra is characterized by its highly braided channel pattern with creation of river bars (locally known as chars) of various sizes and shapes (Best *et al*., 2007) [8]. These braid bars are highly unstable, and they radically change their shape, size, and position both seasonally and annually (Bristow, 1987) [10]. Large scale bedforms (bars and islands) and micro-scale bedforms (ripples and dunes) are the most important riverbed features inducing resistance to flow and its subsequent influence on the bed shear stress (Pareta, 2021d; Blench, 1969) [51, 9]. The bedforms directly influence the water level and shear velocity of the flow and are thus indirectly influencing flood and erosion occurrences along the river. Regular monitoring of the development in the river braids and bars is important for understanding the characteristics of the river and for providing data for various types of analyses such as mathematical modelling (Pareta, 2021e; Mosselman, 2004) [52, 39].

The development in bar position, height, width, and length can be monitored by a combination of annual or bi-annual river surveys and multi-temporal satellite imageries (Pareta *et al*., 2021) [43]. The satellite-based data can be analyzed in remote sensing software to determine the shape, size, and movement of sand bars over time (Pareta, 2021f) [43].

To understand the morphological development of a braided river like the Brahmaputra it is necessary to acquire data and information that describes the river behaviour vertically as well as horizontally (Pareta, 2021[g]; Sarker *et al*., 2006) [54, 60]. Remote sensed data from Landsat satellite enables to monitor the changes in river planform (Horizontal changes) over time and is therefore a strong tool for detecting overall river dynamics and hotpots along the river (Pareta *et al.*, 2021b) [44]. The use of such data has become much easier with the advent of the Google Earth Engine (GEE) which revolutionized operational applications of remote sensing data (Pickens *et al*., 2020; Gomes *et al.*, 2020, and Gorelick *et al*., 2017) [58, 23, 24] by leveraging long-term availability of multi-temporal, multi-spectral, and multi-spatial Landsat satellite data into 50-years of historical maps (1973-2022) (Pareta, 2021d) [51]. The download and geoprocessing of large datasets to cover a major river like the Brahmaputra River have been significantly simplified using cloud-based platforms. Apart from using Google Earth as an analysis tool the long-term development in the river planform can be analyzed in GIS systems such as ArcGIS or QGIS (Pareta *et al*., 2020) [42].

The vertical development of the Brahmaputra River is essentially monitored by conducting river cross section surveys. At locations with water coverage such surveys can be made by using ADCP (acoustic doppler current profiling) technology or using conventional cross section surveys (Pareta, 2021[c]) [50]. The dry parts of a braided river can be survey by either conventional topographical survey techniques or using airborne LiDAR (light detection and ranging) surveys (Pareta *et al*., 2019) [41]. In addition to the topographical and bathymetrical data it is necessary to obtain data on discharge, sediment load (bed load and suspended load), and grain size distribution of bed and bank material (Pareta *et al*., 2019) [41].

The above-mentioned data types can be incorporated into mathematical modelling tools such as MIKE 21C, Delft2D-Rivers, CCHE2D, TELEMAC, etc. for numerical prediction of the morphological behaviour in the short-term and medium-term (Pareta, 2021[h]; Klaassen *et al*., 2011) [55, 35]. Through mathematical modelling, short-term to medium term bank erosion prediction for planning of protection works, hydraulic and morphological development at river reaches, effectiveness of existing riverbank protection and training works, and impact of the existing river training works to their immediate vicinity at upstream and downstream can be determined (DHI, 2014) [16]. Mathematical modelling supports the morphological data analysis by filling information gaps in time and space and is a strong tool for studying what-if-scenarios and therefore for the planning of river protection works (Pareta, 2021[b]) [44]. In complex and dynamic rivers, it is important to realize that a specific engineering project site is part of a larger geomorphic system. Smaller scale projects focus on local scour and their maintenance (Pareta, 2020; Ashmore *et al*., 1983) [42, 6]. While large scale projects require assessment of the river's response for long-term morphological evolution, and at a very detailed scale in the project vicinity for immediate and medium-term development (Pareta *et al*., 2021) [43].

The specific objectives of this paper are: (i) short-term to medium-term bank erosion prediction for planning of river training works, (ii) hydraulic and morphological development at Palasbari and Gumi reach of erosion affected areas along the south bank, and (iii) impact of the existing river training works to their immediate vicinity both at upstream and downstream.

Study Area

The Palasbari-Gumi reach of Brahmaputra River extends from latitude 26° 05' 57.13" N to 26° 15' 52.63" N, and longitude 91° 08' 0.87" E to 91° 41' 41.99" E and covers an area of 596.18 Km^2 (

Fig **1**). Administratively, the reach area falls in 4 districts (Barpeta - 15.33%, Nalbari - 35.66%, Kamrup - 46.69%, and Dispur - 2.32%) of Assam state. The topography of the area is generally plain but uneven. The soil of the area is light textured (sandy loam) highly fertile, neural in reaction (pH 6.8 to 7.2). The area is agroclimatic sub-zone, characterized with prevalence of tropical humid climate. The summer in the area is from March to May followed by monsoons till September and cool winter from October to February. The. average temperature varies from 12 °C to 33 °C and starting raining from April and end it the month of August attains maximum temperature. It experiences generally 1500 mm to 2700 mm rainfall in a year.

Data Used and their Sources

The data have been collected from secondary as well as primary sources for the Palasbari-Gumi reach to fulfil the objectives of the study. The collected data were analysed using appropriate analytical procedures. It includes, but are not limited to, rainfall for fixed stations, rainfall forecasts from numerical simulations, river cross-sections, river water level, river discharge, bathymetry, topography, grain size characteristics, ADCP velocity measurement, available high-resolution DEM, and satellite images. These datasets have been collected from different sources as listed in Table 1.

Survey of India (SoI) toposheets at 1:50,000 scale have been downloaded from SoI website at https://onlinemaps.surveyofindia.gov.in/. Total 5 Survey of India toposheets have been downloaded, which has covered the study area. Future, these toposheets have been geo-processed and have been used for base mapping and analysis of general topography of the study area.

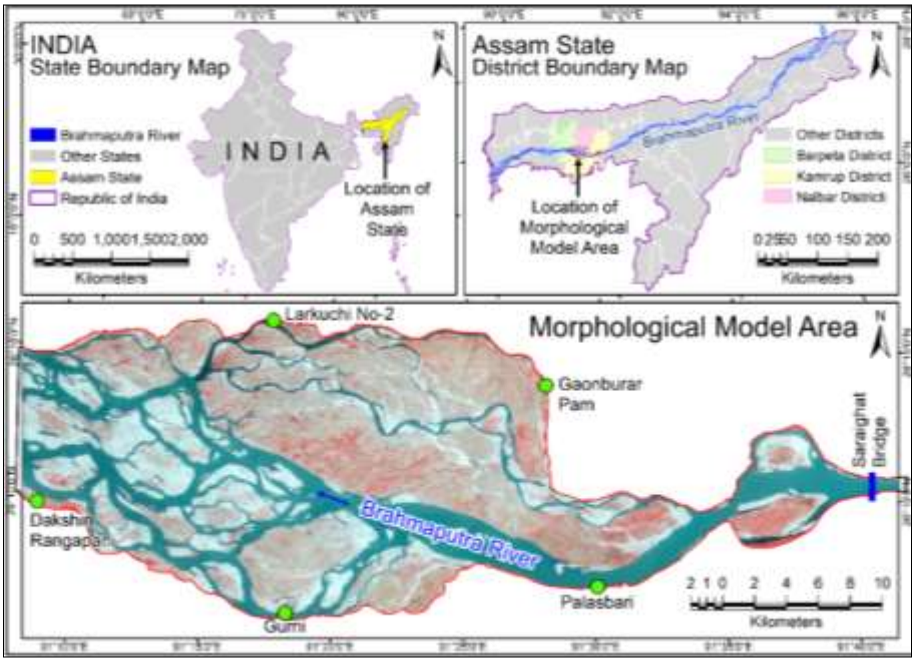

Fig 1: Location Map of Study Area

Shuttle Radar Topography Mission (SRTM) DEM data with 30 m spatial resolution has been download from https://earthexplorer.usgs.gov/ of year 2014 for study area covering an area of 596.13 Km^2. This dataset has been used for verification of cross-section data of topography, and analysis of topography of the study area.

Landsat-5 Thematic Mapper (TM), Landsat-7 Enhanced Thematic Mapper Plus (ETM+), and Landsat-8 Operational Land Imager (OLI), Landsat-9 Operational Land Imager-2 (OLI-2) satellite imageries with 30 m spatial resolution have been downloaded from 1998 to 2022 from https://earthexplorer.usgs.gov/ for planform and riverbank erosion analysis.

The available cross-section data has been obtained from the Water Resource Department, Assam at https://waterresources.assam.gov.in/. Future, these cross-section data has been updated with available bathometry data.

Observed water level from 2018 to 2022 have been collected from Central Water Commission (CWC) at https://ffs.tamcnhp.com/. The water level has been verified through rainfall (TRMM and GPM) by using numerical simulations.

Discharge data from 2017 to 2022 have been collected from Global Flood Monitoring System (GFMS) at http://flood.umd.edu/. The water level and discharge data has been used for hydrological boundaries of 2D model.

Bathymetry, grain size characteristics, and ADCP velocity measurements data for year 2018 have been collected from an ISC report of Flood and River Erosion Management Agency of Assam (FREMAA), Govt. of Assam at https://fremaa.assam.gov.in/. The list of data used, and their sources are given in Table 1.

Table 1: List of Data Used and Sources

S. No.	Data Type	Period	Sources
1	Toposheet at 1:50,000 Scale	2006	• Survey of India (SoI). • Toposheet No.: 78N/03, 04, 07, 08, and 12. • Source: http://www.soinakshe.uk.gov.in
2	Topography / SRTM DEM Data with 30 m Spatial Resolution	2014	• Shuttle Radar Topography Mission (SRTM). • USGS Earth Explorer • Source: http://earthexplorer.usgs.gov
3	Landsat Satellite Imageries with 30 m Spatial Resolution	1998-2022	• United States Geological Survey (USGS), Earth Explorer. • Landsat-5 TM: 1998, 1999, 2004, 2005, 2006, 2007, 2009, 2011. • Landsat-7 ETM+: 2000, 2001, 2002, 2003, 2008, 2010, 2012, 2013. • Landsat-8 OLI: 2014, 2015, 2016, 2017, 2018, 2019, 2020. • Landsat-9 OLI-2: 2021, 2022. • Source: http://earthexplorer.usgs.gov
4	The Tropical Rainfall Measuring Mission (TRMM) Rainfall (TMPA 3B42 v7) with 0.25^o x 0.25^o Spatial Resolution	2000-2022	• National Aeronautics and Space Administration (NASA). • Source: http://trmm.gsfc.nasa.gov/
5	The Global Forecast System (GFS) Rainfall Data with 0.25^o x 0.25^o Spatial Resolution	1980-2022	• National Oceanic and Atmospheric Administration (NOAA). Source: http://www.nco.ncep.noaa.gov/pmb/products/gfs/
6	Global Precipitation Measurement (GPM) Rainfall Data with 0.1^o x 0.1^o Spatial Resolution	2014-2022	• National Aeronautics and Space Administration (NASA) • Source: http://trmm.gsfc.nasa.gov/
7	Cross-Section Data	2007	• Water Resources Department (WRD), Govt. of Assam.

			• Source: https://waterresources.assam.gov.in/
8	Water Level Data	2021	• Central Water Commission (CWC), Govt. of India • Source: https://ffs.tamcnhp.com/
9	Global Flood Monitoring System (GFMS) Discharge Data with 13.87 Km (0.125°) Spatial Resolution	2017-2022	• Global Flood Monitoring System (GFMS) • Source: http://flood.umd.edu/
10	Bathymetry Data	2018	• An ISC report of Flood and River Erosion Management Agency of Assam (FREMAA), Govt. of Assam. • Source: https://fremaa.assam.gov.in/
11	Grain Size Characteristics		
12	ADCP Velocity Measurements		
13	Topography, Bathymetry Data	2022	• Primary Survey Data. 2022

Result and Discussion

Development of Morphological Model

The 2D model is 57 Km long and covers the full width of the Brahmaputra River, which is starting from Saraighat Bridge, Guwahati, and end at Bahari (Barpeta district) in the north bank, and Sontoli (Kamrup district) in the south bank. The Brahmaputra River width at Saraighat Bridge is only 1.49 Km, and 37 Km downstream of Saraighat bridge nearby Palasbari-Gumi, the river width is 18.83 Km, which shows the world's largest river-width variation (Pareta, 2021).

Model Set-up: Computational Grid

The 57 Km long model is built on 148,200 (260 x 570) computational cells in curvilinear orthogonal grid system of MIKE 21C modelling technology. The model covers full width of approximately 20 Km of the Brahmaputra River. There are 570 computational cells along 57 Km of length of the river, and 260 across the width. Finer resolution across the width is more important, and it is necessary for assessing bend scour, obstruction scour and bank erosion. Given the width of the river and the width of the anabranches, the resolution would be satisfactory to simulate bend scour and other forms of scours, and bank erosion. Computational resolution of the present model is sufficient.

Model Topography and Bathymetry

Bathymetry of the 2D model has been generated from available sources of data. The source data is available only in the navigational part of the main channels and some deep anabranches. WRD cross-sections at the Palasbari-Gumi reach (CS=22 to CS=15) is also available. These cross-sections were used only for estimating formation level of relatively stable and permanent islands. This was done on the assumption that changes in the formation level of stable islands are minimal, at least over the recent years. It should be emphasized that the model bathymetry has been built with a very limited bathymetric data available. Nevertheless, the present model has showed good potential of describing the hydraulics and morphological development in the study area, and has generated hydraulic and morphological design parameters, which are essential for planning and design of river training works, such as revetment work, groynes, dikes, dredging for navigation etc.

Hydrological Conditions

Discharge and water level has been applied as hydrological boundaries to the 2D model simulation. Discharge from Pandu gauging station has been used as inflow at upstream boundary of the model (which is 3 Km downstream from Pandu). Water level has been used at downstream boundary, which is at 54 Km downstream from Pandu. Model calibration was carried out for 2021 hydrological year (Fig **2**), and validation for June 2022. Discharge at Pandu gauging station for 2021 hydrological year and water level at D/S boundary of 2D model. Discharge generated from rating curve using water level at Pandu.

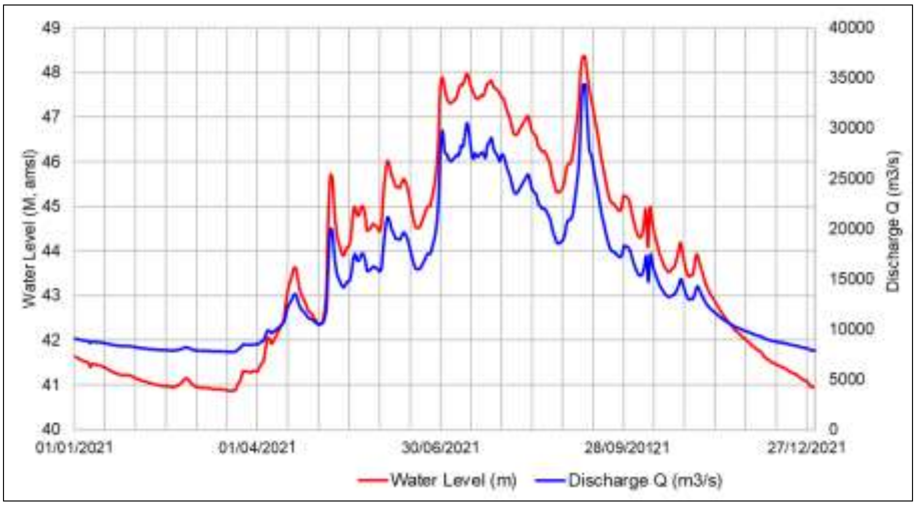

Fig 2: Inflow Discharges at Upstream Boundary and Water Level at Downstream Boundary of the 2D Model

Grain Size Characteristics

Grain size data has been obtained from available sources, which they had collected in 2018. These data have used to determine the characteristics of grain sizes, gradation and grain sorting processes that are relevant for morphological studies such as roughness, sediment transports and morphological prediction. Total 20 samples were collected at Palasbari-Gumi reach at 7 cross-sections within the 51 Km reach of the 2D model domain. At each cross-section, three samples were collected from the bed of the river, one in the middle, and two on either side of the cross-section. Samples were collected by Van veen Grab sampler. Different size classes including the median grain size (D_{50}) of the respective river reach is presented in Table 2. The grain size data has good correspondence with the citation of grain size of the Brahmaputra in literatures (Table 3).

Table 2: Grain Size Distribution Data at Palasbari-Gumi Reach of the Brahmaputra River (2018)

Sample Number	Sample ID	D16 (mm)	D50 (mm)	D65 (mm)	D84 (mm)	σ= √D84/D16
1	PG-1	0.130	0.290	0.350	0.830	2.53
2	PG-2	0.150	0.225	0.260	0.330	1.48
3	PG-2(I)	0.155	0.210	0.240	0.330	1.46
4	PG-2(II)	0.150	0.310	0.380	0.460	1.75
5	PG-3(I)	0.160	0.220	0.260	0.320	1.41
6	PG-3(II)	0.145	0.210	0.240	0.310	1.46
7	PG-4	0.135	0.320	0.385	0.480	1.89
8	PG-8	0.170	0.295	0.360	0.480	1.68
9	PG-9	0.155	0.215	0.250	0.325	1.45
10	PG-10	0.180	0.370	0.530	1.500	2.89
11	PG-11	0.150	0.215	0.245	0.330	1.48
12	PG-12	0.150	0.210	0.250	0.325	1.47
13	PG-13	0.150	0.220	0.240	0.340	1.51
14	PG-14	0.160	0.295	0.370	0.450	1.68
15	PG-15	0.150	0.215	0.250	0.320	1.46
16	PG-16	0.160	0.220	0.265	0.335	1.45
17	PG-17	0.160	0.215	0.260	0.330	1.44
18	PG-18	0.145	0.215	0.240	0.320	1.49
19	PG-19	0.140	0.210	0.240	0.310	1.49
20	PG-20	0.135	0.210	0.230	0.325	1.55

The grain sorting parameter (σ) indicates well sorted sediment in riverbed; sorting parameter less than 1.6 represents well sorted sediment (Schumm *et al*. 1973; ASCE, 2007) [62, 5]; therefore, sediment transport formulae applicable for uniform sediment (with median grain size, D50) can be ap-plied in the sediment transport and morphological prediction.

Table 3: Bed Material Grain Size Distribution at Palasbari-Gumi Reach of the Brahmaputra River (2018)

Grain Class	Palasbari-Gumi Reach	Brahmaputra Assam sGoswami *et al.* 1985 [25]	Brahmaputra at Jamuguri Karmakar *et al.* 2010 [34]
D_{16} (mm)	0.15		
D_{50} (mm)	0.24	0.25 to 0.16	0.16
D_{65} (mm)	0.29		
D_{84} (mm)	0.44		
σ (Grain Sorting Parameter), $(D_{84}/D_{50})^{0.5}$	1.65		

Model Calibration, Hydrodynamics and Sediment Transports

Hydrodynamic variables, mainly ADCP velocity measurements, have been used to compare with model calculation for the calibration purpose. Satisfactory calibration of model velocity with ADCP data will build confidence of the model for predicting sediment load, and thus morphological development for scour and erosion. For sediment load, the historical data at Pandu (from literature) has been used to compare with model predicted load.

Model calibration has been carried out by adjusting Chezy’s flow friction factor (C) through trial model runs and by comparing with measured variables (velocity and sediment load). MIKE21C modelling software has ability to apply spatial variation in use of Chezy’s C. Roughness is expected to be different over shallow islands than in the deep channels. Moreover, presence of bed forms (dunes and ripples) will also influence the roughness. MIKE21C is also able to parameterize the effect of bed form in the roughens by employing the formula: $C = C_0h^n$. Where C_0 is the coefficient matrix, which can vary spatially over the 2D model domain, h is the unsteady value of depth which varies temporally and spatially as flooding/drying of bedforms and islands continue with the rise and fall of annual hydrograph, and erosion / deposition develops in channels and over the bars; n is the calibration parameter; both C_0 and n can be a two dimensional matrix and can be obtained through calibration of the model. MIKE 21C has ability to account for the flow friction due to the dynamic growth of bars and bedforms in braided river.

Many researchers (i.e. van Rijn, 1984) [67] proposed empirical relations for assessing flow friction due to skin roughness (from sediment grains) and due to form roughness (ripples and dunes). A hand calculation of van Rijn formula for Brahmaputra gives values in the range of 55-60 for deep channel, 40-45 to more average depth channel, and 25-30 for shallow islands. The calibrated Chezy’s C values for the 2D model provided satisfactory matching with ADCP velocities and sediment load; the values (C) are also in the similar range as obtained by hand calculation of van Rijn formula.

Hydrological Scenarios for Predicting Design Variables

The model runs were carried out with different hydrological scenarios for predicting design variables along the river reach of

Palasbari area of Brahmaputra River. The model runs were carried out for the monsoon period when the model is morphologically more dynamic. The simulation period is May to October with (i) bankfull discharge condition (which has approximately 1 in 2 year return period), (ii) 1 in 100 year discharge condition, (iii) recent hydrological discharge of 2021. The discharge and water level hydrographs of 2021 used for model calibration was scaled to obtain the peak magnitude of 1 in 2 year and 1 in 100 year flood event. Model runs were carried out in fixed bed with the recent topography of June 2022 in the overall model area, and August 2022 bathymetry at the river reach of Palasbari and Gumi.

Hydrodynamic Design Variables at Palasbari

Hydraulic condition for computation of design variables was follows: (i) the model runs were carried out in fixed bed: over the recent topography of June 2022 in the overall model area, and (ii) August bathymetry at the river reach of Palasbari and Gumi, (iii) Bankfull discharge condition (1 in 2 year return period), (iv) 1 in 100 year discharge condition, and (v) recent hydrological discharge of 2021 peak flow condition.

Depth, velocity, and water level in the area were calculated with reference to a given bathymetry. Therefore, the variables, particularly the depth can be different in another riverbed topography; however, on water level, very minor change is expected for the same hydrologic condition. Therefore, the water level given in the

Table 4 could be used to find out depth for any recent condition of bathymetry, and depth average velocity, also significant changes are not expected with latest changes in bathymetry. Summary results of the variables for both Palasbari and Gumi are presented in

Table 4, and it should be noted that the depth can be useful for determining the dimensions of protection work such as length of falling and launching apron of bank revetment work and length of spurs and groynes. However, design scour depth should be calculated inclusive of the local scour. It is also recommended that the performance of any protection work (revetment / geo-bags and spurs) can be assessed by the present 2D model. An overall distribution of flow velocities for 1 in 100 year event is shown in Figure 3.

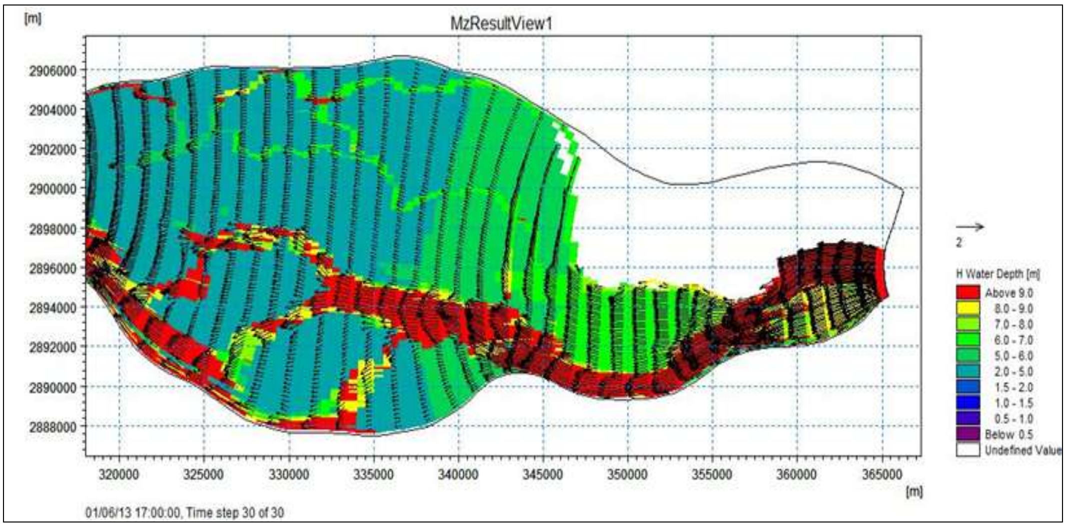

Fig 3: Flow Velocities and Depth Distribution for 1 in 100 Year Flood Event (Peak Flow: 66000 m^3/s)

Table 4: Hydraulic Design Variables at River Reach of Palasbari and Gumi Area of the Brahmaputra River

		Hydrology of 2021		**1 in 2 Year Flood (Bankfull Discharge)**		**1 in 100 Year Flood**	
		Palasbari	**Gumi**	**Palasbari**	**Gumi**	**Palasbari**	**Gumi**
Depth (m)	Maximum	33.06	14.38	33.82	15.03	35.51	16.51
	Average	09.06	05.23	09.82	05.87	11.49	07.35
Water Level (m) amsl	Maximum	46.89	45.68	47.73	46.33	49.58	47.81
	Average	46.41	45.42	47.16	46.06	48.83	47.54
	Minimum	46.03	-	46.71	-	48.24	-
Speed (m/s)	Maximum	02.53	2.367	02.81	2.428	03.33	2.430
	Average	01.21	00.61	01.40	00.66	01.77	00.73
Pandu gauging station variables (observed data or from frequency analysis)							
Discharge (m^3/s)		34,333		42,500		66,000	
Water Level (m) amsl		48.36		48.74		49.94	

The predictive performance of the model has been validated against a permanent bench-mark. The average flood level predicted by the model for the Gumi reach is 46.06, and maximum flood level is 46.33, which is at the upstream end of the reach. This shows an excellent similarity of the model with field data.

Prediction of Bank Erosion

Forecasting of bank erosion has been made along the south bank at Palasbari and Gumi reach. 1-year, 3-year and 4-year

prediction has been issued. Following development scenarios has been considered: (i) river reach at Palasbari and Gumi protected by geo-bags, which is the existing condition or baseline condition, (ii) entire Palasbari bend assumed protected and existing Gumi training work. However, the bank-erosion management at Palasbari and Gumi should have to be integrated with the development of the north bank at immediate upstream of Palasbari and at further upstream; development at north bank bend seems to be a key control for erosion and channel development at further downstream (
Fig **5**). For all prediction for bank erosion, bankfull discharge whose probability of occurrence is frequent (1 in 2-year) has been applied. For medium term forecast for 3 and 4-year prediction, the one year monsoon hydrograph has been multiplied to prepare the 3 and 4 year hydrographs.
The erosion affected banklines under bankfull discharge condition is shown in
Fig **4**; bank length shown in red lines would be affected by erosion. The gaps, where no erosion is shown, are the exiting reach protection works at Palasbari and Gumi. Yearly erosion rate is about 10-30 m. There are some reaches, although shown as erosion affected, have very minimal yearly erosion rate, below 5 m annually: for example, the protruded (convex) banklines downstream of Palasbari bend.

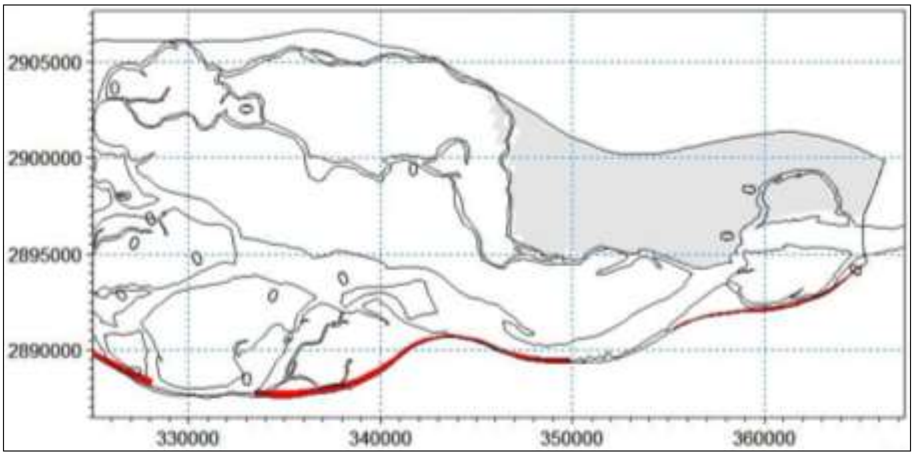

Fig 4: Erosion Affected Reaches along South Bank from Palasbari to Gumi

The development scenario considered for medium term prediction is "if entire Palasbari bend protected". This will bring benefit to the morphological development for the reach between Palasbari and Gumi; this is mainly due to the exit angle of velocities at the obstruction point at the end of Palasbari bend. This benefit is more prominent in the bed formation level along the riverbank at downstream of this protruded convex bend. The ground level will rise (island formation) to 4-6 m during the course of 3-years, the ground level almost rises to permanent or semi-permanent island level. However, this creates negative impact with more bank erosion at downstream of the bank protection work at Gumi, probably indicating extension of bank protection work towards downstream. The yearly rate of bank erosion is approximately 15 m, though the rate seems to decline in the following years to 8 m yearly in the fourth year.

Although along the north bank, bank erosion has not been predicted on the assumption that main flowing channels are general away from that bank, this bank is crucial at up-stream end of the model near to Pandu; the north bank at present and immediate future is vulnerable to erosion as high velocity and deep scoured channel have been predicted there. This bend at north bank is clearly a control node for bank erosion at downstream at Palasbari bend and for channel development further down-stream, see the historic planform development in this area in
Fig **5**. Therefore, erosion management in this area needs to consider in more integrated approach; model should be extended further up to Pandu Bridge, and the effect of more control work due to the second bridge and its river training work should be considered for making long-term prediction in this area.

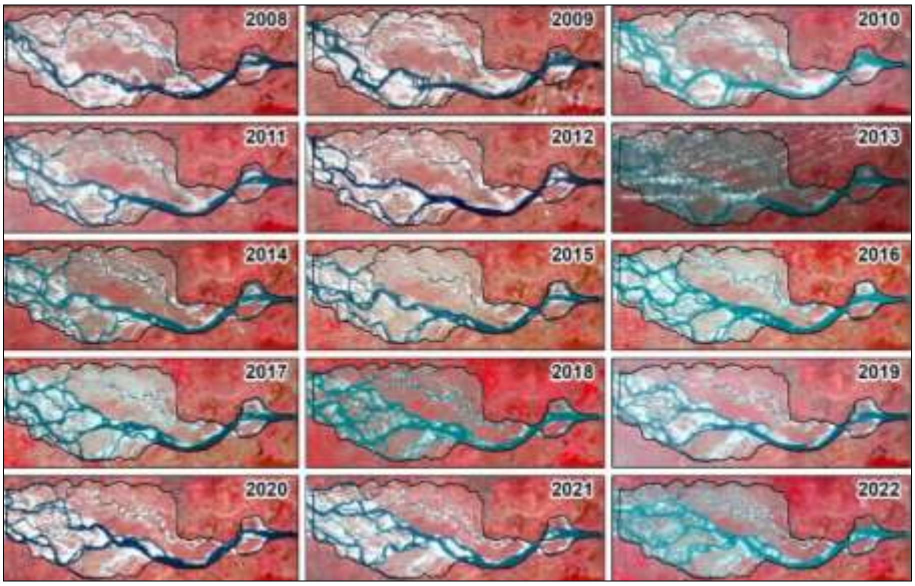

Fig 5: Historic Planform Development at Palasbari and Further Downstream

Conclusion

The morphological model for erosion prediction and planning of protection work has been developed for Palasbari-Gumi reach of Brahmaputra River. The 2D model has been carefully set-up to resolve satisfactory simulation of bend scour, confluence scour, obstruction scour and other forms of scours, and bank erosion considering the spatial and temporal characteristic length scales of those processes. The modelling technology has such ability by employing multi-block grid generation facility. The model bathymetry is based on topographic survey carried-out in 2022, and WRD cross-section surveys. The 2D model covers a length of 57 Km for full width of approx. 20 Km of the Brahmaputra River at Palasbari-Gumi reach. The model is calibrated for hydrology of 2021; validated against flow of June 2022. The model predicted results show excellent similarity with ADCP velocities, design flood levels and yearly sediment load. Difference of peak model velocities with ADCP measurement is lower than 10% with majority of measured data; velocities are compared at five river sections. Predicted flood level for bankfull discharge condition were almost 98% accurate at Gumi site.

Predicted mean annual sediment load for 2021 hydrological year and bankfull discharge are 257 and 314 Mt/year for coarse sand fraction; historical observed sediment load in the Brahmaputra is 400 Mt/year. Hydraulic design variables such as depth, velocity, and water level in Palasbari and Gumi sites have been predicted. The average depth in 2022 is 9.82 m and 5.87 m at Palasbari and Gumi respectively, which may exceed to 11.49 m and 7.35 m after 100 years, respectively. The average water level in 2022 is 47.73 m and 46.33 m at Palasbari and Gumi respectively, which may overdo to 48.83 m and 47.54 m after 100 years, respectively. The average speed in 2022 is 1.4 m/s and 0.66 m/s at Palasbari and Gumi respectively, which may go over to 1.77 m/s and 0.73 m/s in 2122, respectively. In general, on average 12-25 m bed scour have been predicted for the three flood events along Palasbari bend. Scour along Gumi bend is comparatively low, generally between 4-8 m. Both short-term (1-year) and medium-term (3-year) predictions do not show evidence of the Gumi anabranch to develop further in the coming year.

Prediction of bank erosion has been made along the south bank at Palasbari and Gumi reach. 1-year, 3-year and 4-year predictions have been produced for the following development scenarios. The sites at Palasbari and Gumi protected by geo-bags, which is the existing condition or baseline condition. Entire Palasbari bend assumed protected and existing Gumi work. The yearly erosion rate is about 10-30 m. There are some reaches, although shown as erosion affected, have very minimal yearly erosion rate, below 5 m annually. This erosion is mainly at im-mediate downstream of the sites at Palasbari and Gumi. There is minor embayment development at immediate upstream of each of the sites, with maximum of 10 m bank erosion. The development scenario “if entire Palasbari bend protected” will bring benefit to the morphological development for the reach between Palasbari and Gumi. This would attract significant siltation along the bend at upstream of Gumi sites. However, this creates negative impact with more bank erosion at downstream of the bank protection work at Gumi. This study has shown how to improve the planning and execution of river training works in highly braided river like Brahmaputra by predicting morphological changes over a 2-3 year period.

Acknowledgement

Author is grateful to Managing Director, DHI (India) Water and Environment Pvt Ltd, New Delhi, India for providing the necessary facilities to carry out this work.

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