MATHEMATICAL MODEL STUDIES FOR RIVER REGULATORY MEASURES FOR THE IMPROVEMENT OF DRAFT IN HOOGLY ESTUARY, INDIA

R.P. Dubeyⁱ, S.Samarawickramaⁱⁱ, P.P. Gunaratnaⁱⁱⁱ, L. Halgahawatta^{iv},
K.P.P. Pathirana^v, K. Raveenthiran^{vi}, K. Subasingha^{vii} B. Das^{viii}
and T.A.N. Sugandika^{ix}

ⁱ Chief Engineer, WAPCOS Ltd., India

ⁱⁱ Professor, University of Moratuwa, Sri Lanka

ⁱⁱⁱ Marine Project Specialist, Dubai Municipality, Dubai

^{iv} Engineering Manager, Lanka Hydraulic Institute, Sri Lanka

^v Professor, University of Peradeniya, Sri Lanka

^{vi} Senior Engineering Manager, Lanka Hydraulic Institute, Sri Lanka

^{vii} Engineering Manager, Lanka Hydraulic Institute, Sri Lanka

^{viii} Professor & Dean, KIIT University, Bhubaneswar, Orissa

^{ix} Engineering Manager, Lanka Hydraulic Institute, Sri Lanka

Corresponding Author: R.P. Dubey Email: rajeshpdubey@gmail.com

Keywords: River Hydraulics, Hydrodynamics, Sand Transport, Mud Transport, Siltation, Dredging, Ship Simulation, Physical Modelling, Navigation and Estuary Dynamics

ABSTRACT. The Haldia port is situated in the Hooghly estuary, 104 km downstream of Kolkata Port. As a result of high sedimentation, the navigational channel to the Haldia Port is maintained with great amount of dredging (25 MCM per Annum). The paper presents a study carried out to find a solution to improve the channel depth together with minimum maintenance dredging. A desk study was carried out to identify the historical formation of the estuary and the remedial measures implemented in the past. A detailed field investigation was carried out to obtain the relevant data for the calibration of numerical models. 1D (MIKE 11) river hydrodynamic modelling was carried out using the available bathymetric data to supply upstream boundary conditions for the 2D (MIKE 21) and 3D (MIKE 3) numerical models. Number of possible scenarios were tested through MIKE 21 hydrodynamic modelling to select more feasible options. Selected options were further assessed through morphodynamic and 3D hydrodynamic modelling to examine the long term sustainability of the proposed solutions. Finally, the option which comprise of; approach channel through Balari Passage & closure of the Shore Attached Channel was selected as the best option. The selected option was further studied taking navigational aspects, dredging efforts and construction sequence into consideration.

INTRODUCTION

The Haldia Port is situated 104 km downstream of Kolkata Port (KoPT) in the Hooghly estuary, which has the longest navigational channel. At present, estuary is divided in to two channels due to the formation of Nayachara Island. As a result of high sedimentation, the navigational channel to the Haldia Port is maintained with great amount of dredging (25 MCM per annum).

A study was carried out to find out a solution to improve the channel depth together with minimum maintenance dredging. The Hooghly Estuary with existing formations is shown in the Figure 1.

Fig. 1. Hooghly Estuary (Existing Condition)

OBJECTIVES

The objectives of the Mathematical Model Studies for River Regulatory Measures for Improvement of Draft in Hooghly Estuary can be outlined as follows;

- To review and revalidate / refine / modify the recommendations of National Institute of Ocean Technology (NIOT).
- Improvement of depths in the governing bars by at least 0.5m from the existing comfort level of 5.0m at Jellingham and 5.5m at Auckland.
- Reduction in annual maintenance dredging by at least 2.0 million cubic meters.
- Feasibility of shipping channel for KoPT through Balari area.
- Recommendations regarding alternative / refined / modified scheme with recommended time schedule.

The investigative studies were carried out through Desk Studies, Field Investigations, Mathematical Modelling (1D, 2D and 3D), Navigation Studies, estimation of the Dredging Effort and Physical Modeling.

DESK STUDY

Desk study was carried out at the early stage of the project, with the objective of making an initial assessment of the problem evolution and to review the historical behaviour and existing condition

of the estuary. This information was used to identify the chronological changes in Hooghly River and River Regulatory Measures (RRMs) adapted to control negative impacts due to such changes. The Desk Study was also extended to determine Morphological Changes in Hooghly Estuary over last 50 years. The summary and main findings of this study were used to analyze the problem and possible alternative solutions. The 3D view of bathymetry for the year 2007 is given in Figure 2. It is evident from the figure that the nature was in the process of separating Haldia system from Rangafalla system through raising of Jiggerkhali flat, formation of Balari Island, Nayachara Island and gradual extension of Nayachara tail. The Rangafalla channel has become a straight guided channel.

Fig. 2. Three Dimensional View of the Year 2007 Bathymetry

FIELD INVESTIGATIONS

Field Measurements have been carried out to understand the Hydrodynamics of the Estuary and calibrate the numerical models. Since the characteristics of the Estuary (Discharge, Tide, etc) vary during different periods of the year, the measurements were carried out in three different periods:

- ✓ Dry Season (March - May) - Phase I
- ✓ Monsoon Season (June - September) - Phase II
- ✓ Post Monsoon (October - November) - Phase III

The measurements carried out include; Current and Salinity Measurements, Tidal Measurements, Transect Measurements and Water & Sediment Sampling. The tidal measurements carried out indicate that the spring tidal range was 4.1m at Sagar, amplified to 5.5m at the diamond Harbour and reduced to 4.2m at the Garden Reach. The peak velocity at strength of flood and ebb during spring tide was 2.5m/s. This shows that the estuary is characterized by the presence of high flood and ebb velocities.

Sediment samples collected at different points were analysed and D50 values were found. The samples collected at several locations indicated that most of the bed material was fine sand, except in the Jellingham channel. A significant proportion of clay fractions were present in the Jellingham channel.

Water samples collected at several points showed that highly sediment laden water was present in the estuary. High silt concentration at the junction of upper and lower Jellingham was noticeable. This area was also susceptible to heavy siltation. Salinity was observed at several points and analysed. From the values it was noted that the salinity was uniform over depth but varied along the estuary. During rainy season it was pushed towards sea.

1D HYDRODYNAMIC MODELLING

The use of one dimensional model was needed to provide time series at the boundaries of two dimensional models and to quantify the change in tidal prism due to River Regulatory Measures. For this purpose, MIKE 11 Rainfall Runoff (RR) and MIKE 11 Hydrodynamic (HD) modules were used.

Table 1. MIKE 11 Predicted Tidal Prism for a Tidal Cycle (Existing Condition)

Scenarios		Flood	Ebb
Tidal Prism for a Tidal Cycle in Selected Locations (Mm³)	2D Boundary	186	-255
	Hooghly Point	382	-453
	Diamond Harbour	433	-504
	S1	67	-64
	B	48	-79
	R3	639	-823
	J1	459	-345
	DS2	2375	-2446

Fig. 3. Selected Sections for Discharge Calculations

The model was well proven for water levels observed at various points. In general most of the sections (refer Fig. 3) provide a greater ebb volume with compared to the flood volume due to the influence of the upstream river flow. However, Jellingham Channel (J1) and Shore Attached Channel (S1) provided a lesser ebb volume with compared to the flood volume. This clearly indicates that the Jellingham-Haldia channel is dominated by the flood flow, whereas Rangafalla channel is dominated by the ebb flow. Moreover, out of total volume of 2375 MCM entered at entrance (DS2) only 1100 MCM passed through Rangafalla (R3) and Jellingham (J1). Again out of

1100 MCM only 382 MCM passed through Hooghly point. This indicates that the estuary is still capable of accommodating a large volume.

2D HYDRODYNAMIC MODELLING

Two dimensional models were used to examine the performance of the proposed River Regulatory Measures and to identify an optimum solution. For this purpose, MIKE 21 Hydrodynamic (HD) and Spectral Wave (SW) modules were used.

The objectives of the MIKE 21 Modelling were:

- Review the efficacy of the RRM scheme proposed by NIOT studies with the recent bathymetry.
- Evaluation of new schemes which will provide the solution for the existing siltation problem.
- Detail investigation of promising RRM schemes.
- To test main components of the scheme for various stages of construction.

To achieve those objectives, 2-D Hydrodynamic Modelling was carried out under three different stages. Before the experimental runs, model was proved against observed water level and velocities.

Model Calibration

A good model calibration was achieved with the use of Phase I Field Measurements and model verification was done using the Phase II Field Measurements.

Stage I Modelling

Ten River Regulatory Measures (RRMs) were initially formulated for model testing. These include three NIOT proposals and seven schemes proposed by Lanka Hydraulic Institute (LHI). Based on the results of ten scenarios (RRMs), two main options with several sub options were selected for further studies. From analysis of bathymetry, huge deposition of sediment was observed along the Balari channel. During stage I modelling, individual components of the proposed improvement schemes were tested. The results of the modelling indicate that all the schemes tested in the model fail to improve velocity in the targeted area (Auckland and Jellingham).

Due to a situation prevailed in the Auckland area; KoPT had been exploring the possibilities of using the western channel as the navigation channel to the Haldia Dock Complex. This was being considered as a mid-term measure. KoPT requested LHI to carry out detailed modelling of the impediment removal and restoration to understand its possible impacts. Three different scenarios were considered in numerical modelling for impediment removal and another three different scenarios were considered for restoration of spurs and submerged guide wall. The results of the modelling carried out indicated that removal of impediments will only have a local effect without having any positive/negative impact on the estuary. Restoration of the damaged spur and submerged guide wall up to design level indicated that the impact on the estuary dynamics will be very small. However the restorations above design (+3m from CD) level showed a significant reduction in flood and ebb flow volumes as the structure at a higher level act as a barrier for both flood and ebb flow conditions.

Stage II Modelling

Option 1: Navigation through Jellingham – Haldia Channel

The objective under this option was to explore the possibilities of maintaining the Jellingham – Haldia Channel with reduced dredging efforts. Initial modelling indicated that dredging in the Balari Passage and in the Shore Attached Channel would not give any benefit to the Jellingham area. Even though the initial results were not beneficial, additional effort was made to understand

the impact by considering different options (8 alternatives). None of these options were able to give a desirable outcome to improve flushing ability in the Auckland Jellingham Channel.

Option 2: Navigation through Rangafalla Channel and Balari Area

The objective under this option was to explore the possibilities of using the Balari Passage or Shore Attached Channel as the entrance channel to the Haldia Port through the Rangafalla channel. It may be noted that Stage II options contemplates closure of shore attached channel.

Table 2. Different Scenarios Modelled under Stage II - Option 2

Option	Modifications
2A	Closure of the Shore Attached Channel, No dredging in the Balari Passage
2B(i)	Closure of the Shore Attached Channel Dredging in the Balari Passage (Dredging 300m wide × 5m deep channel)
2B(ii)	Closure of the Shore Attached Channel Dredging in the Balari Passage (Dredging 300m wide × 7m deep channel)
2C(i)	Closure of the Shore Attached Channel Northern guide wall raised (4.82m above chart datum) Dredging in the Balari Passage (Dredging 300m wide × 5m deep channel)
2C(ii)	Closure of the Shore Attached Channel Northern guide wall raised (4.82m above chart datum) Dredging in the Balari Passage (Dredging 300m wide × 7m deep channel)
2D(i)	Closure of the Shore Attached Channel Northern guide wall existing condition Dredging in the Balari Passage (Dredging 300m wide × 5m deep channel) Closure of the Haldia Channel (North of Hal di River)
2D(ii)	Closure of the Shore Attached Channel Northern guide wall existing condition Dredging in the Balari Passage (Dredging 300m wide × 5m deep channel) Closure of the Haldia Channel (South of Hal di River)

For the selection of the best scheme, it was necessary to consider, (i) convenience of implementation, (ii) ease of subsequent maintenance and (iii) least interferences. The proposal 2B(i) satisfy all the above considerations. 13% reduction in tidal prism in Haldia channel was compensated by 14% increase in tidal prism in Rangafalla channel. This scheme will be beneficial as the present dredging effort in the Jellingham channel will not be required (Rangafalla channel and the Balari Passage will be used as the navigation channel). Maintenance dredging will have to be carried out in the Balari Passage and in the Port Area. This could be easily achieved by shifting the dredging efforts from Jellingham Channel to Balari Passage.

Stage III Modelling

Additional nine options were selected for further modelling based on the results and conclusions drawn from the short-term modelling of 11 combined RRM schemes under Stage II – Modelling as indicated in the Table 3 and Fig. 4.

Table 3. Different Scenarios Modelled under Stage III

Option	Modifications
3A(i)	Capital Dredging in Shore Attached Channel (250m wide X 3m deep) Closure of the Balari Passage, Closure of Flow Passage between Southern tip of Nayachara Island and Island to the South Removal of Impediment (2500m) from Submerged Guide wall at Auckland area
3A(ii)	3A(i) Modifications + Two Parallel Guide Walls aimed at Narrowing the Width of Jellingham-
3B(i)	Haldia Channel (6.0m ACD) Closure of the Shore Attached Channel

	Dredging of the Balari Passage (300m wide X 5m deep) Closure of flow passage between southern tip of Nayachara island and island to the south Removal of impediment (2500m) from submerged guide wall at Auckland area Raising of Northern Guide Wall at Nayachara Tip (+7.0m from Chart Datum)
3B(ii)	3B(i) Modifications + Two Parallel Guide Walls aimed at Narrowing the Width of Jellingham-Haldia Channel (6.0m ACD)
3C	Closure of the Shore Attached Channel Closure of the Balari Passage Closure of flow passage between southern tip of Nayachara island and island to the south Removal of impediment (2500m) from submerged guide wall at Auckland area
3D	Guide wall at Jellingham (3.0m above Chart Datum) Removal of impediment (2500m) from submerged guide wall at Auckland
3E	Guide wall at Jellingham (3.0m above Chart Datum)
3F	Closure of the Shore Attached Channel Closure of the Balari Passage Capital dredging in the flow passage between southern tip of Nayachara Island and island to the south (500m x 5m from CD) Closure of the Jellingham Channel
3G	3F Modifications + Sand Trap at the Southern End of the Nayachara Island

Under these options besides entrance through Balari Passage, entrance through Shore Attached Channel was also considered. The proposals were investigated together with Closure of flow passage between southern tip of Nayachara island and the island to the south, Removal of impediment (2500m) from submerged guide wall at Auckland area and Raising the Northern Guide Wall at Nayachara Tip (+7.0m from Chart Datum), providing two parallel guide bunds in Jellingham area and Removal of impediments.

It may be noted that in this stage attempts were also made to have an access channel from south side through options 3C, 3F and 3G by closing Balari Passage and Shore Attached Channel. In 3D & 3E attempts were made to take advantage of guiding the flow at downstream without closing upstream. In proposal 3F and 3G, besides Balari closure, downstream closure was also proposed keeping a gap between Nayachara and Nayachara Tail for ship entry.

Fig. 4. Proposed RRM for Stage III

Option 3B (i) gave better results with compared to the entrance through the Shore attached channel. There was a slight increase in flow through the Haldia Channel (H1) under 3B (i), whereas a reasonable reduction of flow could be seen under 3A (i). A small reduction in flow through the Jellingham Channel (J1) was observed under both cases due to the closure of the Flow Passage between Southern tip of Nayachara Island and Island to the South. However, the percentage reduction under 3B (i) was much smaller with compared under 3A (i). There was no change in the total quantity of flood water entering the estuary under both cases (DS2). The Option 3B(i) contemplated 2B(i) along with raising of northern guide wall. Experiment showed there was slight increase in flow through Haldia channel by raising of Northern guide wall. It was observed that construction of guide bunds in downstream regions and restoring spurs have adverse effect on tidal prism. Efficacy of proposal 3C and 3F which contemplates total closure of Balari area can be tested only through long-term morphological simulation.

PHYSICAL MODELLING

Physical model tests were carried out for few selected model scenarios at the physical model centre maintained by the Kolkata Port Trust. The objective of the physical modelling was to compare hydrodynamic conditions given by the mathematical model and to visualise any specific changes to local flow patterns due to the proposed RRM. It was observed that the closure of Haldia Channel, upstream or downstream of Haldi River will grossly change the river hydraulics.

2D MORPHOLOGICAL MODELLING: Based on the results of Hydrodynamic Modelling four schemes were selected for long-term simulations, i.e. 2B(i), 3A(i), 3C and 3F. Sand (ST) and Mud Transport (MT) modelling were carried out for a one year period to predict the morphological behaviour of selected options.

Fig. 5. Areas Identified for Comparison of Deposition Volumes

It could clearly be seen that the annual deposition quantities predicted by the models with option 2B(i) in Haldia channel was less than the existing condition. Deposition quantity predicted for Haldia channel under option 3A(i) was considerably higher than the existing and option 2B(i) conditions. No significant change in the siltation quantities of the upper Jellingham, lower Jellingham, Auckland, Rangafalla channel and Sagar Anchorage were noted in the simulation results for option 2B(i) and option 3A(i).

The option 3C did not seem to be effective in controlling siltation rates in the study area as the long term predictions indicate that the deposition quantities are almost same as in the case of existing condition in all areas except in Haldia channel and Upper Jellingham. Considerably high deposition quantities have been predicted in these two areas.

Table 4. Total Deposition Quantities Predicted by ST and MT Models for Different Options

Option		Existing	2B(i)	3A(i)	3C	3F
Deposition Quantities at Different Locations	1	2	1	5.5	6	10
	2	4.5	4.5	5.5	5	6
	7	-	-	6.5	-	-
	3	i	5	6.5	6	10
		ii	6	5.5	5.5	6
	4	6.5	6	6	6	8
	5	6	6	6	5	10
	6	3.5	2	2.5	4	-3
Total Dredging		25.5	13.5	20.5	33	38

The deposition rates in Haldia and Upper Jellingham channels were very high in option 3F. Fine sand was deposited in Upper Jellingham channel and silt and clay fractions were carried up to Haldia channel. In this option, Sagar Anchorage was also subjected to more deposition. The Table 5 gives the total annual dredging requirement predicted by ST and MT models. The estimated quantities were based on the model predictions and actual dredging quantities.

The dredging needs of Bedford and Maraguliya, which may arise in future, have also been taken into consideration.

Table 5. Summary of the different options considered

Option	Total	Annual	Dredging	Ranking
	Model	Estimated	Estimated	
Existing	25.5	27	-	
2B(i)	13.5	15	13	1
3A(I)	20.5	22	20	2
3C	33.0	33	-	
3F	38.0	38	-	

Based on the Numerical Model results and Engineering Judgment, Option 2B(i) could be considered as the best solution for the existing problem in the Hooghly Estuary. Option 3A(i) could be considered as the 2nd best option. Options 3C and 3F do not provide the expected results and could not be considered for implementation.

3D HYDRODYNAMIC MODELLING

It was observed from field investigation results that the salinity variation over the depth was negligible. Hence the estuary can be considered as a vertically mixed estuary. In this respect the salinity effect was not expected to have a significant influence in the modification of velocity field. However, the influence of secondary currents on formation of Balari Bar due to presence of curvature at this zone and its effect in changed scenario with the proposed RRM in place was better evaluated in terms of 3D modelling which considers variation of velocity over the depth of flow. 3D model experiments were carried out using 6 layers for existing condition and for the most promising Option, 2B(i). From the results, it was evident that even under existing condition, Balari Passage channel was more active than the shore attached channel. In fact there was a kind of

separation of flow at entry of shore attached channel due to protruding bank before entry. Stream lined closure bund in proposal 2B(i) improved flow through Balari Passage.

NAVIGATION ASPECTS

Navigational aspects of Rangafalla – Balari channel and existing channel were studied in detail. The results of the study indicate that the time of travel through the proposed path of Rangafalla-Balari-Haldia would be 4 ½ hours in place of 2 ½ hours in the existing Rangafalla channel. Pilots confirm that the existing channel being straight, it is possible to cover the distance within 2 ½ hours. Keel clearance for vessels having a draft of 7.5 m or less was considered in the study. Travel time being more in the proposed channel, only limited number of ships could make through in a tidal window. During a neap tide, navigation will be possible for vessels having a draft of 6.5m or less.

A critical point indicated by marine department regarding turning of a ship in the mid estuary is the prevalent high velocities. The ship has to reach the turning circle in appropriate time suitable for turning. This would lead to loss of additional time. Taking all these into consideration, existing shipping route will be followed in near future. Alternative route through Rangafalla – Balari could only be used after stabilization of Balari passage channel and further improvement of depth at governing bars in the Rangafalla channel.

DISCUSSION OF RESULTS

The comparative analysis of hydraulic and engineering aspects of Option 2B(i) and 3A(i) was carried out and presented in the Table 6. It is clear that the proposal 2B(i) which contemplated access channel through Balari passage is superior to 3B(i) in almost all aspects. The most important was the creation of a dumping area having a total capacity of 55MCM. Beside this, it was also proposed to create a dumping area along the Nayachara Island. These two dumping areas would provide sufficient space to accommodate 10 years of maintenance dredging after accommodating the capital dredging quantity. In the first 10 years, if 5 to 6 MCM of effective sediment would be taken out from the system there will be a very good possibility of revival of Haldia system. Much bigger amount of sediment is playing role in shaping lower estuary. However, a 5 to 6 MCM is responsible in shaping the Balari area, forming and expanding Balari Island, chocking the passage of Haldia Channel. Hence tackling of sediment load from this location efficiently was the key to revival of Haldia Channel, besides keeping the access channel clear for ship movement from Rangafalla to Haldia Port through Balari Passage.

Table 6: Comparative Analysis Showing Merits and Demerits of Option 2B(i) and 3A(I)

Sr. No	Description	Option 2B(i)	Option 3A(I)
1	Details of the Proposal	Closure of the Shore Attached Channel and Dredge Cut in the Balari Passage with Dimensions of 300m x 5.0m BCD	Closure of the Balari Passage and Dredge Cut in the Shore Attached Channel with Dimensions of 300m x 5.0m BCD
2	Components		
	(i) Dredge length	11.5 km	12.5 km
	(ii) Dyke Length	10.5 km	9.5 km
3	Capital Dredging	17.0 MCM	18.0 MCM
4	Maintenance Dredging		
	(i) In Access Channel	4.5 MCM	6.5 MCM

	(ii)Total	13.5 MCM	20.5 MCM
5	Creation of Dumping		
	(i) Up to 0.0m MSL	7.0 sq. Km	4.0 sq. Km
	(i) Up to +3.5m MSL	11.5 sq. Km	4.5 sq. Km
6	Length of Navigation Channel, Starting from Turning Circle of Option LT-1	13.5 km	21.0 km
7	Interference with Nature	Least interference: closure of the Shore Attached Channel follows the stream line. Dredge material dumped in a closed basin	The natural flow area of channel is getting blocked
8	Dumping Ground		
	(i) Dyke Crest 0.0m MSL	19.0 MCM	14.0 MCM
	(i) Dyke Crest +3.5m	55.0 MCM	30.0 MCM
9	Total Prism (Through Haldia Channel)		
	(i) Influx	387 / 388 *	362 / 388 *
	(ii) Efflux	359 / 341 *	335 / 341 *

Note: * Existing Condition and Flux was given as MCM

CONCLUSIONS AND RECOMMENDATIONS

More than 30 alternatives were tried and the Modified Scheme 2B(i) was found to be the best solution. The benefits of the scheme could be identified as follows:

- ✓ Improved efficiency of disposal method by creating shore disposal grounds at different places along the bank i.e. Balari Island, Nayachara Island, Rasoolpur & Sagar Island.
- ✓ Increase in ebb tidal prism and recovery of flood tidal prism.
- ✓ Increase in average draft by 1.0m (minimum) from the existing draft of Haldia Dock
- ✓ Reduction of annual maintenance dredging to the tune of 20MCM in place of 24MCM
- ✓ Gradual reduction of maintenance dredging at Auckland and Jellingham channel due to increased ebb flow.

Fig. 6. Proposed River Regulatory Measures

1.1. Recommendations for the RRM

- ✓ Closure of the area from the northern tip of Balari Island to the main land and from the southern end of the Island to the main bank surrounding proposed dock area
- ✓ Creation of dumping areas on Balari Island and Nayachara Island
- ✓ Capital dredging in the Balari Passage area
- ✓ Strengthening of the bank at the eastern side of Balari as well as Nayachara Island
- ✓ Dumping area of dredged material (capital dredging) at the closure portion and Nayachara Island (northern end)
- ✓ Dumping area of dredged material (maintenance dredging) over Nayachara Island (southern end) within the dyke through shore disposal terminal plus a small amount (1–2 MCM) in the Kulpi deep water pocket
- ✓ Development of a shore disposal terminal and dyke at the western edge of Sager Island for accommodating dredge material of Bedford, Maragolia and Auckland
- ✓ Requirement of annual maintenance dredging is 20.00 MCM
- ✓ Creation of a dock basin at downstream of shore attached channel
- ✓ Strengthening of the bank at Kulpi and Ghoramara Island to hold the frame of the left bank as well stop outflanking of the river
- ✓ Dumping area of Dredged material (Maintenance Dredging in Jellingham/Auckland area)
- ✓ Trimming of western face of Nayachara Island

REFERENCES

- [1] Danish Hydraulic Institute, 2009, MIKE 21 – Coastal Hydraulics and Oceanography – User Guide and Manuals.
- [2] National Institute of Ocean Technology, 2005, Implementation and Performance Monitoring of Experimental Submerged Dyke in the Jellingham Channel.
- [3] KOPT: Simulation Studies on Training Measures in Hugli Estuary at CPT Scale Model.