HYDRODYNAMIC AND MORPHOLOGICAL ANALYSES OF NEW DHALESWARI RIVER OFFTAKE USING MATHEMATICAL MODEL

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CERTIFICATION OF APPROVAL

We hereby recommended that the M.Sc.Engg. Research work presented by A.Z.M. Sanaul Haque, Roll No. 0412162072(P), Session: April 2012, entitled "**Hydrodynamic and Morphological Analyses of New Dhaleswari River Offtake Using Mathematical Model**" has been accepted as satisfactory in partial fulfilment of the requirements for the degree Master of Science in Water Resources Engineering on 19th September 2018.

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This is to certify that this project work entitled **"Hydrodynamic and Morphological Analyses of New Dhaleswari River Offtake Using Mathematical Model"** has been done by me under the supervision of Dr. Md. Abdul Matin, Professor, Department of Water Resources Engineering, Bangladesh University of Engineering and Technology, Dhaka. I do hereby declare that this project or any part of it has not been accepted elsewhere for the award of any degree or diploma from any other institution.

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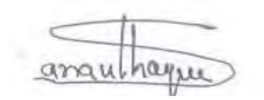

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g	Acceleration due to gravity
D	Amount and size of bed material load
V	Average flow velocity
$\bar{u}$	Average velocity
z	Bed level
n	Bed porosity
τo	Bed shear stress
x,y	Cartesian coordinated system
B	Channel breadth
i	Channel slope
E_h	Characteristics of the bank material
C	Chezy roughness coefficient
a	Coefficient
a'	Coefficient of alluvial resistance
s,n	Coordinates in the curvilinear coordinate system
Vcr	Critical average flow velocity
τ_{cr}	Critical shear stress
u*, Vc	Critical shear velocity
ρ_s	Density of soil
ρ_w	Density of water
d	Depth
Ψcr	Dimensionless critical Shields shear stress parameter for specific material
Q	Discharge
β	Erodobility coefficient
b	Exponent
b'	Exponent of alluvial resistance
ω	Fall velocity
R	Hydraulic radius
ν	Kinematic viscosity
ΔSe	Lateral sediment supply from bank erosion
p,q	Mass fluxes in the s and n direction
D	Median sieve diameter
ks	Nikuradse roughness height
Rs,Rn	Radius of curvature of s and n line
Δm	Relative density of submerged material
R*	Reynolds number
Qs	Sediment discharge
Sb	Sediment transport capacity parallel to the bank
gs	Sediment transport per unit time per unit width
qs	Sediment transport per unit width
τ_o	Shear stress exerted along the bank/bed boundaries
u*	Shear velocity

θ	Shields parameter
Z	Side slope
P	Sinuosity
d_{50}	Size of bed material load
S	Slpoe
γ_s	Specific weight of sediment particles
γ	Specific weight of water
u	The averaged flow velocity
zo	The zero velocity level
t	Time
Eu	Time averaged erosion coefficient
Ct	Total sediment concentration in parts per million (ppm) by weight
Sx	Total sediment transport in x-direction
Sy	Total sediment transport in y-direction
Øx	Transport parameter
ub	Velocity near bank
h	Water depth
H	Water level
H	Water Level
W	Width
F	Width/depth ratio

LIST OF ABBREVIATION

1-D	One-Dimensional
2-D	Two-Dimensional
BRRP	Buriganga River Restoration Project
BTM	Bangladesh Transverse Mercator
BWDB	Bangladesh Water Development Board
CEGIS	Center for Environment and Geographic Information Services
DEM	Digital Elevation Model
DHI	Danish Hydraulic Institute
DPP	Development Project Performa/Proposal
DS	Down-Stream
DTM	Digital Terrain Model
EGIS	Environment and GIS Support Project
ESRI	Environmental Systems Research Institute
FAP	Flood Action Plan
GBM	Ganges Brahmaputra Meghna
GIS	Geographic Information System
GoB	Government of Bangladesh
GRRP	Gorai River Restoration Project
IWM	Institute of Water Modelling
m^3/s	Cubic meter per second
MIKE 11	One-dimensional One Layer Model Develop by MIKE ABBOTT
MIKE 21 C	Two-dimensional One Layer Curvilinear Model Develop by MIKE ABBOTT
PWD	Public Works Datum
SWMC	Surface Water Modelling Centre
US	UP-Stream
UTM	Universal Transverse Mercator

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ABSTRACT

Bangladesh is a riverine delta formed largely by the alluvial flood plains of the three major rivers of Ganges-Brahmaputra-Meghna (GBM). These river systems carry huge sediment loads mostly originated from transboundary river basins. The distributaries of GBM river system have been silting up and the hydraulic conditions are disturbed. As for example, the New Dhaleswari river is one of the distributaries of the Jamuna river. Now-a-day, the mouth of this river becomes dying up due to serious siltation in the vicinity of the offtake. The offtake channel conveys a fraction of flow from it's discharge of the main river Jamuna. In order to increase the dry season flow of New Dhaleswari, a better offtake management is necessary to feed the downstream part of the river. This study deals with the hydrodynamic and morphological analysis of river offtake of New Dhaleswari using mathematical model.

Model has been setup for the study area and simulated for various options. The study area covers 40 km reach of Jamuna river starting from the 22 km upstream of the mouth of New Dhaleswari offtake to 18 km downstream. In model setup, it also covers the 30 km reach of New Dhaleswari River. Morphological analysis i.e. planform analysis, cross section analysis have also been carried out using historical images and cross-sectional data collected from Bangladesh Water Development Board (BWDB). Two-dimensional mathematical model MIKE21C has also been applied for the study. The model has been successfully calibrated and validated against the data for the year of 2015 and 2012 respectively. Simulation runs have been made with three flow conditions such as at high (1998), medium (2005) and low (2001) flood event of Jamuna and New Dhaleswari. For each flow conditions nine different options have been considered for model run. The options are mainly include river training works (Guided banks), inclusion of silt trap, weir and dredging work. Descriptions and outcome of various options have been discussed and presented in this thesis. Thus, a total of 42 model runs with various options have been carried out. Model runs with option-9 produces the amount of flow diversion 3.08% in the monsoon for medium flood event. Here the maximum discharge is 1731 m^3/s for medium flood event and net bed degradation is 6.20 Mm^3 for 5 km reach of New Dhaleswari River. The model results reveal that, among the various options, the Option-9 which describes the placement of a silt trap, river training works at offtake, a weir near offtake and 50m bed dredging is found to be more favorable way for this offtake management.

CHAPTER 1
INTRODUCTION

1.1 General

The development of an offtake depends to a large extent on the hydro-morphological characteristics and behavior of its parent river and distributaries channel. The Ganges, Brahmaputra and Meghna river system carried huge sediment. Sediment brought by these rivers has built up over thousands of years what is now one of the largest deltas in the world: the Bengal Delta (Sarker et al., 1999). The dynamics of such offtakes have undoubtedly been of great significance during channel avulsion, such as: the occupation of the current Jamuna channel and abandonment of the New Dhaleswari. The mouth of the river is not stable and changes when the left bank anabranch of the Jamuna river has a changing discharge. At present, serious deposition has taken place at the mouth, induced by intense char movement. For analyzing the siltation problem of this river, two-dimensional morphological model has been a useful tool to investigate the present problem to propose a better solution for the offtake management. The detail study on offtake morphology has been helpful for engineers, planners involved in offtake management. To some extent the study has suggest the possible restoration measures to be undertaken of New Dhaleswari offtake region.

1.2 Background of the Study

Bangladesh is a riverine country formed largely out of the alluvial processes of Ganges-Brahmaputra-Meghna (GBM) river system that carries huge amount of sediment loads. A balance has been revised after FAP24 (1996) using the data from 1990 to 2012 and it is conclude that 1.05 billion tons sediment per year passed through the main river system to the Bay of Bengal (Mohiuddin, F. A. , 2016). Most of the distributaries of GBM river system of Bangladesh have been silted up. The recent increase in river bed levels due to the huge sediment inflow on the major river system introduces many problems such as flooding and navigation problem. In dry season mouth of the many spill channels are now disconnected from the main channels, for example, Gorai, Old Brahmaputra, Dhaleswari etc.

There are four offtakes of the Jamuna river are also hydraulically connected towards Buriganga river system around the western part of the Dhaka city. These are

i) Old Brahmaputra offtake- Jhenai-Futikjani-Bangshi-Turag-Buriganga system.

ii) Dhaleswari North offtake-Pungli-Bangshi-Turag-Buriganga system.

iii) New Dhaleswari offtake-Pungli-Bangshi-Turag-Buriganga system (so-called New Dhaleswari river system).

iv) Dhaleswari South offtake-Barinda-Bangshi South-Karnatali Khal-Buriganga system.

During dry period, all the systems have not enough flow carrying capacity to feed rivers at the downstream parts. Planed dredging works on these rivers are inevitable options to increase the carrying capacity. Mathematical modeling analysis of the river can play important role for the suitable dredging options. As per example, BWDB carried out the feasibility study. The study recommended the option-iii i.e. New Dhaleswari river system will be the better restoration option. In this case channel dredging works and bank protective work had been considered by using mathematical modeling but flow diversion structure had not been used in their analyses. It is also worth mentioning that the implementation of the project has not been realized in practice. Therefore, the present study will be directed towards detail hydro morphological analyses of the system using mathematical modeling with recently collected flow and bathymetric data incorporating weir like flow structure at the offtake.

1.3 Objectives of the Study

Objectives of the study are as follows:

i. To assess the existing hydrodynamic and morphological condition of off-take of the New Dhaleswari river using field data.

ii. To apply mathematical modeling for the hydrodynamic analyses of various dredging options for the restoration of the river system.

iii. To carry out morphological analyses for the New Dhaleswari river system after simulating various options.

1.4 Structure of the Thesis

The thesis has been organized under nine chapters. Chapter 1 describes the background and objectives of the study. Chapter 2 describes different definition of relevant topics, literatures, previous studies related to this study. Theories regarding this thesis work have been described in Chapter 3 and a brief description of the approach and methodology of this study has been described in Chapter 4. Chapter 5 describes the data collection from various sources and

Chapter 6 is processing. The hydrological and morphological analysis is also represented in this chapter. Chapter 7 illustrates the model set up for the study area, its hydrodynamic and morphological calibration as well as validation. Chapter 8 demonstrates the results in terms of bed level, discharge, siltation, water depth, velocity etc. obtained from different option and scenario simulations. Finally, conclusion and recommendations for further study are outlined in Chapter 9.

CHAPTER 2

LITERATURE REVIEW

2.1 General

In Bangladesh, studies have been done on the morphological aspects such as planform, hydraulic geometry, erosion deposition and bed level variation in many rivers. Most of these studies were carried out for the major rivers like Ganges, Jamuna, Padma and Meghna. Few studies have been done on the New Dhaleswari river offtake in Bangladesh. The present study has been directed towards an assessment of siltation problem around the New dhaleswari river offtake by using two-dimensional mathematical modelling approach. In addition, previous studies and researches relevant to current study has been discussed,

2.2 Previous Studies and Researches on River Morphology

Hossain (1992) made an analysis of the total sediment load in the lower Ganges and Jamuna. The study revealed that the total average sediment flow through the major rivers of Bangladesh was of the order of 1.2 billion tons with a maximum of 1.5 billion tons. The estimated total sediment flow when compared with the finding of previous studies showed good compliance, moreover, correlation was developed between water flow and sediment flow for use of in practical design problems.

Halcrow (1993) studied the hydro-morphological behavior of the Ganges river as part of regional investigations performed under the Flood Action plan (FAP). Also as a part of the FAP, ISPAN (1995) used satellite images to study some of the morphological aspects of the Ganges river for a project on the physical environment of the char lands. Delft Hydraulics and DHI (1996a and 1996b) and also EGIS (2000) studied the channel dimensions of the Ganges river and its morphological behavior around the off-take of the Gorai river.

Mukherjee (1995) studied the morphological behavior of the Brahmaputra and Jamuna river. This study was mainly based on cross-sectional data for several selected stations. This study revealed that the variation of effective width was more rapid than the variation of total width and left and right banks have shifted significantly. The roughness co-efficient was found to vary between 0.0103 to 0.0337 in dry season and from 0.019 to 0.037 in wet season.

Dey, K. C, Mahmood, S. and Matin, M.A. (1998) have taken attempts to derive the exponent “b” analytically for different total and bed load predictors with some assumptions. Seven total load and three bed load prediction formula were considered in this analysis. The relation between the exponent "b" and Shields parameter (ϴ) also analyzed. The analysis shows that the exponent "b" varies between 3.1 to 8.5 for total load and 3.3 to 10.5 for bed load predictors. The sensitivity of the exponent "b" for variation with the grain sizes (d_{50}) is found to be significant for Ackers and White and Van Rijn formula. The water level slope has a small influence on the exponent "b" as observed at low values of the Shields parameter (ϴ).

Surface Water Modeling Center, SWMC (2001) studied the morphological behavior of the river Brahmaputra and some other rivers of Bangladesh with special emphasis on the river Brahmaputra under the project titled "Morphological Assessment of the rivers of Bangladesh." The study revealed that the river was in overall aggradations during the period 1988-89 to 1997-98.

Akhand (2008) found that the Ganges is flowing within a morphologically active corridor within which the channel is highly mobile. Erosion or deposition is prevalent in all bends of this river. The rate of erosion varies largely from one year to another. All the interlinked processes such as rate of widening, rate of bank migration and annual rate of erosion in the Ganges river were very high in the period of the study. The planform of the Padma river, during the last three decades (1980-2008) varied from a braided to straight pattern and from straight to braided pattern. The upstream part of the Ganges is meandering nature, where bends migrates within an active corridor.

CEGIS (2018) studied the prediction of river bank erosion along the Jamuna, Ganges and Padma river. River bank erosion has one of the major natural disasters in Bangladesh. Predictions for morphological changes have been conducted for Jamuna river. The magnitude of erosion under different ranges of uncertainty and the consequent assessment of vulnerability for 15 predictor erosion locations are presented separately in Jamuna river. National agency of Bangladesh, responsible to river management for planning and designing for protective works and emergency interventions are using the predictor.

2.3 Previous Studies and Researches on Offtake

FAP 24 (1996b) studied the Gorai offtake in detail on the Special Report No 10. The distributary was selected because of the importance of the Gorai for the fresh water inflow to the Southwest region, but also because the Gorai is a well-defined single channel without any tidal influence and therefore is less complex. They mainly focused on three elements: the analysis of historical data in order to understand how the hydraulic conditions at Gorai offtake have changed over the last 30 years, the collection and analysis of detail data in special surveys of the RSP, the development of two-dimensional morphological modeling to improve the understanding of which processes are important for the development of the dry season flow to the Gorai.

Imteaz, M. A. and Hassan, K. I., (2001) developed a mathematical model for the Old Dhaleswari river as well as other offtakes from Jamuna river. Due to the construction and associated river bank protection works of Jamuna Multipurpose Bridge on Jamuna river at Bangladesh, water flow through the Old Dhaleswari river was reduced significantly. As a result, effectiveness and usefulness of irrigation project named "Compartmentalization Pilot Project (CPP)" area at Tangail located at the downstream end of Old Dhaleswari river became at a stake. A link canal was proposed with mouth at the Jamuna river connecting the Old Dhaleswari river. The model was simulated to check the effectiveness of the proposed link canal in terms of water availability to the downstream users. It is found that proposed link canal could augment water supply for the irrigators significantly.

Obasi et. al (2008) constructed a physical model with meandering features and used to investigate the effect of off-take angles on the flow distribution at a concave channel bifurcation. Seven different off-take angles with varied main channel flow rates were used for the study. Predicting equations for the off-take discharge dependent on the off-take angles, main channel discharges, dispersion coefficients and Reynolds numbers were developed and calibrated statistically. Results of the study and predicting equations showed that the offtake discharge increased positively with increases in off-take angles as well as main channel discharges. The developed empirical predicting equations for the offtake discharge gave correlation coefficient values of 9.9974x10-1 for both model equations with corresponding standard errors of 9.754x10-5 and 9.42x10-5, respectively. It was observed that the predicted off-take discharge values from the model equations compared closely with those of the study suggesting that off-take discharges for concave channel bifurcations could be fairly predicted with the established model equations.

Mosselman, E. (2004) employs different categories of methods: theoretical analysis, field measurements, laboratory experiments (elementary process experiments as well as physical scale modelling) and mathematical modeling to define the morphology of river bifurcation. As a consequence, different categories of methods have been used in research on sediment transport and morphology at river bifurcations. A theoretical analysis revealed that the morphological development of bifurcated channels depends sensitively on the way in which sediment transport rates are divided over the two branches. A combination of field measurements and mathematical modelling provided an insight in the effects of grain sorting and alluvial roughness that was not given by previous physical modelling.

Agunwamba et. al. (2009) showed how different offtake angles influence velocity distribution around the canal entrance which will in turn influence the quantity of sediments deposited along the canal bed. The problem of excessive siltation in canals (navigation, irrigation, water supply, etc) was tackled by the Schwarz-Christoffel transformation, neglecting gravity and assuming a constant depth of flow. This implies that large off take angles will encourage more intake of sediments by the canal. In addition, it was also observed that large off take angles exhibit higher and lower (wider range) velocities. That is, near the stagnation point, a large off take angle will possess lower velocities than small off take angles thus encouraging siltation, while near the point of infinite velocity, a large off take angle will possess higher velocities thereby increasing sediment intake by canal. It is therefore recommended that canals off take angles should be as small as possible but not too small. If the offtake angle is too small, the bank between the branch canal and the main canal will be eroded gradually leading to flooding and eventual destruction of the canal. The results obtained can be applied to navigation, irrigation and water supply canals. The results obtained show that the larger the offtake angle, the higher will be the offtake discharge as well as the offtake entrance velocity distribution. The results were found to agree with both laboratory data obtained using a model and field data, giving correlation coefficients of 0.76, 0.77 and 0.62.

Mamun et. al. (2012) has studied the hydro-morphological analysis of the offtake of the Arial Khan river of Bangladesh to predict its sustainability. The study shows that water levels and discharges are in rising trend in both the rivers. In 1975, 2% peak flows of the Padma river are diverted to the Arial khan river which has been increased to about 3% in 2004. The Arial Khan offtake is losing conveyance due to aggradations resulted from long-term sedimentation. It reveals that heavy sedimentation has been occurring which leads to formation of sand bars. Bed topography generated from bathymetric data of 2005 at the junction with the Padma clearly demonstrate that the main channel of the Padma is aligned far north which is opposite to the offtake and there is a char formed at the mouth of the Arial Khan hindering the flow and the channel has become narrowed. It has been observed from the satellite images of 1974 to 2006 and the yearly development rate of char area is 2%. The

Arial Khan Upper offtake is in the trend of abandoning stage and there must be a shifting offtake which has been dynamically under development to keep the river morphologically active. Recent bed topography of the offtake, conveyance, trend analysis of recent inflows and stages in the Arial Khan river support that the river is going to be the cause of sufferings in terms of flooding in the monsoon and navigability losses and other water resources activities will be hampered due to inadequate inflows in the river.

Obasi et. al (2012) examined the effect of offtake angles on spatial distribution of silt material at concave bifurcation. For this purpose, a meandering physical channel was constructed. Four different off-take angles of 300, 450, 600 and 900 with varied main channel flow rates were used for this study. Predicting statistical equations dependent on the off-take angles and main channel discharges for the evaluation of the tributary channel sediment intake were developed. Results of the studies showed that even with constant main channel discharge, the tributary channel sediment intake increased significantly with higher off-take angles. It was observed that the predicting equation under estimated the tributary channel sediment yield for off-take angles between 30^o – 70^o and for those between 70^o- 90^o the sediment values were overestimated for all the main channel flow rates considered. The predicting tributary sediment values equaled the experimental values at the off-take angles of 50^o–70^o but varied differently for each of the main channel flow rates. It could be seen from the various off-take angles considered that the divergence in results obtained from the experimental works and predicting equation is in the range of 2.9% - 17.8% for minimum main channel flow rate and 12% - 36% for maximum main channel flow rate suggesting that the predicting equation could be useful in the evaluation of sediment yield at concave channel bifurcation.

Haskoning (2012) in collaboration with IWM carried out the Bangladesh river Information and Conservation Project (BRIC). The main objective of this project is to develop a two-dimensional hydraulic and morphological model for the Gorai offtake area and its surroundings (including data collection and re-calibration) and use this model to assess the effectiveness of the engineering interventions of the selected option that could potentially help improve water flows into the Gorai sub-basin and reduce salinity in the downstream areas. Based on the changes over the last ten years such as planform changes and river training works constructed in the Gorai or Ganges, the structural interventions of the option might need to be modified. The model is used to analyze the effectiveness of the modified option. As a result, suitable modifications will be made, for which the engineering designs will be updated.

Noor, F. (2013) studied the of Old Bramaputra river Offtake. Analysis of the flow diversion during dry period is continuously decreasing in the last few decades. The offtake was changes in every year. In this study, model domain has been fixed by observing the position of offtake in the bathymetry of 2011. The dredging alignment or river training works proposed in this study should be modified per the planform of the river. During the onset of monsoon, dredging will be done to initiate the scouring and finally in monsoon nature continues and finishes these morphological processes. Jamuna is an alluvial river in a deltaic region of Bangladesh, so morphological activities are very dynamic in this river. In this study suggest, capital sustainable for a long period, so frequent maintenance dredging is required.

Santamaria R. V. (2017) studied the the major characteristics of the river system of Bangladesh include extremely variable flows and fast morphological changes which present exceptional challenges for river engineering. Distributary rivers from the major rivers in Bangladesh are a key element in providing fresh water as well as carrying sediment to the South-West and Central regions of the country. During the monsoon season, when sediment transport is larger and the rivers are more dynamic, the river bed morphology experiences the most significant changes. In some cases these changes produce a more favorable configuration for an offtaking distributary, but they can also lead to an unfavorable layout that reduces the conveyance capacity of the distributary, increasing the probability of offtake closure. Aggradations at the offtake that occurs during the monsoon period makes some of the distributaries become disconnected from their parent rivers with the arrival of dry season. That is why the analysis of the offtake system holds a significant importance. The offtake behavior simulated by the model reveals that dredging the upstream part of the distributary river during the recession period of the monsoon can prevent the discontinuation of flow in the distributary river for the entire dry season, and improves the flow conditions for the following year.

Malik L. (2018) studied the experimental flow and sediment distribution at river offtake. Two relationships have been derived and proposed for the prediction of flow and sediment distribution of the main and offtake channel. Both equations have been proposed for the estimation of water and sediment discharge ratios for main and offtake channel. The observation made in the study will help in understanding the flow and sedimentation behavior of offtake.

2.4 Previous Studies and Researches on Dredging

Lagasse (1986) examined the impact of dredging on the Mississippi river system. He reveals that the dredge provides the river engineer with a means of rapidly altering channel configuration and accelerating morphologic processes. In this respect, dredging constitutes a morphologic agent responsive to engineering requirements. This application is overshadowed by the volume of material moved and the number of reaches involved indredging operations for navigation channel maintenance. Dredging and disposal of dredged material in support of channel maintenance implies the repeated moving of alluvial sediments from the main channel region toward the periphery of the channel. The combined use of dredging, contraction dikes, and disposal of dredged material in the dike fields can induce major changes in the cross-sectional characteristics of a river. This direct physical displacement of bed material and the resulting change in channel shape can retard the movement of bed-load sediments through a river system. In both the Columbia and Mississippi river systems this lateral redistribution of sediment by dredging, when combined with contraction works, has constituted an agent for long-term morphologic change.

Van Rijn (1986) developed a detailed mathematical model for sedimentation of dredged channels, based on a detailed representation of all relevant transport processes such as convection, mixing and settling. This is an important advantage compared with the traditional prediction formulas, which are based on a rather strong schematization of the transport processes. This study presented a sensitivity analysis showing the influence of the streamline refraction effect and the wave shoaling effect in the channel on the sedimentation process. Two applications of the proposed mathematical model are given and show reasonable agreement between measured and computed concentrations and sedimentation rates. Finally, a set of graphs was presented which can be used to get a rough estimate of the trapping efficiency of dredged channels.

Mead (1999) presented two-dimensional horizontal and vertical mathematical models of flow and suspended sand transport. He used in typical engineering predictions of deposition in a dredged trench across an estuary. The results of the models were compared with experimental data, and it is found that the sedimentation predictions are fundamentally dependent on the specification of mobile bed sand, and that the predictions of the two types of model are qualitatively different. He provided an insight into the benefits of both modelling techniques, and indicated the need for further model development.

Groot and Groen (2001) have found that the intervention by dredging should be included in any long term solutions for the restoration of the river and can be seen as an alternative for building any conventional hard construction in the river.

BWDB (2010) has taken up steps to carry out dredging from the Gorai offtake, for a length of 30 km of the river. The objectives of the mathematical modelling study are to support the Gorai River Restoration Project Phase-II (GRRP-II), during the capital dredging operation, for monitoring through application of mathematical modelling, alongside other monitoring mechanism (which BWDB had put in place through Bathymetric Survey), and during operation of maintenance dredging activities and to study hydrodynamic, morphological and salinity intrusion phenomena of the river systems, situated at the downstream of the Gorai river, namely the Modhumoti-Kaliganga-Baleswar-Haringhata and Noboganga-Atai-Rupsha Kazibacha-Pussur systems under base (without dredging of the Gorai) and project condition (with dredging implemented in the Gorai).

2.5 Previous Studies and Researches on New Dhaleswari River

SWMC (1997) studied of the New Dhaleswari Spill Channel to suggest the mitigation measures against the heavy erosion that took place along the right bank of the mouth of the new Dhaleswari spill channel in the 1995 monsoon. The study suggested bank protection mainly at the bend by a series of groynes and recommended for further study including 2D model for better understanding and effective mitigation measures. With the construction of control structure at offtake, this erosion problem might no longer continue. However, for any alternative option of proposed offtake structure which will very costly requiring substantial silt clearing every year, this study might be of very useful as basic information source.

IWM, (August 2004); studied of Approaching and Investigating Strategy for Rehabilitating the Buriganga-Turag-Shitalakhya river System and Augmentation of Dry Season Flow in the Buriganga river. The review of feasibility study will thus remain limited to Buriganga river flow augmentation concerned activities. The Jamuna river is the main natural source of water for augmentation in the Buriganga. Major offtakes on the left bank of the Jamuna have been considered to identify possible routes for augmentation. Accordingly, major four offtakes of the Jamuna i.e. Old Brahmaputra, Dhaleswari North, New Dhaleswari spill channel and Dhaleswari South have been considered and the approximate route lengths of the above four options are 356, 182, 162.5 and 140 km. The study recommended New Dhaleswari river system as the best possible augmentation route (option-3) and identified the improvement works to ensure the planned augmentation of flow in order to improve the quality of water of the river Buriganga to acceptable limit. The Study made it clear that only augmentation and rehabilitation of the rivers would not solve the pollution problem completely. The study will suggest 162.5 km dredging of rivers and 1 Km Guide Bund along the Jamuna left bank and one Regulator and Fish Pass at New Dhaleswari offtake.

Khan A.S. (2004) analysis has been done to assess the hydro-morphological consequences of the selected four options for improving the dry season flow condition through the offtake as well as through the respective routes. These are i) Old Brahmaputra offtake- Jhenai-Futikjani-Bangshi-Turag-Buriganga. ii) Dhaleswari North offtake-Pungli-Bangshi-Turag-Buriganga. iii) New Dhaleswari offtake-Pungli-Bangshi-Turag-Buriganga (so-called New Dhaleswari river system). iv) Dhaleswari-South offtake-Barinda-Bangshi South-Karnatali Khal-Buriganga system. It has been found that Option-iii may be considered best among others and thus Option would further be required to be detailed out through application of modelling scenarios as well as other analysis for selecting the best scenario for the dry season flow augmentation. Finally, the evaluation of a particular scenario will be assessed with the results of the individual scenario having single or combination of engineering measures for comparing the performance or the effect of a scenario.

IWM, (May 2013); studied at Offtake Management of the New Dhaleswari river and Hydraulic Monitoring of New Dhaleswari river System. In this study 2D model was developed 21km reach of the Jamuna river and 5km reach of the New Dhaleswari river from its off-take point. Dredging bed width gradually reduces from 82.50m to 46.00m from the offtake to outfall. Flood inundation along the augmentation route has been assessed both with provision of offtake structure and without offtake structure. The comparison of flooding for both the situations illustrates the performance of the offtake structure. The 2D model simulated to assess the sedmetation pattern during high floods, with and without offtake structure and the quantity of sediment that deposits over a long 33km reach beyond the proposed structure location (structure location is at 1.8 km) during the high flood of 1998 was about 25.47 lac cum with no structure at the offtake, and 12.92 lac cum with structure at the offtake. Sedimentation in front of structure location will be around 10.5 lac cum in both the cases. The yearly sediment deposition for average flood has been 17.65 lac cum with no structure, and 14.74 lac cum for structure condition. Sedimentation in front of structure location will be around 6.71 lac cum. The lining of the channel at the offtake will make the channel stable and check erosion within this reach.

China National Areo-Technical International Engineering Corporation and Henan Water & Power Engineering Consulting CO. Ltd (2015) jointly studied for Feasibility Study on Buriganga River Restoration Project (BRRP). The feasibility study had to consider bank protection of 8.5km long river system. In this study, they follow four options at the New Dhaleswari river offtake. These are i) Stop Log Sand barrier-Flush Sluice-Training Bank-Sediment basin. ii) Flush Sluice-Training Bank-Sediment basin. iii) Stop Log Sand barrier - Sediment basin. iv) No structure with sediment basin. It has been found that Option-i may be considered best among others and thus Option-i would further be required to be detailed out through application of schemes comparison and demonstration. The channel section of the rivers along the augmentation route has also been designed to induce minimum required discharge of 300 cumec during dry season.

Ahmed T.S. (2016) evaluates a technical solution to sedimentation problem at the off-take area of branch channel with introduction of spur dyke to control stream line curvature of flow and associated generation of secondary currents. That secondary current transports sediment from the off-take area towards the center part of the river and it diverts more clear water (less turbid water) into the branch channel. river is addressed under this study. Numerical computations for different shapes of spur dykes at varying locations and flow pattern, bed variation characteristics, sediment transport behavior and discharge scenario are observed. 100 m spur constructed at 50 m downstream of the off-take point is found the most suitable form of spur dyke that establishes the idea of study. After employment of spur dyke, average velocity as well as discharge is increased at the Off-take area, possibility of closing of channel due to sediment deposition is diminished and sediment is being flushed from the off-take. The established idea can be implemented as solution to sedimentation problem at the New Dhaleswari river off-take area.

CHAPTER 3
THEORETICAL BACKGROUND

3.1 General

The river bifurcation point from the major rivers is called Offtake. It is vital for the sustainability of a river. The sustainability also depends on the conveyance characteristics of the river. For example, New Dhaleswari, Dhaleswari, Old Brahmaputra is some of the main distributaries of Jamuna river. Gorai, Chandana, Hisna, Mathabhanga are some of the main distributaries generated from Ganges river. River offtake has been the most uncertain part of the river. The purpose of this chapter is to give a brief description of the related theories regarding offtake and offtake management through dredging or incorporating different river training structures. Moreover, various mathematical equations and formulas of MIKE21C have been also explained in the following section.

3.2 Offtake and Offtake Management

Offtake of the river is the most potential part of the river. At offtake both flow velocity and sediment is divided over the two branches. The flow velocity distribution is governed by the conveyance capacity and hydraulic gradient at the offtake with the condition that water levels at the offtake must be the same (Jansen et al., 1979; Kleinhans et al., 2008). Circulation inside this eddy, sediment near the bed moves towards the center of the eddy (Mosselman, 2014). However, sediment flow depends on the details of local conditions at the offtake.

3.3 River Training Structures

River training structure refers to the structural measures which are taken to improve a river and its banks. River training is an important component in the prevention and mitigation of flash floods and general flood control, as well as in other activities such as ensuring safe passage of a flood under a bridge. This structures work by using the rivers energy to move sediment out of the navigation channel, reducing the need for dredging. For examples of manmade river training structures are guide bund, groyne, bandalling, hardpoint, bank revetments etc.

Objective of river training structure are

- Safe and quick passage of high flood.

- Make river course stable and prevent bank erosion.
- Provide sufficient draft for navigation.
- Prevent outflanking of a structure by directing the flow in a defined stretch of the river

3.4 Dredging

Dredging is the removal of sediments and debris from the bottom of lakes, rivers, harbors, and other water bodies. It is a routine necessity in waterways around the world because sedimentation. The natural process of sand and silt washing downstream and gradually fills rivers channels and harbors. Dredging often is focused on maintaining or increasing the depth of navigation channels, anchorages, or berthing areas to ensure the safe passage of boats and ships. Vessels require a certain amount of water to float and not touch bottom. The material removed during dredging can vary greatly and can be any combination of rocks, clays, silts or sands (Bray, 1979).

Dredging is mainly of two types – Capital dredging and Maintenance dredging.

Capital Dredging is the formation of a new bed configuration by dredging, whether it is stable or not, is known as capital dredging. It is carried out to create a new harbor, berth or waterway, or to deepen existing facilities to allow larger ships access.
Maintenance Dredging means the periodic removal of accumulated sediments from existing navigational channels, berthing pockets and turning basins to re-establish their original dredge design levels. It is a vital component of operations in most ports and harbors around the world. Most ports cannot sustainably function without maintenance dredging.

3.5 Morphological Variables

Rivers being a very dynamic system are one of the most sensitive and dynamic components of the physical landscape and are influenced by a variety of interconnected factors. Each river responds to a number of independent inputs, the river characteristics being the resulting dependent outputs. Lane (1957) established the major factors affecting alluvial stream channel forms. The independent variables of the river catchment are determined by the climate and the geology of the basin, but not directly; also, the vegetation, the weathering process and human interference play a role. The dependent variables in a particular river reach are the river characteristics which comprises of both river morphology and hydraulics.

3.5.1 Independent Variables

Factors result in variables like discharge, sediment volumes, sediment characteristics and valley slope. These factors are climate (precipitation, temperature, evaporation, humidity), hydrology (water levels and discharge versus major river shifts), topography (relief versus sediment concentrations), geology (tectonics, faults, soil types and sedimentary yields), base-level changes (sea level rise versus sedimentary structure), human interference (deforestation, sediment transport)

The climatic factor is an important geo-morphological control of a river system. It governs the amount of precipitation and consequently the surface runoff and river discharge to determine the extent and intensity of basin denudation (denudation is an erosive process of breaking and removing the rocks from the surface of the earth) and indirectly the sediment yield. Hydrological factors like water level and discharge important parameters which may change the characteristics of river behavior. River basin areas of various topographies such as hilly, mountainous and coastal relief offer different sediment yield in the form of sediment amount, sediment size and shape etc. Geology and climate do not determine the discharges and the sediment transport rates in a river system directly. There are the role of the vegetation and the weathering process. The geology in combination with the climate determines the rate of weathering and this again has a significant influence on the growth of the vegetative cover. However, each independent variable is different for different river reaches; e.g. a more downstream reach usually has to carry more sediment. Hence for all independent variables at the river reach level it holds that they are a function of the longitudinal coordinate. Otherwise, the sediments transported in a river are distinguished as far as their origin and their mode of transport is concerned. In line with this the total volume of sediment that must be transported is divided in bed material and wash load.

3.5.2 Dependent Variables

The dependent variables are classified into primary dependent variables and secondary dependent variables as follows:

Primary Dependent Variables: The primary dependent variables are the combination of morphological characteristics and hydraulic characteristics of a river reach. The offtakes and confluences are nodes of a river system and considered to belong to the primary dependent characteristics. The primary dependent variables are:

Dependent morphological characteristics is Number of channels (n), Average width of channel(s) Bb, where the index b stands for bankfull conditions, Sinuosity p of the river channel(s), Typical wave length of the curved channels L, Total width B_t, occupied by the river channel(s), Bankfull depth h_b of the river channel(s), Slope of the river i_b.
Dependent hydraulic characteristics are Average water depth in the main channel; Wet width either in the main channel or including the floodplain; Inundation depth of the floodplain; the roughness coefficient of the main channel and of the floodplain; the average velocity.

Secondary Dependent Variables: The secondary dependent variables in a particular river reach are more detailed, local and dynamic in nature. These are bars, bifurcations, scour holes, bank erosion, and cutoffs. The dependent variables are linked to the independent variables through relationships of river mechanics. There is no single-valued relationship between the imposed variables and the dependent characteristics. The excess flow strength leads to bed degradation when banks are fixed. This bed degradation increases the water depth and reduces the longitudinal slope until the flow strength reaches a value which matches the transport of the sediment supplied from upstream. When the banks are erodible there are three additional modes of adjustment. Firstly, the river can become wider. Secondly, the longitudinal slope can be reduced by increasing the sinuosity through the expansion of meander loops. Thirdly, new channels can be carved in the floodplain at discharges above bank full, which leads to an anabranches system. The vertical responses of rivers with fixed banks are rather unambiguous, but the distribution of horizontal response over the three modes of adjustment depends on the initial state of the river and the time series of discharge and sediment supply during the transition to new equilibrium.

3.6 Sediment Transport

Sediment transport is the movement of solid particles. Typically due to a combination of gravity acting on the sediment and the movement of the fluid in which the sediment is entrained. Sediment transport occurs in natural systems where the particles are caustic rocks (sand, gravel, boulders, etc.), mud or clay; the fluid is air, water or ice; and the force of gravity acts to move the particles along the sloping surface on which they are resting. Sediment transport due to fluid motion occurs in rivers, oceans, lakes, seas, and other bodies of water due to currents and tides. Transport is also caused by glaciers as they flow, and on terrestrial surfaces under the influence of wind. Sediment transport due only to gravity can occur on sloping surfaces in general, including hill slopes, scarps, cliffs, and the continental shelf continental slope boundary. Sediment transport is important in the fields of sedimentary geology, geomorphology, civil engineering and environmental engineering. Sediment transport aspects have been studied for the major rivers of Bangladesh. Studies were conducted by Bari (1978), Alam and Hossain (1988), Sultana (1989) and Hossain (1989). These studies were mainly concentrated to assess the applicability of few well-known sediment transport equations against the data of Ganges and Jamuna. Some of these investigators however, while adjudging the efficiency of various transport equations also computed the total annual sediment flow.

3.7 Sediment Transport Equations

Sediment movement in rivers has been studied by both hydraulic engineers and geologists for centuries because of its importance in the understanding of river hydraulics, river morphology, and related matters. Sediment transport is complex and often subject to semi empirical or empirical treatment. Most theoretical treatment is based on the idealized and simplified assumption that the rate of sediment transport can be determined by one or two dominant factors, such as water discharge, average flow velocity, energy slope, shear stress, etc. Only a single equation cannot incorporate all these variables and predicts the sediment load. For this reason, different equations have been put forward based on different independent variables. Out of many available empirical formulas the following three well known equations has been selected for the present study.

Engelund-Hansen Equation (1967)

Engelund-Hansen's (1967) equation is based on the shear stress approach. In developing the equation Engelund-Hansen's relied on data from experiment in a specific series of test in a large flume. The sediment used in this flume had mean diameter of 0.19mm, 0.27 mm, 0.45 mm and 0.93 mm. The equation 3.1 can be written as:

$$gs = 0.05\gamma s V^2 \sqrt{\{\frac{D50}{g}\left(\frac{\gamma s}{\gamma} - 1\right)\}}\ [\frac{\tau o}{(\gamma s - \gamma) D5}]^{3/2} \qquad (3.1)$$

Where, g_s is sediment transport per unit time per unit width, γ_s is specific weight of sediment particles, γ is specific weight of water, τ_o is bed shear stress, D_{50} is median diameter of bed material, V is average flow velocity and g is acceleration due to gravity

This equation is dimensionally homogeneous and any consistent set of units can be used.

Yang's Equation (1976)

Yang (1976) proposed a sediment transport formula based on the concept of unit stream power, which can be utilized for the prediction of total bed material concentration transported in sand bed flumes and rivers. The equation 3.2 can be written as:

$$\log C = 5.435 - 0.286 \log(\frac{\omega D50}{\upsilon}) - 0.457 \log(\frac{u*}{\omega}) + \{1.799 - 0.409 \log(\frac{\omega D50}{\upsilon}) - 0.314 \log(\frac{u*}{\omega})\} \log(\frac{VS}{\omega} + \frac{Vcr}{\omega}) \tag{3.2}$$

The Value $\frac{Vcr}{\omega}$ is given by:

$$\frac{Vcr}{\omega} = \frac{2.5}{\log\frac{u*D}{\upsilon} - 0.06} \quad 0<\frac{u*D}{\upsilon}<70 \qquad \text{and} \qquad \frac{Vcr}{\omega} = 2.05 \quad 70<\frac{u*D}{\upsilon}$$

Where, C_t is total sediment concentration in parts per million (ppm) by weight, D_{50} is median diameter of bed material, V is average flow velocity, D is median sieve diameter, u_* is shear velocity, ν is kinematic viscosity, V_{cr} is critical average flow velocity and ω is fall velocity. This equation is dimensionally homogeneous and any consistent set of units can be used.

Van Rijn's Equation (1984)

A simplified method was given by Van Rijn for calculating suspended sediment transport. This method is based on computer computations in combination with a roughness 32 predictor. Using regression analysis, the computational results for a depth range of 1 to 20 m, a velocity range of 0.5 to 2.5 m/s and a particle range of 100 to 2000 µm were represented by a simple power function, as follows 3.3 is

$$\frac{q_{s,c}}{\bar{u}h} = 0.012 \left(\frac{\bar{u} - \bar{u}_{cr}}{(s-1)g d_{50}^{0.5}}\right)^{2.4} \left(\frac{d_{50}}{h}\right) \left(\frac{1}{D*}\right)^{0.6} \tag{3.3}$$

Where, q_s, is volumetric suspended load transport (m^2/s), u_{cr} is critical depth-averaged velocity according to Shields, h is water depth and u is depth-averaged velocity

Equation 3.4 only requires u, h and d_{50} as input data and can be used to get a first estimate of the suspended load transport. It is assumed that the instantaneous bed-load transport rate is related to the instantaneous T parameter, as follows

$$q_b = 0.1\,(s-1)^{0.5} g^{0.5} d_{50}^{1.5} D_*^{-0.3} T_m^{2.1} \tag{3.4}$$

Where, Tm is $(\tau_{b'} - \tau_{b,cr})/\tau_{b,cr}$ is instantaneous shear stress parameter, τb,is $\mu\tau b$ is instantaneous effective bed shear stress, $\tau b,r$ is instantaneous critical bed shear stress, $D*$ is dimensionless particle parameter,

When the bed load transport and the suspended load transport are known, the total load transport of bed material can be determined by summation of Equations 3.5

$$q_t = q_b + q_s \quad (3.5)$$

3.8 Mathematical Modelling

A mathematical model is a description of a system using mathematical concepts and language. The process of developing a mathematical model is termed mathematical modeling. Many modelling tools are available which can simulate hydrodynamic as well as morphological characteristics of a river. Moreover, modelling packages are so advances that it can now simulate intervention phenomenon on river through control structure. There are few tools available that can simulate the flow through control structures and sediment transport with bed level changes in river systems. There are mainly MIKE 21C, MIKE 11, HEC-RAS, River 2D, Delft 3D, SMS etc.

Characterized by assumptions using mathematical modeling are: Variables (the things which change), Parameters (the things which do not change), Functional forms (the relationship between the two). There are several situations in which mathematical models can be used very effectively in all relevant aspects.

- Mathematical models can help people understand and explore the meaning of equations or functional relationships.
- After developing a conceptual model of a physical system it is natural to develop a mathematical model that will allow one to estimate the quantitative behavior of the system.
- Quantitative results from mathematical models can easily be compared with observational data to identify a model's strengths and weaknesses.
- Mathematical models are an important component of the final "complete model" of a system which is actually a collection of conceptual, physical, mathematical, visualization, and possibly statistical sub-models.

3.8.1 MIKE 21C

MIKE 21C is a computer program that simulates the development in the river bed and channel plan form in two dimensions. MIKE 21C was developed by DHI. MIKE 21C uses curvilinear finite difference grids. Simulated processes with MIKE 21C include bank erosion, scouring and shoaling brought about by activities such as construction and dredging, seasonal fluctuations in flow, etc. The numerical grid is created by means of a user-friendly grid generator. Areas of special interest can be resolved using a higher density of grid lines at these locations. The MIKE 21C is particular suited for river morphological studies and includes modules to describe:

- Flow hydrodynamics, i.e. water levels and flow velocities are computed over a curvilinear or a rectangular computational grid covering the study area by solving the vertically integrated St. Venant equations of continuity and conservation of momentum.
- Helical flow (secondary currents) which is developing in channel bends due to curved streamlines is included. The time and space lag in the development of the helical flow is also described.
- Sediment transport, based on various model types (e.g. Van Rijn, Meyer-Peter & Müller, Engelund-Hansen, Engelund-Fredsoe, Yang, or user-defined empirical formulas). The effect of helical flow, gravity on a sloping river bed, shapes of velocity and concentration profiles are taken into account in separate bed load and suspended load sub-models based on the theories by Galappatti. Graded sediment descriptions can be applied as well by defining a number of different sediment fractions, which are treated separately by the sediment transport module
- Alluvial resistance due to bed material and bed forms (calculation of skin friction from the grain sizes and form drag friction from the bed forms).
- Scour and Deposition: Large-scale movement of bed material is computed. The continuity equation for sediment is solved for determining changes in bed elevations at each grid cell at every time-step. The effect of supply limited sediment layers can be incorporated as well. This is used for simulating for instance downstream migration of fine material on a coarse riverbed, or for representing non-erodible (protected) riverbed areas in the modelling domain.

3.8.2 Governing Flow Equation of MIKE 21C

By introducing the simplification of three dimensional Navier Stokes theorems the three dimensional flow pattern of river can be reduced to two-dimensional equations of conservations of mass and conservation of momentum in the two horizontal directions. Three directional (secondary flow) effects are maintained in the depth averaged model by introducing helical flow component in the flow equation.

Flow model is valid for the shallow, gently varying topography and mildly curved wide river channels with small Froude numbers. The flow equations solved in the curvilinear hydrodynamic model of MIKE 21C are equation 3.8:

$$\frac{\delta p}{\delta t} + \frac{\delta}{\delta s}\left(\frac{P^2}{h}\right) + \frac{\delta}{\delta n}\left(\frac{pq}{h}\right) - 2\left(\frac{pq}{hR^n}\right) + \frac{p^2-q^2}{hR\dot{s}} + gh\frac{\delta H}{\delta s} + \frac{g}{C^2}\frac{p\sqrt{(p^2+q^2)}}{h^2} = RHS \quad (3.6)$$

$$\frac{\delta q}{\delta t} + \frac{\delta}{\delta s}\left(\frac{pq}{h}\right) + \frac{\delta}{\delta n}\left(\frac{q^2}{h}\right) + 2\left(\frac{pq}{hR\dot{s}}\right) - \frac{q^2-p^2}{hR^n} + gh\frac{\delta H}{\delta n} + \frac{g}{C^2}\frac{q\sqrt{(p^2+q^2)}}{h^2} = RHS \quad (3.7)$$

$$\frac{\delta H}{\delta t} + \frac{\delta p}{\delta s} + \frac{\delta q}{\delta n} - \frac{q}{R\dot{s}} + \frac{p}{R^n} = 0 \quad (3.8)$$

Where, s, n is Coordinates in the curvilinear coordinate system, p, q is Mass fluxes in the s and n direction, H is Water Level, h is Water Depth, G is Acceleration of Gravity, C is Chezy roughness coefficient, Rs, Rn is Radius of curvature of s and n line and RHS is the right hand side in the force balance, which contains Reynolds stresses, Coriolis force and atmospheric pressure.

These equations are solved by an implicit finite differential technique with variables (water flux density p and Q in two horizontal directions and water depth H) defined on a space staggered computational grid.

3.8.3 Morphological Model of MIKE 21C

A morphological model of MIKE 21C is a combined sediment transport and hydrodynamic model (DHI 2009). The hydrodynamic flow field is updated continuously according to changes in bed bathymetry.

Morphological model is an uncoupled model. In uncoupled model, the solution of hydrodynamics is solved at a certain time step prior to solution of the sediment transport equations. Subsequently, a new bed level is computed and the hydrodynamic model proceeds with the next time step.

Sediment Continuity Equation

Following calculation of sediment transport of bed material (bed load and suspended load), the bed level change can be computed from the equation:

$$(1\text{-n})\frac{\delta z}{\delta t} + \frac{\delta Sx}{\delta x} + \frac{\delta Sy}{\delta y} = \Delta Se \qquad (3.9)$$

Where, Sx is Total sediment transport in x-direction, Sy is Total sediment transport in y-direction, n is Bed porosity, Z is Bed level, t is Time, x,y is Cartesian coordinated system and Se is lateral sediment supply from bank erosion,

MIKE 21C morphological model solves the sediment continuity equation implicitly.

Sediment Transport Model Time-Step Selection

The sediment transport time-step is usually much larger than the hydrodynamic and advection-dispersion time-steps. The sediment continuity equation is solved using an explicit scheme and as such the Courant number must be less than 1

$$\Delta t_{ST,max} = \Delta x \, \frac{Cr.ST}{CST} \qquad (3.10)$$

Where, Δt is the maximum sediment transport time-step, Cr is the Courant number and c is the celerity of bed form waves.

CHAPTER 4
METHODOLOGY

4.1 General

Mathematical modeling is a method of simulating real-life situations with mathematical equations to forecast their future behavior. It is also an established, habitual, logical, or prescribed practice or systematic process of achieving certain ends with accuracy and efficiency, usually in an ordered sequence of fixed steps. The general approach that has been followed in the current study can be summarized in the flowchart given in Figure 4.1. A brief description of the methodology and approaches are provided in this section to achieve the study objectives. It includes

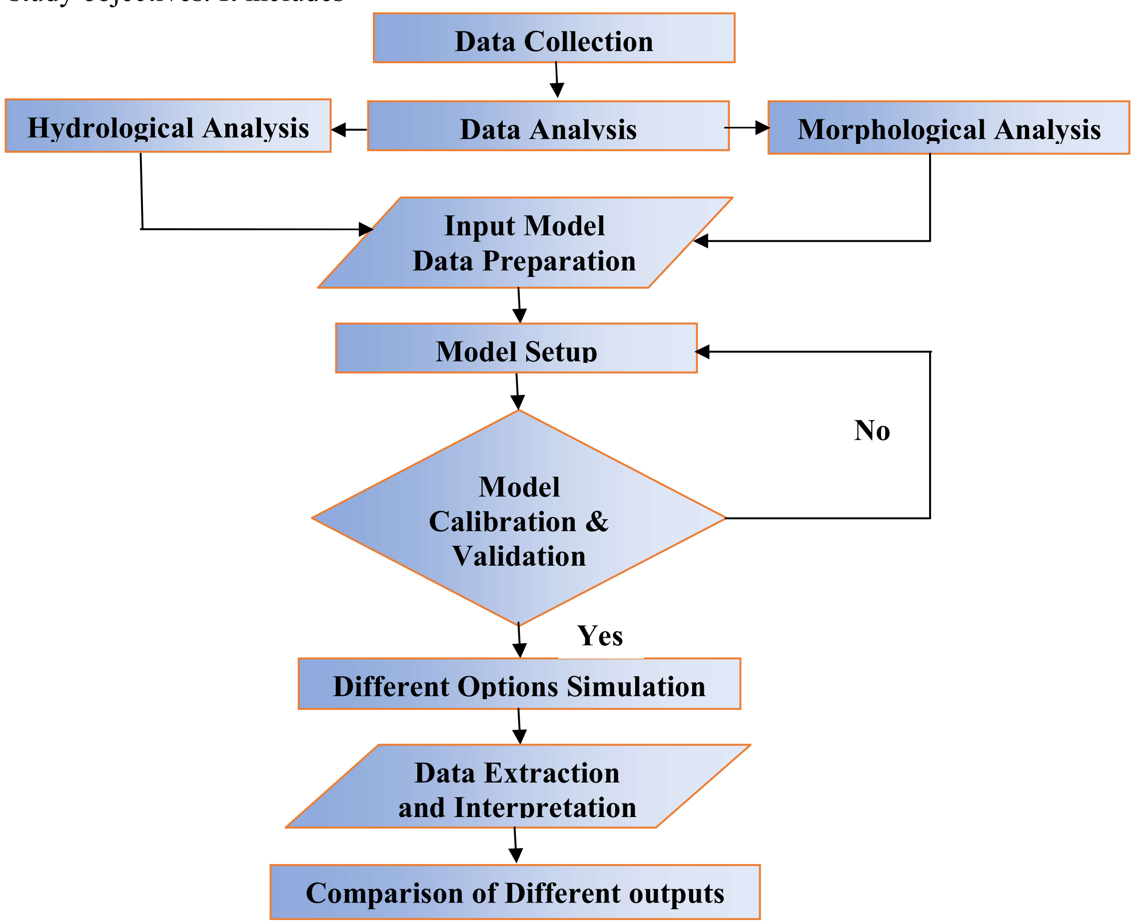

Figure 4.1: Flow chart of methodology applied in the study

4.2 Study Area

The study area covers the 40 km reach of Jamuna river starting from the 25 km upstream of the offtake of New Dhaleswari river to 15 km downstream of offtake and upto 30 km reach of New

Dhwleswari river. Figure 4.2 are shown in the study area along the Jamuna river. Figure 4.3 are shown in the details of New Dhaleswari river offtake study map.

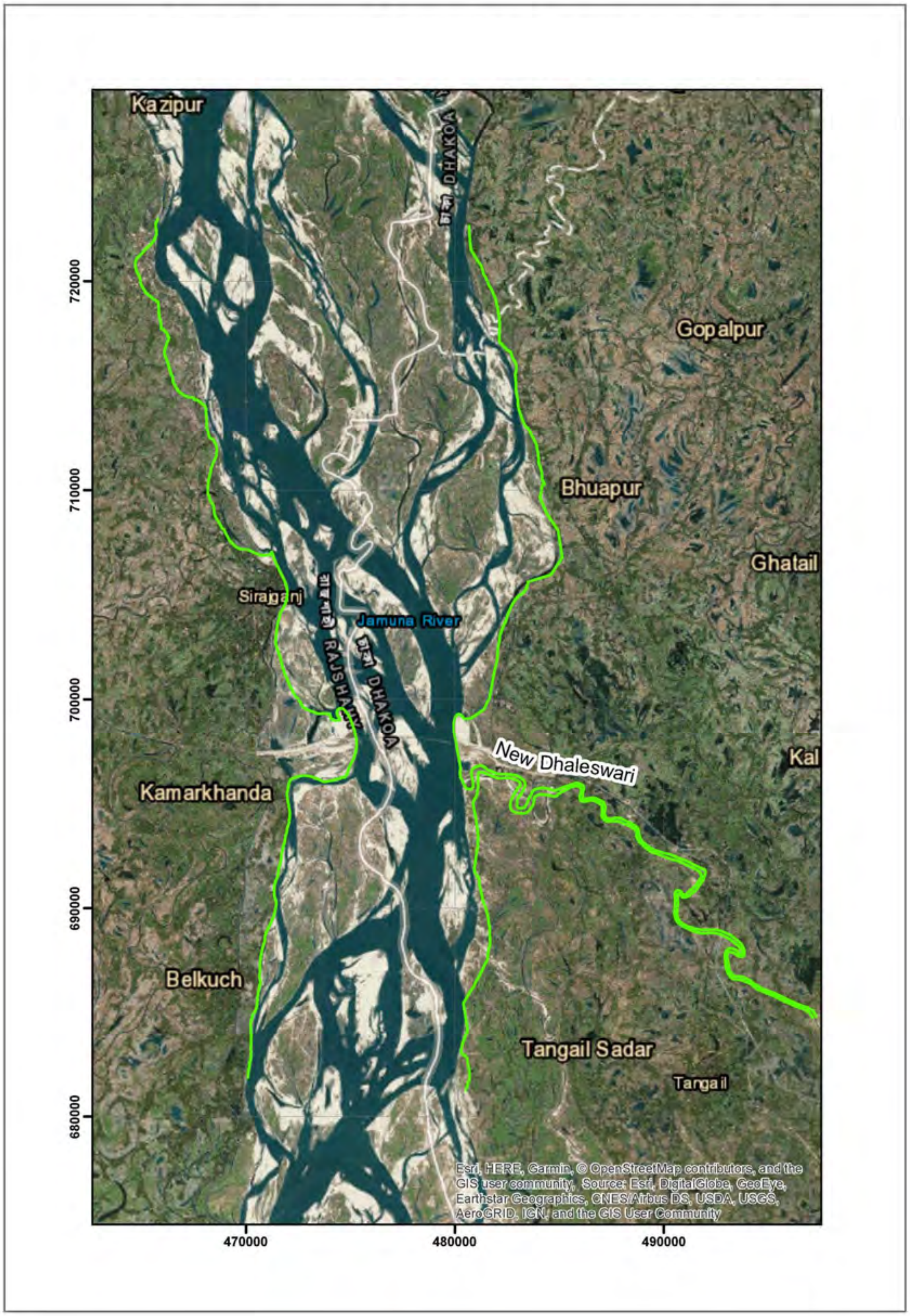

Figure 4.2: Study Area at New Dhaleswari and Jamuna river

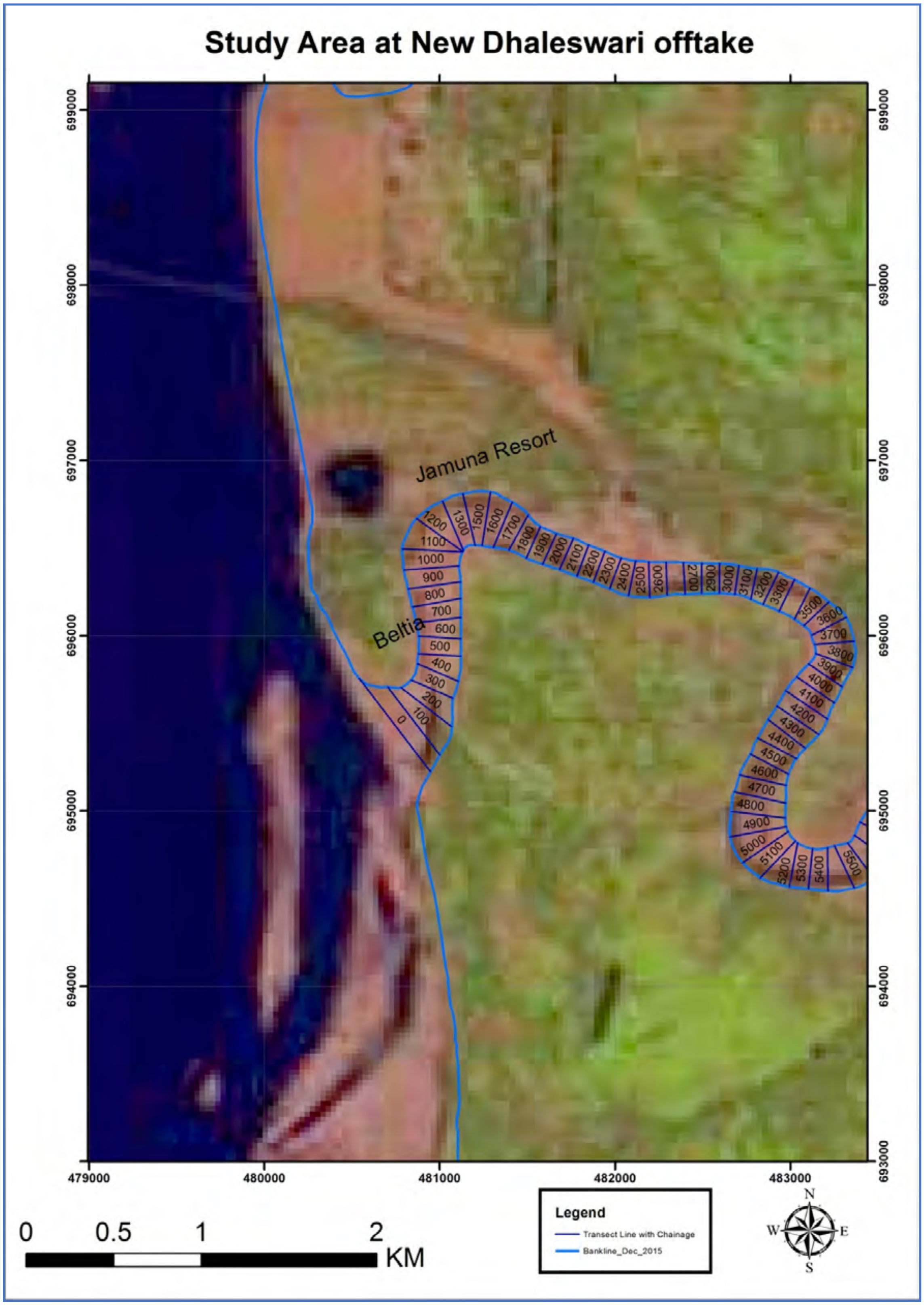

Figure 4.3: Study Area at New Dhaleswari offtake with Jamuna river

4.3 Data Collection

Historical water level and discharge data of New Dhaleswari and Jamuna river have been collected from BWDB. Satellite image of various years will be collected from USGS. Recent data on river cross section, sediment transport within the study area and satellite images have also been collected from BWDB. All the collected data were then compiled, processed and analyzed to the required extent for use in the model development and application. The detail description of data collection is discussed in next chapter.

4.4 Data Analysis

The trend of bankline shifting has been analyzed by two different methods, one from satellite image and the other from MIKE21C based study. Planform analysis of New Dhaleswari offtake and adjoining areas will be done with various satellite images. Historical water level and flow data will also be used to correlate between New Dhaleswari and Jamuna to set the boundary condition. Hydrological and morphological data has been analyzing by hydrological condition and morphological condition. Data analysis is based on two methods. These are GIS based Study and MIKE 21C based study

4.4.1 Hydrological Analysis of the Collected Data

Based on the historical water level and discharge data, an extensive hydrological analysis has been done to understand the hydrological condition of the study area.

4.4.2 Morphological Analysis of the Collected Data

Morphological analysis such as planform analysis, bankline shifting, shifting of offtake etc have been carried out by using different satellite images. Moreover, cross section analysis at different reaches of New Dhaleswari river and longitudinal bed profile has been also conducted to observe the bed level condition and thalweg of the river.

4.5 Mathematical Model Setup

The core of the mathematical modeling study is the application of the MIKE21C modeling system, which is an advanced two-dimensional mathematical modeling technology for simulation of unsteady flow, sediment transport and morphology. A morphological model is a combined hydrodynamic and sediment transport model. Hydrodynamic and morphological assessment has been carried out with the aid of 2D model to resolve the governing physical processes to a sufficient degree of detail. The hydrodynamic flow field has been updated continuously according to changes in bed bathymetry. The solution of hydrodynamics has been solved at a certain time step prior to solution of the sediment transport equations. Subsequently, a new bed level has been computed and the hydrodynamic model proceeds with the next time step. Other sub-models such as bank erosion, bank line update, alluvial bed resistance, bed forms, and graded sediment have been included in the simulation also. Model has been setup for 40 km reaches of Jamuna including 30 km reach of New Dhaleswari river from the offtake towards downstream. The model is based on the cross section data of post-monsoon 2015. The base model is based on the banklines data of these two rivers measured in 2015 also.

4.6 Modeling of River with Offtake

The morphological behavior of river offtake has also been studied numerically with two-dimensional (2D) MIKE21C model. Model does not require any specification of an empirical nodal point relation, because the distribution of sediment transport is computed from the same morphological equations as the development of the bed. Two-dimensional modeling of river offtake is not without problems. These problems are the relative contributions of total load (bed load and suspended load) and sediment transport over upward slopes.

4.7 Model Calibration and Validation

The model is calibrated for both hydrodynamic and morphological conditions for the hydrological monsoon of 2015. The model is also validated for hydrological monsoon of 2012 using the same calibrated parameters.

4.8 Analysis of Model Result under Various Conditions

Assessment of flow of New Dhaleswari system for high, medium and low flow of source river will be carried out for following management options.

a) River training works at the mouth of New Dhaleswari river.
b) For various dredging options with different design channel sections.
c) Combination of two options and weir like structure near the mouth to assess the flashing flow of boundary.

The options has been selected in such a way that the maximum amount of flow should be passed through the New Dhaleswari river. In this regard, nine different options and four different scenarios have been chosen for the simulation. Assessment of flow (at high, medium and low flow of Jamuna) for existing and design river bed condition of offtake has been conducted for the following management options which are shown in Table: 4.1.

Table: 4.1 various options and scenarios are used for the study

Options	Description of options
Option-1	Placing of two guide bunds at the offtake of New Dhaleswari river.
Option-2	30m Dredging at New Dhaleswari river.
Option-2- Scenario-1	30m Dredging, two guide bunds and silt trap (Offtake) at New Dhaleswari river.
Option-2- Scenario-2	30m Dredging, two guide bunds and silt trap (1.0 Km) at New Dhaleswari river.
Option-3	50m Dredging at New Dhaleswari river.
Option-3- Scenario-1	50m Dredging, two guide bunds and silt trap (Offtake) at New Dhaleswari river.
Option-3- Scenario-2	50m Dredging, two guide bunds and silt trap (1.0 Km) at New Dhaleswari river.
Option-4	Placing a silt trap and a groyne at Jamuna and two guide bunds at New Dhaleswari river.
Option-5	Placing a silt trap and a groyne at Jamuna, two guide bunds and 30m dredging at New Dhaleswari river.
Option-6	Placing a silt trap and a groyne at Jamuna, two guide bunds and 50m dredging at New Dhaleswari river.
Option-7	Placing a silt trap and a groyne at Jamuna, two guide bunds and weir at New Dhaleswari river.
Option-8	Placing a silt trap and a groyne at Jamuna, two guide bunds, weir and 30m dredging at New Dhaleswari river.
Option-9	Placing a silt trap and a groyne at Jamuna, two guide bunds, weir and 50m dredging at New Dhaleswari river.

CHAPTER 5

DATA COLLECTION

5.1 General

To develop the mathematical model for the hydrodynamic and morphological analyses, various kinds of historical data had been collected. These data also form the basis for further analysis and interpretation of the model results leading to accurate assessment of hydro-morphological condition of the study area. According to the modelling requirements, a significant amount of data includes water level, discharge, cross-section, sediment; satellite images and other relevant information like bank characteristics etc have been collected. This chapter describes a brief discussion about the collected data.

5.2 Data collection

Different types of data were collected for this study. Among these, satellite images of the New Dhaleswari and Jamuna river confluence for several years, river cross section, bank line data, and hydrometric data such as water level, discharge, suspended sediment and bed material data of the study area have been collected. For this study, hydrometric and cross section survey data were collected from BWDB on the New Dhaleswari River and Jamuna River during year of 2015. A brief description of data is given below:

5.2.1 Satellite image data

A time-series of satellite images for the New Dhaleswari River and Jamuna River confluence has been collected from United States Geological Survey (USGS). For this study, satellite images covering the period 2000-2015 were collected. Satellite Image information is given in Table 5.1. Earth observing satellites have been operating since 2000, collecting images from much of the earth surface. For the analysis discussed here the main source of information are satellite images, notably LANDSAT. The image data used in this study acquired over 15 years between 2000 and 2015. The images were taken when the cloud free imagery was most available and where the vegetation cover, and other ground condition were relatively consistence.

Table 5.1: Satellite Image Information

Year	Month	Image type	Resolution		Year	Month	Image type	Resolution
2000	February	LANDSAT 7	30 m x 30 m		2009	January	LANDSAT 5	30 m x 30 m
2002	February	LANDSAT 7	30 m x 30 m		2010	February	LANDSAT 5	30 m x 30 m
2003	March	LANDSAT 7	30 m x 30 m		2011	November	LANDSAT 5	30 m x 30 m
2004	March	LANDSAT 8	30 m x 30 m		2012	February	LANDSAT 7	30 m x 30 m
2005	January	LANDSAT 5	30 m x 30 m		2013	November	LANDSAT 8	30 m x 30 m
2006	January	LANDSAT 5	30 m x 30 m		2014	November	LANDSAT 8	30 m x 30 m
2007	May	LANDSAT 5	30 m x 30 m		2015	December	LANDSAT 8	30 m x 30 m
2008	May	LANDSAT 5	30 m x 30 m					

Processing and analyzing of the satellite images were performed using the image processing and GIS software such as Arc Map10.1. All the digital satellite data were pre-processed to remove data errors and anomalies. For comparison to be made between the images of different dates, it is vital that the images are all geo-referenced to a common projection and co-ordinate system. To achieve this, all the data were geo-referenced and projected on to the Bangladesh Transverse Mercator (BTM) projection system.

5.2.2 Bankline Data

Bankline survey has been carried throughout the specified 40 km length of the banks of New Dhaleswari River & 30 km length of Jamuna River by taking GPS positions of the bankline. Both banks were surveyed for delineation of the boundaries of the model area to generate the computational grid of the model. Features surveyed in bank line survey includes alignment of the river bank, location of significant features e.g. bridges, junction of roads, khals, river training works etc. Bankline data has been collected during the bathymetry survey in the month of December 2015.

5.2.3 Water Level Data

Water level data from 1945 to 2015 of the Jamuna and 1998 to 2015 New Dhaleswari were collected for this study. BWDB measures water level data at different stations along the Jamuna and New Dhaleswari River.

Table 5.2: Time series Water level data of Jamuna & New Dhaleswari River

Sl No.	Station ID	Station	River	Data Coverage	Source
1.	SW46.9L	Bahadurabad	Jamuna	1962-2015	BWDB
2.	SW49.0R	Sirajganj	Jamuna	1945-2015	BWDB
3.	SW134	Jokerchar	New Dhaleswari	1998-2015	BWDB,IWM

5.2.4 Discharge data

Discharge data from 1956 to 2015 of the Jamuna were collected for this study. BWDB measures discharge data at Bahadurabad station (SW46.9L) along the Jamuna River.

5.2.5 Cross Sectional data

The pre-monsoon 2015 cross section data of New Dhaleswari River has been collected from BWDB. This surveyed cross section data covers the reach from 30 km from offtake. The spacing between the transect line is about 40 m interval.

And other hand, the pre-monsoon 2015 bathymetry data of Jamuna River has been collected from BWDB. This surveyed bathymetry data covers the reach from 25 km upstream of Dhaleswari offtake to 15 km downstream of that Dhaleswari offtake. The spacing between the transect line is about 50 m to 200 m interval.

5.2.6 Sediment data

Sediment data were used in the model as input. The suspended sediment and bed sample data at Bahadurabad from BWDB and FAP 24.

Table 5.3 Available Sediment Data for the Study Area

Station	Suspended Sediment Data		Bed Sample Data	
	Data Period	Source	Data Period	Source
Bahadurabad	1966-70, 1976-1982, 1983-1988 and 1993-1996	BWDB and FAP 24	1993-1996	FAP 24

CHAPTER 6

DATA ANALYSIS

6.1 General

To develop the mathematical model for the hydrodynamic analyses and morphological analyses, various kinds of data of recent and previous years had been compiled. These data also form the basis for further analysis and interpretation of the model results leading to accurate assessment of hydro-morphological condition of the study area. According to the modelling requirements, a significant amount of data includes water level, discharge, cross-section, sediment; satellite images and other relevant information like bank characteristics etc have been collected. This chapter describes a brief discussion about the data analysis.

6.2 Data Analysis

Data analysis has been carried out for important information relevant to this study. It includes determination of maximum or minimum water level, water surface slope of the New Dhaleswari river and Jamuna river, standard high or low water levels as well as the frequency analysis and plan form analysis has been used for the study.

6.2.1 Hydrological Analysis

Hydrological analyses at the study area have been carried out using available water level data, discharge and velocity data. The water level data have been analyzed of yearly maximum, minimum and average water level data of New Dhaleswari River and Jamuna River. Yearly maximum discharges analyzed of Jamuna River have been discussed below

6.2.1.1 Water Level Analysis

Yearly maximum, minimum and average water level data of Jamuna River at Bahadurabad and Sirajganj stations have been plotted as shown in Figure 6.1 to Figure 6.2 respectively. And water level data of New Dhaleswari River at Jokerchar have been plotted as shown in Figure 6.3.

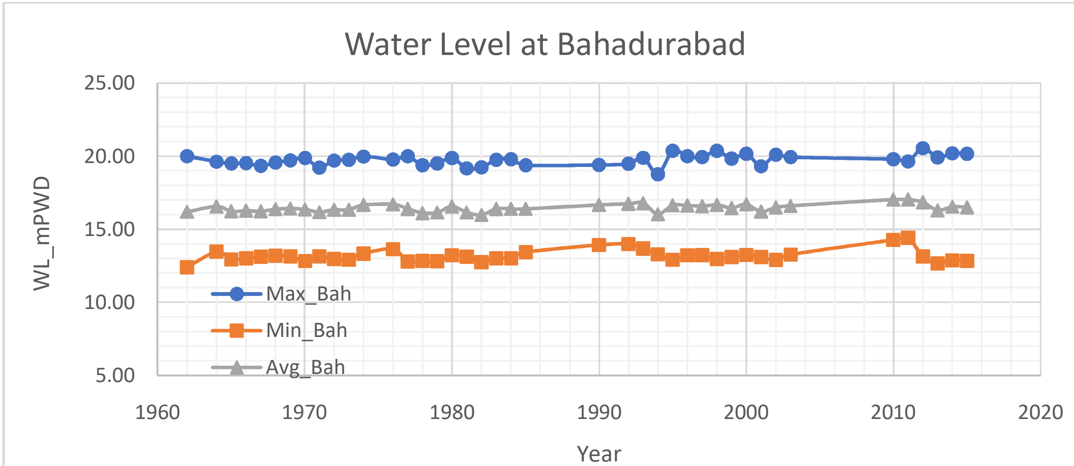

Figure 6.1: Maximum, minimum and average water level at Bahadurabad of Jamuna river

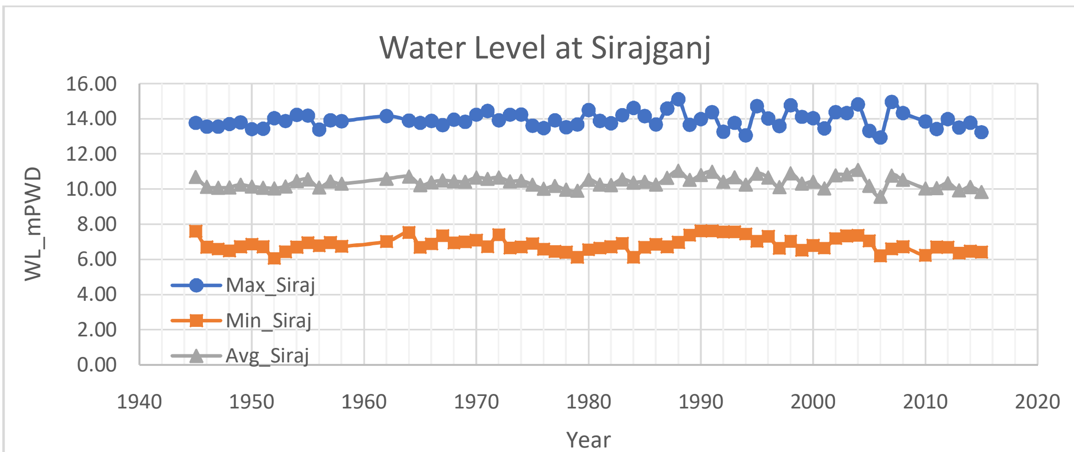

Figure 6.2: Maximum, minimum and average water level at Sirajganj of Jamuna river

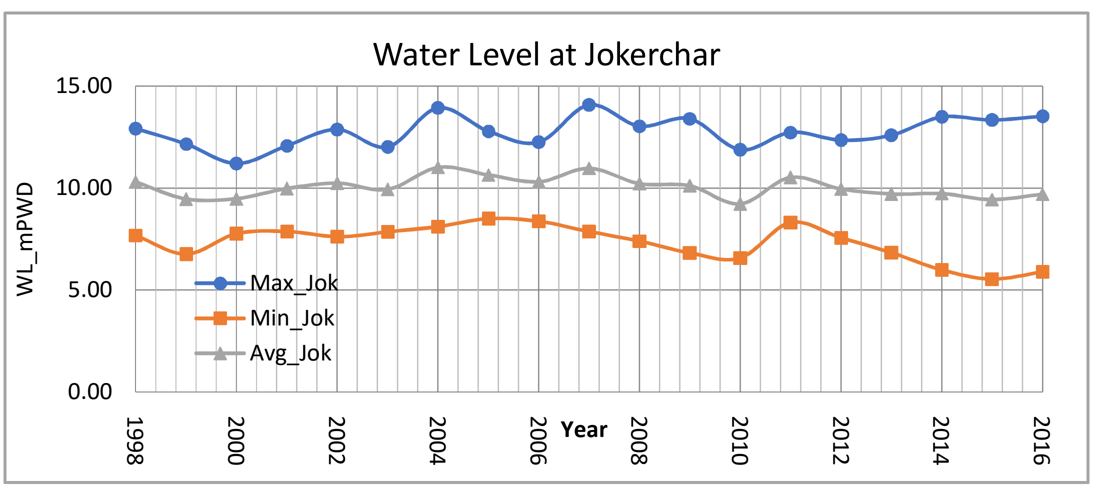

Figure 6.3: Maximum, minimum and average water level at Jokerchar of New Dhaleswari

6.2.1.2 Frequency Analysis of Discharge Data

Historical discharge data of Jamuna River at Bahadurabad station that have been collected from BWDB are analyzed and plotted in Figure 6.4. From this figure, it is evident that maximum discharge occurred in the year 1998. Table 6.1 shown in discharge data in following years.

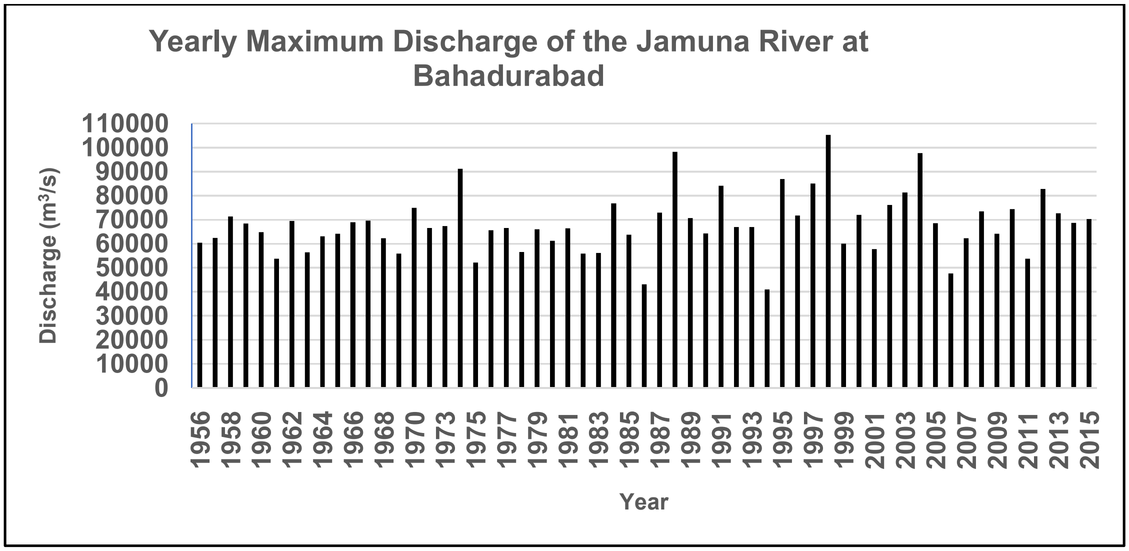

Figure 6.4: Yearly Maximum discharges at Bahadurabad station of Jamuna River

Table 6.1 Yearly maximum Discharge (m^3/s) at Bahadurabad of Jamuna River from 1956-2015

Year	1950s	1960s	1970s	1980s	1990s	2000s	2010s
0		64800	75000	61200	64300	71907	74339
1		53800	66600	66500	84100	57803	53864
2		69400	67300	55900	67000	76093	82746
3		56400	91100	56200	67000	81365	72661
4		63100	52200	76800	40900	97709	68720
5		64200	65600	63700	87000	68565	70234
6	60400	68900	66600	43100	71747	47626	
7	62500	69600	56600	73000	85090	62379	
8	71300	62300	66100	98300	105249	73509	
9	68500	56000	61200	70700	60047	64217	

The flood frequency analysis is one of the important studies of river hydrology. It is essential to interpret the past record of flood events in order to evaluate future possibilities of such occurrences. The estimation of the frequencies of flood is essential for the quantitative assessment of the flood problem. Frequency of a hydrologic event, such as the annual peak flow is the probability that a value will be equaled or exceeded in any year. The length of record should be sufficient to justify extrapolating the frequency relationship. For example, it might be reasonable to estimate a 50-year flood on the basis of a 30-year record, but to estimate a 100-year flood on the basis of a 10-year record would normally be absurd (BWDB 2010). Frequency analysis is cautioned when working with shorter records and estimating frequencies of hydrologic events greater than twice the record length (Viessman and Lewis 1996). The flood frequency analysis is one of the important studies of river hydrology which was conducted based on maximum instantaneous flow (Yadav 2002) Frequency analysis can be conducted in two ways: one is the analytical approach and the other is the graphical technique in which flood magnitudes are usually plotted against probability of exceedance. Deferent frequency analysis method are described the following section.

Gumbel's method

The Gumbels method (Gumbel Distribution) is the most widely used probability distribution function for extreme values in hydrologic and meteorological studies for prediction of flood peaks and maximum rainfalls (Chow et al. 1988). In this method the variate X (maximum rainfall or flood peak discharge) with a recurrence interval T is given by

$$X_T = u + \alpha y_T \tag{6.1}$$

Where, X_T is a flood of specified probability or return period T;

$$u = X_{avg} - 0.5772\alpha \tag{6.2}$$

Where, Xavg is the mean of the flood series;

$$\alpha = \frac{\sqrt{6}}{\pi} S \tag{6.3}$$

Where, S is standard deviation of sample size;

$$N = \sqrt{\frac{\Sigma(x - xavg)2}{N-1}} \tag{6.4}$$

$$y_{T} = -\ln(\ln(\frac{T}{T-1}) \tag{6.5}$$

Log Pearson Type III method

Log Pearson Type III Distribution (LP3) describes a random variable whose logarithms are P3 distributed. Thus

$$y = \ln x \tag{6.6}$$

This method of estimating the parameters of the LP3 distribution is similar to that for the P3 distribution except that logarithms of the data are to be taken before estimating moments. Thus for a set of observations x_1, x_2,……x_n the transformed data are given by $y_1 = \ln x_1$. y2 = $\ln x_2$; $y_n = \ln x_n$. Estimate of flood flow corresponding to T-year return period can be obtained from

$$X_T = \text{antilog}\,(y_{avg} + K_T S_y) \tag{6.7}$$

$$K_T = \frac{2}{gx\,(1+ZT\,gx} \; \frac{2}{gx} \tag{6.8}$$

Where, g_y is the coeficient of skewness of log transformed data.

Log Normal method

If a random variable x has a log normal distribution (LN2) then the log transformed variable has a normal distribution. The transformed variable is denoted by

$$y = \ln x \tag{6.9}$$

Where; X > 0.

The maximum likelihood method is generally best for fitting the LN2 distribution. The maximum likelihood method gives:

$$S_y \;= \frac{\sum_{i=1}^{n}[\ln(Xi) - yav\ ]}{n} \tag{6.10}$$

$$y_{avg} \;= \frac{\sum_{i=1}^{n} \ln(Xi)}{n} \tag{6.11}$$

Estimate of flood flow corresponding to T-year return period can be obtained from

$$X_T = \text{antilog}\,(y_{avg} + Z_T S_y) \tag{6.12}$$

Where for flood flow

$$Z_T = \frac{\left(1-\frac{1}{T}\right)^{0.195} - \left(\frac{1}{T}\right)^{0.135}}{0.1975} \tag{6.13}$$

And for low flow

$$Z_T = \frac{\left(\frac{1}{T}\right)^{0.135} - \left(1-\frac{1}{T}\right)^{0.135}}{0.1975} \tag{6.14}$$

Frequency analysis is merely a procedure for estimating the frequency of occurrence or probability of occurrence of past or future events. To determine the discharge of Bahadurabad in response to 2, 5, 10, 25, 50, 100 and 200-year return periods flood frequency analysis has been conducted based on the discharge data for the year 1956 to 2015. To select the appropriate distribution a total of three distributions have been compared in this study. These are Gumble Distribution, Log Pearson Type III Distribution and Log Normal Distribution. The comparison is based upon goodness-of-fit analysis. Based on 2, 5, 10, 25, 50, 100 and 100- year return periods. Table 6.2 shows the discharge of different return periods for different distribution methods.

Table 6.2 Peak flows of Jamuna River at Bahadurabad for selected return periods using different distribution

Probability Distribution	Return Period in year						
	2	2.33	5	10	25	50	100
Gumbel (EV1)	65985	68120	76923	84165	91111	100103	106841
Log Pearson-III	67019	68959	77909	84237	91513	96519	101226
Log Normal	68018	69546	78434	83879	88376	93437	96811

Frequency analysis has been made based on the probability plots and goodness of fit tests (Binomial Test, Chi square test and K-S test). The following Probability Plots in Figure 6.5 to Figure 6.3 show the Probability values using Gumbel, Log Pearson three parameters and Log Normal distribution respectively. From these figures it is seen that the confidence level of log-normal distribution is less variable among the three distributions.

Table 6.3: Peak flow according to Log-Normal distribution

Return period	**Peak flow according to Log Normal distribution (m^3/s)**	**Observed peak flow (m^3/s)**	**Corresponding year**
2.33	69546	68565	2005
100	96811	105249	1998

The hydrological year of 1998 and 2005 represents the high and medium flood events, respectively. The low flood event has been selected by analyzing the historical minimum discharge (2688 m3/s) for the past 55 years. The corresponding year of low flood event is 2001.

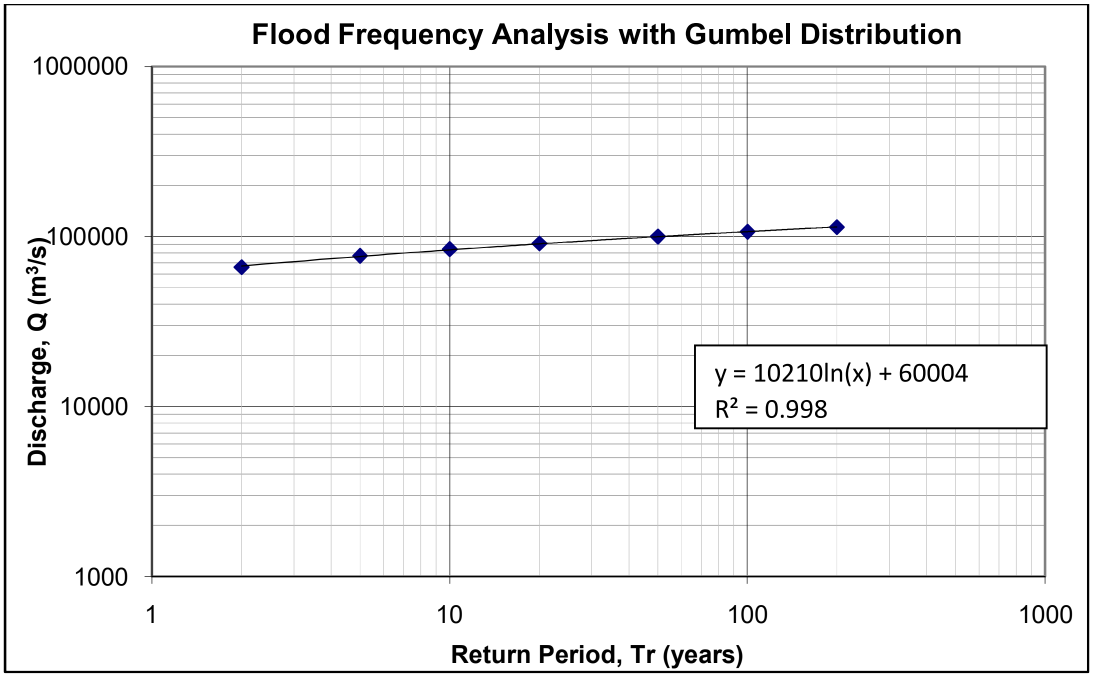

Figure 6.5: Gumbel Distribution of discharge data at Bahadurabad station

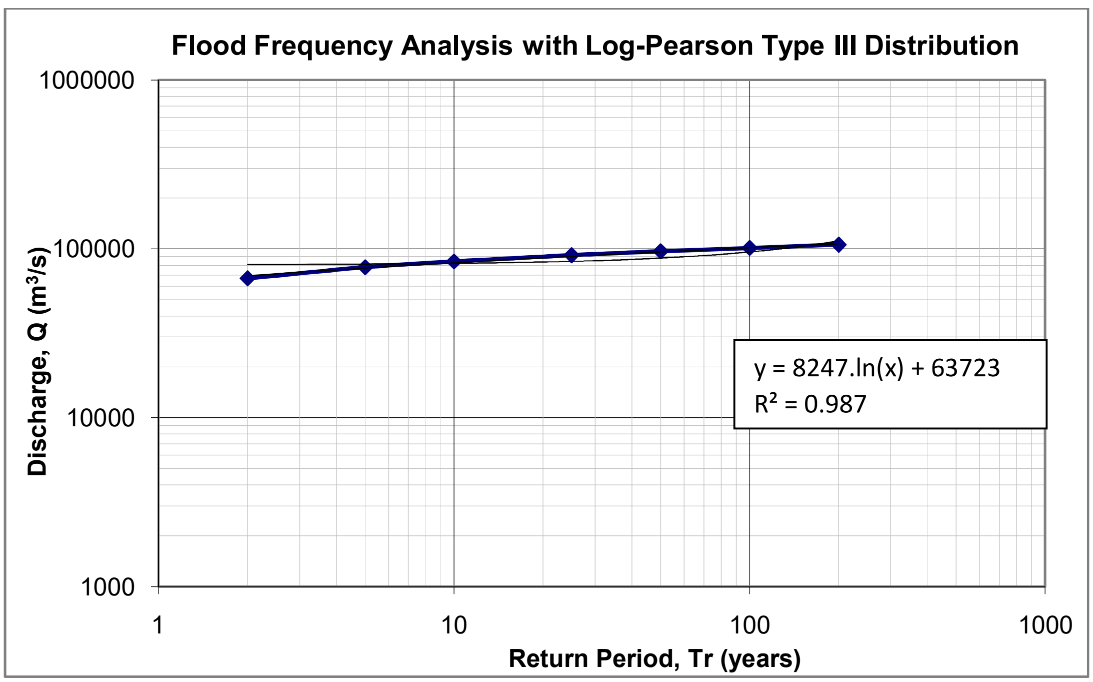

Figure 6.6: Log-Pearson Type-III Distribution of discharge data at Bahadurabad station

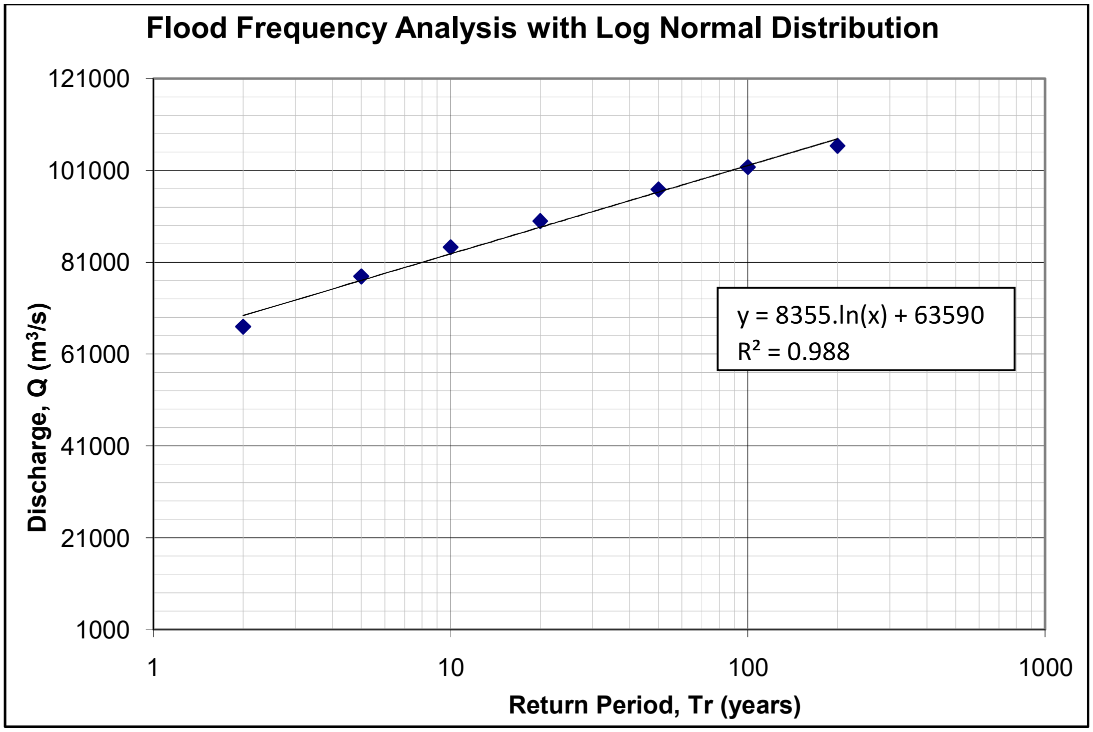

Figure 6.7: Log-Normal Distribution of discharge data

To select the best fit among the three distributions Binomial test, Chi square test and Kolmogprov-Smirnov (K-S) test has been made. The values of Binomial test, Chi Square and Kolmogprov-Smirnov test varieties are presented in Table 6.4.

Table 6.4 Goodness of fit test among three distributions

Distribution / Test	Gumbel	Log-Pearson	Log-Normal
Binomial Test	0.1555	0.1683	0.1439
Chi Square Test	0.8667	0.8333	0.7667
K-S Test	0.6693	0.6081	0.5737

It is found from Table 6.4 that the probability of exceedance of Binomial, Chi square and K-S value is found minimum for Log-Normal distribution. For Log-Pearson III and Gumbel distribution it is slightly higher compared to Log-Normal distribution. Again It is known that if Chi square is equal to zero the theoretical and observed frequencies agree exactly; while if chi square is greater than zero they do not agree exactly and the larger the value of Chi square the greater is discrepancy between the observed and expected frequencies.

6.2.2 Morphological Analysis

Morphological analyses at the study area have been carried out using available satellite images and cross-sectional data. The planform analysis, bankline shifting, changes of New Dhaleswari offtake sediment transport analysis, cross section and longitudinal bed profile as well as historical changes of cross sections at different reaches of New Dhaleswari River have been discussed below:

6.2.2.1 Planform Analysis

Satellite images starting from the year 2000 up to 2015 has been utilized for the purpose of this study. All the images have a ground resolution of 30m x 30m. For the planform analysis the channel networks and the bank line of the New Dhaleswari and Jamuna River were converted into digital data using GIS. GIS is a computer based technology for recording, manipulating, analyzing and playing data such as digital maps, images or other information with a spatial reference such as latitude and longitude. Technique of GIS can be quite valuable in studying the river morphological behavior. The GIS output in form of color contours, river from change maps, convenient for studies, for example to predict the morphological development. Thus, GIS is an important tool for bank line shifting trend analysis, movement of offtake and identify the critical location for erosion and deposition and construction of river training work. Satellite images in study area showing the offtake of the New Dhaleswari river in 2015 is shown in figure 6.8. Appendix-A are shown in map of various years satellite image analysis.

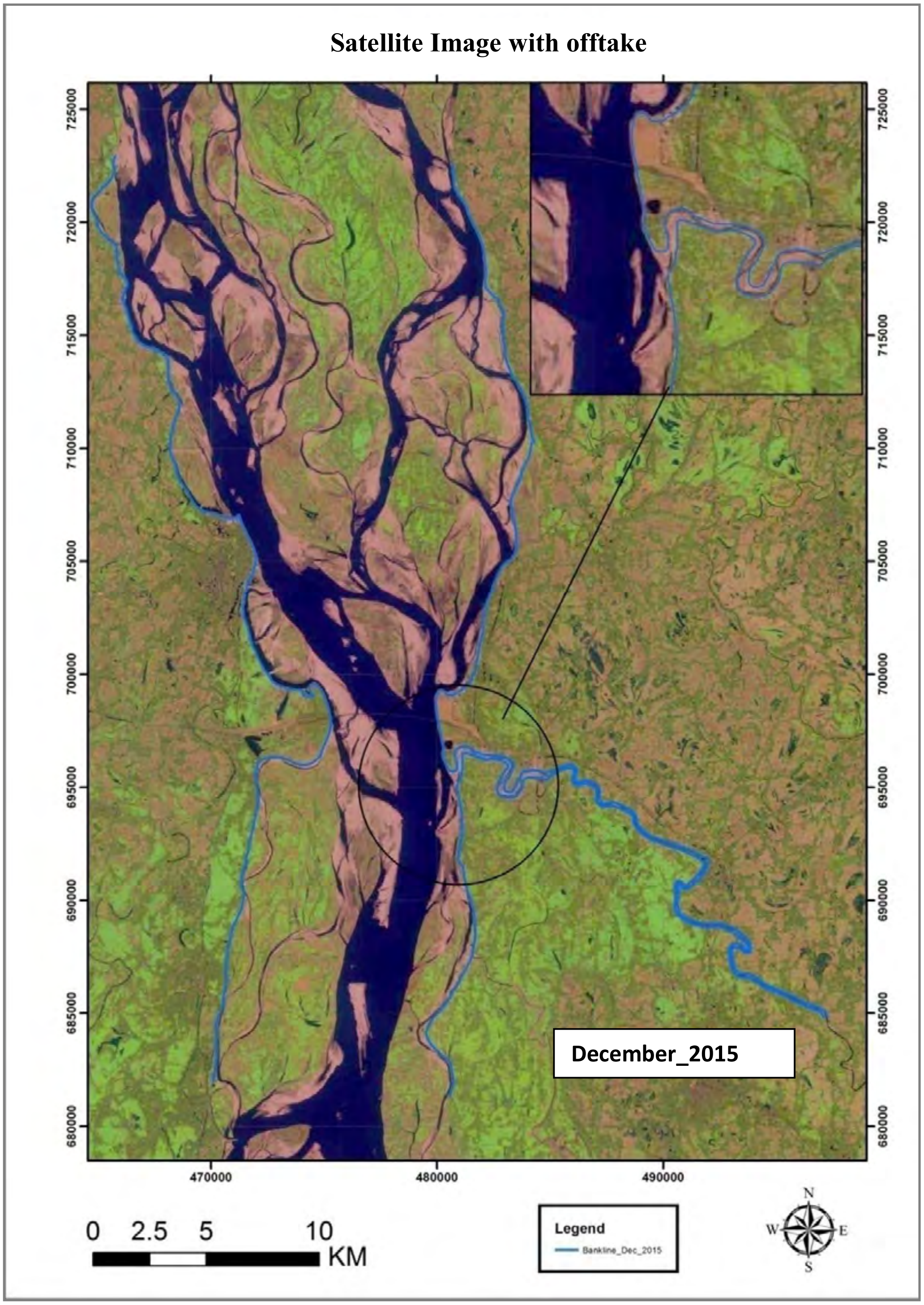

Figure 6. 8: Satellite images showing the offtake of the New Dhaleswari River at 2015

6.2.2.2 Average Width Analysis using Satellite images

From the analysis, the current average width of the Jamuna River was found to be 40 km and New Dhaleswari river was found to be 30 km. But the average width in this reach is showing an increasing trend which is better visible in Figure 6.9 to Figure 6.11. In this figure the calculated average width for the last fifteen years are shown.

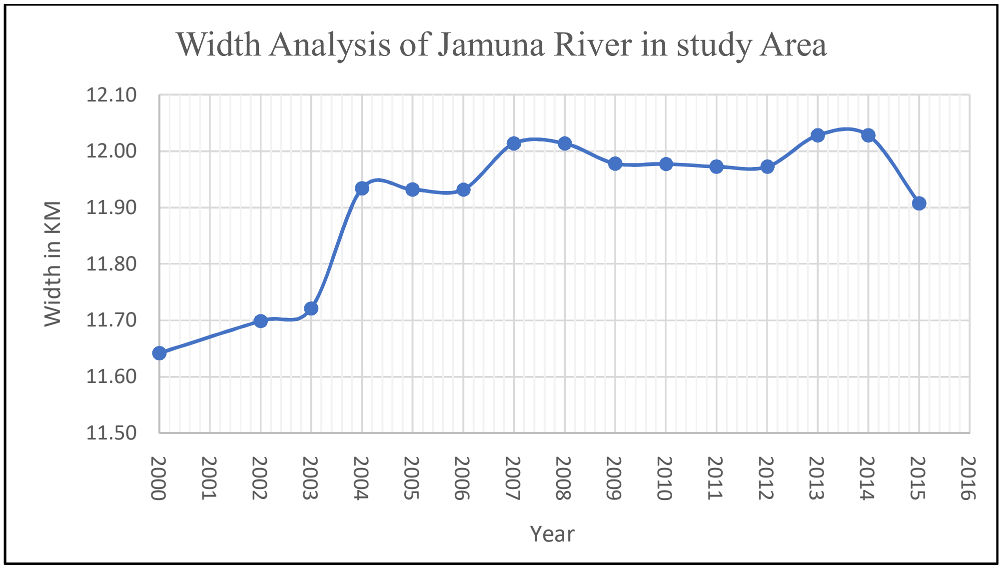

Figure 6.9: Average Width of Jamuna River in the study Area

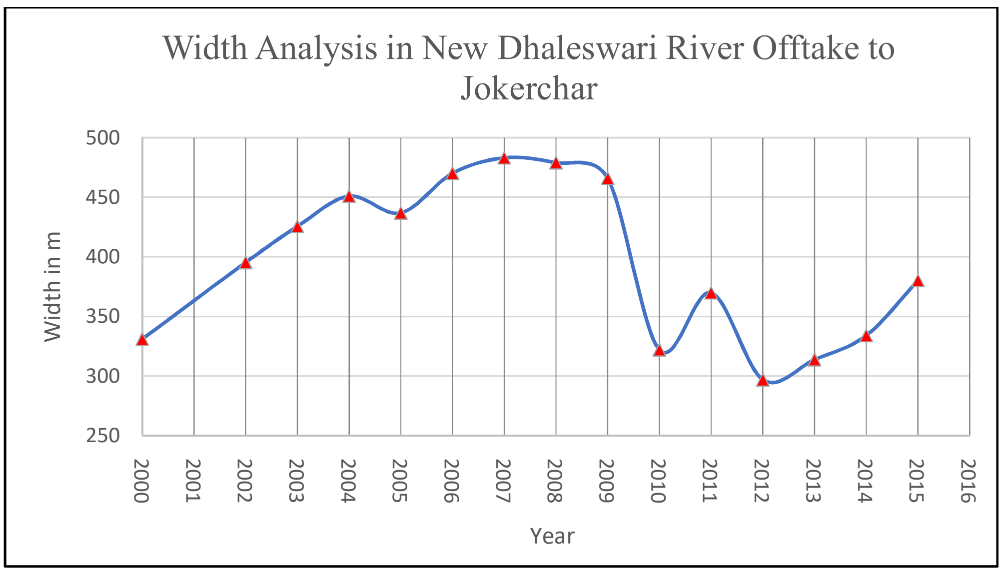

Figure 6.10: Average Width of New Dhaleswari River in the Offtake to Jokerchar

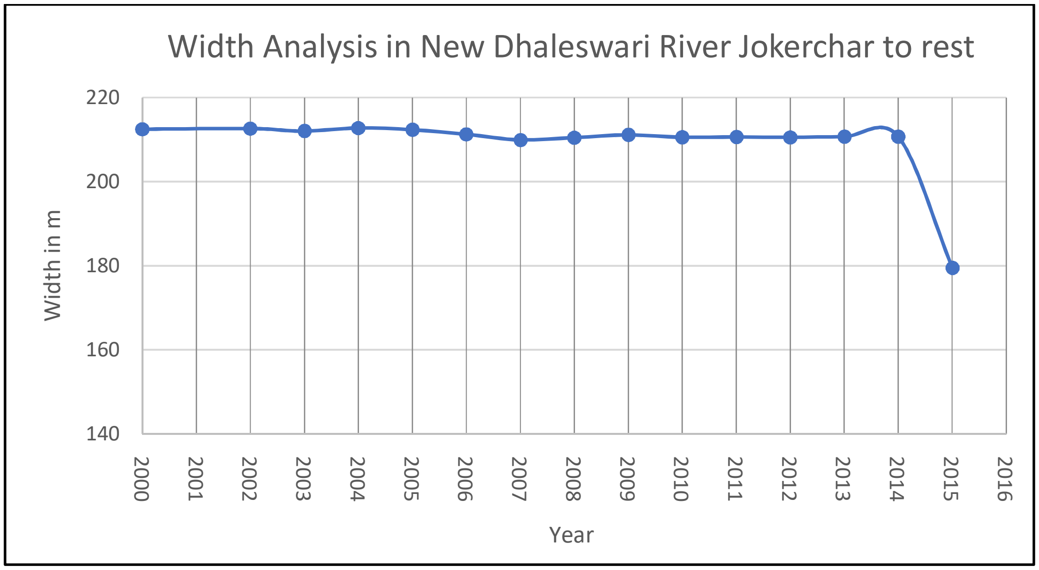

Figure 6.11: Average Width of New Dhaleswari River in the Jokerchar to rest length

6.2.2.3 Bankline Shifting Analysis using Satellite images

Changing channel alignment brings high degree of bankline shifting in the New Dhaleswari river and Jamuna river. The ever changing banklines of the New Dhaleswari river and Jamuna river were digitized using the available satellite images to assess the location and magnitude of bankline shifting in the project extent. The digitized bankline for the last fifteen years is shown in Figure 6.12. It has been seen from the figure that the bankline of New Dhaleswari offtake to Jokerchar is shifting drastically from year to year and it didn't follow any trend.

Figure 6.12: Bankline Shifting of the New Dhaleswari River offtake

5.2.2.4 Cross Section Analysis

The importance of using good quality cross-sectional data to describe channel topography cannot be overemphasized. It has been necessary to checking field level data before they were accepted. The checking procedure becomes even more important when data from several sources of varying reliability have to be used (SWMC Hand Book).

- Plotting of X-section Profile – Visual observation
- Plotting of Long Profile– Visual observation
- Comparison with nearby cross sections
- Comparison with cross sections of previous measurements

Plotting of Cross-Section Profile

Cross-section can be described as a two dimensional dataset where the horizontal distances were represented on the x-axis and the depth on the y-axis. It is shows the shape of a feature such as slop, thalweg, permanent object etc.

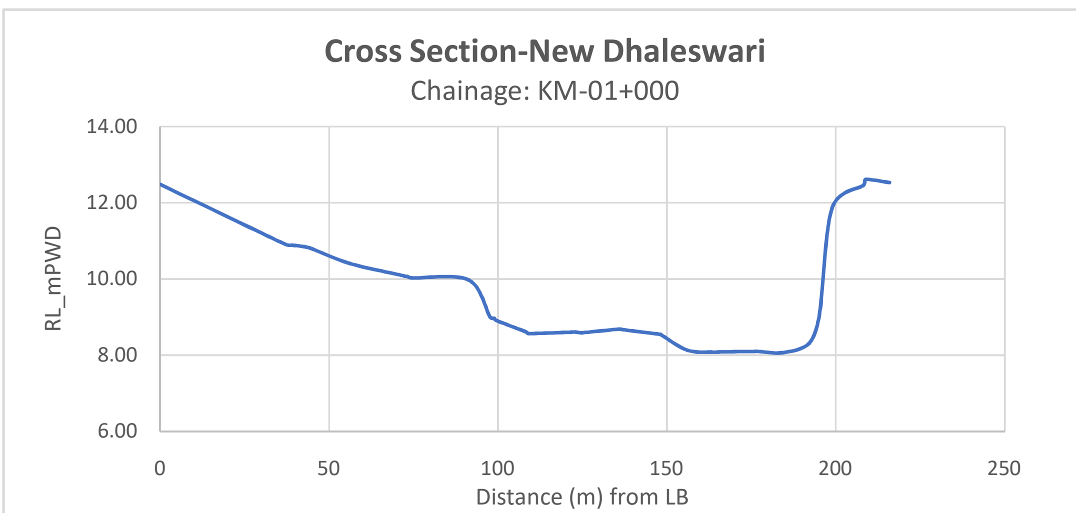

Figure 6.13: Plotting of X-section Profile–Visual observation of the New Dhaleswari River

Plotting of Long Profile

The long profile shows how a river's gradient changes as it flow from its source to its mouth. It is a diagram of a river's by plotting distance and Reduce Level (RL) or depth. In a river highly charged with sediment, the bed configuration changes drastically under different flow regimes. Deposition of sediment in one place causes deepening by scour in another place. Thus the thalweg tends to wander continuously from one position to another within the river bank lines.

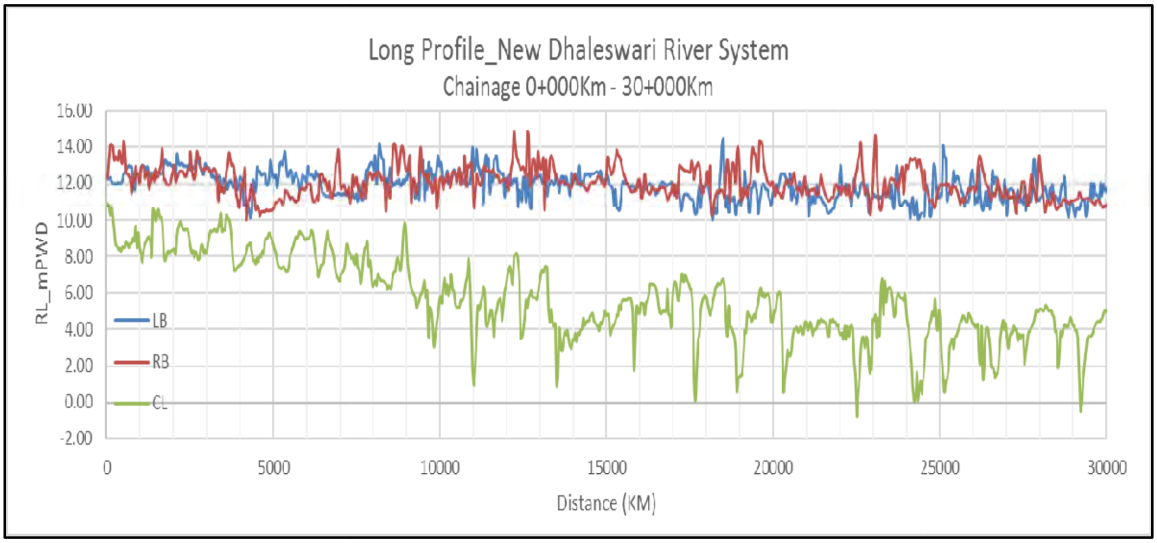

Figure 6.14: Plotting of Long Profile – Visual observation of the New Dhaleswari River

Comparison with nearby cross sections

Comparisons of near two sections are one of the methods of checking cross section data. In straight portion, all section is tentatively more or less same in next section of the river. It is not applicable in bend.

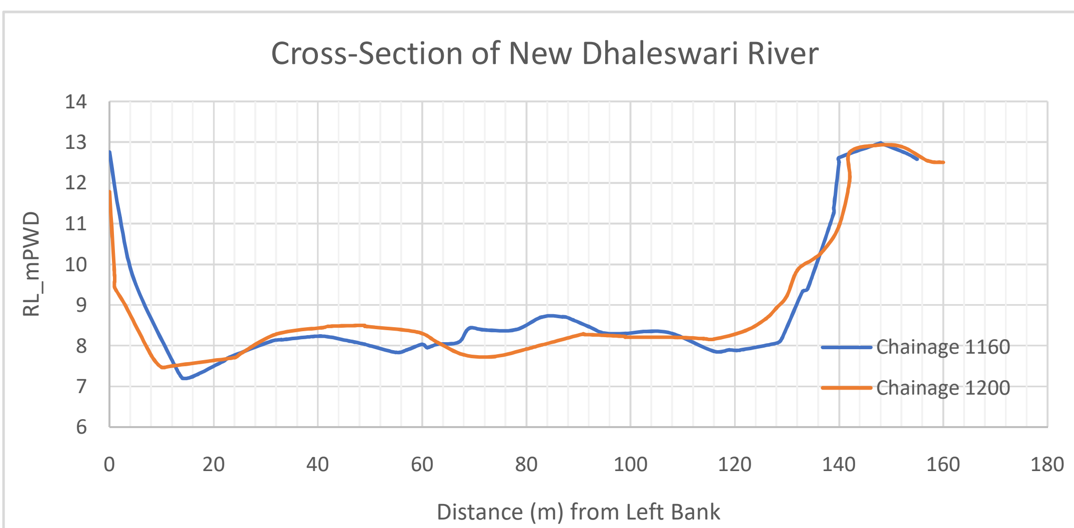

Figure 6.15: Comparison with nearby cross sections of the New Dhaleswari River

Comparison with cross sections of previous measurements

In one location (Station) of measurement of various years cross section is one of the methods of checking cross section data. The alteration of morphology of a river along transverse direction from year to year due to the consequence of erosion of the river bed and shifting in bank line can be revealed with the tool like superimposition of a cross-section at a particular location for different years. A sample of historical section is shown in Figure 6.16. Cross Section graph Shown in Appendix-B.

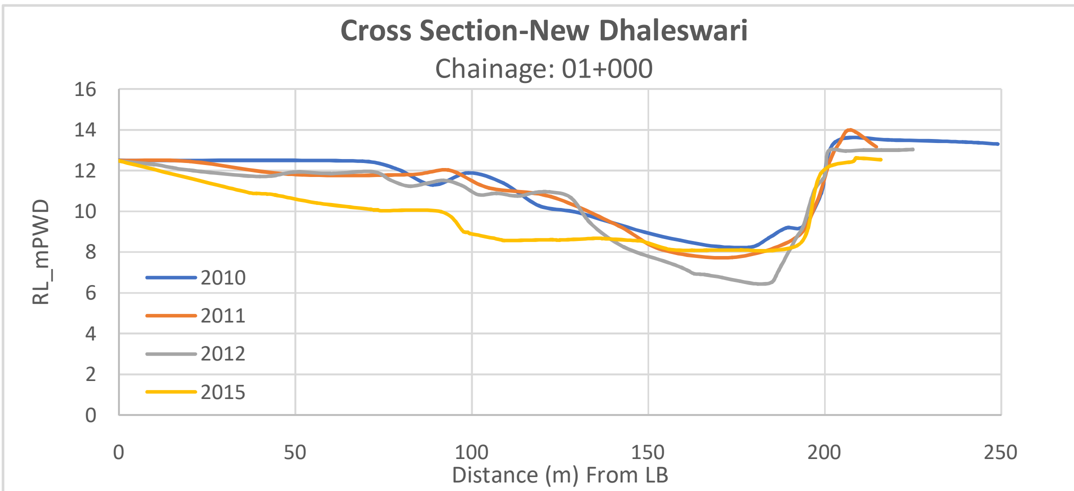

Figure 6.16: Comparison with cross sections of previous measurements of the New Dhaleswari River

Equi-convenience capacity analysis

Equi convenience analysis is an important procedure to check the river flow capacity in various water depths.

The term K is known as the conveyance of the channel section; it is a measure of the carrying capacity of the channel section.

$$K = \frac{1}{n} AR\hat{}(\frac{2}{3}) \tag{6.15}$$

In Figure 6.17 shown in Equi-Conveyance Capacity of New Dhaleswari River. In chainage 1 km at the start of 1st bend river channel are narrow so the convenience capacity much more low because this channel is narrow.

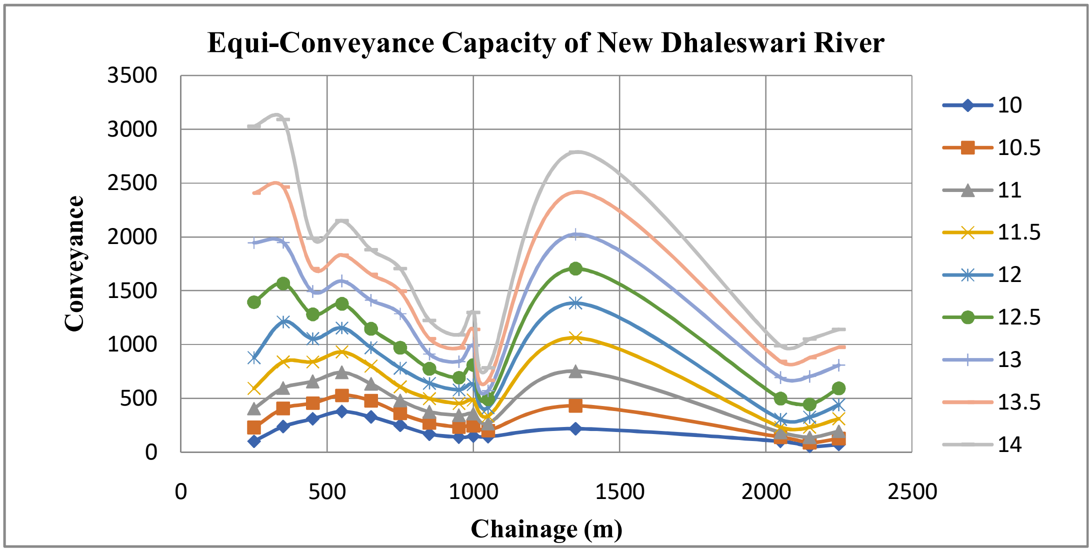

Figure 6.17: Equi-convenience of the New Dhaleswari River

5.2.2.5 Sediment Transport Analysis

Sediment rating curve of Jamuna have been prepared from the available historical sediment data of Bahadurabad station. The sediment discharge and corresponding flow discharge of Jamuna River have been plotted on log-log paper, shown in Figure 6.18. From trend line analysis the following relationships have been found. For Jamuna River the equation 6.15 is as follows:

$$Qs = 0.125\ Q^{1.480} \qquad (6.16)$$

Where, Qs and Q is the sediment discharge and water discharge.

Sediment transport analysis has been done for Jamuna River by using the suspended sediment data from the period 1968 to 2002. For the Jamuna River, the combined yearly sediment transport is found 1200 million tons per year on the average (FAP 24).

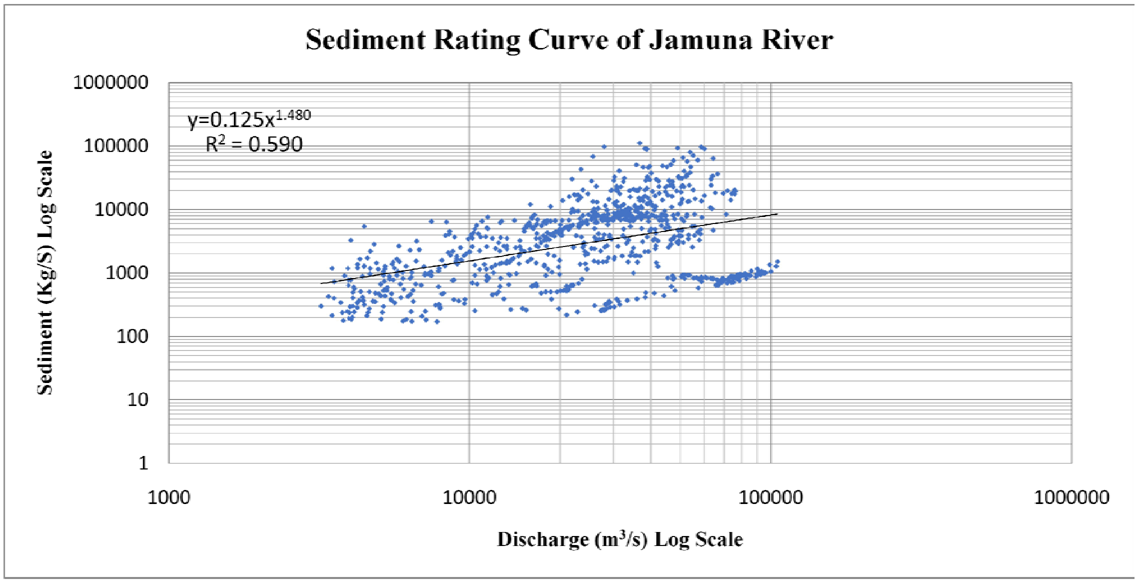

Figure 6.18: Sediment rating curve of Jamuna River at Bahadurabad station during 1968-2002

CHAPTER 7

MODEL SETUP

7.1 General

Mathematical modeling is an advance technology in engineering practice for predicting variables. In mathematical model is tedious to find in hand calculation. To evaluate such variables, a two-dimensional morphological model (MIKE 21C) has been used. Using this modeling software a mathematical model of 40 km reach of Jamuna river including 30km reach of New Dhaleswari river has been set-up. The various key steps during processing the model has been described below

7.2 Model Setup

The model setup includes the generation of computational grids, the preparation of the bathymetry, boundary conditions and selection of calibration parameters. Followed by the set up, the model has been calibrated with the tuning of hydrodynamic parameters (like Chezy's bed roughness, eddy viscosity etc.), the parameters in the sediment transport magnitude formula e.g., bed load and suspended load factors. Then the model has been be simulated for different applications runs. Detail methodology for model set-up, calibration and option simulations has been presented in the following sections.

7.2.1 Generation of Computational Grid

The curvilinear grid has been generated based on the bankline surveyed in October to December of 2015. The grid has the dimension of 335 grid points along the river and 258 grid points across the river in New Dhaleswari river and of 335 grid points along the river and 258 grid points across the river in Jamuna river, i.e. 69850 grid points in total. The grid has land boundaries as well. The model simulates the hydrodynamic and morphological parameters in every computational grid point. The computational grid has been shown in Figure 7.1.

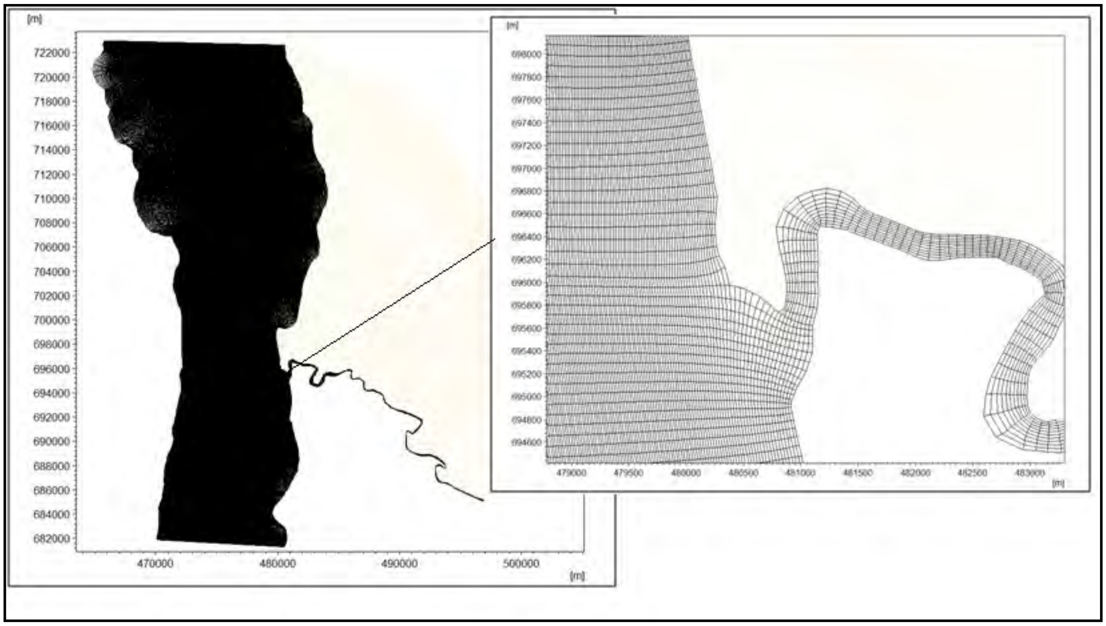

Figure 7.1: Computational Grid cell of New Dhaleswari and Jamuna river in the study area

7.2.2 Generation of Model Bathymetry

The Cross-sectional data of the model has been prepared based on data from the IWM cross section (bathymetric) survey carried out during Post-monsoon 2015. A part of the initial bathymetry of the model appears in Figure 7.2. To simulate the morphological model with different hydrological events, the bathymetry data has been superimposed on the curvilinear grid. Hence every grid cell contains river cross-section data and after model simulation every grid cell produces hydrological and hydraulic parameters like, water level, discharge, water depth, velocity, bed scour and others.

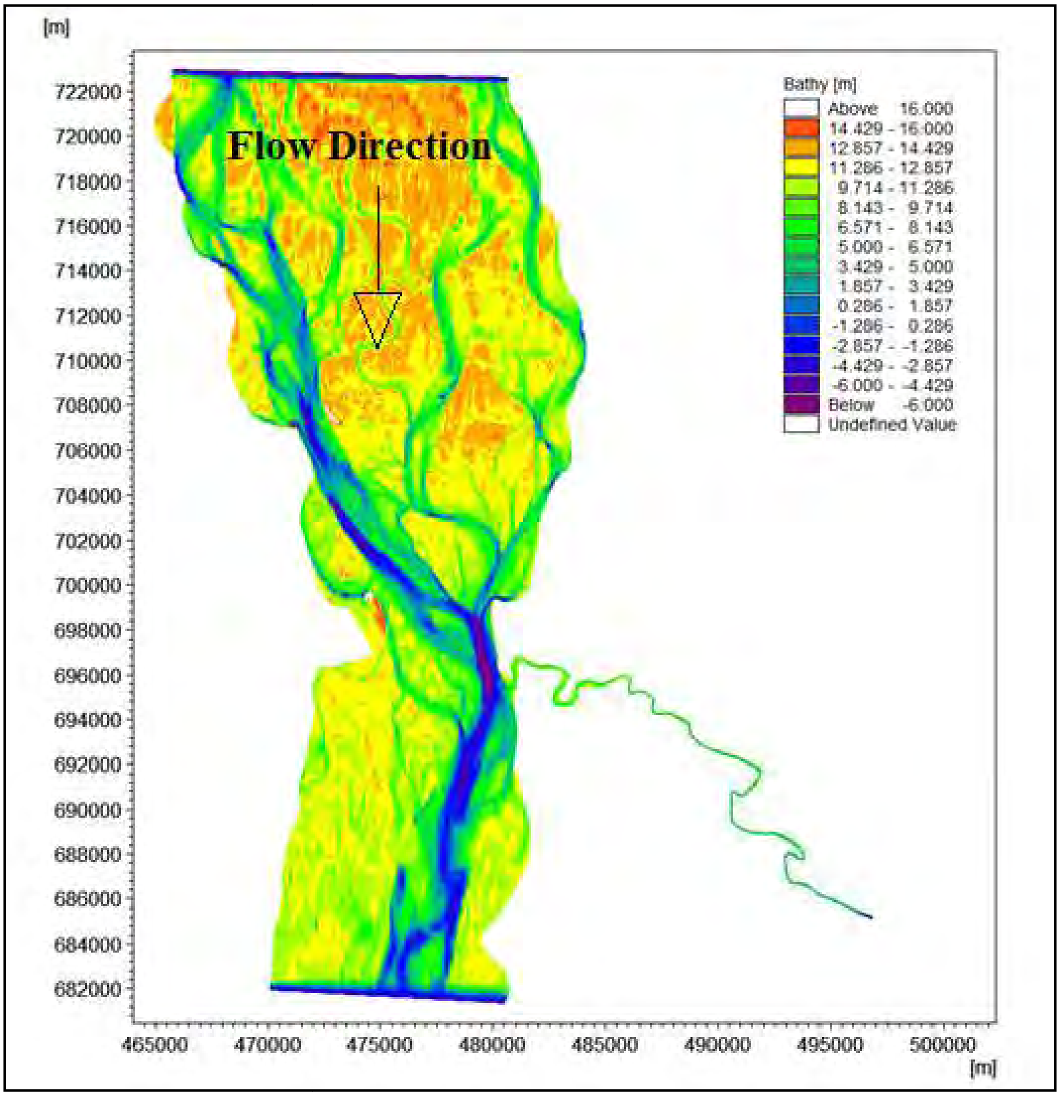

Figure 7.2: Model bathymetry of New Dhaleswari river and Jamuna River in the study area for post-monsoon 2015

7.2.3 Boundary Condition

To simulate the morphological model, it is necessary to use the following hydrological data at the model boundaries.

- Discharge at the upstream boundary at Jamuna river US of Sirajgonj.
- Water level at the downstream boundary at New Dhaleswari river near Char Pauli.
- Water level at the downstream boundary at Jamuna river near at Pungli Bridge.

Calibration and validation boundary hydrograph were shown in Figure 7.3 and Figure 7.4. The application run of the model has been done for high, medium and low flood events. The

1 in 100 year return period and 1 in 2.33 year return period flood events represents the high and medium flood events. The corresponding year of high and medium flood events are 1998 and 2005, which have been found by doing frequency analysis (Figure 7.5 & Figure 7.6). The low flood event has been selected by analyzing the historical minimum discharge for the past 55 years. The corresponding year of low flood event is 2001 (Figure 7.7).

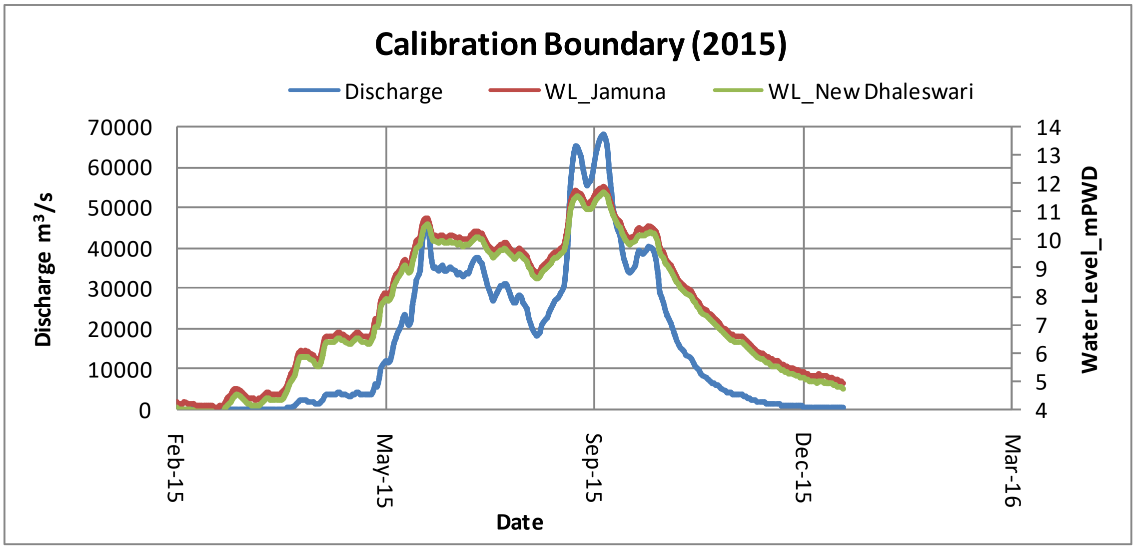

Figure 7.3: Discharge and Water level boundary for Model Calibration (2015)

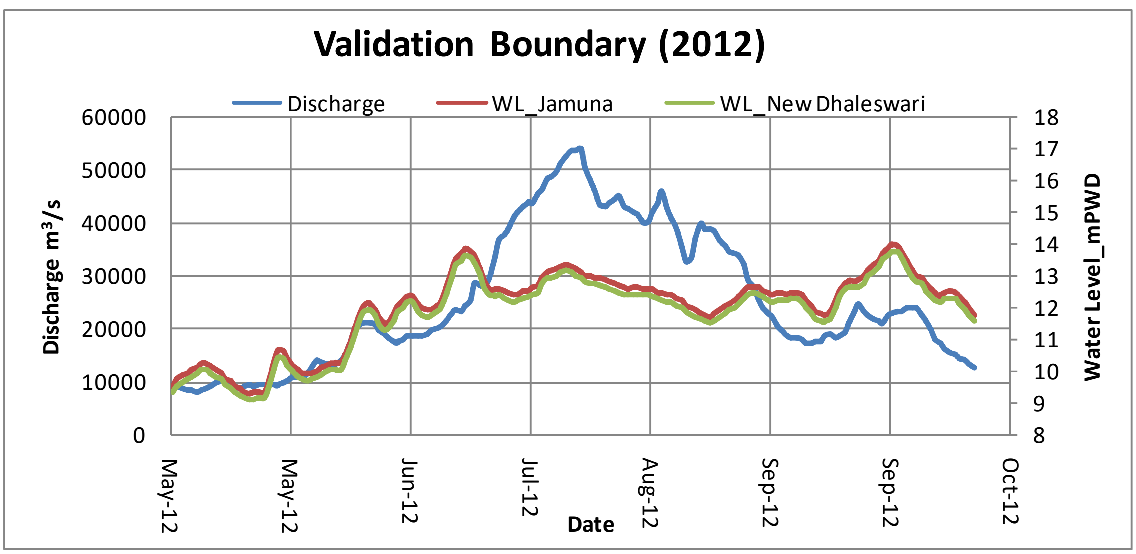

Figure 7.4: Discharge and Water level boundary for Model Validation (2012)

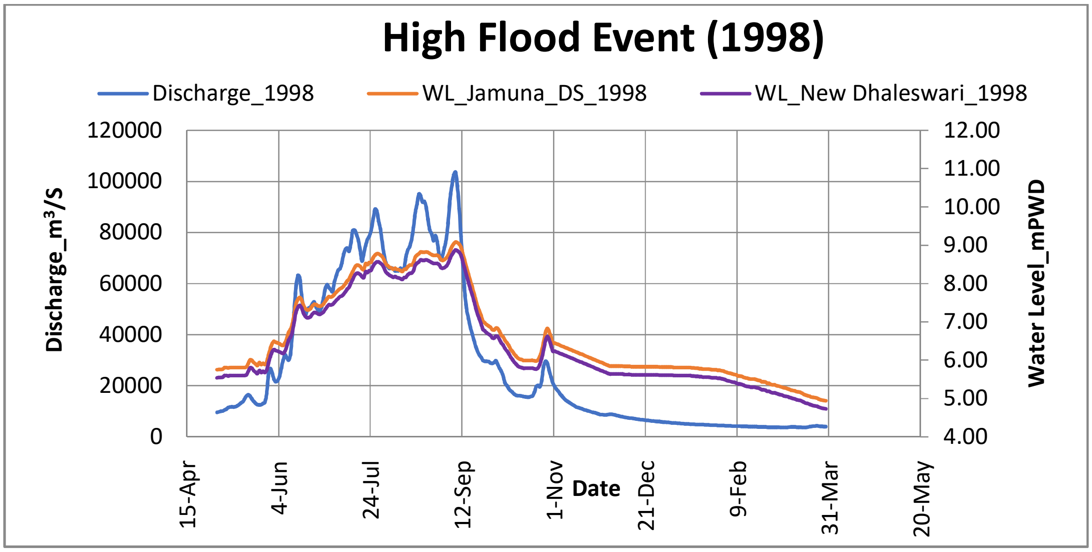

Figure 7.5: Discharge and Water level boundary for the high flood event (1998)

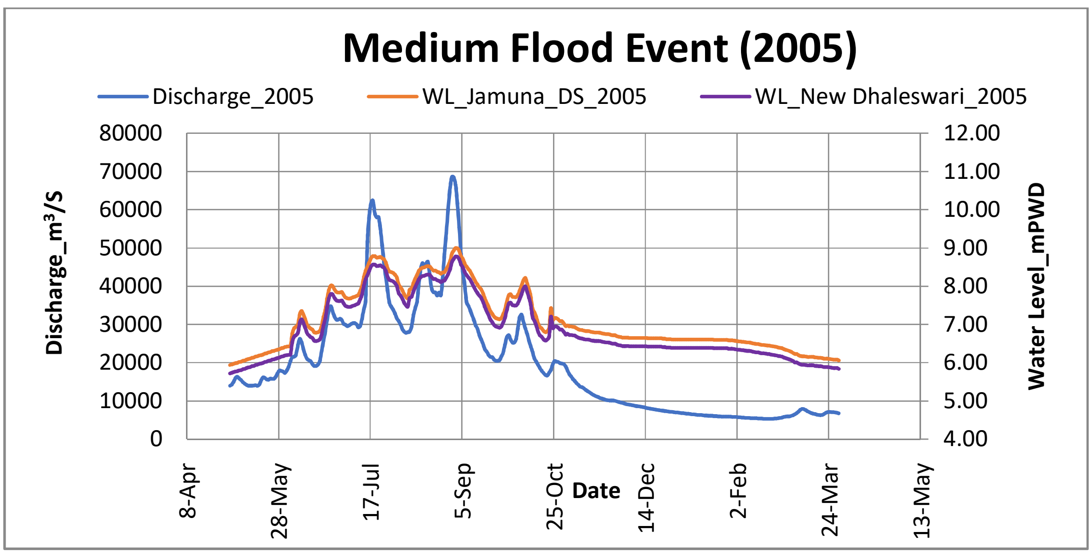

Figure 7.6: Discharge and Water level boundary for the medium flood event (2005)

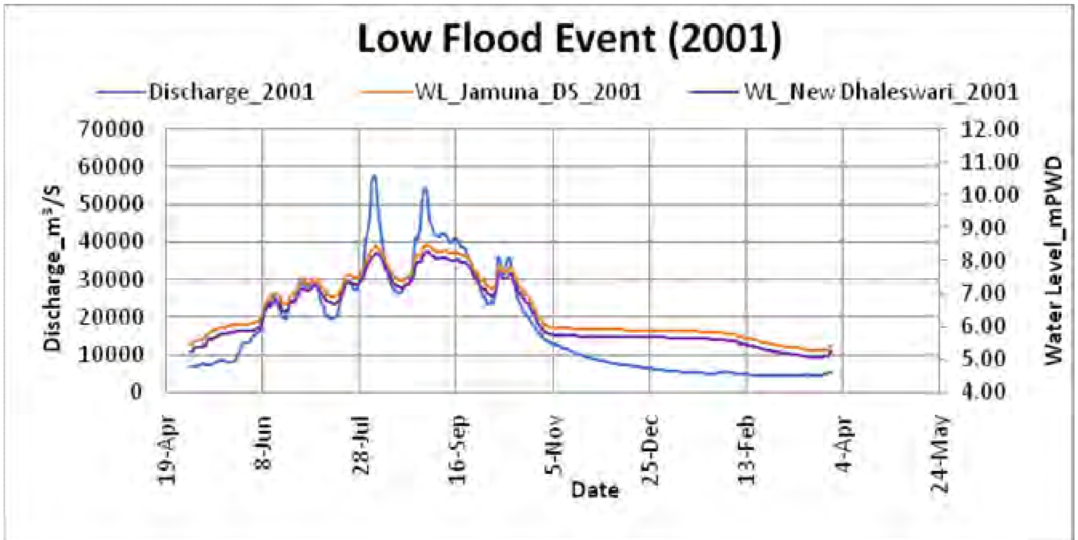

Figure 7.7: Discharge and Water level boundary for the low flood event (2001)

7.2.4 Model Calibration

It is always customary to calibrate and validate the model before making any predictions using the model, so that the reliability of the predictions can be made as much as perfect. Model calibration is the process of estimating model parameters by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions. In this study, model has been calibrated by using the boundary of 2015 as shown in Figure 7.8 & Figure 7.9.

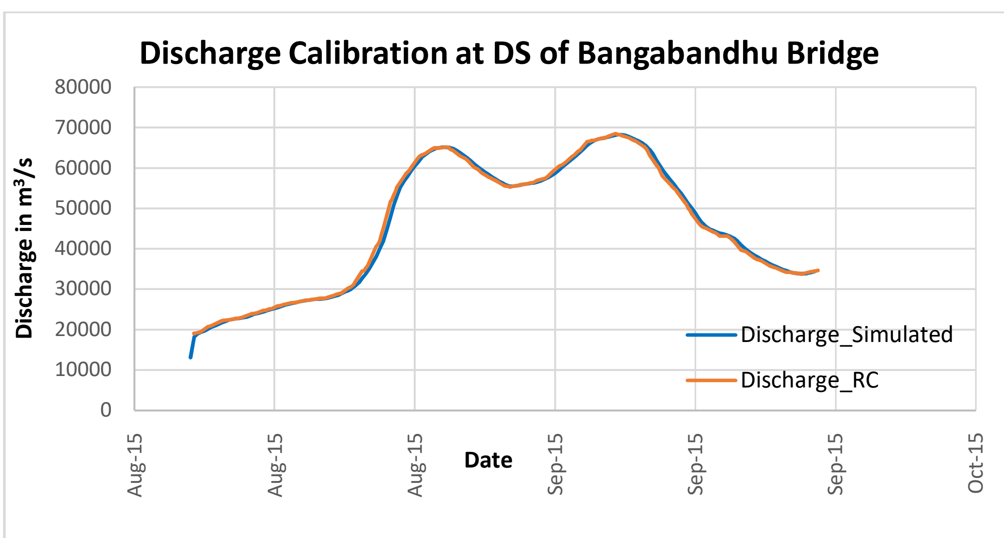

Figure 7.8: Discharge Calibration at Downstream of Bangabandhu Bridge

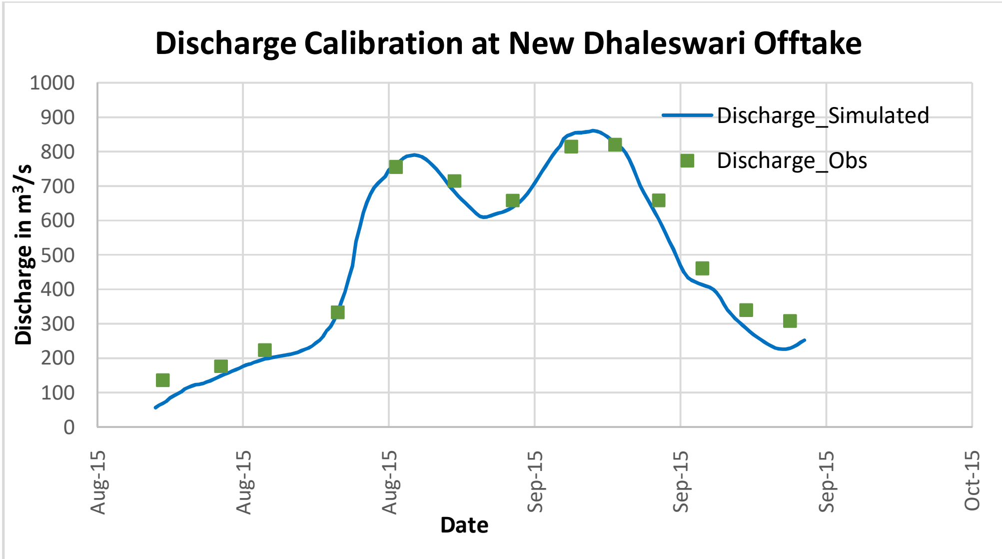

Figure 7.9: Discharge Calibration at Beltia Ghat of New Dhaleswari river

7.2.4.1 Hydrodynamic Calibration of the Model

Hydrodynamic calibration is done with the fixed bed model. Water level calibration has been done at Sirajganj station in Jamuna river. The parameters which contribute in adjusting the hydrodynamic misbalance or fine tuning the numerical models in the hydrodynamic field in MIKE21C are mainly roughness (Chezy's C), co-efficient of eddy viscosity (E) where Chezy's C influence in adjusting the water level and co-efficient of eddy viscosity used for the distribution of flow by exchanging lateral momentum of flow. The Chezy value can vary spatially and is also a function of depth. The functional relation can be updated after each computational time step. In this model, Chezy value is updated at every time step according to the updated depth from the following equation 7.1.

$$C = aH^b \qquad (m^{1/2}/s), \qquad (7.1)$$

Where, H represents the water depth while a and b are alluvial resistance coefficient and exponent respectively.

Numbers of trial simulations were carried to verify the selection of the C and finally C=60 has been fixed as initial Chezy value and for the selection of the value for alluvial resistance coefficient and the exponent, as 25 and the exponent, b as 0.5 were used. So by taking these values, the equation stands in the form of $C = 25*h^{0.5}$. The maximum limit for Chezy's factor C is considered as 95 and the minimum as 15. The reason for using the limiting value of the Chezy's factor is to control the extreme roughness of the model domain. In all the simulations, the value of eddy viscosity is 1.0 for the project. The summary of the parameters used in the model domain are shown in Table 7.1.

Table: 7.1 Summary of the parameters used for the model domain

General Time Step (s)	Momentum Time Step (s)	Pressure Time Step (s)	Sediment transport Equation	Chezy $C = aH^b$		Eddy Viscosity m^2/s
				a	b	
10	10	10	Van Rijn	30	0.5	1

The model is simulated for a specified period. Since the morphological changes and bank erosion take place primarily during the high discharges, the simulation period is selected so that it can include the main contributing part of the monsoon. On this basis the period has been chosen. So, for representing the scenario of the hydrological year total 176 days were considered starting from 15th May to the 11th November for calibration purpose. The hydrodynamic time-step has been set to 10 second for the simulation. Figure 4.15 shows the calibration results at Sirajganj station in Jamuna river. The comparison shows more or less good agreement between the simulations.

7.2.4.2 Sediment Transport Calibration of the Morphological Model

The calibration of the morphological model is basically meant in MIKE21C to deal with the sediment transport and its associated parameters, such as the grain size diameter, the selection of sediment transport formula, the helical flow strength etc. In this study, calibration was done on the basis of the sediment transport rating curve at Bahadurabad station for Jamuna river. For the application and for calibration of the model, sediment transport found from Van Rijn formula is applied for better result, shown in Figure 7.8 and Figure 7.9. In this case, the value of d_{50} for the whole model domain is given by interpolating the value from 0.19mm to 0.17mm.

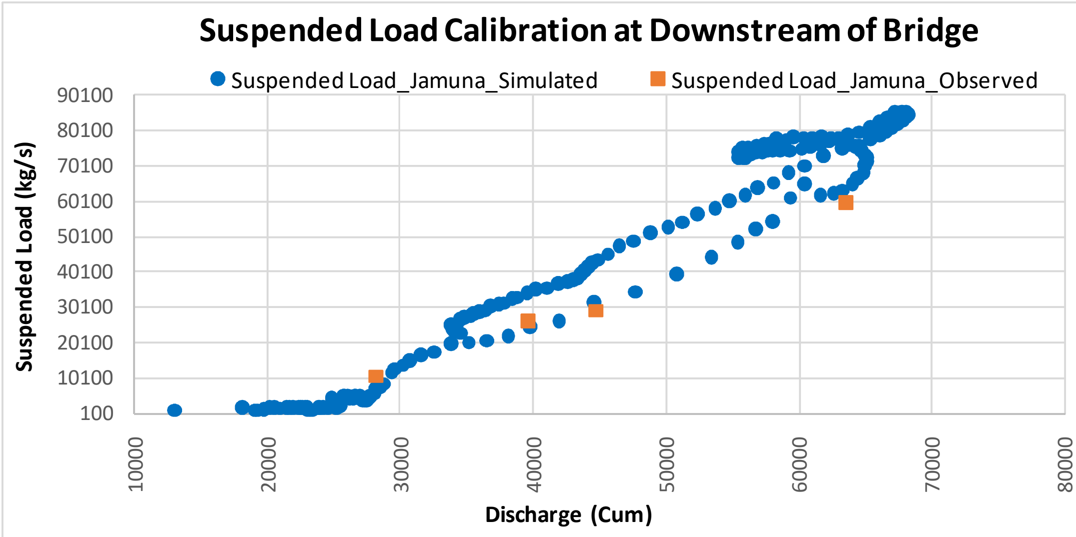

Figure 7.10: Sediment transport calibration at DS of Bridge in Jamuna river

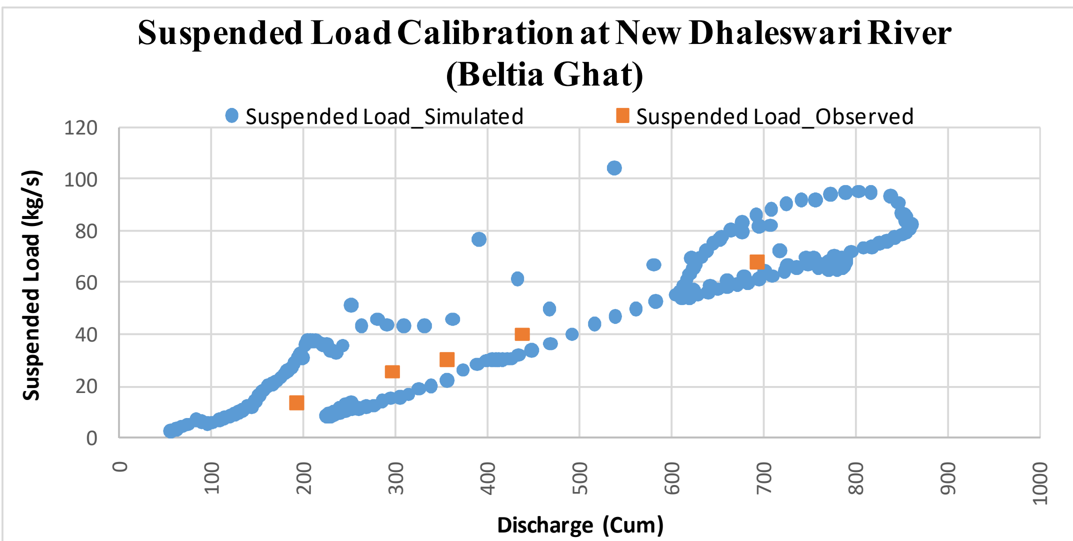

Figure 7.11: Sediment transport calibration at Beltia ghat in New Dhaleswari river offtake

7.2.5 Model Validation

The calibrated model is validated by running for one or more simulations for which measurements are available without changing any tuning parameters. Here, model has been hydro-dynamically and morphologically validated by using the boundary of 2012.

7.2.5.1 Hydrological Validation

The comparison of observed and simulated water level is shown in Figure 7.12 to Figure 7.13 at Sirajgonj and New Dhaleswar offtake (Beltia ghat). And also discharge is compare, which is shown in Figure 7.14 to Figure 7.15. It is seen that the simulated water level is almost matched with the observed locations. The simulated discharge is also more or less similar with the observed discharge.

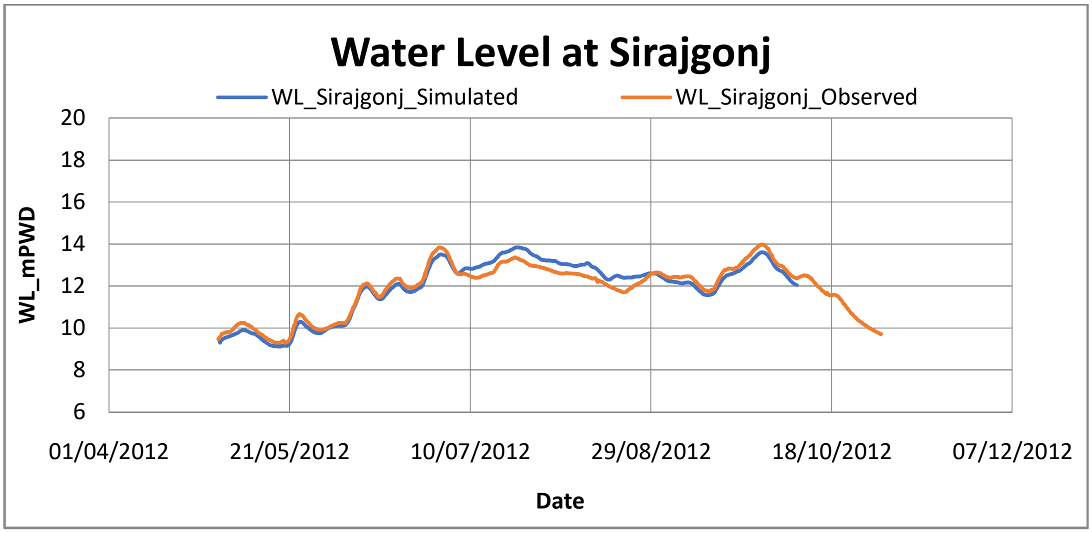

Figure 7.12: Water Level Validation at Sirajgonj in Jamuna River

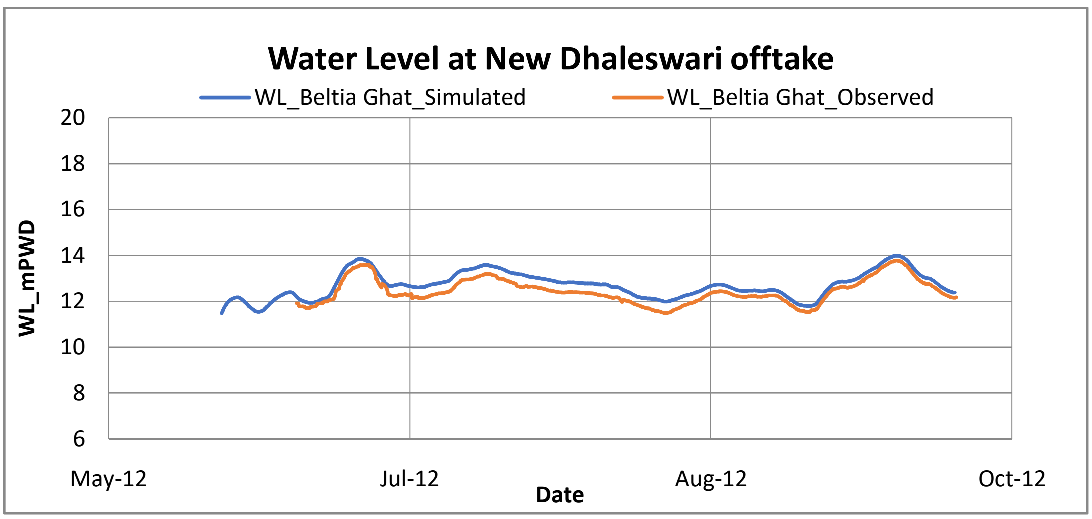

Figure 7.13: Water Level Validation at New Dhaleswari offtake (Beltia Ghat)

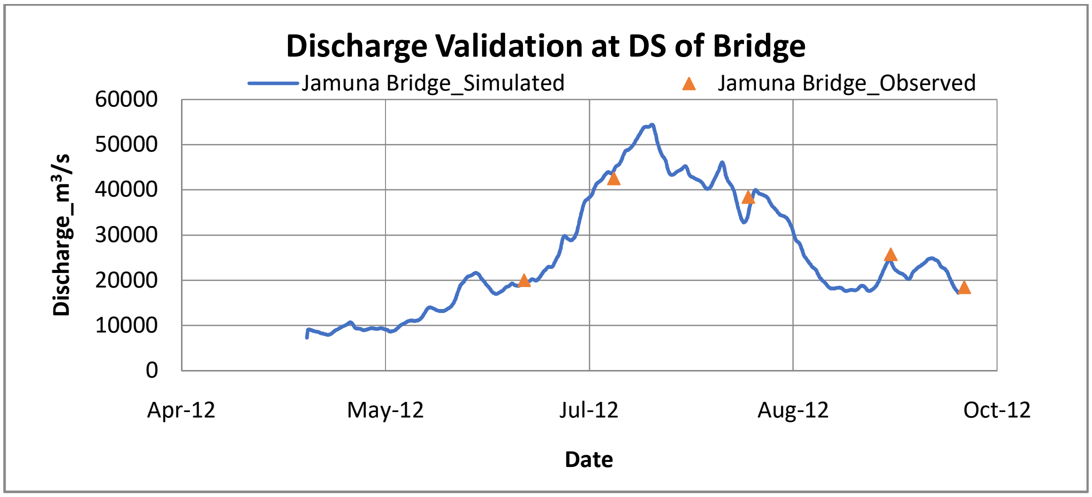

Figure 7.14: Discharge Validation at Down Stream of Bridge in Jamuna River

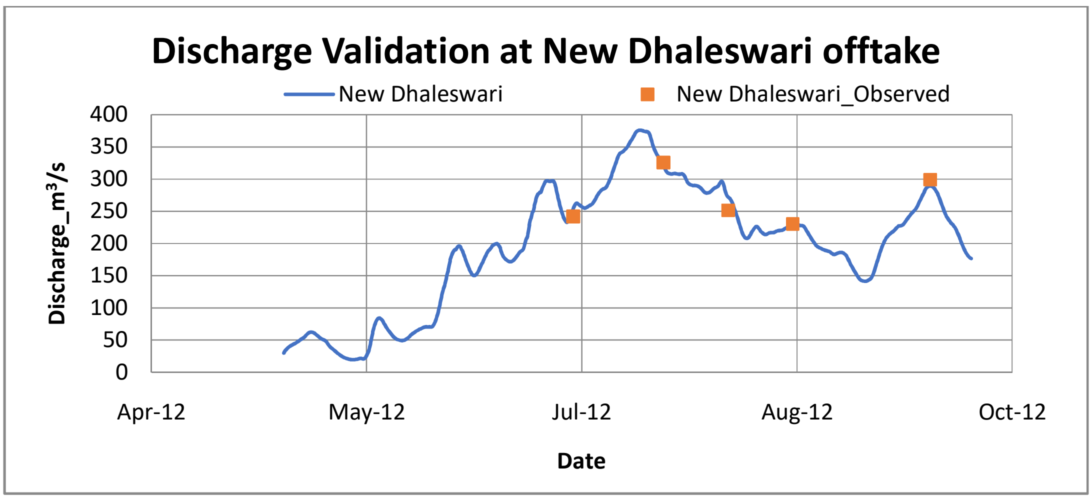

Figure 7.15: Discharge Validation at New Dhaleswari offtake (Beltia Ghat)

7.2.5.2 Morphological Validation

The model has been morphologically validated against the year of 2012. The sediment transport for 2012 is also compared with the observed sediment data of 2012 at DS of Bridge and offtake (Beltia ghat) locations and shown in Figure 7.16 to Figure 7.17. The simulated value is present within the range of observed sediment transport value.

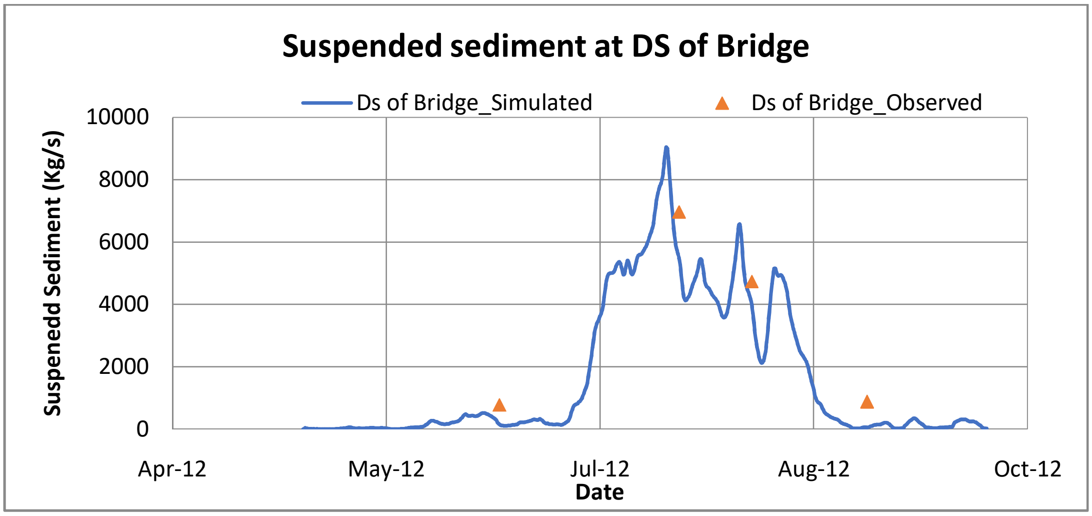

Figure 7.16: Sediment transport Validation at DS of Bridge in Jamuna River

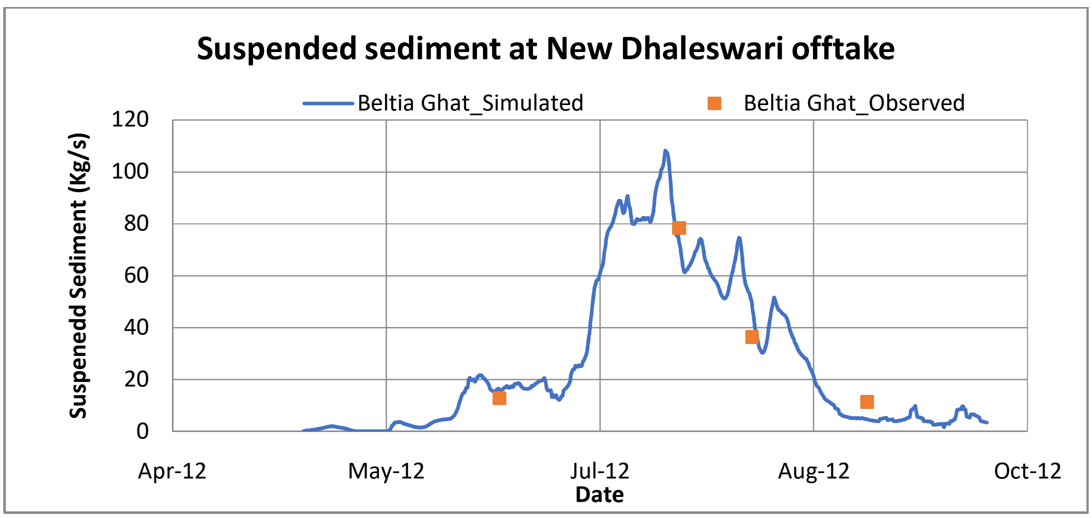

Figure 7.17: Sediment transport Validation at New Dhaleswari offtake (Beltia ghat)

7.2.6 Model Stability

Initially, the model has made stable by simulating hydro-dynamic condition only for a while. The simulation period was about 27 days. After some time the model become stable as shown in Figure 7.18. All data have been extracted after the model become stable. Morphological simulation also carried out after the stability has been reached.

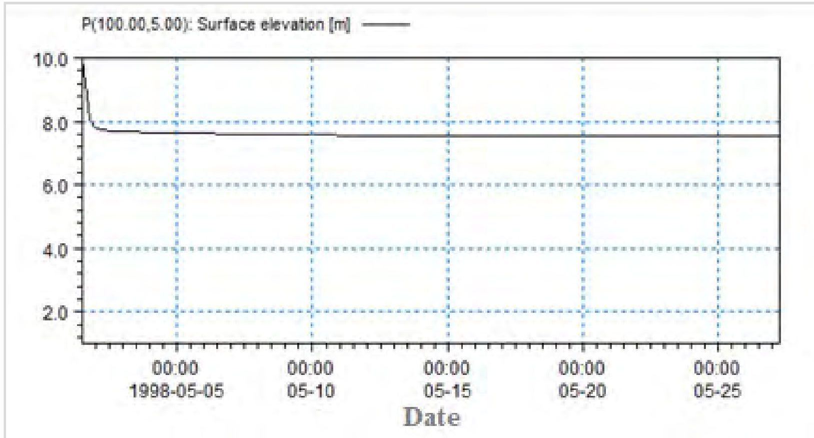

Figure 7.18: Model stability check for the study area

7.2.7 Model Sensitivity Analysis

It may happen that a sensitivity analysis of a model-based study is meant to underpin an inference, and to certify its robustness, in a context where the inference feeds into a policy or decision making process. Sensitivity analysis is the process of determining the rate of change in model output with respect to changes in model inputs (parameters). For Sensitivity analysis of model are considering finer grid (used in analysis) and course grid (50000). Discharge compares both grid are shown in Figure 7.19 to Figure 7.22. Maximum percentage of discharge comparison is 16% (Base), 18% (Option-6), 20% (Option-8) and 20% (Option-9).

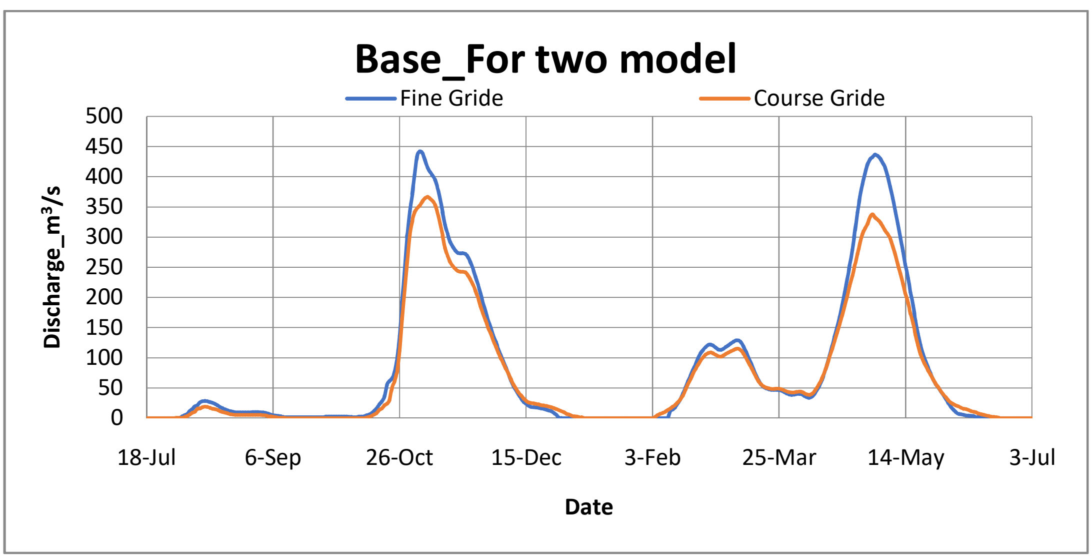

Figure 7.19: comparison of two models for sensitivity check at base condition

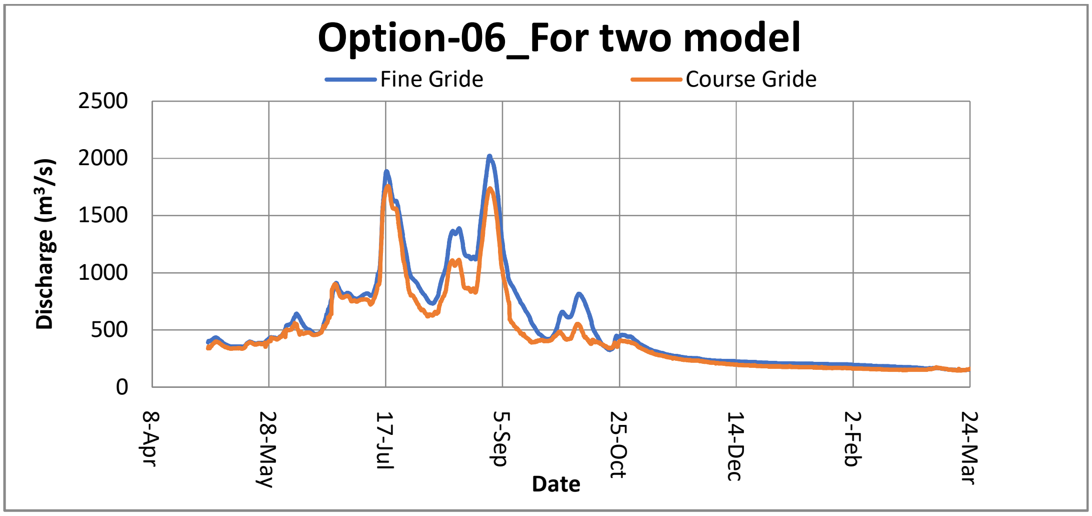

Figure 7.20: comparison of two model for sensitivity check at Option-6 condition

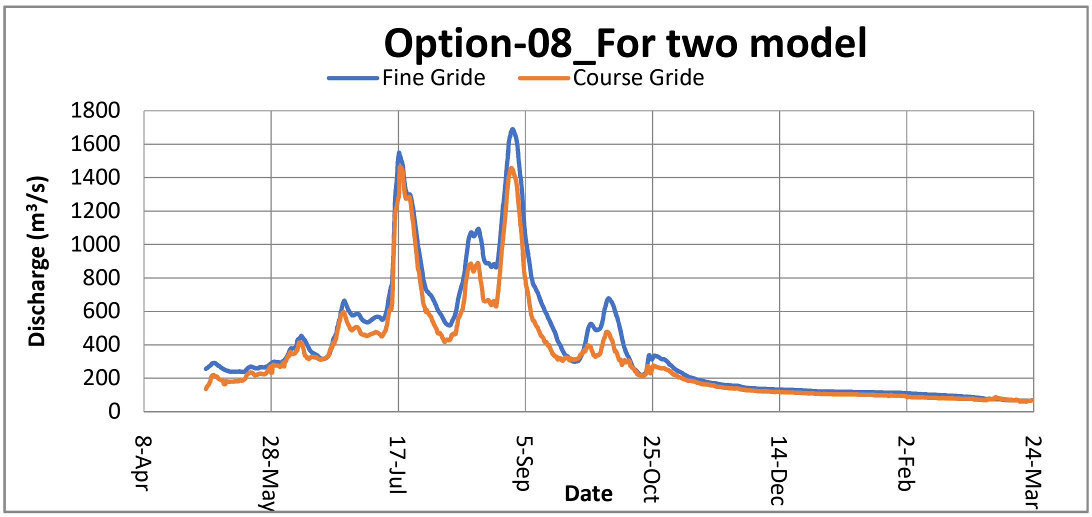

Figure 7.21: comparison of two model for sensitivity check at Option-8 condition

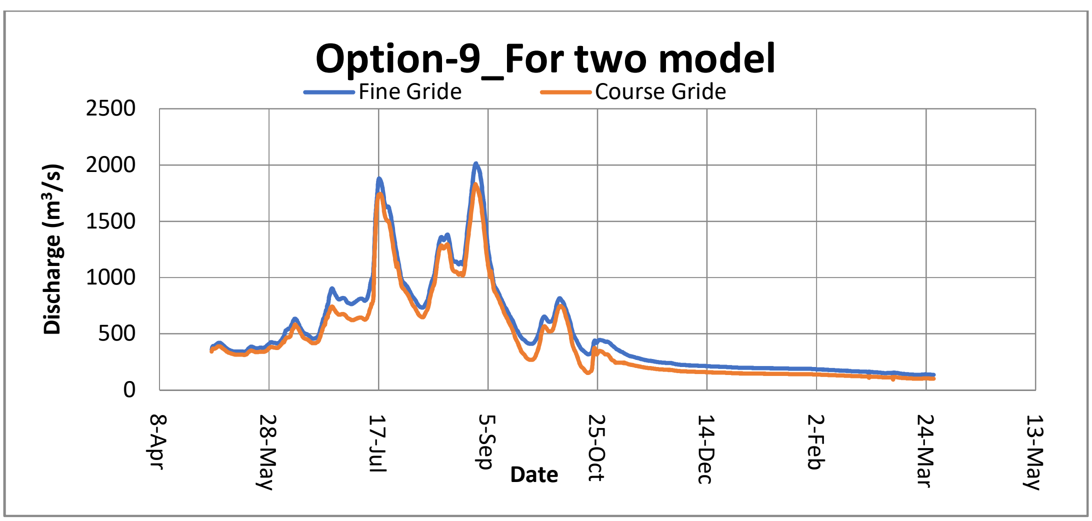

Figure 7.22: comparison of two model for sensitivity check at Option-9 condition

7.3 Model Simulation for Various Options

As well as with the base condition simulations have been done for various options. Nine different options and four different scenarios have been employed in this study to suggest the better offtake management for New Dhaleswari river. The details of options and scenarios have been described below:

Option-1 (Placing of guide bunds at the offtake of New Dhaleswari River)

In Option 1, two guide bunds are placed left and right bank at the offtake in the existing cross section data of river. This option has been selected to observe the response of river due to placing a river training structure at the offtake. Figure 7.23 is shown in The Option 1 condition.

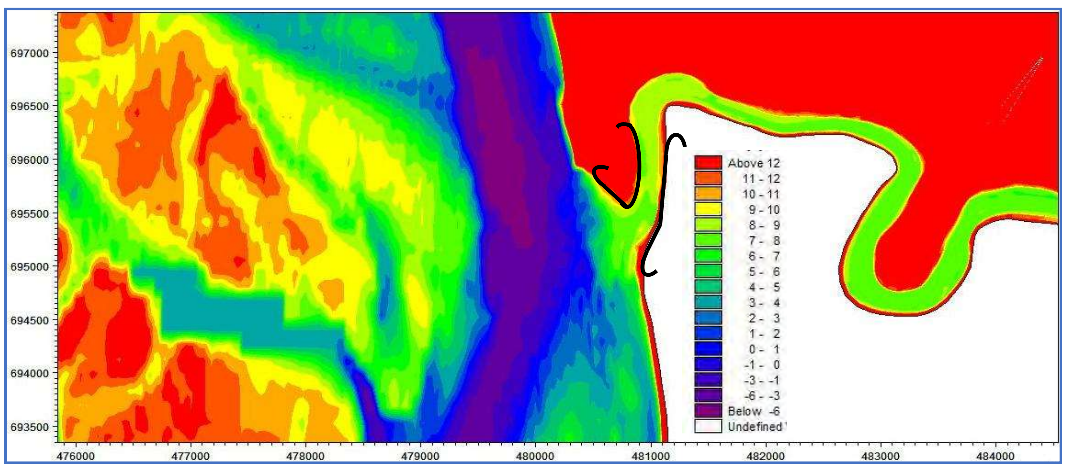

Figure 7.23: Initial Condition for option-1 with placing two guide bund of New Dhaleswari river offtake

Option-2 (30m Dredging at New Dhaleswari river)

In Option-2, 30m bed width dredging has been done in the vicinity of offtake to the 30 km downstream of New Dhaleswari river. Figure 7.24 is shown in The Option-2condition.

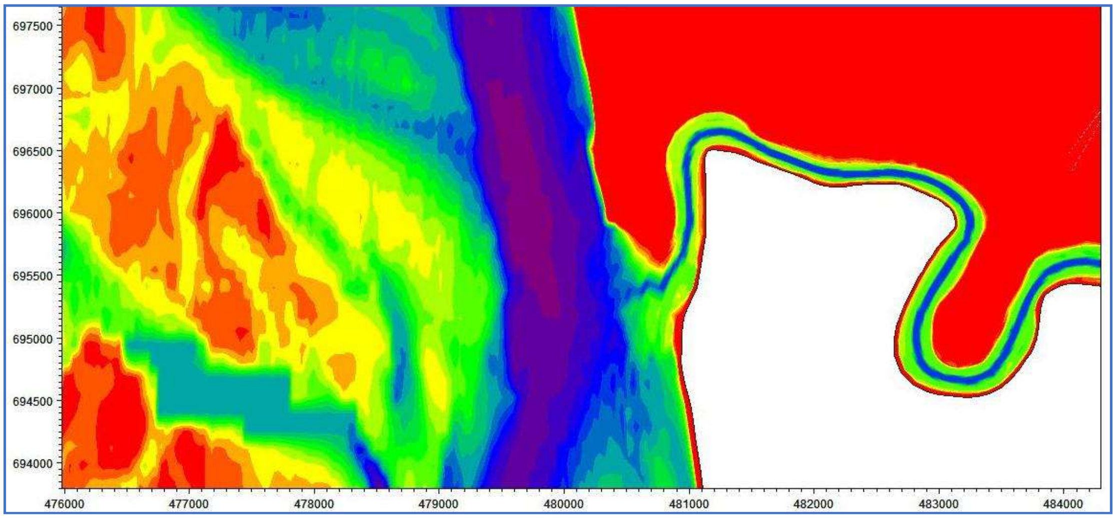

Figure 7.24: Initial Condition for option-2 with 30m bed width dredging of New Dhaleswari river

Option-2- Scenario-1 [30m Dredging and silt trap (Offtake) at New Dhaleswari river]

In Option-2- Scenario-1, 30m bed width dredging has been done in the vicinity of offtake to the 30km downstream of New Dhaleswari River and also places a silt trap of the offtake. Two guide bunds are placing at left bank and right bank at New Dhaleswari River. Figure 7.25 is shown in The Option 2- Scenario-1 condition.

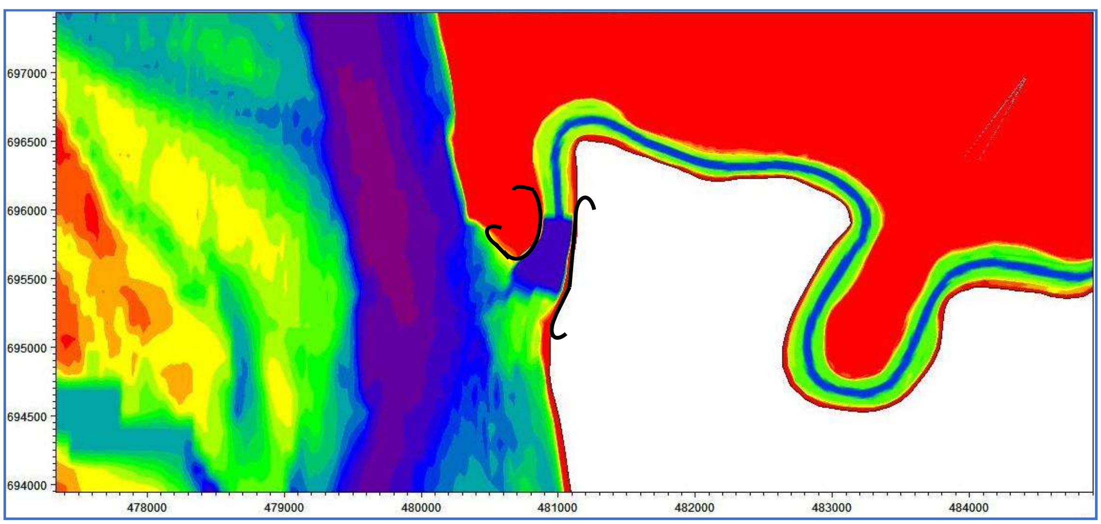

Figure 7.25: Initial Condition for option 2**-** Scenario-1 with placing two guide bund and a silt trap of New Dhaleswari river offtake

Option-2- Scenario-2 [30m Dredging and silt trap (1.0 Km) at New Dhaleswari river]

In Option 2- Scenario 2, 30m bed width dredging has been done in the vicinity of offtake to the 30km downstream of New Dhaleswari River and also places a silt trap of the 1.0 Km. Two guide bunds are placing at left bank and right bank at New Dhaleswari River. Figure 7.26 is shown in The Option 2- Scenario-2 condition.

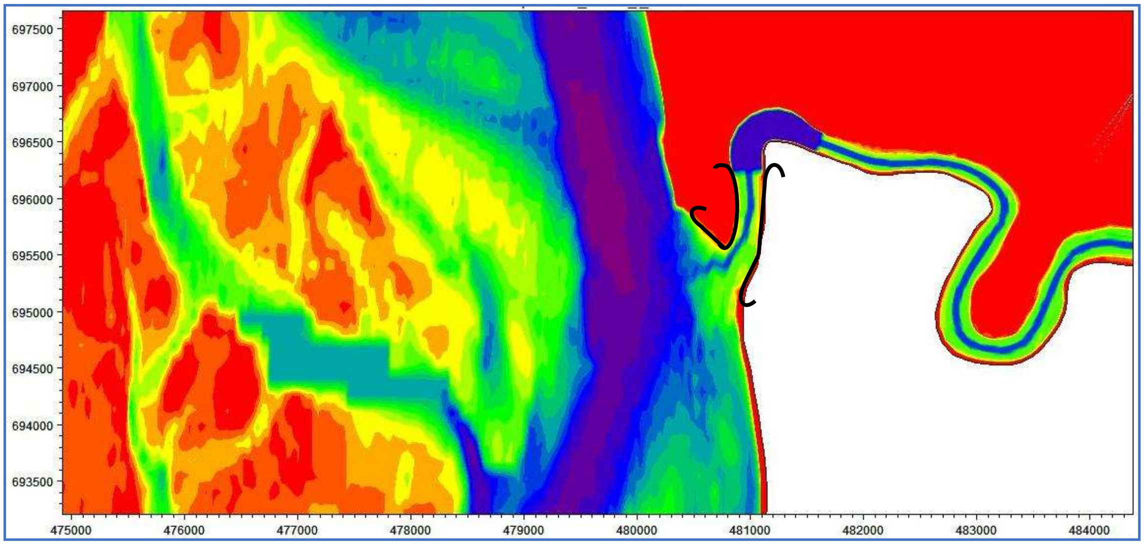

Figure 7.26: Initial Condition for option 2**-** Scenario-2 with placing two guide bund and a silt trap (1 Km) of New Dhaleswari river offtake

Option-3 (50m Dredging at New Dhaleswari river)

In Option-3, 50m bed width dredging has been done in the vicinity of offtake to the 30 km downstream of New Dhaleswari river. Figure 7.27 is shown in The Option-3 condition.

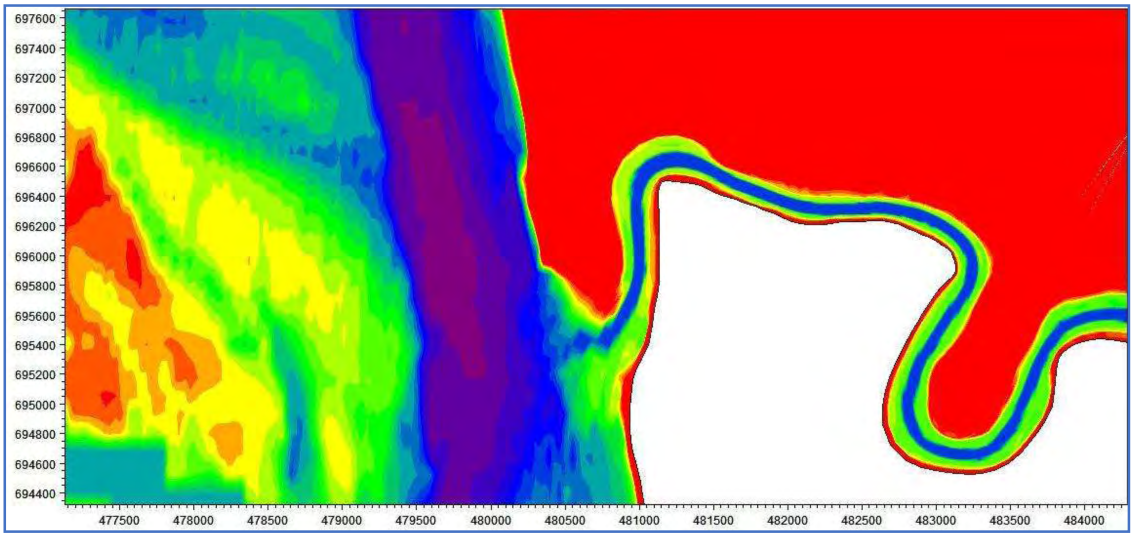

Figure 7.27: Initial Condition for option-3 with 50m bed width dredging of New Dhaleswari river

Option-3- Scenario-1 [50m Dredging and silt trap (Offtake) at New Dhaleswari river]

In Option-3- Scenario-1, 50m bed width dredging has been done in the vicinity of offtake to the 30km downstream of New Dhaleswari river and also places a silt trap of the offtake. Two guide bunds are placing at left bank and right bank at New Dhaleswari river. Figure 7.28 is shown in The Option-3- Scenario-1 condition.

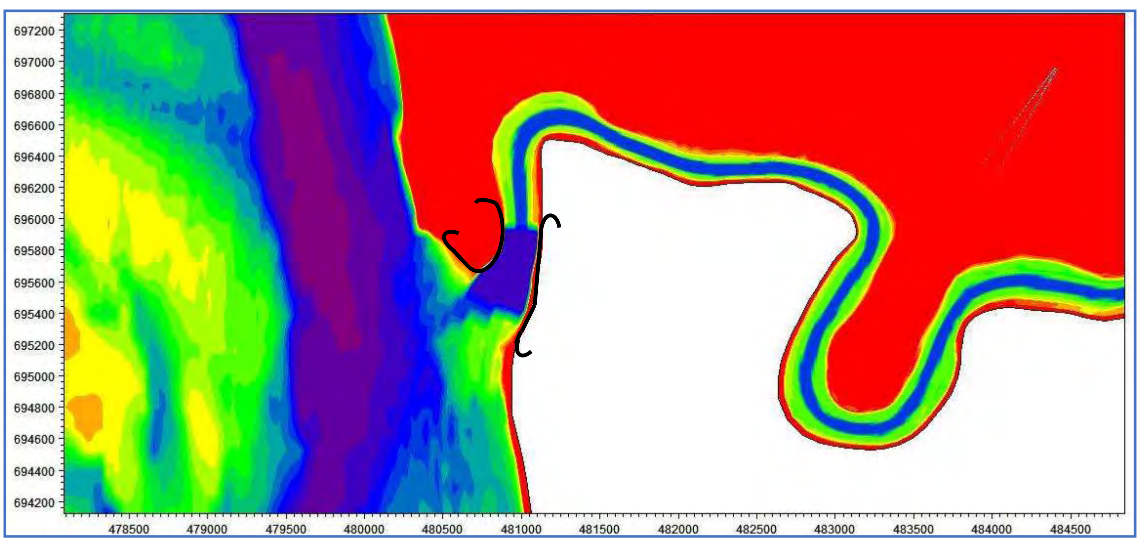

Figure 7.28: Initial Condition for option 3**-** Scenario-1 with placing two guide bund and a silt trap of New Dhaleswari river offtake

Option-3- Scenario-2 [50m Dredging and silt trap (1.0 Km) at New Dhaleswari river]

In Option-3- Scenario-2, 50m bed width dredging has been done in the vicinity of offtake to the 30km downstream of New Dhaleswari river and also places a silt trap of the 1 Km. Two guide bunds are placing at left bank and right bank at New Dhaleswari river. Figure 7.29 is shown in The Option-3- Scenario 2 condition.

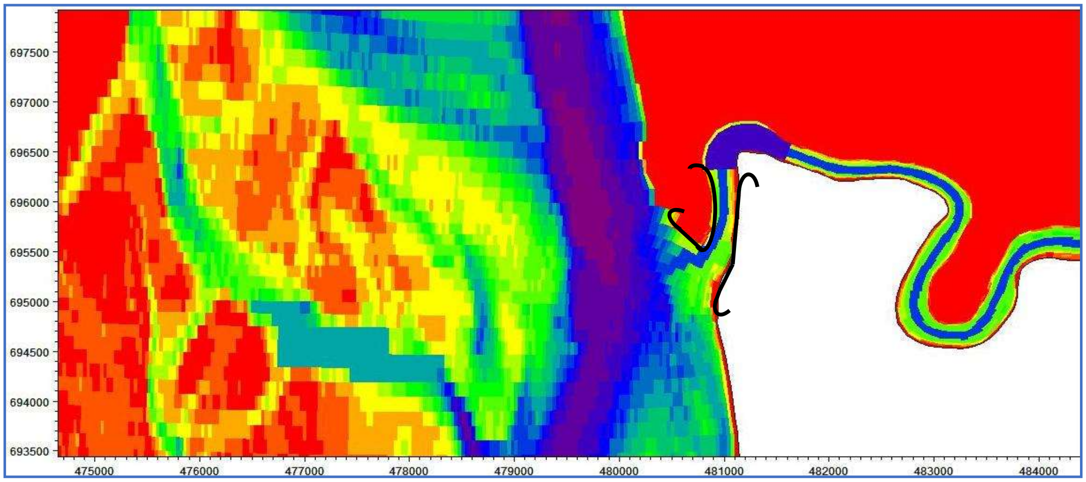

Figure 7.29: Initial Condition for option-3**-** Scenario-2 with placing two guide bund and a silt trap (1 Km) of New Dhaleswari River offtake

Option-4 (Placing a silt trap at Jamuna and two guide bunds at New Dhaleswari river)

In Option-4, a silt trap has been place at Jamuna river near offtake at New Dhaleswari River. Two guide bunds are placing at left bank and right bank at New Dhaleswari river. Figure 7.30 is shown in The Option-4 condition.

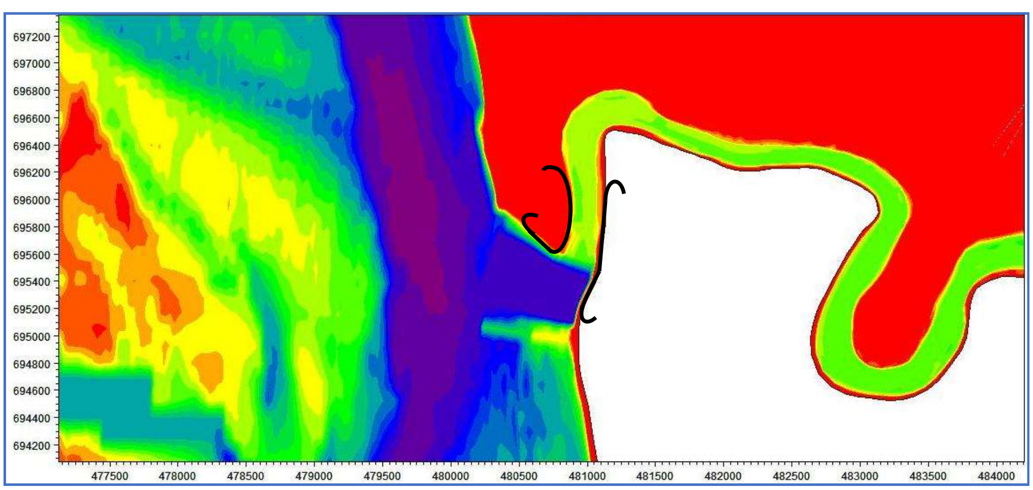

Figure 7.30: Initial Condition for option 4 with placing two guide bund of New Dhaleswari river offtake, groyne and a silt trap of Jamuna river

Option 5 (Placing a silt trap at Jamuna, two guide bunds and 30m dredging at New Dhaleswari river)

In Option 5, a silt trap has been place at Jamuna river near offtake at New Dhaleswari river. Two guide bunds are placing at left bank and right bank at New Dhaleswari river offtake. 30m bed width dredging has been done in the vicinity of offtake to the 30km downstream of New Dhaleswari river. Figure 7.31 is shown in The Option 5 condition.

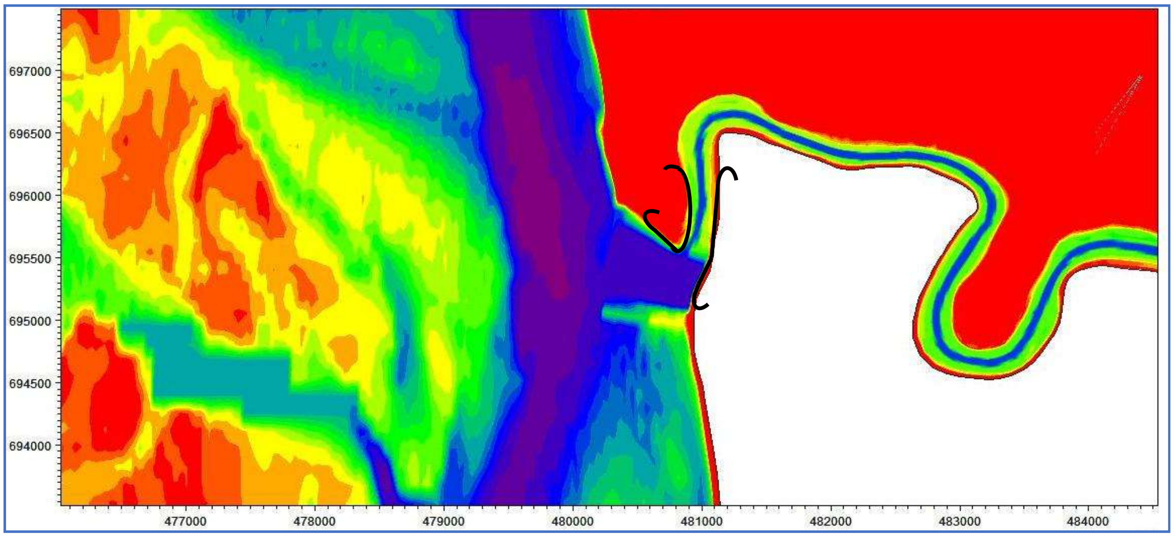

Figure 7.31: Initial Condition for option 5 with placing two guide bund of New Dhaleswari River offtake, 30m bed width dredging of New Dhaleswari River, groyne and a silt trap of Jamuna River

Option 6 (Placing a silt trap at Jamuna, two guide bunds and 50m dredging at New Dhaleswari river)

In Option 6, a silt trap has been place at Jamuna River near offtake at New Dhaleswari River. Two guide bunds are placing at left bank and right bank at New Dhaleswari River offtake. 50m bed width dredging has been done in the vicinity of offtake to the 50km downstream of New Dhaleswari River. Figure 7.32 is shown in The Option 6 condition.

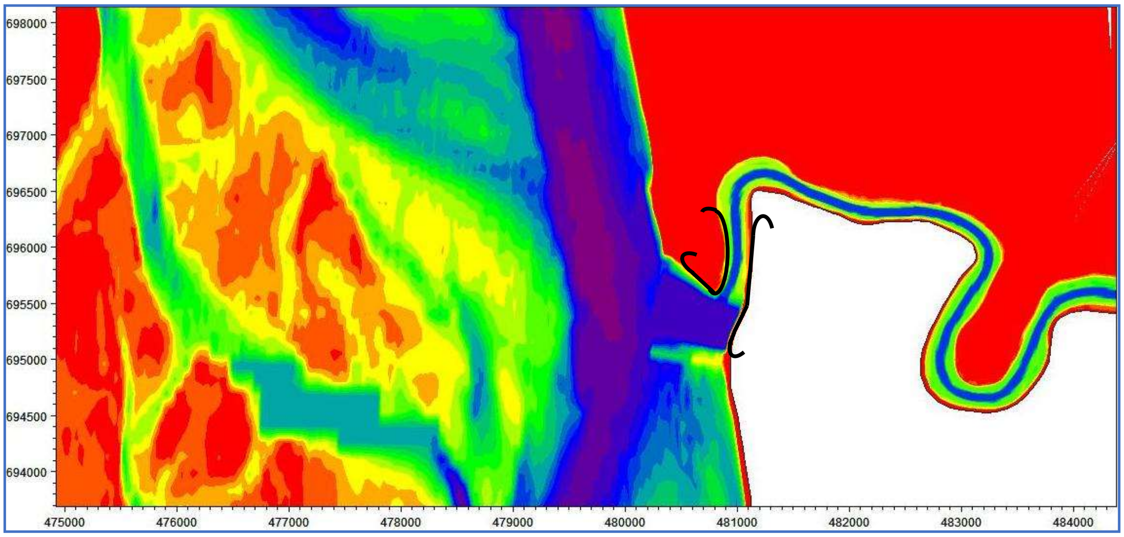

Figure 7.32: Initial Condition for option-6 with placing two guide bund of New Dhaleswari river offtake, 50m bed width dredging of New Dhaleswari river, groyne and a silt trap of Jamuna river

Option-7 (Placing a silt trap at Jamuna and two guide bunds and weir at New Dhaleswari river)

In Option-7, a silt trap has been place at Jamuna River near offtake at New Dhaleswari River. Two guide bunds are placing at left bank and right bank at New Dhaleswari River. A weir like structure are placing at 400m downstream of New Dhaleswari river offtake. Figure 7.33 is shown in The Option-7 condition.

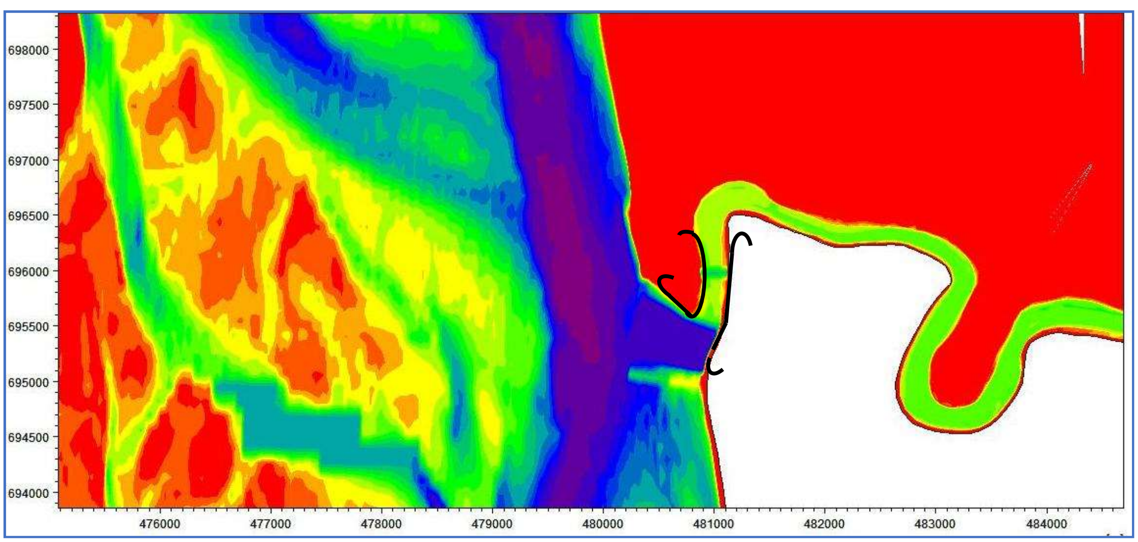

Figure 7.33: Initial Condition for option 7 with placing two guide bund of New Dhaleswari river offtake, a weir placing near offtake of New Dhaleswari River, groyne and a silt trap of Jamuna river

Option-8 (Placing a silt trap at Jamuna, two guide bunds and 30m dredging at New Dhaleswari river)

In Option-8, a silt trap has been place at Jamuna river near offtake at New Dhaleswari river. Two guide bunds are placing at left bank and right bank at New Dhaleswari river offtake. A weir like structure are placing at 400m downstream of New Dhaleswari river offtake. 30m bed width dredging has been done in the vicinity of offtake to the 30km downstream of New Dhaleswari river. Figure 7.34 is shown in The Option-8 condition.

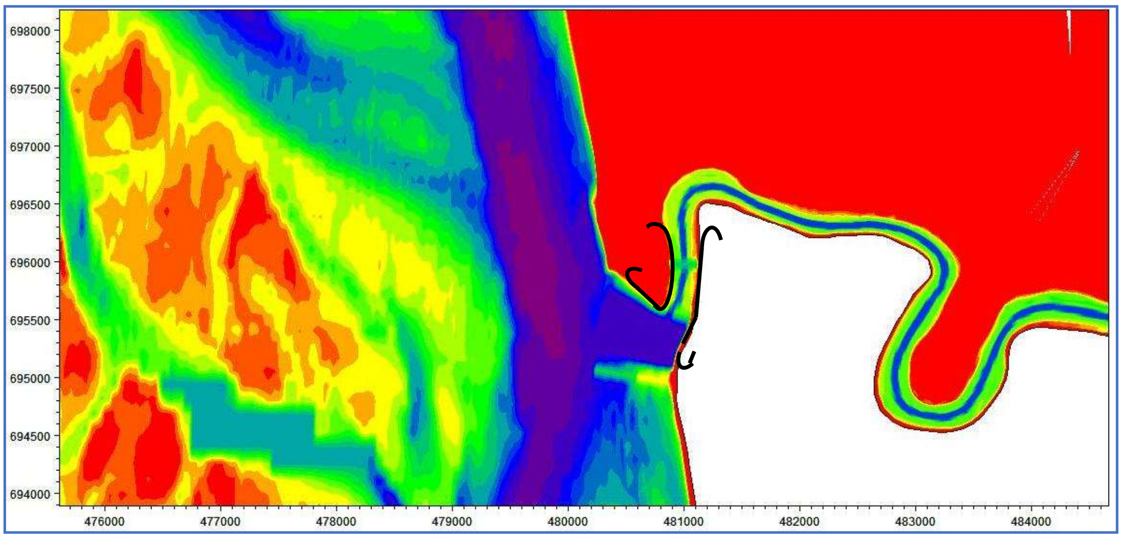

Figure 7.34: Initial Condition for option-8 with placing two guide bund of New Dhaleswari River offtake, a weir placing near offtake and 30m dredging bed of New Dhaleswari River, groyne and a silt trap of Jamuna river.

Option-9 (Placing a silt trap at Jamuna, two guide bunds and 50m dredging at New Dhaleswari river)

In Option-9, a silt trap has been place at Jamuna river near offtake at New Dhaleswari river. Two guide bunds are placing at left bank and right bank at New Dhaleswari River offtake. A weir like structure are placing at 400m downstream of New Dhaleswari river offtake. 50m bed width dredging has been done in the vicinity of offtake to the 50km downstream of New Dhaleswari river. Figure 7.35 is shown in The Option-9 condition.

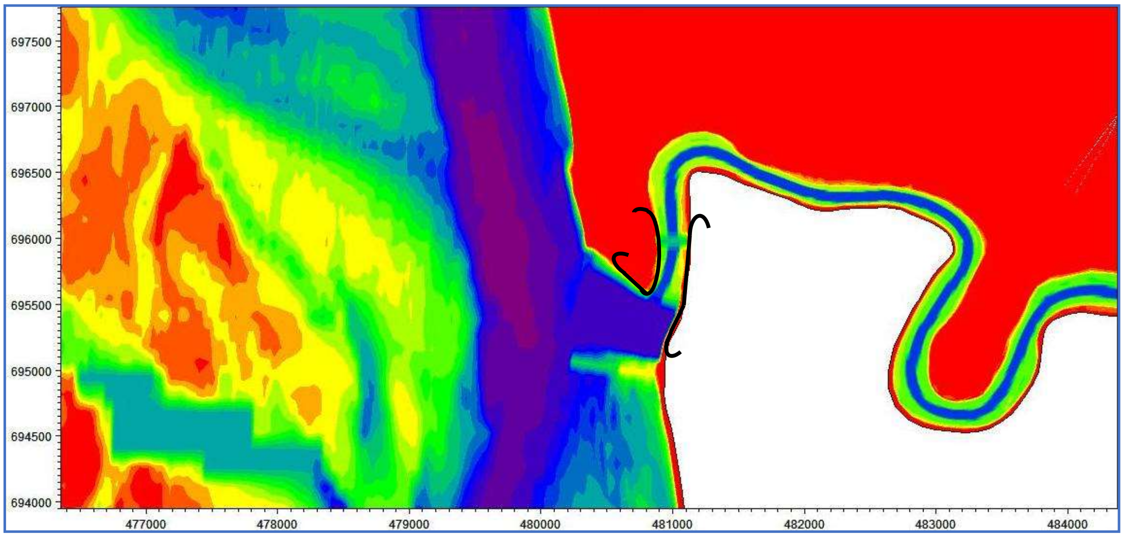

Figure 7.35: Initial Condition for option 9 with placing two guide bund of New Dhaleswari River offtake, a weir placing near offtake and 50m dredging bed of New Dhaleswari River, groyne and a silt trap of Jamuna River

CHAPTER 8

RESULTS AND DISCUSSIONS

8.1 General

In this thesis work various models have been simulated including the base condition and followed by various options. These options have been selected analyzing the offtake feature of New Dhaleswari. To identify the benefits from these different options, various outputs have been analyzed. The bed level changes near the mouth of offtake for different options have been judged through planform basis and cross sectional analysis. The cumulative erosion and deposition at the end of monsoon in the selected reach of New Dhaleswari has been also analyzed. The discharge and percentage of flow through the New Dhaleswari river has been plotted for different options varying the flood events. Finally, a suggestion has been given for better offtake management through these comparative analyses.

8.2 Results and Discussions

Different types of analyses have been done to understand the outcomes of different option simulation. The results are discussed below in terms of bed level changes, cross section analysis, volume of siltation and erosion, discharge and percentage of flow diversion in the New Dhaleswari river.

8.2.1 Analysis of Bed level changes

The model simulated planform near the offtake of New Dhaleswari for different options varying the flood events have been shown in Figure 8.1 to Figure 8.14. For the base condition that means in the existing condition, a huge siltation has occurred at the mouth of offtake for high flood, medium and low flood event. However, it is seen that in case of high flood event, offtake bed level is higher than other flood events. End of the simulation average bed levels of offtake various from 9.66 mPWD to 9.24 mPWD from all flood events. Figure 8.1 shown in base condition.

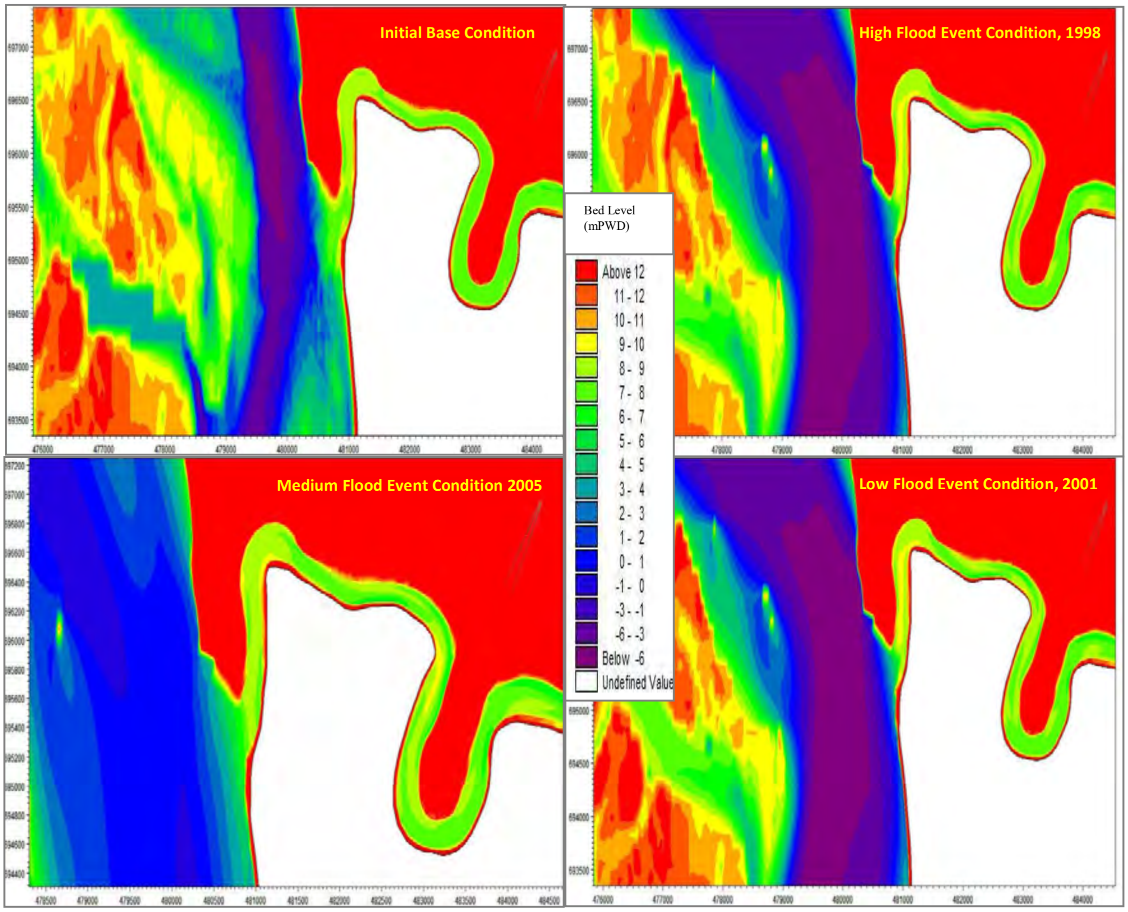

Figure 8.1: Initial and simulated data for different flood events at the end of simulation (Base Condition)

For option-1, siltation occurred at two guide bund places in both bank of New Dhaleswari at the end of monsoon for high, medium and low flood events. Huge siltation has occurred at the mouth of offtake for high flood, medium and low flood event. End of the simulation average bed levels of offtake various from 9.38 mPWD to 8.63 mPWD from all flood events. Figure 8.2 are shown in option-1 condition.

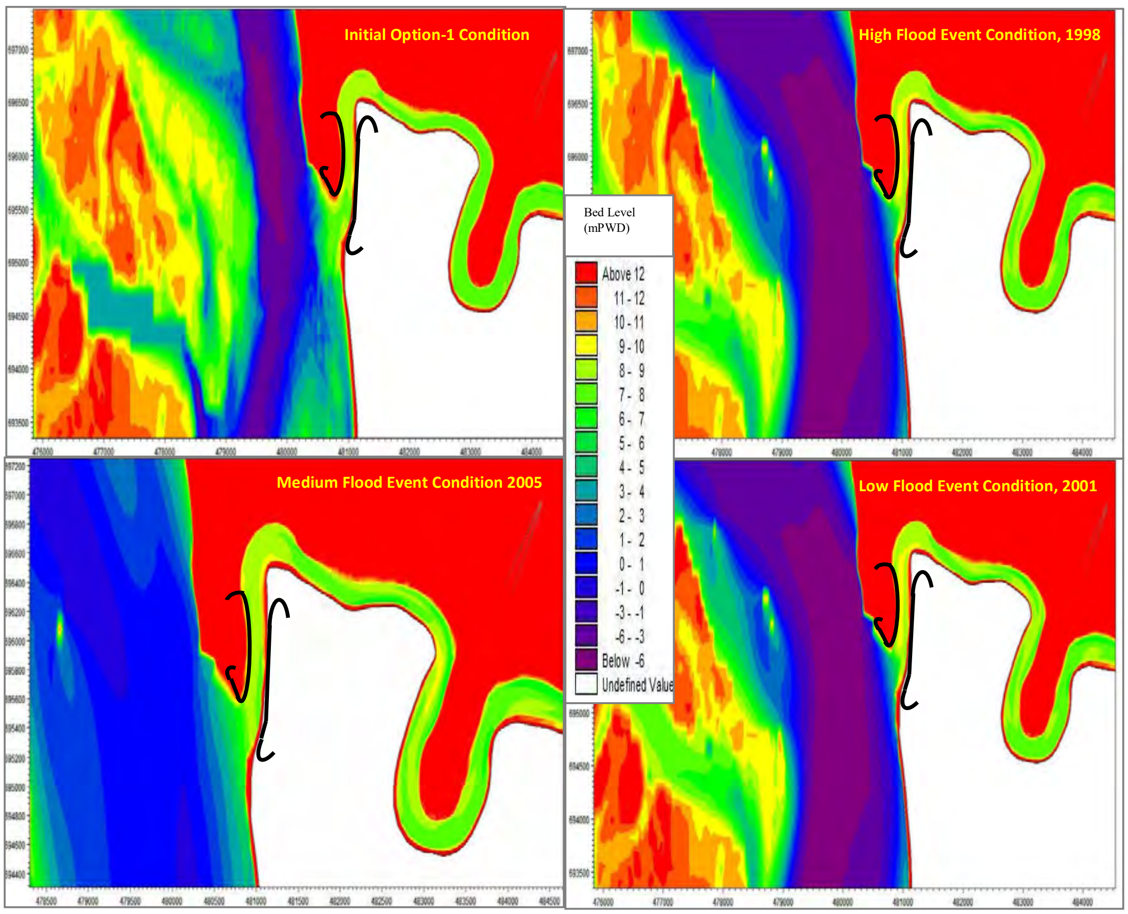

Figure 8.2: Initial and simulated data for different flood events at the end of simulation (Option-1)

For Option-2, siltation occurred at 30m dredge channel with river training at the end of monsoon for high, medium and low flood events. Siltation has occurred at the mouth of offtake for high flood, medium and low flood event. End of the simulation average bed levels of offtake various from 8.85 mPWD to 8.39 mPWD from all flood events. Figure 8.3 are shown in option-2 condition.

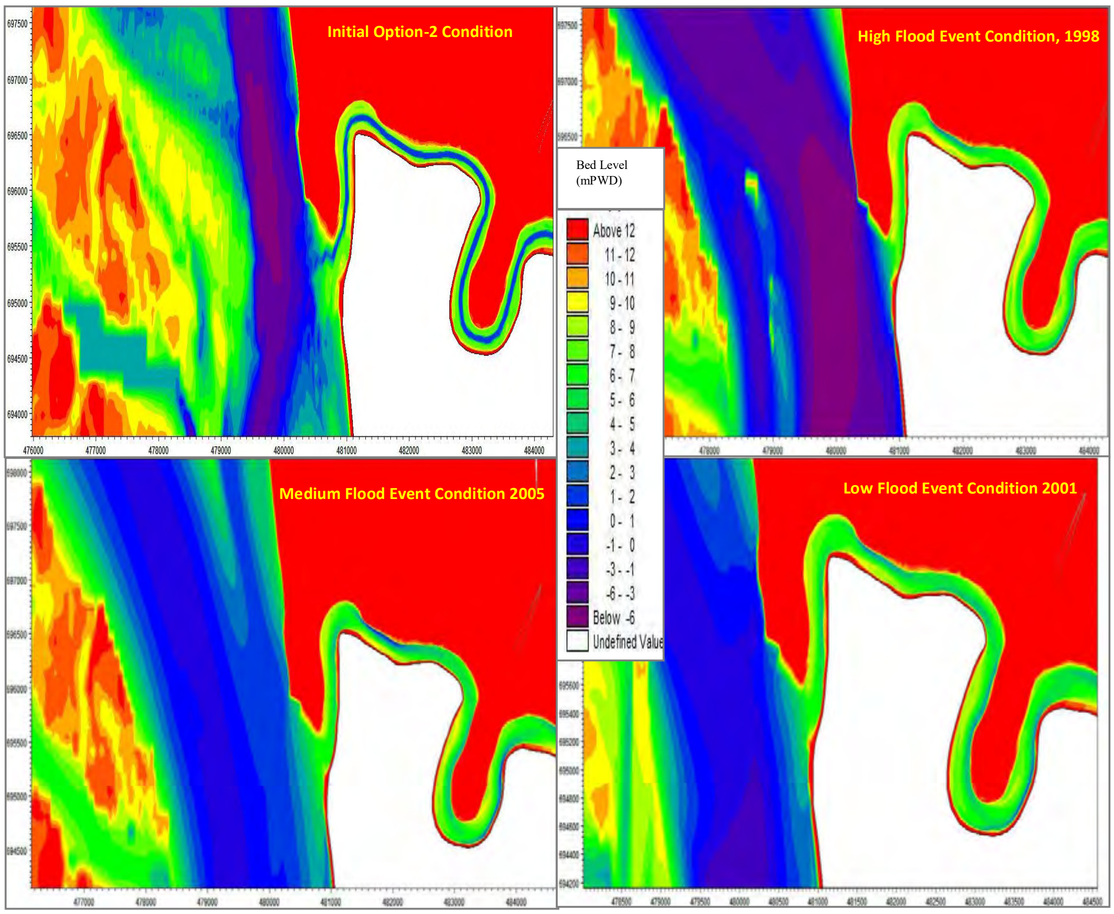

Figure 8.3: Initial and simulated data for the different flood events at the end of simulation (Option-2)

For option-2- scenario-1, siltation occurred at 30m dredge channel with a silt trap at offtake and river training works at the end of monsoon for high, medium and low flood events. End of the simulation average bed levels of offtake various from 8.60 mPWD to 8.22 mPWD from all flood events. Figure 8.4 are shown in option-2- scenario-1 condition.

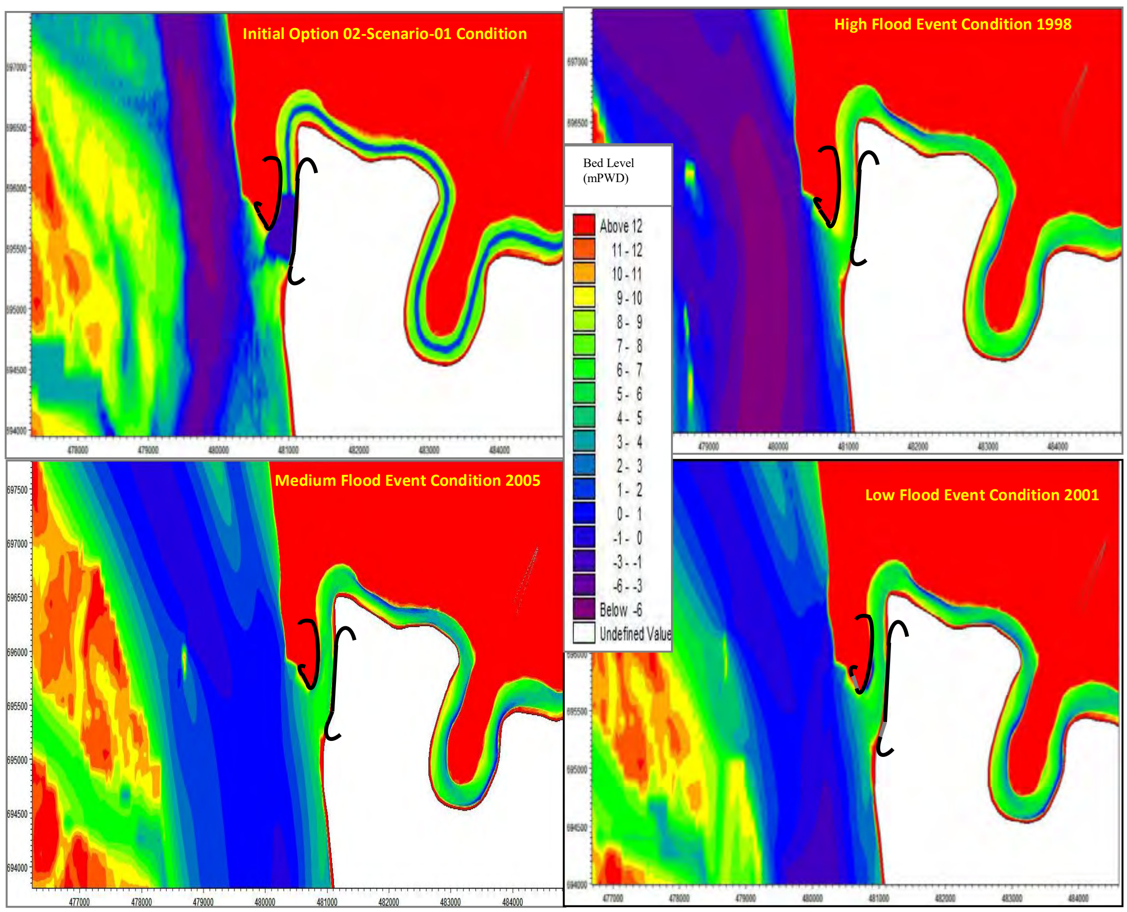

Figure 8.4: Initial and simulated data for the different flood events at the end of simulation (Option-2- Scenario-1)

For option-2- scenario-2, siltation occurred at 30m dredge channel with a silt trap near offtake and river training works at the end of monsoon for high, medium and low flood events. End of the simulation average bed levels of offtake various from 8.72 mPWD to 7.95 mPWD from all flood events. Figure 8.5 are shown in option-2- scenario-2 condition.

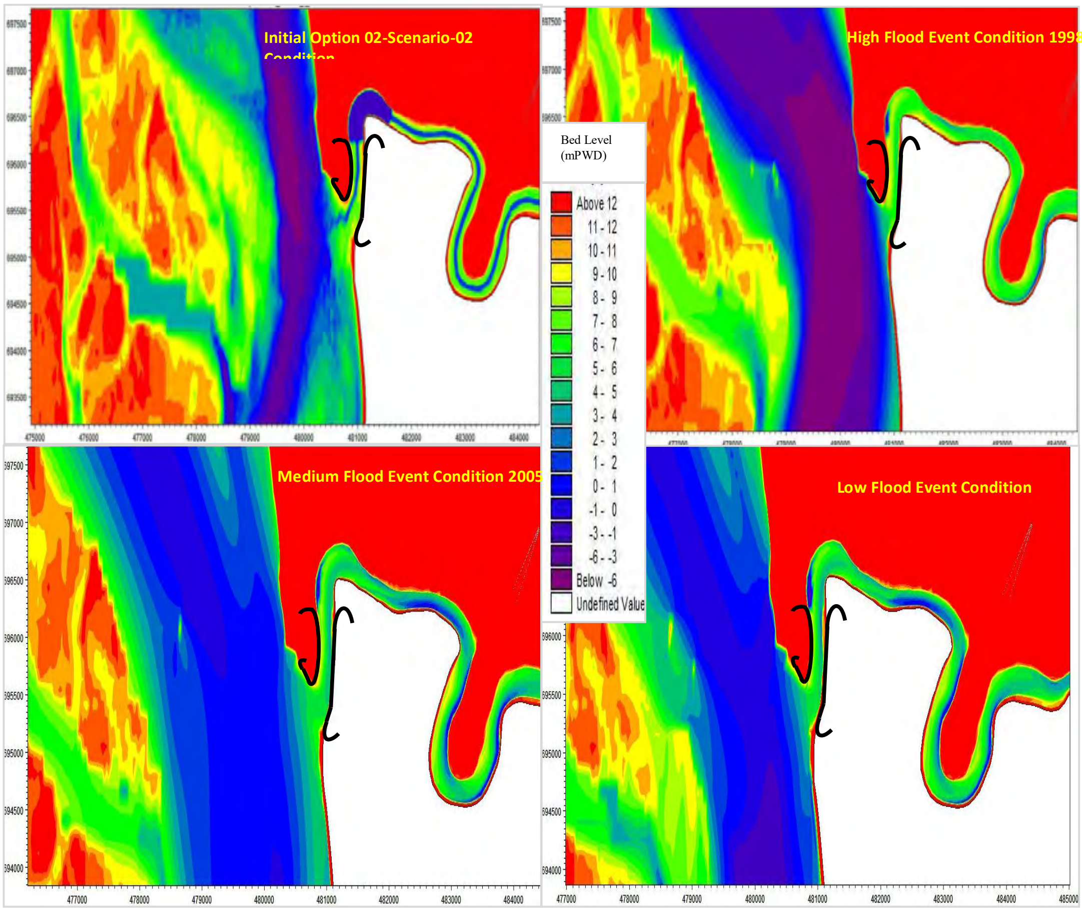

Figure 8.5: Surveyed and simulated data for the different flood events at the end of simulation (Option-2- Scenario-2)

In case of option-3, siltation occurred at 50m dredge channel at the end of monsoon for high, medium and low flood events. End of the simulation average bed levels of offtake various from 8.86 mPWD to 7.97 mPWD from all flood events. Figure 8.6 are shown in option-3 condition.

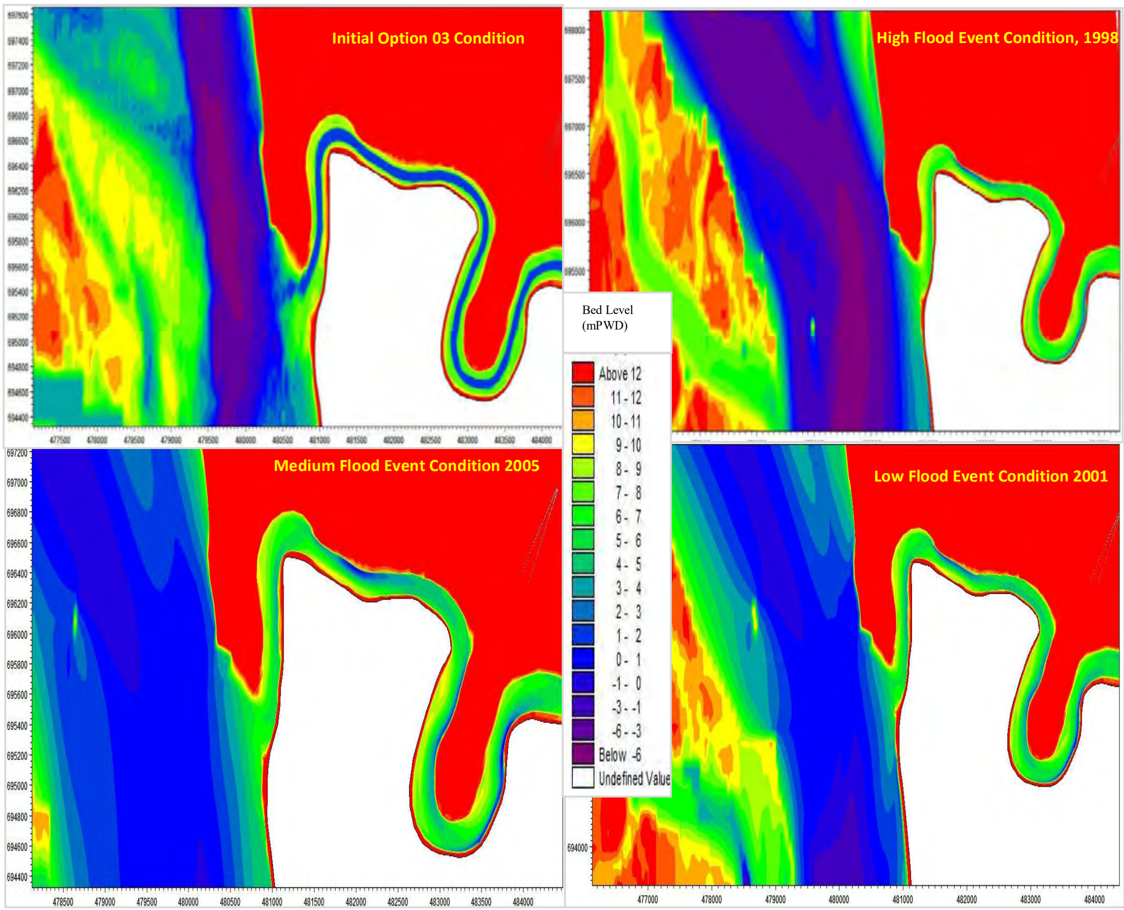

Figure 8.6: Surveyed and simulated data for the different flood events at the end of simulation (Option-3)

In case of option-3- Scenario-1, siltation occurred at 50m dredge channel with a silt trap at offtake and river training works at the end of monsoon for high, medium and low flood events. End of the simulation average bed levels of offtake various from 8.54 mPWD to 7.71 mPWD from all flood events. Figure 8.7 are shown in base condition.

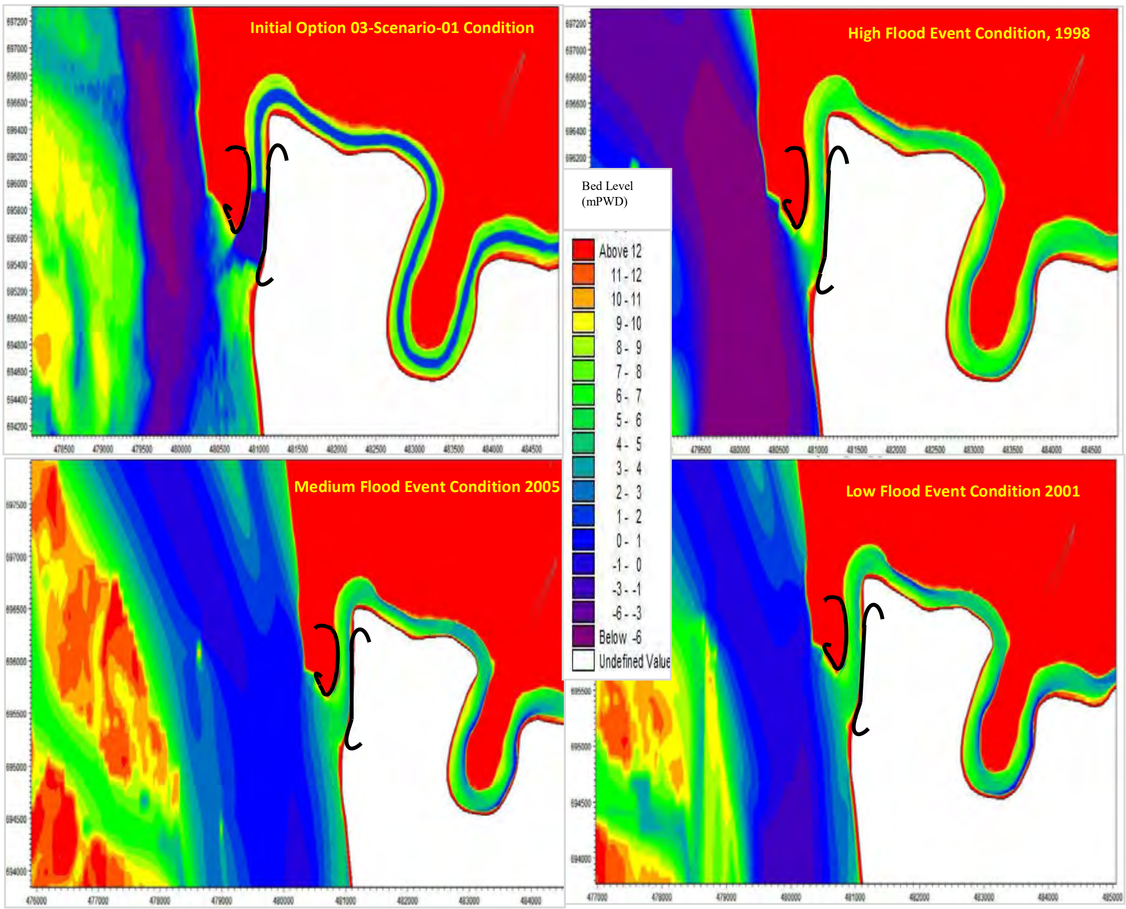

Figure 8.7: Surveyed and simulated data for the different flood events at the end of simulation (Option-3- Scenario-1)

In case of option-3- scenario-2, siltation occurred at 50m dredge channel with a silt trap near offtake and river training works at the end of monsoon for high, medium and low flood events. End of the simulation average bed levels of offtake various from 8.42 mPWD to 7.46 mPWD from all flood events. Figure 8.8 are shown in base condition.

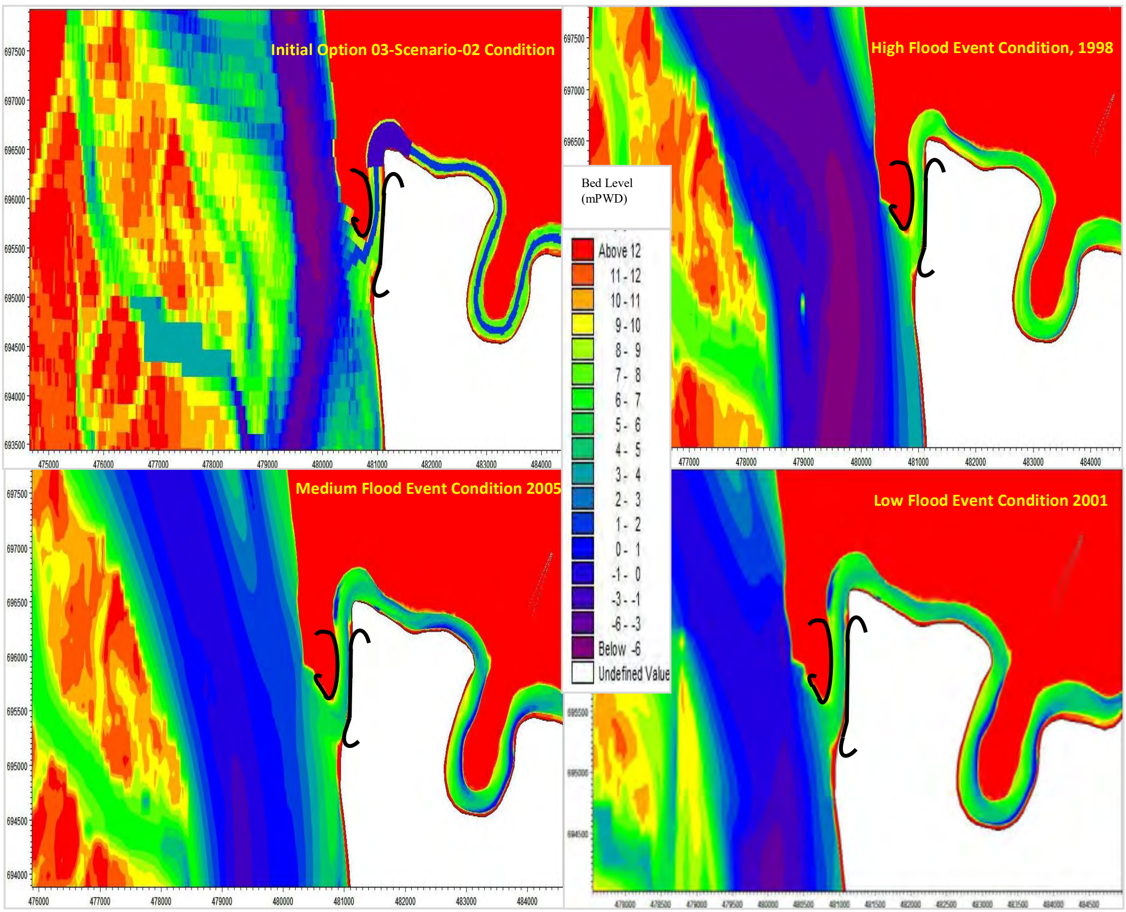

Figure 8.8: Surveyed and simulated data for the different flood events at the end of simulation (Option-3- Scenario-2)

In case of option-4, established a silt trap at offtake and river training works but does not improve the situation of the channel. The offtake is more or less close again at the end of monsoon for all the flood events. End of the simulation average bed levels of offtake various from 9.03 mPWD to 8.59 mPWD from all flood events. Figure 8.9 are shown in option-4 condition.

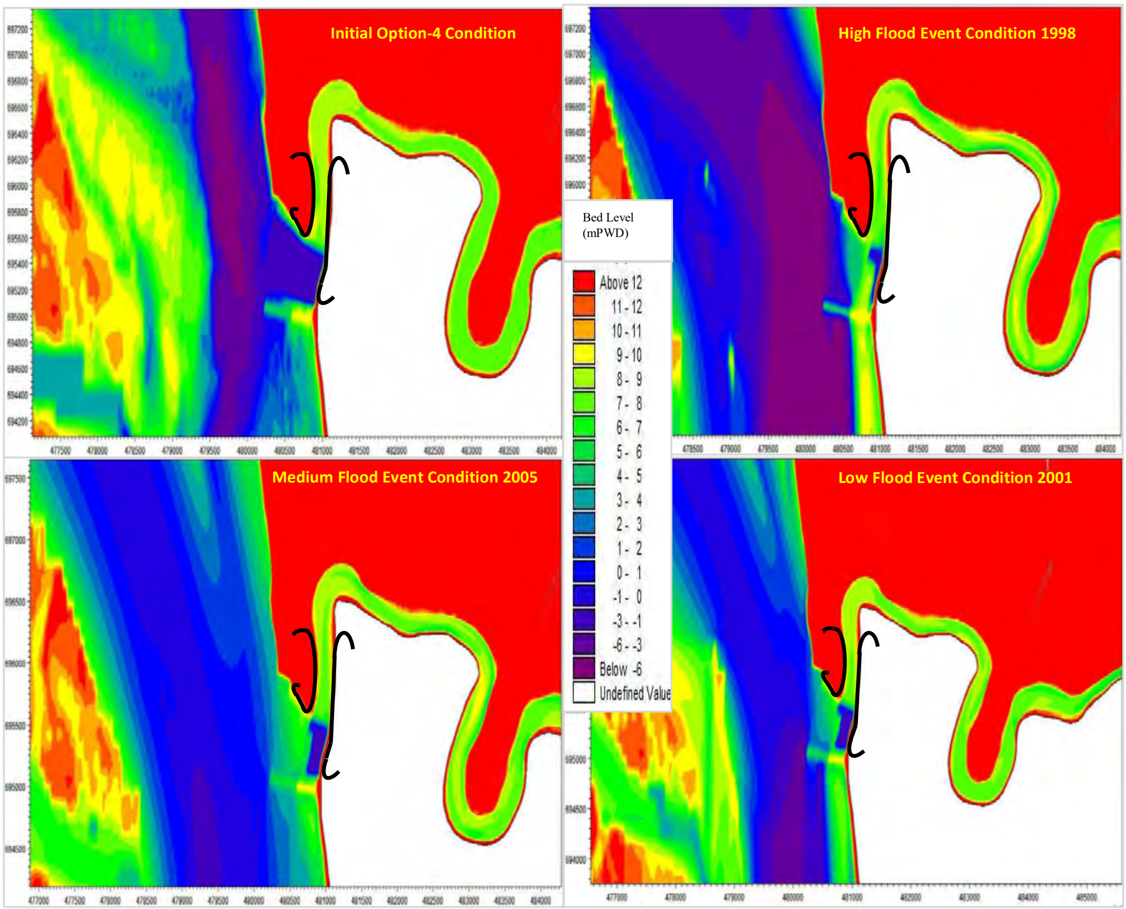

Figure 8.9: Surveyed and simulated data for the different flood events at the end of simulation (Option-4)

In case of option-5, established a silt trap at offtake, river training works and 30m bed width dredging does not improve the situation of the channel. The offtake is more or less close again at the end of monsoon for all the flood events. End of the simulation average bed levels of offtake various from 8.43 mPWD to 7.86 mPWD from all flood events. Figure 8.10 are shown in option-5 condition.

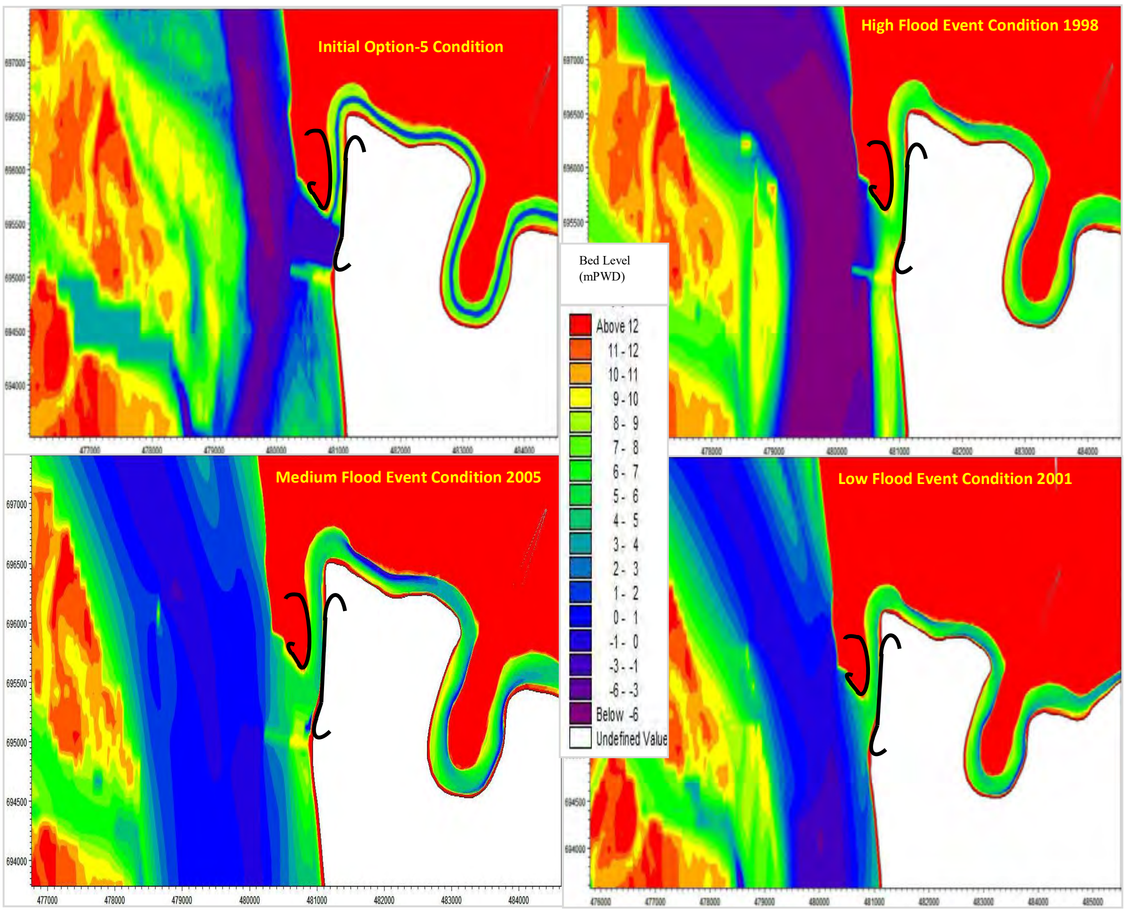

Figure 8.10: Surveyed and simulated data for the different flood events at the end of simulation (option-5)

In case of option-6, established a silt trap, river training works at offtake and 50m bed width dredging but does not improve the situation of the channel. The offtake is more or less close again at the end of monsoon at high flood event but Low and medium flood events improve offtake. End of the simulation average bed levels of offtake various from 8.43 mPWD to 7.36 mPWD from all flood events. Figure 8.11 are shown in option-6 condition.

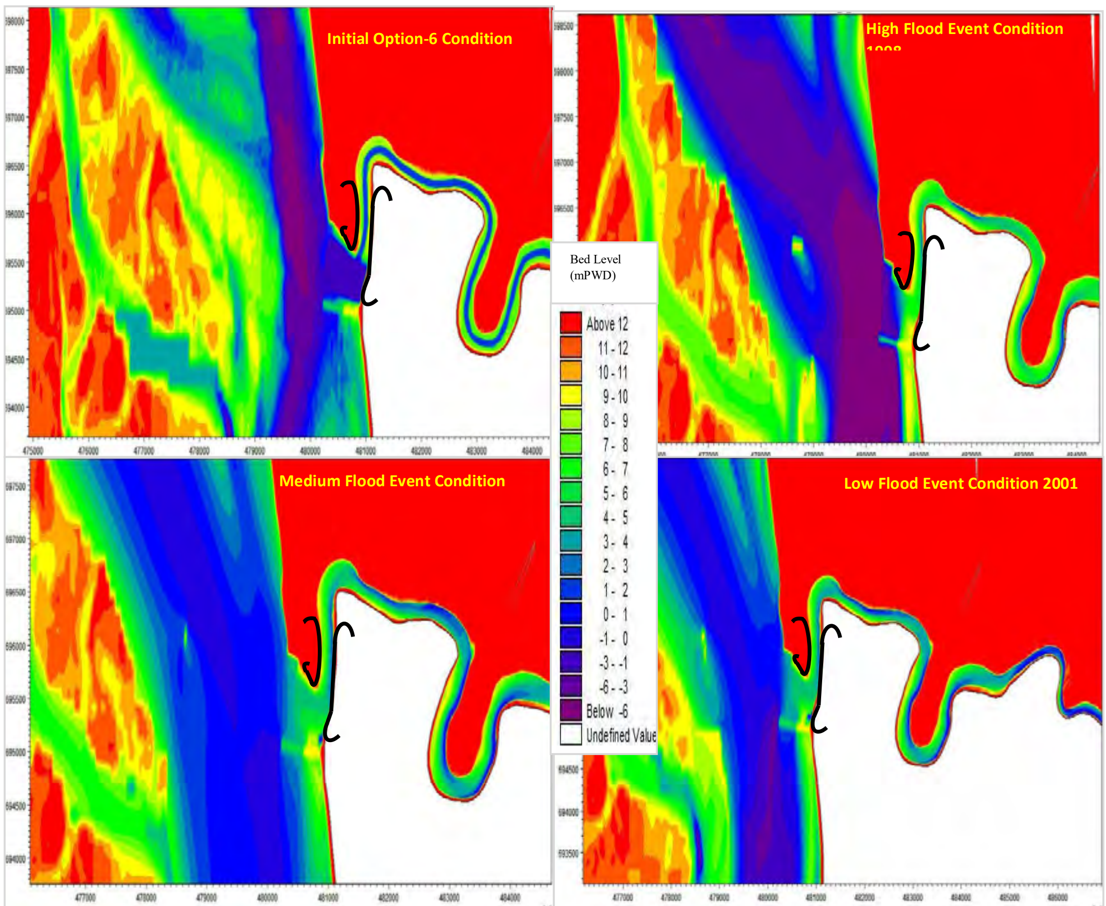

Figure 8.11: Surveyed and simulated data for the different flood events at the end of simulation (option-6)

In case of option 7, established a silt trap, river training works at offtake and a weir near offtake but does not improve the situation of the channel. The offtake is more or less close again at the end of monsoon for all the flood events. End of the simulation average bed levels of offtake various from 9.01 mPWD to 8.48 mPWD from all flood events. Figure 8.12 are shown in option-7 condition.

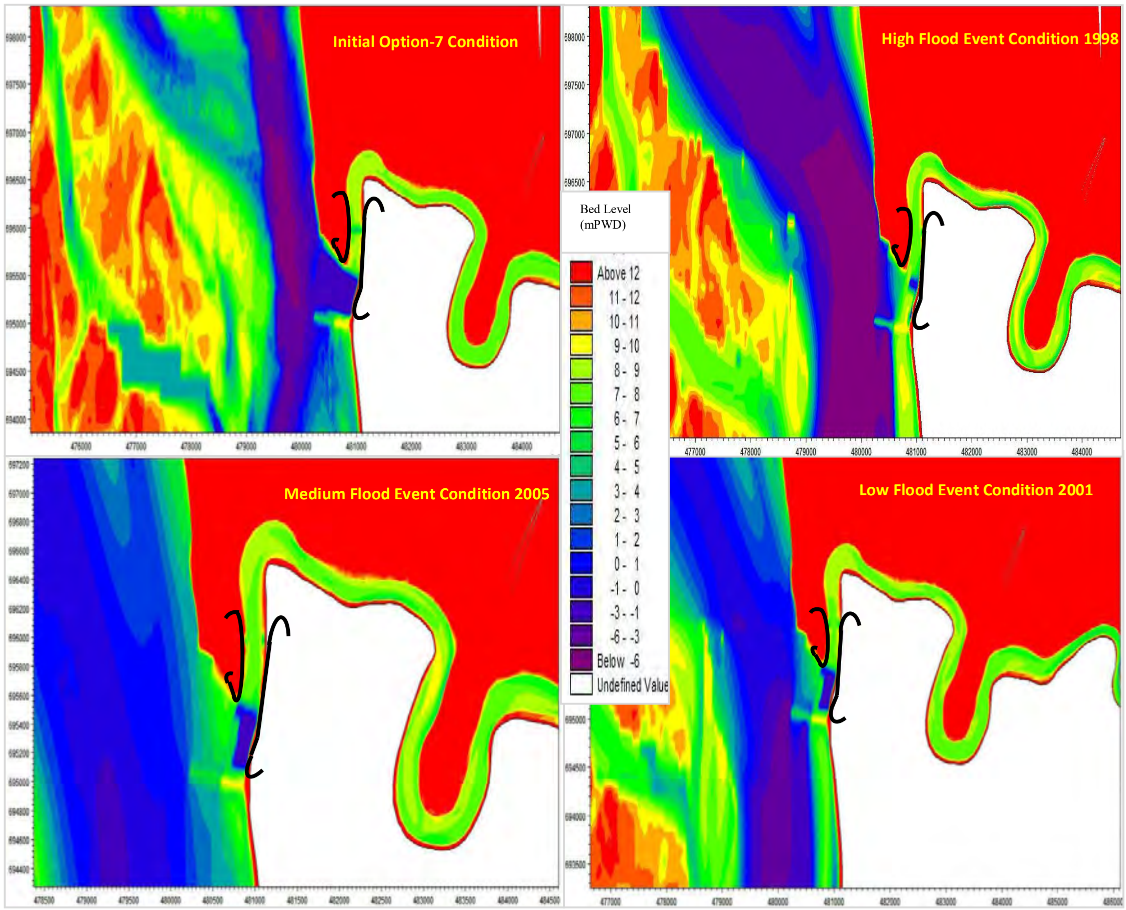

Figure 8.12: Surveyed and simulated data for the different flood events at the end of simulation (option-7)

In case of option-8, established a silt trap, river training works at offtake, a weir near offtake and 30m bed width dredging are shown in option. So this is option improve the situation of the channel. The offtake is more or less improved again at the end of monsoon for all the flood events. End of the simulation average bed levels of offtake various from 5.42 mPWD to 5.16 mPWD from all flood events. Figure 8.13 are shown in option-8 condition.

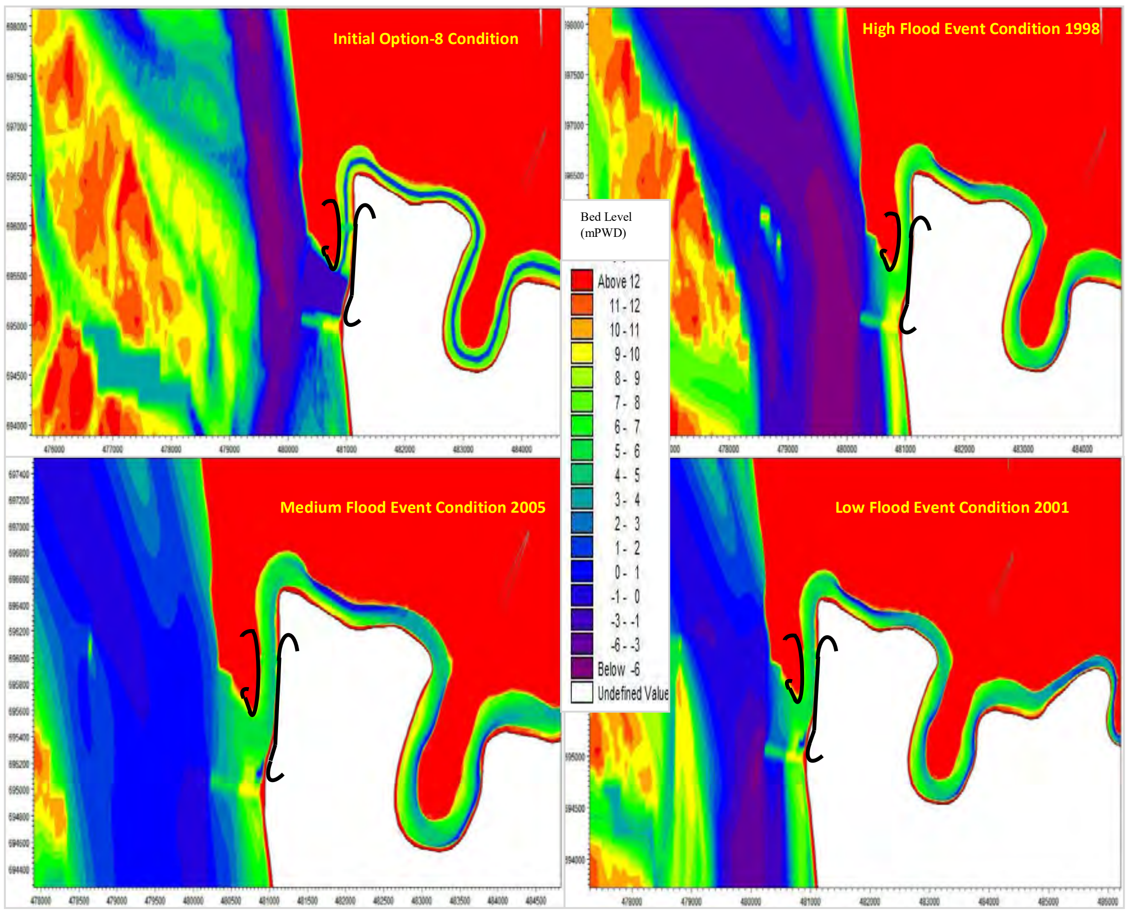

Figure 8.13: Surveyed and simulated data for the different flood events at the end of simulation (Option-8)

In case of Option 9, established a silt trap, river training works at offtake, a weir near offtake and 50m bed width dredging are shown in option. So this is option improve the situation of the channel. The offtake is more or less improved again at the end of monsoon for all the flood events. End of the simulation average bed levels of offtake various from 5.37 mPWD to 4.07 mPWD from all flood events. Figure 8.13 are shown in option-9 condition.

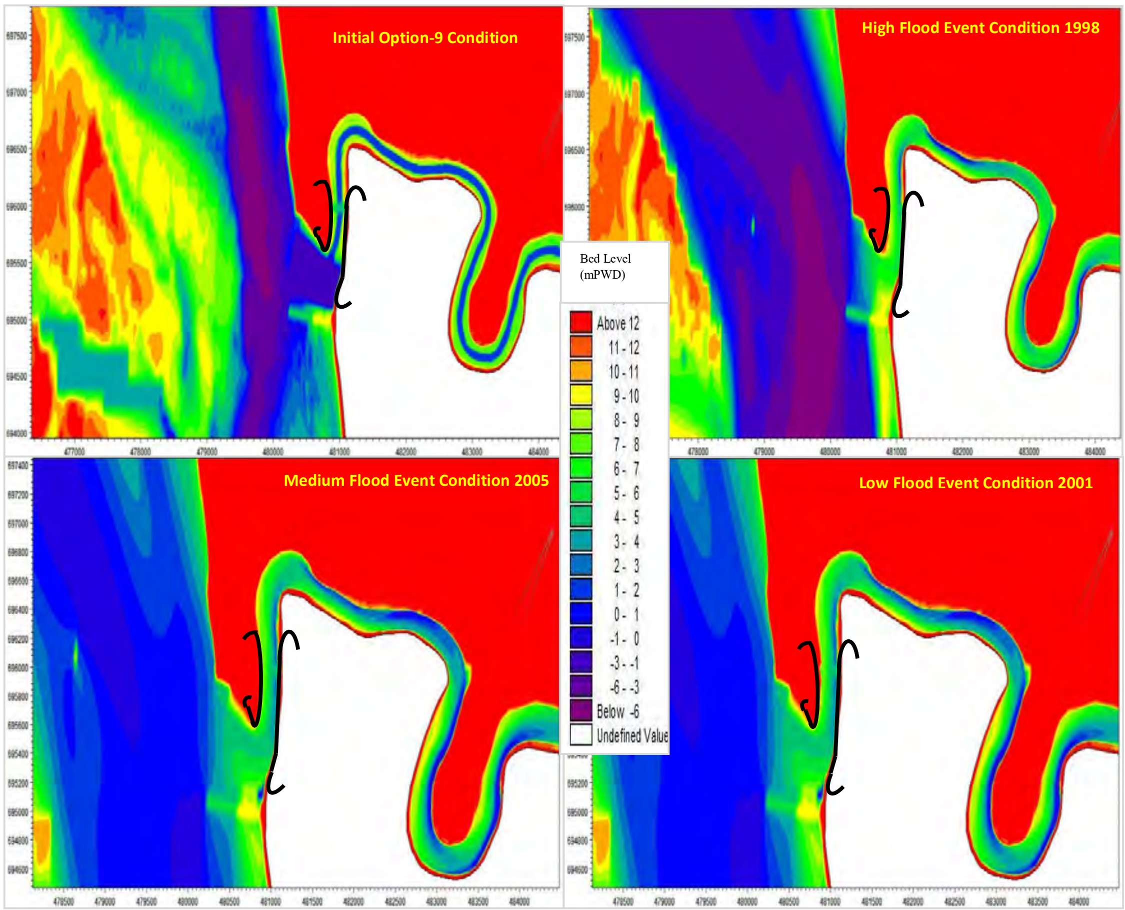

Figure 8.14: Surveyed and simulated data for the different flood events at the end of simulation (Option-9)

8.2.2 Cross section Analysis

Simulated cross sections for different options have been taken at different locations for different flood events. Here, the cross sections of 700m downstream of offtake are shown in Figure 8.15 to Figure 8.17. The rest of the cross section at different locations are also plotted and given in Appendix C. Simulated cross section near the offtake has been plotted for High flood event, shown in Figure 8.15. In this case, both Option 8 and Option 9 shows stable channel along the section at the end of simulation.

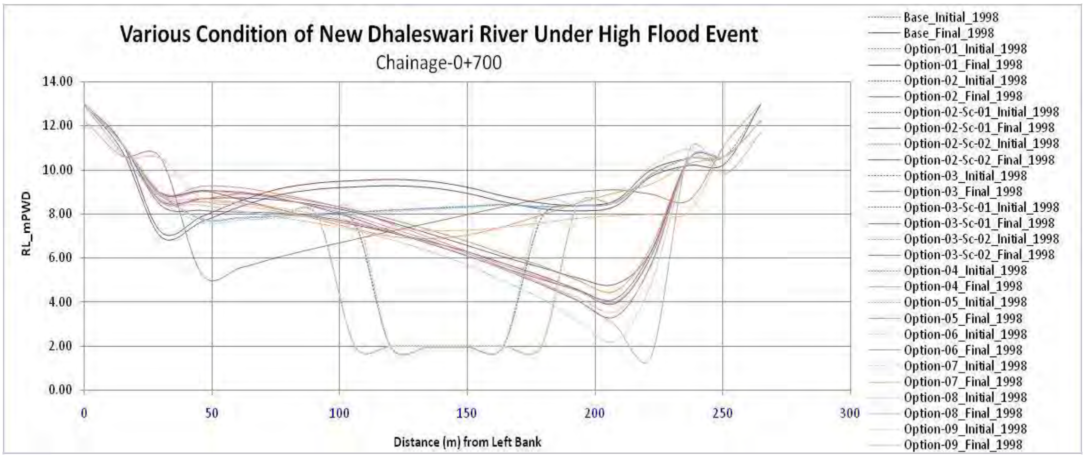

Figure 8.15: Simulated cross sections at 700m of offtake for high flood event for different options

Similarly, simulated cross section near the offtake has been plotted for medium flood event, shown in Figure 8.16. In this case, both Option 8 and Option 9 shows stable channel along the dredge section at the end of monsoon.

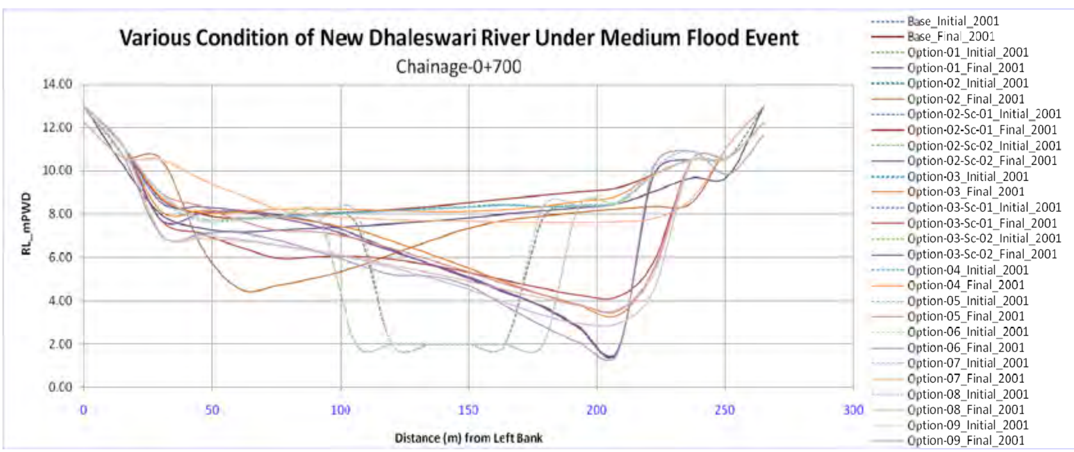

Figure 8.16: Simulated cross sections at 700m of offtake for medium flood event for different options

The simulated cross section for low flood event shows almost similar pattern of bed level changes near offtake (Figure 8.17). In this case, both option-8 and option-9 shows stable channel along the dredge section at the end of monsoon.

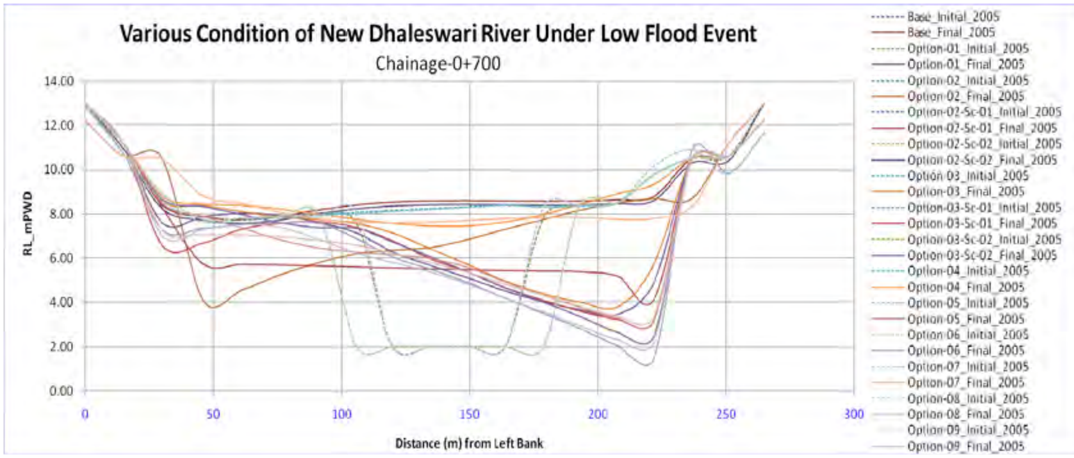

Figure 8.17: Simulated cross sections at 700m of offtake for low flood event for different options

Month wise bed level changes are shown in Appendix D up to weir like structure. Sample cross section are shown in Figure 8.18 to Figure 8.20

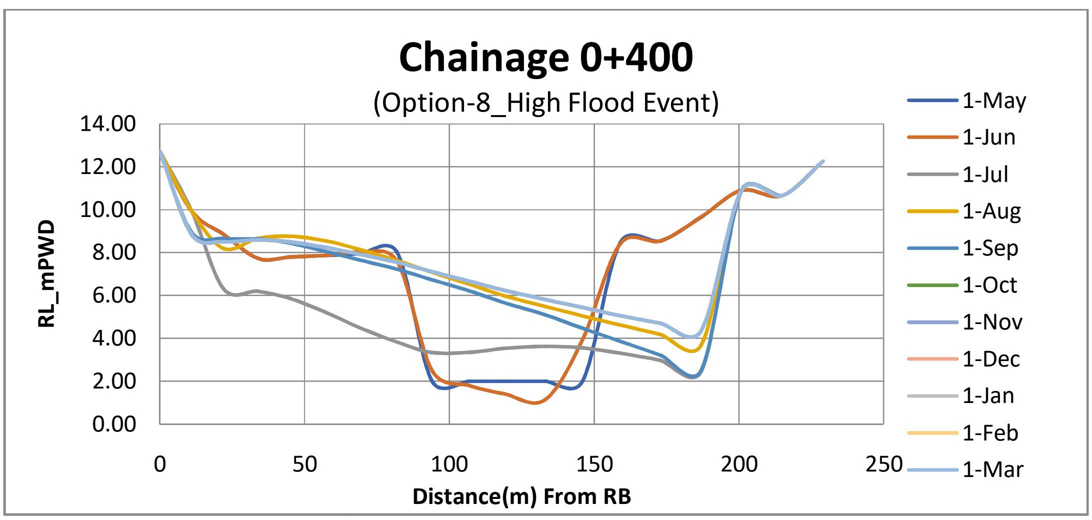

Figure 8.18: Month wise simulated cross sections at 400m of offtake for high flood event

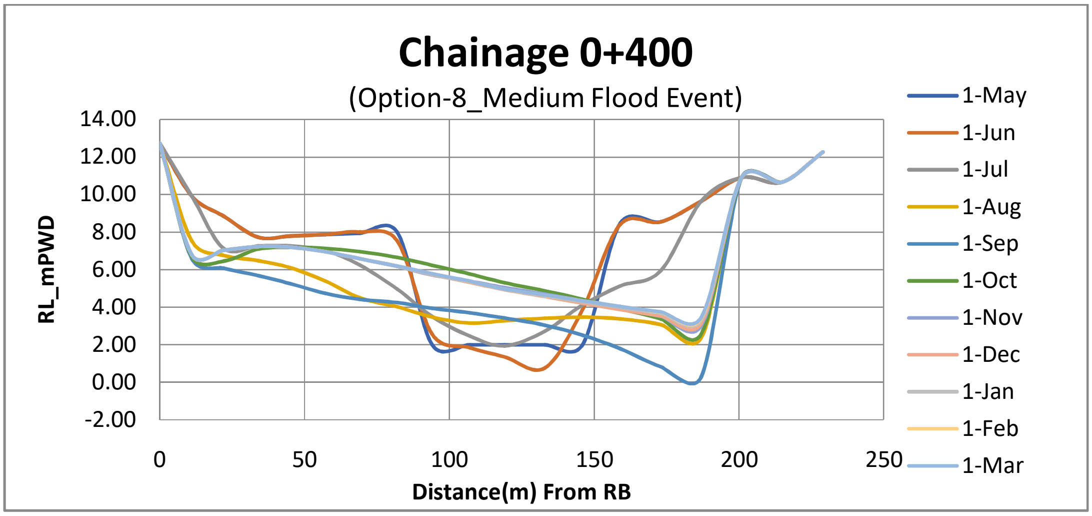

Figure 8.19: Month wise simulated cross sections at 400m of offtake for medium flood event

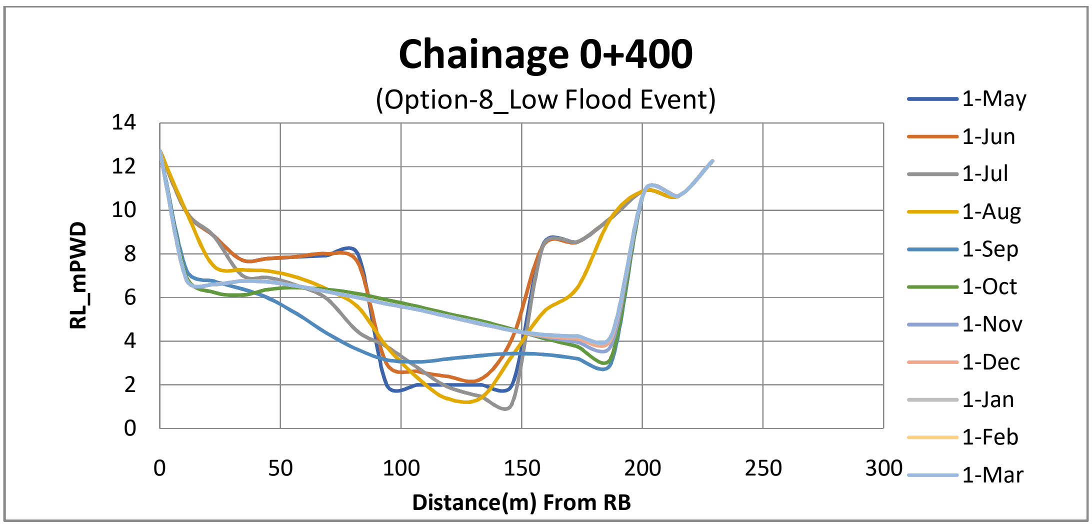

Figure 8.20: Month wise simulated cross sections at 400m of offtake for low flood event

8.2.3 Erosion or Deposition of River Bed Analysis

For high medium and low flood events, it is seen that total volume of bed erosion in the 30 km reach of New Dhaleswari is higher than the volume of deposition for all options. In case of Option-8 and Option-9, the volume of bed erosion is much higher compare to other options and base condition. The net balance is almost 4 Mm^3 bed erosion for these two options during high flood event. On the other hand, for medium and low flood event the net balance is approximately 20 Mm^3 bed erosion. Figure 8.21 to Figure 8.23 represent the simulated bed erosion and deposition at the end of monsoon in the 30 km reach of New Dhaleswari river for different flood event.

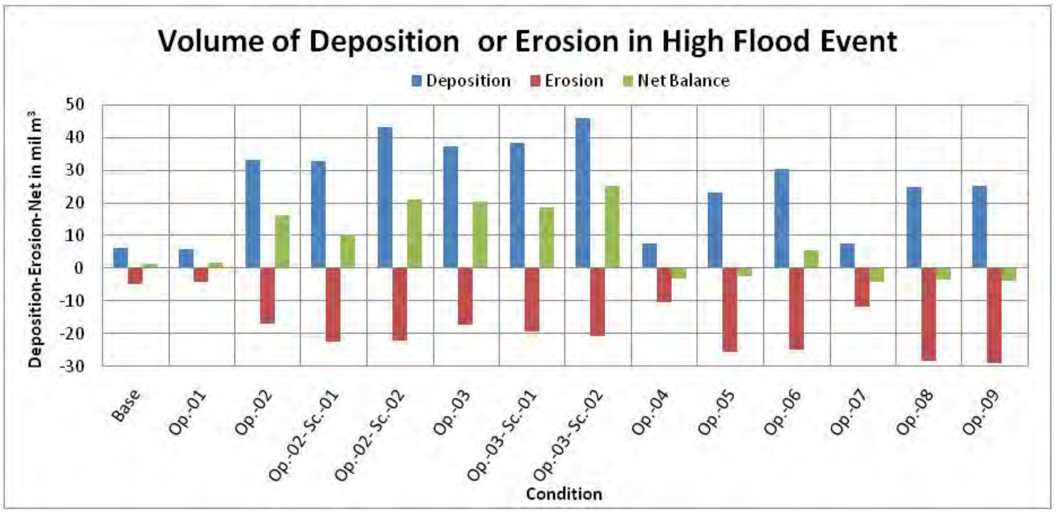

Figure 8.21: Simulated bed deposition or erosion at the end of the simulation in high flood event at 30km length

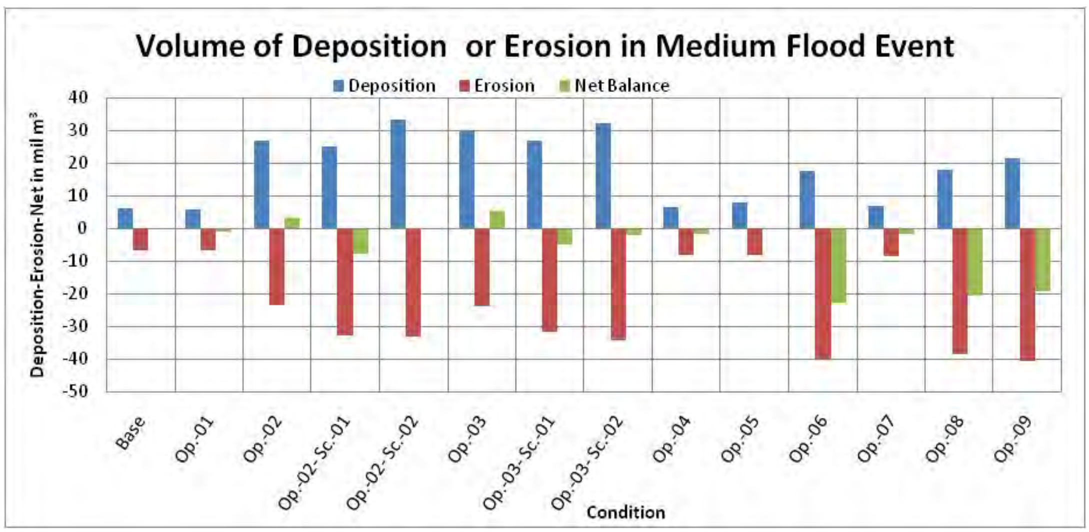

Figure 8.22: Simulated bed deposition or erosion at the end of the simulation in medium flood event at 30 km length

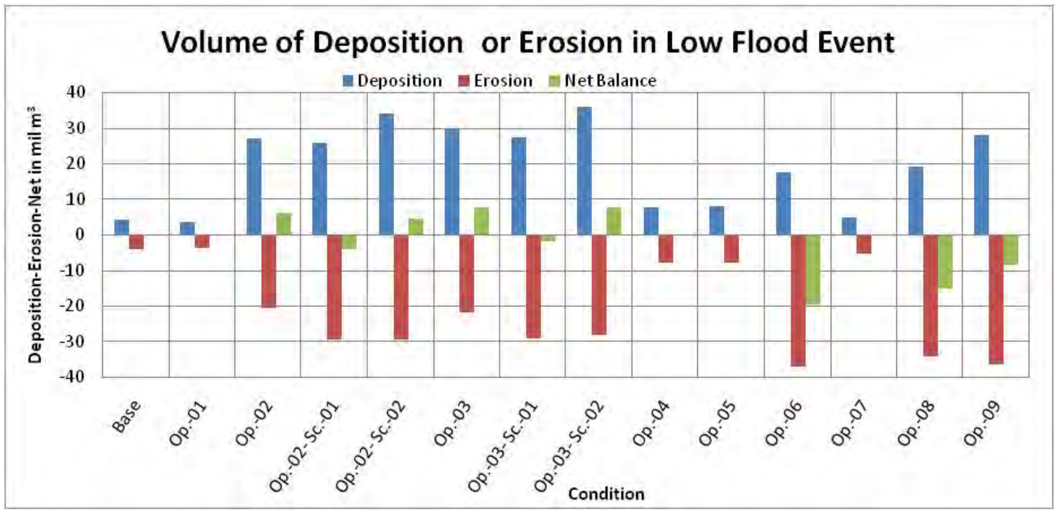

Figure 8.23: Simulated bed deposition or erosion at the end of the simulation in low flood event at 30km length

The volume of deposition and erosion from the mouth of offtake to 5 km reach of New Dhaleswari river for high flood events are also plotted and shown in Figure 8.24 to Figure 8.26. Figure 8.25 shows bed deposition and erosion in chainage 0 km to 2.2 km and Figure 8.26 shows chainage 2 km to 5 km.

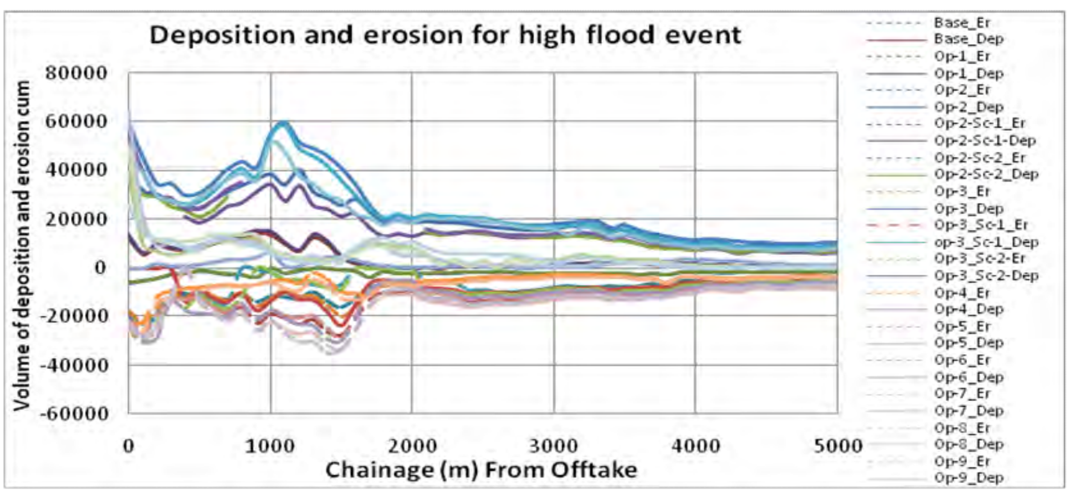

Figure 8.24: Bed deposition or erosion at the end of the simulation in high flood event

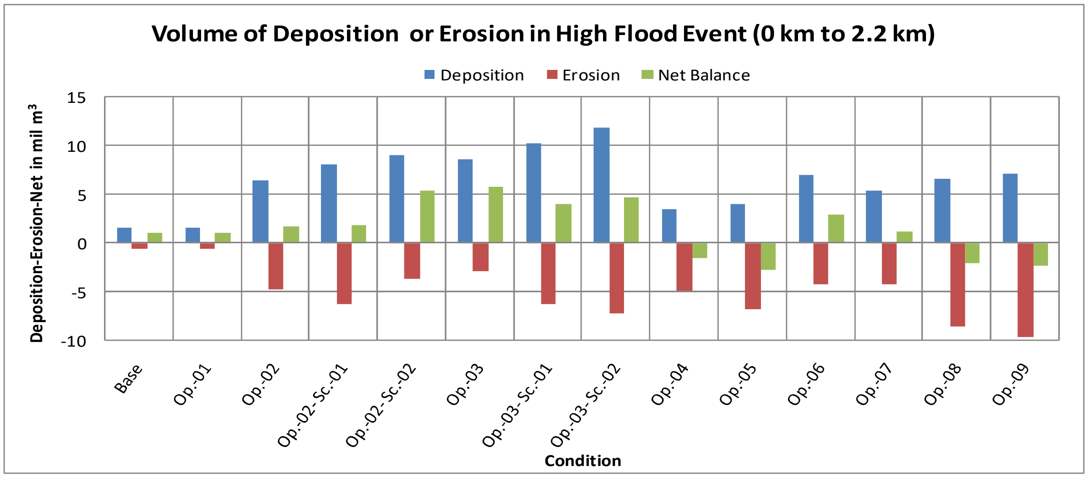

Figure 8.25: Simulated bed deposition or erosion at the end of the simulation in high flood event at 0 km to 2.2 km length

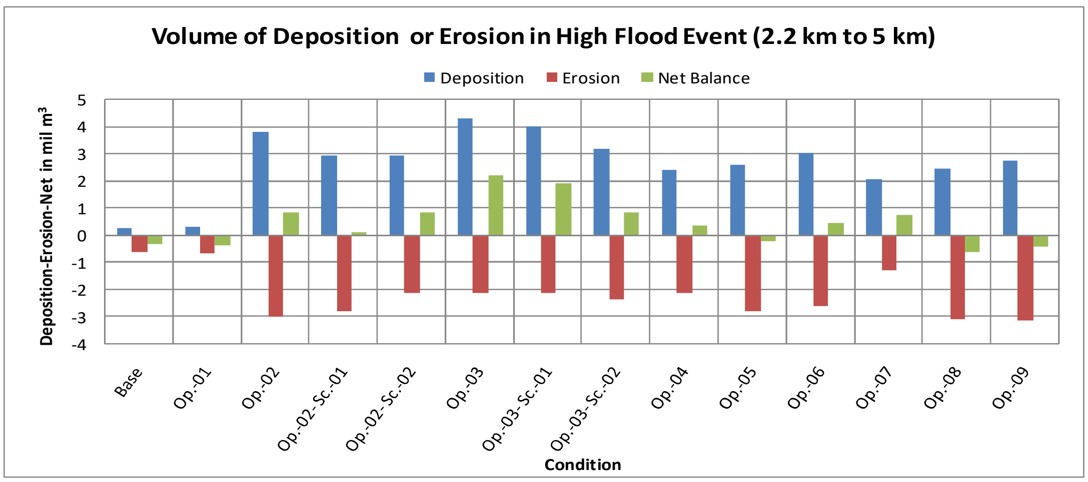

Figure 8.26: Simulated bed deposition or erosion at the end of the simulation in high flood event at 2.2 km to 5 km length

The volume of deposition and erosion from the mouth of offtake to 5 km reach of New Dhaleswari river for medium flood events are also plotted and shown in Figure 8.27 to Figure 8.29. Figure 8.28 shows bed deposition and erosion in chainage 0 Km to 2.2 Km and Figure 8.29 shows chainage 2.2 Km to 5 Km

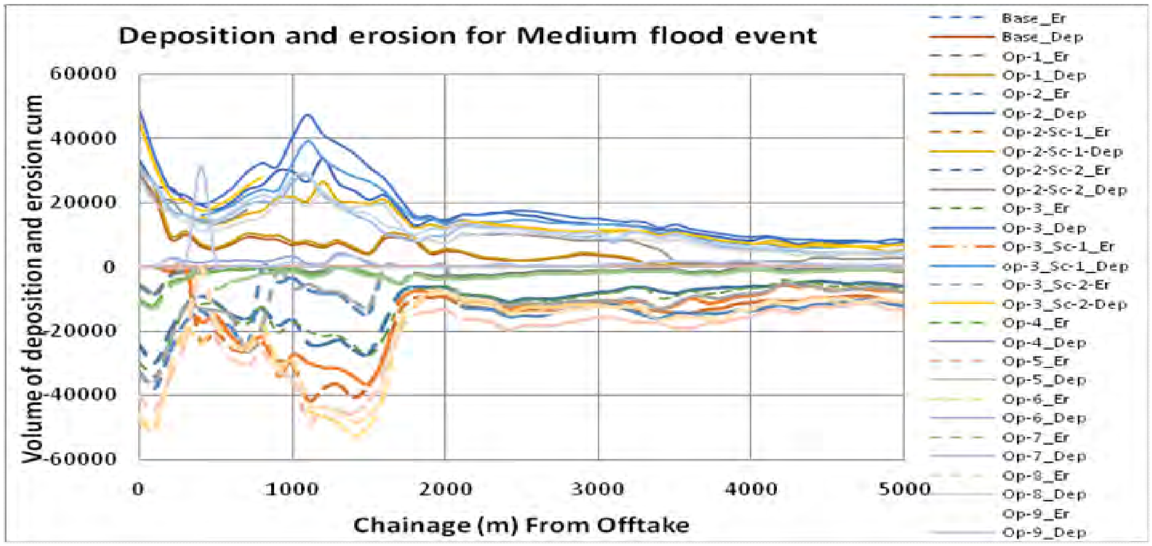

Figure 8.27: Bed deposition or erosion at the end of the simulation in medium flood event

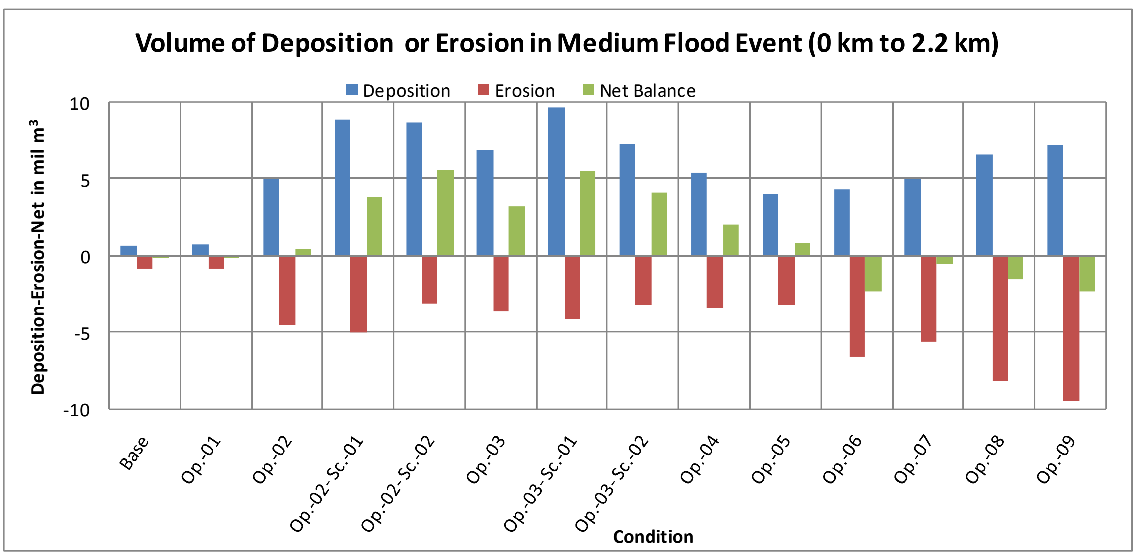

Figure 8.28: Simulated bed deposition or erosion at the end of the simulation in medium flood event at 0 km to 2.2 km length

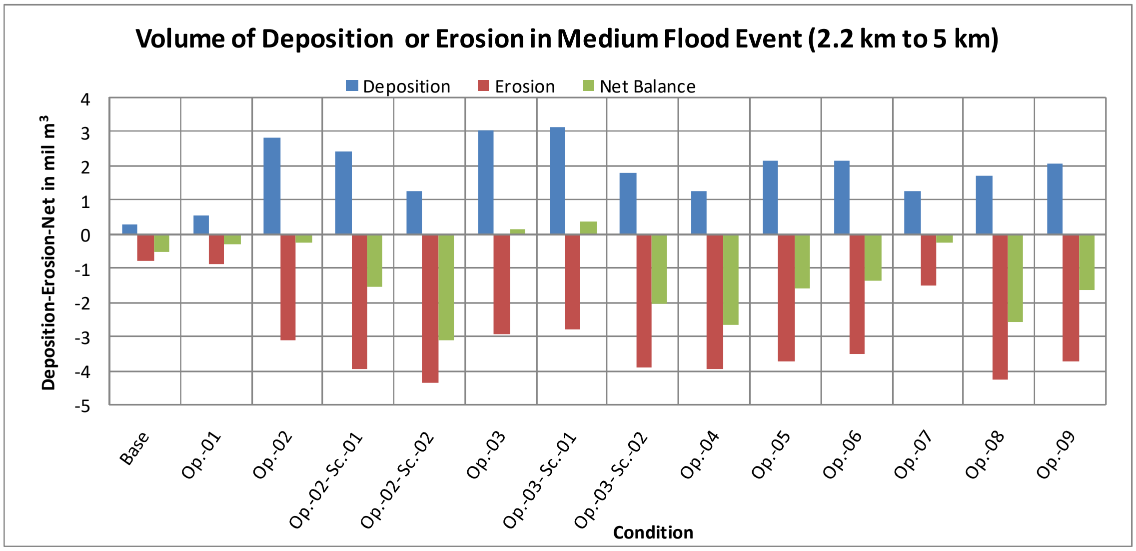

Figure 8.29: Simulated bed deposition or erosion at the end of the simulation in medium flood event at 2.2 km to 5 km length

The volume of deposition and erosion from the mouth of offtake to 5 km reach of New Dhaleswari river for low flood events are also plotted and shown in Figure 8.30 to Figure 8.32. Figure 8.31 shows bed deposition and erosion in chainage 0 Km to 2.2 Km and Figure 8.32 shows chainage 2.2 Km to 5 Km.

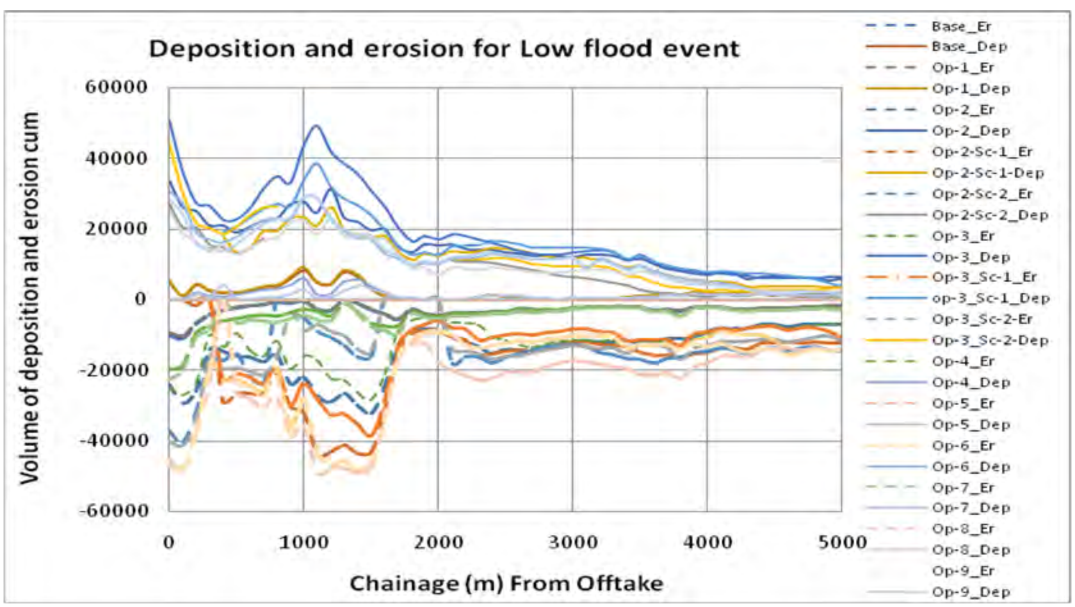

Figure 8.30: Bed deposition or erosion at the end of the simulation in low flood event

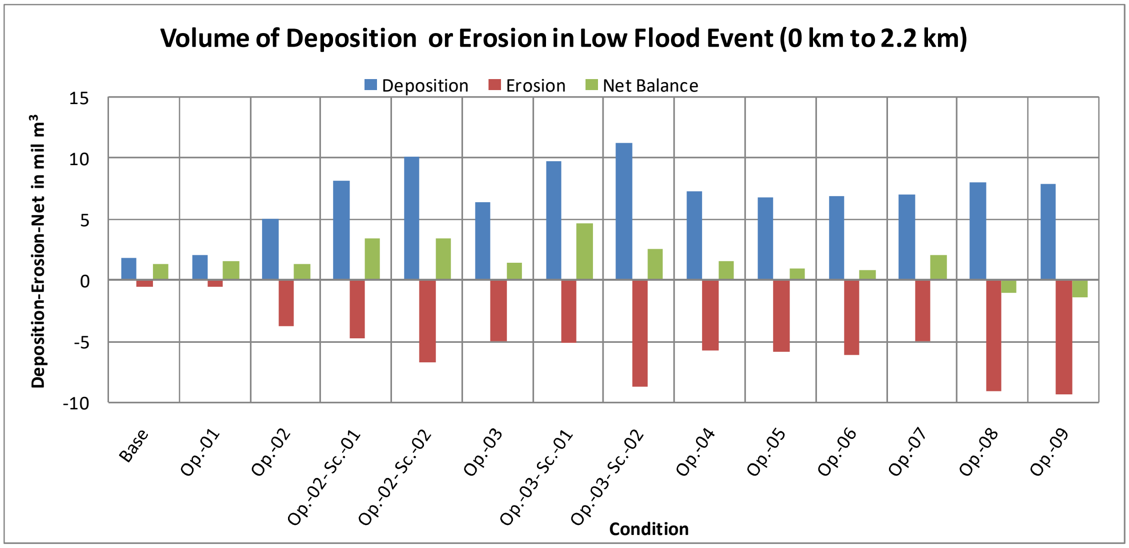

Figure 8.31: Simulated bed deposition or erosion at the end of the simulation in low flood event at 0 km to 2.2 km length

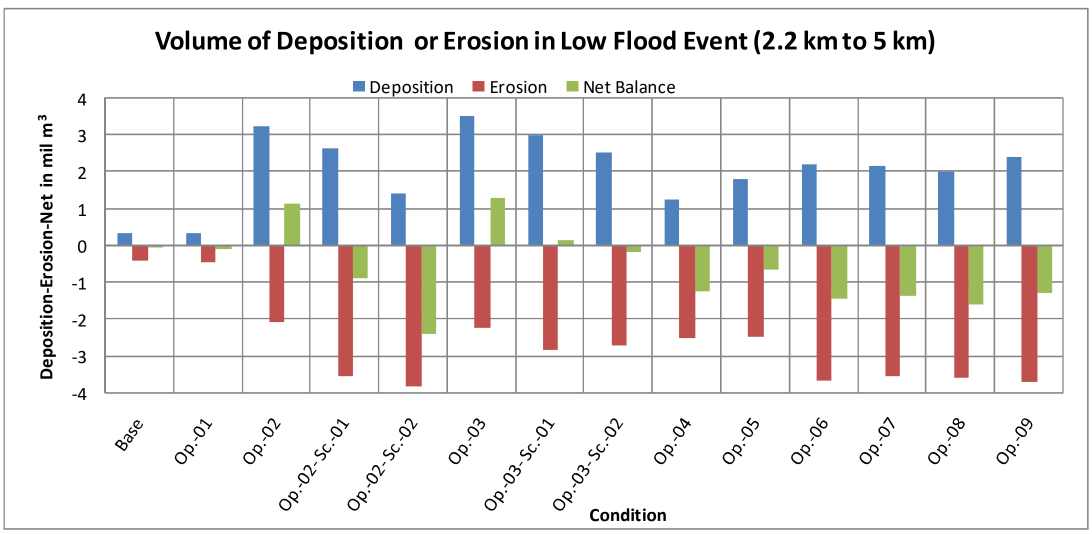

Figure 8.32: Simulated bed deposition or erosion at the end of the simulation in low flood event at 2.2 km to 5 km length

Net deposition or erosion in various options in model run at 5 Km reaches in New Dhaleswari river is shown in Table 8.1.

Table 8.1 Net deposition or erosion in various options up to 5 km

Options	Deposition (mil m^3)			Erosion (mil m^3)		
	High	Medium	Low	High	Medium	Low
Base	1.87	-	2.82	-	0.73	-
Option-1	1.81	-	3.02	-	0.63	-
Option-2	7.31	0.70	3.93	-	-	-
Option-2- Scenario-1	9.78	6.08	6.17	-	-	-
Option-2- Scenario-2	27.52	18.11	16.59	-	-	-
Option-3	13.66	6.57	5.34	-	-	-
Option-3- Scenario-1	16.98	11.45	10.59	-	-	-
Option-3- Scenario-2	26.31	-	18.32	-	1.58	-
Option-4	-	0.62	1.02	3.53	-	-
Option-5	-	0.87	1.07	6.64	-	-
Option-6	6.84	-	-	-	5.99	3.29
Option-7	0.37	-	1.56	-	2.13	-
Option-8	-	-	-	6.93	8.42	6.59
Option-9	-	-	-	7.09	6.20	4.70

8.2.4 Discharge Analysis

Discharge of New Dhaleswari river has been extracted from the simulated results for all the options. Figure 8.33 represents the discharge for high flood event for different options during dry period. At the end of October, it is seen that the flow is getting null for Option 1, 2 , 3, 4, 5, 6 and 7 (Figure 8.30). But there is still certain amount of flow in Option 8 and 9 at that time.

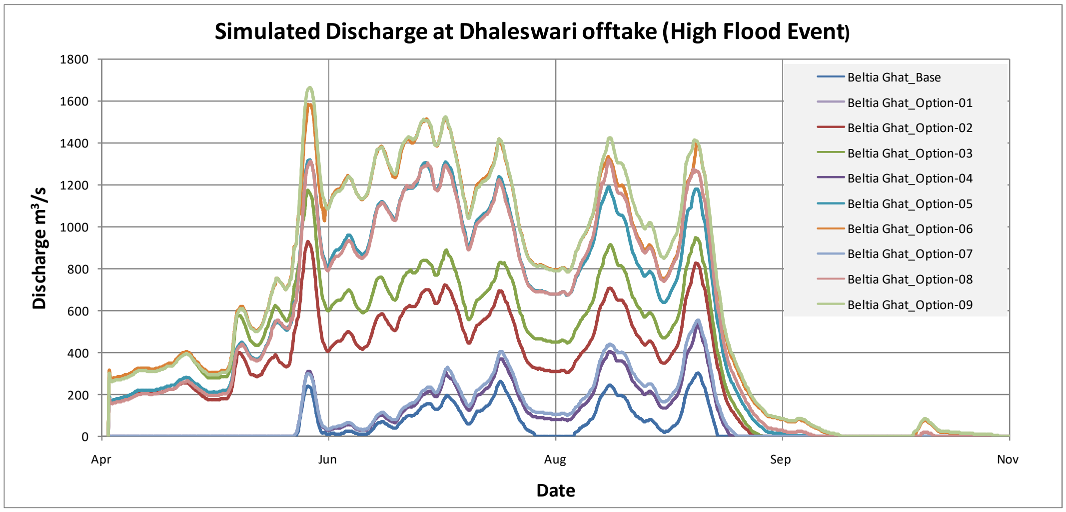

Figure 8.33: Simulated Discharge at New Dhaleswari river in high flood event

In medium flood event, the flow is continuously decreasing from mid October and is getting zero at the end of November for Option 1, 2, 3, 4 and 5. On the other hand, there is still few amount of flow is available in others Options for this flood event (Figure 8.34).

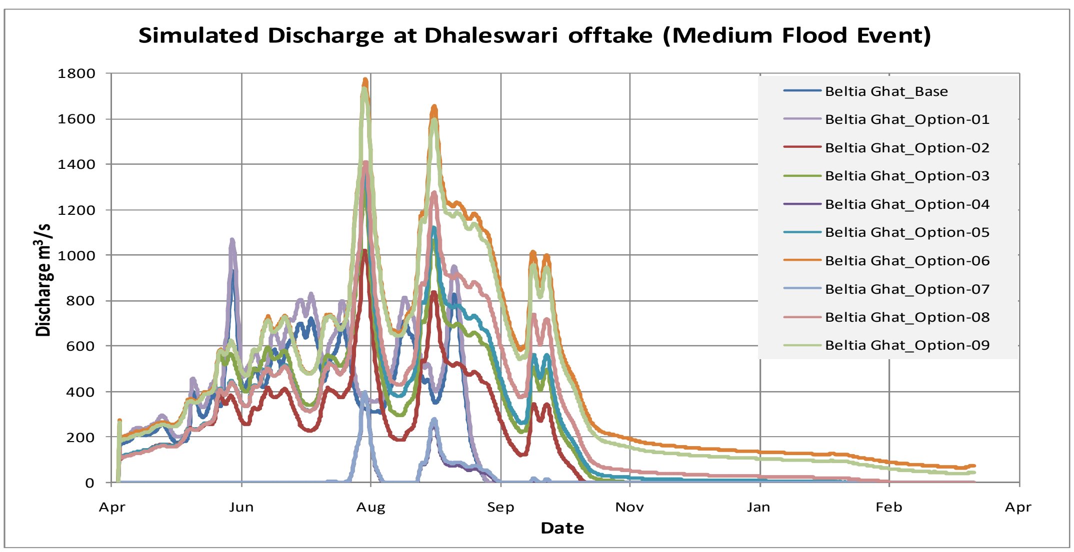

Figure 8.34: Simulated Discharge at New Dhaleswari river in medium flood event

In low flood event, the flow is continuously decreasing from mid October and is getting zero at the end of November for Option 1, 2, 3, 4 and 5. On the other hand, there is still few amount of flow is available in others Options for this flood event (Figure 8.35).

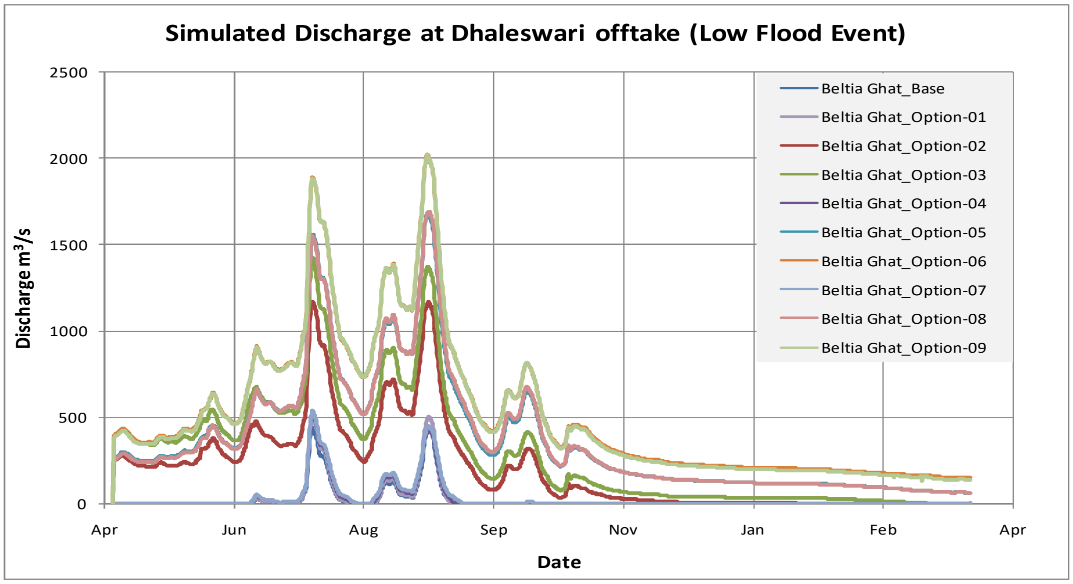

Figure 8.35: Simulated Discharge at New Dhaleswari river in low flood event

On the contrary, the ratio of flow diversion sustains few days more for Option 6, 7, 8 and 9. Simulated discharge of New Dhaleswari at the end of simulation for different options throughout the months shown in Table 8.2

Table 8.2 Simulated discharge of New Dhaleswari at the end of simulation for different options

Event / Conditions	High Flood Event (Q m^3/s)	Medium Flood Event (Q m^3/s)	Low Flood Event (Q m^3/s)
Base	302	929	424
Option-1	347	1068	508
Option-2	928	1020	1170
Option-2- Scenario-1	1024	1118	1284
Option-2- Scenario-2	1156	1194	1305
Option-3	1174	1300	1423
Option-3- Scenario-1	1202	1325	1477
Option-3- Scenario-2	1288	1384	1489
Option-4	536	376	512
Option-5	1318	1378	1672
Option-6	1583	1772	2001
Option-7	554	396	535

Event / Conditions	High Flood Event ($Q\ m^3/s$)	Medium Flood Event ($Q\ m^3/s$)	Low Flood Event ($Q\ m^3/s$)
Option-8	1318	1408	1689
Option-9	1663	1731	2017

8.2.5 Percentage of flow diversion Analysis

The flow of the New Dhaleswari river is totally dependent on the flow of the Jamuna; ratio of the flow of New Dhaleswari to the Jamuna has been extracted and presented in Figure 8.36 to Figure 8.38. During monsoon, the ratio is in the range 0.5% to 2.8 % for high flood event whereas during dry period i.e. at the end of October it diminishes drastically and reaches zero percentage for all options, except for Option 7, 8 and 9 shown in Figure 8.36.

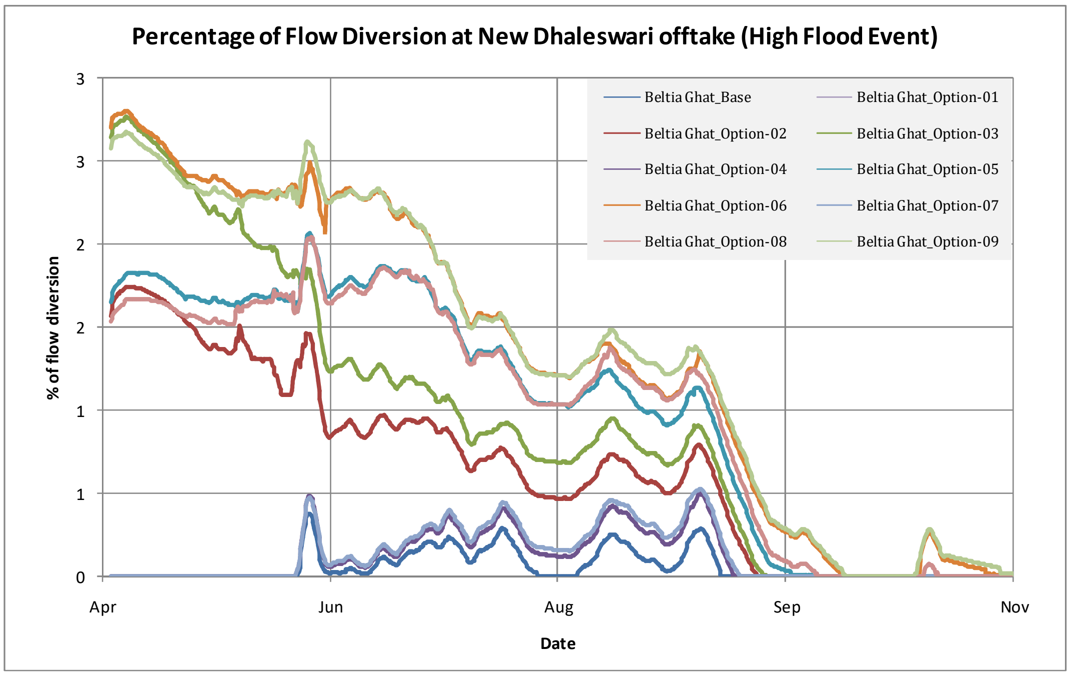

Figure 8.36: Percentage of flow diversion at New Dhaleswari offtake in high flood event

For medium flood event, the flow diversion ratio is in the range of 0.6% - 3.2% during monsoon (Figure 8.37). The flow ratio decreases early for Option to Option at the end of October for this flood event. On the contrary, the ratio of flow diversion sustains few days more for Option 6, 8 and 9.

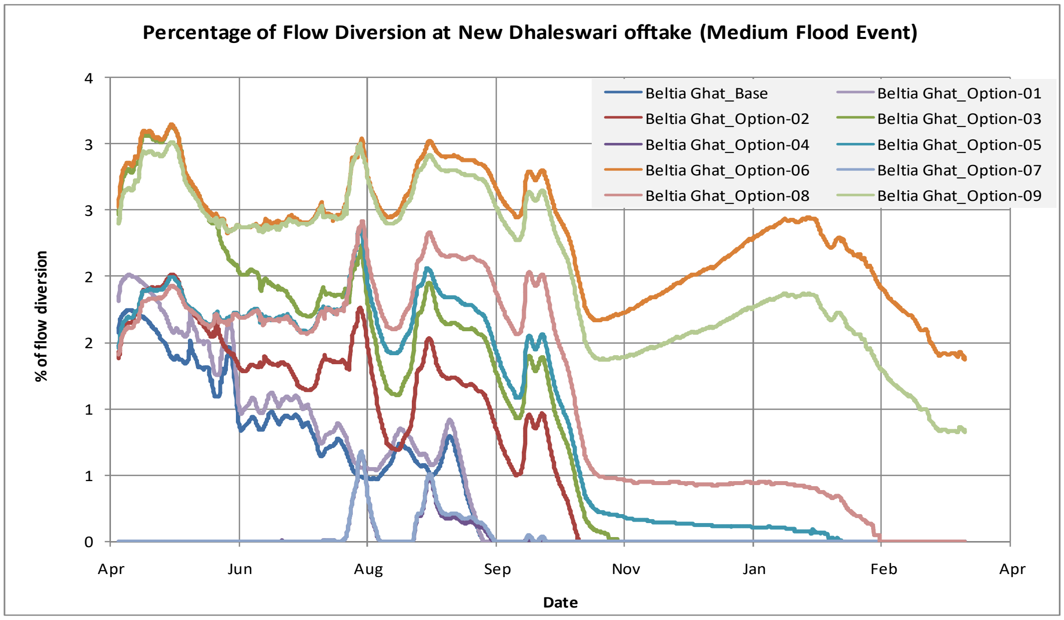

Figure 8.37: Percentage of flow diversion at New Dhaleswari offtake in medium flood event

For low flood event, the flow diversion ratio is in the range of 0.8% - 3.4% during monsoon (Figure 8.38). The flow ratio decreases early for Option to Option at the end of October for this flood event. On the contrary, the ratio of flow diversion sustains few days more for Option 3, 6, 8 and 9.

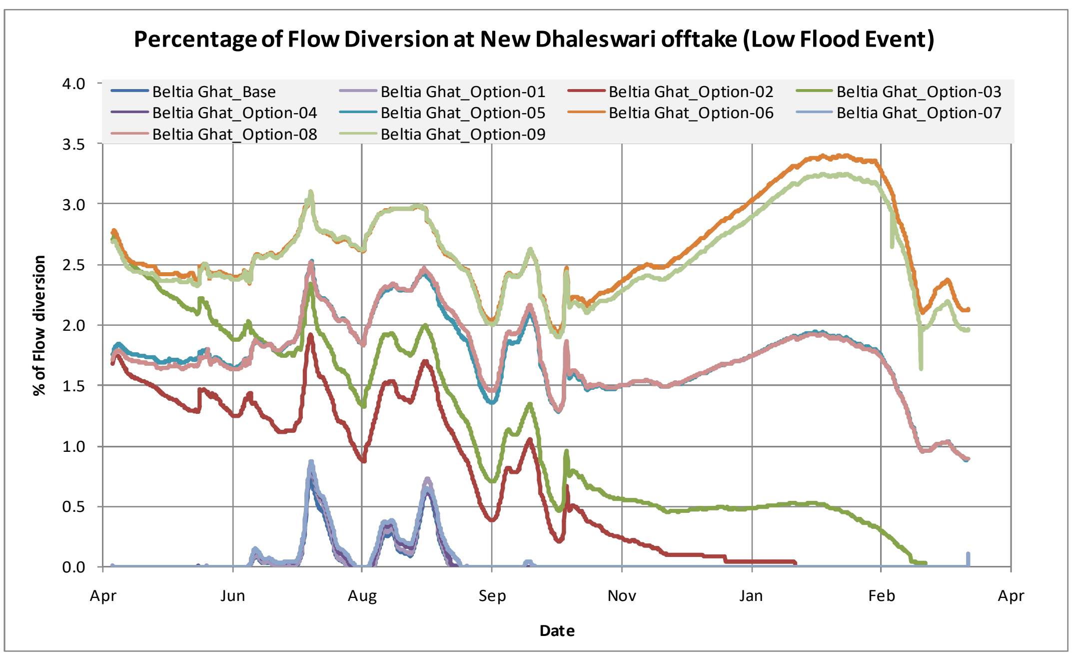

Figure 8.38: Percentage of flow diversion at New Dhaleswari offtake in Low flood event

The ratio of flow all option condition to the base has been extracted and presented in Figure 8.39 to Figure 8.41. Minimum discharge is considered 1 m^3/s. The ratio increase in high, medium and low is 120 (June), 250 (August) and 170 (July) respectively.

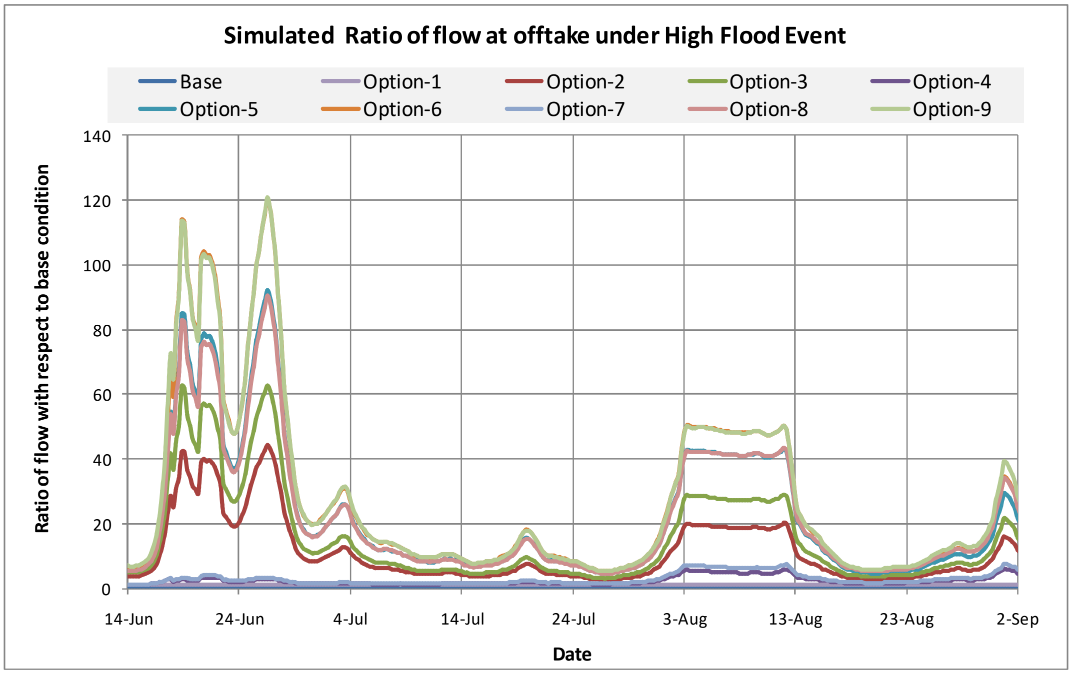

Figure 8.39: Ratio of flow at New Dhaleswari river offtake in high flood event with respect to base condition

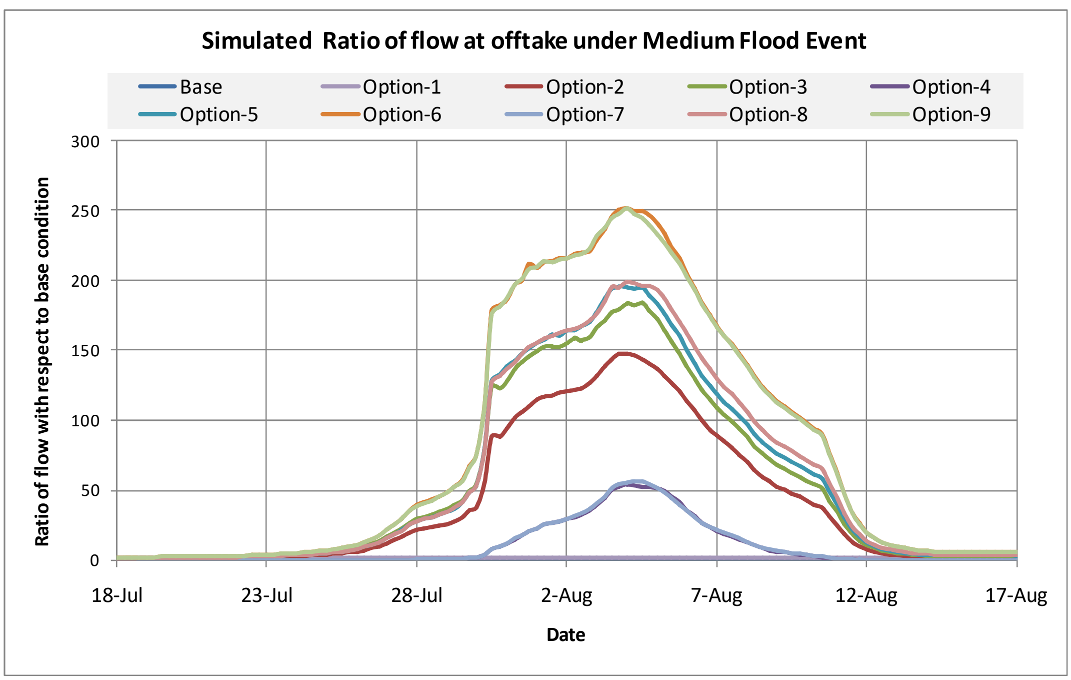

Figure 8.40: Ratio of flow at New Dhaleswari river offtake in medium flood event with respect to base condition

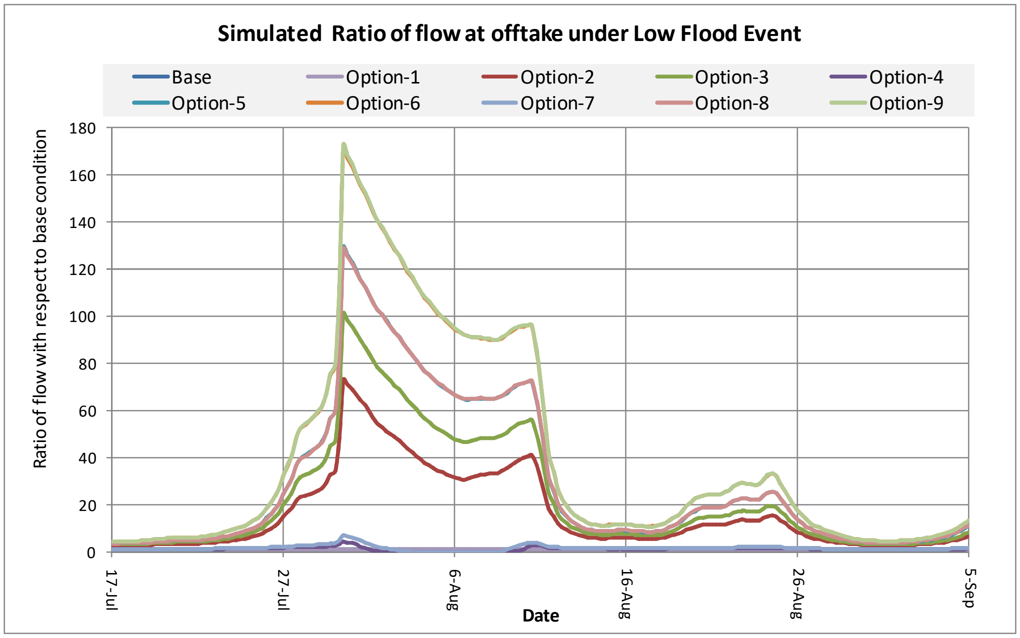

Figure 8.41: Ratio of flow at New Dhaleswari river offtake in low flood event with respect to base condition

8.2.6 Sediment Transport Analysis

Sediment load has been extracted at 500 meters downstream of the offtake of New Dhaleswari river and at the downstream location of river for each option and plotted in Figure 8.42 to Figure 8.44. Figure 8.42 indicates that due to high sediment flow in high flood event, huge sediment has been transported through the offtake. On the contrary, for medium and low flood event, sediment transport is found lower at the offtake. Due to increase the conveyance area of Option-8 and Option-9, velocity is getting lesser in that location (Figure 8.42) and probably for that reason the rate of sediment transport is reduced at the offtake. However, at the downstream location of river, sediment transport is increasing with the flow and the velocity is also high in this area.

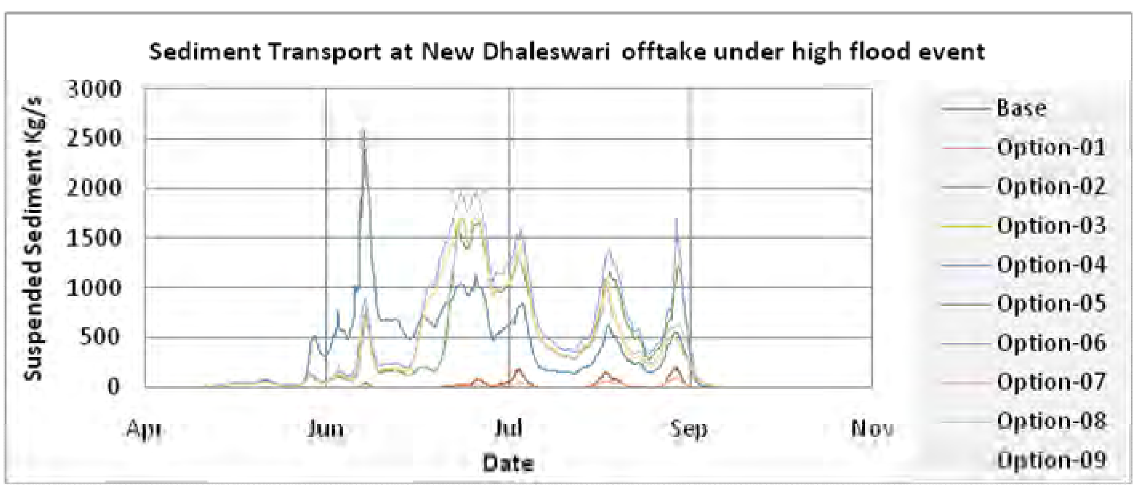

Figure 8.42: Sediment transport at New Dhaleswari river offtake in high flood event

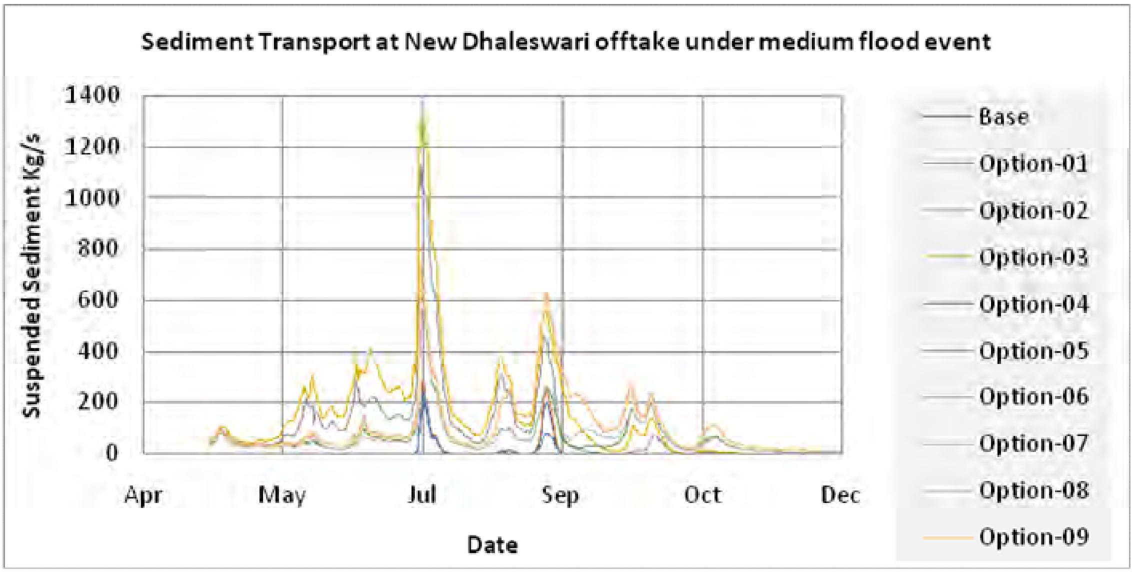

Figure 8.43: Sediment transport at New Dhaleswari river offtake in medium flood event

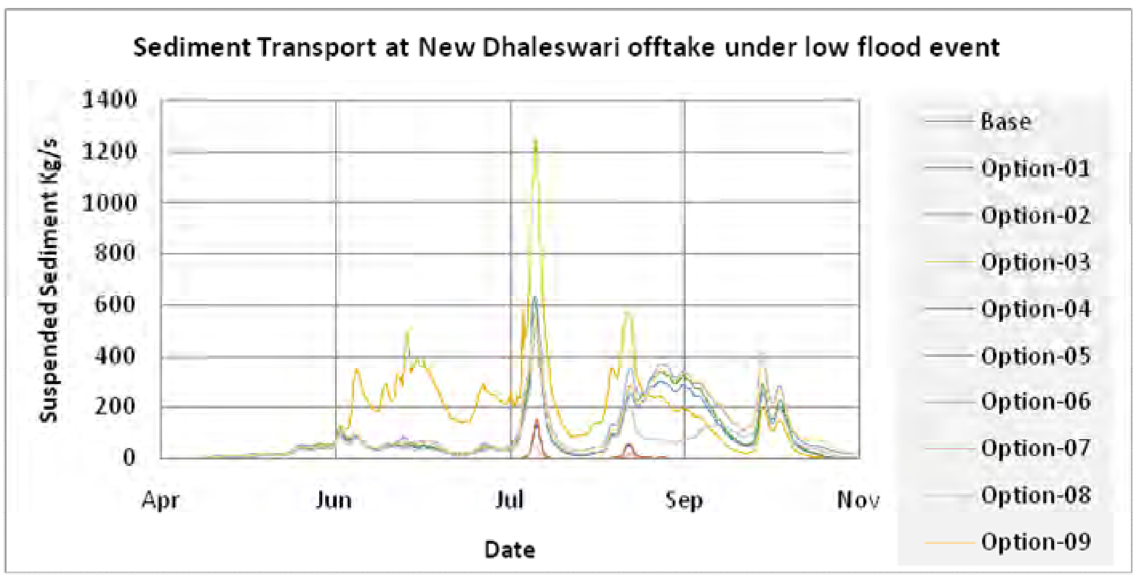

Figure 8.44: Sediment transport at New Dhaleswari river offtake in low flood event

8.2.7 Velocity Distribution

Velocity is defined as the rate of change in position of an object. It is a vector quantity which means that velocity is expressed in terms of the magnitude of change in position of an object as well as the direction of change in position of an object. The water velocity for different options is shown in all flood events are represented in Appendix-E. The velocity distribution is shown in July to August. A sample velocity distribution is shown in Figure 8.45.

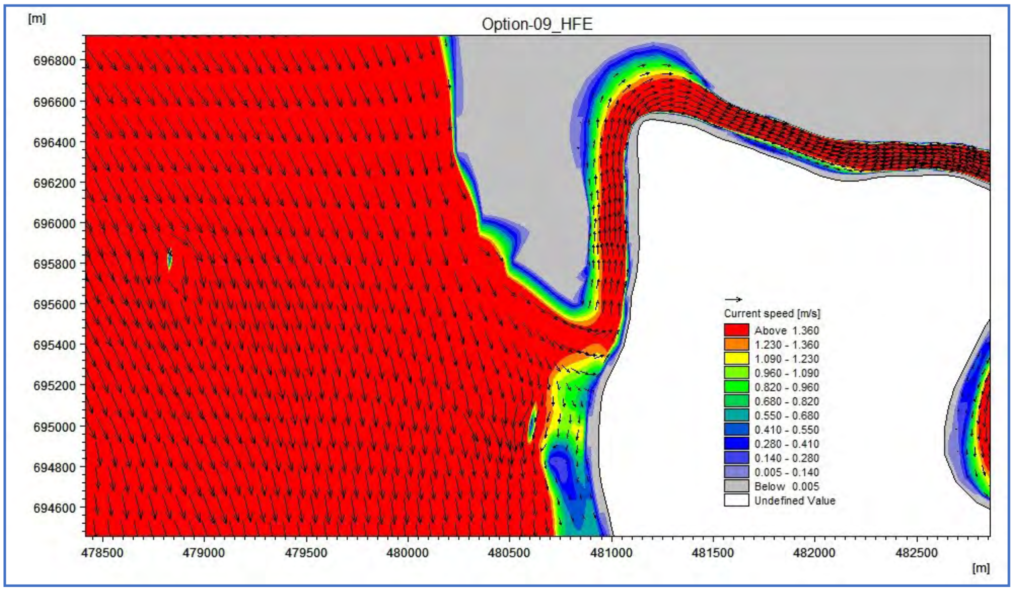

Figure 8.45: Velocity distribution at offtake area in highest flood event

7.2.8 Water Depth Analysis

The water depth hydro graph for different options is shown in all flood events are represented in Figure 8.46 to Figure 8.48 at the end of simulation run. The link between the Jamuna and New Dhaleswari river is getting connected for Option-9 for all flood events. Option-8 and Option-6 are connected in medium and low flood events. So the river alive in dry seasons in option-9 all the flood events.

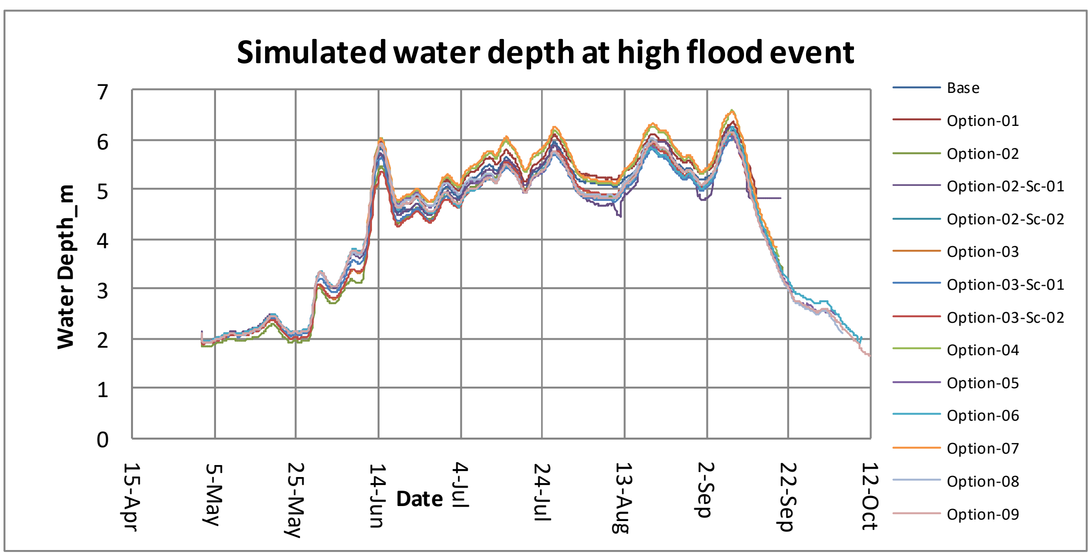

Figure 8.46: Simulated water depth near New Dhaleswari offtake at high flood event

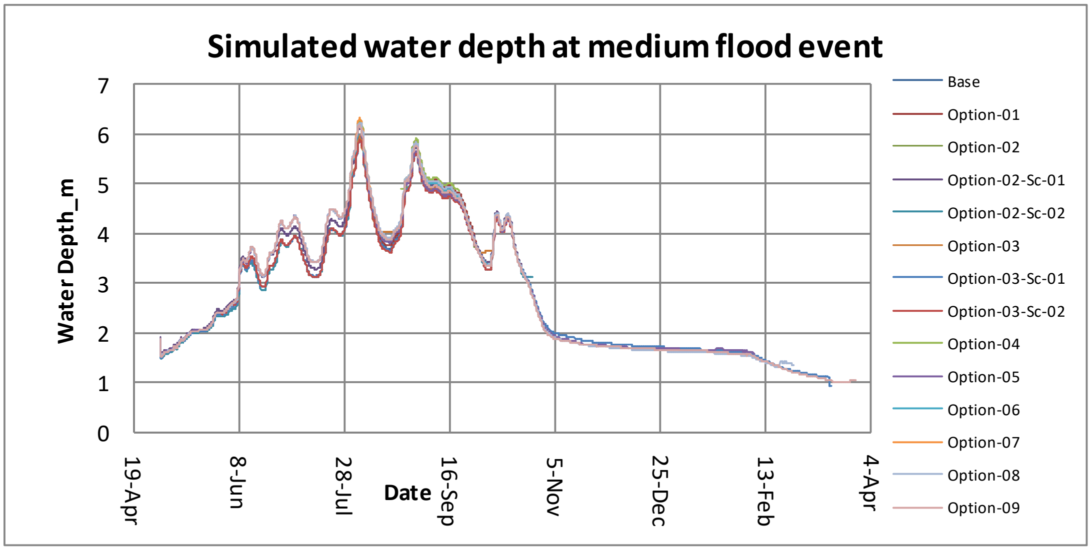

Figure 8.47: Simulated water depth near New Dhaleswari offtake at medium flood event

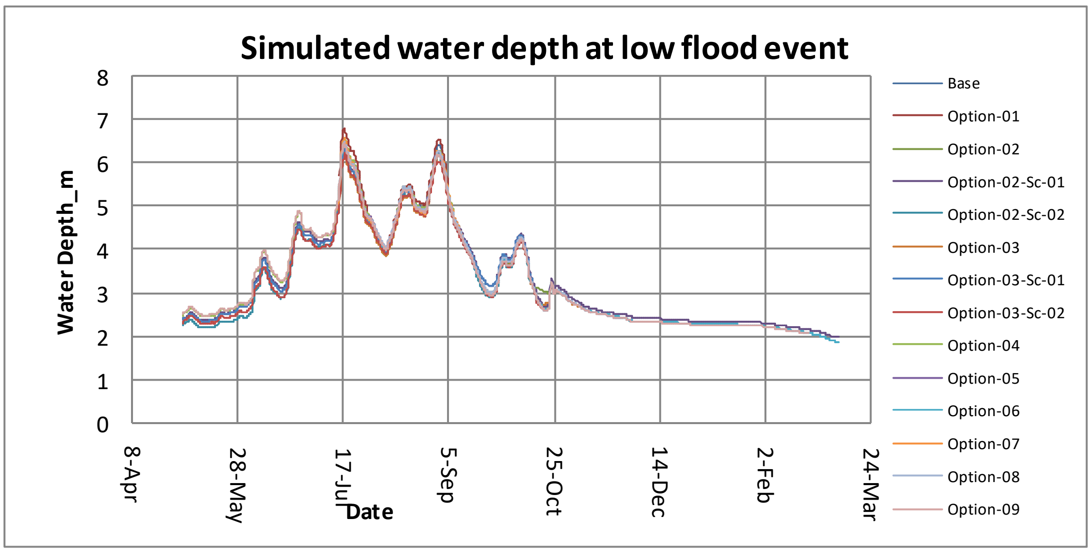

Figure 8.48: Simulated water depth near New Dhaleswari offtake at low flood event

7.3 Sustainability of Option-9

To check the sustainability of Option-9, a morphological simulation has been given for the four successive monsoon periods that means from the year 2005 to 2008. The boundary for this simulation is represented in Figure 8.49 and 8.51, respectively.

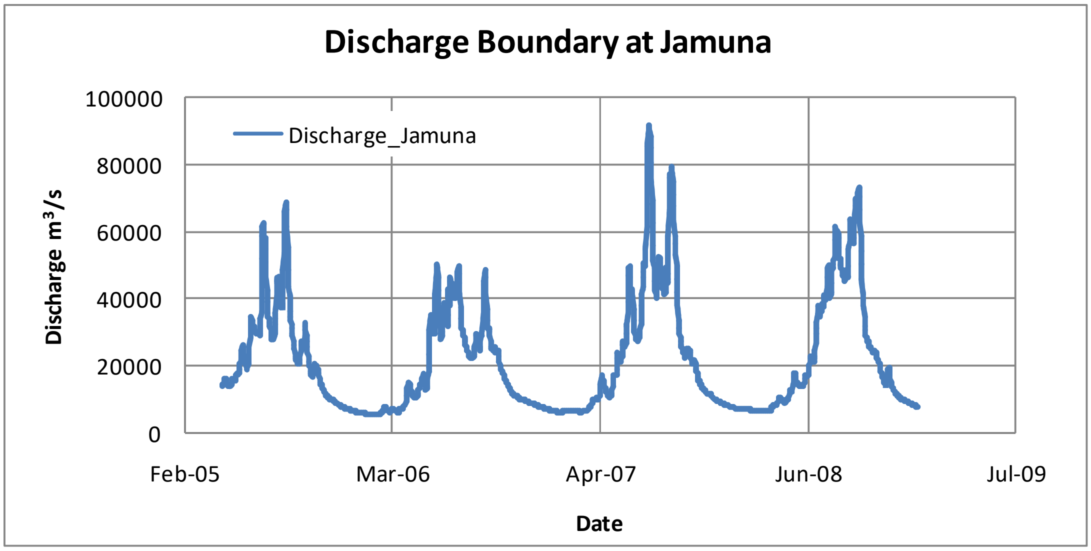

Figure 8.49: Discharge boundary for long term simulation of option-9

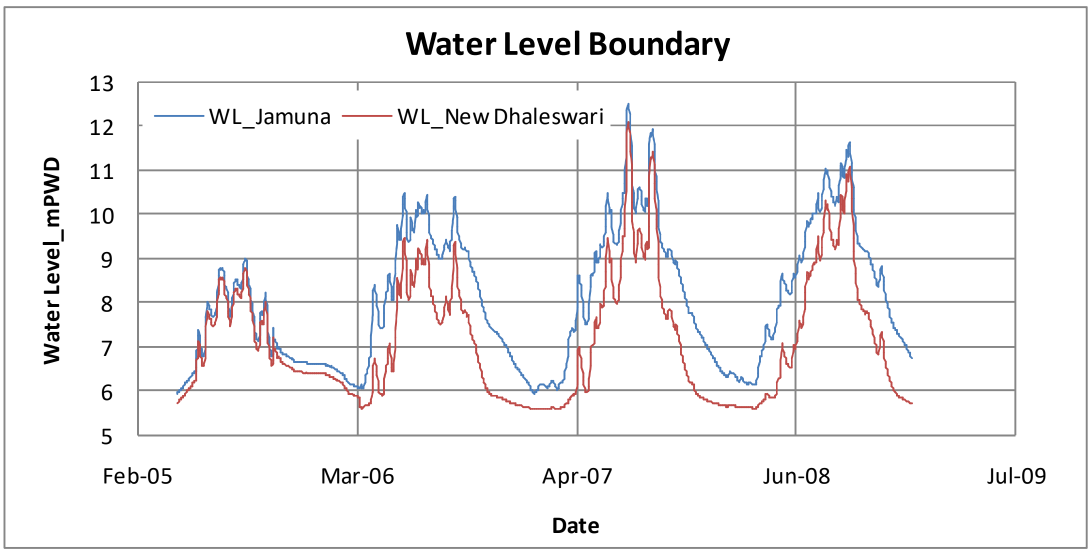

Figure 8.50: Water level boundary for long term simulation of option-9

Figure 8.51 shows the simulated flow discharge for the long term simulation near the offtake of New Dhaleswari river. It is seen from the figure that New Dhaleswari river shares continuous flow from the Jamuna.

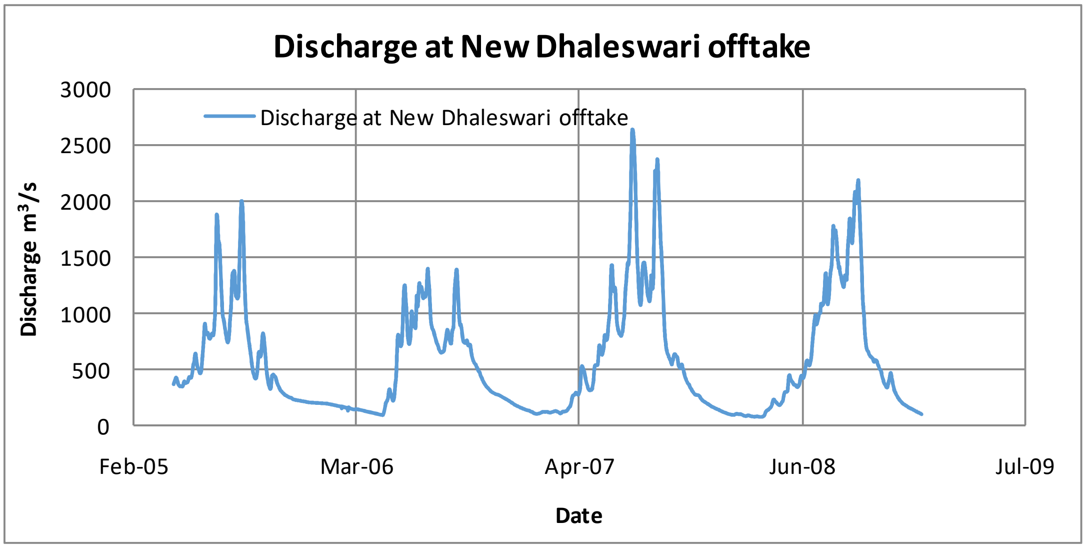

Figure 8.51: Simulated discharge data for long term simulation of option-9

The flow of the New Dhaleswari river is totally dependent on the flow of the Jamuna; ratio of the flow of New Dhaleswari to the Jamuna has been extracted and presented in Figure 8.52.

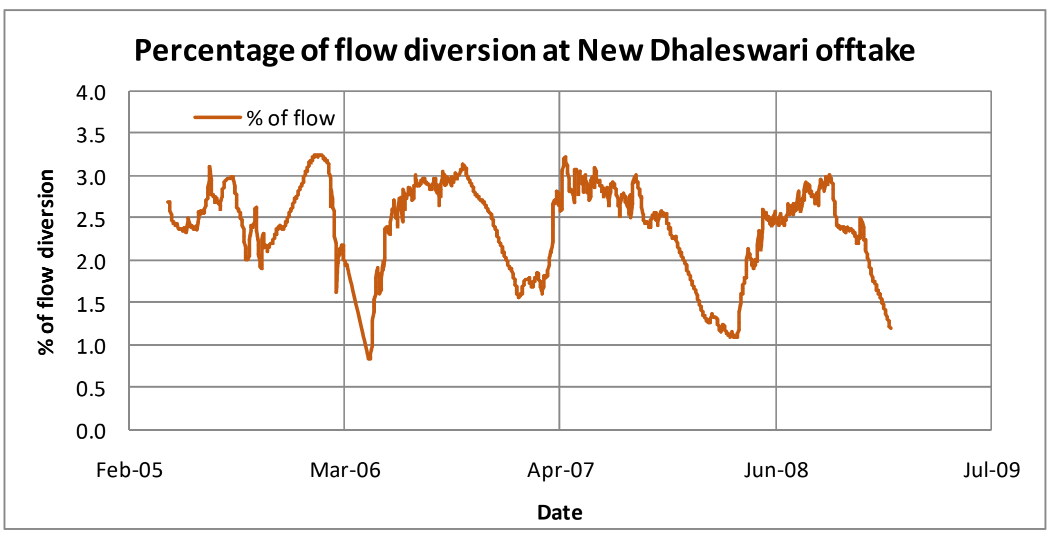

Figure 8.52: Percentage of flow at New Dhaleswari offtake for long term simulation of option-9

8.4 Summary of Results

To suggest the better offtake management, a comparative analysis of different options has been done in the above section. It is understood from the analysis that Placement of river training work (Option-1) does not improve the flow condition of New Dhaleswari River. The offtake get silted up massively at the end of monsoon. In addition, there are no connection exist between the two rivers at the beginning of dry period.

From the bed level and cross-sectional analysis, it is observed that only 30m bed width dredging along the New Dhaleswari (Option-2) is not a suitable solution. The offtake get silted up massively at the end of monsoon. It does not improved two scenarios also.

From the bed level and cross-sectional analysis, it is observed that only 50m bed width dredging along the New Dhaleswari (Option-3) is not a suitable solution. The offtake get silted up massively at the end of monsoon. It does not improved two scenarios also.

From the bed level and cross-sectional analysis, it is observed that established a silt trap at offtake and river training works along the New Dhaleswari (Option-4) is not a suitable solution. The offtake get silted up massively at the end of monsoon. It does not improved two scenarios also.

From the bed level and cross-sectional analysis, it is observed that established a silt trap at offtake, river training works and 30m bed width dredging along the New Dhaleswari (Option-5) is not a suitable solution. The offtake get silted up at the end of February.

From the bed level and cross-sectional analysis, it is observed that established a silt trap at offtake, river training works and 50m bed width dredging along the New Dhaleswari (Option-6) is not a suitable solution. The offtake get silted up at the end of February.

From the bed level and cross-sectional analysis, it is observed that established a silt trap, river training works at offtake and a weir near offtake of the New Dhaleswari (Option-7) is not a suitable solution. The offtake get silted up at the end of November.

From the bed level and cross-sectional analysis, it is observed that established a silt trap, river training works at offtake, a weir near offtake and 30m bed width dredging are shown in option-8. So this is option improve the situation of the channel.

From the bed level and cross-sectional analysis, it is observed that established a silt trap, river training works at offtake, a weir near offtake and 50m bed width dredging are shown in option- 9. So this is option improve the situation of the channel. So, among all options, it can be said that option-9 shows superior result. Table 8.3 are shows summary of the results.

For simulation run of all flood events at Base condition medium flood event are higher than high flood event. This picture is shown in all conditions also. Figure 8.53 are shown in comparison of high and medium flood event at base condition.

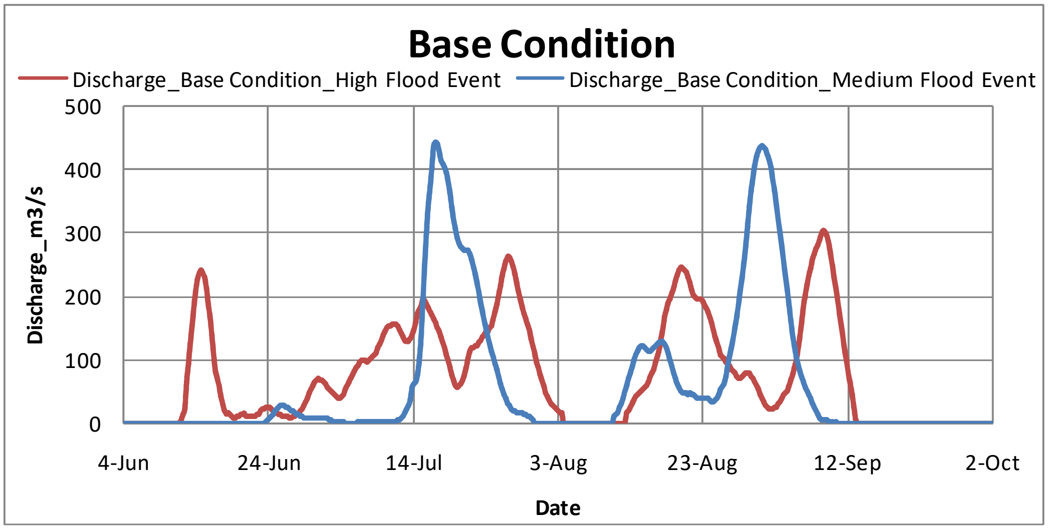

Figure 8.53: Comparison at base condition

In theoretically high flood event are provided higher discharge rather than medium or low flood event. But in model simulation of medium flood events, discharge value is higher than high flood event. For the checking of model, run the model at fixed bed condition. Than it is shown that, high flood event are higher than medium flood event. Figure 8.54 are shown in comparison of high and medium flood event at fixed bed condition.

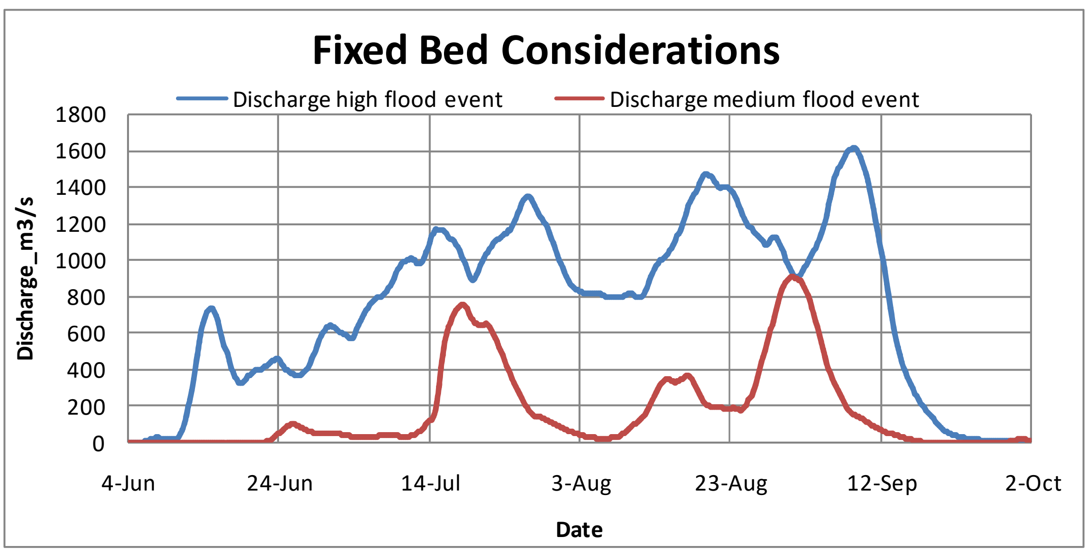

Figure 8.54: Fixed bed consideration for high and medium flood event

Table 8.3 The summary results in Hydrological and morphological analysis

Condition	High Flood Event (Pick Flow) (8th September)						
	Discharge (m^3/s)		Water Level (mPWD)		Convenience capacity		% of flow diversion
	Jamuna	New Dhaleswari	Jamuna	New Dhaleswari	Jamuna	New Dhaleswari	New Dhaleswari
Base	102862	302	10.41	10.42	4646678	9087	0.29
Option-01	108005	338	10.56	10.58	4805955	10636	0.31
Option-02	102733	824	10.61	10.62	5373361	25710	0.80
Option-02- Scenario-01	102364	1134	10.65	10.67	4723225	45121	1.11
Option-02- Scenario-02	102193	1158	10.50	10.51	4185372	48268	1.13
Option-03	102535	1081	10.52	10.53	4386367	30821	1.05
Option-03- Scenario-01	102241	1486	10.54	10.56	4618625	31054	1.45
Option-03- Scenario-02	102535	1244	10.56	10.57	4562554	39994	1.21
Option-04	103091	514	10.60	10.61	4469734	24714	0.50
Option-05	102131	1152	10.47	10.49	4494367	34663	1.13
Option-06	101704	1370	10.46	10.47	4416504	55112	1.35
Option-07	102573	553	10.55	10.56	4633623	26904	0.54
Option-08	102084	1245	10.58	10.59	4564244	42364	1.22
Option-09	102031	1376	10.58	10.59	5364992	55430	1.35
Condition	**High Flood Event (Dry Flow) (31st December)**						
	Discharge(m3/s)		**Water Level (mPWD)**		**Convenience capacity**		**% of flow diversion**
	Jamuna	**New Dhaleswari**	**Jamuna**	**New Dhaleswari**	**Jamuna**	**New Dhaleswari**	**New Dhaleswari**
Base	5702	-	5.83	-	257582	-	-
Option-01	5987	-	5.83	-	270456	-	-
Option-02	5713	-	5.83	-	258079	-	-
Option-02- Scenario-01	5822	-	5.83	-	263002	-	-
Option-02- Scenario-02	5699	-	5.83	-	257446	-	-
Option-03	5714	-	5.83	-	258124	-	-
Option-03- Scenario-01	5806	-	5.83	-	262280	-	-
Option-03- Scenario-02	5814	-	5.83	-	262641	-	-
Option-04	5702	-	5.83	-	257582	-	-
Option-05	5684	-	5.83	-	256768	-	-
Option-06	5696	10	5.83	5.84	257311	487	0.18
Option-07	5687	-	5.83	-	256904	-	-
Option-08	5708	-	5.83	-	257853	-	-
Option-09	5712	15	5.83	5.84	258033	604	0.26
Condition	**Medium Flood Event (Pick Flow) (30st August)**						
	Discharge(m3/s)		**Water Level (mPWD)**		**Convenience capacity**		**% of flow diversion**
	Jamuna	**New Dhaleswari**	**Jamuna**	**New Dhaleswari**	**Jamuna**	**New Dhaleswari**	**New Dhaleswari**

Condition	High Flood Event (Pick Flow) (8th September)						
	Discharge (m^3/s)		Water Level (mPWD)		Convenience capacity		% of flow diversion
	Jamuna	New Dhaleswari	Jamuna	New Dhaleswari	Jamuna	New Dhaleswari	New Dhaleswari
Base	68246	429	10.68	10.68	3082938	19380	0.63
Option-01	71658	433	10.77	10.78	3188604	19267	0.69
Option-02	67432	1154	10.64	10.64	3046167	52131	1.71
Option-02- Scenario-01	66973	1557	10.66	10.67	2980133	69283	2.32
Option-02- Scenario-02	67006	1577	10.65	10.66	3026923	71239	2.35
Option-03	67228	1367	10.64	10.64	2991479	60828	2.03
Option-03- Scenario-01	66758	1759	10.60	10.61	3015719	79461	2.63
Option-03- Scenario-02	66891	1739	10.52	10.52	2976484	77381	2.60
Option-04	68280	416	10.53	10.53	3084474	18792	0.61
Option-05	66923	1655	10.61	10.62	2977908	73643	2.47
Option-06	66676	2001	10.67	10.67	3012015	90393	3.00
Option-07	68222	444	10.57	10.57	3035710	19757	0.65
Option-08	66948	1679	10.64	10.64	3024302	75847	2.51
Option-09	66563	2017	10.65	10.65	3006910	91116	3.03

Condition	Medium Flood Event (Dry Flow) (31st December)						
	Discharge(m3/s)		Water Level (mPWD)		Convenience capacity		% of flow diversion
	Jamuna	New Dhaleswari	Jamuna	New Dhaleswari	Jamuna	New Dhaleswari	New Dhaleswari
Base	6922	-	6.66	-	312694	-	-
Option-01	7268	-	6.66	-	323408	-	-
Option-02	6926	3	6.66	6.66	312874	136	0.04
Option-02- Scenario-01	6849	73	6.66	6.66	304764	2248	1.07
Option-02- Scenario-02	6814	107	6.66	6.66	307815	3834	1.57
Option-03	6888	33	6.66	6.66	306499	1468	0.48
Option-03- Scenario-01	6786	134	6.66	6.66	306550	5053	1.97
Option-03- Scenario-02	6769	156	6.66	6.66	301204	5942	2.30
Option-04	6925	-	6.66	-	312829	-	-
Option-05	6799	121	6.66	6.66	302539	5384	1.78
Option-06	6708	199	6.66	6.66	303027	8990	2.79
Option-07	6926	-	6.66	-	308190	-	-
Option-08	6799	120	6.66	6.66	307137	4421	1.76
Option-09	6719	207	6.66	6.66	303523	9351	3.08

Condition	Low Flood Event (Pick Flow) (4th August)						
	Discharge(m3/s)		Water Level (mPWD)		Convenience capacity		% of flow diversion
	Jamuna	New Dhaleswari	Jamuna	New Dhaleswari	Jamuna	New Dhaleswari	New Dhaleswari
Base	57456	331	10.37	10.37	2595512	14953	0.58
Option-01	60329	367	10.44	10.44	2684491	16579	0.61

Condition	High Flood Event (Pick Flow) (8th September)						
	Discharge (m^3/s)		Water Level (mPWD)		Convenience capacity		% of flow diversion
	Jamuna	New Dhaleswari	Jamuna	New Dhaleswari	Jamuna	New Dhaleswari	New Dhaleswari
Option-02	56813	1015	10.33	10.34	2566465	45852	1.79
Option-02- Scenario-01	56265	1297	10.36	10.36	2503653	58591	2.31
Option-02- Scenario-02	56380	1237	10.35	10.36	2546905	55880	2.19
Option-03	56301	1260	10.42	10.43	2505255	56919	2.24
Option-03- Scenario-01	56173	1546	10.36	10.36	2537554	69839	2.75
Option-03- Scenario-02	56081	1410	10.31	10.31	2495466	63695	2.51
Option-04	57324	369	10.36	10.36	2589549	16669	0.64
Option-05	56191	1341	10.42	10.42	2500360	60578	2.39
Option-06	55704	1707	10.39	10.39	2516367	77112	3.06
Option-07	56947	379	10.35	10.36	2534000	17121	0.67
Option-08	56123	1366	10.36	10.36	2535295	61708	2.43
Option-09	56052	1731	10.37	10.37	2532088	78196	3.09
Condition	**Low Flood Event (Dry Flow) (31st December)**						
	Discharge(m3/s)		**Water Level (mPWD)**		**Convenience capacity**		**% of flow diversion**
	Jamuna	**New Dhaleswari**	**Jamuna**	**New Dhaleswari**	**Jamuna**	**New Dhaleswari**	**New Dhaleswari**
Base	5982	-	5.95	-	270230	-	-
Option-01	6281	-	5.95	-	279489	-	-
Option-02	5978	-	5.95	-	270050	-	-
Option-02- Scenario-01	5982	-	5.95	-	266184	-	-
Option-02- Scenario-02	5958	24	5.95	5.96	269146	1084	0.40
Option-03	5986	-	5.95	-	266362	-	-
Option-03- Scenario-01	5944	33	5.95	5.96	268514	1491	0.56
Option-03- Scenario-02	5936	42	5.95	5.96	264137	1897	0.71
Option-04	5968	-	5.95	-	269598	-	-
Option-05	5974	7	5.95	5.96	265828	316	0.12
Option-06	5836	136	5.95	5.96	263635	6144	2.33
Option-07	5967	-	5.95	-	265517	-	-
Option-08	5935	27	5.95	5.96	268107	1220	0.45
Option-09	5862	156	5.95	5.96	264809	7047	2.66

Parameter	**Bed level (m_PWD) End of the simulation**			**Cross- section at offtake End of the simulation**		
Condition	High	Medium	Low	High	Medium	Low
Base	9.66	9.24	9.52	Silted up	Silted up	Silted up
Option-01	9.38	8.63	8.81	Silted up	Silted up	Silted up
Option-02	8.85	8.63	8.39	Silted up	Silted up	Silted up
Option-02- Scenario-01	8.60	8.37	8.22	Silted up	Silted up	Silted up
Option-02- Scenario-02	8.72	7.95	8.55	Silted up	Silted up	Silted up
Option-03	8.86	7.97	8.35	Silted up	Silted up	Silted up
Option-03- Scenario-01	8.54	7.71	7.86	Silted up	Silted up	Silted up

Condition	High Flood Event (Pick Flow) (8th September)						
	Discharge (m^3/s)		Water Level (mPWD)		Convenience capacity		% of flow diversion
	Jamuna	New Dhaleswari	Jamuna	New Dhaleswari	Jamuna	New Dhaleswari	New Dhaleswari

Option-03- Scenario-02	8.42	7.46	7.79	Silted up	Silted up	Stable
Option-04	9.03	8.95	8.59	Silted up	Silted up	Silted up
Option-05	8.43	7.86	8.16	Silted up	Silted up	Stable
Option-06	8.43	8.15	7.36	Silted up	Silted up	Stable
Option-07	9.01	8.87	8.48	Silted up	Silted up	Silted up
Option-08	5.42	5.29	5.16	Silted up	Stable	Stable
Option-09	5.37	5.03	4.07	Stable	Stable	Stable

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 General

Due to high sedimentation at the offtake mouth, the New Dhaleswari river has already lost its capacity of flow diversion originated from the river Jamuna during the lean period. Therefore, an offtake flow options at the offtake mouth are necessary for the augmentation of flow. In the connection two-dimensional morphological model has been utilized to assess the various management options to keep New Dhaleswari river alive.The key findings of the present study have been summarized below.

9.2 Conclusions

The following conclusions drawn of the present study are as follows:

i) Analyzing the historical discharge and water level data of Jamuna river and New Dhaleswari offtake it has been found that flow diversion through the New Dhaleswari River is decreasing during the dry and monsoon period continuously in the last few decades. These analyses have been described in chapter 6.

ii) Analyzing the historical satellite images from year 2000 to 2015, it can be seen that the planform of offtake is being continuously moving within the stretch of 1 km to 1.5 km of the river in the vicinity of the new Dhaleswari offtake. Moreover, it was found that the mouth of the offtake was not well defined. As a result, it is very difficult to identify the mouth of offtake. These analyses have been described in chapter 6.

iii) 9 (nine) different options and 4 (four) scenarios have been simulated using MIKE21C model. These options have been described in chapter 7. Comparison of model results option-1, 2 and 3 shows that the amount of flow diversion with respect to Jamuna is 1.6% 1.72%, 2.20% in the monsoon period. And also flow diversion 1.83%, 1.85%, 2.23% and 2.27% is for scenario of Option 2 and Option 3. But in lean period the flow diversion has been found 0% (zero). Maximum discharge obtained using those options is 1068 m^3/s, 1170 m^3/s, 1423 m^3/s and also maximum discharge of scenarios are 1284 m^3/s, 1305 m^3/s, 1477 m^3/s, 1489 m^3/s. Deposition of sediment is shown in all options and scenarios. Deposition of

5 km reach of those options is 3.02 Mm^3, 7.31 Mm^3, 13.66 Mm^3 and for scenarios runs it is shown 9.78 Mm^3, 27.52 Mm^3, 16.98 Mm^3 and 26.31 Mm^3.

iv) Similarly, model results as obtained using option-4, 5 and 6 shows that the amount of flow diversion with respect to Jamuna is 1.05% 2.36%, 3.02% respectively in the peak season. But in lean period the flow diversion has been found 0%, 1.49% and 2.49% respectively. Maximum discharge of those options is 536 m^3/s, 1672 m^3/s, 2001 m^3/s. Erosion of 5 km reach of options 4 and option 5 is 3.53 Mm^3, 6.64 Mm^3 and deposition 6.84 Mm^3 in option 6.

v) The amount of flow diversion is 0.83% 2.82%, 3.08% in the monsoon of Option 7, Option 8 and Option 9. But in lean period the flow diversion has been found 0%, 1.49% and 2.39% for option opttion7, 8,9 . Maximum discharge of those options is 554 m^3/s, 1689 m^3/s, 2017 m^3/s. Erosion of sediment is shown in all options. Erosion of 5 km reach of all options is 2.13 Mm^3, 8.42 Mm^3 and 7.09 Mm^3.

vi) Option-9 (Placing a silt trap and a groyne at Jamuna, two guide bunds, weir and 50m dredging at New Dhaleswari river) is found to be more suitable solution to sustain the offtake.

9.3 Recommendations for Future Study

The recommendations for future study can be suggested as follows:

i) New Dhaleswari offtake is changes in every year, so it is quite difficult to identify the offtake for preparing the model domain. In this study, model domain has been fixed by observing the position of offtake in the bankline and bathymetry at 2015.

ii) The char movement of Jamuna River is a continuous process due to its braided nature. Most of the time offtake are silted up. Therefore, the dredging alignment or river training works of New Dhaleswari river, proposed in this thesis should be revised according to the planform of the river for future model simulation.

iii) New Dhaleswari River flow is dependent on Jamuna River. Jamuna is an alluvial river in a deltaic region of Bangladesh, and morphological activities are very dynamic in this river. Dredging of New Dhaleswari River may be sustainable option with the with respect to which can be future studied.

iv) Data availability of New Dhaleswari River and its offtake was limited. Extensive hydrometric and hydrologic and sediment data collection program need to be undertaken for more detailed further study related to the river offtakes of the country.

v) The suggested options used can be further investigated using physical modeling techniques.

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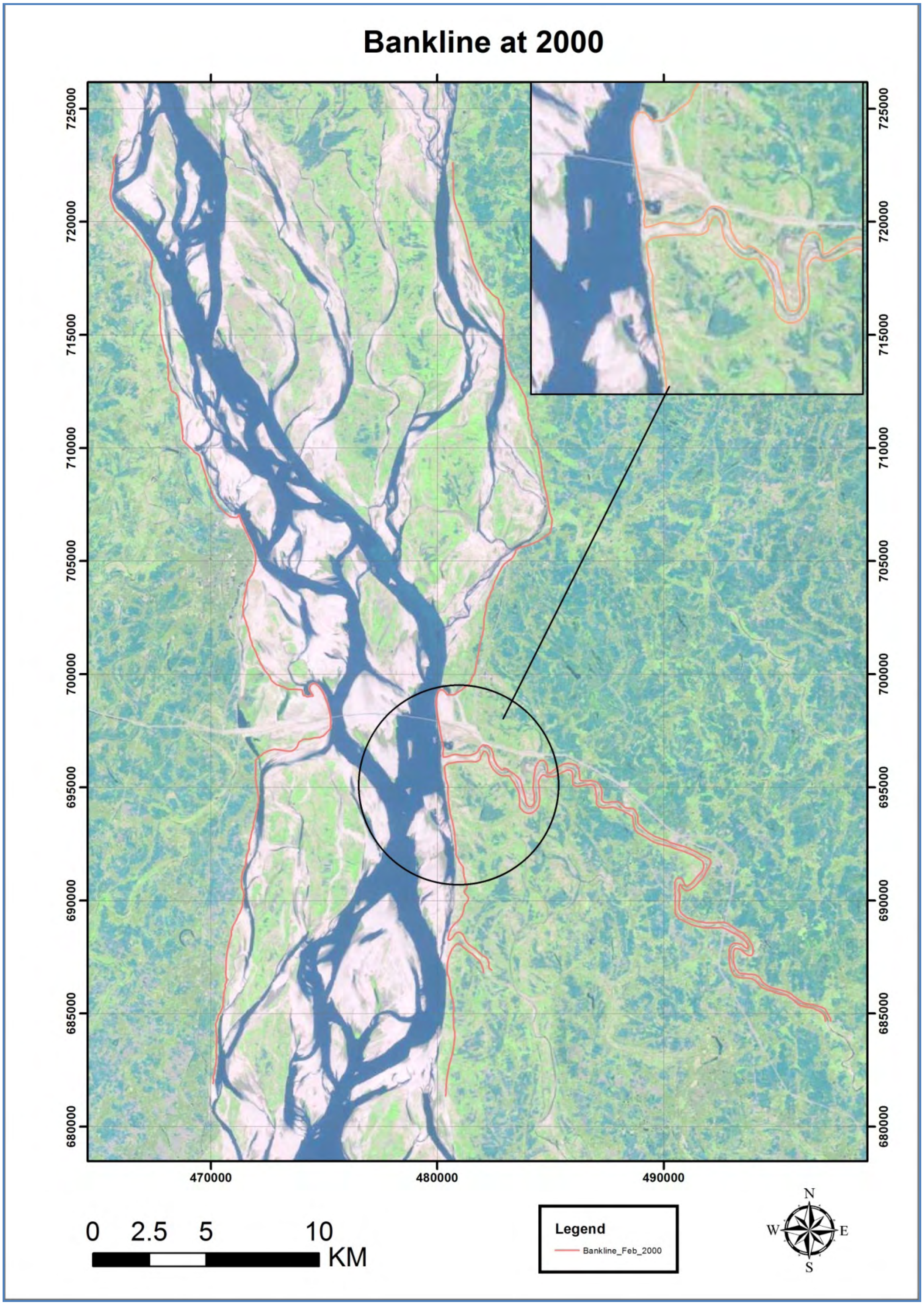
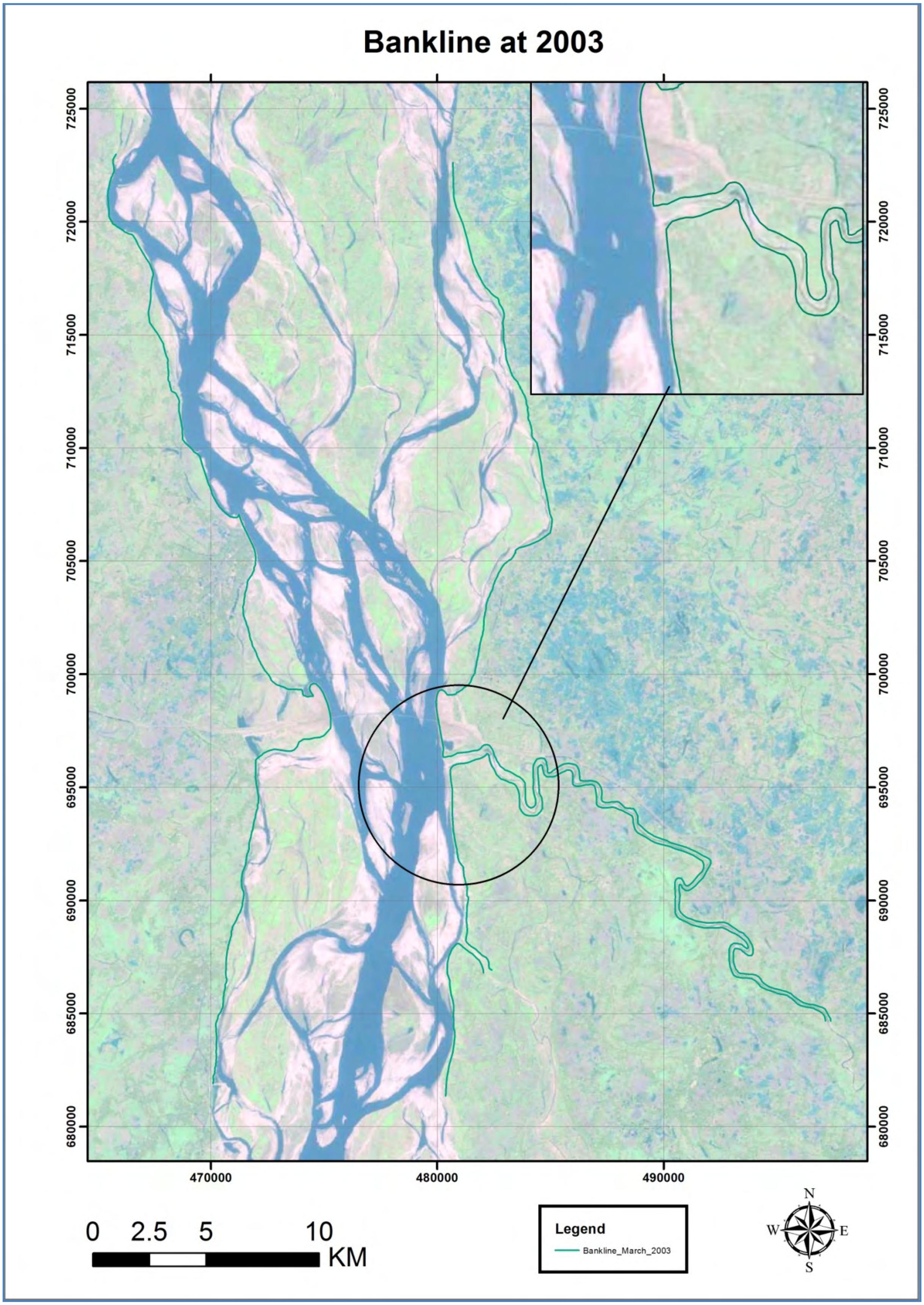
APPENDIX-A

Map of Bankline Analysis

Appendix-A


Bankline at 2000
725000
720000
715000
710000
705000
700000
695000
690000
685000
680000
470000
480000
490000
0 2.5 5 10
KM
Legend
Bankline_Feb_2000
N
S
E
W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720000
715000
710000
705000
700000
695000
690000
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680000
470000
480000
490000
0 2.5 5 10
KM
Legend
Bankline_March_2003
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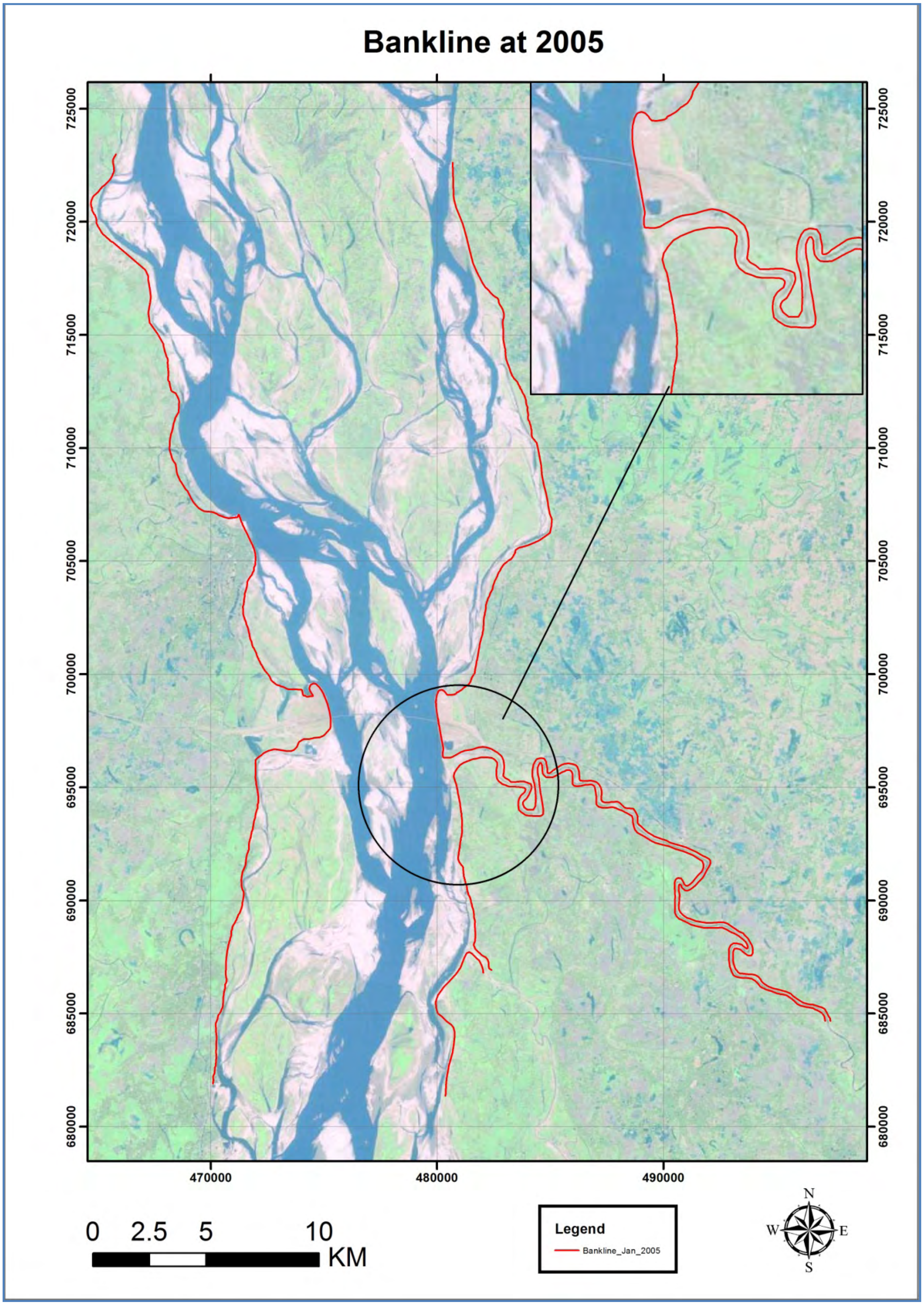
W
E
S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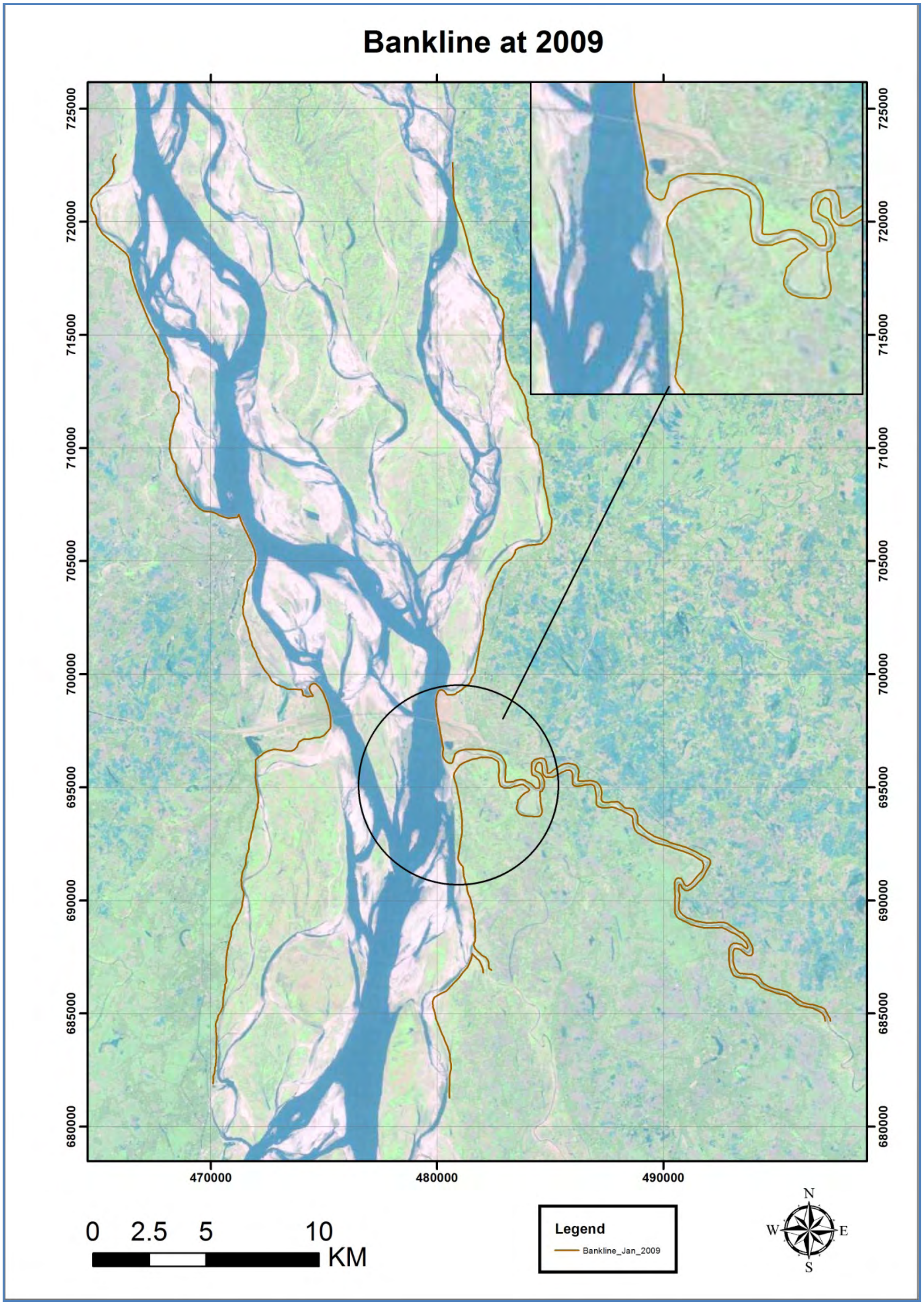
715000
710000
705000
700000
695000
690000
685000
680000
470000
480000
490000
0 2.5 5 10
KM
Legend
Bankline_Jan_2005
N
W
E
S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715000
710000
705000
700000
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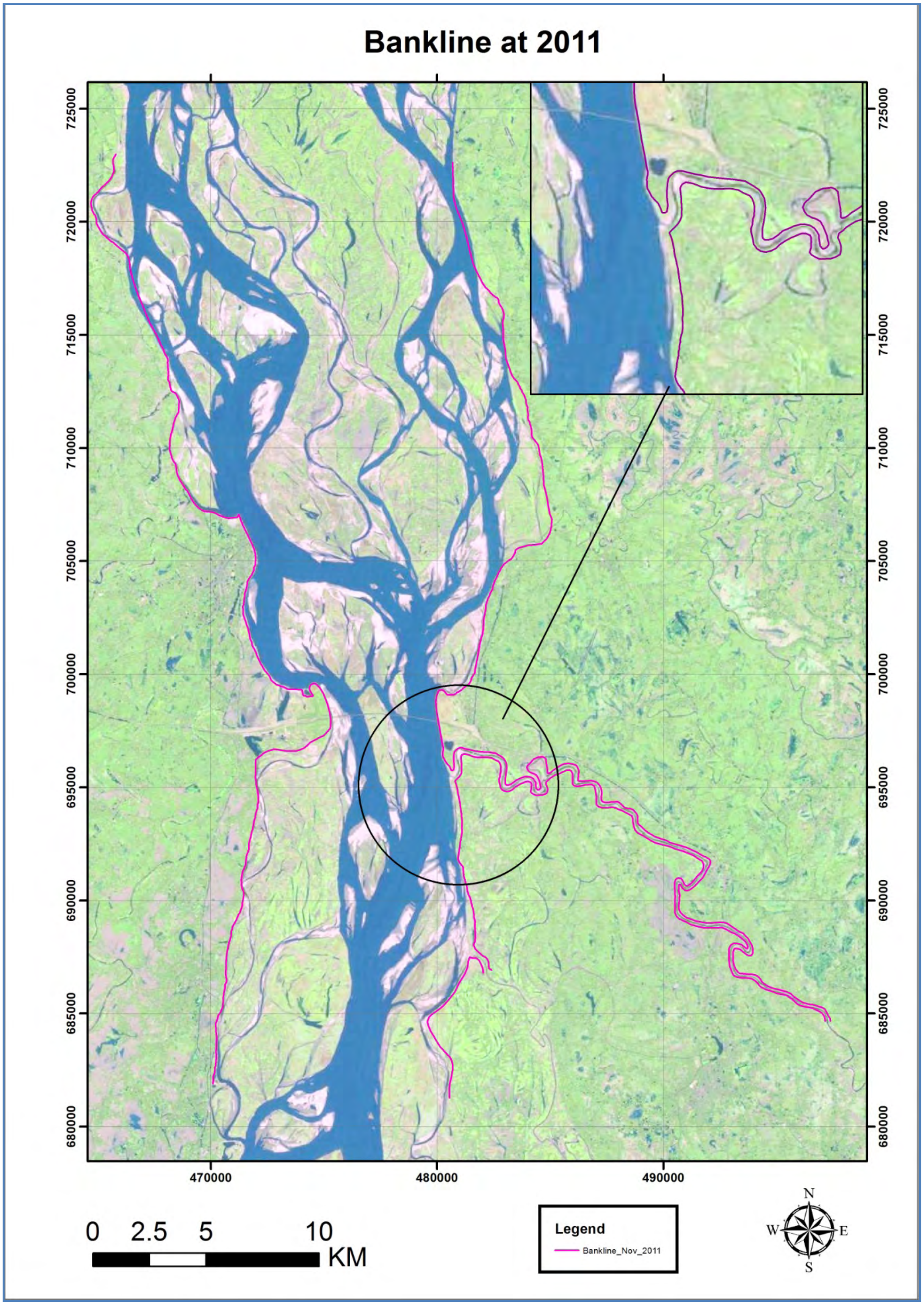
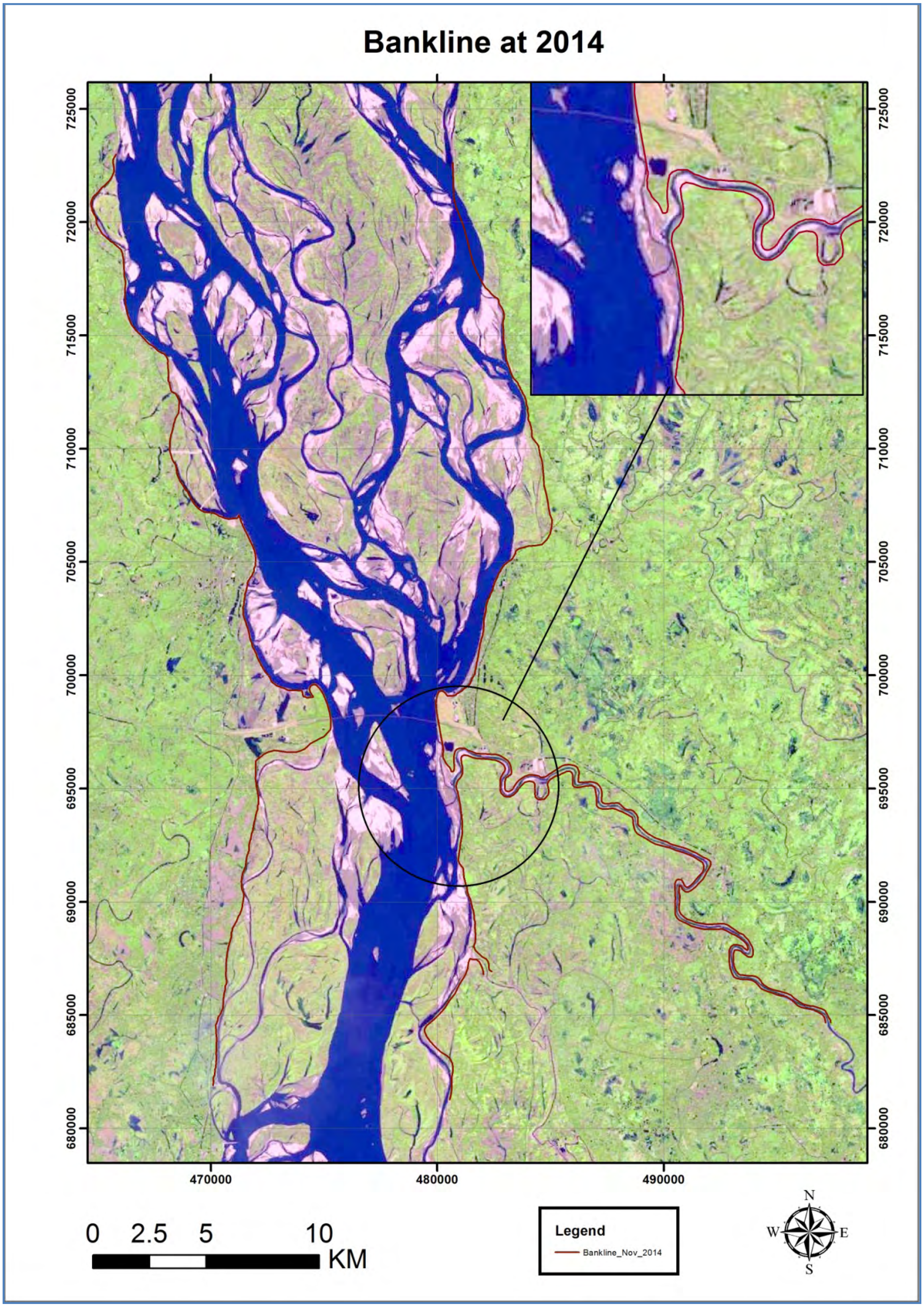
680000
470000
480000
490000
0 2.5 5 10
KM
Legend
Bankline_Jan_2009
N
S
W
E


Bankline at 2011
725000
720000
715000
710000
705000
700000
695000
690000
685000
680000
470000
480000
490000
0 2.5 5 10
KM
Legend
Bankline_Nov_2011
N
W
E
S


Bankline at 2014
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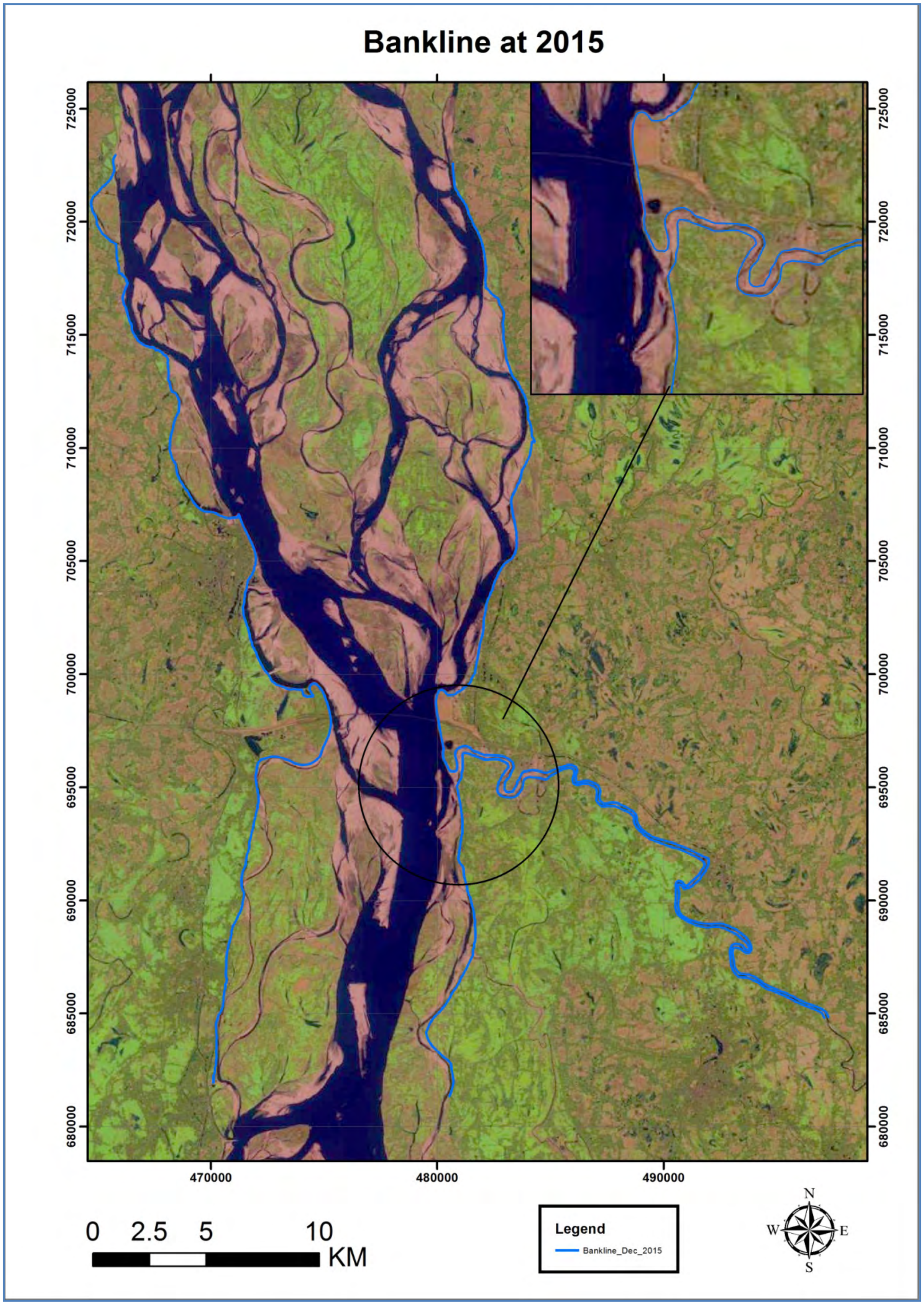
720000
715000
710000
705000
700000
695000
690000
685000
680000
470000
480000
490000
0 2.5 5 10
KM
Legend
Bankline_Nov_2014
N
W
E
S


Bankline at 2015
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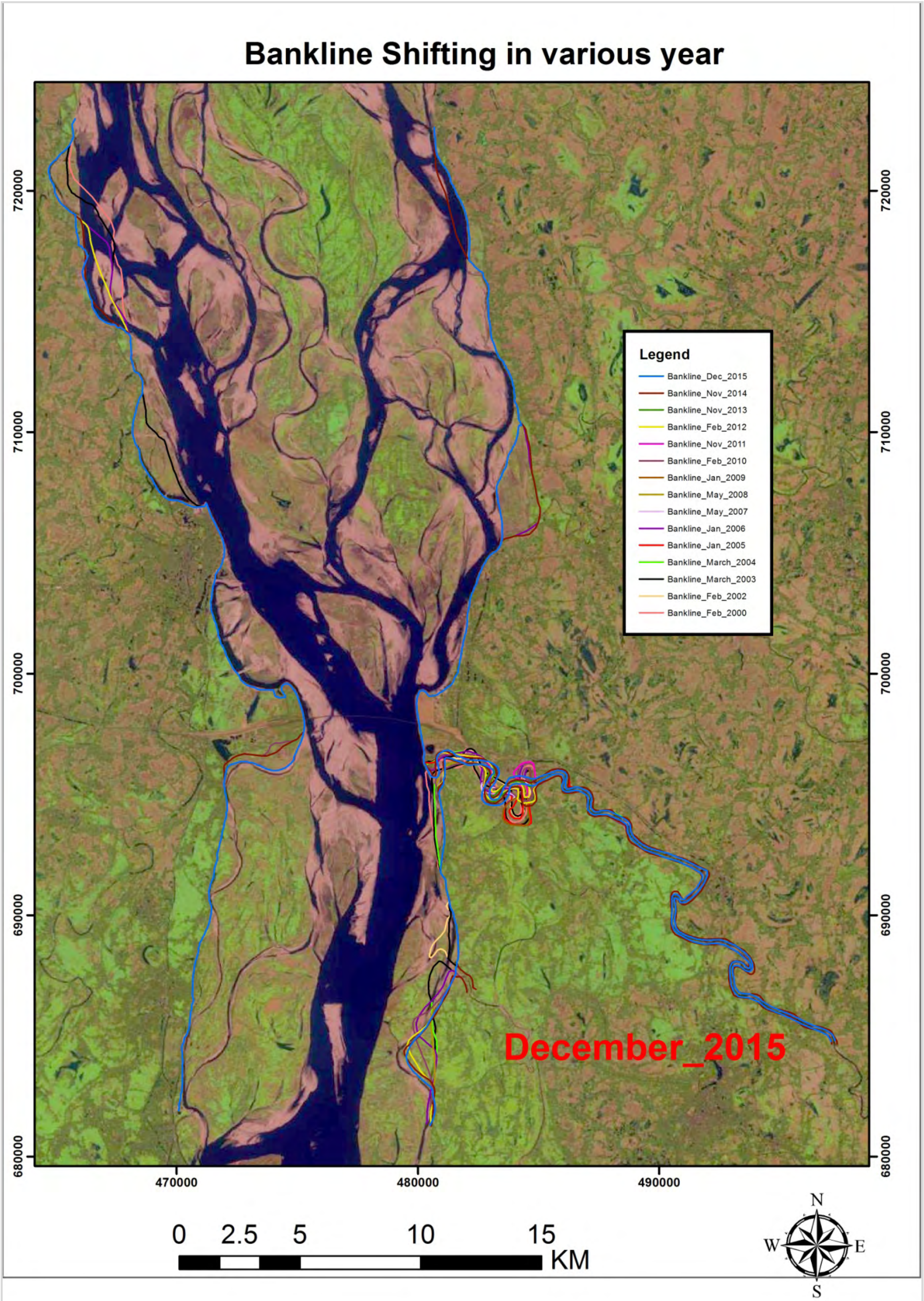
715000
710000
705000
700000
695000
690000
685000
680000
470000
480000
490000
0 2.5 5 10
KM
Legend
Bankline_Dec_2015
N
S
E
W



Bankline Shifting in various year
Legend
Bankline_Dec_2015
Bankline_Nov_2014
Bankline_Nov_2013
Bankline_Feb_2012
Bankline_Nov_2011
Bankline_Feb_2010
Bankline_Jan_2009
Bankline_May_2008
Bankline_May_2007
Bankline_Jan_2006
Bankline_Jan_2005
Bankline_March_2004
Bankline_March_2003
Bankline_Feb_2002
Bankline_Feb_2000
December_2015
720000
710000
700000
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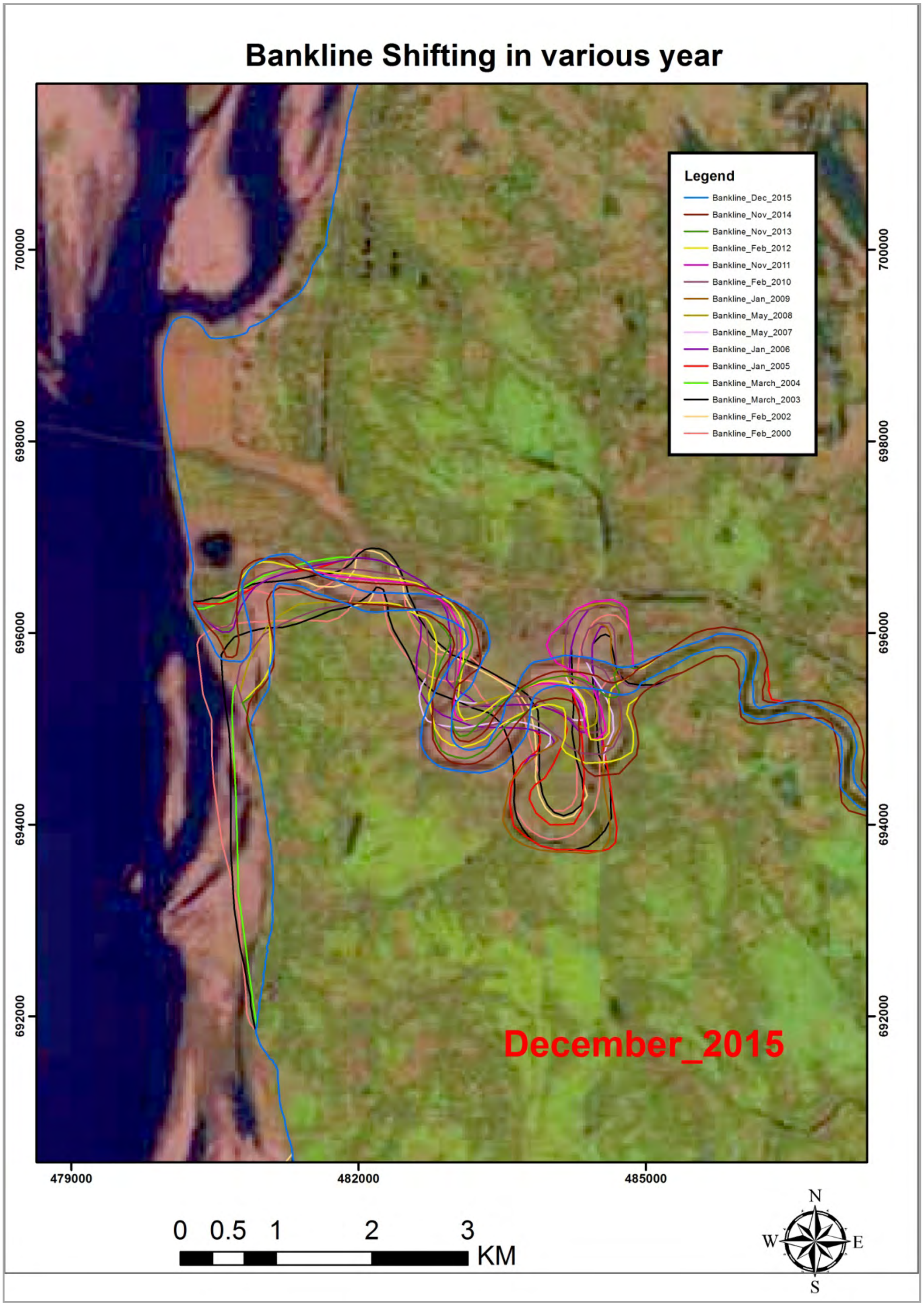
680000
470000
480000
490000
0
2.5
5
10
15
KM
N
W
E
S

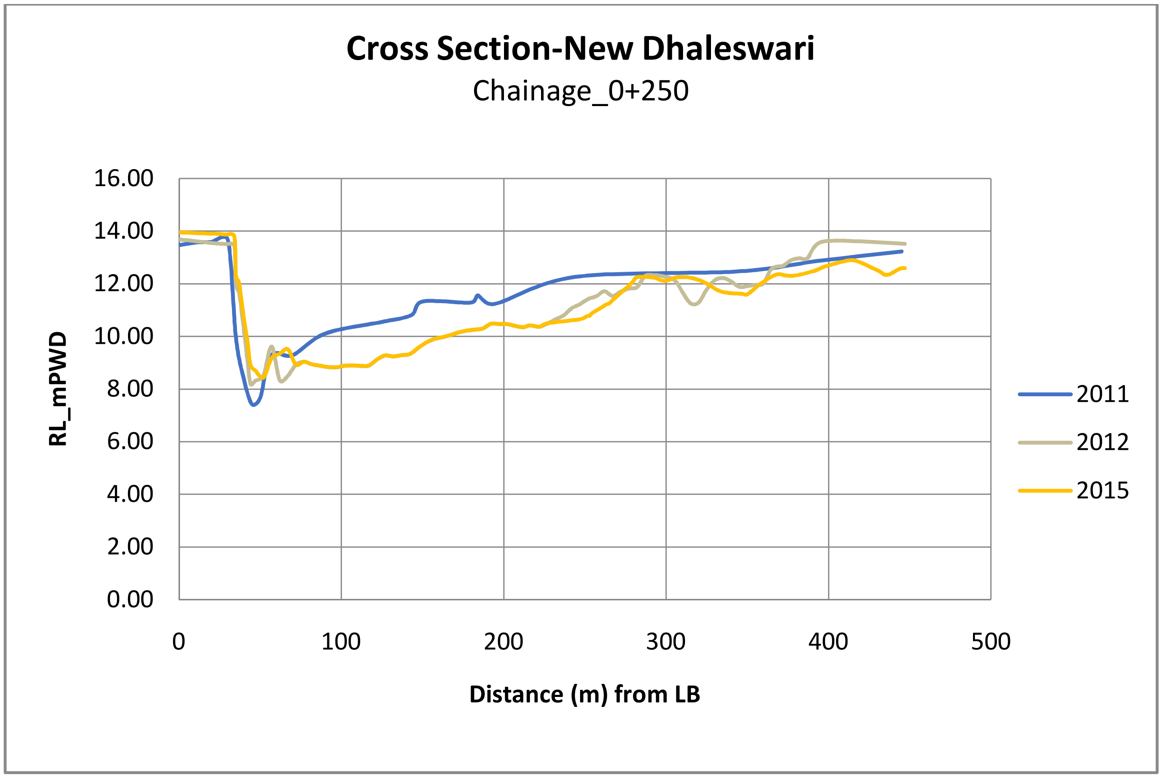


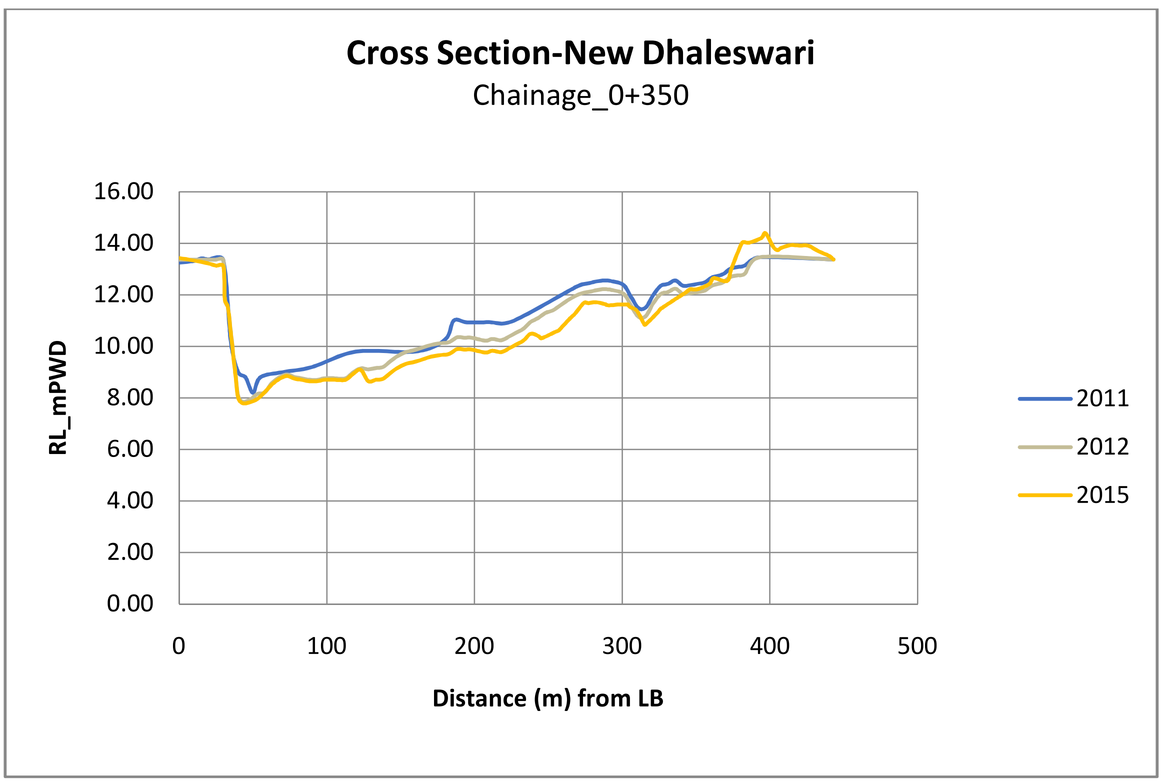
Bankline Shifting in various year
Legend
Bankline_Dec_2015
Bankline_Nov_2014
Bankline_Nov_2013
Bankline_Feb_2012
Bankline_Nov_2011
Bankline_Feb_2010
Bankline_Jan_2009
Bankline_May_2008
Bankline_May_2007
Bankline_Jan_2006
Bankline_Jan_2005
Bankline_March_2004
Bankline_March_2003
Bankline_Feb_2002
Bankline_Feb_2000
700000
698000
696000
694000
692000
479000
482000
485000
December_2015
0 0.5 1 2 3
KM
N
W
E
S

APPENDIX-B

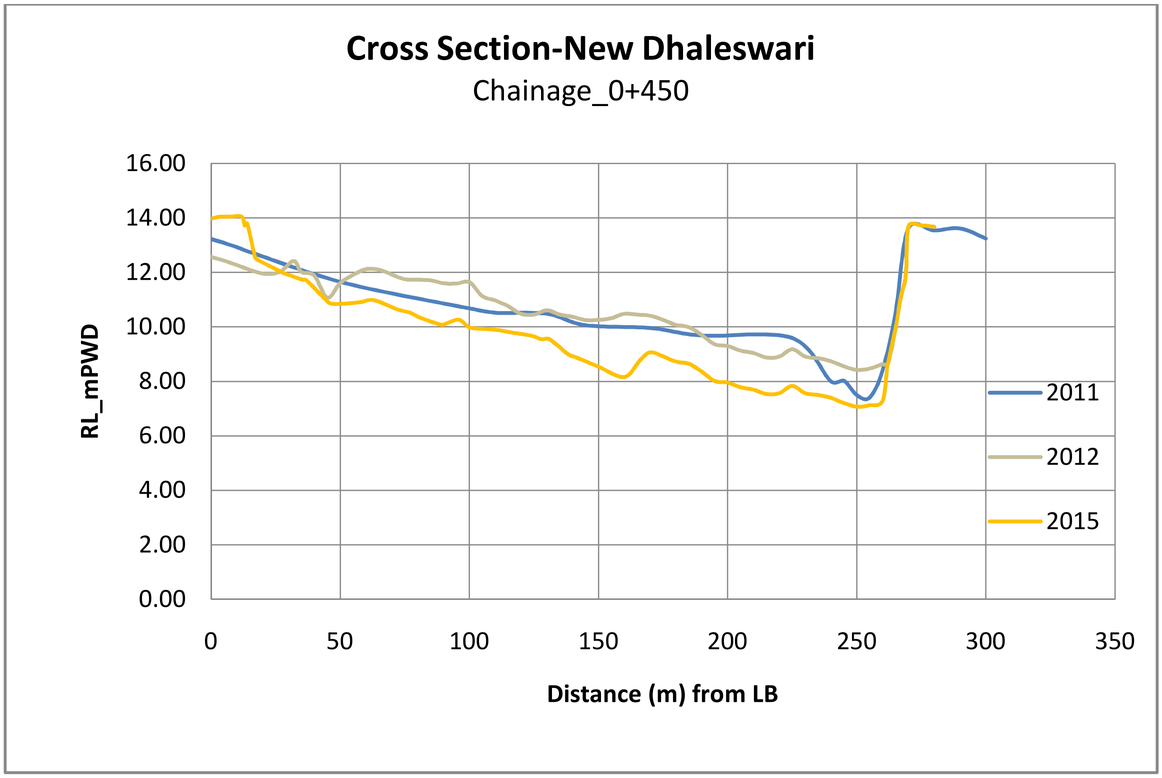
Cross section Analysis of New Dhaleswari River

Appendix-B


Cross Section-New Dhaleswari
Chainage_0+250
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
RL_mPWD
0
100
200
300
400
500
Distance (m) from LB
2011
2012
2015


Cross Section-New Dhaleswari
Chainage_0+350
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
RL_mPWD
0
100
200
300
400
500
Distance (m) from LB
2011
2012
2015

Appendix-B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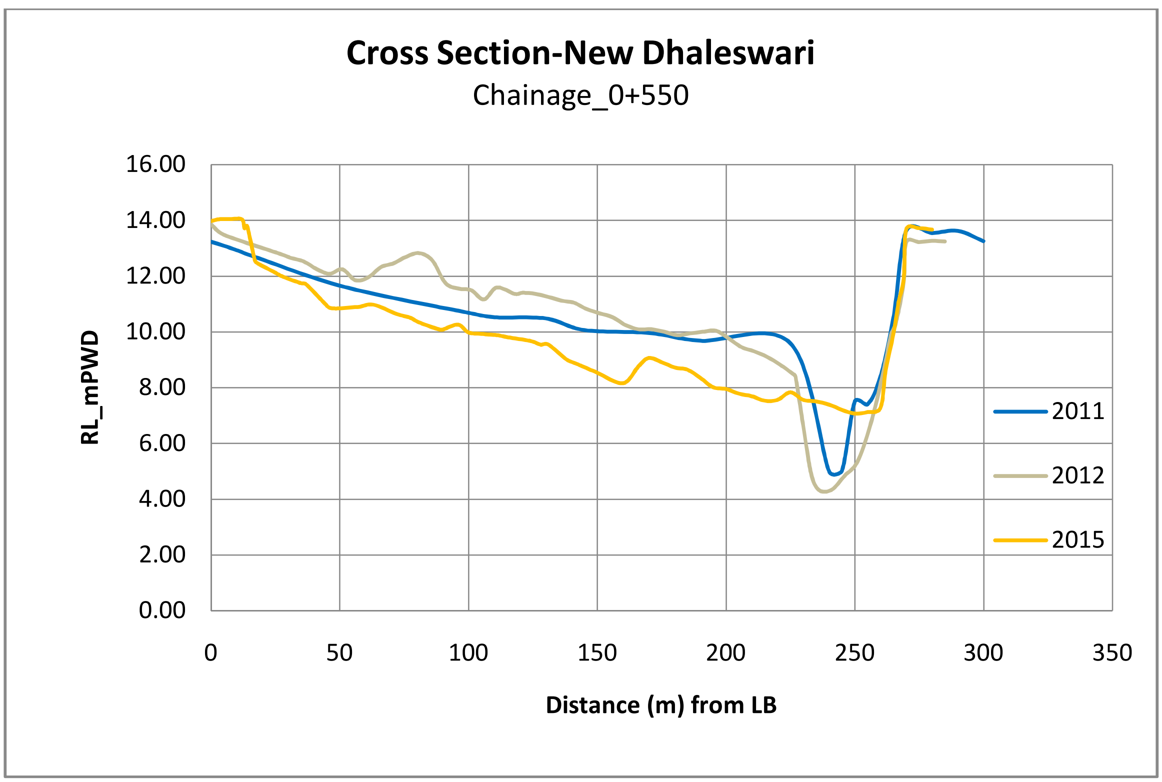
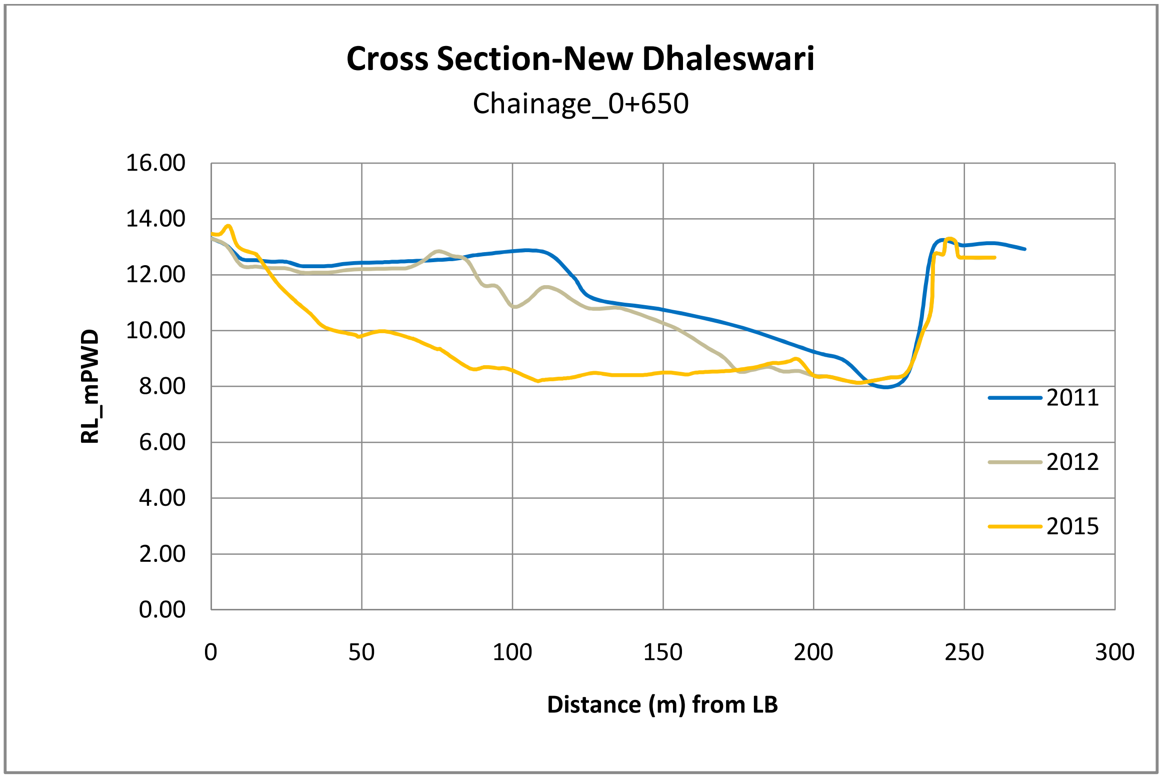
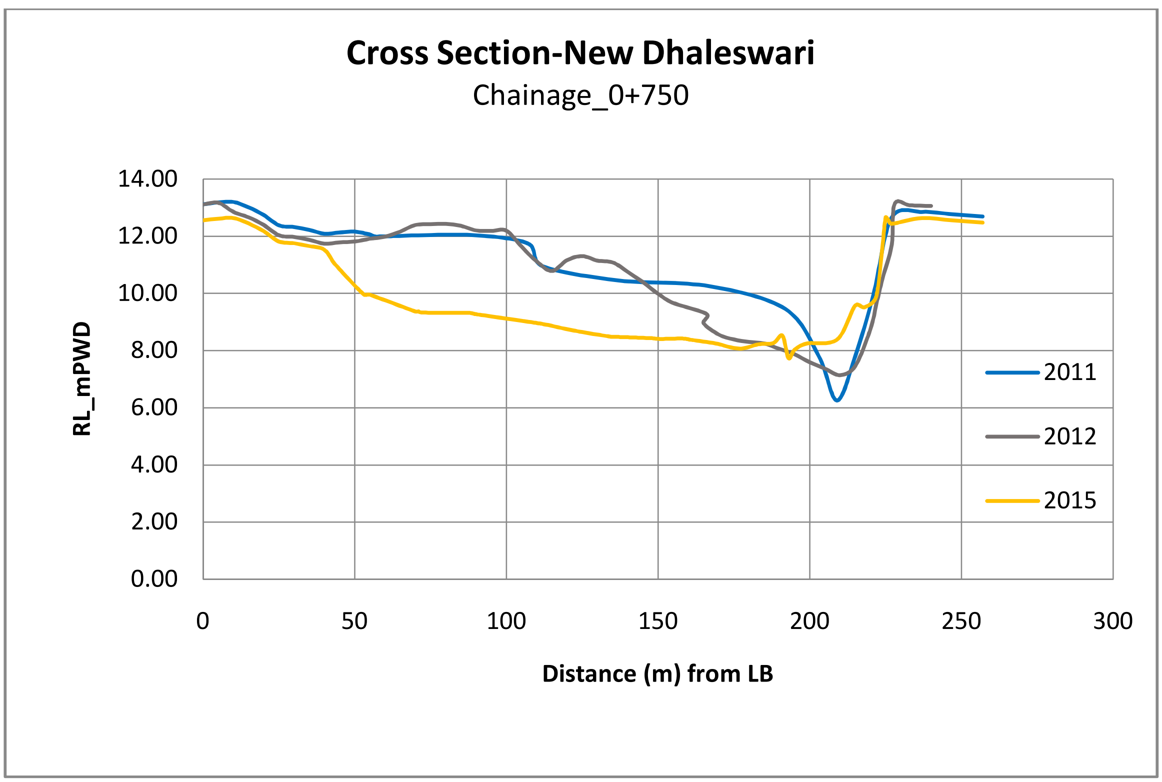
Chainage_0+450
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
RL_mPWD
0
50
100
150
200
250
300
350
Distance (m) from LB
2011
2012
2015


Cross Section-New Dhaleswari
Chainage_0+550
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
RL_mPWD
0
50
100
150
200
250
300
350
Distance (m) from LB
2011
2012
2015

Appendix-B

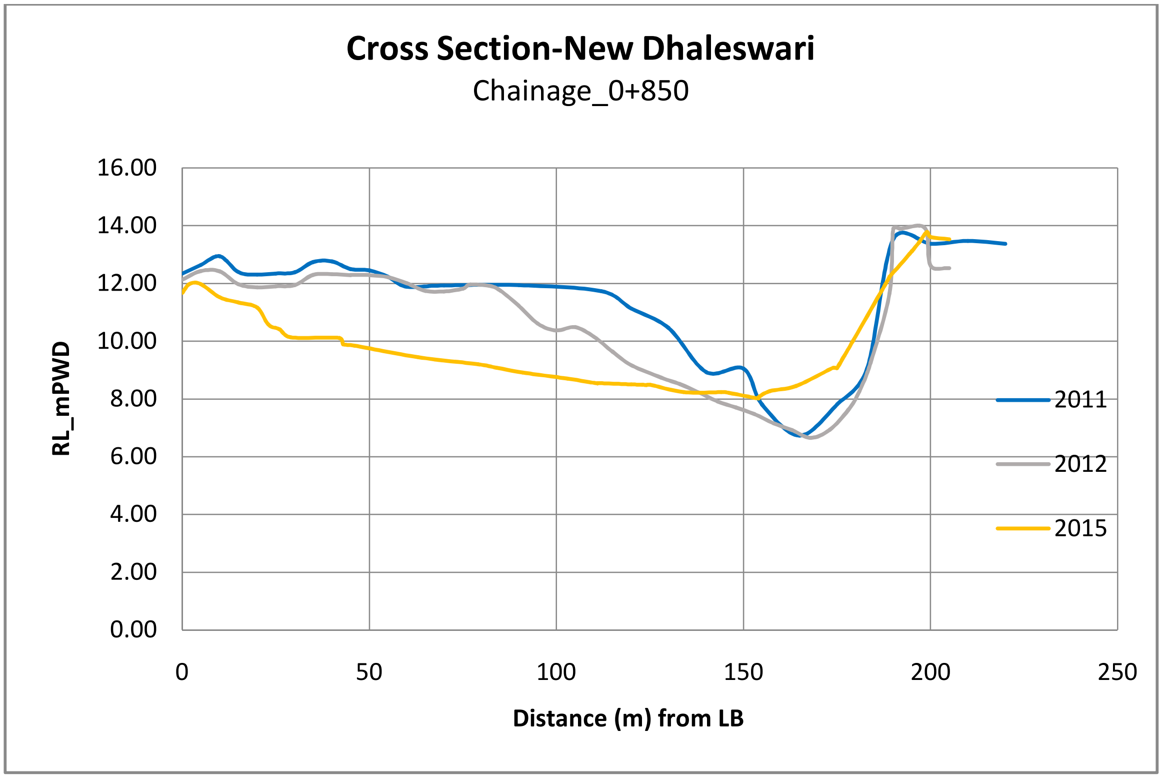


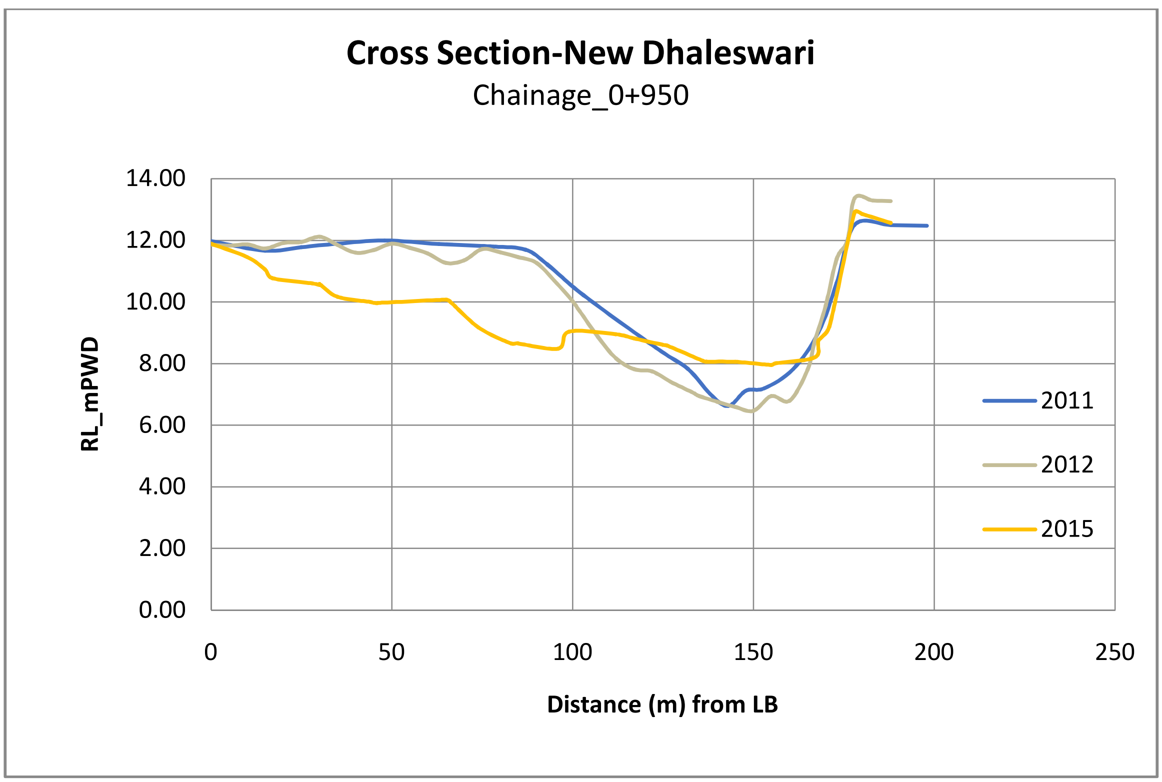
Cross Section-New Dhaleswari
Chainage_0+650
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
RL_mPWD
0
50
100
150
200
250
300
Distance (m) from LB
2011
2012
2015



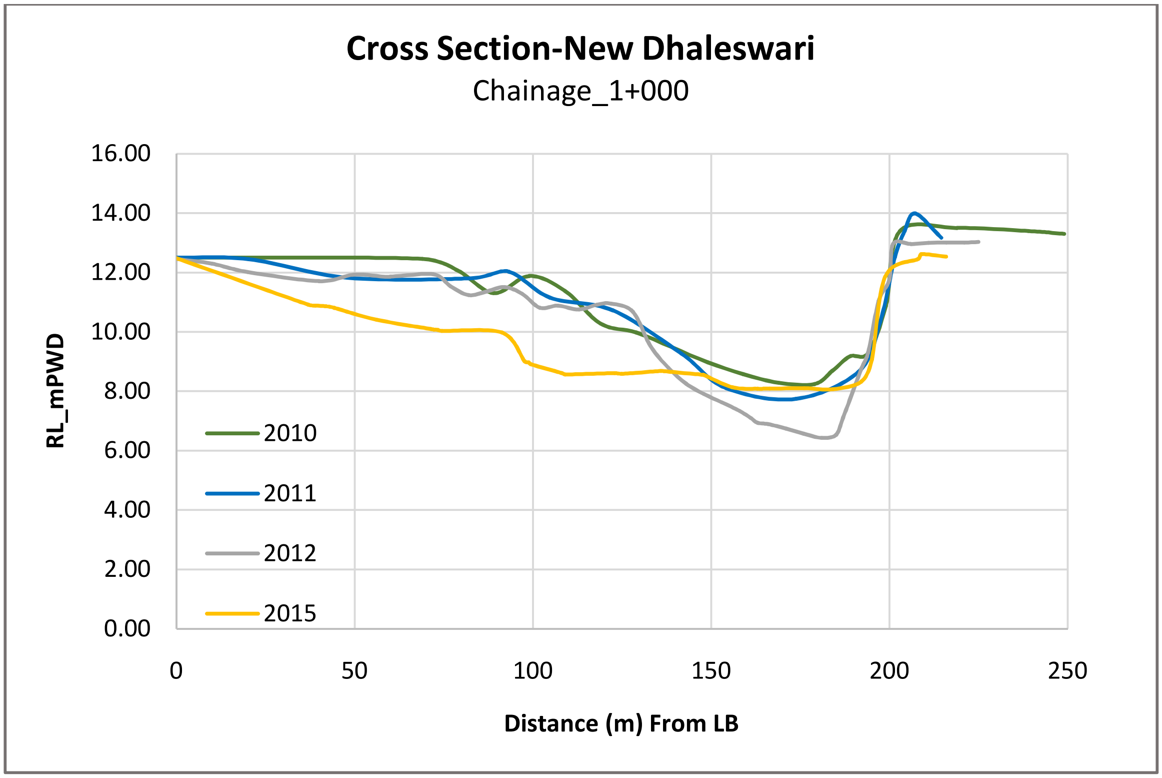
Cross Section-New Dhaleswari
Chainage_0+750
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
RL_mPWD
0
50
100
150
200
250
300
Distance (m) from LB
2011
2012
2015

Appendix-B

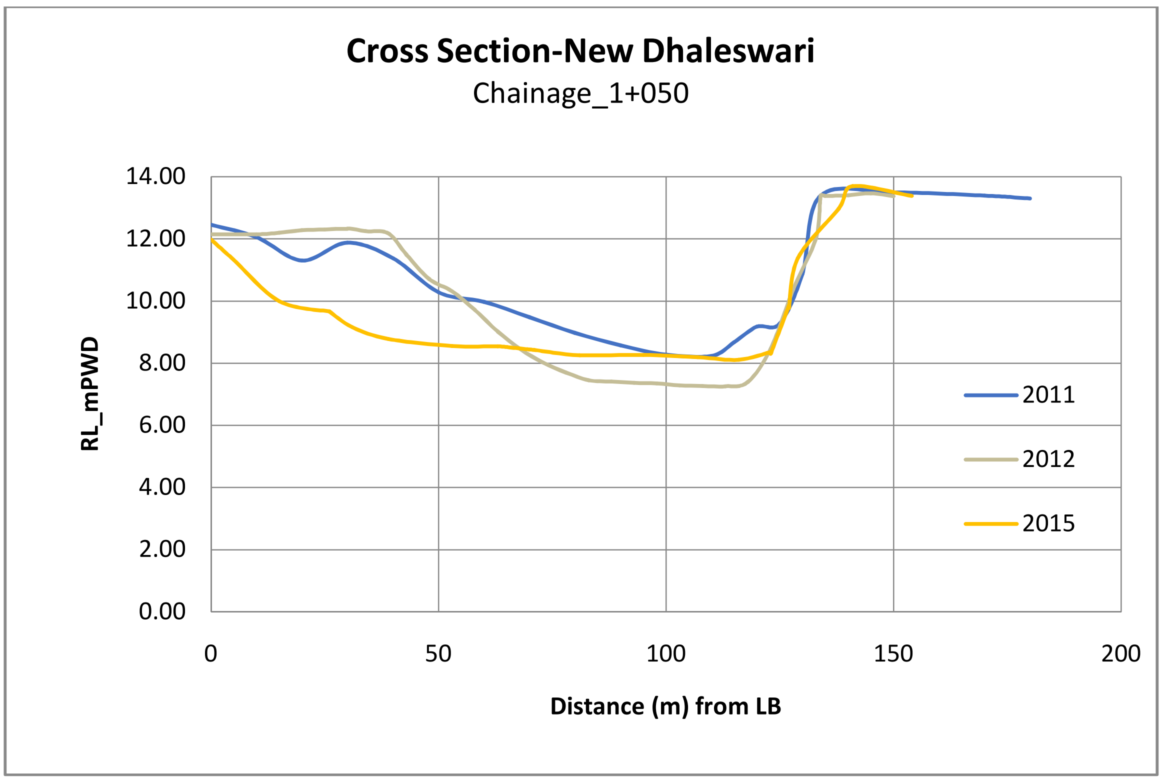

Cross Section-New Dhaleswari
Chainage_0+850
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
RL_mPWD
0
50
100
150
200
250
Distance (m) from LB
2011
2012
2015


Cross Section-New Dhaleswari
Chainage_0+950
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
RL_mPWD
0
50
100
150
200
250
Distance (m) from LB
2011
2012
2015

Appendix-B

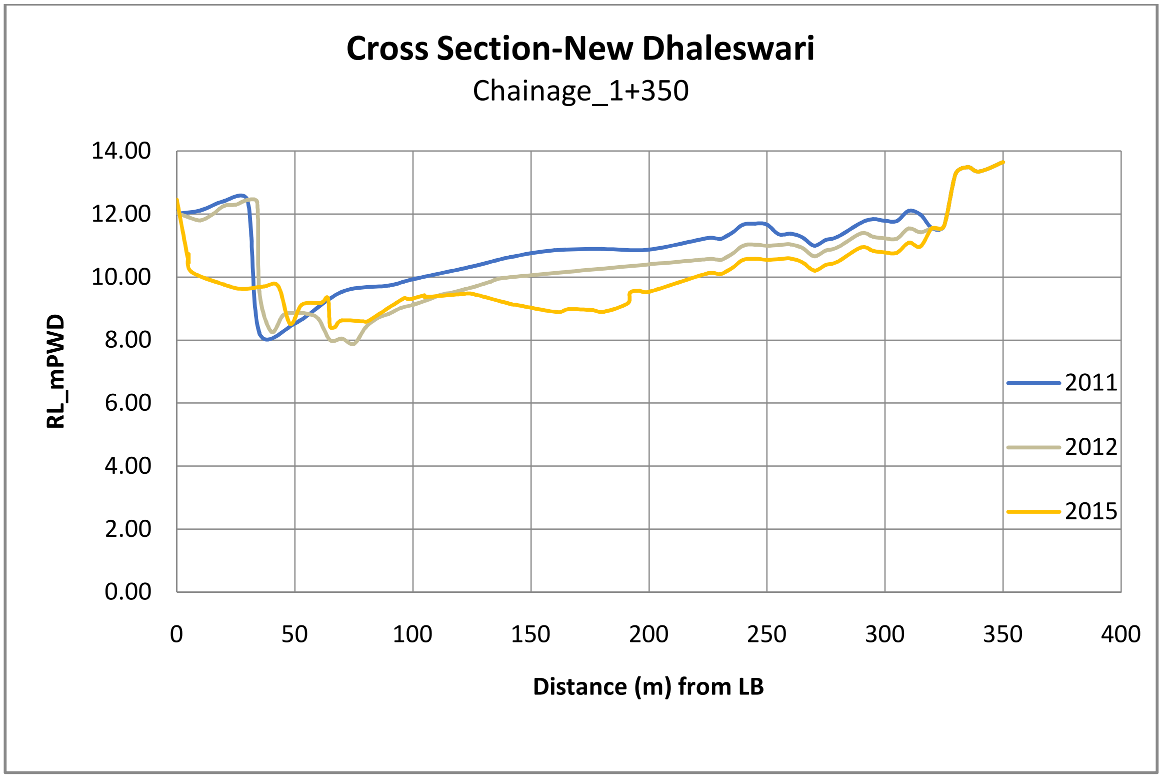


Cross Section-New Dhaleswari
Chainage_1+000
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
RL_mPWD
2010
2011
2012
2015
0
50
100
150
200
250
Distance (m) From LB

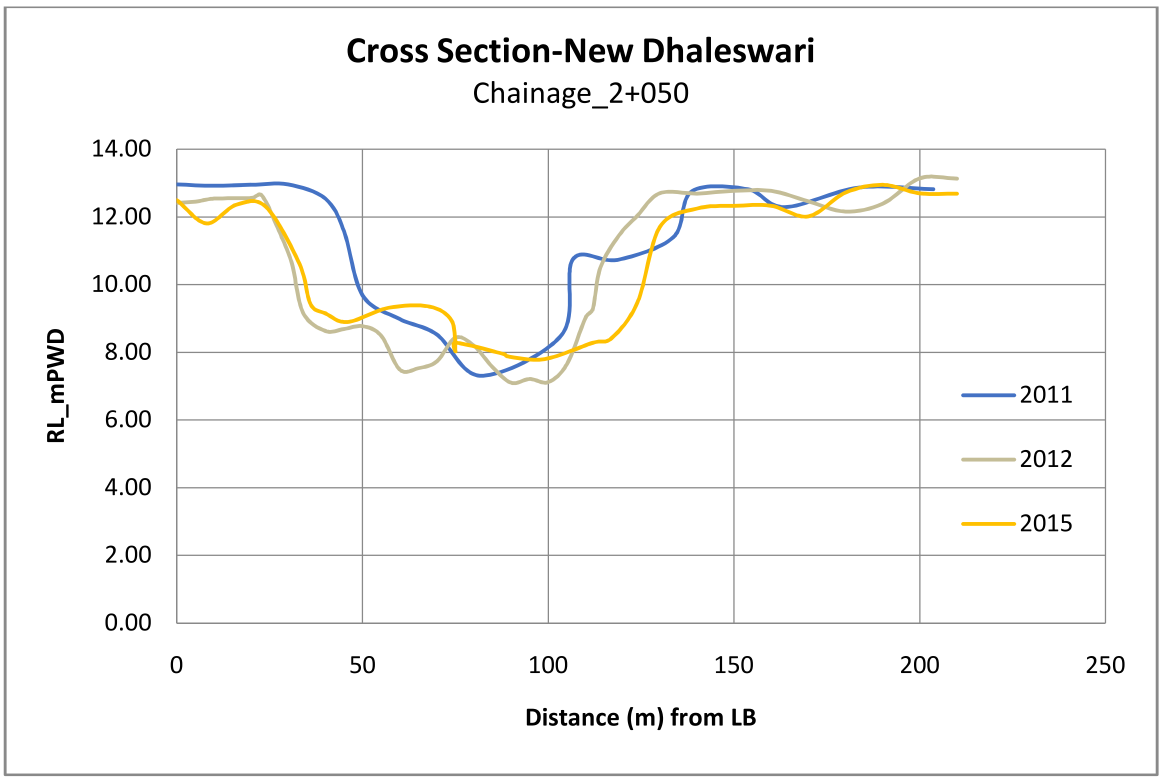


Cross Section-New Dhaleswari
Chainage_1+050
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
RL_mPWD
2011
2012
2015
0
50
100
150
200
Distance (m) from LB

Appendix-B

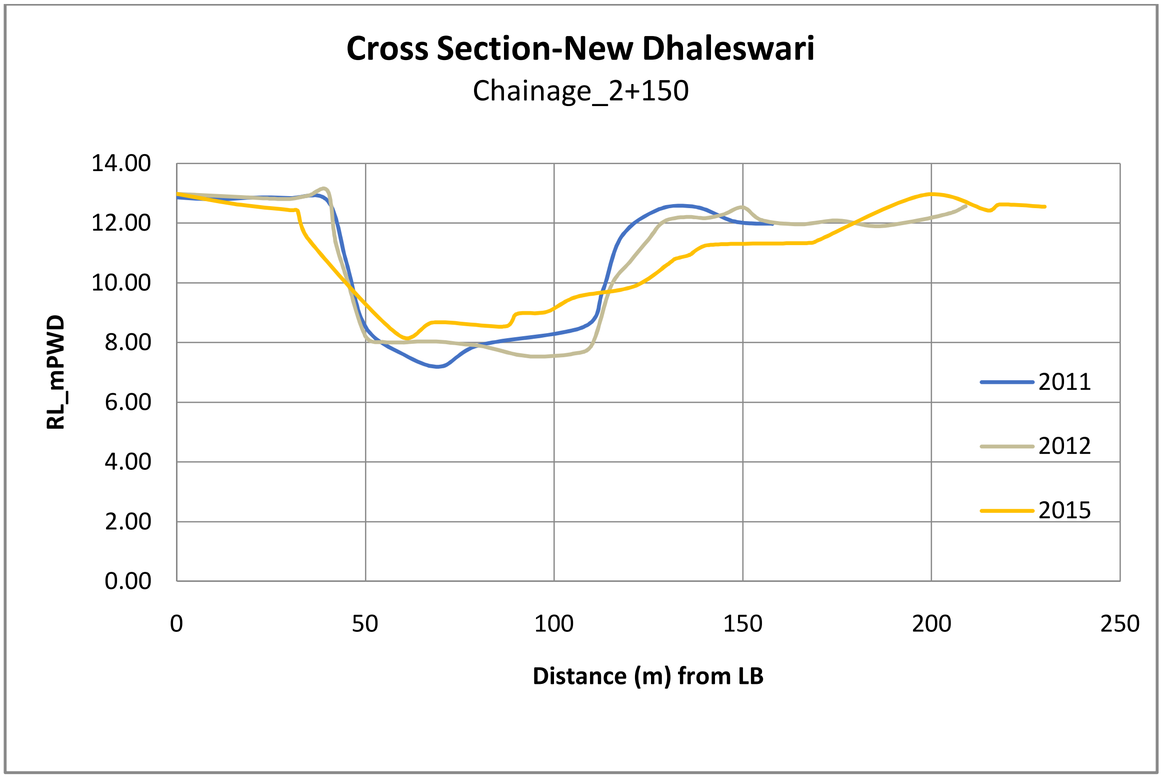


Cross Section-New Dhaleswari
Chainage_1+350
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
RL_mPWD
0
50
100
150
200
250
300
350
400
Distance (m) from LB
2011
2012
2015

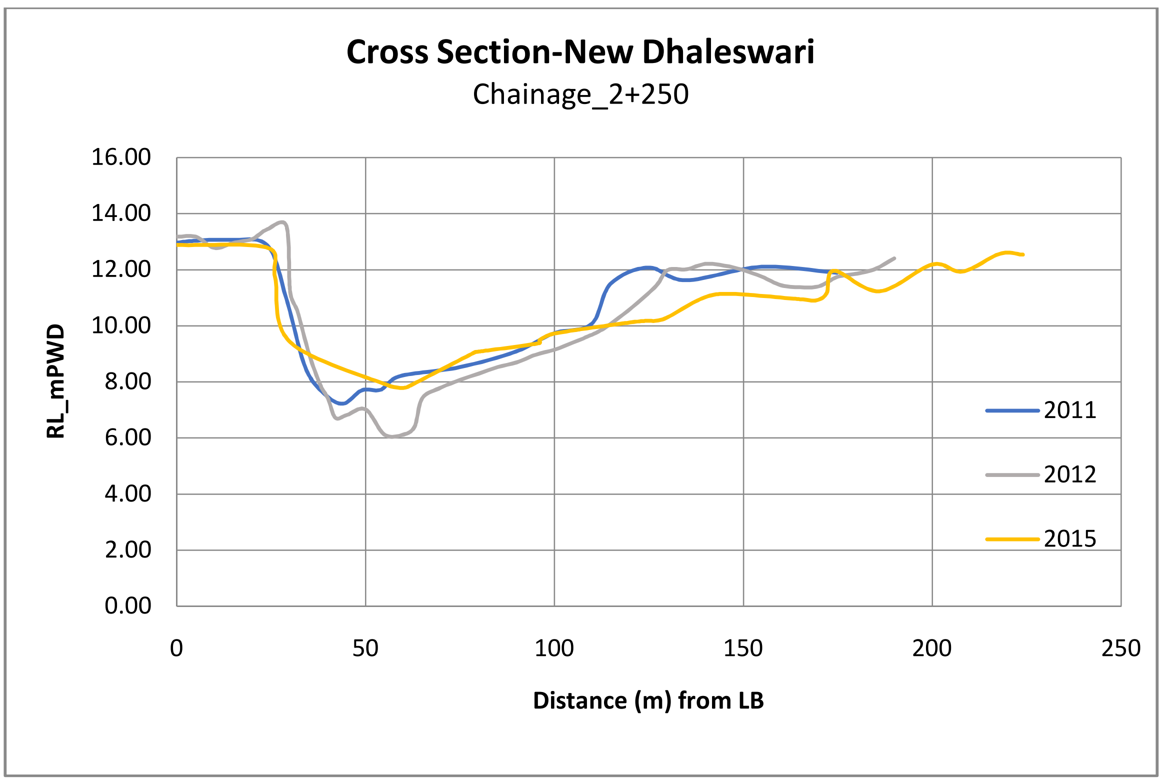


Cross Section-New Dhaleswari
Chainage_2+050
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
RL_mPWD
0
50
100
150
200
250
Distance (m) from LB
2011
2012
2015

Appendix-B



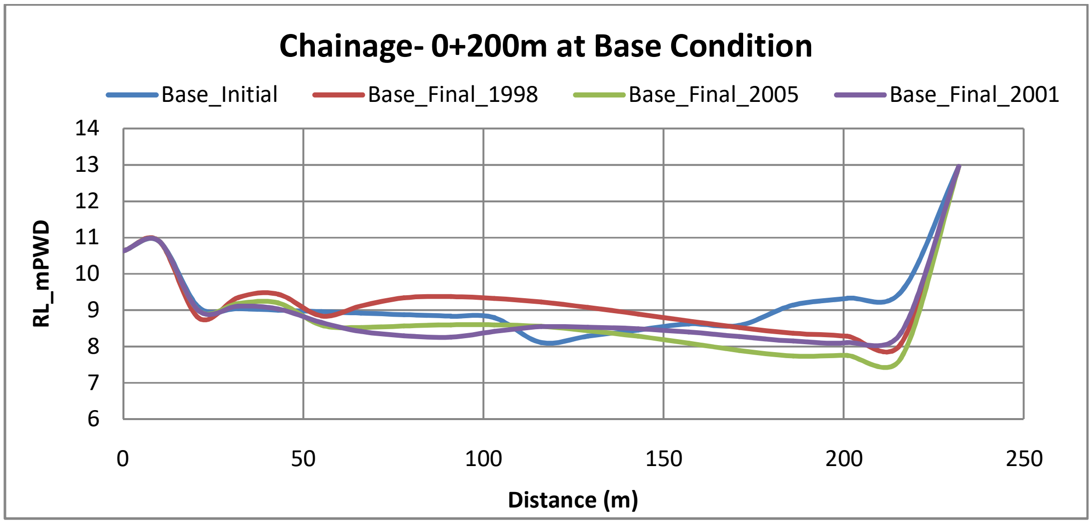
Cross Section-New Dhaleswari
Chainage_2+150
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
RL_mPWD
0
50
100
150
200
250
Distance (m) from LB
2011
2012
2015

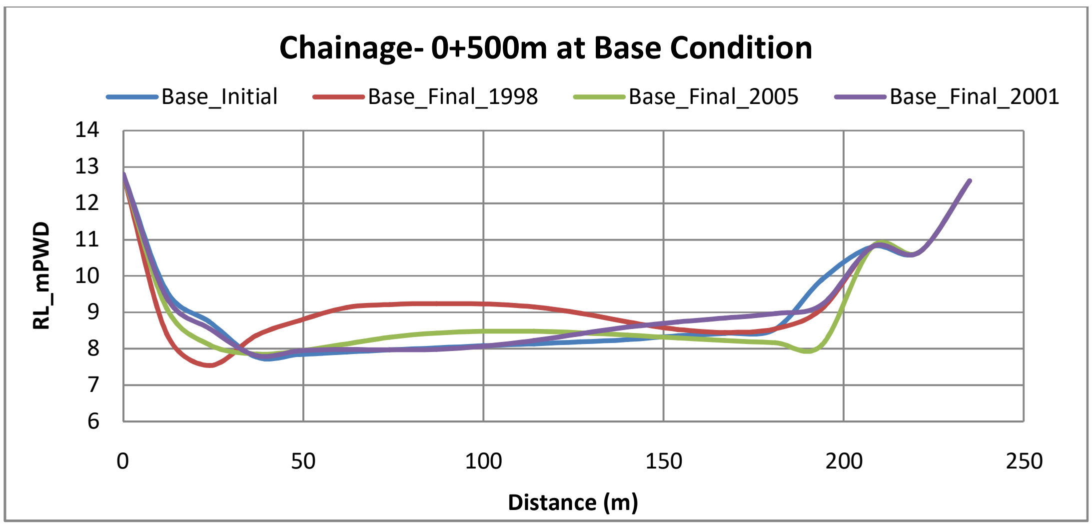


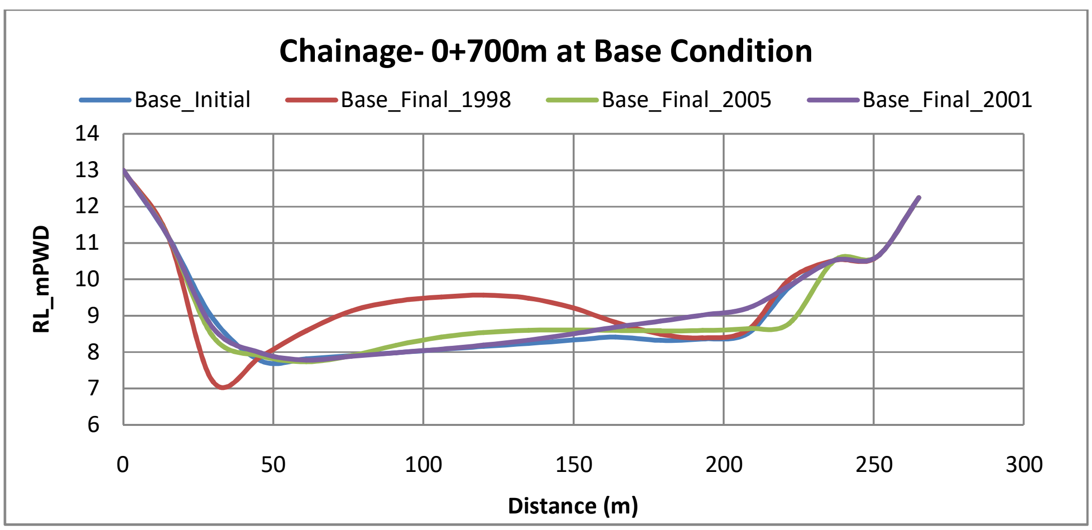
Cross Section-New Dhaleswari
Chainage_2+250
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
RL_mPWD
0
50
100
150
200
250
Distance (m) from LB
2011
2012
2015

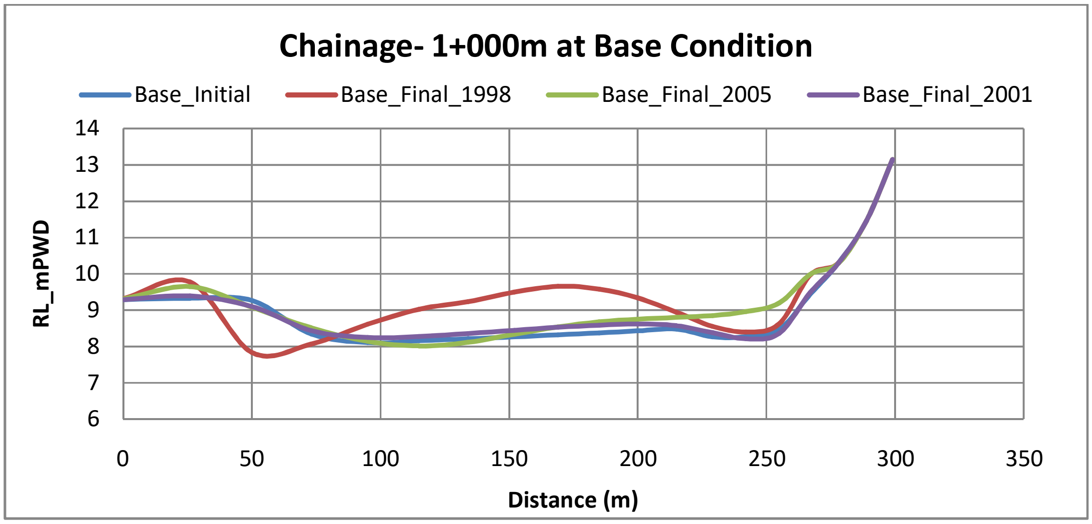
APPENDIX-C

Analysis of Simulated Cross section

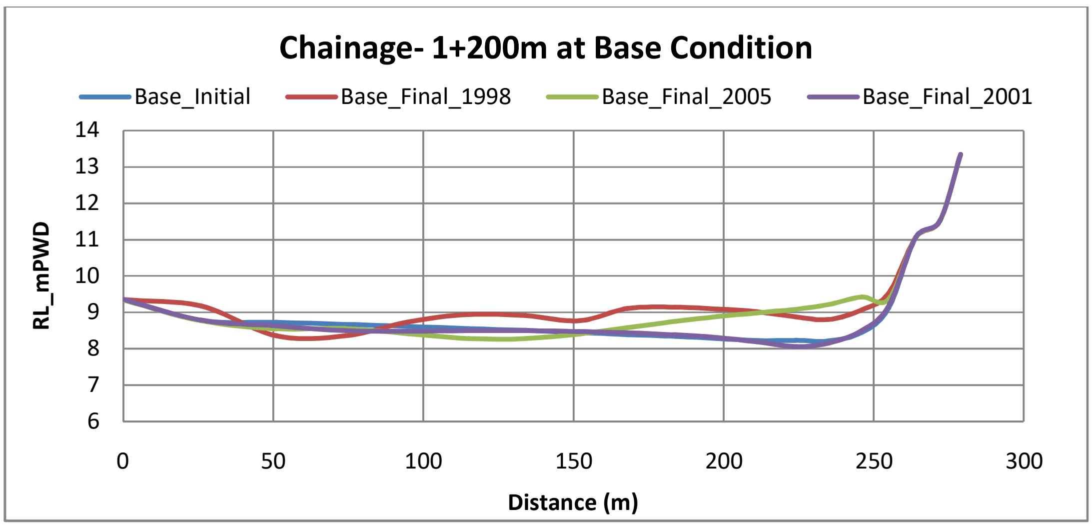

Chainage- 0+200m at Base Condition
Base_Initial
Base_Final_1998
Base_Final_2005
Base_Final_2001
RL_mPWD
14
13
12
11
10
9
8
7
6
0
50
100
150
200
250
Distance (m)


Chainage- 0+500m at Base Condition
Base_Initial
Base_Final_1998
Base_Final_2005
Base_Final_2001
RL_mPWD
14
13
12
11
10
9
8
7
6
0
50
100
150
200
250
Distance (m)

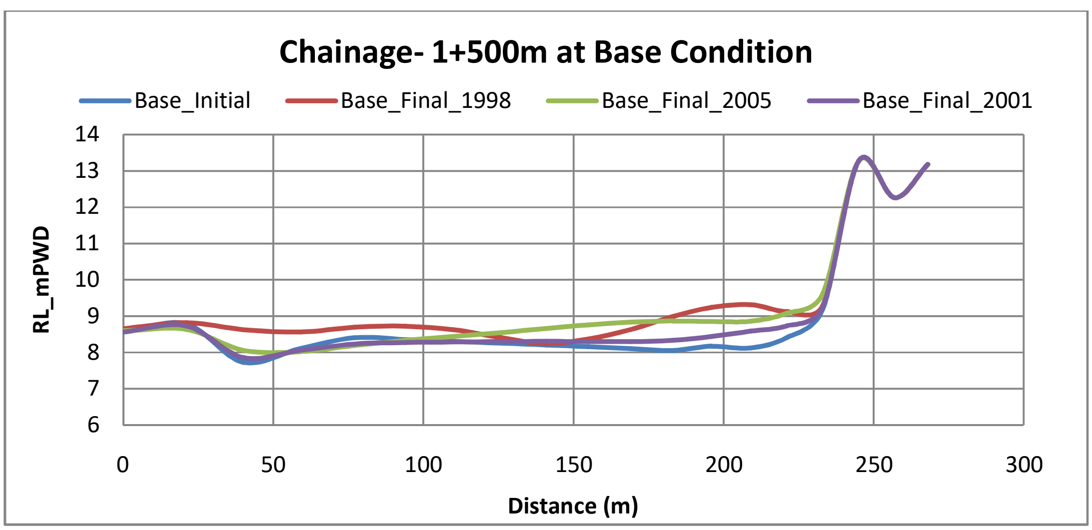

Chainage- 0+700m at Base Condition
Base_Initial
Base_Final_1998
Base_Final_2005
Base_Final_2001
RL_mPWD
14
13
12
11
10
9
8
7
6
0
50
100
150
200
250
300
Distance (m)



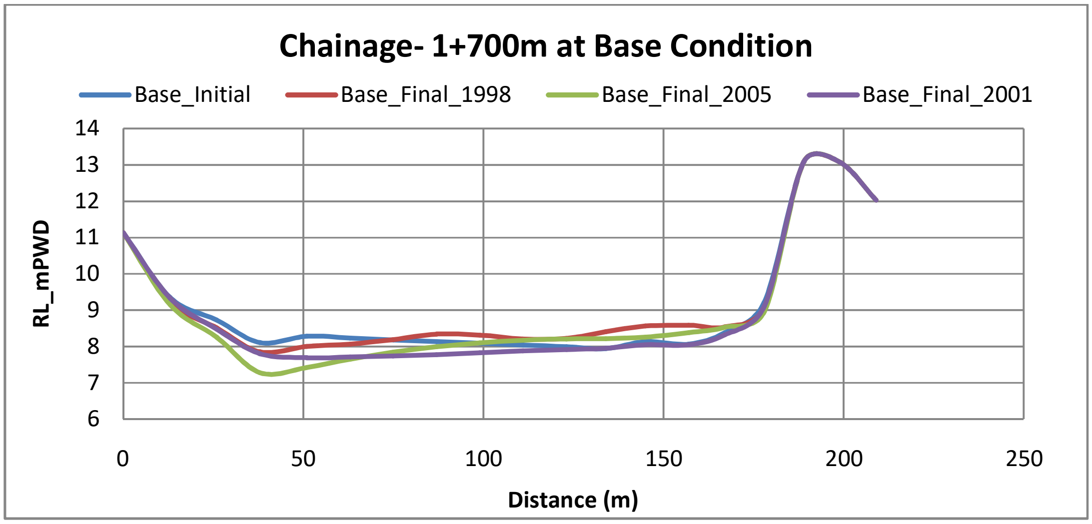
Chainage- 1+000m at Base Condition
Base_Initial
Base_Final_1998
Base_Final_2005
Base_Final_2001
RL_mPWD
14
13
12
11
10
9
8
7
6
0
50
100
150
200
250
300
350
Distance (m)



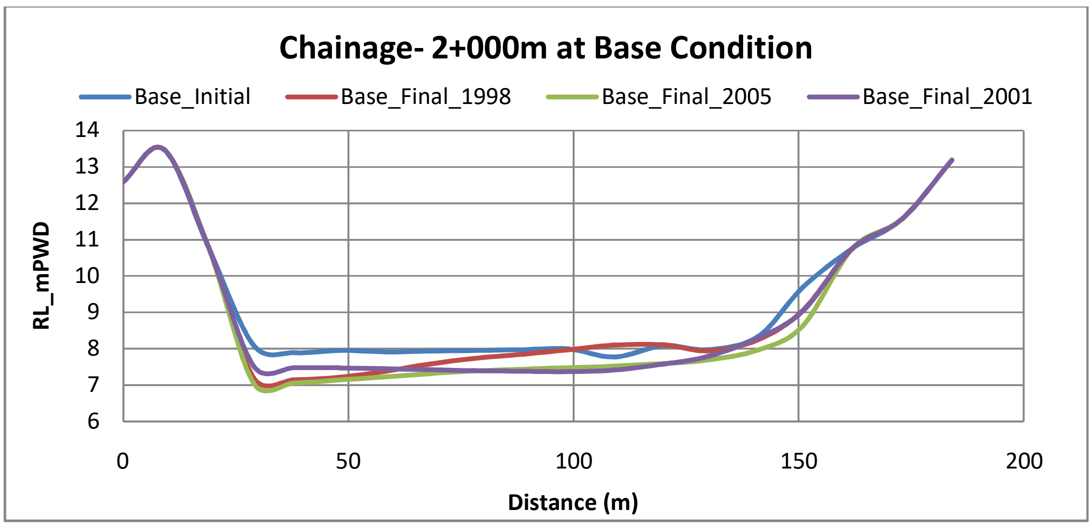
Chainage- 1+200m at Base Condition
Base_Initial
Base_Final_1998
Base_Final_2005
Base_Final_2001
RL_mPWD
14
13
12
11
10
9
8
7
6
0
50
100
150
200
250
300
Distance (m)



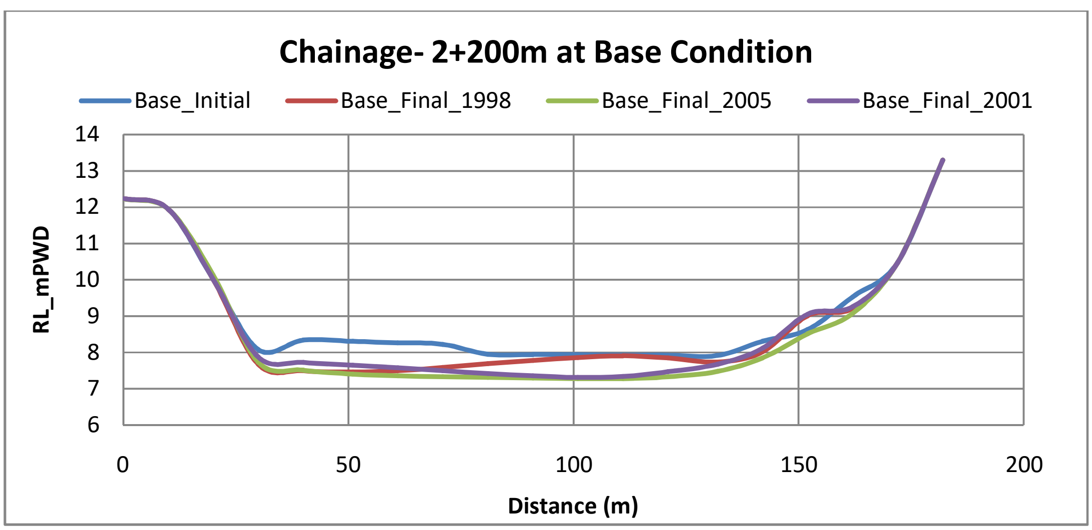
Chainage- 1+500m at Base Condition
Base_Initial
Base_Final_1998
Base_Final_2005
Base_Final_2001
RL_mPWD
14
13
12
11
10
9
8
7
6
0
50
100
150
200
250
300
Distance (m)



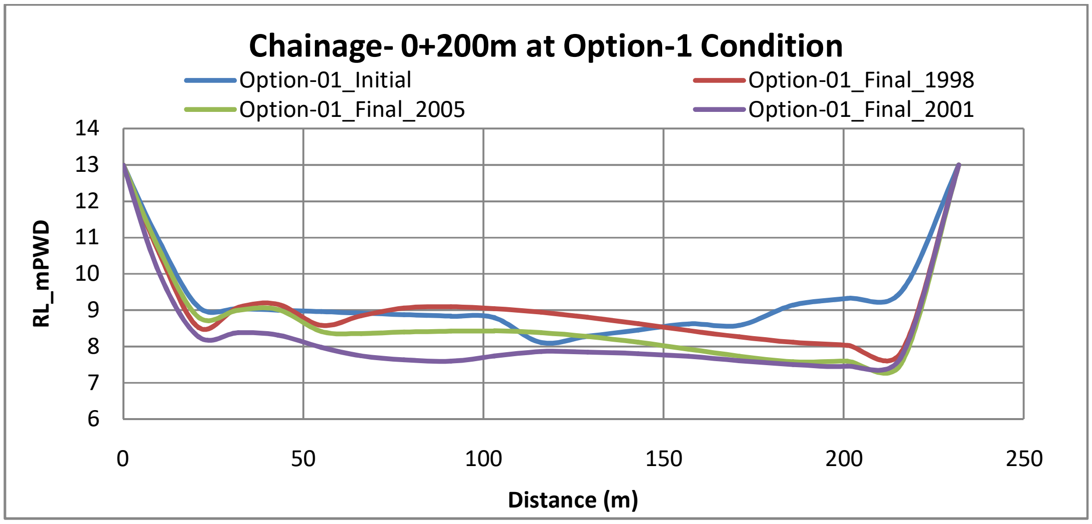
Chainage- 1+700m at Base Condition
Base_Initial
Base_Final_1998
Base_Final_2005
Base_Final_2001
RL_mPWD
Distance (m)
14
13
12
11
10
9
8
7
6
0
50
100
150
200
250

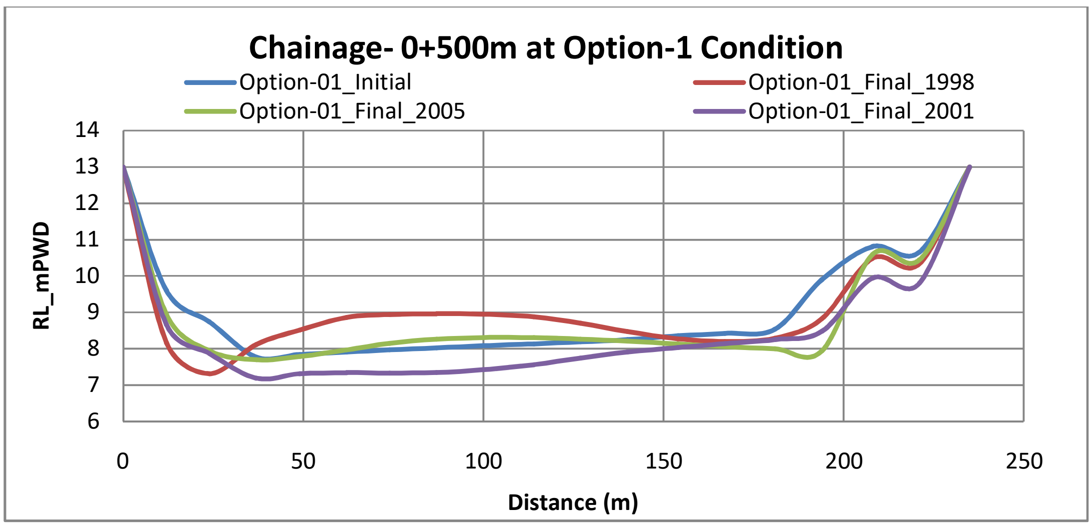


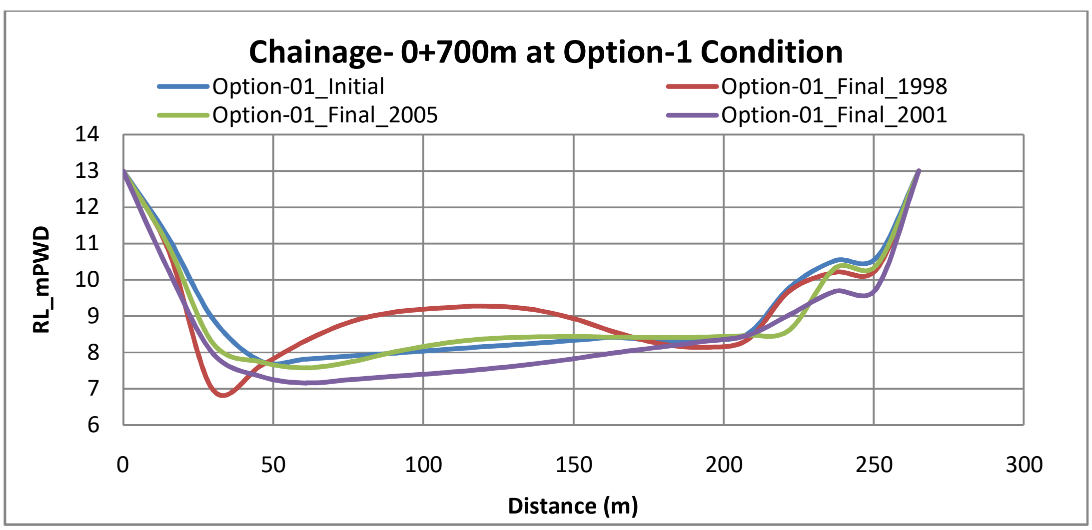
Chainage- 2+000m at Base Condition
Base_Initial
Base_Final_1998
Base_Final_2005
Base_Final_2001
RL_mPWD
Distance (m)
14
13
12
11
10
9
8
7
6
0
50
100
150
200

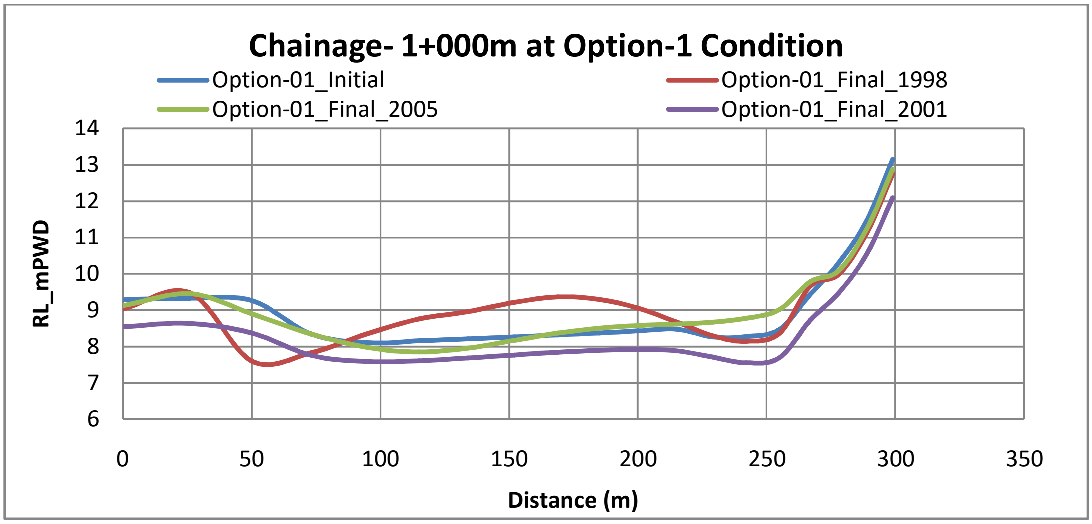


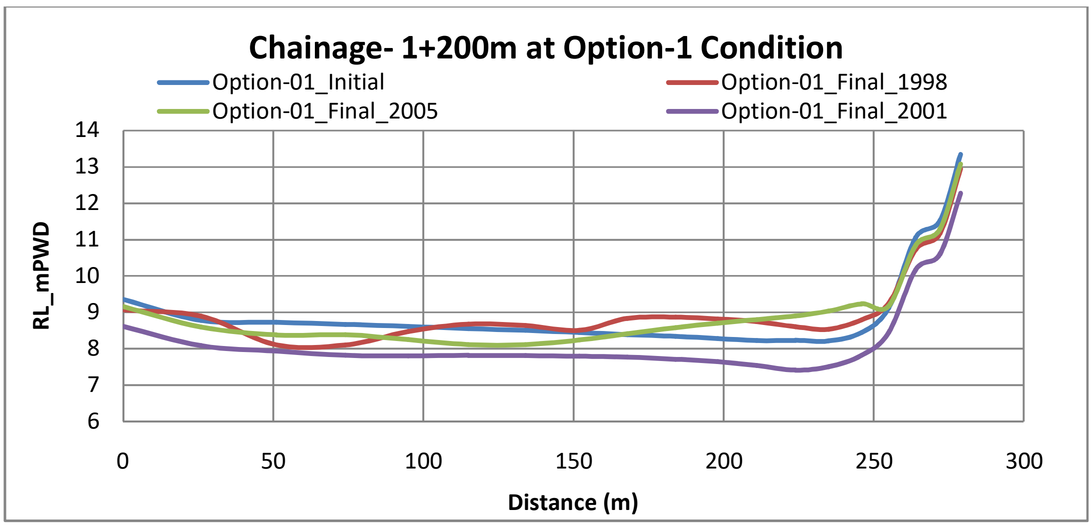
Chainage- 2+200m at Base Condition
Base_Initial
Base_Final_1998
Base_Final_2005
Base_Final_2001
RL_mPWD
Distance (m)
14
13
12
11
10
9
8
7
6
0
50
100
150
200

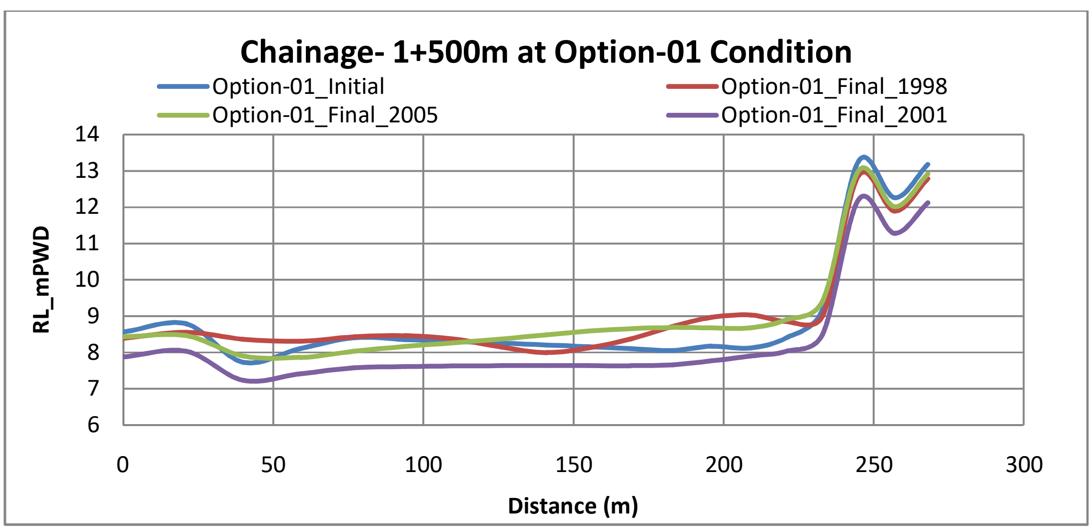

Chainage- 0+200m at Option-1 Condition
Option-01_Initial
Option-01_Final_1998
Option-01_Final_2005
Option-01_Final_2001
RL_mPWD
14
13
12
11
10
9
8
7
6
0
50
100
150
200
250
Distance (m)

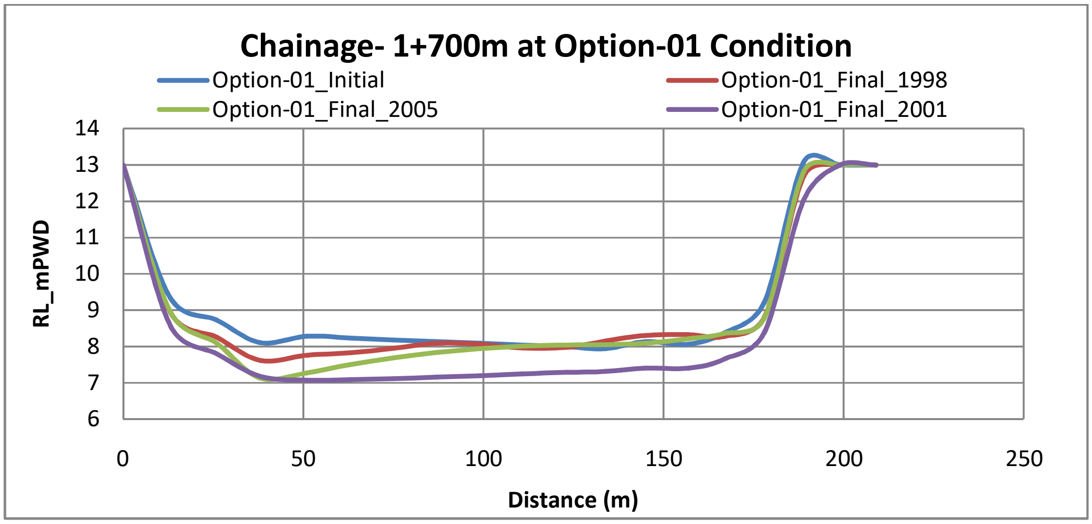

Chainage- 0+500m at Option-1 Condition
Option-01_Initial
Option-01_Final_1998
Option-01_Final_2005
Option-01_Final_2001
RL_mPWD
14
13
12
11
10
9
8
7
6
0
50
100
150
200
250
Distance (m)

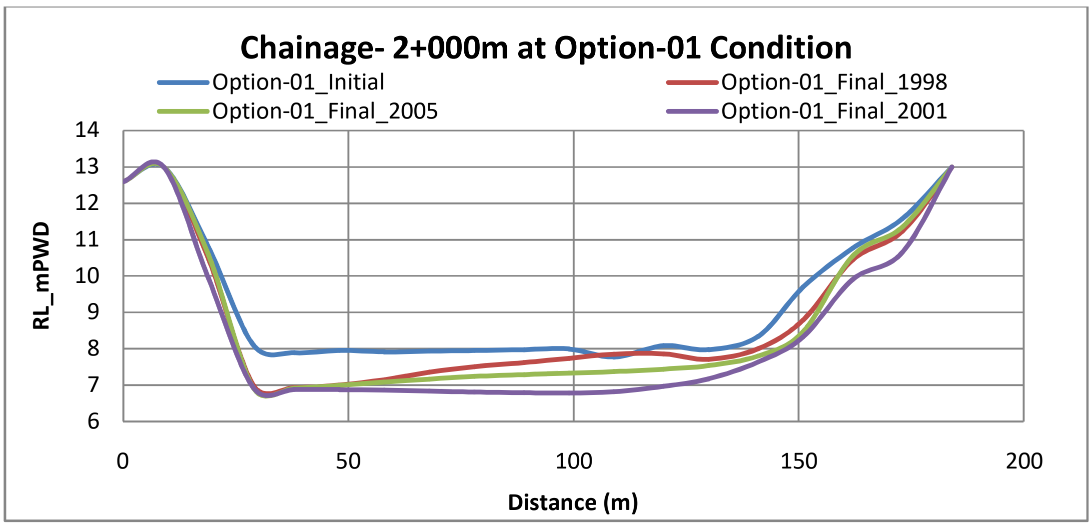

Chainage- 0+700m at Option-1 Condition
Option-01_Initial
Option-01_Final_1998
Option-01_Final_2005
Option-01_Final_2001
RL_mPWD
14
13
12
11
10
9
8
7
6
0
50
100
150
200
250
300
Distance (m)

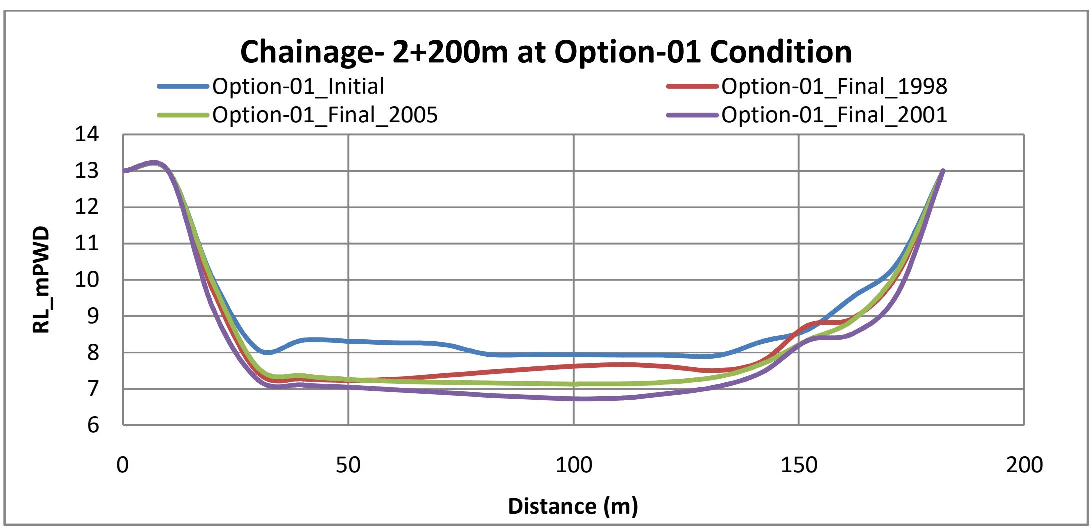

Chainage- 1+000m at Option-1 Condition
Option-01_Initial
Option-01_Final_1998
Option-01_Final_2005
Option-01_Final_2001
RL_mPWD
14
13
12
11
10
9
8
7
6
0
50
100
150
200
250
300
350
Distance (m)

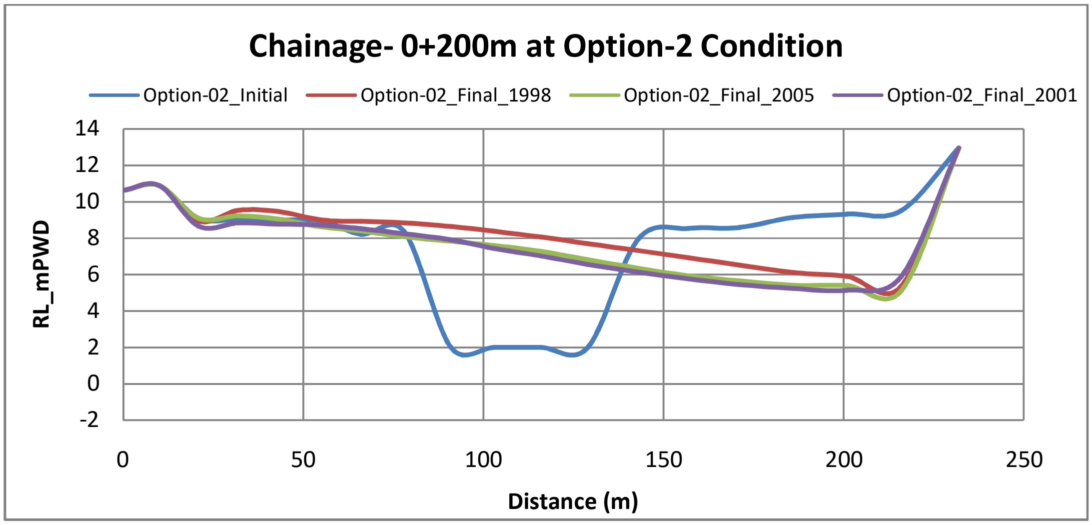

Chainage- 1+200m at Option-1 Condition
Option-01_Initial
Option-01_Final_1998
Option-01_Final_2005
Option-01_Final_2001
RL_mPWD
14
13
12
11
10
9
8
7
6
0
50
100
150
200
250
300
Distance (m)

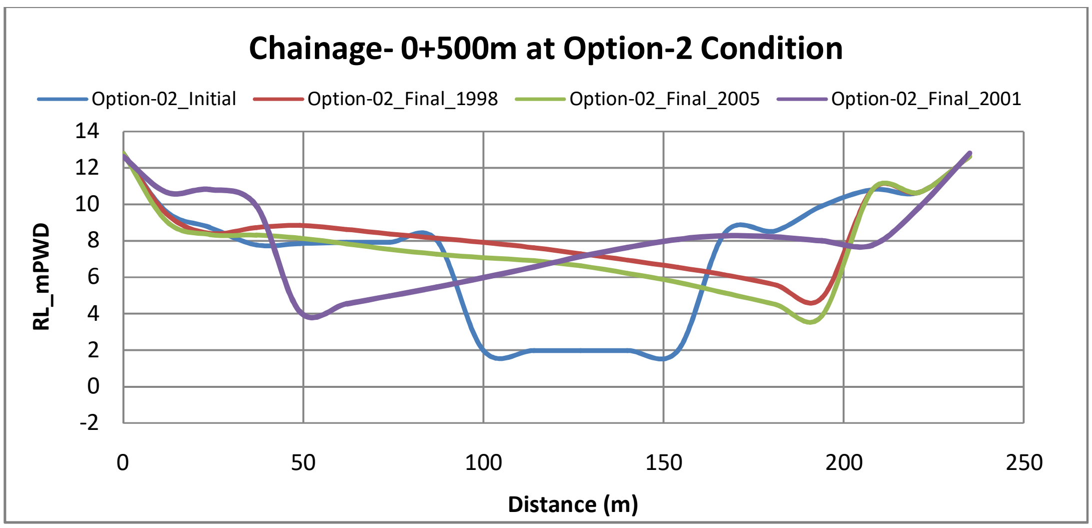

Chainage- 1+500m at Option-01 Condition
Option-01_Initial
Option-01_Final_1998
Option-01_Final_2005
Option-01_Final_2001
RL_mPWD
14
13
12
11
10
9
8
7
6
0
50
100
150
200
250
300
Distance (m)

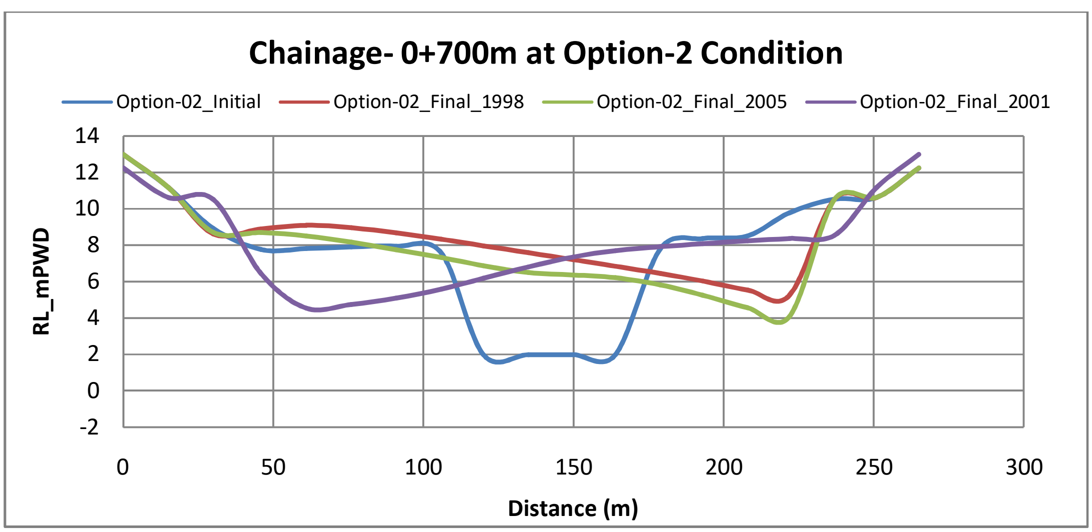

Chainage- 1+700m at Option-01 Condition
Option-01_Initial
Option-01_Final_1998
Option-01_Final_2005
Option-01_Final_2001
RL_mPWD
14
13
12
11
10
9
8
7
6
0
50
100
150
200
250
Distance (m)

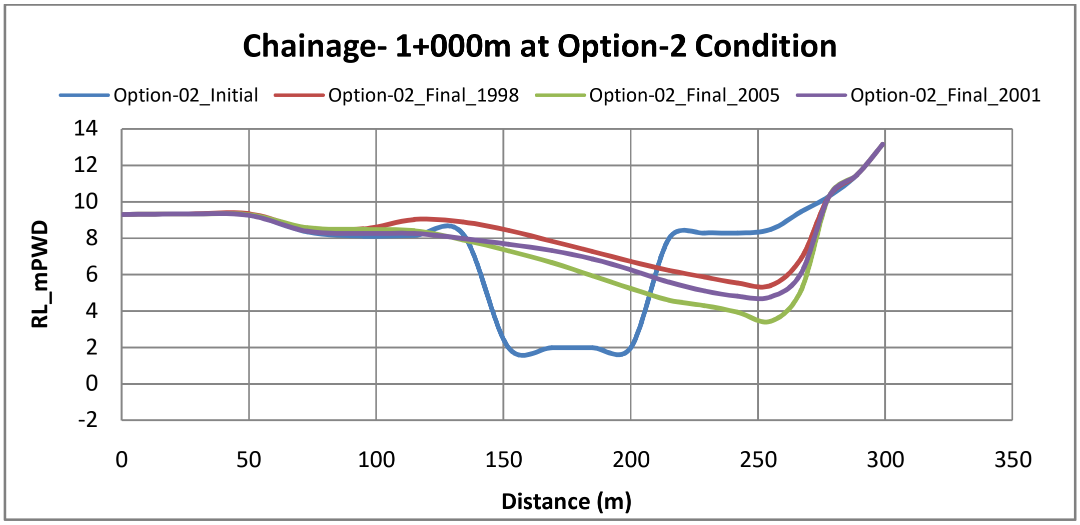

Chainage- 2+000m at Option-01 Condition
Option-01_Initial
Option-01_Final_1998
Option-01_Final_2005
Option-01_Final_2001
RL_mPWD
14
13
12
11
10
9
8
7
6
0
50
100
150
200
Distance (m)

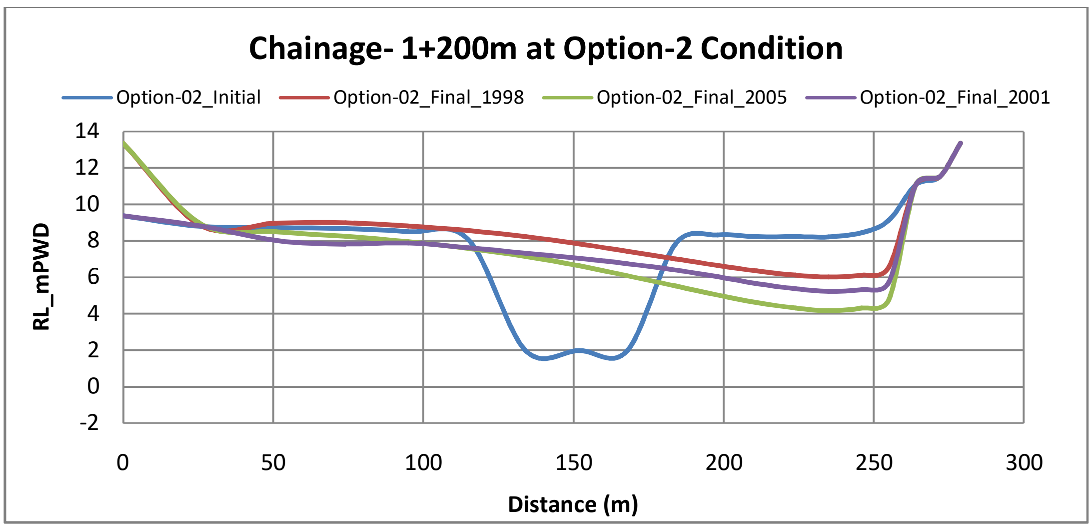

Chainage- 2+200m at Option-01 Condition
Option-01_Initial
Option-01_Final_1998
Option-01_Final_2005
Option-01_Final_2001
RL_mPWD
14
13
12
11
10
9
8
7
6
0
50
100
150
200
Distance (m)

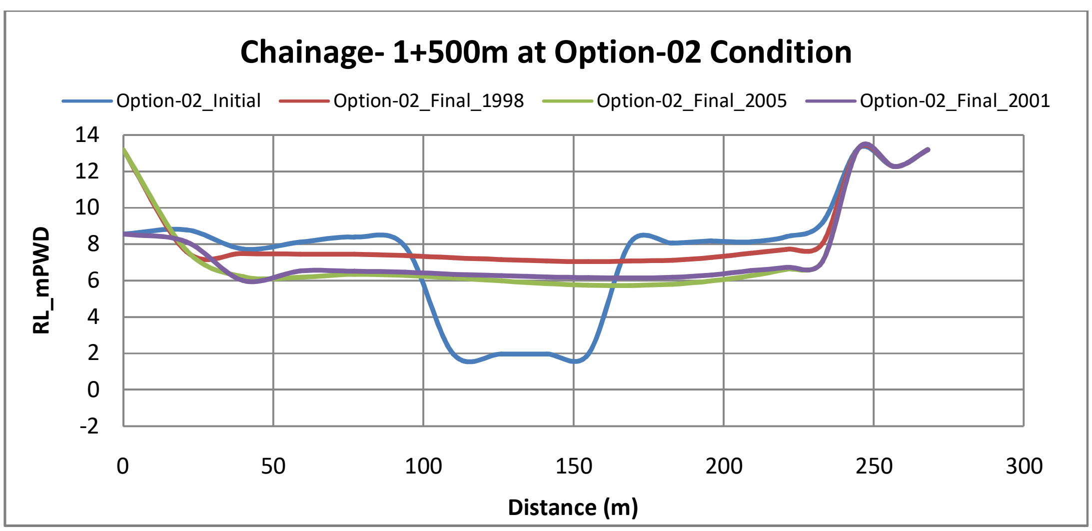

Chainage- 0+200m at Option-2 Condition
Option-02_Initial
Option-02_Final_1998
Option-02_Final_2005
Option-02_Final_2001
RL_mPWD
Distance (m)
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250

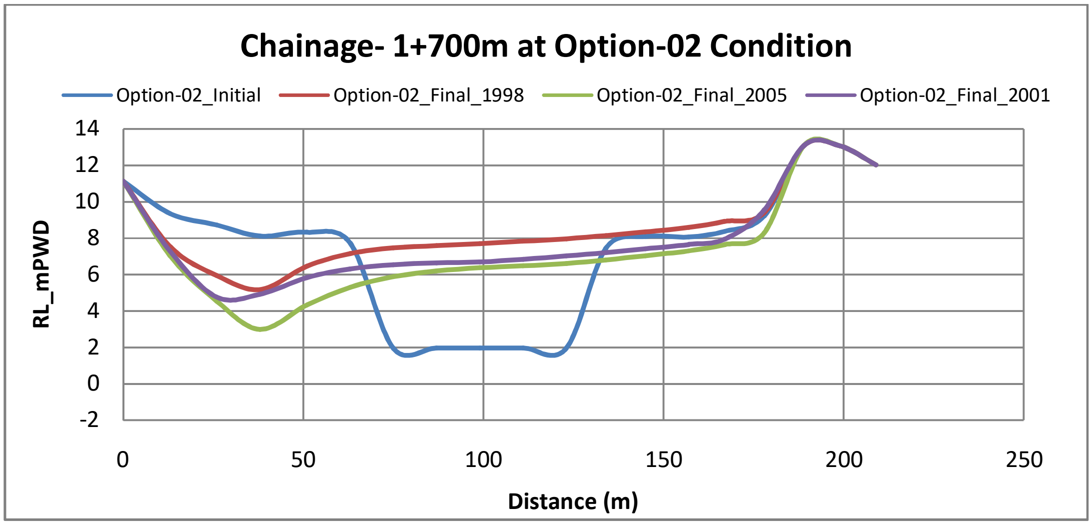

Chainage- 0+500m at Option-2 Condition
Option-02_Initial
Option-02_Final_1998
Option-02_Final_2005
Option-02_Final_2001
RL_mPWD
Distance (m)
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250

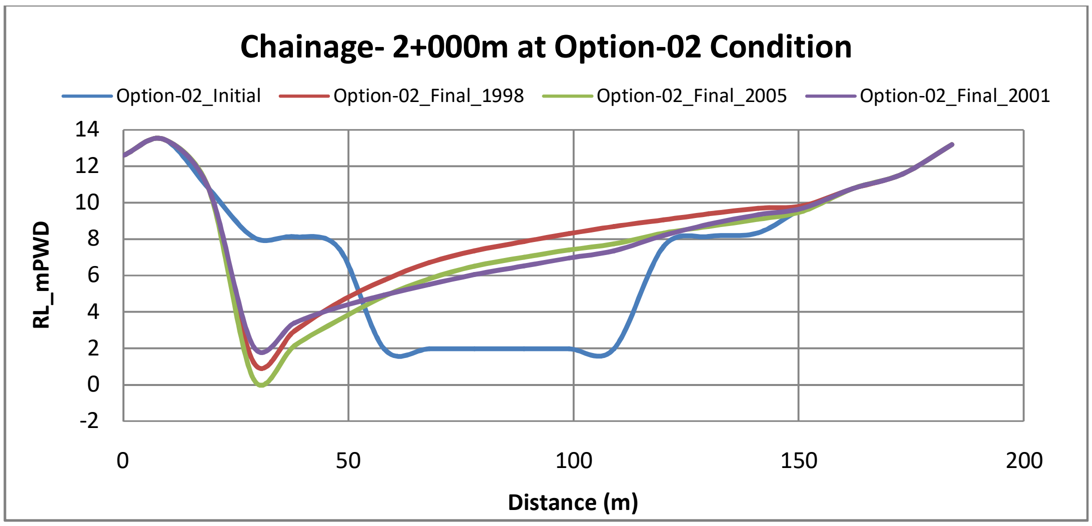

Chainage- 0+700m at Option-2 Condition
Option-02_Initial
Option-02_Final_1998
Option-02_Final_2005
Option-02_Final_2001
RL_mPWD
Distance (m)
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250
300

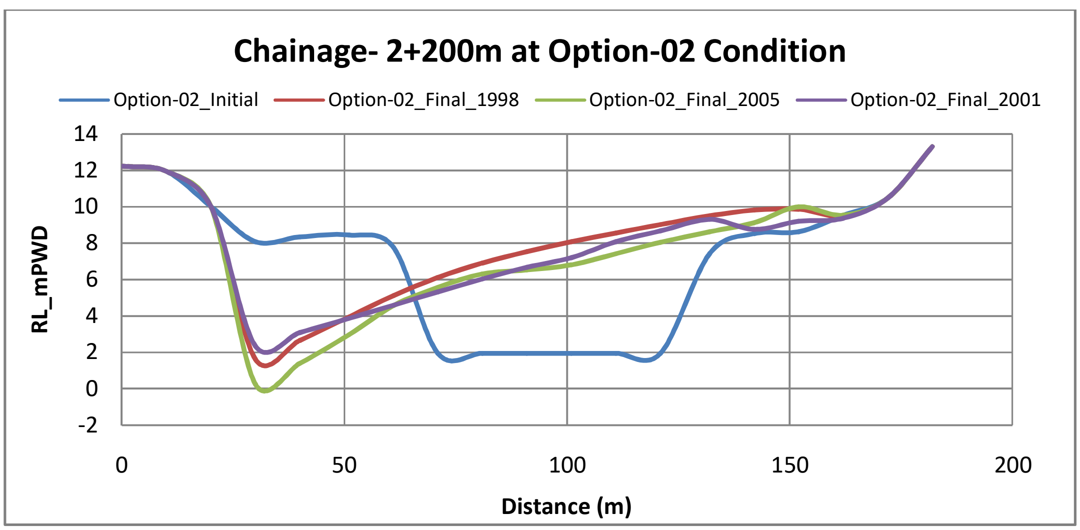

Chainage- 1+000m at Option-2 Condition
Option-02_Initial
Option-02_Final_1998
Option-02_Final_2005
Option-02_Final_2001
RL_mPWD
Distance (m)

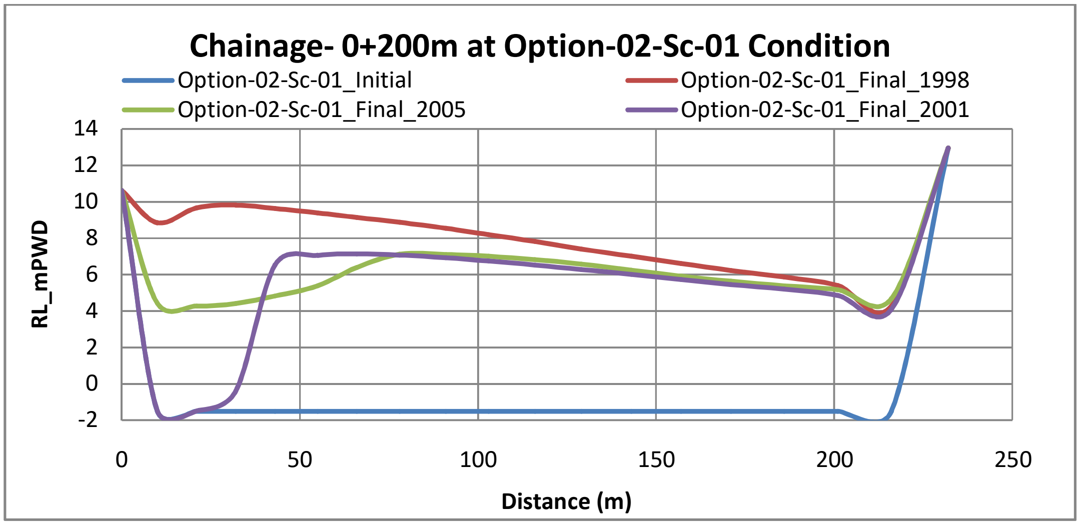

Chainage- 1+200m at Option-2 Condition
Option-02_Initial
Option-02_Final_1998
Option-02_Final_2005
Option-02_Final_2001
RL_mPWD
Distance (m)

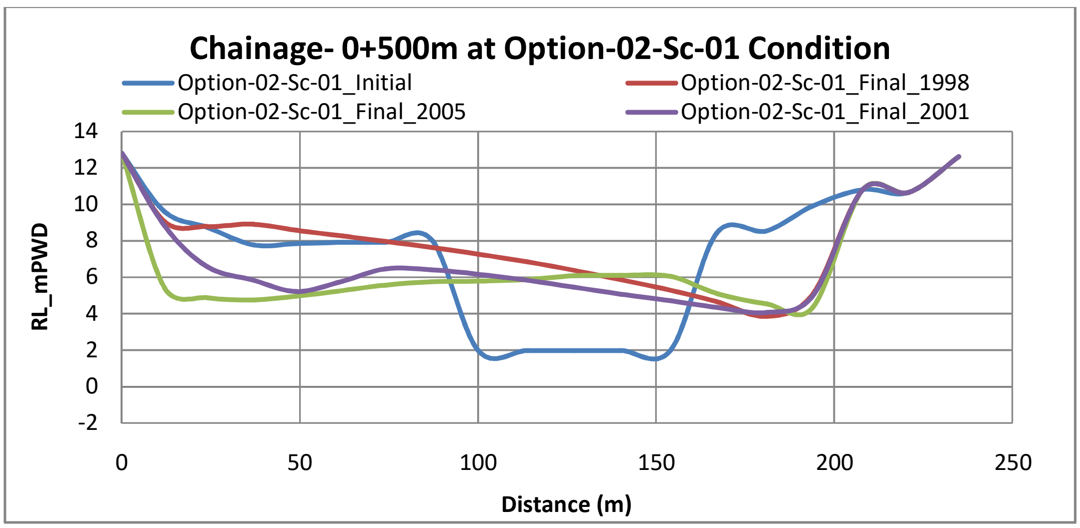

Chainage- 1+500m at Option-02 Condition
Option-02_Initial
Option-02_Final_1998
Option-02_Final_2005
Option-02_Final_2001
RL_mPWD
Distance (m)

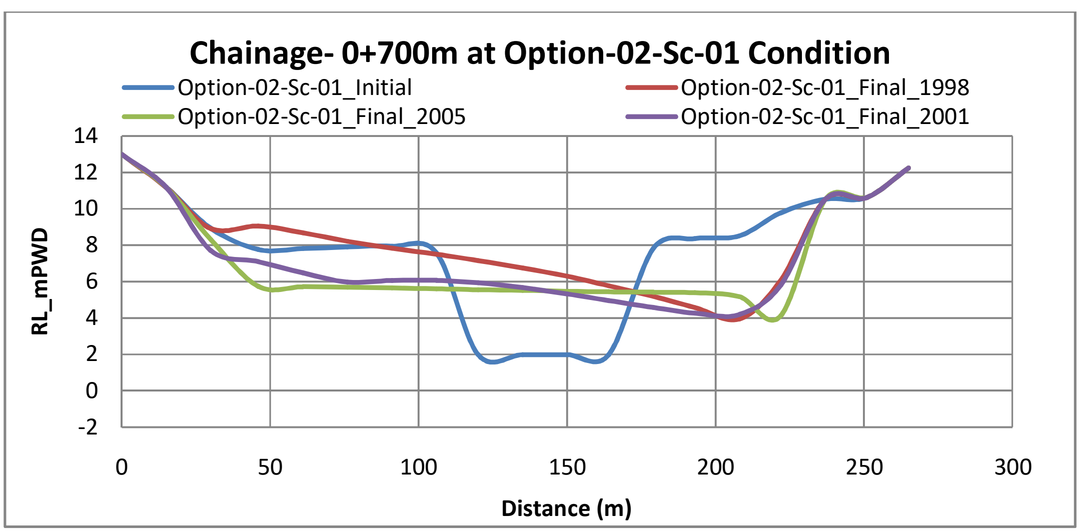

Chainage- 1+700m at Option-02 Condition
Option-02_Initial
Option-02_Final_1998
Option-02_Final_2005
Option-02_Final_2001
RL_mPWD
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250
Distance (m)

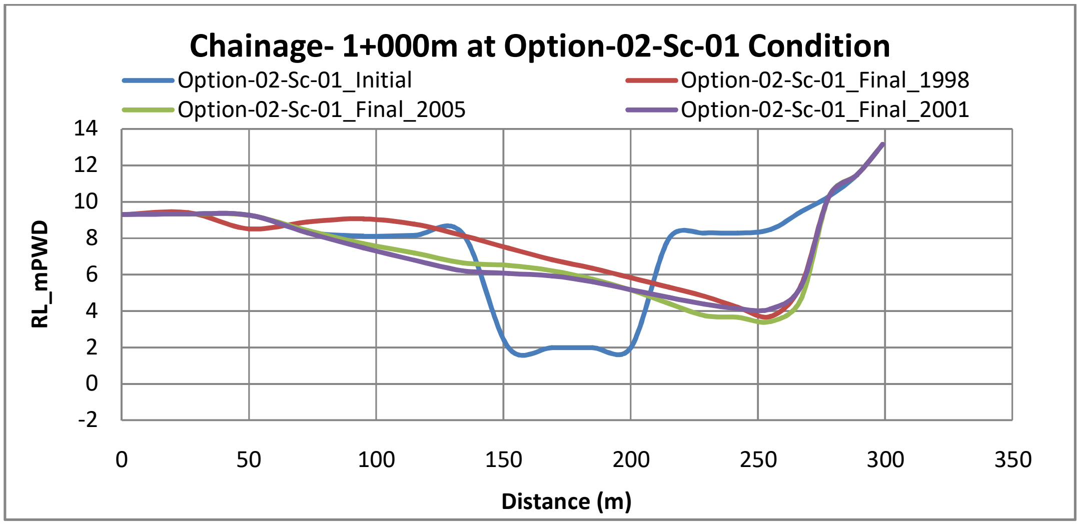

Chainage- 2+000m at Option-02 Condition
Option-02_Initial
Option-02_Final_1998
Option-02_Final_2005
Option-02_Final_2001
RL_mPWD
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
Distance (m)

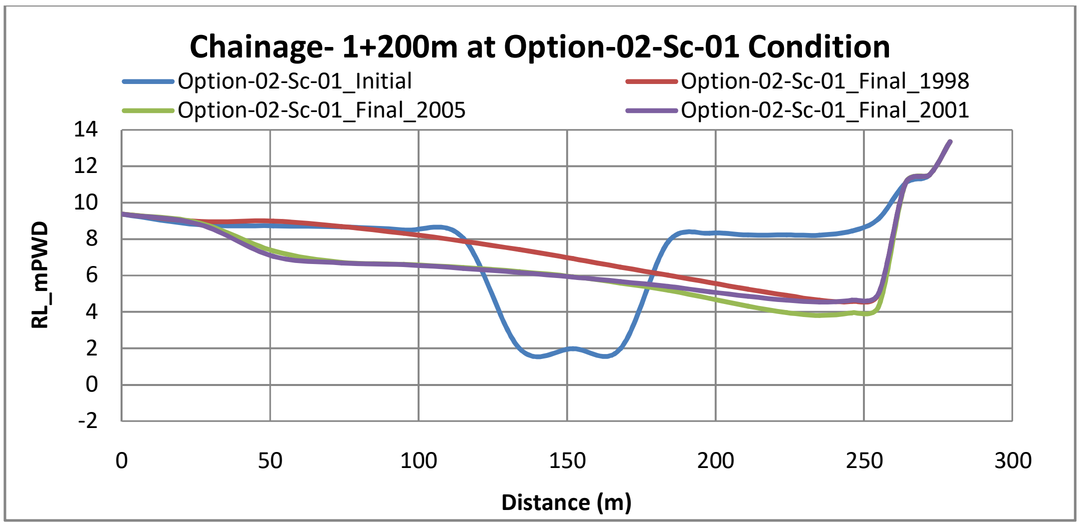

Chainage- 2+200m at Option-02 Condition
Option-02_Initial
Option-02_Final_1998
Option-02_Final_2005
Option-02_Final_2001
RL_mPWD
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
Distance (m)


Chainage- 0+200m at Option-02-Sc-01 Condition
Option-02-Sc-01_Initial
Option-02-Sc-01_Final_1998
Option-02-Sc-01_Final_2005
Option-02-Sc-01_Final_2001
RL_mPWD
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250
Distance (m)


Chainage- 0+500m at Option-02-Sc-01 Condition
Option-02-Sc-01_Initial
Option-02-Sc-01_Final_1998
Option-02-Sc-01_Final_2005
Option-02-Sc-01_Final_2001
RL_mPWD
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250
Distance (m)


Chainage- 0+700m at Option-02-Sc-01 Condition
Option-02-Sc-01_Initial
Option-02-Sc-01_Final_1998
Option-02-Sc-01_Final_2005
Option-02-Sc-01_Final_2001
RL_mPWD
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250
300
Distance (m)


Chainage- 1+000m at Option-02-Sc-01 Condition
Option-02-Sc-01_Initial
Option-02-Sc-01_Final_1998
Option-02-Sc-01_Final_2005
Option-02-Sc-01_Final_2001
RL_mPWD
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250
300
350
Distance (m)


Chainage- 1+200m at Option-02-Sc-01 Condition
Option-02-Sc-01_Initial
Option-02-Sc-01_Final_1998
Option-02-Sc-01_Final_2005
Option-02-Sc-01_Final_2001
RL_mPWD
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-2
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200
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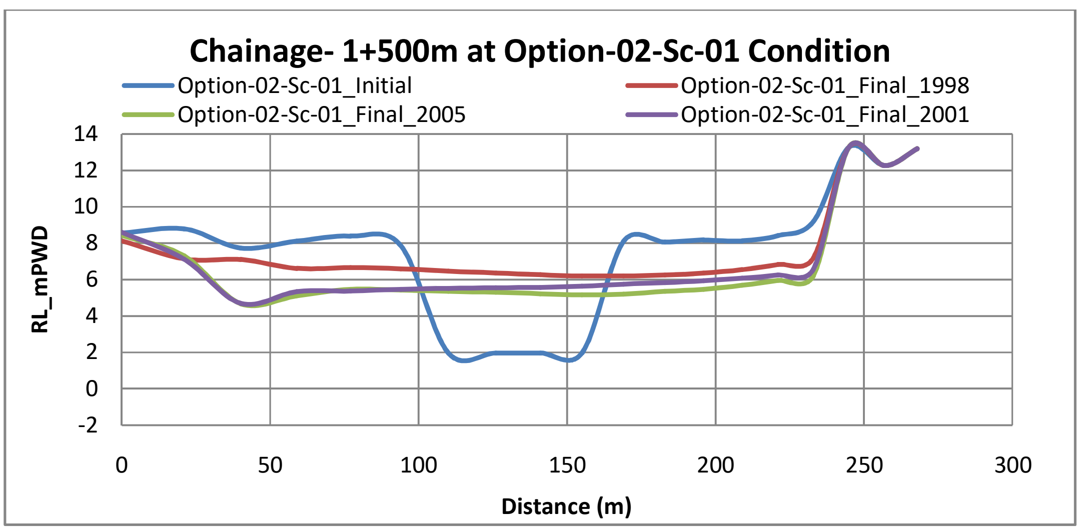
300
Distance (m)


Chainage- 1+500m at Option-02-Sc-01 Condition
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Option-02-Sc-01_Final_1998
Option-02-Sc-01_Final_2005
Option-02-Sc-01_Final_2001
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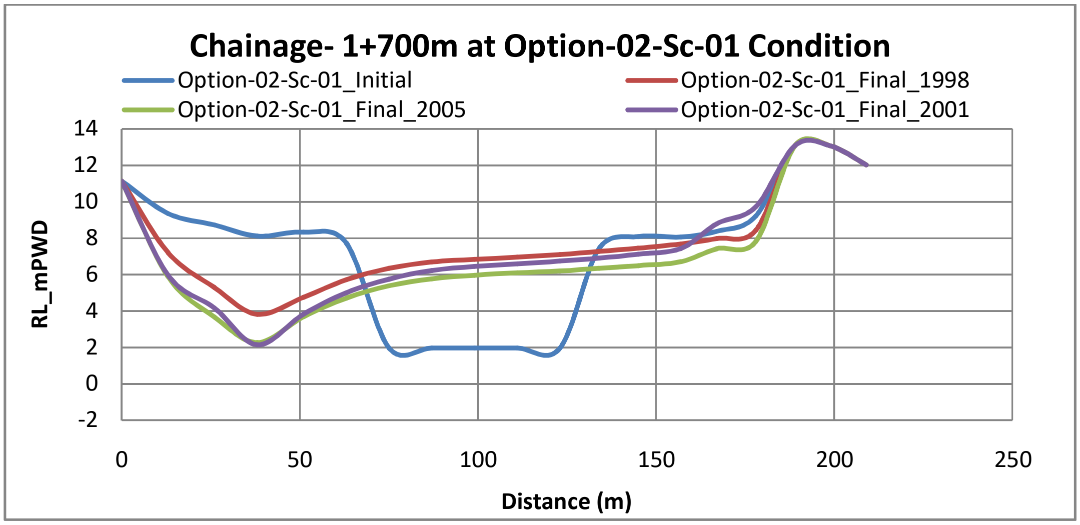
Distance (m)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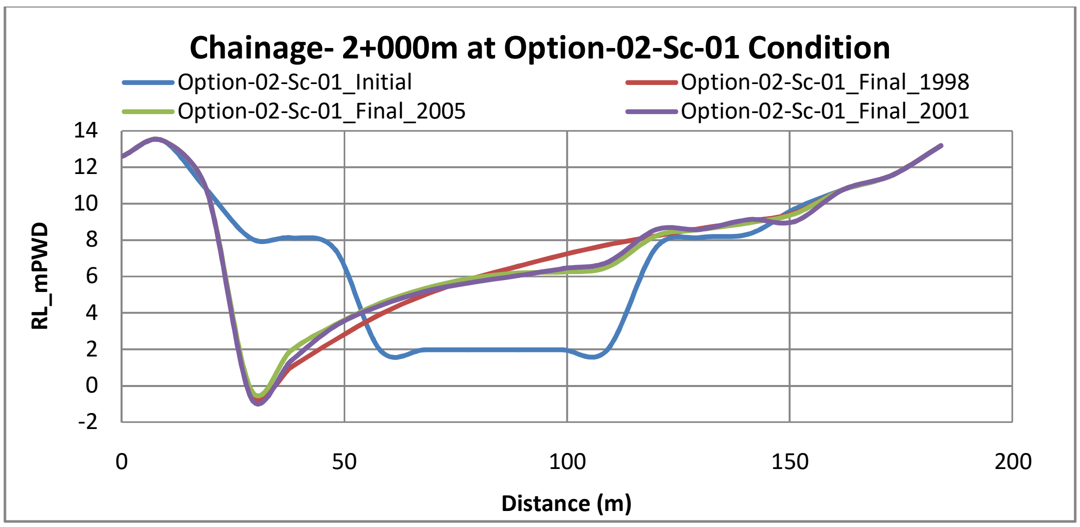
Option-02-Sc-01_Final_2005
Option-02-Sc-01_Final_2001
RL_mPWD
Distance (m)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Option-02-Sc-01_Final_2001
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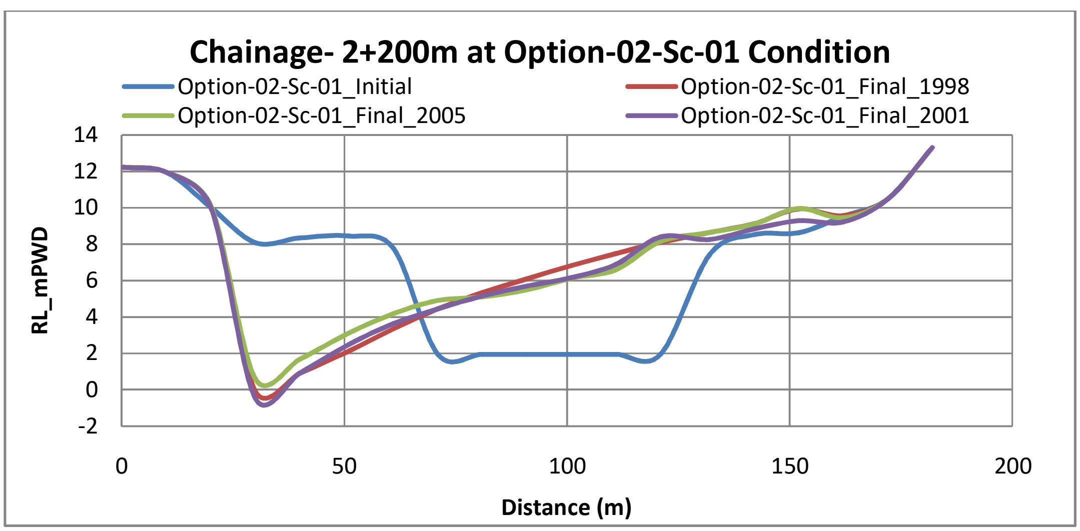
Distance (m)


Chainage- 2+200m at Option-02-Sc-01 Condition
Option-02-Sc-01_Initial
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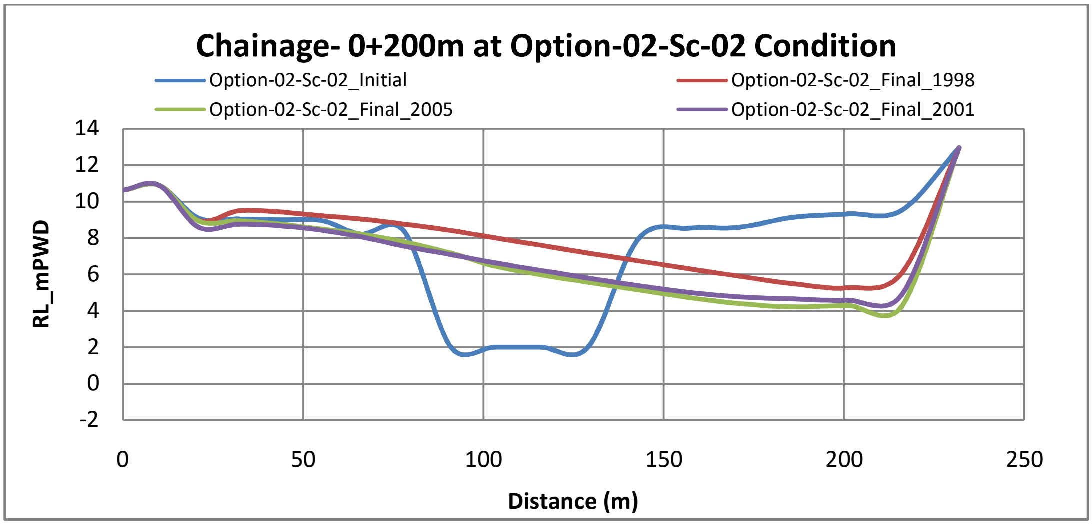
Option-02-Sc-01_Final_2001
RL_mPWD
Distance (m)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Option-02-Sc-02_Final_1998
Option-02-Sc-02_Final_2005
Option-02-Sc-02_Final_2001
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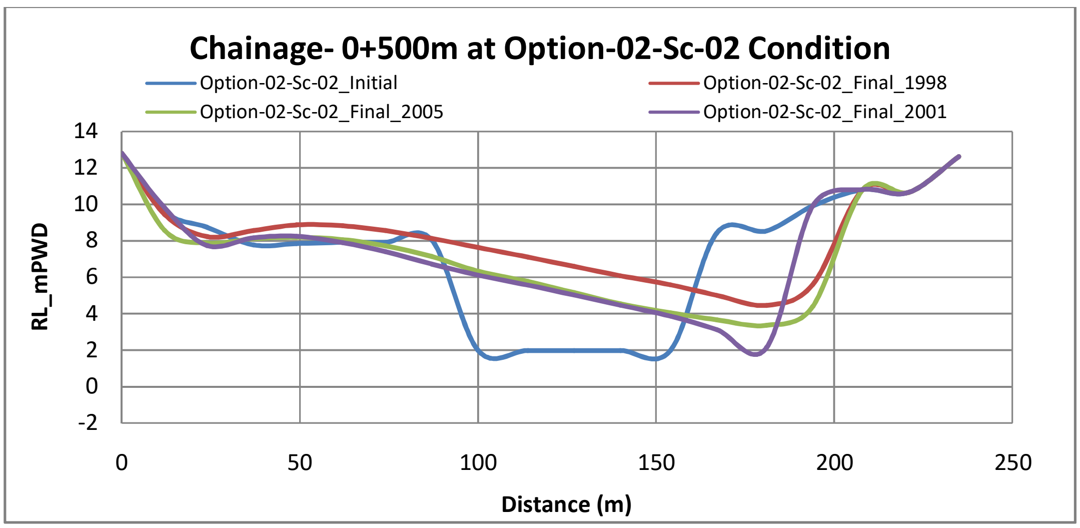
Distance (m)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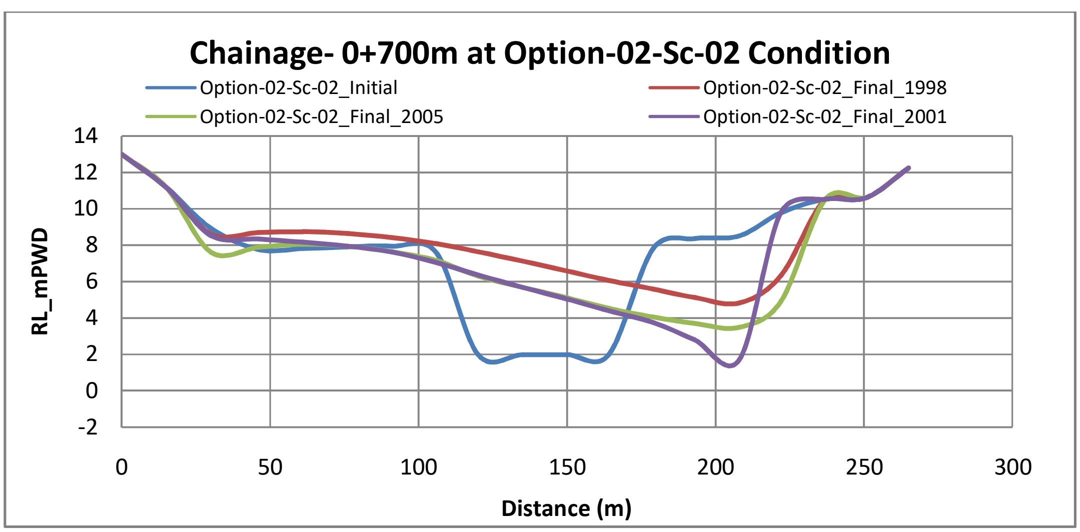
Distance (m)


Chainage- 0+700m at Option-02-Sc-02 Condition
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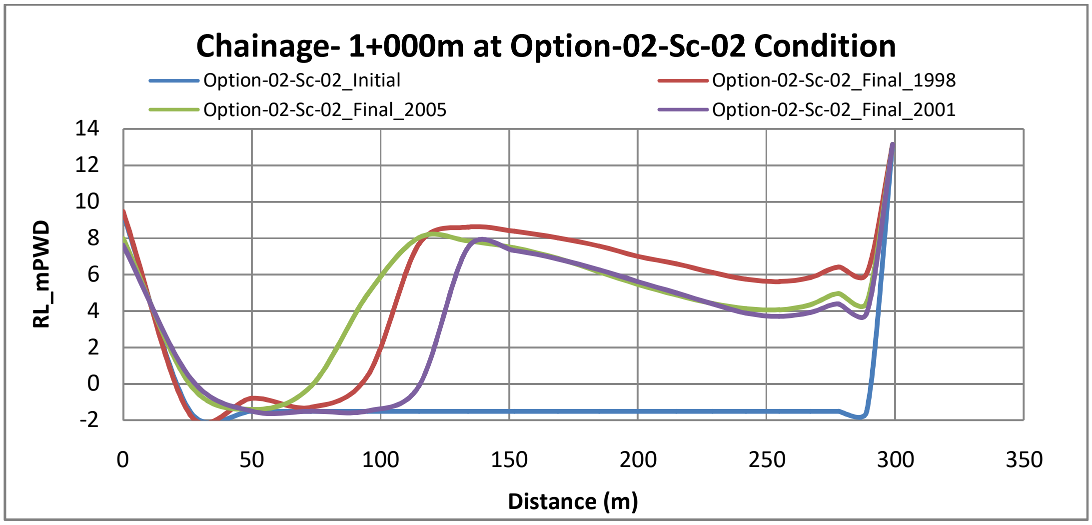
Distance (m)


Chainage- 1+000m at Option-02-Sc-02 Condition
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Option-02-Sc-02_Final_2001
RL_mPWD
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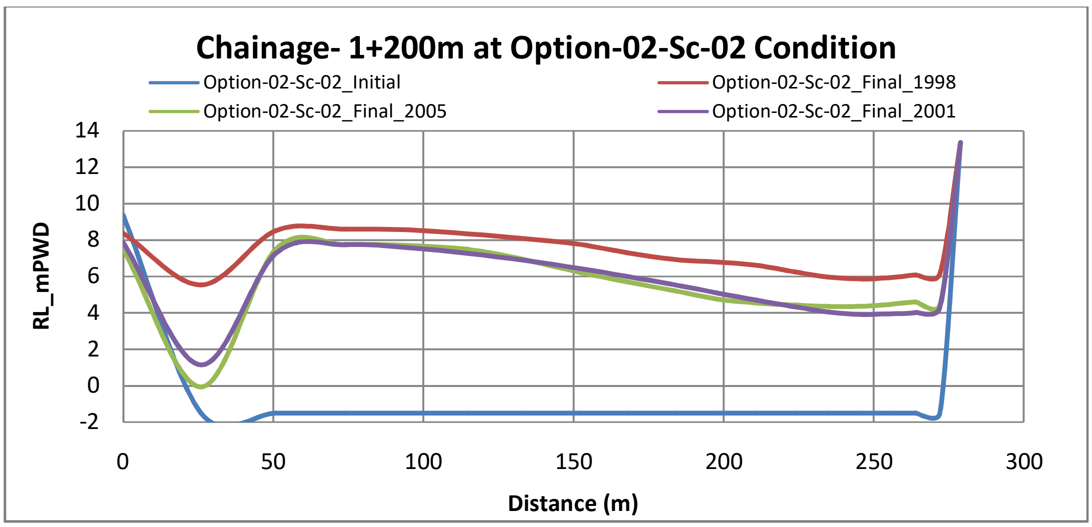
Distance (m)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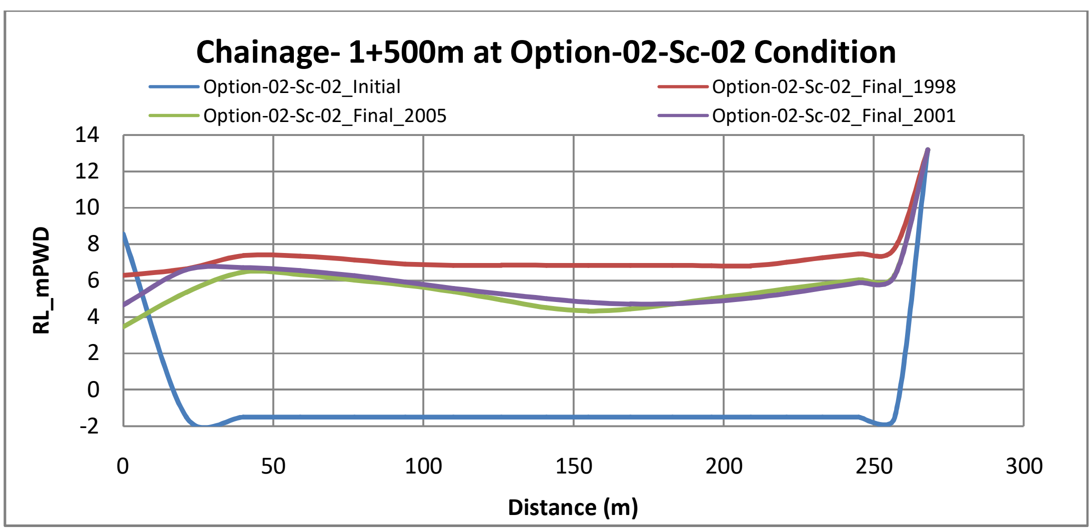
Distance (m)


Chainage- 1+500m at Option-02-Sc-02 Condition
Option-02-Sc-02_Initial
Option-02-Sc-02_Final_1998
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Option-02-Sc-02_Final_2001
RL_mPWD
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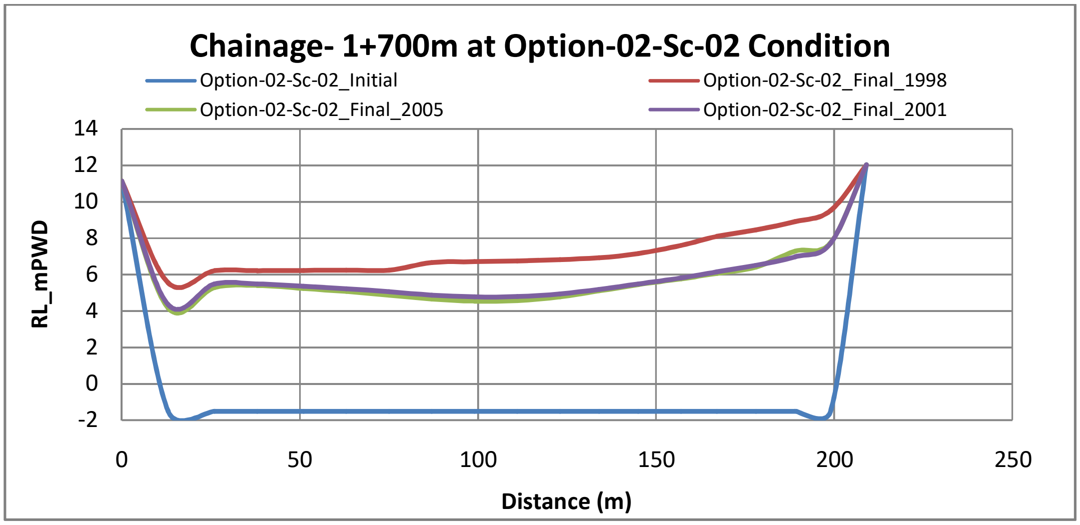
Distance (m)


Chainage- 1+700m at Option-02-Sc-02 Condition
Option-02-Sc-02_Initial
Option-02-Sc-02_Final_1998
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RL_mPWD
Distance (m)
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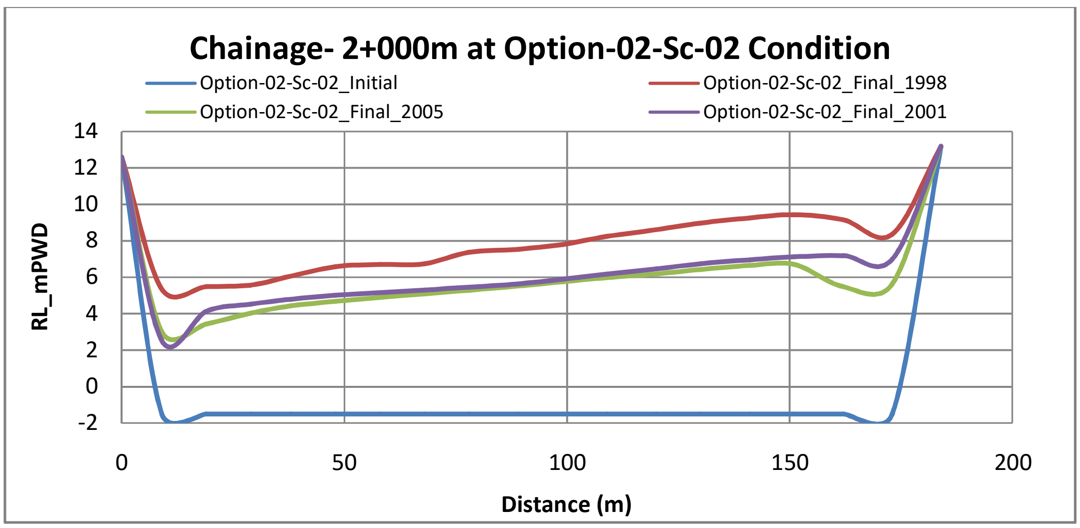
Chainage- 2+000m at Option-02-Sc-02 Condition
Option-02-Sc-02_Initial
Option-02-Sc-02_Final_1998
Option-02-Sc-02_Final_2005
Option-02-Sc-02_Final_2001
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Distance (m)
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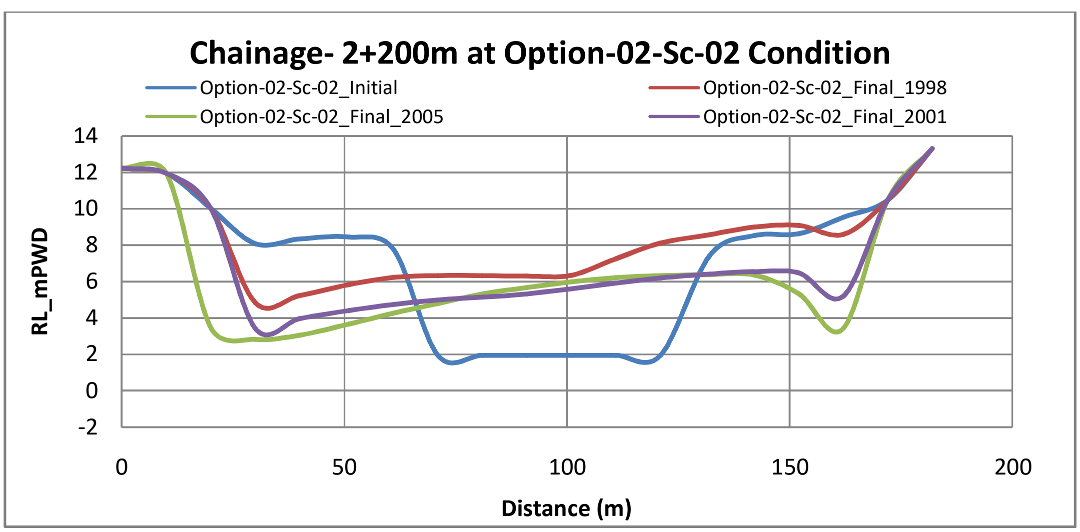
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Option-02-Sc-02_Final_2005
Option-02-Sc-02_Final_2001
RL_mPWD
Distance (m)
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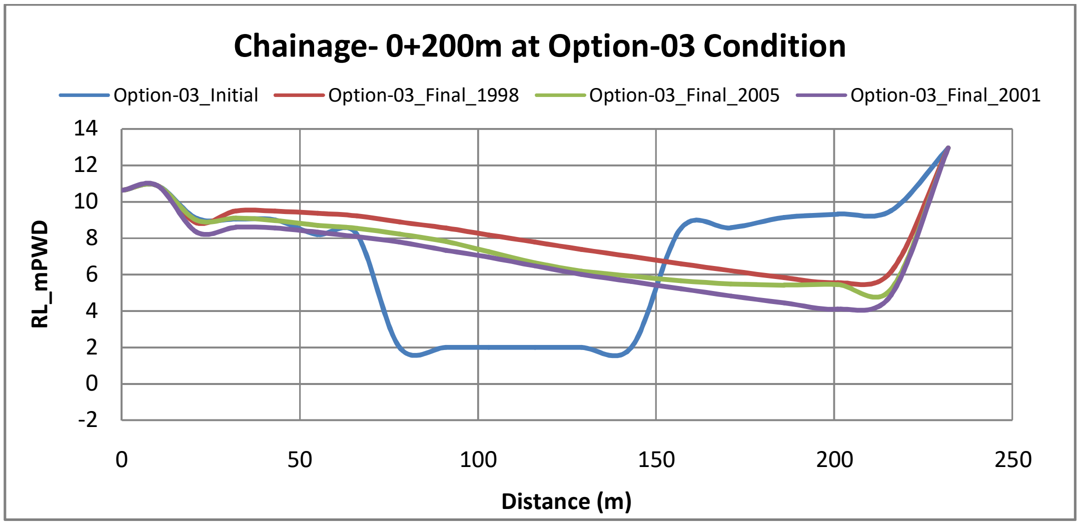
Chainage- 0+200m at Option-03 Condition
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Option-03_Final_2005
Option-03_Final_2001
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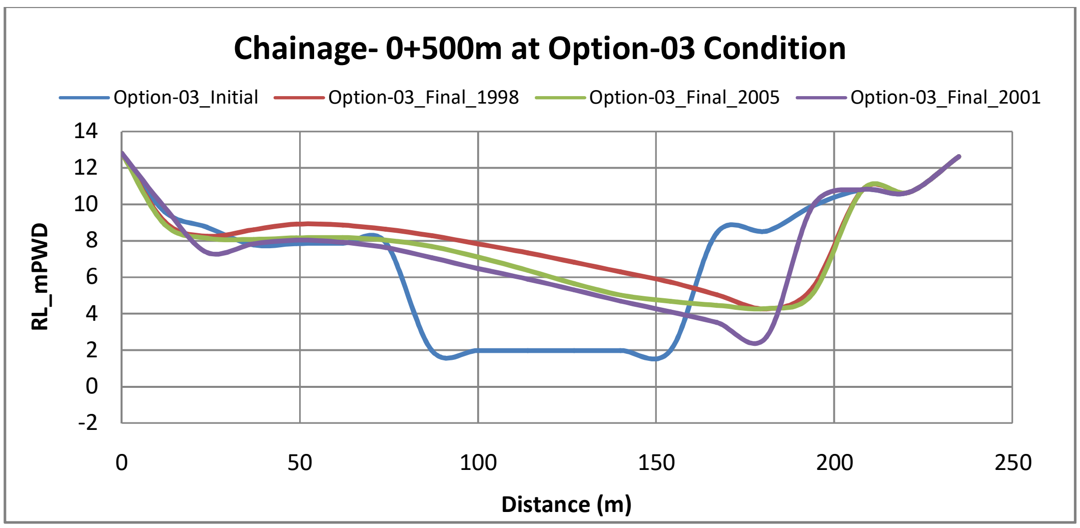
Distance (m)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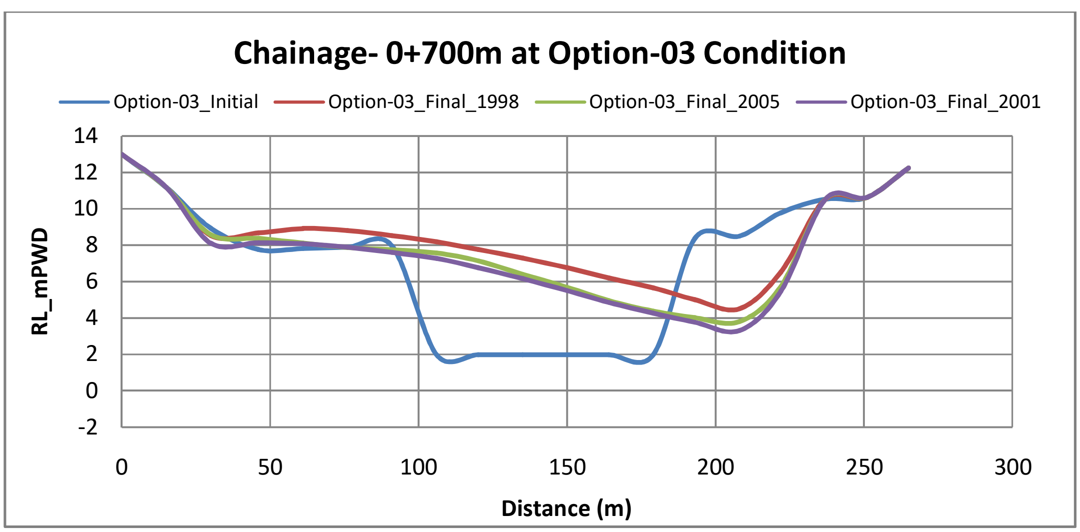
Distance (m)


Chainage- 0+700m at Option-03 Condition
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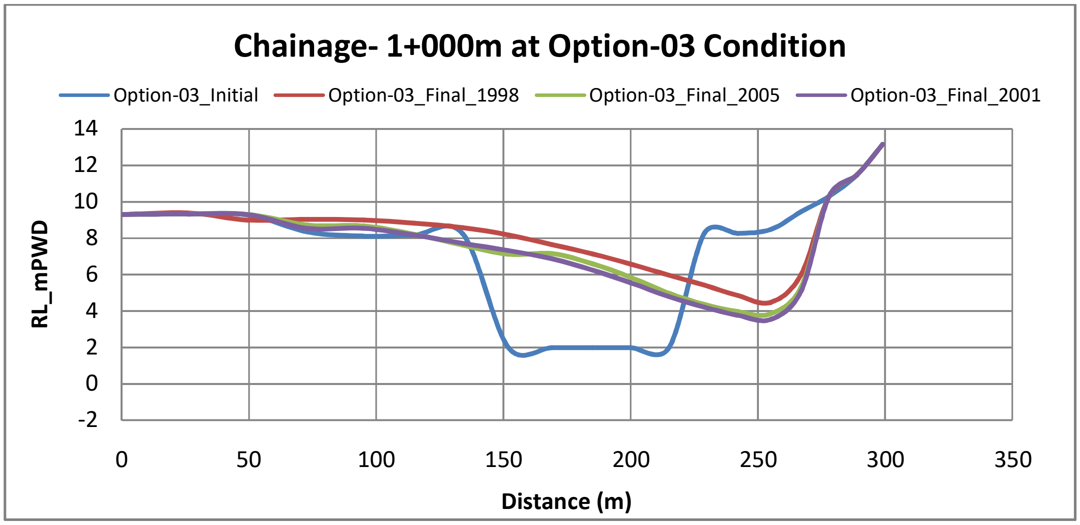
Distance (m)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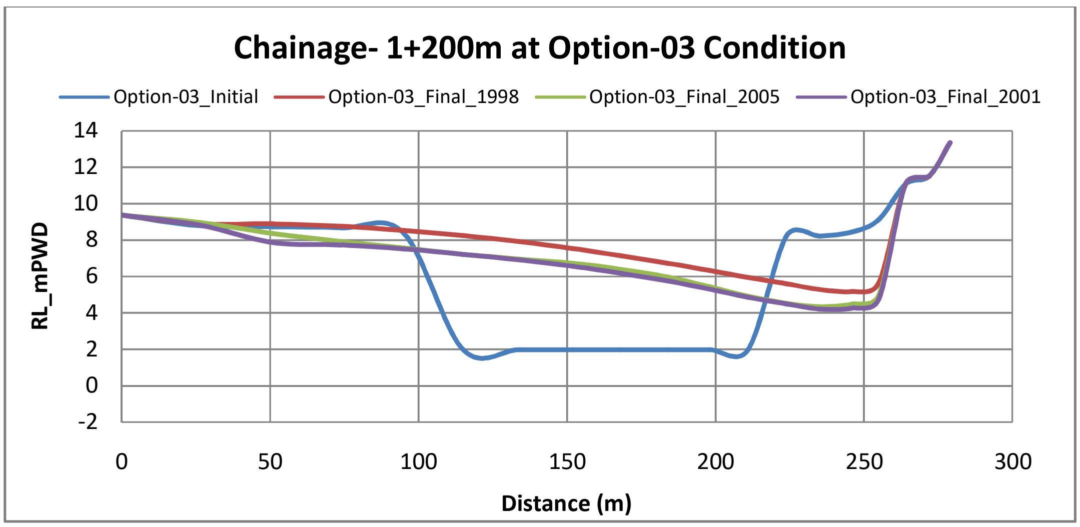
Distance (m)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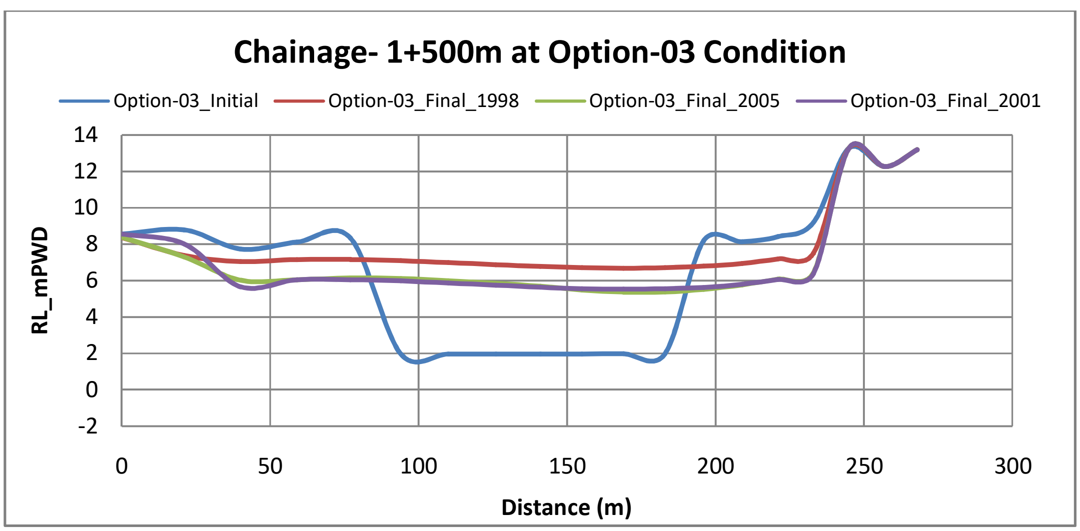
Distance (m)


Chainage- 1+500m at Option-03 Condition
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Option-03_Final_2001
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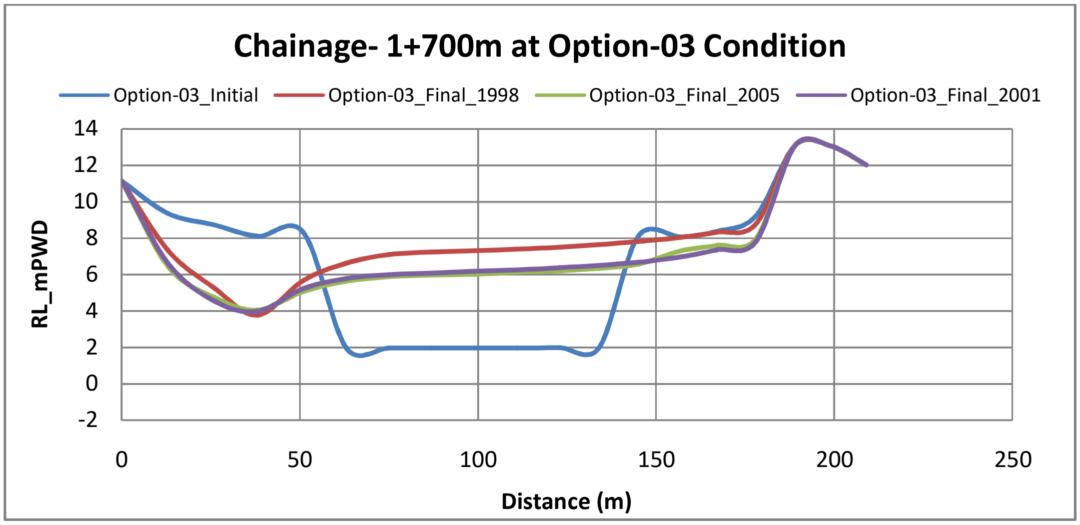
Distance (m)


Chainage- 1+700m at Option-03 Condition
Option-03_Initial
Option-03_Final_1998
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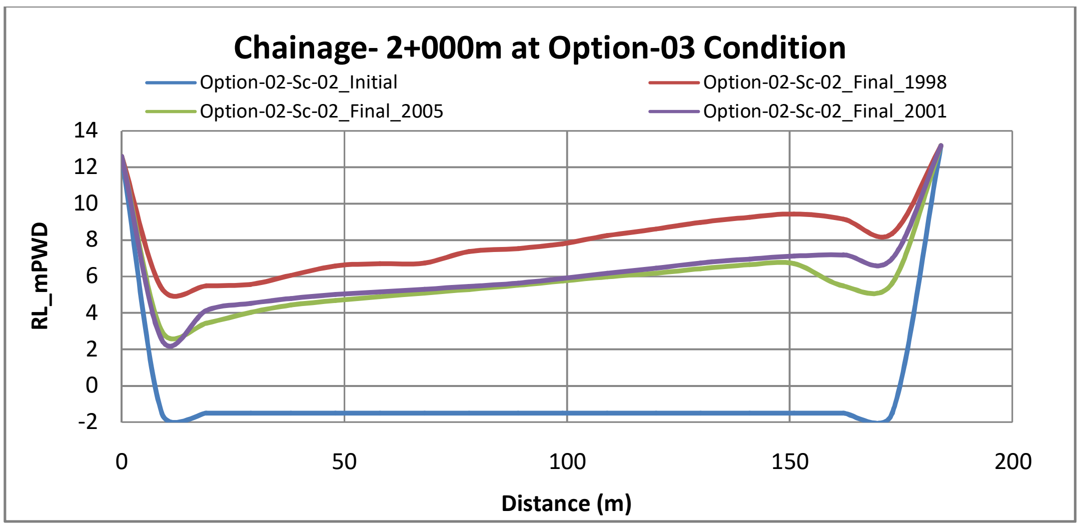
Distance (m)


Chainage- 2+000m at Option-03 Condition
Option-02-Sc-02_Initial
Option-02-Sc-02_Final_1998
Option-02-Sc-02_Final_2005
Option-02-Sc-02_Final_2001
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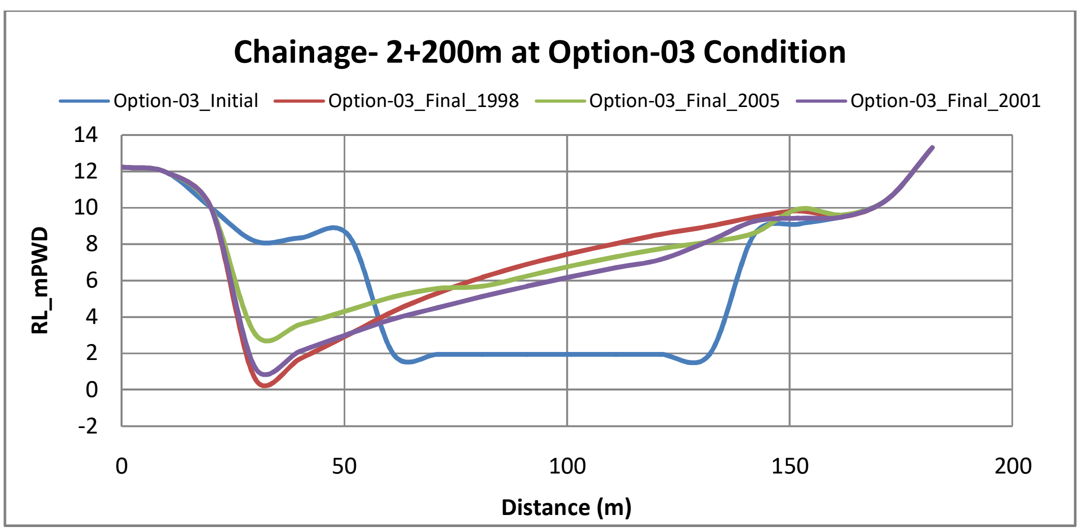
Distance (m)


Chainage- 2+200m at Option-03 Condition
Option-03_Initial
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Option-03_Final_2005
Option-03_Final_2001
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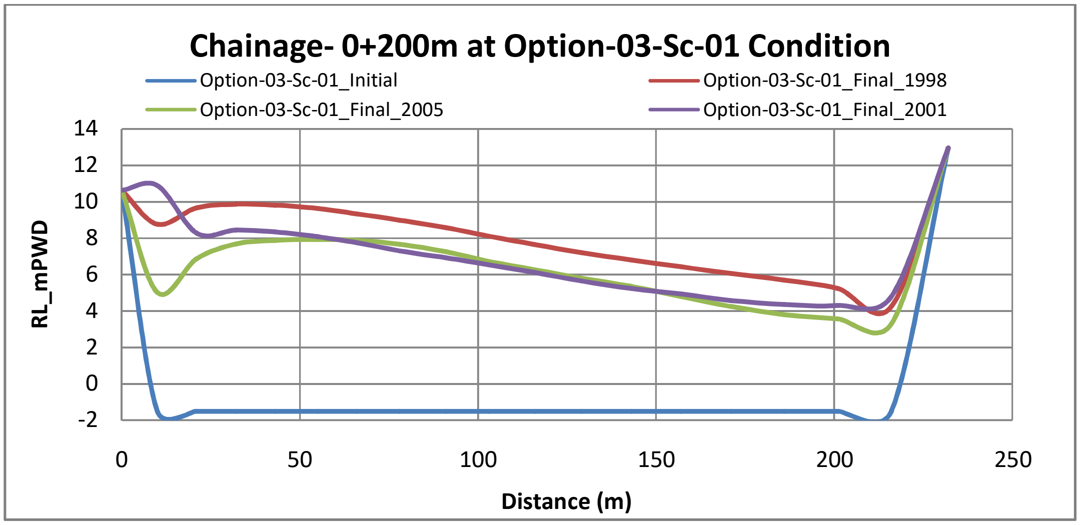
Distance (m)


Chainage- 0+200m at Option-03-Sc-01 Condition
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Option-03-Sc-01_Final_2001
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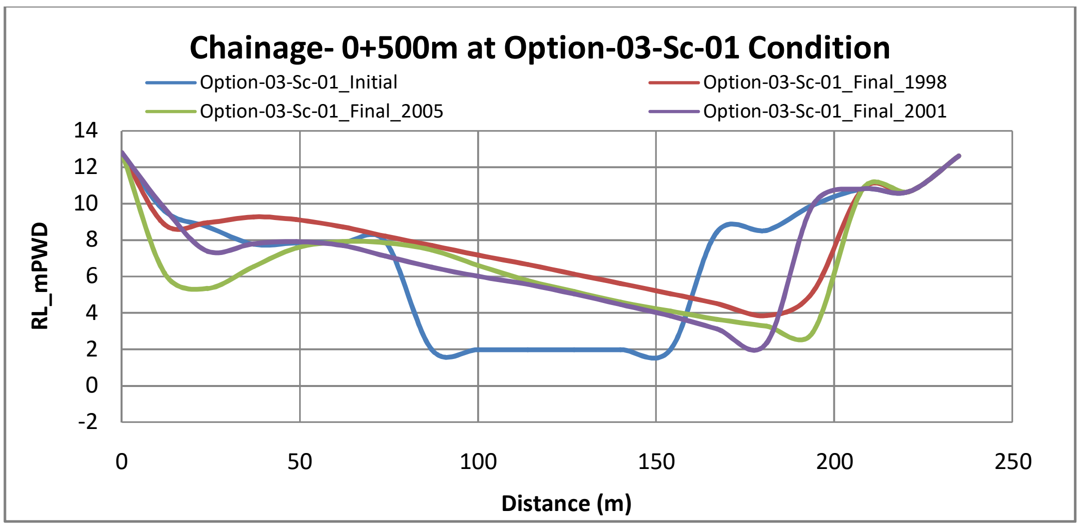
Distance (m)


Chainage- 0+500m at Option-03-Sc-01 Condition
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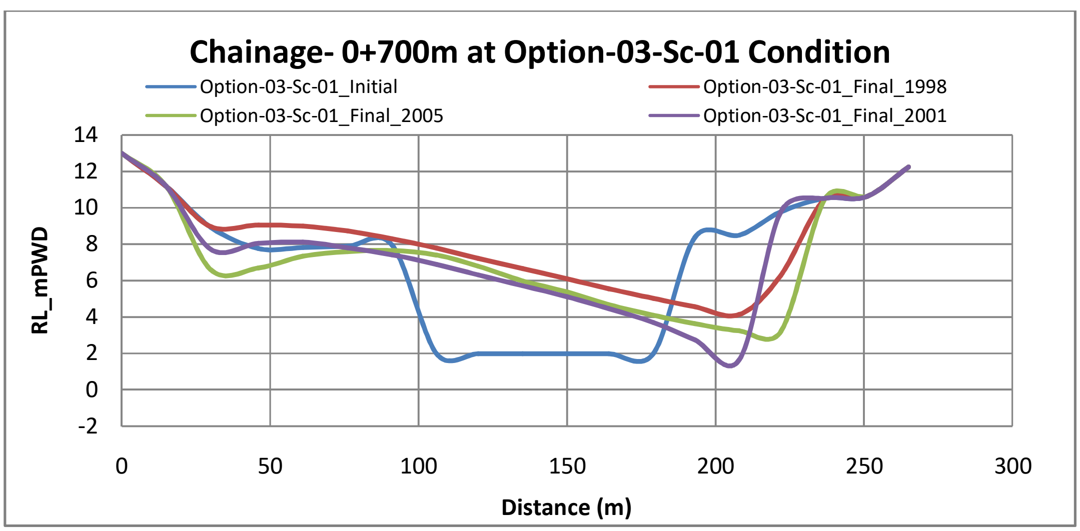
Distance (m)


Chainage- 0+700m at Option-03-Sc-01 Condition
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RL_mPWD
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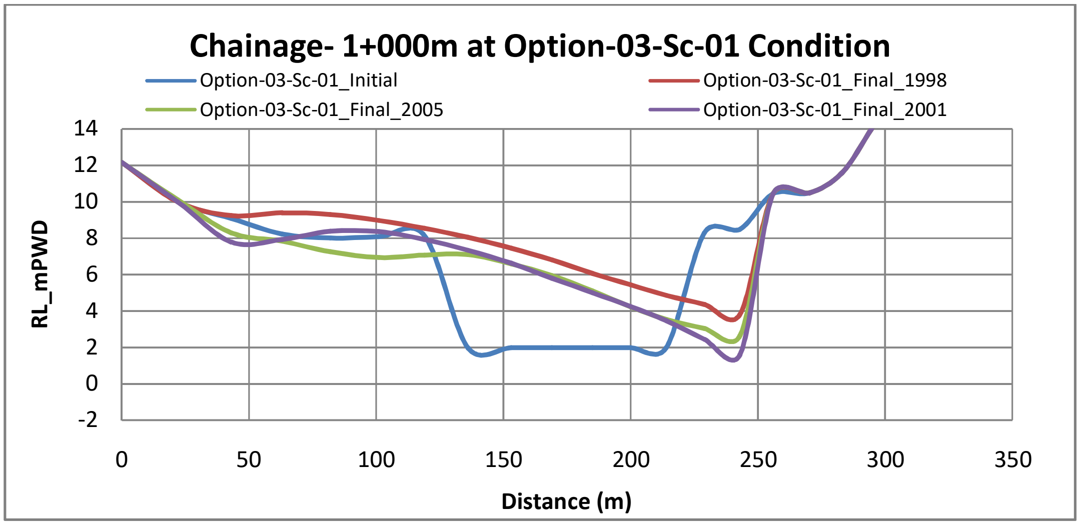
Distance (m)


Chainage- 1+000m at Option-03-Sc-01 Condition
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Option-03-Sc-01_Final_2005
Option-03-Sc-01_Final_2001
RL_mPWD
Distance (m)
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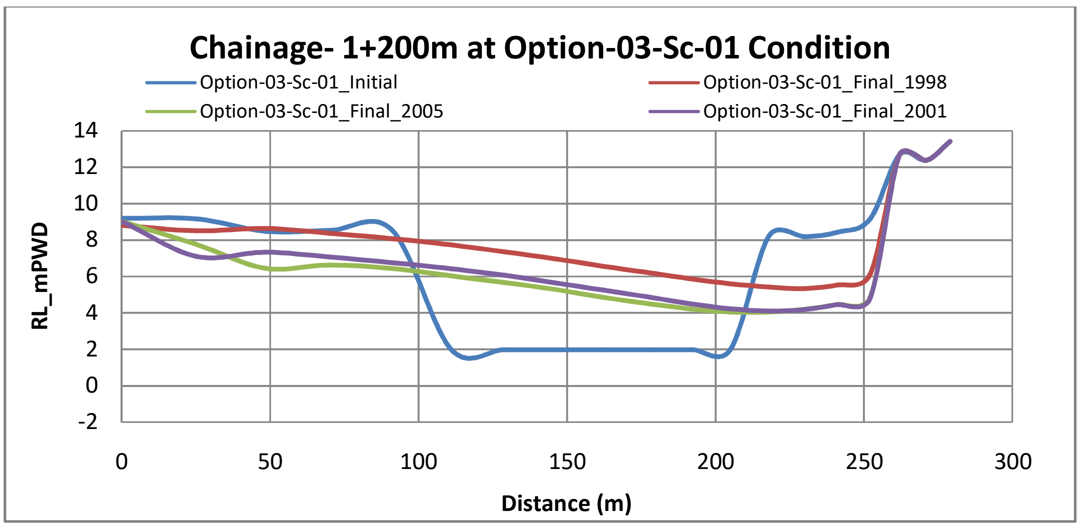
Chainage- 1+200m at Option-03-Sc-01 Condition
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Option-03-Sc-01_Final_2001
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Distance (m)
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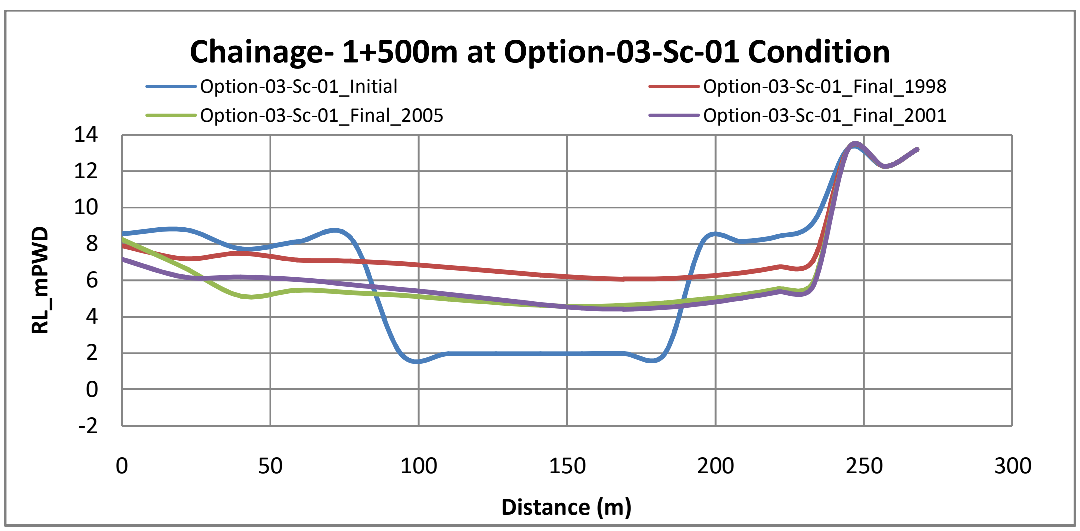
Chainage- 1+500m at Option-03-Sc-01 Condition
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Distance (m)
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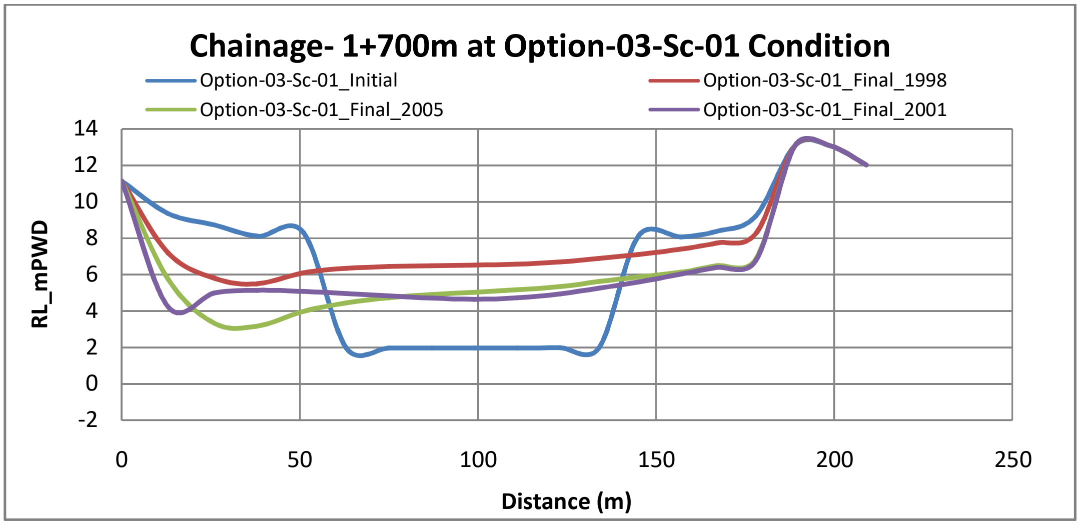
Chainage- 1+700m at Option-03-Sc-01 Condition
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Option-03-Sc-01_Final_2001
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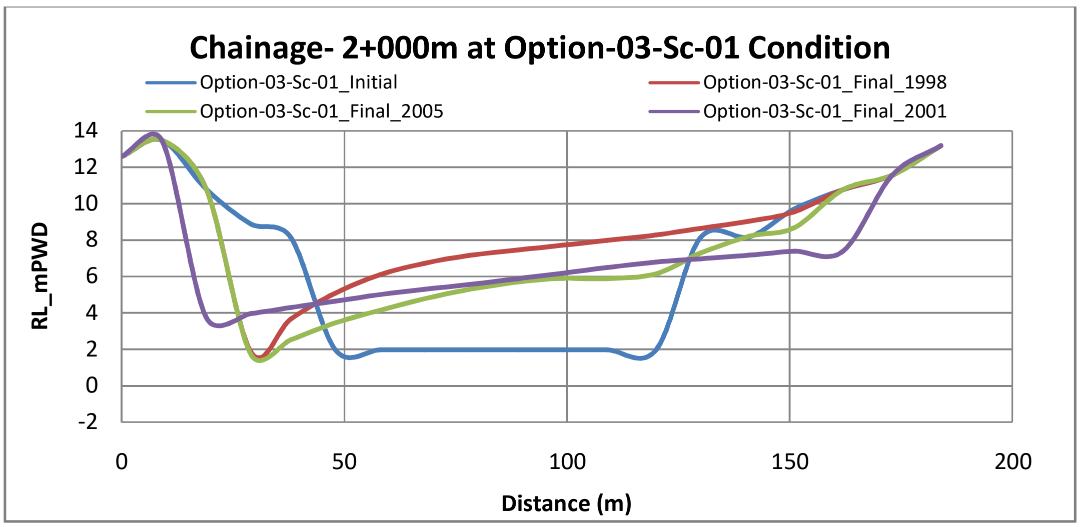
Distance (m)


Chainage- 2+000m at Option-03-Sc-01 Condition
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Option-03-Sc-01_Final_2005
Option-03-Sc-01_Final_2001
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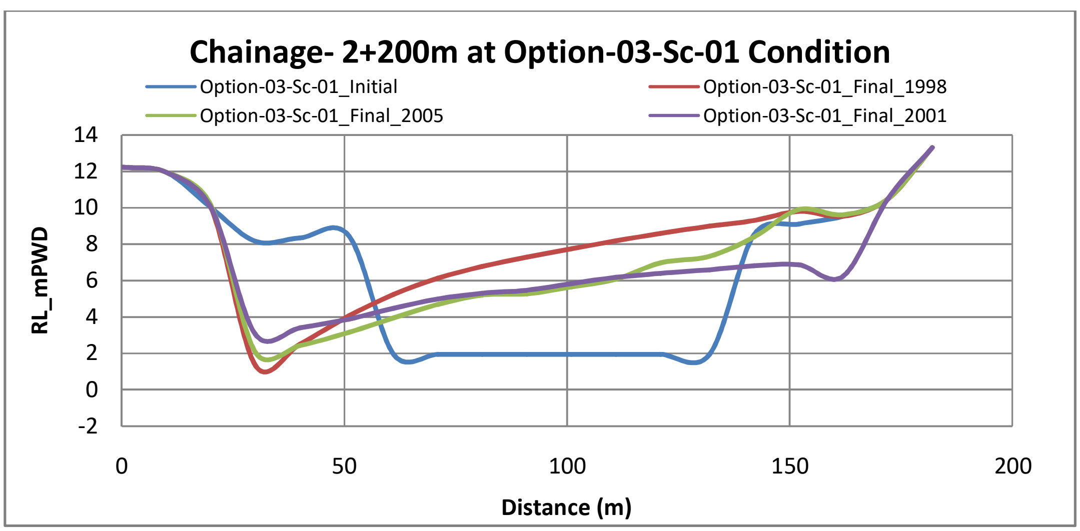
Distance (m)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Option-03-Sc-01_Final_2001
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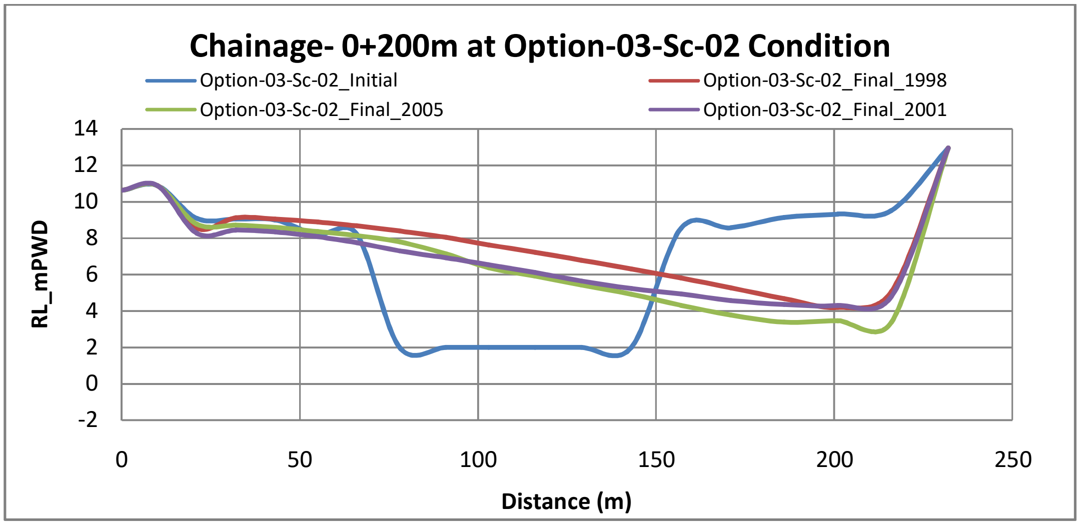
Distance (m)


Chainage- 0+200m at Option-03-Sc-02 Condition
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Option-03-Sc-02_Final_2001
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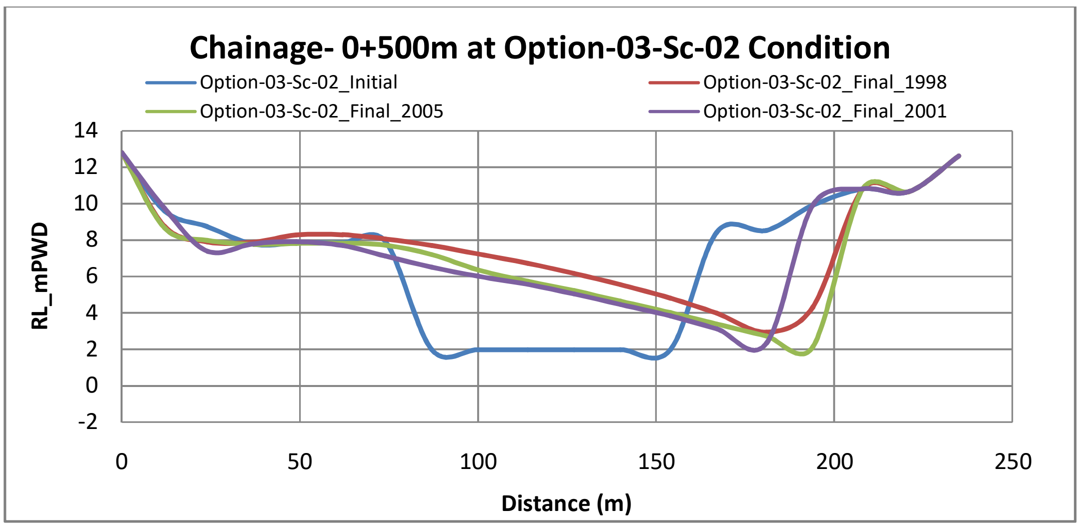
Distance (m)


Chainage- 0+500m at Option-03-Sc-02 Condition
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Option-03-Sc-02_Final_2001
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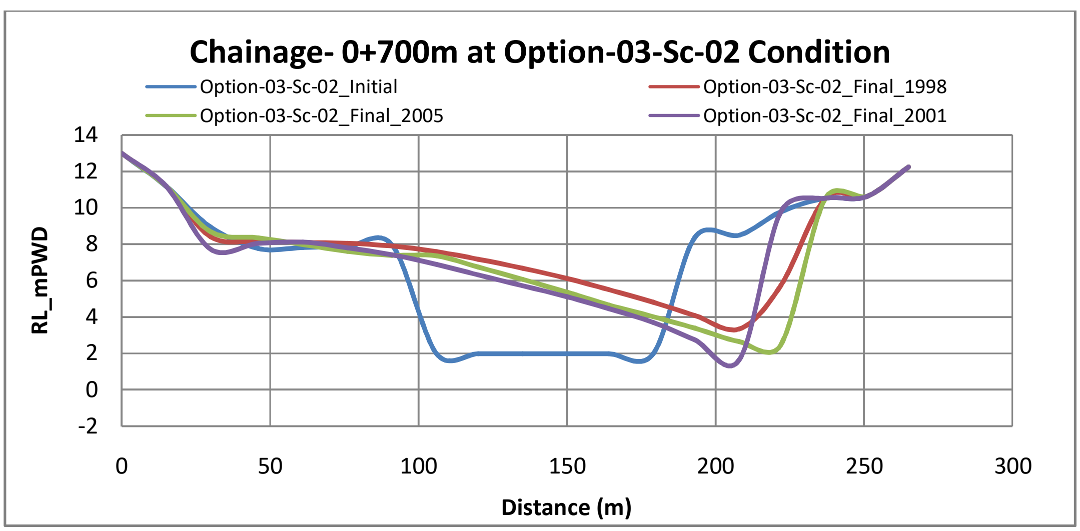
Distance (m)


Chainage- 0+700m at Option-03-Sc-02 Condition
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Option-03-Sc-02_Final_2001
RL_mPWD
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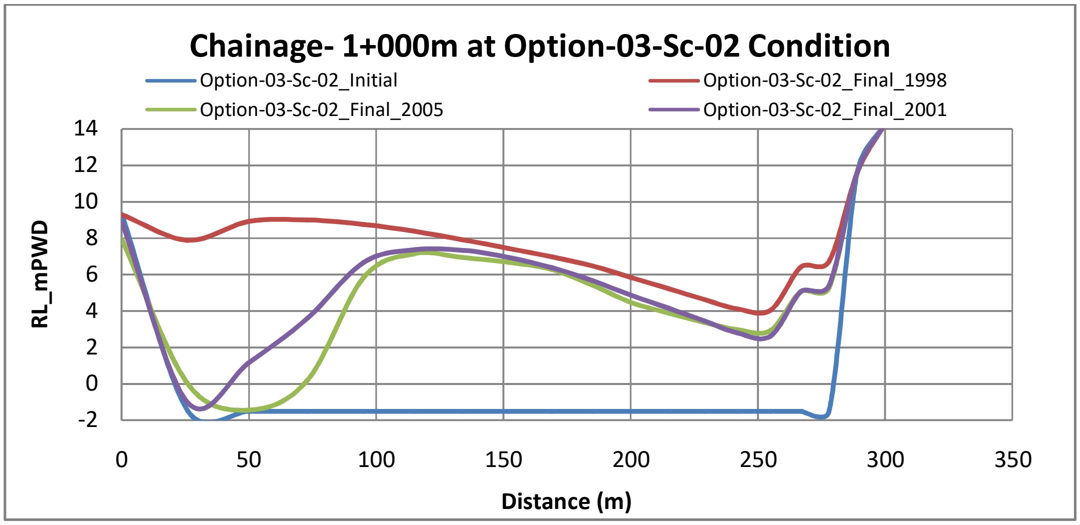
Distance (m)



Chainage- 1+000m at Option-03-Sc-02 Condition
Option-03-Sc-02_Initial
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Option-03-Sc-02_Final_2005
Option-03-Sc-02_Final_2001
RL_mPWD
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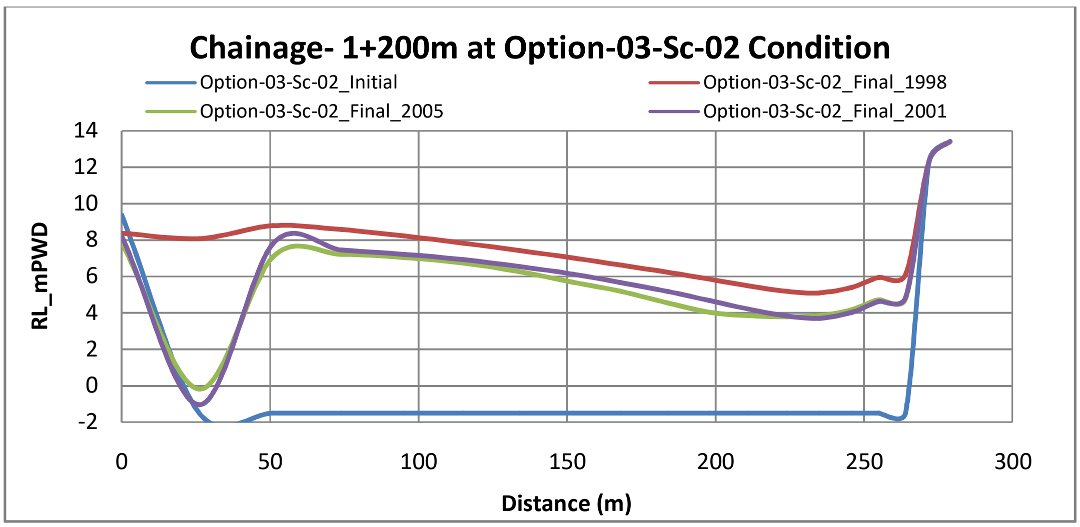
Distance (m)



Chainage- 1+200m at Option-03-Sc-02 Condition
Option-03-Sc-02_Initial
Option-03-Sc-02_Final_1998
Option-03-Sc-02_Final_2005
Option-03-Sc-02_Final_2001
RL_mPWD
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6
4
2
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-2
0
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100
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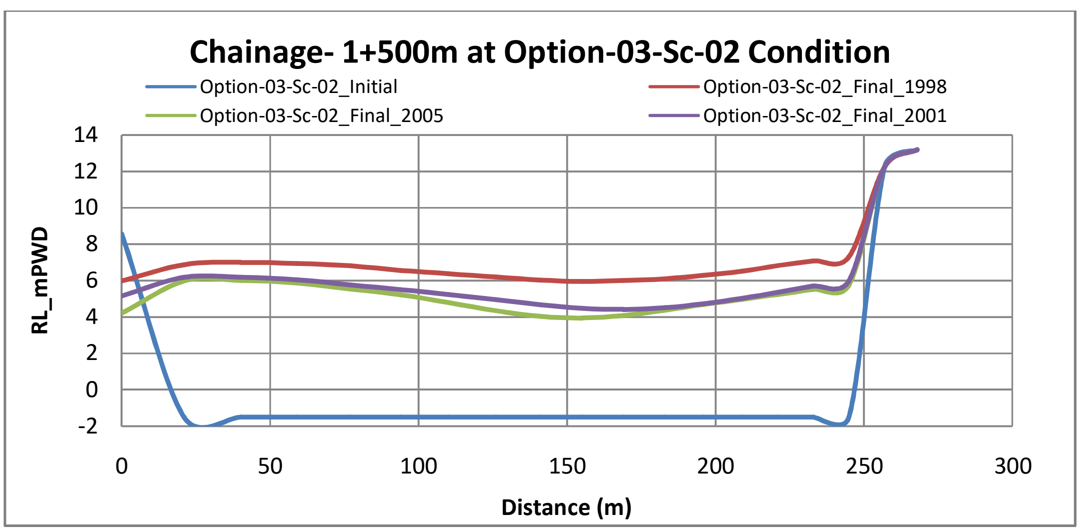
200
250
300
Distance (m)



Chainage- 1+500m at Option-03-Sc-02 Condition
Option-03-Sc-02_Initial
Option-03-Sc-02_Final_1998
Option-03-Sc-02_Final_2005
Option-03-Sc-02_Final_2001
RL_mPWD
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-2
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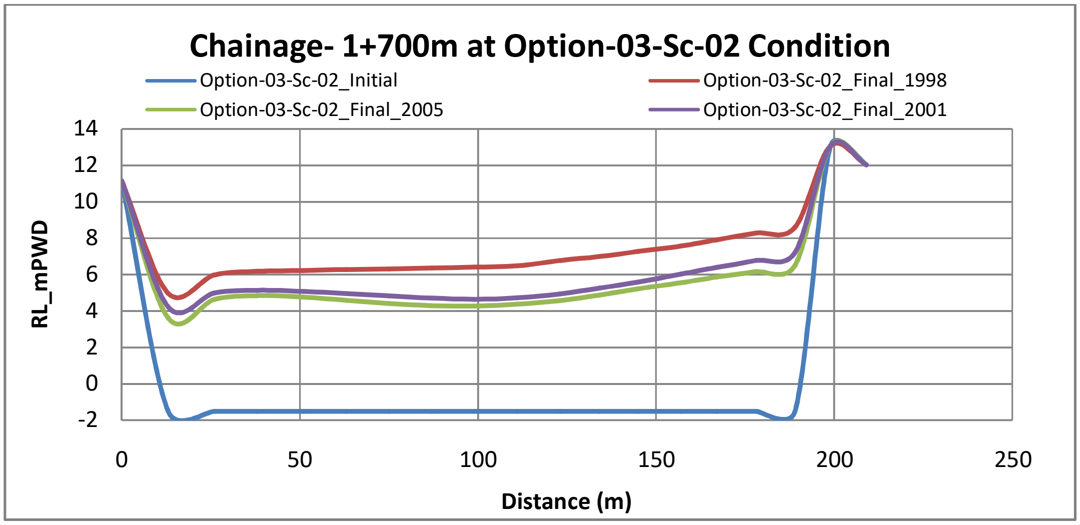
Distance (m)


Chainage- 1+700m at Option-03-Sc-02 Condition
Option-03-Sc-02_Initial
Option-03-Sc-02_Final_1998
Option-03-Sc-02_Final_2005
Option-03-Sc-02_Final_2001
RL_mPWD
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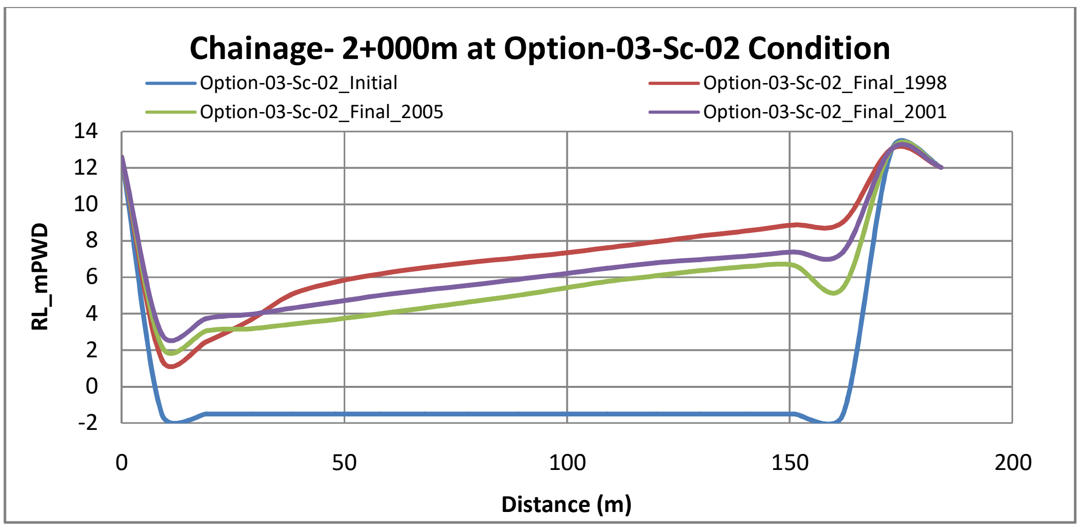
Distance (m)


Chainage- 2+000m at Option-03-Sc-02 Condition
Option-03-Sc-02_Initial
Option-03-Sc-02_Final_1998
Option-03-Sc-02_Final_2005
Option-03-Sc-02_Final_2001
RL_mPWD
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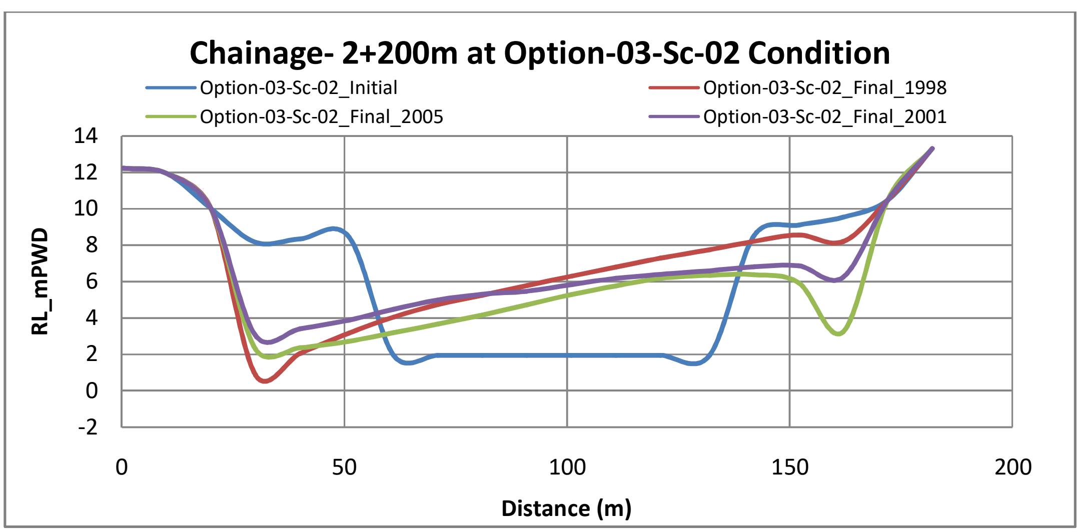
Distance (m)


Chainage- 2+200m at Option-03-Sc-02 Condition
Option-03-Sc-02_Initial
Option-03-Sc-02_Final_1998
Option-03-Sc-02_Final_2005
Option-03-Sc-02_Final_2001
RL_mPWD
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150
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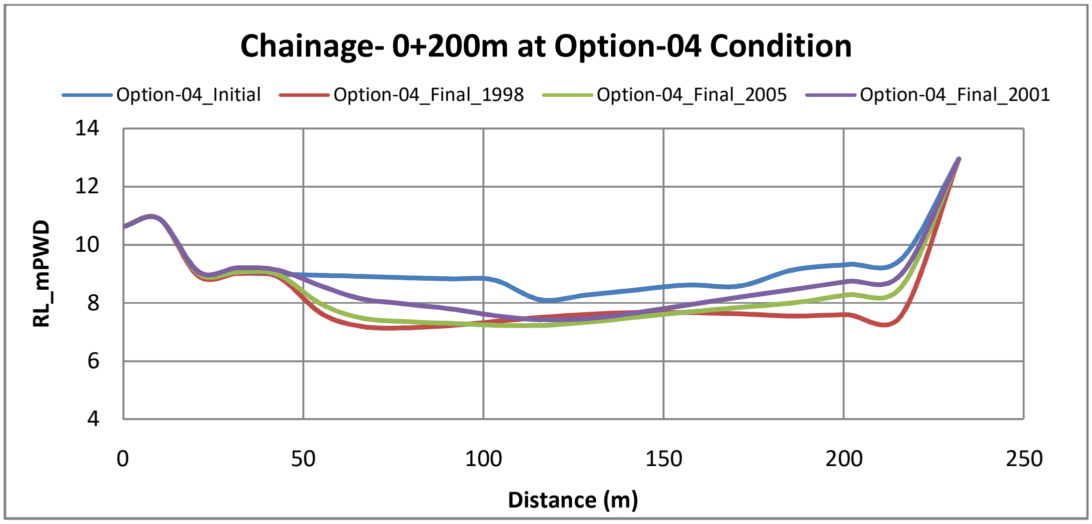
Distance (m)


Chainage- 0+200m at Option-04 Condition
Option-04_Initial
Option-04_Final_1998
Option-04_Final_2005
Option-04_Final_2001
RL_mPWD
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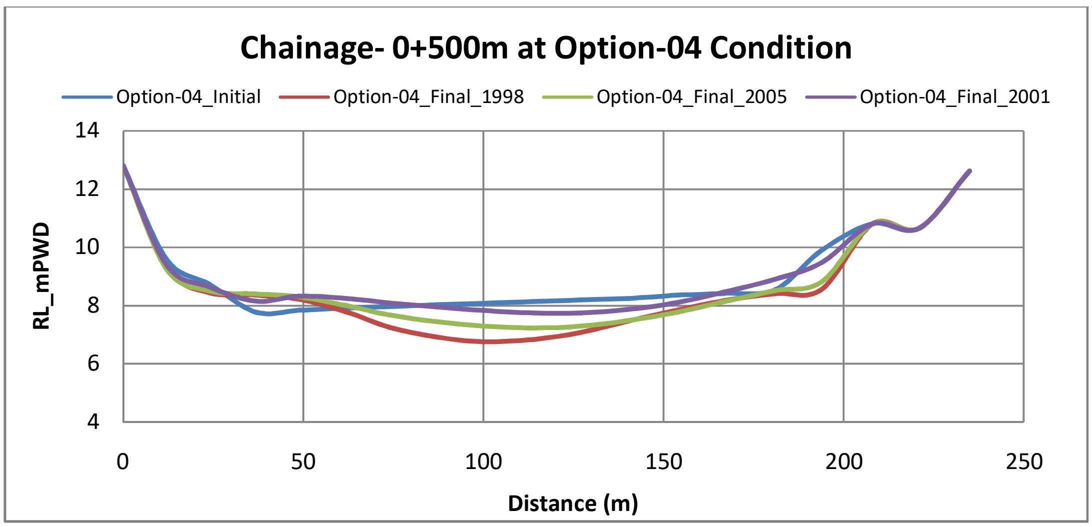
Distance (m)


Chainage- 0+500m at Option-04 Condition
Option-04_Initial
Option-04_Final_1998
Option-04_Final_2005
Option-04_Final_2001
RL_mPWD
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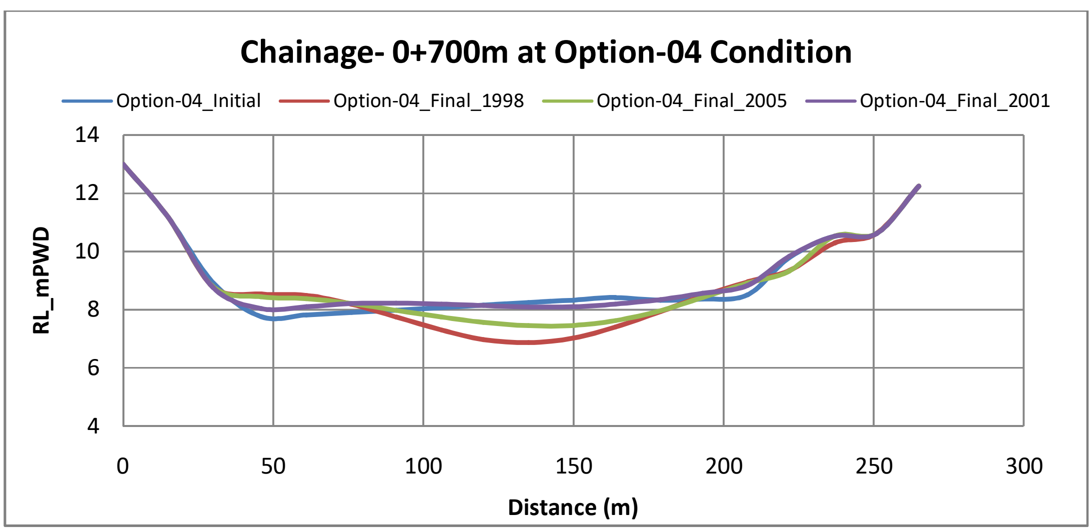
Distance (m)


Chainage- 0+700m at Option-04 Condition
Option-04_Initial
Option-04_Final_1998
Option-04_Final_2005
Option-04_Final_2001
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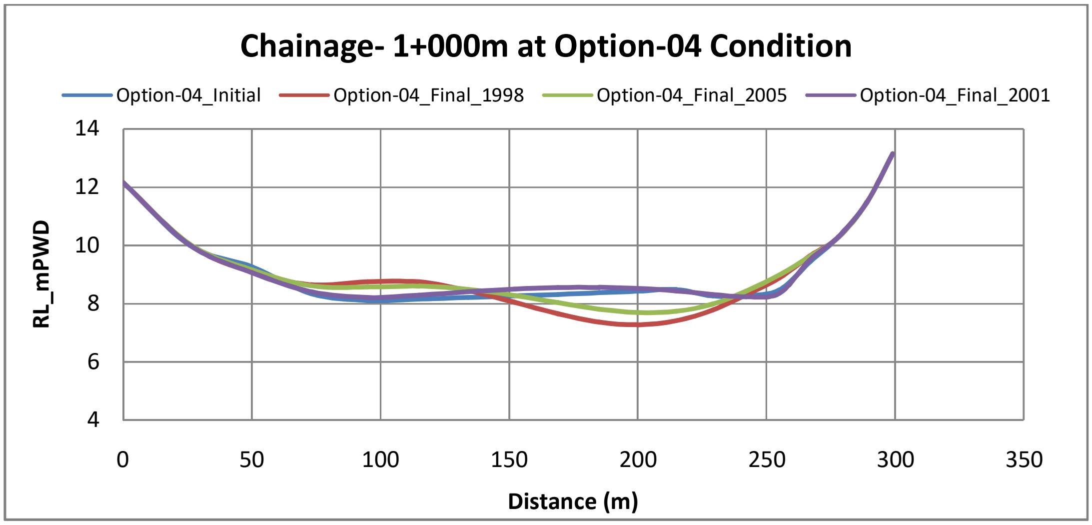
Distance (m)


Chainage- 1+000m at Option-04 Condition
Option-04_Initial
Option-04_Final_1998
Option-04_Final_2005
Option-04_Final_2001
RL_mPWD
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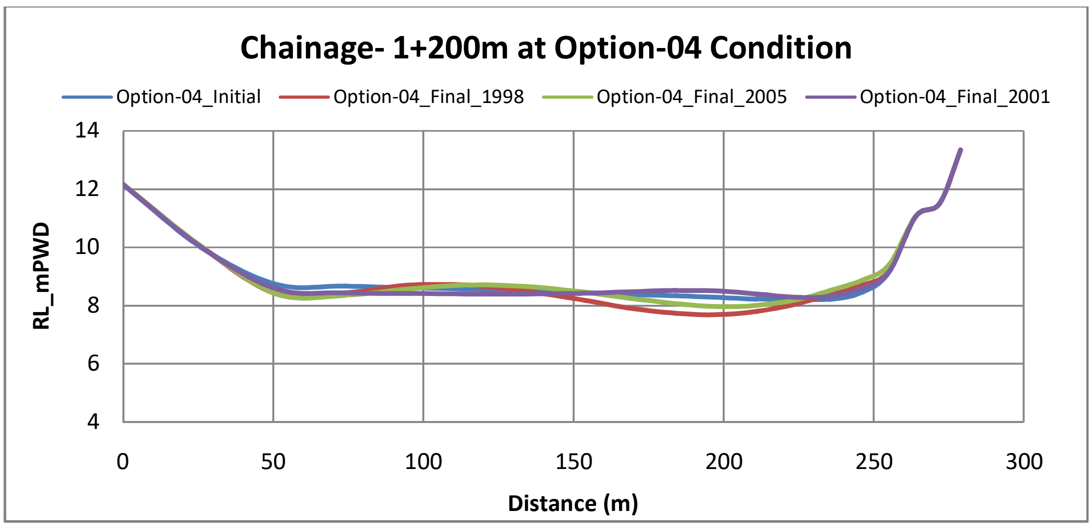
Distance (m)


Chainage- 1+200m at Option-04 Condition
Option-04_Initial
Option-04_Final_1998
Option-04_Final_2005
Option-04_Final_2001
RL_mPWD
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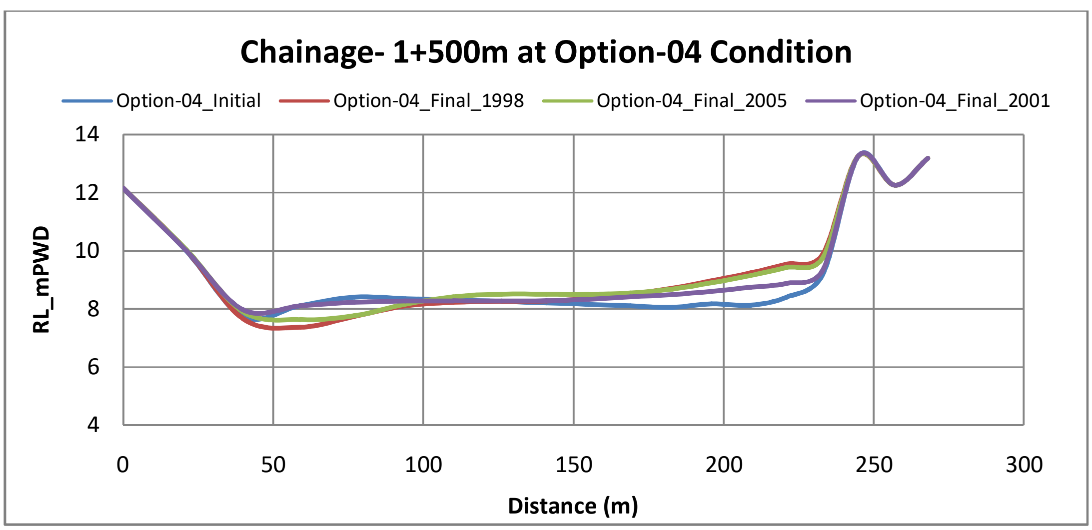
Distance (m)


Chainage- 1+500m at Option-04 Condition
Option-04_Initial
Option-04_Final_1998
Option-04_Final_2005
Option-04_Final_2001
RL_mPWD
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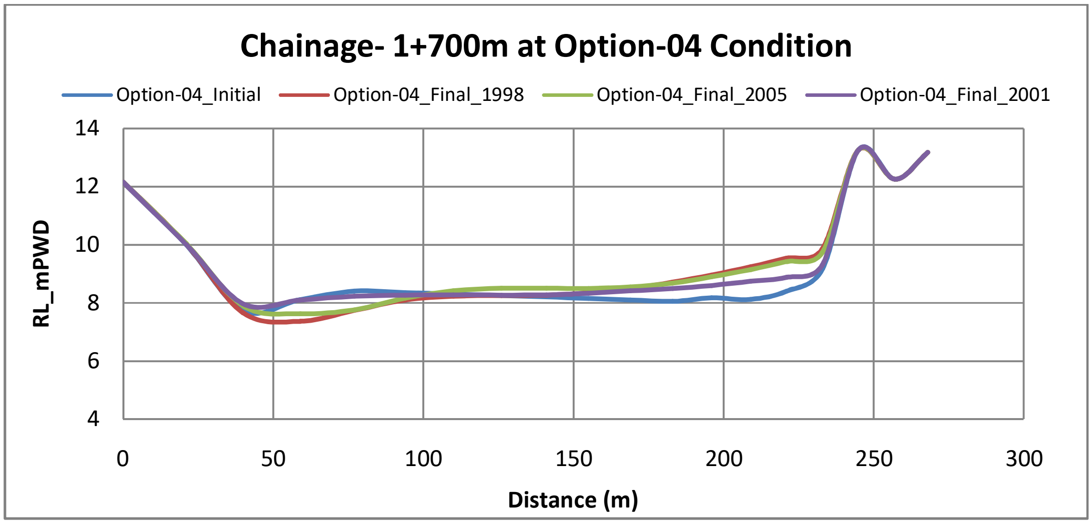
Distance (m)


Chainage- 1+700m at Option-04 Condition
Option-04_Initial
Option-04_Final_1998
Option-04_Final_2005
Option-04_Final_2001
RL_mPWD
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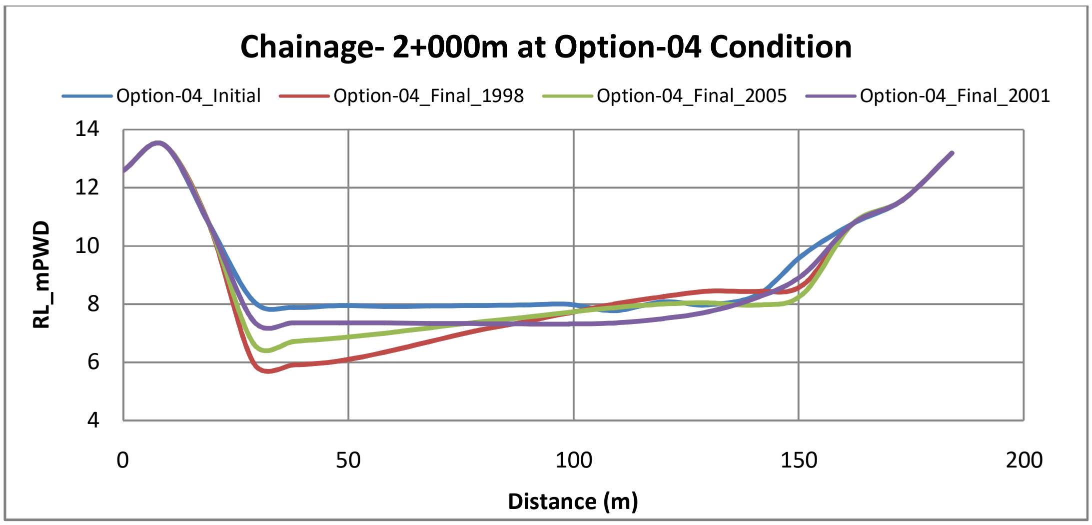
Distance (m)


Chainage- 2+000m at Option-04 Condition
Option-04_Initial
Option-04_Final_1998
Option-04_Final_2005
Option-04_Final_2001
RL_mPWD
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4
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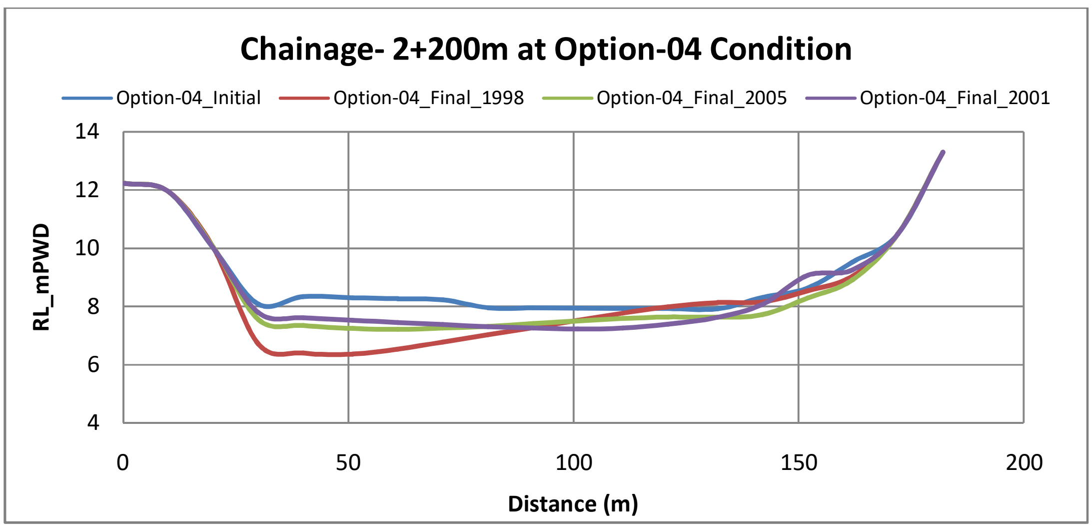
Distance (m)


Chainage- 2+200m at Option-04 Condition
Option-04_Initial
Option-04_Final_1998
Option-04_Final_2005
Option-04_Final_2001
RL_mPWD
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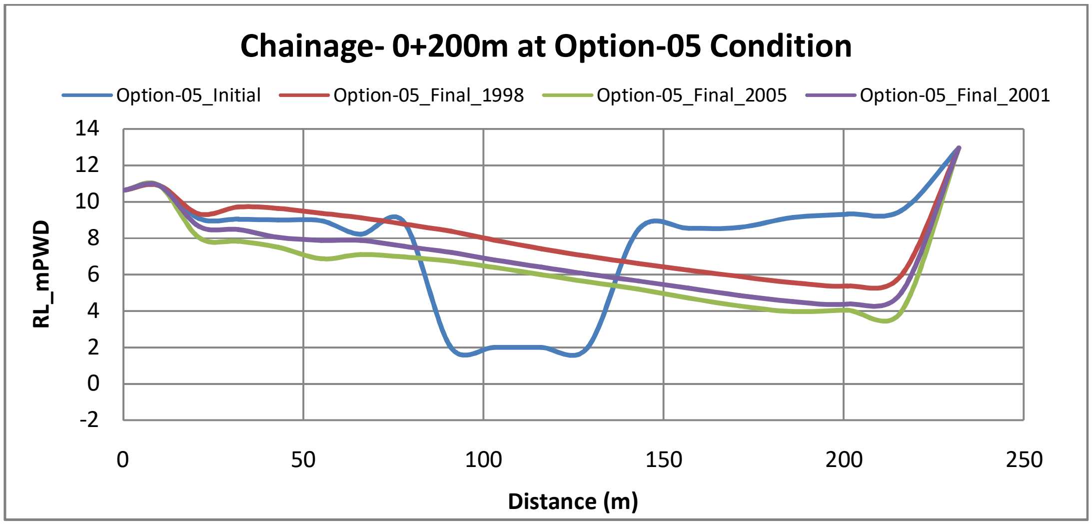
Distance (m)


Chainage- 0+200m at Option-05 Condition
Option-05_Initial
Option-05_Final_1998
Option-05_Final_2005
Option-05_Final_2001
RL_mPWD
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8
6
4
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0
-2
0
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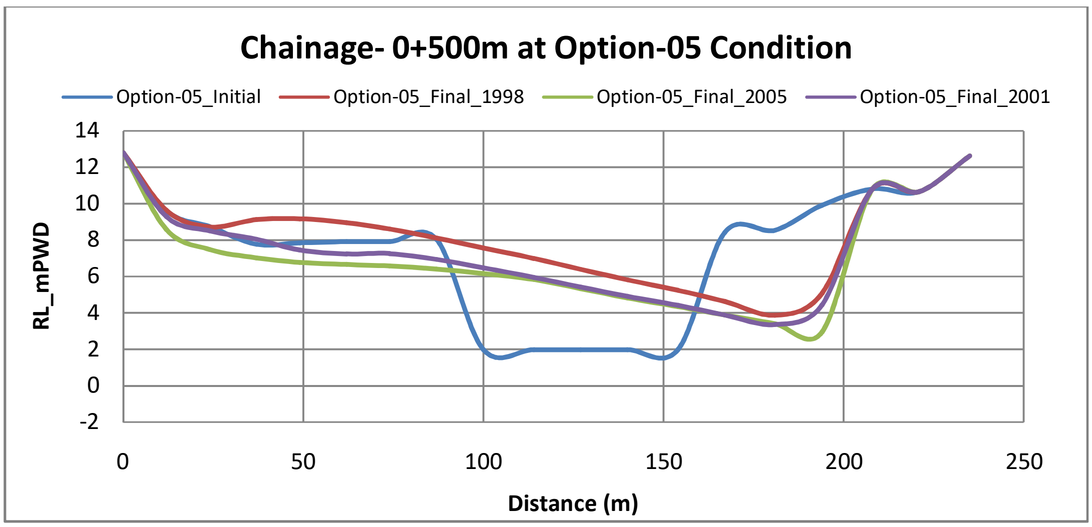
150
200
250
Distance (m)


Chainage- 0+500m at Option-05 Condition
Option-05_Initial
Option-05_Final_1998
Option-05_Final_2005
Option-05_Final_2001
RL_mPWD
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6
4
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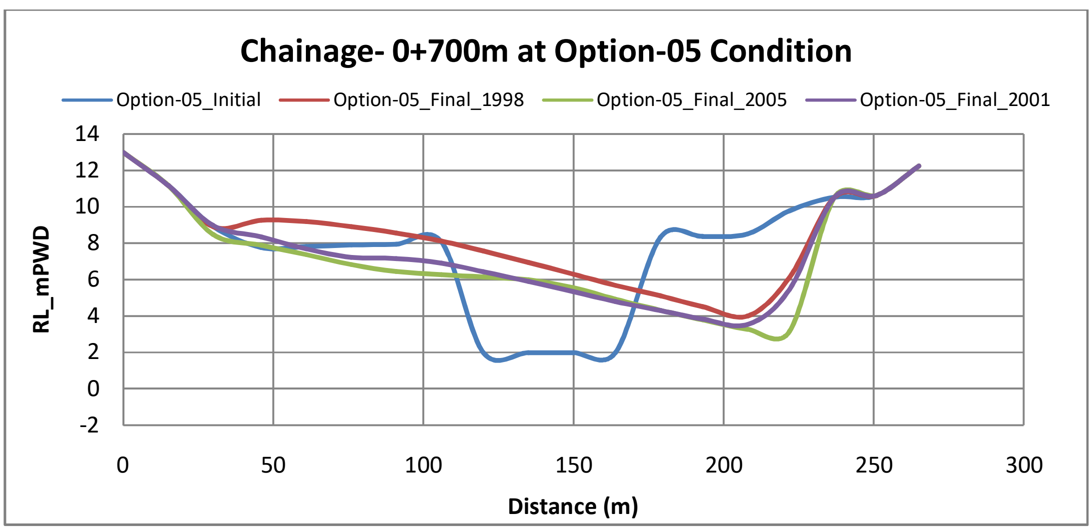
0
-2
0
50
100
150
200
250
Distance (m)


Chainage- 0+700m at Option-05 Condition
Option-05_Initial
Option-05_Final_1998
Option-05_Final_2005
Option-05_Final_2001
RL_mPWD
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-2
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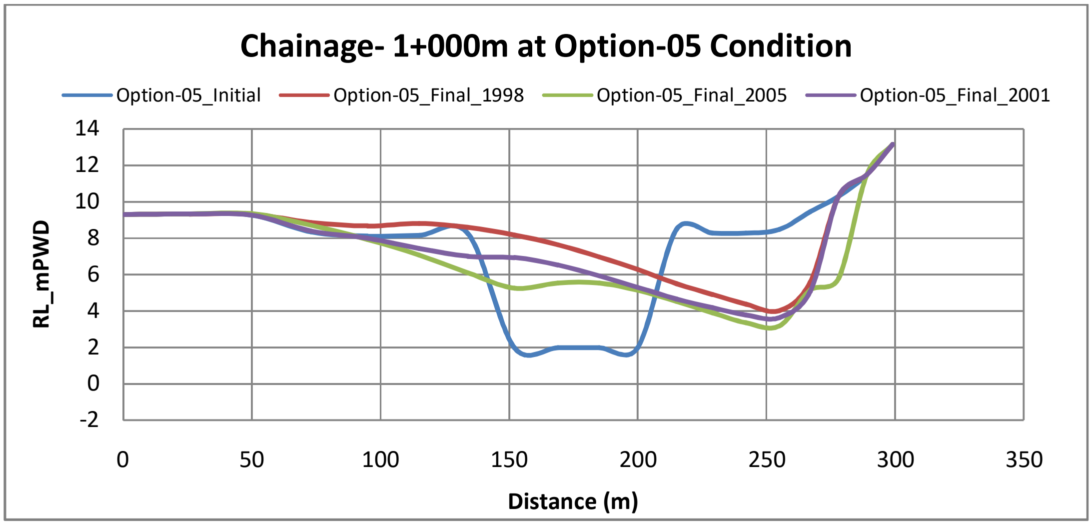
250
300
Distance (m)


Chainage- 1+000m at Option-05 Condition
Option-05_Initial
Option-05_Final_1998
Option-05_Final_2005
Option-05_Final_2001
RL_mPWD
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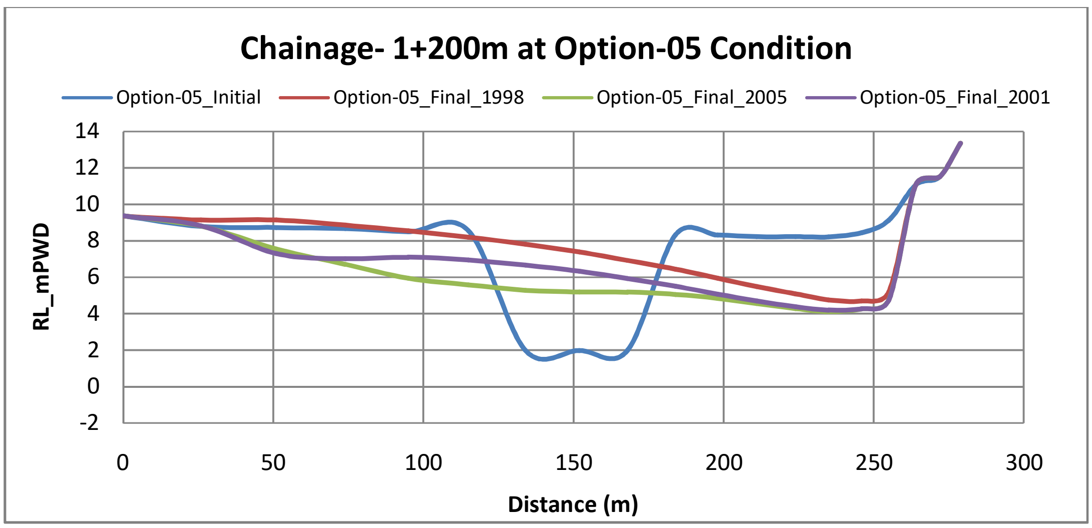
Distance (m)


Chainage- 1+200m at Option-05 Condition
Option-05_Initial
Option-05_Final_1998
Option-05_Final_2005
Option-05_Final_2001
RL_mPWD
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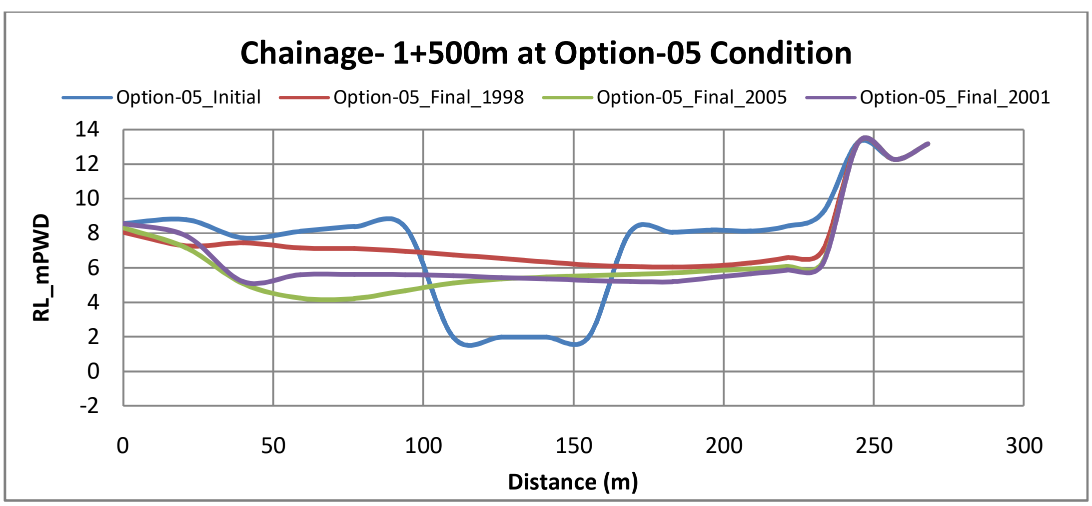
Distance (m)


Chainage- 1+500m at Option-05 Condition
Option-05_Initial
Option-05_Final_1998
Option-05_Final_2005
Option-05_Final_2001
RL_mPWD
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2
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-2
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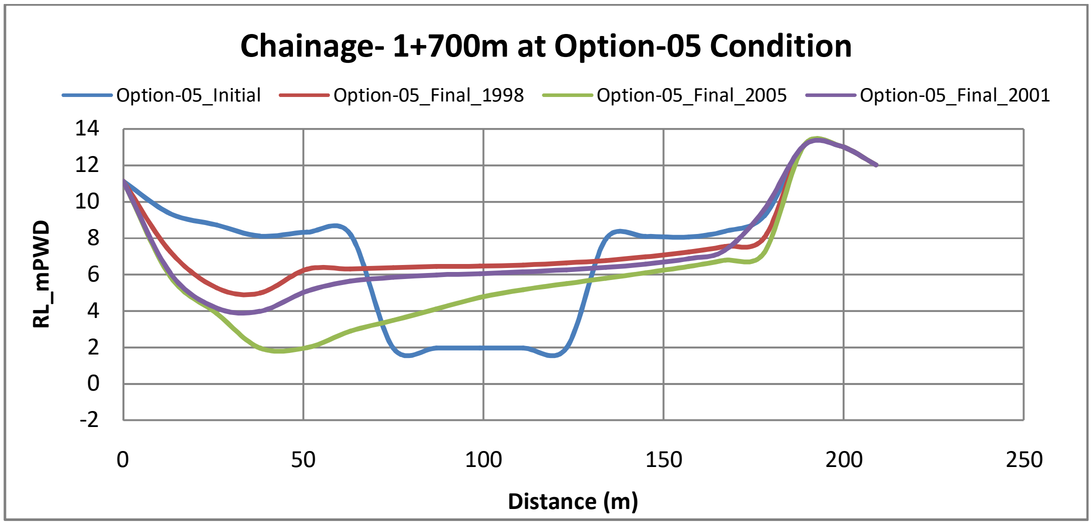
Distance (m)


Chainage- 1+700m at Option-05 Condition
Option-05_Initial
Option-05_Final_1998
Option-05_Final_2005
Option-05_Final_2001
RL_mPWD
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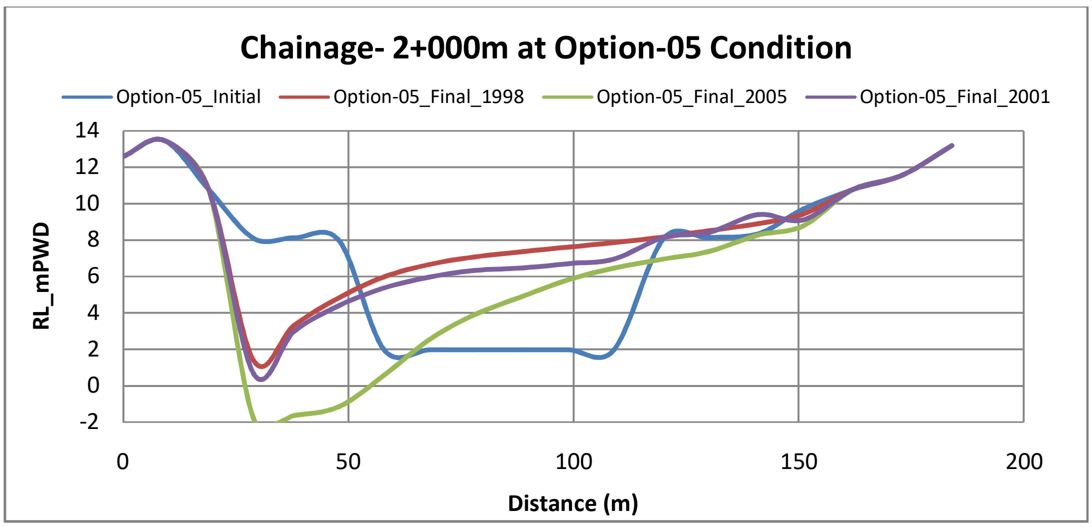
Distance (m)


Chainage- 2+000m at Option-05 Condition
Option-05_Initial
Option-05_Final_1998
Option-05_Final_2005
Option-05_Final_2001
RL_mPWD
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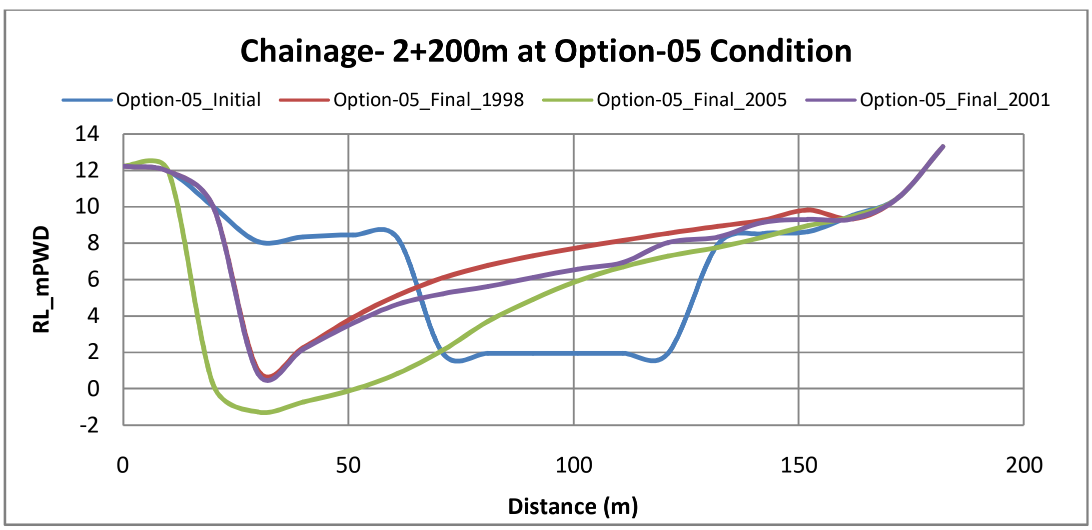
Distance (m)


Chainage- 2+200m at Option-05 Condition
Option-05_Initial
Option-05_Final_1998
Option-05_Final_2005
Option-05_Final_2001
RL_mPWD
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-2
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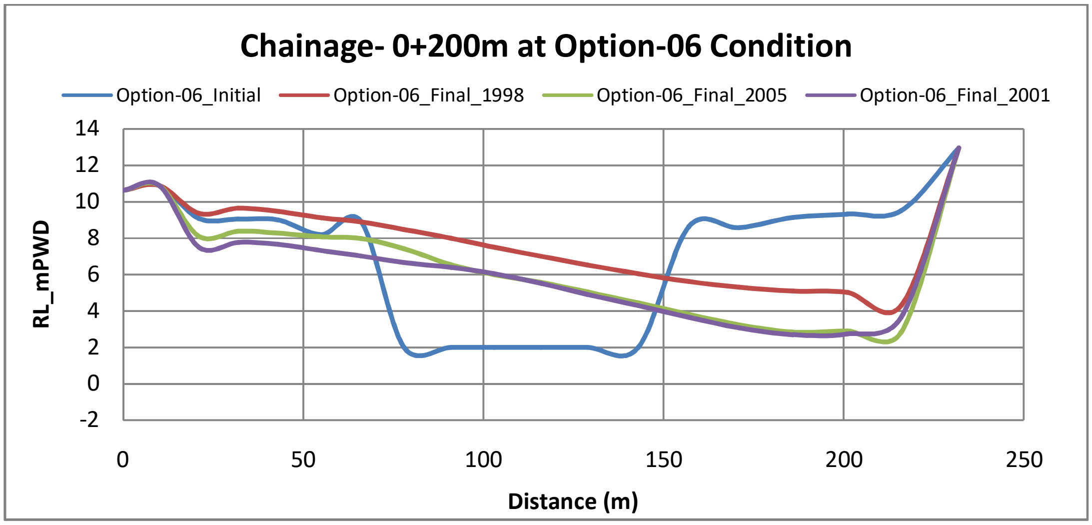
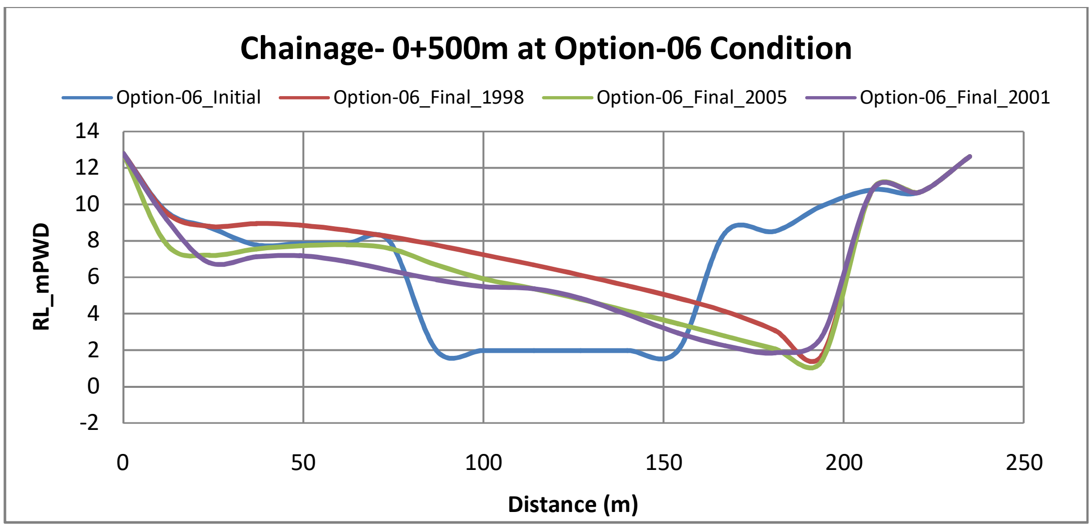
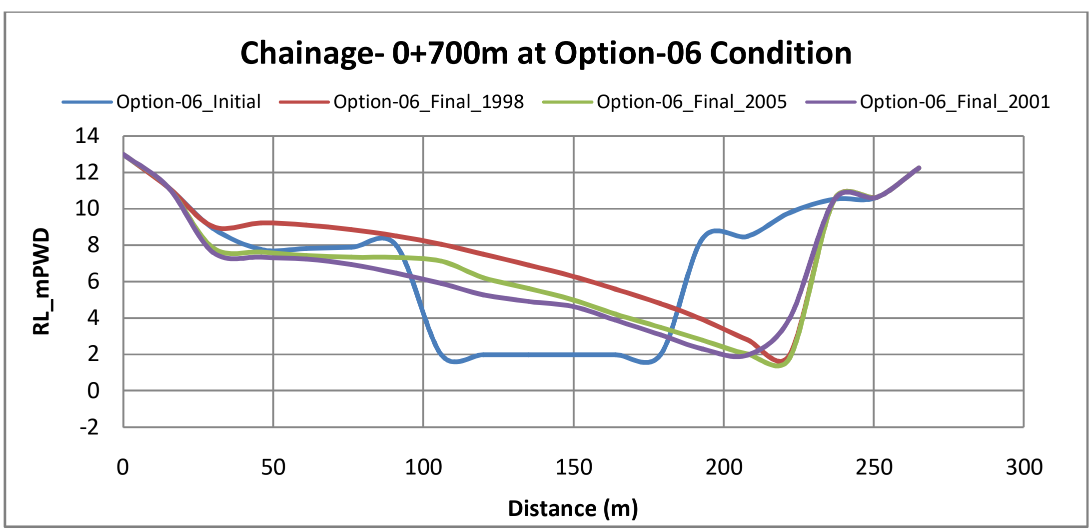
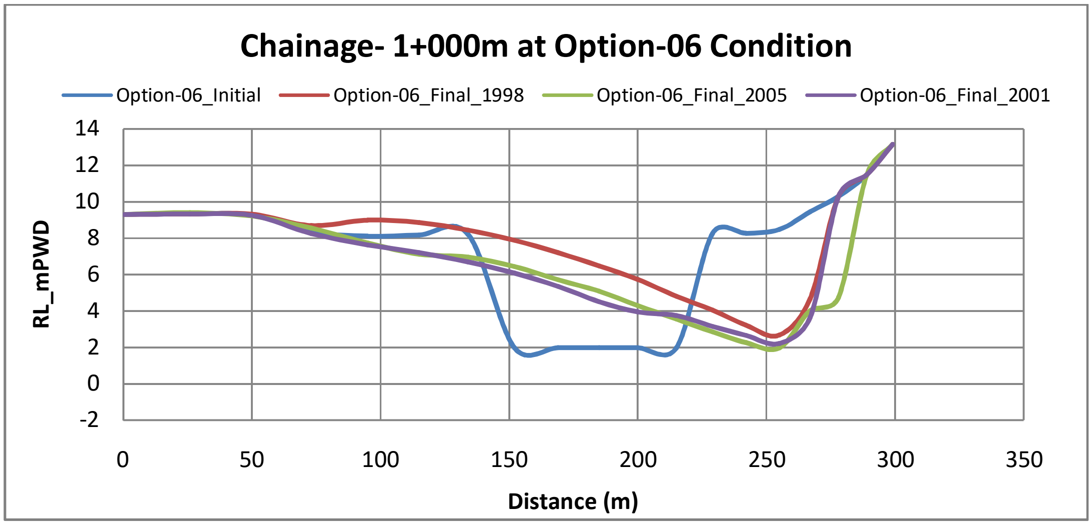
150
200
Distance (m)


Chainage- 0+200m at Option-06 Condition
Option-06_Initial
Option-06_Final_1998
Option-06_Final_2005
Option-06_Final_2001
RL_mPWD
Distance (m)


Chainage- 0+500m at Option-06 Condition
Option-06_Initial
Option-06_Final_1998
Option-06_Final_2005
Option-06_Final_2001
RL_mPWD
Distance (m)


Chainage- 0+700m at Option-06 Condition
Option-06_Initial
Option-06_Final_1998
Option-06_Final_2005
Option-06_Final_2001
RL_mPWD
Distance (m)


Chainage- 1+000m at Option-06 Condition
Option-06_Initial
Option-06_Final_1998
Option-06_Final_2005
Option-06_Final_2001
RL_mPWD
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0
-2
0
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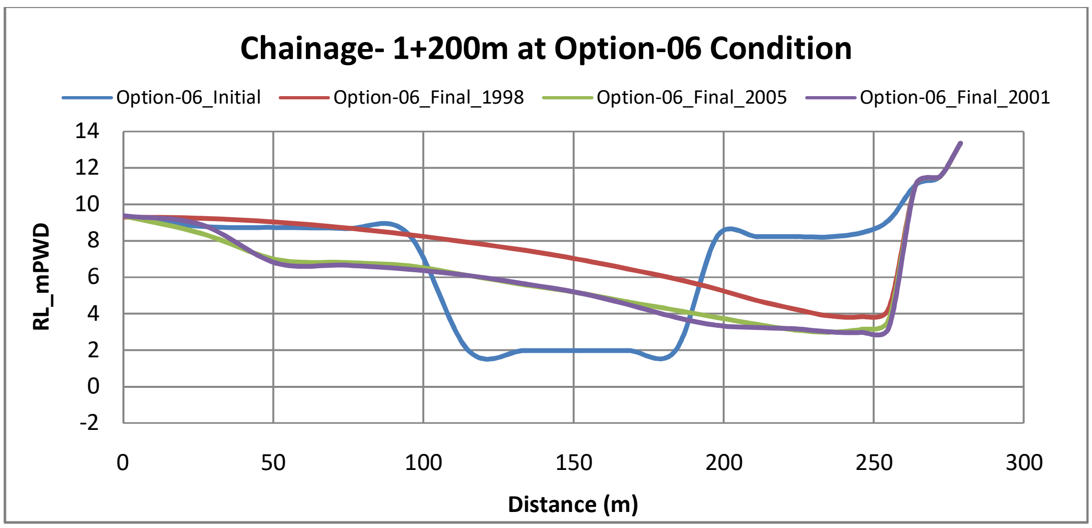
100
150
200
250
300
350
Distance (m)


Chainage- 1+200m at Option-06 Condition
Option-06_Initial
Option-06_Final_1998
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Option-06_Final_2001
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-2
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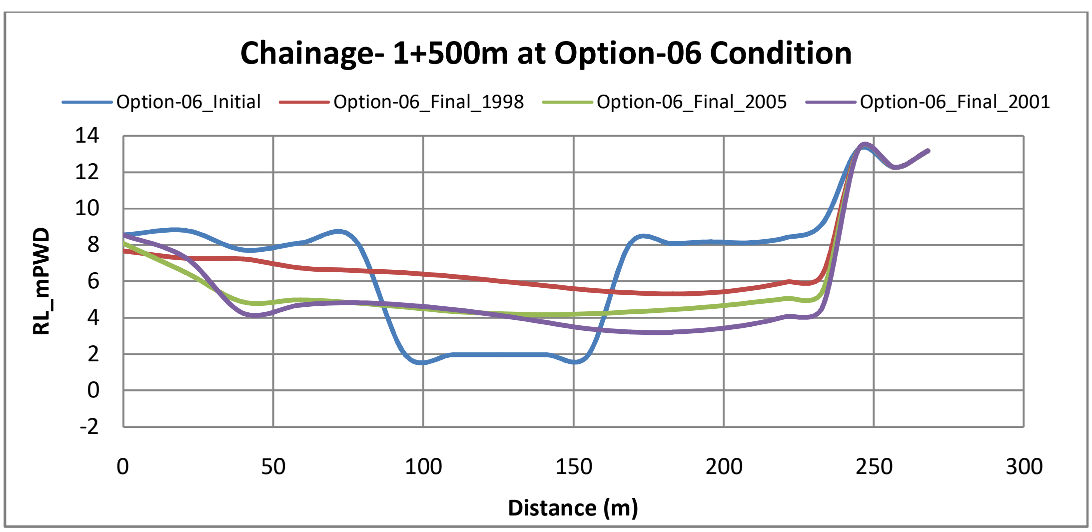
300
Distance (m)


Chainage- 1+500m at Option-06 Condition
Option-06_Initial
Option-06_Final_1998
Option-06_Final_2005
Option-06_Final_2001
RL_mPWD
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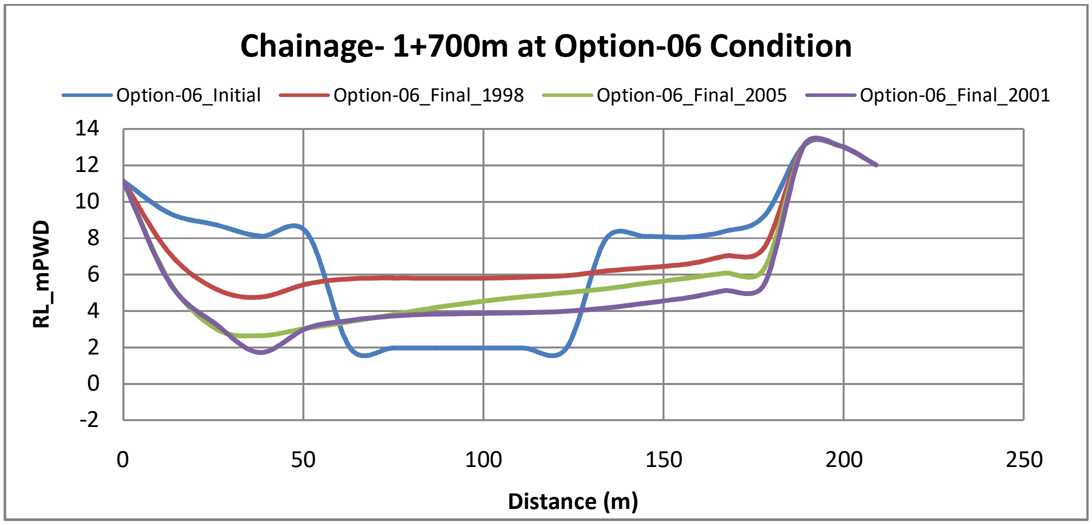
Distance (m)


Chainage- 1+700m at Option-06 Condition
Option-06_Initial
Option-06_Final_1998
Option-06_Final_2005
Option-06_Final_2001
RL_mPWD
Distance (m)
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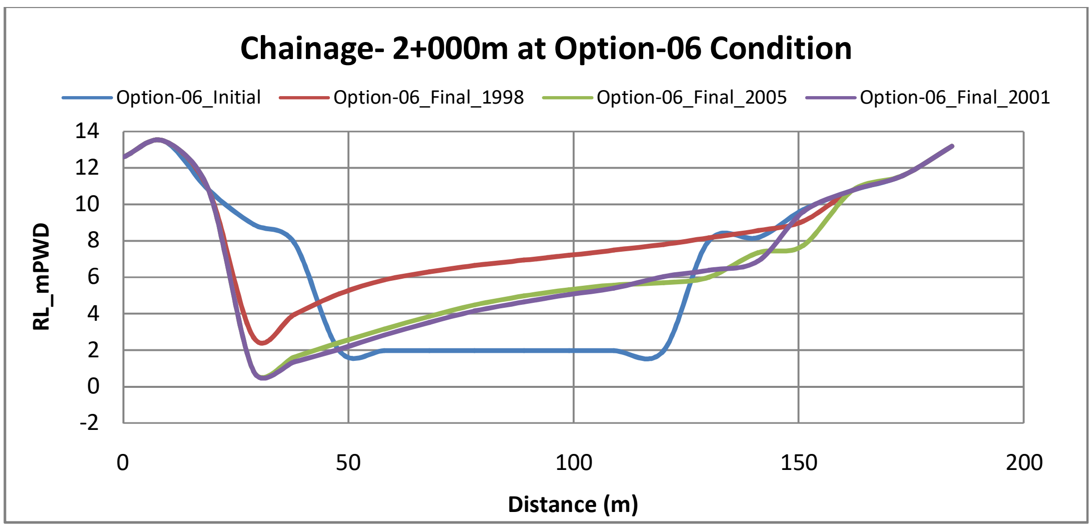
Chainage- 2+000m at Option-06 Condition
Option-06_Initial
Option-06_Final_1998
Option-06_Final_2005
Option-06_Final_2001
RL_mPWD
Distance (m)
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2
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-2
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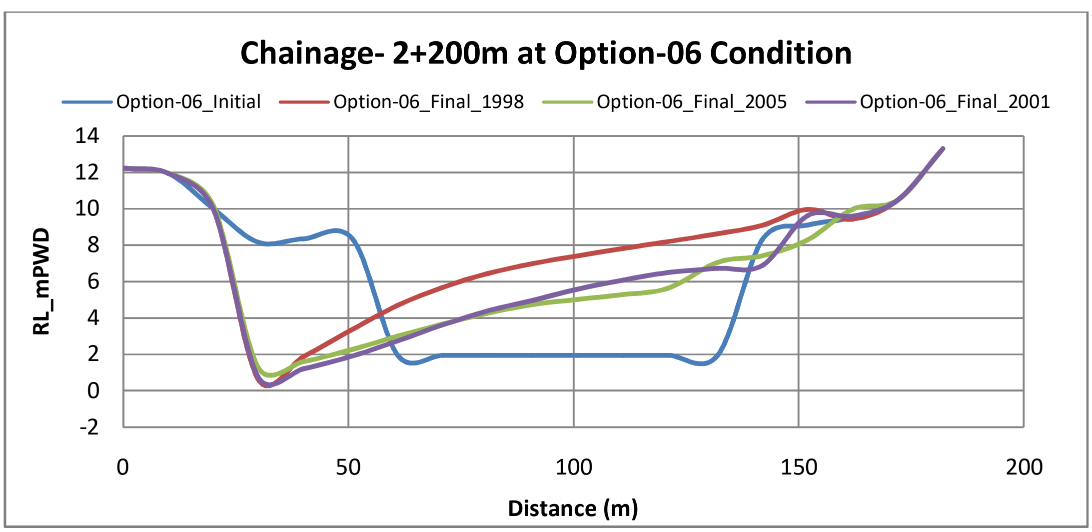
150
200


Chainage- 2+200m at Option-06 Condition
Option-06_Initial
Option-06_Final_1998
Option-06_Final_2005
Option-06_Final_2001
RL_mPWD
Distance (m)
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10
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2
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-2
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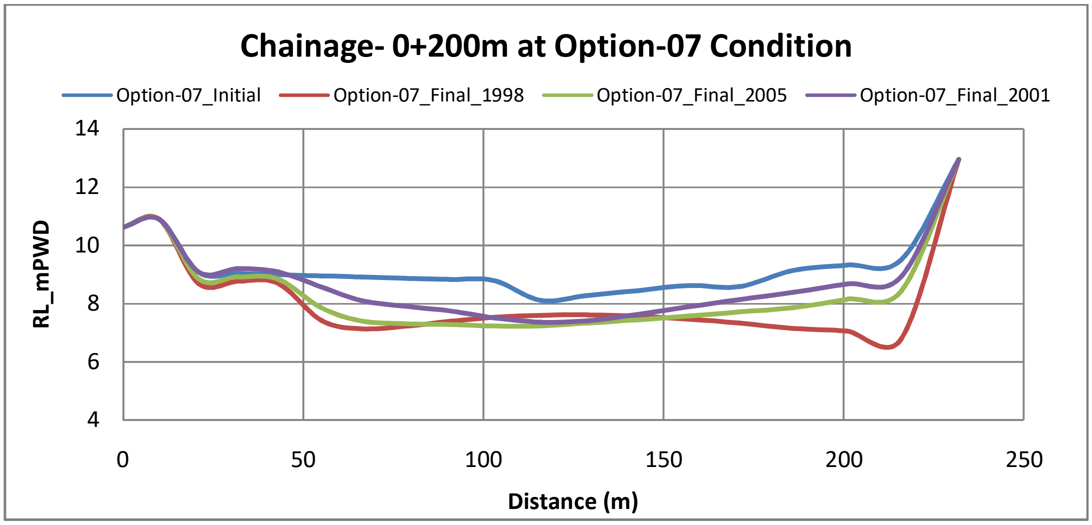
150
200


Chainage- 0+200m at Option-07 Condition
Option-07_Initial
Option-07_Final_1998
Option-07_Final_2005
Option-07_Final_2001
RL_mPWD
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0
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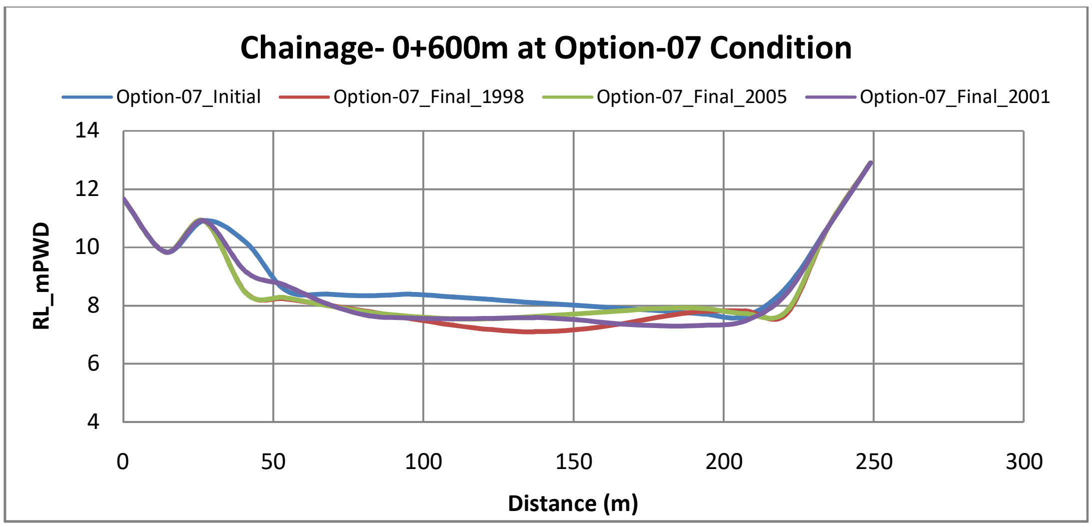
100
150
200
250
Distance (m)


Chainage- 0+600m at Option-07 Condition
Option-07_Initial
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Option-07_Final_2005
Option-07_Final_2001
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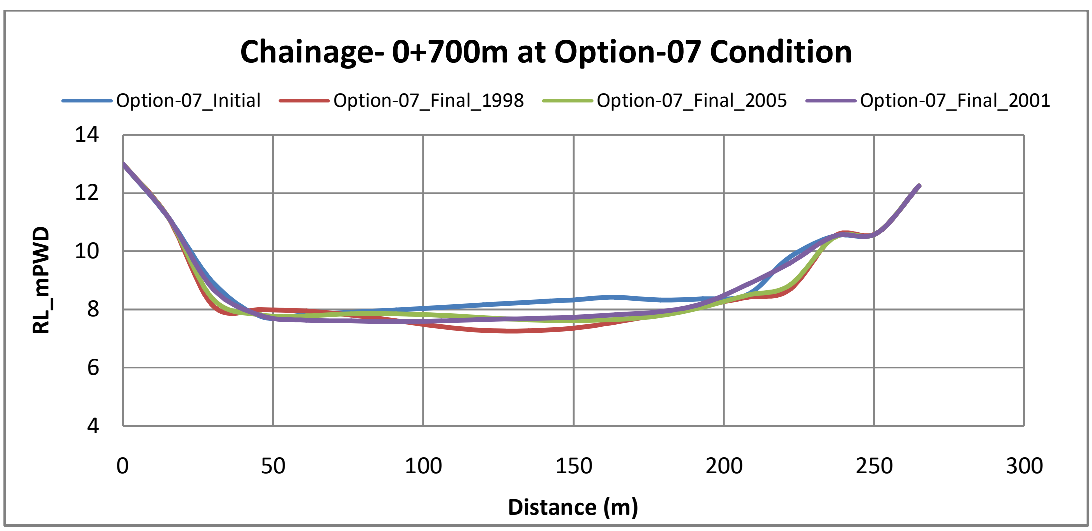
250
300
Distance (m)


Chainage- 0+700m at Option-07 Condition
Option-07_Initial
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Option-07_Final_2005
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RL_mPWD
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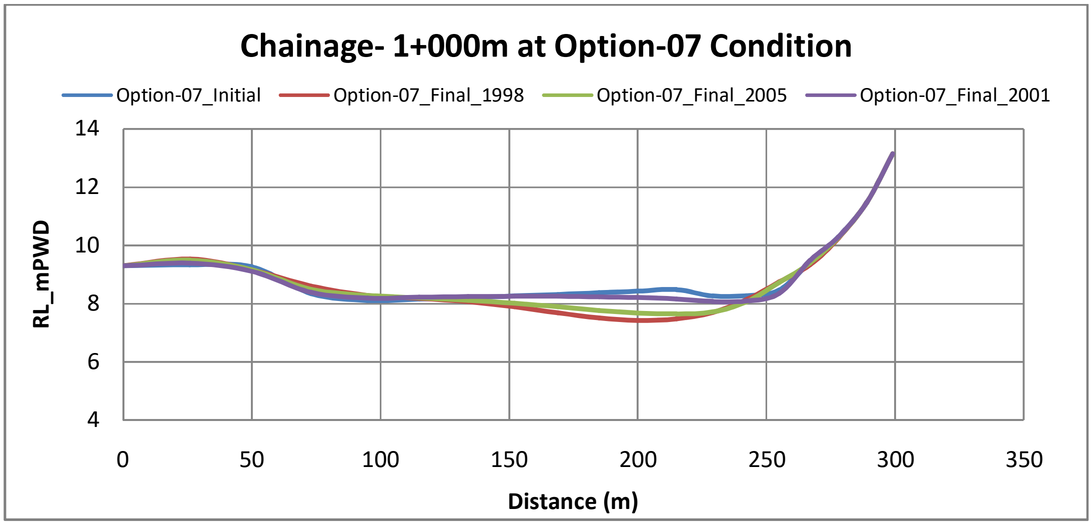
Distance (m)


Chainage- 1+000m at Option-07 Condition
Option-07_Initial
Option-07_Final_1998
Option-07_Final_2005
Option-07_Final_2001
RL_mPWD
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150
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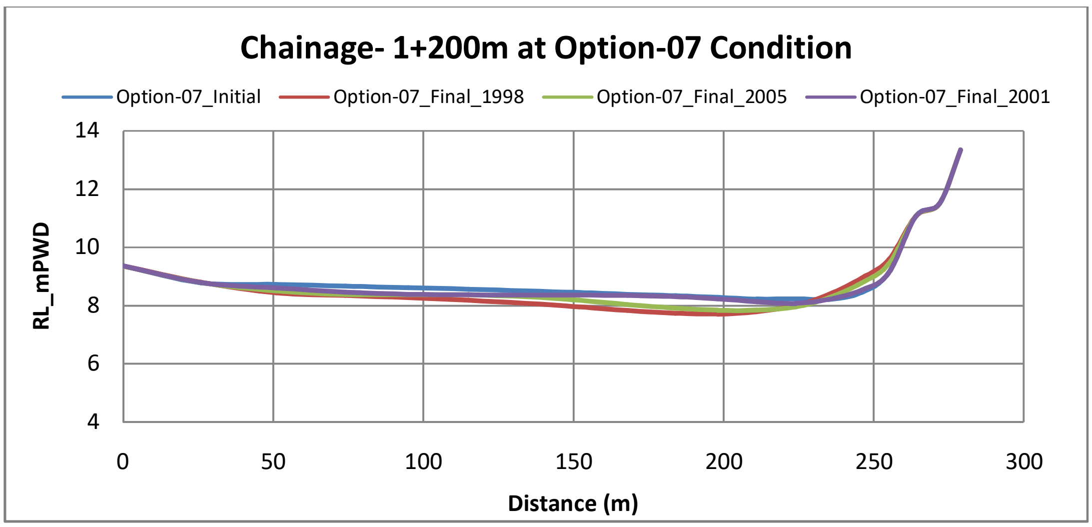
300
350
Distance (m)


Chainage- 1+200m at Option-07 Condition
Option-07_Initial
Option-07_Final_1998
Option-07_Final_2005
Option-07_Final_2001
RL_mPWD
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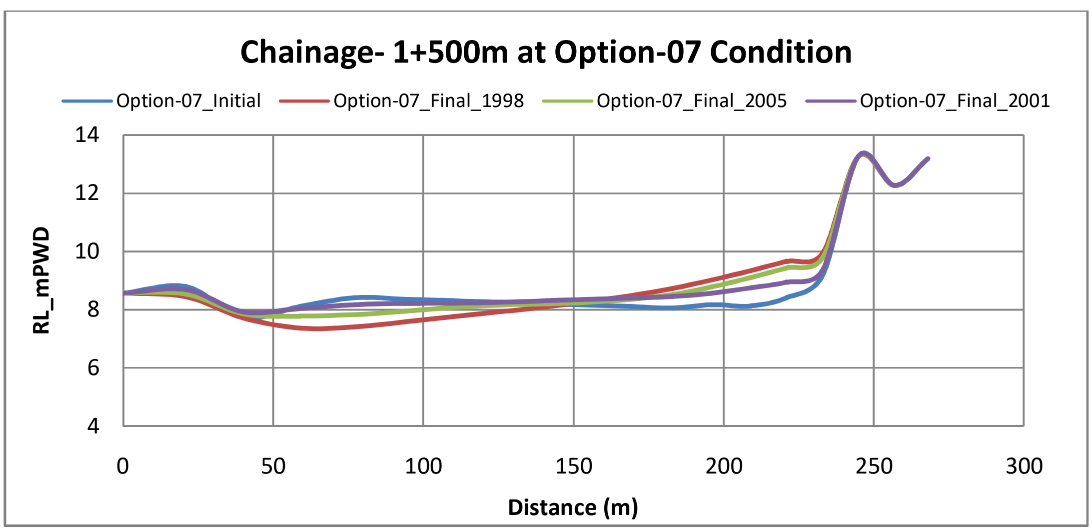
300
Distance (m)


Chainage- 1+500m at Option-07 Condition
Option-07_Initial
Option-07_Final_1998
Option-07_Final_2005
Option-07_Final_2001
RL_mPWD
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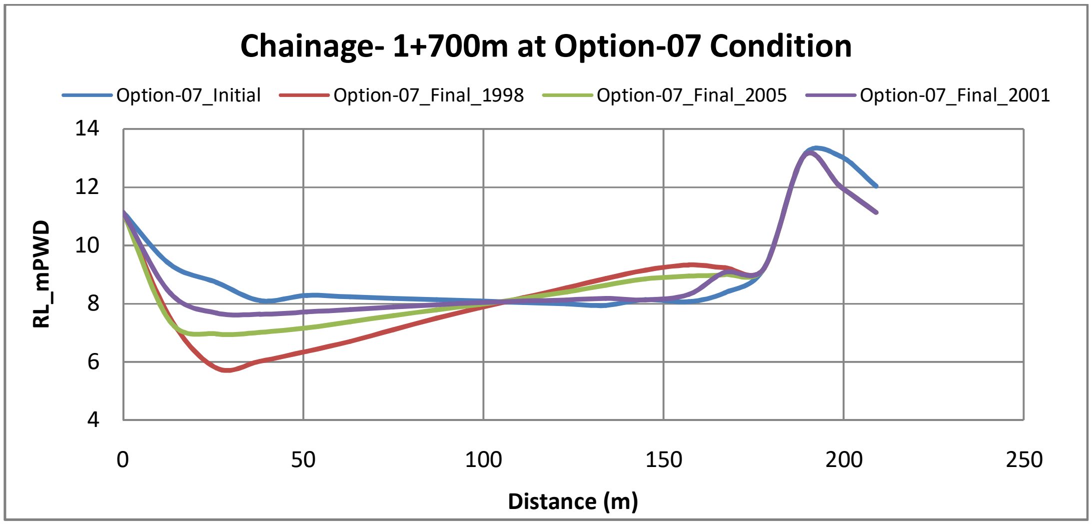
Distance (m)


Chainage- 1+700m at Option-07 Condition
Option-07_Initial
Option-07_Final_1998
Option-07_Final_2005
Option-07_Final_2001
RL_mPWD
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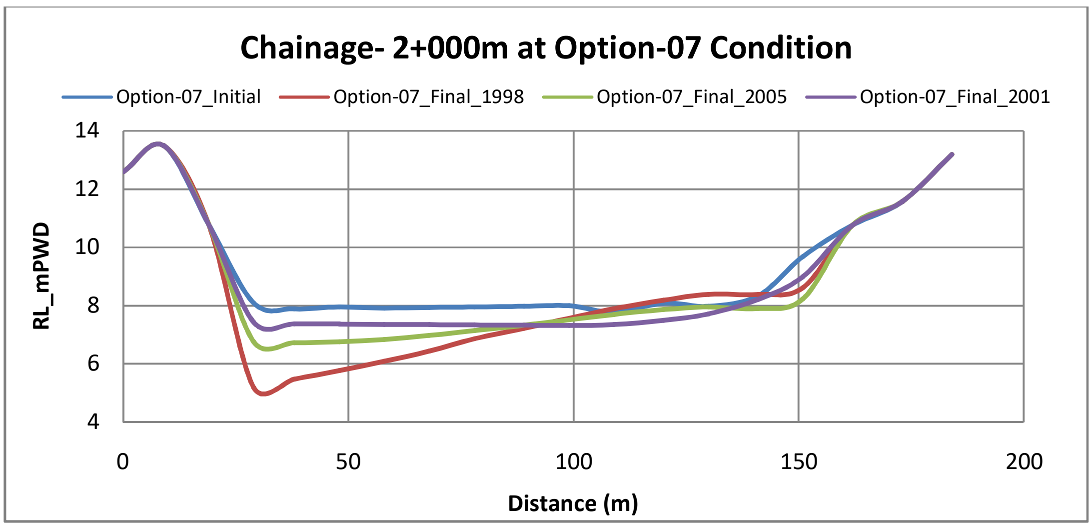
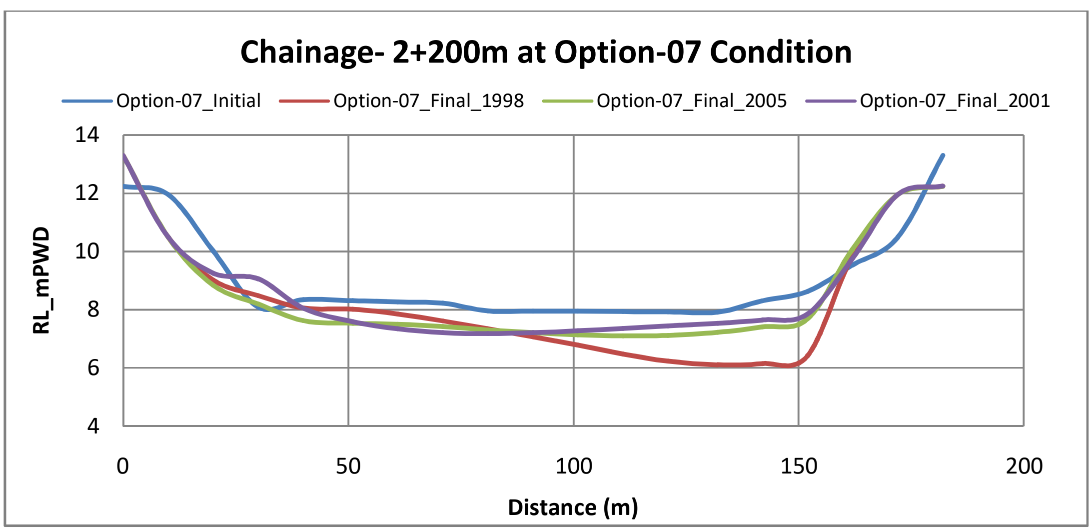
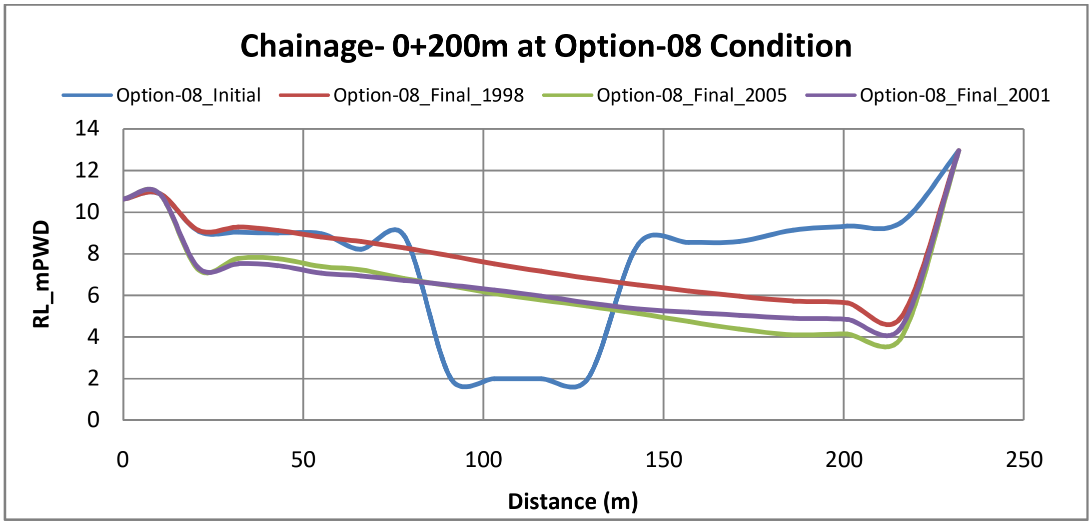
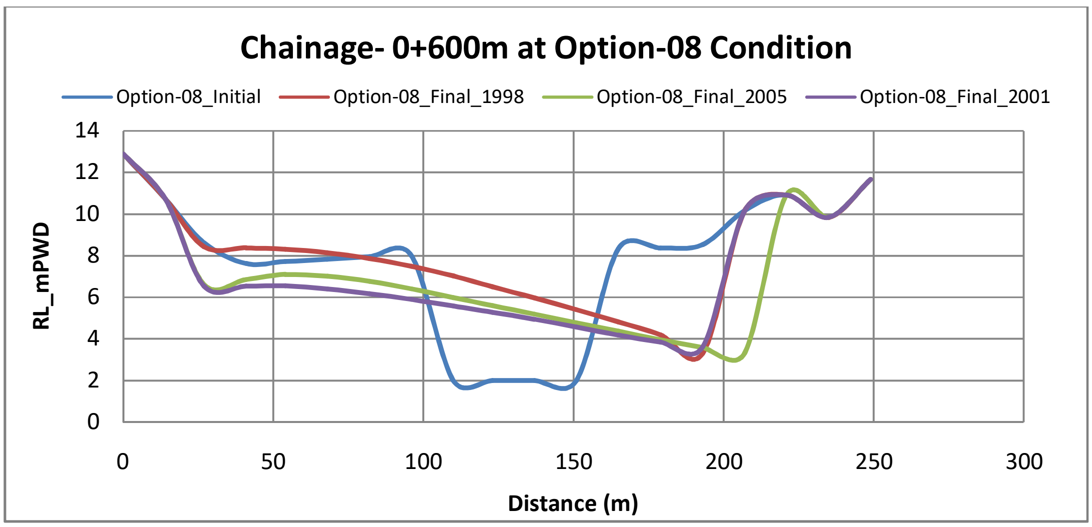
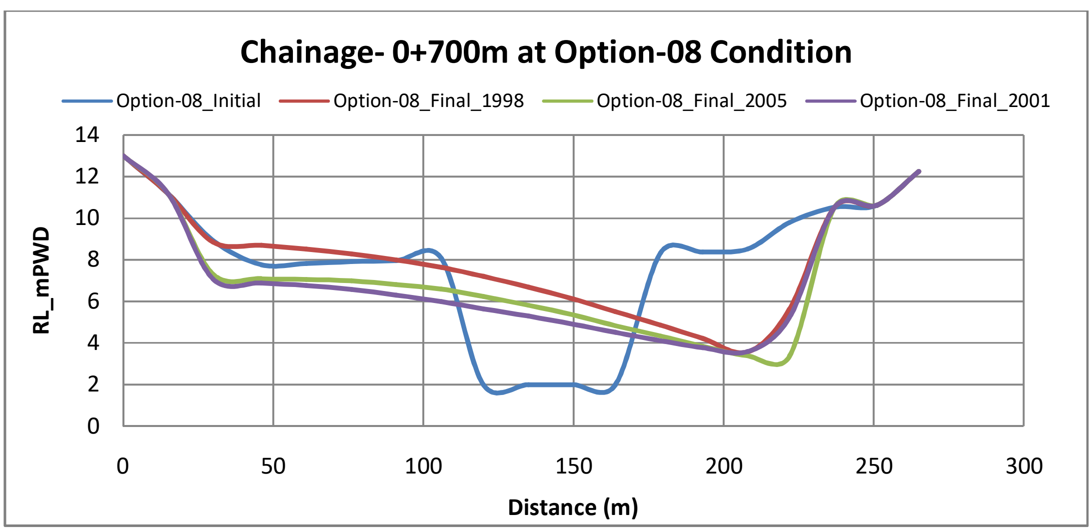
Distance (m)

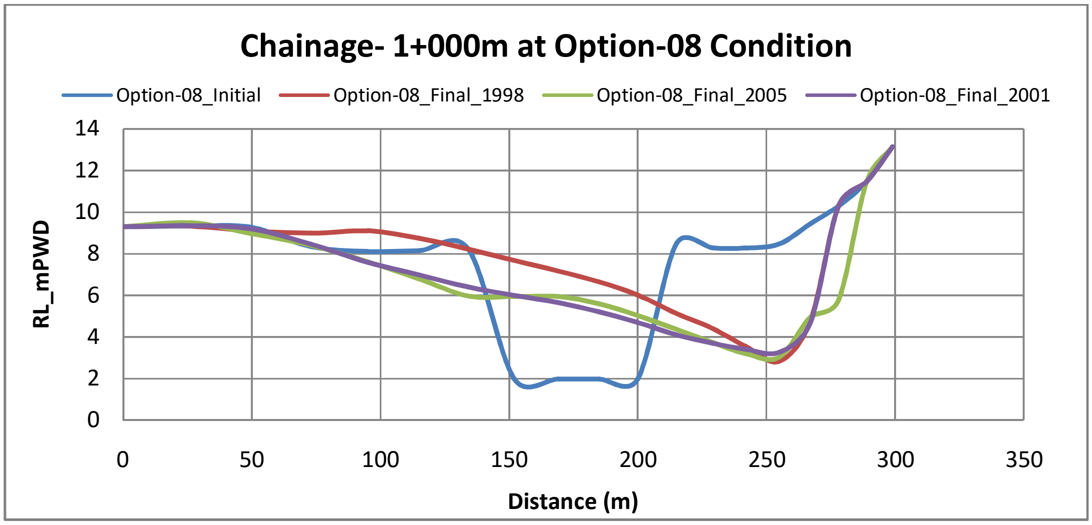

Chainage- 2+000m at Option-07 Condition
Option-07_Initial
Option-07_Final_1998
Option-07_Final_2005
Option-07_Final_2001
RL_mPWD
14
12
10
8
6
4
0
50
100
150
200
Distance (m)

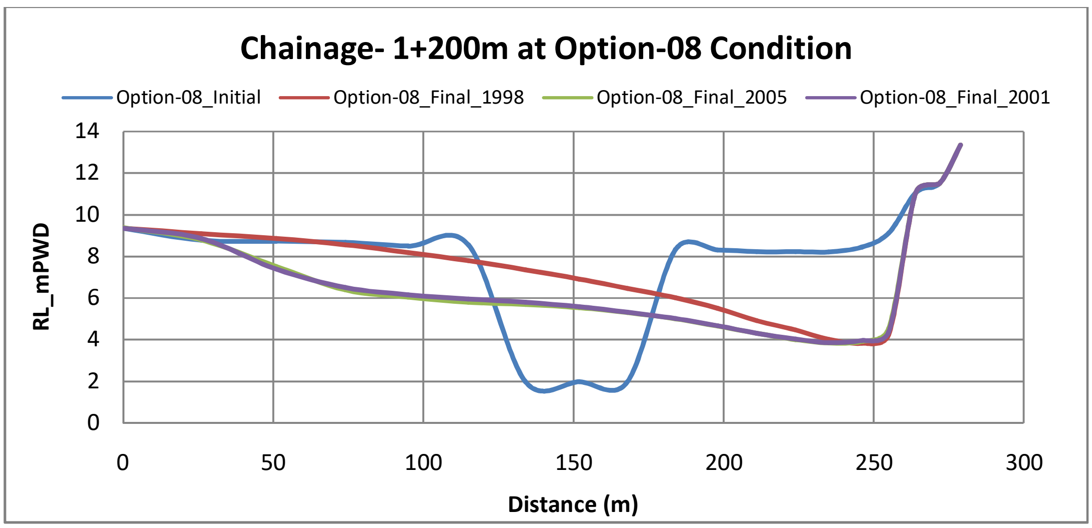

Chainage- 2+200m at Option-07 Condition
Option-07_Initial
Option-07_Final_1998
Option-07_Final_2005
Option-07_Final_2001
RL_mPWD
14
12
10
8
6
4
0
50
100
150
200
Distance (m)

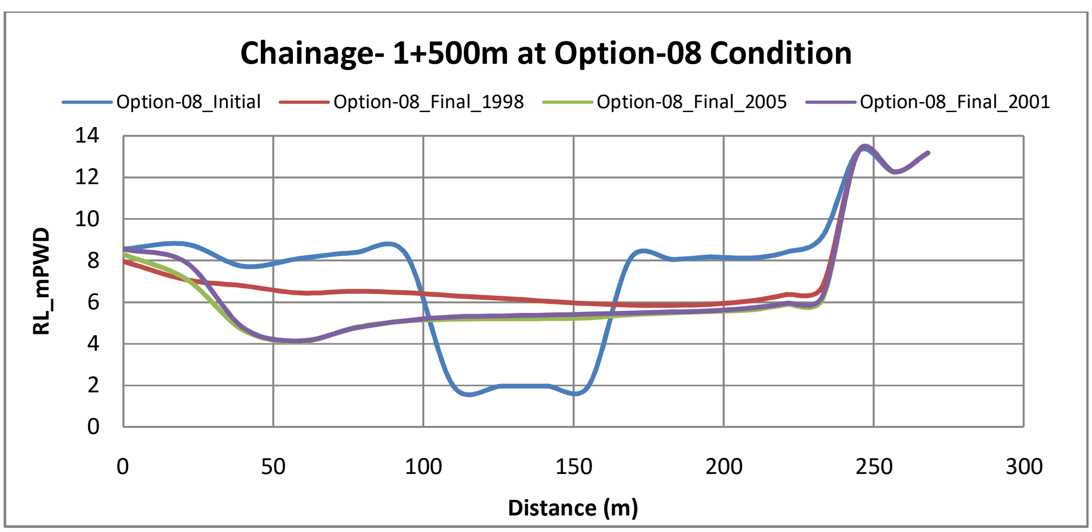

Chainage- 0+200m at Option-08 Condition
Option-08_Initial
Option-08_Final_1998
Option-08_Final_2005
Option-08_Final_2001
RL_mPWD
0
2
4
6
8
10
12
14
0
50
100
150
200
250
Distance (m)

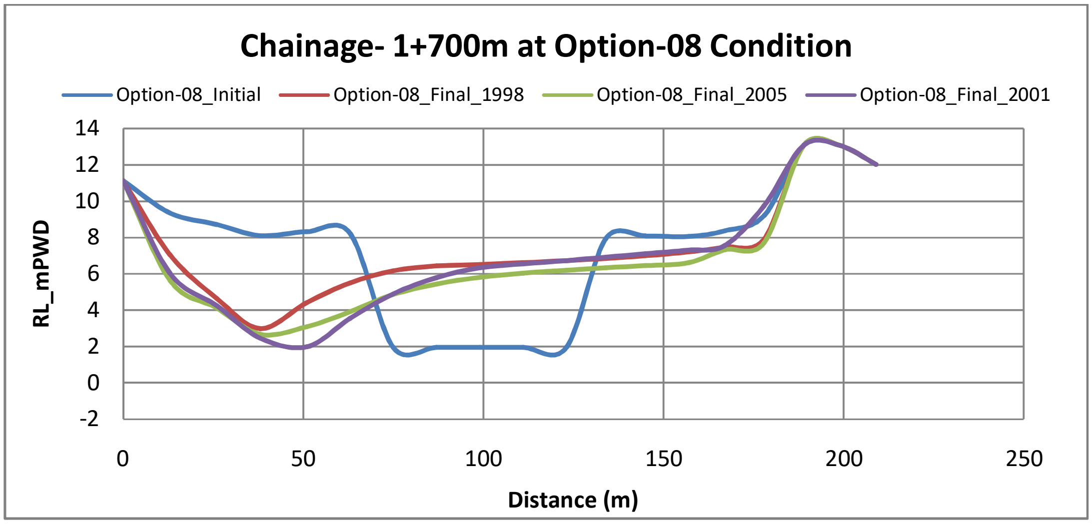

Chainage- 0+600m at Option-08 Condition
Option-08_Initial
Option-08_Final_1998
Option-08_Final_2005
Option-08_Final_2001
RL_mPWD
0
2
4
6
8
10
12
14
0
50
100
150
200
250
300
Distance (m)


Chainage- 0+700m at Option-08 Condition
Option-08_Initial
Option-08_Final_1998
Option-08_Final_2005
Option-08_Final_2001
RL_mPWD
0
2
4
6
8
10
12
14
0
50
100
150
200
250
300
Distance (m)

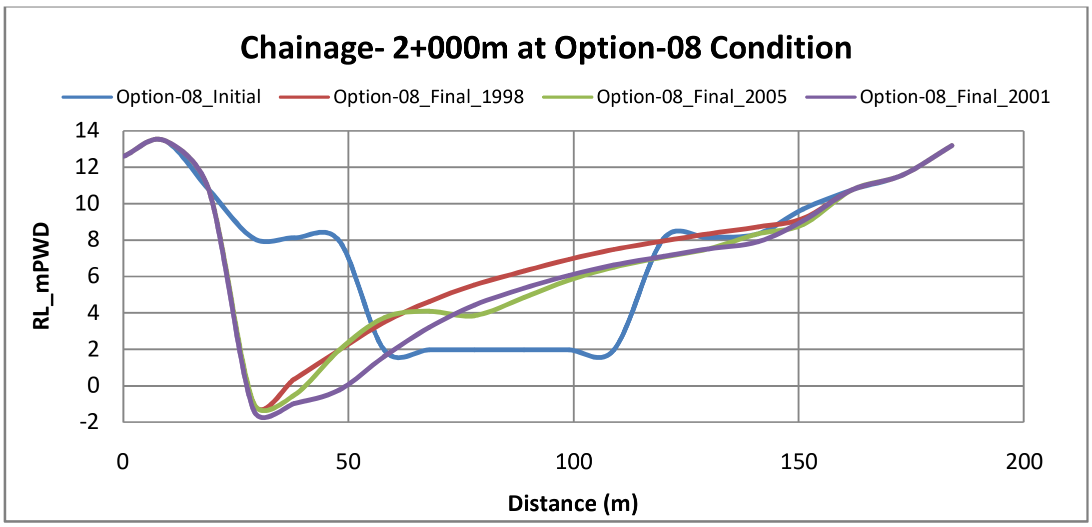

Chainage- 1+000m at Option-08 Condition
Option-08_Initial
Option-08_Final_1998
Option-08_Final_2005
Option-08_Final_2001
RL_mPWD
14
12
10
8
6
4
2
0
0
50
100
150
200
250
300
350
Distance (m)


Chainage- 1+200m at Option-08 Condition
Option-08_Initial
Option-08_Final_1998
Option-08_Final_2005
Option-08_Final_2001
RL_mPWD
14
12
10
8
6
4
2
0
0
50
100
150
200
250
300
Distance (m)

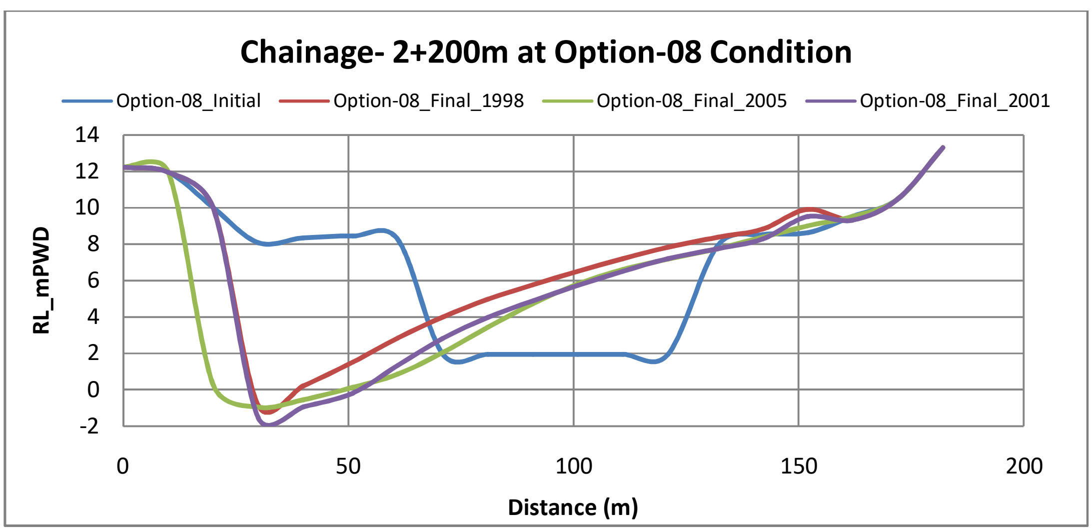

Chainage- 1+500m at Option-08 Condition
Option-08_Initial
Option-08_Final_1998
Option-08_Final_2005
Option-08_Final_2001
RL_mPWD
14
12
10
8
6
4
2
0
0
50
100
150
200
250
300
Distance (m)



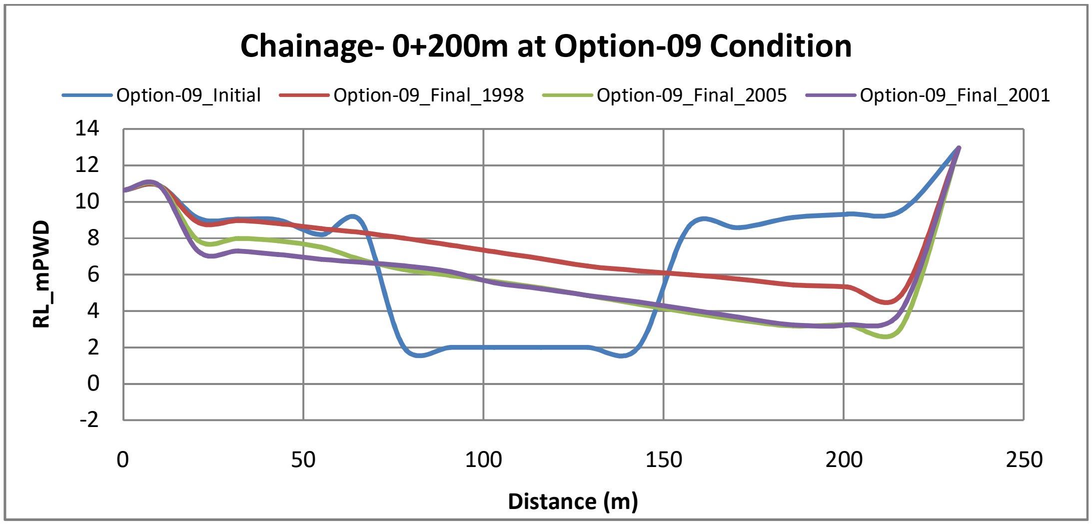
Chainage- 1+700m at Option-08 Condition
Option-08_Initial
Option-08_Final_1998
Option-08_Final_2005
Option-08_Final_2001
RL_mPWD
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250
Distance (m)



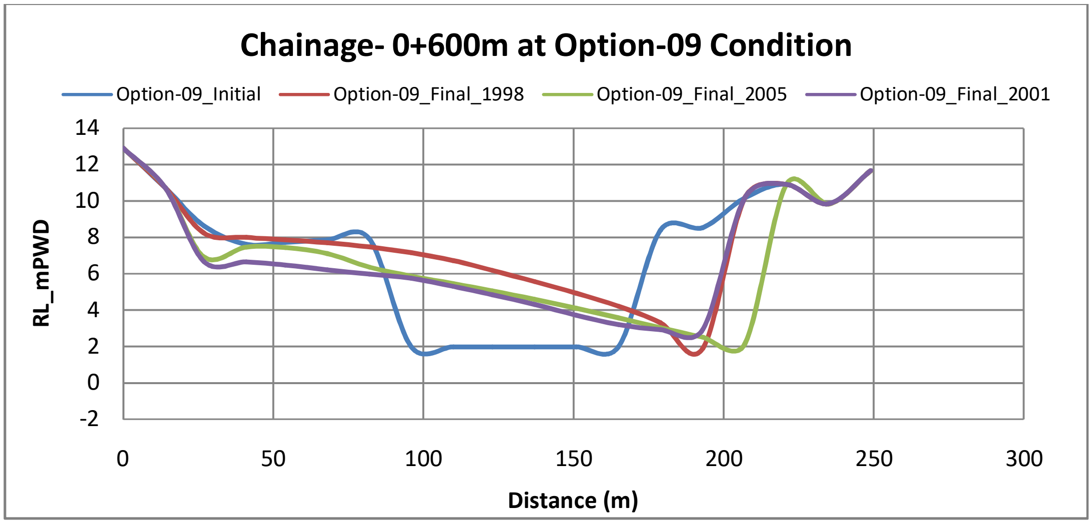
Chainage- 2+000m at Option-08 Condition
Option-08_Initial
Option-08_Final_1998
Option-08_Final_2005
Option-08_Final_2001
RL_mPWD
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
Distance (m)



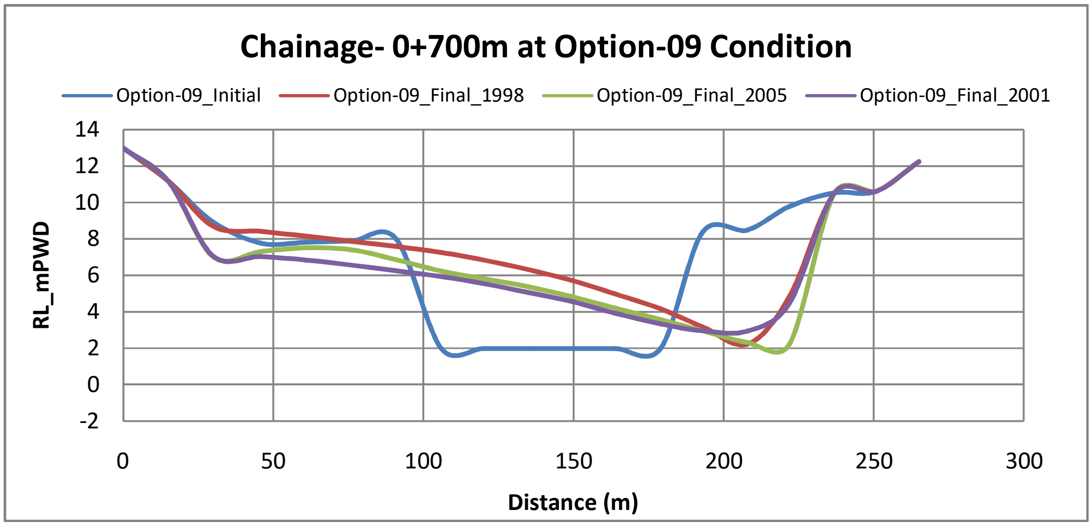
Chainage- 2+200m at Option-08 Condition
Option-08_Initial
Option-08_Final_1998
Option-08_Final_2005
Option-08_Final_2001
RL_mPWD
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
Distance (m)



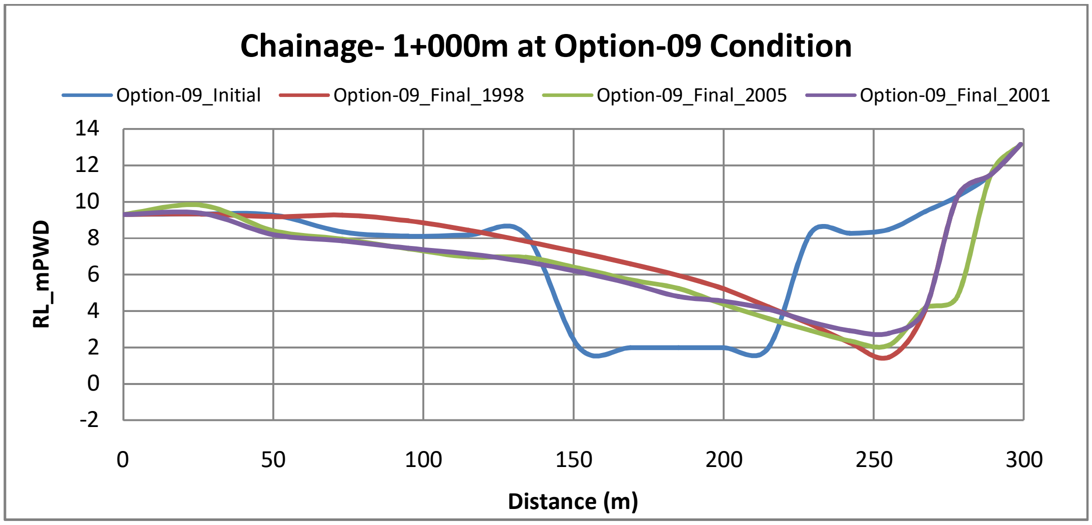
Chainage- 0+200m at Option-09 Condition
Option-09_Initial
Option-09_Final_1998
Option-09_Final_2005
Option-09_Final_2001
RL_mPWD
Distance (m)
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250

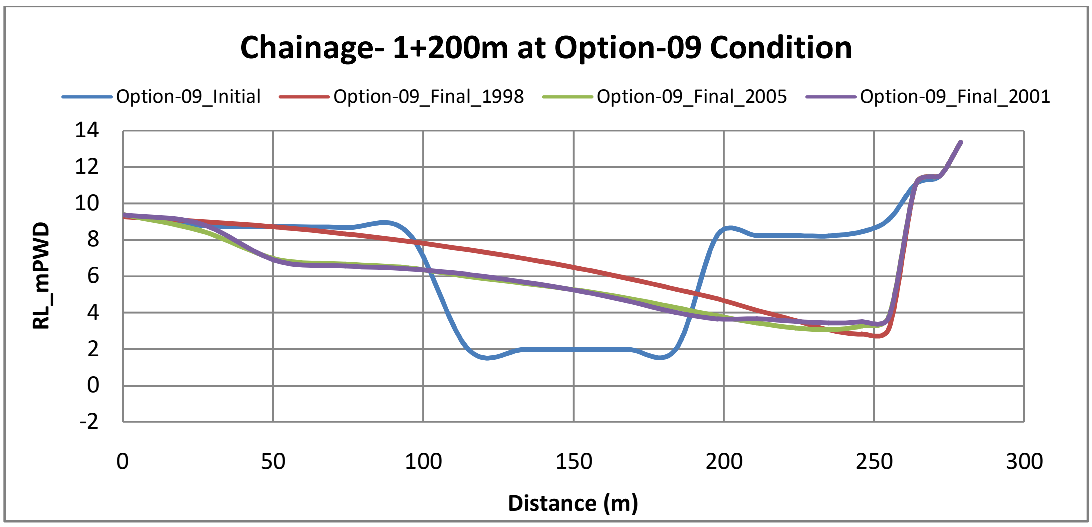


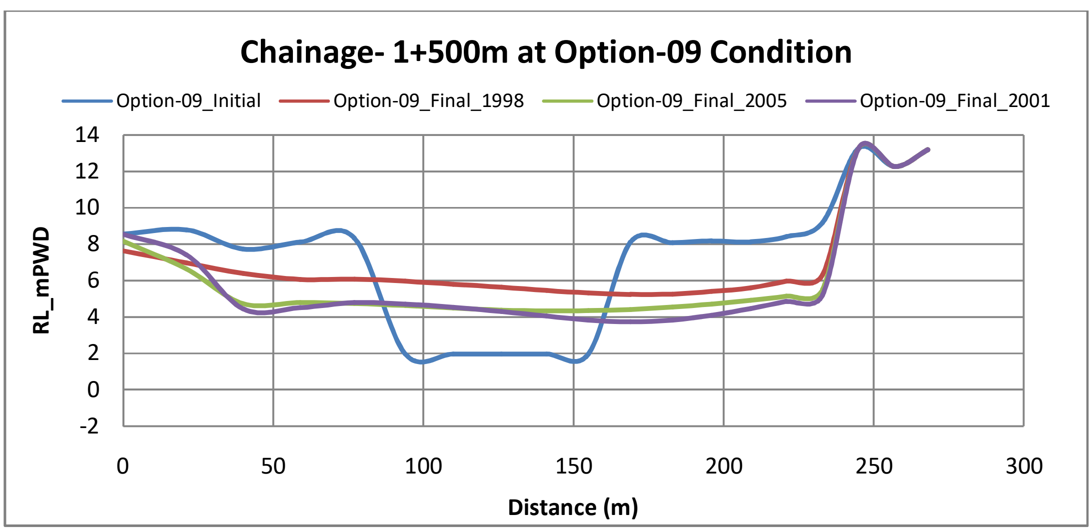
Chainage- 0+600m at Option-09 Condition
Option-09_Initial
Option-09_Final_1998
Option-09_Final_2005
Option-09_Final_2001
RL_mPWD
Distance (m)
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250
300

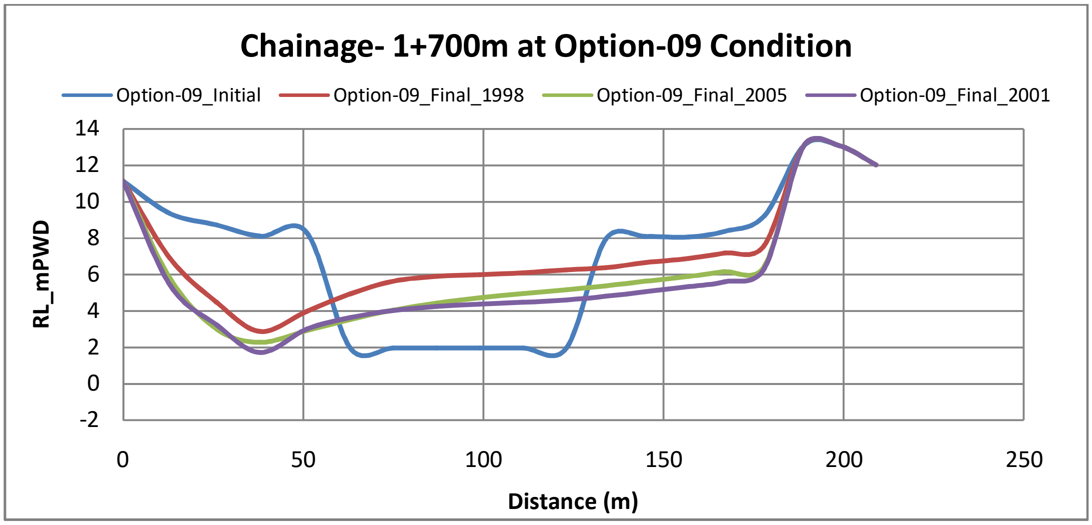


Chainage- 0+700m at Option-09 Condition
Option-09_Initial
Option-09_Final_1998
Option-09_Final_2005
Option-09_Final_2001
RL_mPWD
Distance (m)
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250
300

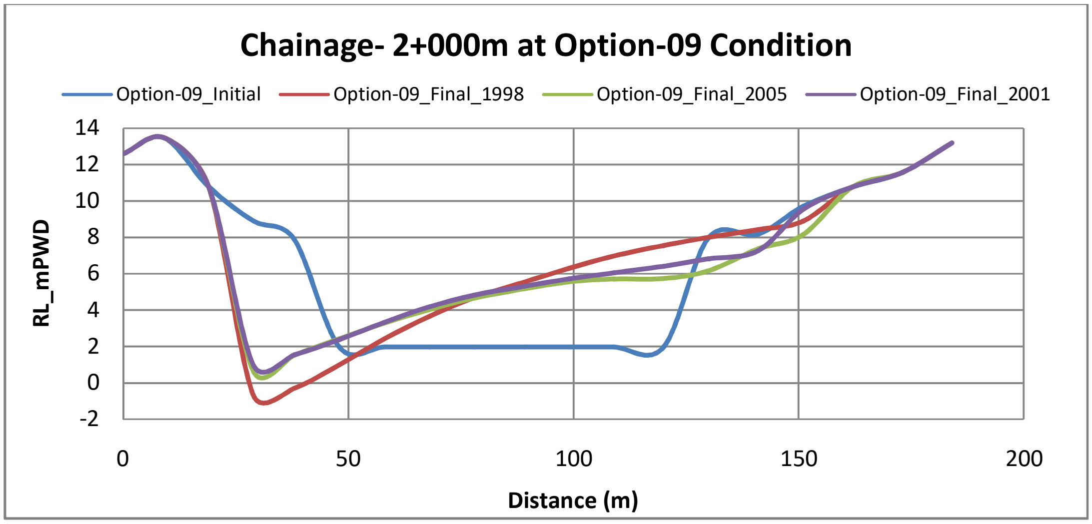

Chainage- 1+000m at Option-09 Condition
Option-09_Initial
Option-09_Final_1998
Option-09_Final_2005
Option-09_Final_2001
RL_mPWD
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250
300
Distance (m)


Chainage- 1+200m at Option-09 Condition
Option-09_Initial
Option-09_Final_1998
Option-09_Final_2005
Option-09_Final_2001
RL_mPWD
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250
300
Distance (m)

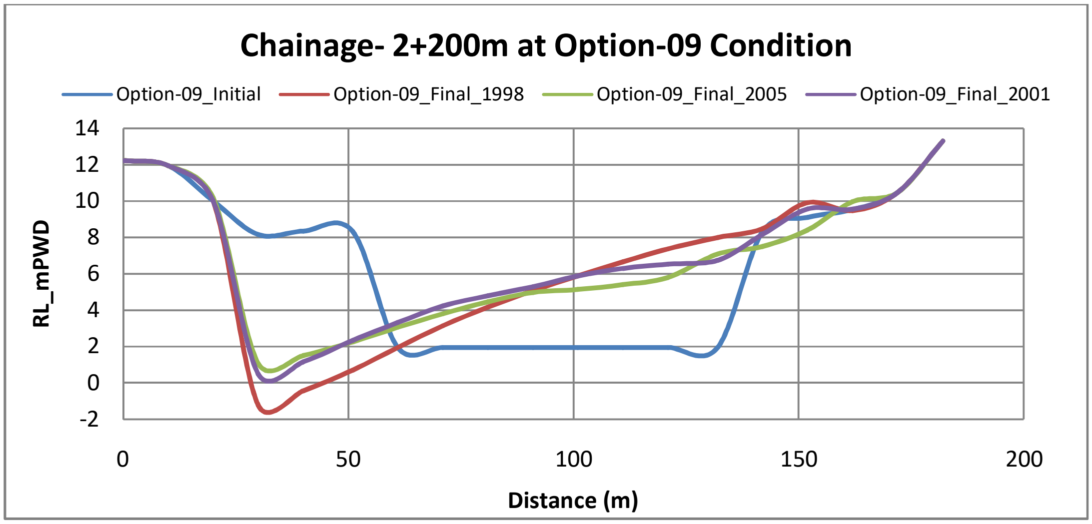

Chainage- 1+500m at Option-09 Condition
Option-09_Initial
Option-09_Final_1998
Option-09_Final_2005
Option-09_Final_2001
RL_mPWD
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250
300
Distance (m)



Chainage- 1+700m at Option-09 Condition
Option-09_Initial
Option-09_Final_1998
Option-09_Final_2005
Option-09_Final_2001
RL_mPWD
Distance (m)
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250



Chainage- 2+000m at Option-09 Condition
Option-09_Initial
Option-09_Final_1998
Option-09_Final_2005
Option-09_Final_2001
RL_mPWD
Distance (m)
14
12
10
8
6
4
2
0
-2
0
50
100
150
200

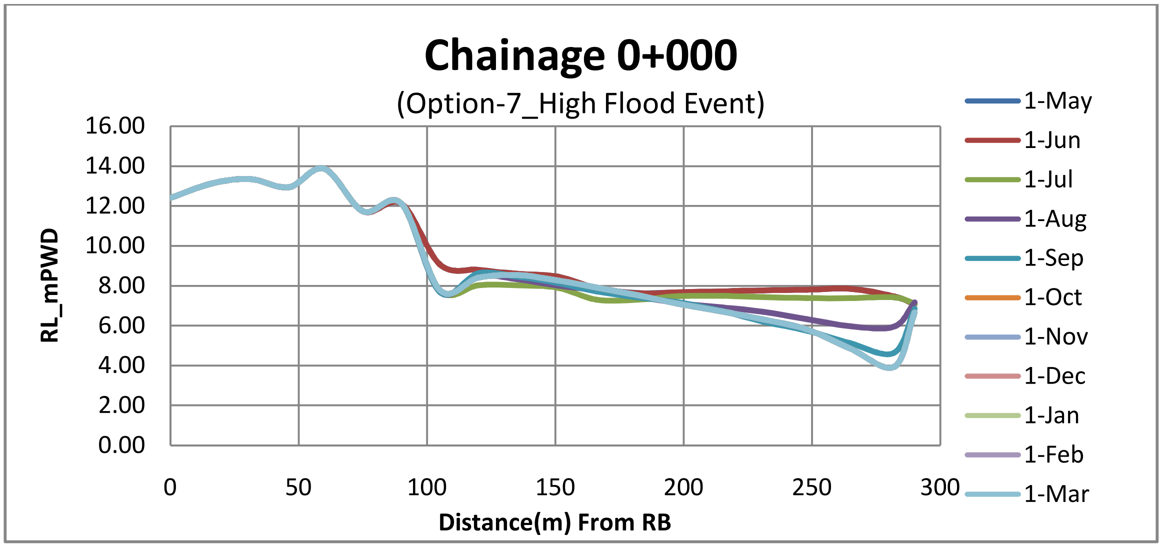


Chainage- 2+200m at Option-09 Condition
Option-09_Initial
Option-09_Final_1998
Option-09_Final_2005
Option-09_Final_2001
RL_mPWD
Distance (m)
14
12
10
8
6
4
2
0
-2
0
50
100
150
200

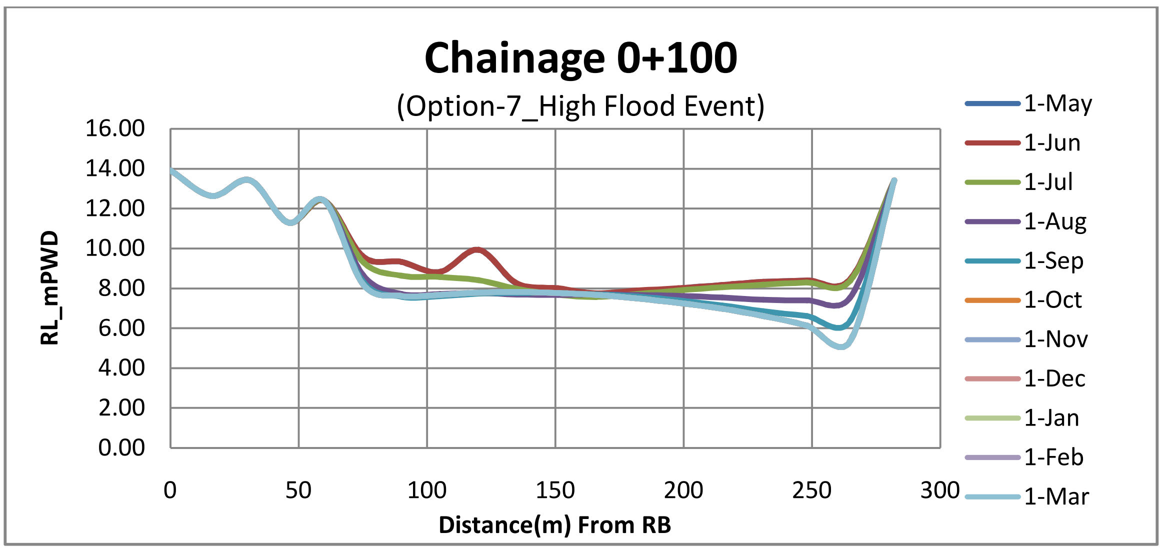
APPENDIX-D

Month Wise Bed Level Changes Analysis up to structure

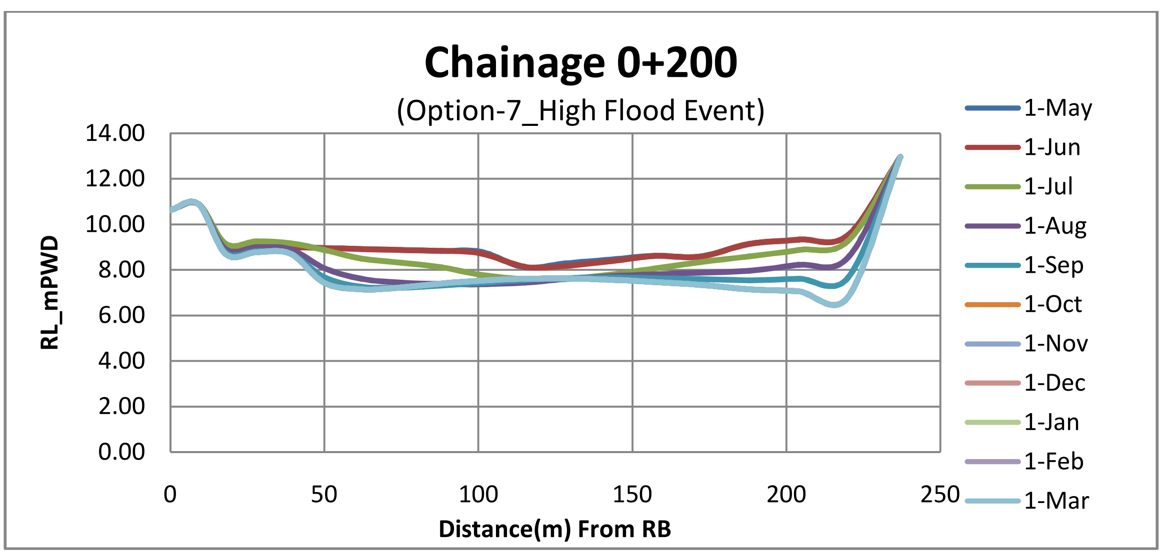
Appendix-D



Chainage 0+000
(Option-7_High Flood Event)
RL_mPWD
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

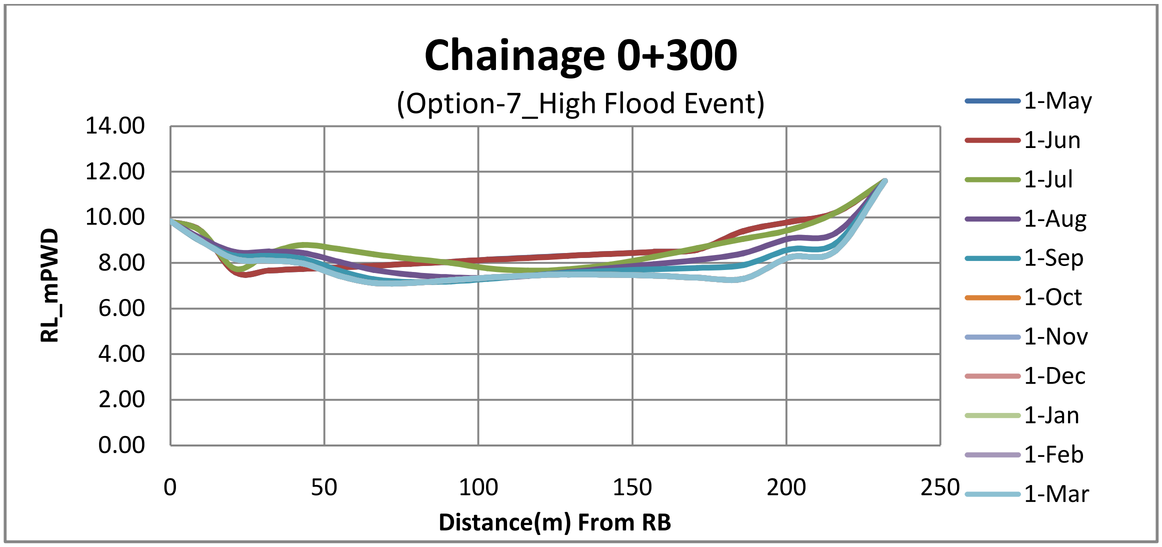


Chainage 0+100
(Option-7_High Flood Event)
RL_mPWD
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

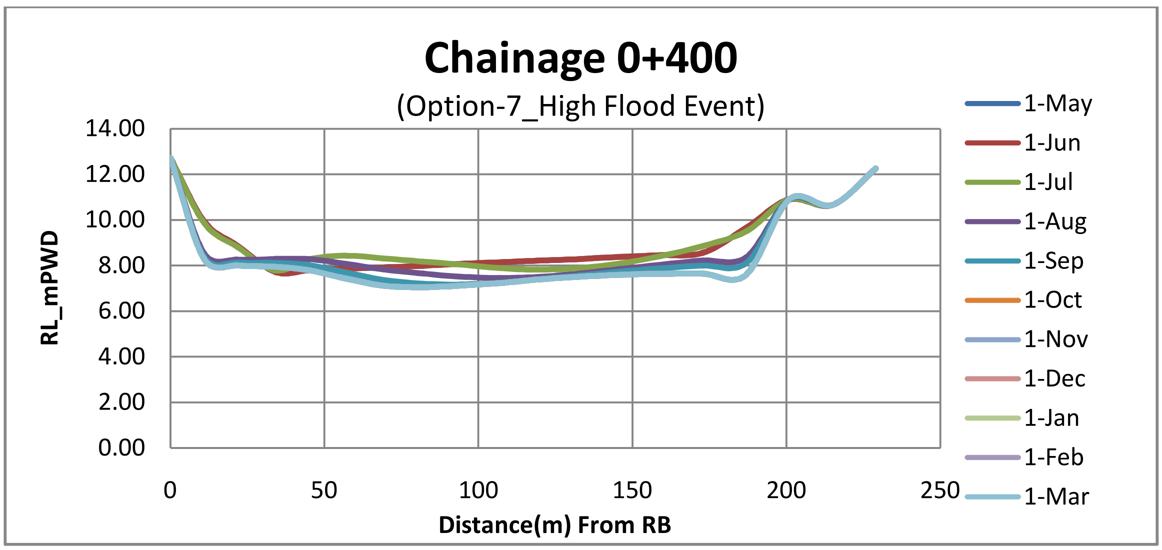


Chainage 0+200
(Option-7_High Flood Event)
RL_mPWD
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
50
100
150
200
250
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

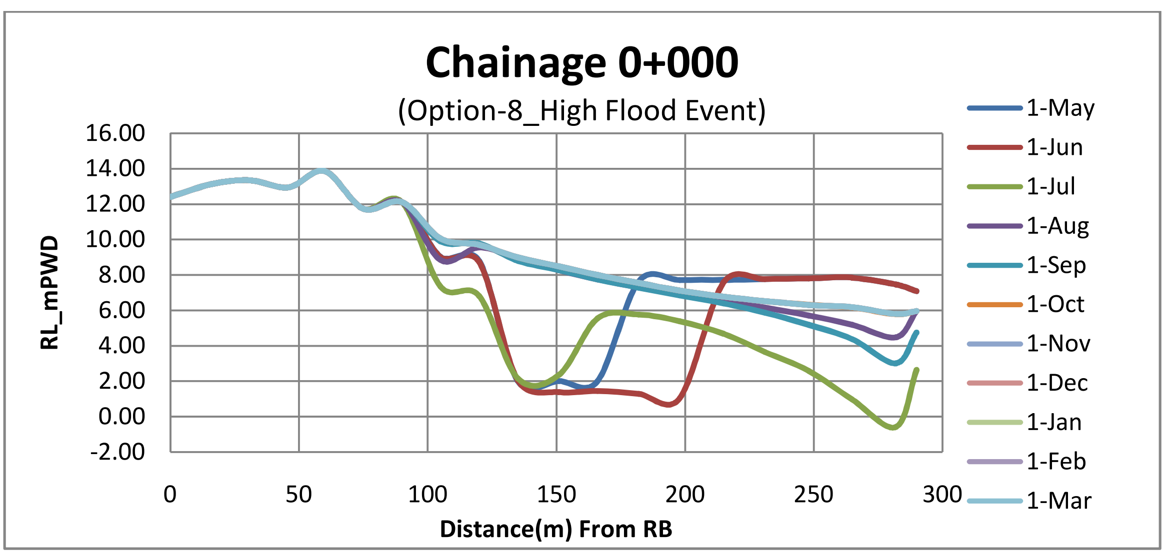
Appendix-D



Chainage 0+300
(Option-7_High Flood Event)
RL_mPWD
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
50
100
150
200
250
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

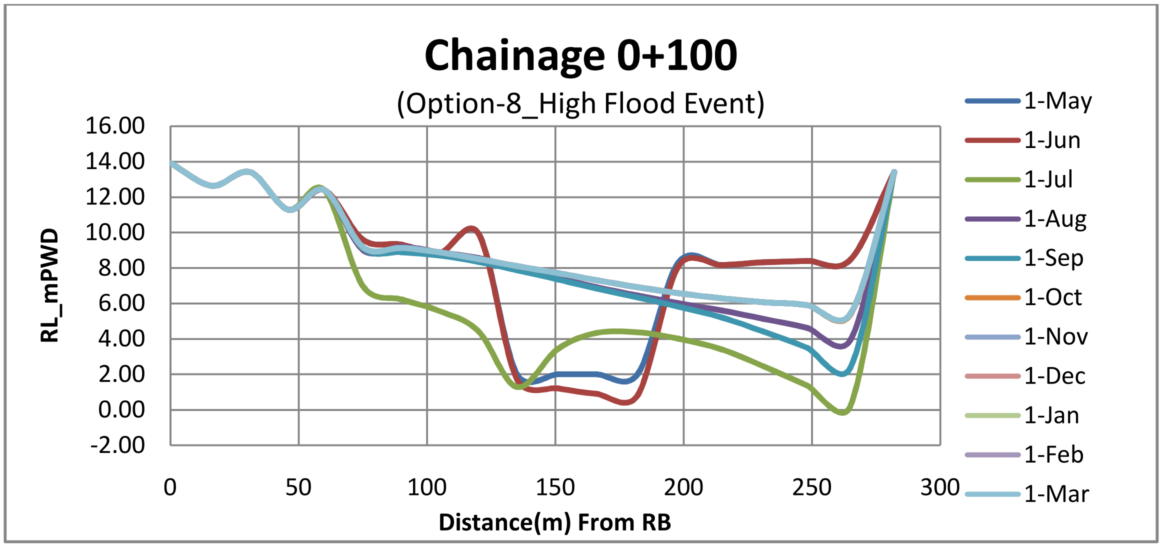


Chainage 0+400
(Option-7_High Flood Event)
RL_mPWD
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
50
100
150
200
250
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

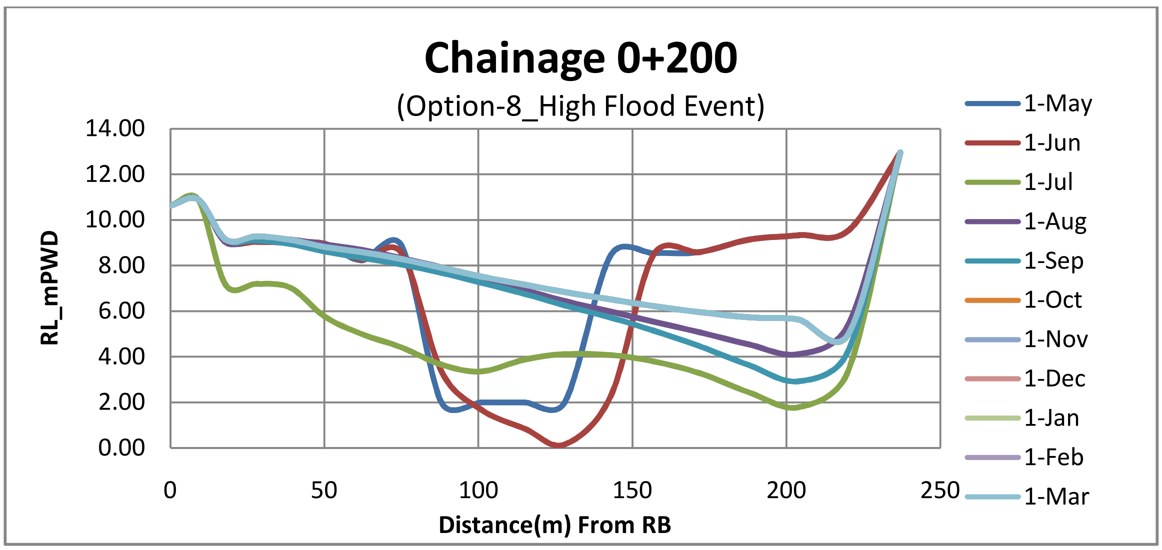


Chainage 0+000
(Option-8_High Flood Event)
RL_mPWD
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

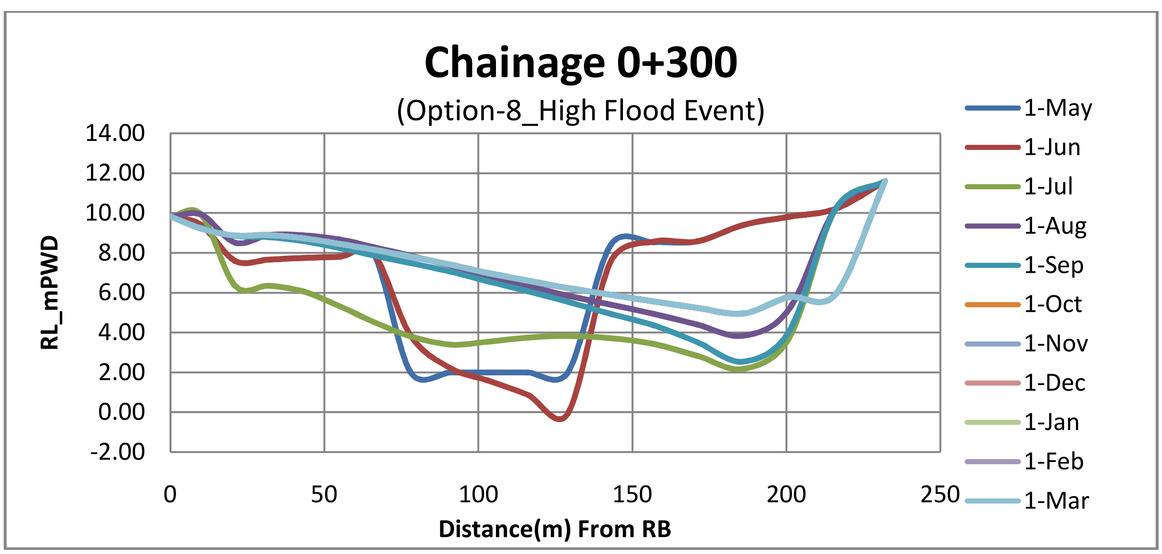
Appendix-D



Chainage 0+100
(Option-8_High Flood Event)
RL_mPWD
Distance(m) From RB
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
300
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

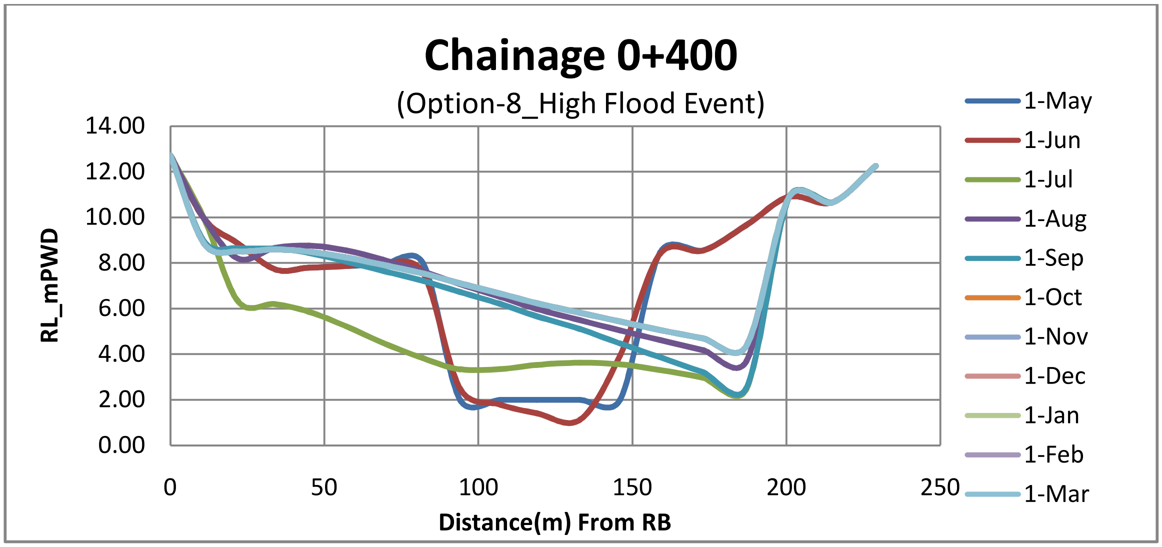


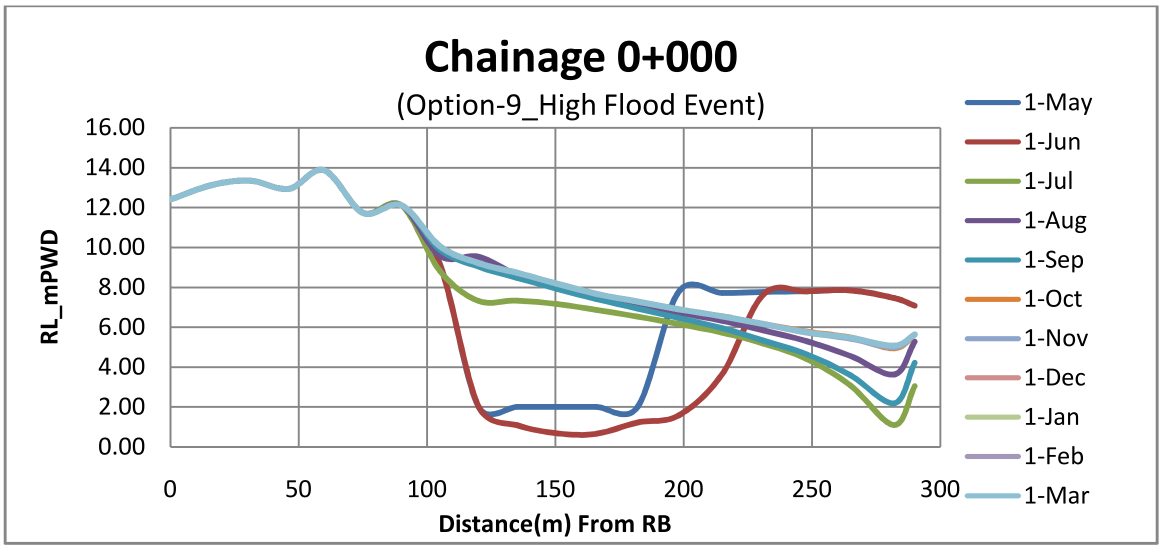
Chainage 0+200
(Option-8_High Flood Event)
RL_mPWD
Distance(m) From RB
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
50
100
150
200
250
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

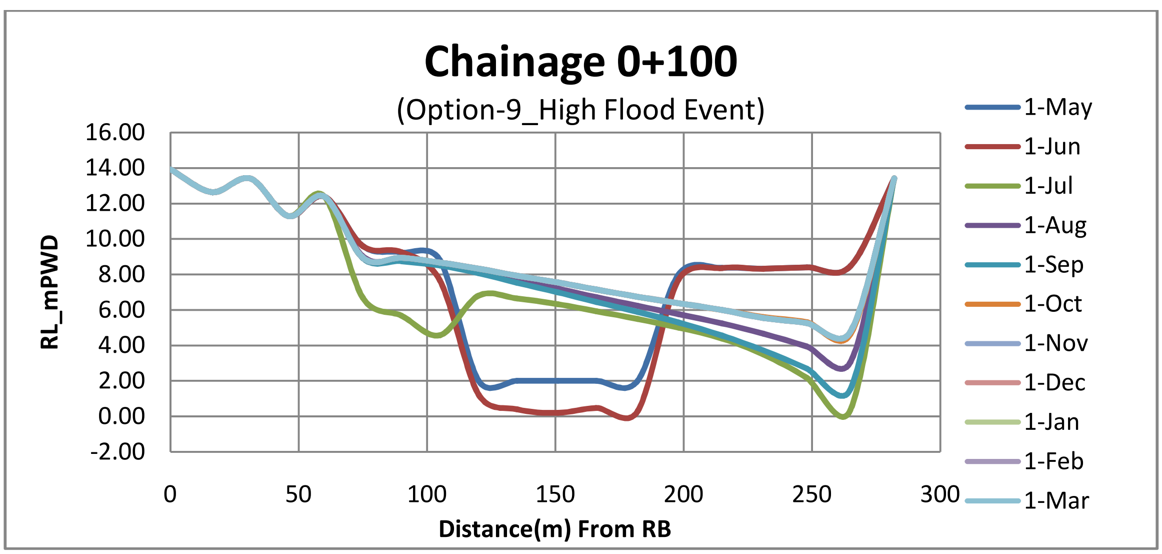


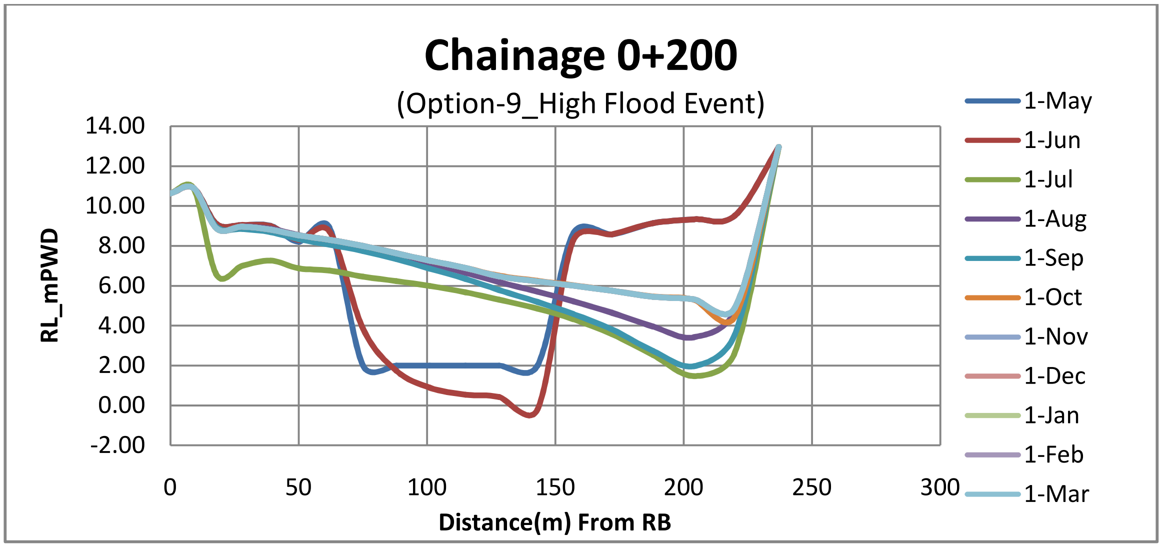
Chainage 0+300
(Option-8_High Flood Event)
RL_mPWD
Distance(m) From RB
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

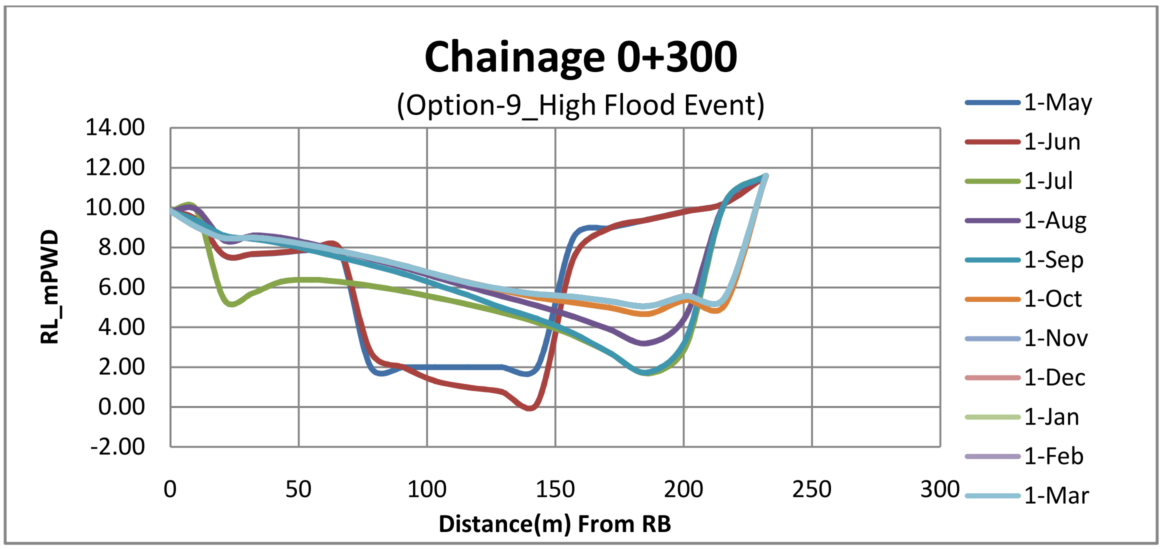
Appendix-D

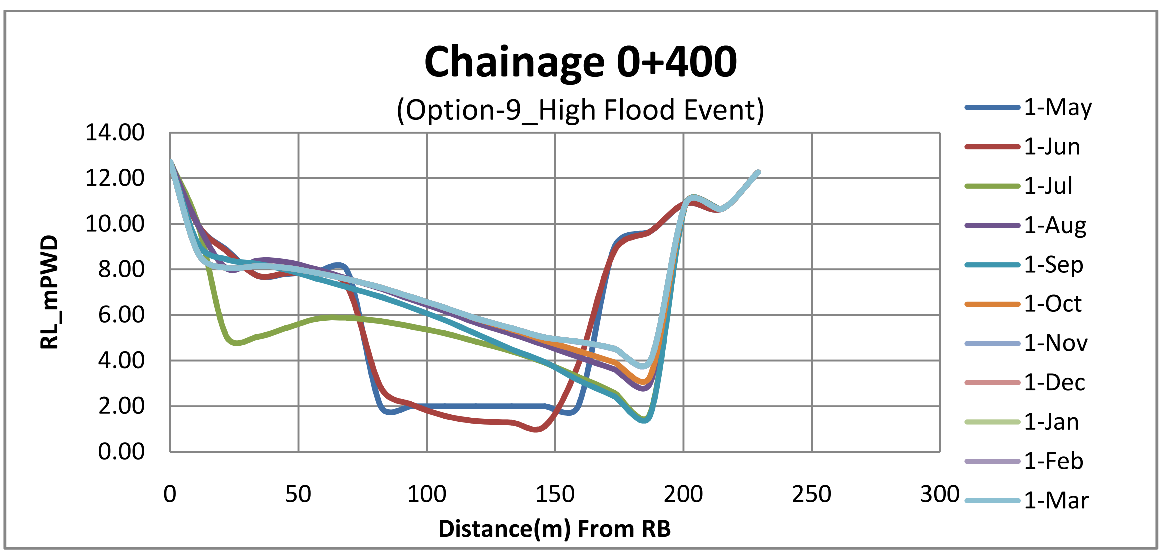

Chainage 0+400
(Option-8_High Flood Event)
RL_mPWD
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
50
100
150
200
250
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar


Chainage 0+000
(Option-9_High Flood Event)
RL_mPWD
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

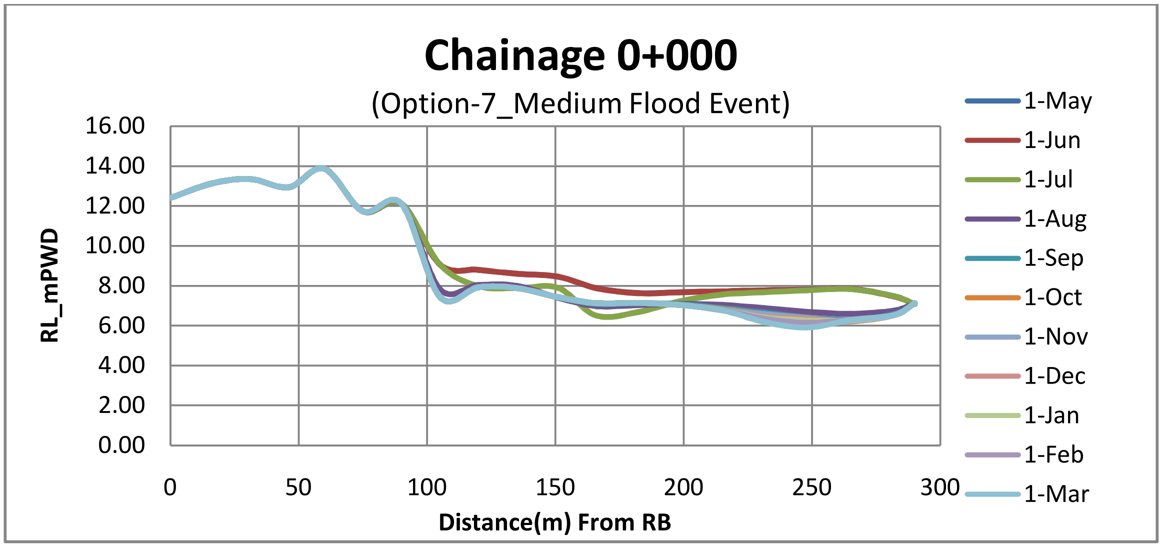

Chainage 0+100
(Option-9_High Flood Event)
RL_mPWD
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar


Chainage 0+200
(Option-9_High Flood Event)
RL_mPWD
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

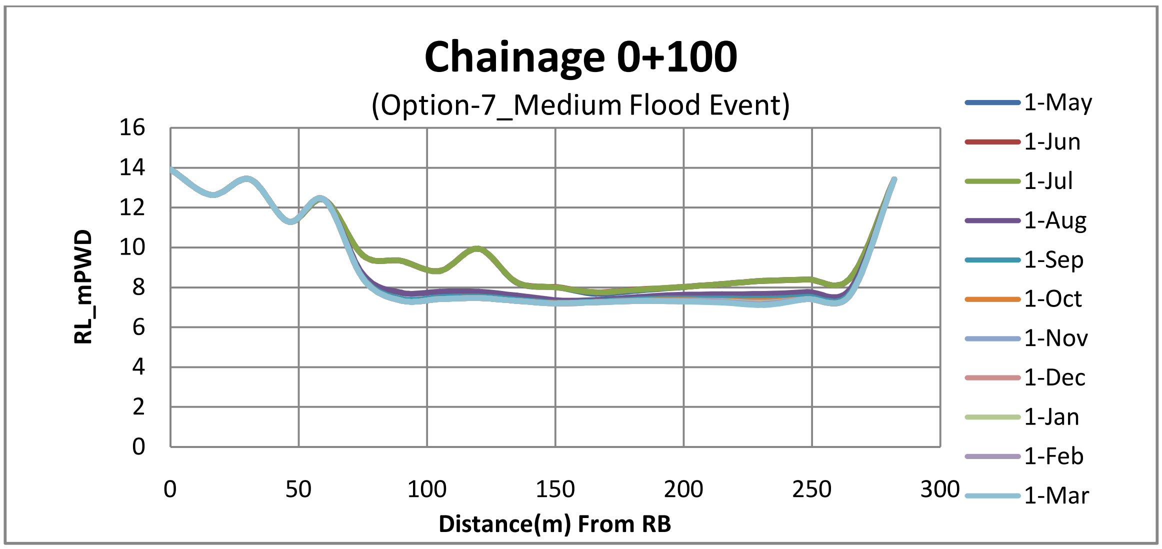

Chainage 0+300
(Option-9_High Flood Event)
RL_mPWD
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar


Chainage 0+400
(Option-9_High Flood Event)
RL_mPWD
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

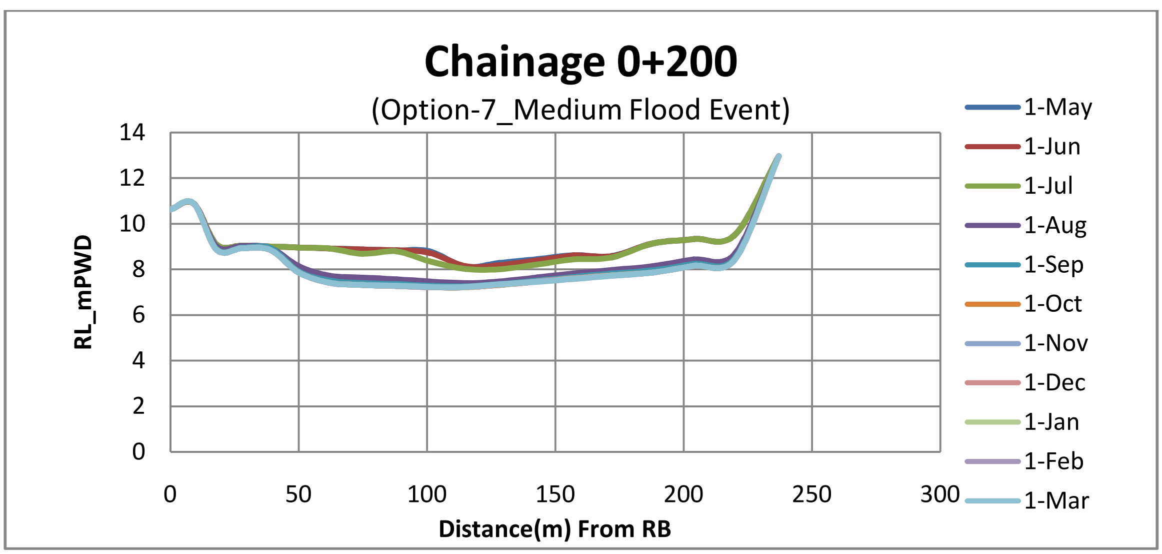
Appendix-D



Chainage 0+000
(Option-7_Medium Flood Event)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
RL_mPWD
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

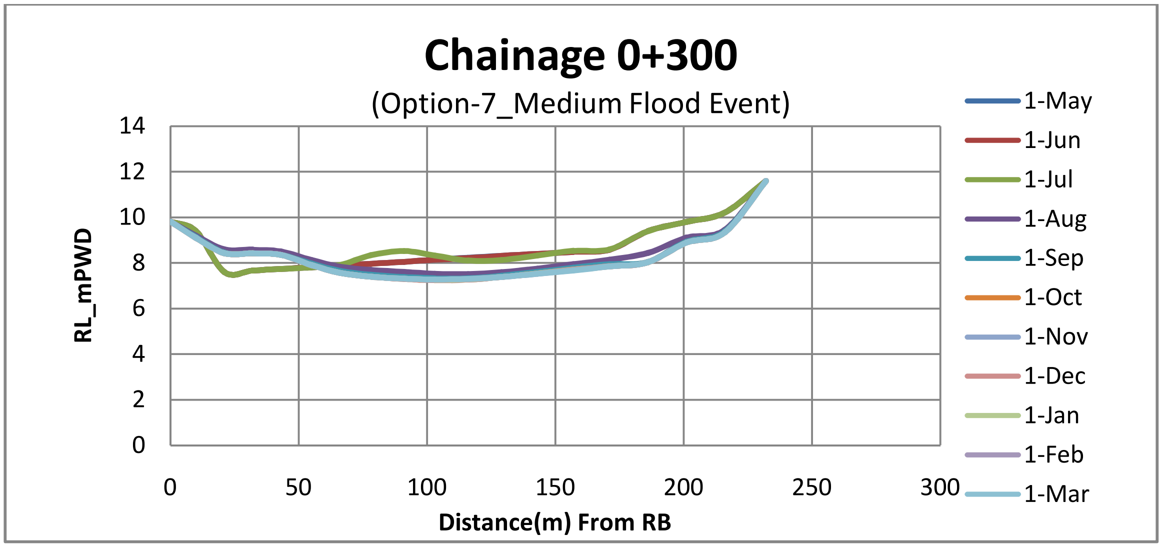


Chainage 0+100
(Option-7_Medium Flood Event)
16
14
12
10
8
6
4
2
0
RL_mPWD
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

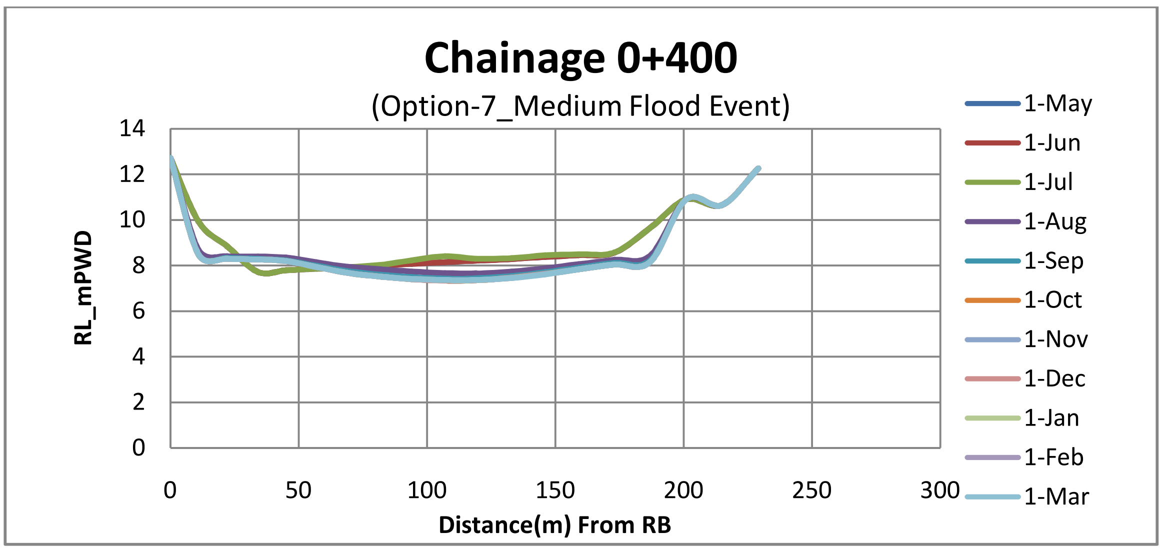


Chainage 0+200
(Option-7_Medium Flood Event)
14
12
10
8
6
4
2
0
RL_mPWD
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

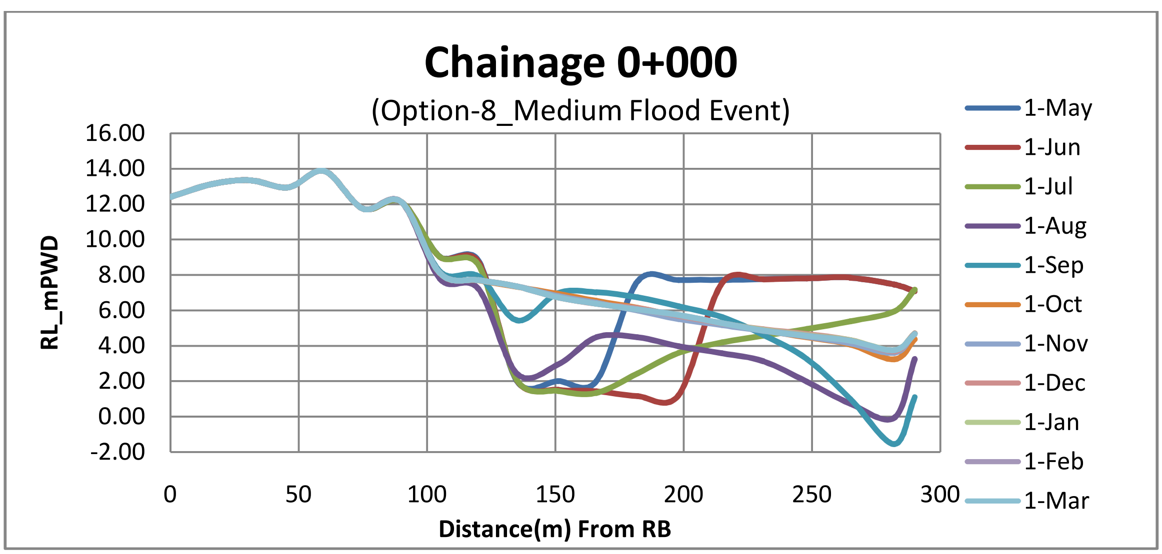
Appendix-D



Chainage 0+300
(Option-7_Medium Flood Event)
RL_mPWD
14
12
10
8
6
4
2
0
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

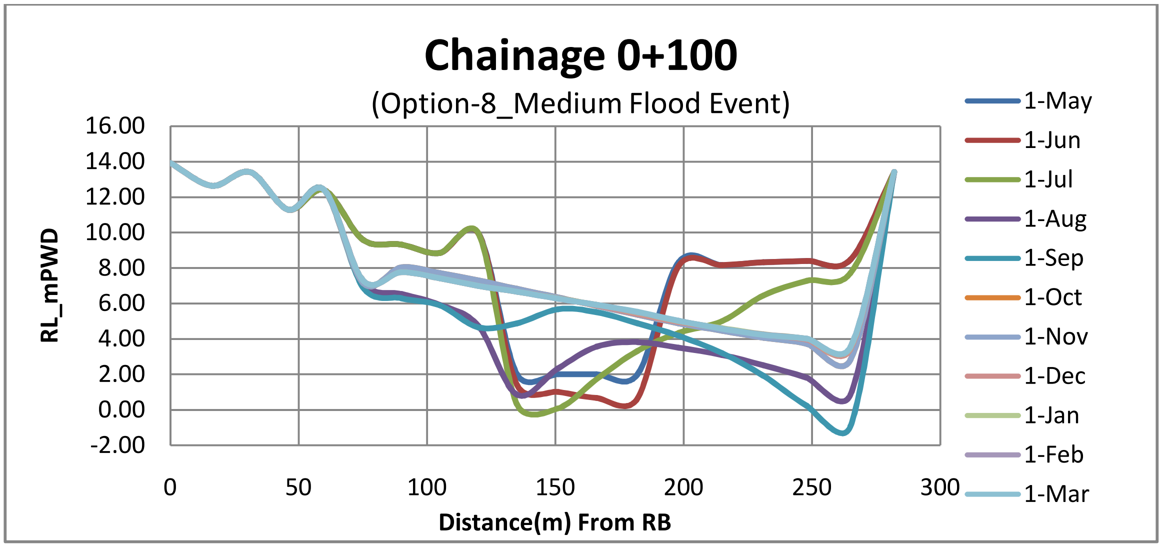


Chainage 0+400
(Option-7_Medium Flood Event)
RL_mPWD
14
12
10
8
6
4
2
0
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

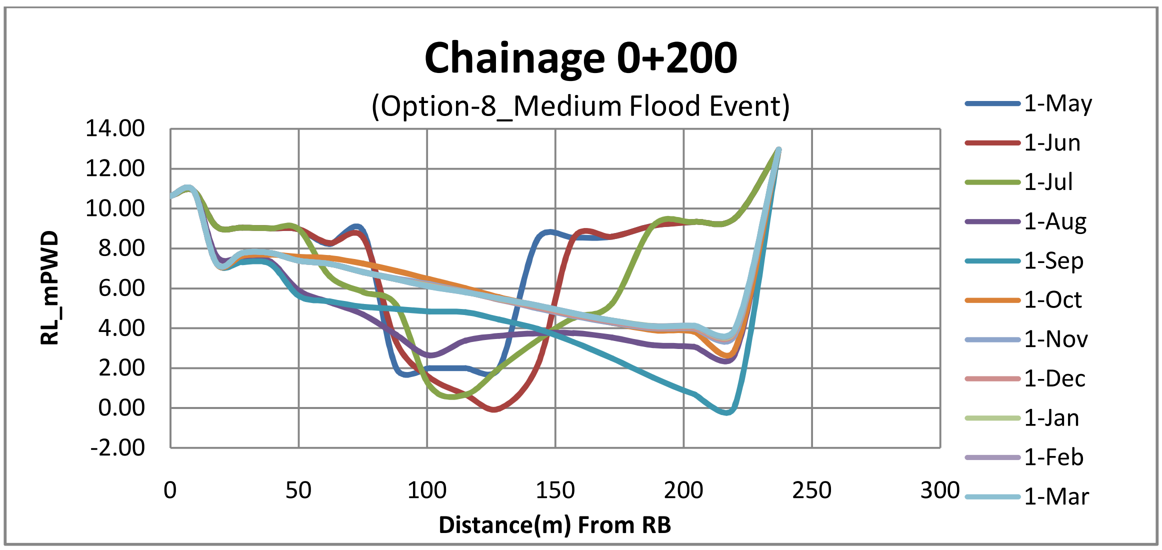


Chainage 0+000
(Option-8_Medium Flood Event)
RL_mPWD
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

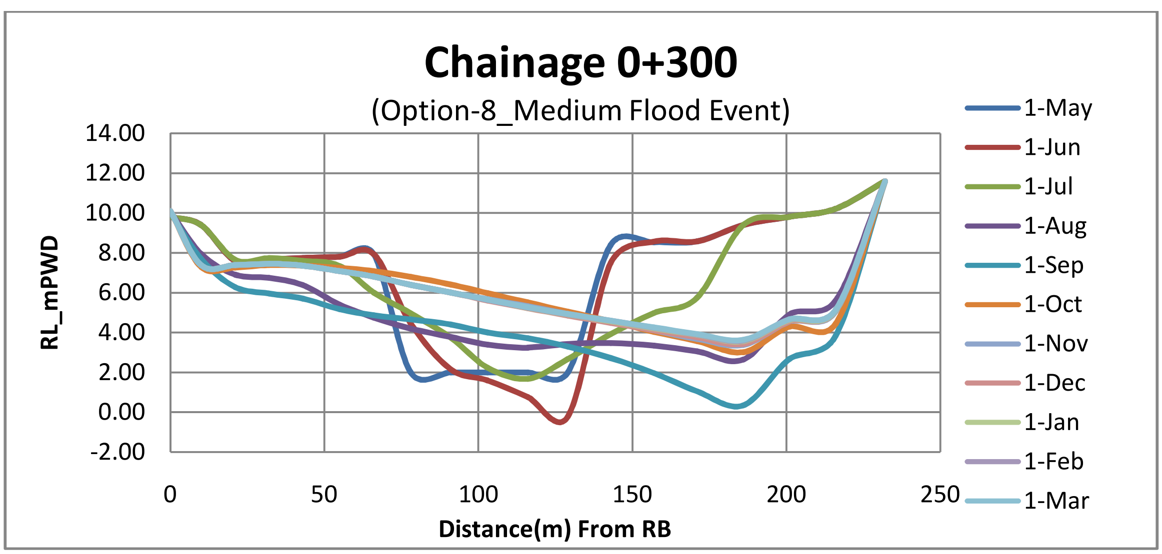
Appendix-D



Chainage 0+100
(Option-8_Medium Flood Event)
RL_mPWD
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

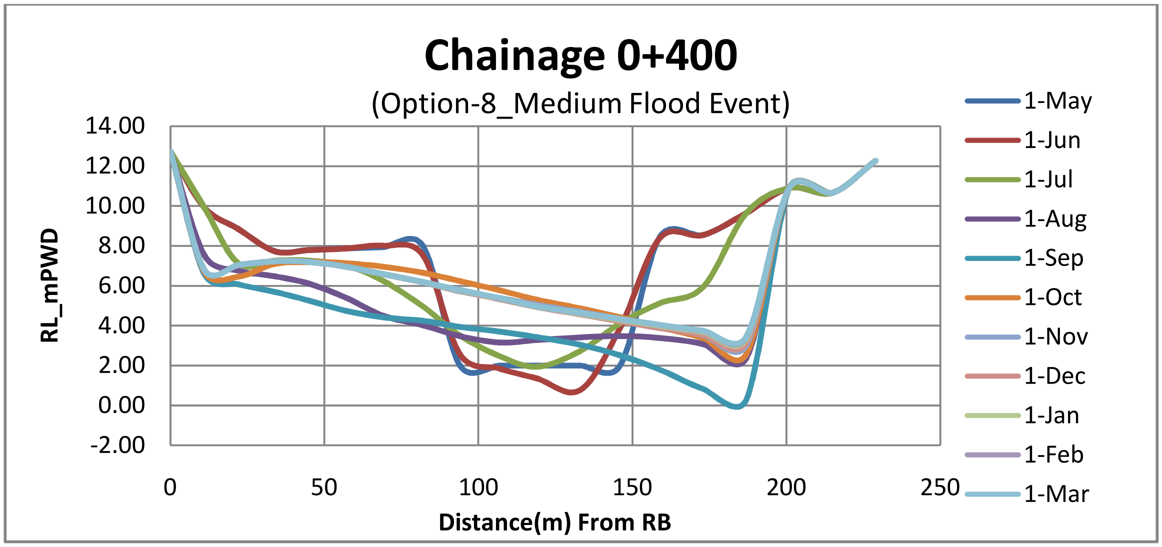


Chainage 0+200
(Option-8_Medium Flood Event)
RL_mPWD
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

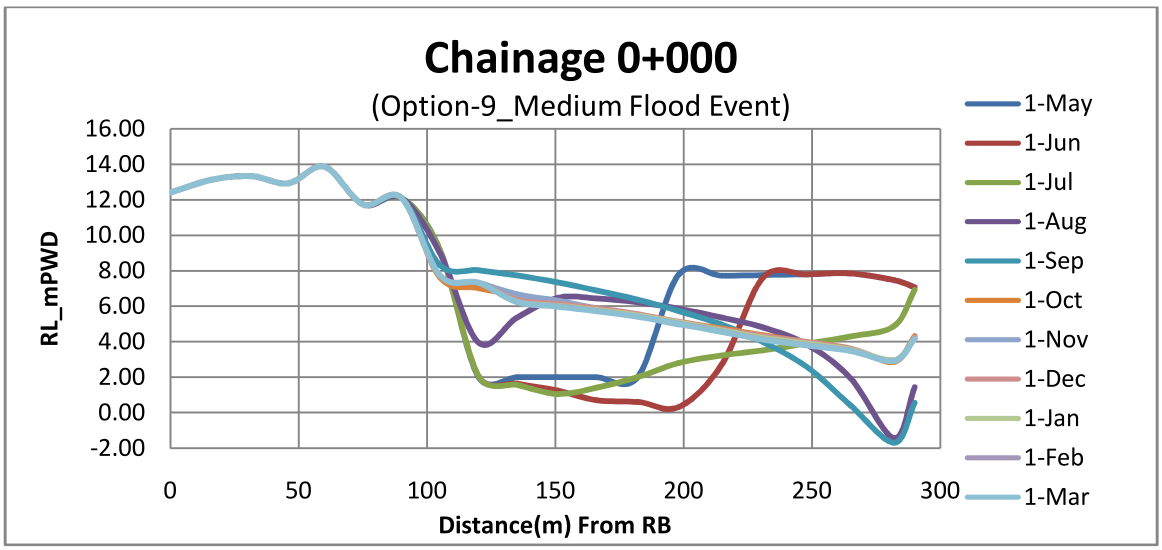


Chainage 0+300
(Option-8_Medium Flood Event)
RL_mPWD
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

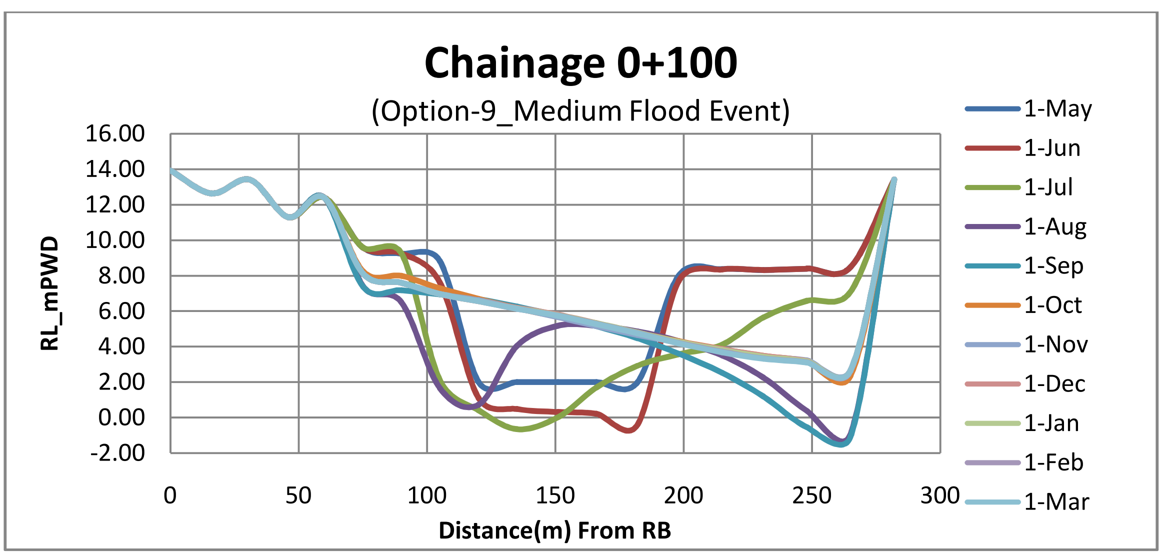
Appendix-D



Chainage 0+400
(Option-8_Medium Flood Event)
RL_mPWD
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

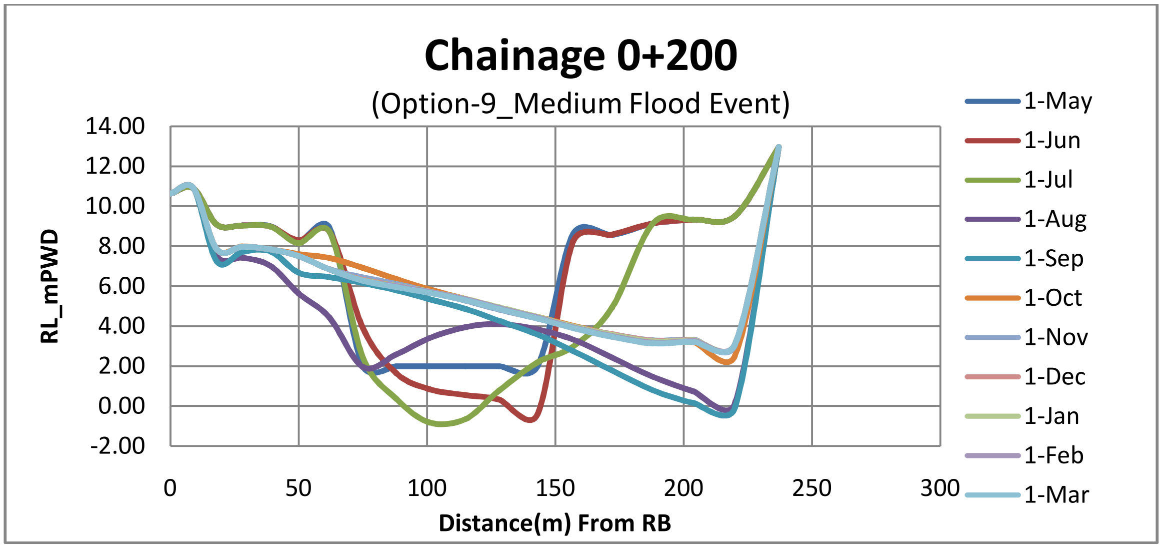


Chainage 0+000
(Option-9_Medium Flood Event)
RL_mPWD
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

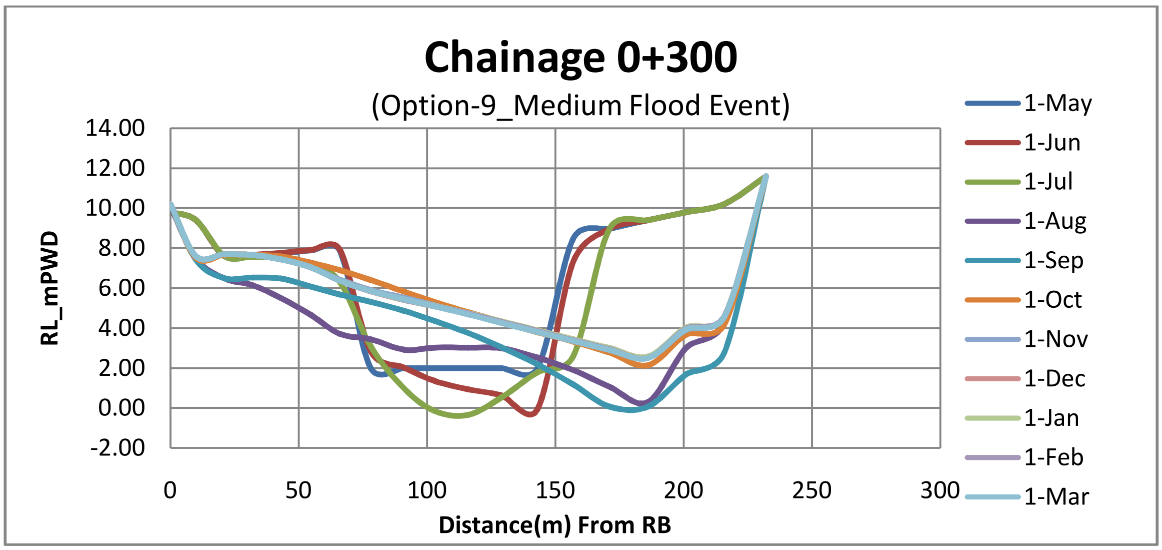


Chainage 0+100
(Option-9_Medium Flood Event)
RL_mPWD
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

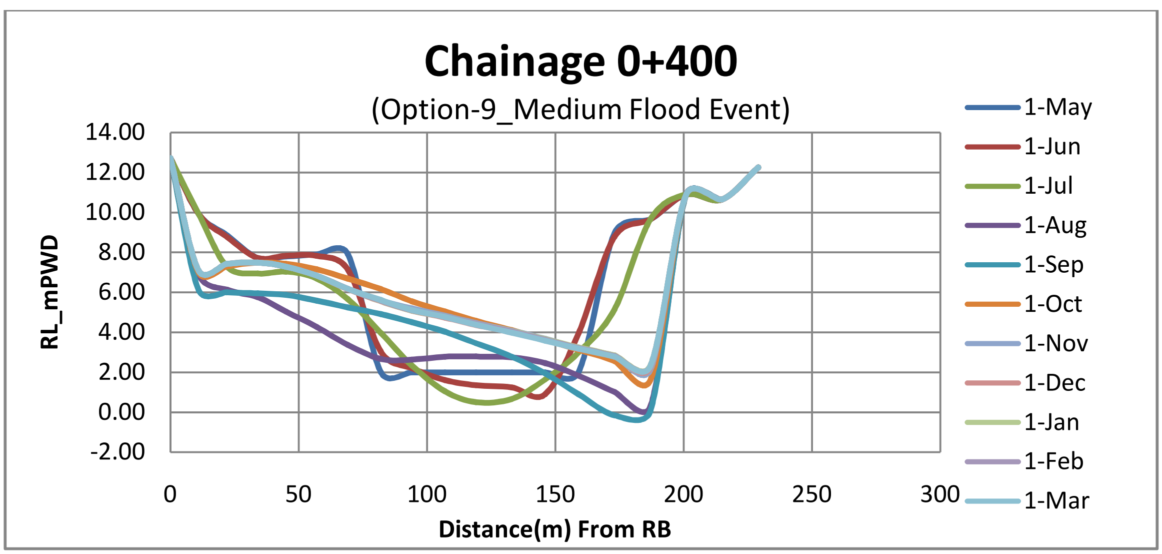
Appendix-D



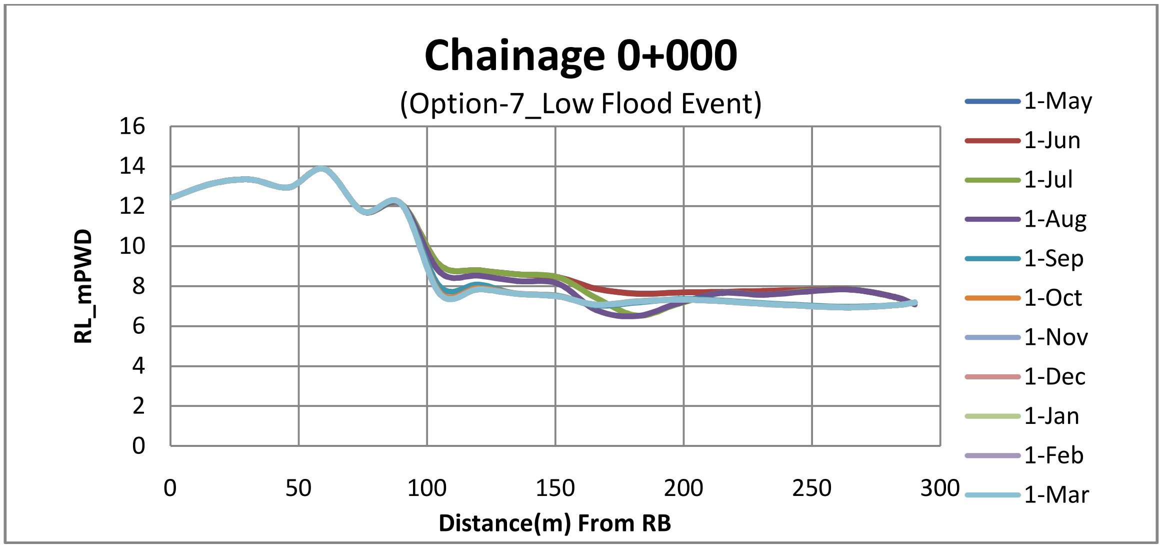
Chainage 0+200
(Option-9_Medium Flood Event)
RL_mPWD
Distance(m) From RB
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
300
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

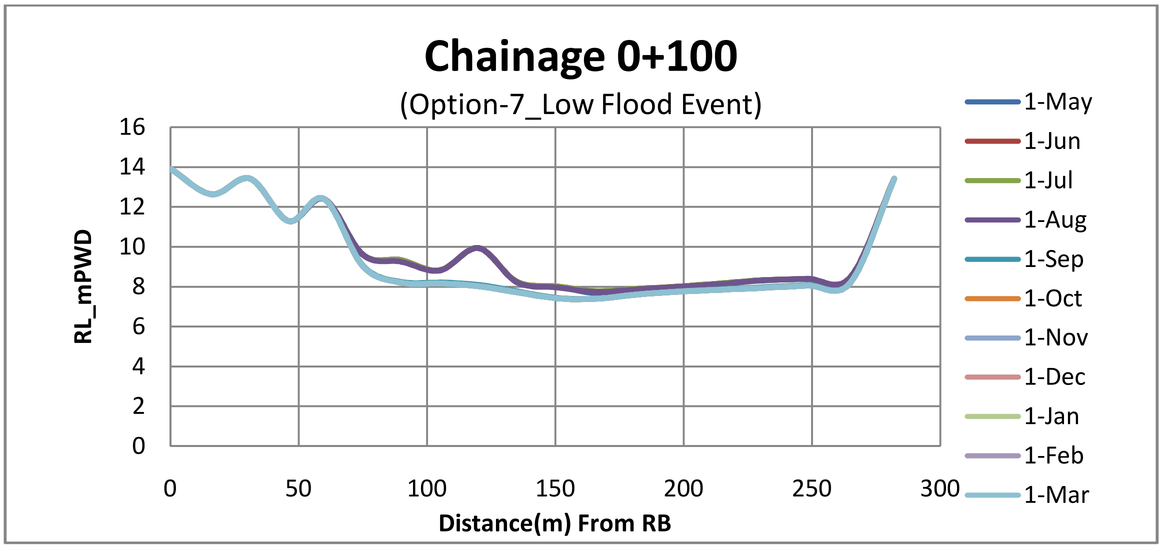


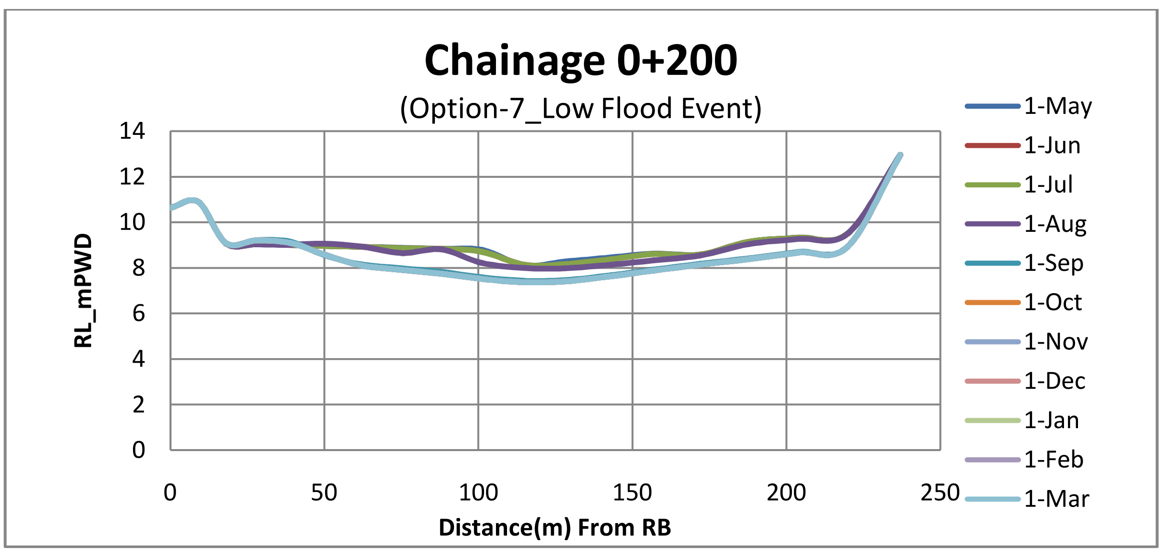
Chainage 0+300
(Option-9_Medium Flood Event)
RL_mPWD
Distance(m) From RB
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
300
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar



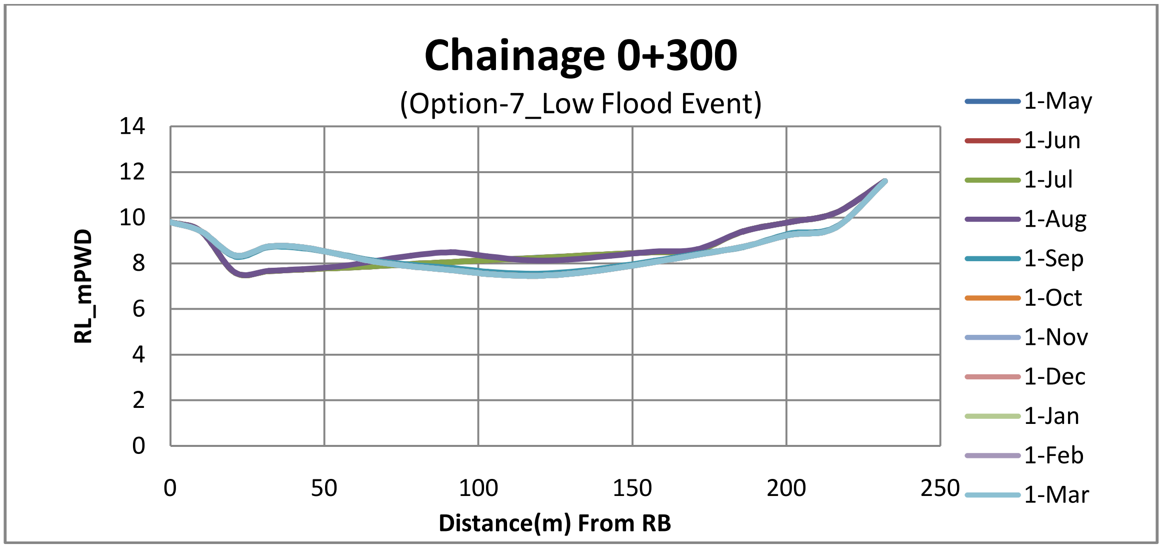
Chainage 0+400
(Option-9_Medium Flood Event)
RL_mPWD
Distance(m) From RB
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
300
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

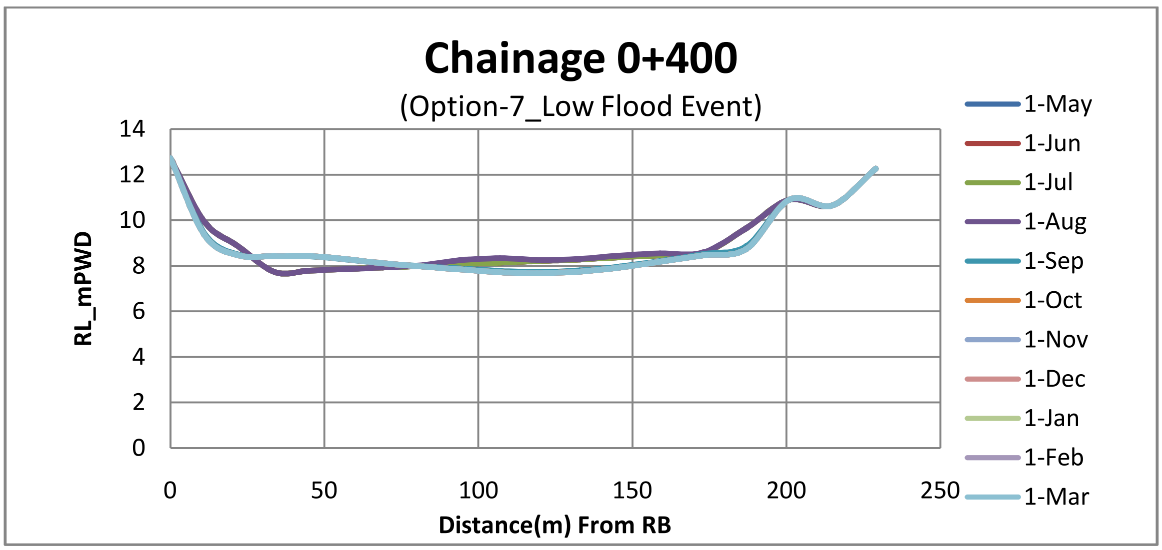

Chainage 0+000
(Option-7_Low Flood Event)
RL_mPWD
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

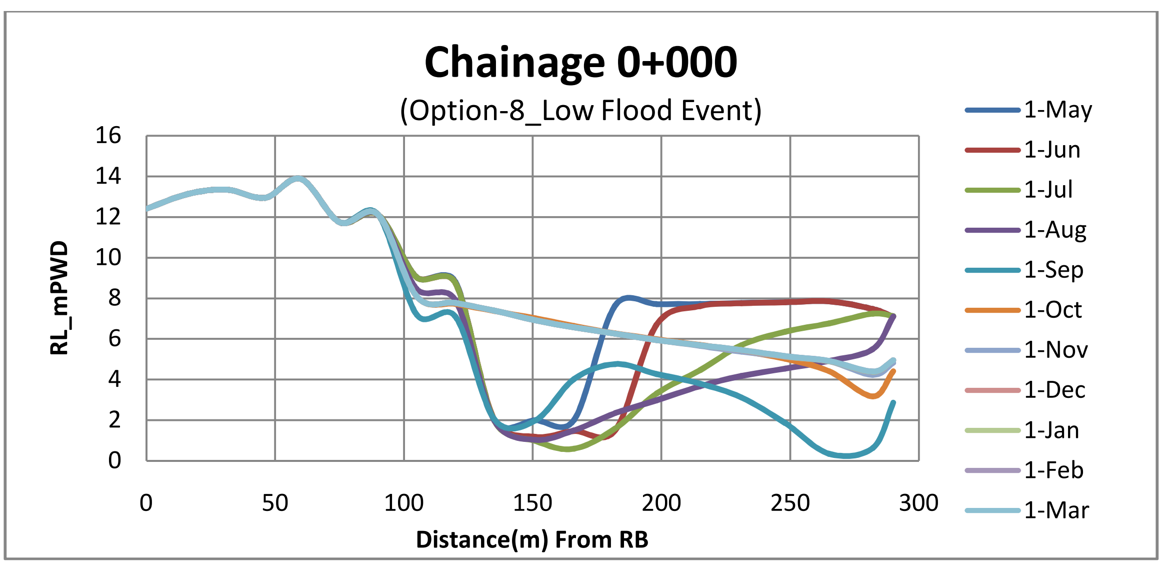

Chainage 0+100
(Option-7_Low Flood Event)
RL_mPWD
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar


Chainage 0+200
(Option-7_Low Flood Event)
RL_mPWD
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

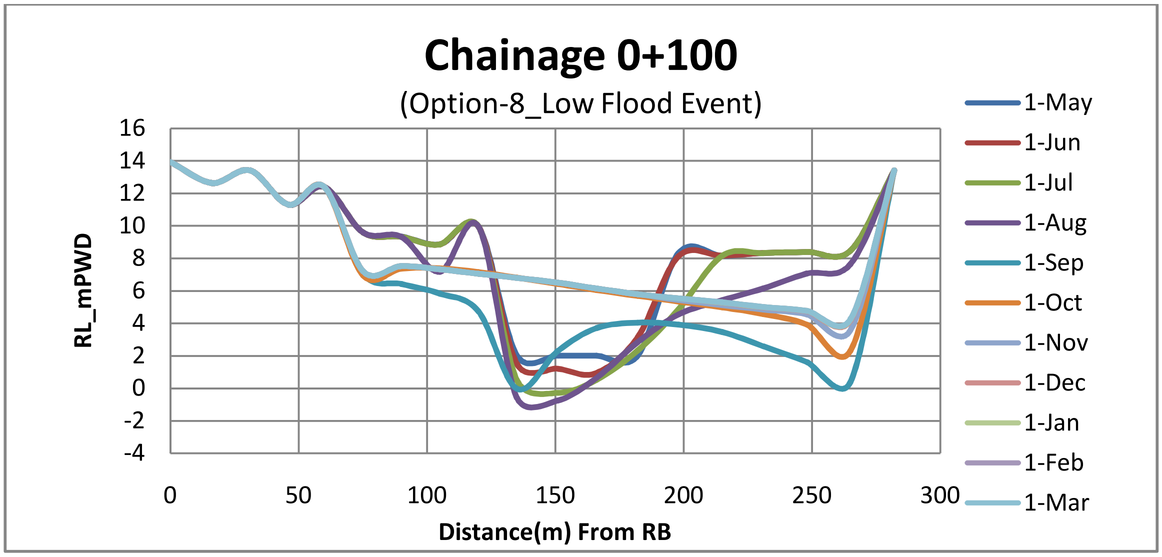
Appendix-D

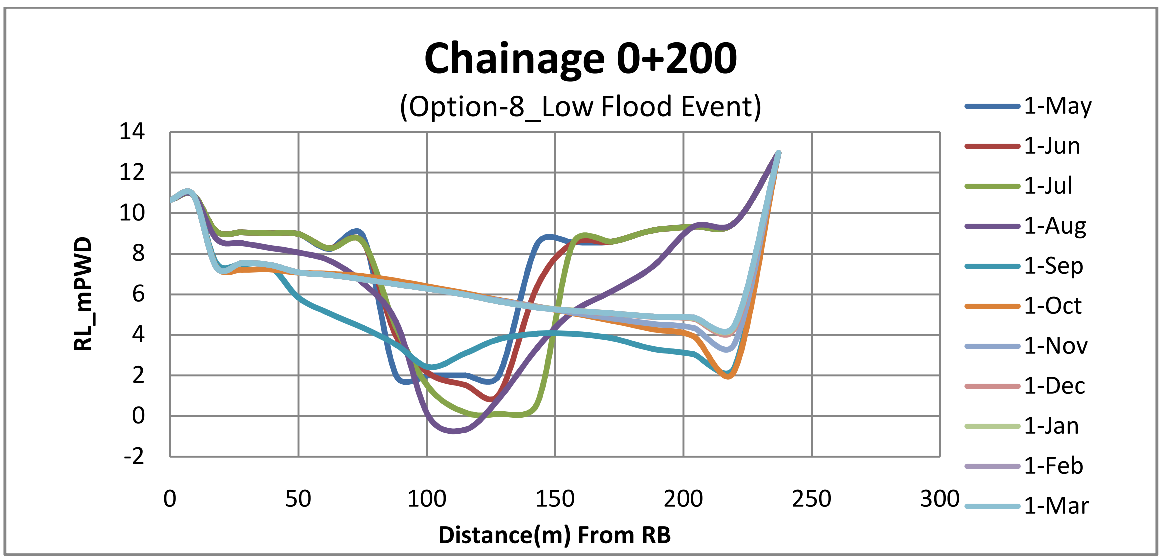

Chainage 0+300
(Option-7_Low Flood Event)
RL_mPWD
14
12
10
8
6
4
2
0
0
50
100
150
200
250
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

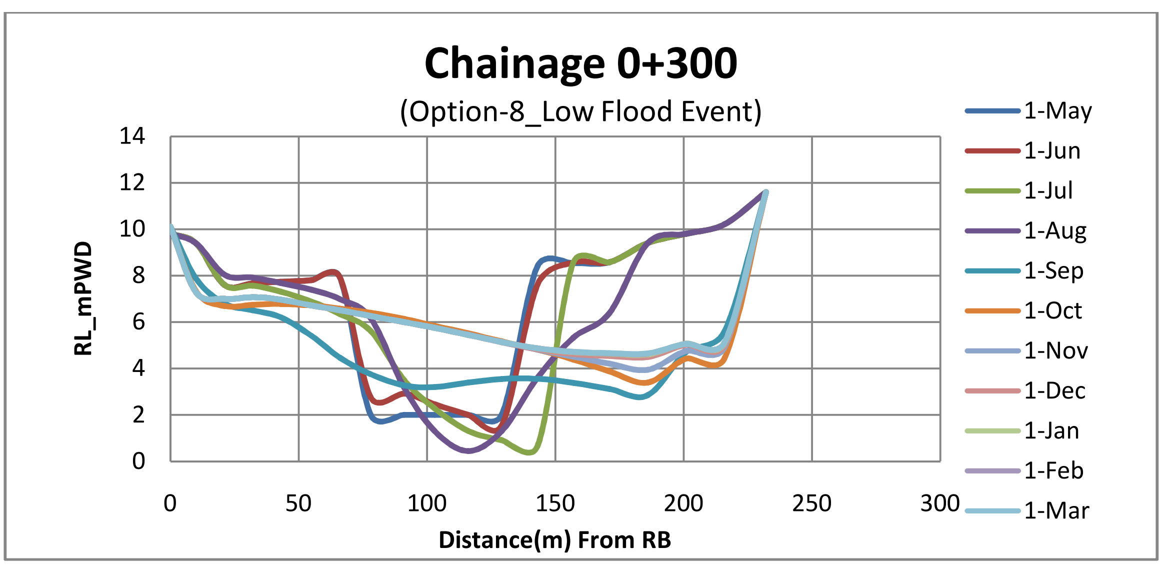

Chainage 0+400
(Option-7_Low Flood Event)
RL_mPWD
14
12
10
8
6
4
2
0
0
50
100
150
200
250
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar


Chainage 0+000
(Option-8_Low Flood Event)
RL_mPWD
16
14
12
10
8
6
4
2
0
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

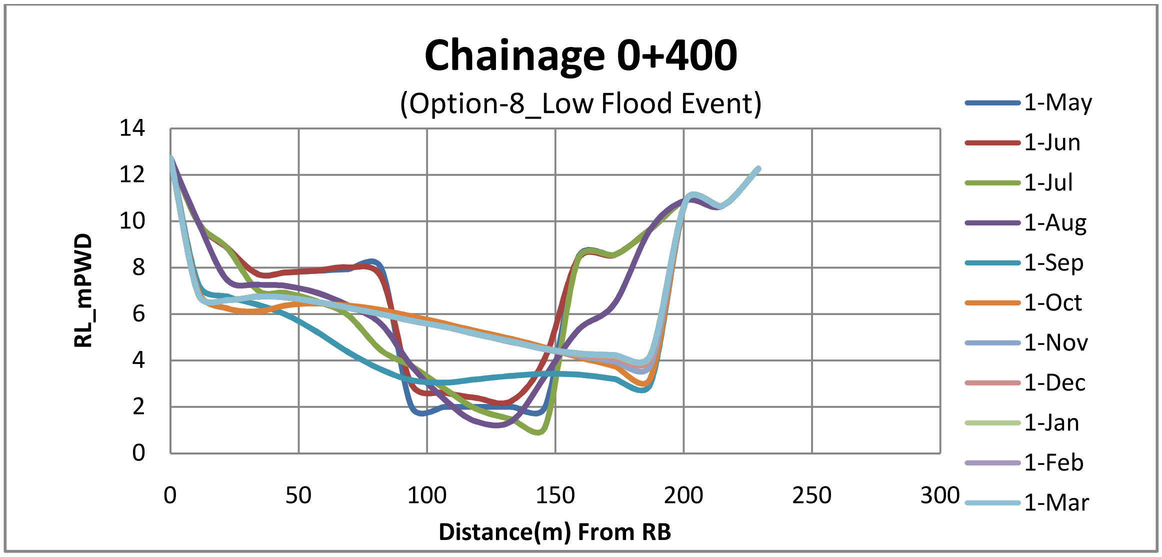
Appendix-D

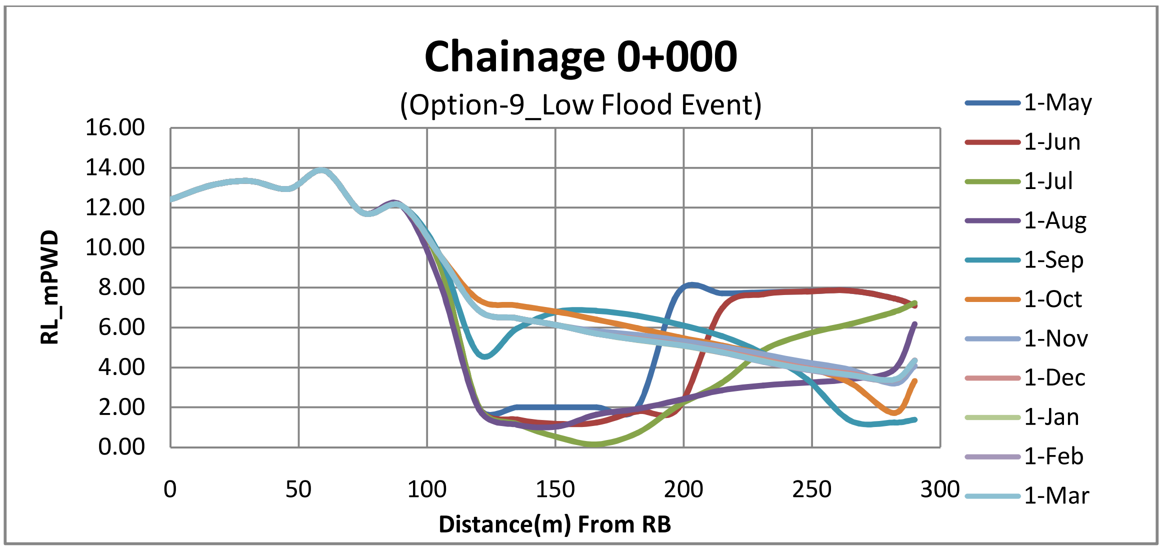

Chainage 0+100
(Option-8_Low Flood Event)
RL_mPWD
16
14
12
10
8
6
4
2
0
-2
-4
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

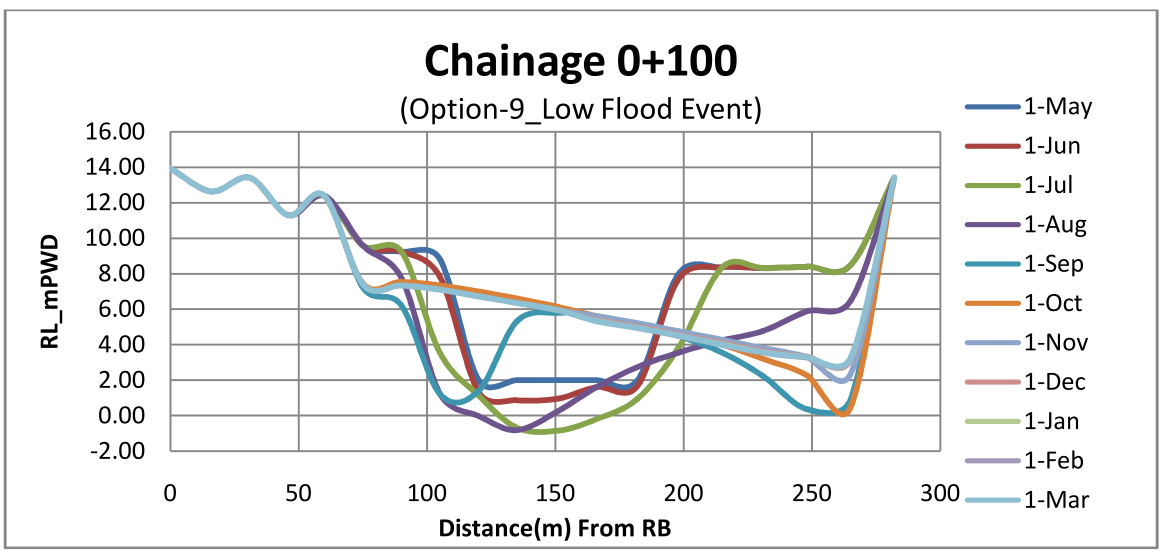

Chainage 0+200
(Option-8_Low Flood Event)
RL_mPWD
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar


Chainage 0+300
(Option-8_Low Flood Event)
RL_mPWD
14
12
10
8
6
4
2
0
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

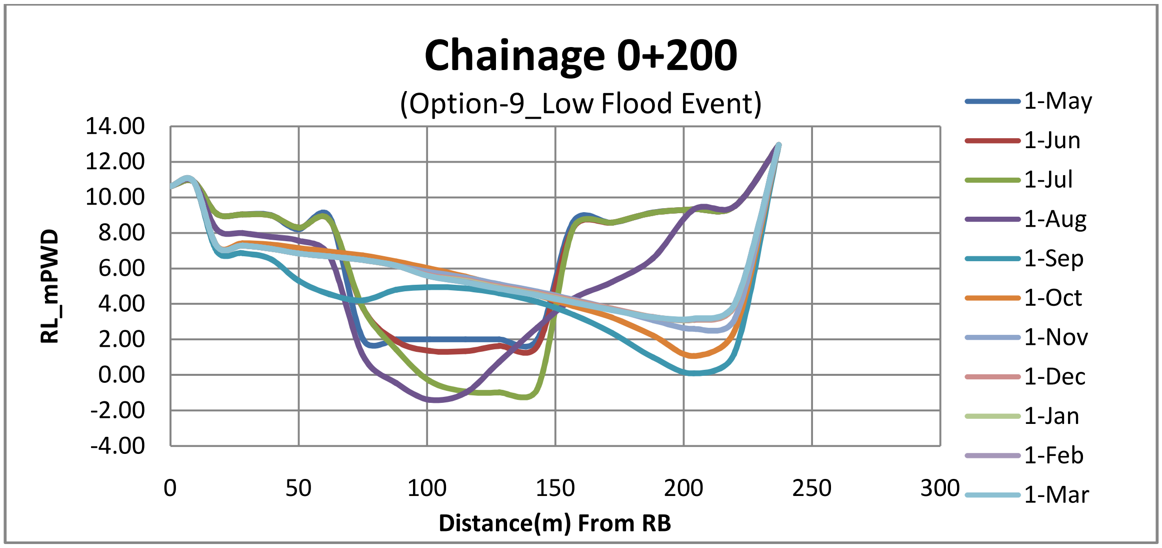
Appendix-D

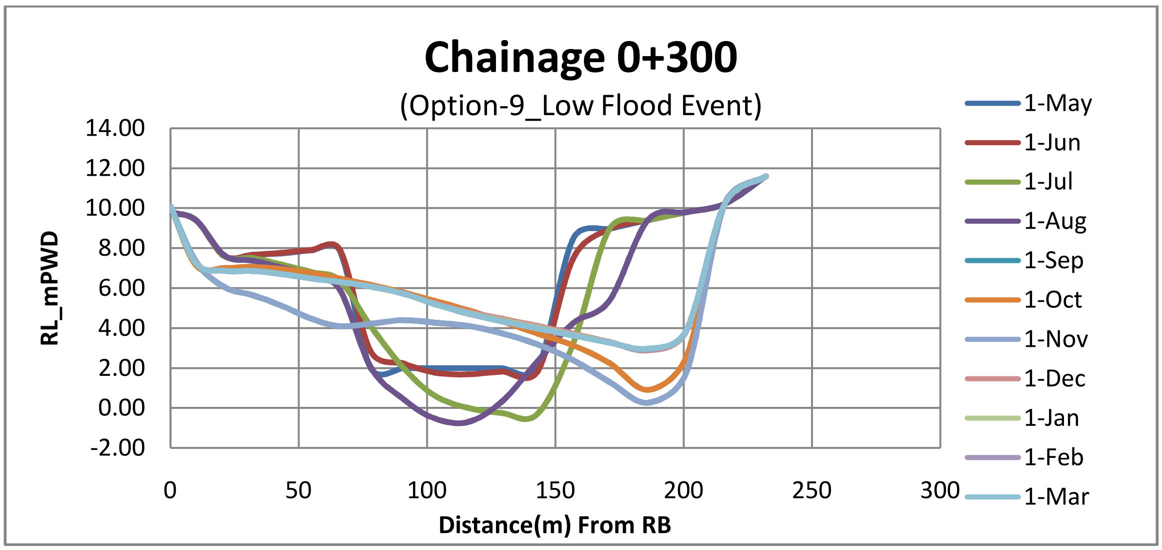

Chainage 0+400
(Option-8_Low Flood Event)
RL_mPWD
14
12
10
8
6
4
2
0
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

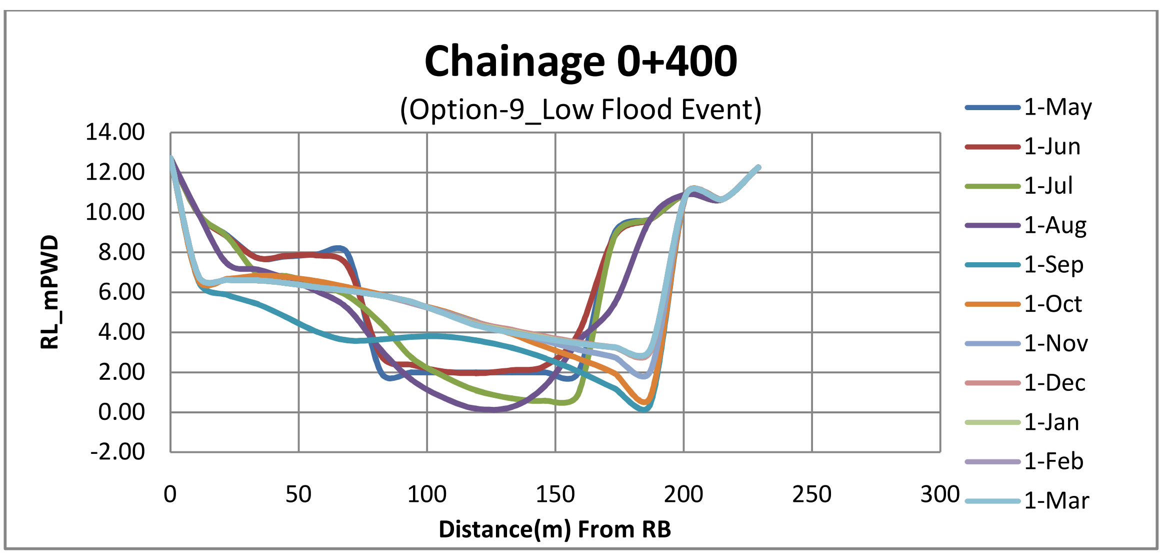

Chainage 0+000
(Option-9_Low Flood Event)
RL_mPWD
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar


Chainage 0+100
(Option-9_Low Flood Event)
RL_mPWD
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

Appendix-D


Chainage 0+200
(Option-9_Low Flood Event)
RL_mPWD
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

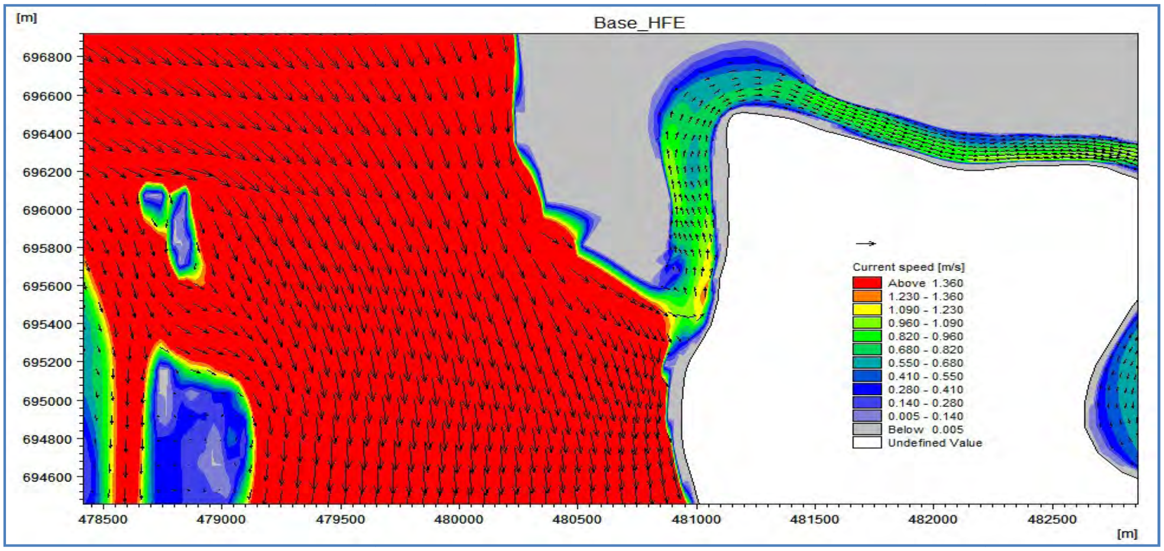

Chainage 0+300
(Option-9_Low Flood Event)
RL_mPWD
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

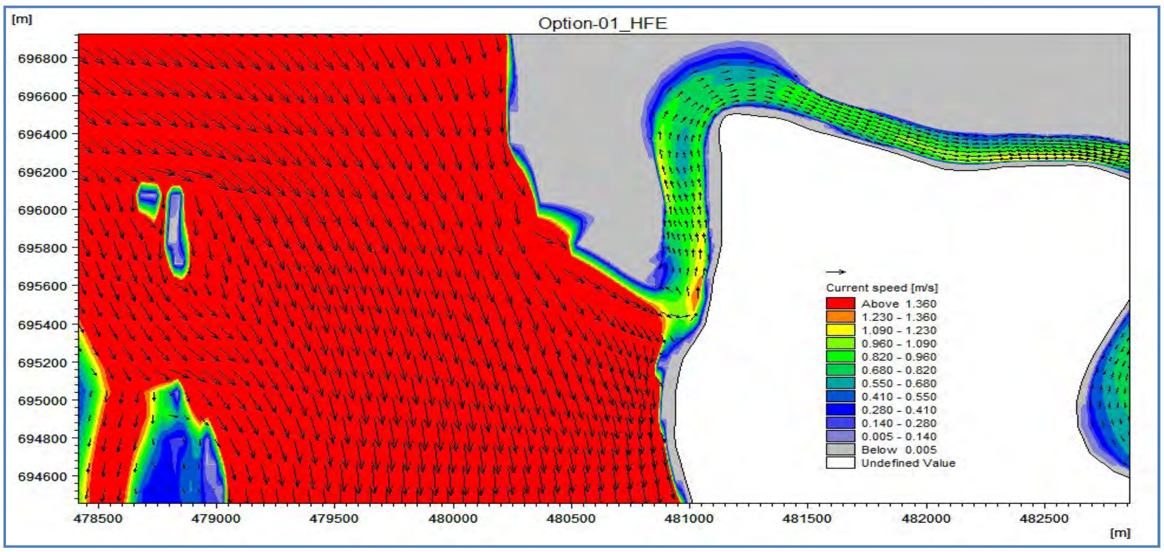

Chainage 0+400
(Option-9_Low Flood Event)
RL_mPWD
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
50
100
150
200
250
300
Distance(m) From RB
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar

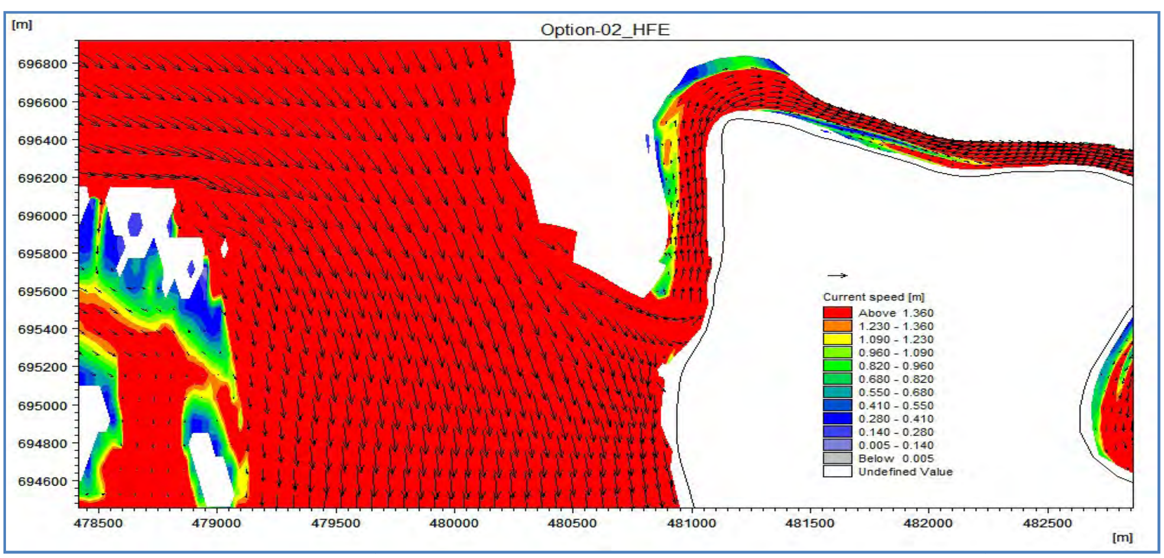
APPENDIX-E

Velocity Vector for Various Options

Appendix-E


Base_HFE
[m]
696800
696600
696400
696200
696000
695800
695600
695400
695200
695000
694800
694600
478500
479000
479500
480000
480500
481000
481500
482000
482500
[m]
Current speed [m/s]
Above 1.360
1.230 - 1.360
1.090 - 1.230
0.960 - 1.090
0.820 - 0.960
0.680 - 0.820
0.550 - 0.680
0.410 - 0.550
0.280 - 0.410
0.140 - 0.280
0.005 - 0.140
Below 0.005
Undefined Value


Option-01_HFE
[m]
696800
696600
696400
696200
696000
695800
695600
695400
695200
695000
694800
694600
478500
479000
479500
480000
480500
481000
481500
482000
482500
[m]
Current speed [m/s]
Above 1.360
1.230 - 1.360
1.090 - 1.230
0.960 - 1.090
0.820 - 0.960
0.680 - 0.820
0.550 - 0.680
0.410 - 0.550
0.280 - 0.410
0.140 - 0.280
0.005 - 0.140
Below 0.005
Undefined Value


Option-02_HFE
[m]
696800
696600
696400
696200
696000
695800
695600
695400
695200
695000
694800
694600
478500
479000
479500
480000
480500
481000
481500
482000
482500
[m]
Current speed [m]
Above 1.360
1.230 - 1.360
1.090 - 1.230
0.960 - 1.090
0.820 - 0.960
0.680 - 0.820
0.550 - 0.680
0.410 - 0.550
0.280 - 0.410
0.140 - 0.280
0.005 - 0.140
Below 0.005
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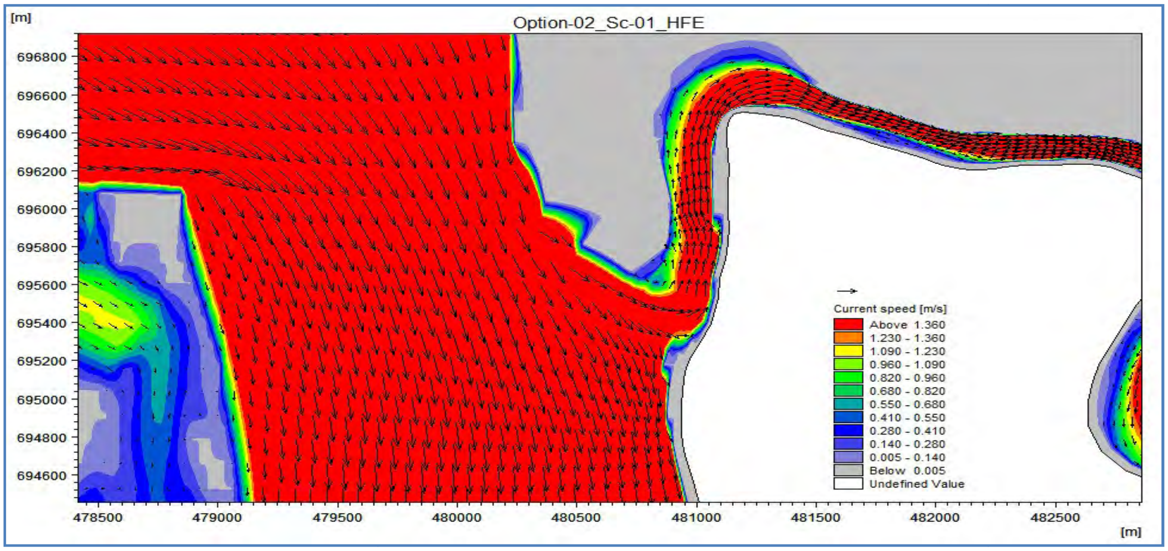
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[m]
Current speed [m/s]
Above 1.360
1.230 - 1.360
1.090 - 1.230
0.960 - 1.090
0.820 - 0.960
0.680 - 0.820
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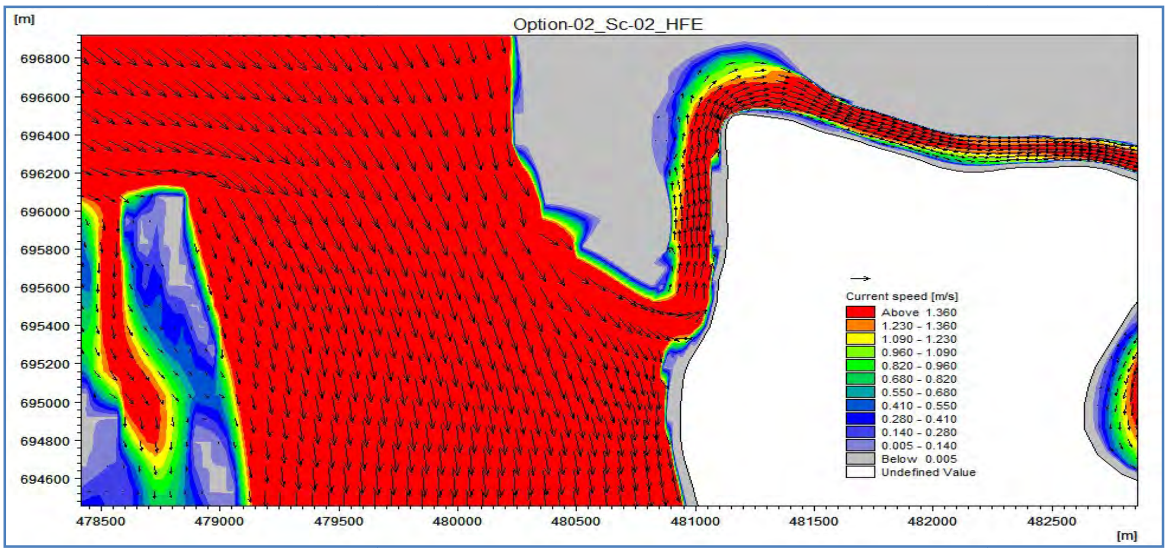
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Current speed [m/s]
Above 1.360
1.230 - 1.360
1.090 - 1.230
0.960 - 1.090
0.820 - 0.960
0.680 - 0.820
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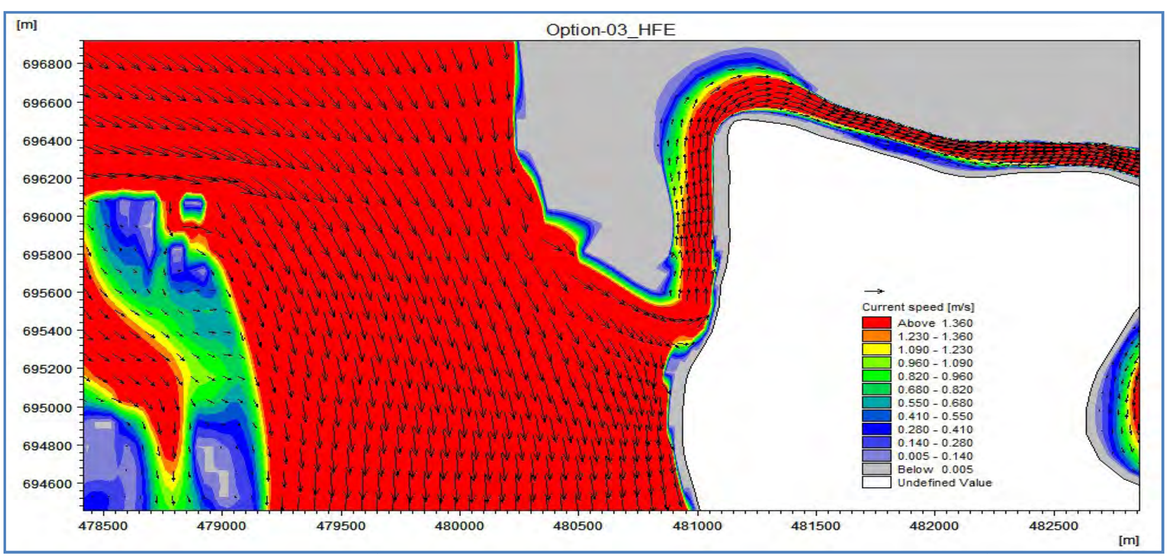
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[m]
Current speed [m/s]
Above 1.360
1.230 - 1.360
1.090 - 1.230
0.960 - 1.090
0.820 - 0.960
0.680 - 0.820
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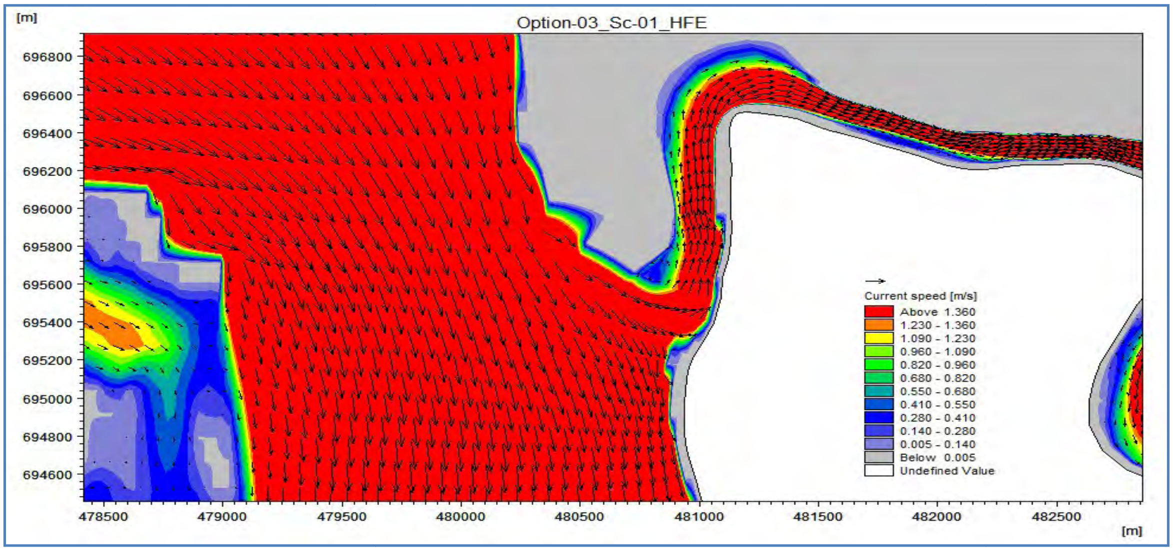
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[m]
Current speed [m/s]
Above 1.360
1.230 - 1.360
1.090 - 1.230
0.960 - 1.090
0.820 - 0.960
0.680 - 0.820
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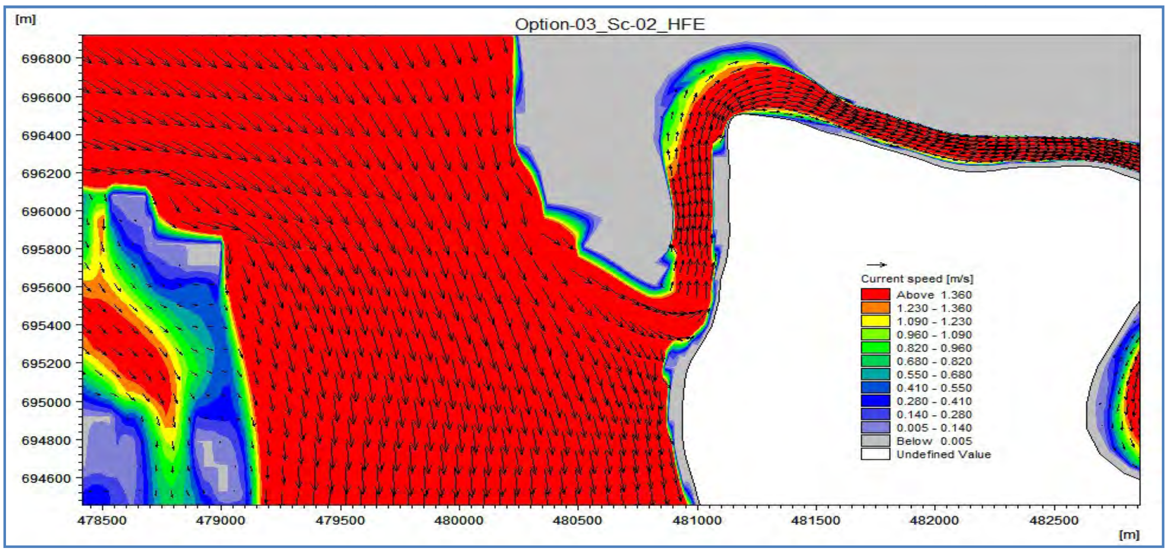
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[m]
Current speed [m/s]
Above 1.360
1.230 - 1.360
1.090 - 1.230
0.960 - 1.090
0.820 - 0.960
0.680 - 0.820
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0.005 - 0.140
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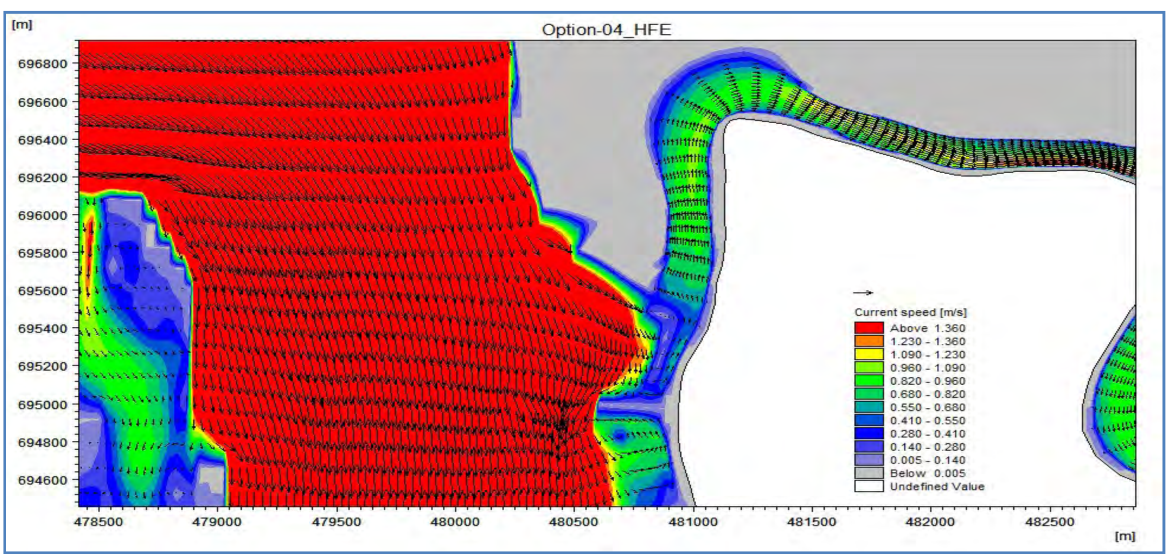
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[m]
Current speed [m/s]
Above 1.360
1.230 - 1.360
1.090 - 1.230
0.960 - 1.090
0.820 - 0.960
0.680 - 0.820
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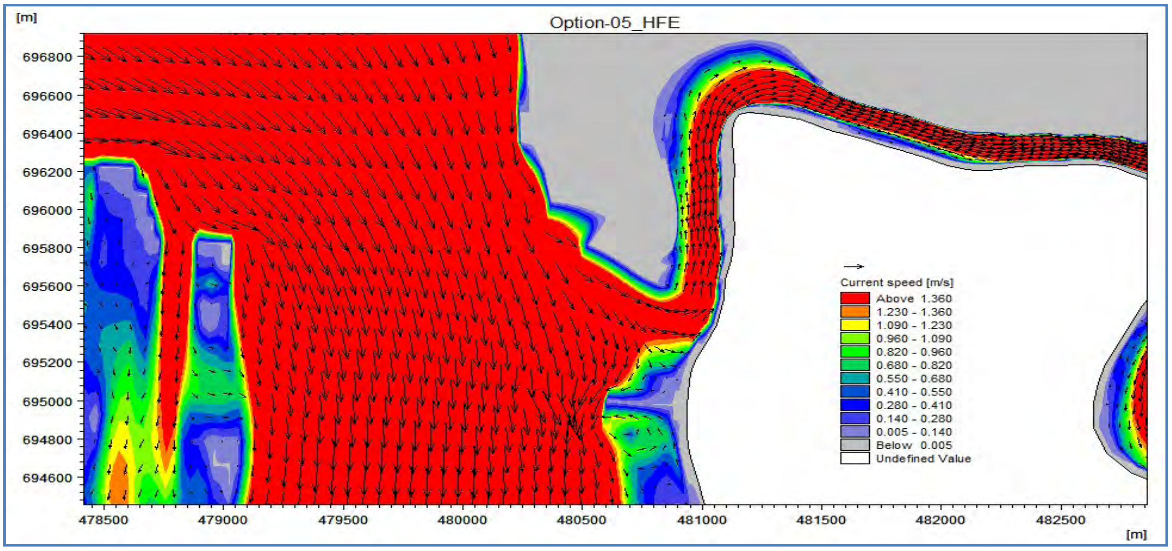
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0.680 - 0.820
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0.140 - 0.280
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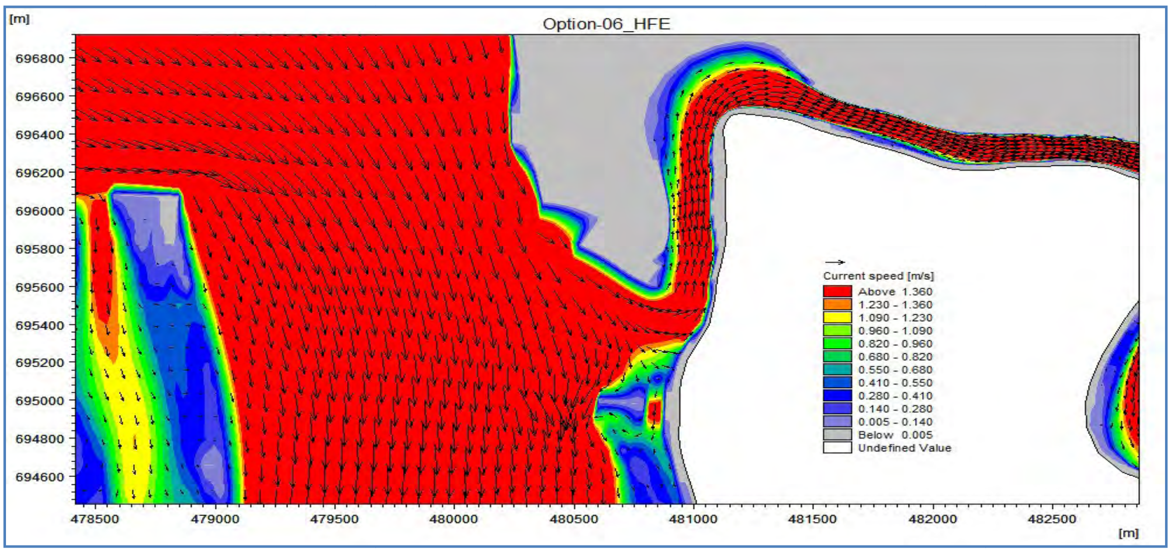
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Current speed [m/s]
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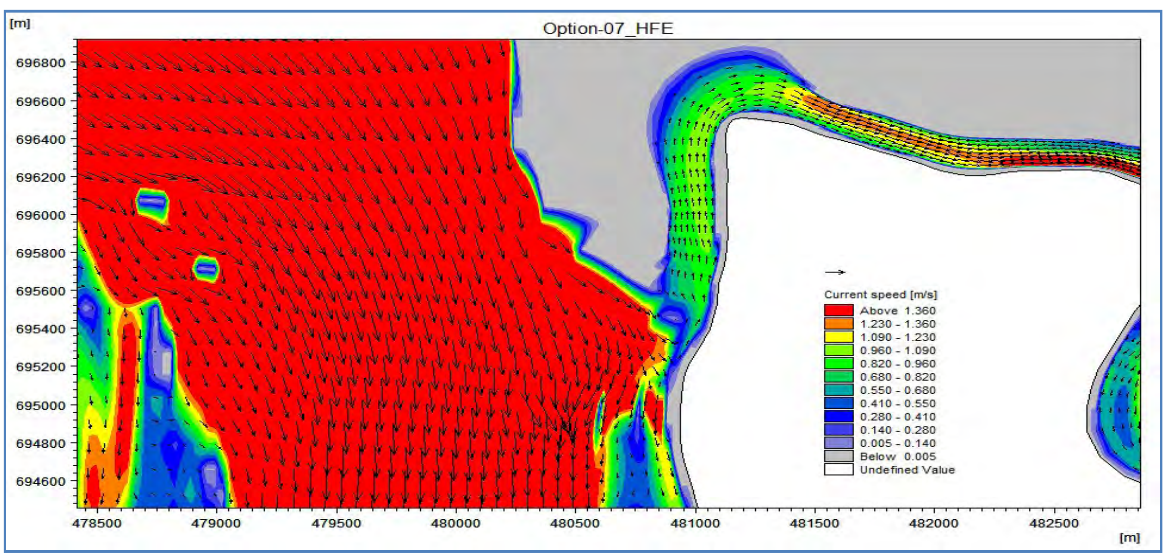
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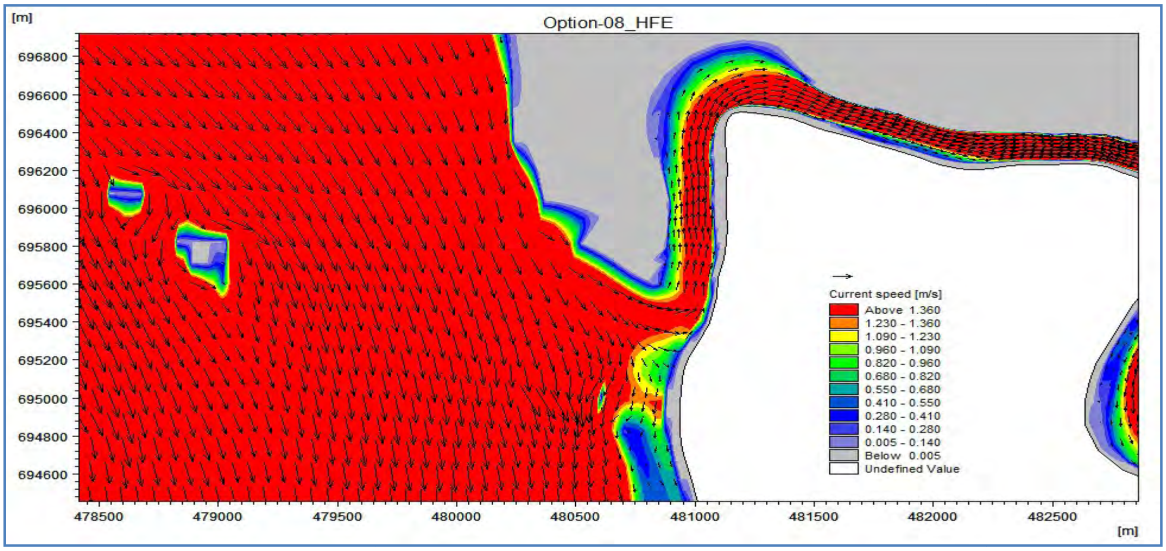
Undefined Value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[m]
Current speed [m/s]
Above 1.360
1.230 - 1.360
1.090 - 1.230
0.960 - 1.090
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0.680 - 0.820
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Below 0.005
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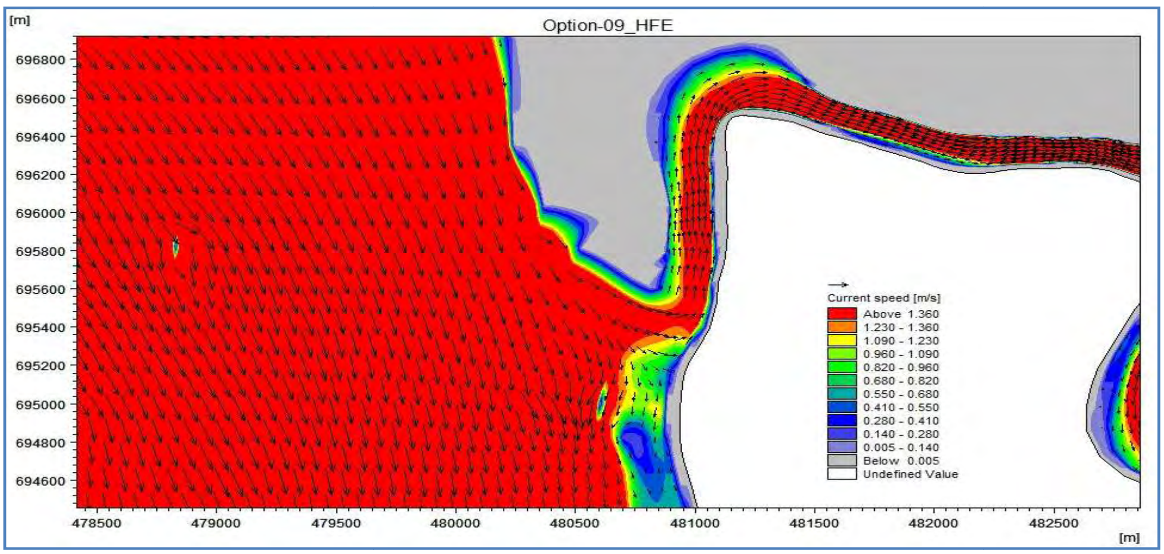
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[m]
Current speed [m/s]
Above 1.360
1.230 - 1.360
1.090 - 1.230
0.960 - 1.090
0.820 - 0.960
0.680 - 0.820
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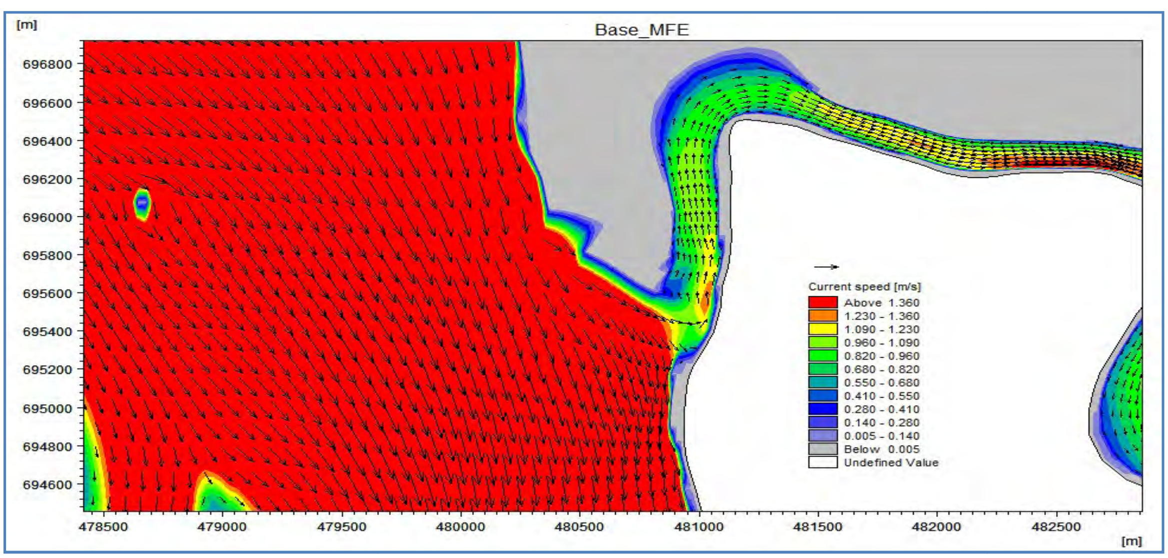
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[m]
Current speed [m/s]
Above 1.360
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0.960 - 1.090
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0.680 - 0.820
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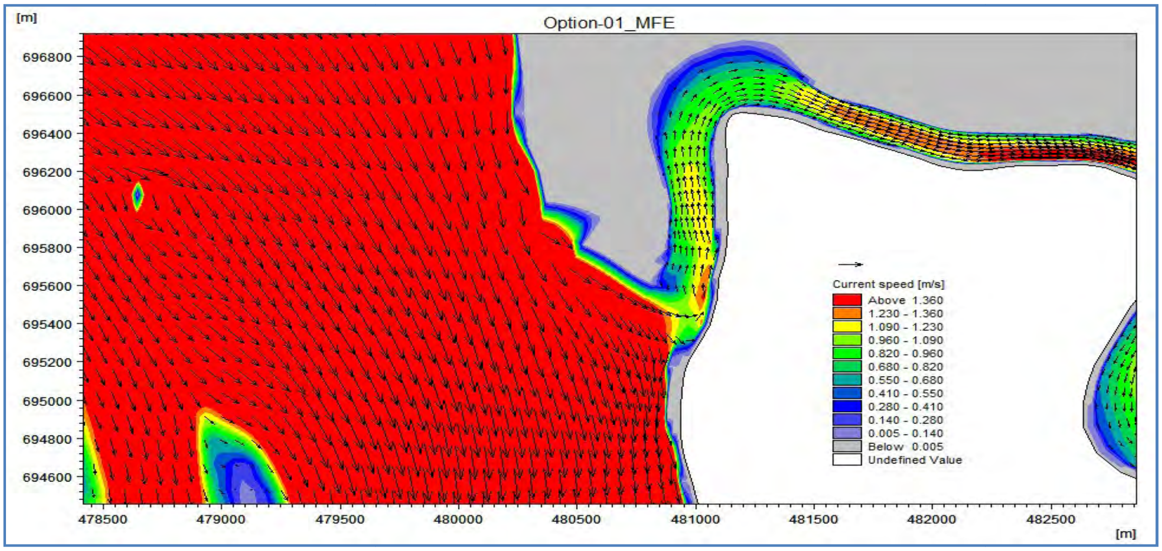

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[m]
Current speed [m/s]
Above 1.360
1.230 - 1.360
1.090 - 1.230
0.960 - 1.090
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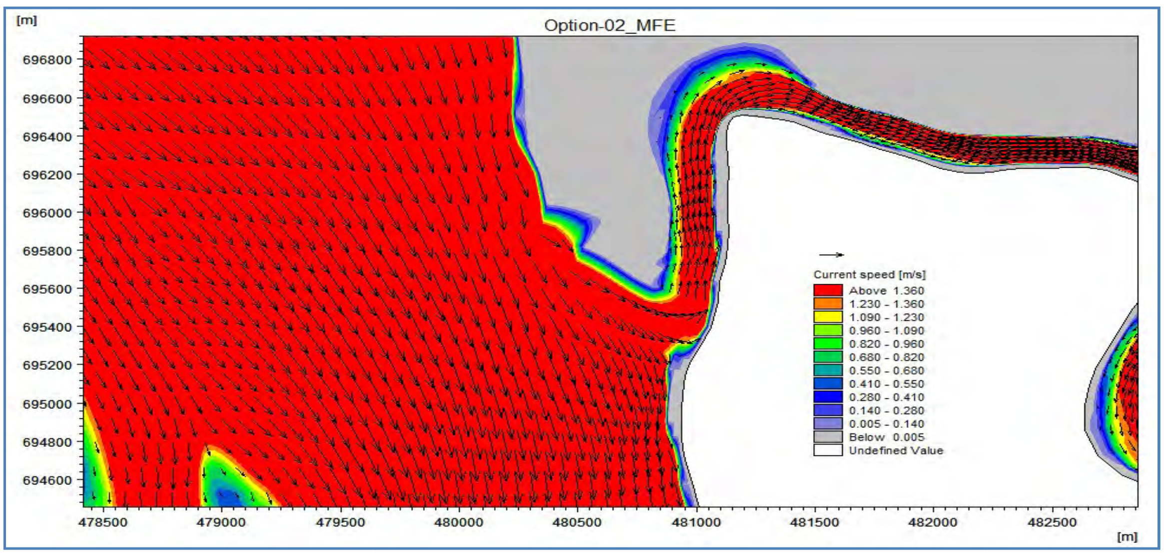

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[m]
Current speed [m/s]
Above 1.360
1.230 - 1.360
1.090 - 1.230
0.960 - 1.090
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0.680 - 0.820
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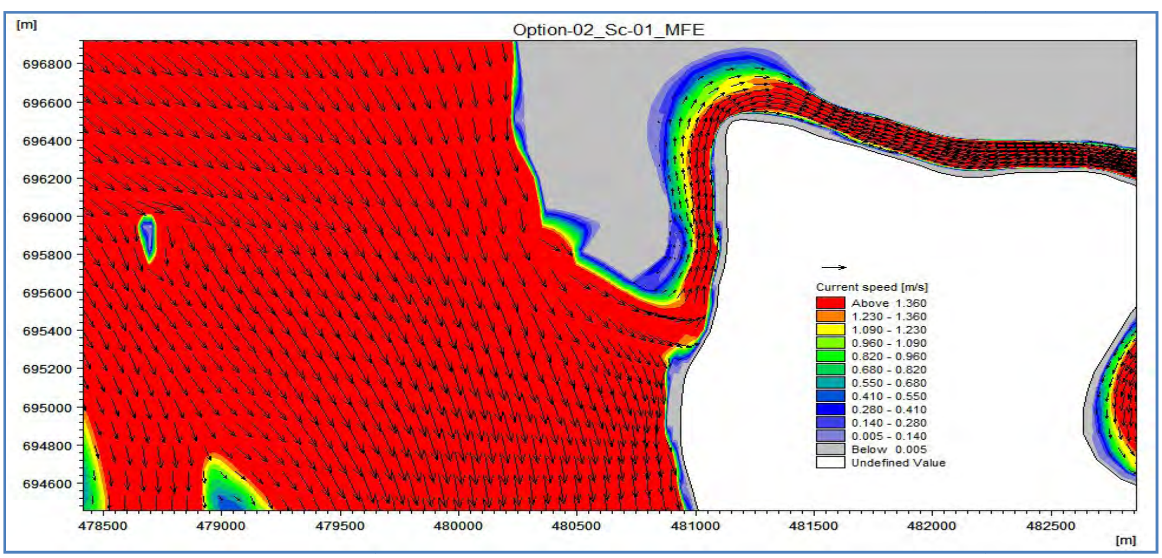

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[m]
Current speed [m/s]
Above 1.360
1.230 - 1.360
1.090 - 1.230
0.960 - 1.090
0.820 - 0.960
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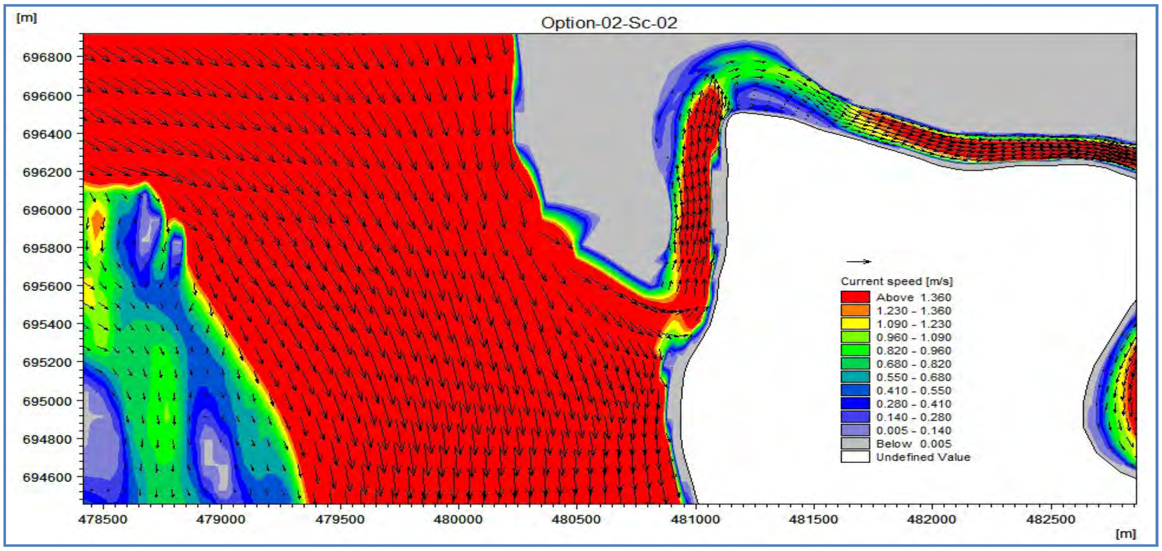
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Current speed [m/s]
Above 1.360
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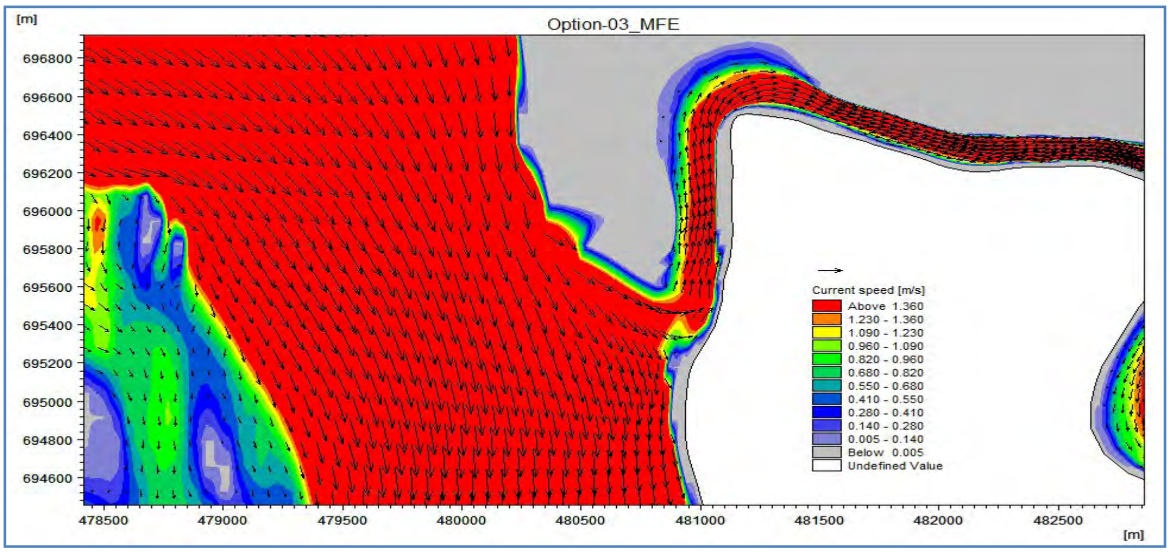
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Current speed [m/s]
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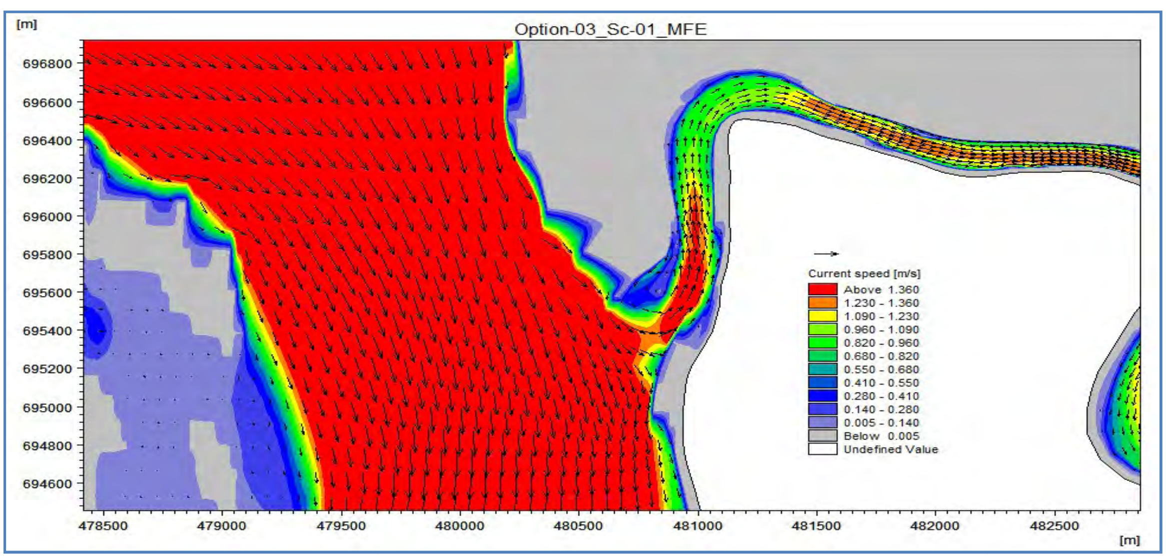
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Current speed [m/s]
Above 1.360
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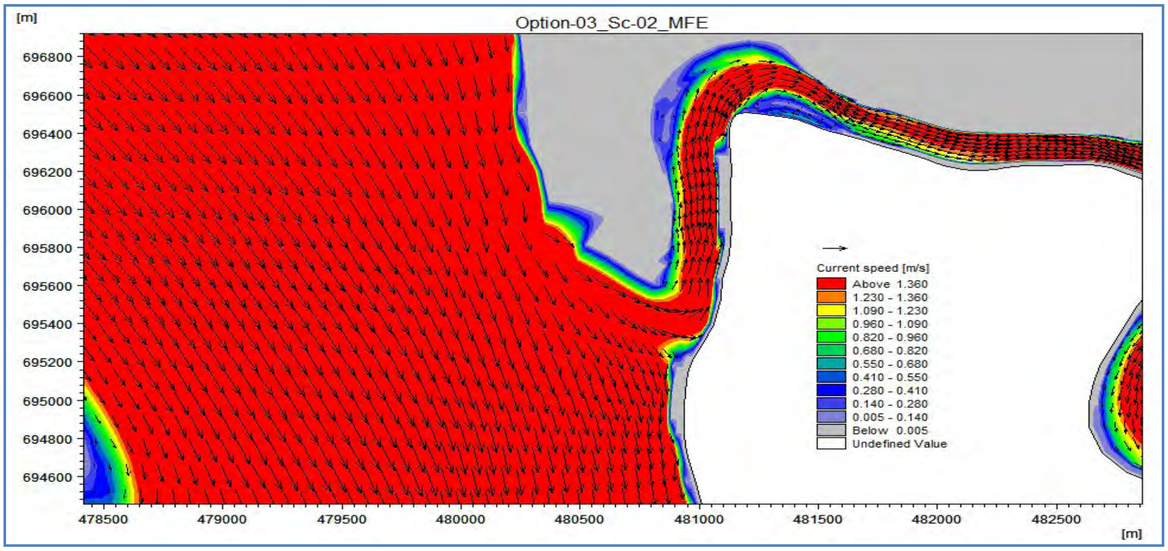
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[m]
Current speed [m/s]
Above 1.360
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0.960 - 1.090
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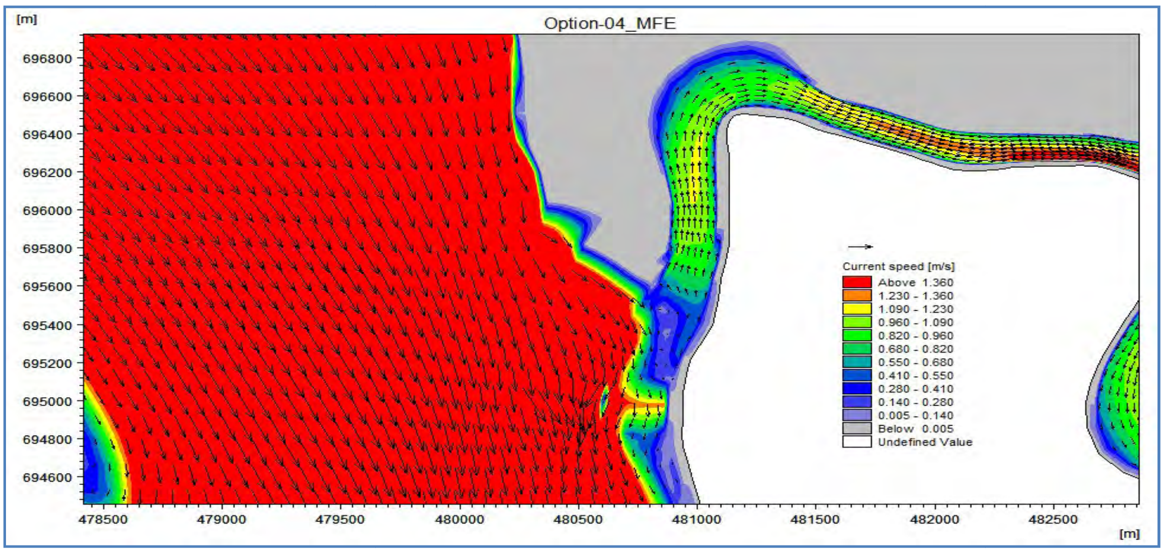
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[m]
Current speed [m/s]
Above 1.360
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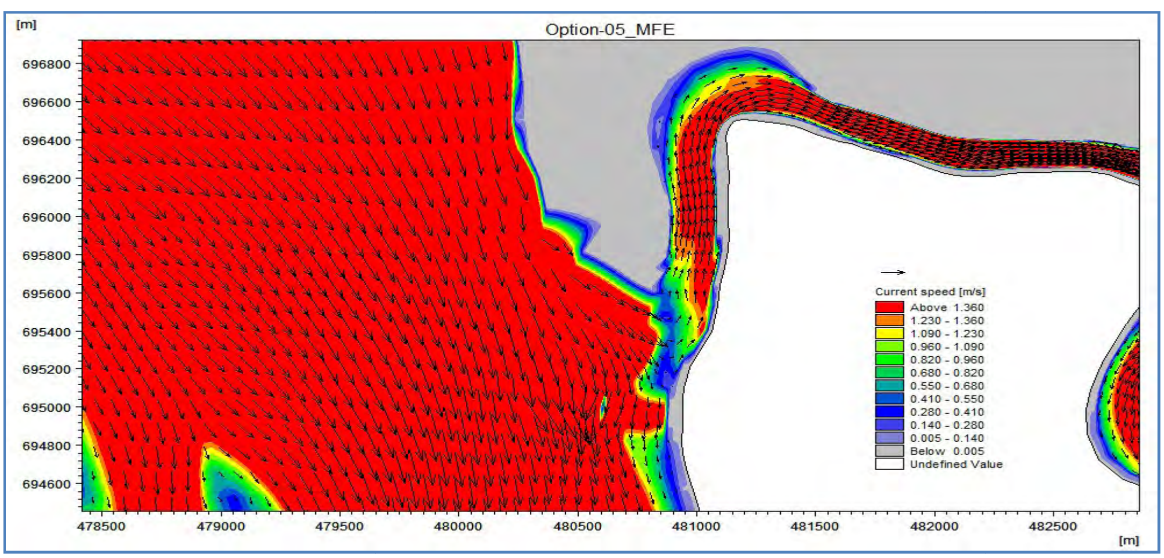
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[m]
Current speed [m/s]
Above 1.360
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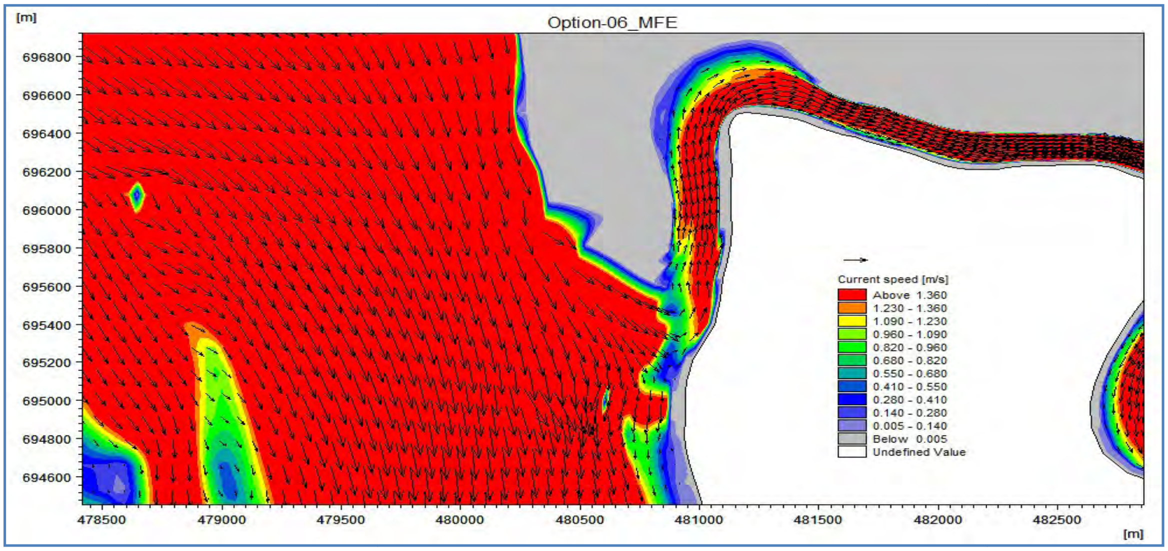
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[m]
Current speed [m/s]
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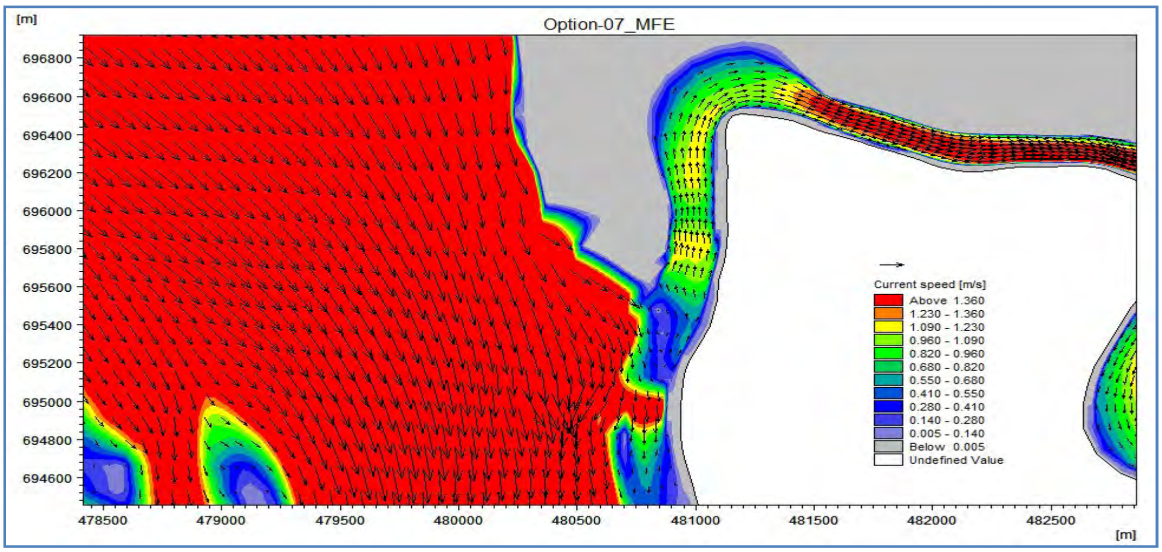
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[m]
Current speed [m/s]
Above 1.360
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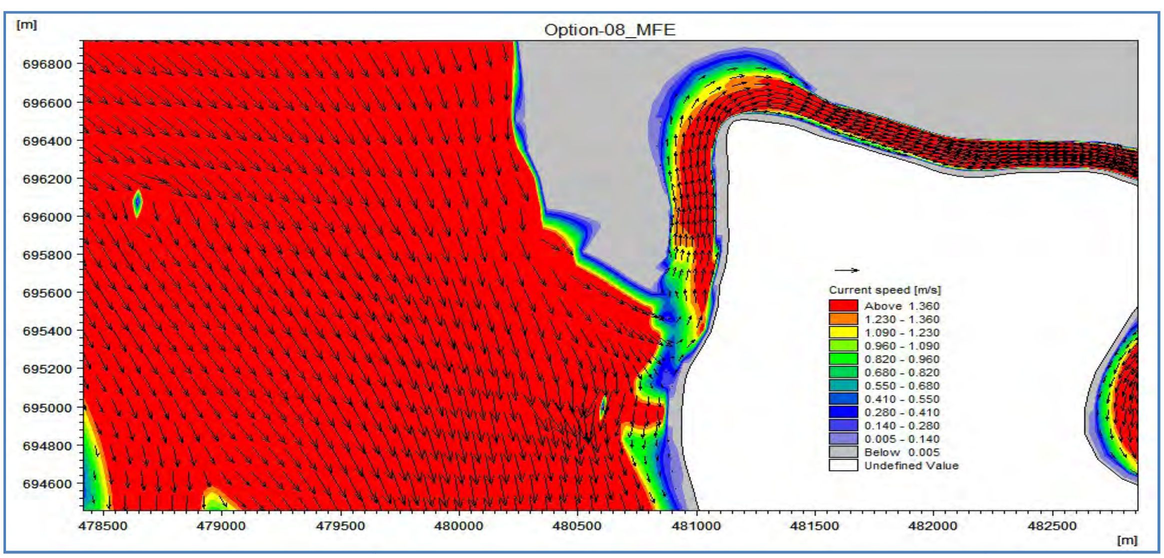
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[m]
Current speed [m/s]
Above 1.360
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1.090 - 1.230
0.960 - 1.090
0.820 - 0.960
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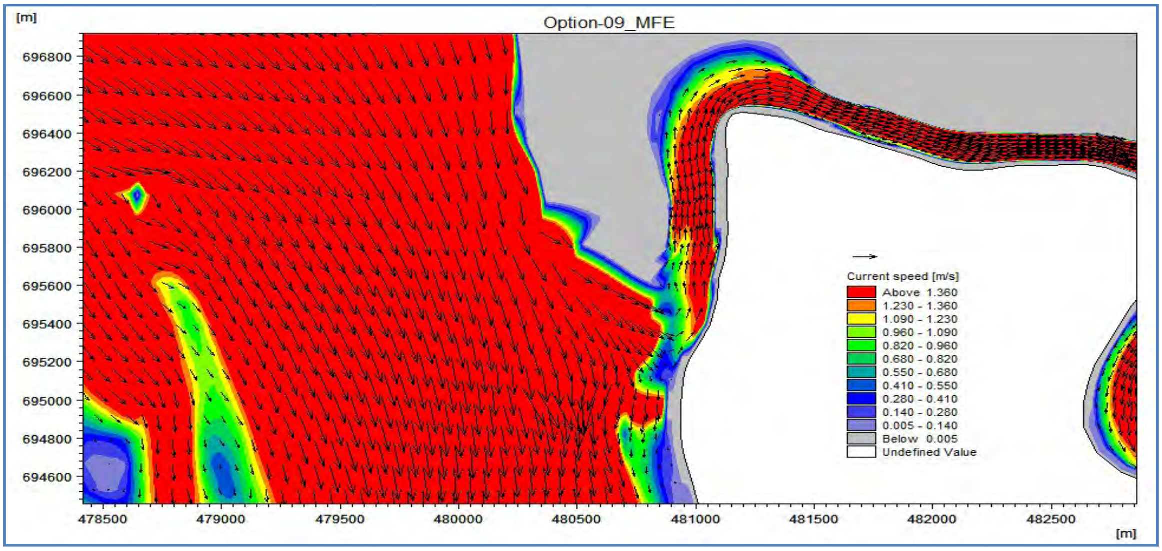
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[m]
Current speed [m/s]
Above 1.360
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1.090 - 1.230
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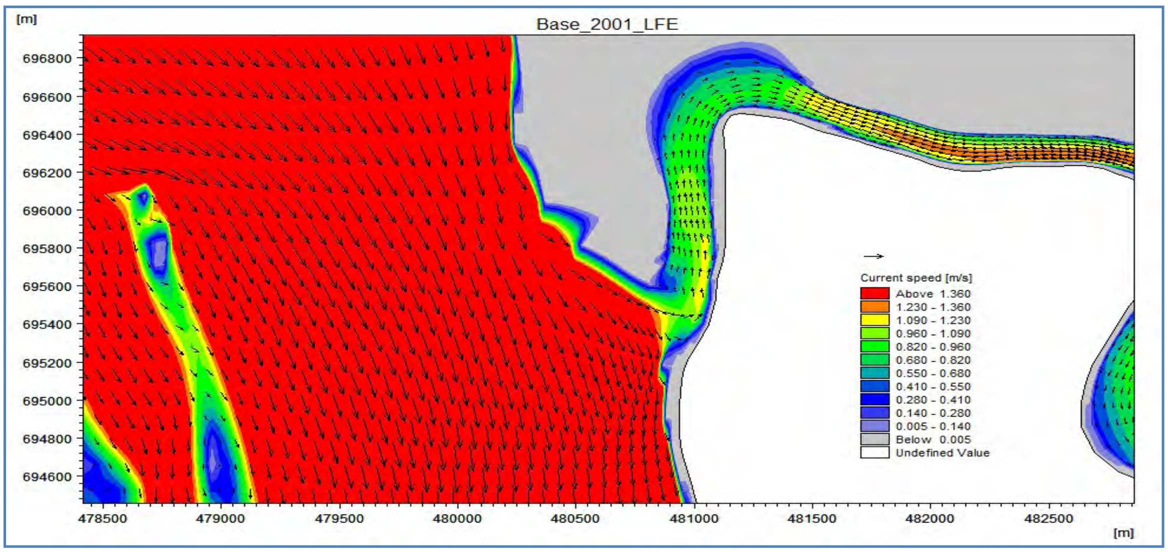
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Above 1.360
1.230 - 1.360
1.090 - 1.230
0.960 - 1.090
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0.680 - 0.820
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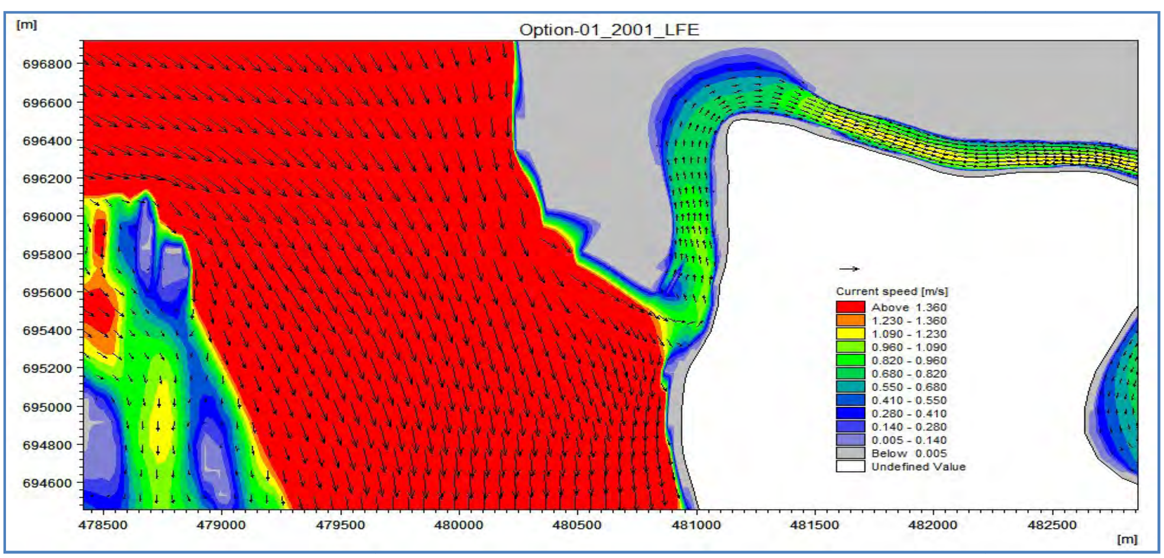
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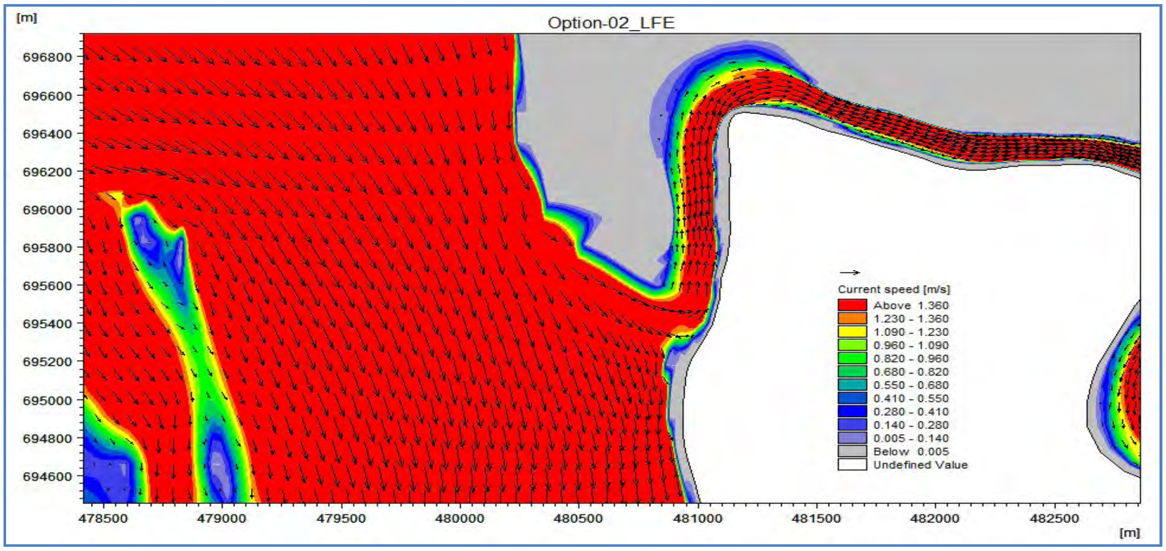
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[m]
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Above 1.360
1.230 - 1.360
1.090 - 1.230
0.960 - 1.090
0.820 - 0.960
0.680 - 0.820
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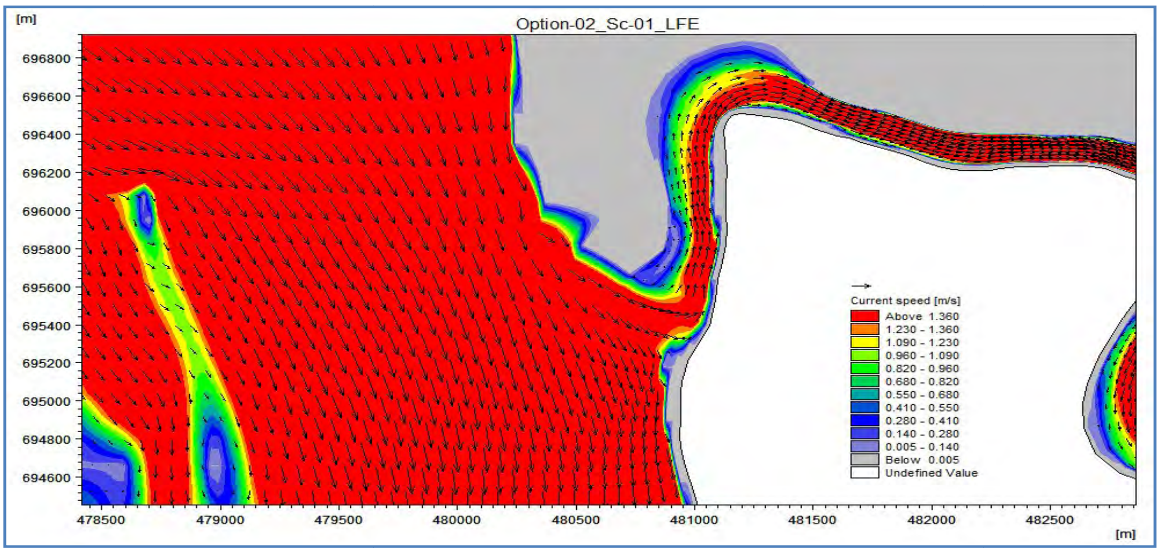
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[m]
Current speed [m/s]
Above 1.360
1.230 - 1.360
1.090 - 1.230
0.960 - 1.090
0.820 - 0.960
0.680 - 0.820
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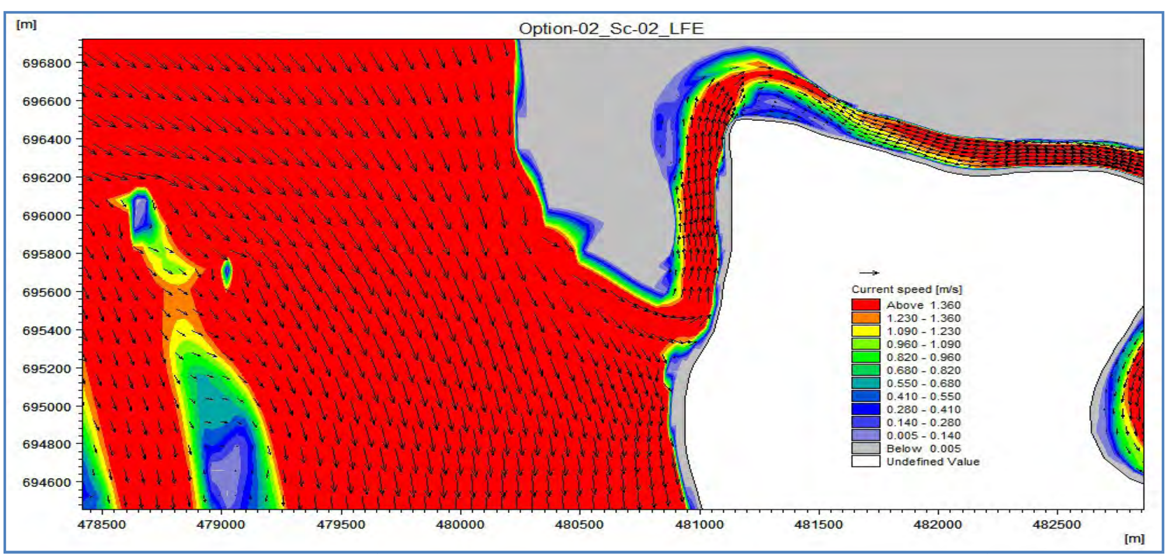
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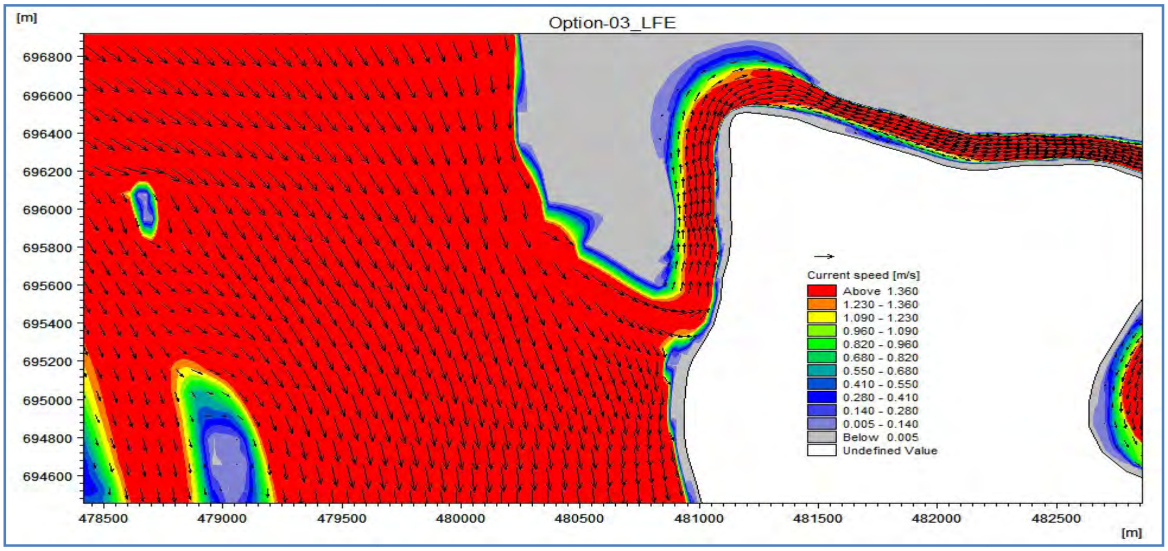

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1.230 - 1.360
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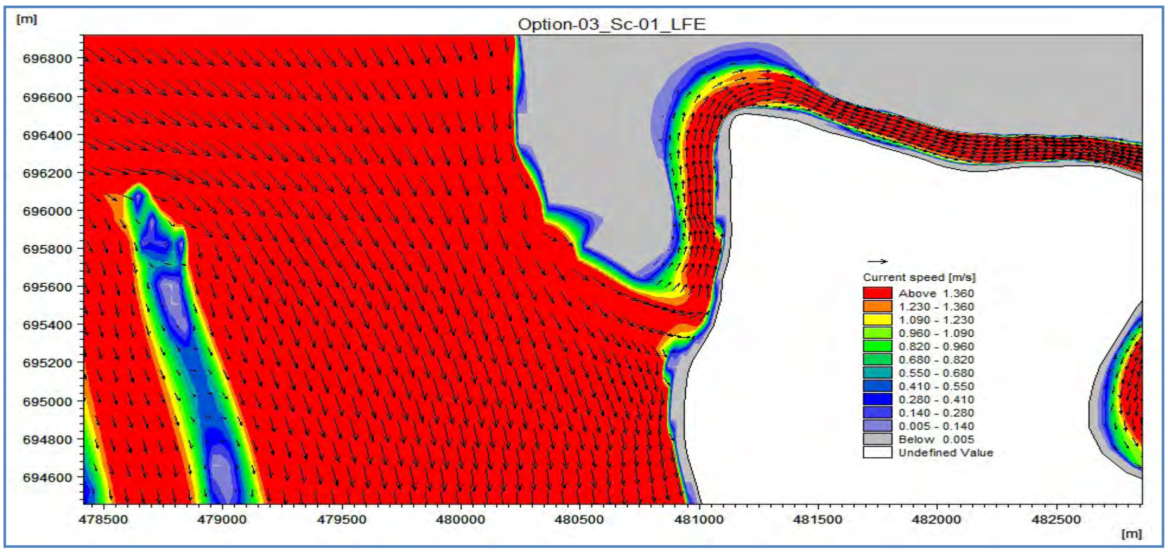

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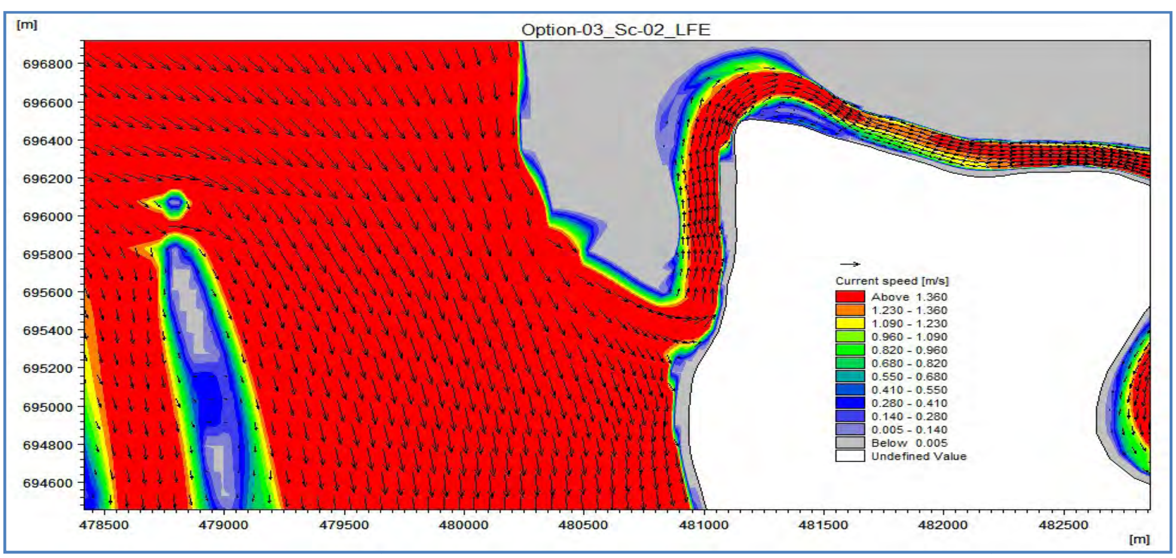

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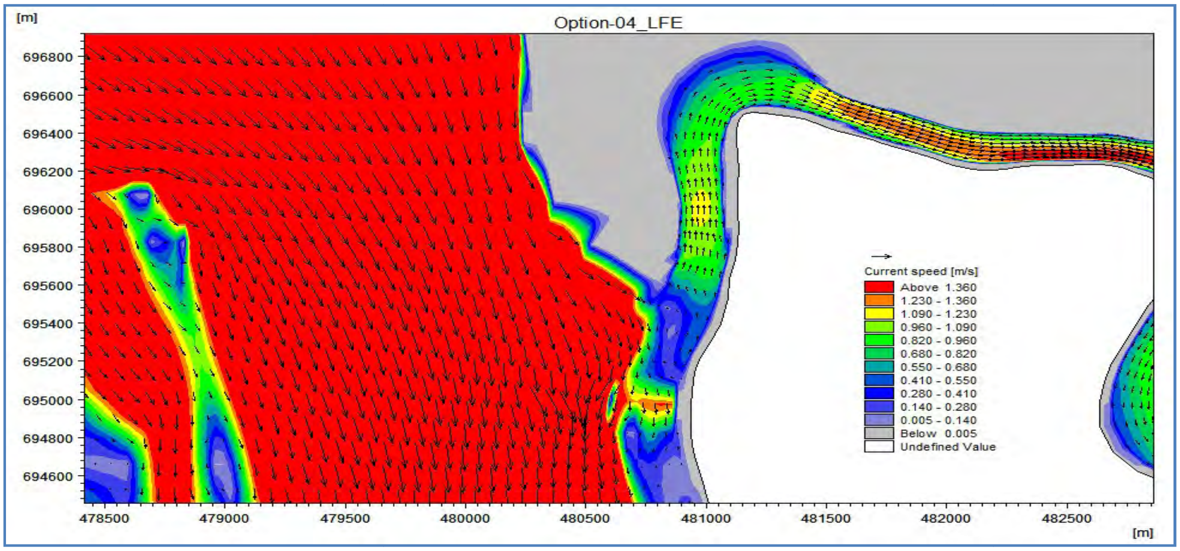
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[m]
Current speed [m/s]
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0.960 - 1.090
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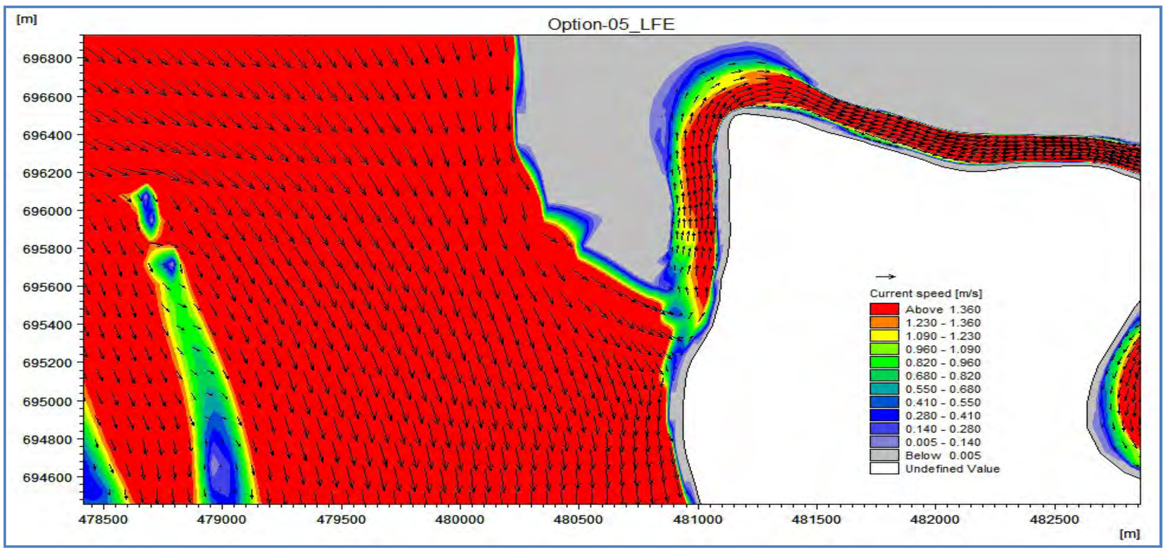
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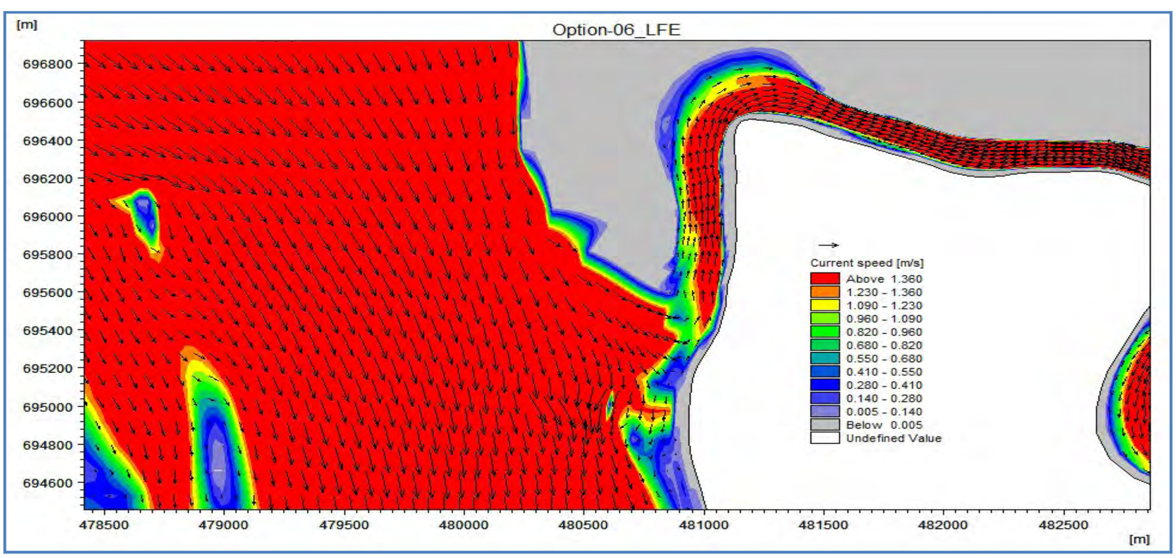
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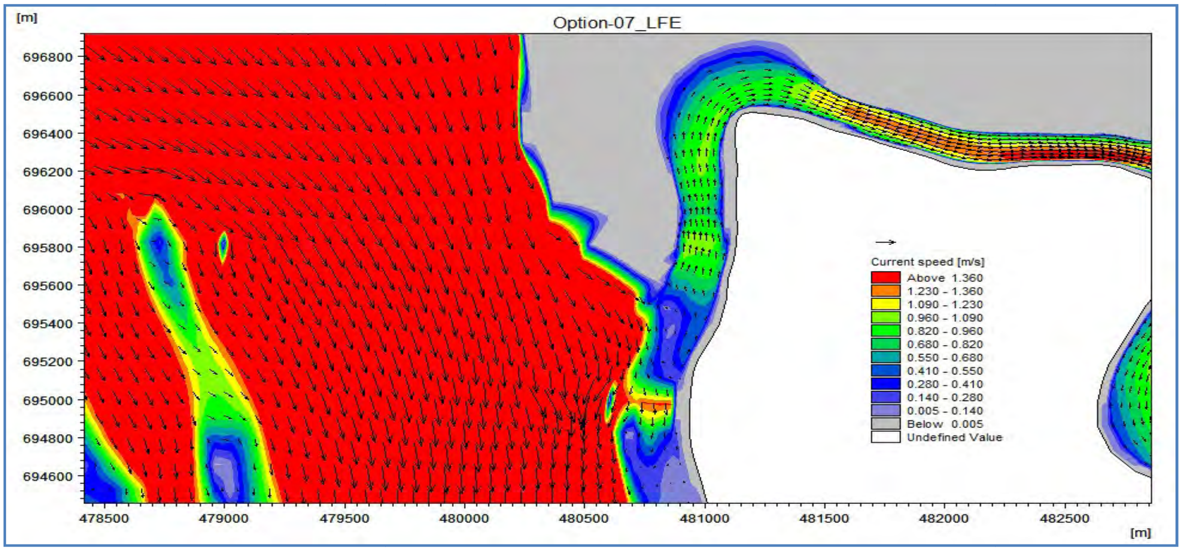
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Current speed [m/s]
Above 1.360
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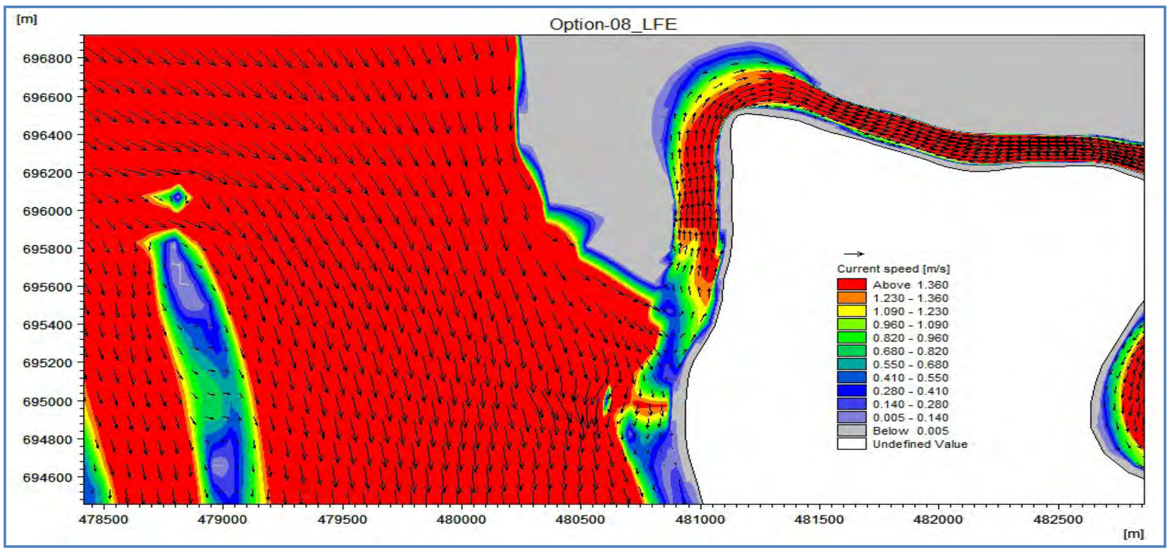
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[m]
Current speed [m/s]
Above 1.360
1.230 - 1.360
1.090 - 1.230
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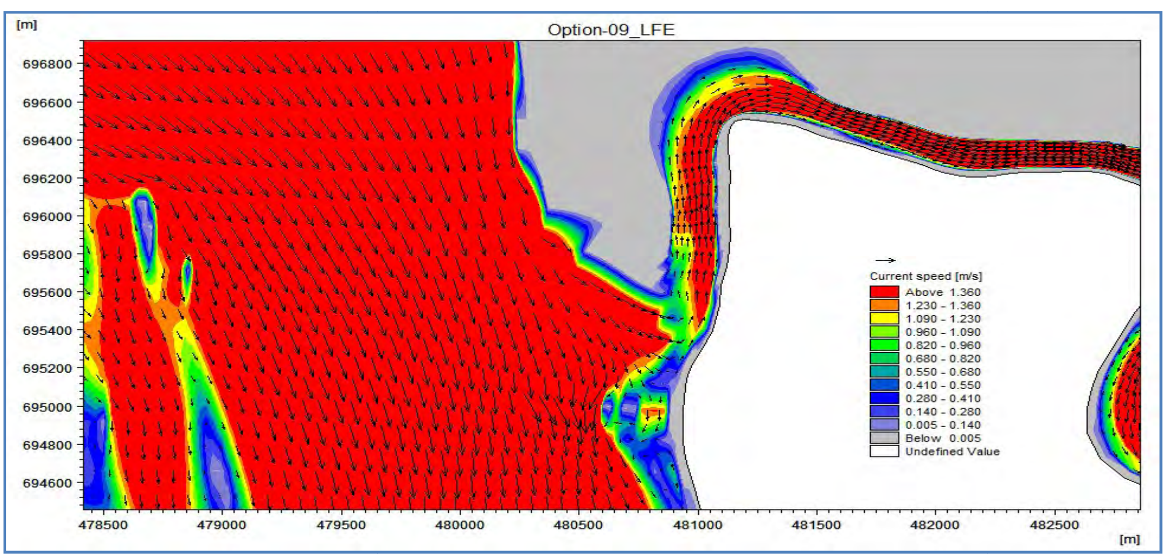
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[m]
Current speed [m/s]
Above 1.360
1.230 - 1.360
1.090 - 1.230
0.960 - 1.090
0.820 - 0.960
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0.550 - 0.680
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0.280 - 0.410
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Below 0.005
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APPENDIX-F

Weir Analysis

Broad Crested Weir Calculations - S.I. units
Minimum Weir Height and Flow Rate Over Weir

1. Calculation of Minimum Weir Height for Critical Flow over the Weir

Inputs	9.9109		**Calculations**		
Channel width, **B** =	160	m	Approach veloc., $\mathbf{V_1}$ =	0.81	m/s
Maximum anticipated flow rate, $\mathbf{Q_{max}}$ =	907.051	m^3/s	Critical depth, $\mathbf{y_c}$ =	1.49	m
			Critical veloc., $\mathbf{V_c}$ =	3.82	m/s
Approach depth of flow at Qmax, $\mathbf{y_1}$ =	7	m	Min. weir height, $\mathbf{P_{min}}$ =	4.81	m

2. Calculation of flow rate over weir for measured head, H, with $P \geq P_{min}$

Inputs			**Calculations**		
Head over weir, **H** =	4.85	m	Vol. Flow rate, **Q** =	1514.1	m^3/s

$$Q = 0.886\ L\ H^{3/2},$$