Char Development and Settlement Bridging Project (Phase IV Additional Finance) Bangladesh

Quality Control of Main Hydro-morphological Study of Meghna Estuary

Technical Report No. 5

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- **Ministry of Land (MoL)**
- **Local Government Engineering Department (LGED)**
- **Department of Public Health Engineering (DPHE)**
- **Forest Department (FD)**

CDSP-B(AF) Quality control analysis of main hydro-morphological study Meghna estuary

2080/U22331/A/FDW

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1 INTRODUCTION

Within the CDSP-I until CDSP-IV projects, living and agricultural areas were created on chars in the southern Meghna Delta (CDSP is an acronym for Char Development and Settlement Project). The CDSP-B(AF) project is a bridging phase between CDSP-IV and CDSP-V. Within this bridging project, among others two important topics are dealt with. Firstly, the future of eroding CDSP-IV chars is investigated. Secondly, the stability of potential new chars is explored for CDSP-V. Within the CDSP-B(AF) project, the main Hydro-Morphological Study of the Meghna Estuary was awarded by the Bangladesh Water Development Board (BWDB) to the Institute of Water Management (IWM) in Bangladesh.

Technical assistance in the project is provided by the TA-team, which is headed by MottMacDonald Euroconsult. The TA-team has requested Svašek Hydraulics to submit a proposal for the Quality Control Analysis of the main Hydro-Morphological Study of the Meghna Estuary performed by IWM, which was accepted.

1.1 Scope of work

The Scope of Work of this Quality Control Analysis follows the "Terms of Reference (ToR) for the Quality Control Analysis of the Main Hydro-morphological Study of the Meghna Estuary" of 26th August 2021 (Appendix A).

The main elements of the scope are:

- Review of reports and interim results of the main hydro-morphological study and discussions with the main study consultant on the study methodology, assumptions and results.
- Set-up and limited validation of Second Opinion model of the main hydro-morphological processes that determine the erosion and accretion patterns in the area and comparison of the results with the main study model output.
- Advise and recommendation on some of the conclusions and topics in the CDSP project.

This report fulfils these elements of the Quality Control Analysis. To do so, most information is obtained from two sources:

1. Intermediate meetings, presentations, and discussions between IWM, Svašek Hydraulics and the TA team.
2. The final reports delivered by IWM (under their study: Hydro morphological Model Study and Strategic Planning for Char Development in the Meghna Estuary under Char Development and Settlement Project Bridging (Additional Financing) (BWDB Part)), namely:
   - Volume I - Draft Final Report – March 2022
   - Volume II - STRATEGIC PLANNING FOR FUTURE DEVELOPMENT IN THE MEGHNA ESTUARY – March 2022

1.2 Content and outline of the report

This report follows the following structure. In Chapter 2, we run through all the items of the ToR. Those items related to the verification of the IWM methodology and results are immediately addressed in this chapter. To achieve high readability, the items in the ToR associated with the second opinion reference model are separately dealt with in Chapter 3. This report ends with conclusions and recommendations in Chapter 4. If in this report mentions "we" or "our", this refers to the consultants from Svašek Hydraulics.

2 QUALITY CONTROL VERIFICATION TASKS

2.1 Data analysis

2.1.1 Verification of analyses of water level measurements (spatial variation in tidal difference, mean sea level, phase of tidal components) and assessment of seasonal effects and changes over time.

IWM has performed a decent analysis of the water levels for both the dry period and the monsoon period and presented figures and statistics. The data analysis gives a good overview of the hydrodynamic conditions in the estuary but could still be improved in a number of ways:

- Performing a thorough data quality check before presenting statistics (e.g., sensor at Hatiya is dry at low water in monsoon -> thereby the minimum water level is too high, the tidal range too low and the mean water level too high. If this is not properly documented, the reader does not know, and models might be calibrated with erroneous measurements).
- Also, after calculating the statistics, some errors in the data can be found. For instance, it is unlikely that the highest mean water level occurs at Chairman Ghat, whereas there are several stations further upstream. This shows that most probably there is an error in the data of Chairman Ghat.
- More insight can be provided by not only looking at the total water level time-series but separating them in a mean, tidal and residual timeseries. Subsequently, tidal analysis can be applied to see spatial and seasonal variations in the amplitude and phase of the different tidal components (M2, S2, etc.). For an example see Figure 2-1.

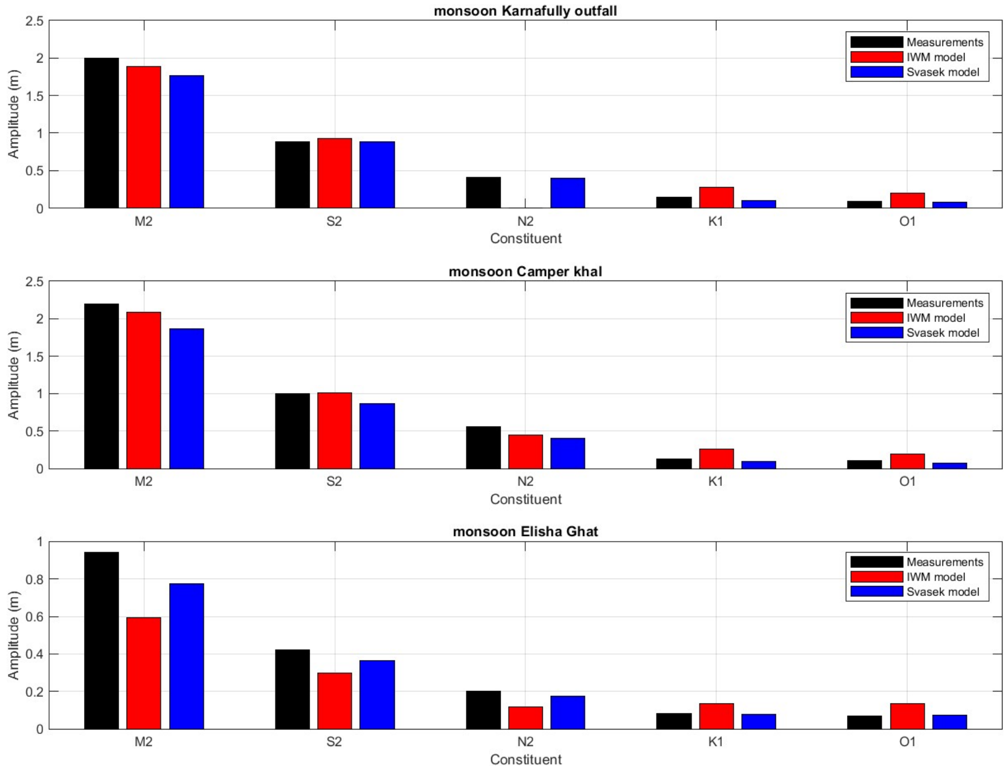


Figure 2-1: Amplitudes of M2, S2, N2, K1, and O1 tidal constituents for the measurements, IWM model and Svašek model at 3 different locations in the Meghna Estuary.

2.1.2 Verification of analyses of seabed bathymetry development, based on bathymetrical data.

IWM has done a great job in combining all available bathymetric and topographic data sources. They compared the bathymetries of 2000, 2010, and 2020 to show patterns of erosion and sedimentation.

However, for a highly dynamic area like the Meghna estuary, a period of 10 years is quite long. For a specific area, it could be that over the course of 10 years there is an erosional trend, although in the last 2 of these 10 years this has already shifted to sedimentation. Therefore, such long trends can give an incorrect representation of the present status. That is why we recommend in future to perform bathymetric surveys at a higher frequency (e.g., once every 2 or 3 years). This improves the understanding of the system and provides more insight into the present status of certain char areas.

Note: Figures 3.4 and 3.5 of Volume 1 of the IWM report are the same, suggesting that the erosion/sedimentation patterns are identical for 2000-2010 and 2010-2020, this must be a mistake.

2.1.3 Verification of satellite image analysis, check on bank shifting pattern, erosion vulnerability and morphological changes, bar and char movement, etc. Verification of the predicted bank line shifting of river and char.

Also, for the bankline changes based on the bathymetric surveys, the time resolution is very coarse (3 instances in 21 years), this makes it difficult to see whether these are gradual trends or that there have been many changes in between. Luckily, the satellite images analysis can help with this as these are more frequently available.

IWM has performed a neat analysis of the satellite images and determined the bank shifting pattern. However, some of the observed erosional/depositional trends might be a consequence of the local water level at the time of the satellite image. For new satellite imagery, the exact time stamp is also known. If the water level would be approximately known (from measurements or tidal model), it is possible to compensate for it, or at least only consider satellite images at high or low water. Alternatively, it would also be possible to process more than 1 image per year, this would give an indication of the range in bank lines for low and high water.

It is not completely clear how the yearly bankline shifting trend is computed from the different satellite images (probably distance between banklines in 2010 and 2020 divided by 10). It should be noted that in this highly dynamic area, trends are not always linear. In the analysis it is assumed that the previous trend will linearly continue for the next 5/10/15 years, which is quite a big assumption. In future, the trend could also accelerate, decelerate, or even turn around. Nevertheless, this is probably the best estimate possible with the available data and therefore this analysis gives the best indication for the future.

2.1.4 Verification of analyses of current velocity, discharge and sediment concentration measurements and assessments of seasonal effects and relation with seabed developments and water level gradients.

- No separate analysis of the current velocities is found in the documentation of IWM. The velocities are, however, used to determine the discharges. For a next project, it would also be helpful to show the current velocities, as these might explain mismatches in measured and modelled discharges.
- Discharges are presented for the monsoon and dry season. It is not clear how measurements of depth and velocities are processed to obtain the discharges. Only the minimum and maximum discharges is presented for each location, whereas the mean discharge is also an important parameter.
- A nice overview of the sediment concentrations is provided. Similarly as with the discharges, it would help to not only provide the minimum and maximum sediment

concentration but also the mean sediment concentration. Regarding the grain size, now the d50 is determined and based on this number conclusions are drawn on the type of sediment. It would give more insight to present grain size distributions, than it is possible to see for each location how much sand, silt, mud is present.

- It is good that also salinity numbers are presented. To give even more insight it is recommended to add dates and times when the salinity was measured and to present a range of salinity values. Those are expected to show significant variation with the season and with the tidal phase. The high spatial variation in maximum salinity numbers may be caused by seasonal effects and are not expected to be present simultaneously.

2.2 Verification of model calibration of main hydro-morphological study

2.2.1 Verification of main model calibration results and conclusion on quality of this model.

- Many efforts and discussions amongst IWM and Svašek have been devoted to the hydrodynamic calibration of the model. Eventually, satisfactory hydrodynamic calibration results were achieved in which the tidal range, tidal phase and mean water levels are reasonably well predicted at all water level stations. At the more upstream locations of the Meghna River, the mismatch between modelled and measured water levels is slightly higher. But luckily, the match is good at the locations near the CDSP char areas. To improve the calibration results further in the future, ways forward are improving the bathymetry, friction fields and including fresh-salt water interactions.
- The hydrodynamic model (built in 2021 using recent bathymetry) is validated with measurement data from 2009. This is remarkable as the bathymetry, grid and friction fields have changed since 2009. These results seem more like a validation/verification of the 2009 model than a validation of the 2021 model.
- Another aspect which is doubtful, is that the settings for the calibrated model are different than the settings for the morphological simulations. For instance, there is a different way of imposing the tide and discharge. Also, the addition of the seasonally dependant water level, which proved to be important to get the modelled water level correct in the calibration phase, seems to be not included in the morphological simulations. Formally, it would have been good to also run the calibration period with the settings being used for the morphological simulations to see the model's accuracy under these settings.
- IWM also performed a morphodynamic calibration, where the positive, negative and net bottom changes are evaluated for 7 different areas of the Meghna delta. We agree on the conclusion of IWM on this part that the trends of the model are quite acceptable, definitely given the time restraint IWM had and the limited field data. Nevertheless, it should be noted that the model shows a tendency where erosion is overestimated in the channels and sedimentation is overestimated at the shoals. This is also reflected in Table 3.3 of IWM's Volume 1 report, where distinctions between modelled and measured bottom changes can be off by a factor 5. In conclusion, the morphodynamic model captures well the general qualitative trends. However, quantitatively results should be treated with care as there is a significant range of uncertainty.

2.2.2 Verification of the model is built on the specified grid spacing (2-5km in the open sea and 100-300m in the dynamic char areas).

The model is built on the specified grid spacing. The grid cells (and also friction fields) are aligned with the present channel locations. This might lead to a preferential current flow in the direction of the “former” channel even after morphological developments. This might partially explain why the existing channels tend to get deeper and deeper. For a future study it would be interesting and insightful to apply a completely unstructured grid (triangles) in the model to see what the difference is with the presently used grid.

2.2.3 Verification of the model used the latest bathymetry where it is available.

The model uses the latest and most up to date bathymetry.

2.2.4 Verification the model stability and the depth average flows are satisfactory.

Although we have not seen proof that the model simulations are unconditionally stable, IWM stated in progress meetings that there were no stability issues. Therefore, we believe this is correct. The same holds for the depth averaged flows, as far as we have seen them in intermediate presentations and reports, these look reasonable.

2.2.5 Verification of tides, waves, and storm surge levels assessment.

- As the tides are dominantly available in the total water level timeseries, these are dealt with in great detail throughout the intermediate meetings and also in the report.
- No assessment of waves is seen.
- Quite an extensive table with storm surge levels is presented (Table 4.1 of Volume 1 report). It is, however, not fully clear how these numbers are derived. Also, it is unclear what the first column in this table is referring to (with header 1970).

2.2.6 Verification of the climate change sensibility analysis-river discharge, sea level rise and wave climate/ cyclone frequency.

No real climate change sensibility analysis of different river discharges, sea level rise scenarios, wave climate and/or cyclone frequency is found in the reports. As mentioned, waves are not included, so nor is the sensitivity. The river discharge is applied in the calibration, validation and morphodynamic simulations, but as far as we know no sensitivity is performed. Again, as far as we know, the effect of cyclones and sea level rise is only included in the storm surge simulations and not in the morphodynamic simulations.

Given the complexity of other parts of the project we understand that this had lower priority. Nevertheless, it would be good to perform these analyses in the future as this will increase understanding of the system if the river discharge, sea level rise or cyclone frequency turns out to be much higher or lower.

2.2.7 Verification of availability of option to intervene online with wave model

No option is seen to intervene online with a wave model. However, as IWM uses the Delft3D modelling software, it would in theory be possible to include waves in the model. As far as we know, this has not been done.

2.2.8 Verification of model log and confirmation on all modelling assumptions, limitations, input parameters are recorded adequately.

No model log has been shared by IWM. There have been extensive discussions on the modelling assumptions, limitations, and parameters. As a result of these discussions, the model results significantly improved. The eventual reporting on the model settings is quite brief and thereby not always very clear.

2.2.9 Set-up of separate 2DH hydro-morphodynamical model to verify the results of the model of the main study. Focus points will be the water level differences and phase lags between the main Meghna tidal channel (between CDSP area and Hatiya Island) and the eastern channel (between Sandwip Island and the Chattogram mainland).

Svašek Hydraulics has set up a reference model with our in-house hydro-morphodynamic modelling software FINEL. A description of the model set-up and results is presented in Chapter 3.2 of this report.

2.2.10 Indicative hindcast calculation of the historical channel developments in this area and comparison with observed changes and outcomes of the model of the main study.

Using the same model as mentioned at the previous item, some indicative morphodynamic simulations are performed. Unfortunately, only the most recent (2020-2021) bathymetry was available for us. Therefore, we were not able to perform hindcast simulations, but we did run a number of morphodynamic forecast simulation predicting future scenarios. The set-up and results are presented in Chapter 3.3.

2.3 Assessment of future development

2.3.1 Developments without human intervention (definition of “safe” line in existing chars).

Figures 3-39 and 4-2 of the Volume 1 report (to our understanding these are the same) show the evolution of the 2020 bathymetry after 5, 10 and 15. These results show the same pattern as was observed during the calibration: an excessive deepening of the main channels. They also show ongoing erosion for the CDSP Char Area (CDSP-IV chars). Provided the uncertainties mentioned in Section 2.2.1, this looks like a reasonable scenario.

2.3.2 Verification of impact assessment (in main study) of the implementation of various cross dams and any other interventions in the Estuary including anthropogenic changes/ activities that may be considered.

The impact of two cross dam scenarios is investigated by IWM:

- A cross-dam between Jahazer Char and Char Nangulia (in Option-2)
- A cross-dam between Jahazer Char and Char Nangulia and a cross-dam between Urir Char and Noakhali (in Option-3).

The impact of both options is nicely simulated and visualized. Both options lead to reduced flow velocities and thus reduced erosion at the south-east side of Noler Char and Char Nanguliar, which is positive for the CDSP-IV areas. It should be noted that due to these closures, the river will need to find another way. Areas of risk are the east side of Sandwip Island, where a significant deepening is observed. Although not predicted by the model, there is also a risk that the channel between Jahazer Char and Sandwip Island will erode. It may be considered to also close this connection to avoid unexpected developments there.

The cross dam between Jahazer Char and Char Nanguliar is protected in the vicinity of the tidal meeting point to minimize the current velocities during the closure operation. It should be noted that the position of the tidal meeting point in this area is not fixed, but it may vary during the spring-neap cycle of the tide and over the seasons. This may complicate finding a closure location without excessive current velocities during critical phases of the closure.

Additionally, also the effect of a bank protection along the main Meghna River branch along the west bank of Noler Char is studied. Such bank protection would stabilize the riverbank here and would certainly improve the stability of the chars behind.

2.3.3 Verification of long-term forecast of the morphological developments for 5,10, 15, and 20 years.

We do believe that the long-term morphological forecast trends look reasonable and the prediction is state-of-the-art. The rate of erosion and sedimentation is more uncertain. Therefore, it is not entirely sure whether the scenario of e.g., 15 years will happen after 10, 15, or 20 years. This is just a consequence of long-term morphodynamic modelling in general. The morphological development for 20 years is not shown and is erroneously indicated in the title of the figure.

2.3.4 Participation in the discussions on effectiveness of various interventions and which interventions are to be considered in the main study.

Svašek Hydraulics actively participated in the discussions on the effectiveness of various interventions. We believe that it is good to aim for “safe lines” for 15 or 20 years, but at minimum the 10-year line. This is because it takes some time before the new dikes are constructed and then the remaining lifetime is still reasonable. Furthermore, as there is quite some uncertainty involved with the construction of the cross-dams, we advise to use the interventions without cross-dams as a starting point. If it would work to construct the cross-dams this would be an added value after all.

Finally, the protective works along Boyer Char, Noler Char and Nanguliar Char seems to be a very effective solution. The construction should be carefully planned though, as erosion will probably continue as long as the full protection is not completed. If this is not done carefully, there is a risk that parts that are already completed will collapse due to erosion of other sections where the protection is not yet in place.

2.4 Recommendations on long term monitoring and analysis program of the Meghna Estuary

2.4.1 Participation in the discussions on the development of a long-term monitoring and development assessment programme of the Meghna Estuary taking into account available human and financial resources.

As known and mentioned by IWM several times, the Meghna Estuary is a dynamic and constantly changing environment. What added to the complexity of this project is that the previous bathymetries were from 11 years ago, a timespan which is too long for such a dynamic system. To increase system understanding and to detect morphological trends in an early stage it is instrumental to do bathymetrical surveys at a shorter time interval (for instance every 2/3 years).

During this CDSP-B project, a high-quality dataset is obtained. Models are now tuned towards this single dataset. However, it is not known whether a certain behaviour is just coincidental for one specific measurement period or that it happens every season. Also, it is not known whether a certain unexpected higher mean water level is reality or an error in the measurement. Therefore, it would be very good to repeat such water-level and discharge measurements on a yearly or 2-yearly basis. In this way, the model can be tuned such that it works for multiple seasons and years and thereby its predictability for the upcoming years will continuously improve in future. The present data collection and modelling effort should be considered as the starting point for developing reliable tools for predicting the future development of the lower Meghna estuary and the stability of new and existing land.

2.4.2 Verification of deliverables specified in the original scope for IWM.

IWM delivered two extensive reports (Volumes I and II of the draft final report). These reports demonstrate the large amount of work done by IWM and as can be read from the previous items discussed in this Chapter, these reports fulfil for a large part the scope of IWM's study. There where this is not fulfilled, for instance including wave assessments and modelling, we understand the decision to focus on other, more important aspects. The clarity of the reporting could definitely be improved. There are still many typos in the report, it is not always clear what certain figures show, and methodologies are sometimes only very briefly explained.

2.5 Recommendations to TA Team of CDSP-B (AF)

2.5.1 On the "safe" line to be defined in the chars of CDSP I-IV for the implementation of high-cost infrastructure (sluices and embankments).

We can agree on the findings by IWM to define the safe line at the predicted 10-year contour. Ideally, we would prefer to have guarantees for a longer time span (e.g., 15 or 20 years), but we understand that than more than 70% of the CDSP-IV area is not behind the new embankments. Hopefully, by including the bank protection works at the banks of Boyer Char and Char Nangulia, the high-cost infrastructure is not reached within the anticipated 10 years but has a longer lifetime.

2.5.2 On the locations that may be considered for new Char Development and Settlement Project areas.

Here we have focused on the hydrodynamic and satellite analysis of the new locations considered for new CDSP areas. We did not take into account the socio-economic aspects as these are out of our scope. Table 8-19 of Volume I of the Final Report provides a list with potential chars for future development in the Meghna estuary. The satellite images analysis performed in Chapter 8 by IWM to obtain the erosion and sedimentation of the chars is not very in-depth and thereby involves high uncertainty. This is because there is a large difference in waterline between high and low water for these mildly sloped and low-lying chars. By taking a single image per 5 years not knowing whether the image was taken at high or low water, a large part of the water line differences might be attributed to erosion or sedimentation, whereas in reality it is just caused by high or low water level. Therefore, it is recommended to analyse many more satellite images per year. This is easily possible with the Sentinel 2 satellites providing free satellite images every 5 days since 2017. We compiled a number of animated satellite movies of the past 5 years; these are delivered alongside this report. Visually analysing these movies provides additional insights about the proposed 12 new chars, which are summarized in Table 2-1. It is advised in the next feasibility study to extend this analysis to better determine how much of the chars are stable and above high water level. For the next phase of the feasibility study, it is also advised to do a proper bathymetric survey. This provides insight about how much of the char area is above high spring tide water level and how much is above storm surge level.

Table 2-1: Insights from Sentinel2 satellite analysis of the proposed new char areas.

Char Moksumul Hakim	Char Moksumul Hakim seems stable, although the south side shows the same erosion as observed at Char Nangulia.
Char Kolatoli	Chars Kolatoli, Char Mozzammel and Dhal Char (CDSP-V) seem stable. Although the channels between the three chars seem to grow over the past 6 years. This should be monitored and taken into account for the lay-out of these chars.
Char Mozzammel	
Dhal Char (CDSP-V)	
Domer Char	A significant part of the east and west side of Domer Char is low-lying and seems to drown with high water.
Nijhuim Djip	Nijhuim Djip seems stable.
Andhar Char	East side of Andhar Char is low-lying and floods with high waters.
Char Kukri Mukri	Char Kukri Mukri seems stable.
Char Lakshmi	Char Lakshmi seems stable.
Char Nizam	The southern central part of Char Nizam is low-lying and floods with high waters.
Char Sakuchi	The eastern and southern part of Char Sakuchi are low-lying and flood with high water levels. The eastern side floods more frequently than the southern side.
Dhal Char	The northern part of Dhal Char eroded more than 1km over the past 5 years. The western part of Dhal Char is low-lying and floods with high water.

3 REFERENCE MODELLING BY SVASEK HYDRAULICS

3.1 Introduction

A separate hydro-morphodynamical FINEL model is setup to verify the results of the IWM model and to increase system understanding of the Meghna Estuary. This chapter describes the results of this (in-house) FINEL model, separated in the hydrodynamic and morphodynamic modelling. Setup of these models is described in Appendices B and C.

3.2 Hydrodynamic modelling

The observed water levels at Karnafully outfall, Camper Khal and Elisha Ghat are compared with the water levels obtained by the FINEL (Svašek) and Delft3D FM (IWM) models. The locations are shown in Figure 3-1. Measurements are available in both the monsoon season (September 2020) and dry season (January 2021). The measured and modelled water levels for these two periods are shown in Figure 3-2, Figure 3-3 and Figure 3-4 for respectively Karnafully outfall, Camper Khal and Elisha Ghat.

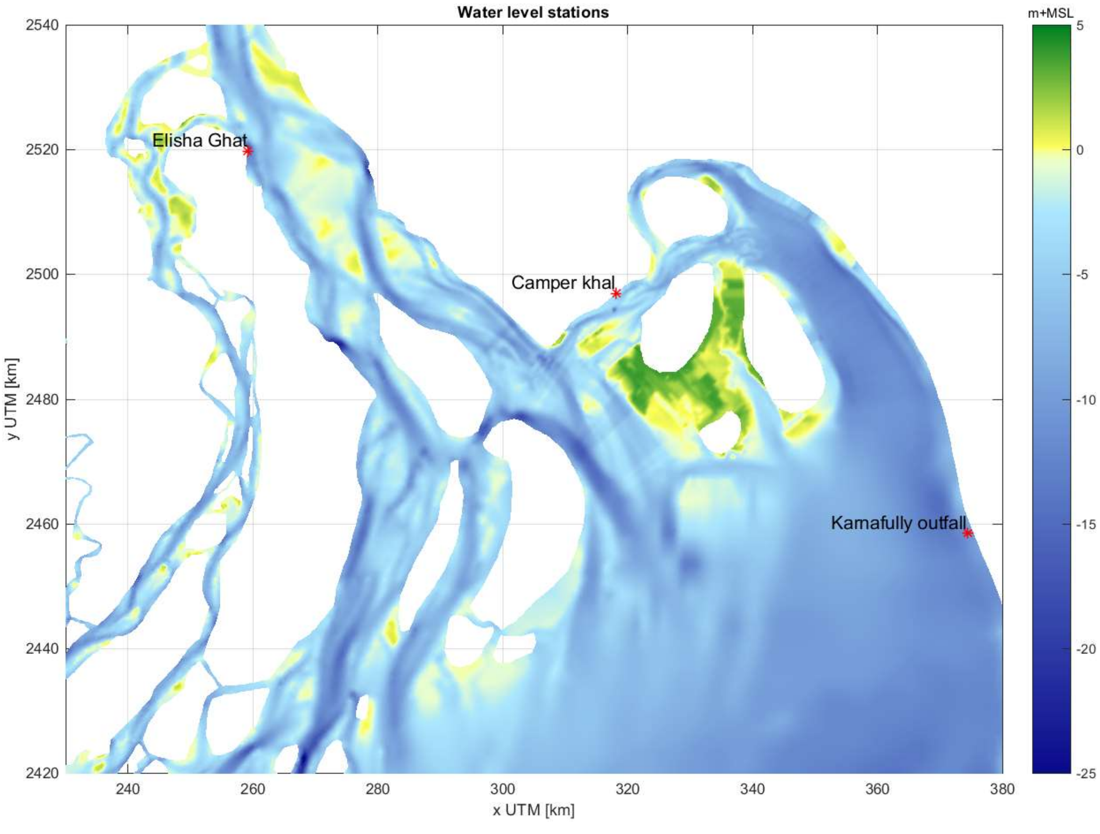


Figure 3-1: Locations of the compared water level stations.

In general, both models show similar results which are considered state of the art. There are only some minor deviations:

- At Karnafully outfall, the water level amplitude obtained by FINEL is slightly underestimated during the monsoon season and overestimated during the dry season.
- The IWM model results in a slight phase shift during the monsoon season at Camper Khal and both models are too high at low water during monsoon.

- At Elisha Ghat both models, and especially the IWM model, overestimate the low water levels. This can partially be attributed to bathymetric uncertainties at the bifurcation of the Tetulia River and the Lower Meghna River.

Future steps to increase model performance would be to further improve the bathymetric charts and to further optimize the bottom friction of the different river branches. Another potential model improvement could be to include the effect of interactions between salt water (from the sea) and fresh water (from the rivers).

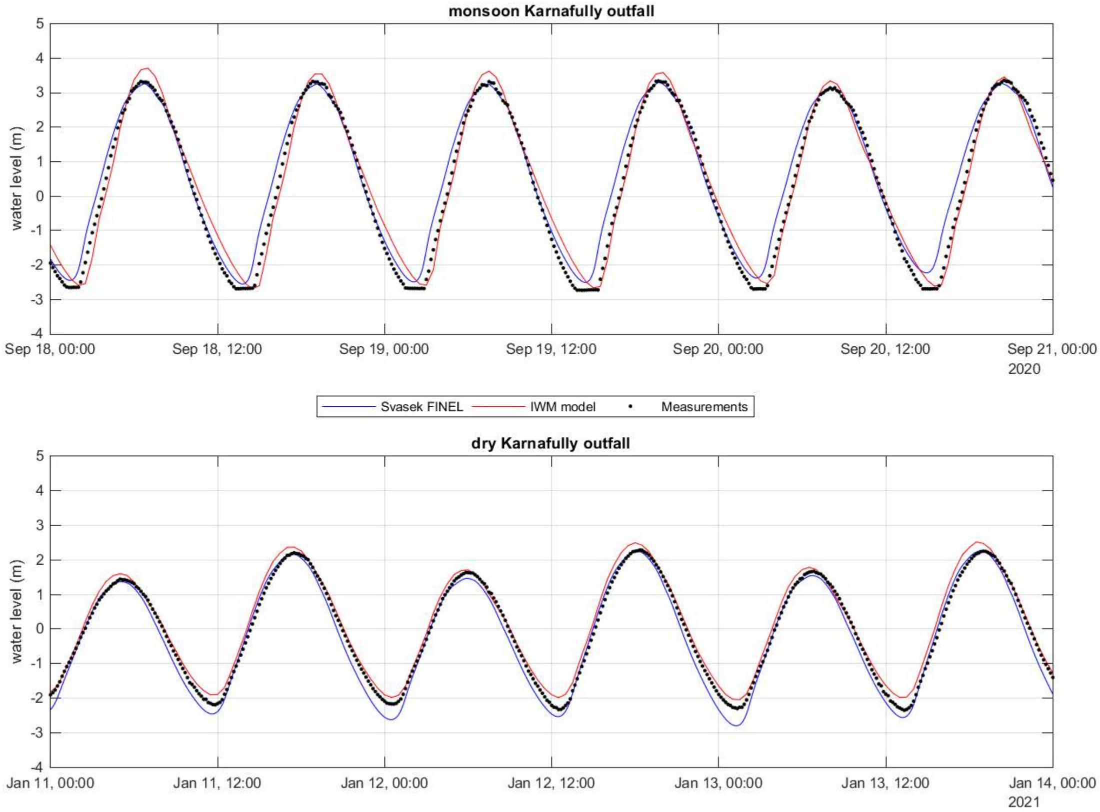


Figure 3-2: Water levels at Karnafully outfall in the monsoon season (top panel) and dry season (bottom panel).

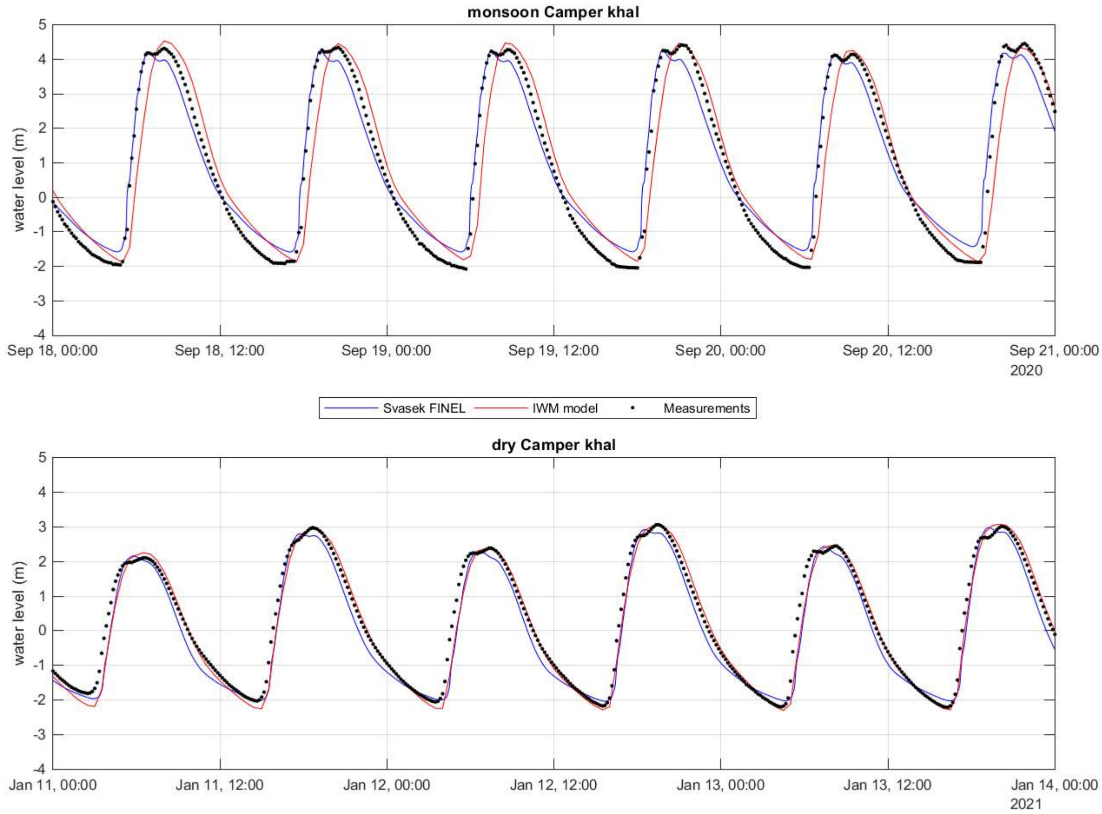


Figure 3-3: Water levels at Camper khal in the monsoon season (top panel) and dry season (bottom panel).

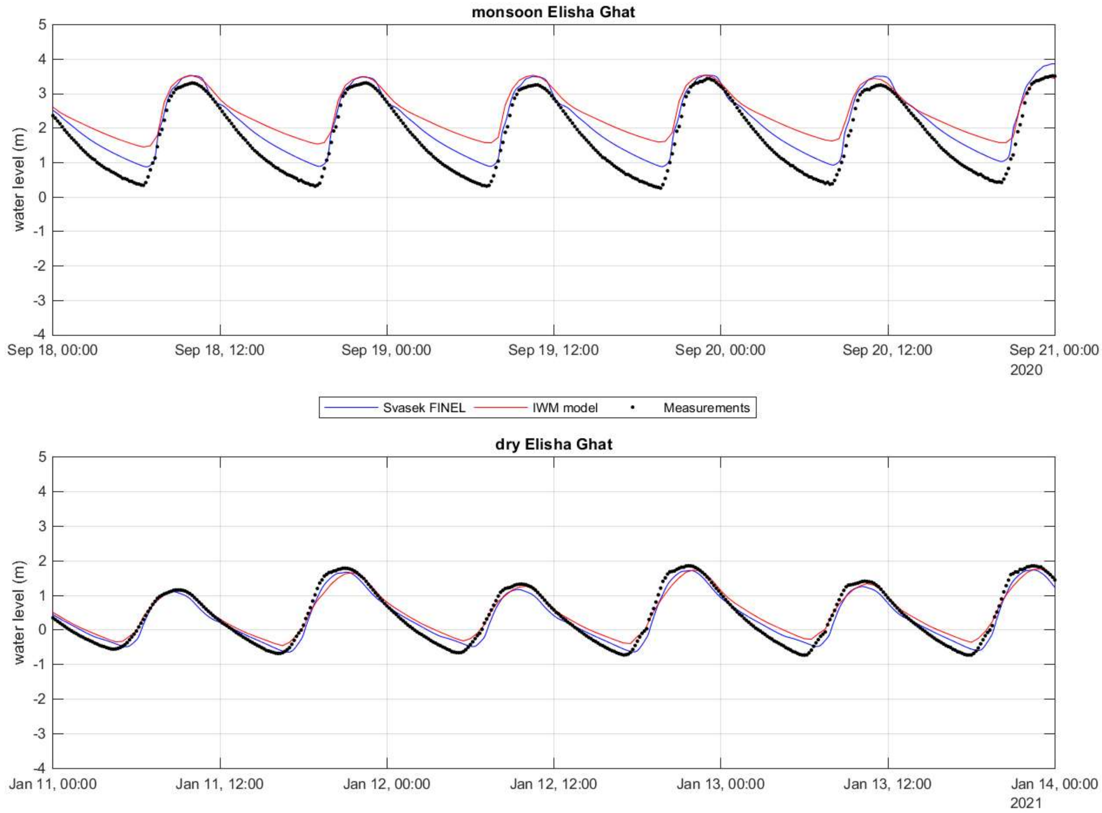


Figure 3-4: Water levels at Elisha Ghat in the monsoon season (top panel) and dry season (bottom panel).

3.3 Morphodynamic modelling

A morphodynamic FINEL model is setup for an indicative simulation period of 10 years. This Section mainly shows the model results, for a description of model settings, see Appendix C. The initial bathymetry near the CDSP area is shown in Figure 3-5, which is based on bathymetric data obtained from IWM (see Appendix B.4). No topographic data is available for the CDSP area. Estimated levels are manually included in the model.

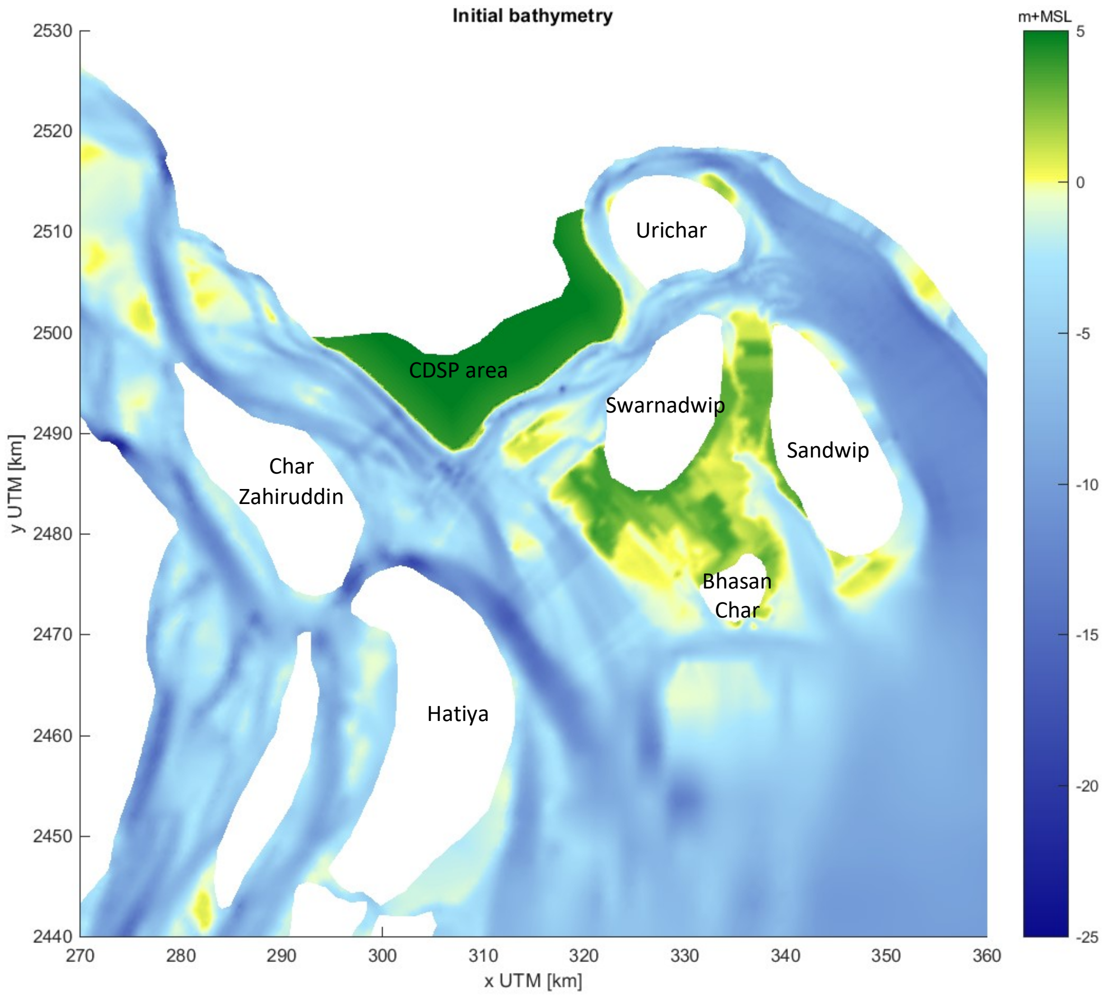
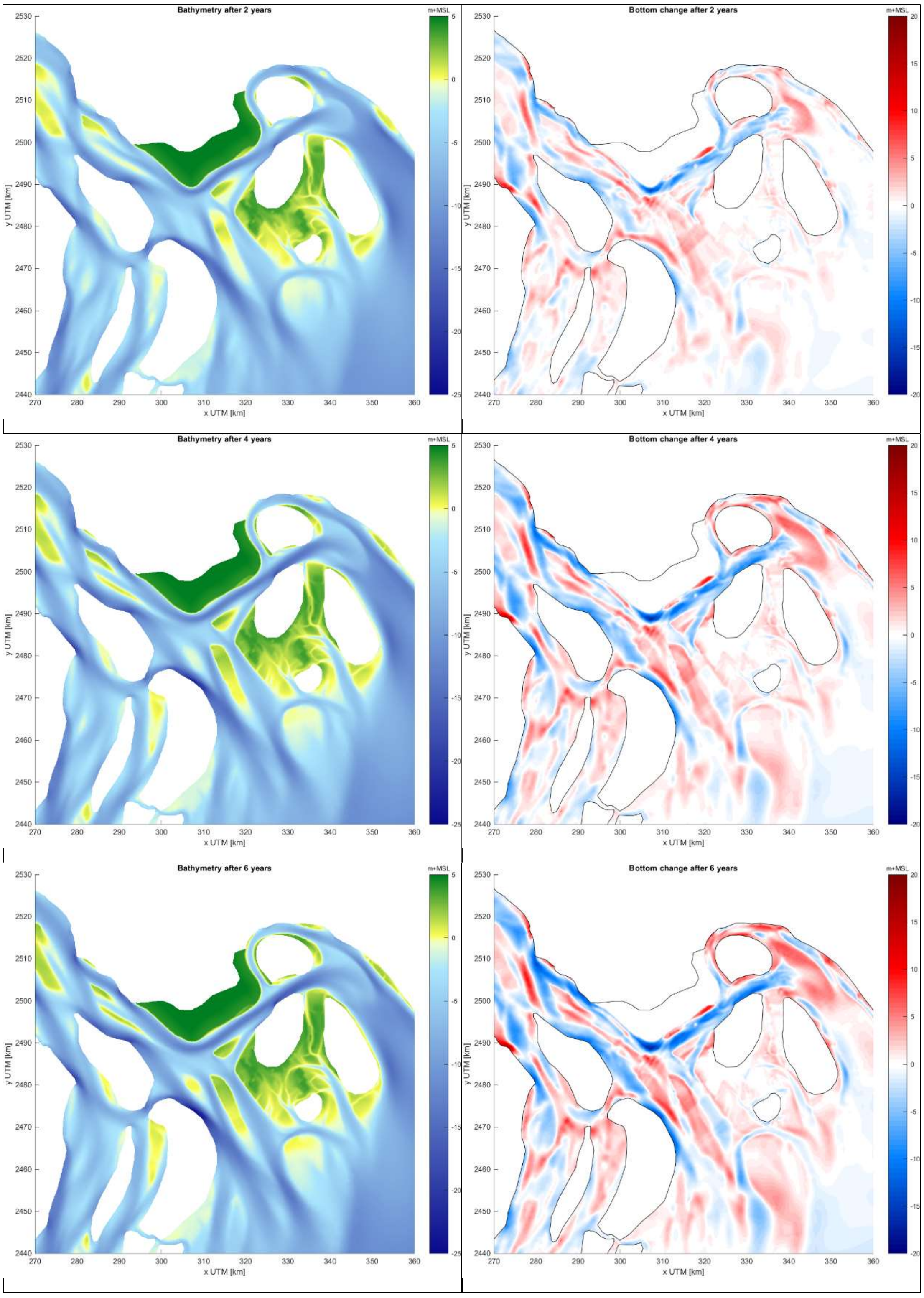


Figure 3-5: Detail plot of the applied initial bathymetry of the morphodynamic FINEL model.

The morphological development of the bathymetry is shown in Figure 3-6 for each 2 years up to the simulation period of 10 years. Channel deepening between the CDSP area and Swarnadwip is clearly visible causing erosion at the southern edge of the CDSP area (Noler Char) and resulting in a retreating shoreline. These developments are in line with the morphological development shown by IWM model results and a continuation of recent observations.

At the southeast side of the CDSP area (Char Nangulia) a different development appears. Initially, erosion is visible in this area but after a few years it turns to sedimentation of the area. From the IWM report it is hard to state what the development in this area is, resulting from their model. The sedimentation predicted by the FINEL model might indicate a change in shoreline development due to the erosion of Noler Char. However, these model predictions do not give any guarantees due to large uncertainties in the models.

Large amounts of sediment are deposited around Urir Char. The main channel develops and deepens south of Urir Char but in the channel around the north of Urir Char sedimentation is clearly visible. The channel southwest of Urir Char remains mainly in position.



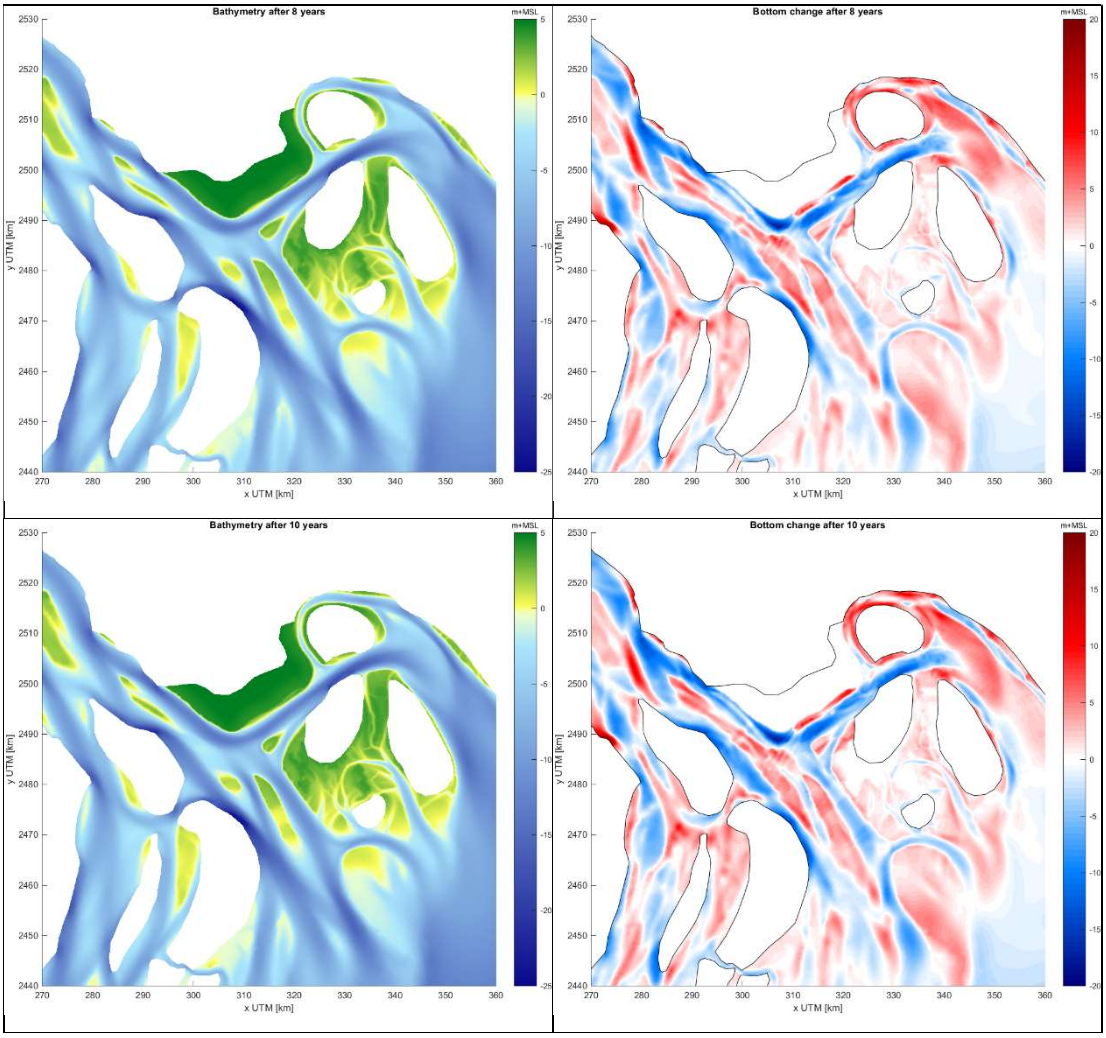


Figure 3-6: Bathymetry (left panels) and Bottom change (right panels) after 2, 4, 6, 8 and 10 years.

4 CONCLUSIONS AND RECOMMENDATIONS

- The study performed by IWM and the modelling results are considered state of the art. The hydro-morphological study by IWM is based on a mix of [a] historical bathymetrical charts, [b] satellite images of coastline development, [c] historical and recent monitoring data on water levels, currents and sediment load, and [d] detailed hydrodynamic and morphodynamical modelling of the Meghna Estuary from upstream of Chandpur down to the open sea. The development of the estuary over de past 2 decades is addressed properly and the calibration of the numerical model results with the field data in general shows a good match. This makes the hydrodynamic and morphodynamical study a good and state-of-the-art basis for the analysis of the impact of various management options in the estuary for the future, like the definition of set-back lines of embankments in eroding chars, new stable char development locations, bank protection works and/or cross dam implementation.

- For the existing CDSP land an assessment is made of the development of the coastline over a period of 5, 10 and 15 years starting from (approximately) 2021. The assessment shows that a significant area of developed land is prone to erosion and will probably be lost to the sea in the coming years if no measures are taken. It is recommended that the 10-year forecast be taken as the set-back line for the construction of new embankments and drainage regulators. It should be noted that in general for civil infrastructure works a 10-year lifetime is (too) short, but in view of the large impact of further land loss on the local community in this case such limited expected lifetime is acceptable. In addition to this infrastructure, it may also be considered to construct small dwarf embankments as a basic protection of existing farmland from being flooded by the tide each monsoon.

- The 10-year period has to be used to develop additional protection measures of the CDSP land in Boyer Char, Noler Char and Char Nangulia to increase the lifetime of the embankments and regulator structures and to minimize the ongoing loss of land. Such additional protection measures may consist of bank protection along the riverbank at the west side of Noler Char and/or a cross dam between Char Nangulia and Jahazer Char to stop the eroding power of the channel along Char Nangulia. In view of the high current velocities, it should be realised that these measures will be costly and require a significant preparation time for feasibility study and design, cost estimates and budget allocation.

- In the IWM study a scan is made of the whole estuary to make an inventory of char areas with low, medium and high risk of bank line erosion. This inventory is very useful and gives a first indication of areas that may be considered for future char development and settlement projects. It should be realized that for further elaboration of the char development potential of these areas each of them will need to go through its own feasibility study and design process, where the future bank stability and all other relevant development aspects need to be addressed in detail.

- The bank line erosion of Caring Char, Noler Char, Char Nangulia and Boyer Char over the last years was not envisaged in the feasibility phase of the CDSP-IV project. When the erosion became more and more significant it was decided that a hydrodynamic and morphological study be undertaken consisting of field work (surveys of seabed, water levels and currents) and desk work (analysis of data and numerical modelling). The study was organised by the CDSP-Bridging (Additional Financing) Project and was financed by BWDB. The study is now being completed by IWM. The Terms of Reference and Quality Control are done by the TA-Team of CDSP-B. For the future it is recommended that monitoring and forecasting of the morphological developments of the whole Meghna estuary be done on a permanent institutional basis, instead of organizing ad-hoc activities when the urgency needs to. The CDSP institutional framework and the results of the present work are a good starting point for this future monitoring and study programme.

- For the assessment of new potential CDSP areas, satellite analysis has been applied by IWM. Due to low time resolution, it is unclear if bank line changes are gradual trends or if there have been many changes in between. Also there has been no compensation for high or low water levels, which could substantially influence erosional or depositional trends. It is therefore recommended to perform a detailed satellite images analysis with multiple images per year.

- Monitoring data were crucial for improving model results. It is recommended to continuate the monitoring program on institutional basis and regularly update the model. Continuation of modelling development and improvement in future, integrate the concept of modelling by IWM and quality control by TA team of future CDSP projects in plans for CDSP-V. Ultimately, update existing feasibility studies of new CDSP-V chars by making model forecast and detailed satellite images analysis on short term.

A TERMS OF REFERENCE

1 Data analysis

- Verification of analyses of water level measurements (spatial variation in tidal difference, mean sea level, phase of tidal components) and assessment of seasonal effects and changes over time.

- Verification of analyses of Seabed bathymetry development, based on bathymetrical data.

- Verification of satellite image analysis, check on bank shifting pattern, erosion vulnerability and morphological changes, bar and char movement, etc. Verification of the predicted bank line shifting of river and char.

- Verification of analyses of current velocity, discharge and sediment concentration measurements and assessments of seasonal effects and relation with seabed developments and water level gradients.

2 Verification of model calibration of main hydro-morphological study

- Verification of main model calibration results and conclusion on quality of this model.

- Verification of the model is built on the specified grid spacing (2-5km in the open sea and 100-300m in the dynamic char areas).

- Verification of the model used the latest bathymetry where it is available.

- Verification the model stability and the depth average flows are satisfactory.

- Verification of tides, waves, and storm surge levels assessment.

- Verification of the climate change sensibility analysis-river discharge, sea level rise and wave climate/ cyclone frequency.

- Verification of availability of option to intervene online with wave model

- Verification of model log and confirmation on all modelling assumptions, limitations, input parameters are recorded adequately.

- Set-up of separate 2DH hydro-morphodynamical model to verify the results of the model of the main study. Focus points will be the water level differences and phase lags between the main Meghna tidal channel (between CDSP area and Hatiya Island) and the eastern channel (between Sandwip Island and the Chattogram mainland).

- Indicative hindcast calculation of the historical channel developments in this area and comparison with observed changes and outcomes of the model of the main study.

3 Assessment of future development

- Developments without human intervention (definition of “safe” line in existing chars).

- Verification of impact assessment (in main study) of the implementation of various cross dams and any other interventions in the Estuary including anthropogenic changes/ activities that may be considered.

- Verification of long-term forecast of the morphological developments for 5,10, 15, and 20 years.

- Participation in the discussions on effectiveness of various interventions and which interventions are to be considered in the main study.

4 Recommendations on long term monitoring and analysis program of the Meghna Estuary

- Participation in the discussions on the development of a long-term monitoring and development assessment programme of the Meghna Estuary taking into account available human and financial resources.

- Verification of deliverables specified in the original scope for IWM.

5 Recommendations to TA Team of CDSP-B (AF)

- On the “safe” line to be defined in the chars of CDSP I-IV for the implementation of high-cost infrastructure (sluices and embankments);

- On the locations that may be considered for new Char Development and Settlement Project areas.

B HYDRODYNAMIC MODELLING

B.1 Introduction

To determine the water level and current conditions in the Meghna delta the FINEL flow model is used. The flow model is run for two periods with measurement data, September 2020 (monsoon season) and January 2021 (dry season). Water levels at the area of interest are obtained. These water level time series are visualized in Chapter 3. The FINEL model setup is described in this Appendix.

B.2 Description FINEL flow model

The computational flow model FINEL[1] has been developed in-house by Svašek Hydraulics. FINEL is used at the Bangladesh coast as a two-dimensional numerical flow model. Based on the shallow water equations, FINEL is able to simulate flow and transport processes in rivers and coastal waters. Since FINEL contains a robust procedure for drying and flooding of tidal flats it is also suitable to model flow and morphology in estuaries.

B.3 Computational mesh

The model domain for the FINEL flow model is depicted in Figure B.1 (white line). The model extends offshore to deeper water (approximately 50m or more), to the Indian border in the West and beyond Chandpur in the North. This ensures that the tidal and wind driven currents are well captured by the model.

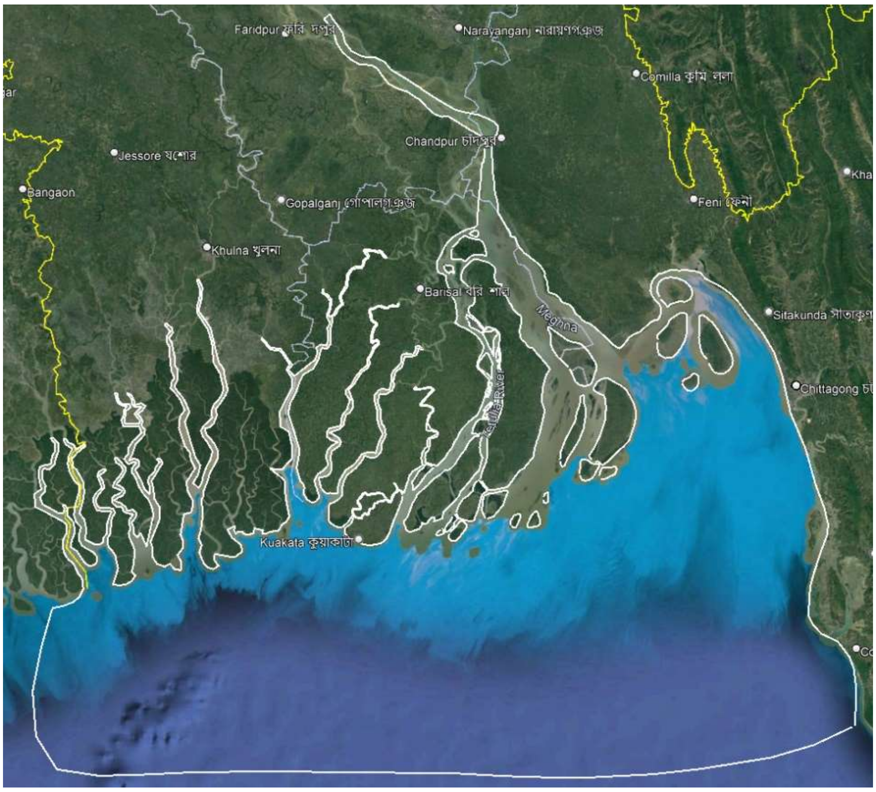


Figure B.1 Model domain of the FINEL model.

[1] https://www.svasek.nl/en/model-research/finel/

FINEL employs an unstructured triangular mesh, which enables the user to fit boundaries accurately within the model and to increase resolution in the region of interest in a very flexible way, without the need for nesting of grids. The grid resolution at the ocean boundaries is around 1200m and refines to 100 - 200m near the CDSP area. Figure B.2 shows an overview of the computational mesh of the complete model domain, and Figure B.3 depicts a detailed image of the mesh of the FINEL model.

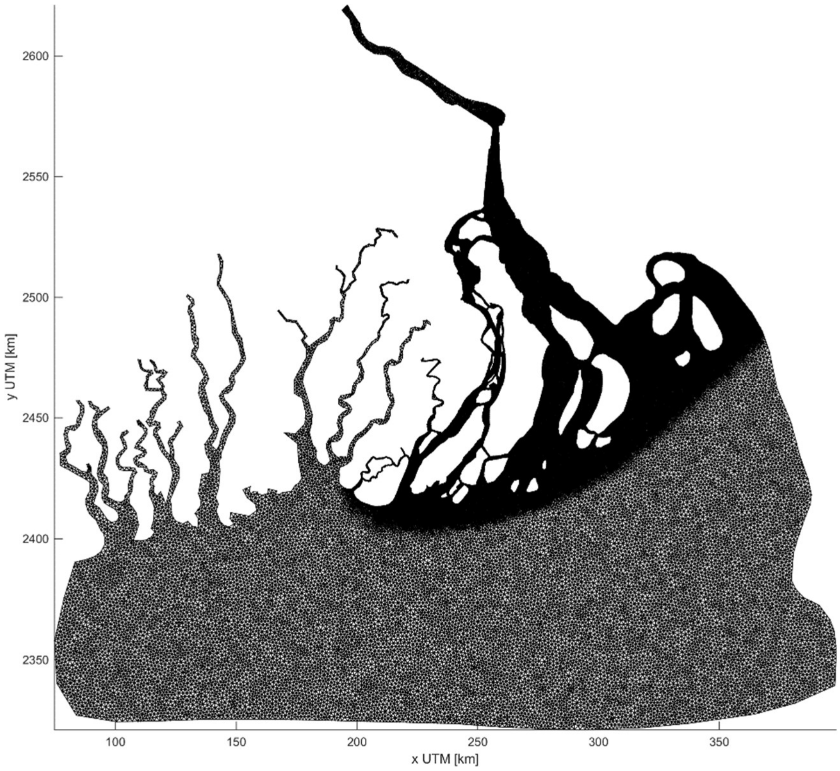


Figure B.2: Computational grid in FINEL model.

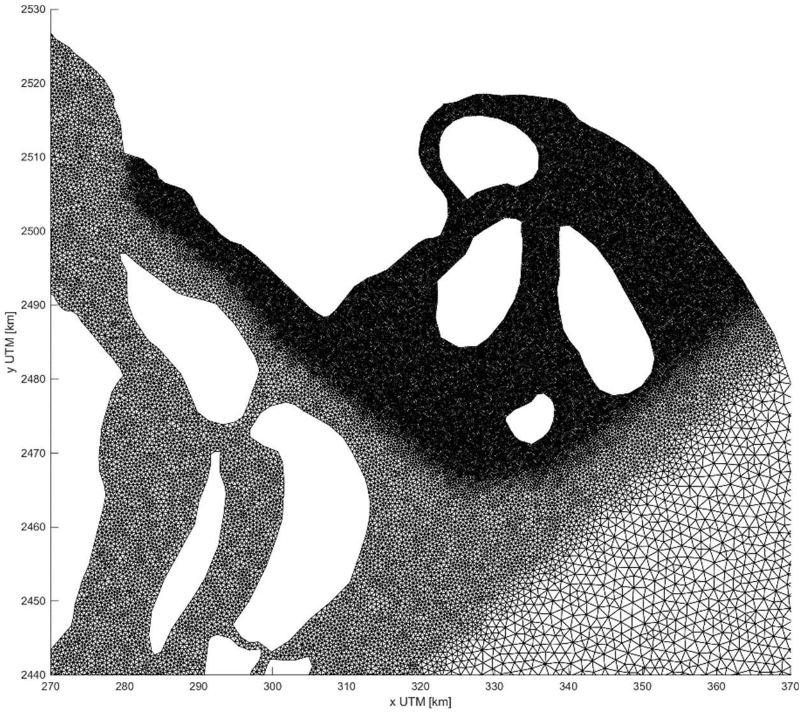


Figure B.3: Detail plot of computational grid in FINEL model.

B.4 Bathymetry

The bathymetry of the FINEL model is set-up by interpolating the bathymetry of different sources to the computational grid (all converted to Mean Sea Level, MSL). Bathymetry data sections received from IWM consist of the following:

- Padma2011
- Upper_Meghna2017
- LTRM2019
- Cymmyt2015
- Bathy_Lower_Meghna_2020
- Tentulia_2017
- Tentulia_2019
- Sandwip_2018

The gaps are filled with less accurate sources like Nautical charts and satellite imagery. Figure B.4 shows an overview of the applied bathymetry of the complete model domain, and Figure B.5 depicts a more detailed image of the applied bathymetry.

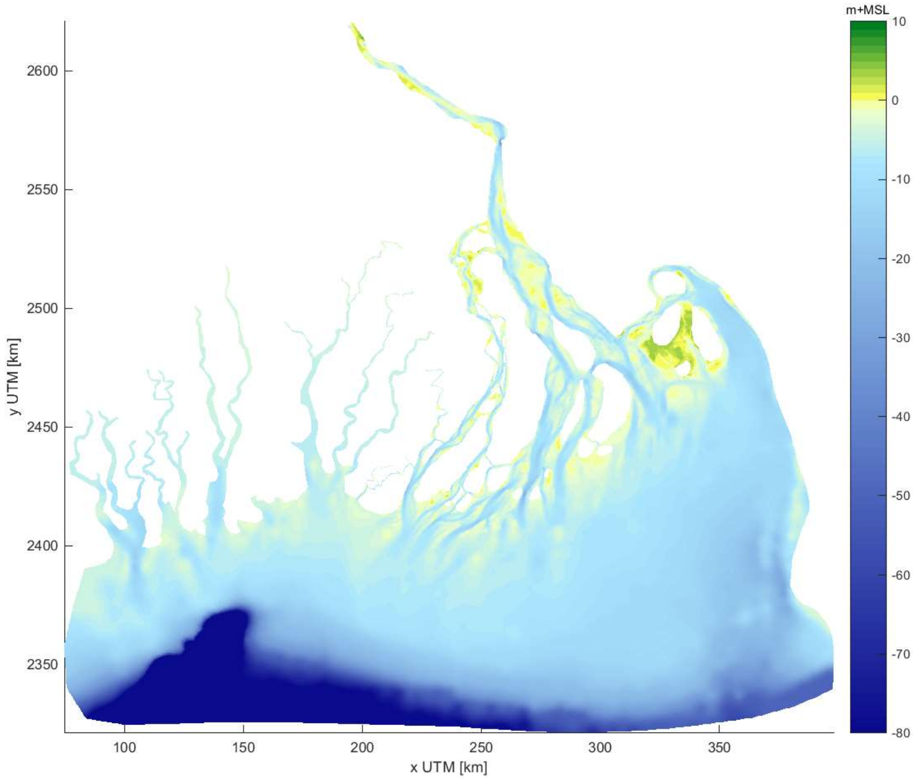


Figure B.4: Applied bathymetry in the FINEL model.

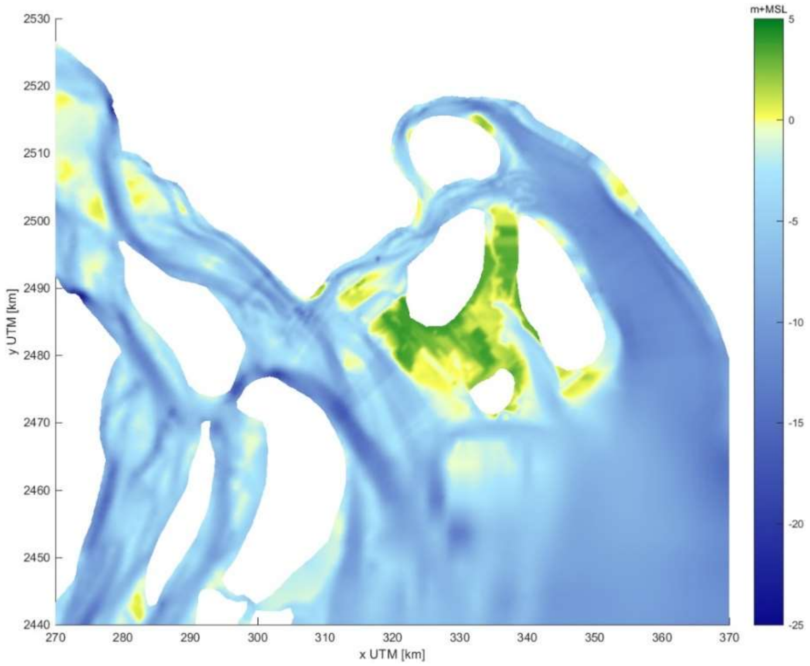


Figure B.5: Detail plot of applied bathymetry in the FINEL model.

B.5 Boundary conditions and forcing

B.5.1 Water level

The tidal amplitudes and phases used as harmonic tidal boundary conditions are extracted from the global FES2014a[2] (32 harmonic components, 1/16° grid) world tide database. To include seasonal variations in tidal water levels an annual harmonic component with 0.3m amplitude is added to the tidal boundary conditions, based on Tazkia et al. (2017)[3].

B.5.2 Wind and air pressure

To account for wind and air pressure variations, temporarily (hourly) and spatial varying wind and pressure fields from the global high resolution (0.25° x 0.25°) hindcast database ERA5 are imposed to the FINEL model.

B.5.3 Discharge

Additional boundary conditions are applied to implement the discharge from the Meghna River. The discharge from the Meghna River is schematized in the dry and monsoon seasons, as shown in Table B.1. The discharges presented in this table are applied for the specific seasons.

Table B.1: Discharge schematization in dry and monsoon seasons

Season	Period	Discharge [m^3/s]
Dry	December – March	8.000
Monsoon	June – September	75.000

[2] www.aviso.altimetry.fr

[3] Tazkia, A. R., Krien, Y., Durand, F., Testut, L., Islam, A. S., Papa, F., & Bertin, X. (2017). Seasonal modulation of M2 tide in the Northern Bay of Bengal. Continental Shelf Research, 137, 154-162.

B.6 Final settings

For the computations FINEL2D version 7.30 (released 9 February 2021) is used. The most important model settings are summarized in Table B.2.

Table B.2: FINEL hydrodynamic model settings

Parameter	Setting
Manning roughness	0.010 – 0.012 $s/m^{1/3}$
Water density	1025 kg/m^3

C MORPHODYNAMIC MODELLING

C.1 Introduction

A morphodynamic FINEL model is setup simulating sediment transport including bed update. An indicative simulation is run for a period of 10 years. Bathymetry development and bottom change results are visualized in section 3.3.

The starting point for the morphological FINEL model is the hydrodynamic FINEL model. The model settings have not been adjusted and the model outline is mainly the same, except for the manual inclusion of the CDSP area. The included CDPS area is shown in Figure C.1.

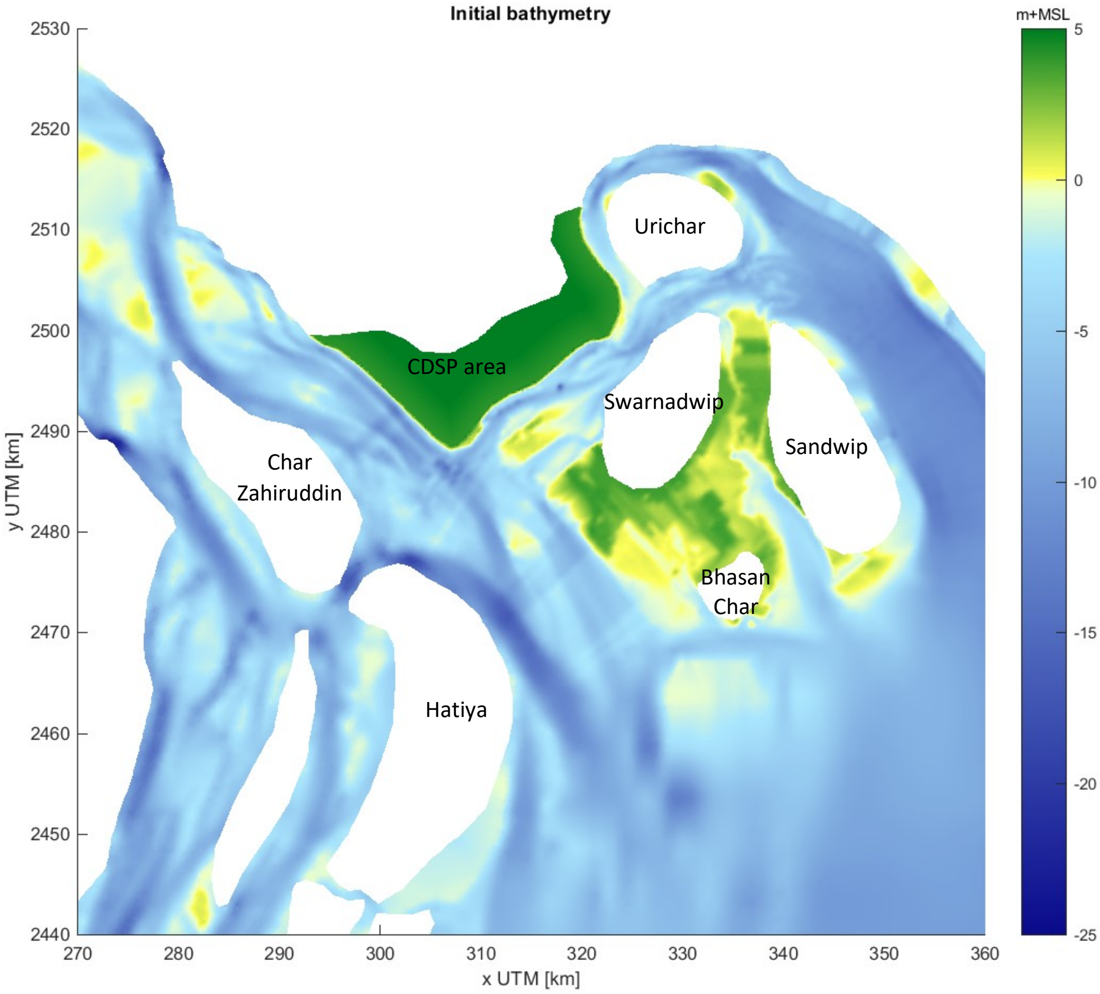


Figure C.1: Detail plot of applied initial bathymetry in the morphodynamic FINEL model including the CDSP area.

C.2 Discharge

A discharge timeseries is applied to the model for the morphodynamic simulation, see Figure C.2. The discharge timeseries is based on two timeseries (Baruria and Bhairab) for the period of 2019-2020, received from IWM. This two-year timeseries is repeated to obtain a 10-year timeseries for the morphodynamics simulation.

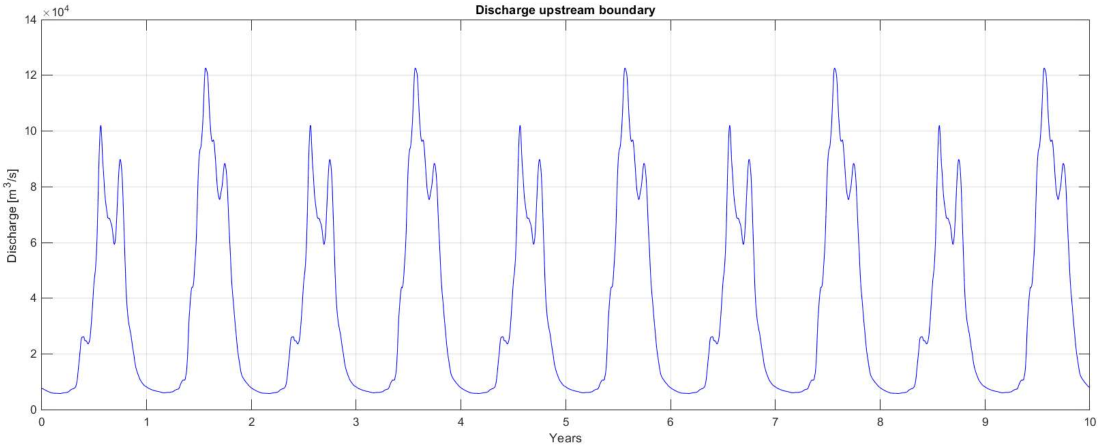


Figure C.2: Discharge timeseries applied to the upstream boundary.

C.3 Morphodynamic settings

The most important morphodynamic model settings are summarised in Table C.1.

Table C.1: FINEL morphodynamic model settings

Sand transport	
Transport formula	Van Rijn 2007
D50	120 µm
D90	240 µm
Silt transport	
Transport formula	Van Ledden (2001)
Silt fraction	
Fall velocity	0.55 mm/s
Critical shear stress	0.4 N/m²
Erosion rate, E-silt	0.0006 $kgm^{-2}s^{-1}$
Clay fraction	
Fall velocity	0.1 mm/s
Critical shear stress	0.4 N/m²
Erosion rate, E-Mud	0.0010 $kgm^{-2}s^{-1}$
Other parameters	
Morphological roughness type	Manning
Morphological roughness value, k_s	0.010 $s/m^{1/3}$

The morphological roughness differs from the hydrodynamic roughness. The hydrodynamic roughness determines the amount of bottom friction that is exerted on the flow, where a higher hydrodynamic roughness leads to a reduction of the flow velocities. The morphological roughness on the other hand does not influence the flow properties, it only alters the amount of shear stresses exerted on the sediment, where a higher morphological roughness increases the pick-up of sediment.

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