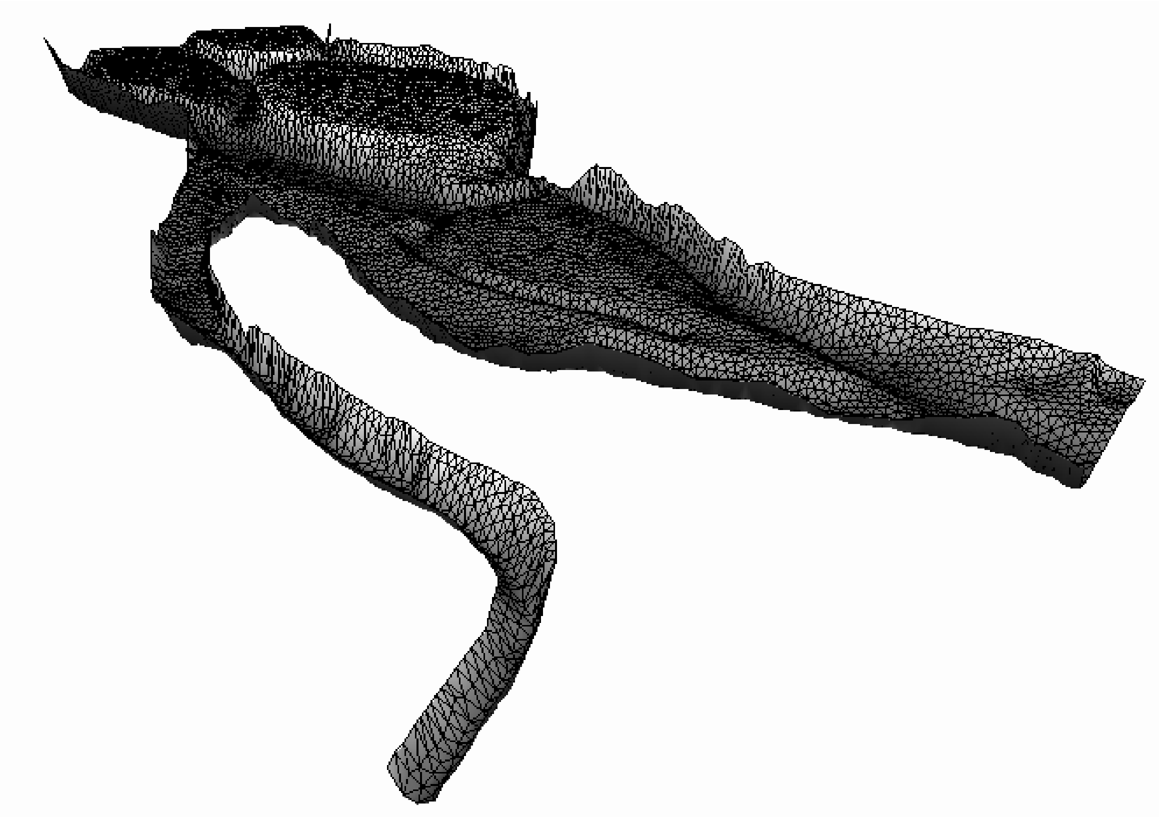

MIKE 21 Flow Model FM

Sand Transport Module

Step-by-step training guide: River application

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MIKE 21 Flow Model FM
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1 Introduction

The intention of this Step-by-step training guide is to give some insight into how the MIKE Flow Model FM can be used to carry out a morphological study on a river. Morphological studies are often very complex and time demanding due to the fact that not only the flow and sediment transport have to be calculated, but also the container of the flow itself. Furthermore, it is often necessary to calculate long periods and different scenarios in order to obtain the characteristic trends of the system.

Figure 1.1 Aerial photo of the bifurcation of the Ganges and the Gorai River

1.1 Background

This Step-by-step training guide is build up around a siltation problem of the Gorai offtake in Bangladesh. The Gorai River is a spill channel to the Ganges River. The morphological behaviour at the offtake is of great interest, because the Gorai River is an important source of fresh water supply in the region. If the closure of the mouth becomes too severe, it will imply that the River dries out during critical dry periods. Furthermore, the closure of the offtake will be responsible for a more significant tide generated intrusion of salinity in the lower part of the Gorai River. However, the impact of salinity intrusion on the fresh water supply is not treated in this Step-by-step training guide.

The purpose of this step-by-step guide is to estimate the morphological changes of the system after the period of one monsoon. In a real/more detailed study the purpose could be to investigate the effect of maintenance dredging or construction of large groynes. Hereby, a number of scenarios can be defined and compared with each other in order to find the best design to prevent siltation of the offtake or estimate how much and how often maintenance dredging is required in order to maintain the opening of the offtake.

1.2 Objective

The objective of this Step-by-step training guide is to set up a morphological sand transport model for the bifurcation of the Ganges and Gorai River, see Figure 1.1.

Attempts have been made to make this exercise as realistic as possible although some short cuts have been made with respect to the data input and resolution and extension of the area covered by the mesh. This mainly relates to quality assurance and pre-processing of raw data to bring it into a format readily accepted by the MIKE Zero software. Depending on the amount and quality of the data sets this can be a tedious, but indispensable process. For this example, all 'raw' data has already been filtered into a MIKE Zero format.

The files used in this Step-by-step training guide are a part of the installation. You can install the examples from the MIKE Zero start page.

Please note that all future references made in this Step-by-step guide to files in the examples are made relative to the main folders holding the examples.

User Guides and Manuals can be accessed via the MIKE Zero Documentation Index in the start menu.

All the MIKE Zero input parameter files required to run the example are included and the simulation can be initiated right away.

2 Creating the Computational Mesh

Creation of the mesh file is a very important task in the modelling process. At this stage, the first part of the modelling process, the extension and resolution of the modelling area are decided.

Please note that the choice of these settings in the end can have a great impact on the modelling results.

The mesh file couples water depths with different positions and contains the following information:

1. Computational Grid
2. Water Depths
3. Boundary Information

Creation of the mesh requires either an xyz file(s) for positions of land boundaries or a map/geo-referenced aerial photo that can be used to digitise the boundaries of the model. Furthermore, an xyz file(s) that couples geographical positions with water depths is needed for the interpolation of the model bathymetry. A MIKE 21 bathymetry can also be used as an alternative to an xyz file with water depths.

Creation of the Computational Mesh typically requires numerous modifications of the data set, so instead of explaining every mouse click in this phase, the main considerations and methods are explained in MIKE 21 & MIKE 3 Flow Model FM HD Step-by-step guide, which can be accessed via the MIKE Zero Documentation Index in the start menu:

MIKE 21 & MIKE 3 Flow Model FM, Hydrodynamic Module, Step-by-Step Training Guide

When creating the computational mesh you should work with the mdf file, which contains information about settings for the mesh. In this example focus is on Sand Transport. Thus, the necessary xyz files, the mdf file and a mesh file are already supplied with the example, so that the training time can be spent on specific Sand Transport subjects.

However, some additional information is given in the following, because the grid generation process and bathymetry interpolation differs slightly from the procedure described in the document link above.

The first step in the mesh generating process is to choose the **Workspace projection**. For the present example the ’Local Coordinates’ system has been chosen, see Figure 2.1.

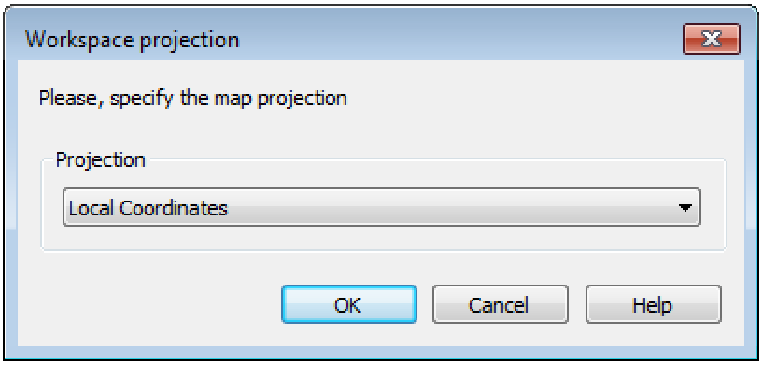

Figure 2.1 The 'Local Coordinates' system is chosen for the generation of the mesh

The next step is to define the **Workspace area**. The specifications for the Workspace area are shown in Figure 2.2.

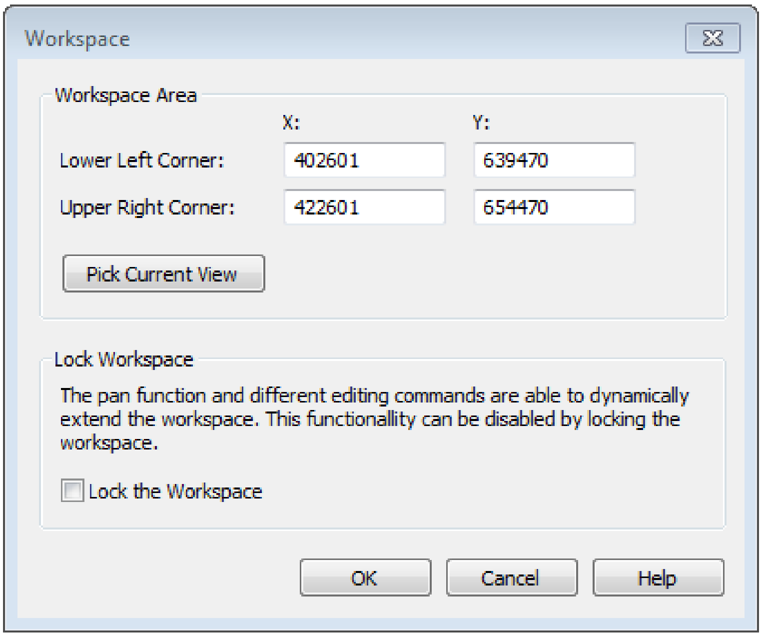

Figure 2.2 Specification of workspace coordinates

With the new workspace settings the aerial photo can be imported by application of the **Import Graphic Layers** facility. The name of the background picture is gorai.jpg. It can be imported as an image file. When the picture has been imported then click on the **Edit** button and specify the coordinates for the image origin and the size of the area as shown in Figure 2.3. The information of the aerial photo can also be extracted from the worldfile gorai.jpgw (ASCII file).

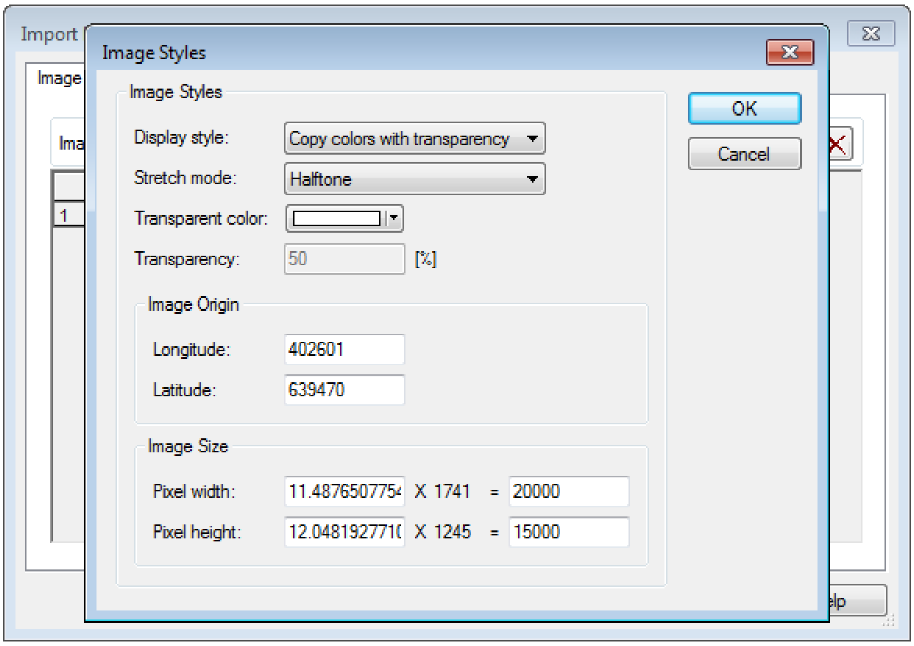

Figure 2.3 Specification for the imported aerial photograph

Based on the aerial photo the extension of the model can now be digitised. Figure 2.4 shows the digitised boundaries and the coarse mesh generated for the Gorai step-by-step application.

The model area is defined, so that it consists of three open boundaries and four land boundaries. The island defined by one of the land boundaries is excluded from the mesh generation. Each open boundary has been given an individual attribute value (2, 3, and 4). If not specified, the open boundaries will automatically be given an attribute value of 1 corresponding to a land boundary. Internal points are given an attribute value of 0.

The attribute values should be defined before the mesh is generated and the bathymetry is interpolated.

Figure 2.4 Digitised boundaries and generated mesh

The mesh and bathymetry that is used for the tutorial are shown in Figure 2.5. Figure 2.6 shows a graphical presentation of the mesh of the bifurcation area, as it can be displayed with MIKE Animator.

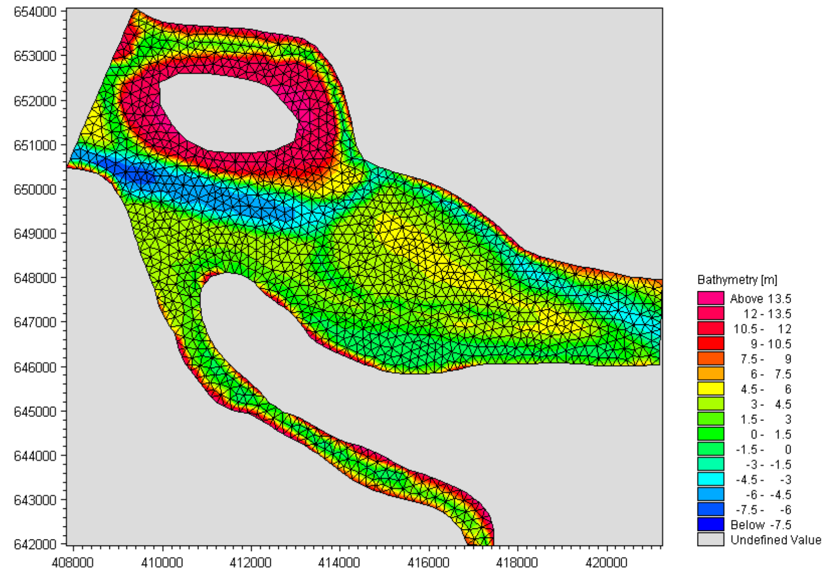

Figure 2.5 The computational mesh and bathymetry for the Ganges Gorai bifurcation, as it can be presented with the Data Viewer tool

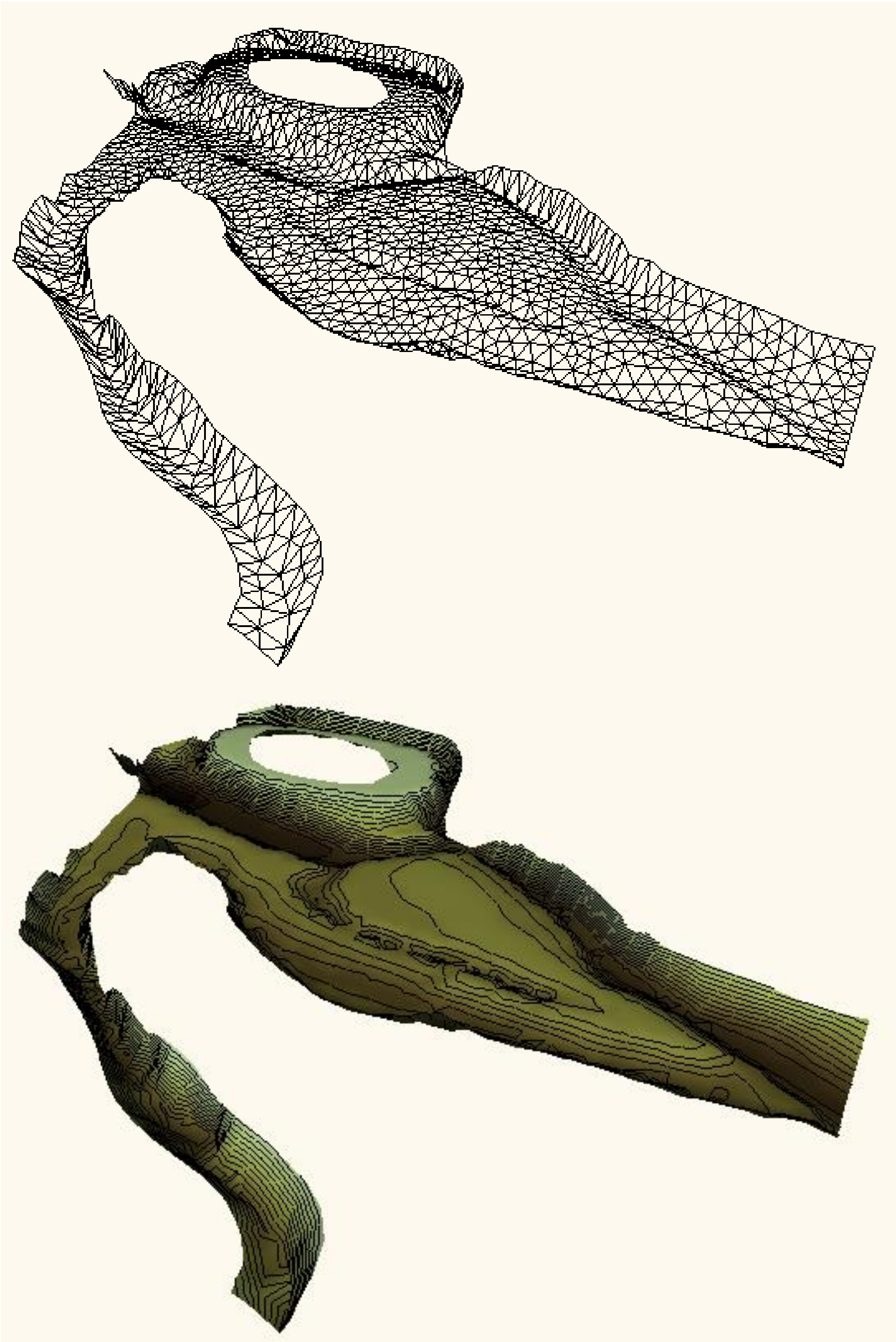

Figure 2.6 The computational mesh for the Ganges Gorai bifurcation, as it can be presented with the MIKE Animator tool.
Top: Wire frame
Bottom: Surface and contours plot

3 Creating the Input Parameters for the MIKE 21 Flow Model FM Simulation

Before the MIKE 21 Flow Model FM complex can be established, the necessary input data must be generated from relevant observations. The model has been created with three open boundaries, so three boundary time series need to be established for the Hydrodynamic (HD) model.

The following observations are available:

1. Rated flow discharges at Hardinge Bridge (661644N, 402470E) obtained for the 1999 monsoon
2. Water level observations at the Gorai Railway Bridge (641907N, 417118E) for the 1999 monsoon
3. Water level observations at Shelaidah (646302N, 421259E) for the 1999 monsoon

The location of the Hardinge Bridge, the Gorai Railway Bridge, and Shelaidah can be found on the map shown in Figure.3.1, or by their coordinates in the model. Hardinge Bridge is located about 11 km upstream the modelled area. However, it is not a problem to apply flow discharge information further downstream if tributaries are not present. The two water level time series can be applied directly, because they fit with the location of the two downstream boundaries in the model.

The measured/rated data covering the 1999 monsoon is included in the file named WLQ.dfs0.

Preparation of input data is often made by use of various tools in MIKE Zero. Therefore reference is also made to the MIKE Zero User Guide, which can be accessed via the MIKE Zero Documentation Index in the start menu:

MIKE Zero Pre- and Postprocessing, Generic Editors and Viewers, User Guide

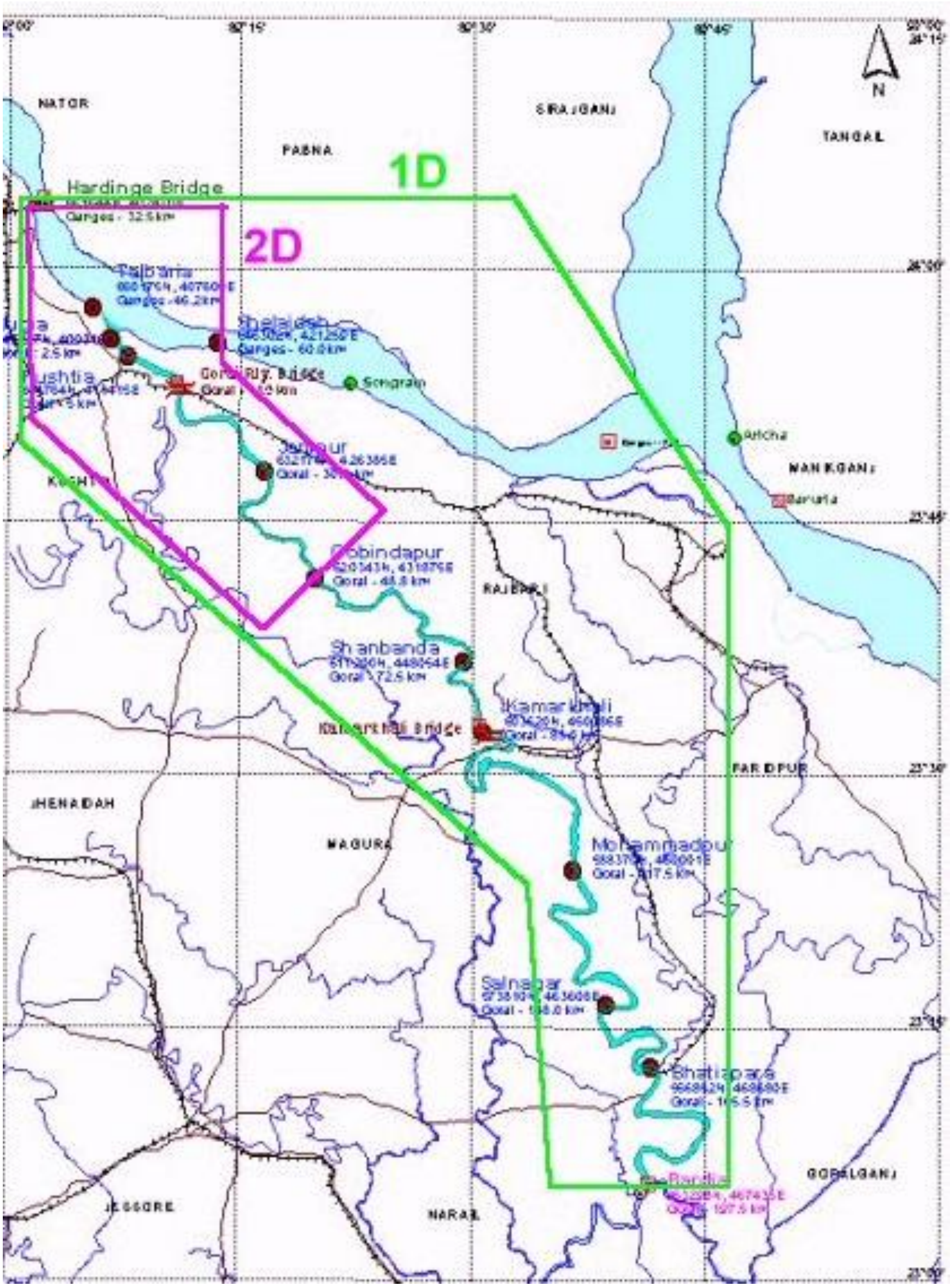

Figure.3.1 Map of the Ganges and Gorai area

3.1 Flow Discharge Boundary Conditions

The flow discharge in the model has been obtained from rated values, i.e. from a relation that links the observed water level at Harding Bridge to flow discharge. The rating relation has been obtained based on ADCP surveys carried out on 11 September 1998, 21 August 1999 and 11 September 1999 in addition to low flow measurement by conventional approach during the two monsoon periods.

The rated relation at Hardinge Bridge is given by:

$$Q = 0.043(H + 2.53)^{4.8262} \quad , H \leq 10.7428$$

$$Q = 52.222(H - 4.8702)^{3.0372} \quad , H > 10.7428 \qquad (3.1)$$

Where *Q* is the flow discharge and *H* is the surface elevation.

Figure 3.2 shows the rated flow discharge applied for the simulation of the 1999 monsoon.

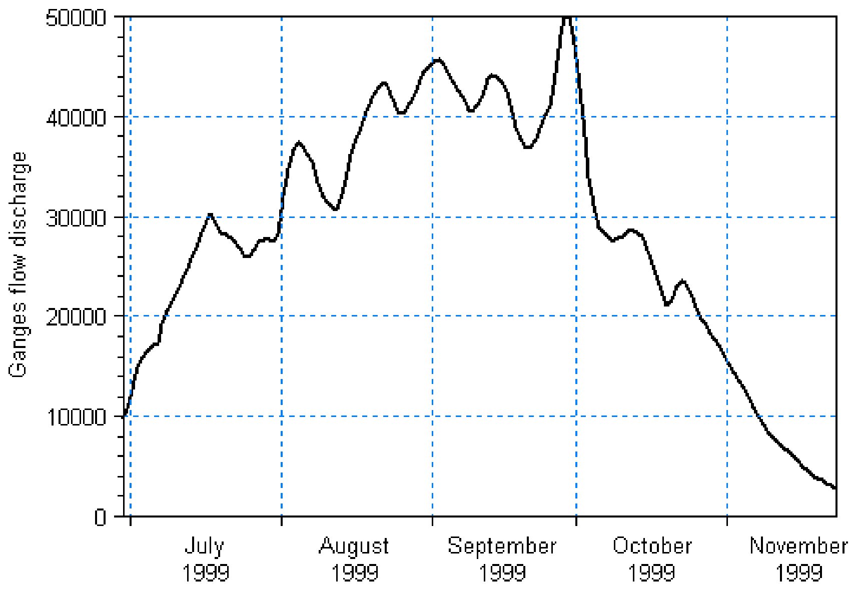

Figure 3.2 Rated flow discharge applied at the upstream Ganges boundary for the 1999 monsoon

3.2 Water Level Boundary Conditions

The Ganges and Gorai downstream boundaries have been located so that they correspond with the location of the water level gauging station at Gorai Railway Bridge and Shelaidah, respectively. Hereby, the water level observations can be directly applied for the modelling.

If the downstream boundaries are defined at locations where no water level information is directly available, the normal procedure would be to extract the information from a one-dimensional model, say MIKE 11, or use interpolated values determined from a gauging station upstream and downstream the location of interest. Also, a rated relation can be applied.

The water levels applied at the Ganges downstream boundary and the Gorai downstream boundary for the 1999 monsoon are shown in Figure 3.3 and Figure 3.4, respectively.

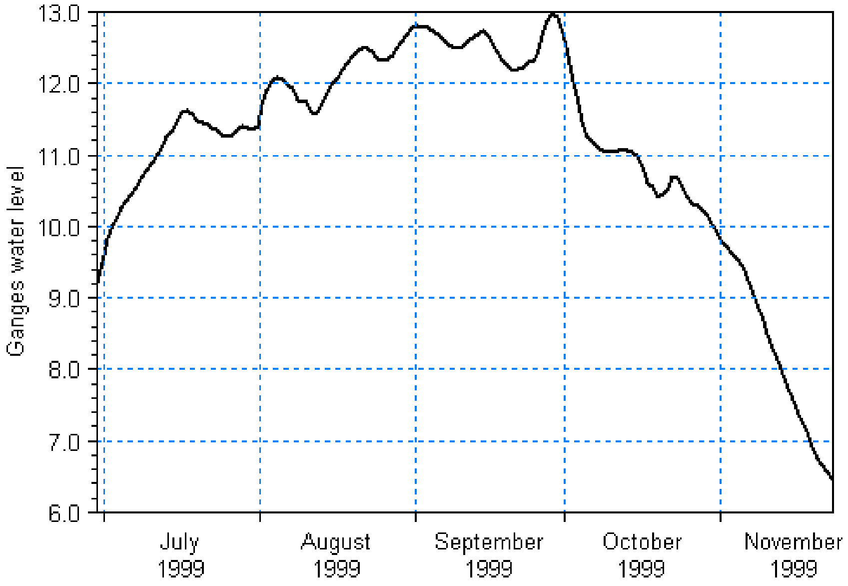

Figure 3.3 Ganges water level variation applied as downstream boundary condition for the simulation of the 1999 monsoon

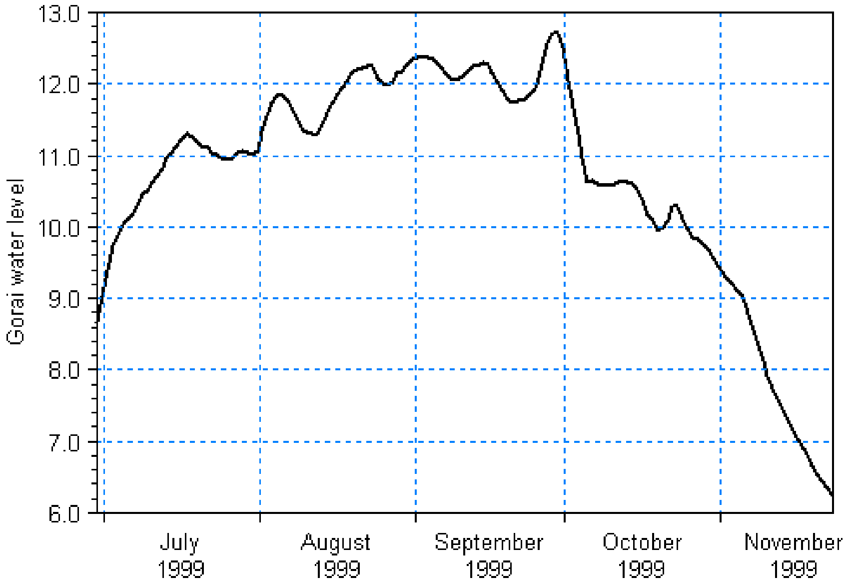

Figure 3.4 Gorai water level variation applied as downstream boundary condition for the simulation of the 1999 monsoon

3.3 Initial Conditions

A number of initial conditions need to be specified for the model. However, the most crucial is the initial surface elevation, because a bad choice will force blow up of the model almost immediately. The choice of initial surface level depends on the starting time (boundary conditions) of the model. The procedure chosen for the specification of the initial surface elevation in this tutorial is to use the maximum value of the two downstream water level boundary conditions applied at the time step, where the simulation is started - perhaps in combination with a soft start for the flow discharge and the lowest water level boundary.

3.4 Time Step

Before running the monsoon period with morphological update of the bed, the minimum and maximum time step should be estimated. This analysis is important, because it not only reduces the risk for getting flow instabilities (model blow-up), but also ensures an optimal model performance.

The HD time step is limited by the CFL stability criterion,

$$CFL = \frac{\left|\sqrt{gh} + u\right|\Delta t}{\Delta x} + \frac{\left|\sqrt{gh} + v\right|\Delta t}{\Delta y} < 1 \qquad (3.2)$$

where g is the acceleration of gravity, h is the flow depth, (u,v) is the flow velocity, Δx and Δy are characteristic length scale in the x- and y-direction for each element and Δt the time step.

Δt is set dynamically by the program to its maximum value, which fulfils the CFL criterion. However, the maximum time step must not exceed the overall time step.

For flow simulations on large flow depths, it is the shallow water wave celerity term that dominates the CFL number, while at low flow depths, it is the local velocity. Information about the part of the CFL number related to the shallow water wave can be saved as an additional output in the HD result file.

At the peak of the 1999 monsoon simulation the largest flow depth reaches a value around 20 metres in the river, so it is evident that for the present model, it will be the flow depth that determines the limit for the time step. The largest flow depths occur during the passage of the peak.

The peak discharge and the corresponding water levels at the downstream boundaries can be identified from the boundary time series file or Figure 3.2 to Figure 3.4 to be:

- Maximum flow discharge: 50000 m^3/s
- Water level at Shelaidah (Ganges): 12.97 metres
- Water level at Gorai Railway Bridge: 12.7 metres

In Section 3.5, it is described how the HD model can be established with the boundary conditions specified above.

The CFL numbers in the model related to shallow waves under peak conditions are shown in Figure 3.5.

The minimum and maximum time steps were specified to 1 s and 180 s, respectively. However, during the simulation described in Section 3.5, the program internally found the dynamic time step to be between 2 and 4 seconds.

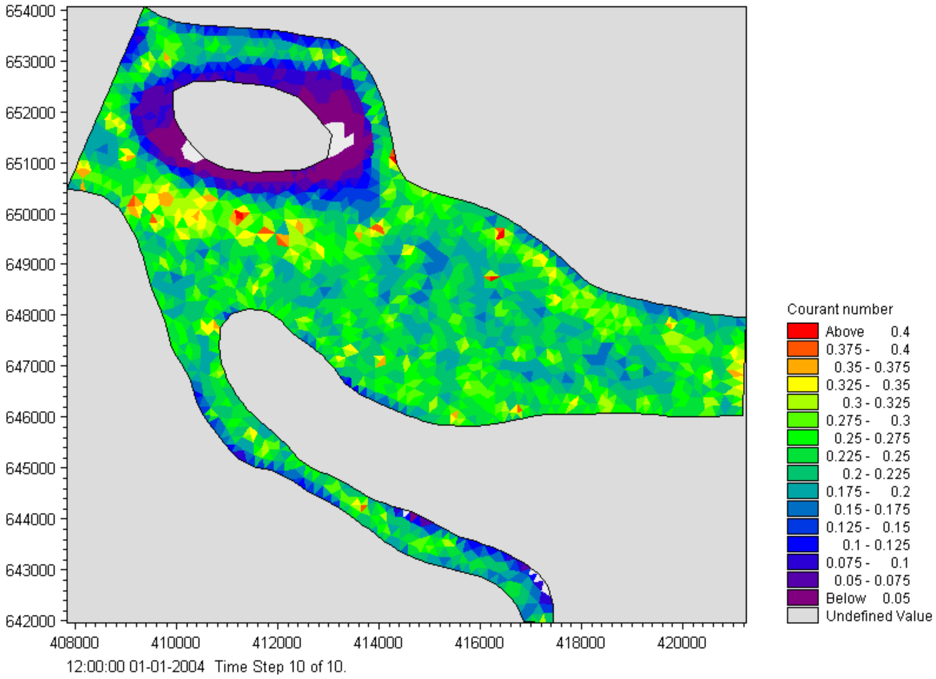

Figure 3.5 Shallow water wave Courant number for peak flow conditions

The overall time step determines the interaction with the process modules. When running a morphological model, it is necessary top consider the update rate of the transport field, because the bed level changes through the simulation. If the overall time step becomes too large, the changes in bed level may become too abrupt, leading to instability and errors in the mass conservation scheme and subsequently inaccurate results.

In a highly dynamic flow like this the bed level update rate might be high and rapidly changing as the bed level changes.

Remembering the resulting dynamic time step of 2-4 seconds, the overall time step for the morphological simulation may be set to 10 s (instead of 180 s) without any significant increase in simulation time.

3.5 Hydrodynamic Simulation for Peak Discharge

To investigate the influence of the various input parameters to the hydrodynamic model, you may simulate the conditions during peak discharge.

The setup of the hydrodynamic simulation for the peak discharge is described in the following by a number of screen dumps and some additional information.

Specify the bathymetry and mesh file Gorai.mesh in the **Domain** dialogue, see Figure 3.6. The projection zone has already been specified in the mesh as local coordinates. In the mesh file, each boundary has been given a code. In this Gorai example the Ganges discharge boundary has 'Code 2', the Ganges water level boundary has 'Code 3' and the Gorai water level boundary has 'Code 4'. Rename the boundary 'Code 2' to 'Discharges Ganges', 'Code 3' to 'Water level Ganges' and 'Code 4' to 'Water level Gorai' in the **Boundaries** Sheet, see Figure 3.7.

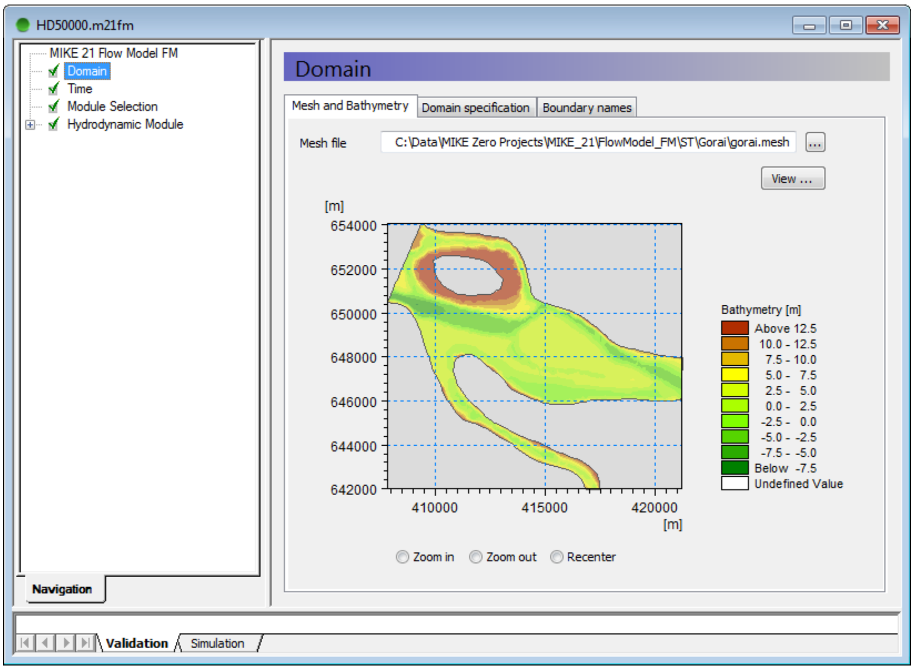

Figure 3.6 Mesh and bathymetry specification for the model of Gorai and Ganges

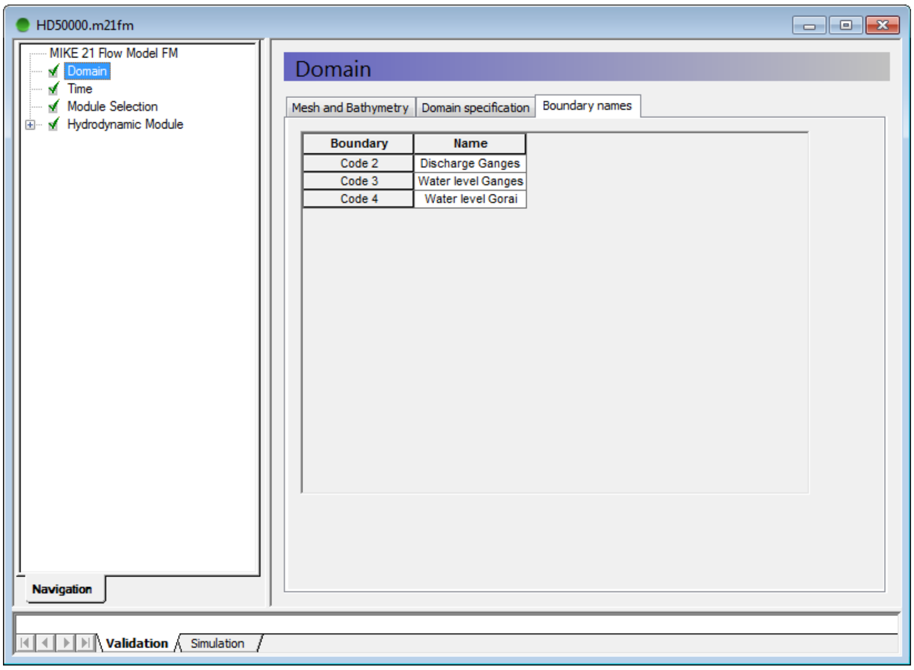

Figure 3.7 Renaming of boundaries

Return to the **Mesh and Bathymetry** sheet, right-click and activate the **Show Mesh** facility. The computational mesh and the location of the different types of boundaries will then occur as shown in Figure 3.8.

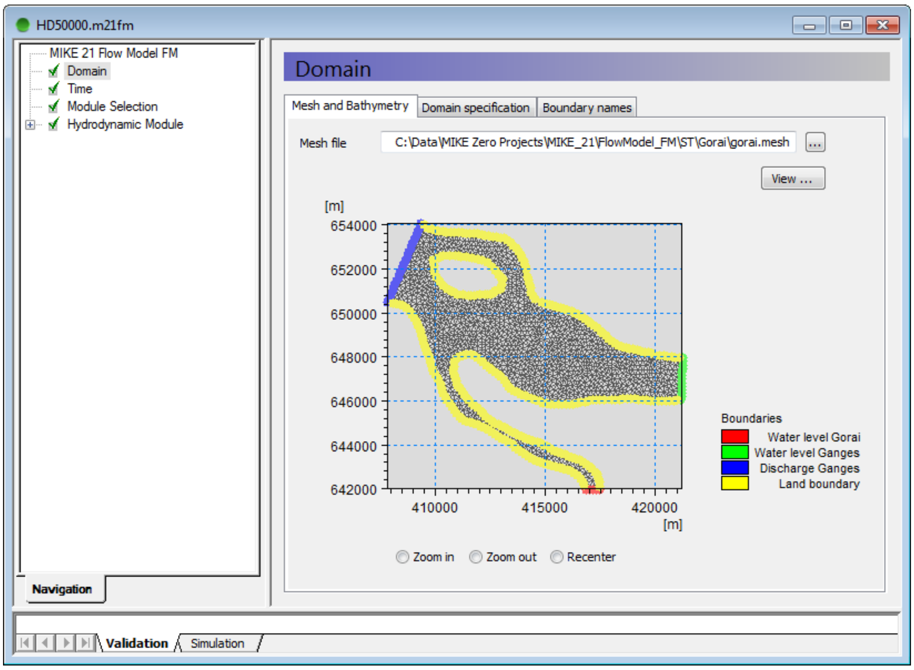

Figure 3.8 Computational mesh and location of boundaries

Click on the **Time** dialogue and specify the number of time steps, the overall time step, and the simulation start date, as shown in Figure 3.9.

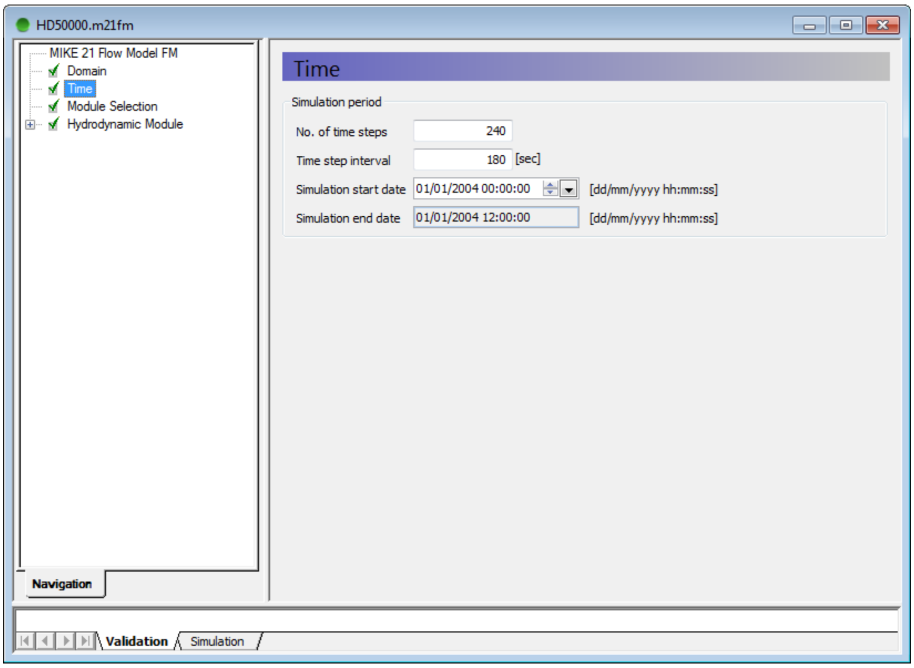

Figure 3.9 Specification of simulation period and time step for peak discharge

The next dialogue is the **Module Selection**. The Hydrodynamic Module is automatically selected, so just click on it to get a validation sign in the tree structure to the left.

Open the tree structure for the Hydrodynamic Module and click on the **Solution Technique** dialogue. Select 'low order, fast algorithm' for the shallow water equation. Specify the minimum time step as 1 s, the maximum time step as 180 s and the critical CFL number as 0.8.

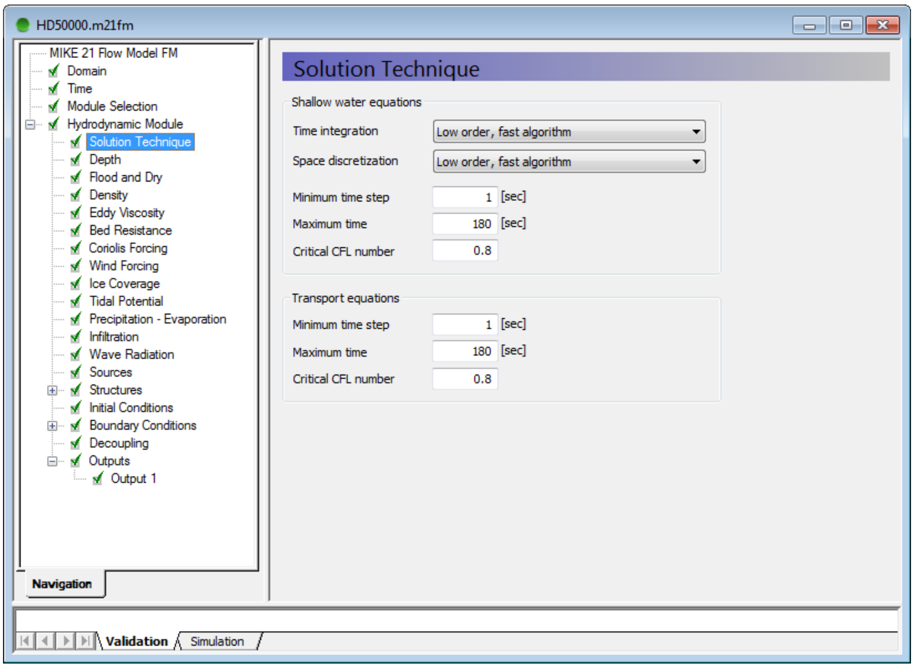

Figure 3.10 Specification of solution technique

Proceed to the **Flood and Dry** dialogue. Hereby, you will get a dialogue window as shown in Figure 3.11.

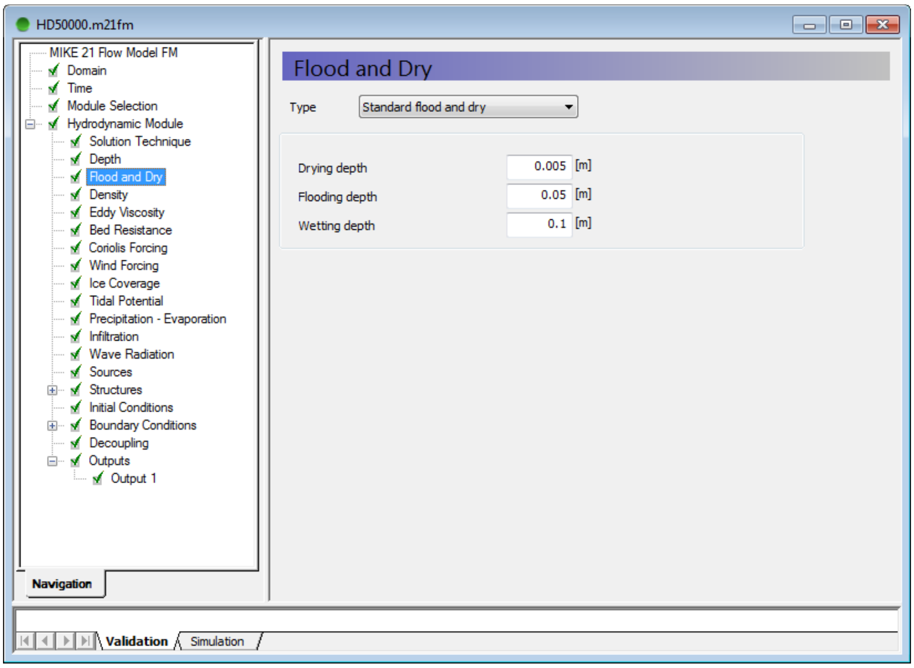

Figure 3.11 Specification of flooding and drying

Keep the default settings and proceed to the **Density** dialogue. The **Density** dialogue is shown in Figure 3.12.

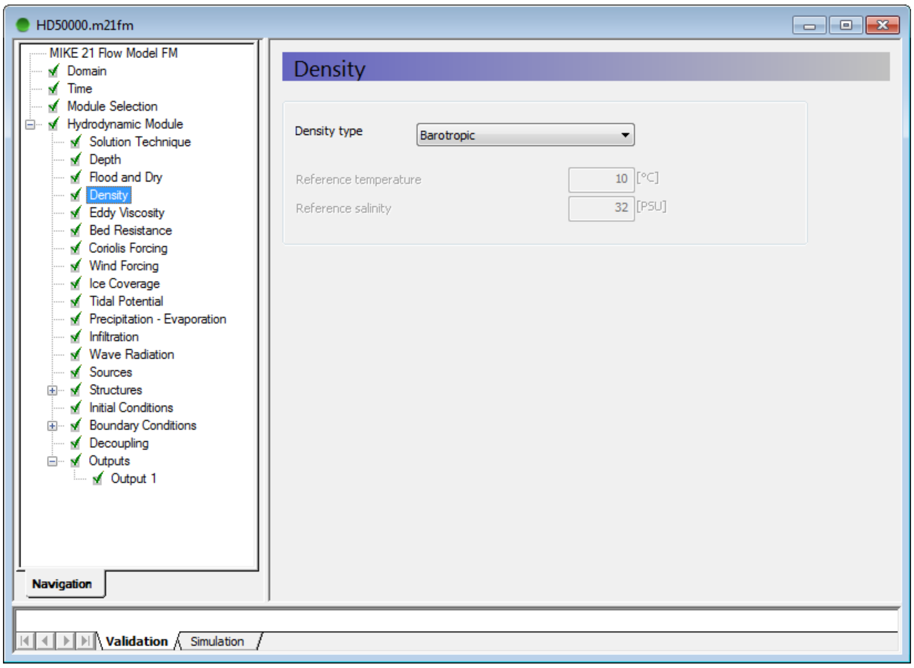

Figure 3.12 Specification of density - only important for temperature and salinity simulations

Keep the default setting (barotropic pressure) and click on the **Eddy Viscosity** dialogue. The dialogue is shown in Figure 3.13.

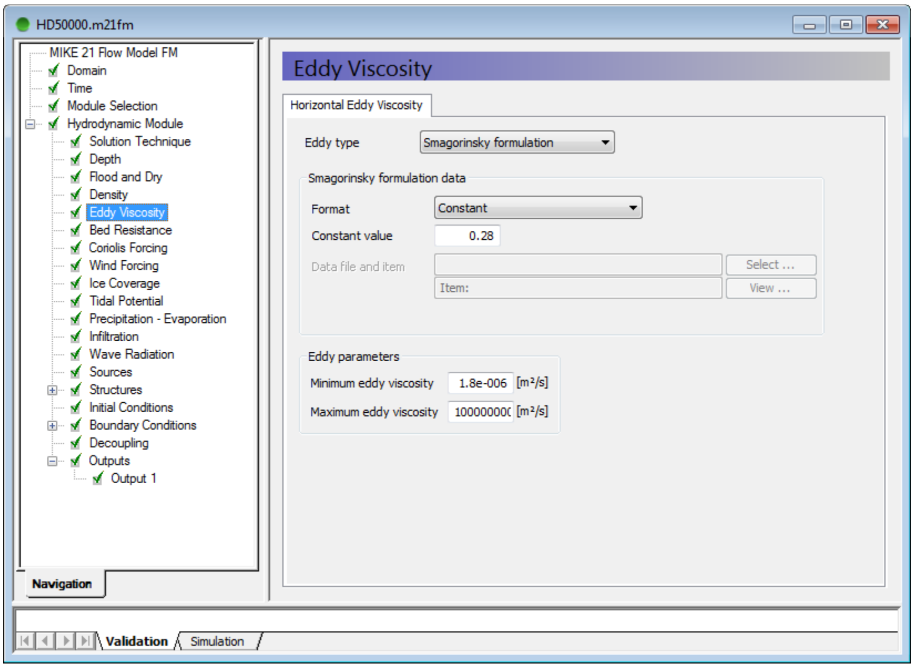

Figure 3.13 Specifications for the eddy viscosity

River flow is mainly convection dominated, i.e. that as a rule of thumb the eddy viscosity should be chosen small in order to prevent too much smoothing of the velocity field. One approach could therefore be to use a **Constant Eddy** of say 0.8 m^2/s.

Please note that the impact from the eddy viscosity depends on the mesh resolution and the HD time step.

Another approach can be to use the **Smagorinsky Formulation**, which is a dynamic calculation of the eddy viscosity. For the analysis of the peak flow discharge, the Smagorinsky formulation has been applied with the default settings. You could also try to make a run with a constant eddy formulation and compare the HD results with the ones obtained based on the Smagorinsky formulation.

The eddy viscosity affects the transverse distribution of the flow velocity, so it is mainly of relevance to calibrate on the eddy viscosity, if the model results can be compared with ADCP data.

The next dialogue is the **Bed Resistance**, which is the most important calibration parameter for river flow applications. The dialogue box is shown in Figure 3.14. Two approaches exist for the modelling of bed resistance; a Manning number formulation and a Chezy number formulation. For the Gorai example, a constant Manning number of 40 is applied.

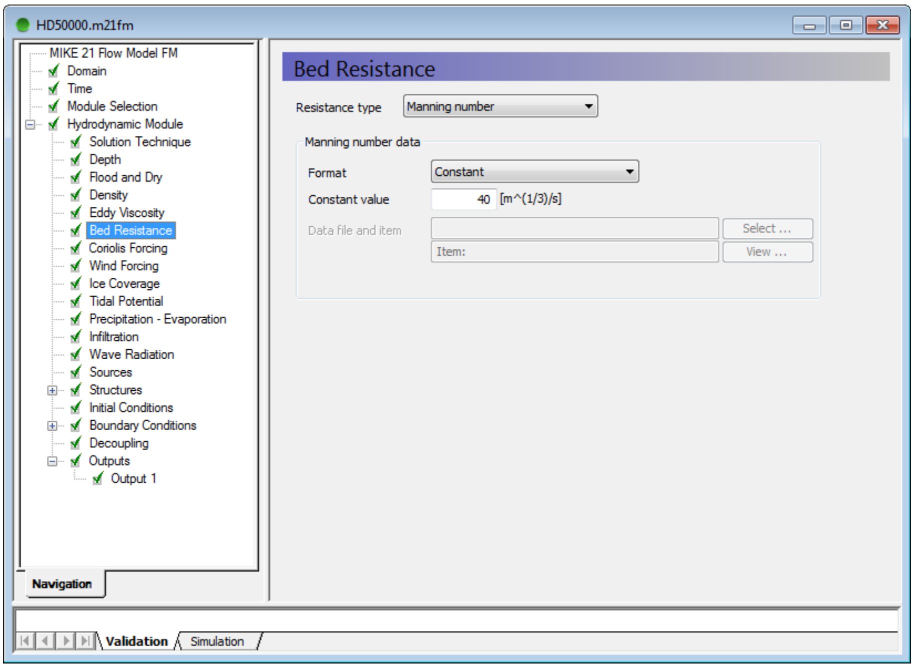

Figure 3.14 Specifications for the bed resistance

The Manning number can be obtained by calibration of the model against known water levels inside the model domain, or generated as a map that tries to take additional resistance from vegetation, bed forms and/or structures into account. A Manning resistance map can be generated in the same way as the mesh. The only difference is that the interpolated values must reflect the Manning resistance instead of the bathymetry. Furthermore, the resistance map should be exported to a dfsu file instead of a mesh file.

Please note: When calibrating the flow resistance for a model to be used for morphological simulations, it is important to be aware of the fact that the conveyance of the system can be significantly improved in a branch like the Gorai River due the applied coarse resolution and the erosion of 'noisy' points in the initial bathymetry. For this reason one should be very cautious with comparison of low flow behaviour based on the initial bathymetry (with a lot of noise included) and the final bathymetry at the end of the monsoon simulation. To do this requires a finer resolution of the Gorai branch.

The next dialogue is the **Coriolis Forcing** shown in Figure 3.15. For the Gorai example it has been chosen not to include the Coriolis forcing due to the use of a non-UTM coordinate system and the limited extent of the model. However, a constant Coriolis forcing can be included if the latitude is specified. For the Gorai example a value of 24 degrees should be specified. Try to make a comparison between model results created with and without inclusion of Coriolis forcing.

The next seven dialogues **Wind Forcing**, **Ice Coverage**, **Tidal Potential**, **Precipitation-Evaporation**, **Infiltration**, **Wave Radiation** and **Sources** are not essential for the Gorai example, i.e. default settings are applied. Try to click on them to see what kind of options can be applied.

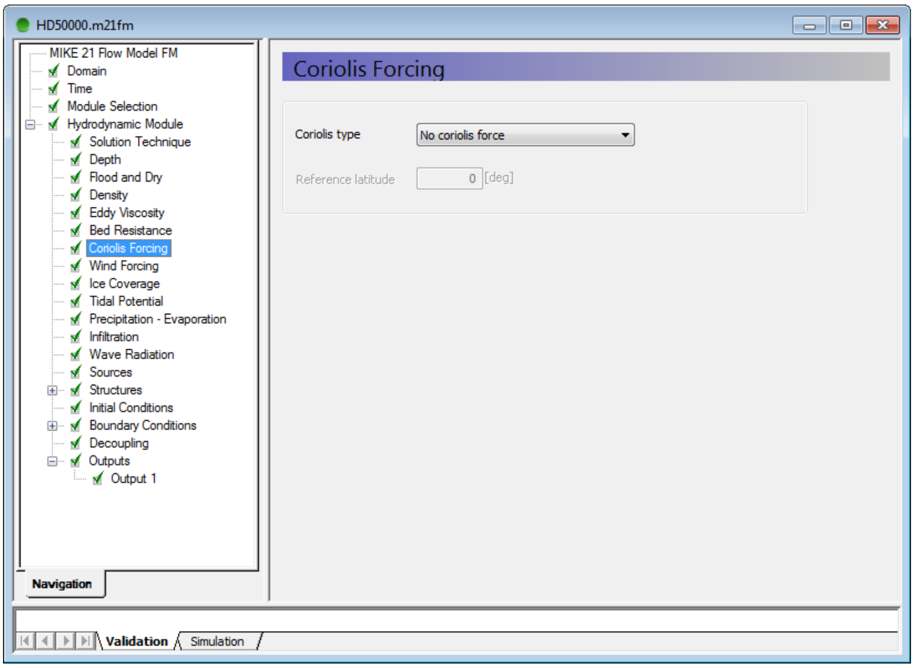

Figure 3.15 Specification window for Coriolis forcing

Figure 3.16 shows the dialogue window for **Initial Conditions**. For the peak flow discharge simulation the initial surface elevation is chosen as the maximum value of the two water levels at the downstream boundary in Gorai and Ganges. Furthermore, the model is initialised with zero flow velocities.

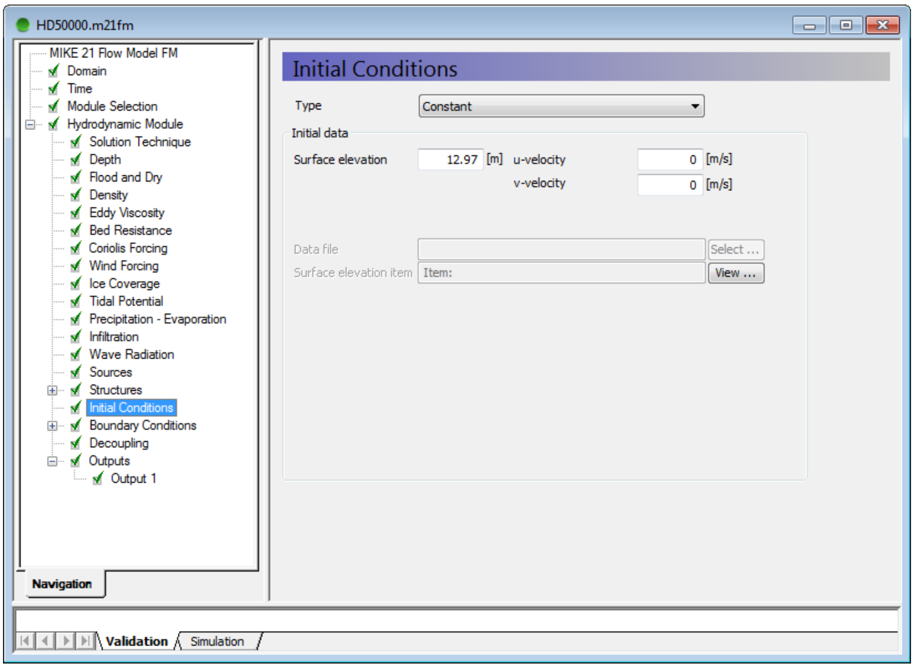

Figure 3.16 Specification window for Initial conditions

The hydrodynamic boundary conditions are specified in three separate sheets under the **Boundary Conditions** dialogue. Figure 3.17 and Figure 3.18 show the specification dialogues for the Ganges discharge boundary and the Gorai water level boundary, respectively.

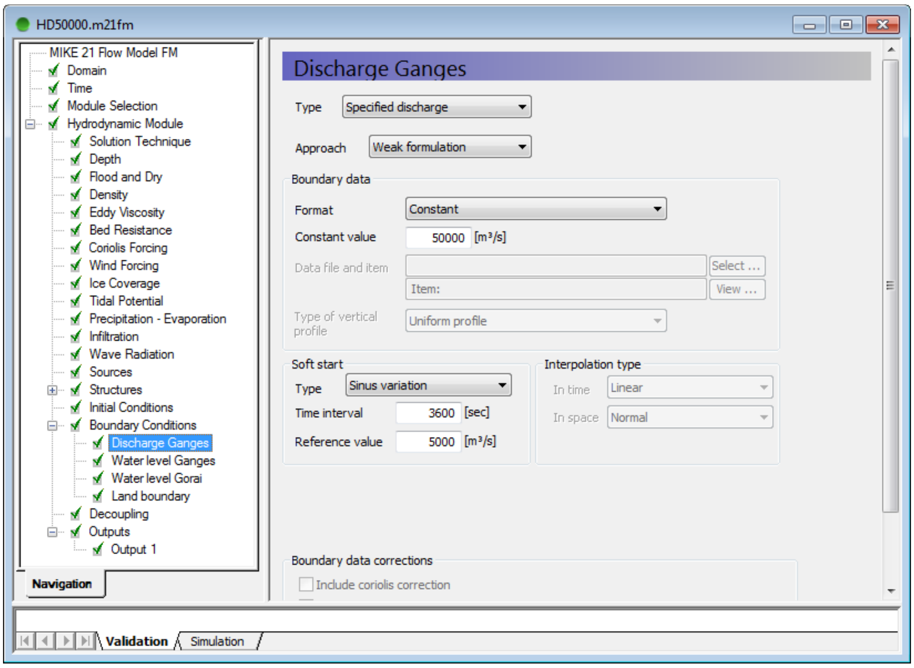

Figure 3.17 Specification window for Ganges discharge boundary condition

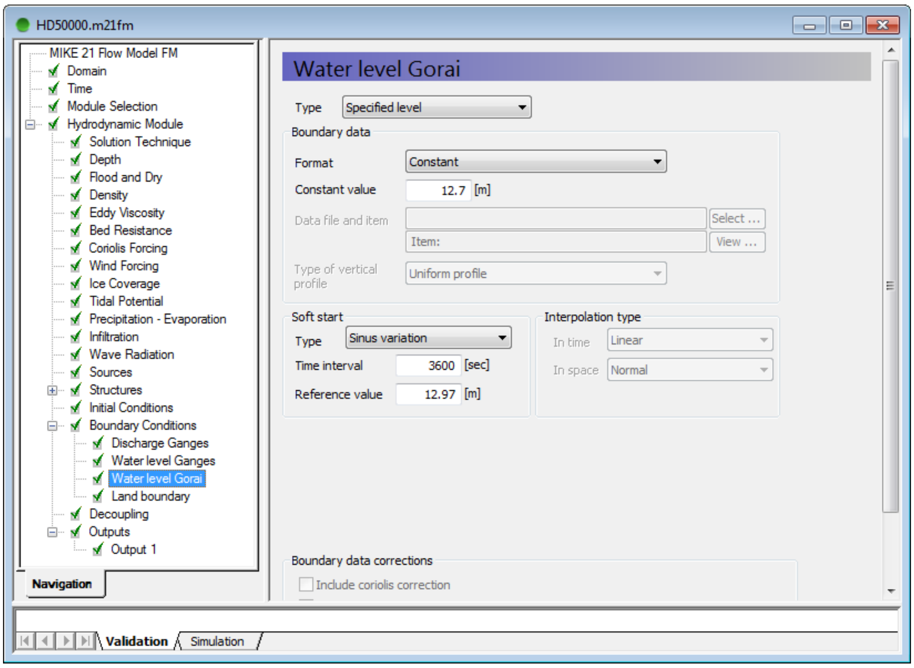

Figure 3.18 Specification window for Gorai water level boundary condition

On both boundaries a soft start approach is used. As reference value for the water level the value of the initial surface elevation is applied.

The next dialogue is **Decoupling**. This dialogue is only relevant when running additional modules without morphological update.

The final dialogue box shows the **Output** windows, see Figure 3.19. In the first window the output file name, output format, and storing frequency are specified. Output can be specified as area series, line series, and point series. In the second window the output variables can be selected.

The resulting input file, HD50000.m21fm, can be used to carry out sensitivity analysis of the various input parameters as mentioned previously.

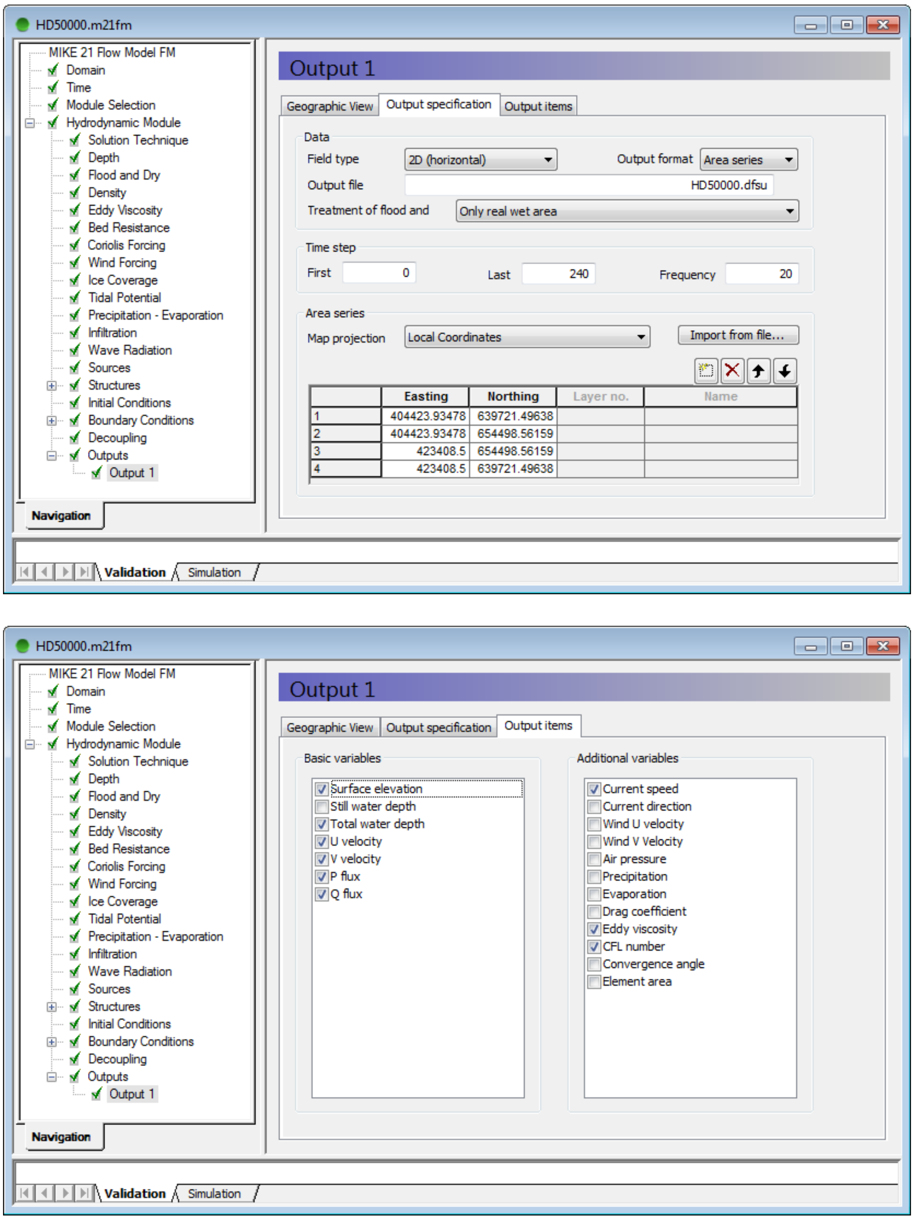

Figure 3.19 Specification windows for the HD output

3.6 Sediment Data

Analysis of sediment samples from different locations in the river is of great importance for a morphological study. However, it is only the conclusion of the analysis that is of relevance for the modelling. So we will just list the relevant parameters obtained from the analysis of sediment samples.

The sediment properties are assumed to be constant over the area in the start of the simulation. The sediment is quartz sand with a density of 2650 kg/m^3. The porosity of the bed is estimated to 0.35.

When using only a single fraction for the simulation the median grain size is 0.18 mm.

When using a multi-fraction approach two grain fractions are used: one with a median grain size of 0.18 mm and one with a median grain size of 2.0 mm. These two fractions each represent 50% of the total amount in the start of the simulation.

The porosity is only of importance for the morphological modelling (bed update), because it affects the bed volume of the transported sediment, not the magnitude of the transported load.

Sand Transport Module - © DHI A/S

4 Set-Up of MIKE 21 Flow Model FM

We are now ready to create the specification file for the morphological simulation of the Gorai Ganges system for the passage of the 1999 monsoon. For the HD part the parameters are kept the same as for the peak flow simulation, except for the simulation period, solution technique, initial conditions, boundary conditions, and output extraction.

The sand transport simulation is carried out using two different approaches; single fraction and multi-fraction.

4.1 Specifications for the MIKE 21 Flow Model FM

In Table 4.1 the parameters applied for the morphological simulation are listed in short.

Table 4.1 Specifications for the morphological simulation

Parameter	Value
Specification Mesh File	Gorai.m21fm
Mesh and Bathymetry	Gorai.mesh 1645 Nodes 2948 triangular elements
Simulation Period	1999-06-29 00:00 – 1999-11-23 00:00 (147 days)
Time Step Interval	10 s
No. of Time Steps	1270080
HD: Solution Technique	Minimum Time Step: 0,1 s Maximum time Step: 10 s
HD: Enable Flood and Dry	Yes
HD: Initial Surface Level	9.19 m
HD: Boundary time Series: Ganges Discharge Ganges Water Level Gorai Water Level	WLQ.dfs0 (daily values) Item 3: Obs. Q, Hardinge Br. Item 2: Obs. WL, Ganges Item 1: Obs. WL, Gorai
HD: Eddy Viscosity	Smagorinsky formulation
HD: Resistance	Manning number. Constant in domain: 40 $m^{1/3}/s$
ST: Model Type	'Pure current' / 'Pure current – Multi fraction/Multi layer'
ST: Sediment properties	Constant, d50 = 0.18 mm / 0.18 mm and 2.0 mm
ST: Morphology	Include feedback on hydrodynamic, helical flow, and sand transport calculation
ST: Boundaries	Zero sediment flux gradient for outflow, zero bed change for inflow
Result Files	HD.dfsu, ST.dfsu
Simulation Time	About 1.25 hour with a 2.2 GHz PC, 8 GB RAM, 4 cores

Additional information about the Sand Transport Module can be found in the User Guide, which can be accessed via the MIKE Zero Documentation Index in the start menu:

MIKE 21 Flow Model FM, Sand Transport Module, User Guide

4.2 Specifications for Basic Parameters

The specifications for the **Basic Parameters** were described in Section 3.5 for the peak flow simulation, so only parameters that have changed are described in the following by a number of screen dumps.

Figure 4.1 shows the specifications for the simulation period that covers the monsoon period.

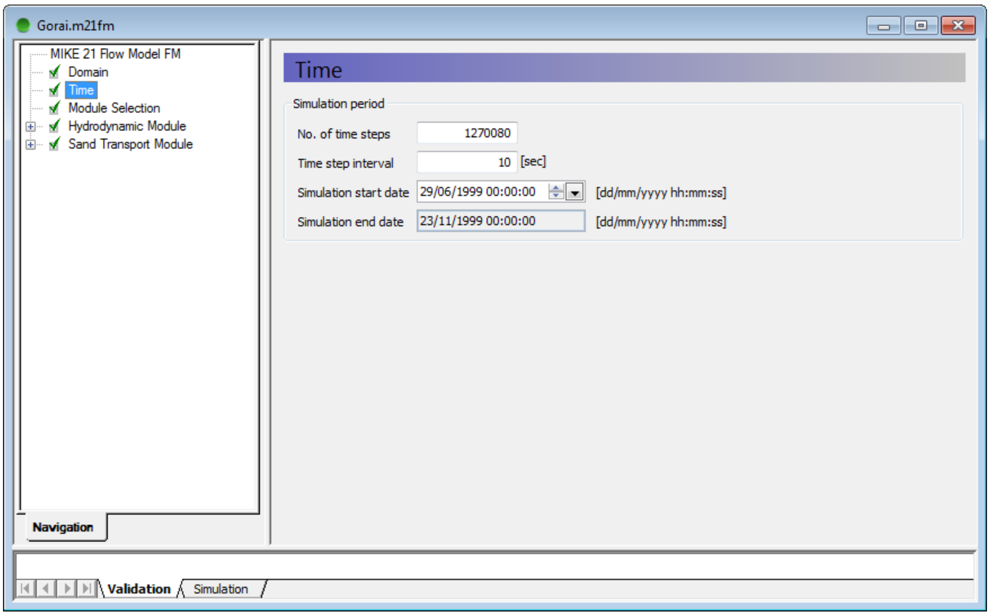

Figure 4.1 Specification window for simulation period and time step

Figure 4.2 shows the **Module Selection** dialogue from which the **Sand Transport Module** is activated.

When a module is selected, the specification parameters for the module are automatically added to the tree structure.

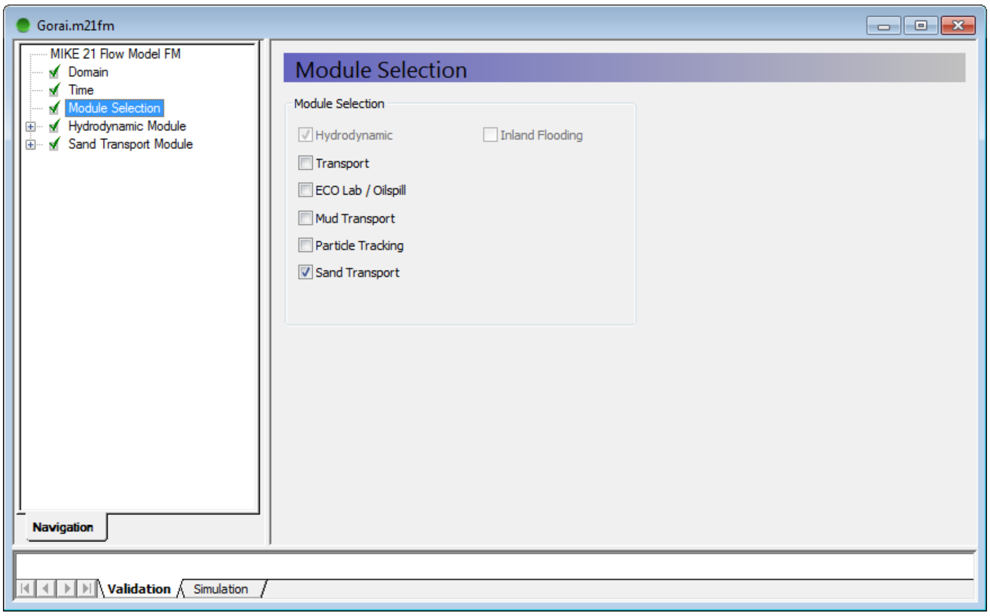

Figure 4.2 Module selection window

4.3 Specifications for the Hydrodynamic Module

For the HD parameters, not only the solution technique, initial conditions and the boundaries conditions have changed, but also the output specifications.

Figure 4.3 shows the solution technique values for the morphological simulation.

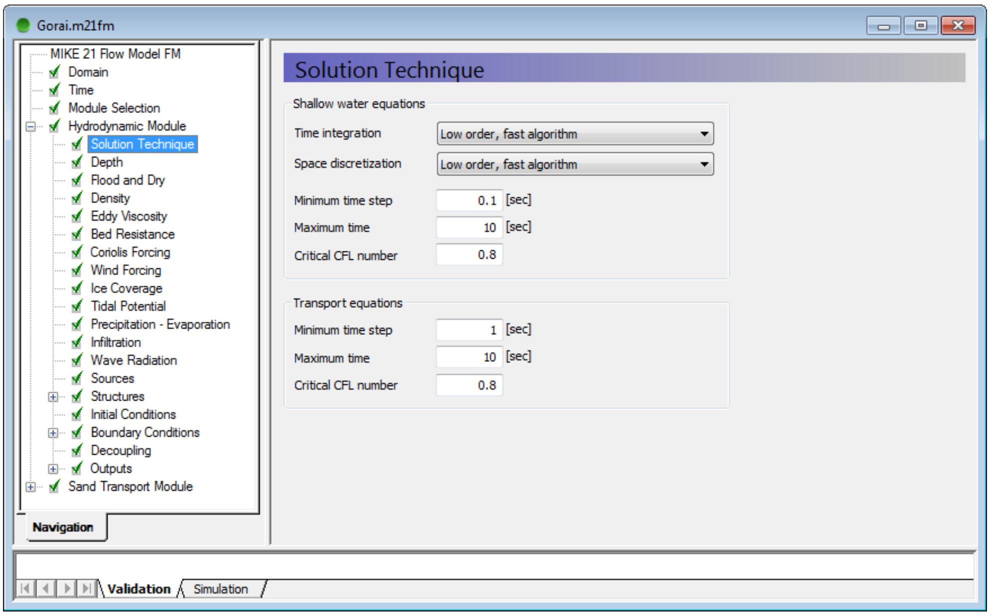

Figure 4.3 Specification of solution technique

Figure 4.4 shows the initial conditions for the surface elevation, which correspond to the initial downstream boundary conditions for Ganges.

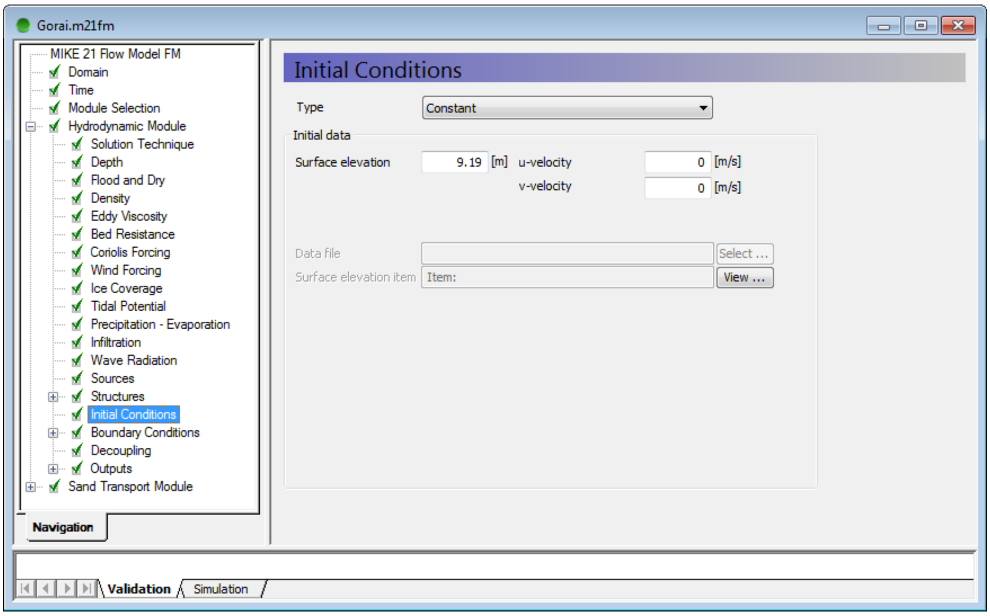

Figure 4.4 Specification of initial conditions

In the following Figure 4.5 to Figure 4.7 show the specifications for the boundary conditions along the three open boundaries.

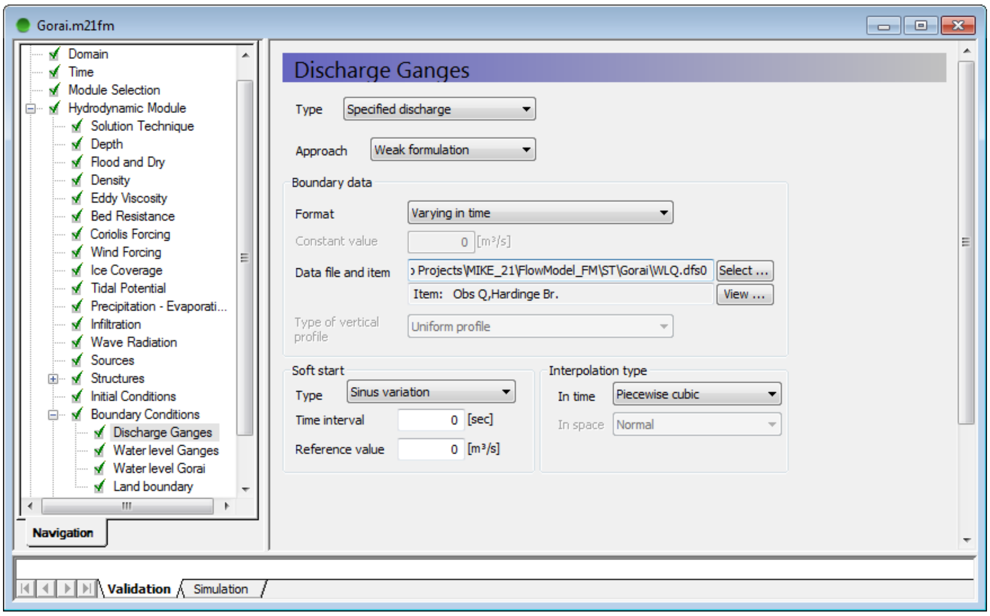

Figure 4.5 Specifications for the upstream discharge boundary in Ganges

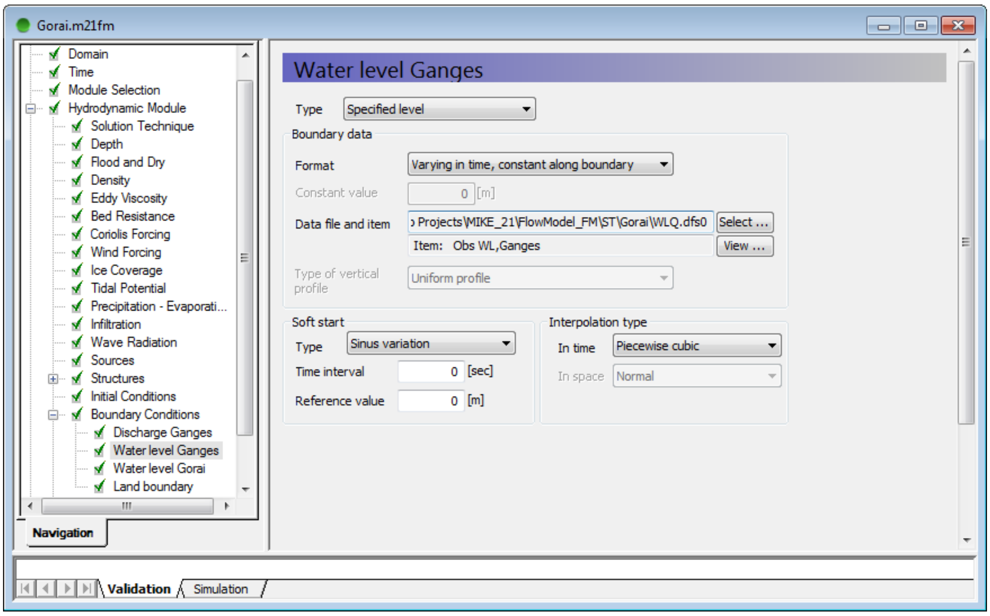

Figure 4.6 Specifications for the downstream water level boundary in Ganges

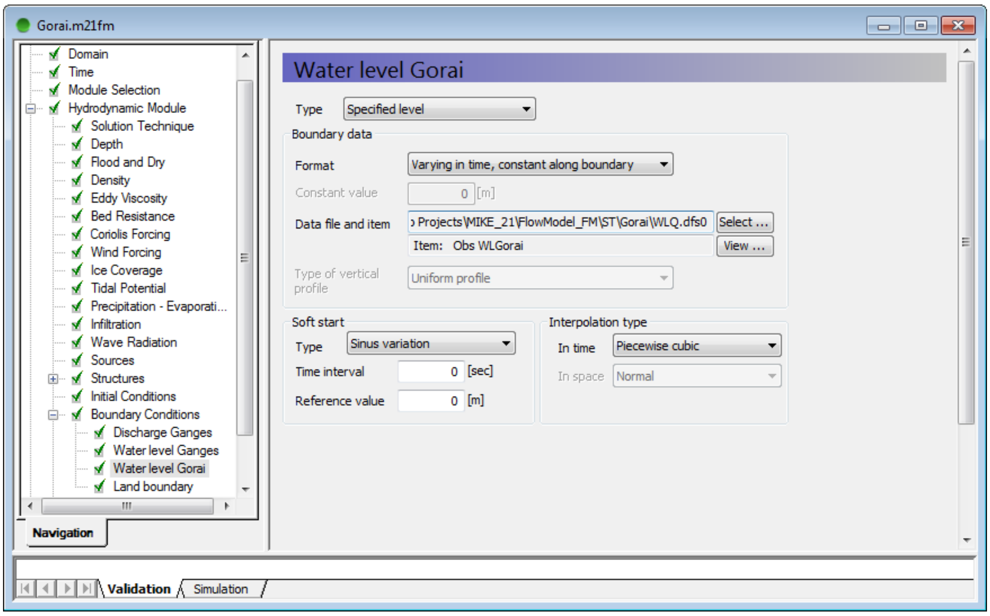

Figure 4.7 Specifications for the downstream water level boundary in Gorai

The HD output is saved daily, i.e. for every 8640 time step. Only the total water depth, P and Q fluxes and current velocity are saved.

4.4 Specifications for the Sand Transport Module (Single fraction)

For a river application waves are not considered. The specifications for the sediment transport and morphological model when the sediment is considered by a single fraction are described in the following by a number of screen dumps.

Figure 4.8 shows the specification window for the type of model. For a river application with uniform sediment the **Model type** should be specified as: **Pure current**.

Please note that if suspended sediment transport is of significance you should always choose the **Non Equilibrium** description; and if flow curvature is of significance you should always **include helical flow effects** on the bed load and suspended load.

The theory applied for calculation of the sediment transport is shown in Figure 4.9. Four types of formulas can be selected:

- Engelund and Hansen (total transport formula)
- Van Rijn (separate description of bed load and suspended load)
- Engelund and Fredsøe (separate description of bed load and suspended load)
- Meyer-Peter & Müller (only bed load)

For the Gorai example the Van Rijn models are applied for both the bed load and suspended load. The magnitude of the transport rates can be modified by use of the load factor. This is only relevant for cases where the modelled transport rates can be calibrated against observations. Furthermore, a threshold value for the sediment concentration is specified.

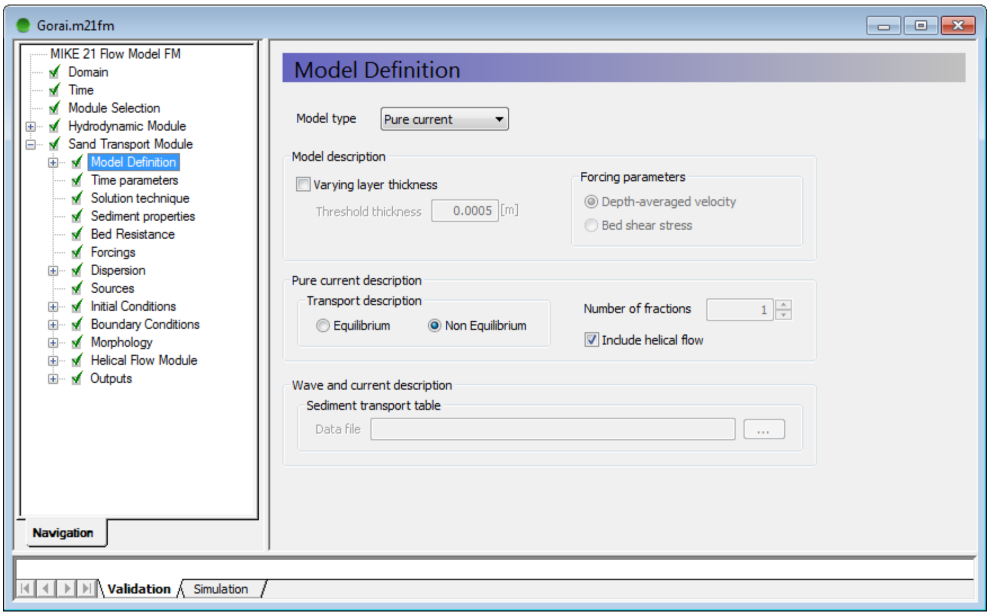

Figure 4.8 Model definition window for the ST model

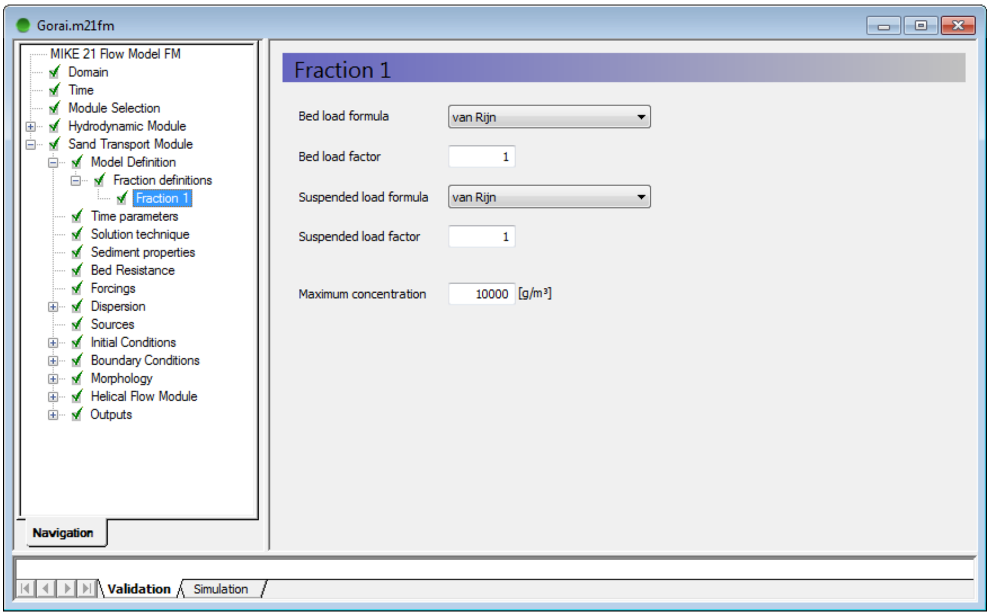

Figure 4.9 Specification of transport formulas for bed load and suspended load

Figure 4.10 shows the **Time parameters** window, where the start time step for the sediment transport model is defined. In the Gorai model it is activated after 12 hours, i.e. at a time step, where the hydrodynamics has reached 'equilibrium conditions'. Furthermore, define the time step factor to 30, such that the rate of bed level change is recalculated for every 5 minutes.

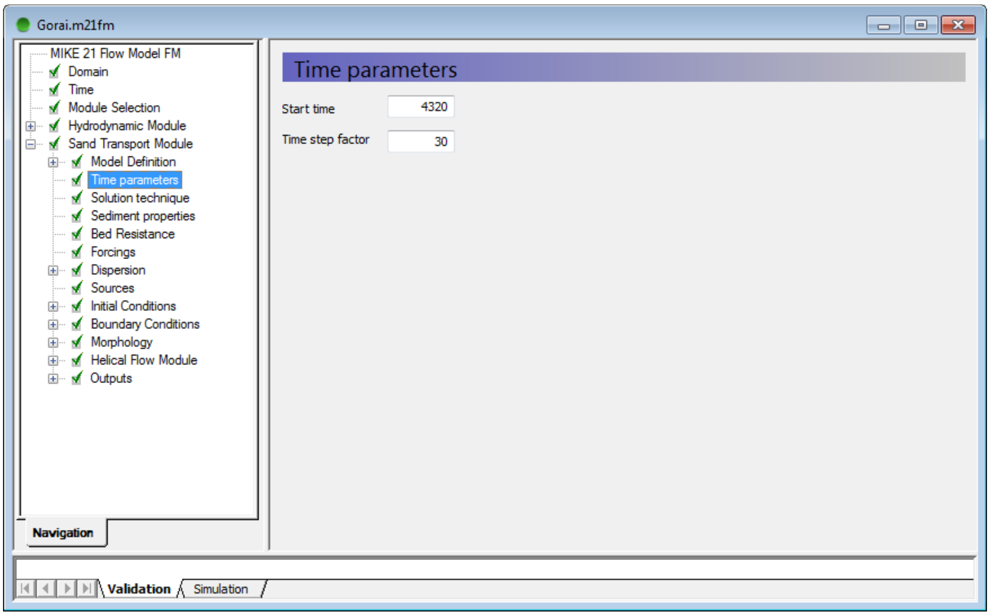

Figure 4.10 Time step factor for calculation of the bed level rate used for morphological update

The next step is to specify the characteristics for the sediment as shown in Figure 4.11. The grain diameter can be defined as a constant value or by a map. If defined by a map, the distribution will remain static through the simulation and not reflect any migration of the sediment distribution. The porosity is only of relevance for morphological simulations, because it links the transport rate into bed volumes.

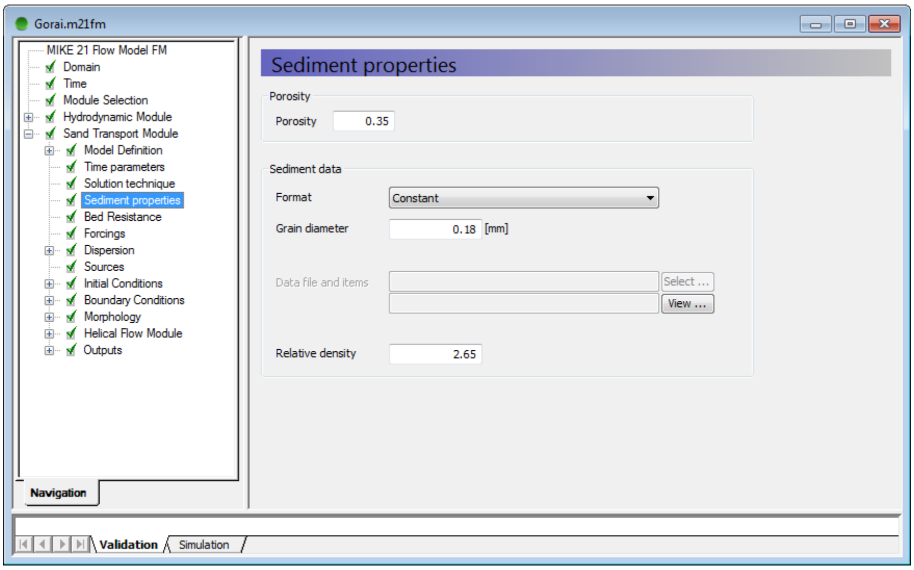

Figure 4.11   Specifications for sediment properties

The **Bed Resistance** is chosen similar to the one used for the Hydrodynamic Module, but the model actually allows use of a decoupled resistance formulation. **Forcing** is not relevant in this example because it is related to impact from waves.

The dispersion settings can be of great importance for the behaviour of the suspended sediment (Figure 4.12), especially if the **Scaled eddy viscosity formulation** based on the Smagorinsky model is applied and the spatial gradients in sediment concentration are large. When the scaled eddy viscosity approach is applied, the dispersion of the concentration of the suspended sediment is obtained as the sum of the eddy viscosity and the sediment model estimated dispersion. If **No dispersion** is selected the dispersion coefficients are obtained as the sediment model estimated dispersion. The dispersion coefficients from the sediment model are anisotropic. Information about how the sediment model dispersion is obtained can be found in the Scientific Documentation for the Sediment Transport - Pure Current.

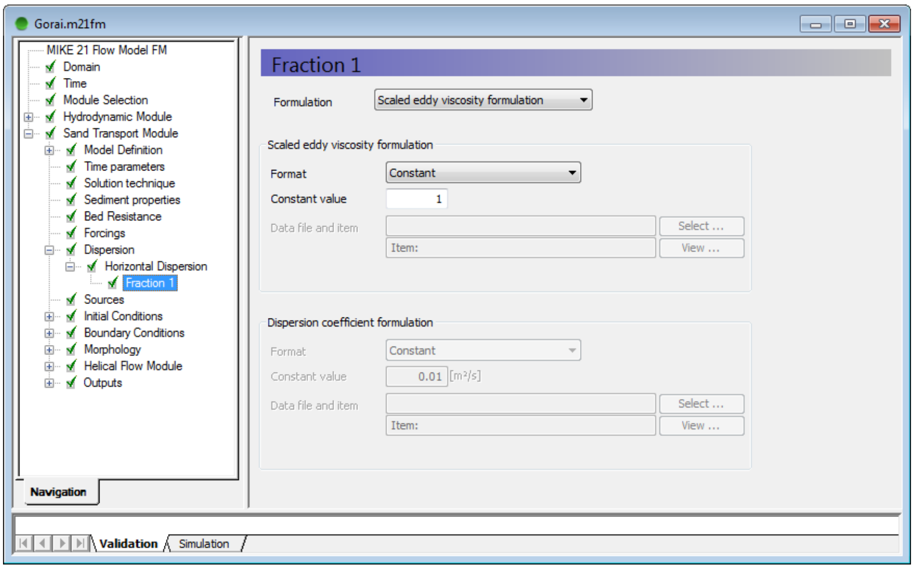

Figure 4.12   Specifications for the dispersion in the transport equation for the suspended sediment

For the present model (mesh), the morphological results will almost not be influenced by the use of a different modelling approach for dispersion. The reason for this is the coarse mesh, which is not able to resolve steep gradients properly.

When solving an advection-dispersion equation, **Initial Conditions** for the concentration of the suspended sediment need to be defined, see Figure 4.13. As initial condition the equilibrium concentration should be applied. However, the initial condition is quite irrelevant if the morphological bed update is activated later as in this example.

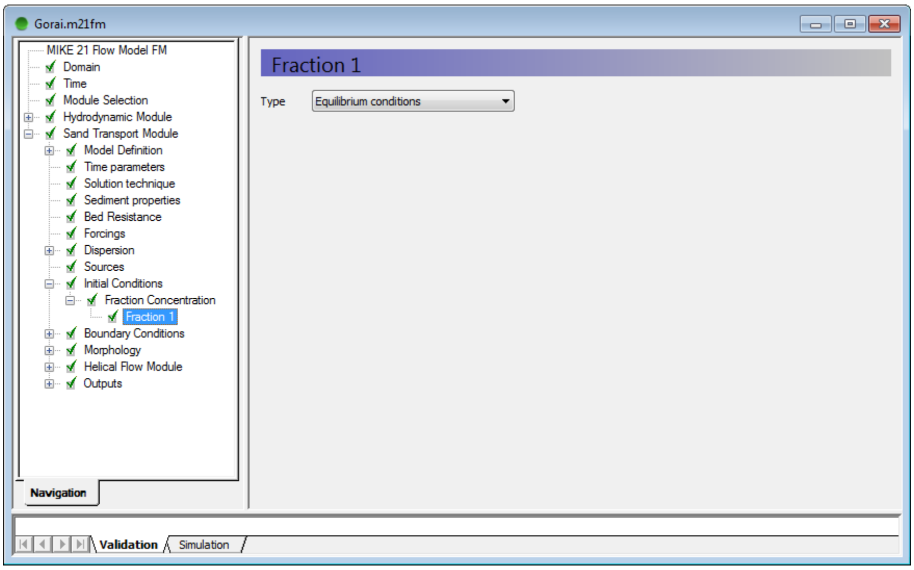

Figure 4.13 Equilibrium conditions are applied as initial concentration for the suspended sediment

Also the boundary conditions for the suspended sediment need to be defined. At the Ganges inflow boundary an equilibrium assumption is applied, see Figure 4.14. While at the two outflow boundaries a symmetry condition (zero-gradient) is applied, see Figure 4.15.

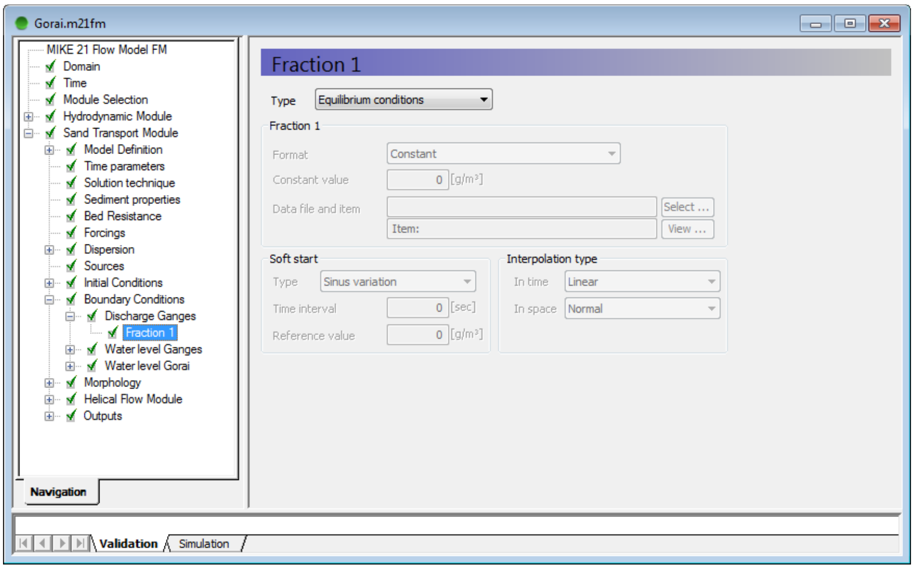

Figure 4.14 Specification of the boundary condition for the suspended sediment at the inflow boundary

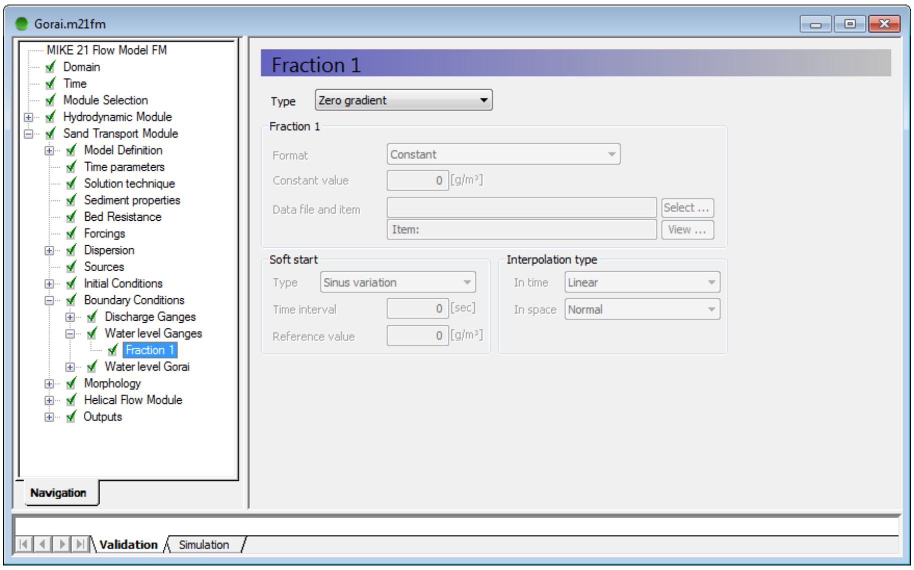

Figure 4.15 Specification of the boundary condition for the suspended sediment at the outflow boundaries

For the morphological part of the model, a few parameters need to be specified, as shown in Figure 4.16. The speedup factor should be kept equal to 1, unless steady HD boundary conditions are applied or the hydrograph has been squeezed in order to run a scaled HD-simulation.

Feedback on HD and ST should always be activated when working with river applications.

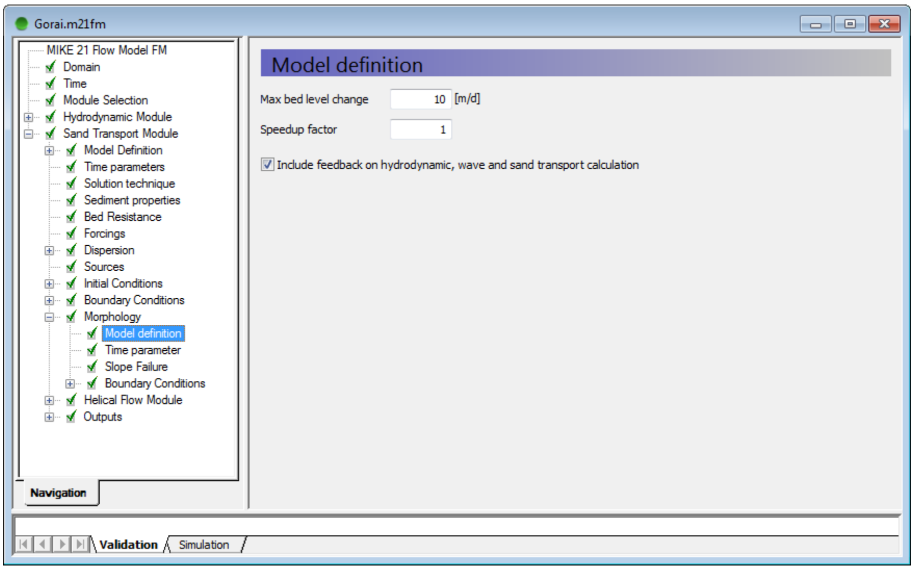

Figure 4.16 Specification of maximum allowed bed level changes per day and feedback to the Hydrodynamic Module

Also information on the start time step of the morphological bed update must be specified as shown in Figure 4.17. For the Gorai example the morphological update is activated after 8640 time steps corresponding to after 1 day.

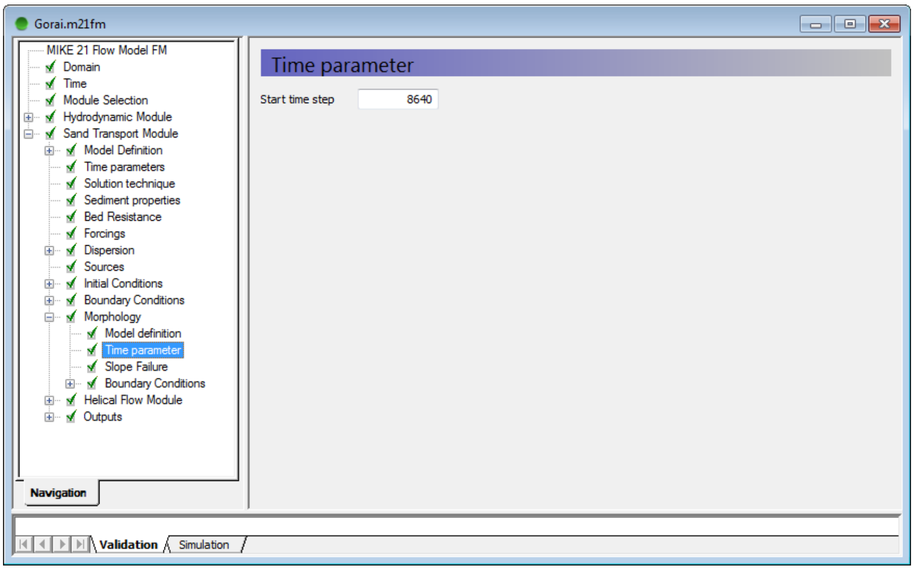

Figure 4.17 Specification of start time step for morphological bed update

For the morphological update, also boundary conditions need to be specified. For all open boundaries the **Zero sediment flux gradient for outflow, zero bed change for inflow** is applied, see Figure 4.18.

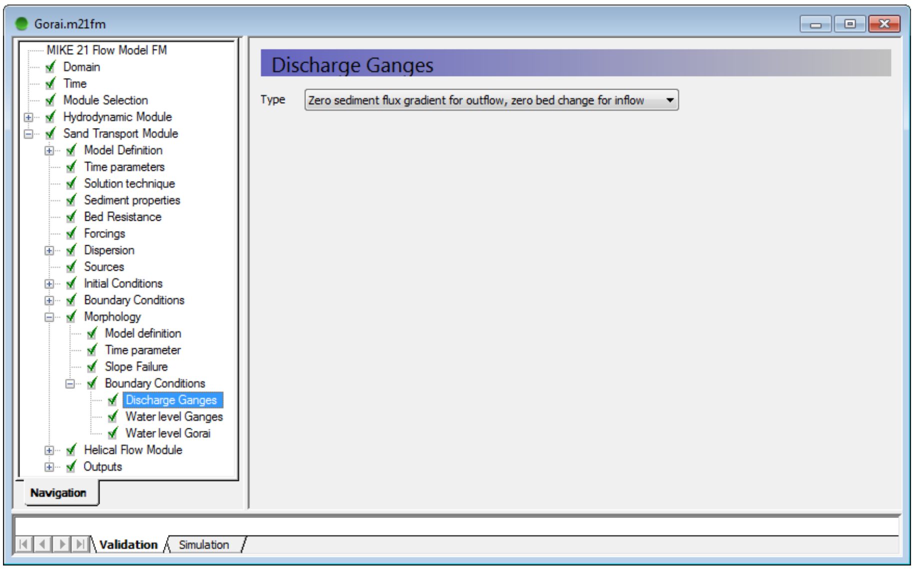

Figure 4.18 Specification of the morphological boundary conditions

Before solving the advection-dispersion equation for the concentration of the suspended sediment, the advection-dispersion equation for the helical flow must be solved. The relevant parameter settings for the helical AD-module are shown in the following figures. Figure 4.19 shows the specification for the **time start step**, which has been chosen to 4320 corresponding to 12 hours and similar to the choice used for sediment transport.

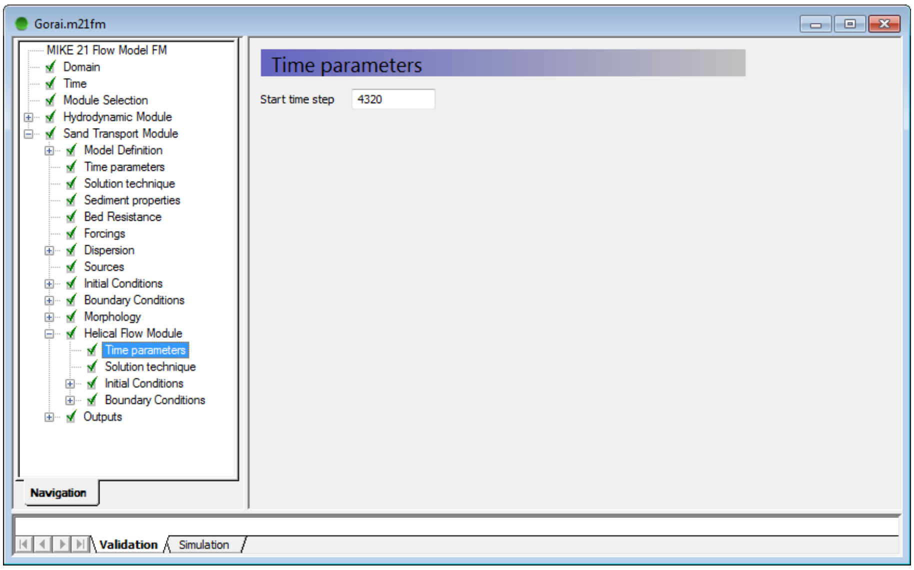

Figure 4.19 Specification of start time step for calculation of the helical flow

The solution technique is set to the same type as in the HD simulation, namely 'low order, fast algorithm'.

As Initial Conditions for the helical flow, you should choose Equilibrium conditions, see Figure 4.20.

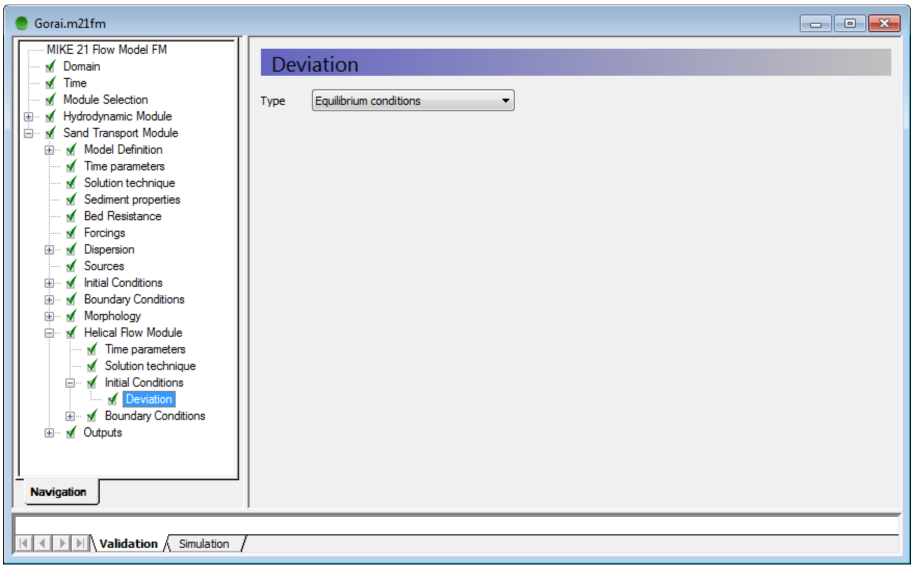

Figure 4.20 Specification of initial conditions for the helical flow

Finally, a symmetry condition (zero-gradient) is applied at all three open boundaries, as shown in Figure 4.21.

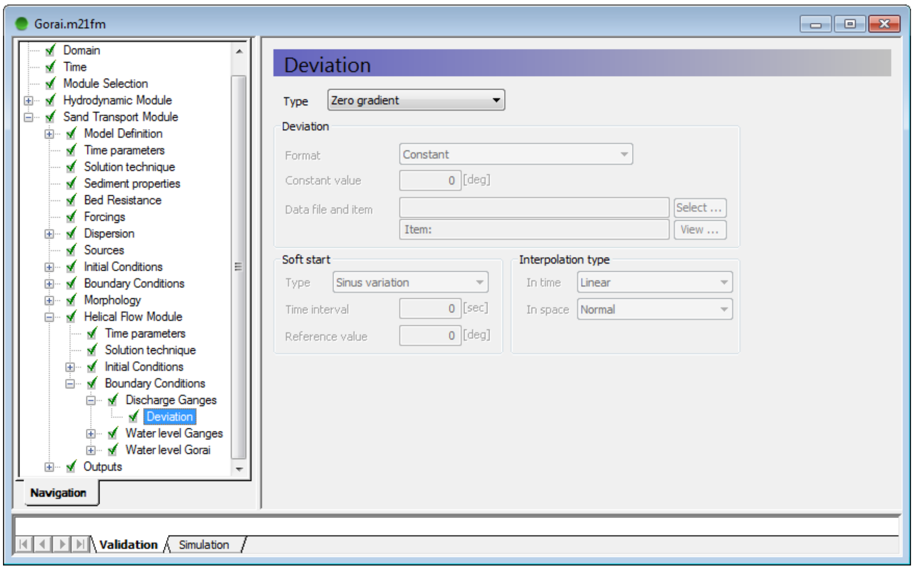

Figure 4.21 Specification of the boundary conditions for the helical flow

The last piece of information that needs to be specified is the type of output from the sediment transport module. From Figure 4.22 it can be seen that outputs are saved as an area series with a frequency corresponding to daily extraction.

Figure 4.23 shows the output items that are saved during the simulation.

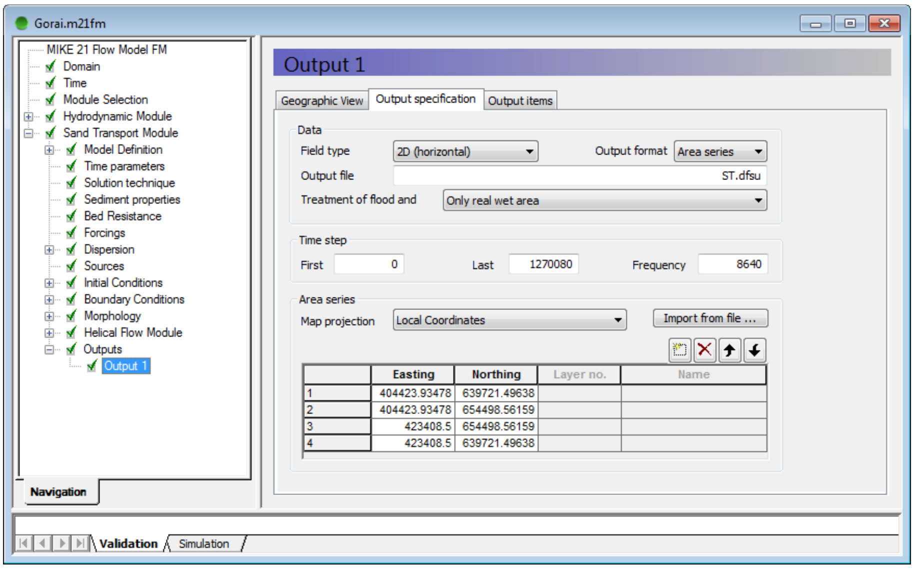

Figure 4.22 Specification window for the type and location of ST output

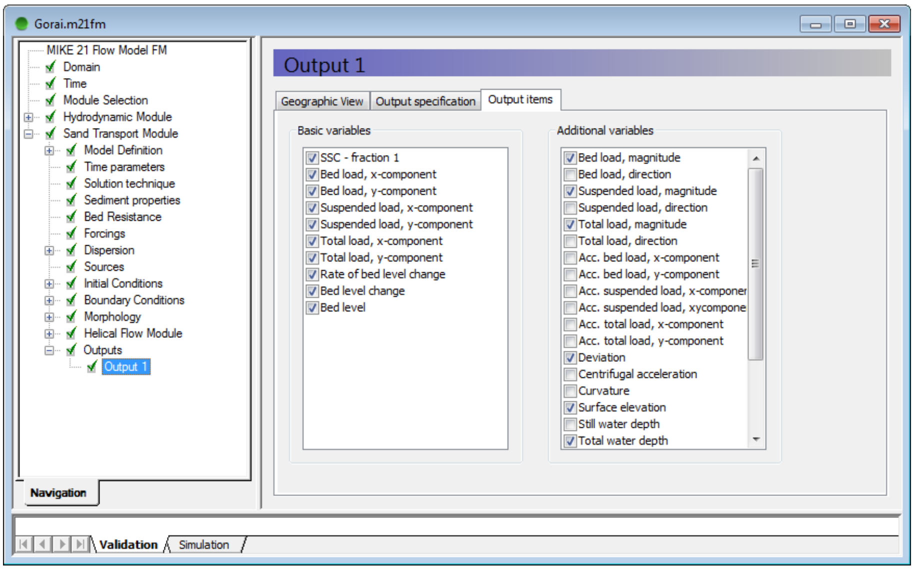

Figure 4.23 Specification of output parameters from the sediment transport module

Especially, the magnitude of the bed load, suspended load, and total load are useful to extract and easy to understand due to their scalar nature. The x and y-components of the different types of sediment loads are only relevant for vector plotting.

The result files can be viewed during the simulation. New processed results will automatically be made available for the **Data Viewer**, i.e. it is not necessary to reload the files.

4.5 Specifications for the Sand Transport Module (Multi fraction)

For a river application waves are not considered. The specifications for the sediment transport and morphological model when the sediment is mixed and considered using a multi-fraction/multi-layer approach are described in the following by a number of screen dumps.

Figure 4.24 shows the specification window for the type of model. For a river application with mixed sediment the **Model type** should be specified as: **Pure current – Multi fraction/Multi layer**.

If flow curvature is of significance you should always **include helical flow effects** on the bed load and suspended load.

For this simulation we assume that the sediment consists in a mixture of sand and gravel. In this example the number of fractions is set to 2 and we use 2 layers. More layers can be used when more information about the vertical distribution of sediment layers is available. The magnitude of the transport rates can be modified by use of the load factor as shown in Figure 4.25. This is for example relevant for cases where the modelled transport rates can be calibrated against observations. In this example a factor is used to compensate the fact that we use a mixed sand-gravel sediment and stay consistent with the pure current example using uniform sediment.

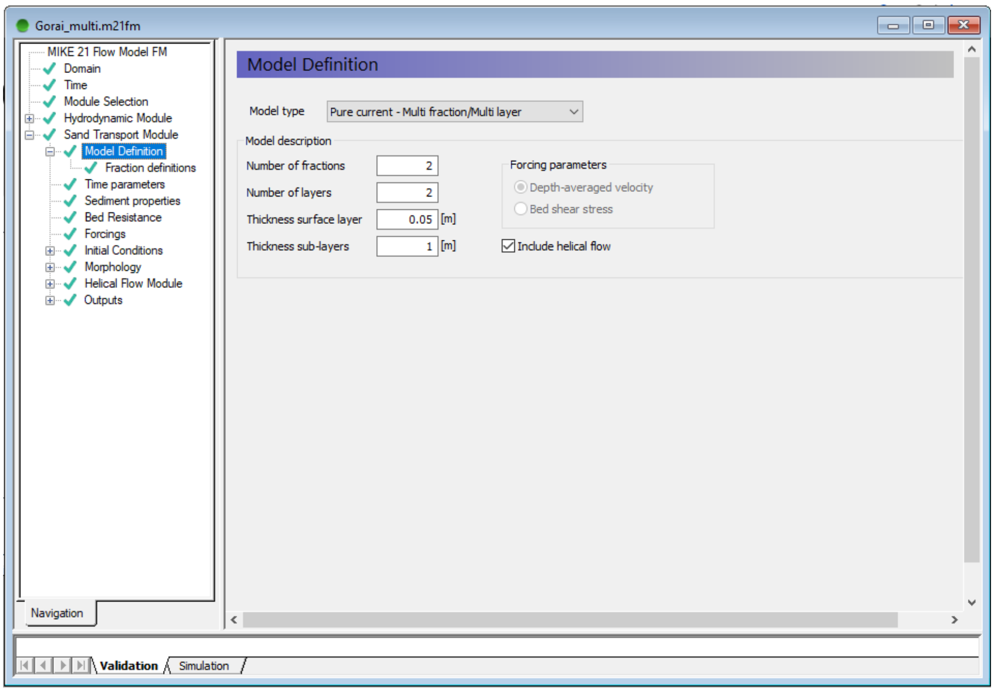

Figure 4.24 Model definition window for the ST model

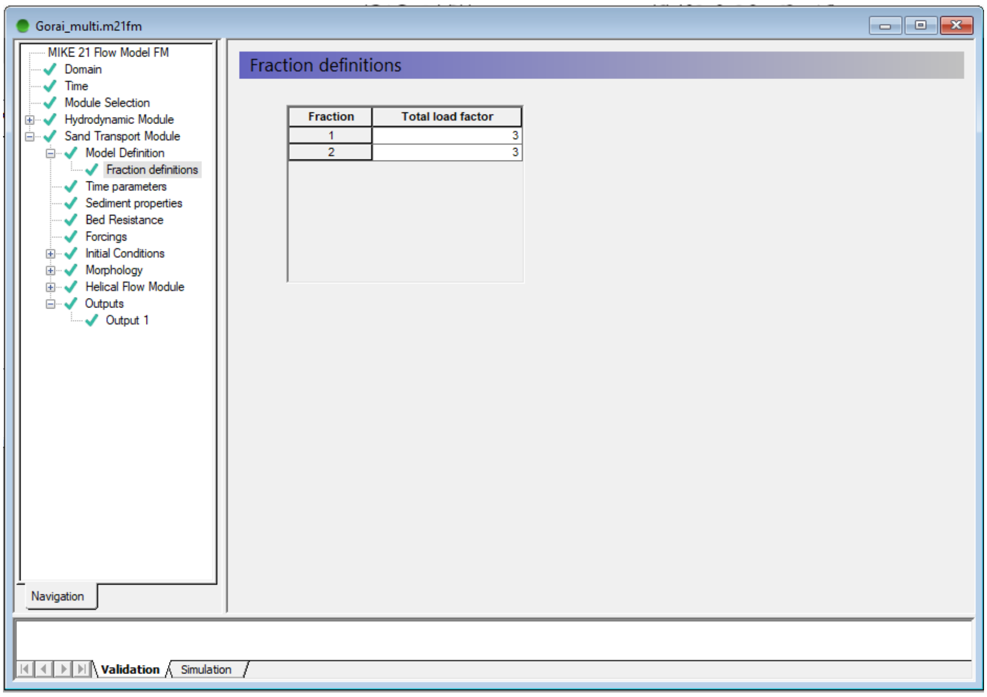

Figure 4.25 Specification of load factors for multi fraction

Figure 4.26 shows the **Time parameters** window, where the start time step for the sediment transport model is defined. In the Gorai model it is activated after 12 hours, i.e. at a time step, where the hydrodynamics has reached 'equilibrium conditions'. Furthermore, define the time step factor to 30, such that the rate of bed level change is recalculated for every 5 minutes.

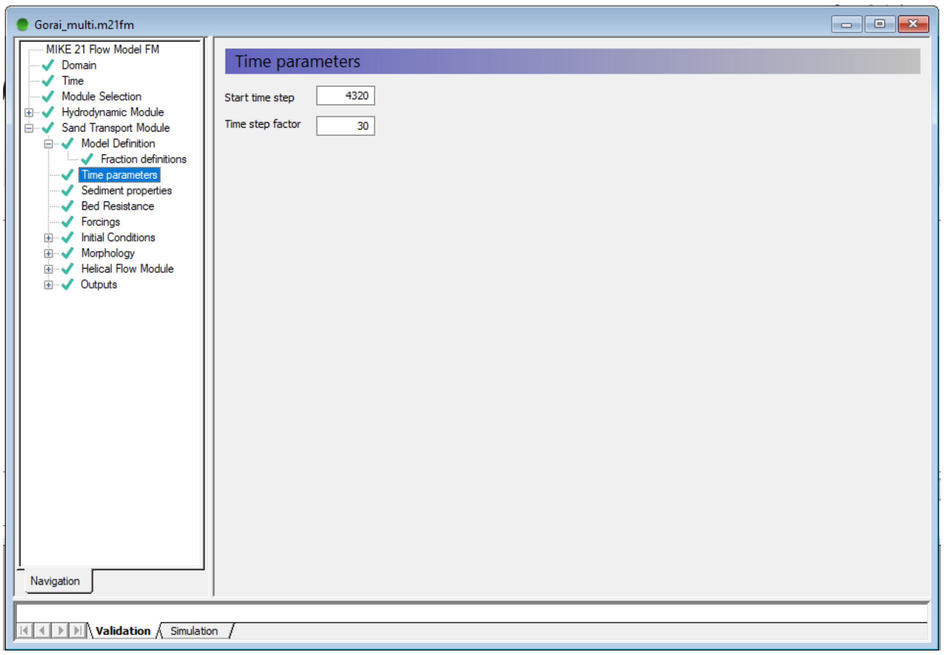

Figure 4.26 Time step factor for calculation of the bed level rate used for morphological update

The next step is to specify the characteristics for the sediment as shown in Figure 4.27. The grain diameter for each of the fractions has to be specified. The porosity is only of relevance for morphological simulations, because it links the transport rate into bed volumes.

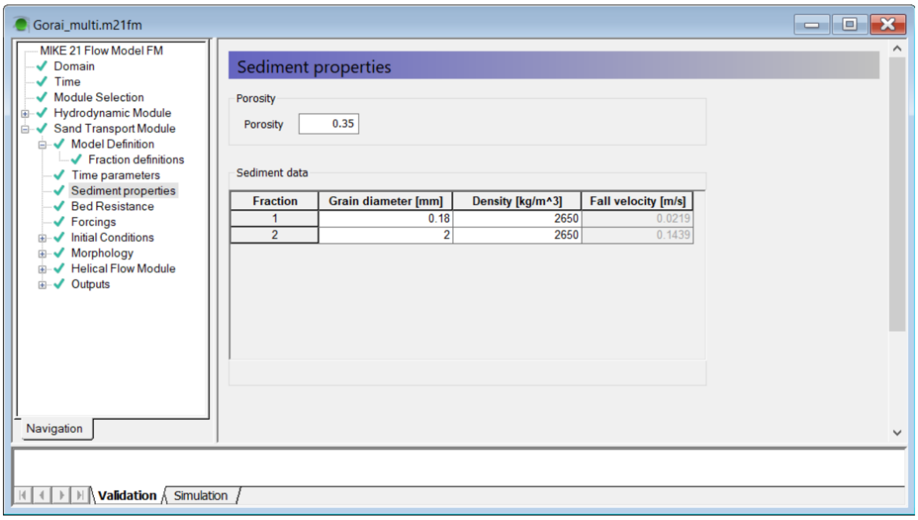

Figure 4.27 Specifications for sediment properties

The **Bed Resistance** is chosen similar to the one used for the Hydrodynamic Module, but the model actually allows use of a decoupled resistance formulation. **Forcing** is not relevant in this example because it is related to impact from waves.

Initial Conditions for the layer thickness and fraction composition are specified in the next menu, see Figure 4.28. The initial thickness and bed composition can both be constant over the domain or varying over the domain. For the latter, a map of the initial layer thickness or fraction distribution can be specified in input for each one of the layers.

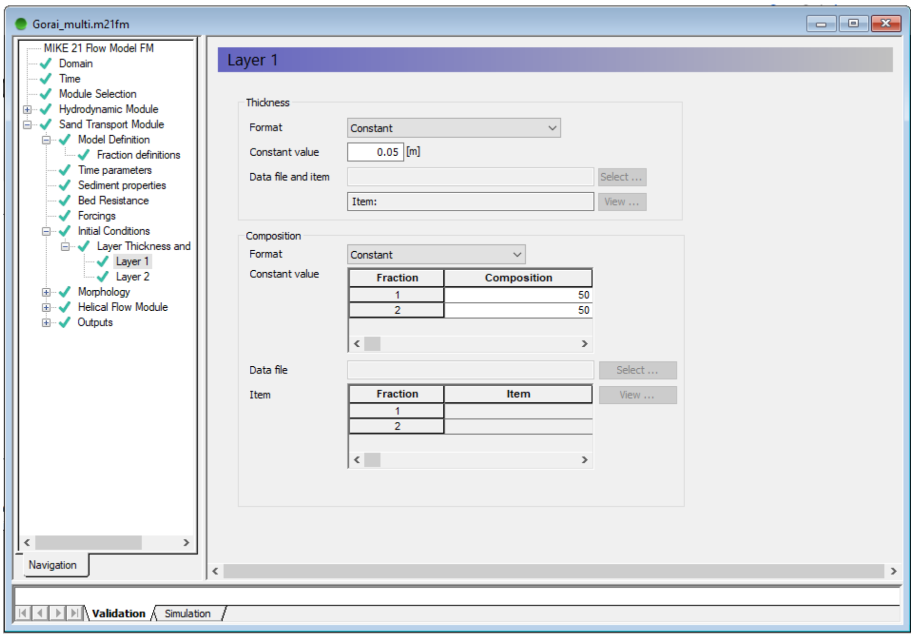

Figure 4.28 Initial thickness of top sediment layer (Layer1)

For the morphological part of the model, a few parameters need to be specified, as shown in Figure 4.29. The speedup factor should be kept equal to 1, unless steady HD boundary conditions are applied or the hydrograph has been squeezed in order to run a scaled HD-simulation.

Feedback on HD and ST should always be activated when working with river applications.

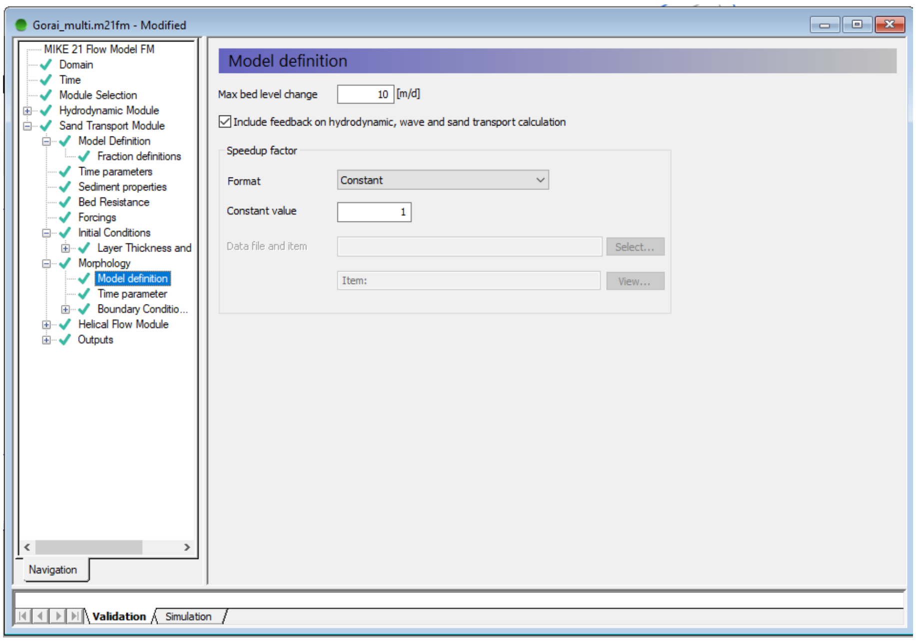

Figure 4.29 Specification of maximum allowed bed level changes per day and feedback to the Hydrodynamic Module

Also information on the start time step of the morphological bed update must be specified as shown in Figure 4.30. For the Gorai example the morphological update is activated after 8640 time steps corresponding to after 1 day.

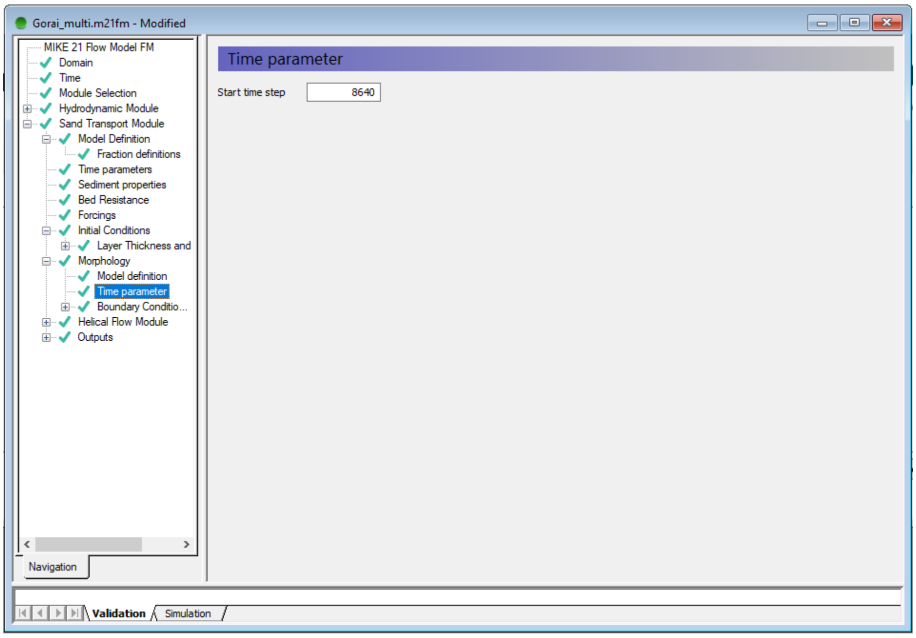

Figure 4.30 Specification of start time step for morphological bed update

For the morphological update, also boundary conditions need to be specified. For all open boundaries the **Zero sediment flux gradient for outflow, zero bed change for inflow** is applied, see Figure 4.31.

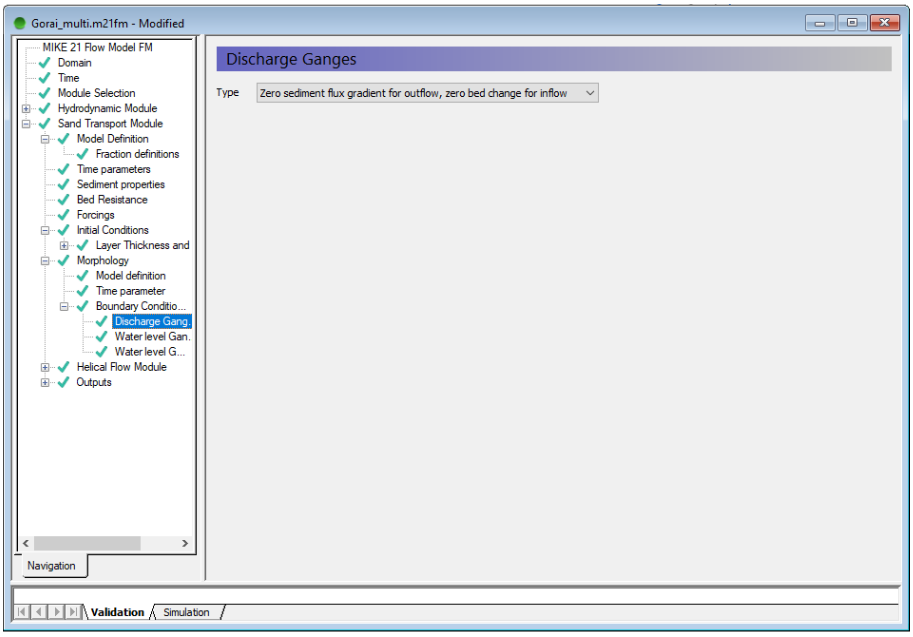

Figure 4.31 Specification of the morphological boundary conditions

Before solving the advection-dispersion equation for the concentration of the suspended sediment, the advection-dispersion equation for the helical flow must be solved. The relevant parameter settings for the helical AD-module are shown in the following figures. Figure 4.32 shows the specification for the **time start step**, which has been chosen to 4320 corresponding to 12 hours and similar to the choice used for sediment transport.

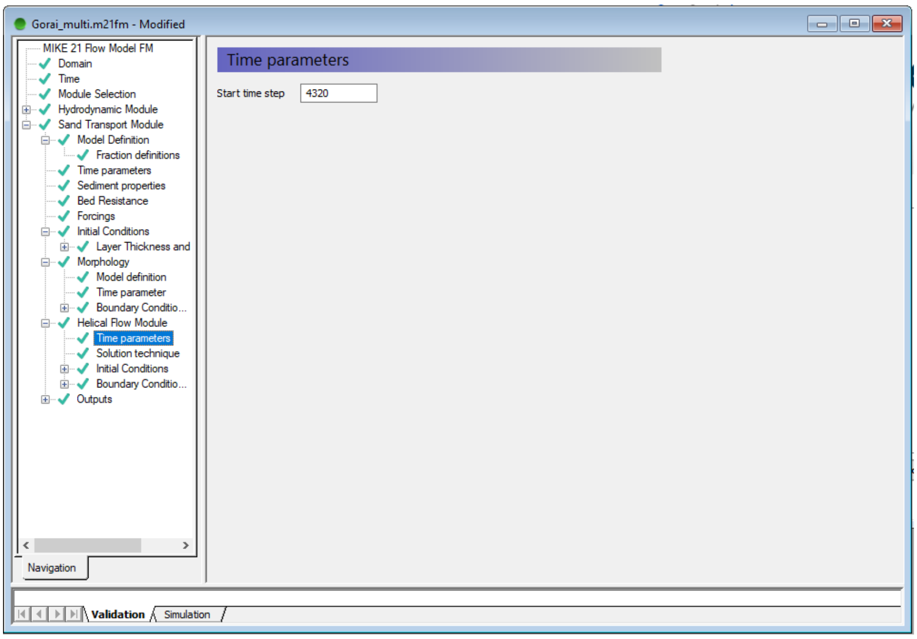

Figure 4.32 Specification of start time step for calculation of the helical flow

The solution technique is set to the same type as in the HD simulation, namely 'low order, fast algorithm'.

As Initial Conditions for the helical flow, you should choose Equilibrium conditions, see Figure 4.33.

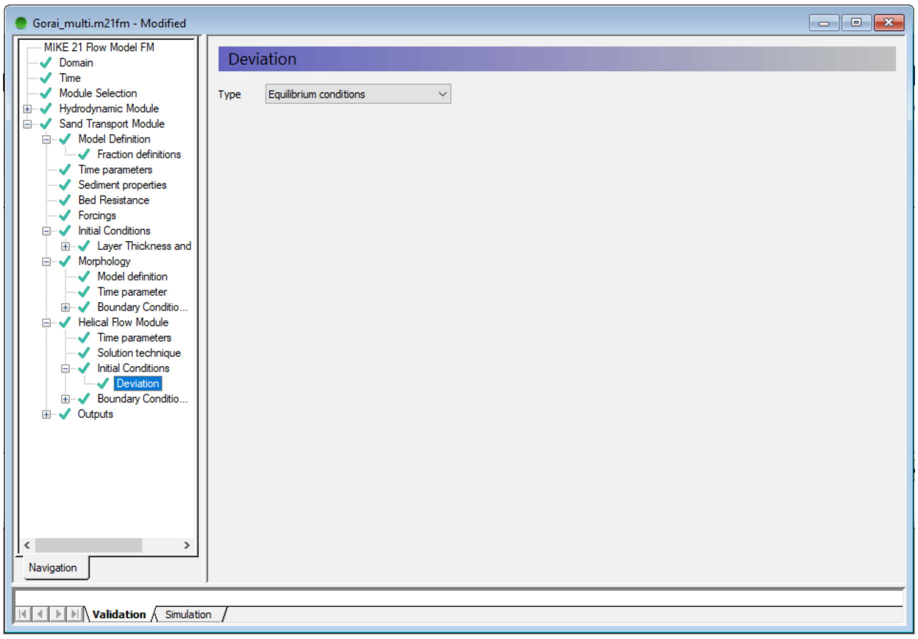

Figure 4.33 Specification of initial conditions for the helical flow

Finally, a symmetry condition (zero-gradient) is applied at all three open boundaries, as shown in Figure 4.34.

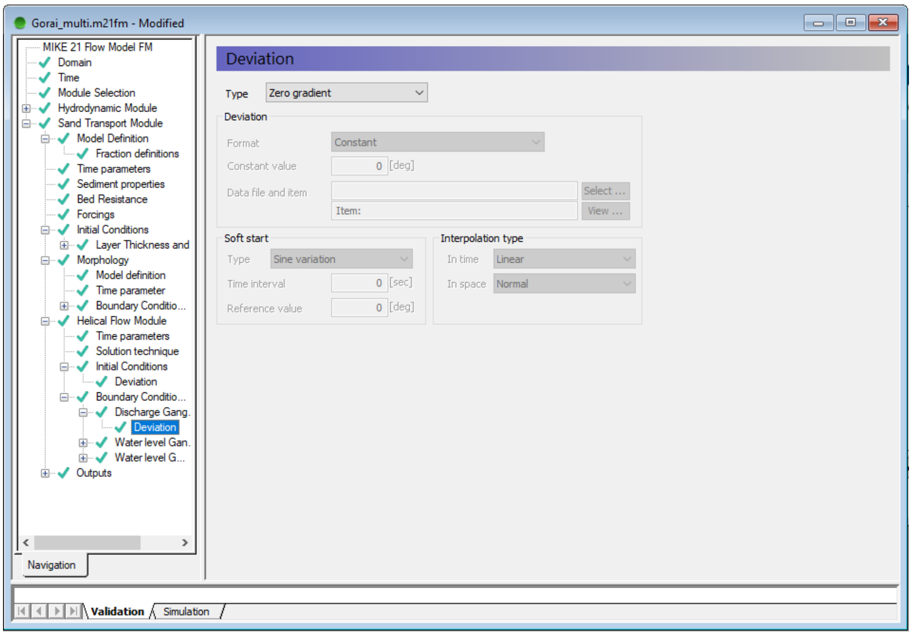

Figure 4.34 Specification of the boundary conditions for the helical flow

The last piece of information that needs to be specified is the type of output from the sediment transport module. From Figure 4.35 it can be seen that outputs are saved as an area series with a frequency corresponding to daily extraction.

Figure 4.36 shows the output items that are saved during the simulation.

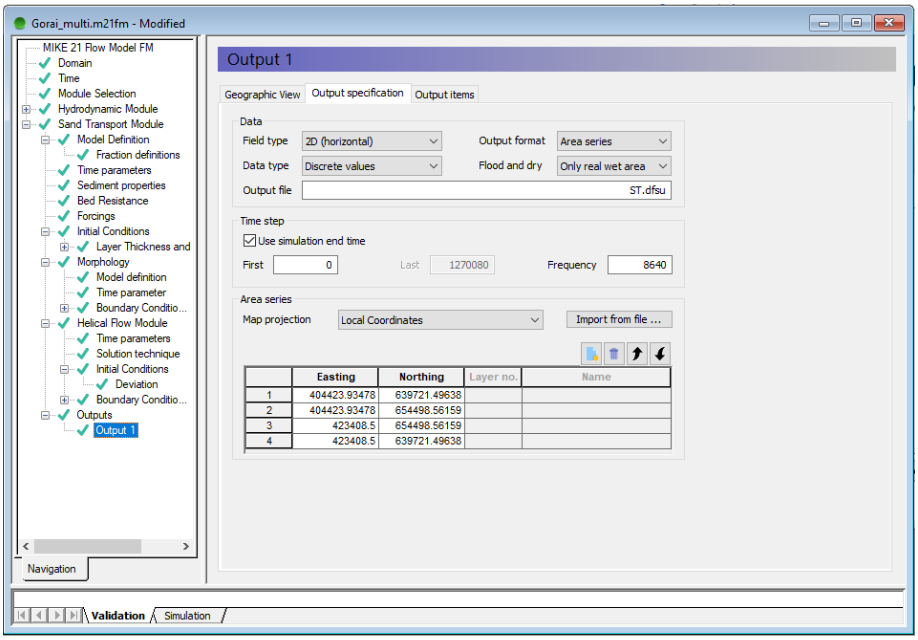

Figure 4.35 Specification window for the type and location of ST output

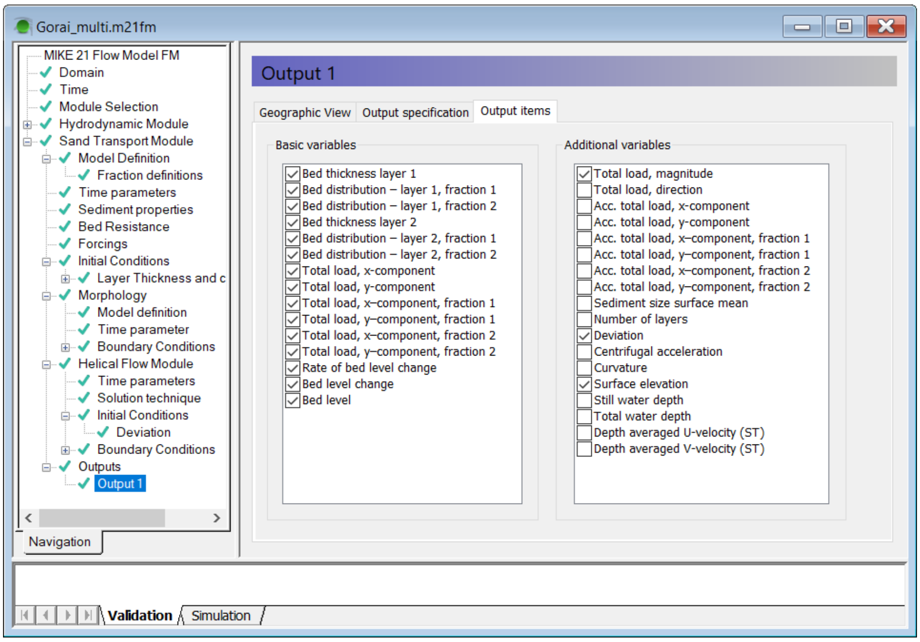

Figure 4.36 Specification of output parameters from the sediment transport module

Especially, bed distribution layer, the magnitude of the bed load, suspended load, and total load are useful to extract and easy to understand due to their scalar nature. The x- and y-components of the different types of sediment loads are only relevant for vector plotting.

The result files can be viewed during the simulation. New processed results will automatically be made available for the **Data Viewer**, i.e. it is not necessary to reload the files.

5 Model Results and Analysis

The objective of this Step-by-step training guide is to show how the morphological model can be applied to simulate the closure of the Gorai offtake. Even though the extent of the area is chosen so small that the boundary conditions have a too strong impact on the results and the mesh is made too coarse, we can still learn a lot from the model.

Figure 5.1 shows the initial bed topography used for the morphological simulation. The initial bathymetry always contains some noisy points that will be attacked (eroded or deposited) by the morphological model in the beginning of the simulation. In particular, in the Gorai branch, which has a very coarse transverse resolution, an improved conveyance can be expected after smoothing of the noisy points.

This means that if the model was run with steady (HD) boundary conditions, the flow passing through the Gorai branch would gradually increase as a result of the improved conveyance. Furthermore, it is the primary reason that we have not used much effort on calibration of the resistance in the model.

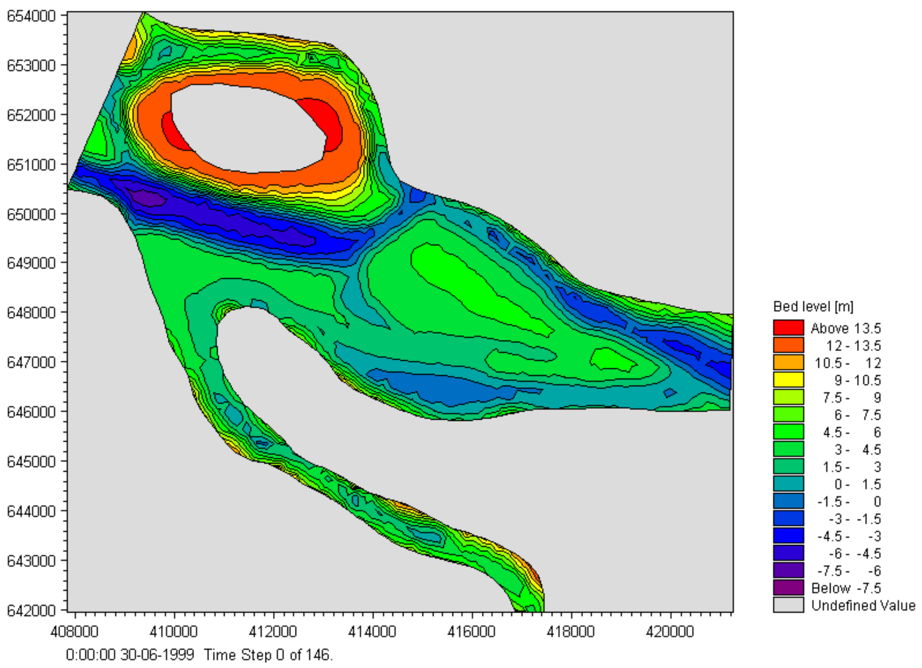

Figure 5.1 Initial bed levels

To prevent these effects, it is necessary to use a mesh with a finer resolution. However, this will end up with computational times that are not appropriate for a step-by-step training guide.

5.1 Results using Single Fraction

Figure 5.2 shows the model predicted bed topography after the passage of the 1999 monsoon, using a single sand fraction. It is seen that sedimentation at the mouth of Gorai is quite significant and will cause a blocking from the Ganges into Gorai during low flow periods unless maintenance dredging is carried out.

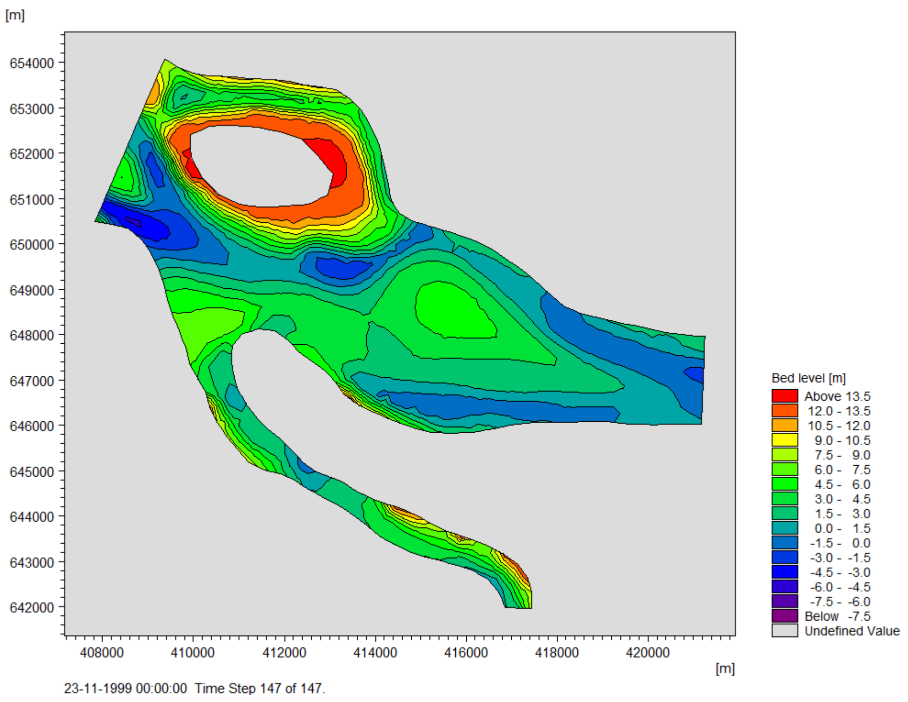

Figure 5.2 Model predicted bed levels after the passage of the 1999 monsoon

Figure 5.3 shows the predicted bed level changes induced by the passage of the 1999 monsoon, and from this plot it is even clearer to see the sedimentation of the mouth. It is also important to note the severe erosion just inside the upstream Ganges boundary. This behaviour is caused by a wrong flux distribution along the boundary. The flux distribution cannot feel the chars just upstream the model area, so model results could be improved if the inflow boundary was moved further upstream.

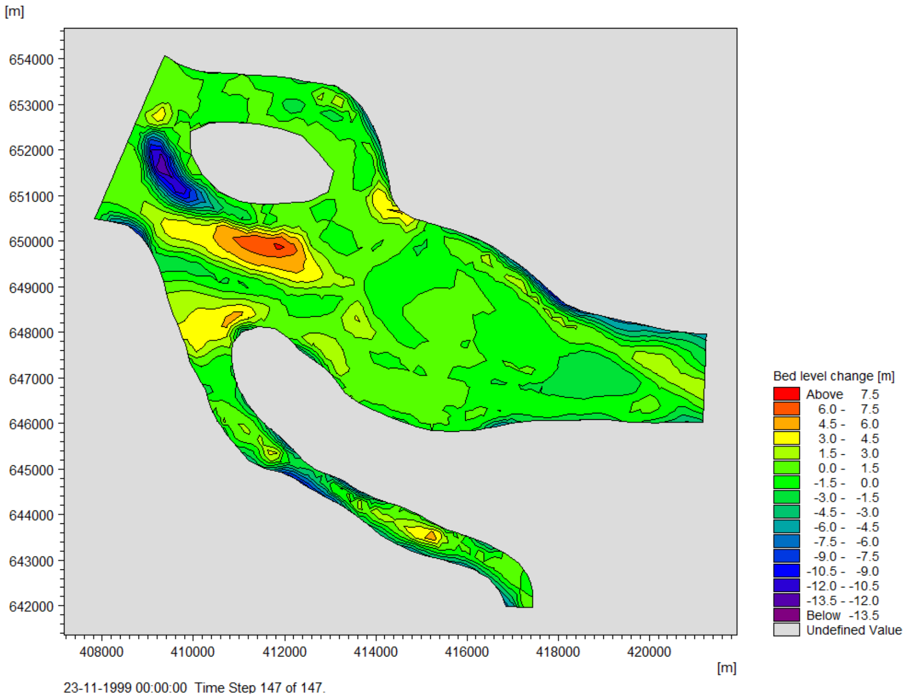

Figure 5.3 Model predicted bed level changes induced by the passage of the 1999 monsoon

Figure 5.4 and Figure 5.5 show the flow depths and surface elevation at the end of the simulation for the individual elements. It is seen that when the water levels are low (as it is in the end of the simulation) the Gorai spill channel will be almost blocked from the Ganges River.

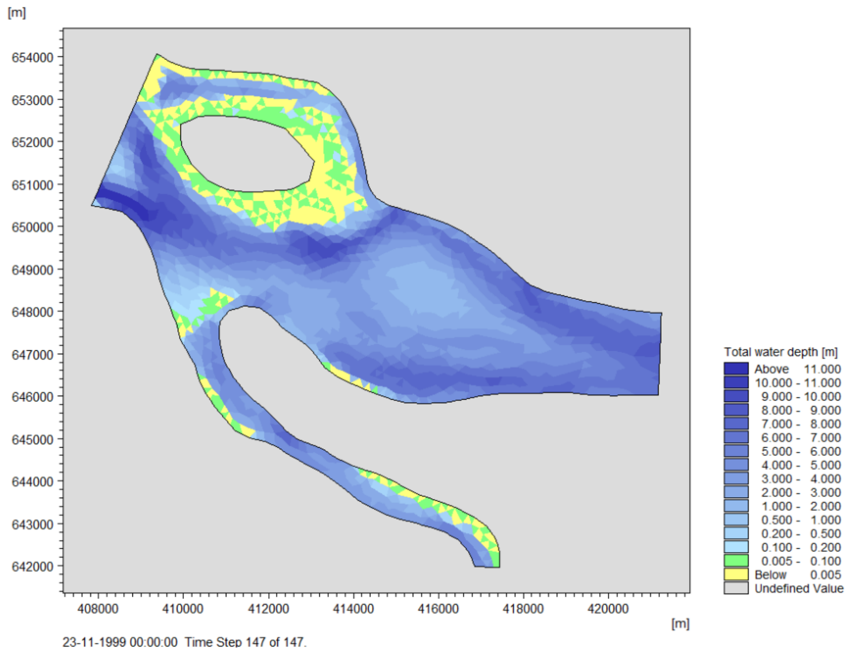

Figure 5.4 Model predicted flow depths at the end of the modelling period

The conclusion that can be made from the simulation is that yearly maintenance dredging is necessary to maintain opening of the Gorai branch during the low flow periods.

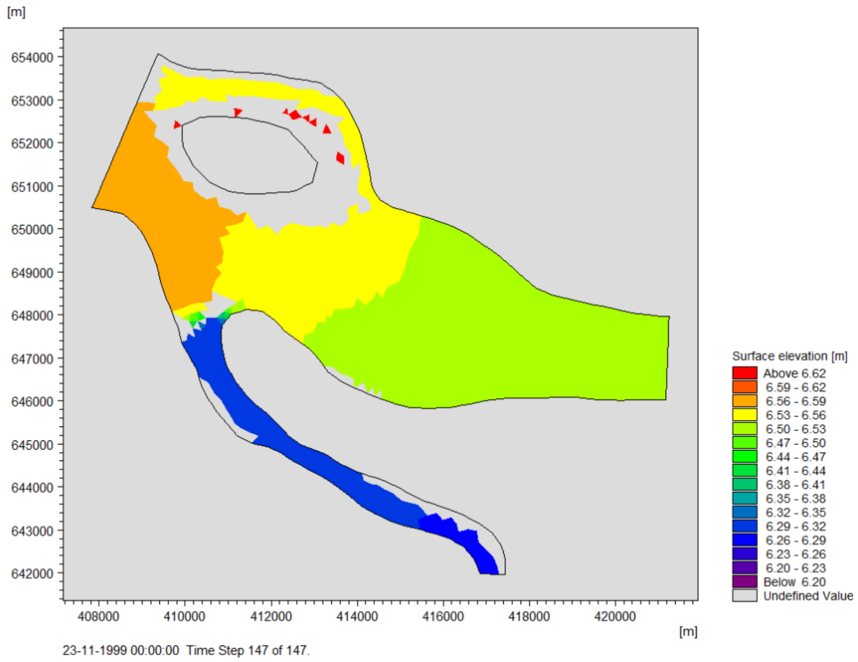

Figure 5.5 Model predicted surface elevation at the end of the modelling period

5.2 Results using Multi-fraction / Multi-layer

Figure 5.6 shows the model predicted bed topography after the passage of the 1999 monsoon. It is seen that sedimentation at the mouth of Gorai is significant.

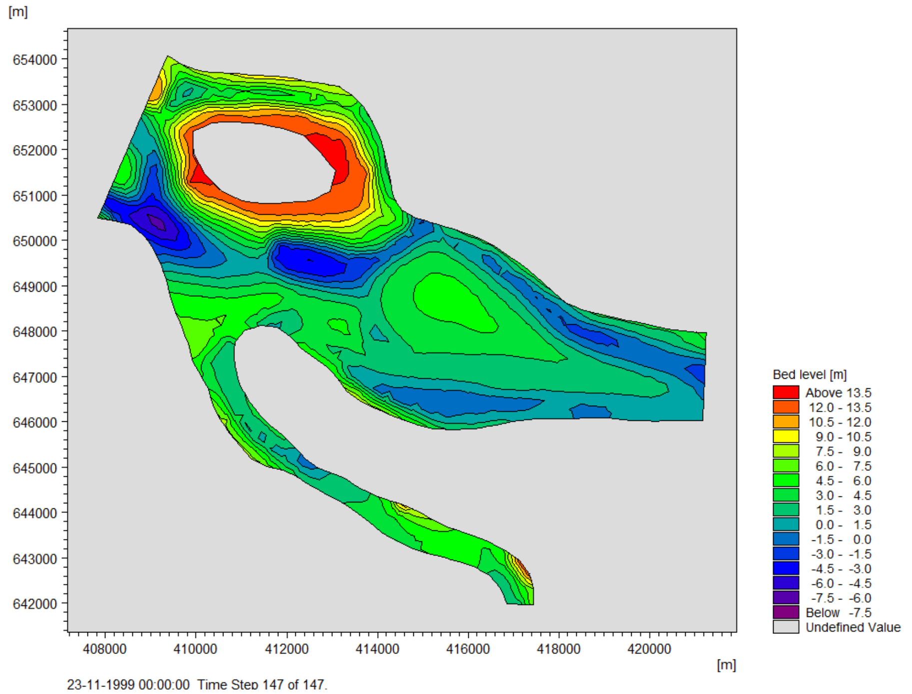

Figure 5.6 Model predicted bed levels after the passage of the 1999 monsoon

Figure 5.7 shows the predicted bed level changes induced by the passage of the 1999 monsoon, and from this plot it is even clearer to see the sedimentation of the mouth. It is also important to note the severe erosion just inside the upstream Ganges boundary. This behaviour is caused by a wrong flux distribution along the boundary. The flux distribution cannot feel the chars just upstream the model area, so model results could be improved if the inflow boundary was moved further upstream.

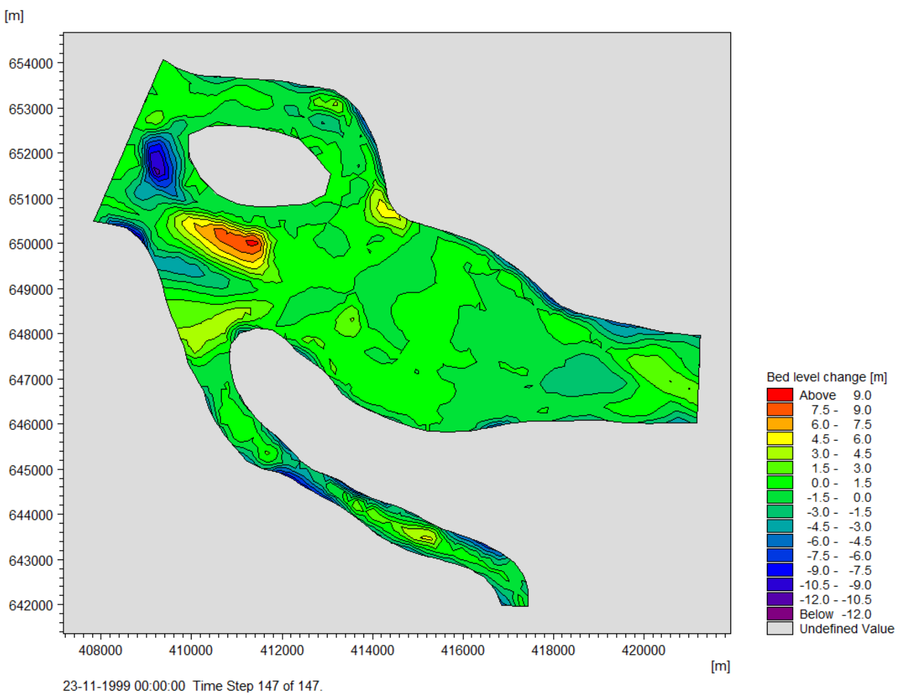

Figure 5.7 Model predicted bed level changes induced by the passage of the 1999 monsoon

Figure 5.8 and Figure 5.9 show the flow depths and surface elevation at the end of the simulation for the individual elements. A comparison with the surface elevation found for a single fraction (Figure 5.5) shows that the use of a multi-fraction approach will result in a wider open channel at the river mouth because the simulated sedimentation in the mouth of the Gorai spill channel will be less severe.

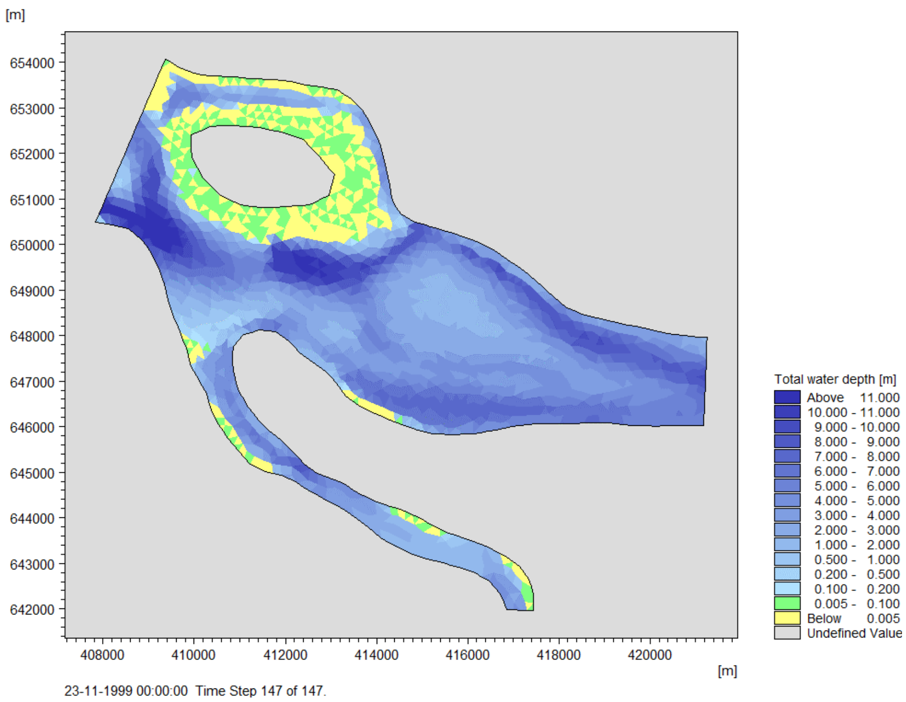

Figure 5.8 Model predicted flow depths at the end of the modelling period

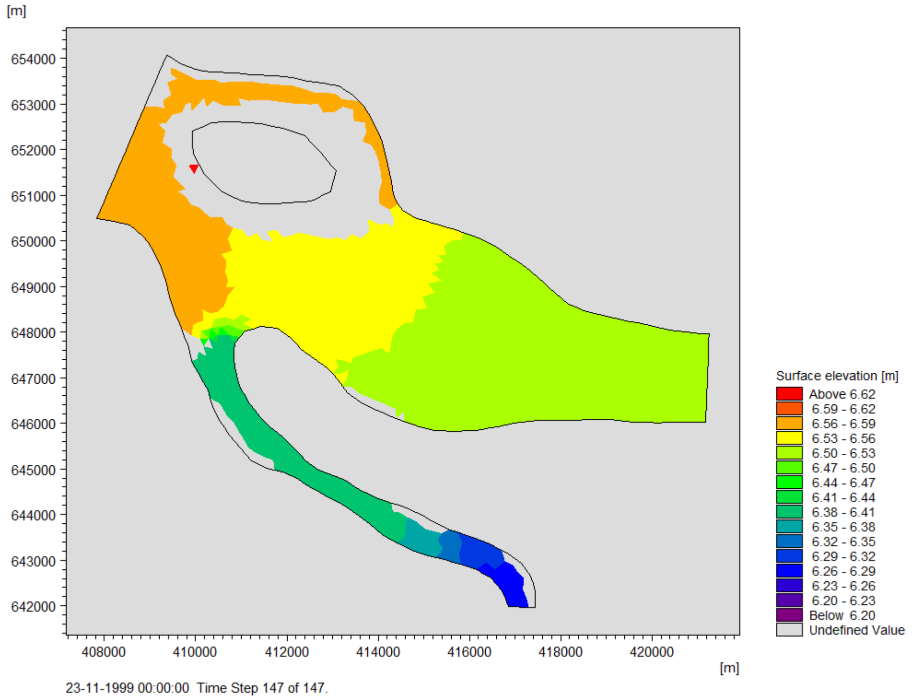

Figure 5.9 Model predicted surface elevation at the end of the modelling period

A reason for the less severe sedimentation at the river mouth is the smaller amount of fine material. Figure 5.10 shows the amount of fine material in the top layer at the end of the simulation. Initially the top layer consisted of 50% fine material and 50% coarse material. During periods of high flow, the finer material is eroded and deposited downstream. This leaves less fine material that can settle by the river mouth during low flows.

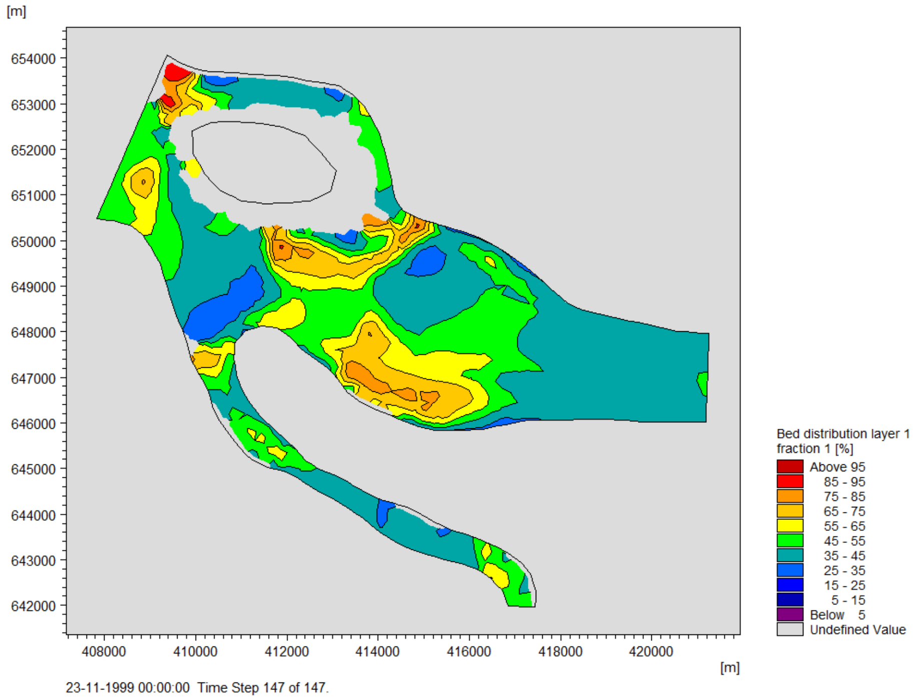

Figure 5.10 Model predicted bed distribution of fraction 1 (fine fraction) in top layer