



MIKE 21 Flow Model FM

Sand Transport Module

Step-by-step training guide: River application



DHI A/S headquarters Agern Allé 5 DK-2970 Hørsholm Denmark

+45 4516 9200 Telephone +45 4516 9333 Support +45 4516 9292 Telefax

mike@dhigroup.com www.mikepoweredbydhi.com



CONTENTS

MIKE 21 Flow Model FM Sand Transport Module Step-by-step training guide: River application

3	Creating the Input Parameters for the MIKE 21 Flow Model FM Simulation	9
3.1	Flow Discharge Boundary Conditions	11
3.2	Water Level Boundary Conditions	11
3.3	Initial Conditions	13
3.4	Time Step	13
3.5	Hydrodynamic Simulation for Peak Discharge	14
3.6	Sediment Data	24

4	Set-Up of MIKE 21 Flow Model FM	
4.1	Specifications for the MIKE 21 Flow Model FM	
4.2	Specifications for Basic Parameters	
4.3	Specifications for the Hydrodynamic Module	27
4.4	Specifications for the Sand Transport Module (Single fraction)	
4.5	Specifications for the Sand Transport Module (Multi fraction)	

5	Model Results and Analysis	47
5.1	Results using Single Fraction	47
5.2	Results using Multi-fraction / Multi-layer	50





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 preprocessing 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.



Workspace projection	
Please, specify the map projection	
Projection	
Local Coordinates 🔹	
OK Cancel Help	

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.

Workspace		X		
Workspace Area				
Lower Left Corner:	402601	639470		
Upper Right Corner:	422601	654470		
Pick Current View				
Lock Workspace				
The pan function and different editing commands are able to dynamically extend the workspace. This functionallity can be disabled by locking the workspace.				
Cock the Workspace				
OK Cancel Help				

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).



Import			
Image	Image Styles		
_	Image Styles		ОК
Ima	Display style:	Copy colors with transparency -	Cancel
	Stretch mode:	Halftone	
1	Transparent color:		
	Transparency:	50 [%]	
	Image Origin		
	Longitude:	402601	
	Latitude:	639470	
	Image Size		
	Pixel width:	11.4876507754 X 1741 = 20000	
	Pixel height:	12.048192771(X 1245 = 15000	
			elp

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:

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

$$Q = 52.222 (H - 4.8702)^{3.0372} , H > 10.7428$$
(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 onedimensional 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,

$$CFL = \frac{\left|\sqrt{gh} + u\right|\Delta t}{\Delta x} + \frac{\left|\sqrt{gh} + v\right|\Delta t}{\Delta y} < 1$$
(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 m³/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.





MIKE 21 Row Model FM M Domain M Time Module Selection Boundary Name Code 2 Discharge Ganges Code 3 Water level Goral Domain specification Boundary names Code 2 Discharge Ganges Code 4 Water level Goral
✓ Time ✓ ✓ Module Selection ⊕ ✓ Hydrodynamic Module Boundary Name Code 2 Discharge Ganges Code 3 Water level Ganges Code 4 Water level Gorai
Mesh and Bathymetry Domain specification Boundary names Boundary Name Code 2 Discharge Ganges Code 3 Water level Garai
Boundary Name Code 2 Discharge Ganges Code 3 Water level Ganges Code 4 Water level Gorai
Boundary Name Code 2 Discharge Ganges Code 3 Water level Ganges Code 4 Water level Gorai
Code 3 Water level Gorai
Code 4 Water level Gorai
Navigation

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.

HD50000.m21fm		
MIKE 21 Flow Model FM	Time	
Module Selection	Simulation period	
	No. of time steps 240 Time step interval 180 [sec]	
	Simulation start date 01/01/2004 00:00:00 🔄 [dd/mm/yyyy hh:mm:ss]	
	Simulation end date 01/01/2004 12:00:00 [dd/mm/yyyy hh:mm:ss]	
Navigation		
Validation Simulation		

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.

HD50000.m21fm		- • ×
HD50000.m21fm MKE 21 Row Model FM	Solution Technique Shallow water equations Time integration Low order, fast algorithm Space discretization Low order, fast algorithm Minimum time step 1 [sec] Maximum time 180 [sec] Critical CFL number 0.8 Transport equations Minimum time step 1 [sec]	
	Maximum time 180 [sec] Critical CFL number 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.

HD50000.m21fm		- • •
MIKE 21 Flow Model FM & Domain & Time & Module Selection & Hydrodynamic Module	Flood and Dry Type Standard flood and dry	
	Drying depth 0.005 [m] Flooding depth 0.05 [m] Wetting depth 0.1 [m]	
Navigation		





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

HD50000.m21fm		- • •
MIKE 21 Flow Model FM	Density	
	Density type Barotropic	
✓ Flood and Dry ✓ Density ✓ Eddy Viscosity ✓ Bed Resistance	Reference temperature 10 [°C] Reference salinity 32 [PSU]	
Coriolis Forcing Wind Forcing Ge Coverage Tidal Potential		
Precipitation - Evaporation Infiltration Wave Radiation Servere		
 ✓ Decoupling ✓ Outputs ✓ Output 1 		
Navigation		
Validation Simulation		

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.

HD50000.m21fm		_ • •
MIKE 21 Flow Model FM Mike 21 Flow Model FM Mike 21 Flow Model FM Mike 20 Flow Flow Mike 20 Flow Mike 2	Eddy Viscosity Horizontal Eddy Viscosity Eddy type Smagorinsky formulation Smagorinsky formulation data Format Constant Constant value 0.28 Data file and item Item:	Select View
	Eddy parameters Minimum eddy viscosity 1.8e-006 [m²/s] Maximum eddy viscosity 100000000 [m²/s]	
Validation Simulation		

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 m²/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.

HD50000.m21fm		
MIKE 21 Flow Model FM	Bed Resistance	
Module Selection	Resistance type Manning number	
Solution Technique	Manning number data	
✓ Depth ✓ Flood and Dry	Format Constant	
Eddy Viecosity	Constant value 40 [m^(1/3)/s]	
Bed Resistance	Data file and item Select	
Wind Forcing	Item: View	
✓ Ice Coverage		
Precipitation - Evaporation		
Wave Radiation		
Sources		
Initial Conditions		
Boundary Conditions Decoupling		
Outputs		
Navigation		
, <u> </u>		
Validation / Simulation /		

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.

HD50000.m21fm			
MIKE 21 Flow Model FM	Coriolis For	rcing	
	Coriolis type Reference latitude	No coriols force	
Navigation			
Validation Simulation			

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.



HD50000.m21fm MIKE 21 Flow Model FM				
- 🗹 Domain	Initial Condi	tions		
✓ Time ✓ Module Selection	Туре	Constant	•	
E-	Initial data			
- M Depth	Surface elevation	12.97 [m] u-velocity	0 [m/s]	
Flood and Dry		v-velocity	0 [m/s]	
V Density				
✓ Bed Resistance				
Coriolis Forcing	Data file		Select	
Wind Forcing	Surface elevation item	Item:	View	
V Tidal Potential				
Precipitation - Evaporation				
Infiltration				
Wave Radiation				
Sources				
Structures				
Boundary Conditions				
Decoupling				
Outputs				
····· ≰ Output 1				
L Navigation				
Validation Simulation				

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.

HD50000.m21fm				
MIKE 21 Flow Model FM	Discharge Gang	es		^
	Type Specified discharge Approach Weak formula Boundary data Format Consta Constant value 50 Data file and them	tion • nt • 000 [m³/s]	Select	
✓ Wild forcing ✓ Ice Coverage ✓ Tidal Potential ✓ ✓ Precipitation - Evaporation	Type of vertical Uniform	n profile v	View	E
Sources	Soft start	Interpolation type		
	Type Sinus variation Time interval 360 Reference value 500	In time Linear 10 [sec] In space Normal 10 [m³/s] In space Normal	* *	
✓ Water level Gorai ✓ Land boundary ✓ Decoupling ✓ Outputs ✓ Output 1	Boundary data corrections			
Navigation	Include coriolis correction	1		

Figure 3.17 Specification window for Ganges discharge boundary condition



MIKE 21 Flow Model FM	Water leve	l Gorai				
✓ Time ✓ Module Selection ✓ Hydrodynamic Module	Type Specified Boundary data	level	•			
Depth	Format	Constant		•		
Flood and Dry	Constant value	12.7 [m]				
Eddy Viscosity	Data file and item				Select	
Coriolis Forcing		Item:			View	
✓ Wind Forcing ✓ Ice Coverage	Type of vertical profile	Uniform profile		Ŧ		
Precipitation - Evaporation	Soft start		Interpolatio	on type		
Mayo Padiation	Type Sinus var	iation 🔻	In time	Linear		
Sources	Time interval	3600 [sec]	In space	Normal	•	
Structures	Reference value	12.97 [m]				
Boundary Conditions M Boundary Conditions M Discharge Ganges M Water level Ganges M Land boundary M Coupling M Outputs M Output 1	Boundary data corre	ections				
Navigation	Include coriolis	correction				

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/m³. 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.



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.

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

Table 4.1Specifications for the morphological simulation



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.

🧶 Gorai.m21fm		- • ×
MiKE 21 Row Model FM	Time Simulation period No. of time steps 1270080 Time step interval 10 Simulation start date 29/06/1999 00:00:00 Simulation end date 23/11/1999 00:00:00 [dd/mm/yyyy hh:mm:ss]	
Validation Simulation		

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.



e Gorai.m21tm		
MIKE 21 Flow Model FM	Module Selection	
Module Selection	Module Selection	
Hydrodynamic Module Sand Transport Module	Hydrodynamic Inland Flooding	
	Transport	
	ECO Lab / Oilspill	
	Mud Transport	
	Particle Tracking	
	Sanu Hansport	
Navigation		
Validation Simulation		

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.

		and the fourth of the second s	and a market of a set of a state of the set
$H(\alpha)$ $\Gamma(\alpha) / \Gamma(\alpha)$ $C(\alpha)$	na cali itian tachni	ALLA VALLAS TAT TAA	morphological similiation
	116 301411011 16611111		

🔵 Gorai.m21fm			
MIKE 21 Flow Model FM	Solution Techni	que	
	Shallow water equations Time integration Le Space discretization Le Minimum time step Maximum time Critical CFL number	ow order, fast algorithm ow order, fast algorithm	
Wind rorong Wind rorong Wind Potential M Tidal Potential M Precipitation - Evaporation M Infiltration M Wave Radiation M Sources M Structures	Transport equations Minimum time step Maximum time Critical CFL number	1 [sec] 10 [sec] 0.8	
Validation Simulation			



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



MIKE 21 Flow Model FM						
- 🖌 Domain 🛛 🔰 Init	tial Conditi	ons				
- ✓ Time	r				r	
Module Selection Type		Constant		•		
Hydrodynamic Module	data					
Solution Technique	ice elevation	0.10 [m]	uvolocity	0	[m/c]	
M Depth Suite	ice elevation	9.19 [0]	u-velocity		[[[]]]	
✓ Density			v-velocity	0	[m/s]	
Eddy Viscosity						
Bed Resistance						
Coriolis Forcing Data	file				Select	
Wind Forcing Surfa	ce elevation item	Item:			View	
Ice Coverage						
Tidal Potential						
Precipitation - Evaporation						
Wave Padiation						
Initial Conditions						
Boundary Conditions						
- decoupling						
🗄 🖌 Outputs						
🗄 🗹 Sand Transport Module						
Navigation						

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.

🧶 Gorai.m21fm		- • •
	Discharge Ganges Type Specified discharge Approach Weak formulation Boundary data • Format Varying in time Constant value • Data file and item • Type of vertical Uniform profile	E
	Interpolation type Type Sinus variation Time interval 0 Reference value 0 [m³/s]	





✓ Domain 🔺	Water leve	Ganges		
	Type Specified Boundary data Format Constant value	Varying in time, cons		
	Data file and item Type of vertical profile	Projects (MIKE_21) Item: Obs WL,Gang Uniform profile	lowModel_FM\ST\Gorai\WLQ.dfs0 jes	Select
Y Precipitation - Evaporati M Precipitation - Evaporati M Wave Radiation M Sources M Structures M Structures	Soft start Type Sinus var Time interval Reference value	iation	Interpolation type In time Piecewise cubic In space Normal	•
W Uscharge Ganges Water level Gange Water level Gange Water level Gange Water level Gang				



Domain ▲ Time	Water leve	Gorai			-
	Type Specified I Boundary data Format Constant value Data file and item Type of vertical profile	Varying in time, consta Varying in time, consta O [m] > Projects/MIKE_21/Flc Item: Obs WLGorai Uniform profile) int along boundary wModel_FM\ST\Gorai\WLQ.dfs0	Select	
	Soft start Type Sinus var Time interval Reference value	ation	Interpolation type In time Piecewise cubic In space Normal	v	

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.

🧶 Gorai.m21fm	
MIKE 21 Flow Model FM MIKE 21 Flow Model FM M Domain M Dodule Selection M Hydrodynamic Module M Sand Transport Module M Model Definition M Time parameters M Solution technique Conference of the second	Model Definition Model type Pure current Model description Varying layer thickness Threshold thickness (a) Depth-averaged velocity
Sedment properties Sedment properties Sed Resistance ✓ Forcings Sed resistance ✓ Forcings Sed resistance ✓ Sources Sed resistance ✓ Initial Conditions Sed resistance ✓ Initial Conditions Sed resistance ✓ Morphology Sed resistance ✓ Outputs	Pure current description Number of fractions 1 + © Equilibrium Include helical flow
Navigation	Sediment transport table

Figure 4.8 Model definition window for the ST model



Gorai.m21fm			
MIKE 21 Flow Model FM	Fraction 1		
✓ Time ✓ Module Selection ✓ Hydrodynamic Module	Bed load formula	van Rijn 🔹	
Sand Transport Module	Bed load factor	1	
Fraction definitions Fraction 1 Fraction 1 Time parameters	Suspended load formula	van Rijn 👻	
Solution technique	Suspended load factor	1	
	Maximum concentration	10000 [g/m³]	
Navigation			
Validation Simulation			



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.

🔵 Gorai.m21fm				- • •
MIKE 21 Flow Model FM	Time para	ameters		
Module Selection	Start time	4320		
Sand Transport Module	Time step factor	30		
Solution technique				
✓ Bed Resistance ✓ Forcings				
Boundary Conditions Morphology				
teicarnow would teicarnow would teica				
Navigation				
	,			

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.



🔵 Gorai.m21fm				- • •
MIKE 21 Row Model FM	Sediment p Porosity Porosity 0.	roperties 35		
	Sediment data			
Solution technique	Format	Constant	-	
Ged Resistance Ged Resistance	Grain diameter	0.18 [mm]		
Initial Conditions Initial Conditions Monthology Helical Row Module	Data file and items		Select	
🗄 🗹 Outputs	Relative density	2.65		
Navigation				
Validation Simulation				

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. Information about how the sediment model dispersion is obtained can be found in the Scientific Documentation for the Sediment Transport - Pure Current.

🥚 Gorai.m21fm				
MIKE 21 Flow Model FM	Fraction 1			
 ✓ Time ✓ Module Selection ✓ Hydrodynamic Module 	Formulation	Scaled eddy viscosity formulation		
Sand Transport Module	Scaled eddy viscosity	y formulation		
···· ✓ Time parameters ···· ✓ Solution technique	Format	Constant		
Sediment properties	Constant value	1		
Forcings	Data file and item	Item:	View	
Horizontal Dispersion				
···· ✔ Sources B··· ✔ Initial Conditions B··· ✔ Boundary Conditions	Dispersion coefficien	t formulation		
Morphology Melical Flow Module	Format	Constant		
🖅 🗹 Outputs	Constant value	0.01 [m²/s]		
	Data file and item	Item:	View	
Navigation				
Validation / Simulation				

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.

🔮 Gorai.m21fm		- • •
MIKE 21 Row Model FM	Fraction 1 Type Equilibrium conditions •	
Validation & Simulation	1	

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.

🔵 Gorai.m21fm					- • •
MIKE 21 Flow Model FM	Fraction 1				
	Type Equilibrium Fraction 1 Format Constant value	Constant	•		
	Data file and item	Item:	• to a state to a	Select View	
	Type Sinus vari Time interval Reference value	ation	Interpoleuon type In time Linear In space Normal	v	
Navigation					
Validation Simulation					

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



Gorai.m21fm					- • •
MIKE 21 Flow Model FM	Eraction 1				
Jomain √ Time	FIACTION				
Module Selection	Type Zero gradie	nt 🔻			
Hvdrodynamic Module	Type Lero grade				
🗐 🖌 🖌 Sand Transport Module	Fraction 1				
😟 🗹 Model Definition	Format	Constant	~		
Time parameters	Constructionalise	0 [n/m2]			
Solution technique	Constant Value	Ulahusi			
Sediment properties	Data file and item			Select	
Forcings		Item:		View	
Sources	Soft start		Interpolation type		
🖅 🖌 Initial Conditions	Type Sinus varia	ation 👻	In time Linear		
🖻 🗹 Boundary Conditions	Time interval	0 [sec]	In space Normal		
Discharge Ganges					
Fraction 1	Reference value	0 [g/m*]			
₩ Water level Gorai					
🗈 🖌 Morphology					
🗈 🗹 Helical Flow Module					
🗄 🖌 🖌 Outputs					
Navigation					
,,					
KANN Validation (Simulation					

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.

🔵 Gorai.m21fm	
MIKE 21 Flow Model FM	l definition
Module Selection Max bed lev Module Selection Max bed lev Module Speedup fac	2l change 10 [m/d] tor 1
⊕ - ✓ Model Definition ✓ Time parameters ✓ Solution technique ✓ Solution technique ✓ Sediment properties ✓ Bed Resistance	eedback on hydrodynamic, wave and sand transport calculation
B → x Forcings B → x Dispersion → x Sources B → x Initial Conditions B → x Boundary Conditions	
Morphology Moled definition Time parameter Sope Failure	
⊕ ★ Helcal flow Module ⊕ ★ Outputs	
Navigation	
Validation Simulation	

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.



(
e Gorai.m21fm		
MIKE 21 Flow Model FM	Time parameter Start time step 8640	
· · · · · · · · · · · · · · · · · · ·		
Navigation		
Validation Simulation	/	

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.

🔵 Gorai.m21fm		- • ×
MIKE 21 Flow Model FM		
🚽 🗹 Domain	Discharge Ganges	
- v Time		
Module Selection 1	Type Zero sediment flux gradient for outflow, zero bed change for inflow 🔹	
🗈 🗹 Hydrodynamic Module		
🖃 🖌 Sand Transport Module		
🔬 🗹 Model Definition		
Time parameters		
Solution technique		
Sediment properties		
M Bed Resistance		
Porcings		
V Sources		
Boundary Conditions		
Model definition		
Time parameter		
Slope Failure		
🖻 🖌 Boundary Conditions		
🖌 Discharge Ganges		
₩ Water level Ganges		
🖌 🖌 Water level Gorai		
🗈 🗹 Helical Flow Module		
😟 🗹 Outputs		
Navigation		
,,		
Validation Simulation		

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.



Gorai.m21fm	Time parameters	
	Start time step 4320	
Validation Simulation		

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.

🔵 Gorai.m21fm		- • •
MIKE 21 Flow Model FM	Deviation	
	Deviation Type Equilibrium conditions	
B - M Boundary Conditions B - M Outputs		

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.



Domain	Deviation		
Module Selection	Type Zero gradie	ent 🔻	
Model Definition M Time parameters Solution technique	Format	Constant	
✓ Sediment properties ✓ Bed Resistance ✓ Forcings	Constant value Data file and item	0 [deg]	Select
Dispersion Sources Initial Conditions	E Soft start	Item:	View
Boundary Conditions	Type Sinus varia	ation In time Linear 0 [sec] In space Normal	
✓ Time parameters ✓ Solution technique	Reference value	0 [deg]	
Boundary Conditions			
Water level Ganges			
Navigation			

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.

	_ • ×
Output 1 Geographic View Output specification Data Field type 2D (horizontal) Output file ST.dfsu Treatment of flood and Only real wet area	
Time step First 0 Last 1270080 Frequency 8640 Area series Map projection Local Coordinates Import from file () () () () () () () () () () () () () (
Easting Northing Layer no. Name	
1 404423.93478 639721.49638	
2 404423.93478 654498.56159	
3 423408.5 654498.56159	
4 423408.5 639721.49638	
,	
	Output 1 Geographic View Output specification Data Field type 20 (horizontal) Output file ST.dfsu Treatment of flood and Only real wet area Time step First 0 First 0 Last 1270080 Frequency 8640 Area series Import from file Map projection Local Coordinates Import from file 1 404423.93478 64398.56159 3 423408.5 654498.56159 4 423408.5 639721.49638







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.



Osrai_multi.m21fm Image: Construction ✓ Domain Model Selection ✓ Hydrognamic Module Model Uppe Pure current - Multi fraction/Multi layer ✓ Model Selection Model description ✓ Fraction definitions 2 ✓ Fraction definitions 2 ✓ Model Definition 1 ✓ Model Definition 2 ✓ Model Superation 2 ✓ Model Afformations 2 ✓ Model Superation 2 ✓ Model Restance 0.05 [m] ✓ Mital Conditions 1 ✓ Modela Bow Module 1 ✓ Outpuds 1 ✓ Outpuds 1	Gorai_multim21fm Image: Control of the control of	Garai_multim21fm Image: Constant of the selection ✓ Domain Model Selection ✓ Hydrodynamic Module Model Selection ✓ Fraction definition Model type ✓ Fraction definition Model selection ✓ Fraction definition Model type ✓ Fraction definition Model selection ✓ Fraction definition Model type ✓ Fraction definitions 2 ✓ Time parameters 0.05 [m] ✓ Initial Conditions 1 ✓ Antiphology 1 ✓ Antiphology 1 ✓ Outputs 1 ✓ Outputs 1		
MIKE 21 Row Model FM The Module Selection Model Selection Fraction definitions Send Transport Module For Transport For Transport Module For Transport For Transport Module For Transport Module For Transport For Tr	MKE 21 Row Model FM Time Module Selection Module Selection Model Uperintation Model Uperinta	MIKE 21 Row Model FM Time Module Selection Model Selection Model Selection Fraction definitions Model Definition Model Definition Model Vere Pure current - Multi fraction/Multi layer Model description Number of fractions 2 Model Definition Model Vere Pure current - Multi fraction/Multi layer Model description Number of fractions 2 Model Definition Model Vere Pure current - Multi fraction/Multi layer Model description Number of fractions 2 Model description Number of layers 2 Thickness surface layer 0.05 [m] Thickness sub-layers 1 [m] Include helical flow	orai_multi.m21fm	
✓ Domain ✓ Model Selection ✓ Model Selection Model Uptimition ✓ Sand Transport Module ✓ Model Optimition ✓ Model Definition ✓ Model Definition ✓ Model Definition ✓ Model Definition ✓ Model Definition ✓ Model Definition ✓ Sand Transport Module ✓ Model Definition ✓ Model Definition ✓ Model Definition ✓ Time parameters ✓ Sediment properties ✓ Bord Resistance ✓ Forcing Ø with Ital Conditions ② Ø with Ital Conditions ③ Ø with Vodule ③ Ø with Ital Conditions ③ Ø with Ital Conditions ③ Ø with Vodule Ø Ø with Vodule Ø <tr< td=""><td>Model Definition Model type Pure current -Multi fraction/Multi layer Model contract Sediment properties Sediment properties Forcings Helcal Row Module Thickness sub-layers 1 [m] Model type Pure current -Multi fraction/Multi layer Multi fraction/Multi layer Multi fraction/Multi layer Multi fraction/Multi fraction/Multi layer Multi fraction/Multi fraction/Multi layer Multi fraction/Multi fraction/Multi layer Multi fraction/Multi fraction/Multi fraction/Multi layer Multi fraction/Multi fraction/Multi fraction/Multi layer Multi fraction/Mult</td><td>✓ Domain ✓ Time ✓ Model Selection Model Definition ✓ Sand Transport Module ✓ Model Definition ✓ Model Definition ✓ Intraction definitions ✓ Model Definition ✓ Intraction definitions ✓ Model Resistance ✓ Sand Transport Module ✓ Sediment properties ✓ Refraction definitions ✓ Forcings ② Ø V Module Ø V Module ✓ Module Selection Ø V Module ✓ Northology Initial Conditions Ø V Helical Row Module Thickness sub-layers 1 [m] ✓ Module Selection ✓ Initial Conditions Ø V Helical Row Module ✓ Outputs</td><td>MIKE 21 Flow Model FM</td><td></td></tr<>	Model Definition Model type Pure current -Multi fraction/Multi layer Model contract Sediment properties Sediment properties Forcings Helcal Row Module Thickness sub-layers 1 [m] Model type Pure current -Multi fraction/Multi layer Multi fraction/Multi layer Multi fraction/Multi layer Multi fraction/Multi fraction/Multi layer Multi fraction/Multi fraction/Multi layer Multi fraction/Multi fraction/Multi layer Multi fraction/Multi fraction/Multi fraction/Multi layer Multi fraction/Multi fraction/Multi fraction/Multi layer Multi fraction/Mult	✓ Domain ✓ Time ✓ Model Selection Model Definition ✓ Sand Transport Module ✓ Model Definition ✓ Model Definition ✓ Intraction definitions ✓ Model Definition ✓ Intraction definitions ✓ Model Resistance ✓ Sand Transport Module ✓ Sediment properties ✓ Refraction definitions ✓ Forcings ② Ø V Module Ø V Module ✓ Module Selection Ø V Module ✓ Northology Initial Conditions Ø V Helical Row Module Thickness sub-layers 1 [m] ✓ Module Selection ✓ Initial Conditions Ø V Helical Row Module ✓ Outputs	MIKE 21 Flow Model FM	
Nevtodio Novedio Novedio Model esciption Model description Mumber of fractons Depth-averaged velocity Bed Resistance Model description Model description Mumber of fractons Depth-averaged velocity Bed Resistance Model description Model description Model description Model description Model description Model description Model description Model description Model description	avgation A model Selection Model type Pure current - Multi fraction/Multi layer Model Definition Model Definitions Model Definitions Sedment properties Bed Resistance Forcings Initial Conditions Model Properties Bed Resistance Forcings Initial Conditions Model Properties Bed Resistance Outputs Thickness surface layer O.05 [m] Bed shear stress Thickness surface layers Imid Indude helical flow And type in the stress Thickness surface layer Imid Indude helical flow And type intervention Imid Indude helical flow And type intervention Imid Indude helical flow And type intervention Imid Indude helical flow And type intervention Imid Indude helical flow Indude helical flow Indude helical flow Indude helical flow Indude helical flow	Ime Model Selection Model Selection Model Selection Model Selection Model description Traction definitions 2 Traction definitions 2 Sedment properties 2 Sedment properties 2 Forcings 1 Model Description Number of factors Forcings 1 Model Model 0.05 [m] Bed Relatance Sedment properties Forcings Thickness surface layer 0.05 [m] Model All Pow Module Thickness sub-layers 1 [m] Melcal Row Module Thickness sub-layers 1 [m] Melcal Row Module Thickness sub-layers 1 [m] Melcal Row Module Thickness sub-layers 1 [m]	V Domain	
Navigation	lavigation <		 Time Module Selection Hydrodynamic Module Sand Transport Module Constraint ✓ Module Offention ✓ Fraction definitions ✓ Bed Resistance ✓ Forcings ✓ Initial Conditions ✓ Initial Conditions ✓ Morphology ✓ Helda Row Module ✓ Outputs 	Iulti fraction/Multi layer ✓ 2 Fording parameters 2 Depth-averaged velocity Bed shear stress 1 [m] ✓ Indude helical flow
Navigation	avigation <	Newtonia		
		Navigation <	Jvigation	

Figure 4.24 Model definition window for the ST model

/			
🥚 Gorai_multi.m21fm		E	- • ×
MIKE 21 Row Model FM MIKE 21 Row Model FM Modele Selection Hydrodynamic Module Sand Transport Module Model Definition Fraction definitions	Fraction definitions		
Ime parameters Sediment properties Sediment properties Bed Resistance Forcings Image Conditions Morphology Helical Row Module Vorputs Vorputs			
Navigation			
]		

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.



🔵 Gorai_multi.m21fm		- • •
MIKE 21 Flow Model FM		
Domain	Time parameters	
Time		
Module Selection	Start time step 4320	
Hydrodynamic Module	Time step factor	
Model Definition		
Fraction definitions		
Time parameters		
Sediment properties		
Bed Resistance		
Forcings		
Mombeleav		
Helical Flow Module		
Outputs		
Navigation		
]	
Validation Simulation	on /	

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.

@ Gorai_multi.m21fm					
MIKE 21 Flow Model FM ✓ Domain ✓ Time ✓ Module Selection B ✓ Hydrodynamic Module B ✓ Sand Transport Module B ✓ Model Definition ✓ Fraction definitions ✓ Fraction definitions	Sediment prosity Porosity	0.35			
 Sediment properties Bed Resistance 	Fraction	Grain diameter [mm]	Density [kg/m^3]	Fall velocity [m/s]	-
-V Forcings	1	0.18	2650	0.0219	
 Image: A morphology Image: A morphology					
Navigation					~
	1				

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.



Gorai_multi.m21fm					
MIKE 21 Flow Model FM					
🗌 🚽 Domain	ayer 1				
Time					
Module Selection					
Huddale Gelection	Thickness				
Canad Transmet Madule					
Sand Transport Module	Format	Constant	~		
Model Definition	Constant unlus	0.05 [m]			
Fraction definitions	Constant value	0.05 [00			
Time parameters	Data file and item			Select	
Bed Resistance		Item:		View	
- J Forcings					
Initial Conditions					
Laver Thickness and	Composition				
✓ Layer 1	Format	Constant	~		
Layer 2	Constant value	Fraction	Composition		
🔬 🗸 Morphology		1		50	
😟 🗸 Helical Flow Module		2		50	
🗄 🗸 Outputs					
		1		>	
	Data file			Select	
	Item	Fraction	Item	View	
		1			
		2			
		<		>	
		,			
Navigation					
					· · · · · · · · · · · · · · · · · · ·
Validation Simulation					

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.

Gorai_multi.m21fm - Modified				
MIKE 21 Flow Model FM	Model definit	on		
Module Selection	Max bed level change	10 [m/d] hydrodynamic, wave and sand transport calculation		
Model Definition Fraction definitions Time parameters	Speedup factor			
Sediment properties	Format	Constant ~		
Forcings	Constant value	1		
A layer Thickness and A layer Thickness and A layer Thickness and	Data file and item		Select	
Model definition		Item:	View	
Helical Flow Module Outputs				
Navigation				
	n_/			

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.



🧶 Gorai_multi.m21fm - Modified		- • ×
Order Inducting Inflerence Mick 21 Row Model FM Jomain Mick 21 Row Model FM Module Selection Module Selection Module Selection Module Christian Sedemet properties Bed Resistance Forcing 8 Model Definition Mod	Start time step 8640	
	1	

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.

🥚 Gorai_multi.m21fm - Modified			
MIKE 21 Flow Model FM			
Domain	Discharge Gan	ges	
Time		5	
Module Selection	ype Zero sediment fl	lux gradient for outflow, zero bed change for inflow 🛛 🗸	
🗈 🗸 Hydrodynamic Module			
🖃 🗸 Sand Transport Module			
Fraction definitions			
Time parameters			
Sediment properties			
Bed Resistance			
Initial Conditions			
Morphology Madal definition			
Time parameter			
Reundany Condition			
Discharge Gang			
Vater level Gan			
Vater level G			
Helical Flow Module			
🗄 🗸 Outputs			
< >			
Navigation			
Validation Simulation	r		

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.



Gorai multi.m21fm - Modified		
MIKE 21 Flow Model FM	Time parameters	
Domain	Time parameters	
Ime Madala Calastra	Chart King along 4220	
Wodule Selection	Start une step 4320	
Grad Transact Madda		
Madel Definition		
Fination definition		
Time parameter		
Sedment properties		
Bed Resistance		
Forcings		
Laver Thickness and		
- V Morphology		
Model definition		
Time parameter		
Boundary Conditio		
- V Helical Flow Module		
Time parameters		
Solution technique		
Initial Conditions		
Boundary Conditio		
< >		
Navigation		
Validation Simulation	n /	
,		

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.

🔵 Gorai_multi.m21fm - Modified			
MIKE 21 Flow Model FM			
- ✓ Domain	Dev	iation	
Time			
Module Selection	Type	Equilibrium conditions	
🕀 🗸 Hydrodynamic Module			
⊟ ✓ Sand Transport Module			
🖶 🗸 Model Definition			
Fraction definitions			
Time parameters			
Sediment properties			
Bed Resistance			
Forcings			
Initial Conditions			
Layer Thickness and			
Morphology			
Time parameter			
Boundary Conditio			
E Helical Bow Module			
Time parameters			
Solution technique			
Initial Conditions			
Boundary Conditio			
Outputs			
< >			
Navigation			
	ļ		
Validation Simulation	on /		



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



E 21 Flow Model FM	eviation				
Time Module Selection Tv	je Zero gradi	ent 🗸	1		
Hydrodynamic Module	viation				
Sand Transport Module					
Fo	rmat	Constant	~		
✓ Time parameters Co	nstant value	0 [deg]			
Sediment properties	ta file and item			Select	
Bed Resistance Forcings		Item:		View	
Initial Conditions			• • • • •		
Layer Thickness and Sol	tstart		Interpolation type		
Morphology Ty	pe Sine varia	ition ~	In time Linear	\sim	
Tine parameter	ne interval	0 [sec]	In space Normal		
Boundary Conditio	ference value	0 [deg]			
Helical Flow Module					
Time parameters					
Jointial Conditions					
Deviation					
🖻 🗸 Boundary Conditio					
Discharge Gang.					
Water level Gan					
⊕ ✓ Water level G					
Outputs					
>					
tion					

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.

Gorai_multi.m21fm - Modified		
MIKE 21 Row Model FM Domain Time	put 1	
Module Selection Geogr Geogr	aphic View Output specification Output items	
Model Definition	ald type ZD (horizontal) V Output format Area series V	
Comparison of the parameters Sediment properties Out	Ita type Discrete values V Flood and dry Only real wet area V utput file ST.dfsu	
	le step]Use simulation end time st 0 Lost 1270080 Frequency @640 as series ap projection Local Coordinates Import from file Easting Northing Layer no. Name 1 404423 93476 639721 49638 2 404423 93476 659721 49638 3 4423408.5 6539721 49638	
< >		
Navigation		
A surgeon V surgeon V		

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 5.8 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