MIKE 3 Flow Model

Mud Transport Module

User Guide

MIKE 2017

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CONTENTS

MUD TRANSPORT MODULE

User Guide

1 About This Guide

1.1 Purpose

The main purpose of this User Guide is to get you started in the use of MIKE 3 Flow Model, Mud Transport Module (MT), for applications involving the modelling of cohesive sediment transport. This User Guide is complemented by the Online Help.

1.2 Assumed User Background

Although the mud transport module has been designed carefully with emphasis on a logical and user-friendly interface, and although the User Guide and Online Help contains modelling procedures and a large amount of reference material, common sense is always needed in any practical application.

In this case, “common sense” means a background in sediment transport problems, which is sufficient for you to be able to check whether the results are reasonable or not. This User Guide is not intended as a substitute for a basic knowledge of the area in which you are working: mathematical modelling of cohesive sediment transport.

2 Introduction

2.1 General Description

The MIKE 3 Flow Model, Mud Transport Module (MT) describes erosion, transport and deposition of mud or sand/mud mixtures under the action of currents and waves.

The Mud Transport Module is applicable for:

- Mud fractions alone
- Sand/mud mixtures

The following processes can be included in the simulation.

- Forcing by waves, and/or currents
- Salt-flocculation
- Detailed description of the settling process
- Erosion and resuspension of bed.
- Layered description of the bed

In the MT-module, the settling velocity varies, according to the salinity, if included, and the concentration taking into account flocculation in the water column. Waves, as calculated by MIKE 21 PMS for example, may be included. Furthermore, hindered settling and consolidation in the fluid mud and underconsolidated bed are included in the model. Bed erosion can be either non-uniform , i.e. the erosion of soft and partly consolidated bed, or uniform, i.e. the erosion of a dense and consolidated bed. The bed is described as layered and characterised by the density and shear strength.

2.1.1 Application Areas

The Mud Transport Module can be applied to the study of engineering problems such as:

- Sediment transport studies for fine cohesive materials or sand/mud mixtures in estuaries and coastal areas.
- Siltation in harbours, navigational fairways, canals, rivers and reservoirs.
- Dredging studies.

3 Examples

3.1 General

One of the best ways of learning how to use a modelling system such as MIKE 3 Flow Model, Mud Transport Module is through practice. Therefore, we have included two applications in the installation:

1. Deposition in a harbour basin
2. Lagoon sedimentation

3.2 Deposition in a Harbour Basin

3.2.1 List of data and specification files

The following data files are supplied with MIKE 3:

Name: Harbor\Bathy.dfs2

Specification file: Harbor\input.M3

3.2.2 Defining the hydrodynamic model

This example has been chosen as a fairly simple one. The problem is to asses the deposition of fine sediment in a harbour basin located in a river or an estuary. The example is simplified to a situation with a constant flow of water and sediment. In reality the deposition in a harbour basin may also be influenced by factors such as density flows near the bottom and sediment gradients as well as tide.

The hydrodynamic conditions are:

- The model area has a uniform depth of 10.5m The bathymetry is shown in Figure 3.1.
- The upstream (western) boundary has a constant surface elevation of 0,05m and the downstream boundary (eastern) has a constant elevation of 0 m. This configuration will create a steady flow passing the harbour basin.

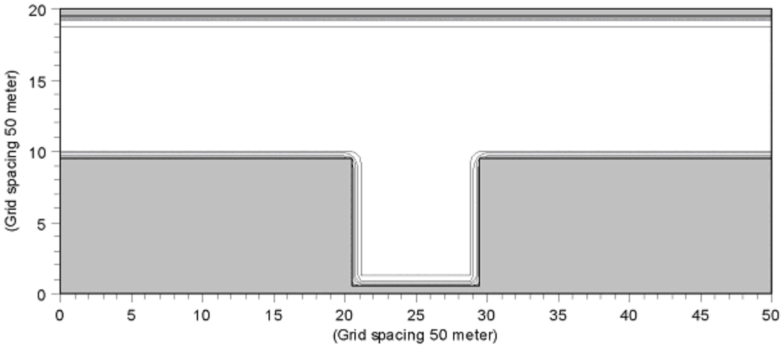

Figure 3.1 Deposition in harbour basin, model layout.

Additional basic information required is:

- The horizontal grid spacing, which on the basis of the size of the channel and harbour basin is selected to be 50 metres.
- The vertical grid spacing and the number of layers. Ten layers with a grid spacing of 1m have been specified. Notice that because of definition of the vertical discretisation the top layer will be 1,5m.
- The time step is, on the basis of the grid spacing and the water depth, selected as 5 seconds. (Corresponding to a Courant number of about 1). The simulation period is 24 hours.
- The initial surface elevation is 0.0m.

3.2.3 Defining the mud transport model

The various steps for setting up the mud transport model for this exampel are outlined below:

1. Enter Parameter selection. Choose one layer and one fraction.
2. Enter initial conditions. Check that the initial bed thickness is 1 m. Set the initial concentration to 0.0 kg/m^3.
3. Enter the dispersion and make sure that the dispersion factors are 0.5 and 0.1. Check that the limits for the dispersion doesn't violate the AD stability criteria.
4. Enter boundary conditions and set the left boundary to 0.5 kg/m^3 corresponding to a high sediment load from the river, and the right hand boundary to 0.5 kg/m^3.

5. Enter water column parameters and make sure that no sand fractions are chosen.

6. Enter settling and choose constant settling velocity.

7. Enter settling parameters and set the settling velocity to 0.0005 m/s.

8. Enter deposition and set the critical shearstress for deposition to 0.15 N/m^2.

9. Enter erosion under bed parameters and choose hard mud formulation.

10. Enter Critical shearstress under erosion and set the critical shearstress for layer 1 to 0.5 N/m^3.

11. Enter power of erosion under erosion and set the value to 1.

12. Enter erosion coefficient under erosion and set the value to 0.00005 kg/m^2/s.

13. Enter density of bed layer and set this to 300 kg/m^3.

14. Enter bed roughness and set this to 0.01m.

15. Enter results and choose the relevant output parameters. (SSC and bed thickness change).

Run the model.

3.2.4 Results

Figure 3.2 shows a plane plot of the surface velocity vectors at the end of the simulation when the flow has become steady. It is seen how the flow generates an eddy within the harbour basin. This eddy transports the sediment into the harbour basin hereby acting as transport mechanism for the sediment.

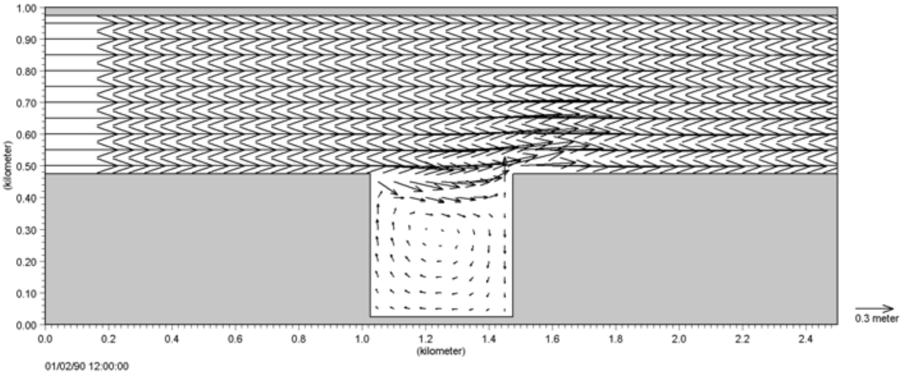

Figure 3.2 Surface velocity vectors after 24 hours simulation.

After execution you may extract time series of suspended sediment concentrations at the top and at the bottom layer of the water column in order to see the effect of the settling. The time series extraction tools are located in the MIKE Zero toolbox.

In Figure 3.3 time series of the suspended sediment concentrations in points (25,15,10) and (25,15,1) are plotted. The time series are extracted in the main channel and show how a vertical sediment profile is developed with a relative high concentration near the bed and a two times lower concentration near the surface.

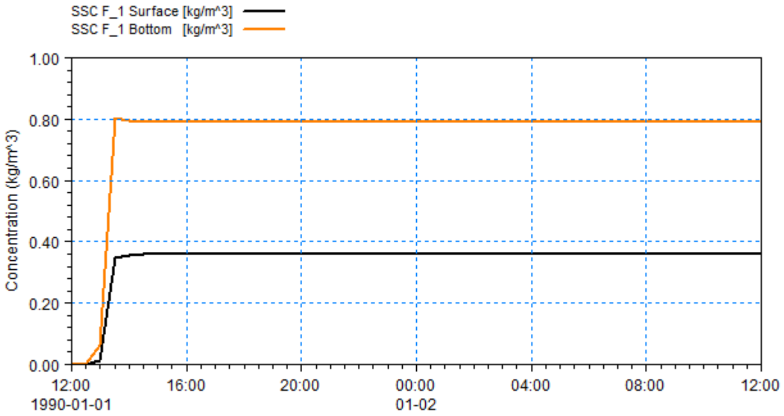

Figure 3.3 Suspended sediment concentrations (kg/m3) at the surface and at the bed.

Figure 3.4 shows the suspended sediment concentrations in the surface layer at the end of the simulation. It can be seen in the figure that the large surface concentration at the inflow boundary is decreased towards the outflow boundary due to the development of a suspended sediment profile.

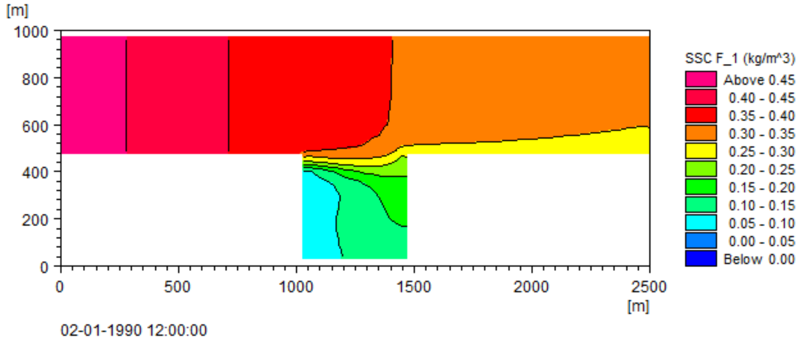

Figure 3.4 Surface sediment concentrations after 24 hours simulation

Figure 3.5 shows the accumulated net deposition of sediment during the 24 hour simulation period. It is seen that in the main channel a slight erosion is taking place whereas in the harbour basin sediment is deposited.

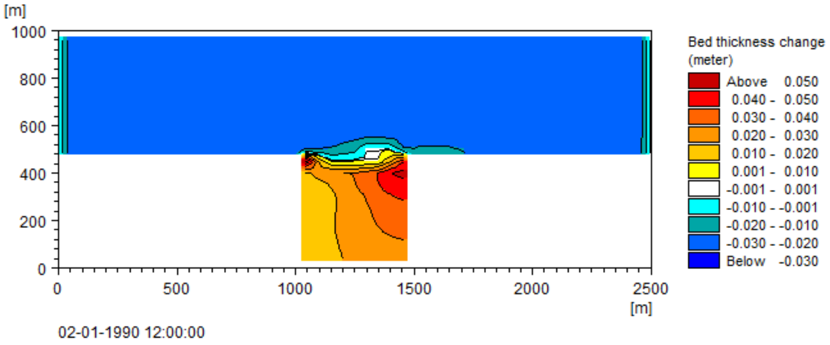

Figure 3.5 Accumulated net sedimentation (m) during simulation.

3.2.5 Exercises

In general it is always recommended to do a sensitivity test on the results to check the effect of possible uncertainties. Try the following:

1. Try to increase the settling velocity 50% and see the effect on the concentration profile.

2. Change the critical shearstress for erosion by 20% to 0.4 N/m^2. Does this affect the net sedimentation in the harbour?

3. What happens with the suspended sediment if the dispersion was doubled, will the net sedimentation in the harbour be effected?

3.3 Lagoon

3.3.1 List of data and specification files

The following data files are supplied with MIKE 3:

Name: Lagoon\Bathy.dfs2

Name:Lagoon\HDinit.dfs3

Name:Lagoon\MTinit.dfs3

Specification file: Lagoon\input.M3

3.3.2 Purpose of the study

A lagoon is connected to a nearby ocean by a narrow channel closed by a gate only letting water out at low tide. The lagoon is subject to outlets from several rivers. A local group wants to remove the gate to help fish pass and enter the rivers for spawning. The area looks as sketched in Figure 3.6

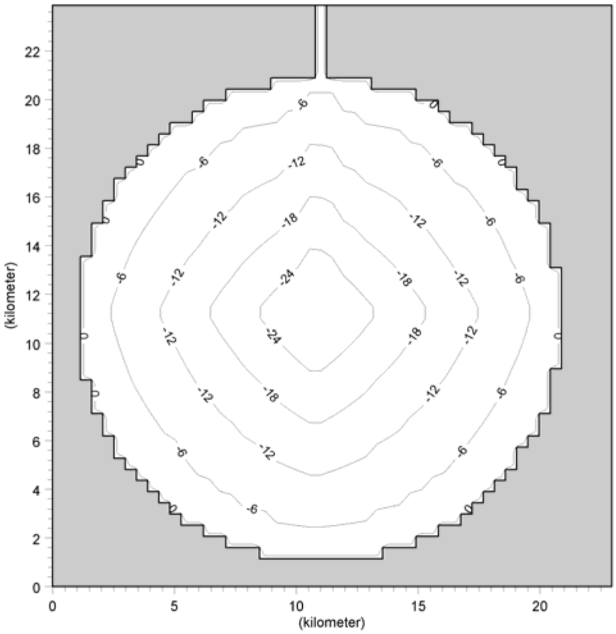

Figure 3.6 Bathymetry

3.3.3 Defining the hydrodynamic model

For simplicity the hydrodynamic model is defined in only one case. It is estimated that almost all the sediment discharged from the adjoining rivers are further carried out into the sea. Therefore only the case with salinity intrusion is considered. The background concentration from the sea will be transported into the lake by the intruding water hereby creating extra sedimentation in the lake and lowering the visibility in the lake.

In this case there is a tidal signal coming in from the sea. Three rivers discharge into the lagoon. The discharge is considered constant during simulation period. The spacial resolution is 459m and the vertical resolution is 0.5m. The time step is 60s. The simulation time is 2 days.

3.3.4 Hydrodynamic setup

The tidal signal is assumed to be sinosoidal with an amplitude of 1m. Average salinity in the ocean is 21PSU. The three rivers are discharging 1000m^3/s each.The temperature doesn’t vary significantly during the period so no temperature is included. The wind is 7m from west.

3.3.5 Defining the mud transport model

The mean concentration in the rivers are 0.001kg/m^3. The mean sediment concentration in the ocean is 0.05kg/m^3. Due to the mixing of saline and fresh water the salinity is expected to get within the interval of salinity flocculation (2-10 PSU) and therefore this effect is included. Based on measurements carried out around the lake a 3D map of the concentration has been created.

3.3.6 Mud transport setup

1. Enter Parameter selection. Choose one layer and one fraction.

2. Enter initial conditions. Specify that the initial bed thickness is 1m. Choose to read the initial concentration field from file. Choose the dfs3 file named mtinit.dfs3.

3. Enter the dispersion and make sure that the dispersion factors are 0.1 and 1. Check that the limits for the dispersion doesn’t violate the AD stability criteria.

4. Enter the boundary section and specify the boundary concentration as 0.05 kg/m^3.

5. Enter the source section and specify the source concentration as 0.001 kg/m^3.
6. Enter water column parameters and specify no sand fractions.
7. Enter settling and choose constant settling velocity.
8. Enter settling parameters and set the settling velocity to 0.0001 m/s.
9. Enter deposition and set the critical shearstress for deposition to 0.05 N/m^2.
10. Enter erosion under bed parameters and choose hard mud.
11. Enter Critical shearstress under erosion and set the critical shearstress for layer 1 to 0.15 N/m^3.
12. Enter power of erosion under erosion and set the value to 1.
13. Enter erosion coefficient under erosion and set the value to 0.0005 kg/m^2/s.
14. Enter density of bed layer and set this to 300 kg/m^3.
15. Enter bed roughness and set this to 0.01m.
16. Enter results and choose the relevant output parameters. (SSC and bed thickness change).
17. Run the model.
18. Run the model again with a boundary concentration of 0 and no salinity. Give the input and output files different names.

3.3.7 Mud transport results

Use the extraction tools to extract a profile at the middle of the lake in Position (24,25). Extract also a vertical section at position (x,y) = (24,35) closer top the entrance. Use the plot composer to create isoplet plots for the two positions.

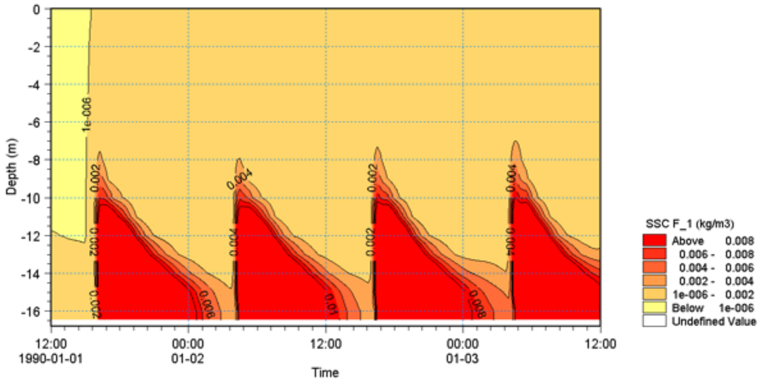

Figure 3.7 Time series of vertical changes at point (24,35)

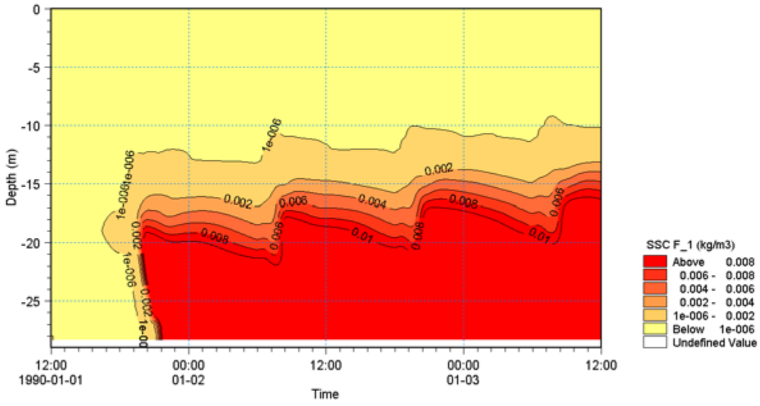

Figure 3.8 Time series of vertical changes at point (24,25)

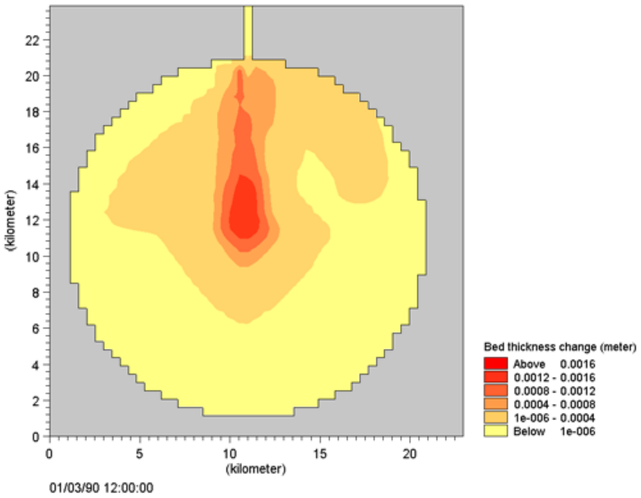

Figure 3.9 Bed thickness change

The results show that the sediment will travel in from the sea with the dense saline water. As the salt water hits the lake the water will travel along the bottom as a dense bottom plume taking the sediment with it. As the plume travels along the bottom the sediment will sediment on the bed and the concentration will diminish. The concentration in the upper water will remain very low. The maximum sedimentation during the 2 day simulation is around 1mm.

3.3.8 Exercises

In general it is always recommended to do a sensitivity test on the results to check the effect of possible uncertainties. Try the following:

1. Plot a profile of the settling velocity. Check the effect of lowering the boundary salinity by 5 psu.

2. Try to switch off the salinity and check the difference in settling velocity and net sedimentation.

3. What happens with the suspended sediment if the dispersion was doubled?

4. Try to increase the settling velocity by 50%.

4 Dialog Overview

A description of each dialog in the MIKE 3 MT Editor is given in the sections below, in the order in which the dialogs appear.

Additional information is also given in the Reference Manual *(p. 35)*.

4.1 Parameter Selection

Number of fractions

Here you must select the number of fractions you wish to include in the present simulation.

The maximum number is 8.

Number of layers

Here you must select the number of layers you wish to include in the present simulation. The maximum number is 8. It is recommended to keep the number of layers as low as possible. The number of layers should be sufficient to represent the strength variation in the bed.

Include salinity flocculation

If salinity flocculation should be included mark this check box.

Include Heavy Metals/Xenobiotics

If xenobiotics should be included mark this check box.

4.2 Initial Conditions

Initial concentration

Here you must specify the initial concentration for each fraction. This can be done as either a constant or a type 3 map for each area. Typical background concentration is 0.01 kg/m^3.

Initial bed thickness

Here you must specify the initial bed thickness for each layer. This can be done as either a constant or a type 2 map for each area.

Initial bed distribution

Here you must specify the content of a given fraction in a given layer in %. This means that for a layer the total value in each point must be 100%. The distribution can be given as a constant for each area.

4.3 Dispersion

On this dialog page you specify the dispersion coefficients for the movable components. The dispersion coefficients can be set either as dependant of the eddy viscosity, the velocity in the x and y directions or the speed.

If you have selected “Proportional to eddy viscosity”, you should specify a proportionality factor for each direction. For each area, you can specify the coefficients as a constant. The first one is for the horizontal plane, and the second is for the vertical plane. With this selection, the dispersion coefficients are at all times scaled in accordance with the calculated eddy viscosity. To avoid values that would make the computation unstable, reasonable cut-off limits should be specified. For further information see reference manual, Dispersion Factors *(p. 43)*.

If you have selected “Proportional to velocity”, you should specify a proportionality factor for each direction. For each area, you can specify the coefficients as a constant. The first one is for the horizontal plane, and the second is for the vertical plane. With this selection, the dispersion coefficients are at all times scaled in accordance with the calculated velocities. To avoid values that would make the computation unstable, reasonable cut-off limits should be specified. For further information see reference manual, Dispersion Factors *(p. 43)*.

If you have selected “Proportional to speed”, you should specify a proportionality factor for each direction. For each area, you can specify the coefficients as a constant. The first one is for the horizontal plane, and the second is for the vertical plane. With this selection, the dispersion coefficients are at all times scaled in accordance with the calculated speeds. To avoid values that would make the computation unstable, reasonable cut-off limits should be specified. For further information see reference manual, Dispersion Factors *(p. 43)*.

NOTE: Remember that dispersion coefficients in a mathematical model are dependent on the grid size and time step, in addition to the physics of the problem.

4.4 Boundary

At each open boundary in the model you should specify the concentration for each movable component. The components are each of the sediment fractions specified.

The concentration at the open boundary can be specified in one of four ways:

- As a constant value, which will be used at all times at all grid points along the open boundary.

- From a type 0 data file with time-variant values, which will be used at all grid points along the open boundary.
- From a type 1 data file where time-variant values are defined for each grid point along the open boundary.
- From a type 2 data file where time-variant values are defined for each grid point along the open boundary.
  If no boundary concentrations are known a typical background concentration is $0.01 kg/m^3$.

4.5 Sources

For each movable component you should specify the concentration at each defined source in the model. The components are each of the sediment fractions specified.

You can either specify the source concentration as constant in time or read and interpolate the concentration from a type 0 data file.

NOTE: At one source you cannot mix the two different types. Also, any possible data file must have the same number of items as there are components in the simulation. This file must contain the suspended sediment fractions in numerical order.

4.6 Forcings

The only forcing that is included at this time is waves. In this menu you must choose to include waves or not.

4.6.1 Waves

Waves will contribute to increased shear stress in the bottom layer leading to higher concentrations of suspended sediment. The shearstress will be calculated using a combined wave-current shearstress formulation.

You can include waves in your calculations in three ways.

- Constant waves
- Time and space varying waves
- Wave database

For all wave calculations the effect of liquefaction can be included. Liquefaction is a weakening of the sediment due to pore-pressure flocculations caused by the waves.

To include this you must specify a liquefaction factor.

You must specify which formulation to use for calculating the bed shear stress for combined wave-current action.

You must also specify the minimum waterdepth for waves. This is the water depth below which the bed shear stress is found by using a pure current solution instead of a wave-current solution. For further information see reference manual, Wave Forcing *(p. 63)*.

4.6.2 Constant waves

If you choose constant waves the waves will be sinusoidal with no directional spreading. You must specify the significant wave height and period and the angle to true north.

4.6.3 Time and space varying waves

If you choose time and space varying waves you must specify a type 2 file containing mean heights, periods and angles to true north, in this order!

The program will interpolate if the time step is not equal to that of the simulation. If nested simulation the wave parameters will be interpolated from the coarse grid to the fine grid.

4.6.4 Wave database

If you choose wave database you must specify a number of 2D wave maps corresponding to a number of combinations of the governing parameters wind speed, wind direction and water level. These combinations are defined by specifying starting value, increment and number of values for each of the three parameters.

The wave maps are normally generated in the MIKE 21 PMS (Parabolic Mild Slope) module. They must contain mean wave height, mean wave period, and mean wave direction in that order.

The wave database works by taking the water level and the wind speed and direction in every grid point at every time step and interpolate in the wave database getting the wave height, wave period, and wave direction.

The wave maps are given for the main area only. In case of a nested model, the model will interpolate the values into the sub areas. Be aware that there is a maximum number of 120 wave maps. Each wave map should include wave height, wave period and wave direction in that order.

4.7 Water Column Parameters

Here you must specify if the simulation is purely cohesive or if some of the fractions are to be treated as noncohesive fractions. (Sand). Normally sediment with a diameter greater than 60µm are considered non cohesive. Under water column parameters the following sections are included:

- Viscosity and Density *(p. 29)*
- Settling *(p. 29)*
- Sand Fractions *(p. 30)*
- Deposition *(p. 30)*

4.7.1 Viscosity and Density

Under viscosity and density you must specify parameters for a possible feedback from the MT on the density and viscisty in the HD. You must specify a bulk density of the suspended sediment, a base for the paramterisation of the feedback, and a reference concentration for the feedback on the viscosity.

4.7.2 Settling

Under basic settling you must choose if you want to do the calculations with a constant settling velocity or if you want the calculation to consider the influence of flocculation. The effect is shown in the Reference Manual *(p. 35)*. If you choose constant settling velocity the constant part will continue for indefinite concentrations. If flocculation is chosen the settling velocity will rise until the concentration for hindered settling (c_{hinder}) is reached. From this point the settling velocity will remain constant.. If flocculation is chosen you must choose if the effect of hindered settling is to be included. If hindered settling is chosen the settling velocity will from the point when c_{hinder} is reached and until the concentration hits the gelling point at which time the settling velocity is negligible. For further information see reference manual, Settling Velocity *(p. 53)*.

4.7.3 Settling Parameters

If you have chosen constant settling velocity you must specify the value as either a constant or a type3 file.

If you have chosen to include flocculation:

For the part below c_{floc} the formulation is:

$$w_s = w_0\left(\frac{c_{floc}}{\rho_{sediment}}\right)^{\gamma} \tag{4.1}$$

For the part between c_{floc} and $c_{hindered}$ the formulation is:

$$w_s = w_0 \left(\frac{c_{total}}{\rho_{sediment}} \right)^{\gamma} \tag{4.2}$$

For the part above $c_{hindered}$ the formulation is:

$$w_s = w_0 \left(\frac{c_{hindered}}{\rho_{sediment}} \right)^{\gamma} \tag{4.3}$$

If hindered settling is applied, the formulations of Richardson and Zaki are available (see reference manual).

You must specify the following parameters:

Gelling point (c_{gel}):	The point for which the settling velocity is negligible
Density of sediment:	(ρ saliment) Density of the sediment

Concentration for hindered settling: ($c_{hindered}$) The minimum concentration for which hindered settling occurs.

Concentration for flocculation: (c_{floc}) The minimum concentration for which flocculation occurs.

γ is set to 1.

W_{sn} is set to 1.

For further information see reference manual, Settling Velocity *(p. 53)*.

4.7.4 Sand Fractions

Here the properties for the selected sand fractions must be specified. The mean settling velocity for each sand fraction must be specified. This is used to calculate a corresponding diameter used in the erosion description. The equilibrium concentration for sand will then be calculated. If the concentration is below the one calculated with the fraction as mud, the exceeding part of the sediment will be deposited. For further information see the reference manual, Sand Fractions *(p. 52)*.

4.7.5 Deposition

The critical shearstress for deposition must be specified as either a constant or a type2 file.

For further information see reference manual, Deposition *(p. 42)*.

4.8 Bed Parameters

Bed parameters consist of the following points:

- Erosion *(p. 31)*
- Density of bed layers *(p. 32)*
- Bed roughness *(p. 32)*
- Consolidation *(p. 32)*

4.8.1 Erosion

Here you must choose if a given layer is to be considered a hard consolidated layer or a softly consolidated layer.

The hardly consolidated bed is characterized by being uniform with nearly constant strength with increasing depth.

The soft partly consolidated bed is characterized by the layers showing a gradually increasing strength and resistance against erosion with depth.

MIKE 3 MT offers two erosion descriptions:

Soft bed description:

Erosion: $S_E = E \exp[\alpha (\tau_b - \tau_{ce})^{½}]$
where

α: power of erosion

Hard bed description:

$$E^i = E_0^i {p_E^i}^{E_m} \tag{4.4}$$

where p_E^i is a probability ramp function of erosion, E_0 is the erosion coefficient and E_m is the power of erosion.

$$p_E^i = max\left(0, \frac{\tau_b}{\tau_{ce}^i} - 1\right) \tag{4.5}$$

You have the opportunity to set an upper limit to the concentration by setting C_{max}. If the concentration exceeds C_{max} the erosion will be scaled down until it doesn't.

For further information see reference manual, Erosion *(p. 45)*.

4.8.2 Erosion coefficient

A calibration factor for calculating the erodibility of the bed must be given either as a constant or as a type 2 file for each layer and each computational area.

4.8.3 Power of erosion

You must specify a calibration factor for the erosion of the bed. This can be done as a constant for each layer.

4.8.4 Critical shear stress

The critical shear stress for erosion must be given for each layer either as a constant or as a type 2 file for each computational area.

For further information see reference manual, Erosion *(p. 45)*.

4.8.5 Density of bed layers

The density of the bed layer must be specified for each layer as either a constant or a type 2 file for each computational area. The bed density is defined as dry density.

Note that the density is specified for the whole layer containing all fractions.

For further information see reference manual, Bed Density *(p. 36)*

4.8.6 Bed roughness

In order to calculate the bed shear stress you must specify the bed roughness. This can be done either as a constant or as a type 2 file.

4.8.7 Consolidation

If transition of mud between layers is included you must specify a transition rate. This can be done either as a constant or a type 2 file.

For further information see reference manual, Consolidation *(p. 41)*.

4.9 Mass Budget

Initially the number of mass budget files is specified.

Subsequently each mass budget file is defined by an associated mass budget polygon, information on which time steps to store, filename and title, and selected model components.

Notice that it is not possible to specify any mass budget files before one or more polygons have been specified under the Basic Parameters Dialog.

For futher ínformation see Mass Budget in the MT Reference Manual.

4.10 Results

The detailed specifications of the result files are set by editing settings for each individual output area.

Up to 18 normal output data files (type 2 or 3) containing the computed concentration fields. You specify the spatial and temporal output range and the associated area number, and you specify a name and (optionally) a title for the output data file.

NOTE: Result files tends to become very big, so have that in mind when specifying the area, number of items and period. Also note that if 3D output file is choosen, 2D parameters can not be written to this file. 2D components are usually compåonents that only occur at the bottom, or the surface eg. bottom shearstress.

5 Reference Manual

This manual is intended for use when you are making model applications and need to know how various inputs, outputs, etc. can be specified for the MIKE 3 Flow Model, Mud Transport Module.

It is assumed that you are familiar with the operation of MIKE 3 under the MIKE Zero platform.

All entries listed below are included in the reference manual.

5.1 Bed Density

Different sediment types have different densities depending on their previous geological history, the chemical properties, the organic content and several other factors.

If the area of interest is large it may be necessary to obtain knowledge of sediment in different locations within the area in order to generate a representative density map of the area for each layer. This can be done from either measurements or through researching the geological history of the area. In the vertical the density varies with the degree of compression and with the type of mud. Different geological periods have left soils with different densities. For instance areas that have been covered by glaciers can have very hard layers, and areas that has been sedimentation areas for a long time can be covered by relatively loose mud. Therefore it is necessary to assess the density and the strength at different depths of the seabed in order to determine the vertical resolution of the bed and the bed densities for each layer.

The bed density is defined as dry density as follows:

$$\rho_d = \frac{\text{Mass of grains}}{\text{Volume of mixture}} \tag{5.1}$$

5.1.1 Specifying the bed density

The bed density is specified under the *Bed density* dialog.

It can be specified as either a constant or a type 2 file and it is defined as the dry density.

5.1.2 Recommended values

Following values can be used as guidelines for the range of the bed density.

Table 5.1 Typical bed densities

Sediment stage	**General description**	**Rheological behaviour**	**Dry density (kg/m^3)**
Freshly deposited (1 day)	Fluff	Mobile fluid mud	50-100
Weakly consolidated (1 week)	Mud	Fluid stationary mud	100-250
Medium consolidated (1 month)		Deforming cohesive bed	250-400

Table 5.1 Typical bed densities

Sediment stage	**General description**	**Rheological behaviour**	**Dry density (kg/m^3)**
Highly consolidated (1 year)		Stationary cohesive bed	400-550
Stiff mud (10 years)	Stiff clay	Stationary cohesive bed	550-650

5.1.3 Remarks and hints

If only the bulk density (or wet density) is known, the density is determined as:

$$\rho_d = \frac{\rho_s(\rho_b - \rho)}{(\rho_s - \rho)} \tag{5.2}$$

in which ρ_b is bulk density in kg/m^3, ρ_s, is grain density in kg/m^3 and ρ is water density in kg/m^3.

5.2 Bed Description

The sediment bed in the Mud Transport Module consists of one or more bed layers. Each bed layer is defined by the sediment contained in the layer and by the dry density and erosion properties of the layer. The sediment mass of a bed layer is comprised by the summation of the mass of each sediment fraction present in the layer. The bed layer masses are considered the state variables of the sediment bed, which means that the model during simulation tracks their evolution in space and time. The dry density and erosion properties, on the other hand, are considered properties of each of the bed layers and are therefore kept constant in time.

The bed layers are perceived as “functional” layers, where each layer is characterised by its dry density and erosion properties, rather than physical layers, whose physical properties will typically vary in time due to consolidation and other processes. In the present bed description, the consolidation process is expressed as a transfer of sediment mass from one bed layer to another.

The bed layers are organised such that the “weakest” layer (typically fluid mud or newly deposited sediment) is defined as the first (uppermost) layer and that the subsequent layers have increasing dry density and strength. Figure 5.1 shows an example of a bed description including two bed layers and the processes affecting it. During a simulation one or more layers may be completely eroded such that the layer becomes ‘empty’ in some places. The active bed layer at a certain time in a certain place is defined as the first bed layer taken from the top, which is not empty. Erosion will always take place from the active layer. Depositing sediment will, on the other hand, always enter the uppermost bed layer.

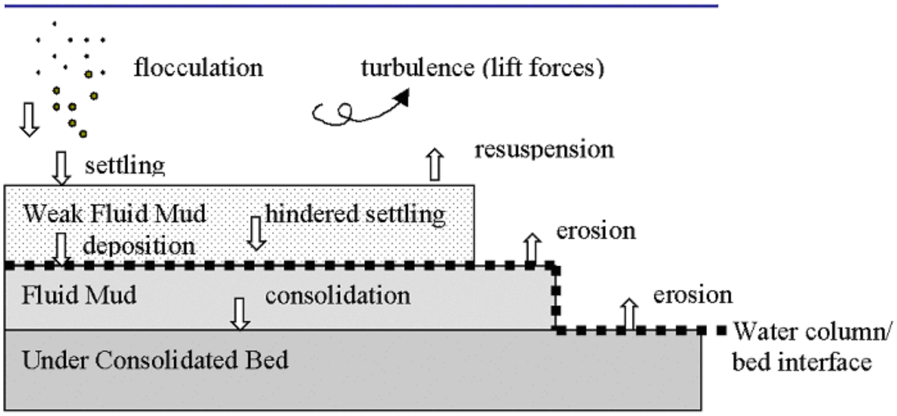

Figure 5.1 Processes included in Mud Transport Module. The bed layers are the layers below the water column-bed interface (dotted line)

The mass of the i'th sediment fraction in the j'th bed layer in a certain horizontal grid point is updated every time step following the expression:

$$m_{i,j}^{new} = m_{i,j}^{old} + (D_i - E_i)\Delta t + (T_{i,j\text{-}1} - T_{i,j}), \tag{5.3}$$

where m (kg/m^2) is sediment mass, D (kg/m^2/s) is a possible deposition (only in the uppermost bed layer), E (kg/m^2/s) is a possible erosion (only from the active bed layer), T (kg/m^2/s) is a possible downward transfer of sediment and Δt (s) is simulation time step.

Other processes such as sliding can further affect the spatial bed sediment distribution.

The thickness of the i'th bed layer is a derived parameter determined as:

$$H_j^{new} = \frac{M_j}{\rho_{d,j}} = \frac{\sum_i m_{i,j}^{new}}{\rho_{d,j}}, \tag{5.4}$$

where H (m) is bed layer thickness, M (kg/m^2) is total sediment mass and ρ_d(kg/m^3) is dry density.

5.3 Bed Parameters

Bed parameters are defined as the parameters governing everything going on in the bed. The following processes are included under bed parameters:

- Bed Density
- Erosion
- Consolidation
- Bed roughness

5.4 Bed Roughness

The bed roughness is the resistance against the flow. It is included for calculating the bottom shearstress. The bed roughness depends on the shape of the bed (dunes, ripples, etc.) and the grain size. Despite the dynamic nature of the dunes and ripples the bed roughness is constant in time since the local bed shape change is considered constant in time on average. The bed roughness is independent of the other bed parameters.

5.4.1 Specifying the bed roughness

The bed roughness is specified under the *Bed roughness* dialog.

It can be specified as either a constant or a type 2 file. It is defined as the Nikuradse roughness (k_n).

5.4.2 Recommended values

K_n is generally defined as 2.5 times the diameter of the sediment. However, for fine sediment the bottom shape becomes the dominant factor and the recommended value is around 0.001m.

5.5 Boundary Conditions

As for the hydrodynamic set-up, the conditions at the open boundaries are of great importance.

For each suspended sediment fraction you must specify the boundary concentrations in one of the following ways:

- A constant value used throughout the whole simulation. The value is applied at all points along the boundary.
- A time series (**type 0 data file**) where the value at a time step is applied at all points along the boundary. The time series is automatically interpolated to match the simulation time step.

- A time series of line values (**type 1 data file**) which automatically is interpolated to match the simulation time step. The number of grid points in the data file must match the number of horizontal grid points along the open boundary, i.e. the boundary concentration will be vertically constant. The file may be generated by several means, e.g.: using the type 1 data editor **(ProfileEditor)**, using the MIKE 21 advection-dispersion transfer data program with results from a previous MIKE 21 MT run, or using the tools in the MIKE Zero Toolbox to extract line series from 2D and 3D data.

- A time series of values at a vertical section (type 2 data file) which automatically is interpolated to match the simulation time step. The number of grid points, both horizontally and vertically, in the data file must match the number of grid points at the open boundary. There are several ways to generate such a file of boundary values, e.g. using the type 2 data editor **(GridEditor)** or the tool in the MIKE Zero Toolbox to extract 2D data from a type 3 data file.

For all the different ways of specifying boundary values, it is necessary to specify them for all open boundaries.

5.5.1 Remarks and hints

It is recommended, if possible, to place the open boundaries away from both the areas of interest and areas of influence. Doing this, the boundary concentrations can be given as the background concentration.

5.6 Calibrating the MT-model

The MIKE 3 Flow Model, Mud Transport Module simulations offer a large number of parameters to adjust during calibration.

It is very important to keep the number of adjusted parameters down from simulation to simulations. Preferably only change one parameter at a time in order to assess the effect of the change.

5.6.1 Calibrating water column parameters

In order to keep track of the effects when calibrating it is highly recommended to keep the settling velocity constant when beginning the calibration. This makes the effects more visible. When the effects are known, the dependence on the concentration can be switched on.

5.6.2 Calibrating bed parameters

Normally the critical shear stress for erosion and the erosion coefficient are the main calibration parameters along with the selection of weak or hard bed. Other parameters are most often used for fine tuning later.

5.7 Consolidation

Once the sediment has settled on the sea bed it will start consolidating. It will do this due to the weight of the sediment settled over it. This process leads to a slow compression of the sediment in the lower layers. Therefore the sediment will increase in density and strength with time. This process also leads to a drop in the bed level if no further sediment is present.

The consolidation of the bed can be described by means of a transfer function T_f, which transfers sediment between the bed layers in the downward direction at a constant rate. The sediment fractions will be transferred as a mass with the given fraction distribution in the given time step. The transfer function for the i'th bed layer is:

Tf,i = constant,

The sediment is hereby transferred from a layer with a certain density and critical shear strength to a layer with (typically) higher density and shear strength.

5.7.1 Specifying consolidation

The consolidation parameters can be set in the *transition* dialog under *bed parameters*

The transfer function for each subarea is specified as a **Constant** or a **Type 2 file** in the model (varying in the horizontal plane) in the model for each interface between two bed layers. The transfer function is constant in time.

5.7.2 Recommended values

General values are between 10^{-8} kg/m^2/s and 10^{-5} kg/m^2/s. Generally the transition coefficient is decreasing down through the layers corresponding to more consolidated layers.

5.7.3 Remarks and hints

Consolidation is only relevant for time scales of several weeks or more. It is thus relevant for e.g. simulation periods covering neap-spring tidal cycles.

5.8 Courant Number

The transport Courant number is defined as follows:

$$C_{rU} = \frac{U\Delta t}{\Delta s} \tag{5.5}$$

where Δt is the time step used in the advection-dispersion solver, U the current speed in one direction and Δs the grid spacing in the direction corresponding to U.

The transport Courant number actually expresses how many grid points the given matter moves in one time step. For stability reasons the Courant number should always be below 1.

5.9 CPU Time

The CPU time required by a hydrodynamic and mud transport simulation depends on the size of your model, on the number of time steps in your simulation, on the number of fractions and layers, on which features you have specified for the simulation and on the general computational speed of your computer.

5.9.1 Factors Influencing the CPU time

If you wish to estimate how a change in your specifications for the hydrodynamic part changes the CPU time required without specifying the model set-up, please refer to the user guide for the Hydrodynamic Module.

However, if you wish to estimate how changes in your mud transport set-up changes the CPU time required, the following guidelines can be used:

- The CPU time varies linearly with the number of water points (or computational points) in the model.
- The CPU time also varies linearly with the number of time steps if flooding and drying is not selected. If this feature is selected the variation as a function of the number of time steps is only approximately linear.
- The CPU time varies with the number of equations to be solved. In addition to the advection-dispersion equation for the suspended sediment, the hydrodynamic equations are solved.

5.10 Deposition

The deposition of suspended sediment is the transfer of sediment from the water column to the bed. Deposition takes place where the bed shear stress

(τ_b) is smaller than the critical shear stress for deposition (τ_{cd}):The deposition for the i´th mud fraction is described as:

$$D^i = w_s^i c_b^i p_D^i \tag{5.6}$$

where p_D^i is a probability ramp function of deposition, w_s is the fall velocity and c_b is the bottom concentration of fraction i, ie the concentration in the bottom cell.

$$p_D^i = max\left(0, min\left(1, 1 - \frac{\tau_b}{\tau_{cd}^i}\right)\right) \tag{5.7}$$

5.10.1 Specifying deposition

The critical bed shear stress for deposition and the applied concentration profiles are specified in the *Deposition* dialog.

The critical shear stresses for deposition for each subarea are specified as either a **Constant** or a **Type 2 data file** for each layer (varying in the horizontal plane). Both parameters are constant in time.

5.10.2 Recommended values

The critical shear stress for deposition is generally a calibration parameter. The value is less than the critical shear stress for erosion. Normal values are in the interval 0-0.1 N/m^2. Relative height of centroid is generally close to 0.3.

5.10.3 Remarks and hints

If the critical shear stress for deposition is high more sediment will deposit and opposite if it is low.

5.11 Dispersion Factors

5.11.1 General Description

The transport equation for a component concentration c is formulated as:

$$\frac{Dc}{Dt} = \frac{\partial}{\partial x_j}\left(\delta_j \frac{\partial c}{\partial x_j}\right) + SS \tag{5.8}$$

where SS is the source/sink term and δ_j is the dispersion coefficient in the j-direction. You have three choices:

- The dispersion can vary proportionally to the local effective eddy viscosity with the factor of proportionality being $1/\sigma_T$, the dispersion factor. σ_T is the Prandtl number. Values of σ_T greater than one imply that diffusive transport is weaker for the concentration c than for momentum. See also the section *Dispersion Factors* in the *Hydrodynamic Module, Reference Manual*.
- The dispersion coefficients can be specified as being proportional to the local velocity components in each grid direction, e.g. in the x-direction δ_x is proportional |u|.
- The dispersion coefficients can vary proportionally to the local current vector, i.e. there are separate dispersions in the longitudinal, the transverse and the orthogonal directions.

5.11.2 Specifying Dispersion Factors

In the **Dispersion Specifications dialog** you choose the dispersion variation for each of the components from the combo-box selection placed to the right of each component's name.

In the **Dispersion Specification dialog** you also give the factor of proportionality. You must also specify the dispersion limits, i.e. the limits within which the dispersion coefficients are allowed to vary, for each grid direction: Defining the dimensionless dispersion coefficient for direction j as

$$D_j = \frac{\delta_j \Delta t}{(\Delta s_j)^2} \tag{5.9}$$

where Δs_j is the grid spacing in the j-direction. A stability requirement is that the sum of all three D_j is less than 0.5.

5.11.3 Recommended Values

A wide range of values for σ_T occurs in the literature. In many cases a value of 10 can be applied, corresponding to a dispersion factor of 0.1.

When the mixed Smagorinsky/k-ε turbulence model is applied, the temporally and spatially varying values of σ_T are calculated as an integrated part of the turbulence model, and a dispersion factor of 1 is recommended.

5.11.4 Remarks and Hints

A constant dispersion coefficient may be obtained by entering a positive value for the proportionality factor and setting all dispersion limits equal to the desired value.

The above mentioned dispersion stability criterion often leads to a restriction, which yields a small time step due to a very fine vertical resolution, see *Time Step*.

The above mentioned dispersion stability criterion often leads to a restriction, which yields a small time step due to a very fine vertical resolution, see Time Step. Therefore, it might advantageous to select an implicit scheme for the vertical dispersion.

5.12 Erosion

The erosion of a bed layer is the transfer of sediment from the bed to the water column. Erosion takes place from the active bed layer (see *Bed Description*) in areas where the bed shear stress (τ_b) is larger than the critical shear stress for erosion (τ_{ce}). The bed parameters are considered constant for each layer. Therefore erosion is calculated for the active layer. The eroded material is then distributed to the different fractions according to the distribution in the bed.

5.12.1 Critical shear stress for erosion

The criteria for erosion is that the critical shear stress for erosion is exceeded corresponding to the driving forces exceeding the stabilising forces. The critical shear stress for erosion is constant throughout the si-mulation.

5.12.2 Hard bed description

For a dense consolidated bed the erosion rate for the j´th layer is described as (Metha et al, 1989).

$$E^j = E_0^j \, {p_E^j}^{E_m} \tag{5.10}$$

where p_E^j is a probability ramp function of erosion and E_0 is the erosion coefficient and E_m is the power of erosion.

$$p_E^j = \max\left(0, \frac{\tau_b}{\tau_{ce}^j} - 1\right) \tag{5.11}$$

5.12.3 Soft bed description

For a soft, partly consolidated bed the erosion rate for the j'th layer is described as:

$$E = E_o^j \exp(\alpha(\tau_b - \tau_{ce}^j)) \tag{5.12}$$

5.12.4 Specifying erosion

The erosion parameters are specified in the *Erosion* dialog (see *Erosion*).

The erosion parameters are specified as a **Constant** in time for each bed layer.

The critical shear stresses for erosion for each layer and for each subarea are specified as either a **Constant** or a **Type 2 data file** (varying in the horisontal plane).

5.12.5 Recommended values

The value E is a proportion factor governing the speed of erosion. For soft bed it is generally between 5e^{-6} and 2e^{-5} kg/m^2/s. For hard bed it is usually around 1e^{-4} kg/m^2/s.

If the values E_0 or α are set the erosion rates will evolve exponentially. α usually lies between 4.2 and 25.6.

For critical shear stress the following typical values are given:

Table 5.2 Critical shear stresses

Mud type	**Density [kg/m^3]**	**Typical τ_b [N/m^2]**
Mobile fluid mud	180	0.05-0.1
Partly consolidated mud	450	0.2-0.4
Hard mud	600+	0.6-2

The critical shear stress for erosion can be estimated from the residual yield shear stress in the following way:

$$\begin{aligned} \tau_{ce} &= \sqrt{0.00001\tau_{yj}} & \tau_{yj} &\le 0.00015 N/m^2 \\ \tau_{ce} &= 0.0000025\tau_{yj} & \tau_{yj} &> 0.00015 N/m^2 \end{aligned} \tag{5.13}$$

In which τ_{yj} is the residual yield shear stress for the layer j.

5.12.6 Remarks and hints

Generally only layers which recently has been relocated are considered soft layers. All other layers are normally considered hard layers.

5.13 Initial Conditions

Under initial conditions the starting values for the bed composition and the suspended sediment are given. In the input this is given as suspended sediment, bed thicknesses and distributions of grain fractions. When calculating the model it will convert the thickness to mass using the specified densities and do all the calculations on masses.

5.14 Initial Concentration

A specification of the initial concentrations of suspended sediment in all water points is necessary as initial condition for the AD solver. The initial concentrations define the amount and distribution of sediment in the water column at simulation start. There are two possibilities for specifying the initial concentrations: A **constant** value used everywhere in the model or the initial concentrations can be read from **type 3data file**. A type 3 data file covering the model area as defined through the bathymetry may be created from an **xyz-file** (ASCII file containing positions and values) with the **Digitizing** tool in the MIKE 21 Toolbox.

For recommendations on the initial concentrations see *Suspended Sediment (p. 60).*

5.14.1 Initial layer thickness

The initial thickness of the specified bed layers and the larger densities, define the mass of sediment present in the bed at simulation start. The initial bed layer thickness can for each layer be specified as either a constant value or as a type 2 data file.

5.14.2 Initial bed distribution

The distribution of the sediment fractions must be given for each layer.

This is done by giving the percentage of fraction i within the layer. The total sum of fraction should be 100 per cent.

The distributions can be given as **constants**.

5.15 Liquefaction

The liquefaction by waves is taken into account as a weakening of the bed due to the breakdown of bed structure. This may cause increased surface erosion because of the reduced strength of the bed top layer. What happens is that due to the waves the pore pressure within the bed will rise because it builds up at the wave crest faster than it decreases at the trough. This leads to a point where the pressure at a given point exceeds the weight of the sediment above and the bed sediments starts acting as thick liquid. The thickness of the liquefied layer is defined as from the surface and down to the point where the weight of the above sediment is equal to the pore pressure.

The liquefaction process is modelled assuming that the bed is liquefied to a depth proportional to the wave boundary layer thickness, i.e. a thin layer close to the bed. The process is described as:

$$E_L = \rho_b \cdot d_m / \Delta t \tag{5.14}$$

where

E_L	erosion rate due to liquefaction (kg/m^2/s)
ρ_b	density of mud material (kg/m^3)
d_m	thickness of liquefied material (m)
Δt	time step (s)

The liquefaction process is only invoked, if waves are present. The thickness of liquefied material is given as

$$d_m = F_{liq} \cdot \delta_{wav} \tag{5.15}$$

where

F_{liq}	liquefaction (proportional) factor
δ_{wav}	wave boundary layer thickness (m)

If d_m is less than the thickness, which corresponds to the thickness of the bed eroded during normal erosion, then the liquefaction is not invoked.

The factor, F_{liq}, is considered as a calibration factor.

5.15.1 Specifying liquefaction

Liquefaction is specified under *waves* provided that waves are switched on.

5.15.2 Remarks and hints

Liquefaction is a process depending on the accumulation of pore pressure in the bed.This accumulation takes some time and requires significant waves. Including liquefaction should therefore not be applied for cases with small waves or for cases where the wave climate is only active for a short period of time.

5.15.3 Recommended values

The recommended value for the liquefaction factor is 1.

5.16 Mass Budget

The mass budget facility provides the user with a possibility to establish the mass budget of one or more model components within a certain area of the model domain. In the case of the Mud Transport Module, the model components comprise both the suspended mud fractions and the bulk variables Total Suspended Mass, Total Bed Mass and Total Mass (sum of suspended and bed masses). The specification of a mass budget comprises two steps: Firstly the area (or polygon) corresponding to the mass budget has to be defined and secondly the mass budget contents and output file have to be defined. The former is performed in the Basic Parameters Dialog whereas the latter is performed in the Mud Transport Parameters Dialog.

At first the number of mass budget files is specified. A mass budget file contains the mass budget of one or more model components. A mass budget of a model component consists of time series of:

- Mass within polygon
- Accumulated mass transported over lateral limits of polygon
- Accumulated mass added/removed by sources/sinks within polygon. (This item also includes any AD Solver mass corrections.)
- Accumulated mass added/removed by “internal” processes such as deposition or erosion within polygon
- Accumulated mass deviation (error) within polygon determined as the difference between the mass change and the transported, added and removed mass
- If the ‘Section transports’ switch is enabled in the Basic Parameters Dialog, one or more additional time series will be provided in the mass budget. These correspond to the transports through each lateral section of the mass budget polygon. Notice that the sum of the section transports equals the total transport over the lateral limits of the polygon

This means that for every model component selected, five or more items will be included in the corresponding mass budget file.

The mass budget file is thus defined by an associated polygon, information on which time steps to store, filename and title, and selected model components. Notice that the mass budget file is a Type 0 data file, since it contains simple time series.

The units of the masses in the mass budget file are defined as the equivalent of the unit of the corresponding model component multiplied by 10^6 m^3 (or 10^6 m^2 for bed components). This means that if the unit of the model component is kg/m^3, the mass unit will be 10^6 kg.

Please note: It is not possible to specify any mass budget files before one or more polygons have been specified under the Basic Parameters Dialog (see Mass Budget).

5.16.1 Specifying Mass Budget

Under the *Basic Parameters – Mass Budget* section, the mass budget polygons are defined. First the number of polygons is specified. For each polygon the associated sub-area (only relevant if a nested model is applied) and the number of corner points are specified. Finally the grid coordinates of the corner points are given. Notice that a polygon can only contain points one grid point or more inside the associated grid; i.e. grid points on boundaries or on borders between nested grids cannot be included. Further a polygon cannot contain a finer nested grid. A polygon can, on the other hand, contain land points; the model will simply exclude the land points when calculating the mass budget. Please also notice that the dialog will not allow the user to specify mass budget polygons unless a module (e.g. the MT Module), which includes the mass budget facility, has been invoked.

Having specified the mass budget polygon(s), the mass files can be specified. This is done under the *Mud Transport Parameters – Mass Budget* section. First the number of mass files is specified. For each mass file the associated polygon, the time range, the file name, position and title, and the items to be included are specified. Notice that several mass files can have the same associated polygon. Notice also that for each suspended sediment fraction selected, the number of items in the mass file will be 5 (cf. above).

5.17 Nested Model Setups

Before starting the simulation make sure that the initial suspended sediment concentrations are reasonably consistent along the boundaries of the nested models. If this isn't done, the effect might be undesired erosion and/or deposition close to the nestings in the beginning of the simulation.

When running nested setups including the Mud Transport Module the following points should be considered:

5.17.1 Waves

If waves are to be applied, be aware that the waves from the coarsest net is interpolated to the finer grids. If more than one nesting is applied, this may lead to a reduction in accuracy of the wave results, since it is based on very few points in the coarse grid. If it is necessary to use many nestings and waves, run the outer grids first and use this to generate boundary conditions for the finer grids. Then run the finer grids with the externally generated wavefields for them.

5.17.2 Flooding and drying

Nestings are not to be placed in areas of frequent flooding and drying. If the nestings dry out the HD will crash. If the bathymetry is manipulated so that this doesn't happen the AD/MT might react by giving strange results on the nesting. This is a natural consequence of the manipulated bathymetry. First of all the waves were probably generated without this change and therefore, the wave data that is used is not consistent with the bathymetry, Secondly, as the flow crosses this artificial trench, it will decelerate on the upstream side, and accelerate downstream, which will give unphysical results.

5.17.3 AD stability

For nestings it should be noted that the AD stability criteria's should be fulfilled in the finest grid.

If a blowup in the concentration is encountered in the fine grid, it is usually because the stability criteria is not met in the finer grid.

5.17.4 Sliding

Be aware that sliding can not be applied in nested setups.

5.18 Output Area

In order to assess the outcome of a simulation, it is necessary to store parts of the results on disk. MIKE 3 allows for storage of multiple parts of the mud transport related output in multiple files.

5.18.1 Specifying the output area

On the results menu the desired number of output data files and the content of each data file can be specified by writing the number of wanted output areas.

- Several specifications have to be set:
- Data file name and data title.
- Area to be included in file. By default the whole area is chosen but it is possible to specify only the area of interest. The dimension of the output data file(s) depends on the selected output area: If a grid point is specified a type 0 data file will be generated, If a grid line is specified a type 1 data file will be generated, etc.
- Range of time steps to be saved and if every time step should be included or only every second, third, etc.
- Finally, the desired output items can be chosen.

5.18.2 Remarks and hints

One way of following the progression of the simulation is by following the number of time steps written in the output data files (or one of them). Most post-processing tasks start by specifying the data name and after having done so, the description of the data are presented. This description includes the number of time steps already written and thus finished.

5.19 Sand Fractions

5.19.1 General

Sediment transport is dependent on the hydrodynamic conditions. In general there are two types of sediment transport. Cohesive and non cohesive. The cohesive is characterized by low settling velocities and long response times for hydrodynamic changes. Therefore the transport is dominated by the advection of the water column. For non cohesive sediments the settling velocities are in general larger and the concentration profile will therefore quickly adjust to changes in hydrodynamics. As a consequence of this a major part of this transport will take place on or very close to the bed as bed-load.

Mike3 MT can take suspended transport of fine grained non-cohesive sediment into account. This is done by calculating an equilibrium concentration profile based on the sediment properties and the hydrodynamics.

The bed is assumed to erode as flakes which means that the distribution of fractions within the bed is also the distribution when eroded. This means that the erosion formula used in the MT section controls the maximum erosion of all fractions. After the flakes has been eroded it is assumed that they are destroyed or regrouped by turbulence. Since the sand fractions has no cohesive properties it will be freed by this and behave independently. The model does this by calculating the maximum possible equilibrium concentration for the given sand under the given hydrodynamic properties. If this is above the concentration of the sand fraction, the extra sand will be deposited so that the concentration is the equilibrium concentration.

For more information see Scientific Documentation for the Mud Transport Module.

5.19.2 Specifying sand fractions

The sand fractions are switched on under *Water Column Parameters*.

Mean settling velocity is specified under *Sand Fractions*.

5.19.3 Recommended values

The mean settling velocity can be estimated using Stokes law. See *Settling Velocity*.

5.19.4 Remarks and hints

No bedload is included. Therefore if including sand, make sure that only sand for which the main transport can be expected to be suspended transport is included.

5.20 Settling Velocity

The settling velocity is dependent on the size of the particles. The settling velocity of a single free particle can be roughly estimated through Stokes law:

$$w_s = \frac{(\rho_s - \rho)}{\rho} \frac{gd^2}{18 \cdot v} \tag{5.16}$$

in which:

ρ_s: Sediment density (kg/m^3) (Quartz = 2650 kg/m^3)
ρ: Density of water
g: Gravity (9.82m/s^2)
d: Grain size [m]

ρ_s: Sediment density (kg/m^3) (Quartz = 2650 kg/m^3)
ν: Viscosity [m^2/s]
w_s: Settling velocity [m/s]

In case of fine grained cohesive sediment (<0.004 mm) the size of the particles and thereby the settling velocity will depend on the rate of flocculation.

With low concentrations of suspended sediment the probability for collision between the cohesive particles is low and the settling velocity will be close to the settling velocity for a single grain. With increasing concentration collision between particles will occur more frequently and the cohesiveness of the particles will result in formation of flocs. This leads to an increase in average particle/floc size and with that an increase in settling velocity.

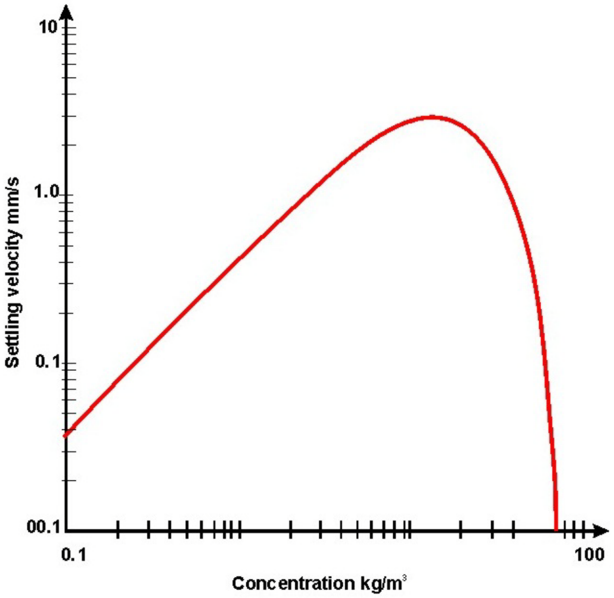

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Figure 5.2 Typical settling velocity variation

Many other factors can increase or decrease the floc size. Salinity between 0 and 9 psu will increase flocculation as will high levels of organic material. High levels of turbulence will decrease the floc size due to destruction of flocs.

If sediment concentration increases further the flocs will eventually interact hydrodynamically so that effectively the flocs during settling cause an upward flow of the liquid they displace and hindered settling occurs which leads to a reduction in settling velocity.

Further increase in sediment concentration will result in decreasing distance between the flocs which leads to negligible settling velocity and the mixture will act as fluid mud.

The MT-module deals with this in the following way:

The settling velocity for mud in suspension can be divided into four categories

- Constant settling velocity
- Flocculation
- Hindered settling
- Fluid mud

5.20.1 Constant settling velocity

Constant settling velocity can be selected if the concentrations are assumed not to influence each other.

If constant settling velocity is selected the settling velocity will be kept constant and independent of the concentration of sediment throughout the simulation.

5.20.2 Flocculation

Flocculation is when the concentration of sediment is high enough for the sediment flocs to influence each other's settling velocity. This happens because collisions between flocs will increase floc size leading to higher settling velocities.

Standard flocculation calculations occur when hindered settling is neglected. The calculations goes as sketched Figure 5.3.

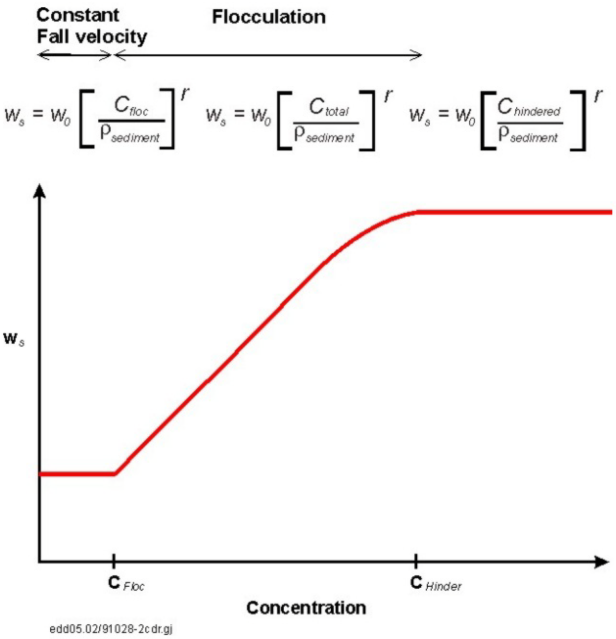

Figure 5.3 Applied concentration profile when flocculation selected

c_{floc}:	Concentration at which flocculation begins
c_{total}:	Total concentration of sediment (sum of concentrations of all fractions)
$c_{hindered}$:	Concentration at which hindered settling begins
W_0	Settling velocity coefficient
r	Settling velocity coefficient
$\rho_{sediment}$	Density of sediment

5.20.3 Hindered settling

Hindered settling is when the concentration of sediment gets high enough for the flocs to influence each other's settling velocity. The concentration gets high enough for the flocs not to fall freely. This results in a lower settling velocity.

When the specified concentration for hindered settling is exceeded hindered settling sets in. The calculation goes as showed in Figure 5.4.

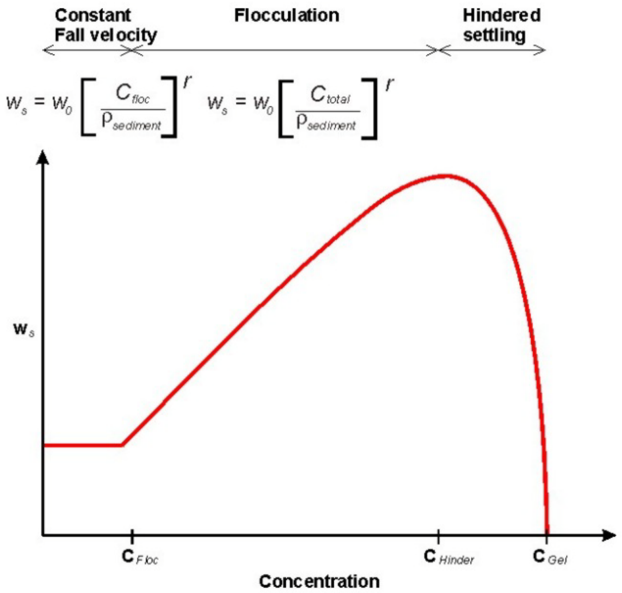

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Figure 5.4 Calculation when hindered settling is applied

Two formulations for the settling velocity in this regime are offered.

Formulation by Richardson and Zaki (1954)

For a single mud fraction, the standard Richardson and Zaki formulation is

$$w_s = w_{s,r}\left(1 - \frac{c}{c_{gel}}\right)^{w_{s,n}} \tag{5.17}$$

For multiple mud fractions, the Richardson and Zaki formulation is extended to

$$w_s^i = w_{s,r}^i(1 - \Phi_*)^{w_{s,n}^i} \tag{5.18}$$

where

$$\Phi = \frac{\sum_i c^i}{c_{gel}} \tag{5.19}$$

$$\Phi_* = min(1.0, \Phi) \tag{5.20}$$

In which:

$W_{s,r}$: velocity coefficient
W_{sn}: Settling velocity coefficient
c_{gel}: Gelling point for sediment

Formulation by Winterwerp (1999)

$$w_s^i = w_{s,r}^i \frac{(1-\Phi_*)(1-\Phi_p)}{1+2.5\Phi} \tag{5.21}$$

where

$$\Phi_p = \frac{\sum_i c^i}{\rho_s} \tag{5.22}$$

In which ρ_s is the dry density of the sediment.

5.20.4 Fluid mud

Fluid mud is in this model considered as a bottom layer and the settling velocity for this will be treated as consolidation.

5.20.5 Modification of settling velocity due to salinity variation

In fresh/brackish water, the flocculation processes are reduced, which have an impact on the settling velocity. Due to the smaller floc sizes, the settling velocity will be reduced. This can be modelled by multiplying the settling velocity with a factor.

$$w_s^i = w_s^i(1 - C_1 e^{S \cdot C_2}) \tag{5.23}$$

where C_1 and C_2 are calibration parameters.

C_1 and C_2 are not shown in the menu and is default set to $C_1 = 0.5$ and $C_2 = -0.33$.

5.20.6 Specifying settling velocity

The possible effect of salinity can be included if salinity is included under *Parameter Selection*. The choice of formulation can be made under the *Settling Dialog*.

Under *Settling* you get the choice of using constant velocity or apply flocculation in the calculations.

If constant settling velocity is chosen the value used under constant settling velocity will be applied.

If flocculation is chosen the choice of including hindered settling is offered as formulated by either Richardson and Zaki or Winterwerp.

The relevant input values for the selections should be given in *Settling Parameters*.

5.20.7 Recommended values

The following values crudely mark the different regimes within the settling process.

Table 5.3 Settling regimes

Sediment stage	**Concentration/dry density (kg/m^3)**	**Remarks**
Suspension	0-0.01	No flocculation.
Suspension	0.01-10	Flocculation may begin.
Suspension	10-50	Void ratio larger than 6. No effective stresses between grains. Hindered settling begins.

5.20.8 Remarks and hints

Note that salinity effect on flocculation does not grow when the salinity exceeds 10PSU. If the salinity is always above 10PSU it is recommended not to include salinity in the simulations since the salinity will not affect the settling velocity further. The parameters C_1 and C_2 are default set to 0.5 and -0.33 and are not shown in the menu. Nor is W_{sn} and r. The default values for those are 1.

5.21 Source and Sink

The effects of rivers, intakes and outlets from e.g. power stations, outlets from sewers, etc., can be included in a simulation. MIKE 3 distinguishes between three different kinds of sources:

- Isolated source, is a point where a certain amount of water is discharged into the model with a certain velocity, affecting both momentum and continuity equations, therefore the introduction of a source affects both the MT and the HD simulations.
- Isolated sink, a point where a certain amount of water is discharged out of the model, affecting only the continuity equation
- Connected source-sink pair, used for recirculation studies, the amount of water removed at the sink is re-entered at the source point with a specified velocity.

The sources and sinks are included in the hydrodynamic equations as described in *Hydrodynamic Module, Reference Manual*.

5.21.1 Specifying Sources and Sinks

A large number of sources and sinks can be specified in the model. The location is specified in the *Source and Sink* dialog of the Basic parameters section while the strength of the sources/sinks is set in the Hydrodynamic Parameters section.

The suspended sediment concentration in the source is specified in the sources dialog of the mud transport section. These may be given as constants or as included in a **type 0 data file**. Run through all sources one by one. For isolated sources the absolute value of the component concentration is specified whereas for connected source-sink pairs the excess source value is specified. If salinity is included in the simulation this should also be specified here.

5.22 Suspended Sediment

In the water column, the sediment is modelled as one or more fractions of suspended sediment. Each fraction is defined by the (mass) concentration and settling properties. The total concentration of suspended sediment is determined as the summation of the concentrations of each sediment fraction. The suspended sediment concentrations are considered state variables of the model, which means that the model during simulation tracks their evolution in space and time. The settling properties, on the other hand, are maintained constant in time.

The transport and spreading of the i'th suspended sediment fraction is described by the mass conservation equation for cohesive sediment in two dimensions, which takes the form of the advection-dispersion (AD) equation:

$$\frac{\partial c}{\partial t} + \frac{\partial}{\partial x_i}(c(u_i - w_{s,i})) = \frac{\partial}{\partial x_i}\left(D_c \frac{\partial c}{\partial x_i}\right) + S_c \tag{5.24}$$

where

c (kg/m^3) is the suspended sediment concentration

h (m) is the water depth

u and v (m/s) are the horizontal current velocities

D_x and D_y (m^2/s) are the dispersion coefficients

S (kg/m^3/s) is a local source/sink term.

The current velocities are provided by the hydrodynamic model, which forms the basis of the mud transport model. The local source/sink term in the AD equation represents the possible external sources/sinks (outlets, intakes, spills, etc.) as well as the bed-water column coupling in terms of the possible deposition or erosion.

This equation is solved by the operator-splitting technique. For each simulation time step, the AD equation for a passive substance (no deposition or erosion) is solved by the selected AD scheme and subsequently the suspended sediment concentrations are (explicitly) updated by means of the equation:

$$\frac{\partial c}{\partial t} + \frac{\partial}{\partial x_i}(c(u_i - w_{s,\,i})) = \frac{\partial}{\partial x_i}\left(D_c \frac{\partial c}{\partial x_i}\right) + S_c \qquad (5.25)$$

where E (kg/m^2/s) is the possible erosion and D (kg/m^2/s) is the possible deposition.

In order to solve the AD equation, an initial concentration field has to be specified (see below and *Initial Conditions*) and lateral boundary concentrations have to be given at the open boundaries (see *Boundary Conditions*).

5.22.1 Remarks and hints

In high-turbid environments, it is advised to initiate the simulation with suspended sediment concentrations of zero (all sediment placed in the bed) leaving the model to establish an equilibrium between the bed, the water column and possible external sediment supplies from open boundaries and/or external sources. In low-turbid environments, on the other hand, it is recommended, when specifying the initial concentrations, to try to reflect the real conditions in the water column in order to avoid excessive warm-up periods.

5.23 Parameter Selection

The Parameter Selection comprises the definition of the particular sediment transport model with respect to number of grain size fractions and number of bed layers.

The inclusion of salinity in the simulation is also switched on here. This is only relevant for estuarine environments with salinity < 10 PSU.

5.23.1 Remarks and Hints

It is highly recommended to use as few layers and fractions as possible. The use of many layers and fractions is not recommended for others than very experienced users. It makes calibration of models very complicated (many parameters) and the simulation time will increase. Therefore if possible keep the number of fractions and layers as low as possible.

If salinity is selected be aware that this is another AD component which will affect the simulation time. Furthermore the effect of salinity on sediment flocculation is mainly between 1 and 10 PSU. Salinities beyond this will not affect the settling velocity significantly.

5.24 Transition

See consolidation.

5.25 Viscosity and Density

These two processes impact the HD-module by impacting the density and viscosity.

Mud impact on density

The influence from the mud on the water density is by definition given by:

$$\rho_m = \rho_w + \sum_i \left(1 - \frac{\rho_w}{\rho_s}\right) c^i \tag{5.26}$$

Mud influence on viscosity

The influence on the kinematic viscosity from the mud can be parameterised by:

$$\frac{\upsilon_M}{\nu} = k_{v1}^{\frac{\sum_i c^i}{k_{v2}}} \tag{5.27}$$

Where k_{v1} and k_{v2} are calibration parameters. This expression is assumed to be valid for applying a lower limit for the eddy viscosity, hence:

$$\upsilon_T = \max(\upsilon_T, \upsilon_M) \tag{5.28}$$

Utilizing:

$$\frac{\upsilon_M}{\nu_T} = k_{v1}^{\frac{\sum_i c^i}{k_{v2}}} \tag{5.29}$$

5.26 Water Column Parameters

Water column parameters consist of all processes in the water column.

The following processes are included:

- Settling
- Sand fractions
- Viscosity and density

5.27 Wave Forcing

5.27.1 General description

It is possible to specify wave forcing as constant or varying in time and space.

Constant waves are specified as wave parameters, i.e. significant wave height (H_s), mean wave period (T_m), mean wave direction (θ), which are constant in time and space.

Varying waves can be specified as a **Type 2 time-series** (interpolation of wave fields in time) or a **wave database**. In both cases the wave fields may be simulated using e.g. the parabolic mild-slope wave module, MIKE 21 PMS.

5.27.2 Wave time-series

The interpolation of wave fields in time means that you specify some pre-simulated wave fields, corresponding to a certain wind and water level estimate and then the model interpolates in time between these wave fields, see figure below.

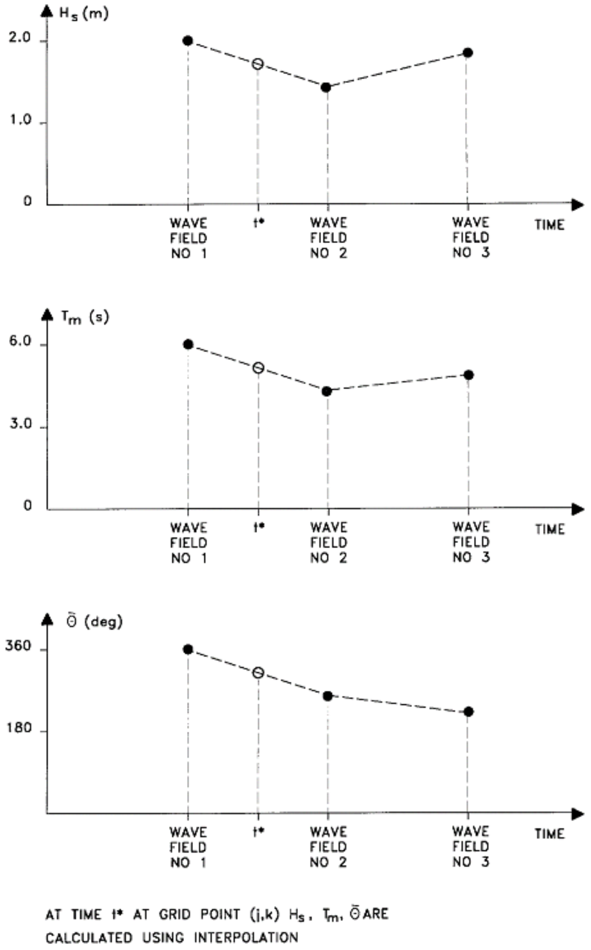

Figure 5.5 Interpolation of wave fields in time

The wave time-series may be used if the response to wind field changes does not happen immediately. In this way, you may minimise the number of wave field simulations

5.27.3 Wave database

In an area dominated by wind-waves, and where the waves respond quickly to a change in water level, wind speed and direction, it is possible to use a wave database description. The wave database consists of discrete wave fields, which are simulated using combinations of water level, wind speed and direction. It is important to try to minimise the number of wave fields within the database. E.g. if the water level variations are small compared to the water depth, then the water level does not need to be discretized. Or if the wind is mainly blowing from the same direction (s), the wind direction discretization can be minimised.

For every grid point, the local values of water level (calculated by MIKE 3 Flow Model, Hydrodynamic Module), wind speed and direction (specified as wind input in the Hydrodynamic Module) are used to determine the wave parameters (significant wave height (H_s), zero-crossing wave period (T_{02}) and mean wave direction (Θ) by interpolating the wave fields within the wave database, see example in Figure 5.6.

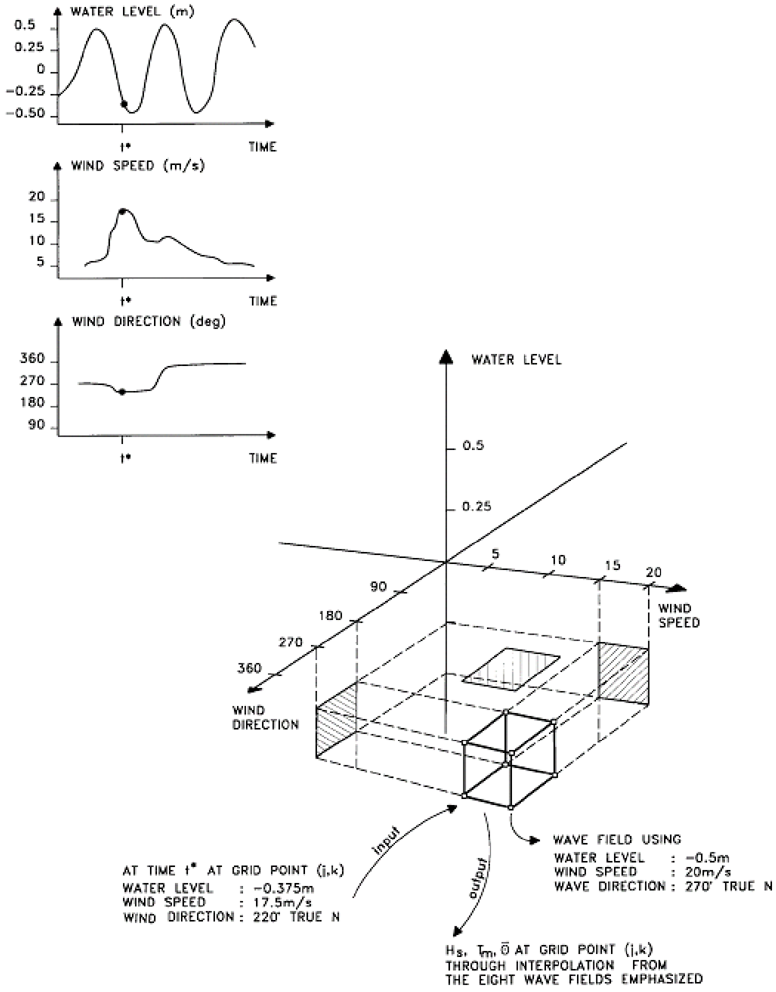

Figure 5.6 Interpolation of wave fields from wave database

5.27.4 Bed shear stress

It is possible to select which formulation to use when calculating the bed shear stress for combined wave-current action.

The solution can be a parameterised version by Soulsby et. al. (1993), calculating the mean shear stress or the maximum shear stress, respectively.

It is also possible to choose an approach by Fredsøe (1981), where the bed shear stress is found by the maximum value of a pure current solution and a solution that considers a modified bed roughness due to the waves.

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