MIKE 21 Flow Model

Mud Transport Module

User Guide

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MIKE 21 MUD TRANSPORT

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 21 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 21 Flow Model, Mud Transport Module (MT) describes erosion, transport and deposition of mud or sand/mud mixtures under the action of currents and waves.

MIKE 21 Flow Model, Mud Transport Module, is applicable for:

- Mud fractions alone, and
- Sand/mud mixtures

The following processes can be included in the simulation.

- Forcing by waves
- Sliding
- Salt-flocculation
- Detailed description of the settling process
- Layered description of the bed, and
- Morphological update 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 in which environmental aspects are involved and degradation of water quality may occur.

- 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 21 Flow Model, Mud Transport Module (MT), is through practice. Therefore, we have included four applications are included in the installation:

1. Access channel
2. Dredging study
3. Sedimentation study
4. Multiple dredgers

The specification files for the four examples are included with the installation of MIKE Zero. A directory is provided for each example. The directory names are as follows :

Access channel example:
.\Examples\MIKE_21\FlowModel\mt\access channel

Dredging example:
.\Examples\ MIKE_21\FlowModel\mt\Dredging

Sedimentation example:
.\Examples\ MIKE_21\FlowModel\mt\Sedimentation

Multiple dredgers example:
.\Examples\ MIKE_21\FlowModel\mt\Dredging_Oresund

3.2 Access channel

List of data and specification files:

The following data files are supplied with MIKE 21:

Name: Bathy.dfs2
Name: Elevation-n.dfs0
Name: Elevation.dfs0
Name: Init.dfs2
Specification files: Scenario1.M21, Scenario2.M21

Purpose of the study

A small harbour is proposed in a river close to the ocean. The purpose of this study is to assess the amount of dredging needed in the access channel as well as the amount of deposition in the harbour. By applying a bathymetry

including the access channel and the harbour the amount of sediment depositing in the access channel and in the harbour can be modelled and consequently the amount of dredging needed can be quantified. Figure 3.1 shows the model area.
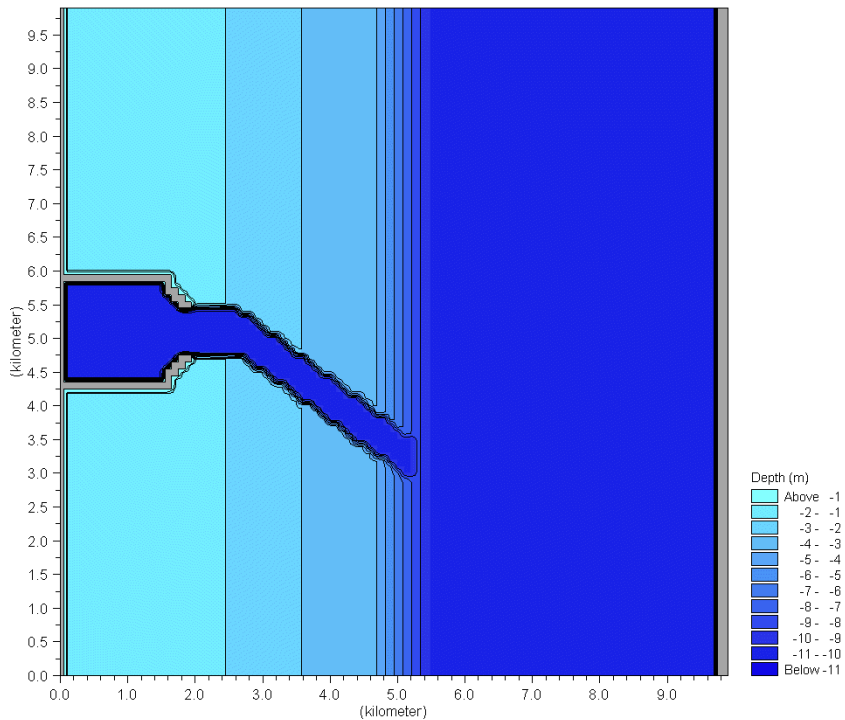
Figure 3.1   Bathymetry

Defining the hydrodynamic model

The model area is very sheltered due to its location in a river. It is dominated by two flow situations. During neap tide it is dominated by the constant current from the river discharge. At spring tide the flow is dominated by the tidal induced flows. Therefore the hydrodynamics are divided in two cases. A no tide scenario with a water level difference of 10cm from upstream to downstream boundary, and a tidal scenario with a tidal variation on the boundaries with a delay of 15 minutes.

Hydrodynamic set-up

For scenario 1 a water level difference of 0.1m was applied from the north to the south boundary.

For scenario 2 the elevation series illustrated in Figure 3.2 was used on the boundary.
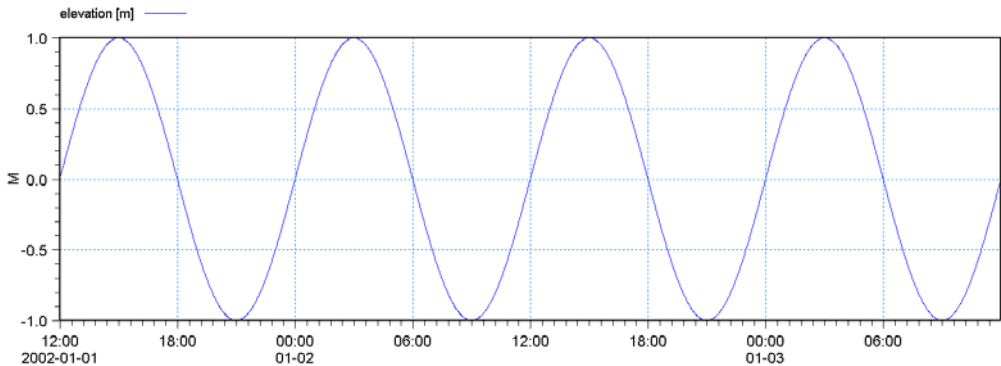
Figure 3.2   Boundary condition

Defining the mud transport model

Not much data is available. The sediment concentration in the river is measured to be 0.01 kg/m³. The settling velocity of the sediment is known from laboratory tests to be 0.01mm/s. No measurements of bed parameters have been made. Therefore the erosion parameters have been taken from literature values from places with similar physical parameters. With the given bathymetry the effect of waves is negligible.

Mud transport set-up

The set-up given below is to be applied in both scenarios.

1. Enter *Starting conditions* and make sure that the AD and MT simulation period is equal to the HD simulation period. Choose cold start.

2. Enter *Parameter selection*. Choose one layer and one fraction. No data is available to support more than this. Salinity should be switched off.

3. Enter *Initial conditions*. Check that the initial bed thickness is 0.00m and the initial concentration is 0.05 kg/m³.

4. Enter *Dispersion* and make sure that the dispersion coefficients in both directions are 1 m²/s.

5. Enter the *Boundary* section and make sure that the boundary concentrations are 0.01 kg/m³.

6. Enter *Water column parameters* and make sure that no sand fractions are switched on.

7. Enter *Settling* and choose constant settling velocity

8. Enter *Settling parameters* and set the constant settling velocity to 0.00001m/s.

9. Enter *Deposition* and set the critical shear stress for deposition to 0.05 N/m².

10. Enter *Erosion* under *Bed parameters* and choose soft mud.

11. Enter *Power of erosion* under *Erosion* and set this to 1.

12. Enter *Erosion coefficient* under *Erosion* and set this to 0.00001 kg/m²/s.

13. Enter *Critical shear stress* under *Erosion* and set the critical shear stress for erosion to 0.05 N/m².

14. Enter *Density of bed layer* and set this to 180 kg/m³ corresponding to weak mud.

15. Enter *Bed roughness* and set this to 0.001 m.

16. Enter *Results* and choose the relevant output parameters.

17. Run the model

Mud transport results
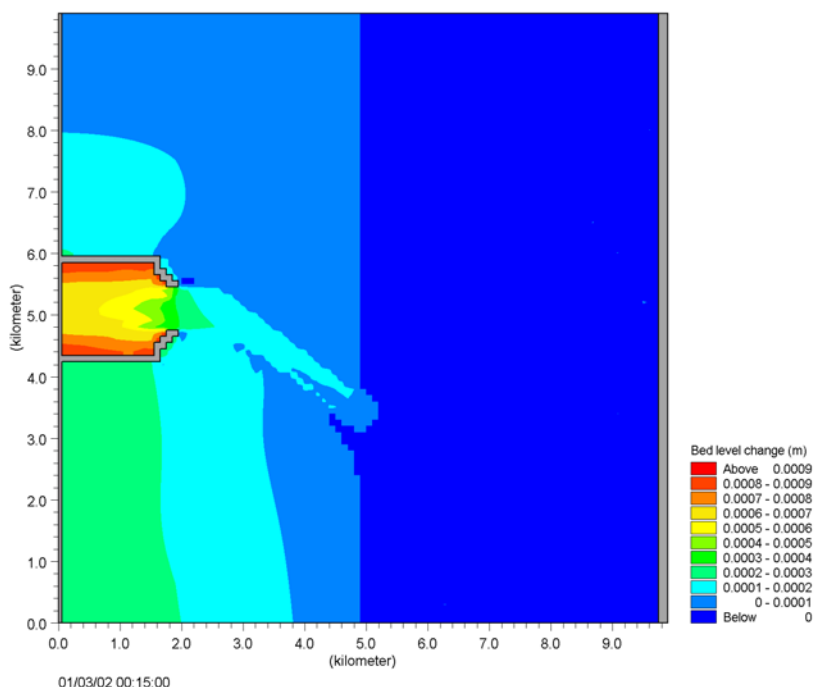
Figure 3.3   Net sedimentation scenario 1

01/03/02 00:15:00
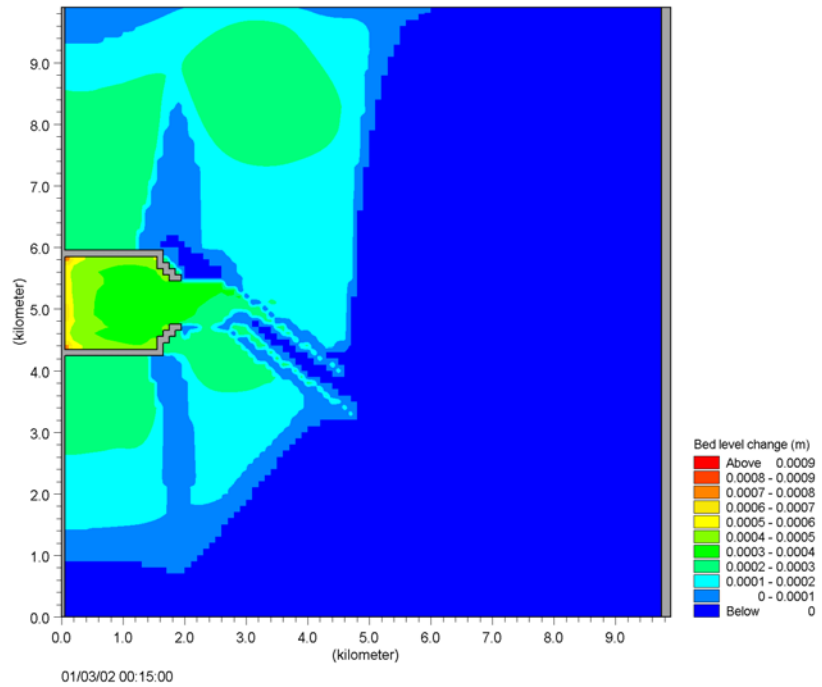
Figure 3.4   Net sedimentation scenario 2

From a current rose it is known that the hydrodynamic pattern in scenario 2 is dominant in 75% of the time while the hydrodynamics in scenario 1 dominates the remaining 25% of the time. By using the MZ editor this information can be used to produce a yearly net sedimentation based on the two scenarios. This is given in Figure 3.5.
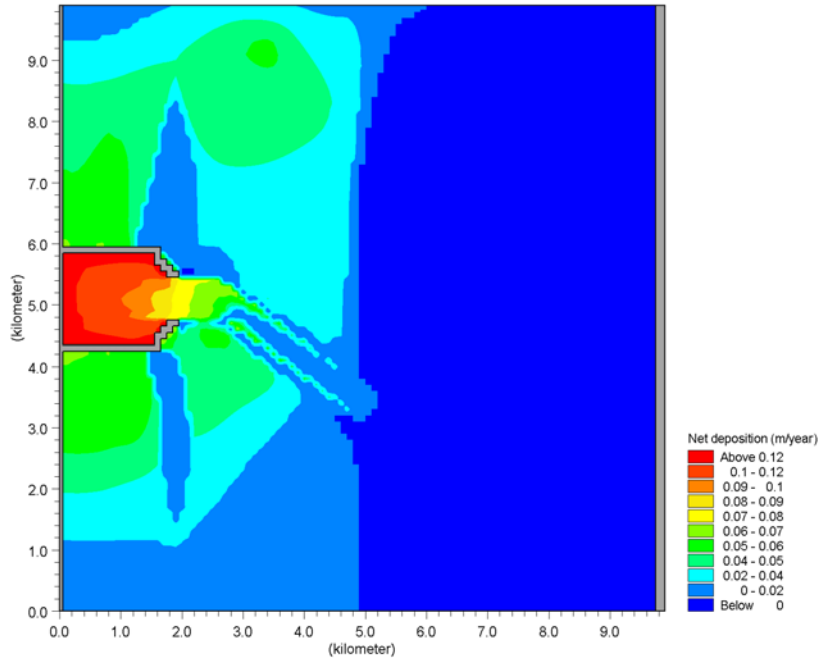
Figure 3.5   Total net sedimentation in m per year

The result shows that the yearly net sedimentation is about 10-12cm/year inside the harbour and in the access channel the deposition varies between 0 and 8cm/year.

The method is generally applicable. In this case only two scenarios are considered, however, in general more scenarios are necessary in order to cover different wind, waves and current scenarios.

Exercises

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

1. Check the effect of raising the settling velocity to 0.0001 m/s.

2. Check the effect of raising the critical shear stress for erosion to 0.1 N/m^2.

3. Does it affect the results if the hydrodynamic pattern in scenario 1 accounts for 40% of the period while the hydrodynamics in scenario 2 dominates in 60% of the period?

4. Check the sensitivity of the erosion coefficient.

5. Change the concentration at the boundaries to 0.02 kg/m^3. Does this affect the final result?

3.3 Dredging

List of data and specification files

The following data files are supplied with MIKE 21:

Name: Bathy.dt2
Name: Elevation.dfs0
Specification file: Scenario1.M21

Purpose of the study

A harbour on a small island is expanding and need a deeper access channel to accommodate bigger ships. Therefore it is proposed to dredge a new and deeper access channel between the islands at the dots marked in Figure 3.6. As a consequence of the dredging operations a certain amount of sediment spill will occur. The local fish farmers are concerned if the spilled material will reach the fish farm resulting in an increased sediment concentration which can affect the taste of their fish. Therefore the purpose of this study is to investigate possible effects of spilled material from dredging on the fish farm.
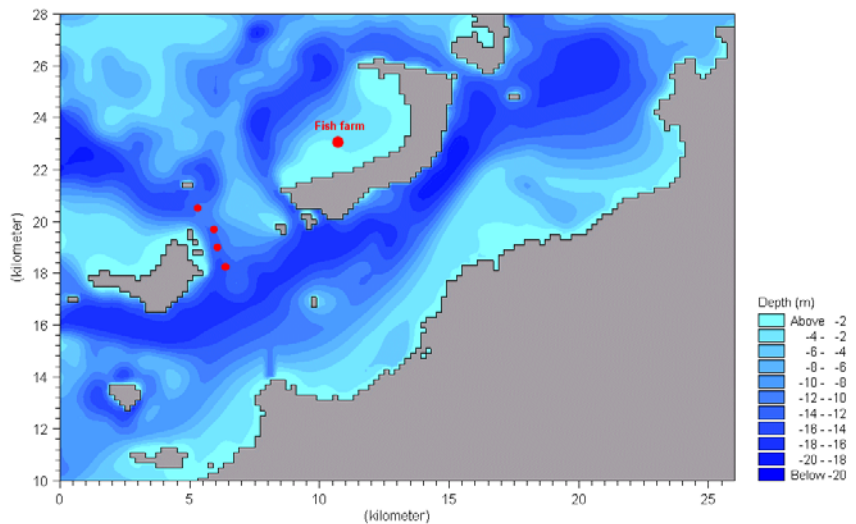
Figure 3.6   Bathymetry

Defining the hydrodynamic model

The dredging is to take place during a calm weather period. Therefore only the tidally induced currents are considered.

Hydrodynamic set-up

Figure 3.7 shows the tidal boundary.
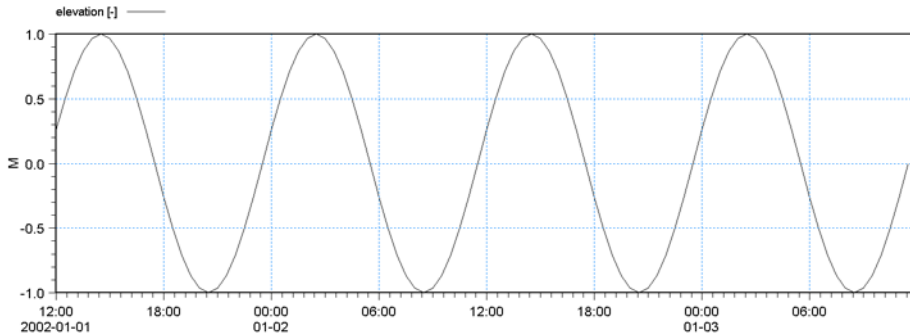
Figure 3.7   Boundary condition

Defining the mud transport model

The amount of dredged material is about 4800 m³/day, and the dredging operation takes places 24 hours a day. The settling velocity of the material is estimated to be 0.0005 mm/s. The bulk density of the dredged sediment is estimated to 1800 kg/m³. It is estimated that the sediment spill will be 10% of the dredged amount of sediment i.e. the daily spill amount will be 864 tonnes corresponding to a spill rate of 10 kg/s.

Four dredging sites are considered. They are represented as point sources. The discharge of water for each source is set to 0.1 m³/s in order not to affect the hydrodynamics. This corresponds to a sediment concentration of 100kg/m³ in order to keep the correct amount of sediment. Four fractions have been chosen. Each fraction represents a different dredging site. Since the settling velocity will be set to constant and no erosion from the actual bottom will be allowed the fractions will act independently.

Mud transport set-up

1. Enter *Starting conditions* and make sure that the AD and MT simulation period is equal to the HD simulation period. Choose cold start.

2. Enter *Parameter selection*. Choose one layer and four fractions. Salinity should be switched off.

3. Enter *Initial conditions*. Check that the initial bed thickness is 0.0m and the initial concentration is 0.0 kg/m³.

4. Enter *Dispersion* and make sure that the dispersion coefficients in both directions are 1 m²/s.

5. Enter the *Boundary* section and make sure that the boundary concentrations are 0.0 kg/m³.

6. Enter *Sources* and set the source concentration for each fraction to 100 kg/m³.

7. Enter *Water column parameters* and make sure that no sand fractions are switched on.

8. Enter *Settling* and choose constant settling velocity

9. Enter *Settling parameters* and set the constant settling velocity to 0.0005 m/s.

10. Enter *Deposition* and set the critical shears stress for deposition to 0.05 N/m^2.

11. Enter *Erosion* under *Bed parameters* and choose soft mud.

12. Enter *Power of erosion* under *Erosion* and set this to 1.

13. Enter *Erosion coefficient* under *Erosion* and set this to 0.00001 kg/m^2/s.

14. Enter *Critical shear stress* under *Erosion* and set the critical shear stress for erosion to 0.05 N/m^2.

15. Enter *Density of bed layer* and set this to 180 kg/m^3 corresponding to weak mud.

16. Enter *Bed roughness* and set this to 0.001 m.

17. Enter *Results* and choose the relevant output parameters.

18. Run the model

Mud transport results

Use the *txstat* under MIKE Zero toolbox to create plots for the maximum values of each fraction of the suspended sediment concentrations during the simulations.
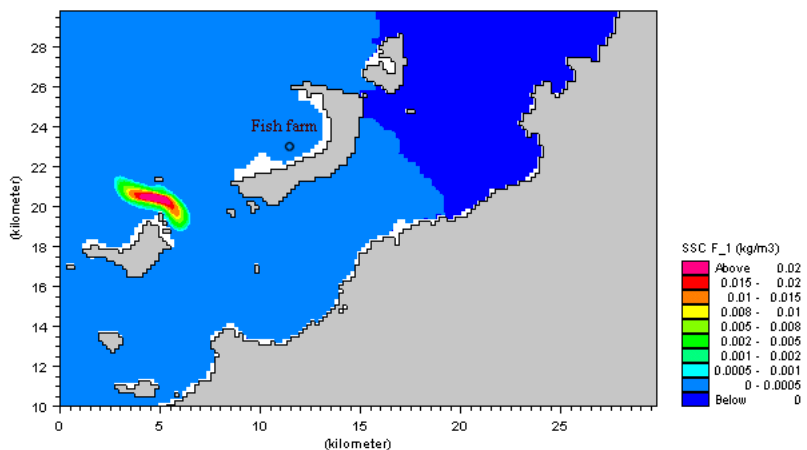
Figure 3.8   Maximum suspended sediment concentration site 1
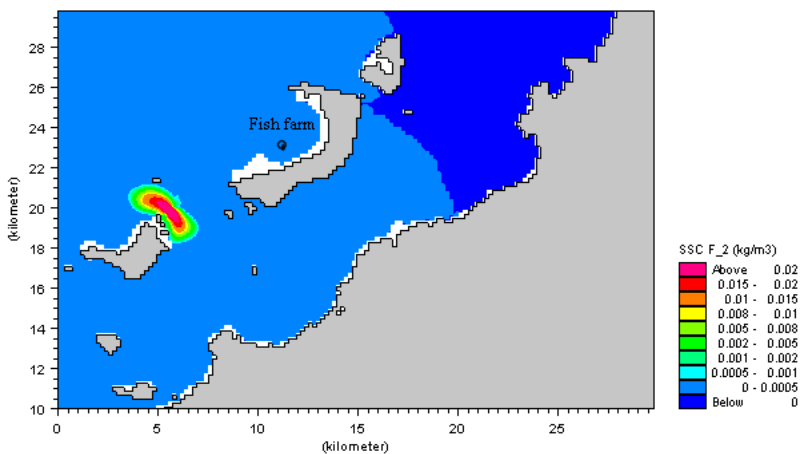
Figure 3.9   Maximum suspended sediment concentration site 2
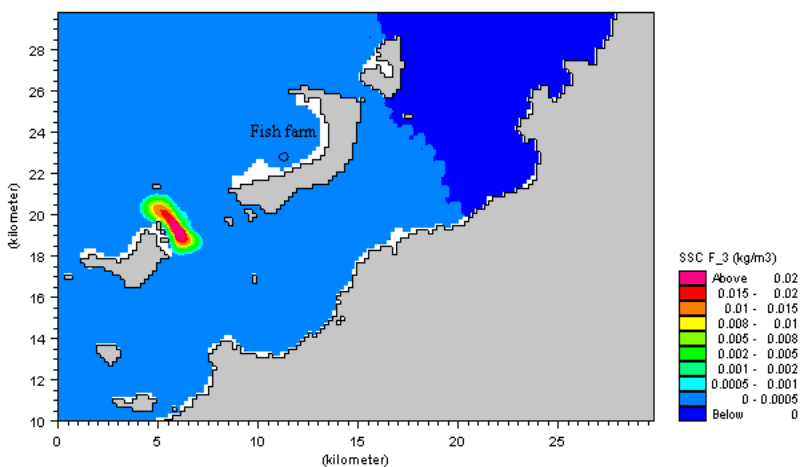
Figure 3.10   Maximum suspended sediment concentration site 3
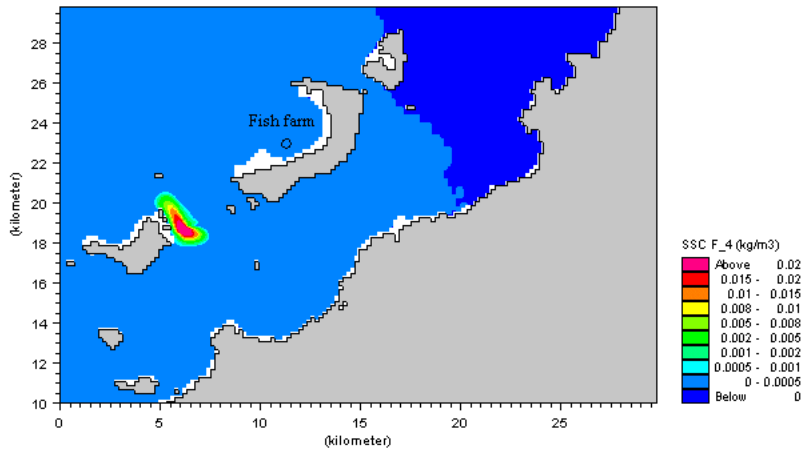
Figure 3.11   Maximum suspended sediment concentration site 4

The results show that during the dredging operation the spilled sediment will cause an increase in suspended sediment concentration of up to 0.0005 kg/m^3 near the fish farm.

Exercises

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

1. Check the effect of raising the dispersion coefficient by a factor of 2.
2. Apply a wind direction of 90 degrees and wind speed of 10 m/s.
3. Decrease the settling velocity by a factor of 10.
4. Switch on 30cm constant waves from 10 degrees and a wave period of 6 sec.

3.4   Sedimentation

List of data and specification files

The following data files are supplied with MIKE 21:

Name: Bathy.dt2
Name: Source1.dfs0
Name: Elevation.dfs0
Specification file: Scenario1.M21, Scenario2.M21

Purpose of the study

A mining company plans to start mining activities in the mountains close to San Francisco bay. During the mining process a large amount of sediment will be washed out into a nearby creek and from here into the bay. The purpose of this study is to assess the short-term net sedimentation in the bay.
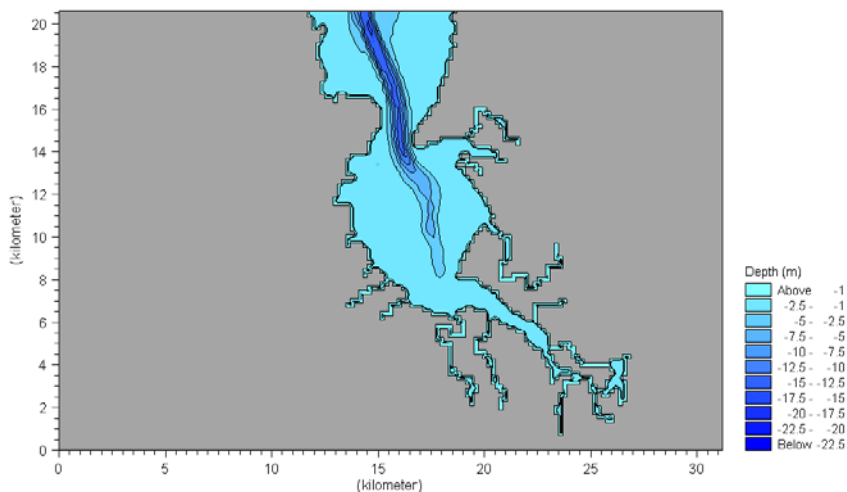
Figure 3.12   Bathymetry

Defining the hydrodynamic model

The bay is a relatively sheltered area therefore only tidal induced currents are considered.

Hydrodynamic set-up

In Figure 3.13 the tidal boundary is given.
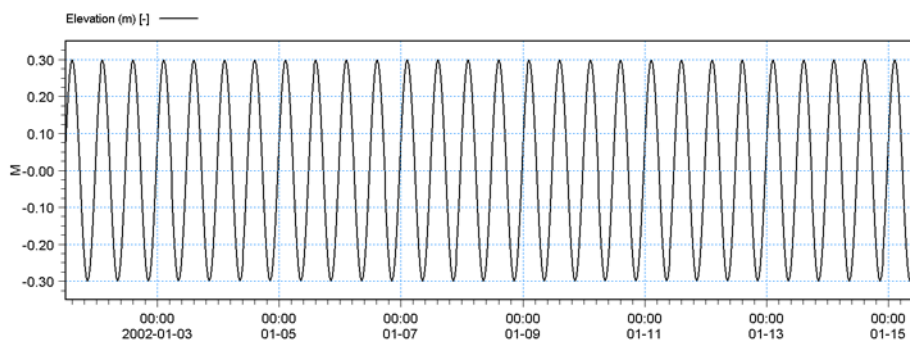
Figure 3.13   Boundary condition

A rainfall period is selected in order to see the maximum outlet of sediment. The discharge for all rivers is given in Figure 3.14.
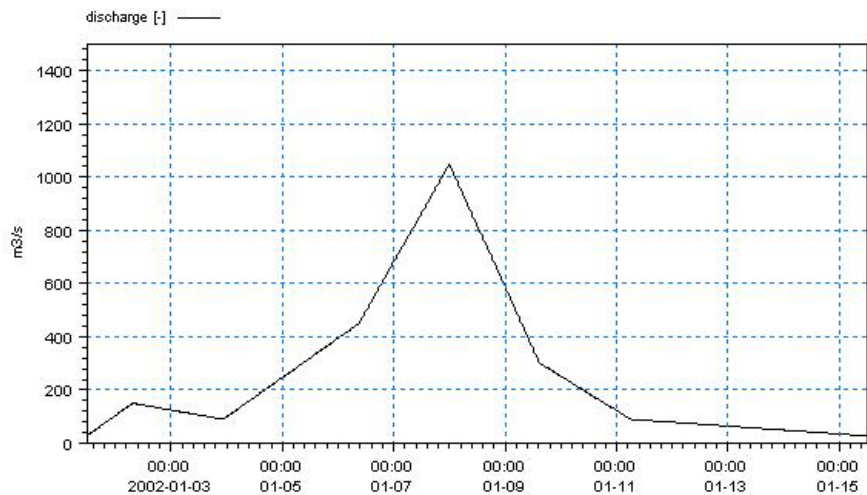
Figure 3.14   Runoff during rainfall

Defining the mud transport model

The amount of dredged material corresponds to an extra load of 0.1 kg/m³ in the creek. Normal concentrations are 0.05 kg/m³. In scenario 1 a situation with no mining activities is simulated to assess the net deposition of sediment in the bay. All creeks within the bay do in this scenario have a source with 0.05 kg/m³, which is the normal sediment concentration in the bay. In scenario 2 the source concentration in the creek where sediment will be washed out due to the mining activity is increased to 0.15 kg/m³.

Mud transport setup

1. Enter *Starting conditions* and make sure that the AD and MT simulation period is equal to the HD simulation period. Choose cold start.

2. Enter *Parameter selection*. Choose one layer and one fraction. Salinity should be switched off.

3. Enter *Initial conditions*. Check that the initial bed thickness is 0.0m and the initial concentration is 0.01 kg/m³.

4. Enter *Dispersion* and make sure that the dispersion coefficients in both directions are 1 m²/s.

5. Enter the *Boundary* section and make sure that the boundary concentrations are 0.01 kg/m³.

6. Enter *Sources* and set all sources to 0.05 kg/m³. For scenario 2 set source 5 to 0.15 kg/m³.

7. Enter *Water column parameters* and make sure that no sand fractions are switched on.

8. Enter *Settling* and choose constant settling velocity.

9. Enter *Settling parameters* and set the constant settling velocity to 0.00001 m/s.

10. Enter *Deposition* and set the critical shear stress for deposition to 0.05 N/m^2. Apply Rouse profile, relative centroid height is 0.3.

11. Enter *Erosion* under *Bed parameters* and choose hard mud.

12. Enter *Power of erosion* under *Erosion* and set this to 1.

13. Enter *Erosion coefficient* under *Erosion* and set this to 0.00001 kg/m^2/s.

14. Enter *Critical shear stress* under erosion and set the critical shear stress for erosion to 0.05 N/m^2.

15. Enter *Density of bed layer* and set this to 300 kg/m^3 corresponding to semi-consolidated mud.

16. Enter *Bed roughness* and set this to 0.001 m.

17. Enter *Results* and choose the relevant output parameters.

18. Run the model for each scenario.

Mud transport results
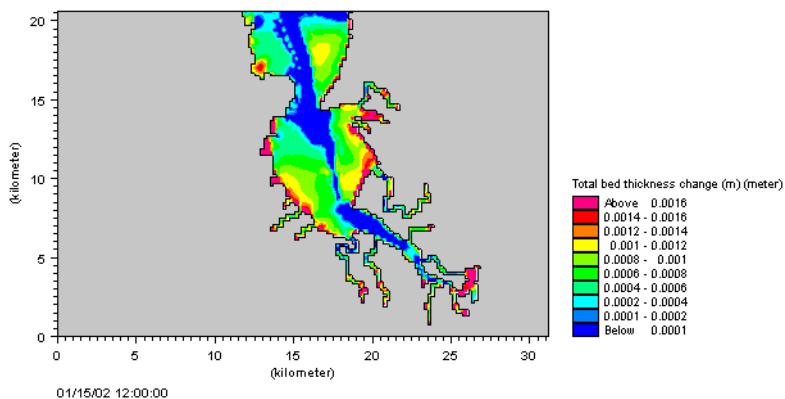
Figure 3.15   Bed thickness change scenario 1 with no mining activities

01/15/02 12:00:00
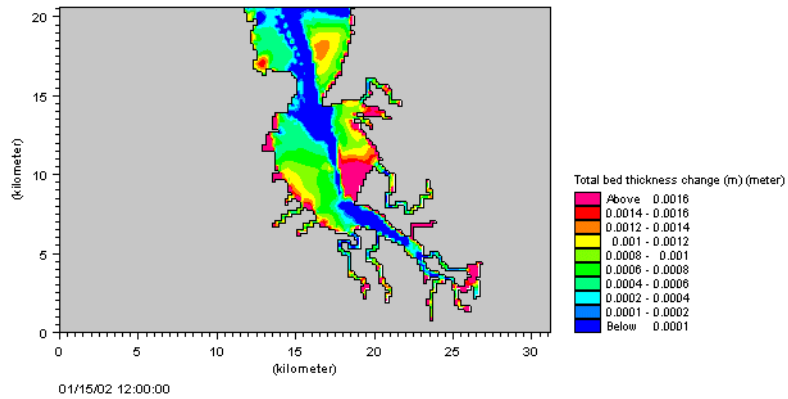
Figure 3.16   Bed thickness change scenario 2 with mining activities

Use the MIKE Zero editor and t2-turn to deduct the two results, which will give the total excess deposition due to mining. This is given in Figure 3.17.
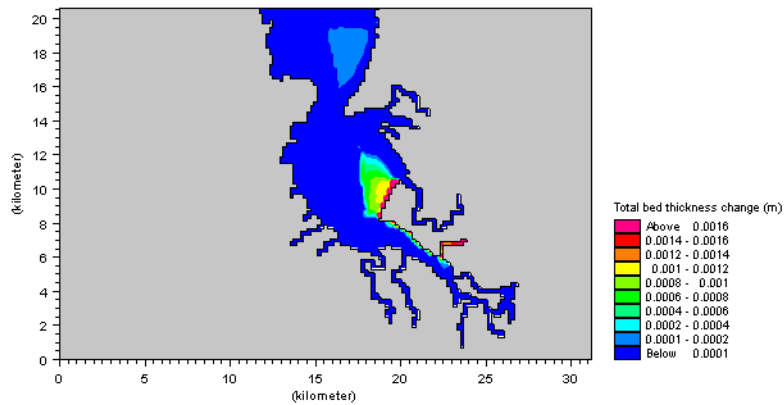
Figure 3.17   Excess deposition due to mining

As it can be seen the material from the mining will travel along the eastern coast of the bay where it will cause an extra deposition in the shallow areas.

Exercises

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

1. Apply a wind direction of 270 degrees and a wind speed of 10 m/s.

2. Raise the settling velocity by a factor of 10.

3. Switch on 30cm constant waves from 10 degrees and a wave period of 6 sec.

4. Would it matter if the runoff was doubled?

5. Test the sensitivity if the sediment wash out takes place in another creek.

6. What if the erosion was considered soft bed, would that affect the result?

7. Double the dispersion coefficient. What is the effect of this?

3.5 Multiple Dredgers

List of data and specification files

The following data files are supplied with the MIKE 21 installation:

Name: Bathy900.dfs2
Name: wln.dfs1
Name: wls.dfs1
Name: WindKastrup.dfs0
Name: castor.dfs0
Name: bastion.dfs0
Name: manupeka.dfs0
Specification file: Sound_HD.m21

Purpose of the study

During the construction works of the Øresund Crossing in the mid 1990s, simultaneous dredging operations were undertaken in the sound between Denmark and Sweden. The 16-km crossing comprises an immersed tunnel, an artificial island and a cable stayed bridge. Comprehensive monitoring of the spilled sediment from the numerous dredgers present during the operation was undertaken.

The purpose of this sample is to model a 12-day evolution of the spilled sediment under the combined action of tidal and wind-induced currents.

The simulation includes following three dredgers:

- Castor

- Bastion

- Manupeka

The dredgers are operating independently at different locations in the sound, each defined by their individual dredging and spill rate (castor.dfs0, bastion.dfs0 and manupeka.dfs0).

Defining the hydrodynamic model

In the present application, only currents related to tidal and wind forcing are included, wave-induced currents are thus not considered.

Hydrodynamic set-up

The hydrodynamic model setup is described in details in the step by step training example provided at the default installation directory:

.\Examples\MIKE_21\FlowModel\HD\Sound\M21_Sound.pdf

Figure 3.18   Dredging operation in the Sound between Denmark and Sweden. The lower right image shows a photo of Cutter suction dredger Castor
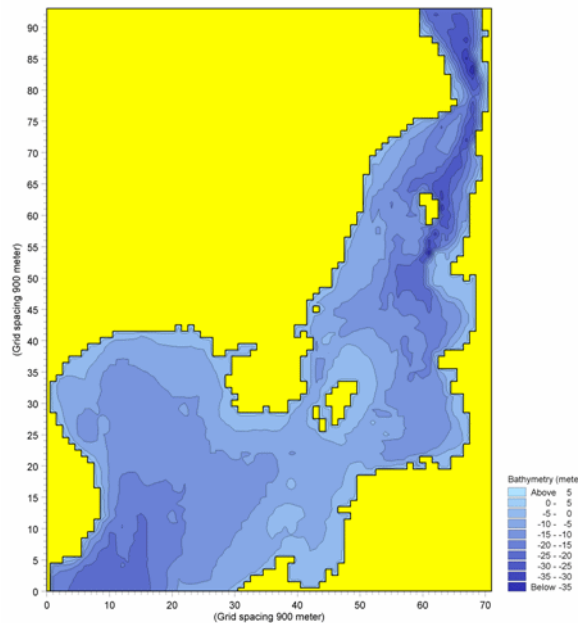
Figure 3.19   Bathymetry

Defining the mud transport model

The amount of dredged material varies from day to day and from dredger to dredger. The dredging operation takes place 24 hours per day. The settling velocity of the material is set to 0.00003 m/s. The bulk density of the dredged sediment is estimated to be 1980 kg/m³ and it is estimated that the sediment spill is 5% of the dredged material.

Three dredgers are considered. Each represented as a spatio-temporal varying forcing define in a DFS0 file.

Mud transport set-up

1. Enter *Starting Conditions* and make sure that the AD and MT simulation periods are equal to the HD simulation period. Choose cold start.

2. Enter *Parameter Selection*. Choose one layer and one fraction. Salinity should be switched off.

3. Enter *Initial Conditions*. Check that the initial bed thickness is 0 m and the initial concentration is 0 kg/m³.

4. Enter *Dispersion* and make sure that the dispersion coefficients in both directions are 0 m²/s.

5. Enter the *Boundary* section and make sure that the boundary concentrations are 0 kg/m³.

6. Enter *Sources* and check that no sources are switched on.

7. Enter the *Forcings* section and switch on the dredging option to include 3 dredging files and load these files.

8. Enter *Water Column Parameters*. Set the settling velocity to be constant at a value of 0.00003 m/s and apply a Teeter profile for the deposition with a critical shear stress of 0.07 N/m^2.

9. Enter *Erosion* under *Bed Parameters* and choose soft mud.

10. Enter *Power of Erosion* under *Erosion* and set the factor to 1.

11. Enter *Erosion Coefficient* under *Erosion* and set this to 0.00005 kg/m^2/s.

12. Enter *Critical Shear Stress* under *Erosion* and set the critical shear stress for erosion to 3.0 N/m^2.

13. Enter *Density of Bed Layer* under *Erosion* and set the dry density to 180 kg/m^3 corresponding to weak mud.

14. Enter *Sliding* under *Erosion* and do not include sliding.

15. Enter *Morphology* under *Erosion* and switch off morphological calculations.

16. Enter *Bed Roughness* under *Erosion* and set this to 0.01 m.

17. Enter *Transition Between Layers* under *Erosion* and exclude the transition of mud between layers.

18. Enter *Line discharge* and make sure that no line discharges are switched on.

19. Enter *Results* and choose the relevant output.

20. Run the model.

Mud transport results

Use the *Plot Composer* included in MIKE Zero to create plots of suspended sediment concentrations during the simulations. The results show that the dredging operations engendered a large-scale plume that dispersed throughout the sound under the combined action of tidal and wind-induced currents.

12/14/1993 00:00:00
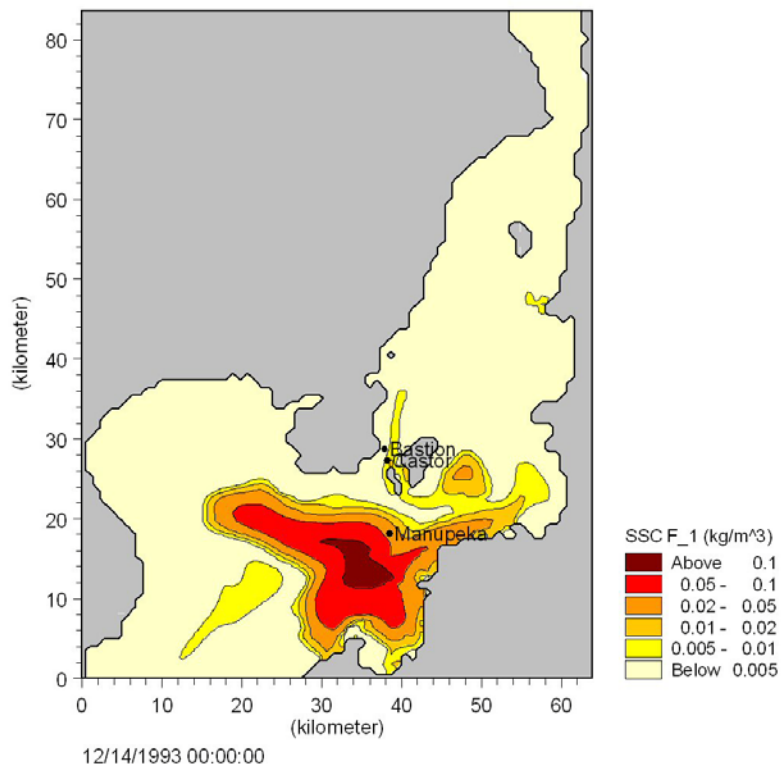
Figure 3.20   Plan view of the dispersion of suspended sediment concentrations (SSC), here shown on 14 December 1993 at 00:00:00. The initial position of the three dredgers are indicated

Exercises

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

1. Check the effect of raising the settling velocity to 0.0001 m/s.
2. Check the effect of changing the critical shear stress for erosion to 0.2 N/m².
3. Include a wave field in the hydrodynamic set-up. What is the effect of the waves on the plume?
4. Apply a wind direction of 90 degrees and wind speed of 10 m/s.

4 Dialog Overview

A description of each dialog in the MIKE 21 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. 47)*.

4.1 Starting Conditions

Under starting conditions you must specify the amount of time the suspended sediment should be advected around. This is called AD-simulation period. Similarly the amount of time in which the mud transport processes should be active must be specified. This is called the MT-simulation period.

You must also choose between a hot started simulation and a cold started simulation.

If hotstart is selected you must specify a hotstart file generated from a previous run. This file contains all initial data and therefore you do not have to specify any initial concentrations or MT and AD simulation periods.

If cold start is selected you must specify an initial concentration field under Initial Conditions *(p. 36)*.

4.2 Parameter Selection

4.2.1 Number of fractions

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

The maximum number is 8.

4.2.2 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.

4.2.3 Include salinity

If salinity is included mark this check box. If salinity isn't included here salinity flocculation can not be included later. Note that flocculation due to salinity is insignificant for salinities above 8-10 PSU. For further information see reference manual Settling Velocity *(p. 71)*.

4.2.4 Include XE

If xenobiotics should be included mark this check box.

4.3 Initial Conditions

4.3.1 Initial concentration

Here you must specify the initial concentration for each fraction. This can be done as either a constant or a type 2 map for each area. A typical background concentration is 0.01 kg/m^3.

4.3.2 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.

4.3.3 Initial bed distribution

Here you must specify the content of a given fraction in a given layer in percent (%). 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.

4.4 Dispersion

On this dialog page you specify the dispersion coefficients for the movable components. The dispersion coefficients can be set either as independent of the current, or scaled in accordance with the calculated fluxes proportional to the current.

If you have selected "Independent of the current", you should specify the dispersion coefficients. You must specify a value for both model directions. For each area, you can specify the coefficients either as a constant value applied to all points in an area or as read from a type 2 data file.

If you have selected "Proportional to current", you should specify a proportionality factor for each direction. With this selection, the dispersion coefficients are at all times scaled in accordance with the calculated fluxes. To avoid values that would make the computation unstable, reasonable cut-off limits should be specified. For further information see reference manual, Dispersion Coefficients *(p. 57)*.

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.

4.5 Boundary

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

The concentration at the open boundary can be specified in one of three 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.

  If no boundary concentrations are known a typical background concentration is 0.01 kg/m^3.

NOTE: At one open boundary you cannot mix the different types of boundary data. Also any possible data file (type 0 or 1) must have the same number of items as there are components in the simulation. This file must contain salinity as last item, if selected, after the suspended sediment fractions in numerical order.

4.6 Sources

For each movable component you should specify the concentration at each defined source in the model. The components are salinity, if selected, and 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 salinity as last item, if selected, after the suspended sediment fractions in numerical order.

4.7 Forcings

At this time two types of forcing can be selected

- Waves
- Dredging

Including waves implies including the effect of the waves on the erosion deposition terms through the combined wave-current shear stress.

Including dredging implies the effect of dredging activities on the re-suspension (spill).

4.8 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. 83)*.

4.8.1 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.

4.8.2 Time and Space Varying Waves

If you choose time and space varying waves you must specify a type 2 file containing significant wave 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.

4.8.3 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 the significant 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.

4.9 Dredging

Dredging activities contribute to the suspended concentration through spilled material and it contributes to changing the morphology through the dredging itself.

In this dialog you must select the how many active dredgers the calculation should include.

For each dredger a file and a number of parameters must be defined.

4.9.1 Dredging file

For each dredger a dfs0 file must be specified. The data file must have 4 items:

1. Easting or longitude coordinate of dredger position
2. Northing or latitude coordinate of dredger position
3. Dredge rate
4. Dredge Spill (%)

The position of the dredger can be given in any map projection available.

Positive dredge rates correspond to dredging. Negative dredge rates correspond to dumping.

4.9.2   Parameters

For each dredger you must select if you want to update the bed due to the dredging itself. The spill will be included through the normal channel but an update from the dredger itself can be selected. If this is selected the weight of the different fractions in the dredged material will be determined based on the weights in the bed.

In case of dumping the weight for each fraction of the dumped material will have to be given. In case of both dredging and dumping the weight in the dredged material will be determined from the bed, or if no update is selected from the given weights. The dumping is always from the given weights.

In case of nested setups one dredger can operate inside one grid. Therefor the area for dredging must be given for each dredger. Default is the finest grid.

4.10   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 $60\mu m$ are considered non cohesive. Under water column parameters the following sections are included:

- Settling *(p. 40)*
- Sand Fractions *(p. 41)*
- Deposition *(p. 42)*

4.10.1   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. 47)*. If you choose constant settling velocity the constant part will continue for indefinite concentrations. If flocculation is chosen the settling velocity will vary as sketched 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 vary as sketched until the concentration hits the gelling point at which time the settling velocity is negligible. For further information see reference manual, Settling Velocity *(p. 71)*.

4.10.2   Settling Parameters

If you have chosen constant settling velocity you must specify the value as either a constant or a type2 file.

If you have chosen to include flocculation:

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

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

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

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

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

$$w_s = w_0 \left(\frac{c_{hindered}}{\rho_{sediment}} \right)^{\gamma}$$ (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. 71)*.

4.10.3 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. 70)*.

4.10.4 Deposition

MIKE 21 MT offers two types of concentration profiles:

- Stationary concentration profile (Rouse profile)
- Dynamic concentration profile (Teeter profile)

If stationary concentration profile is chosen the concentration profile will be assumed constant with the specified height of centroid.

If dynamic concentration profile is chosen the concentration profile will be calculated dynamically from time step to time step. This means that the relation between near-bed concentration of sediment and the depth-averaged sediment concentration is automatically calculated for each time step on the basis of gravitational and lifting forces.

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

For further information see reference manual, Deposition *(p. 55)*.

4.11 Bed Parameters

Bed parameters consist of the following points:

- Erosion *(p. 43)*
- Density of Bed Layers *(p. 42)*
- Sliding *(p. 44)*
- Morphology *(p. 44)*
- Bed Roughness *(p. 45)*
- Transition between Layers *(p. 44)*

4.12 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. 48)*

4.13 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 21 MT offers two erosion descriptions:

Soft bed description:
Erosion: $S_E = E \exp[\alpha \, (\tau_b - \tau_{ce})^{1/2}]$
where

α: power of erosion

Hard bed description:

$$E^i = E_0^i p_E^{i\,E_m}$$
(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.

$$p_E^i = max\left(0, \frac{\tau_b}{\tau_{ce}^i} - 1\right)$$
(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. 60)*.

4.13.1 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.

4.13.2 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.

4.13.3 Critical Shearstress for Erosion

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. 60)*.

4.14 Sliding

If you are modelling areas with very steep slopes it can be necessary to include sliding in the calculations. In order to do this you must specify whether you want to use Constant Friction or Variable Friction sliding coefficients. For further information see reference manual, Sliding *(p. 78)*.

4.14.1 Variable friction coefficient

If you choose variable sliding coefficients you must specify a value as either a constant or a type 2 file. Furthermore you must specify a solid density of the mud in the top layer. Varying sliding coefficients means that the coefficient will be calculated on the basis of grain-size, water depth, and current velocity.

4.14.2 Constant friction coefficient

If you choose constant values you must specify these as either a constant or a type 2 file.

4.15 Transition between Layers

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

For further information see reference manual, Transition *(p. 82)*.

4.16 Morphology

If you are doing long term simulations it may be necessary to include the net sedimentations impact on the hydrodynamics. This is done by including morphological calculations.

If the simulation is very long it can be necessary to speed-up the morphological changes. This can be done by including the speed-up factor.

For further information see reference manual, Morphology *(p. 67)*.

4.17 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.

4.18 Mass Budget (MT)

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 .

See also Reference Manual, Mass Budget *(p. 65)*.

4.19 Line Discharge

The line discharge facility is used to calculate the transport of a substance through a user specified cross section of the model area.

Both the instantaneous and the accumulated transports are calculated.

You must set the number of lines, and then for each line specify:

- the position of the line
- the associated area number
- the period you want the line transport calculations to be active
- the name and (optionally) the title of the type 0 data file where the line transports are to be written
- which components to be included in the line transport calculations

NOTE: The calculated transports are not projected onto the line normal in order to integrate the flow across the line. The program transforms the specified line into little pieces of line that follow the grid instead, see the manual.

4.20 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) containing the computed concentration fields. You specify the spatial and temporal output range and the associ-

ated area number, and you specify a name and (optionally) a title for the output data file.

Additionally, special hot-start data can be created. These data can be used for a later continuation of the simulation. You have to specify the name of the hot-output file for each area. You can specify a title too, if you want to.

NOTE: Result files tends to become very big, so have that in mind when specifying the area, number of items and period.

NOTE: In case of applying nested model areas, then only items which are calculated on fine grid points which are common to coarse grid points will be inherited and displayed in the result file for the coarser grid. The magnitude of the item inherited from the fine grid to the coarse grid will be the same on both grids (no resolution related scaling!).

5   Reference Manual

This manual is intended for use when you are doing model applications and need to know how various input, output, etc. can be specified for the MIKE 21 Mud Transport module (MT).

It is assumed that you are familiar with the operation of MIKE 21 under the MIKE Zero platform.

All entries listed below are included in the reference manual.

- Transition *(p. 82)*
- Water Column Parameters *(p. 82)*
- Wave Forcing *(p. 83)*

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 has large extends 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. It is defined as the dry density and the unit is typically [kg/m^3].

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
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, ρ_s, is grain density and ρ is water density.

5.2 Bed Description

The sediment bed consists of one or more bed layers. Each bed layer is defined by the sediment mass 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.
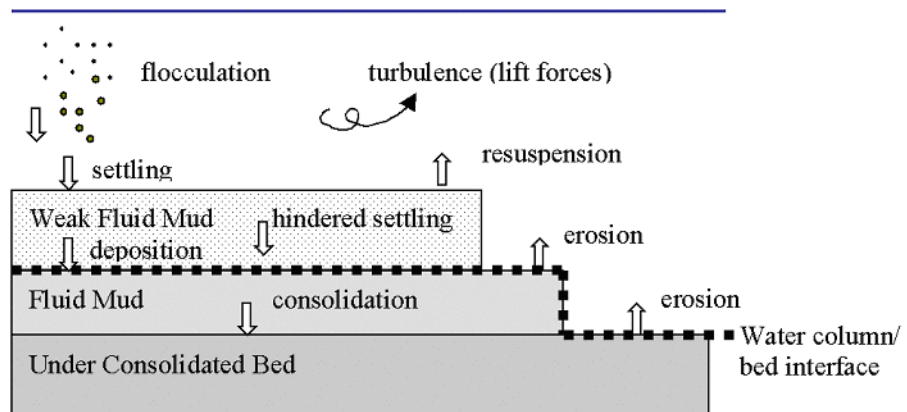
Figure 5.1   Processes included in the Mud Transport Module. The bed layers are the layers below the water column-bed interface (dotted line)

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:

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

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:

$$H_j^{new} = \frac{M_j}{\rho_{d,j}} = \frac{\sum\limits_i m_{i,j}^{new}}{\rho_{d,j}},$$

(5.4)

where H is bed layer thickness, M is total sediment mass per area and ρ_d 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
- Sliding
- Consolidation
- Bed roughness
- Morphology

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) and the unit is typically [m].

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 Flow Model, Mud Transport Module 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 Mud Transport Module

MIKE 21 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

When calibrating the bed parameters it is recommended to start without sliding and transition switched on. They do not directly affect the erosion pattern and they slow the simulation. When the erosion/ deposition pattern is established they can be switched on.

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 timestep. The transfer function for the i'th bed layer is:

$T_{f,i}$ = 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^{-6} 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 (Peclet) 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 setup, please refer to your Hydrodynamic Module, Reference Manual and Hydrodynamic Module, Examples.

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.

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

Teeter profile

The deposition for the i'th mud fraction is described as:

$$D^i = w_s^i c_b^i p_D^i \tag{5.8}$$

where p_D^i is a probability ramp function of deposition, w, is the settling velocity and c_b is the near-bed bottom concentration of fraction i. The probability ramp function is defined as:

$$p_D^i = max\left(0, min\left(1, 1 - \frac{\tau_b}{\tau_{cd}^i}\right)\right) \tag{5.9}$$

The mud concentration c_b^i is related to the depth-averaged concentration $\bar{c}^i$ using the Teeter profile:

$$c_b = \bar{c}^i \left(1 + \frac{p_e^i}{1.25 + 4.75 p_D^{i^{2.5}}} \right)$$

(5.10)

where p_e^i is the peclet number corresponding to the i'th fraction, defined as:

$$p_e^i = 6 \frac{w_s^i}{\kappa U_f}$$

(5.11)

in which U_f is the friction velocity, and κ is 0.4.

Rouse profile

The mud concentration c_b^i is related to the depth-averaged concentration $\bar{c}^i$ using the Rouse profile. Using this the bottom concentration can be defined as:

$$c_b = \frac{\bar{c}^i}{RC}$$

(5.12)

In which RC is the relative height of centroid, which is defined as the distance from the seabed to the mass centre of the concentration profile divided by the water depth. It is time independent and therefore the concentration profile is considered stationary. The deposition rate can then be calculated as:

$$D = c_b \cdot w_s, \text{ when } \tau_b < \tau_{cd} \,,$$

(5.13)

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 generally less than the critical shear stress for erosion. Normal

values are in the interval 0-0.1 N/m². 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 Coefficients

Physical flow processes occur simultaneously at different spatial and temporal scales with a continuous spectrum ranging from molecular agitation to tidal, barotropic and baroclinic residual flows. The need to express conservation laws by means of mathematical methods imposes the treatment of fluid motions as part of continuum mechanics. This implies the use of spatial scales much larger than the intermolecular spacings associated with molecular agitation processes, in order to define the properties such as concentrations. Furthermore, for the study of practical problems only the flow processes above a certain minimum scale are of interest, hence the direct modelling of smaller scales gives rise to unnecessary and, in practice, inestimable computational costs. By using convenient filtering procedures it is possible to avoid the explicit inclusion of those scales in the dependent variables used in the mathematical formulations. These non-resolved scales cannot be ignored, as part of the energy of the flow is absorbed by them. Therefore they have to be empirically related to the dependent variables (representative of all the resolved scales) through specific terms that naturally appear as a consequence of the filtering procedures. The relationships to be used and the respective empirical coefficients will then reflect the existence of non-resolved scales, the main effects of which can be classified as follows:

- Dissipative, which account for the amount of energy present in the non-resolved scales or/and the decay/growth of flow properties. In two-dimensional hydrodynamic models for example, bottom friction explains not only the energy losses due to shear stresses, but also the total amount of energy contained in the non-resolved scales along the vertical.

- Dispersive, which account for the transfer of energy or properties between resolved scales, due to the existence of non-resolved scales. These effects are represented by the so-called viscosity/diffusion coefficients.

The wide range of time and length scales involved, as well as the variability of flow conditions, makes it impossible to develop a unified approach with universally applicable expressions for the evaluation of the referred empirical coefficients. Therefore, one has to resort to calibration values through the use of reliable and sufficient data. However, the values of those coefficients are subject to large variations, thus raising the need for good first estimates,

which can be obtained both by theoretical analysis of the physical processes and through the use of experience acquired in similar applications.

For further reading, see the Scientific Documentation of the Advection-Dispersion Module of MIKE 21 Flow Model.

5.11.1 Specifying the dispersion coefficients

The dispersion coefficients can be given in the following ways:

- Specified as constant in space, as a coefficient for the x-direction and a coefficient for the y-direction

- Specified as two-dimensional maps (**type 2 files**) of coefficients, similar to the bathymetry map

- Calculated every time step, proportional to the hydrodynamic current densities. If you choose this formulation, proportionality constants, minimum and maximum values are also required

Regardless of the different ways of defining the dispersion coefficients, it is necessary to specify them for all movable components. The movable components are:

- salinity, if specified, and suspended sediment.

5.11.2 Recommended Selection and Values

Selecting dispersion coefficients is very difficult. The optimum method is to obtain the coefficients from a calibration process, where simulated and measured concentration fields are compared. Very seldom are measurements available for the calibration of mud transport processes. These processes have very long response times (months or years) and, therefore, empirical estimates have to be utilized.

Many different formulations can be applied e.g.

$$D = K_1 \cdot \Delta x^2 / \Delta t$$

$$D = K_2 \cdot \Delta x.u$$

or

$$D = K_3 \cdot \Delta t.u^2$$

D_x is the dispersion coefficient

Δx is the grid spacing

Δt is the time step and

u is the local current speed

Table 5.2   Effective coefficients of scale 4

Case	h (m)	u (m/s)	Δx (m)	Δt (S)	Dx (m²/s)	K_1	K_2	K_3
A	8	0.7	50	30	1-5	0.06-0.01	0.14-0.03	0.34-0.07
B	20	1.0	500	300	40-50	0.06	0.10	0.17
C	30	0.5	6000	600	-500	0.008	0.17	3.3
D	40	1.0	20	10	1-3	0.075-0.025	0.15-0.05	0.30-0.10
E	1000	0.1	30000	900	-6000	0.006	2.0	667

5.11.3   Remarks and hints

Using too high values of the dispersion coefficients will cause instabilities. Stability is a function of the local transport courant number and the dispersion coefficient. For practical applications it is not possible prior to a simulation, to judge whether the upper limit of the dispersion coefficients has been reached. If you insist on using a specific value of the dispersion coefficient, even though you get instabilities, you must decrease the time step.

When running MIKE 21 it is possible that you will be prevented from specifying a dispersion coefficient. The program does not accept all values, since an upper limit can be reached:

$$D_x/Dx^2 + D_y/\Delta y^2 \cdot \Delta t \leq 0.5 \qquad (5.14)$$

where

D_x is the dispersion coefficient in the x direction
D_y is the dispersion coefficient in the y direction
Δx is the grid size in the x direction
Δy is the grid size in the y direction
Δt is the time step

The stability criteria given is valid for a pure diffusive problem, but since transport as advection of sediment is included in normal applications as current fields, the upper limit will be smaller than 0.5.

5.12 Dredging

5.12.1 Calculation of dredged material from bed

When the dredging from the bed goes on the dredger will dredge the dredgerate times the timestep for each timestep. The dredgerate is the amount of sediment that enters the boat pr timestep. The amount moved from the bed per timestep is:

$$D_{bed} = Dredgerate \cdot dt \tag{5.15}$$

where
D_{bed} is amount of mass moved from bed
S is spill percent and
dt is time step

In case of dumping, the specified distribution is used. If the dredger during a time step hits a layer boundary the dredger will dredge down to the boundary and stop. Continuing in the next layer in the next timestep.

5.12.2 Calculation of spill percent

The spill percent is specified. The amount of spill is calculated in the following way:

$$Spill = \frac{S}{100} Dredgerate \cdot dt \tag{5.16}$$

If multiple fraction are present in the bed, the mass of each fraction is distributed in the water column according to the distribution in bed. In case no update of the bed is used, the specified distribution is used.

5.13 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.

5.13.1 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.

5.13.2 Hard bed description

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

$$E^j = E_0^j \, p_E^{j\,E_m} \qquad (5.17)$$

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.

$$p_E^j = \max\left(0, \frac{\tau_b}{\tau_{ce}^i} - 1\right) \qquad (5.18)$$

5.13.3 Soft bed description

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

$$E = E_0^j \exp(\alpha(\tau_b - \tau_{ce}^j))$$

5.13.4 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).

5.13.5 Recommended values

The value E is a proportion factor governing the speed of erosion. For soft bed it is generally between 0.000005 and 0.00002 kg/m^2/s. For hard bed it is usually around 0.0001 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 5.3   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:

$$\tau_{ce} = \sqrt{0.00001\,\tau_{yj}} \qquad\qquad \tau_{yj} \leq 0.00015\,N/m^2$$
$$\tau_{ce} = 0.0000025\,\tau_{yj} \qquad\qquad \tau_{yj} > 0.00015\,N/m^2$$

(5.19)

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

5.13.6 Remarks and hints

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

5.14 Hot Data

You can start your simulation either from scratch (a "cold start") or on the basis of a previous simulation (a "hot start"), see *Simulation Type*. In the latter case you need to save information about the simulation you wish to continue. These data are called "hot data".

In addition to the information described in the Hot Data section in the *Hydrodynamic Module, Reference Manual* the hot data includes suspended sediment concentrations and bed layer masses.

5.14.1 Specifying the hot data

The hotstart file is specified under *Starting Conditions*.

5.15 How to Recreate Old MIKE Zero MT Simulations

There are two cases:

- Multifraction from scratch
- Multilayer from scratch

5.15.1 Multifraction from scratch

To recreate a multifraction simulation, a number of settings have to be set.

- Set number of layers to 1 under *Parameter Selection*.
- Exclude hindered settling under *Settling*.
- Choose hard bed erosion under *Erosion* and set power of erosion to 1.
- Exclude sliding under *Sliding*.
- Exclude Transition under *Transition*.
- Exclude morphology under *Morphology*.
- Exclude waves under *Forcings.*
- Translate critical velocity for erosion and deposition to critical shear stress for erosion and deposition.

5.15.2 Multilayer from scratch

To recreate a multilayer simulation, a number of settings have to be set.

- Set number of fractions to 1 under *Parameter Selection.*
- Exclude sand fractions under *Sand Fractions*.

5.16 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.

5.16.1 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 concentra-

tions: A **constant** value used everywhere in the model or the initial concentrations can be read from **type 2 data file**.

For recommendations on the initial concentrations see *Suspended Sediment.*

5.16.2 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.

5.16.3 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**.

5.16.4 Remarks and hints

When starting a simulation be aware that initially a cold started HD may give undesired erosion and/or deposition, therefore it may be an idea to start the MT calculation a number of Timestep later than the HD. See *Starting Conditions*.

5.17 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 high peak of the wave faster than it decreases at the low peak. 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:

$$E_L = \rho_b \cdot d_m / \Delta t \qquad (5.20)$$

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	timestep (s)

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

$$d_m = F_{liq} \cdot \delta_{wav} \tag{5.21}$$

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.

5.17.1 Specifying liquefaction

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

5.17.2 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.

5.17.3 Recommended values

The recommended value for the liquefaction factor is 1.

5.18 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.

- 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

This means that for every model component selected, five 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.

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 (see Mass Budget).

5.18.1 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 Mud Transport 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).

5.19   Morphology

If the morphological changes within the area of interest are expected to be comparable to the water depth in certain areas then it is necessary to take the morphological impact on the hydrodynamics into consideration. Typical areas where this is necessary are shallow areas where long term effects are being considered or dredging/dumping sites in shallow areas.

The Mud Transport Module has the ability of updating the bed dynamically in the following way:

The morphological development is included by updating the bathymetry for every timestep with the net sedimentation. This ensures a stable evolution of the bed that will not destabilize the hydrodynamic simulation.

$$Z^{n+1} = Z^n + netsed^n \qquad (5.22)$$

where:

Z^n	Bathymetry level at present timestep
Z^{n+1}	Bathymetry level at next timestep
n	Timestep

The morphological update also offers to speed-up the morphological evolution in the following way.

$$Z^{n+1} = Z^n + netsed^n Speedup \qquad (5.23)$$

In which *speed-up* is a dimension less speed-up factor. The layer thicknesses are updated in the same way. Note that the amount of suspended sediment is not affected by this. Only the bed is affected.

5.19.1 Specifying the morphology

Including the morphological update is done by entering the *Morphology* editor and switching on morphology by marking this. Also the speed-up factor is specified here.

5.19.2 Remarks and hints

Specifying a large speed-up factor may destabilize the hydrodynamic solution by generation of internal waves during the update.

5.20 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 Mud Transport Module setups the following points should be considered:

5.20.1 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.

5.20.2 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.

5.20.3 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.

5.20.4 Sliding

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

5.21 Output Area

In order to assess the outcome of a simulation, it is necessary to store parts of the results on disk. MIKE 21 allows for storage of multiple parts of the mud transport related output in multiple files.

5.21.1 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.

5.21.2 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.

5.22   Sand Fractions

5.22.1   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.

The Mud Transport Module 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 ore 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 MIKE 21 Flow Model, Mud Transport Module, Scientific Documentation.

5.22.2   Specifying sand fractions

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

Mean settling velocity is specified under *Sand Fractions*.

5.22.3   Recommended values

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

5.22.4 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.

5.23 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:

$$
w_s = \frac{(\rho_s - \rho)}{\rho} \frac{g d^2}{18 \cdot \nu}
\tag{5.24}
$$

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]

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.
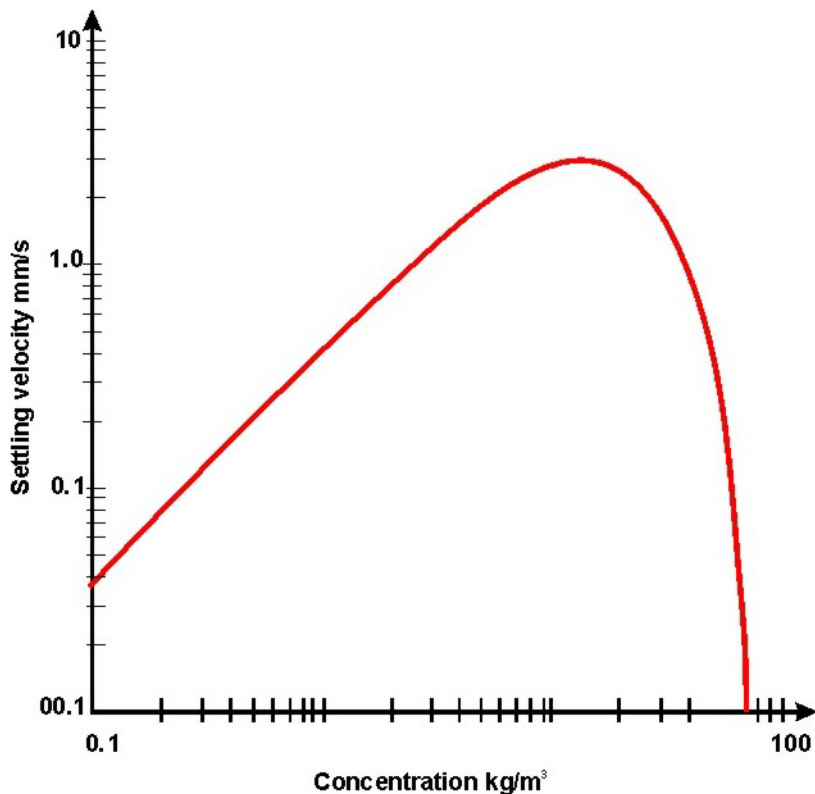
edd05.02/91028-3cdr.gj

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

5.23.1 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.

5.23.2 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 5.2.
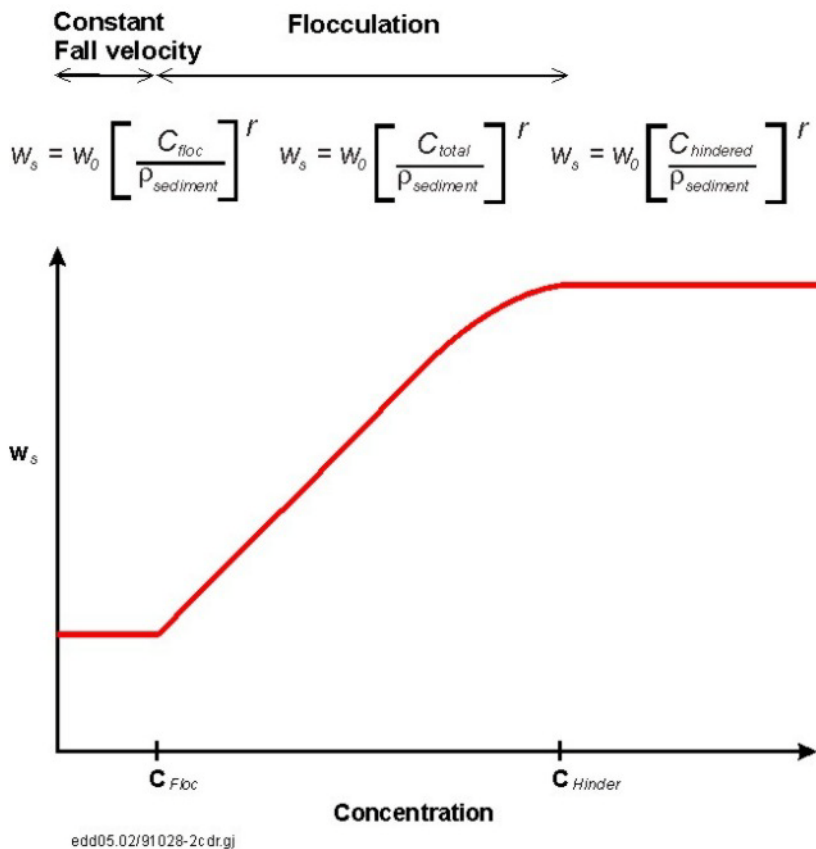
Figure 5.3   Applied concentration profile when flocculation selected

$\rho_{sediment}$:	Density of grain material (2650 kg/m3)
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
γ	Power constant (per default set to 1.0)

5.23.3 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.
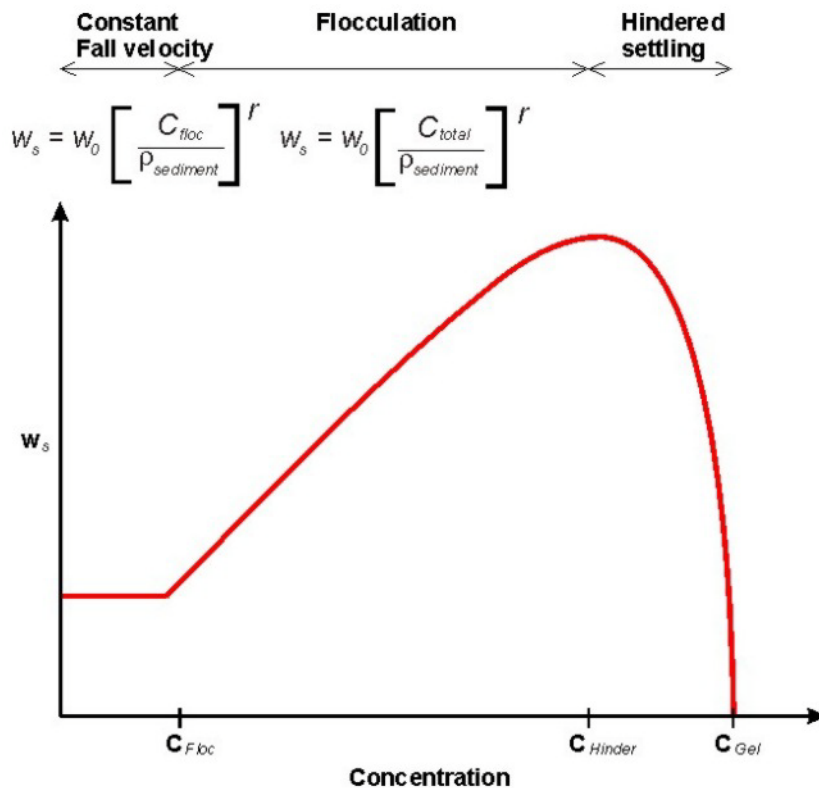
Figure 5.4   Calculation when hindered settling is applied

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

$$w_s = w_{s,r}\left(1 - \frac{c}{c_{gel}}\right)^{w_{s,n}} \tag{5.25}$$

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

$$w_s^i = w_{s,r}^i (1 - \Phi_*)^{w_{s,n}^i} \tag{5.26}$$

where

$$\Phi = \frac{\sum_i c^i}{c_{gel}} \tag{5.27}$$

$$\Phi_* = min(1.0, \Phi) \tag{5.28}$$

In which:

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

Formulation by Winterwerp (1999)

$$w_s^i = w_{s,r}^i \frac{(1 - \Phi_*)(1 - \Phi_p)}{1 + 2.5\Phi} \tag{5.29}$$

where

$$\Phi_p = \frac{\sum_i c^i}{\rho_s} \tag{5.30}$$

In which ρ_s is the dry density of the sediment.

5.23.4 Fluid mud

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

5.23.5 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.

$$w_s^i = w_s^i(1 - C_1 e^{S \cdot C_2}) \tag{5.31}$$

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.

5.23.6 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*.

5.23.7 Recommended values

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

Table 5.4   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.

5.23.8 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 γ. The default values for those are 1.

5.24 Simulation Type

5.24.1 General description

There are three ways of starting your simulation:

- From scratch, also called a "cold start", which means that you have to specify the model bathymetry as well as all other model parameters in the hydrodynamics section as well as the MT section.

- As the continuation of a previous simulation, also called a "hot start", in which case you must prepare "hot data" when doing the previous simulation. This is done by requesting that a file containing "hot data" be prepared in the **Hot Start dialog** in the MT-output section. Select this file after selecting hot start in the Starting conditions dialog.

- As a cold start on a running hydrodynamic setup. This can be done in the following way.

  In the starting conditions dialog there are two periods to be specified. AD-simulation period and MT-simulation period. The first controls the period in which the sediment is being advected around. The latter controls the period in which the mud processes, erosion, deposition, etc. are being carried out. By setting these it is possible to start the mud transport some time after the hydrodynamics have started hereby insuring that the hydrodynamics are in balance when the MT is started.

When your simulation is a continuation of a previous one the bathymetry, flooding and drying information, time step, turbulence and density variation selection, etc., as well as the suspended sediment concentration and bed layer thickness(es) are reused from the previous simulation and cannot be changed. The rest of the model parameters you specify as for a "cold start".

5.24.2 Remarks and hints

In most applications all simulations will be "cold started". However, it is wise to use the "hot start" facility if you have very long simulations, if your computer system often stops (intentionally or unintentionally) or if output from your simulation fill up your disk space.

5.25 Sliding

In areas where large bathymetry gradients are present, i.e. in navigational channels, it is possible to invoke a process describing the sliding of sediment from shallow parts into the channels. This will especially be possible in the top bed layers, where weak mud often will be present.

The initiation of the sliding process depends on the slope of the bathymetry, and the dry density of the actual bed layer, ρ_j (unit: kg/m^3), which corresponds to an equilibrium slope (α_e) of the bed. The relation is

Sliding: $\qquad \alpha \geq \alpha_e$
No sliding: $\qquad \alpha < \alpha_e$

where

α - actual slope of bathymetry

$$\alpha_e = \arctan\left[2.5 \cdot 10^{-13}\left(\frac{\rho_{b,j}}{1000}\right)^{4.7}\right] \tag{5.32}$$

The sliding process is modelled by a dispersion equation, see Teisson (1991).

$$\frac{\partial_{zb}}{\partial t} = K_{sx}\frac{\partial^2 zb}{\partial x^2} + K_{sy}\frac{\partial^2 zb}{\partial y^2} \tag{5.33}$$

where

z_b	bed level
K_{sx}, K_{sy}	dispersion coefficients in x,y directions.

The dispersion coefficients, K_{sx}, K_{sy} may be either constant or related to some model parameters, Grishanin and Lavygin (1987).

where

$\vec{K}_{ss}$	(K_{sx}, K_{sy})
ε	medium porosity factor
s	relative density of bed layer material
d_{50}	mean diameter of bed layer material
h	water depth
$\vec{v}$	(V_x, V_y) - components of depth-averaged flow velocities
v	kinematic viscosity of water
g	gravity acceleration

All other parameters besides the K_{sx}, K_{sy} are explicitly calculated by the model. The lack of proper sediment characteristics (ε,s) prevents a satisfactory calibration of the sliding process. At present this feature is only present for one area simulations.

5.25.1 Specifying sliding

Sliding is specified under the sliding editor. The sliding coefficients are equal in both directions.

5.25.2 Remarks and hints

Be aware that at present sliding can only be switched on for non nested simulations.

5.26 Sources and Sinks

The effects of rivers, intakes and outlets from e.g. power stations, outlets from sewers, etc., can be included in a simulation. MIKE 21 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*.

5.26.1 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.

5.27   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:

$$\frac{\partial c}{\partial t} + \frac{\partial}{\partial x_i}(c(u_i - w_{s,i})) = \frac{\partial}{\partial x_i}\left(D_c\frac{\partial c}{\partial x_i}\right) + S_c \tag{5.34}$$

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:

$$\frac{\partial c}{\partial t} + \frac{\partial}{\partial x_i}(c(u_i - w_{s,i})) = \frac{\partial}{\partial x_i}\left(D_c\frac{\partial c}{\partial x_i}\right) + S_c \tag{5.35}$$

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*).

5.27.1 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.

5.28 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.

5.28.1 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.

5.29 Transition

See Consolidation.

5.30 Water Column Parameters

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

The following processes are included:

- Settling
- Sand fractions

5.31 Wave Forcing

5.31.1 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 module, MIKE 21 PMS.

5.31.2 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.

AT TIME t* AT GRID POINT (j,k) H_s, T_m, $\bar{\Theta}$ ARE
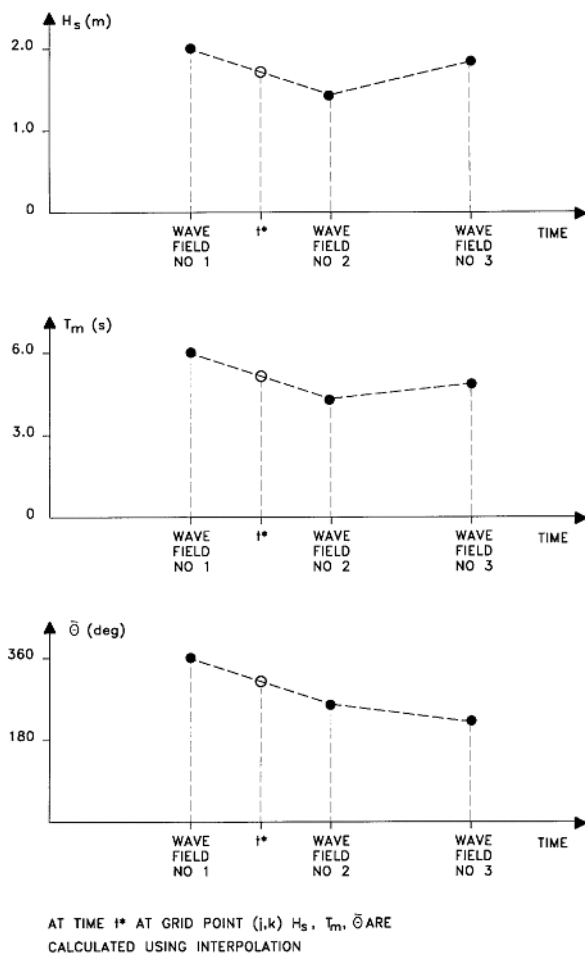CALCULATED USING INTERPOLATION

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

5.31.3 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 21 HD), wind speed and direction (specified as wind input in MIKE 21 HD) 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.
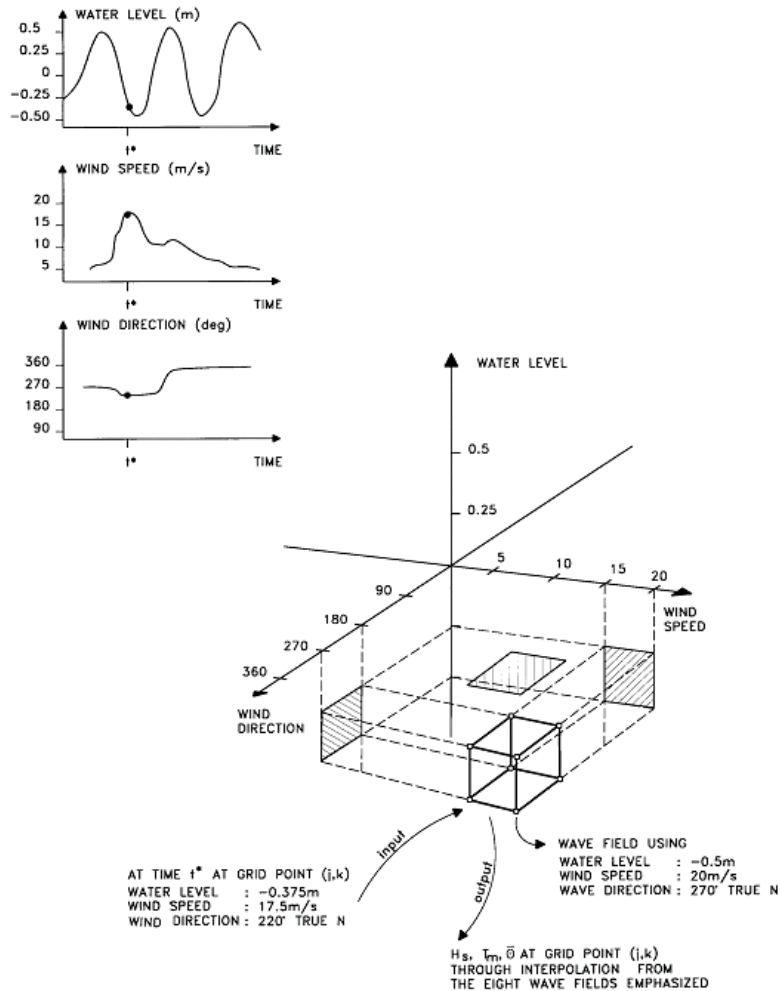

Figure 5.6   Interpolation of wave fields from wave database

5.31.4 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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