MIKE
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# MIKE 21 ST

## Non-Cohesive Sediment Transport Module

## User Guide

# PLEASE NOTE



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# CONTENTS

# 1 About This Guide

## 1.1 Purpose

This guide provides you with elaborate examples and reference material not found in the online help for the MIKE 21 ST software.

## 1.2 Prerequisites

Though basic computer user skills are enough to operate the MIKE 21 ST software, you need some understanding of sediment transport concepts in order to validate results and understand all input parameters.

In order to compute the sand transport based on pure current, MIKE 21 ST needs the output of a hydrodynamics simulation done by MIKE 21 HD. And if you want to take waves into consideration too you need a file with wave parameters calculated by MIKE 21 PMS.

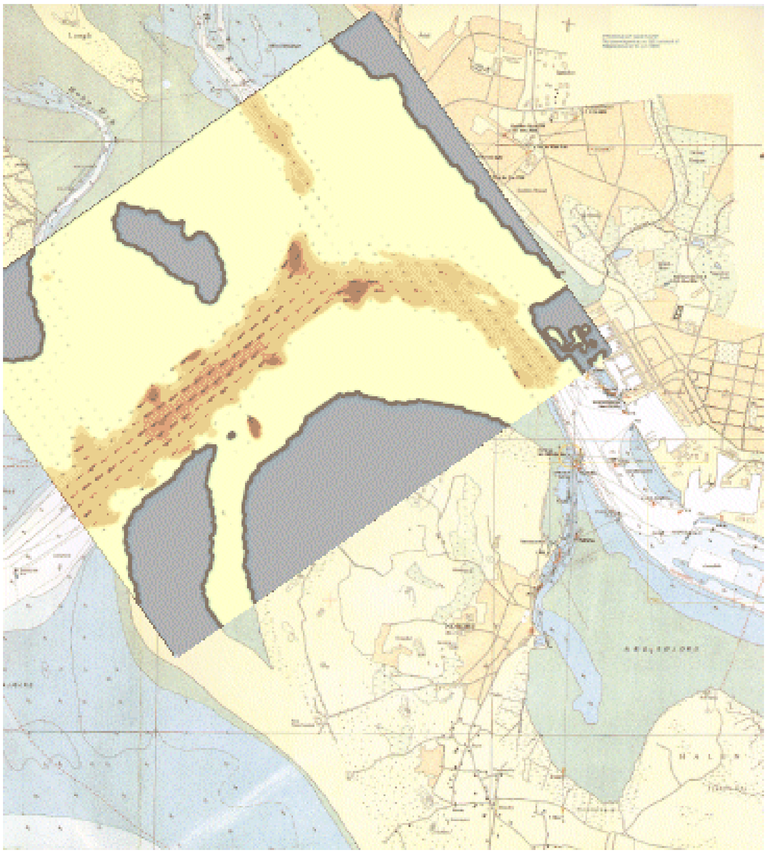
MIKE 21 ST ships with a handful of examples, including the output files needed to run simulations in both pure current and combined current and wave conditions. Please refer to "Examples" on page 11.

# 2 Introduction

## 2.1 What is MIKE 21 ST?

MIKE 21 ST is a module in the MIKE 21 application suite for calculating non-cohesive sediment (sand) transport rates. You can calculate sand transport based on pure current information, or you can take waves into consideration too.

In addition to sand transport rates, a simulation will give you the initial rates of bed level changes. This is sufficient to identify potential areas of erosion or deposition, but can not take the place of a full morphological model.



## 2.2 Application Areas

MIKE 21 ST can simulate sand transport rates in a wide array of settings, including natural environments like tidal inlets, estuaries and coast lines, and man made constructions like harbours and bridges.

Tide, wind, wave and current can all be taken into consideration for optimum precision in the simulations.

## 2.3 Key Features

Here is a list of selected highlights in the MIKE 21 ST software:

- Constant or spatially varying bed material (i.e. median grain size and gradation)
- Five different sand transport theories available in pure current conditions:
  - The Engelund and Hansen total-load transport theory
  - The Engelund and Fredsøe total-load (determined as bed load + suspended load) transport theory
  - The Zyserman and Fredsøe total-load (bed load + suspended load) transport formulation
  - The Meyer-Peter and Müller bed-load transport theory
  - The Ackers and White total-load transport formulation
- Two simulation methods available in combined current and wave conditions:
  - Application of DHI's deterministic intra-wave sediment transport model, STP
  - Bijker's total-load transport method
- The STP model provide these features to MIKE 21 ST:
  - Arbitrary direction of wave propagation in respect to the current
  - Distinguish between breaking and unbroken waves
  - Geometric properties of bed material is described through a single grain size or a grain size distribution curve
  - Plane/ripple-covered bed
- When using the STP model in combined current and wave simulations, two-dimensional (2DH) or quasi three-dimensional (Q3D) sand transport methods are available
- Speed up simulations by using predefined sand transport tables
- Finite differences technique on space-staggered rectangular grid
- Courant-Friedrichs-Lewy stability criterion

# 3 Examples

## 3.1 Introduction

To demonstrate the capabilities of MIKE 21 ST we have included four real-life examples of simulations.

- Corner (see "Corner Example" on page 11)
- Harbour (see "Harbour Example" on page 14)
- Structures (see "Structures Example" on page 17)
- Nourishment (see "Nourishment Example" on page 21)

You can use the examples to get an understanding of the data you need to feed MIKE 21 ST for a successful simulation, and you are free to modify the input data and parameters and see how the results change accordingly.

In a standard installation you will find the files needed to run the examples in the default installation directory: .**\Examples\MIKE_21\ST**.

## 3.2 Corner Example

### 3.2.1 Purpose

We investigate a sharp channel corner with steady flow. The example will illustrate sand transport patterns and initial bed level change rates.

### 3.2.2 Scenario

The channel flow is forced from the southern open boundary to the western open boundary by a difference in water level of 0.05m. The bottom of the channel is horizontal and positioned 20m below datum.

The bed material consists of uniform sand with median size d50 = 0.150mm and geometric standard deviation sg = 1.10.

### 3.2.3 Parameters

The bathymetry is described using grid cells of 50 times 50 meters, and the hydrodynamic simulation from MIKE 21 HD is made with 30 second time slots. Adding it all up it correspond to a Courant number of eight.

To avoid oscillations we increase the water level at the southern boundary gradually over 60 time slots, and we run the simulation for three hours to make sure that we arrive at a stable solution.

The entire model area has a bed resistance specified by a constant Manning number of 32 $m^{1/3}/s$, and a constant value of $\varepsilon$ = 3 $m^2/s$ is used for the velocity-based eddy viscosity.

Finally, the transport formulation of Engelund and Hansen is used to calculate the sand transport rates over the last two time slots in the MIKE 21 HD data file.

### 3.2.4 Results

Based on data files and the parameters defined in the previous section the MIKE 21 ST software can now calculate a number of things for us and the Plot Composer can be used to plot some nice charts.

Figure 3.1 below shows the initial rates of bed level changes after running the simulation (this is the file called dzdt.plc). The red area is where sand will aggregate, and the green areas are the ones prone to erosion.

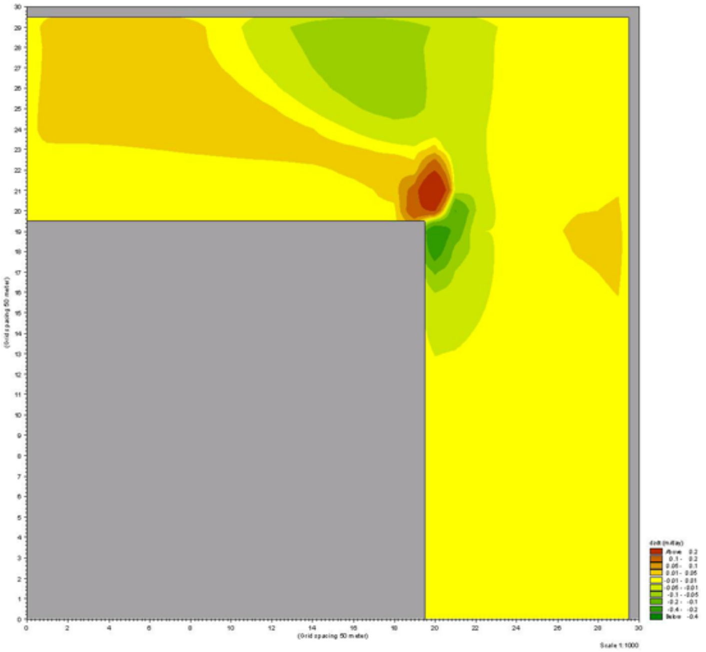


Figure 3.1 Initial rates of bed level change dz/dt (m/day)

Figure 3.1 shows an area immediately upstream of the corner and adjacent to the wall where erosion will occur due to enhanced flow velocities and sediment transport capacity.

As the velocity of the current drops due to flow expansion downstream of the corner, the transport capacity also decreases. As a result of these mechanisms, an area where sediment will tend to deposit can be seen immediately downstream of the corner in Figure 3.1.

Other files of interest are Cornerflow.plc that gives you an overview of the current and transportrates.plc that shows the sand transport rates.

### 3.2.5 Files

Here are the files provided with this example:

Name: bathy.dfs2
Description: Corner example, bathymetry

The following specification files were used to run the simulations and plot the results:

File: corner_HD.M21
Task: Model: MIKE 21 Flow Model
Description: Corner example, hydrodynamic simulation

File: corner_ST.ST2
Task: Module: Mike 21 Non-Cohesive Sediment Transport
Description: Corner example, sediment transport simulation

File: CornerBathy.plc
Task: MIKE Zero Plot Composer
Description: Plot of model bathymetry

File: CornerFlow.plc
Task: MIKE Zero Plot Composer
Description: Plot of current field

File: TransportRates.plc
Task: MIKE Zero Plot Composer
Description: Plot of sediment transport rates

File: Dzdt.plc
Task: MIKE Zero Plot Composer
Description: Plot of initial rates of erosion/deposition

# 3.3 Harbour Example

## 3.3.1 Purpose

We investigate a harbour and the surrounding area on a sandy coast. Harbours tend to have an asymmetric design that protects them from the ocean, but this often lead to the formation of large-scale eddies in the separation area downstream of the harbour and subsequently sediments piling up right at the harbour entrance.

This example looks at wave driven current and littoral transport patterns illustrating the phenomena just described.

## 3.3.2 Scenario

The harbour is on a sandy coast consisting of sand with $d_{50}$ = 0.22mm and $s_g$ = 1.25 in the entire area. Irregular, directional waves (JONSWAP spectrum) move towards the coast from 102°. Waves move over a water level corresponding to MWL = 1m. The wave characteristics at the offshore boundary of the model are $H_{m0}$ = 2.11m and $T_p$ = 9.96s.

## 3.3.3 Parameters

We are looking at an area that spans 1500m in the long-shore direction and 1625m in the cross-shore direction. The bathymetry is described with grid cells of five times five meters - this goes for both for the wave simulation with MIKE 21 PMS, and the hydrodynamic simulation with MIKE 21 HD. The model grid has an orientation of 201× measured from True North.

Irregular, directional waves are added at the offshore boundary of the wave model. The frequency spectrum is of JONSWAP type, but around the mean direction of wave propagation (102°) a $\cos^n$ distribution of wave energy is used. At the other two open boundaries (left and right to the harbour) symmetry boundary conditions are used.

The wave simulation takes wave breaking into consideration, using default values of the breaking parameters $\gamma_1$ and $\gamma_2$. Bed roughness is not considered.

When simulating the wave driven currents with MIKE 21 HD we use constant values of velocity-based eddy viscosity $\varepsilon$ = 1m$^2$/s and Manning number M = 32m$^{1/3}$/s all over the model area. The time slots are set to four seconds and the simulation runs for four and a half hours to ensure stable conditions.

The updrift boundary (left) is prescribed as flux, the downdrift boundary (right) is prescribed as level, and the offshore boundary is prescribed as zero flux.

Prior to running the flow simulation the updrift and downdrift boundaries (prescribed as flux and level, respectively) was generated by use of the tool for calculation of *Wave Generated Current and Setup* of the MIKE Zero system. The offshore boundary was prescribed as a zero flux one.

Prior to running the sediment transport simulation, a sediment transport table (2DH) was generated with the tool for *Generation of Sediment Transport Tables* of the MIKE Zero system.

### 3.3.4 Results

In the present example, it is of interest to examine how the presence of the harbour influences the waves, the wave-driven current and the sediment transport patterns.

Figure 3.2 below shows the wave-driven current calculated with MIKE 21 HD. The eddy on the right side of the harbour works with the strong offshore-directed current on the opposite side, moving any loose sediment available in the area towards the harbour entrance where it will settle and cause problems for the harbour basin.

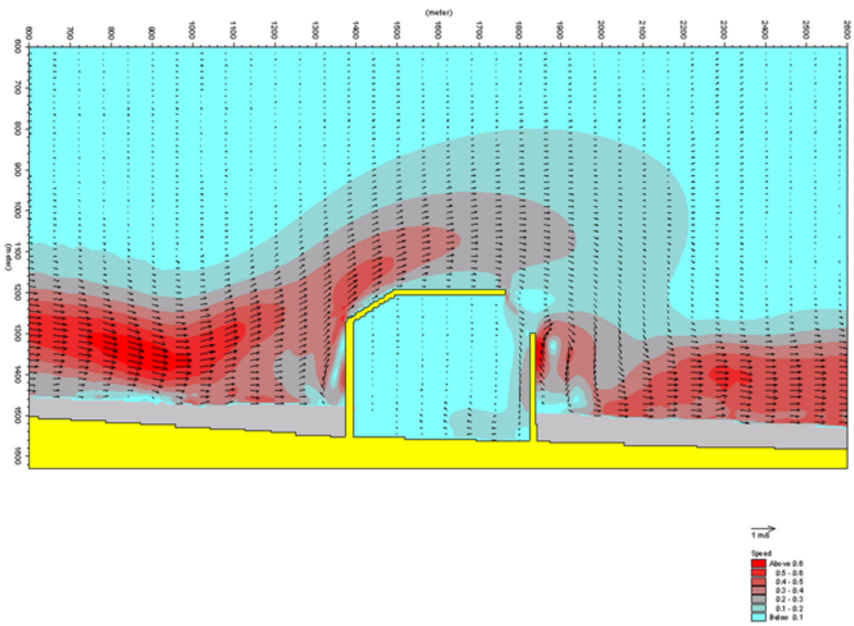



Figure 3.2 Calculated wave-driven current

A number of other results are found in the plot files listed in the next section.

### 3.3.5 Files

Here are the files provided with this example:

Name: ModelBathy.dfs2
Description: Harbour example, bathymetry for wave and flow simulations

Name: IrrDirWaves.dfs2
Description: Directional wave spectrum to be applied at offshore boundary of the wave model

Name: NorthBoundary.dfs1
Description: Profile series of water levels and fluxes along northern boundary of flow model

Name: SouthBoundary.dfs1
Description: Profile series of water levels and fluxes along southern boundary of flow model

The following specification files were used to run the simulations and plot the results:

File: WaveSimulation.PMS
Task: Model: MIKE 21 Parabolic Mild Slope Waves
Description: Harbour example, wave simulation

File: HD_Simulation.M21
Task: Model: MIKE 21 Flow Models
Description: Harbour example, hydrodynamic simulation

File: TranspTable.21T
Task: Tool: Generation of Sediment Tables
Description: Harbour example, sediment transport table

File: ST_Simulation.ST2
Task: Module: Mike 21 Non-Cohesive Sediment Transport
Description: Structures example, sediment transport simulation

File: Bathymetry.plc
Task: MIKE Zero Plot Composer
Description: Plot of model bathymetry

File: WaveField.plc
Task: MIKE Zero Plot Composer

| | |
|---|---|
| Description: | Plot of calculated wave height and direction of propagation |
| | |
| File: | CurrentField.plc |
| Task: | MIKE Zero Plot Composer |
| Description: | Plot of wave-driven current field |
| | |
| File: | TransportField.plc |
| Task: | MIKE Zero Plot Composer |
| Description: | Plot of sediment transport rates |

## 3.4 Structures Example

### 3.4.1 Purpose

We investigate a coastline with contructions placed in parallel with the coastline. This example will highlight how sand transport becomes very complex in such a setting and how sand tends to pile up behind the constructions.

### 3.4.2 Scenario

Two shore-parallel breakwaters with a length of 300 meters are placed 300 meters from the water line with 700 meters in between them. One of the breakwaters is 1.5 meters below the surface.

Irregular, unidirectional waves with $H_{rms}$ = 1.65m and $T_p$ = 7.8s move towards the coast from 352°. The normal to the beach points towards North.

The bed consists of uniform sand with $d_{50}$ = 0.25mm and $s_g$ = 1.0.

### 3.4.3 Parameters

We are investigating an area that spans 2700 meters along the shore and 840 meters into the ocean.

For the hydrodynamic simulation with MIKE 21 HD we use grid cells of 10 times 10 meters, but for the wave simulation with MIKE 21 PMS we use grid cells of five times five meters to get at least six to seven grid points per wave length. We use constant values of velocity-based eddy viscosity e = 1.5$m^2$/s and Manning number M = 28$m^{1/3}$/s all over the model area. The time steps are set to four seconds and the simulation runs for four hours to ensure stable conditions.

The wave simulation takes wave breaking into account with default values of the breaking parameters $\gamma_1$ and $\gamma_2$. Bed roughness is not considered.

The model grid has an orientation of 90° measured from True North.

The updrift boundary (bottom) is prescribed as flux, the downdrift boundary (top) is prescribed as level, and the offshore boundary is prescribed as zero flux.

We use a sediment map to describe the bed and to make sure that no sand transport is calculated where the submerged construction sits. This isachieved by prescribing a value of $d_{50}$ = -99 at the relevant grid points.

Prior to running the flow simulation we generate the upstream and downstream boundaries (prescribed as flux and level, respectively) by use of the tool for calculation of *Wave Generated Current and Setup*. The offshore boundary was prescribed as a zero-flux one.

Before running the sediment transport simulation, a sediment transport table (2DH) was generated with the tool for *Generation of Sediment Transport Tables* of the MIKE Zero system.

### 3.4.4 Results

In the present case, it could be of interest to compare the wave, current and sediment transport fields calculated along the open coast (i.e. away from the structures) and in the vicinity of the submerged and surface-piercing breakwaters. Such comparison permits to assess the different ways in which the structures influence the hydrodynamics and the sediment transport depending on their freeboard. Specification files for the presentation of the results in graphical form have been provided together with your installation of MIKE 21.

The sediment transport field computed for the stationary flow conditions of the present test is shown in Figure 3.3 below. The figure shows how the sand tends to pile up lee areas behind the construction because the ability to transport sand is weaker here:

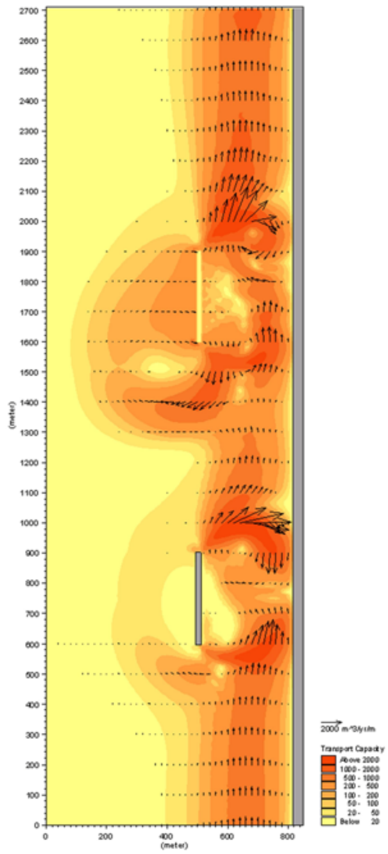



Figure 3.3 Calculated sediment transport rates in the vicinity of shore-parallel structures

## 3.4.5 Files

Here are the files provided with this example:

Name: PMSbathy.dfs2
Description: Structure example, bathymetry for wave simulation

Name: Hdbathy.dfs2
Description: Structure example, bathymetry for flow simulation

Name: NorthBND.dfs1
Description: Line series of water levels and fluxes along northern boundary of flow model

Name: SouthBND.dfs1

| | |
|---|---|
| Description: | Line series of water levels and fluxes along southern boundary of flow model |

| | |
|---|---|
| Name: | Sediment.dfs2 |
| Description: | Sediment map ($d_{50}$ and $\sigma_g$) for sediment transport run |

The following specification files were used to run the simulations and plot the results:

| | |
|---|---|
| File: | WaveSimulation.PMS |
| Task: | Model: MIKE 21 Parabolic Mild Slope Waves |
| Description: | Structures example, wave simulation |

| | |
|---|---|
| File: | HD_Simulation.M21 |
| Task: | Model: MIKE 21 Flow Models |
| Description: | Structures example, hydrodynamic simulation |

| | |
|---|---|
| File: | TransportTable.21T |
| Task: | Tool: Generation of Sediment Tables |
| Description: | Structures example, sediment transport table |

| | |
|---|---|
| File: | ST_run.ST2 |
| Task: | Module: Mike 21 Non-Cohesive Sediment Transport |
| Description: | Structures example, sediment transport simulation |

| | |
|---|---|
| File: | ModelBathy.plc |
| Task: | MIKE Zero Plot Composer |
| Description: | Plot of HD model bathymetry |

| | |
|---|---|
| File: | Wave Results.plc |
| Task: | MIKE Zero Plot Composer |
| Description: | Plot of calculated wave height and direction of propagation |

| | |
|---|---|
| File: | HD_Results.plc |
| Task: | MIKE Zero Plot Composer |
| Description: | Plot of wave-driven current field |

| | |
|---|---|
| File: | ST_Results.plc |
| Task: | MIKE Zero Plot Composer |
| Description: | Plot of sediment transport rates |

## 3.5 Nourishment Example

### 3.5.1 Purpose

We investigate a coast that has been subject to a shoreface nourishment on an otherwise uniform sea bed. Using Q3D sand transport patterns the example shows how the beach is protected behind the nourishment since waves break on it. You also see how return currents evolve around the nourishment from the excess water created by the breaking waves.

### 3.5.2 Scenario

The nourishment spans about 1450 meters along the coast. It is placed at a water depth of six meters and the water depth on top of the nourishments is 3.52 meters. The bed is made up of sand with $d_{50}$ = 0.20mm and $s_g$ = 1.5, whereas the sand for the nourishment is $d_{50}$ = 0.28mm.

Parametric, random waves with $H_{rms}$ = 1.7.5m and $T_p$ = 9s arrive from 260°. Waves move over a water level of MWL = 0m.

### 3.5.3 Parameters

We are looking at an area that spans 6000 meters along the coast and 1840 meters into the sea. The grid cell size for simulation of hydrodynamics with MIKE 21 HD is 10 times 10 meters, and for wave simulation with MIKE 21 PMS it is $\Delta x$ = 2.5m and $\Delta y$ = 2.5m.

The waves coming from the offshore boundary (left) are defined by a minimax model with aperture 30 degrees. The simulation takes wave breaking into consideration, using default values of the parameters $\alpha$, $\gamma_1$ and $\gamma_2$. Bed roughness, wind generation and wave-current interaction is not considered.

When simulating the wave driven currents with MIKE 21 HD we use constant values of velocity-based eddy viscosity e = 0.75$m^2$/s and Manning number M = 32$m^{1/3}$/s all over the model area. The time step is set to five seconds and the simulation runs for six hours to ensure stable conditions. Furthermore we use a one hour warm hour period.

Prior to running the flow simulation we generate the updrift and downdrift boundaries by use of the tool for calculation of *Wave Generated Current and Setup*. The updrift boundary (bottom) is prescribed as flux, the downdrift boundary (top) is prescribed as level, and the offshore boundary is prescribed as zero flux.

Before running the simulation we use the tool Generation of Q3D Sediment Transport Tables to create the sediment transport tables used by this example.

### 3.5.4 Results

Figure 3.4 below show MIKE 21 ST has calculated the sand transport levels in this setting.

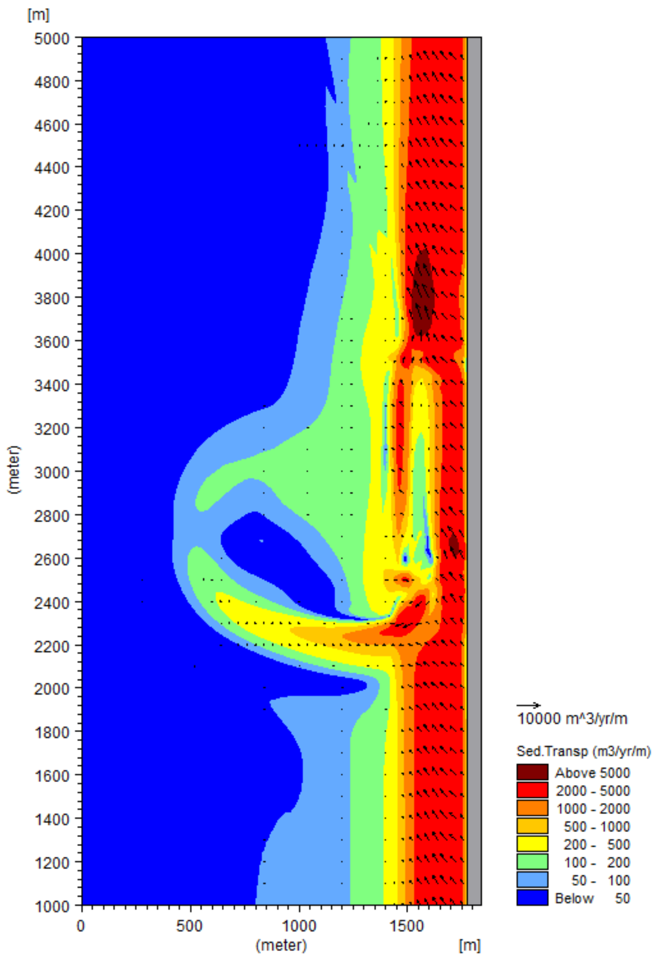



Figure 3.4 Q3D sediment transport rates in the area of the shoreface nourishment

The figure shows how the presence of the nourishment reduces the magnitude of the littoral transport along the coast behind it; thus effectively protecting this stretch of coast against erosion. This protection is achieved at the expense of the erosion of the nourishment, which is indicated by the diverging transport field along it. The figure also shows how the sediment transport vectors within the surf zone point in offshore direction. This is due to the net offshore-directed transport component associated with the undertow that has been calculated by the Q3D version of MIKE 21 ST.

### 3.5.5 Files

Here are the files provided with this example:

| | |
|---|---|
| Name: | PMSbathymetry.dfs2 |
| Description: | Nourishment example, bathymetry for wave simulation |

| | |
|---|---|
| Name: | Hdbathymetry.dfs2 |
| Description: | Nourishment example, bathymetry for flow simulation |

| | |
|---|---|
| Name: | NorthBoundary.dfs1 |
| Description: | Profile series of water levels and fluxes along northern boundary of flow model |

| | |
|---|---|
| Name: | SouthBoundary.dfs1 |
| Description: | Profile series of water levels and fluxes along southern boundary of flow model |

| | |
|---|---|
| Name: | SedimentMap.dfs2 |
| Description: | Sediment map ($d_{50}$ and $\sigma_g$) for sediment transport run |

| | |
|---|---|
| Name: | Q3D_Transport_Table.lon and Q3D_Transport_Table.crs |
| Description: | Q3D sediment transport table (longshore and cross-shore transport rates) |

The following specification files were used to run the simulations and plot the results:

| | |
|---|---|
| File: | WaveSimulation.PMS |
| Task: | Model: MIKE 21 Parabolic Mild Slope Waves |
| Description: | Nourishment example, wave simulation |

| | |
|---|---|
| File: | FlowSimulation.M21 |
| Task: | Model: MIKE 21 Flow Models |
| Description: | Nourishment example, hydrodynamic simulation |

| | |
|---|---|
| File: | Nourishment_Example.21T |
| Task: | Tools: Generation of Q3D Sediment Tables and Wave Generated Current and Setup |
| Description: | Nourishment example, Q3D sediment transport tables and boundary conditions for MIKE 21 HD |

| | |
|---|---|
| File: | STsimulation.ST2 |
| Task: | Module: Mike 21 Non-Cohesive Sediment Transport |
| Description: | Nourishment example, Q3D sediment transport simulation |

| | |
|---|---|
| File: | WaveResults.plc |
| Task: | MIKE Zero Plot Composer |
| Description: | Plot of calculated wave height and direction of propagation |
| File: | FlowResults.plc |
| Task: | MIKE Zero Plot Composer |
| Description: | Plot of wave-driven current field |
| File: | SedimentTransportResults.plc |
| Task: | MIKE Zero Plot Composer |
| Description: | Plot of sediment transport rates |

# 4 Dialog Overview

A description of each dialog in the MIKE 21 ST Editor is given in the sections below, in the same order in which the dialogs appear in the Editor.

Additional information is also given in the Reference Manual.

## 4.1 Basic Parameters

Before configuring the model parameters for MIKE 21 ST you need to enter a few basics about the simulation you are about to run:

- Simulation type
- HD input data
- Sub area
- Sub series

Your choices here might affect the number of Model Parameters *(p. 27)* you have the enter later.

### 4.1.1 Simulation type

MIKE 21 ST can run in two types of simulations.

**Current Only**
This is the simplest simulation type where only the steady flow is considered. This type requires you to

- Specify a file containing data from a hydrodynamic simulation - see HD input data *(p. 26)*
- Choose a theory to use for the simulation - see Pure current theory *(p. 27)*

**Current and Waves**
This type add waves to the equation and gives you a combined picture. This type requires you to

- Specify a file containing data from a hydrodynamic simulation - see HD input data *(p. 26)*
- Specify a file containing data from a wave simulation - see Wave input data *(p. 30)*
- Choose the relevant theory to use for the simulation - see Waves and current theory *(p. 28)*

### 4.1.2 HD input data

Here you must specify the file containing data from a hydrodynamic simulation made with MIKE 21 HD. You can type in the file path or click the file chooser on the right and navigate to the file.

Once selected, MIKE 21 ST will validate that the file is actually a data file from MIKE 21 HD.

Please note that the size of the grid cells used in the hydrodynamic simulation is mirrored directly in the simulation made by MIKE 21 ST, so make sure to account for this when setting the parameters for the sand transport simulation.

### 4.1.3 Sub area

Here you can specify which slice of the hydrodynamic map will be used when running the sand transport simulation - you do not have to run a simulation for the entire area from the hydrodynamic data (HD input data *(p. 26)*).

These coordinates are relative to the HD file, but please note that the (0,0) coordinate in the output field not necessarily translates to the (0,0) coordinate in the HD file.

### 4.1.4 Sub series

#### Time steps

This parameter maps the size of time steps used in the data file from MIKE 21 HD to the ones used in MIKE 21 ST.

If the size of time steps are equal, set the parameter to one. If there is a difference, enter a number that describes how many HD steps that go on one ST step.

For example: If the HD simulation is run with time steps of five seconds and the ST is run with time steps of 10 seconds, you must enter the value two in this field.

#### Simulation start set

This is the step number (starting from zero) in the HD data file where you start the ST simulation.

#### Simulation end set

This is the step number (starting from zero) in the HD data file where you end the ST simulation.

## 4.2 Model Parameters

Here, you have to select the transport theory that will be used to calculate the rates of non-cohesive sediment transport in pure current or current and waves. In the second case, you have also to specify the wave data that will be used as input for the simulation.

You also have to specify the type and vales of Bed Resistance *(p. 32)* and the characteristics of the Sediment data *(p. 32)* that will be used in the simulation.

### 4.2.1 Pure current theory

Note that this dialog will only be activated if you chose “Current only” in the Simulation type *(p. 25)* dialog.

#### Sediment transport theory

Five different transport theories are available to calculate the sediment transport rates of non-cohesive sediment in pure current:

- The Engelund & Hansen total-load transport theory
- The Engelund & Fredsøe total-load (bed load plus suspended load) transport theory
- The Zyserman & Fredsøe total-load (bed load plus suspended load) transport formulation
- The Meyer-Peter & Müller bed-load transport theory
- The Ackers & White total-load transport method

#### Parameters - relative density of sediment

The relative density of the bed material, s, is defined as the ratio of the sediment density, $\rho_s$, to that of water, $\rho$.

When setting the value of **s** it is important to keep in mind that the transport formulations used by MIKE 21 ST have been developed for normal sand. MIKE 21 ST will yield results for light materials (s smaller than 2.50) and heavy sediments (s larger than 2.70), but care should be exercised in the interpretation of these results

#### Parameters - critical Shields parameter

The critical value of the Shields parameter, $\theta_c$, is used to indicate the threshold value of the dimensionless bed shear stress for initiation of motion. No transport will take place for values of the dimensionless bed shear stress $\theta$ less than or equal to $\theta_c$.

Values of $\theta_c$ between 0.040 and 0.060 may be specified.

Note that the user-specified value is not used in the Engelund & Hansen, the Ackers & White and the Zyserman & Fredsøe transport theories. The first two methods do not include a threshold value for the initiation of motion, and in the third method $\theta_c$ is internally set to 0.045.

### Parameters - water temperature

The water temperature, **T**, is used together with the grain size, **d**, and the relative density of the sediment, **s**, for the determination of the settling velocity of suspended sediment for those transport theories which calculate suspended load transport separately. All other parameters kept unchanged, higher water temperature will yield lower transport rates than otherwise, because higher water temperature means lower density of water and, consequently, higher settling velocity.

A value between 0 and 50°C may be selected.

### Include/exclude effect of bed slope

You must also specify whether you want MIKE 21 ST to account for the effect of bed slope on the bed-load transport rates or not. The influence of the bed slope on the rates of bed-load transport is much more noticeable for a transverse slope than for a longitudinal one. This option is only available for the Engelund & Fredsøe and Zyserman & Fredsøe transport theories.

## 4.2.2 Waves and current theory

### Sediment transport method

In this dialogue, you have to choose between the two available methods for calculation of the sediment transport rates in combined waves and current:

- The approach based on the interpolation of the transport rates from tables created using the STP Transport Model *(p. 48)*
- Direct calculation of the total load (bed + suspended) transport using Bijker's method

### STP model

If you select the STP Transport Model *(p. 48)*, you must first of all specify whether you want to use the classical two-dimensional (2DH) approach to calculate the sediment transport rates, or whether the quasi three-dimensional (Q3D) approach should be used.

In the classical (2DH) approach it is assumed that the flow is mainly described by wave-driven currents, i.e. the angle between the wave and current direction is betweeen 0 and 90 degrees.
If this is not the case, e.g. by river outflow or tidal currents, you may apply the Q3D approach (that covers all angles between 0 and 360 degrees) or use the

option parameters for using input values outside the limits of the transport table (see Table 5.1 on p. 45).

## Sediment transport table

Here, you have to specify the path and the name of the files containing the sediment transport tables. You can do this by typing the information required or by browsing the disk by clicking your mouse on the button to the right of the Data File entry.

If the 2DH approach was selected, a sediment transport table created with the tool for *Generation of Sediment Tables* and saved as an ASCII file with extension **.dat** is expected as input. If the effect of bed slope has been taken into account when calculating the rates of non-cohesive sediment transport stored in this table, then MIKE 21 ST will check that a table with the same name and extension **.bsl** exists in the directory where the table with extension **.dat** is located.

If the Q3D approach was chosen, a sediment transport table created with the tool for *Generation of Q3D Sediment Tables* and saved as an ASCII file with extension **.lon** is expected as input. MIKE 21 ST will always check that a table with the same name and extension **.crs** exists in the same directory.

## Bijker method parameters

The relative density of the bed material, s, is defined as the ratio of the sediment density, $\rho_s$, to that of water, $\rho$.

The water temperature, **T**, is used together with the grain size, **d**, and the relative density of the sediment, **s**, for the determination of the settling velocity of suspended sediment.

These input parameters need to be defined only if Bijker's transport method has been selected.

## Bed load transport coefficient B

The bed load transport coefficient, **B**, is a proportionality factor in Bijker's total-load transport method. Therefore, it may be used as a calibration parameter when calculating sediment transport rates.

You may specify the bed load transport coefficient as constant or spatially varying. If the coefficient is chosen as constant over the model area, you have to specify only one value for B. If you choose to specify a spatially varying coefficient, a data file containing one item (B) must be specified. You may do this by typing the path and name of the data file (a .dt2 file in the old format and a .dfs2 file in the new format) or by clicking the mouse on the button to the right of the Data File entry. The grid spacing(s) and extent of the data file must be the same as in the HD data file.

## Coefficients

A value of B between 1 and 5 is expected by MIKE 21 ST. B = 1 is suggested for the calculation of transport rates outside the surf zone, whereas a value of B = 5 is recommended within the surf zone.

## 4.2.3 Wave input data

### Wave height definition

You must also specify whether the wave heights in the data file are significant wave heights $H_{m0}$ or root-mean-square wave heights $H_{rms}$.

### Origin of wave grid

The origin of the wave grid may not be coincident with the origin of the hydrodynamic grid, as long as it is coincident with one of the nodes of this grid. If this is the case, the position of the origin of the wave grid relative to the origin of the HD grid must be specified (in HD grid-point co-ordinates).

### Wave period definition

You have to specify whether the wave period (as read from the data file or user-specified) is a mean wave period $T_m$ or a peak wave period $T_p$.

## Wave data

First of all, you have to indicate whether the wave data file is output from the simulation of stationary conditions (i.e. that the data file will have only one time step) or quasi-stationary conditions (i.e. several time steps have been saved to the wave data file).

Then, you have to specify the path and the name of the wave data file. They may be typed directly or found browsing the disk by clicking the mouse on the button to the right of the Data File entry in the menu. The wave data may have been generated as the output from a wave simulation with MIKE 21 PMS. After the wave data file has been selected, you must indicate which items in it correspond to the wave height, the direction of wave propagation and the wave period.

The wave data file must contain at least two items (wave height and direction of propagation) or more than the three items (wave height, period and direction) required for the calculation of transport rates. In either case it is possible to choose a user-specified wave period rather than reading it from the wave data file.

The sediment transport rates will only be calculated in the area where wave and current data exist, i.e. in the region which is common to the hydrodynamic and wave model grids. Therefore, the user should carefully check that the area of interest for the transport computations is covered by both grids.

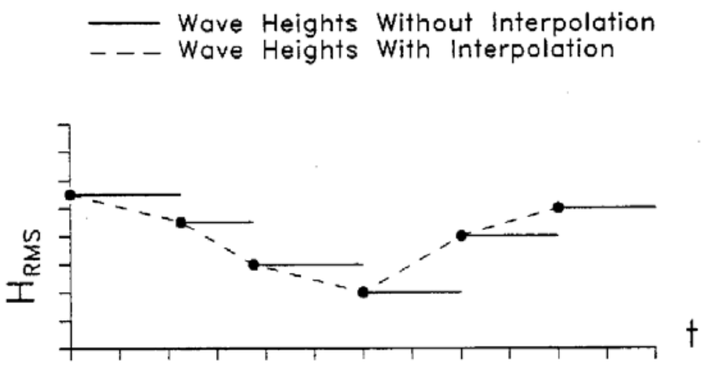
The grid spacing(s) of the wave data file does/do not need to be equal to the spacing(s) used for the hydrodynamic model grid. However, the grid spacing in the hydrodynamic data must be an integer number of times the spacing in the wave grid, both in the x- and the y-directions. The proportionality factors **n** and **m** need not to be equal.

$$\begin{aligned} \Delta x_{HD} &= n \cdot \Delta x_{WV} \text{ with } n \geq 1 \\ \Delta y_{HD} &= n \cdot \Delta y_{WV} \text{ with } m \geq 1 \end{aligned} \tag{4.1}$$

## 4.2.4 Wave Options

### Wave interpolation

If the Wave input data *(p. 30)* includes more than one time step, you may select either a linear variation in time of the wave parameters (height, period and direction of propagation) or a stepwise variation of these parameters from time step to time step, as shown by the figure below.




You do this by selecting either “Interpolate between wave data sets” or “Constant between wave data sets”, respectively, in the Wave Options dialogue.

### Wave breaking parameters

The influence of the breaking waves on the calculated rates of non-cohesive sediment transport is accounted for through the production of turbulent kinetic energy by the surface rollers, which results in increased eddy viscosity close to the free surface. The production of turbulent kinetic energy is controlled by the wave breaking parameters $\gamma_1$ and $\gamma_2$, according to the theory of Battjes and Janssen (1978).

The values of $\gamma_1$ and $\gamma_2$ that you specify in this dialogue have to be identical to those used in the wave simulation with MIKE 21 PMS. If you cannot remember the values, you can read them from the specification file for the wave module.

Default values for the wave breaking parameters are 1.0 and 0.8, respectively, in agreement with the default values used in MIKE 21 PMS.

## 4.2.5 Bed Resistance

### Bottom friction

You have to indicate whether a constant value of the bed friction coefficient has been used in the MIKE 21 HD simulation from which the HD input data *(p. 26)* for the present run was obtained, or whether the coefficient varied according to a 2D map.

### Formulation

You have to define whether the bed friction has been defined by means of Chezy numbers C or Manning numbers M. These parameters are related by the local water depth h according to

$$C = Mh^{1/6} \tag{4.2}$$

### Data selection

If the a constant value of the bottom friction over the model area was selected, you have to specify only one value for C or M. If you choose to specify spatially varying bed roughness, a data file containing one item (C or M) must be specified. You may do this by typing the path and name of the data file (a dt2 file in the old format and a dfs2 file in the new format) or by clicking the mouse on the button to the right of the Data File entry. The grid spacing and extent of the bed resistance data file must be the same as in the HD data file.

## 4.2.6 Sediment data

### Sediment properties

You have to define whether the bed sediment will be characterised through constant values of the median diameter $\mathbf{d_{50}}$ and the grading coefficient $\sigma_\mathbf{g}$ over the model area, or whether these parameters will vary according to a 2D map. $\sigma_g$ is defined as $(d_{84}/ d_{16})^{0.5}$.

### Porosity

The porosity of the bed material, **n**, must be specified as a constant for the whole area where sediment transport will be calculated. A default value of n = 0.40 (usual value for normal sand) is chosen by MIKE 21 ST.

### Data selection

If constant values of the sediment properties over the model area were selected, you have to specify only one value for $d_{50}$ and $\sigma_g$. If you choose to specify spatially varying sediment properties, a data file containing two items ($d_{50}$ and $\sigma_g$) must be specified. You may do this by typing the path and name of the data file (a dt2 file in the old format and a dfs2 file in the new format) or by clicking the mouse on the button to the right of the Data File entry. The grid spacing and extent of the sediment data file must be the same as in the HD data file.

You can specify uniform bed material by defining $\sigma_g = 1$. You can identify areas where sediment transport will not take place, or where it should not be calculated (e.g. areas where the sea bottom is covered by rocks, revetments, etc.), by setting the value of the grain size in the sediment map to -99.

### Non-erodible surface

In this entry, you have to specify whether a non-erodible surface underlying the sandy bed has to be included in the sediment transport simulation or not. If you choose to include a non-erodible surface, the calculated sediment transport rates will be adjusted in such a way that erosion of the bed below the level of the hard surface will not occur. On the other hand, deposition of sediment on top of the non-erodible surface is allowed.

If you choose to included a non-erodible surface, you have to specify its level, which must be coincident or below the bed levels in the bathymetry for your set-up. Spatial constant or spatial varying levels may be chosen.

In the first case, you have to define only one value for the hard-bottom level. If you choose to specify spatially varying non-erodible surface, a data file containing one item (its top level) must be specified. You may do this by typing the path and name of the data file (a dt2 file in the old format and a dfs2 file in the new format) or by clicking the mouse on the button to the right of the Data File entry. The grid spacing and extent of the data file must be the same as in the HD data file.

## 4.3 Output

Two types of output data can be obtained from a MIKE 21 ST simulation. These are:

- Averaged sediment transport rates and initial rates of bed level change

- Time series of transport rates saved at user-specified intervals

Averaged sediment parameters are always saved after completion of the simulation, whereas it is optional to save time series of sediment transport. In either case, results are only saved on the sub-area selected for the sediment transport simulations.

In addition to the data file(s), two ASCII files will be saved in your working directory:

- A file with extension **.st2** containing all the specifications for your sediment transport simulation
- A file with extension **.log** containing information about the simulation setup, the input data files used, and the CPU time used in the simulation.

## 4.3.1 Output specification

You must specify the name and the path for the output data file where the sediment transport rates (per unit width) - $P_s$ and $Q_s$ - averaged over the simulation period will be saved. The initial rates of bed level change dz/dt (calculated on the basis of the averaged transport rates) will also be saved in the output file. The transport components Ps and Qs are expressed in solid volume, i.e. not taking into account the porosity of the bed material.

You may specify the name and location (path) of the output file (dfs2 file) by typing this information or by browsing your disk clicking the mouse on the button to the right of the Data File entry. The grid spacing of the output data file will be the same as in the HD data file, whereas its extent will be that of the sub-area selected for the simulation.

You may also provide a title for the output file.

## 4.3.2 Transport time series

You have to specify whether you want the sediment transport rates that were calculated at every time step of the simulation period to be saved into a separate output file.

If you choose to save time series of sediment transport, you must specify the name and the path for the output data file where the sediment transport rates (per unit width) $P_s$ and $Q_s$ will be saved for each time step in your simulation period. Remember that $P_s$ and $Q_s$ are expressed in **solid volume**. Again, you may also provide a title for the output file.

You can choose to type the path and name of this output file directly or to define the directory and file name by browsing your disk. This is done by clicking your mouse on the button to the right of the **Data file** entry.

### 4.3.3 Output size

Once you have completed the output specifications for you MIKE 21 ST run, an estimate of the disk space (in Mb) required to save your output files will be shown in the Size of Output entry of the Output Size section. The disk space required depends on the extension of the sub-area used in the simulation of the transport rates, whether you chose to save results for transport time series or not and, if you did, the extension and time step of your simulation period.

# 5 Reference Manual

In this section, additional information is provided on MIKE 21 ST. The topics in this section are arranged alphabetically.

## 5.1 Ackers & White Transport Formulation

The dimensionless total-load transport rate $G_{gr}$ is calculated as

$$G_{gr} = C\left[\frac{F_{gr}}{A} - 1\right]^m \tag{5.1}$$

in which $C$, $m$ and $A$ are model parameters that depend on the dimensionless particle size, $D_{gr}$, defined as

$$D_{gr} = d\left[\frac{g(s-1)}{\nu^2}\right]^{1/3} \tag{5.2}$$

where $d$ is the grain size, $g$ is gravitational acceleration, $s$ is the relative density of the bed sediment and $\nu$ is the kinematic viscosity of water.

$F_{gr}$ is a general sediment mobility number defined as

$$F_{gr} = \frac{U_f^n}{\sqrt{gd(s-1)}}\left[\frac{V}{\sqrt{32\log\left(\frac{10h}{d}\right)}}\right]^{1-n} \tag{5.3}$$

where $U_f$ is the total shear velocity, $h$ is the water depth, $V$ is the depth-averaged current velocity. $n$ is a constant that also depends on $D_{gr}$ and ranges from 0 for coarse material to 1 for fine material.

The transport parameter $G_{gr}$ is defined as

$$F_{gr} = \frac{Xh}{sd}\left(\frac{U_f}{V}\right)^n \tag{5.4}$$

where $X$ is the sediment mass flux per unit mass flow rate.

## 5.2 Bed Load Transport Coefficient B

The coefficient B is a proportionality constant in the expression for the total load transport in Bijker's Transport Method *(p. 39)*, and can therefore be used as a calibration parameter.

You will be asked to specify this parameter (together with the relative sediment density s and the water temperature T) only if Bijker's Transport Method *(p. 39)* has been selected.

A value of the transport coefficient B has to be assigned to every grid point within the model area. This value can be specified in two different ways:

- a constant value for all grid points
- a map with a value for every grid point

A value of B between 1 and 5 is expected by MIKE 21 ST. B = 1 is suggested for simulations outside the surf zone, whereas the use of B = 5 within the surf zone is advised.

## 5.3 Bed Roughness

The bed roughness parameter is used in MIKE 21 ST to relate the depth-averaged current velocity $V$ to shear velocity $U_f$ through

$$U_f = \frac{\sqrt{g}}{C}V \tag{5.5}$$

where $g$ is gravity and $C$ is the Chezy number.

If the bed roughness has been expressed in terms of Manning numbers, they are internally converted to Chezy numbers through the relation

$$C = Mh^{1/6} \tag{5.6}$$

where $h$ is the water depth.

A value of bed resistance must assigned to every grid point in the model area. The bed resistance can be specified in two ways:

- a constant value for all grid points
- a map with a value for every grid point

If you specify the bed resistance by means of a map, the grid spacing and extent of the bed resistance data file must be the same as in the HD data file.

The specification of bed resistance for your MIKE 21 ST simulation must be consistent with the specification used in the hydrodynamic simulation that constitutes the basis for the sand transport calculation. Check the specification file for MIKE 21 HD if you cannot remember precisely the type and values of bed resistance used.

## 5.4 Bijker's Transport Method

According to Bijker, the total-load sediment transport, $q_t$, is calculated as the sum of bed-load transport, $q_b$, and suspended load transport, $q_s$.

qt = qb + qs = qb(1 + 1.83Q)

*Q* is a dimensionless factor defined as

$$Q = \left[I_1 \ln\left(\frac{33h}{r}\right) + I_2\right] \tag{5.7}$$

where *h* is the water depth, *r* is the bed roughness and $I_1$ and $I_2$ are Einstein's integrals, which must be evaluated numerically on the basis of the dimensionless reference level A = r/h and z*, defined as:

$$z* = \frac{w}{\kappa U_{f,\mathrm{wc}}} \tag{5.8}$$

*w* is the settling velocity of the suspended sediment, $\kappa$ is von Karman's constant and $U_{f,wc}$ is the shear velocity under combined waves and current. The influence of the waves on the suspended-load transport is therefore taken into account through the shear velocity, $U_{f,wc}$.

The roughness, *r*, can be related to the Chezy number, *C*, through

$$C = 18\log\left(\frac{12h}{r}\right) \tag{5.9}$$

Following Bijker, the shear velocity in combined waves and current $U_{f,wc}$ is found as

$$U_{f,\,wc} = U_{f,\,c}\sqrt{1 + \frac{1}{2}\left(\xi\frac{\hat{u}_b}{V}\right)^2} = \frac{V\sqrt{g}}{C}\sqrt{1 + \frac{1}{2}\left(\xi\frac{\hat{u}_b}{V}\right)^2} \tag{5.10}$$

where $U_{f,c}$ is the current-related shear velocity, *V* is the depth-averaged current velocity, $\hat{u}_b$ is the amplitude of the wave-induced oscillatory velocity at the bottom, and $\xi$ is a dimensionless factor that can be expressed in terms of the wave friction factor $f_w$ and Chezy's number $C$.

$$\xi = C\sqrt{\frac{f_w}{2g}} \tag{5.11}$$

The wave friction factor $f_w$ is calculated according to Swart as

$$f_w = \exp\left[-5.977 + 5.213\left(\frac{a_b}{r}\right)^{-0.194}\right] \quad if\ 1.47 < \frac{a_b}{r} < 3000 \tag{5.12}$$

$$f_w = 0.32 \qquad if\ \frac{a_b}{r} \le 1.47$$

$a_b$ is the amplitude of the wave motion at the bottom.

$$a_b = \frac{\hat{u}_b T}{2\pi} \tag{5.13}$$

$a_b$ and $\hat{u}_b$ are evaluated using linear wave theory.

The bed load transport, $q_b$, and suspended load transport, $q_s$, are calculated according to

$$q_b = Bd_{50}U_{f,c}\exp\left(-\frac{0.27\Delta d_{50}g}{\mu U_{f,wc}^2}\right) \tag{5.14}$$

It is interesting to note that the influence of the waves on the bed-load transport, $q_b$, is accounted for through a "stirring term", i.e. the exponential in the previous equation. The "transporting term" is only related to the current by way of $U_{f,c}$. $B$ is a dimensionless bed load transport coefficient, $\Delta$ is the relative density of sediments and $\mu$ is the so-called "ripple factor". $\Delta$ and $\mu$ are defined as

$$\Delta = s - 1 = \frac{\rho_s}{\rho} - 1 \tag{5.15}$$

$$\mu = \left(\frac{C}{C'}\right)^{3/2} \tag{5.16}$$

$\rho_s$ is the density of the sediment, $\rho$ is the density of water and $C'$ is the Chezy number related to the geometric characteristics of the bed material. It is calculated as

$$C' = 18\log\left(\frac{12h}{d_{90}}\right) \tag{5.17}$$

$d_{90}$ is the sediment size for which 90% (in weight) of the bed material is finer. For uniform bed material $d_{90}$ becomes identical to the specified value of $d_{50}$.

## 5.5 Critical Shields Parameter

The critical value of the dimensionless bed shear stress (the Shields parameter), $\theta_c$, is used to indicate the threshold value for initiation of sediment motion. MIKE 21 ST expects and will accept values of $\theta_c$ between 0.040 and 0.060.

The user-selected value for $\theta_c$ will not be used if you select either the Engelund & Hansen Transport Theory or the Zyserman & Fredsøe Transport Formulation. No threshold for initiation of motion is used in the first case, while $\theta_c$ is assigned a value = 0.045 in the second.

## 5.6 Engelund & Fredsøe Transport Theory

The total-load transport rate $q_t$ is calculated as the sum of the bed-load transport $q_b$ and the suspended-load transport rate $q_s$

$q_t = q_b + q_s$

It is assumed that bed-load transport takes place in one single layer of thickness equal to one grain diameter d. The bed-load transport $q_b$ is calculated as

$$q_b = 5p(\sqrt{\theta'} - 0.7\sqrt{\theta_c})\sqrt{(s-1)gd^3} \qquad \text{if } \theta' > \theta_c \tag{5.18}$$

where $p$ is the probability that all particles in a single layer will be in motion, $\theta'$ is the dimensionless bed shear stress (Shields parameter) related to skin friction and $\theta_c$ is the critical bed shear stress for initiation of motion. $s$ is the relative density of the bed material.

$\theta'$ is defined as

$$\theta' = \frac{U_f'^2}{(s-1)gd} \tag{5.19}$$

*p* is defined as

$$p = \left[1 + \left[\frac{\frac{\pi}{6}\beta}{\theta' - \theta_c}\right]^4\right]^{-1/4} \tag{5.20}$$

with $\beta$ = the dynamic friction coefficient.

Following the ideas of Einstein (1950), the suspended load $q_s$ is evaluated as

$$q_s = 11.6 U'_f \; c_b a \left[ I_1 \ln\left(\frac{30h}{k_N}\right) + I_2 \right] \tag{5.21}$$

with $c_b$ = the bed concentration of suspended sediment, $U_f'$ = the shear velocity related to skin friction, a = 2d = the reference level for $c_b$, $I_1$ and $I_2$ = Einstein's integrals, *h* = the water depth and $k_N$ = Nikuradse's equivalent roughness = 2.5d.

The integrals $I_1$ and $I_2$ are a function of the dimensionless reference level A = a/h and of the Rouse number z = $w_s/\kappa U_f$, where $w_s$ is the settling velocity of the suspended sediment and $\kappa$ = von Karman's constant (≈0.40). $I_1$ and $I_2$ are integrated between y = a and y = h, where y is measured upwards from the fixed bed level.

Engelund and Fredsøe developed a semi-empirical relation for the value of $c_b$ at a = 2d

$$c_b = \frac{0.65}{(1 + 1/\lambda)^3} \tag{5.22}$$

where the linear concentration $\lambda$ is given by

$$\lambda = \sqrt{\frac{\theta' - \theta_c - \frac{\pi p \beta}{6}}{0.027 s \theta'}} \qquad \text{if} \quad \theta' > \theta_c + \pi p \beta / 6 \tag{5.23}$$

Note that the transport formulation of Engelund & Fredsøe was developed on the basis of data obtained from experiments with bed material of sand-fraction size. Therefore, you should make sure that the bed material used as input to the model falls within the proper range of grain sizes.

## 5.7 Engelund & Hansen Transport Theory

The dimensionless rate of total-load transport $\Phi_t$ is calculated as

$$\Phi_t = 0.1\frac{C^2}{2g}\theta^{2.5} \tag{5.24}$$

with $C$ = Chezy's number and

$$\Phi_t = \frac{q_t}{\sqrt{(s-1)gd^3}} \tag{5.25}$$

with $q_t$ = the total-load sediment transport and $g$ = gravitational acceleration. The dimensionless bed shear stress $\theta$ is defined as

$$\theta = \frac{U_f^2}{(s-1)gd} \tag{5.26}$$

where $U_f$ is the shear velocity related to total friction, $d$ is the grain diameter and $s$ is the relative density of the bed material.

This formulation assumes that the dimensionless bed shear stress $\theta$ is much larger than the Critical Shields Parameter for initiation of transport $\theta_c$. Therefore, the value of $\theta_c$ specified by the user will not be applied if this formulation has been chosen. Something similar applies to the gradiation of the bed material, since Engelund & Hansen theory is based on the median grain size $d_{50}$.

## 5.8 Grid Sizes

The grid used in the simulation of the sand transport rates and the rate of bed level changes is the same as that used to calculate the flow field using the hydrodynamic module, MIKE 21 HD. The wave grid may have the same grid spacing as the hydrodynamic one, or a smaller one.

The sand transport calculations will only be performed in the area where wave and current data exist, i.e. in the region common to the wave and the hydrodynamic grids. It should be checked that the area of interest for the sediment transport computations be covered by both grids.

The space resolution in the sand transport calculations is given by the spacing of the grid used for the hydrodynamic computations, so care must be taken that all the relevant details are covered when selecting the spacing of the hydrodynamic grid.

The grid spacing of the hydrodynamic grid ($\Delta x_{HD}$, $\Delta y_{HD}$) must be equal to or an integral multiple of the grid spacing used to determine the wave characteristics ($\Delta x_w$, $\Delta y_w$), both for the x-and the y- directions. The proportionality factors need not to be equal.

$$\Delta x_{HD} = n \bullet \Delta x_w \text{with } n \geq 1 \tag{5.27}$$

$$\Delta y_{HD} = m \bullet \Delta y_w \text{with } m \geq 1 \tag{5.28}$$

## 5.9 Meyer-Peter & Müller Transport Formulation

The dimensionless bed-load transport rate $\Phi_b$ is calculated as

$$\Phi_b = 8(\theta' - \theta_c)^{1.5} \tag{5.29}$$

with

$$\Phi_b = \frac{q_b}{\sqrt{(s-1)gd^3}} \tag{5.30}$$

$\theta'$ is the Shields parameter related to skin friction and $\theta_c$ is its critical value. *s* is the relative density of the bed sediment, *g* is the acceleration of gravity and *d* is the grain diameter.

Note that for situations with fine sediment and/or high current speed, this formulation may underestimate the actual transport rates, since only the contribution from the bed load transport is accounted for. In case of doubt, you could repeat the simulation using another transport theory (e.g. Engelund & Fredsøe Transport Theory or Zyserman & Fredsøe Transport Formulation) in order to assess the importance of the suspended-load transport for the case being analysed.

## 5.10 Porosity

The porosity of the bed material n must be specified as a constant value for the whole area where the transport rates of non-cohesive sediment are calculated.

The usual value for sand (n = 0.40) is taken as default value by MIKE 21 ST.

## 5.11 Recovering From Errors During Simulation

In most cases, the source of the error will have been written out to the **log** file generated during your MIKE 21 ST simulation. In order to recover from the error, follow the steps below.

1. Inspect the MIKE 21 ST log file that has been created in your work directory to check at what stage of the calculation the error occurred. The log file can be inspected using any text editor such as Notepad.
2. Inspect the MIKE 21 ST specification file for possible errors. The log file will give you an indication of what to check. The specification file can also be inspected using any text editor.
3. Run the sediment transport simulation again. If the problem persists, repeat steps 1 and 2 above until it has been solved.

In most cases, the problem will be related to the fact that the axes of the sediment transport table(s) do not cover the whole range of variation of the parameters involved when calculating sediment transport under combined waves and current.

You can try to solve the problem by extending the sediment transport table(s). You can either use the tool for *Extension of sediment tables* (if you chose to use the 2DH version of the STP program to calculate the transport rates) or the tool for *Extension of Q3D sediment tables* (if you chose to use the Q3D version of the STP program).

You can also use the facility for limiting the value of the relevant parameters within the Simulation Area *(p. 47)* to the minimum and/or maximum values along the corresponding axes of the sediment transport table(s). In order to do this, the options in Table 5.1 below can be used. The required option parameters have to be defined in the OPTION_PARAMETERS section of the specification file for your MIKE 21 ST run.

By default, all parameters are internally set to 0, implying that an error message will be generated and the simulation will be stopped if the limits of the transport table are exceeded. You can change the defaults for some or all of the parameters to 1, and thus limit the parameter values for calculating sediment transport to the limits in the table.

Table 5.1 Option parameters for avoiding search beyond the limits of the sediment transport table

| Option parameter (limit minimum) | Option parameter (limit maximum) |
|---|---|
| Limit_min_V | Limit_max_V |
| Limit_min_HoD | Limit_max_HoD |
| Limit_min_H | Limit_max_H |

Table 5.1 Option parameters for avoiding search beyond the limits of the sediment transport table

| Option parameter (limit minimum) | Option parameter (limit maximum) |
|---|---|
| Limit_min_T | Limit_max_T |
| Limit_min_Sg | Limit_max_Sg |
| Limit_min_d50 | Limit_max_d50 |
| Limit_min_dddx | Limit_max_dddx |
| Limit_min_dddy | Limit_max_dddy |
| Limit_min_gam | Limit_max_gam |

This facility should be used with utmost caution, since your sediment transport calculations will not be accurate beyond the limiting values of the parameters. Unless results have to be achieved for a quick preliminary assessment, it is always advisable to extend the sediment transport table(s).

## 5.12 Relative Density of Sediments

The relative density of the bed material s is defined as the ratio between the density of the sediment $\rho_s$ and that of water $\rho$.

$$s = \frac{\rho_s}{\rho} \tag{5.31}$$

The transport formulations used by MIKE 21 ST have been developed for sand. The relative density of bed material specified should therefore be within the range of 2.50-2.70.

MIKE 21 ST will accept values of s in the range from 1.65 to 3.65; care should be exercised in the interpretation of the model results for light ( $s \leq 2.5$ ) and heavy ( $s \geq 2.7$ ) materials.

## 5.13 Sediment Size and Gradation

MIKE 21 ST assumes that the bed material is formed by different fractions whose sizes are log-normal distributed. In this way, a grading curve can be built based on two parameters: the median grain size *d* (sometimes represented as $d_{50}$) and the geometric standard deviation $\sigma_g$, defined as:

$$\sigma_g = \sqrt{\frac{d_{84}}{d_{16}}} \tag{5.32}$$

where $d_{16}$ and $d_{84}$ are the particle sizes for which 16% and 84% of the sediment by weight is finer.

The grain size and the geometric standard deviation can be defined in two alternative ways:

- As constant values of $d$ and $\sigma_g$ for the whole simulation area
- As a type 2 file containing the values of $d$ and $\sigma_g$ for every node of the grid

If you choose to specify the sediment size and gradation as a type 2 file, MIKE 21 ST expects a file containing 2 items as input. The first item must be the median grain size and the second one the geometric standard deviation.

The specified grain size $d$ should be within the usual limits for sand.

Uniform bed material is indicated by setting $\sigma_g$ equal to one.

You can identify areas where no sediment transport takes place (e.g. areas of the bottom covered by rocks or revetments) by setting the grain size $d$ to -99 in your sediment map.

## 5.14 Simulation Area

It is possible to limit the calculation of the sediment transport rates to a selected sub-area of the hydrodynamic grid. Output from the MIKE 21 ST module will only be saved on this sub-area.

The limits of the sub-area have to be indicated through the limiting grid nodes in x- and y- directions. The numbering of these nodes is referred to the hydrodynamic grid.

## 5.15 Simulation Period and Time Step

The time step between two consecutive sediment transport calculations in MIKE 21 ST may be chosen to be either equal to or an integral multiple of the time step used in the hydrodynamic simulations. The program will determine the hydrodynamic conditions at the corresponding instant for every water point and will then calculate the sand transport rates.

The simulation period is specified on the basis of the HD-results, and may extend over the whole period used in the hydrodynamic simulation, or cover just a part of it.

Care should be exercised when selecting the simulation period and the time step for the sand transport calculations. Relevant hydrodynamic events that may produce enhanced sediment transport rates (e.g. strong current, maximum wave height during a storm, etc.) and occur during a relatively short period of time should not be left out of the calculations by selecting a too long time step.

## 5.16 Size of Output Files

The disk space required for your simulation depends mainly on the amount of results you request be saved. During a simulation only two files are created in addition to the data files containing the results:

- The specification file that contains the set-up for your MIKE 21 ST run. This file will be placed on your present working directory and will have a file extension of .ST2. It will only take up approximately 2 Kbytes.
- The log file describing the model set up, the input data files used, the statistics of the output files created during the simulation and a message for each time step completed. The extension of this file, which will be placed in the same directory as the specification file, is .log, and will only take up to 200 Kbytes on the disk.

The amount of data generated by a simulation using MIKE 21 ST is rather large. Therefore you should only save as much data as is needed for your further work. Nevertheless very large files will often be generated. These data files will be placed in the directory defined by the user.

If you wish to calculate the disk space required for a single output data file, the following formula yielding the required space in bytes can be used:

$$4 \bullet 4 \bullet ((J_{last} - J_{first}) / J_{frequency} + 1) \bullet ((K_{last} - K_{first}) / K_{frequency} + 1) + 2048 \tag{5.33}$$

If it is also selected to save the time series of sediment transport, a second output data file will be created, with a size in bytes given by:

$$4 \bullet \left( \begin{array}{c} ((J_{last} - J_{first}) / J_{frequency} + 1) \bullet ((K_{last} - K_{first}) / K_{frequency} + 1) \bullet \\ (2 \bullet ((N_{last} - N_{first}) / N_{frequency} + 1) + 1) \end{array} \right) + 2048 \tag{5.34}$$

where $N$ denotes hydrodynamic time steps, $J$ denotes nodes in the x-direction, and $K$ points in the y-direction.

## 5.17 STP Transport Model

DHI's deterministic intra-wave **S**ediment **T**ransport **P**rogram, STP, is used to calculate the rates of non-cohesive sediment transport in combined waves and current.

STP is an advanced sediment transport model which accounts for the influence on the sediment transport rates of processes such as waves propagating at an arbitrary angle with respect to the current, breaking/unbroken waves, plane/ripple-covered bed, uniform/graded sediment, among others.

A premium in the form of increased CPU time compared to the simulation time required by simpler formulations must of course be paid when this method is used. In order to make this method as efficient as possible from a computational point of view, MIKE 21 ST will interpolate the sediment transport rates from sediment transport tables created beforehand. To this purpose, either the tool for *Generation of Sediment Tables* or the tool for *Generation of Q3D Sediment Tables* in the MIKE 21 Toolbox are used, depending whether the two-dimensional (2DH) or the quasi three-dimensional (Q3D) approach is selected when calculating sediment transport rates.

In MIKE 21 ST you only have to specify the path and the name of the ASCII file(s) where the sediment transport tables have been saved. You can do this by typing the information required or by browsing the disk by left-clicking with your mouse on the button to the right of the Data File entry.

For more details regarding the STP model, see STP_Q3 Scientific background.

## 5.18 Water Temperature

The water temperature T is used together with the grain size d for the determination of the settling velocity of suspended sediment $w_s$.

The water temperature must be specified if one of the following three transport formulations has been selected when calculating sediment transport rates of non-cohesive sediment in steady flow (pure current) conditions: (i)Ackers & White Transport Formulation, (ii)Engelund & Fredsøe Transport Theory, (iii)Zyserman & Fredsøe Transport Formulation. The water temperature must also be specified if Bijker's Transport Method is used to calculate sediment transport in current and waves.

The water temperature may be used as a calibration factor in MIKE 21 ST for those formulations calculating suspended load transport separately. Higher temperature yields higher settling velocity for the suspended sediment, and consequently smaller amounts of sediment in suspension and lower rates of suspended load transport than otherwise.

## 5.19 Wave Breaking Parameters

The maximum wave height before breaking $H_m$ is calculated according to the formulation of Battjes and Janssen (1978):

$$H_m = \gamma_1 k^{-1} \tanh(\gamma_2 kD / \gamma_1) \tag{5.35}$$

where $k$ is the wave number, $h$ is the local water depth, and $\gamma_1$ and $\gamma_2$ are wave breaking parameters. $\gamma_1$ controls the wave steepness, whereas $\gamma_2$ controls the height-to-depth ratio.

Waves higher than or equal to $H_m$ are assumed to break and, conversely, waves with a height less than $H_m$ are taken as non-breaking.

In shallow water, the breaking criterion simplifies to

$$H_m = \gamma_2 h \tag{5.36}$$

The values of $\gamma_1$ and $\gamma_2$ that you select should be identical to the values used to specify wave breaking in the wave simulation. If you cannot remember these values by heart, you may take a look at the specification file used to run the wave simulation.

The dissipation of energy due to wave breaking may be reduced by increasing either $\gamma_1$, $\gamma_2$ or both.

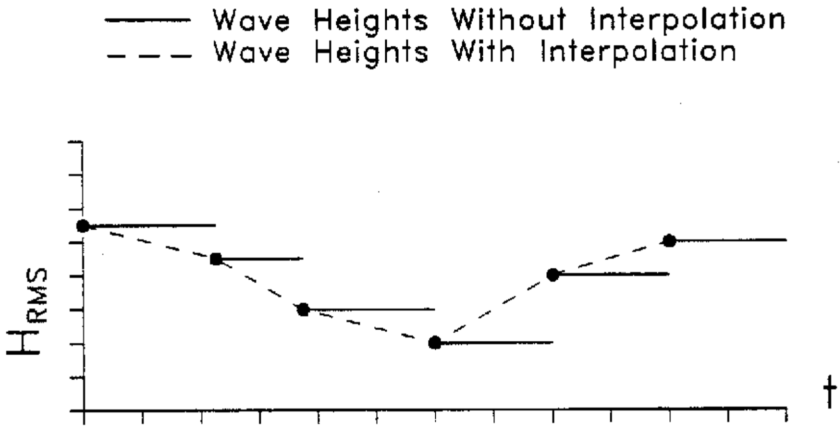
Default values of 1.0 and 0.8 are used in MIKE 21 ST, in agreement with the default values in the Parabolic Mild Slope Module, MIKE 21 PMS.

The specified values for the two parameters will be checked against those used when generating the sediment transport table(s) for the sake of consistency.

## 5.20 Wave Interpolation

In the case when the input wave data consists of a time series of wave parameters, the time variation of the wave height, period and direction of propagation over the simulation period and within the simulation area may be chosen as being constant or linearly varying between wave data sets. An example is shown in the figure below, using the root-mean-square wave height $H_{rms}$ as wave parameter.

You do this by simply selecting **Constant between wave data sets or Interpolate between wave data sets**, respectively.




## 5.21 Zyserman & Fredsøe Transport Formulation

This method of calculating the rates of total-load transport $q_t$ is basically identical to the Engelund & Fredsøe Transport Theory, the only difference being that the bed concentration of suspended sediment $c_b$ is calculated using the empirical relationship

$$c_b = \frac{A(\theta' - \theta_c)^n}{1 + \frac{A}{c_m}(\theta' - \theta_c)^n} \qquad \text{if } \theta' > \theta_c \tag{5.37}$$

The constant parameters $A$, $n$, $\theta_c$ and $c_m$ have the following values:

$A$ = 0.331

$n$ = 1.75

$c_m$ = 0.46

$\theta_c$ = 0.045

# 6 Scientific Background

The scientific background for the calculation of non-cohesive sediment transport in combined waves and current can be found in the documentation and in the copies of the following papers, all included in the MIKE 21 installation CD-ROM:

Deigaard, R., Fredsøe, J., and Hedegaard, I.B. *Suspended sediment in the surf zone*, J. of Waterway, Port, Coast. and Ocean Eng., ASCE, Vol. 112, No. 1, pp. 115-128, 1986.

Deigaard, R., Fredsøe, J., and Hedegaard, I.B. *Mathematical model for littoral drift*, J. of Waterway, Port, Coast. and Ocean Eng., ASCE, Vol. 112, No. 3, pp. 351-369, 1986.

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For a more in-depth description of the physical, mathematical and numerical background related to non-cohesive sediment transport modelling, see References.

# 7 References

## 7.1 Non-Cohesive Sediment Transport in Pure Current


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## 7.2 Non-Cohesive Sediment Transport in Combined Waves and Current


Battjes, J.A. and Janssen, J.P.F.M. *Energy Loss and Set-up Due to Breaking of Random Waves*. Proc. 16th Int. Conf. on Coastal Eng., Hamburg, 1978, pp. 569-587.

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Bijker, E.W. *Some Considerations about Scales for Coastal Models with Movable Bed*. Publication No. 50, Delft Hydraulics Laboratory, Delft, The Netherlands, 1967.

Bijker, E.W. *Littoral Drift as a Function of Waves and Current*. Publication no. 58, Delft Hydraulics Laboratory, Delft, The Netherlands, 1969.

Nielsen, P. *Some Basic Concepts of Wave Sediment Transport*. Institute of Hydrodynamic and Hydraulic Engineering, Technical University of Denmark, Series Paper 20, 1979.

Raudkivi, A.J. *The Roughness Height Under Waves*. Journal of Hydraulic Research, Vol. 26, No. 5, 1988.

Zyserman, J.A. and Fredsøe, J. *Inclusion of the Effect of Graded Sediment in a Deterministic Sediment Transport Model*. MAST G6M-Coastal Morphodynamics Final Workshop, Abstracts-in-depth. Pisa, Italy, May 1992.

## 7.3 Computational Hydraulics

Abbott, M.B. and Basco, D.R. *Computational Fluid Dynamics, an Introduction for Engineers*. Longman, London, and Wiley, New York, 1989.

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