

MIKE 21 & MIKE 3 FLOW MODEL FM
Sand Transport Module
Short Description



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MIKE 21 & MIKE 3 Flow Model FM – Sand Transport Module

This document describes the Sand Transport Module (ST) under the new comprehensive modelling system for two- and three dimensional flows, the Flow Model FM, developed by DHI.

The MIKE 21 & MIKE 3 Flow Model FM, Sand Transport Module (ST) is the module for the calculation of sediment transport capacity and related initial rates of bed level changes for non-cohesive sediment (sand) due to currents or combined waves-currents.

The ST Module calculates sand transport rates on a flexible mesh (unstructured grid) covering the area of interest on the basis of the hydrodynamic data obtained from a simulation with the Hydrodynamic Module (HD) and possibly wave data (provided by MIKE 21 SW) together with information about the characteristics of the bed material.



The MIKE 21 & MIKE 3 Flow Model FM, Sand Transport Module, is a numerical tool for the assessment of non-cohesive sand transport rates, related initial bed level changes and morphological evolution

The simulation is performed on the basis of the hydrodynamic conditions that correspond to a given bathymetry. It is possible to include feedback on the rates of bed level change to the bathymetry, such that a morphological evolution can be carried out.

To achieve a full morphological model in case of combined waves and currents, the wave module SW is applied in coupled mode. This mode introduces full dynamic feedback of the bed level changes on the waves and flow calculations.

Application Areas

The Sand Transport Module can be applied to quantify sand transport capacity in all areas where waves and/or currents are causing non-cohesive sediment movements. The ST module can be used on all scales from regional areas (10 kilometres) to local areas around coastal structures, where resolutions down to metres are needed.

Tidal inlets represent a complex water area where the coastal sections are fully exposed to waves and where the conditions upstream of and in the inlet are dominated by pure currents and where helical motions can have a significant impact on the resulting transport pattern. The Sand Transport Module is developed to span the gap from the river to the coastal zone.



Example of application area: Tidal Inlet

The ST module covers accordingly many different application areas: The most typical ones are:

- Shoreline management
- Optimization of port layouts
- Shore protection works
- Stability of tidal inlets
- Sedimentation in dredged channels or port entrances
- Erosion over buried pipelines
- River morphology

For example, the morphological optimization of port layouts, taking into consideration sedimentation at port entrances, sand bypassing and downdrift impact. Detailed coastal area investigation of the impact of shore protection structures on adjacent shoreline. Sand losses from bays due to rip currents, etc.

Solution Methods

The MIKE 21 & MIKE 3 Flow Model FM, Sand Transport Module covers the range from pure currents to combined waves and currents including the effect of wave breaking.

The numerical implementation is different for the case of pure current and the combined wave-current case.

The sand transport calculations in a 3D model set-up are carried out using a mean horizontal velocity component. The sand transport calculations are thus not truly three-dimensional. However, the findings that a more detailed 3D hydrodynamic model can give of the hydrodynamic conditions near the bed are included either by the depth-integrated currents of the 3D flow field or by using the bottom stress value to calculate a corresponding mean horizontal velocity component.

Sand transport in combined waves and currents – the quasi-3D approach

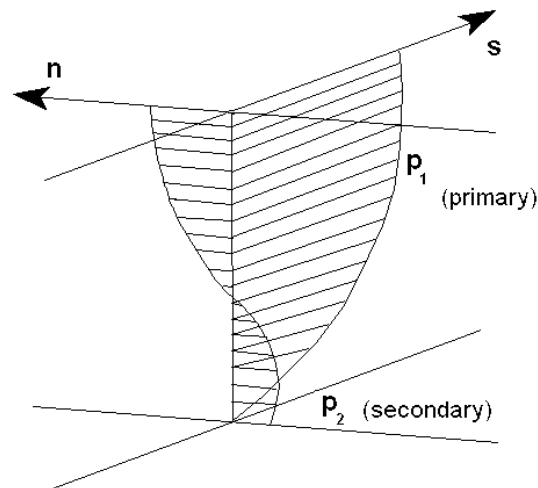
In case of combined waves and currents the sand transport rates are found by interpolation in a table created prior to the simulation. The generation of the transport rates in the table are based on the quasi-3D approach, where the local wave conditions, current profile and grain properties are considered. The effects of the following parameters on the local current profile and thereby on the sand transport can be included in the model:

1. the angle of propagation of waves relative to the flow direction
2. the loss of energy due to wave breaking
3. the gradation of the bed material
4. the formation of ripples on the sea bed
5. the slope of the sea bed
6. undertow
7. wave asymmetry
8. streaming

The inclusion of the effects of 4 – 9 is all optional and offers flexibility for the user to design the most appropriate model set-up for the actual application.

The ‘quasi-3D’ refers to the details of the modelling approach: The vertical sediment diffusion equation is solved on an intrawave period grid to provide a detailed description of the non-cohesive sediment transport for breaking/non-breaking waves and current.

The input to the sand transport model is a mean horizontal velocity component, typically depth-integrated currents. However, as suspended sand transport takes place in the turbulent boundary layer, which is thin in case of waves and covers the whole depth in fully developed steady currents, a description of the vertical distribution of the flow is required. This is obtained by a local ‘point model’, which includes enough computational points over the water column to resolve the wave boundary layer and the distribution of suspended sediment. The secondary flow profile is also having a significant impact on the sand transport



Primary and secondary velocity profiles

The transport rates are then found by interpolation in the tables using the local depth, wave conditions, mean horizontal velocity component and properties of the bed material. The sand transport model is a ‘sub-grid model’, which resolves processes not captured by the hydrodynamic model(s).

Sand transport in pure currents

The sand transport description in pure currents is a state-of-the-art model capable of including lag-effects from the flow and the suspended load in the morphological development.

The lag-effects on the suspended load are determined from an advection-dispersion equation that includes effects from over-loading or under-loading of the concentration of the suspended sediment and the helical flow pattern. This approach is often referred to as a non-equilibrium sediment description, where erosion and deposition of the bed is controlled by under-loading and over-loading of the suspended sediment in the water column.

The inclusion of helical flow (in 2D) and the non-equilibrium sediment description is optional, i.e. the model can also be executed as a 'point model' where lag-effects are disregarded (equilibrium sediment description) or only used to adjust the direction of the bed load.

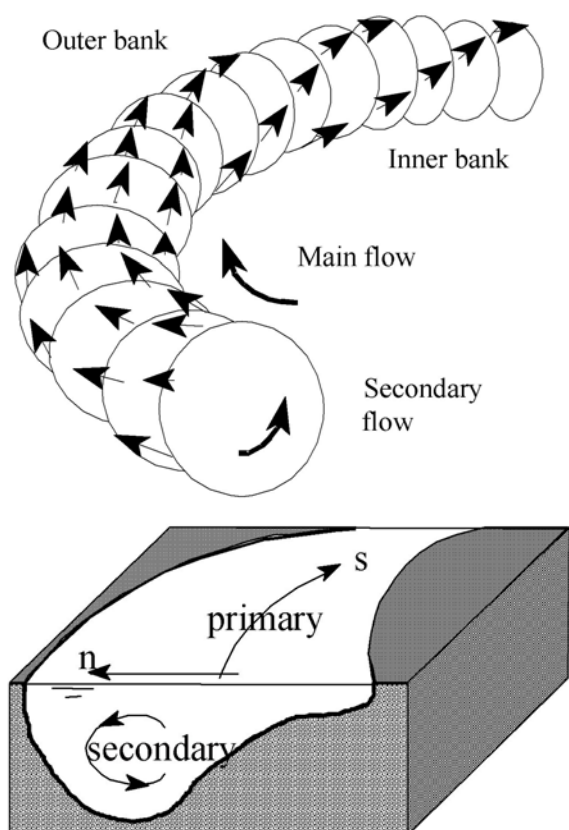


Illustration of helical flow

The bed load description includes gravitational effects forced from longitudinal and lateral bed slopes. Furthermore, it will adjust for the deviation of the bed shear stress from the mean flow, if helical flow is included in the model.

Four different sand transport formulas are available for determination of the equilibrium bed

load capacity, while three formulas are available for the suspended load:

- the Engelund-Hansen total load transport theory
- the Engelund-Fredsoe total load (bed load plus suspended load) transport theory
- the Van Rijn total load (bed load plus suspended load) transport theory
- the Meyer-Peter and Müller bed load transport theory

The equilibrium sand transport capacities are calculated on the basis of local water depth, mean horizontal velocity component, Manning number/Chezy number and properties of the bed material (median grain size and gradation), which may vary throughout the model area.

Model Input Data

The necessary input data can be divided into the following groups:

- Domain
 - bathymetry data (incl. map projection)
 - simulation length
- Hydrodynamic data
 - water depth and flow fields (provided by the Hydrodynamic Module)
- Wave data (if required)
 - wave height, period, direction (provided by the Spectral Wave Module or similar)
- Sediment properties
 - size and gradation of bed material
- Morphology parameters
 - update frequency

The main task in preparing the input data for the ST module is to generate a bathymetry and to assess the hydrodynamic and wave conditions.

In case of sand transport in combined wave and current a sand transport table, that contains a representative number of sand transport rates for interpolation during the simulation, is required as input. The sand transport tables can be generated using the MIKE 21 Toolbox program 'Generation of Q3D Sediment Tables'.

In case of wave influence, a DHI wave module (MIKE 21 NSW, PMS or SW) will simulate the radiation stresses necessary for generating the wave-driven current.

If the simulation is to be run in coupled mode, the MIKE 21 SW module is set up to generate the wave conditions by using the Coupled Model FM input editor.

Per default the hydrodynamic conditions are simulated together with the sand transport rates.

However, for the coupled model it is possible to run in de-coupled mode, providing the hydrodynamic conditions and wave conditions as external data files.

Model Output Data

Two types of output data can be obtained from the model; sediment transport rates and resulting morphological changes.

The format of the data may be as points, lines or areas and in any subset required. In the Outputs dialog output variables are selected between lists of basic and additional output variables. The basic output variables are for example; SSC, bed load-, suspended load- and total load in x- and y-direction including rate of bed level change, bed level change and bed level. The additional output variables are for example load variables given as magnitude and direction as well as accumulated values, including hydrodynamic and wave variables.

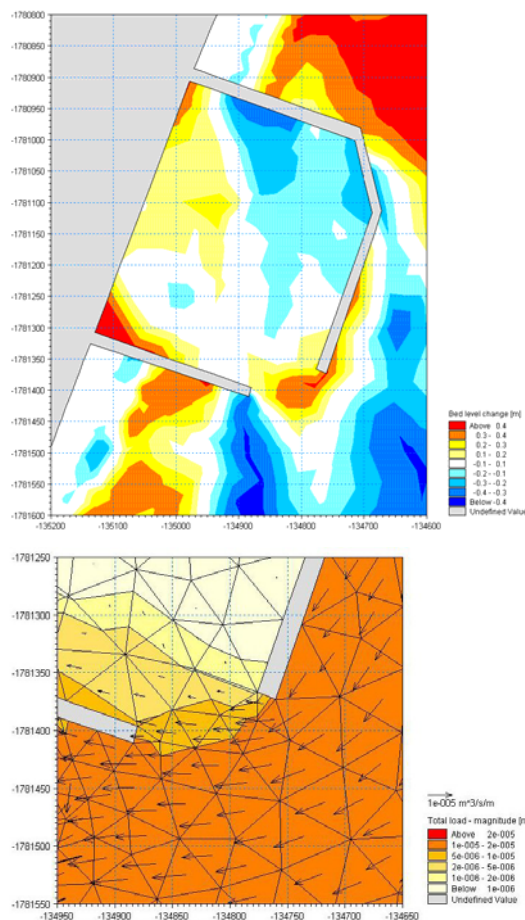
Examples of Applications and Results



Location map for the examples: Grådyb and Torsminde

Grådyb

Grådyb is a tidal estuary facing the North Sea coast. A major port facility is located inside the estuary. An access channel with a depth of 12 m is maintained by dredging. About 1 million m³ of sediment are dredged every year and bypassed to not destabilise the down drift coast.



Simulated morphological change by a harbour and detail of sand transport rates at the harbour entrance



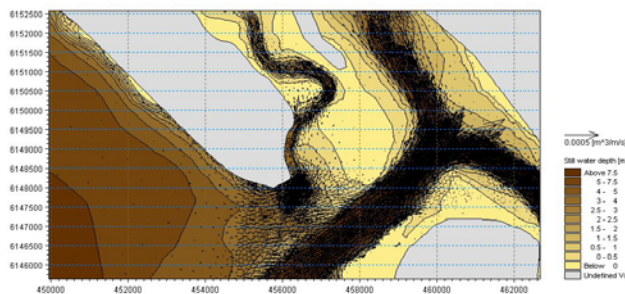
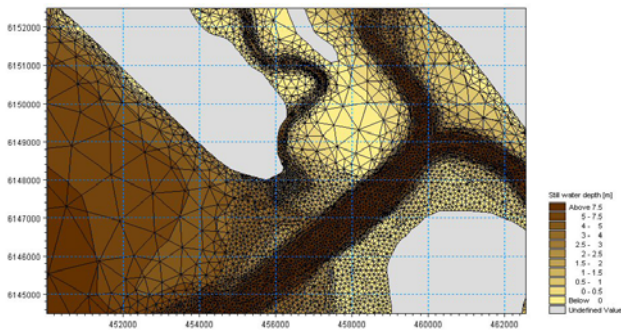
Aerial view of Grådyb estuary. Copyright Port of Esbjerg



Aerial view of Gorai River

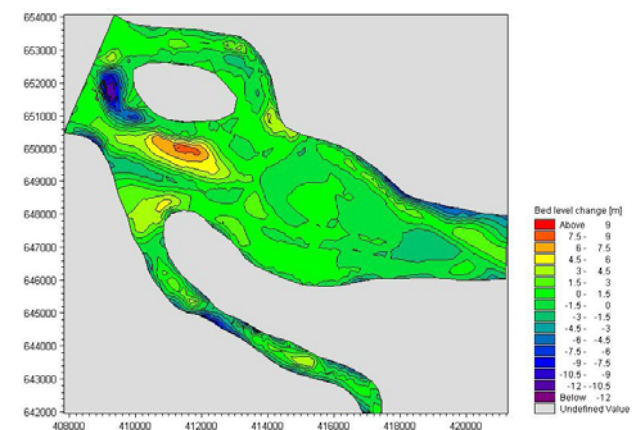
The following figures show a flexible grid bathymetry and a ‘snap shot’ of simulated sand transport in a subset of the model area.

The non-equilibrium concept including helical flow was applied to estimate the morphological changes of the system after the time period of a monsoon.



Sub set of the flexible model grid and simulated sand transport

The plots illustrate the flexibility of the model set-up where the critical areas are covered with a very dense grid and the tidal flats are resolved by a somewhat coarser grid.



Mesh bathymetry in 3D and Model predicted bed level changes induced by the passage of the 1999 monsoon

Gorai River

The Gorai River is a spill channel to the Ganges River. The morphological behaviour at the offtake is of great interest, because the Gorai River is an important source of fresh water supply in the region.

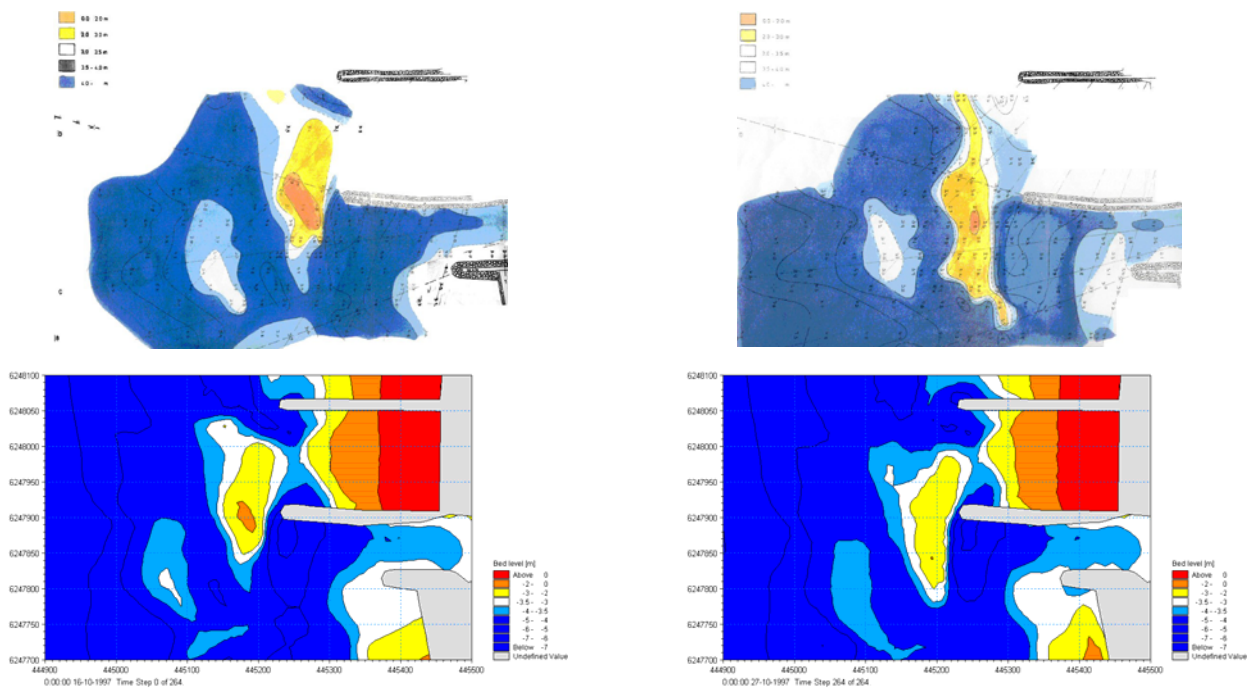
Torsminde Harbour

Torsminde fishery harbour is located at a tidal inlet on the west coast of Jutland, Denmark, on one of the narrow tidal barriers which divide coastal lagoons from the sea. The port is located at the entrance to the coastal lagoon Nissum Fjord. Sluices regulate the water exchange between the lagoon and the sea. Torsminde harbour is located in the central part of a very exposed stretch, where the net littoral drift is southward with an order of magnitude of 0.4 million m³/year, but where the gross transport is several times larger. As a result severe sedimentation and shoaling problems

affected the harbour entrance and a need for alternative layout of the harbour made it necessary to make preliminary investigations of the sand transport pattern in the area.

Running the MIKE 21 Flow Model FM in coupled mode with the SW Module and ST module, the morphological changes during a specified period of time can be estimated.

The following figures show a comparison of the measured and simulated bathymetry in front of the harbour entrance, before and after a 10-day period in October 1997.

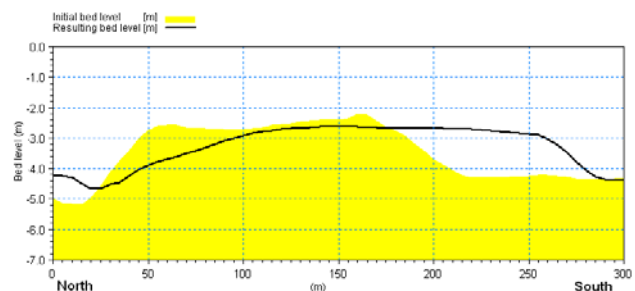


Comparison of measured and simulated bathymetries in front of the harbour entrance. Upper: measured. Lower: calculated. Left: before storm. Right: after storm

The pre-dominant wave direction during the simulation period was from the North-West. This caused the bar in front of the harbour entrance to migrate further south, thus blocking the harbour entrance.

To view the bar migration in detail the simulated bed levels are extracted along a north-south line extending from the northern jetty to past the harbour entrance.

The results are shown in the figure below.



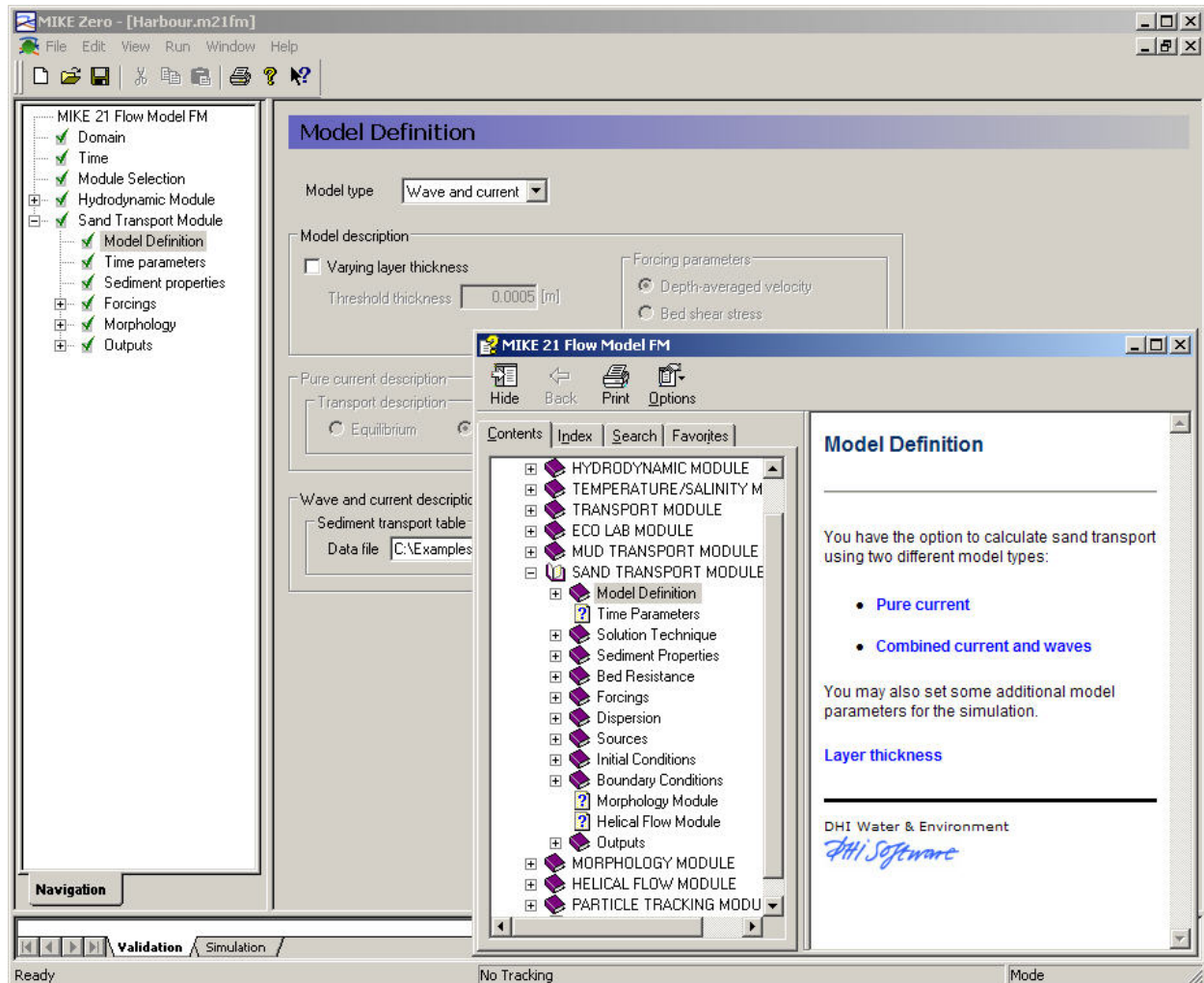
Bed level across the harbour entrance: before and after simulation



Graphical User Interface

The MIKE 21 & MIKE 3 Flow Model FM, Sand Transport Module is operated through a user friendly graphical interface.

Support is provided at each stage by an Online Help System.



Graphical user interface of the MIKE 21 Flow Model FM, Sand Transport Module, including an example of the Online Help System

Hardware and Operating System Requirements

The MIKE 21 & MIKE 3 Flow Model FM Sand Transport Module supports Microsoft Windows XP and Microsoft Windows Vista. Microsoft Internet Explorer 5.0 (or higher) is required for network license management as well as for accessing the Online Help.

The recommended minimum hardware requirements for executing MIKE 21 & MIKE 3 Flow Model FM Sand Transport Module are:

Processor:	2 GHz PC (or higher)
Memory (RAM):	1 GB (or higher)
Hard disk:	40 GB (or higher)
Monitor:	SVGA, resolution 1024x768
Graphic card:	32 MB RAM (or higher), 24 bit true colour
Media:	CD-ROM/DVD drive, 20 x speed (or higher)

Support

News about new features, applications, papers, updates, patches, etc. are available here:

<http://www.dhigroup.com/Software/Download/DocumentsAndTools.aspx>

For further information on MIKE 21 & MIKE 3 Flow Model FM software, please contact your local DHI agent or the Software Support Centre:

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References on applications

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