MIKE 21/3 ECOLOGICAL MODELLING

MIKE 21/3 ECO Lab FM Module

Short Description

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MIKE 21 & MIKE 3 ECO Lab FM

MIKE 21 & MIKE 3 ECO Lab FM is a state-of-the-art numerical tool for 2D and 3D ecological modelling of ecosystems.

The combination of a user-friendly interface, open access to the governing equations and the coupling of ECO Lab to the MIKE 21/3 Flow Model FM makes MIKE 21/3 ECO Lab FM a powerful tool. MIKE 21/3 ECO Lab FM is typically applied in environmental water quality studies in coastal areas, estuaries, and lakes.

MIKE 21/3 ECO Lab FM is capable of simulating the spatial distribution of state variable concentrations in a 2D or 3D domain based on processes such as:

- Advective transport
- Biological, physical, and chemical transformation processes
- Settling

It is possible to describe state variables that are bound to the seabed, the water surface, the sediment, or can be found in the whole water column.

ECO Lab gives easy access to the formulation of the biological, chemical and settling processes. The user has the option of viewing, modifying, or creating the formulation of the processes and to introduce new state variables to simulate. It is therefore possible to create completely new model concepts containing the necessary causal relations to describe the specific phenomena in question.

The ECO Lab model containing the formulation of the biological, chemical interaction between the state variables is saved in an ASCII file called an ECO Lab template. The ECO Lab template is independent of the horizontal discretization into a computational grid and can therefore be shared with the other DHI software models supporting ECO Lab.

A MIKE 21/3 ECO Lab FM setup can include sources, connected sources and sinks and is therefore a very suitable tool for the purpose of assessing the effect of discharging pollutants.

Example of a source: outlet of wastewater

Application Areas

There are three major application areas of MIKE 21/3 ECO Lab FM:

- Environmental Impact Assessment (EIA). The assessment of the impact on the water environment caused by antropogenic changes.
- Surveillance and forecast. Forecast systems can predict water quality parameters in the actual situation and typically 5 days ahead.
- Scientific research.

Examples of specific applications of the MIKE 21/3 ECO Lab FM Module are:

EIA. The impact on water quality from effluents discharging pollutants in a domain at different positions and the fate of these pollutants, both point sources and diffuse sources can be assessed. For instance the impact on dissolved oxygen concentrations in the water from changing nutrients outlets can be assessed. This could be establishment of a wastewater treatment plant, an aquaculture industry, or another new industry. It is possible to simulate the fate of many other variables, e.g. faecal bacteria, BOD, and xenobiotics discharged into the water environment.

EIA. The impact on flora and fauna caused by dredging operations where dredged material is spread in the water environment as a sediment plume can be assessed. Often the shading from the sediment plume can affect the benthic vegetation that is dependent on solar radiation.

Sediment plume from dredging operation affecting benthic flora and fauna

- **EIA.** The impact on the water environment caused by construction works can be assessed, for instance:
  - Changing the bathymetry
  - Diversion of water from one area to another
  - Establishment of a power plant discharging cooling water

Change in the bathymetry by dredging of the seabed and reclamation of artificial island. Peberholm in Øresund, Denmark

- **Surveillance and forecast**. The tool can be used to compute forecasts of bathing water quality by predicting state variables such as coliform bacteria, temperature, jellyfish and toxic algae, for instance blue-greens in coastal areas.
- **Surveillance and forecast.** Forecast systems designed for decision-makers to have a surveillance tool that can explain the environmental situation as it is in the actual situation. The prognostic variables will then typically be parameters that are considered important for the environmental health such as for instance dissolved oxygen.
- **Surveillance and forecast.** Forecast systems designed as a tool for the aquaculture industry, which can predict parameters that are important for the management of the production. The prognostic variables will then typically be parameters that are considered important for either the growth rate or the survival of the production. The prognostic variables could also be the products themselves, for instance mussels.

Filtrators such as blue mussels (Mytilus Edulis) can be modelled with MIKE 21/3 ECO Lab FM

- **Scientific research**. The tool can also be used for analysing ecosystems (System Analysis). Different scientific ecosystem theories/ hypothesis can be tested and help scientists to understand and map the causal relations in a specific ecosystem. The interaction between mud transport and biology can, for instance, be investigated, or the interaction between the nutrients in the sediment with the nutrients in the water phase can be modelled. Another purpose could be to investigate the impact on benthic fauna from xenobiotics in the water environment.

- **Scientific research.** The effect on the water environment caused by natural changes can be assessed, for instance the effect of long time climate changes or extreme weather conditions. A purpose could also be to estimate the natural state of an ecosystem without human influence.
- **Scientific research.** Even though ECO Lab is designed for modelling water quality related variables, it can also be used to simulate other phenomena that can be described with an ordinary differential equation. An example hereof could be a model describing the development of ice at the water surface.

Benthic vegetation such as Eelgrass (Zostera Marina) can be modelled with MIKE 21/3 FM ECO Lab

Model Equations

Fixed state variables

Fixed state variables are state variables that are not moveable, i.e. they have a fixed spatial position. Examples of a fixed state variable could be benthic vegetation or a variable in the sediment.

An ordinary differential equation called P_c describing biological and chemical transformation processes affecting state variables in an ecosystem (also called the ECO Lab equations) is specified for each ECO Lab state variable.

$$P_c = \frac{dc}{dt} = \sum_{i=1}^{n} process_i$$

Symbol list	
c:	The concentration of the ECO Lab state variable
n:	Number of processes involved for a specific state variable
process:	User specified expression containing arguments such as mathematical functions, built-in functions, numbers, forcings, constants, and state variables

The ordinary differential equation summarises the processes involved for the specific state variable. If a process affect more than one state variable, or the state variables affect each other, the set of ordinary differential equations are said to be coupled.

The processes contain mathematical expressions using arguments such as mathematical functions, built-in functions, numbers, constants, forcings and state variables. The arguments are separated by operators such as +-*/, and the syntax also supports other types of expressions such as for instance 'IF THEN ELSE' expressions. The mathematical and built-in functions are functions that are already defined in ECO Lab and can be used directly by referring to them. An example of a built-in function computes the oxygen saturation concentration using arguments such as salinity and temperature.

Processes always describe the rate at which something changes. In this context constants are values always constant in time, and forcings are values that can be varying in time.

Some constants and forcings are already calculated in the hydrodynamic model, e.g. temperature and salinity. These results can be used as so-called built-in forcings and constants in the ECO Lab expressions.

It is possible to specify processes that only take place at specific locations in the water column. For instance the process "Exchange with atmosphere" only takes place at the water surface.

Advective state variables

The dynamics of advective ECO Lab state variables can be expressed by a set of transport equations, which in non-conservative form can be written as:

$$\frac{\partial c}{\partial t}+u\frac{\partial c}{\partial x}+v\frac{\partial c}{\partial y}+w\frac{\partial c}{\partial z}=D_x\frac{\partial^2 c}{\partial x^2}+D_y\frac{\partial^2 c}{\partial y^2}+D_z\frac{\partial^2 c}{\partial z^2}+S_c+P_c$$

Symbol list	
c:	The concentration of the ECO Lab state variable
u, v, w:	Flow velocity components
D_x, D_y, D_z:	Dispersion coefficients
S_c:	Sources and sinks
P_c:	ECO Lab Processes

The transport equation can be rewritten as

$$\frac{\partial c}{\partial t}=AD_c+P_c$$

where the term AD_c represents the rate of change in concentration due to advection (transport based on hydrodynamics), and dispersion (including sources and sinks). AD_c is dependent on discretization and solved with a finite volume technique in MIKE 21/3 ECO Lab FM.

The state variables may be coupled linearly or non-linearly to each other through the ECO Lab source term P_c. The term P_c represents the rate of change due to ECO Lab processes (as for fixed state variables). P_c is independent of horizontal discretization.

The ECO lab numerical equation solver makes an explicit time-integration of the above transport equations, when calculating the concentrations to the next time step.

An approximate solution is obtained in ECO Lab by treating the advection-dispersion term AD_c as constant in each time step.

The coupled set of ordinary differential equations defined in ECO Lab is solved by integrating the rate of change due to both the ECO Lab processes themselves and the advection-dispersion processes.

$$c(t+\Delta t)=\int_t^{t+\Delta t}\left(P_c(t)+AD_c\right)dt$$

The advection-dispersion contribution is approximated by

$$AD_c=\frac{c^*(t+\Delta t)-c^n(t)}{\Delta t}$$

The intermediate concentration c* is found by transporting the ECO Lab state variable as a conservative substance over the time period *Δt* using the AD module.

The main advantage of this approach is that the explicit approach resolves coupling and non-linearity problems resulting from complex source ECO Lab terms P_c, and therefore the ECO Lab and the advection-dispersion part can be treated separately.

The ECO Lab time integration can be performed with different numerical solution methods:

- Euler
- RK 4
- RKQC

The output from MIKE 21/3 ECO Lab FM presents a numerical solution of the above equations for fixed and advective state variables. The solution is discretized into a computational grid, which is common with the hydrodynamic model.

Computational mesh applied in Odense Estuary, Denmark

Process types

There are 2 different process types in ECO Lab:

- Transformation
- Settling

Transformation

The 'Transformation' process is a straightforward transformation of a state variable without exchange with neighbouring points. Examples could be chemical reactions, and degradation processes.

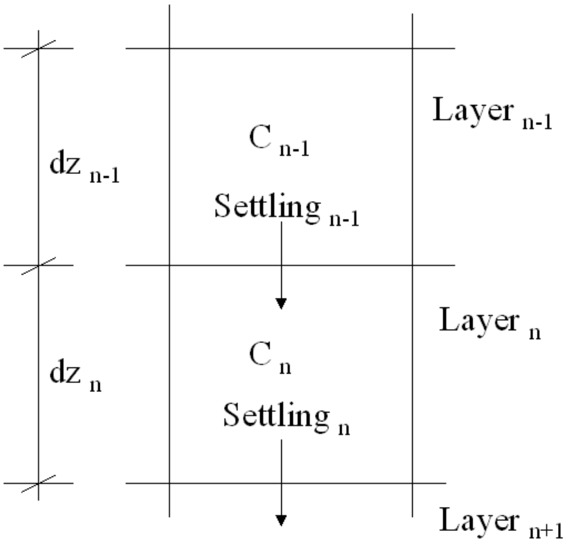
Settling

The 'Settling' process has vertical movement. The process is transporting the state variable vertically towards the seabed.

An expression must be specified describing the 'concentration change' caused by a transport from actual cell to cell below [mg/l/d]:

$$\frac{dc_n}{dt} = -settling_n$$

The sign convention for a settling process is so that it should be specified as negative in the differential equation in order to transport the state variable correctly down the water column.



Schematic illustration of settling process

The numerical solution of a state variable affected by a 'Settling' process is different than if it was a 'Transformation' process. The numerical solution of a state variable with a settling process in a multi-layered system takes into account that contribution to the state variable is received from the layer above (if not top layer) and that the layers can have variations in thickness.

During calculation, ECO Lab substitutes the settling process expression in the differential equation with the following expression:

$$\frac{dc_n}{dt} = \frac{-settling_{n-1} \cdot dz_{n-1} + settling_n \cdot dz_n}{dz_n}$$

Symbol list

settling :	is the user specified expression for 'rate of change' of the state variable concentration in actual layer caused by a settling process transporting from actual layer to layer below
dz :	thickness of layer [m]
n :	layer number [dimensionless]

Calculation of light in multi-layered systems

Light penetration in the water column is important in many ECO Lab studies involving primary production. The light is normally computed with a Lambert Beer expression. In multilayered systems with vertical varying extinction coefficients, the Lambert Beer expression must be calculated for each layer, and therefore, the Lambert Beer expression as argument must use the result of the Lambert Beer expression in the layer above. This operation is easy in ECO Lab because a built-in function is available, so that light can be estimated correctly based on the Lambert-Beer equation.

$$I_n = I_{n-1} \cdot e^{\eta_n \cdot dz_n}$$

Symbol list

I_n :	The light available for primary production in the actual layer *n*
I_{n-1} :	The irradiance in the layer above
η_n :	The extinction coefficient
dz_n :	The layer thickness

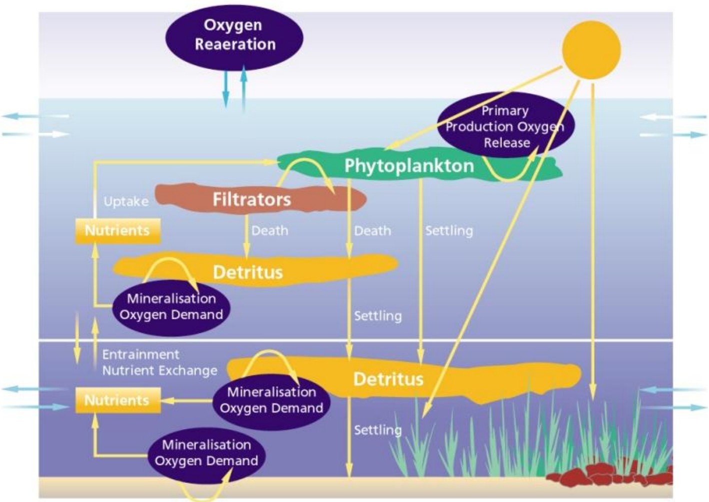
Predefined ECO Lab templates

A set of predefined ECO Lab templates are supplied with the DHI Software.

Eutrophication templates

The family of eutrophication templates describes nutrient cycling, phytoplankton and zooplankton growth, growth and distribution of rooted vegetation and macro algae in addition to simulating oxygen conditions. Simulation results describe the concentrations of phytoplankton, chlorophyll-a, zooplankton, organic matter (detritus), organic and inorganic nutrients, oxygen and area-based biomass of benthic vegetation over time.

In addition, a large number of derived variables are involved, e.g. primary production, total nitrogen and phosphorus concentrations, sediment oxygen demand and Secchi disc depth.

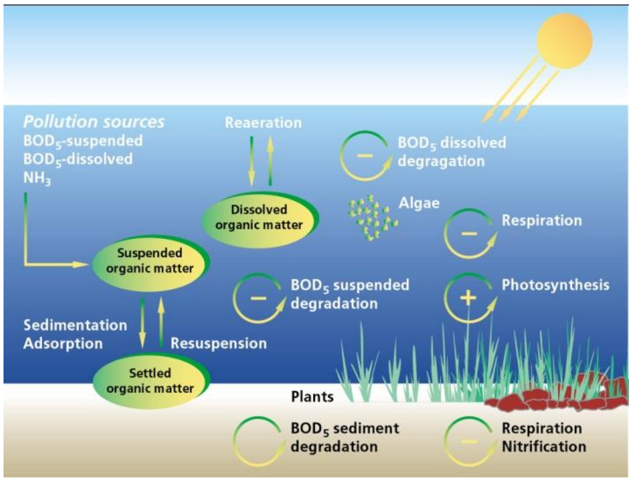


Conceptual diagram illustrating the main state variables and processes of the eutrophication templates

WQ templates

The Water Quality Templates describe water quality phenomena in a simple way: the survival of coliform bacteria, degradation of organic matter, resulting oxygen conditions and excess levels of nutrients in water bodies.

The templates cover simple combinations of variables such as BOD-DO and more complex combinations, including the most significant inorganic forms of nitrogen and phosphorus.



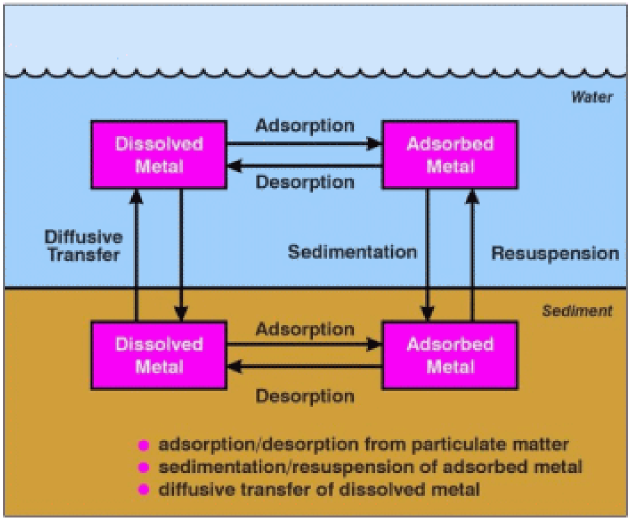
Conceptual diagram illustrating the main processes describing dissolved oxygen in the WQ templates

Heavy Metal template

The Heavy Metal Template describes the adsorption/desorption of metals to suspended matter, the sedimentation of sorbed metals to the seabed as well as resuspension of settled metals. It also includes the exchange of metal between the particulates of the seabed sediment and interstitial waters of the bed.

Removal and transport of contaminated bottom sediment

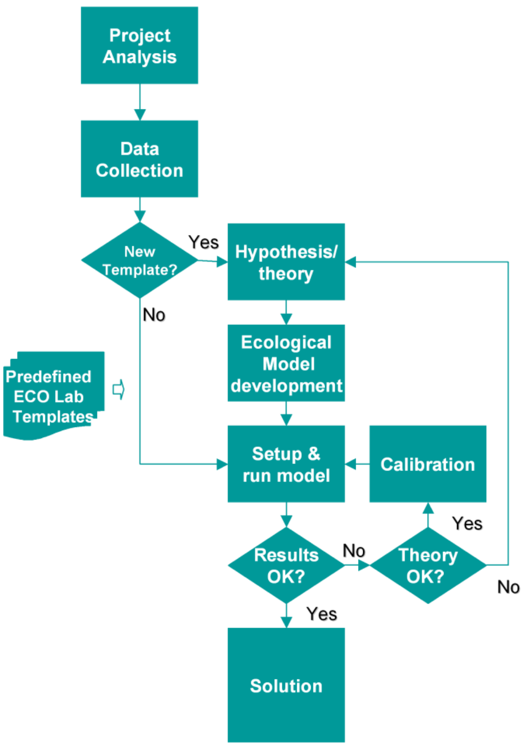
The diffusive exchange of metal in dissolved form in the water and in the interstitial waters is also described. A number of derived values are calculated, e.g. the total concentration of metal in the water and in the bed sediment and potential concentration of metal in algae and plants and in biota like filter feeders (mussels) and fish.



Conceptual diagram showing the main state variables and processes of the heavy metal template

The ECO Lab Work Flow

The work will normally consist of the tasks illustrated in the diagram below:



As the diagram illustrates there can be different ways to reach the solution of your project.

Some tasks are mandatory, such as:

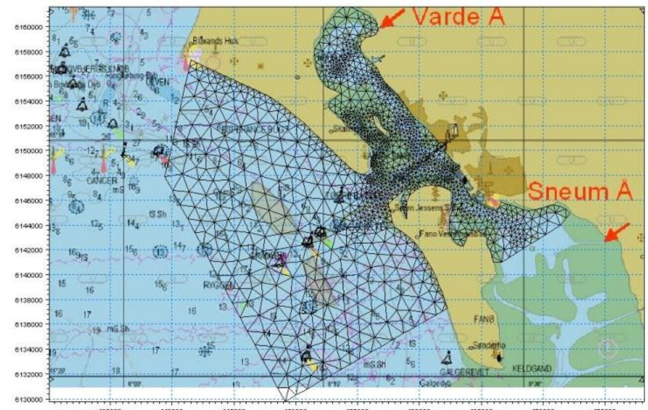
- **Project analysis**: defining and limiting the ECO Lab model
- **Data collection**
- **Set up and run the model**
- **Calibration**
- **Solution**: Running the production simulations and presenting the results

Other tasks in your project are optional and depend on your choice: will you create your own ECO Lab template or will you use a predefined one. In some cases a predefined template covering your specific problem does not exist, and then a new ECO Lab template has to be developed. If you choose to develop your own ECO Lab template, your project will include also the following tasks:

- **Development of hypothesis/theory**: Literature study and formulation of equations
- **Implementation of theory** into an ECO Lab template using the ECO Lab editor

Model Input

ECO Lab modelling requires data as model input. Some parameters can be measured and some are calibration parameters.

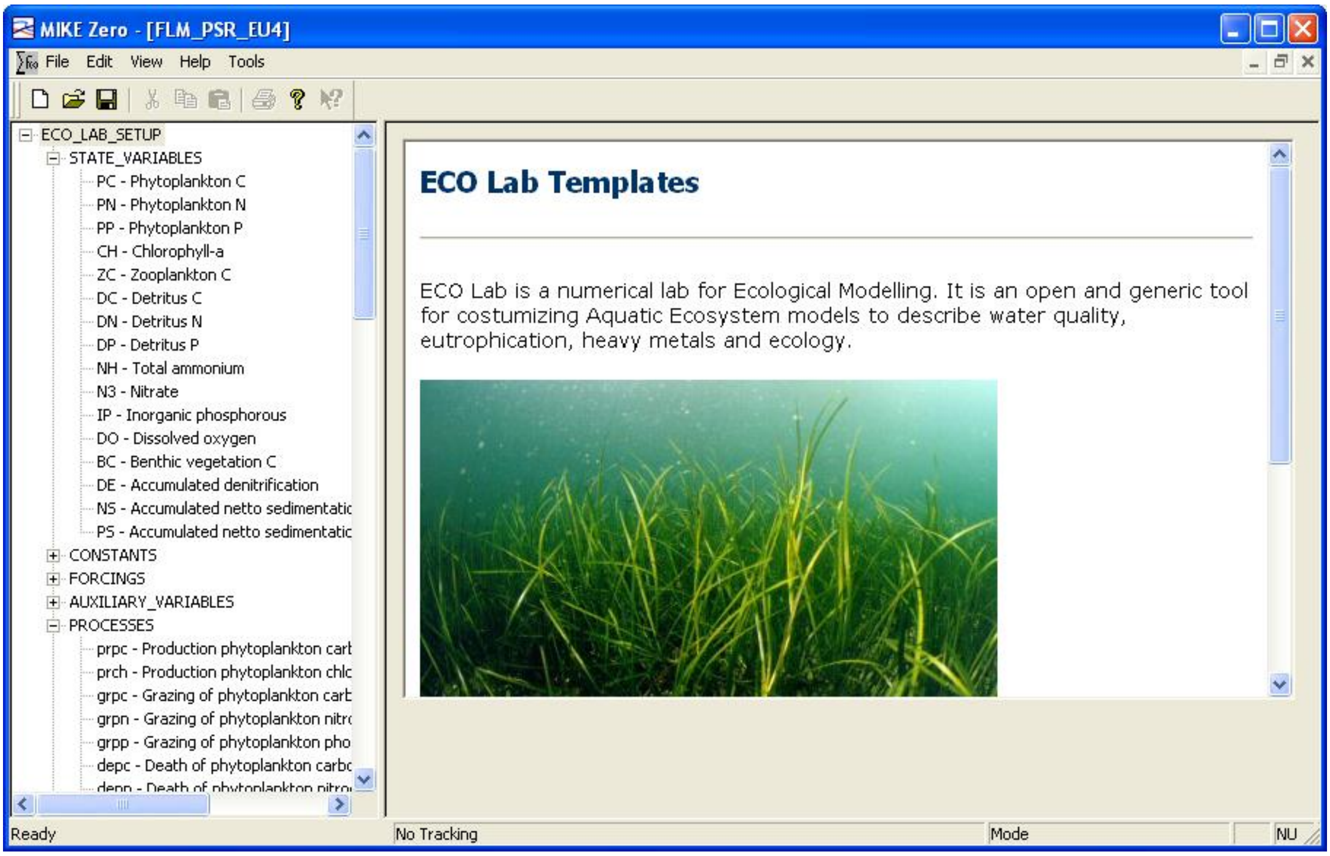


Flexible mesh applied in Ho Bay, Denmark

The following input data must be specified in the model setup:

- Computational mesh containing bathymetric data
- Time step and simulation period
- Hydrodynamic boundary data: salinity, temperature, water levels and/or current velocities
- Hydrodynamic forcings, e.g. wind, air temperature and clearness coefficient
- Hydrodynamic sources, the magnitude of the discharge
- ECO Lab template
- ECO Lab boundary data: concentrations at the boundary of the advective ECO Lab state variables.
- ECO Lab forcings (depend on the content of the ECO Lab template), e.g. solar radiation
- ECO Lab constants (depend on the content of the ECO Lab template). There can be many parameters in an ECO Lab set up. Some are never changed and others are calibration parameters that are often changed
- ECO Lab loadings: concentrations in sources and precipitation of the advective ECO Lab state variables
- ECO Lab initial conditions of ECO Lab state variables

The ECO Lab Template Editor is an efficient tool to formulate new ecological models in ECO Lab templates, which must be specified as input data in MIKE 21/3 ECO Lab FM



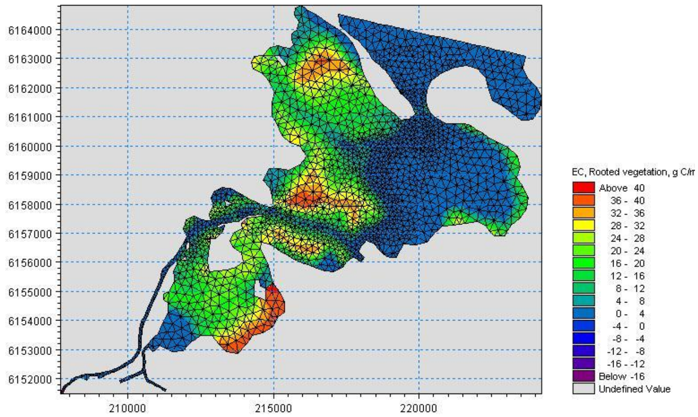
The graphical user interface of the ECO Lab template editor

Model Output

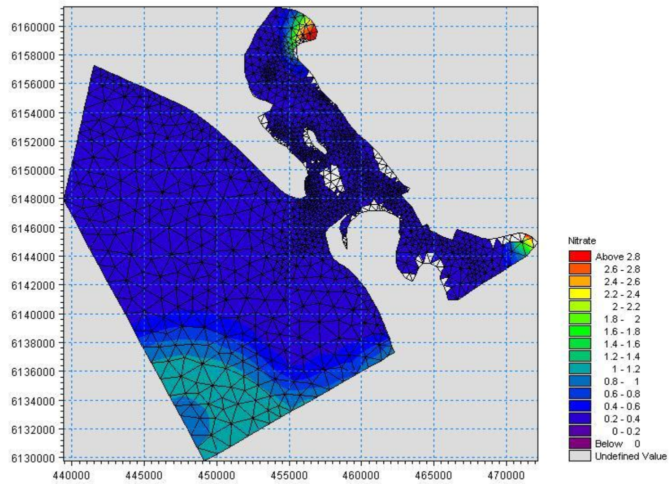
After the setup of the model a simulation can be started. This will produce output data that include deterministic data of the state variables defined in the ECO Lab template.

Other output items than the state variables can be defined as output items in the ECO Lab template, such as processes, auxiliary variables, and derived output.

It is possible to specify the format of the output files in MIKE 21/3 ECO Lab FM as time series of points, lines, areas, and volumes (only MIKE 3 FM).

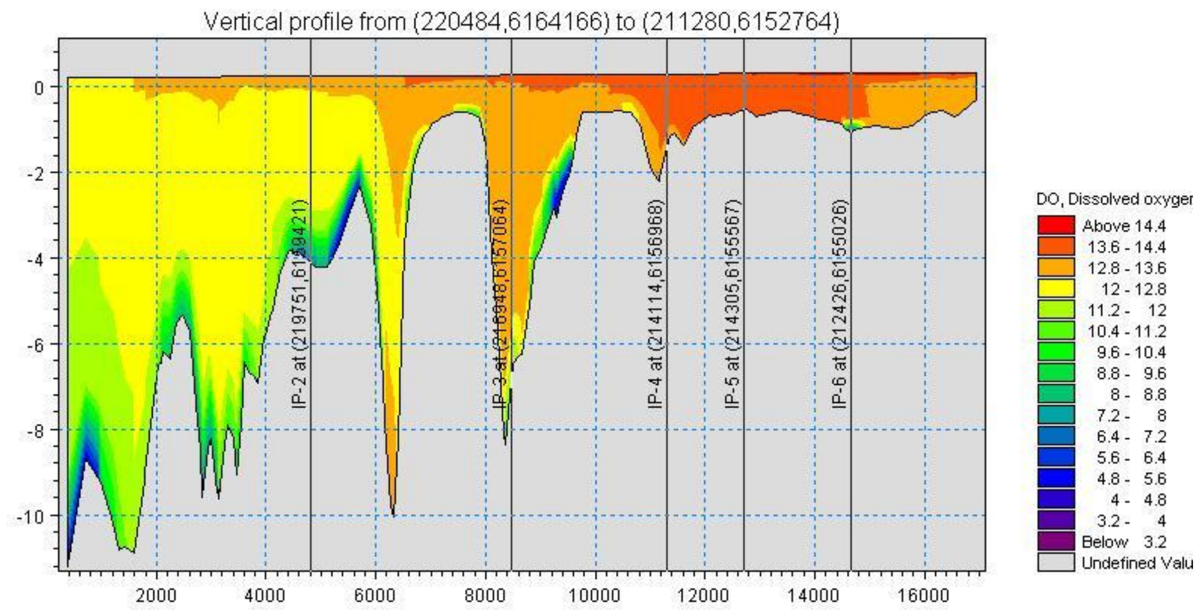


2D output: benthic vegetation in Odense Estuary, Denmark



Superficial layer of a 3D output: Nitrate in Ho Bay, Denmark

Usually the model is calibrated against measured data. These might be measurements from different monitoring stations. Such data are important for documenting the capability and quality of the model.

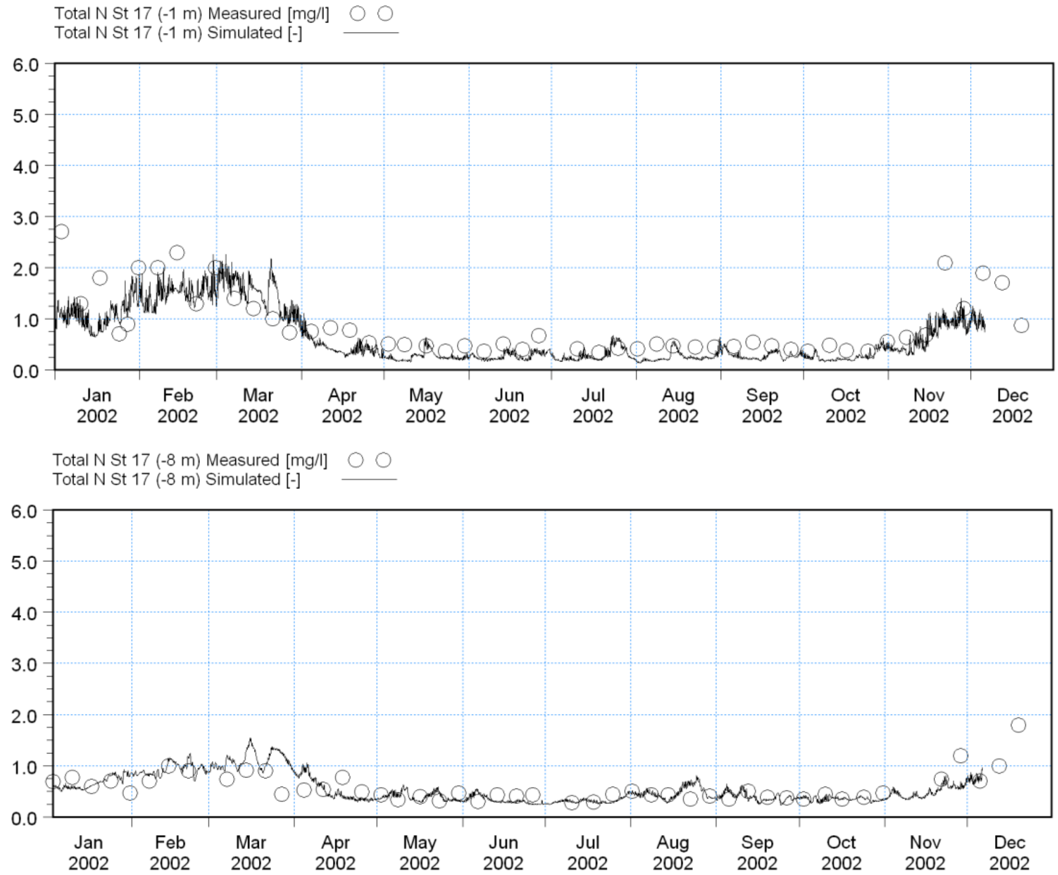


A vertical profile of a 3D output can easily be viewed with the data viewer tool. Dissolved oxygen profile along a line in Odense Estuary, Denmark

Validation

The ECO Lab concept is well proven in numerous studies throughout the world.

The figure below shows a comparison of simulated and measured 'Total Nitrogen' for a MIKE 3 ECO Lab FM model, which was set up for Odense Estuary in Denmark. This model set up is included with the DHI Software, and also a detailed explanation of how the model was set up is included as a manual: Step-by-step training example for MIKE 3 ECO Lab FM.

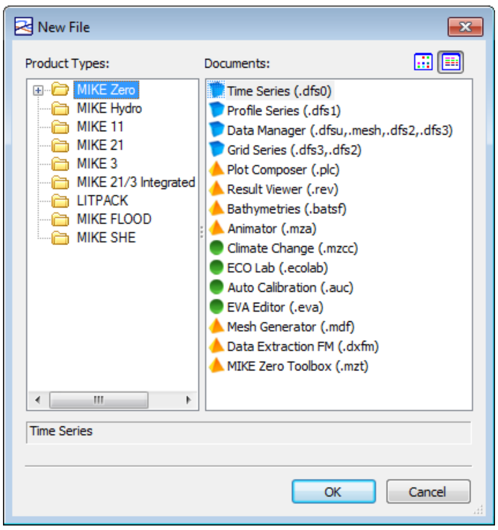


Simulated and measured Total N concentrations at different depths in Odense Estuary, Denmark

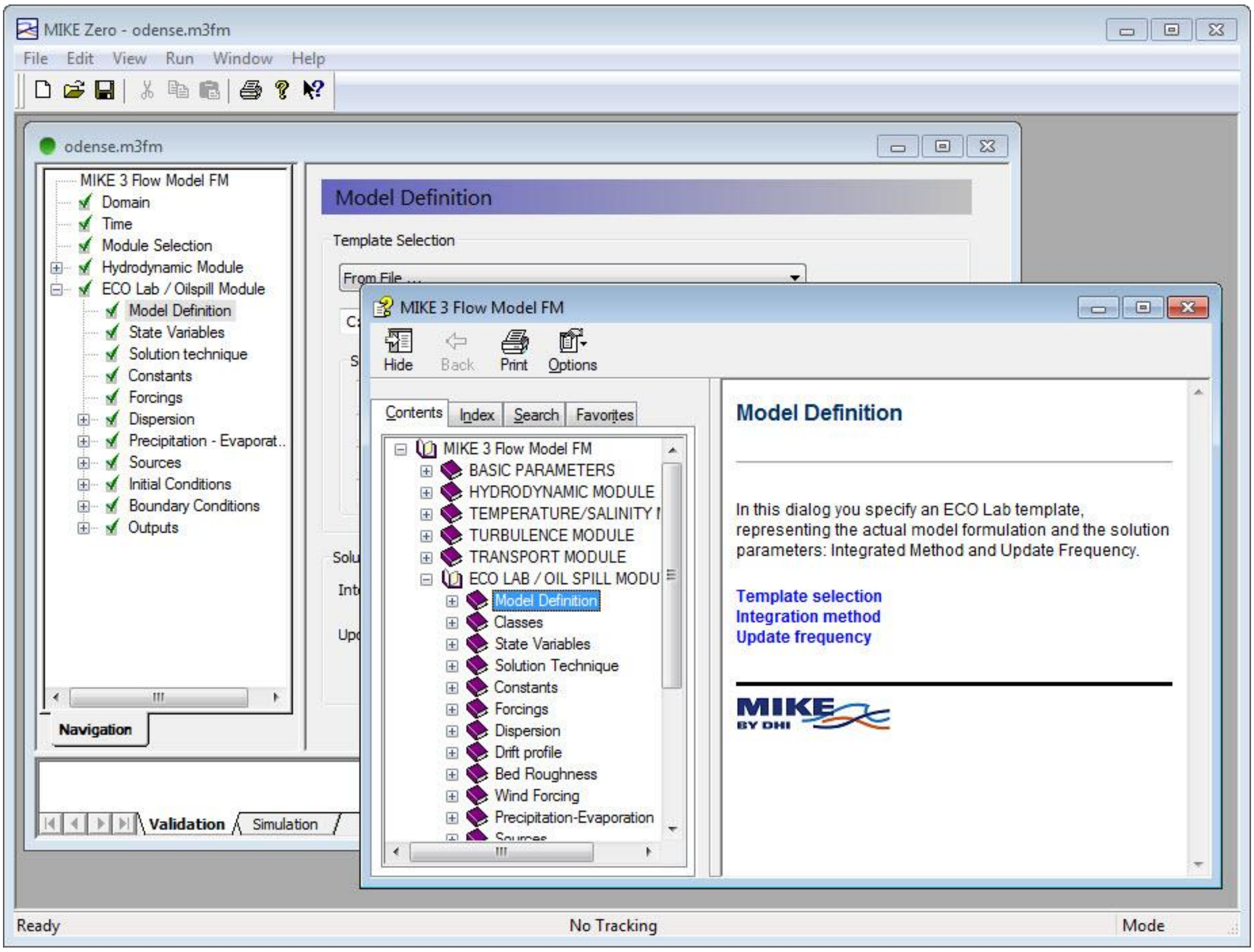
Graphical User Interface

The MIKE 21/3 ECO Lab FM is operated through a fully Windows integrated Graphical User Interface (GUI). Support is provided at each stage by an Online Help System.

The common MIKE Zero shell provides entries for common data file editors, plotting facilities and utilities such as the Mesh Generator and Data Viewer.



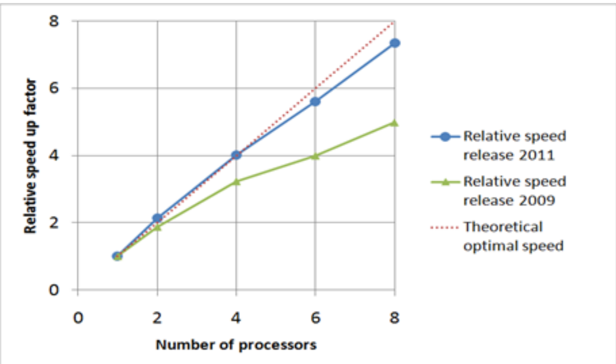
Overview of the common MIKE Zero utilities



Graphical user interface of the MIKE 21/3 ECO Lab FM, including an example of the Online Help System

Parallelisation

The computational engines of the MIKE 21/3 FM series are available in versions that have been parallelised using both shared memory (OpenMP) as well as distributed memory architecture (MPI). The result is much faster simulations on systems with many cores.



MIKE 21/3 FM speed-up using multicore PCs for Release 2011 with distributed memory architecture (blue) and shared memory architecture that was part of Release 2009 (green)

Hardware and Operating System Requirements

The MIKE 21/3 ECO Lab FM supports Microsoft Windows XP Professional Edition (32 and 64 bit), Microsoft Windows Vista Business (32 and 64 bit) and Microsoft Windows 7 Enterprise (32 and 64 bit). Microsoft Internet Explorer 6.0 (or higher) is required for network license management as well as for accessing the Online Help.

The recommended minimum hardware requirements for executing MIKE 21/3 ECO Lab FM are:

Processor:	3 GHz PC (or higher)
Memory (RAM):	4 GB (or higher)
Hard disk:	160 GB (or higher)
Monitor:	SVGA, resolution 1024x768
Graphic card:	32 MB RAM (or higher), 32 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:

www.mikebydhi.com/Download/DocumentsAndTools.aspx

For further information on MIKE 21/3 ECO Lab FM software, please contact your local DHI office or the Software Support Centre:

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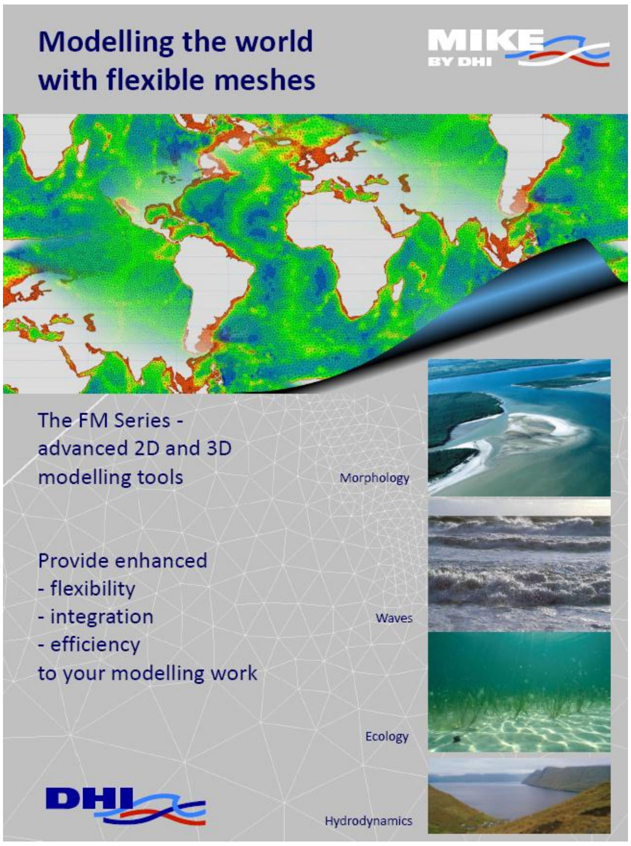

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