

MIKE HYDRO Basin Water Quality Model

MIKE ECO Lab Template Documentation

Scientific Documentation



DHI A/S headquarters

Agern Allé 5
DK-2970 Hørsholm
Denmark

+45 4516 9200 Telephone

mike@dhigroup.com

www.mikepoweredbydhi.com

Company Registration No.: DK36466871

PLEASE NOTE

COPYRIGHT

This document refers to proprietary computer software, which is protected by copyright. All rights are reserved. Copying or other reproduction of this manual or the related programmes is prohibited without prior written consent of DHI A/S (hereinafter referred to as "DHI"). For details please refer to your 'DHI Software License Agreement'.

LIMITED LIABILITY

The liability of DHI is limited as specified in your DHI Software License Agreement:

In no event shall DHI or its representatives (agents and suppliers) be liable for any damages whatsoever including, without limitation, special, indirect, incidental or consequential damages or damages for loss of business profits or savings, business interruption, loss of business information or other pecuniary loss arising in connection with the Agreement, e.g. out of Licensee's use of or the inability to use the Software, even if DHI has been advised of the possibility of such damages.

This limitation shall apply to claims of personal injury to the extent permitted by law. Some jurisdictions do not allow the exclusion or limitation of liability for consequential, special, indirect, incidental damages and, accordingly, some portions of these limitations may not apply.

Notwithstanding the above, DHI's total liability (whether in contract, tort, including negligence, or otherwise) under or in connection with the Agreement shall in aggregate during the term not exceed the lesser of EUR 10.000 or the fees paid by Licensee under the Agreement during the 12 months' period previous to the event giving rise to a claim.

Licensee acknowledge that the liability limitations and exclusions set out in the Agreement reflect the allocation of risk negotiated and agreed by the parties and that DHI would not enter into the Agreement without these limitations and exclusions on its liability. These limitations and exclusions will apply notwithstanding any failure of essential purpose of any limited remedy.

CONTENTS

MIKE HYDRO Basin Water Quality Model
MIKE ECO Lab Template Documentation
Scientific Documentation

1	Introduction	1
2	Process Description	2
2.1	General formulations	2
2.1.1	BOD, Biogeochemical Oxygen Demand	2
2.1.2	DO, Dissolved Oxygen	3
2.1.3	NH ₄ , Ammonia	4
2.1.4	NO ₃ , Nitrate	5
2.1.5	P _{tot} , Total Phosphorous	5
2.1.6	E.coli, Bacteria concentration	6
2.1.7	USER, User defined concentration component	6

APPENDICES

APPENDIX A
Model Default Values

1 Introduction

This document describes the water quality templates generated for MIKE HYDRO Basin. The current MIKE HYDRO Basin module uses DHI's generic MIKE ECO Lab module to implement water quality simulations. MIKE ECO Lab is a generic ordinary differential equation solver. Instead of a fixed set of hardcoded water quality calculations, MIKE ECO Lab offers the possibility to load various water quality models from so called MIKE ECO Lab templates. Generally the user can generate or modify their own templates or use pre-defined water quality models.

DHI provides the following two MIKE ECO Lab templates for MIKE HYDRO:

- MikeHydroWQ_DO.ecolab Water quality model with oxygen
- MikeHydroWQ_noDO.ecolab Water quality model without oxygen

The difference between the two modules is that the first one supports dissolved oxygen whereas the second one does not include dissolved oxygen.

2 Process Description

2.1 General formulations

First order equations

Most of the active processes are modelled as temperature dependent first order process according to

$$process = rate * temp_factor * [Concentration] \quad (2.1)$$

General temperature dependency

Most simulated processes are temperature depended. This temperature dependency is modelled as simple exponential Arrhenius temperature dependency with a reference temperature of 20°C according to

$$temp_factor = k * e^{T-20} \quad (2.2)$$

Where k is the applied temperature coefficient. The default value $k=1.07177$ corresponds to a doubled reaction speed with a temperature increase of 10°C, with $k=1$ no temperature dependency is present ($k = \sqrt[10]{reaction\ speed\ increase\ per\ 10^\circ C}$).

2.1.1 BOD, Biogeochemical Oxygen Demand

BOD is a common characterisation of the pollution load by organic (and inorganic) substances that consume oxygen during their breakdown.

BOD is often measured as the amount of oxygen (in mg O₂/l) consumed within 5 days, the so called BOD₅. You can use the equation below to convert between the BOD₅ and the ultimate BOD. Actually the BOD₅ value is available as extended output in the current model.

$$BOD_5 = BOD * (1 - e^{-kd3*5}) \quad (2.3)$$

Where $kd3$ is the decay constant in d⁻¹.

$$\frac{dBOD}{dt} = -BOD_Degradation \quad (2.4)$$

BOD decay

BOD decay in the current MIKE HYDRO Basin WQ model is simulated as temperature compensated simple 1st order decay with the process rate $kd3$.

$$BOD_Degradation = kd3 * temp_corr * BOD \quad (2.5)$$

2.1.2 DO, Dissolved Oxygen

This state variable and the associate process and in-/outputs are only present in the template "MikeHydroWQ_DO"

This state variable characterises the dissolved oxygen concentration. It is influenced by the exchange with the atmosphere (reaeration), consumption by BOD decay and nitrification process and various other process (bulk flux due photosynthetic O₂ production, respiration etc.).

$$\frac{dDO}{dt} = (\text{Reaeration} - \text{BOD_Degradation} - \text{NOD} - \text{BPR_Flux}) \quad (2.6)$$

Reaeration

Reaeration is the (oxygen) gas exchange with the atmosphere. In the model two different reaeration processes are considered, normal reaeration and reaeration on weirs.

$$\text{Reaeration} = (\text{NormalReaeration} + \text{WeirReaerationRate}) \quad (2.7)$$

Oxygen saturation concentration

For the reaeration, the oxygen saturation concentration DO_{sat} at a given temperature *temp* [°C] is calculated as

$$\text{DOsat} = 14.65 + \text{temp} * (-0.41022 + \text{temp} * (0.007991 - 0.000077774 * \text{temp})) \quad (2.8)$$

Normal reaeration

Normal reaeration is based on a temperature corrected O'Connor-Dobbins formulation, taking the gradient to the saturation concentration, the horizontal flow speed *Hspd* [m/s] and the water depth *Depth* [m] into account.

$$\text{NormalReaeration} = k2 * \text{temp_corr} * (\text{DOsat} - \text{DO}) \quad (2.9)$$

$$k2 = 3.9 * \text{Hspd}^{0.5} * \text{Depth}^{-1.5} \quad (2.10)$$

Weir reaeration

When water flows over weirs along a branch, the accumulated reaeration is based on the height difference *WeirHeight* (accumulated value along the branch) and the coefficient *WeirCoef*, dependent on weir geometry. The model calculates the oxygen concentration after the weir using a Holler equation approach and transforms this into a change rate used in a process equation.

Please note that hydrodynamic structures like weirs are not calculated in MIKE HYDRO Basin. The weir height has to be specified by the user as the height difference between the upstream and downstream water level in a branch if weir reaeration need to be taken into account.

$$\text{WeirReaerationRate} = (\text{DOafterWeir} - \text{DO}) * \frac{86400}{dt} \quad (2.11)$$

$$DO_{afterWeir} = \begin{cases} \text{if } (WeirHeight > 0) & \left(\begin{matrix} \text{then} & MIN \left(DO_{sat}, \left(DO_{sat} - \frac{(DO_{sat} - DO)}{(1 + WeirCoef * WeirHeight)} \right) \right) \\ \text{else} & 0 \end{matrix} \right) \end{cases} \quad (2.12)$$

BOD decay

During BOD decay oxygen is consumed. See eq. 2.5 for details.

NOD, Nitrification Oxygen Demand

The oxygen demand of the nitrification is controlled by the nitrification yield factor y_1 , specifying the relative amount of oxygen needed (g O₂ / g NH₄-N). The default value is $y_1=4.6$.

$$NOD = y_1 * \text{Nitrification} \quad (2.13)$$

BPR fluxes

Various other oxygen fluxes from general respiration and production (photosynthesis) process can be supplied as additional time series.

2.1.3 NH₄, Ammonia

Actually ammonia reacts in water according to the following equation



This reaction is depended on pH and temperature; under normal conditions and a pH < 8 most of the Ammonia is present as Ammonium (NH₄⁺). Ammonium is considered harmless and is a relevant source of nitrogen for many organisms whereas ammoniacal nitrogen (NH₃-N) is toxic, especially to fish.

The current MIKE HYDRO Basin Water Quality model does not include pH and assumes that Ammonia is present in its ionised form (Ammonium, NH₄⁺). It is released during BOD decay and consumed by nitrification.

$$\frac{dNH_4}{dt} = (\text{BOD_NH}_4\text{_Release} - \text{Nitrification}) \quad (2.15)$$

NH₄-release during BOD decay

When organic material decays, NH₄ is released proportional to the nitrogen content in the organic matter. The default for the proportional constant is $Y_d=0.1$ [g O₂ / g NH₄-N]

$$\text{BOD_NH}_4\text{_Release} = Y_d * \text{BOD_Degradation} \quad (2.16)$$

2.1.4 NO₃, Nitrate

Nitrate is another important source for nitrogen. It is generated by nitrification of NH₄. It is assumed that denitrification removes nitrogen from the nitrogen cycle as elementary nitrogen N₂ or N₂O.

$$\frac{dNO_3}{dt} = (\text{Nitrification} - \text{Denitrification}) \quad (2.17)$$

Nitrification

Nitrification is modelled as 1st order process with the process rate k_4 .

$$\text{Nitrification} = k_4 * \text{temp_corr} * \text{NH}_4 \quad (2.18)$$

Denitrification

Denitrification removes nitrogen from the nitrogen cycle as elementary nitrogen N₂ or N₂O. Denitrification is modelled as 1st order process with a process rate k_6 .

$$\text{Denitrification} = k_6 * \text{temp_corr} * \text{NO}_3 \quad (2.19)$$

2.1.5 P_{tot}, Total Phosphorous

$$\frac{dP_{\text{tot}}}{dt} = (-P_{\text{tot_Degradation}} - P_{\text{DepositInSediment}}) \quad (2.20)$$

The phosphorus degeneration is modelled as simple 1st order decay. In lakes and reservoirs phosphorus sedimentation may deposit larger amounts of phosphorus in the sediments.

Phosphorus degradation

Phosphorus degradation is modelled as simple 1st order process with the process rate $k_{P_{\text{tot}}}$.

$$P_{\text{tot_Degradation}} = k_{P_{\text{tot}}} * \text{temp_corr} * P_{\text{tot}} \quad (2.21)$$

Phosphorus sedimentation

This sedimentation in lakes or reservoirs is based on a modified Vollenweider equation. In the model, the sedimentation is active if the value *VollenweiderCoef* is different from zero. In this case the sedimentation rate is computed as:

$$P_{\text{SedRate}} = \text{IF}(\text{VollenweiderCoef}=0) \begin{cases} \text{THEN} & 0 \\ \text{ELSE} & \left(1 - \frac{\text{VollenweiderCoef}}{(1 + \sqrt{\text{ResidenceTime}})} \right) \end{cases} \quad (2.22)$$

The theoretical residence time is calculated as

$$\text{ResidenceTime} = \frac{\text{dt} * \frac{365.25}{12}}{\text{MonthLength}} \quad (2.23)$$

Please note: The phosphorus sedimentation should only be used in lakes and reservoirs. At all other locations the value of the sedimentation should be disabled by *VollenweiderCoef=0*.

2.1.6 E.coli, Bacteria concentration

The bacteria concentration is modelled as simple 1st order decay with the process rate *kEColi* according to:

$$\frac{dEColi}{dt} = -EColi_Degradation \quad (2.24)$$

$$EColi_Degradation = kEColi * \text{temp_corr} * EColi \quad (2.25)$$

2.1.7 USER, User defined concentration component

The MIKE HYDRO Basin water quality model contains a user defined “wildcard” substance with a potential 1st order decay process. If the process rate *kUser* is set to zero, the substance will act as a conservative tracer.

$$\frac{dUSER}{dt} = -User_Degradation \quad (2.26)$$

$$User_Degradation = kUser * \text{temp_corr} * USER \quad (2.27)$$

APPENDICES

APPENDIX A

Model Default Values

A Model Default Values

Table A. 1 Default values for process rates and other constants and forcings

Variable	Description	Default	Unit
RateCorr	Temperature coefficient	1.07177	-
kd3	Decay rate for BOD (20°C)	0.1	d ⁻¹
k4	Nitrification rate (20°C)	0.2	d ⁻¹
k6	Denitrification rate (20°C)	0.2	d ⁻¹
kPtot	Decay rate for P _{tot} (20°C)	0	d ⁻¹
kEColi	Decay rate for E.Coli (20°C)	0	d ⁻¹
kUser	Decay rate for user defined substance (20°C)	0	d ⁻¹
Yd	N/BOD ratio	0.1	g NH ₄ -N/ g BOD
y1*	Nitrification yield factor, g O ₂ / g NH ₃ -N	4.57	g O ₂ / g NH ₄ -N
VollenweiderCoef	Vollenweider coefficient for P sedimentation in lakes and reservoirs	0	-
WeirCoef *	Weir aeration coefficient in Holler formula	0.21	-
dt	MIKE ECO Lab time step	Built-in	Sec
Temp	Water temperature	10	°C
Hspd*	Current speed	Built-in	m·s ⁻¹
Depth*	Water depth	Built-in	m·s ⁻¹
WeirHeight*	Accumulated weir height	0	m
BPR*	Various oxygen flux time series P: production from photosynthesis B: consumption in bottom sediment R: consumption from respiration	0	mg·l ⁻¹ ·d ⁻¹

(* only present in the template "MikeHydroWQ_DO" including oxygen process)