

# MIKE URBAN+

Collection System

User Guide







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# 1 General Settings

The General Settings section contains the 'Modules' and 'Description' editors.

## 1.1 Modules

The 'Modules' editor provides an 'at a glance' view of which MU+ CS computation modules are active.

The Hydrodynamic modules include:

- Hydrodynamic (HD)
- Real Time Control (RTC)
- Long Term Statistics (LTS)
- Water Quality (AD)
- Water Quality (MIKE ECO Lab)

The Rainfall Runoff modules include:

- Rainfall Runoff (RR)
- Stormwater Runoff Water Quality (SWQ)
- Catchment Discharge
- Catchment Discharge WQ

These modules indicate which type of analysis can be used within the existing project.



The screenshot shows a 'Modules' dialog box with the following settings:

- Model type:**
  - Model: Collection system (dropdown)
  - Unit system: MU\_CS\_US (dropdown)
  - Edit button
- Collection system:**
  - ☒ Hydrodynamic (HD)
    - ☒ Real time control (RTC)
    - ☐ Long term statistics (LTS)
  - ☒ Water quality (AD)
    - ☐ Water quality (MIKE ECO Lab)
  - ☒ Sediment transport (ST)
  - ☒ Rainfall runoff (RR)
    - ☐ Stormwater runoff WQ (SWQ)
  - ☐ Catchment discharge
    - ☐ Catchment discharge WQ
- 2D overland:**
  - ☐ Hydrodynamic (HD)
  - ☐ Water quality (AD)

Figure 1.1 The Modules Editor

Please refer to the section 'Selecting an Appropriate Unit Environment' in the Model Manager User guide to select units used in the project.

## 1.2 Description

The General Settings section contains the Description editor. This editor allows addition of information about the project and a free text description of the model. It may also be used as a model build log to make notes on updates and amendments.



The screenshot shows a software window titled "Description". Inside the window, there are two labeled input fields. The first field, labeled "Title", contains the text "My Project". The second field, labeled "Description", contains the text "Description of my project." with a text cursor at the end of the line. The window has a standard grey title bar with a close button (X) in the top right corner.

Figure 1.2 The Description Editor





## 2 Map Configuration

The Map Configuration section contains information on the coordinate system used in the MIKE URBAN+ project and presents options for customising the background image.

### 2.1 Coordinate System

The Coordinate System dialog (Figure 2.1) displays the Projection system used in the project.

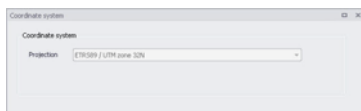


Figure 2.1 The Coordinate System dialog showing information on the projection system used in the project

The Projection system shown matches the specified Projection in the 'New Module Setup' window when the MIKE URBAN+ project was created (Figure 2.2).

It is currently not possible to modify the projection system for a project in MIKE URBAN+.

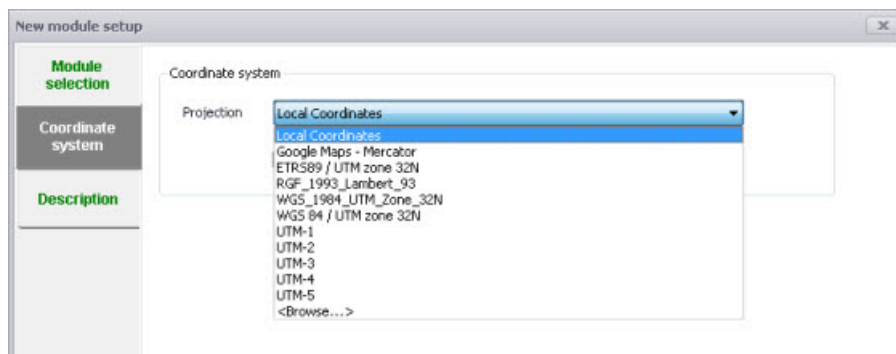


Figure 2.2 Specify the projection system for a new MU+ project on the New Module Setup window

### 2.2 Background Map

The Background Map editor allows the user to select a background image to show on the Map View in MIKE URBAN+ (Figure 2.3).

Activate a background map overlay by ticking the 'Visible' checkbox on the editor.

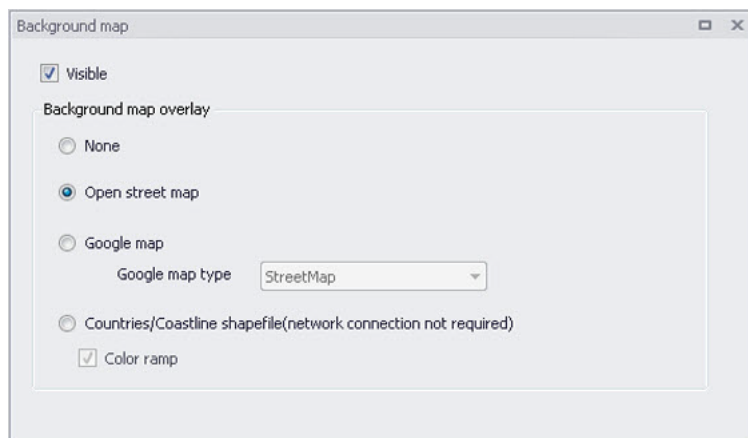


Figure 2.3 The Background Map Editor

The following background map overlay options are available:

- **None**
- **Open Street Map**
- **Google Map.** Select the Google map type to display (i.e. Street map, Satellite image, Terrain, or Hybrid).
- **Countries/Coastline Shapefile.** Polygon features that demarcate coastline or country boundaries. Tick on the 'Color ramp' option to distinguish among features by colour.

An internet connection must be available for Open Street Map and Google Map overlays (Figure 2.4).

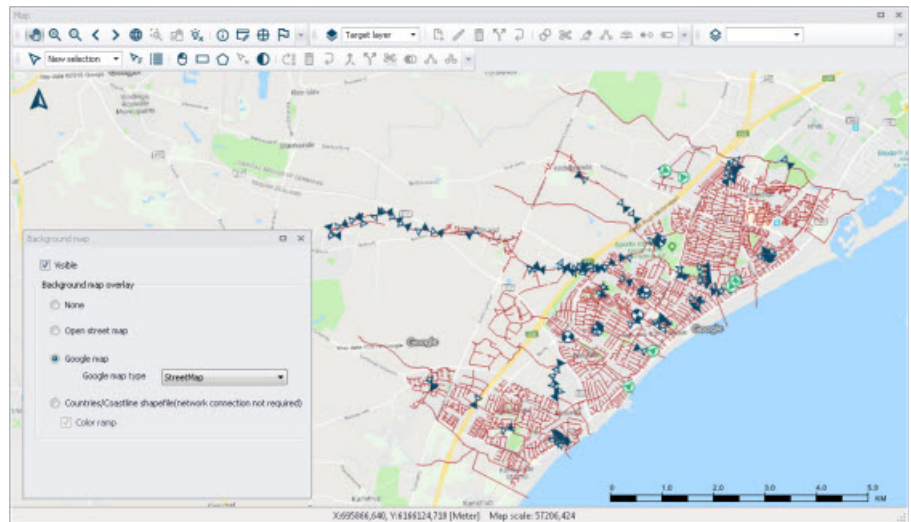


Figure 2.4 An example Google Map background on the Map View in MU+







## 3 Hydraulic Network Modelling

### 3.1 Introduction

MIKE 1D allows for the hydrodynamic simulation of flows and water levels in urban storm drainage and wastewater collection networks, thus providing an accurate information about the network functionality under a variety of boundary conditions. The hydrodynamic simulations can be extended with pollution, sediment transport and water-quality simulations. The model can also be enhanced by the variety of real-time control functions. The simulations can be carried out for single events or as efficient long-term simulations for longer historical periods.

This chapter provides a comprehensive guideline for the preparation of the basic MIKE 1D hydrodynamic simulation models. Information related to Control, Long Term Statistics, Water Quality etc. can be found in respective chapters of this manual.

Modelling of network hydrodynamics in MIKE 1D requires understanding of the information requirements. On the other hand, detailed knowledge of the computational theory is not essential.

The modelling process consists of the following distinct steps:

- Definition of the network data
- Specification of the boundary conditions
- Adjustment of the computation parameters and running the simulations
- Result analysis.

Furthermore, an important part of successful modelling is related to the model calibration and verification, which must ensure that the computed results fit reasonably well with the flow observations. These are important engineering activities in the modelling process.

### 3.2 Definition of a MIKE 1D Network

A MIKE 1D network within MIKE URBAN+ can be defined in one of the following ways:

- Import of existing MIKE URBAN+ CS Project
- Import of a backed up MIKE URBAN+ Classic project saved as a “.mdb” file
- Import of external data (e.g. GIS) into MIKE URBAN+ CS network
- Graphically digitizing and manual data typing within MIKE URBAN+

The last option is frequently used in a combination with one of the previous options as means for achieving a full consistency of the MIKE URBAN+ model.

The following paragraphs provide a comprehensive information on the MIKE 1D network data model and the associated editors.

A model consists of the following hydraulic elements:

- Nodes and Structures
- Pipes and Canals
- Weirs
- Orifices
- Curb Inlets
- Pumps
- Valves

### 3.2.1 Modelling real network elements

When setting up a model some knowledge of the principles used in the numerical solution of the flow equations is useful. This section will provide some information, for further please refer to the “MIKE 1D Reference Manual”.

In all pipes and canals the computational grid is set up in an alternating sequence of h- and Q-points. In these grid points the discharge  $Q$  and water level  $h$ , respectively, are computed at each time step. The links (pipes and canals) will always be setup with h-grid points at each end where the link connects to nodes in the network. This means that links will always have an odd number of computational grid points with three points ( h - Q - h ) as the minimum configuration.

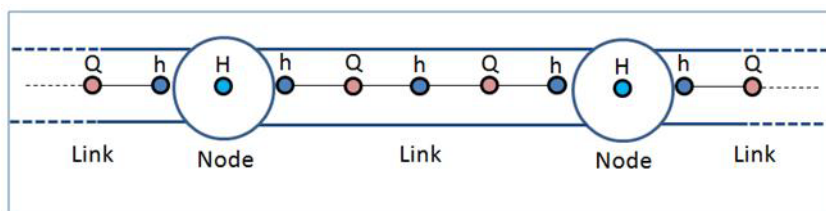


Figure 3.1 The computational grid

The nodes will only have a single computational point where the water level  $H$  is computed. The nodes are typically circular manholes in the sewer network. But it can also be basins or tanks with a significant volume. Still only a single water level computational point is located at the node. Based on the com-

puted water level and the description of the geometry of the node the computation keeps track of the volume of water stored in the node.

It is of importance to notice that only a water level is computed at the nodes. In the simple case with one incoming pipe to a node and one outgoing pipe it may seem simple to compute a "flow through" the node. But think of the more complex situations with more than two pipes connected and also external flow entering the node. Defining a "flow through the node" is in the general situation not possible.

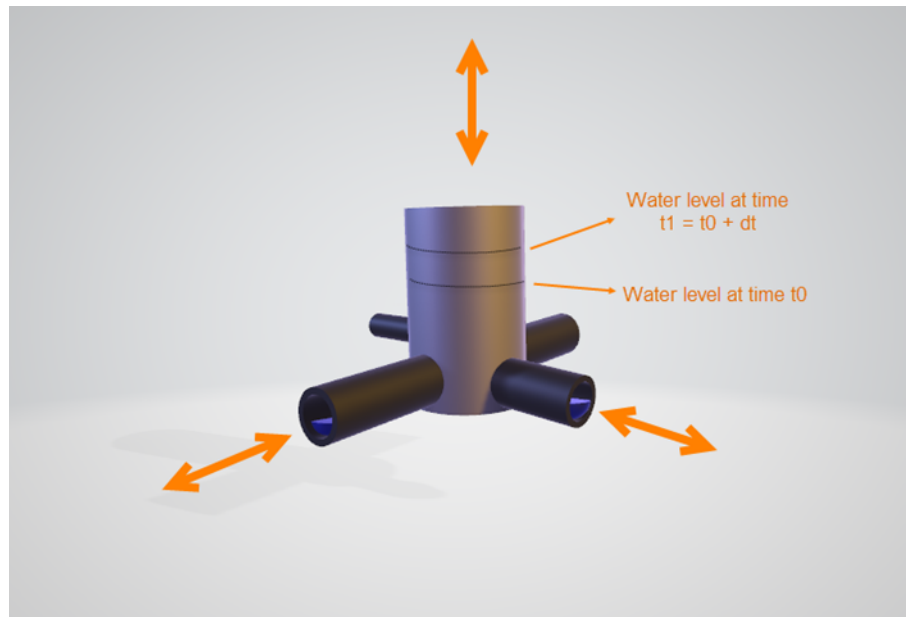


Figure 3.2 Water flowing through a node

At the nodes the water level is computed based on the water level at the previous time step and the flow contributions during the time step from each connected pipe and external connected flow like a catchment runoff discharge. When the computational grid is set up for a network of links and nodes it will end up like shown in Figure 3.3.

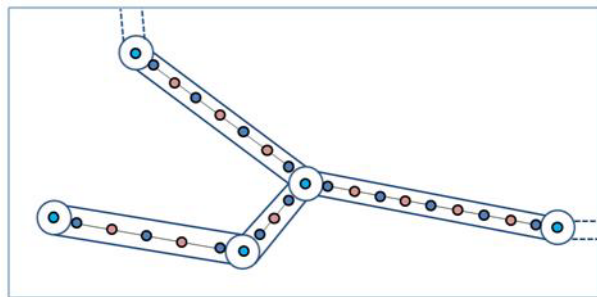


Figure 3.3 The computational grid for a given network

MIKE1D is able to handle various “devices” which basically are related to manholes, basins, soakaways or other constructions in the sewer network. These devices are: pumps, weirs, orifices, valves and storm water inlets. Typically these elements are placed at locations which in the real system could be manholes, basins or other structures. It is also characteristic for all mentioned elements that there will be a discharge computed for the device: pump discharge, discharge over weir, flow through orifice and flow through valve.

The main point to realize is the conflict between computing a discharge for these elements and the fact that only a water level is computed at nodes.

This is why the pump, weir, orifice, valve and storm water inlet elements from the computational and numerical point of view are links and not an element placed in one node. All the elements are links forming a connection between two nodes.

In MIKE URBAN+ we have five functional elements which from the model building point of view are related to nodes like manholes or basins. These are pumps, weirs, valves, orifices and storm-water inlets. The concept of elements related to nodes is reflected in the design of the dialog for editing the parameters for these elements. Here you find a field named “From” for all of the elements. The field takes the ID of a node as input. All elements also have a field for “To:” which also takes a node ID as input.

Seen from the computational solution point of view the five elements are actually connections from one node to another node. This is similar to how pipes are defining the link for flow between nodes as reflected in the dialog where you find fields for entering “From node:” and “To node:”.

### 3.3 Nodes and Structures

The editor makes it possible to define the elements used to model manholes, outlets and basins in a storm and sewer collection system.

The editor organizes the related input data into the following groups:



- ID and position - general identification and location information
- Geometry - allows the user to select the “Node Type”, define diameters, levels and basin geometry volume curves.
- Cover - defining the type of cover for a manhole type node.
- Flow regulation - maximum inflow; in/exfiltration;
- Head loss - information on the head loss approach and coefficients
- Pressure node - used for tail nodes of pressurized branches.
- Soakaway - defining parametrization of the soakaway element
- Description - Descriptive field

	ID	X coordinate [m]	Y coordinate [m]	Node type	Diameter [m]	Ground level [m]	Bottom level [m]	Basin geom
1	Node_1	4,680,725,097,656,25	0,566,711,425,781,25	Manhole	8,00	10,00	8,00	
2	Node_2	7,301,086,425,781,25	4,202,270,507,812,5	Manhole	6,00	10,00	8,00	
3	Node_3	8,729,492,187,5	3,376,098,632,812,5	Manhole	5,00	10,00	8,00	
4	Node_4	1,812,072,753,906,25	2,455,322,265,625	Outlet	5,00	10,00	8,00	

Figure 3.4 Nodes and Structures editor

MIKE 1D distinguishes between four types of nodes: circular manholes, basins, soakaway and outlets. The same dialog is used for all four node categories, but the dialog adapts according to the selected node type.

Manholes and basins are per default considered open at the top (Cover type equal to 'Normal'). This means, that when the water level in a node reaches the ground level, the water spills on the top surface. In that case, MIKE 1D introduces an artificial basin on the top of the node, with a surface area 1000x larger than the node's surface. The surcharged water is stored in the basin, to be returned back into the sewer.



Alternatively, the option of “Use non-standard cover” enhances the possibility to specify a sealed/locked node (Cover type equal to 'Sealed'), i.e. a node with a fixed lid on the top - at the ground level - so water cannot escape although the pressure still builds up inside.

On the other hand, a node can be specified as a 'spilling' node (Cover type equal to 'Spilling'). In a spilling node, water escapes irreversibly from the model, if the water level reaches and exceeds the node's ground level (optionally set off by a 'buffer pressure level'). The rate of spill is approximated as a free overflow over the crest at a given level and with a “conceptual” crest length. For further details, see the MIKE 1D Reference Manual.

In the tables given below each data variable is described shortly and if it is required as input.

### 3.3.1 Identification group

Each node is geographically determined by 'x' and 'y' co-ordinates. The co-ordinates may be specified in any local coordinate system.

The options Insert and Delete allows addition and deletion of network elements directly in the editor.

Table 3.1 The edit fields in the Identification group (Table msm\_Node)

Edit field	Description	Used or required by simulations	Field name in data structure
Asset ID	Reference to an ID used in external data sources	No	AssetName
Data source	Reference to an external data source (table ID) where the record has been imported from	No	DataSource
Node ID	A unique name for the node. Up to 40 characters (letters, numbers, blank spaces and underscore characters)	Yes	MUID
Model	Associates the current node to a specified submodel	No	SubModelNo
Description	User's descriptive information related to the node	No	Description
Status	Data status for the entire record, serves for keeping track on the source of information	No	Element_S



Table 3.1 The edit fields in the Identification group (Table msm\_Node)

Edit field	Description	Used or required by simulations	Field name in data structure
Network type	Attributes the link to a certain type of network. Used in cases when two or more different networks are included in the same project	No	NetTypeNo
X coordinate	X coordinate of the node position	Yes	Shape_X
Y coordinate	Y coordinate of the node position	Yes	Shape_Y
Links	Number of links going to or from the node. Non-editable value.	-	-

### 3.3.2 MIKE 1D model data group

Table 3.2 The edit fields in the MIKE1D model data group (Table msm\_Node)

Edit field	Description	Used or required by simulations	Field name in data structure
Node type	MIKE 1D Node Types: 1. Manhole - node with shaft and chamber storage 2. Basin - node with a more complex geometry 3. Outlet - node where water leaves the system (no storage) 4. Soakaway - node with a similar geometric complexity as a basin but with the features of infiltration and internal porosity.	Yes	TypeNo
Diameter	Diameter of the manhole - not enabled for any other node types	Yes	Diameter
Ground level	Ground level of the node	Yes	GroundLevel
Bottom level	The bottom level of the manhole	Yes	InvertLevel



Table 3.2 The edit fields in the MIKE1D model data group (Table msm\_Node)

Edit field	Description	Used or required by simulations	Field name in data structure
Critical level	User defined critical level. Used in result presentations and in the Pipe Design module	Yes	CriticalLevel
Use maximum flow [Tickmark]	Activates the inlet delimiter function	Yes	InletControlNo
Max. Inflow	Value of maximum possible inflow into the node from runoff	Yes	MaxInlet
Use QH relation [Tickmark]	Switch for choice of the comp. method for hydraulic conditions at the outlet, in a manhole or basin. When toggled on uses Q-H tabulated function, toggled off calculates on the basis of water level (see note below this table)	Yes	QHTypeNo
[Text string]	Reference to a tabulated Q-H relation	Yes	OutletQHID
Use non-standard cover [Tickmark]	Activates the use of non-standard cover	Yes	CoverTypeNo
Type	Choose among available types: 1. Normal 2. Sealed 3. Spilling	Yes	CoverTypeNo
Buffer pressure	Buffer pressure is only active for type = spilling. Equal to the pressure above the ground level needed to cause spills from the manhole	Yes	BufferPressure
Spill coeff.	Spill coefficient is only active for type = spilling. Controls the spill capacity	Yes	SpillCoeff
Geometry ID	Reference to a tabulated area-elevation function for the basin geometry. The H-column for the basin geometry can start at any value, e.g. 0.0 for interpretation of H as depth in the basin. The MIKE 1D Engine will associate the first H-value to the bottom level of the node.	Yes	GeometryID





Table 3.2 The edit fields in the MIKE1D model data group (Table msm\_Node)

Edit field	Description	Used or required by simulations	Field name in data structure
ID	Reference to a head loss parameter set	Yes	LossParID
Method	Method selected for the actual head loss parameter set	-	-
Use local parameters [Tickmark]	Switch for use of local head loss data	Yes	LossParNo
Coeff.	Locally defined interpretation of head-loss coefficient. Km="shape coefficient", Cont. HLC= outlet contraction head losshead loss coeff. (relative to velocity head) , Total HLC = outlet total head losshead loss (relative to velocity head)	Yes	LossTypeNo
[Field next to coeff field]	Local value of loss coefficient	Yes	LossCoeff
Eff. flow area	Locally defined choice of method for the calculation of wetted area 1.Full Node Area 2. Calculated Effective Area 3. Reduced calculated Effective Area	Yes	EffAreaNo
Pressurized tail node	Definition of the node's role in the pressure main as the downstream point of the pressure main's connection to the network. Manholes and basins can be declared as a "Tail Node". Please refer to the MIKE 1D Reference Manual.	Yes	PMTypeNo
Tail level	Water level (absolute elevation) in the "receiving node", used as lower boundary for permanently pressurized parts of the system. Please refer to the MIKE 1DReference Manual for further on pressure mains.	Yes	PMLevel
Porosity of fill material	Porosity of filling material	Yes	Porosity of fill material
Kfs, bottom	Conductivity of soil	Yes	Kfs, bottom



Table 3.2 The edit fields in the MIKE1D model data group (Table msm\_Node)

Edit field	Description	Used or required by simulations	Field name in data structure
[Tickmark]	Activates the bottom conductivity function	Yes	
Infiltration method	Method of infiltration	Yes	Infiltration method
Infiltration rate	Defines the infiltration rate	Yes	Infiltration rate
Initial water level	Initial water level in soakaway	Yes	Waterlevel

### 3.3.3 Q-H relations for nodes

Specifying a Q-H relation for an outlet controls the flow at the outlet. The flow (Q) value in the Q-H relation should be given as a positive value when water enters the node and a negative value for specifying a loss of water from the network model.

### 3.3.4 Outlet head loss

If you wish to make changes to the head loss parameter set that you have made a reference to, you can change this by accessing the Tables| Outlet Head Losses tab. The editor is shown in Figure 3.5.

Figure 3.5 Outlet head loss editor

### 3.3.5 Model Concept of Soakaway

Detailed hydraulic modelling of the green solutions can be done by means of the network point node type in MIKE URBAN+ - named soakaway. The soakaway can be connected to the pipe network as any other node elements for detailed hydraulic studies. With this implementation in MIKE URBAN+ the soakaway represents a generic type of LID control as it can represent a number of different WSUD controls. The soakaway can be digitized graphically and it has its own feature layer which can be viewed in the horizontal plan view.

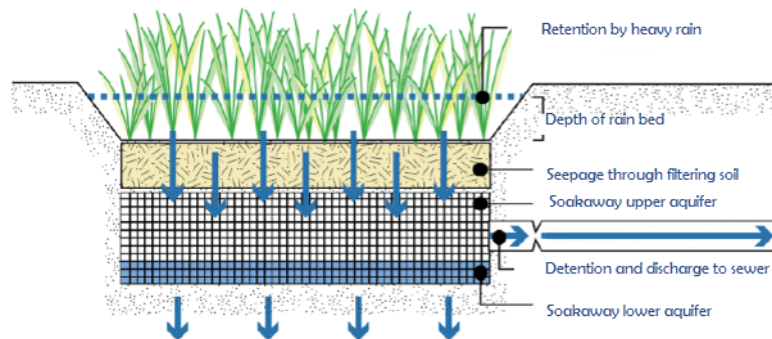


Figure 3.6 Conceptual drawing of a soakaway

A schematic drawing of a soakaway (Bioretention cell) is illustrated in Figure 3.6. The stormwater drains of the surface and enters the soakaway at the upper vegetated layer. Then the stormwater infiltrates vertically through the soakaway and infiltrates out of the sides and bottom of the soakaway.

In some cases the soakaway is not connected to any drainage network and captured runoff to the soakaway is infiltrated and in case of extreme rainfall and exceedance of its infiltration and storage capacity storm water is surcharged to the surface.

In other cases the soakaway is connected to the drainage network by a flow controlled outlet pipe as illustrated in Figure 3.6. During extreme rainfall causing exceedance of its infiltration, storage and outlet flow capacity, the soakaway also surcharges to the surface.

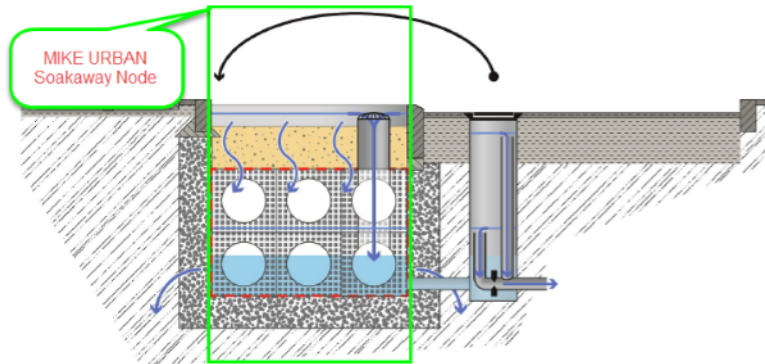


Figure 3.7 Soakaway concept in MIKE URBAN+

A Soakaway will be represented in MIKE URBAN+ as a node (point) as shown in Figure 3.7.

Since a Soakaway is defined as a node type then the remaining configuration is unlimited in terms of

- Inlet pipe(s) + Flow Regulation
- Outlet pipe (s) + Flow Regulation
- Weirs (s) or Orifice (s)

Connection to the existing drainage system can be configured to match the various types of soakaway installations. Soakaway nodes can i.e. be coupled in series to support the modelling of constructed infiltration trenches.

The soakaway can be added graphically and/or imported from any Asset GIS system hence existing soakaways can be illustrated in the plan view of MIKE URBAN+.

The Soakaway node has the following attributes:

- NodeTypeNo = 5 (Soakaway node)
- Invert Level
- Ground Level
- Geometry - defined as basin geometry

The inflow to the Soakaway can be provided as:

- Direct Inflow (constant, time series)
- Inflow from Rainfall Runoff (Runoff model A, B, C, Unit Hydrograph).
- Various infiltration rate options

- No infiltration
- Qinf - constant or as time series through boundary condition system
- Qinf, side - function of wetted side area. This is calculated by MIKE 1D based on basin geometry
- Qinf, bottom - function of bottom area
- Saturated hydraulic conductivity [m/s]
- Porosity of the soakaway material [ ]

The soakaway is modelled as a regular basin in MIKE URBAN+, and it is also MIKE URBAN+ that calculates the water level based on the inflow (runoff), outflow to the drainage network (via overflow pipe, weir, orifices etc.) and the infiltration. The soakaway has, unlike a basin, a porous filling material that affects the water level calculations, this is accounted for in the MIKE 1D and the basin geometry is defined as a usual basin geometry description.

The overflow pipe, weir or orifice is modelled in MIKE URBAN+. Make sure that the up level of the pipe, weir or orifice is set correctly, and not at the bottom of the basin which will be the case if no invert level is specified. If the pipe is placed at the bottom then make sure that flow regulation is applied to the out-going pipe. The inflow pipe is generally not modelled; instead the catchment that generates the runoff to the soakaway (e.g. a road section, a roof) is connected directly to the basin via the catchment connection facility in MIKE URBAN+.

A new point feature layer has been created to illustrate the soakaway in the plan view and to be used for graphical digitization and graphical connection of soakaway to existing drainage network.

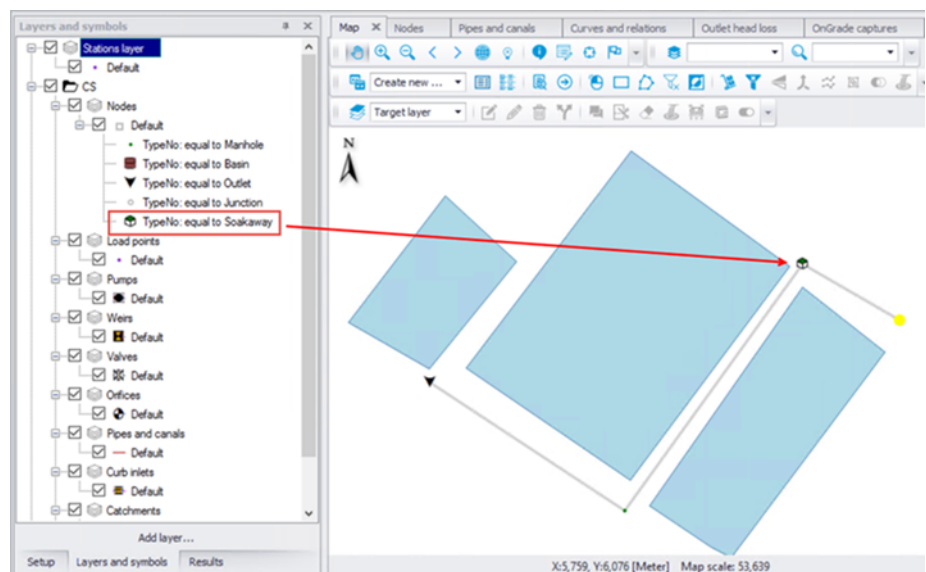


Figure 3.8 Soakaway shown in Feature layer



At the 'Geometry' tab in the dialog the type of node is selected in the Node type combobox and the following attributes are set:

- Ground Level
- Invert Level
- Basin Geometry

The geometry of the soakaway is defined as a standard basin.

## Soakaway

At the 'Soakaway' tab in the Node dialog the type of infiltration, porosity and initial water level is selected.

The following types of infiltration are available:

- No Infiltration
- Constant Infiltration
- Infiltration

The screenshot shows the 'Nodes' dialog box with the 'Soakaway' tab selected. The 'Identification' section shows 'Node\_2' as the ID, with X and Y coordinates of 7,30108642578125 [m] and 4,2022705078125 [m] respectively. The 'Soakaway' tab contains the following fields:

Field	Value	Unit
Infiltration method	Infiltration	
Infiltration rate		[mm/h]
Porosity of fill material		
Initial water level		[m]
Kfs, side		[mm/h]
<input type="checkbox"/> Kfs, bottom		[mm/h]

Figure 3.9 Node Editor

The option 'No Infiltration' is used in cases when there is no infiltration out of the soakaway. The initial water level can be set.

The 'Constant Infiltration' option provides the functionality of defining a constant infiltration rate out of the soakaway. The input required for this option is the Infiltration rate, the porosity of the fill material and the initial water level.

The 'Infiltration' option provides the functionality of having a variation in the infiltration based in the water level in the soakaway. A schematic drawing of the soakaway is provided in Figure 1.5 and Equation 1 describes the water balance of the model. Equation 2 and Equation 3 describe how the infiltration rate is calculated. Parameters and variables are listed and explained and how they are used in MIKE 1D.

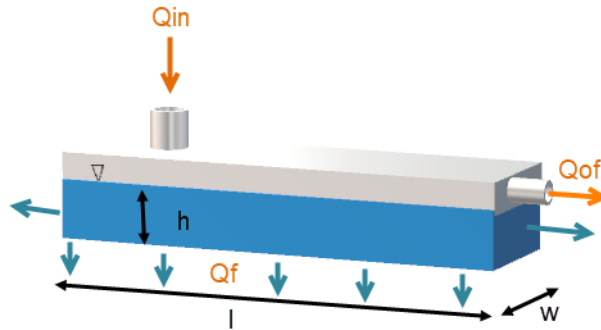


Figure 3.10 Schematic of the soakaway model

The 'Infiltration' option is based on the infiltration rate calculated by Equation (3.1) and Equation (3.2):

$$\frac{dh}{dt} = \frac{1}{l \cdot w \cdot \theta} (Q_{in}(t) - Q_f(t) - Q_{of}(t)) \quad (3.1)$$

$$Q_f = K(l \cdot w + 2h(l + w)) \quad (3.2)$$

where  $\theta$  is the soakaway porosity and  $h$  the calculated water level.

In MIKE 1D the infiltration rate calculated by Equation (3.2) is rewritten to Equation (3.3) to be based on the basin geometry definition in MIKE URBAN+ as well as to support different hydraulic conductivity at the side and at the bottom.

$$Q_f = K_{fs, bottom} \cdot A_{s, h=0} + K_{fs, side} \cdot \left( 2A_c + 2\frac{Vol}{A_c} \right) \quad (3.3)$$

where  $K_{fs, bottom}$  is the field-saturated hydraulic conductivity at the bottom,  $K_{fs, side}$  is the field-saturated hydraulic conductivity at the side,  $A_s$  is the surface area and  $A_c$  the cross-sectional area.



The infiltration from the bottom can be turned off by a flag. However the infiltration from both side and bottom can be shut off by setting the field-saturated hydraulic conductivity to zero.

The porosity of the fill material is used to calculate the water level in the soak-away and the initial water level is used to set the initial water level in the soak-away. Table values of hydraulic conductivity,  $K_{fs}$ , for different soil classes are provided in Table 3.3. Within each soil type the hydraulic conductivity varies significant why it is important to the measure the hydraulic conductivity at the site.

Table 3.3 Hydraulic conductivity for different soil classes

Soil classification	Hydraulic Conductivity [m/s]
Gravel	0.001 to 0.1
Sand	$10^{-5}$ to $10^{-2}$
Silt	$10^{-9}$ to $10^{-5}$
Clay	Below $10^{-9}$ to $10^{-2}$
"Moræneler"	$10^{-10}$ to $10^{-6}$

## 3.4 Pipes and Canals

ID	From node	To node	Enabled	Type	Height [m]	Width [m]	Diameter [m]	Length [m]
1	Link_1	Node_1	Node_2	<input checked="" type="checkbox"/>	Circular			5

Figure 3.11 Pipes and Canals editor

A link is specified as a conduit between two nodes. A link is considered as either a straight line or a drawn polyline between two nodes and per default is assumed to connect the adjacent nodes at bottom levels.





Pipes permanently running under pressure are specified by setting the tick-mark in “Pressure main” in the “Pressurized” tab. Please refer to the MIKE1D Reference Manual (Pipe Flow) for further information on pressure main branches.

In case of a step-wise connection (but not allowed below node bottom level), the elevations of both the upstream and downstream connection must be specified in the editable “UpLevel” and “DwLevel” fields.

Specification of nodes as 'upstream' and 'downstream' does not have any impact on the computations, apart that positive flow is considered from upstream to downstream. Therefore, it is recommended to specify the upstream and downstream in the direction of predominant flows.

Depending on the selected type, a link may take the form of one of the 'standard' pipes (Circular, Rectangular, O Shaped, Egg-Shaped), or any closed or open cross section shape (CRS) and Natural Channels. The CRS and Natural Channels are defined in the Generic CRS and Topography Editors.

Standard pipes are defined by diameter (or cross section width and height for non-circular pipes), the geometry of special cross sections is as mentioned specified under the cross section editor. In this dialog, only the reference to the CRS ID.

The topography is specified through a Cross Section file (.xns) file. This type of file offers the possibility to store several measurement data from different campaigns (e.g. from different years or before and after the construction of infrastructure in the channel).

A link is characterised by material, which determines the Manning friction coefficient (Manning), the Colebrook White coefficient (Equivalent roughness) or Hazen-Williams coefficient. It is optional to use either the default roughness values for specific materials or local values.

Specification of the different kind of materials and roughness coefficients is done through the 'Tables | Materials' in the TOC



ID	Manning [m <sup>1/3</sup> /s]	EQ rough [m]	HW coefficient	Description
1 Ceramics	70,0000000	0,0032500	110,0000000	
2 Concrete (Normal)	75,0000000	0,0015000	120,0000000	
3 Cement Mortar	77,0000000	0,0010000	120,0000000	

Figure 3.12 Materials Editor

The length of a link is calculated from the shape of the line in MIKE URBAN+. The length is displayed in the 'Geometric length' field, and it is updated when the geometric reference is modified. If a user defined length is specified this will overwrite the calculated one during simulation.

### 3.4.1 Identification group

Table 3.4 The edit fields in the Identification group (Table msm\_Link)

Edit field	Description	Used or required by simulations	Field name in data structure
Asset ID	Reference to an ID used in external data sources	No	AssetName
Data source	Reference to an external data source (table ID) where the record has been imported from	No	DataSource
Link ID	A unique name for the node. Up to 40 characters (letters, numbers, blank spaces and underscore characters)	Yes	MUID



Table 3.4 The edit fields in the Identification group (Table msm\_Link)

Edit field	Description	Used or required by simulations	Field name in data structure
Status	Data status for the entire record, serves for keeping track on the source of information	No	Element_S
Description	User's descriptive information related to the link	No	Description
Network type	Attributes the link to a certain type of network. Used in cases when two or more different networks are included in the same project	No	NetTypeNo
From node	Upstream Node	Yes	MUID
To node	Downstream Node	Yes	MUID
Pressure main	Defines a link as pressure main. A link connected to a manhole or basin, can only constitute a pressure main if the manhole/basin is declared to be "tail node". Please refer to the MIKE1D Reference Manual (Pipe Flow) for further on pressure mains.	No	PMAprNo
Use specified Preissmann slot ratio	Rising main conversion factor	No	SlotNo

### 3.4.2 Geometrical properties

Table 3.5 Geometry (Table msm\_Link)

Edt field	Description	Used or required by simulations	Field name in data structure
Shape	Shape of pipe	Yes	TypeNo
Diameter	Nominal size of pipe (diameter of circular pipe, height of Egg-shape pipe and width for O-shaped)	Yes, if Shape = Circular, Egg-Shape and O-Shaped	Diameter



Table 3.5 Geometry (Table msm\_Link)

Edt field	Description	Used or required by simulations	Field name in data structure
Width	Width of rectangular shape	Yes, if Shape = Rectangular	Width
Height	Height of rectangular shape	Yes, if Shape = Rectangular	Height
Cross Section	ID of cross section	Yes, if shape = CRS	CrsID
Topography	ID of topography	Yes, if Shape = natural channel	TopographyID
Max Dx	Max distance between gridpoints	Yes, if Shape = natural channel	Maxdx
Length	Length of link	Yes	Length
UpLevel	Upstream invert level of link	Yes	UpLevel
DwLevel	Downstream invert level of link	Yes	DwLevel



### 3.4.3 Hydraulic friction losses

### 3.4.4 Flow Regulation

Table 3.6 Hydraulic friction losses (Table msm\_Link)

Edit field	Description	Used or required by simulations	Field name in data structure
Material	Material of link	Yes	MaterialID
Formulation	Formula for calculation of the friction loss (Manning Explicit, Manning Implicit, Colebrook White, Hazen-Williams)	Yes	FricTypeNo
Use local data	Determines if roughness values from the material are overwritten by local values	Yes	FricNo
Manning	Manning roughness value	Yes, if 'Manning Explicit' or 'Manning Implicit' is chosen	Manning
Eq. roughness	Equivalent roughness	Yes, if 'Colebrook White' formulation is chosen	Rough
H-W coef	Hazen-Williams roughness coefficient	Yes, if 'Hazen-Williams' is chosen	HWCoeff
Use depth-dependent friction loss	Varying friction resistance depending on the depth	Yes, if depth-dependent friction is selected	FricNo
Top	Depth-variable Manning number on Top	Yes, if depth-dependent friction is selected	ManTop



Table 3.6 Hydraulic friction losses (Table msm\_Link)

Edit field	Description	Used or required by simulations	Field name in data structure
Bottom	Depth-variable Manning number on Bottom	Yes, if depth-dependent friction is selected	ManBott
Exponent		Yes, if depth-dependent friction is selected	ManExp

The 'Regulation' tab provides access to inserting a regulation in the selected link. This regulation does not require the Control module. The regulation can be either a maximum discharge as a function of the water level in a user specified node (Ctrl. Node A) or a maximum discharge as a function of the water level difference between two user specified nodes (Ctrl. Node A and Ctrl. Node B).

Table 3.7 Flow regulation (Table msm\_Link)

Edit field	Description	Used or required by simulations	Field name in data structures
Use flow regulation [Tickmark]	Allows the option to regulate flow to a given link	Yes, if flow regulation is chosen	FlowRegNo
Regulation type	Select the type of function desired to regulate the flow	Yes, if flow regulation is chosen	RegulaitonTypeNo
Function ID	Select the function that regulates the flow	Yes, if flow regulation is chosen	FunctionID
Non return valve [Tickmark]	Allows flow through the link in one direction only.	No	NonReturnNo



## 3.5 Weirs

A weir is actually a functional relation, which connects two nodes of a MIKE 1D urban network (two-directional flow and submerged flow possible), or is associated with only one node (free flow 'out of the system'). The latter case is achieved if the 'To' field is left empty.

Real urban sewer systems configure a weir to be located in a manhole or a similar construction which you normally would define as a node in the digital model. The numerical solutions for the flow equations, however, need a model configuration with two nodes where the weir is defined as the connection between the nodes. The weir will then be placed between the two nodes as the flow connection.

It is possible to define several weirs between the same two nodes if this is required. This is similar to the possibility of having more than one pipe as the link between nodes. The generation of the computational grid shown in Figure 3.14 for the orifice is also applied for pumps, weirs and valves. The numerical solution of the flow equations will depend on the selected device. Please refer to the reference manual on more on this.

It is recommended not to place the two nodes in the same spot, instead place the nodes a short distance apart. The reason is that the node head loss computation will have a component from change of flow direction. If the two nodes surrounding the device are placed exactly at the same location then the computational engine cannot determine the direction of the flow from the coordinates of the nodes and a default direction will be applied. This may unintentionally introduce a change in direction and therefore also an unexpected head loss.

By using a small displacement of the nodes the change in flow direction will be determined based on the coordinates and angles between the connected pipes. Therefore consider carefully the placement of the nodes with respect to the actual construction.

The screenshot shows the 'Weirs' editor window. It has three tabs: 'Geometry', 'Regulation', and 'Description'. The 'Geometry' tab is selected. In the 'Identification' section, the 'ID' is 'Weir\_1', 'From node' is 'Node\_1', and 'To node' is 'Node\_2'. There are 'Insert' and 'Delete' buttons. Below the tabs, there are several input fields: 'Computational method' is set to 'Weir Formula' with a dropdown arrow; 'Crest level' is an empty field with '[m]' unit; 'Discharge coeff.' is '0,403'; 'Crest width' is '0,8' with '[m]' unit; 'Orientation' is 'Side overflow' with a dropdown arrow; 'Q-H table' is an empty field with an 'Edit' button; and 'Crest geometry' is an empty field with an 'Edit' button. At the bottom, there is a table with columns: ID, From node, To node, Type, Crest level [m], Coefficient, Crest width [m], and Orientation. The table has one row with ID 'Weir\_1', From node 'Node\_1', To node 'Node\_2', Type 'Weir Formula', Crest level empty, Coefficient '0,403', Crest width '0,8', and Orientation 'Side overflow'.

Figure 3.13 Weirs editor

A weir is characterised by the computational method, weir type, crest level, crest width, and orientation. If the Q-H relation is specified, only the crestlevel and a DataSetID are specified. With the built-in weir formula, the results are affected by the specified parameters. The computational method for the weir can be set as “Weir Formula”, “Energy loss coefficient”, “Q-H relation” and “CRS Weir Formula”

The parameter 'Orientation' ('degrees') plays an important role (as long as the head loss coefficient is undefined), since depending on the specified orientation, kinetic energy of the flow is included (90°) or is not included (0°) in calculations of the weir flows.

The dimensionless head loss coefficient is optional. If the coefficient is specified, it will overwrite the default and change the computation mode (so that the effect of 'orientation' will not be included) during the simulation.

Weirs are per default static (No Control) but can be controlled through real time control (RTC). Flagging the “Controlled through real time control” gives quick access to the “Control rules” specification dialog.

There are no limitations on the number of weirs specified at one location.





### 3.5.1 Identification and connectivity

Table 3.8 Description (Table msm\_Weir)

Edit field	Description	Used or required by simulations	Field name in data structure
Description	User's descriptive information related to the weir	No	Description
Data source	Reference to an external data source (table ID) where the record has been imported from	No	DataSource
Asset ID	Reference to an ID used in external data sources	No	AssetName
Status	Data status for the entire record, serves for keeping track on the source of information	No	Element_S
Network type	Attributes the weir to a certain type of network. Used in cases when two or more different networks are included in the same project	No	NetTypeNo
Weir ID	A unique name for the weir. Up to 40 characters (letters, numbers, blank spaces and underscore characters)	Yes	MUID
From node	ID of Node where Weir is located	Yes	MUID
To node	ID of Node where Weir is discharging to. If field left empty, then water is discharging out of the system	Yes	MUID

### 3.5.2 Model data

Table 3.9 Weir Geometry and Regulation (Table msm\_Weir)

Edit field	Description	Used or required by simulations	Field name in data structure
Computational method	Selection of computation Method	Yes	MethodNo
Crest level	Crest level of weir	Yes	CrestLevel



Table 3.9 Weir Geometry and Regulation (Table msm\_Weir)

Edit field	Description	Used or required by simulations	Field name in data structure
Discharge coeff.	Discharge coefficient	Yes, if weir formula is chosen	Coeff
Crest width	Width of rectangular weir	Yes, if weir formula is chosen	CrestWidth
Orientation	Weir orientation relative to the main flow direction. "0" is Side weir, "90" is a transversal weir	Yes, if discharge coeff. is not specified	AngleNo
Q-H table	Reference to tabulated Q-H function	Yes, if Q-H is chosen	QHID
Crest Geometry	Reference to tabulated variation of the weir crest along the weir, CRS geometry	Yes	WeirCrestID
Non return flap	Flap indicating a flap-gate built-in weir (i.e. no return flow possible)	Yes	FlapNo
Controlled through real time control	No control or RTC controllable weir	Yes, if RTC control is selected	ControlTypeNo
Max level	The maximum elevation of a movable weir crest	Yes, if RTC control is selected	Max-CrestLevel
Min level	The minimum elevation of a movable weir crest. The fixed weir is not used for RTC weir	Yes, if RTC control is selected	Min-CrestLevel
Max speed up	The maximum velocity for movement of the weir in upward direction	Yes, if RTC control is selected	Max-CrestLevelIncreaseSpeed
Max speed down	The maximum velocity for movement of the weir in downward direction	Yes, if RTC control is selected	Max-CrestLevel-decreaseSpeed

## 3.6 Orifices

An orifice is actually a functional relation, which connects two nodes of a MIKE 1D urban network or is associated with only one node (free flow 'out of the system'). The latter case is achieved if the 'To node' field is left empty.



In real urban systems a flow restriction in the form of an orifice may be located in a manhole or a similar construction which you normally would define as a node in the model configuration. The numerical solutions for the flow equations, however, need a model configuration with two nodes where the orifice is defined as the connection between the nodes. The orifice will then be placed between the two nodes as the flow connection.

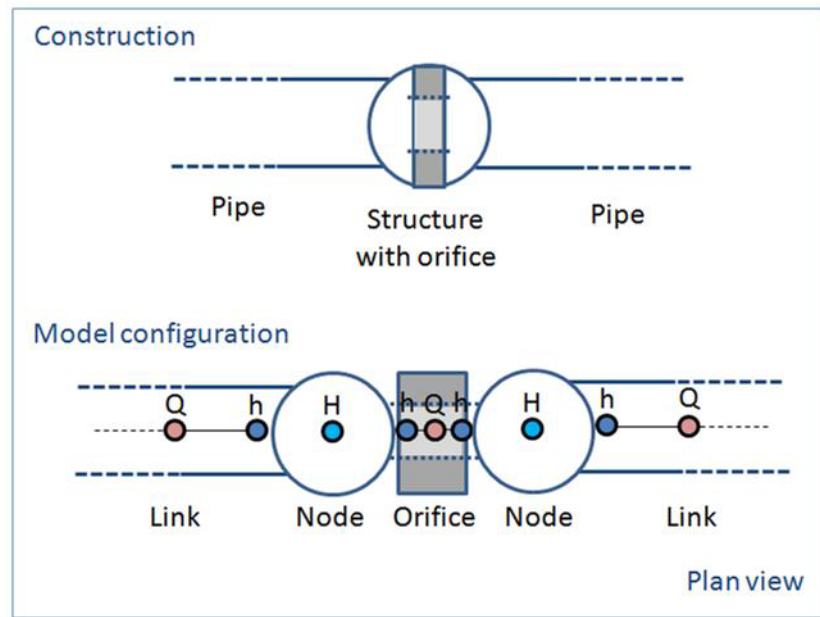


Figure 3.14 The difference between real world orifice and model configuration of orifice

It is possible to define several orifices between the same two nodes if this is required. This is similar to the possibility of having more than one pipe as the link between nodes. The generation of the computational grid shown in Figure 3.14 for the orifice is also applied for pumps, weirs and valves. The numerical solution of the flow equations will depend on the selected device. Please refer to the reference manual on more on this.

It is recommended not to place the two nodes in the same spot, instead place the nodes a short distance apart. The reason is that the node head loss computation will have a component from change of flow direction. If the two nodes surrounding the device are placed exactly at the same location then the computational engine cannot determine the direction of the flow from the coordinates of the nodes and a default direction will be applied. This may unintentionally introduce a change in direction and therefore also an unexpected head loss.



By using a small displacement of the nodes the change in flow direction will be determined based on the coordinates and angles between the connected pipes. Therefore consider carefully the placement of the nodes with respect to the actual construction.

An orifice is specified by a type; circular, CRS or rectangular, and the corresponding diameter, height and width.

A discharge coefficient can be specified (default = 1.0) and a non-return flap can be specified.

Orifices are per default static (No Control) but an orifice can be controlled through Real Time Control (RTC). Clicking on the “RTC” button to the right gives quick access to the RTC specification dialog.

Orifices

Identification

ID:

From node:  ...

To node:  ...

Geometry Regulation Description

☐ Non return flap

☐ Controlled through Real Time Control

Max level  [m] Max speed up

Min level  [m] Max speed down

	ID	From node	To node	Type	Invert level [m]	Discharge Coeff.	Diameter [m]
▶ 1	Orifice_1	1		Rectangular	114,000000	1,000000	

Figure 3.15 Orifice editor



### 3.6.1 Identification and connectivity

Table 3.10 Description (Table msm\_Orifice)

Edit field	Description	Used or required by simulations	Field name in data structure
Description	User's descriptive information related to the orifice	No	Description
Data source	Reference to an external data source (table ID) where the record has been imported from	No	DataSource
Asset ID	Reference to an ID used in external data sources	No	AssetName
Status	Data status for the entire record, serves for keeping track on the source of information	No	Element_S
Network type	Attributes the link to a certain type of network. Used in cases when two or more different networks are included in the same project	No	NetTypeNo
Orifice ID	A unique name for the orifice. Up to 40 characters (letters, numbers, blank spaces and underscore characters)	Yes	MUID
From node	ID of Node where orifice is located	Yes	MUID
To node	ID of Node where orifice is discharging to. If field left empty, then water is discharging out of the system	Yes	MUID

### 3.6.2 Model data

Table 3.11 Geometry (Table msm\_Orifice)

Edit field	Description	Used or required by simulations	Field name in data structure
Type	Type of orifice according to shape, being rectangular, circular or CRS	Yes	TypeNo
Diameter	Diameter of circular orifice	Yes	Diameter
Height	Height of rectangular orifice	Yes	Height
Width	Width of rectangular orifice	Yes	Width



Table 3.11 Geometry (Table msm\_Orifice)

Edit field	Description	Used or required by simulations	Field name in data structure
Discharge coeff	Calibration coefficient. Value = 1 results in the flow as determined by orifice algorithm	Yes	Dis-chargeCoeff
Invert level	Absolute elevation of the orifice invert	Yes	InvertLevel
CRS Geometry ID	Reference of a cross-section ID for irregularly-shaped orifice	Yes, if CRS type is chosen	CrsID
Non return flap	Flap indicating a flap-gate built-in (i.e. no return flow possible)	Yes	FlapNo
Oper. mode	No control or RTC controllable orifice	Yes	ControlTypeNo

### 3.6.3 Defining a gate or a weir in an orifice

The orifice itself is just an opening with a static shape. In real constructions orifices are often equipped with a controlled gate or weir which can be used in real time control for regulating the flow through the orifice. The gate device will move from the top of the orifice opening and downwards until the orifice is fully closed. The weir moves from the bottom of the orifice upwards and closes fully when the weir crest reaches the top of the orifice opening (see Figure 3.16 for an illustration). It is possible to apply both types of movable devices in the computations. In both cases the device is “added” to a defined orifice. This is done from the “Control Rules” dialog.

See more on this in Real Time Control Chapter of the Collection System User Guide.

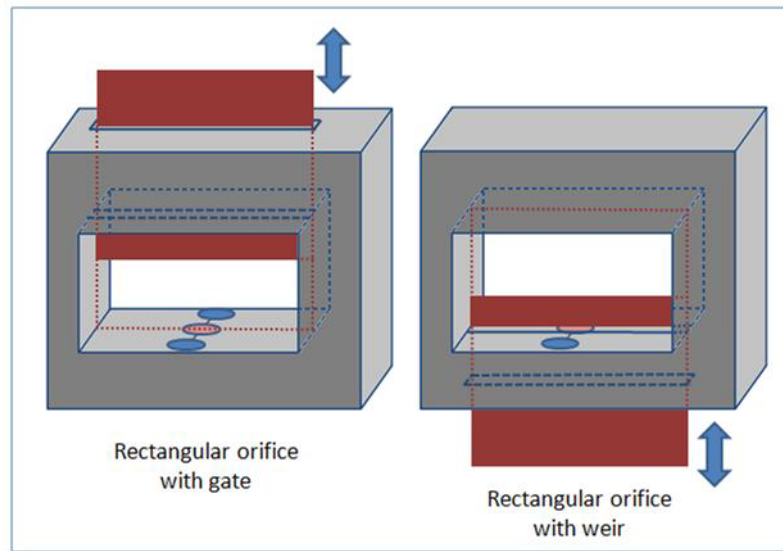
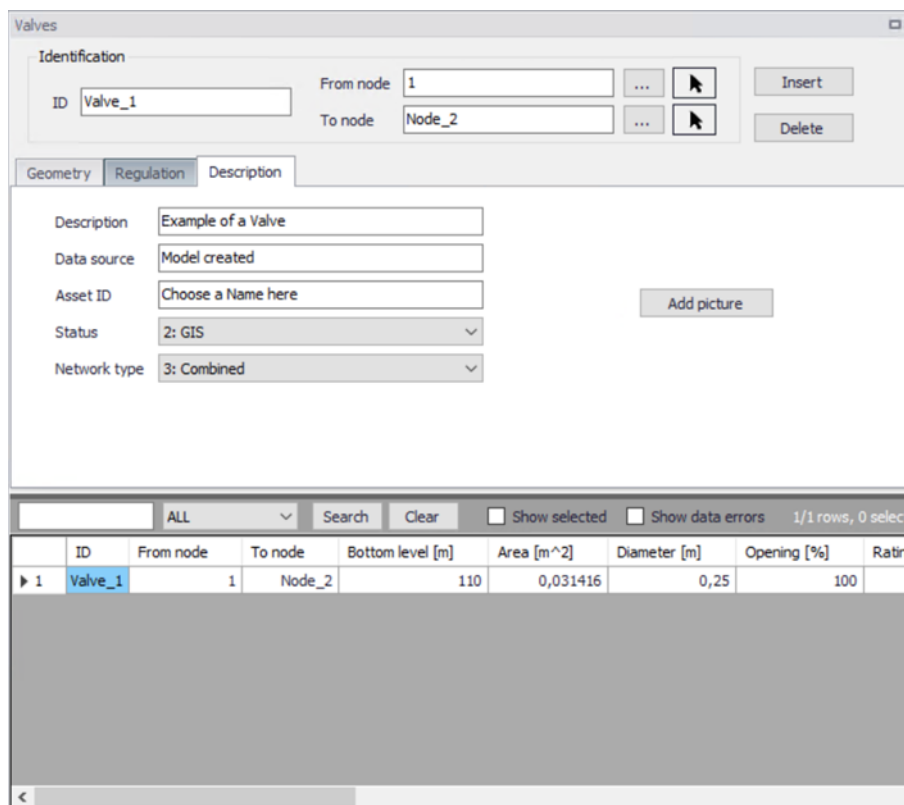


Figure 3.16 Examples on a rectangular orifice with a gate and a weir

### 3.7 Valves

A valve is a functional relation which connects two nodes of a MIKE 1D urban network.



Valves

Identification

ID: Valve\_1

From node: 1

To node: Node\_2

Insert

Delete

Geometry Regulation Description

Description: Example of a Valve

Data source: Model created

Asset ID: Choose a Name here

Add picture

Status: 2: GIS

Network type: 3: Combined

ID	From node	To node	Bottom level [m]	Area [m <sup>2</sup> ]	Diameter [m]	Opening [%]	Rating
1	Valve_1	1	Node_2	110	0,031416	0,25	100

Figure 3.17 Valve dialog

In the real world a valve may be located in a manhole or a similar construction which you normally would define as a node in the model configuration. The numerical solutions for the flow equations, however, need a model configuration with two nodes where the valve is defined as the connection between the nodes. The valve will then be placed between the two nodes as the flow connection.

It is possible to define several valves between the same two nodes if this is required. This is similar to the possibility of having more than one pipe as the link between nodes. The generation of the computational grid shown in Figure 3.14 for the orifice is also applied for pumps, weirs and valves. The numerical solution of the flow equations will depend on the selected device. Please refer to the MIKE 1D Reference Manual for more details about this.

It is recommended not to place the two nodes in the same spot, instead place the nodes a short distance apart. The reason is that the node head loss computation will have a component from change of flow direction. If the two nodes surrounding the device are placed exactly at the same location then the computational engine cannot determine the direction of the flow from the coordinates of the nodes and a default direction will be applied. This may





unintentionally introduce a change in direction and therefore also an unexpected head loss.

By using a small displacement of the nodes the change in flow direction will be determined based on the coordinates and angles between the connected pipes. Therefore consider carefully the placement of the nodes with respect to the actual construction.

A valve is specified by a diameter, flow area (by default calculated on the basis of the diameter, but it is possible to overwrite this value) and an invert level.

It is possible to specify a valve to be a non-return valve and thereby preventing flow in the negative flow direction. A rating curve is specified to define the relation between the valve opening (%) and resistance (k). The rating curve is specified under “Tables| Curves & Relations”.

The valve is by default static, in which case the valve opening must be specified. It is also possible to define a valve to be the RTC controlled and then the valve opening will be controlled by any specified control rules.

**Table 3.12** Identification and connectivity edit fields of the MIKE URBAN+ valve editor (Table msm\_Valve)

Edit field	Description	Used or required by simulations	Field name in data structure
Description	User's descriptive information related to the valve	No	Description
Data source	Reference to an external data source (table ID) where the record has been imported from	No	DataSource
Asset ID	Reference to an ID used in external data sources	No	AssetName
Status	Data status for the entire record, serves for keeping track on the source of information	No	Elements
Network Type	Attributes the valve to a certain type of network. Used in case where two or more different networks are included in the same project	No	NetTypeNo
Valve ID	A unique name for the valve. Up to 40 characters (letters, numbers, blank spaces and underscore characters)	Yes	MUID
From node	ID of Node where valve is located	Yes	FromNodeID



Table 3.12 Identification and connectivity edit fields of the MIKE URBAN+ valve editor (Table msm\_Valve)

Edit field	Description	Used or required by simulations	Field name in data structure
To node	ID of Node where valve is discharging to	Yes	ToNodeID
Valve Type	Specification of type of valve, this information is not used in the simulation engine	No	TypeNo

Table 3.13 Geometrical and hydraulic properties, edit fields of the MIKE URBAN+ valve editor (Table msm\_Valve)

Edit field	Description	Used or required by simulations	Field name in data structure
Diameter	The default value of the area (the field "Flow Area") is calculated on the assumption of a circular valve, with the diameter specified in this field. Furthermore, the transition to a pressurized valve is defined by the invert level plus the diameter.	Yes	Diameter
Invert Level	The invert level defines the minimum water level, which generates flow through the valve	yes	InvertLevel
Flow Area	A user specified flow area overwrites the default valve area computed on the basis of a circular cross section.	Yes	Area
Valve Opening	Defines the opening of the valve in percentages (value between 0 and 100). For an RTC controlled valve, this value is not applied, the opening is controlled by the MIKE URBAN+ build in RTC algorithm	Yes	Opening
Rating Curve	Reference to the tabulated k-opening function	Yes	RatingCurveID
Non return flap	Indicating a flap-gate built-in valve (i.e. no return flow possible)	Yes	FlapNo
Controlled through Real Time Control	No control or RTC controllable valve	Yes	ControlTypeNo

Table 3.13 Geometrical and hydraulic properties, edit fields of the MIKE URBAN+ valve editor (Table msm\_Valve)

Edit field	Description	Used or required by simulations	Field name in data structure
Max opening	Maximum opening condition of the valve during Real Time Control	Yes, if RTC is selected	
Min opening	Minimum opening condition of the valve during Real Time Control	Yes, if RTC is selected	
Max speed	The maximum velocity for movement of the flap	Yes, if RTC is selected	

### 3.8 Curb Inlets

The connections between pipe systems and overland flow networks to simulate the capture capacity (and surcharge) of side inlet pits and grates can be approximated in MIKE 1D using a combination of orifices and weir geometry. However, a method has been developed to incorporate the geometry of the inlet structure (Curb Inlet) via a network element which allows user input of the empirical relationship governing the structure capacity.

A typical Curb Inlet/grate configuration is shown below. Flow into the pit chamber is via both a grate and side weir (operates as an orifice for deeper flow depths).

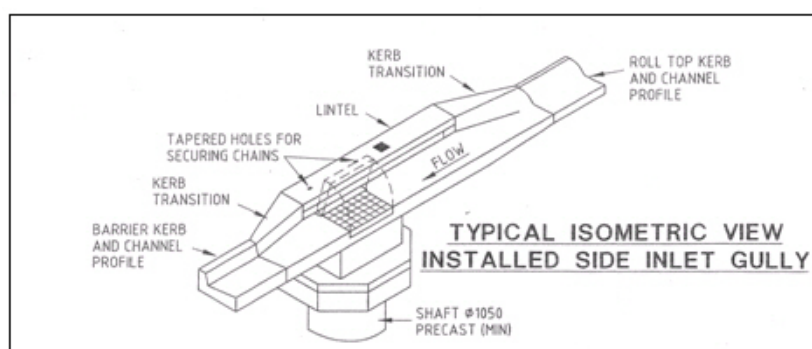


Figure 3.18 A typical curb inlet configuration

Standard curves have been developed in Australia for "ON-GRADE" type (using a  $Q_{\text{approach}}/Q_{\text{capture}}$  relationship where flow can bypass the structure) and "SAG" type (using a Depth/ $Q$  relationship at locations/low points where water collects). However the formulation with MIKE 1D allows for non-specific and user defined relationships. An example of the empirical curves devel-

oped for the ON-GRADE type is shown below, with the flow captured represented as a proportion of the approach flow, and varying with approach slope.

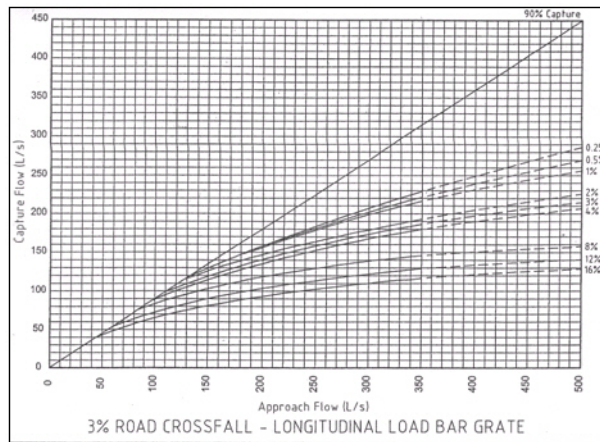


Figure 3.19 Example of empirical curves for On-Grade type

A Curb Inlet (Lintel) is a connection between two nodes of a MIKE 1D urban network (two-directional flow and submerged flow possible), describing the transfer of flow at a grate or inlet from an overland flow network to the sub-surface pipe network. The Curb Inlet dialog is accessed via the “TOC | Network | Curb Inlets” menu.

There are two types of Curb Inlet:

- SAG Type, where the connection node on the overland flow network is located at a sag or low point where water will collect. Transfer capacity of the connection is specified as a DQ-relation (tabular data type).
- ON-GRADE Type, where flow in the overland flow network can continue past the connection node. Transfer capacity of the connection is dependent on the slope of the overland flow network, and specified as a Capture ID (collective of QQ-relations defining the capture rate as a proportion of approach flow).

**Curb inlets**

Identification

ID:  From node:  ...

Type:  To node:  ...

Geometry Hydraulic properties Description

Number of inlets:

Width:  [m]

Height:  [m]

113,0000 107,0000

ALL Search Clear Show selected Show data errors 1/2 rows, 0 selected

ID	From node	To node	Type	Number of inlets	Width [m]	Height [m]	Invert level [m]
1 CurbInlet_2	1	Node_4	On-Grade	1	1	0,5	113,0000
2 CurbInlet_1	Node_6	Node_5	Sag	1	1	0,1	107,0000

Figure 3.20 The Curb Inlet data dialog

**Curb inlets**

Identification

ID:  From node:  ...

Type:  To node:  ...

Geometry Hydraulic properties Description

Freeboard:  [m] DQ relation:  Edit

Invert level:  [m] Capture ID:  Edit

☐ Slope:  [°]

☐ Blockage:  [%]

ALL Search Clear Show selected Show data errors 2/2 rows, 0 selected

ID	From node	To node	Type	Number of inlets	Width [m]	Height [m]	Invert level [m]
1 CurbInlet_2	1	Node_4	On-Grade	1	1	0,5	113,0000
2 CurbInlet_1	Node_6	Node_5	Sag	1	1	0,1	107,0000

Figure 3.21 The Curb Inlet Hydraulic Parameters data

User defined parameters in the Curb Inlet dialog include:

- Invert level (m) defining the point at which spilling starts (similar to weir crest level). The user is shown a system calculated invert level which is the same as the invert of the connection node in the overland flow network. As with weir flow, a crest level at least 0.01 m higher than the connection node invert level is recommended for initial condition stability.



- Freeboard (m), defining a critical water level (Invert - Freeboard) at the connection node in the pipe network below which the defined DQ and QQ-relations apply. For submerged and reverse flow (surcharge), the transfer capacity of the connection reverts to a standard orifice relationship.
- Slope (%), representing the slope of the steepest link in the overland flow network entering the connection node (only applies to ON-GRADE Type). The system calculated slope is used in the calculation unless a user defined slope is specified.
- Blockage factor (%) which can be used to account for debris blockage at the grate/inlet. This linear factor is applied to the tabular data sets defining the transfer capacity of the connection.
- Number of Curb Inlets, allowing multiple curb inlets of the same specified geometry (transfer capacity) applied at the same location within a single connection.
- Default rectangular orifice geometry, applies to those flow cases (submerged and reverse flow) where the defined DQ and QQ-relations do not apply. This generally applies when water levels at the connection node in the pipe network exceed the critical level defined by the Freeboard, including reverse flow (surcharge).

There are no limitations on the number of curb inlets specified at one location; however, the connectivity **must** be 'From' a node in the overland flow network 'To' a node in the pipe network, for correct automatic calculation of slope. *Note: Link slopes must be calculated in the link dialog for automatic calculation of slope to operate.*

The On-grade Capture dialog allows the user to group together QQ-relations (tabular data) that comprise a single On-grade Curb Inlet geometry (similar in function to the Topography dialog). As the transfer capacity for an On-grade Curb Inlet is dependent on the slope in the overland flow network, a number of QQ-relations can apply.



ID	Slope [%]
1	Capture_1

QQ-relation ID	Slope [%]
1	Capture_1

Figure 3.22 The On-Grade Capture data dialog (On-Grade Type)

For calculated or user defined slopes in the Curb Inlet dialog that are outside the range of slopes specified in the On-grade Capture dialog, the closest slope curve will be used. For intermediate calculated or user defined slopes (lying between slope curves in the On-grade Capture dialog), linear interpolation is applied.

In the case of an On-grade Curb Inlet capacity that is not dependent on slope of the overland flow network, the user needs to define the On-grade Capture with a single QQ-relation. *Note: In this case, the calculated or user defined slope in the Curb Inlet dialog for ON-GRADE Type will be ignored.*

## Capacity curves

Two curve types specified in the tabular data (Curves & Relations) can be used with the two different types of Curb Inlets.

- Capacity Curve, DQ (depth/discharge relation specified in the Curb Inlets dialog)
- Capacity Curve, QQ ( $Q_{\text{approach}}$ ,  $Q_{\text{capture}}$  relation specified in the On-grade capture dialog).

The DQ relation specifies the depth based capacity curve for a SAG Type Curb Inlet. Values must be monotonously increasing in depth and discharge and starting at (0,0). For depths in excess of the maximum value specified in the last row of the table, the last corresponding discharge value is used.

The QQ relation specifies the relationship between approach flow in the overland flow network ( $Q_{\text{app}}$ ) and the captured flow at the connection node for an ON-GRADE Type Curb Inlet ( $Q_{\text{cap}}$ ). Values must be monotonously increasing and starting at (0,0). For approach discharges in excess of the maximum value specified in the last row of the table, the last corresponding capture discharge value is used.



## 3.9 Pumps

A pump is a functional relation, which connects two nodes of a MIKE 1D urban network or is associated with only one node (free flow 'out of the system'). The latter case is achieved if the 'To' field is left empty.

In the collector systems a pump may be located in a manhole or a similar construction which you normally would define as a node in the model configuration. The numerical solutions for the flow equations, however, need a model configuration with two nodes where the pump is defined as the connection between the nodes. The pump will then be placed between the two nodes as the flow connection.

It is possible to define several pumps between the same two nodes if this is required. This is similar to the possibility of having more than one pipe as the link between nodes. The generation of the computational grid shown in Figure 3.14 for the orifice is also applied for pumps, weirs and valves. The numerical solution of the flow equations will depend on the selected device. Please refer to the reference manual on more on this.

It is recommended not to place the two nodes in the same spot, instead place the nodes a short distance apart. The reason is that the node head loss computation will have a component from change of flow direction. If the two nodes surrounding the device are placed exactly at the same location then the computational engine cannot determine the direction of the flow from the coordinates of the nodes and a default direction will be applied. This may unintentionally introduce a change in direction and therefore also an unexpected head loss.

By using a small displacement of the nodes the change in flow direction will be determined based on the coordinates and angles between the connected pipes. Therefore consider carefully the placement of the nodes with respect to the actual construction. For pumps the distance between the nodes will often be larger.

### 3.9.1 Pump types

Several pump types can be specified in MIKE URBAN+.

#### Constant flow pumps

This is the simplest way of modelling pumps. In this case the pump will discharge the same constant flow  $Q$  at any time when the pump is switched on. Eventually with the variation as defined during acceleration or deceleration periods.

When specifying a constant flow pump, set the Speed to 'Constant' and choose 'Constant' in the pump type field. In the Capacity tab type the constant flow value set for





Notice: 'Constant flow' pump is different from 'Constant speed' pump. The later may have varying discharge.

## Constant speed pumps

When defining pumps in MIKE URBAN+ models for sewer and drainage systems it will most commonly be pumps with a pump curve of type "Q, dH". The actual pump discharge  $Q$  will be a function of the actual pressure difference  $dH$  between the pump wet well and the receiving point in the model. The pump curves for this type of pumps will in general be as shown in the figure below.

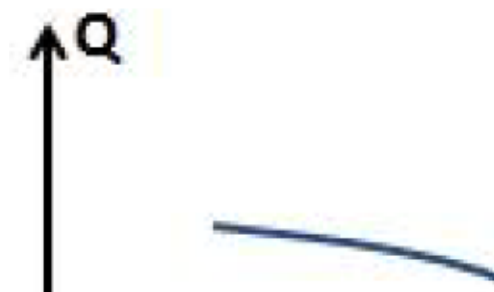


Figure 3.23 Typical example of pump curve

Pump curves are defined in MIKE URBAN+ by tabulating the curve under Curves and Relations. This can be done by selecting representative points on the pump curve as shown in the next figure. Information about pump curves are typically provide by the manufacturer of the pumps.

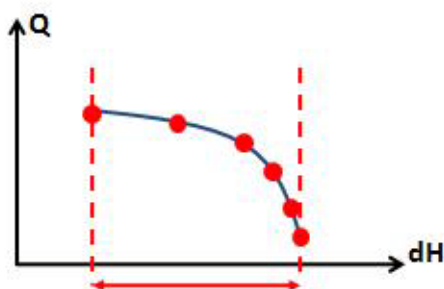


Figure 3.24 Tabulating the curve

When a pump curve is tabulated like this and used in the simulations executed with the MIKE 1D Engine, then the pump is allowed to operate within the range of the  $dH$  values in the table. At any time during the simulation the MIKE 1D Engine will compute the actual  $dH$  and determine the corresponding  $Q$  value from the table, resulting in the actual duty point position for the pump.

As a standard feature the MIKE 1D Engine will stop the simulation with an error message if the hydrodynamic conditions result in an actual dH value outside the range of the pump curve table.

## Variable speed pumps

When applying variable speed pumps the manufacturer typically provides a set of pump curves describing the pump capacity at various percentages of maximum rotation speed or maximum power input. You may have a set of curves available as show in the figure below.

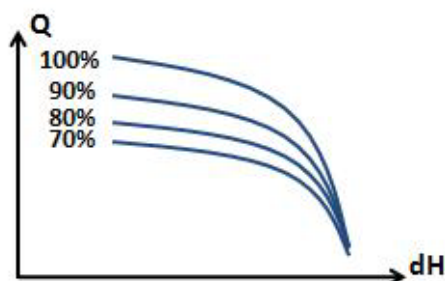


Figure 3.25 Pump curves at various percentages of maximum rotation speed or maximum power input

It is also found that variable speed pumps cannot be regulated over the full range between 0% and 100%. Instead the regulation may be in the range of 70% to 100% as indicated in the figure above. Search for specific information available for the pumps applied at the pumping stations being modelled.

For simplicity in the modelling the actual method of varying the pump capacity is not considered. It is not directly related to the actual number of rotations per minute (RPM) or the actual electrical power input. In the modelling we only consider the pump capacity as varying between a pump curve corresponding to the minimum speed and a pump curve corresponding to the maximum speed.

For variable speed pumps the two pump curves are defined as 'RPMmin' and 'RPMmax' pump curves. For constant speed pumps only the 'RPMmax' pump curve is applied.

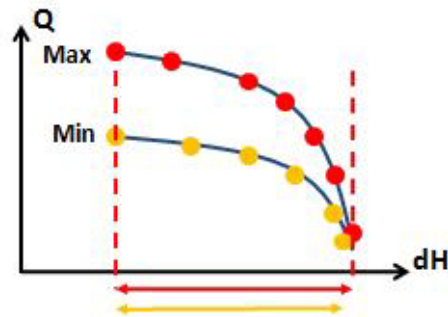


Figure 3.26 The RPMmax and RPMmin pump curves

When the MIKE 1D simulation is executed it is the standard condition that the simulation will stop and give an error message if the conditions exceed the range for the dH value in the pump curve table. This applies both for the 'RPMmax' and the 'RPMmin' pump curve.

### Operation of variable speed pumps

In the Regulation tab it is possible to regulate the pump to maintain a water level in the wetwell. The corresponding 'Wetwell WL Setpoint' must be specified when using this option.

When a variable speed pump is in operation during the simulation with the MIKE 1D Engine the duty point will move between the two pump curves depending on the actual conditions. The actual flow is determined by using a PID function which will attempt to control the water level at the wet well to stay at the specified set point value.

The discharge  $Q$  determined by the PID function and the dH found by the actual hydraulic conditions defines the duty point. This may vary in the area between the two pump curves.

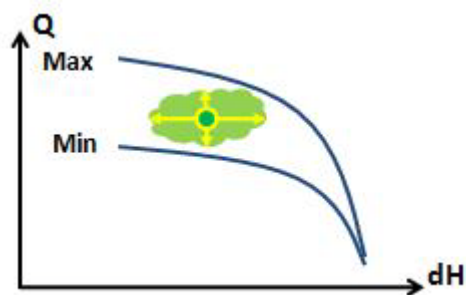


Figure 3.27

Eventually the conditions may result in the duty point ending up on one of the pump curves. If the PID regulation sets the discharge  $Q$  to a value higher

than the limitation by the 'RPMmax' pump curve at the given dH condition, then the discharge will be defined by the pump curve. As a consequence the water level in the wet well will rise above the defined set-point value.

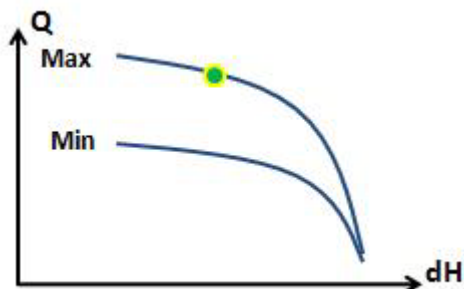


Figure 3.28

If the inflow to the pumping station is low, then the operation of the pump may result in an actual duty point located at the 'RPMmin' pump curve. In this case the water level at the wet well will drop below the defined set-point value. Eventually the water level will reach the stop level defined for the pump and the operation is switched off

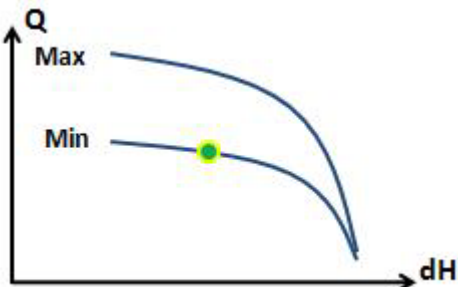


Figure 3.29

The MIKE 1D engine will pump as much flow available to discharge in the structure, which means that the pump works continuously during the simulation if there is lack of water in the pump wet well then the pump will discharge a flow of zero during those lapses but will not be forced stop.

The hydrodynamic network simulation provides a simulation summary report at the end of the computation. The summary for the pumps will show the number of pump starts during the simulation.



## Pumps - Discharge

Pump ID	From Node	To Node	Minimum [m <sup>3</sup> /s]	Maximum [m <sup>3</sup> /s]	Total discharge [m <sup>3</sup> ]	Time of Minimum	Time of Maximum	Pump starts [count]	Speed	Active [hh:mm:ss]
Pump_2_3	Node_02	Node_3	0,000	1,775	141.876,6	16-05-1953 00:00:10	16-05-1953 06:39:59	1	Variable	2.05:
Pump_2a_3	Node_02A	Node_3	0,000	2,000	146.063,3	16-05-1953 00:00:10	16-05-1953 03:01:38	138	Variable	1.05:

Figure 3.30 Summary of pump starts during simulation

The pump flow continues during the specified deceleration period by a linear decrease to zero flow. During this time interval the water level in wet well may eventually drop to the bottom of the wet well during a single time step

The 'Pumps - Discharge' section is only shown in the summary report if 'pumps' has been selected in the "Network Summary" under Result Specifications.

The screenshot shows the 'Pumps' application window with the 'Description' tab selected. The 'Identification' section shows ID '115p1', 'From node' '115', and 'To node' '55'. Below are fields for 'Description', 'Data source', 'Asset ID', 'Status' (set to '3: Imported'), and 'Network type'. An 'Add picture' button is also present. At the bottom, a table lists the pump's details:

ID	From node	To node	Cap type	Start Level [m]	Stop Level [m]	Acc time [sec]	Dec Time [sec]
1 115p1	115	55	Q-H	194	193,35	60	

Figure 3.31 Pumps description tab



Pump type  
Q-H

Start level  
2,0000 [m]

Stop level  
-1,5000 [m]

Acc. time  
180,0000 [sec]

Dec. time  
60,0000 [sec]

2,0000  
0,0000  
-1,5000  
2,0000

Figure 3.32 Pump geometry tab

Pumps

Identification

ID 11Sp1

From node 115

To node 55

Insert

Delete

Geometry Capacity Regulation Description

Constant flow [m<sup>3</sup>/s]

Capacity curve RPMmax

Capacity curve 11Sp1 Edit Offset 0 [m]

Capacity curve RPMmin

Capacity curve Edit Offset 0 [m]

ID ALL Clear Show selected Show data errors 1/1 rows, 0 selected

	ID	From node	To node	Cap type	Start Level [m]	Stop Level [m]	Acc time [sec]	Dec Time [sec]
1	11Sp1	115	55	Q-H	194	193,35	60	

Figure 3.33 Pump Capacity tab



Pumps

Identification

ID: 115p1

From node: 115

To node: 55

Insert

Delete

Geometry Capacity Regulation Description

☒ Use regulation

☒ Variable speed Wetwell Setpoint: 193,4 [m]

☐ RTC

☒ Constant speed

☐ Variable speed

Wetwell Setpoint: 193,4 [m]

Max start level: [m]

Min stop level: [m]

Min time ON: [min]

Min time OFF: [min]

ID: ALL Clear Show selected Show data errors 1/1 rows, 0 selected

	ID	From node	To node	Cap type	Start Level [m]	Stop Level [m]	Acc time [sec]	Dec Time [sec]
1	115p1	115	55	Q-H	194	193,35	60	

Figure 3.34 Pump regulation tab

A pump is characterised by the 'Start Level' and 'Stop Level', acceleration and deceleration time, an offset and a capacity curve. The capacity curve is specified in the Curves and Relations section. The capacity curve can be specified as a 'Capacity Curve QH' relation (for screw pumps) or as 'Capacity Curve QdH' relation (for differential head pumps), where 'H' is the absolute water level in the pump's wet well (at 'Location'), and 'dH' is the water level difference between the 'To node' and the 'From node' location.

A pump type with a 'Capacity Curve QH' relation is named a *screw pump*, while a pump type with a 'dH-Q' relation is named a *differential head pump*.

If an offset is specified this will be added to the capacity curve relation.

Pumps are per default static (No Control) but can be regulated through Real Time Control (RTC). Checking the "RTC" radio button enables the setting of start and stop levels and minimum time ON and OFF.



### 3.9.2 Identification and connectivity

Table 3.14 Identification &amp; Description (Table msm\_Pump)

Edit field	Description	Used or required by simulations	Field name in data structure
Pump ID	A unique name for the pump. Up to 40 characters (letters, numbers, blank spaces and underscore characters)	Yes	MUID
From node	ID of Node where pump is located	Yes	FromNodeID
To node	ID of Node where Pump is pumping to.	Yes	ToNodeID
Description	User's descriptive information related to the pump	No	Description
Data source	Reference to an external data source (table ID) where the record has been imported from	No	DataSource
Asset ID	Reference to an ID used in external data sources	No	AssetName
Status	Data status for the entire record, serves for keeping track on the source of information	No	Element_S
Network type	Attributes the pump to a certain type of network. Used in cases when two or more different networks are included in the same project	No	NetTypeNo

### 3.9.3 Model data

Table 3.15 Overview of the Pumps editor attributes (Table msm\_Pump)

Edit field	Description	Used or required by simulations	Field name in data structure
Pump Type	Type of flow variation, constant or based on a capacity curve. "QH Curve" is applicable for archimed Screw, the "QdH Curve" is applicable for all rotodynamic pumps	Yes	CapTypeNo
Start level	Water level in pump sump which triggers the pump to start	Yes	StartLevel





Table 3.15 Overview of the Pumps editor attributes (Table msm\_Pump)

Edit field	Description	Used or required by simulations	Field name in data structure
Stop level	Water level in pump sump which triggers the pump to stop	Yes	StopLevel
Acc. time	Pump acceleration time. Used to dampen sudden increase of flow at the pumps START events	Yes	AccTime
Dec. time	Pump deceleration time. Used to dampen sudden decrease of flow at the pumps STOP events	Yes	DecTime
Constant flow	Regards to the pump capacity, flow set for a pump in steady state	Yes	DutyPoint
Capacity curve RPMmax	Capacity curve for the nominal (max) rotation speed	Yes	QMaxSetID
Capacity curve RPMmin	Capacity curve for the minimum speed. Applies only for variable speed pumps	Yes	QMinSetID
Offset	Offset of the capacity curve. Applies to Q-H types, which may be specified relative to different datums	Yes, if Q-H type	Offset1
Offset	Offset of minimum capacity curve. Applies only for variable speed pumps	Yes, if variable speed pump	Offset2
Use regulation	Checkbox enabling the option to regulate the pump operation	Yes, if regulation is desired	RegNo
Wetwell WL set-point	Absolute water level in the pump sump (i.e. wet well) which the pump is supposed to maintain	Yes	WetWellSet-Point
Variable Speed	Allows the option to set variable speed pumps. Only variable speed pumps can be used for PID control	Yes	SpeedNo
RTC	Activate Real Time Control (RTC) operation. "Wet-well set point" is a special RTC control, which is accessible also without RTC add-on module	Yes	ControlTypeNo

### 3.10 Generic CRS & Topography

The Generic CRS & Topography editors allows the definition of the conduit cross-sections.



Generic CRS support open and closed cross sections. The X, Z types are appropriate for irregular cross sections, while H, W are best for symmetric cross sections.

Cross sections are classified in seven types: three of them are closed cross sections, and four of them are open cross sections. Each of the types has three sub-types, defined by the way how the CRS geometry is described. Thus, the following CRS types are supported:

- X, Z open: The CRS geometry is described by points defined by co-ordinate pairs (x, z), where 'x' is a horizontal axis, and 'z' a vertical axis. The points are specified in a counter-clockwise direction.
- X, Z closed: The CRS geometry is described by points defined by co-ordinate pairs (x, z), where 'x' is a horizontal axis, and 'z' a vertical axis. The points are specified in a counter-clockwise direction. The first and last points are connected to close the cross section.
- H, W open: The CRS geometry is described by pairs (h, w), where 'h' is relative height, and 'w' is the corresponding cross section width. The pairs are specified in an upward direction.
- H, W closed: The CRS geometry is described by pairs (h, w), where 'h' is relative height, and 'w' is the corresponding cross section width. The pairs are specified in an upward direction. The last specified (h, w) pair defines the top of the closed cross section.
- X-Z-R-M open: The CRS geometry is described by points defined by co-ordinate pairs (x, z), where 'x' is a horizontal axis, 'z' a vertical axis, the relative resistance (R) and the marker (M). The points are specified in a counter-clockwise direction.

This cross section type allows to specify open channel systems to have variable roughness across a cross section (common in urban and drainage studies).

Cross sections can be edited and shown graphically in the *Map View* and in the *tabular view*. The data created will be stored as a external cross section file with the extension xns11.

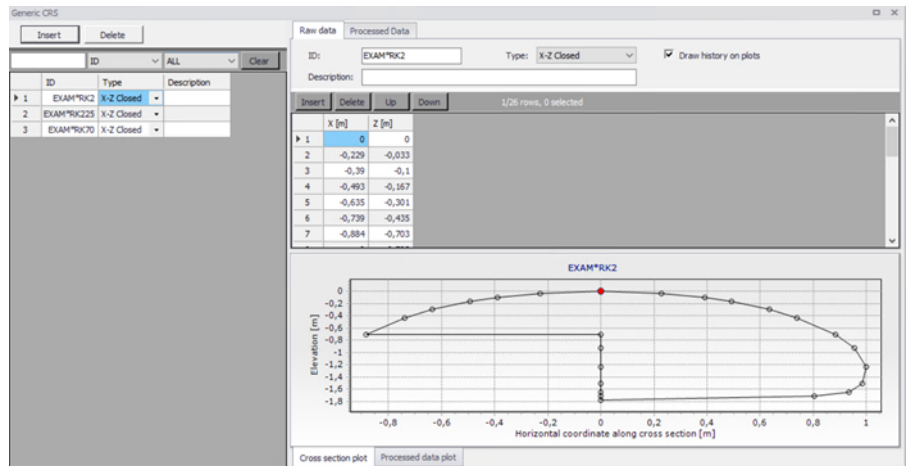


Figure 3.35 The Generic CRS Tabular view

## Cross section tree

The cross section tree window in the tabular view shows the list of all cross sections in the setup. The data are stored in an external cross section file with the extension *xns11*.

In the tabular view it is possible to see all the cross section in the setup. In the first column, cross sections are identified by their branch name, topo ID and chainage.

Clicking a cross section in the tree view will show the details of this cross section on the right-hand side of the Tabular view.

Right-clicking in the first column gives access to options to edit the cross sections. The options offered in the contextual menu depend on where you clicked in the tree view. For instance clicking on a single chainage allows editing the corresponding cross section only, whereas clicking on the topo ID or on the branch name allows editing all or a selection of cross sections.

The “Move...” feature allows to move cross sections to different locations, by changing either the branch name, topo ID and/or chainage. When selecting the “Move...” feature, a dialogue will be displayed. Where the “From” group-box indicates with cross sections are being moved and where the “To” group-box indicates the final destination which has been specified by the user.

Figure 3.36 Dialogue for moving a cross section

The “From” groupbox shows the original chainage only when moving a single cross section. It shows the topo ID only when moving a single cross section or a group of sections from a given topo ID.

The upper part of the dialogue is only active when selecting ‘Move...’ from a branch name or a topo ID. It allows selecting between moving all the cross sections of the branch / topo ID, or only the selection. These options are therefore not relevant for moving a single cross section.

The ‘Copy...’ feature is similar to the ‘Move...’ one except that the original cross sections are kept at their original location.

To insert a cross section, it is possible to use the ‘Insert blank cross section’ feature, which allows creating a cross section on any branch and for any topo ID, which therefore have to be specified as shown in Figure 3.37

Figure 3.37 Insert a blank Cross Section

Alternatively, right-clicking on the branch name or topo ID allows inserting a cross section respectively in the corresponding branch or the corresponding



topo ID. In that case the branch name and eventually the topo ID are automatically filled, as illustrated in Figure 3.38

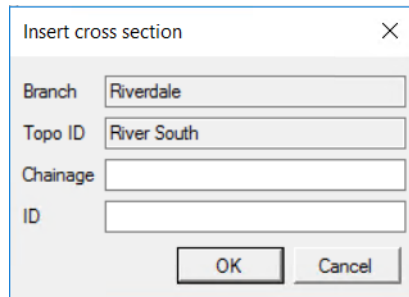


Figure 3.38 Dialogue for inserting a cross section in a selected topo ID

It is possible to insert an interpolated cross section, by right-clicking and selecting 'Insert interpolated cross sections'. This opens up the dialogue illustrated in Figure 3.39, where the branch name and Topo ID where the interpolation is to be conducted must be selected. It is possible to interpolate a single cross section at a given chainage or multiple cross sections. In the latter case a maximum distance between the interpolated cross sections must be specified, along with the range of chainages.

Similarly there are multiple options for deleting cross sections. Right-clicking on a single cross section gives access to the 'Delete this cross section' feature. Clicking on the topo ID allows deleting either all cross sections under this topo ID (using the feature 'Delete topo ID') or only the selected sections under this topo ID (using the feature 'Delete selected in this topo ID'). Finally, clicking on the branch name allows deleting either all cross sections under this branch (using the feature 'Delete river') or only the selected sections under this branch name (using the feature 'Delete selected in this river').

Figure 3.39 Dialogue for inserting an interpolated cross section

Similarly there are multiple options for deleting cross sections. Right-clicking on a single cross section gives access to the 'Delete this cross section' feature. Clicking on the topo ID allows deleting either all cross sections under this topo ID (using the feature 'Delete topo ID') or only the selected sections under this topo ID (using the feature 'Delete selected in this topo ID').

## Cross section properties

### General

The General tab contains options and data which relevant for all or part of all the cross sections.

**Recompute all.** The 'Recompute all' button recomputes processed data for all the cross sections.

**Recompute selected.** The 'Recompute selected' button recomputes processed data for the selected cross sections (those having the 'Select' checkbox checked) only.

**Cross-section filename.** Cross sections are stored in a cross section file, with the xns11 file extension. Click the '...' button to either select an existing file, create a new one or refresh the content of the file.

**Draw history on plots.** When this option is checked, watermarks are added as a history of previous cross sections drawn on the 'Cross section plot' and the 'Processed data plot'. This feature allows comparison of multiple cross sections on a single scale.



## Coordinates

The 'Coordinates' tab provides the list of vertices defining the location of the cross section (i.e. the polyline shown on the map). Each row describes a point identified with its X and Y coordinates expressed in the coordinate system used for features in the setup. The 'S' column provides the horizontal distance of each vertex along the polyline from its left end. These vertices don't have to match the list of points provided in the 'Raw data' tab.

When cross sections have been created from the *Map* view, the table is automatically filled with all vertices defining the location of the polyline and one point at the intersection with the branch.

**Apply.** When coordinates are provided in the table, the 'Apply' option can be checked. When it's checked, cross sections are displayed on the map based on the defined coordinates otherwise the cross section is displayed perpendicular to the branch at the specified chainage.

## Raw data

The 'raw data' tab provides the list of points defining the topography of the river bed along the cross section. These points don't have to match the list of vertices provided in the 'Coordinates' tab.

The 'S' column provides the horizontal distance of each point along the cross section, from the left end of the cross section. The 'Z' column provides the elevation of the points.

The '+' button above the table can be used to insert a new line at the bottom of the table, while the '-' button can be used to delete the active line.

**Markers.** Markers may be assigned to points in the 'Marker' column of the table. Markers can be assigned in two different manners: the first one is to click an element in the 'Marker' column, which opens a marker dialogue as shown in Figure 3.40 from which a requested marker number can be assigned for the selected point.

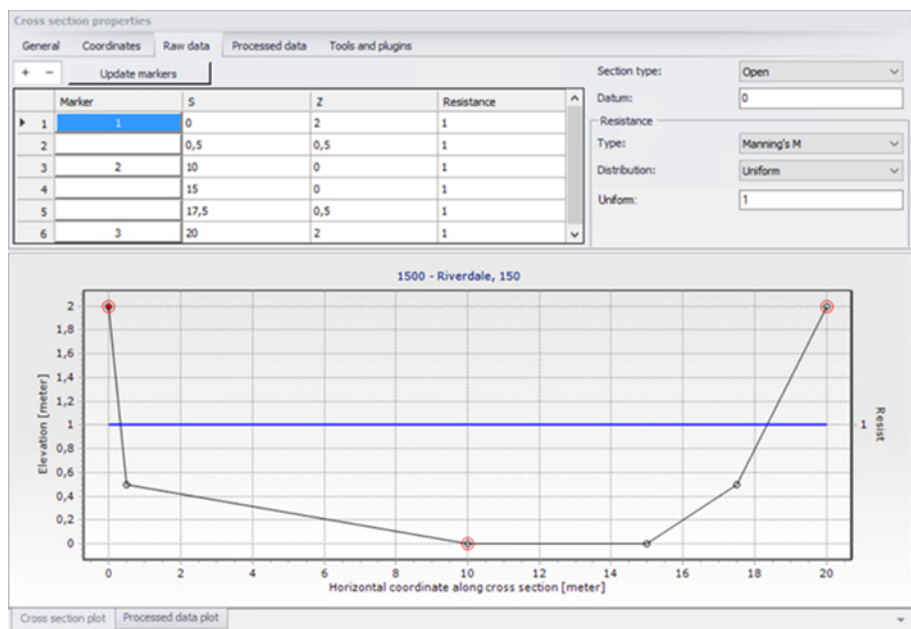


Figure 3.40 The marker options for the cross section type X-Z-R-M

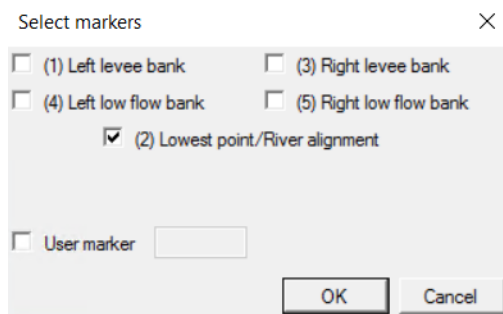


Figure 3.41 Selection of markers

A number of markers may be set in this dialogue:

**Left and right levee mark (Markers 1 & 3):** defines the extent or the active part of the cross section used for the calculations. Default placement of marker 1 and 3 is to apply marker 1 in the very first point in the raw data and marker 3 at the very last point of the raw data. Placing any of these markers at different locations will limit the extent of the active part of the cross section such that only the part of the cross section in between markers 1 and 3 is included in the simulation (that is, Processed data are only calculated for cross section data in between these markers).





**Left and right low flow bank (Markers 4 & 5):** defines the extent of the low flow channel. The markers influence the calculation of the processed data. If defined, the section is internally divided into three major 'slices' at markers 4 and 5 positions and the resulting processed data for such a section is a sum of integration results of three sub-parts of the section instead of calculating a result from one single, large section. Additionally, markers 4 and 5 can be used to define the extent of the low flow channel which is used with the 'High/low flow zones' description of the resistance distribution in the raw cross section data.

**Lowest point/River alignment (Marker 2):** marker 2 typically define the lowest point of the river section, or the location of the intersection with the branch. Marker 2 settings does not affect the calculations at all. Instead, it serves primarily the Map view for placement of cross sections which have no coordinates defined. It is therefore recommended to define the correct position of marker 2 in all sections.

**User marker:** any number above 7 may be used as a user marker. User markers do not impact the simulation results. They are an option for indicating a specific point in a cross section e.g. the location of a measurement gauge.

Marker locations must be defined such that marker 1 is defined to the left of marker 3 in the raw data table.

**Update markers:** This button updates markers 1, 2 and 3 in the current cross section, which are respectively placed at the left end point, lowest point and right end point.

**Section Type.** The type of cross section is set here. Four options are available:

- Open section: the typical setting for river cross sections.
- Closed irregular: closed sections with arbitrary shape.
- Closed circular: closed circular section shape where the geometry is only defined by the diameter.
- Closed rectangular: closed rectangular section shape where the geometry is only defined by the width and height.

**Datum.** A datum value may be entered here. The datum is normally used for adjusting the levels of the cross sections such that they conform to a specific reference datum in the model area. The datum value is added to all elevations in the 'Raw data' tab. The datum is also used for circular and rectangular sections, to set the elevation of the bottom level of the cross section.

**Resistance – Type.** Multiple options exist for defining the desired type of resistance method in the cross sections. The following types are available



Relative resistance: the resistance is given relative to the resistance number specified in the 'Bed resistance' menu. The resistance value specified in the cross section for this resistance type is therefore a coefficient.

A coefficient higher than 1 will increase the actual roughness of the channel (river) bed, whereas a coefficient lower than 1 will decrease the actual roughness. So when the resistance type is Manning (M) in the 'Bed resistance' menu, then the Manning's M value is divided by this coefficient.

When the resistance type is Manning (n), then the Manning's n value is multiplied by this coefficient.

- Manning's n: the resistance number is specified as Manning's n in the unit  $\text{s/m}^{1/3}$ .
- Manning's M: the resistance number is specified as Manning's M in the unit  $\text{m}^{1/3}/\text{s}$  (Manning's  $M = 1/\text{Manning's } n$ ).
- Chezy number: the resistance number is specified as Chezy number in the unit  $\text{m}^{1/2}/\text{s}$ .
- Darcy-Weisbach (k): the resistance is specified in the form of an equivalent grain diameter.

**Resistance – Distribution.** This distribution type defines the description of the transversal resistance across the cross section. Three options are available:

- Uniform: a single resistance number will be applied uniformly throughout the cross section.
- High/Low flow zones: three resistance numbers are to be specified. The 'Left high flow' number applies between markers 1 and 4, the 'Right high flow' number applies between markers 5 and 3, and the 'Low flow' number between markers 4 and 5. If marker 4 and 5 do not exist the low flow resistance number will apply uniformly throughout the cross section.
- Distributed: the resistance number is to be specified for each point, in the raw data table in the 'Resistance' column. The value specified for a given point applies uniformly between this point and the previous one.

**Processed data.** The 'Processed data' tab displays the hydraulic characteristics of the cross section which are used during the simulation. These processed data provide the values of cross section area, radius, width, bed resistance and conveyance as a function of the water level. The details of these variables are provided below:

- Level: levels for which processed data are calculated in the cross section. Default levels definition range from the lowest z-value and up to the highest z-value in the raw data table.



- Cross section area: effective cross sectional flow area calculated from the raw data. Effective area is determined from the total flow area adjusted by eventual relative resistance values different from 1 in the raw data tab (see MIKE 1D Reference manual).
- Radius: a resistance or hydraulic radius depending on the selected type in the 'Radius type' drop-down list.
- Storage width: width of the water surface for the given water level.
- Resistance: this factor can be used to apply a level dependent, variable resistance in the cross section. The resistance factor can contain the following two types of values depending on the Resistance Type definition in the raw data tab:
  - Resistance type defined as relative resistance factor: in this case, the resistance value is interpreted as a factor by which the resistance numbers defined in the 'Bed resistance' menu will be multiplied or divided during the calculation, in order to establish a level dependent resistance in the section. That is, the resistance factor works as a level dependent resistance scaling factor in the current section. It is important to notice in the case of relative resistance type, that a factor higher than 1 will increase the actual roughness of the river bed, whereas a factor lower than 1 will decrease the actual roughness. So when the resistance type is Manning (M), then the Manning's M value is divided by this factor. When the resistance type is Manning (n), then the Manning's n value is multiplied by this factor.
  - Resistance type defined as absolute resistance number (Manning's n, Manning's M or Chezy number): in this case, the resistance column contains the actual resistance number applied in the simulation. The resistance column can therefore have values of either Manning's M, Manning's n or Chezy numbers in this case.
- Conveyance: the conveyance values are not used in the simulation but is primarily displayed as part of the processed data for the purposes of checking that the conveyance is monotonously increasing with increasing water level, which is one of the key assumptions for the open water hydraulics.

Additionally, an additional storage area may also be defined manually, again as a function of the water level. The purpose of the additional storage area is to include an additional volume of storage in the cross section, which is not represented by the geometry in the raw data. The calculated water level in this additional storage remains strictly the same as in the cross section. This is useful for representing small storage's associated with the main branch such as a lakes, bays and small inlets. The additional storage area values describe the area of the water surface for a given water level. Additional storage areas are always user-defined: they will never be given a value from the automatic processing of the raw data. During the simulation, the processed



data will be interpolated in order to cover the full range of water levels encountered during the simulation.

**Note:** Processed data are essentials in the simulation, as they describe the hydraulic aspects of the cross sections. Hence, it is important to inspect processed data and make sure that accurately describe these hydraulic parameters.

It is for example important to make sure that their plots are smooth in order to correctly reproduce the progressive changes with changing water levels. If the plots show abrupt changes, it may be necessary to edit the levels at which processed data are computed. Additionally, a situation where the conveyance column is not monotonically increasing with water levels can relatively easily occur, especially in the case of some closed sections or in situations where the section geometry includes a sudden width increase and the radius type has been selected to 'Hydraulic radius'. Should this situation occur, then it is strongly recommended (not to say a strict requirement) that time is spent on adjusting the section characteristics such that a monotonically increasing conveyance curve is obtained. If not, there is a very significant risk of obtaining instabilities in the simulation for water levels in the range where the non-increasing conveyance values are present.

Typical options for optimising the cross section characteristics in the situation of an open section is to use the 'Resistance radius' type instead. Alternatively, an option using the 'Hydraulic radius' type is to manually subdivide the section into several 'slices' by adjusting the relative resistance numbers in the raw data at locations where the section's shape significantly changes (e.g. changing a relative resistance value from 1.000 to 1.001 'forces' the processed data calculator to divide the integration of the processed data into several slices and the non-monotonically increasing conveyance curve can normally be resolved from this.

It is important to notice that the conveyance numbers presented in the conveyance column are actually not the 'True' conveyance values. Depending on the choice of resistance type in the 'Processed data' tab, the 'True' conveyance may depend on the resistance values specified in the 'Bed resistance' menu. However it has been decided to present conveyance values which does not include these resistance number. Consequently, the conveyance shown in the processed data does not reflect the true conveyance, but is primarily offered as a possibility for analysing the 'conveyance trend' as a function of water levels in the cross sections. And these should be monotonically increasing with water levels to secure a healthy output from the simulations.

The '+' button above the table can be used to insert a new line in the table, while the '-' button can be used to delete the active line.

**Allow for recalculation.** When this option is checked, the table may be automatically recomputed. Data are recomputed when changes are applied to the



cross section's properties, when the 'Recompute' button in the current window is pressed. In case the processed data have been manually adjusted, it may be necessary to uncheck this option in order to make sure to keep them unchanged afterwards.

Processed data are also recomputed when the setup is saved when 'Allow for recalculation' is checked.

**Recompute.** This button is only active when the option 'Allow for recalculation' is checked. Pressing this button recomputes all the processed data in the table.

**Radius type.** The radius type may be chosen between the three following options:

- Resistance radius: a resistance radius formulation is used.
- Effective area, hydraulic radius: a hydraulic radius formulation where the area is adjusted to the effective area according to the relative resistance variation.
- Total area, hydraulic radius: a hydraulic radius formulation where the total area is equal to the physical cross sectional area.

**Number of levels.** The desired number of processed data levels. The automatic level selection method may not use the full number of level specified. This will occur when a smaller number of levels is sufficient to describe the variation of cross sectional parameters.

**Angle correction.** An angle correction may optionally be applied to the cross section. The correction may be used for situations where the cross section profile isn't perpendicular to the center line of the river. To activate the correction, the 'Apply' checkbox must be checked, and the angle must be manually specified.

The correction applied is simply a projection of the cross sectional profile on the normal to the thalweg of the river i.e. the correction reads

$$x_{cor} = x \cos \theta$$

Where  $\theta$  is illustrated below

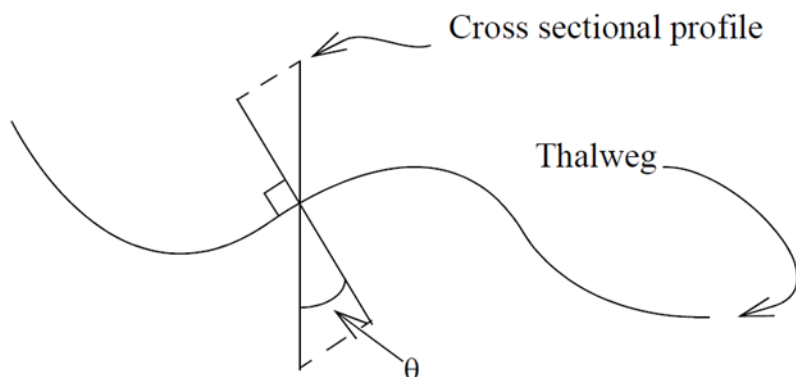


Figure 3.42 Definition sketch of the correction angle

Please note that the correction of X-coordinates is not reflected in a change of S values in the raw data table, but only in the processed data table.

### Cross section plot

The graphical view presents either a single plot for the current cross section, or eventually a number of plots from different sections if the 'Draw history on plots' option in the 'General' tab is active. The curve represents the values defined in the raw data table, with the X axis describing the S values and the Y axis describing Z values plus the datum value.

Points shown with red circles on the plot indicate the locations of markers 1, 2 and 3.

The blue curve describes the resistance value for the current cross section.

To control the settings and appearance of the plot, a number of facilities are available through a contextual menu. To open the pop-up menu point to the graphical view with the mouse cursor and press the right mouse button. A pop-up menu as presented in figure below will appear.

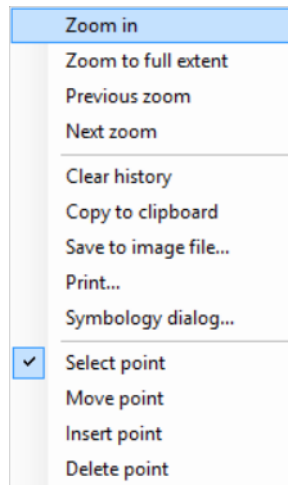


Figure 3.43 Contextual menu for the cross section plot

The pop-up menu includes the following three feature groups:

- The first group of features relates to the zooming facilities: from here the zoom in, zoom to full extent and the previous / next zoom facilities are available.
- The second group of features relates to the appearance and export of the graphical view. From here you can therefore export the image to the clipboard or to an image file on the disk, and you can also print it. Additionally the symbology dialogue allows changing the display settings of the plot.
- The third group of features relates to editing the active cross section's raw data on the plot. The following functions are available:
  - Select: when this mode is active, it is possible to select a cross section's point on the plot, which makes this point active in the raw data table.
  - Move points: when this mode is active, it is possible to move a point graphically from the plot. The raw data table will be updated accordingly.
  - Insert: when this mode is active, new cross section's point may be added. Inserted points are interpolated between two existing points, and may be moved afterwards.
  - Delete: when this mode is active, points may be deleted from the plot.



### Processed data plot

The graphical view presents either the data for the current cross section only, or eventually for a number of cross sections if the 'Draw history on plots' option in the 'General' tab is active. The curve represents the values defined in the processed data table, with the Y axis describing the level values and the X axis describing one of the other items from this table (either area, radius, width, additional storage area, resistance or conveyance). The plotted item is controlled by the drop-down list above the plot.

To control the settings and appearance of the plot, a number of facilities are available through a contextual menu.





## 4 Rainfall-Runoff Modelling

MIKE URBAN+ provides a versatile set of tools and computational models for modelling surface storm runoff and infiltration on urban and semi-rural catchments. The User can quickly prepare a precipitation-runoff model setup of desired level of detail (in terms of spatial discretization and input data) and use the computed runoff as a load to the collection network.

This Chapter provides a comprehensive guide for the preparation of hydrological models.

Modelling of urban storm runoff and infiltration requires understanding of information requirements and the involved processes. This understanding is supported by the illustration in Figure 4.1. Note that MU+ can model rainfall-dependent infiltration (RDI). This is specifically discussed within the Parameters RDI section, and is not visually represented in Figure 4.1.

Although runoff computation and its subsequent use as a network load are, in principle, two distinct steps in the modelling process, MIKE URBAN+ has the facility to simulate the two processes simultaneously.

Runoff modelling engages the following:

- Catchments
- Optionally (only if network computations will follow), definition of the catchment connection, i.e. specification of the point of runoff inflow into the network.
- Definition of the hydrological models
- Precipitation (optionally, temperature and evapotranspiration)
- Runoff computations

The runoff is typically used as a hydraulic load to the collection network. This requires:

- Declaration of the computed runoff as a network hydraulic load
- Execution of the network computation.

Runoff and hydrodynamic network computations are run simultaneously in MIKE URBAN+. Nevertheless, they can also be launched in two distinct steps, if needed.

Furthermore, an important part of successful modelling is related to model calibration and verification, which ensure that the computed results fit reasonably well with the flow observations. The calibration and verification are important engineering activities in the modelling process, and they must be paid due attention.

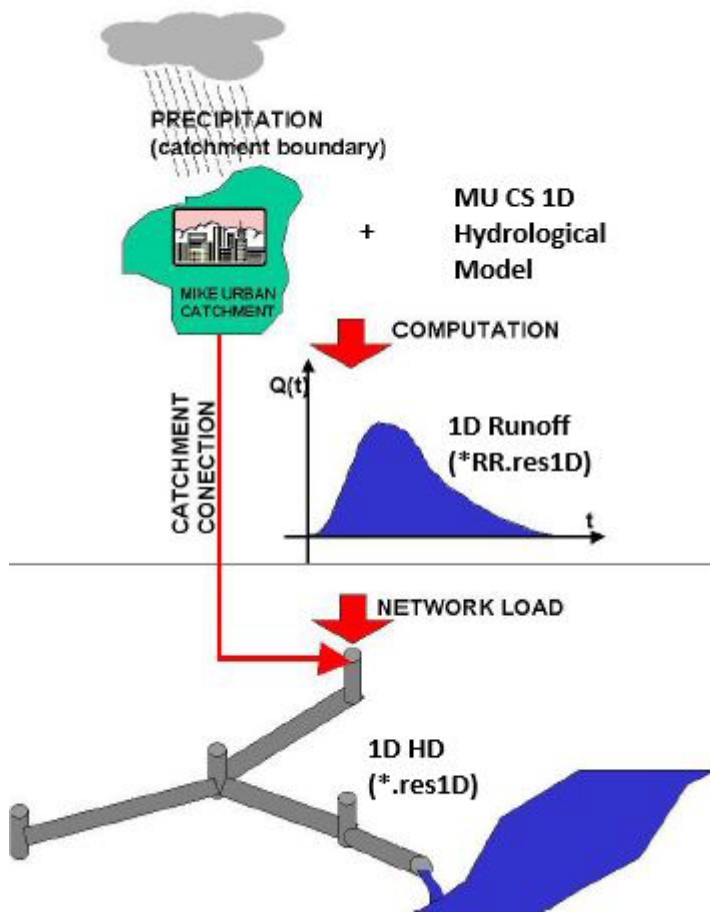


Figure 4.1 Illustrated flow of information in hydrological modelling

## 4.1 Catchments

Catchments are essential for any hydrological model. MIKE URBAN+ catchments are geographical polygon features which represent hydrological urban catchments or wastewater drainage areas. As such, catchments may be used for hydrological modeling or as wastewater sources.

In the context of hydrological modelling, MIKE URBAN+ catchments are treated as hydrological units where storm runoff and infiltration are generated based on a single set of model parameters and input data. Catchments represent the level of spatial discretization of the hydrological model.

Catchments are featured as a single data layer in MIKE URBAN+. After the definition of the catchments' connections to a model network, the catchments become a source of loads for a network model.



Catchments can be managed both graphically on the map and through the Catchments Editor. The two modes complement each other, and efficient management of catchment data can be achieved through joint application of both modes.

The graphical mode (i.e. Edit Features functionality) allows digitisation of catchment extent by tools like Create, Edit, Delete, and Split. Descriptions of graphical catchment tools are found in the Model Manager User Guide.

The Catchments Editor is used for:

- Editing catchment attributes. It is possible to insert catchments through the Editor; these are given a schematised quadratic shape.
- Editing connections to model networks and hydrological data for Rainfall-Runoff models.
- Editing catchment hydrological model attributes. It is possible to edit catchment attributes in relation to various hydrological runoff models available in MIKE URBAN+.

The Catchments Editor can be accessed via Catchments|Catchments.



	ID	X coordinate [m]	Y coordinate [m]	Area [ha]	Geom area [ha]	Persons [0]	Hydrological model
1	S14150801	95797,4007491958	103058,88227831	1,818101	1,818101	364	Kinematic Wave (B) + RDI
2	S14150802	95935,0902106484	102968,910855603	1,816469	1,816467	363	Kinematic Wave (B) + RDI
3	S14151901	95921,2302792918	103132,031686657	2,103456	2,103455	421	Kinematic Wave (B) + RDI
4	S14152801	95827,4897666199	103196,906286722	0,953028	0,9530274	191	Kinematic Wave (B) + RDI
5	S14152901	95841,7881223778	103277,720481906	1,122897	1,122898	225	Kinematic Wave (B) + RDI
6	S14153901	95970,7047324268	103332,424306067	1,073283	1,073283	215	Kinematic Wave (B) + RDI
7	S14154801	95860,0329266578	103416,85802602	3,518696	3,518695	704	Kinematic Wave (B) + RDI
8	S15150001	95997,5864578616	103042,590940678	1,080358	1,080359	216	Kinematic Wave (B) + RDI
9	S15151101	96108,3844326884	103115,748439442	1,474389	1,474388	295	Kinematic Wave (B) + RDI
10	S15152001	96043,037466828	103224,277438429	2,709958	2,709957	542	Kinematic Wave (B) + RDI

Figure 4.2 The Catchments Editor

The Catchments Editor has a general Identification Group containing information on catchment identifier and geographic location.

	ID	X coordinate [m]	Y coordinate [m]
1	S14150801	95797,4007491958	103058,88227831

Figure 4.3 The Catchments Editor Identification Group



**Table 4.1** Overview of the Catchments Editor Identification Group attributes  
(Table msm\_Catchment)

<b>Edit field</b>	<b>Description</b>	<b>Usage</b>	<b>Attribute Table Field</b>
ID	Unique catchment identifier	Yes	MUID
X	X coordinate of the catchment geometry centroid	Calculated (read-only)	-Derived-
Y	Y coordinate of the catchment geometry centroid	Calculated (read-only)	-Derived-

Other catchment attributes related to hydrological modelling and connections to model networks are organized in Tabs within the Catchments Editor and are described in succeeding Sections.

### 4.1.1 Geometry

General catchment attributes related to geometry and Person Equivalents are specified in the Geometry Tab of the Catchments Editor.

In MIKE URBAN+, the geographical extent of a catchment is determined by the catchment polygon perimeter. MIKE URBAN+ provides information on the total catchment area based on polygon geometry.

In some cases, the geographical boundaries of a catchment do not coincide with the actual drainage area. A catchment extent may be defined based on some administrative division, while the drainage network is present only in some parts of the catchment. In such cases, the User may specify the Catchment Area value, which overwrites the actual geometric area in all hydrological computations.



Catchments

Identification

ID S14150801 X 95797,4007491958 [m] Y 103058,88227831 [m]

Insert Delete

Geometry Catchment connections Time-Area Kinematic wave Linear reservoir C1 Linear reservoir C2

Hydrological model Kinematic Wave (B) + RDI

Catchment area 1,818101 [ha] 1,818101 [ha]

Personal Equivalents 364 [0]

Figure 4.4 The Catchments Editor Geometry Tab

Table 4.2 Overview of the Catchments Editor Geometry attributes (Table msm\_Catchment)

Edit field	Description	Usage	Attribute Table Field
Hydrological Model	Dropdown menu for selecting the hydrological runoff model to use for a catchment	Yes	HydrologicalModelNo
Catchment Area	The catchment area of relevance for the project ( $\leq$ Geom Area)	Optional	Area
(Geom. Area)	Program-calculated geometric area of the catchment polygon	Calculated (read-only)	-Derived-
Person Equivalents	Unit per capita loading for the catchment	Yes, Used as a method for wastewater load definition	Persons

### 4.1.2 Description

The Catchments Editor Description Tab allows the User to provide additional information for a catchment record.

Figure 4.5 The Catchments Editor Description Tab

Table 4.3 The Catchments Editor Description Tab attributes (Table msm\_Catchment)

Edit field	Description	Usage	Attribute Table Field
Description	Free text description related to the catchment	Optional	Description
Data source	Reference to an external data source (e.g. table ID) from where the record was taken	Optional	DataSource
Asset ID	Reference to an ID used in external data sources	Optional	AssetName
Status	Data status for the record for keeping track of information source	Optional	Element_S



Table 4.3 The Catchments Editor Description Tab attributes (Table msm\_Catchment)

Edit field	Description	Usage	Attribute Table Field
Network Type	Attributes the catchment to a certain type of network. Used in cases where different network types are in the same project.	Optional	NetTypeNo
Add picture button	Facility for defining an image file for the catchment record. Accepts .PNG, .JPG, and .BMP image files.	Optional	-

## 4.2 Hydrological Models

Catchment records include information related to hydrological modelling. Such information are shown in separate tabs--one tab for each model.

Hydrological models for urban catchments include two distinct classes of models:

- Surface runoff model: These are the most common types in urban runoff analysis. The common characteristic of all the models in this class is that only surface runoff is computed. This implies discontinuous runoff hydrographs where flow starts as a result of rainfall and reduces to zero again after the end of rainfall. As such, these models are suitable for relatively densely urbanized catchments with dominant amount of runoff generated on impervious surfaces, and for single-event analyses (e.g. design rainfall of certain recurrence interval). These models fail to provide realistic results in dominantly rural catchments and for long-term analyses involving multi-event rainfall series.
- Continuous hydrological models: These models treat the precipitation volume balance without any truncation through complex concepts. As a result, the generated runoff includes both the overland and subsurface runoff components. Due to longer time scales involved, the runoff hydrographs appear practically continuous. An important property of continuous hydrological models is hydrological memory, i.e. the ability to simulate the catchment reaction to certain rainfall dependent on previous rainfalls. This type of model is essential for any long-term analysis and for dominantly rural catchments. On the other hand, these models are usually incapable of simulating extremely fast response of heavily impermeable urban catchments.





MIKE URBAN+ includes a series of surface runoff models and one continuous hydrological model. The surface runoff models available are:

- Time-Area Method (A)
- Kinematic Wave (B)
- Linear Reservoir (C1 and C2)
- Unit Hydrograph Method (UHM)

The continuous hydrological model included is Rainfall Dependent Infiltration (RDI).

Any of the surface runoff models can be used on their own, or in combination with RDI.

Combining different models for individual catchments in one runoff computation is also possible in MIKE URBAN+.

Detailed descriptions of the models are available in the following Sections and in the MIKE 1D Reference Manual.

#### 4.2.1 Time-Area Method (A)

The Time-Area Method is a simple surface runoff model with minimum data requirements. The runoff computation is based on a simple treatment of hydrological losses and the runoff routing by the so called Time-Area curve. Technical details on the method can be found in the MIKE 1D Reference Manual.

##### Model Data

A full overview of the editor fields and corresponding attributes is provided in the Table 4.4.

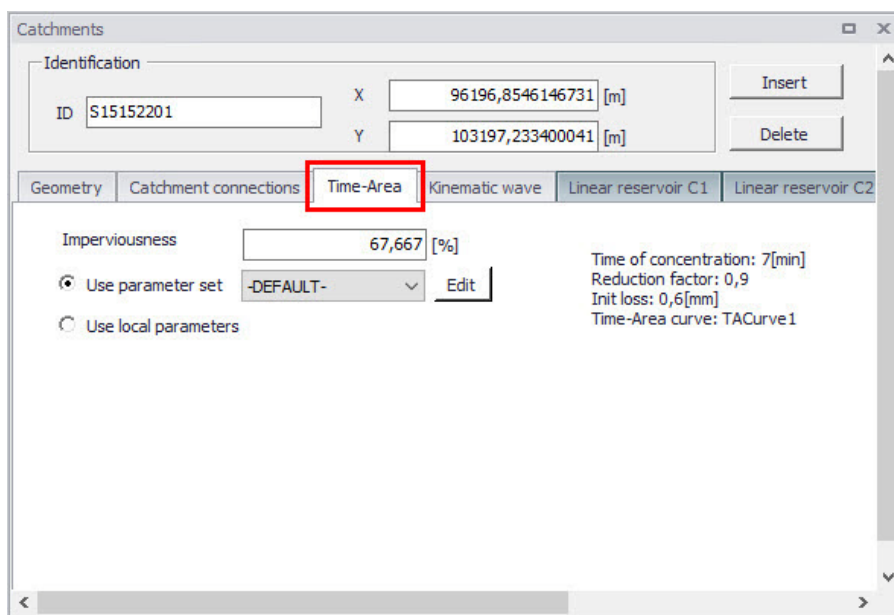


Figure 4.6 The Time-Area Model Tab

Table 4.4 Overview of the Time-Area Model attributes (Table msm\_Catchment)

Edit field	Description	Used or required by simulations	Field name in datastructure
Imperviousness	Impervious catchment area, as percent of the actual model area	Yes	ModelAImpArea
Use Parameter Set	Reference to a set of model parameters to be used for the current catchment	Yes	ModelAParAID
Use Local Parameters	Allows for local use of individual parameters	Optional	ModelALocalNo

## Parameters Time-Area

The Time-Area model uses several parameters. For practical reasons, these parameters have been grouped in parameter sets, which can be associated with certain catchments. This means the entire model setup can be established with a very small amount of information, while still allowing for full spa-

tial variation of model parameters for individual catchments through the application of local values.

New parameter sets can be inserted and values of individual parameters can be edited in the Parameters Time-Area Editor.

MIKE URBAN+ comes with a Default parameter set (-DEFAULT-). The User can insert any number of parameter sets and edit them as needed.

ID	Red Factor [0]	Init Loss [mm]	Conc Time [min]	TA Method	TA Cu
1 -DEFAULT-	0,9	0,6	7	Time-Area Curve No.	

Figure 4.7 The Time-Area Parameter Sets Editor (Catchments|Parameters Time-Area)

A full overview of the editor fields and corresponding database attributes is provided in the Table 4.5.



Table 4.5 Overview of the Time-Area Parameter Set Database attributes (Table msm\_HParA)

Edit field	Description	Used or required by simulations	Field name in datastructure
Parameter Set ID	Parameter set identifier	Yes	MUID
Time of Concentration	Concentration time	Yes	ConcTime
Initial Loss	Initial loss (wetting, interception, local depressions...)	Yes	InitLoss
Reduction Factor	Hydrological reduction factor	Yes	RedFactor
Time-Area curve/coefficient radio buttons	Switch for use of predefined tabulated T-A curves or analytically computed T-A relation	Yes	TAMethodNo
Time-Area Curve	Predefined T-A curve ID	Optional, alternates with TACoeff	TACurveID
Time-Area Coeff.	Value of the analytical T-A curve coefficient	Optional, alternates with TACurveID	TACoeff

## Time-Area Curve Editor

The Time-Area model uses (except if analytical curve is applied) predefined tabulated time-area curves. A Time-Area curve represents the contributing part of the catchment surface as a function of time. Implicitly, the Time-Area curve accounts for the shape of the catchment in relation to the outlet point.

MIKE URBAN+ comes with three Default Time-Area curves: TACurve1, TACurve2, and TACurve3, applicable for rectangular, divergent and convergent catchments, respectively (see the figures below).

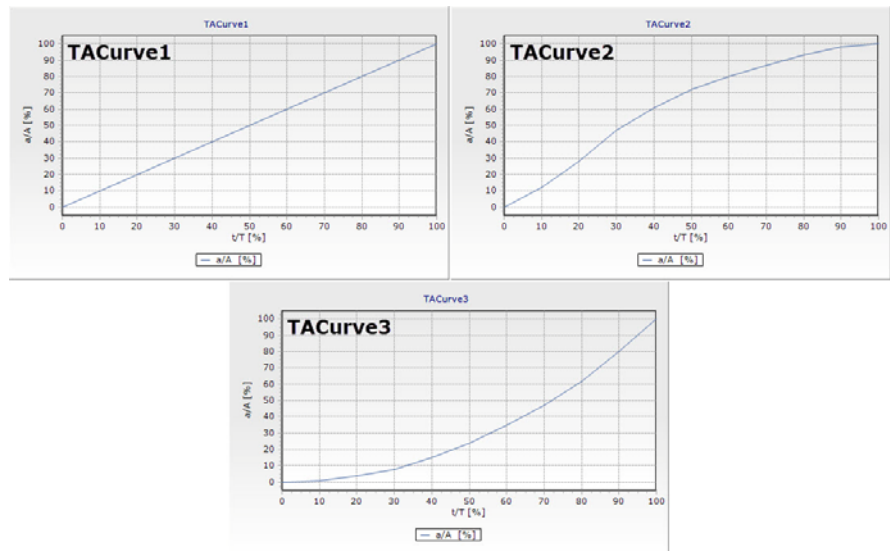


Figure 4.8 Three Default Time-Area curves

You can define any number of custom Time-Area curves. These can be inserted and edited in the editor for Curves and relations (Tables|Curves and Relations). Each Time-Area table must start with a pair of values (0,0) and must end with a pair of values representing the whole (per Default, MIKE URBAN+ maintains T-A curves in percent (%), i.e. the last pair of values in the table must be (100,100).

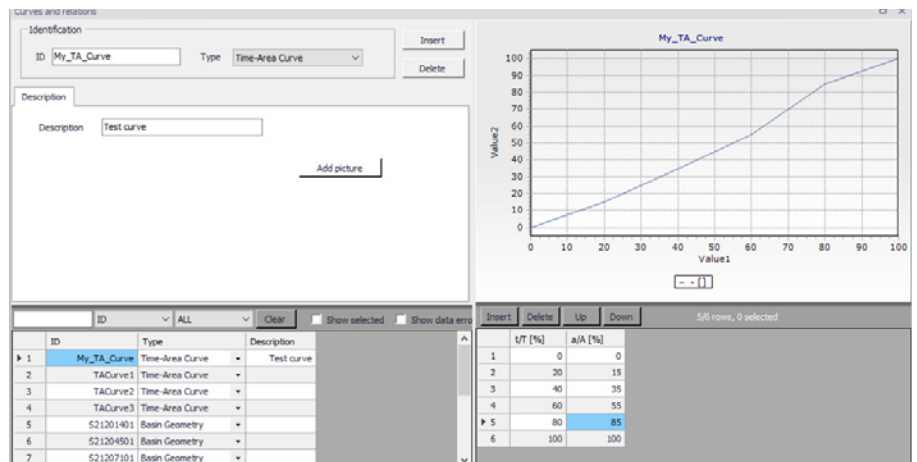


Figure 4.9 The Curves and Relations Editor with a user-defined Time-Area curve

## 4.2.2 Kinematic Wave (B)

The Kinematic Wave (Model B) is a surface runoff model with moderate data requirements. The runoff computation is based on a comprehensive treatment of hydrological losses (including infiltration) and the runoff routing by the Kinematic Wave (Manning) formula. Technical details can be found in the MIKE 1D Reference Manual.

### Model Data

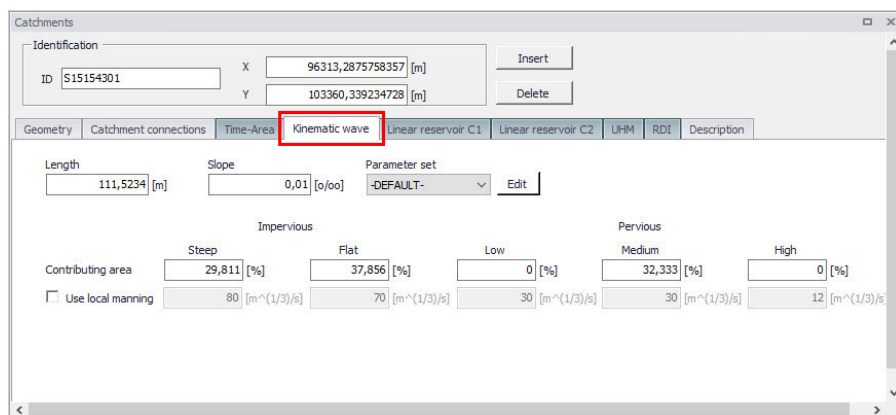


Figure 4.10 The Kinematic Wave Model Tab

A full overview of the editor fields and corresponding attributes is provided in the Table 4.6.

Table 4.6 Overview of the Kinematic Wave model attributes (Table ms\_Catchment)

Edit field	Description	Used or required by simulations	Field name in datastructure
Length	Characteristic length of the catchment	Yes	ModelBLength
Slope	Representative slope of the catchment	Yes	ModelBSlope



Table 4.6 Overview of the Kinematic Wave model attributes (Table ms\_Catchment)

Edit field	Description	Used or required by simulations	Field name in datastructure
Parameter Set	Reference to a set of model parameters to be used for the current catchment	Yes	ModelBParBID
Contributing Area (five fields)	Fraction of the actual model area for each surface category	Yes	ModelBAISteep, ModelBAIFlat, ModelBAPSmall, ModelBAPMedium, ModelBAPLarge
Use Local Manning	Allows for local use of individual parameters	Optional	ModelBLocalNo
Manning Number (five fields)	Local value of the Manning number for various types of catchment surfaces	Optional	ModelBMISlope, ModelBMIFlat, ModelBMPSmall, ModelBMPPMedium, ModelBMPLarge

## Parameters Kinematic Wave

The Kinematic Wave model uses a relatively large number of parameters. For practical reasons, these parameters have been grouped in parameter sets, which, in turn, can be associated with certain catchments. The entire model setup can thus be established with a very small amount of information, while still allowing for full spatial variation of model parameters for individual catchments through the application of local values.

New parameter sets can be inserted and values of individual parameters can be edited in the Parameters Kinematic Wave Editor. This can be activated at Catchments|Parameters Kinematic Wave.

MIKE URBAN+ comes with a Default parameter set (-DEFAULT-). The User can insert any number of parameter sets and edit them as needed.

Parameters Kinematic Wave

Identification

Parameter set ID:

Insert

Delete

Parameters

	Steep	Impervious Flat	Low	Pervious Medium	Height
Initial Loss					
Wetting	<input type="text" value="0,05"/> [mm]	<input type="text" value="0,05"/> [mm]	<input type="text" value="0,05"/> [mm]	<input type="text" value="0,05"/> [mm]	<input type="text" value="0,05"/> [mm]
Storage		<input type="text" value="0,6"/> [mm]	<input type="text" value="1"/> [mm]	<input type="text" value="1"/> [mm]	<input type="text" value="2"/> [mm]
Horton's infiltration capacity					
Maximum			<input type="text" value="3,6"/> [mm/h]	<input type="text" value="36"/> [mm/h]	<input type="text" value="72"/> [mm/h]
Minimum			<input type="text" value="1,8"/> [mm/h]	<input type="text" value="3,6"/> [mm/h]	<input type="text" value="18"/> [mm/h]
Horton's infiltration exponent					
Wet condition			<input type="text" value="0,0015"/> [1/s]	<input type="text" value="0,0015"/> [1/s]	<input type="text" value="0,0015"/> [1/s]
Dry condition			<input type="text" value="5E-6"/> [1/s]	<input type="text" value="1E-5"/> [1/s]	<input type="text" value="5E-5"/> [1/s]
Manning	<input type="text" value="80"/> [m <sup>1/3</sup> /s]	<input type="text" value="70"/> [m <sup>1/3</sup> /s]	<input type="text" value="30"/> [m <sup>1/3</sup> /s]	<input type="text" value="30"/> [m <sup>1/3</sup> /s]	<input type="text" value="12"/> [m <sup>1/3</sup> /s]

ID:  ALL  ☐ Show selected ☐ Show data errors 1/1 rows, 0 selected

ID	Wet Steep [mm]	Wet Flat [mm]	Wet Small [mm]	Wet Medium [mm]	Wet Large [mm]	Storage F
1	-DEFAULT-	0,05	0,05	0,05	0,05	

Figure 4.11 The Kinematic Wave Parameter Sets Editor (Catchments|Parameters Kinematic Wave)

A full overview of the editor fields and corresponding database attributes is provided in the Table 4.7.

Table 4.7 Overview of the Kinematic Wave Parameter Set Attributes (Table msm\_HParB)

Edit field	Description	Used or required by simulations	Field name in datastructure
Parameter set ID	Parameter set identifier	Yes	MUID
Wetting (five fields)	Wetting initial loss on various types of surfaces	Yes	WetSteep, WetFlat, WetSmall, WetMedium, WetLarge
Storage (four fields)	Storage initial loss on various types of surfaces	Yes	StorageFlat, StorageSmall, StorageMedium, StorageLarge





Table 4.7 Overview of the Kinematic Wave Parameter Set Attributes (Table msm\_HParB)

Edit field	Description	Used or required by simulations	Field name in datastructure
Maximum (three fields)	Horton's maximum infiltration capacity on various types of surfaces	Yes	InfMaxSmall, InfMaxMedium, InfMaxLarge
Minimum (three fields)	Horton's minimum infiltration capacity on various types of surfaces	Yes	InfMinSmall, InfMinMedium, InfMinLarge
Wet Condition (three fields)	Horton's exponent for wet conditions on various types of surfaces	Yes	InfExpWetSmall, InfExpWetMedium, InfExpWetLarge
Dry Condition (three fields)	Horton's exponent for dry conditions on various types of surfaces	Yes	InfExpDrySmall, InfExpDryMedium, InfExpDryLarge
Manning (five fields)	Manning number for various types of catchment surfaces	Yes	ManningSteep, ManningFlat, ManningSmall, ManningMedium, ManningLarge

### 4.2.3 Linear Reservoir (C1 and C2)

The Linear Reservoir model (Model C) is a surface runoff model with minimum data requirements. The runoff computation is based on a comprehensive treatment of hydrological losses (including infiltration) and runoff routing by the linear reservoir principle. Technical details can be found in the MIKE 1D Reference Manual.

MIKE URBAN+ includes this model in two versions: C1 and C2. These are variants of the same model, and are used as national standards in the Netherlands and France, respectively.



## Linear Reservoir C1 Model Data

The screenshot shows the 'Catchments' application window. At the top, the 'Identification' section contains an 'ID' field with the value 'S15154601', and 'X' and 'Y' coordinate fields with values '96648,0987280115 [m]' and '103391,606058811 [m]' respectively. Below this are tabs for 'Geometry', 'Catchment connections', 'Time-Area', 'Kinematic wave', and 'Linear reservoir C1'. The 'Linear reservoir C1' tab is selected and highlighted with a red box. In this tab, the 'Effective area' is set to '60,45 [%]'. To the right, it shows 'Time constant: 12[/h]' and 'Initial loss: 0,5[mm]'. There are two radio buttons: 'Use parameter set' (which is selected) and 'Use local parameters'. A dropdown menu for 'Use parameter set' shows '-DEFAULT-' and an 'Edit' button is next to it.

Figure 4.12 The Linear Reservoir C1 Model Tab

A full overview of the editor fields and corresponding attributes for the Linear Reservoir C1 model is provided in the Table 4.8.

Table 4.8 Overview of the Linear Reservoir C1 attributes (Table msm\_Catchment)

Edit field	Description	Used or required by simulations	Field name in datastructure
Effective Area	Contributing area	Yes	ModelC1EffectiveArea
Use Parameter Set	Reference to a set of model parameters to be used for the current catchment	Yes	ModelC1ParCID
Use Local Parameters	Allows for local use of individual parameters	Optional	ModelC1LocalNo

Table 4.8 Overview of the Linear Reservoir C1 attributes (Table msm\_Catchment)

Edit field	Description	Used or required by simulations	Field name in datastructure
Time Constant	Local value of the time constant	Optional	ModelC1TimeConst
Init. Loss	Local value of the initial loss	Optional	ModelC1Iloss

## Linear Reservoir C2 Model Data

The screenshot shows the 'Catchments' software window. The 'Identification' section contains fields for ID (S15154101), X (96066,4013751746 [m]), and Y (103366,558009683 [m]). The 'Geometry' section includes Length (49,86679 [m]) and Slope (3,748835 [0/100]). The 'Imperviousness' section has a value of 67,667 [%]. The 'Linear reservoir C2' tab is selected and highlighted with a red box. Other tabs include 'Time-Area', 'Kinematic wave', 'Linear reservoir C1', 'UHIM', 'RDI', and 'D'. The 'Linear reservoir C2' section shows parameters: Reduction factor: 0,9; Initial loss: 0,5[mm]; Lag time: 5[min]. There are also radio buttons for 'Use parameter set' (selected, -DEFAULT-) and 'Use local parameters', along with an 'Edit' button.

Figure 4.13 The Linear Reservoir C2 Model Tab

A full overview of the editor fields and corresponding Linear Reservoir C2 model attributes is provided in the Table 4.9.

Table 4.9 Overview of the Linear Reservoir C2 attributes (Table msm\_Catchment)

Edit field	Description	Used or required by simulations	Field name in datastructure
Length	Characteristic length of the catchment	Yes	ModelCLength
Slope	Representative slope of the catchment	Yes	ModelCSlope



Table 4.9 Overview of the Linear Reservoir C2 attributes (Table msm\_Catchment)

Edit field	Description	Used or required by simulations	Field name in datastructure
Imperviousness	Impervious area as a fraction of the actual model area	Yes	ModelC2ImperviousArea
Use Parameter Set	Reference to a set of model parameters to be used for the current catchment	Yes	ModelC2ParCID
Use Local Parameters	Allows for local use of individual parameters	Optional	ModelC2LocalNo
Reduction Factor	Local value of the hydrological reduction factor	Optional	ModelC2RedFactor
Init. Loss	Local value of the initial loss	Optional	ModelC2Iloss
Lag Time	Local value of the lag time	Optional	ModelC2LagTime

## Parameters Linear Reservoir

The Linear Reservoir model uses a number of parameters. For practical reasons, these parameters have been grouped in parameter sets, which, in turn, can be associated with certain catchments. This means the entire model setup can be established with a very small amount of information, while still allowing for full spatial variation of model parameters for individual catchments through the application of local values.

New parameter sets can be inserted and values of individual parameters can be edited in the Parameters Linear Reservoir Editor. This can be activated via Catchments|Parameters Linear Reservoir.

MIKE URBAN+ comes with a Default parameter set (-DEFAULT-). The User can insert any number of parameter sets and edit them as needed.

Parameters linear reservoir

Identification

Parameter set ID

Insert

Delete

Parameters

☒ C1 ☐ C2

Initial loss  [mm] Time constant  [h]

Reduction factor  [0] Lag time  [min]

☒ Infiltration

Horton's infiltration capacity

Maximum  [mm/h] Time constants

Minimum  [mm/h] Wet condition  [h]

Dry condition  [h]

ID ALL Clear Show selected Show data errors 1/1 rows, 0 selected

ID	Max Cap [mm/h]	R factor [0]	I loss [mm]	Lag time [min]	Infiltr	Min Cap [mm/h]	Wet Con
1	-DEFAULT-	2	0,9	0,5	5	<input checked="" type="checkbox"/>	0,5

Figure 4.14 The Linear Reservoir C1 Parameter Sets Editor (Catchments|Parameters Linear Reservoir) - Dutch version

Parameters linear reservoir

Identification

Parameter set ID

Insert

Delete

Parameters

☐ C1 ☒ C2

Initial loss  [mm] Time constant  [h]

Reduction factor  [0] Lag time  [min]

☒ Infiltration

Horton's infiltration capacity

Maximum  [mm/h] Time constants

Minimum  [mm/h] Wet condition  [h]

Dry condition  [h]

ID ALL Clear Show selected Show data errors 1/1 rows, 0 selected

ID	Max Cap [mm/h]	R factor [0]	I loss [mm]	Lag time [min]	Infiltr	Min Cap [mm/h]	Wet Con
1	-DEFAULT-	2	0,9	0,5	5	<input checked="" type="checkbox"/>	0,5

Figure 4.15 The Linear Reservoir C2 Parameter Sets Editor (Catchments|Parameters Linear Reservoir) - French version

A full overview of the editor fields and corresponding database attributes is provided in the Table 4.10.

Table 4.10 Overview of the Linear Reservoir Parameter Set attributes (Table msm\_HParC)

Edit field	Description	Used or required by simulations	Field name in datastructure
Parameter Set ID	Parameter set identifier	Yes	MUID
C1/C2	Toggle for editor setting for model C1 and C2, respectively	Yes	-
Initial Loss	Local value of the initial loss	Yes	lloss
Time Constant	Local value of the time constant	Optional, model C1 only	CTime
Reduction Factor	Local value of the hydrological reduction factor	Optional, model C2 only	RFactor
Lag Time	Local value of the lag time	Optional, model C2 only	LagTime
Infiltration	Toggle for switching ON and OFF calculation of infiltration	Optional	InfiltrNo
Maximum Horton's Infiltration Capacity	Maximum infiltration capacity	Optional, if infiltration included	MaxCap
Minimum Horton's infiltration capacity	Minimum infiltration capacity	Optional, if infiltration included	MinCap
Wet Condition Time Constant	Infiltration time constant for wet conditions	Optional, if infiltration included	WetCond
Dry Condition Time Constant	Infiltration time constant for dry conditions	Optional, if infiltration included	DryCond

#### 4.2.4 Unit Hydrograph Method (UHM)

The Unit Hydrograph Method (UHM) is a simple linear surface runoff model used to derive hydrographs for any amount of excess precipitation. The runoff computation includes a comprehensive treatment of hydrological losses (i.e. calculation of excess precipitation) and runoff routing through creation of a composite hydrograph. Technical details can be found in the MIKE 1D Reference Manual.



Figure 4.16 The Unit Hydrograph Model Tab

An overview of the editor fields and corresponding UHM Model attributes is provided in the Table 4.11.

Table 4.11 Overview of the UHM Model attributes (Table msm\_Catchment)

Edit field	Description	Used or required by simulations	Field name in datastructure
Area Adjustment Factor	Relative size of contributing area	Yes	UHMAreaFactor
Cp	Hydrograph peak factor	Optional, SUH Standard method only	UHM Cp
Hydrograph	Method for hydrograph computation	Yes	UHMMethodNo
Slope	Representative catchment slope	Optional, SUH Alameda method only	UHMSuhSlope
Loss Model	Method for computing hydrological losses	Yes	UHMLossModelNo
Initial Loss	Initial loss	Optional, Constant Loss method only	UHMLnitLoss
Constant Loss	Constant loss	Optional, Constant Loss method only	UHMConstLoss



Table 4.11 Overview of the UHM Model attributes (Table msm\_Catchment)

Edit field	Description	Used or required by simulations	Field name in datastructure
Runoff Coefficient	Runoff coefficient	Optional, Proportional Loss method only	UHMRunoffCoeff
Curve Number	Standard hydro-graph curve number	Optional, SCS and SCS Generalized loss methods only	UHMCurveNum
Initial AMC	Antecedent moisture condition	Optional, SCS loss method only	UHMAMC
Initial Abstr. Depth	Initial abstraction depth	Optional, SCS Generalized loss method only	UHMLnitAbstract-Depth
Lag Time Method	Method for lag time computation	Yes	UHMLagTimeMethodNo
Lag Time	User-specified lag time	Optional, User specified lag time method only	UHMLagTime
Hydraulic Length	Hydraulic length of the catchment	Optional, SCS Formula lag time method only	UHMHydraulicLength
LT Curve No.	CSC Curve number used for computing lag time	Optional, SCS Formula lag time method only	UHMLagCurveNum
LT Slope	Average catchment slope	Optional, SCS Formula lag time method only	UHMSlope
L	Length of the main stream from outlet to the divide	Optional, SUH Standard and Alameda lag time methods only	UHMSuhL
Ct	Watershed (catchment) coefficient	Optional, SUH Standard lag time method only	UHMSuhCt
Lc	Length of the main stream from the outlet to the point closest to the catchment centroid	Optional, SUH Standard and Alameda lag time methods only	UHMSuhLc





Table 4.11 Overview of the UHM Model attributes (Table msm\_Catchment)

Edit field	Description	Used or required by simulations	Field name in datastructure
Stream Slope	Average Overland Slope	Optional, SUH Alameda lag time method only	UHMStreamSlope
Basin Factor	Basin factor	Optional, SUH Alameda lag time method only	UHMBasFactor

## 4.2.5 RDI and Additional Flow

Continuous runoff from MIKE URBAN+ catchments can be modelled at two distinct levels: either as a simple specification of a constant additional flow or as an RDI computation.

The latter option involves a continuous hydrological model Rainfall Dependent Infiltration (RDI). RDI provides detailed, continuous modelling of the complete land phase of the hydrologic cycle, providing support for urban, rural, and mixed catchments analyses. Precipitation is routed through four different types of storage: snow, surface, unsaturated zone (root-zone) and groundwater. This enables continuous modelling of the runoff processes, which is particularly useful when long-term hydraulic and pollution load effects are analyzed.

Instead of only performing hydrological load analysis of the sewer system for short periods of high intensity rainstorms, a continuous, long-term analysis is applied to look at periods of both wet and dry weather, as well as inflows and infiltration to the sewer network. This provides a more accurate picture of actual loads on treatment plants and combined sewer overflows.

When studying the real flow conditions in sewer systems, flow peaks during rain events are often found to exceed the values that can be attributed to the contribution from participating impervious areas. This is a consequence of the phenomenon, usually named Rainfall Induced Infiltration. This differs from the Rainfall Induced Inflow by the fact that it does not only depend on the actual precipitation, but is heavily affected by the actual hydrological situation, i.e. the memory from earlier hydrological events. For a certain rainfall event, the increase in flow will therefore differ, depending on hydrological events during the previous period. The Rainfall Induced Infiltration is also distinguished by a slow flow response, which takes place during several days after the rainfall event.

From a hydrological point of view, parts of the infiltration behave in the same way as the inflow. Therefore, classification of total hydrological loads to infiltration and inflow is not suitable for modelling approach. Rather, to describe

appropriately the constitutive components of flow hydrographs distinguished by their hydrological behaviour, the following concept is used instead:

- FRC - Fast Response Component: comprises the rain induced inflow and fast infiltration component;
- SRC - Slow Response Component: comprises slow infiltration component.

Distinctive for the FRC component is that it is not influenced by the previous hydrological situation, i.e. high or low soil moisture content. It occurs as a direct consequence of a rainfall. The FRC component consists of the inflow to the sewer system and the fast flow component of the infiltration, not dependent on previous hydrological conditions.

On the other hand, characteristic of the SRC component is that it is highly dependent on previous hydrological conditions and usually responds slowly to a rainfall. The SRC component consists of the rest of the precipitation-induced infiltration and dry weather infiltration/inflow.

When combined with any of the surface runoff models, RDI provides a platform for accurate and reliable computation of urban runoff free from the limitations inherent to standard urban runoff modelling.

Figure 4.17 shows an example illustrating the influence of previous hydrological conditions for the two components and their response to a rainfall.

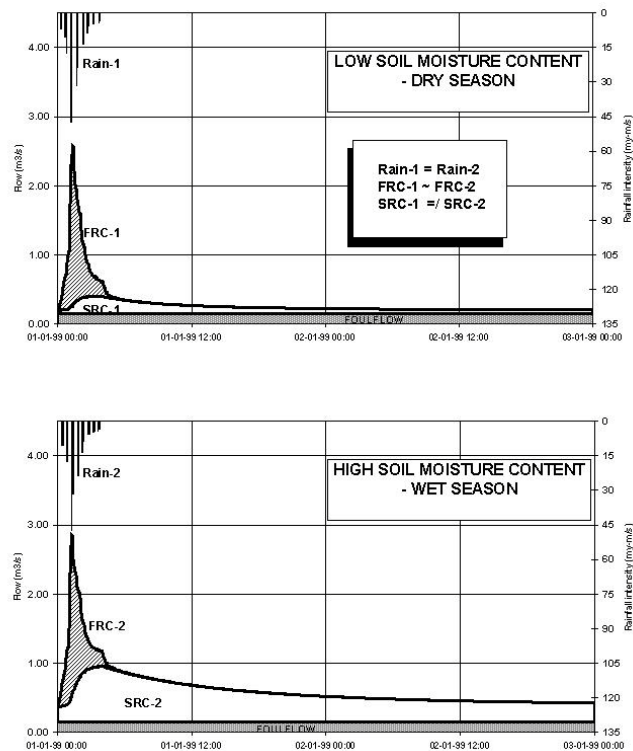


Figure 4.17 Different catchment response under the same rainfall due to different soil moisture conditions at the beginning of the rainfall

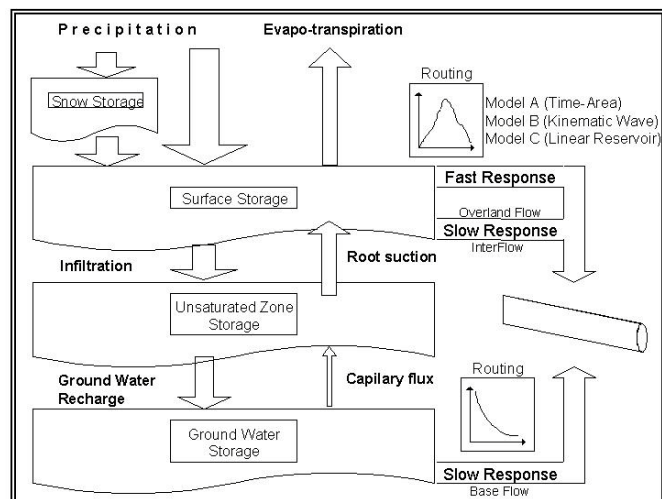
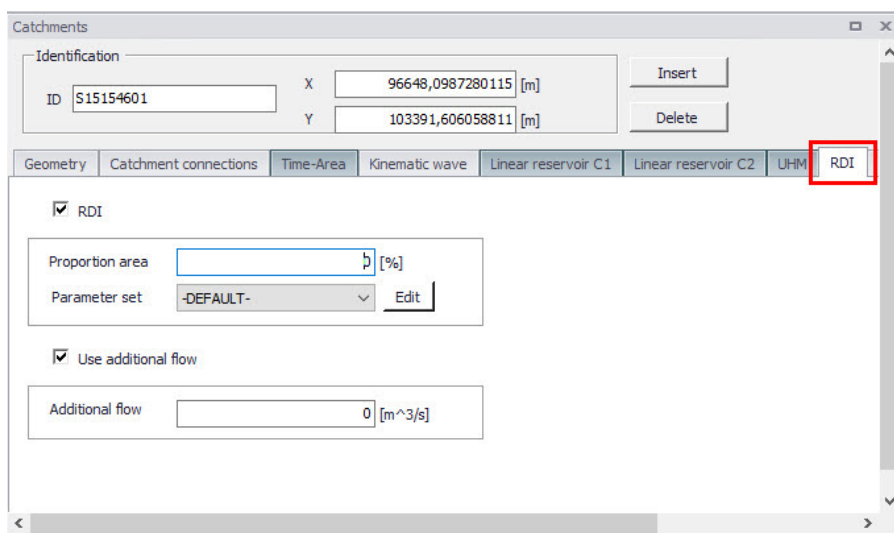


Figure 4.18 Schematics of the RDI Model

## Model Data

The model data for additional catchment flow and RDI are in the database table `msm_Catchment`.



The screenshot shows the 'Catchments' dialog box with the 'RDI' tab selected. The 'RDI' checkbox is checked. The 'Proportion area' field is set to 0 [%]. The 'Parameter set' is set to '-DEFAULT-'. The 'Use additional flow' checkbox is checked. The 'Additional flow' field is set to 0 [m<sup>3</sup>/s]. The 'RDI' tab is highlighted with a red box.

Figure 4.19 The RDI Model and Additional Flow Tab

A full overview of the editor fields and corresponding database attributes is provided in the Table 4.12.

Table 4.12 Overview of the RDI and Additional Flow attributes (Table `msm_Catchment`)

Edit field	Description	Used or required by simulations	Field name in datastructure
RDI checkbox	Toggle for activation of RDI	Optional	RdiiNo
Proportion Area	RDI area as a fraction of the actual model area	Optional, if RDI activated	RdiiArea
Parameter Set	Reference to a set of RDI model parameters to be used for the current catchment	Optional, if RDI activated	ParRDiiID



Table 4.12 Overview of the RDI and Additional Flow attributes (Table msm\_Catchment)

Edit field	Description	Used or required by simulations	Field name in datastructure
Use Additional Flow checkbox	Toggle for activation of additional flow	Optional	AddFlowNo
Additional Flow	Amount of constant additional flow	Yes, Default value = 0	AddFlow

## Parameters RDI

The RDI Model uses a large number of parameters. For practical reasons, these parameters have been grouped in parameter sets, which can be associated with certain catchments. This means the entire model setup can be established with a very small amount of information.

New parameter sets can be inserted and values of individual parameters can be edited in the Parameters RDI Editor. This can be activated via Catchments|Parameters RDI.

MIKE URBAN+ comes with a Default RDI parameter set (-DEFAULT-). The User can insert any number of parameter sets and edit them as needed.

The screenshot shows the 'Parameters-RDI' window with the 'Main parameters' tab selected. The 'Identification' section at the top has an 'ID' field set to '-DEFAULT-' and buttons for 'Insert' and 'Delete'. Below this, the 'Main parameters' tab contains several input fields for different parameters:

- Surface storage(Umax): 10 [mm]
- Root zone storage(Lmax): 100 [mm]
- Overland coefficients(CQof): 0,3 [0]
- Groundwater coefficient(Carea): 1 [0]
- TC overland flow(CK): 20 [h]
- TC interflow(CKif): 500 [h]
- TC baseflow(BF): 2000 [h]
- Snowmelt: ☐ (checked) with a value of 3

At the bottom, there is a table view showing the current parameter set:

ID	Surface storage(Umax) [mm]	Root zone storage(Lmax) [mm]	Overland coefficients(CQof) [0]	Groundwater coefficient(Carea)
1	-DEFAULT-	10	100	0,3

Figure 4.20 The RDI Parameter Sets Editor Main Parameters Tab (Catchments|Parameters RDI)

The RDI parameters are grouped into Tabs in the editor by:

- Main parameters
- Threshold parameters



- Groundwater parameters
- Initial conditions

A full overview of the editor fields and corresponding database attributes is provided in Table 4.13 to Table 4.15.

Table 4.13 Overview of Parameters RDI Main Parameters Tab attributes (Table 'msm\_HParRDII')

Edit field	Description	Used or required by simulations	Field name in datastructure
ID	Parameter set identifier	Yes	MUID
Surface Storage (Umax)	Capacity of surface storage	Yes	Umax
Root Zone Storage (Lmax)	Capacity of root zone (lower) storage	Yes	Lmax
Overland Coefficient (CQof)	Fraction of runoff going to overland flow	Yes	Cqof
Groundwater Coefficient (Carea)	Relative size of groundwater reservoir	Yes	GwCarea
TC Overland Flow (CK)	Time constant for overland runoff component	Yes	Ck
TC Interflow (CKif)	Time constant for interflow runoff component	Yes	Ckif
TC Baseflow (BF)	Time constant for baseflow runoff component	Yes	Ckbf
Snowmelt checkbox	Switch for activation of the snow storage/snowmelt processes	Yes	SnowmeltNo
Snowmelt	Snowmelt coefficient	Optional, if snowmelt activated	SnowmeltC

Parameters-RDI

Identification

ID: -DEFAULT- Insert Delete

Main parameters **Threshold parameters** Groundwater parameters Initial conditions

Overland(Tof)  0 [()]

TC interflow(Tif)  0 [()]

TC baseflow(Tg)  0 [()]

ID	Surface storage(Umax) [mm]	Root zone storage(Lmax) [mm]	Overland coefficients(CQof) [()]	Groundwater coeffi
1	-DEFAULT-	10	100	0,3

Figure 4.21 The RDI Parameter Sets Editor Threshold Parameters Tab

Table 4.14 Overview of Parameters RDI Threshold Parameters Tab attributes (Table 'msm\_HParRDII')

Edit field	Description	Used or required by simulations	Field name in datastructure
Overland (Tof)	Fraction of surface storage capacity at which overland flow starts	Yes	Tof
TC Interflow (Tif)	Fraction of surface storage capacity at which interflow starts	Yes	Tif
TC Baseflow (Tg)	Fraction of surface storage capacity at which ground water recharge starts	Yes	Tg



Parameters-RDI

Identification

ID: -DEFAULT-

Insert

Delete

Main parameters | Threshold parameters | Groudwater parameters | Initial conditions

Surface storage(U) 0 [mm]

Root zone moisture(InitL) 0 [mm]

Overland flow(Of) 0 [mm/h]

Interflow(If) 0 [mm/h]

Groundwater depth(Gwl) 0 [m]

ID ALL Clear Show selected Show data errors 1/1 rows, 0 selected

ID	Surface storage(Umax) [mm]	Root zone storage(Lmax) [mm]	Overland coefficients(CQof) [()]	Groundwater coeff
1 -DEFAULT-	10	100	0,3	

Figure 4.22 The RDI Parameter Sets Editor Initial Conditions Tab

Table 4.15 Overview of Parameters RDI Initial Conditions Tab attributes (Table 'msm\_HParRDI')

Edit field	Description	Used or required by simulations	Field name in datastructure
Surface Storage (U)	Water depth in the surface storage at the simulation start	Yes	InitU
Root Zone Moisture (InitL)	Moisture contents in the root zone at the simulation start	Yes	InitL
Overland Flow (Of)	Overland flow intensity at the simulation start	Yes	InitOf
Interflow (If)	Interflow intensity at the simulation start	Yes	InitIf
Groundwater Depth (Gwl)	Groundwater depth at the simulation start	Yes	InitGwl



Figure 4.23 The Parameters RDI Groundwater Parameters Tab

Table 4.16 Overview of Parameters RDI Groundwater Parameters Tab attributes (Table 'msm\_HParRDII')

Edit field	Description	Used or required by simulations	Field name in datastructure
Specific Yield (GwSy)	Specific yield of the groundwater reservoir (porosity)	Yes	GwSy
Min. GW Depth (GwLmin)	Top of the groundwater storage (depth from surface)	Yes	GwLmin
Max. GW Depth Causing Baseflow (GWLbf0)	Bottom of the groundwater storage (depth from surface)	Yes	GWLbf0
GW Depth for Unit Capillary Flux (GWLf1)	Groundwater depth causing unit capillary flux	Yes	Gwlfl1

## 4.2.6 RDI - Guidelines for Application

### Choice of calculation time step

When calculating with RDI, time steps are given separately for the Surface Runoff Model and for the rain dependent infiltration part.



The RDI calculation can often be performed with a relatively long time step (several hours), while calculation with the Surface Runoff Model is typically performed with a time step in the order of several minutes.

The time step for Surface Runoff computations is primarily about the sufficient resolution of the runoff process in time.

Generally, the RDI simulation time step should be chosen in accordance with the resolution of precipitation data, e.g. a time step of 24 hours could be suitable if only daily precipitation data is available. However, in cases when precipitation data with high resolution of e.g. few minutes are available, the RDI time step should be chosen in accordance with the response of the discharge when raining. E.g. an RDI time step of 2-4 hours should be chosen if the time constant CKOF is given a value of 8 hours.

To minimize the calculation time as well as the size of the result files, the RDI calculations are performed according to the following principle:

The RDI simulation is carried out continuously for the whole period specified. On the contrary, the Surface Runoff simulation is carried out only when raining. Thus, the start time for the Surface Runoff calculation is set as the start time for the rain hydrograph. The Surface Runoff calculation continues until all the surface runoff hydrographs are regressed.

## The RDI hotstart

There is a HOTSTART facility for RDI, i.e. the initial conditions for the various storages can be automatically taken from a former result file at a simulation start time.

The structure and contents of the result file used as a HOTSTART file requires that the time series in the boundary connection start at least for the maximum specified concentration time  $T_c$  earlier than the start time for the HOTSTART is specified. This is required for the correct reconstruction of the surface runoff component (FRC).

## The RDI result files

Two result files are generated by a RDI calculation. These are:

1. \*.RES1D file, containing a maximum of five time series for each sub-catchment, namely:
  - Discharge, calculated with the Surface Runoff Model (the FRC component)
  - Discharge, calculated with the RDI model (the SRC component)
  - Total discharge
  - Variation of water content in the surface storage for the Surface Runoff Model



- Variation of water content in the snow storage for the Surface Runoff Model

The \*.RES1D file is used as input data for a Hydrodynamic calculation.

2. \*.NOF file (optional), containing detailed information about the processes treated by an RDI model, e.g.:

- Different flow components in the RDI model
- Variation of water content in the different storage in the RDI model

The \*.NOF file is used for calibration of the SRC component and for RDI hot-start.

In the \*.RES1D file the time series are saved with two intervals; the shorter one for the periods when the Surface Runoff Model is used, and a larger one in the remaining periods. In the \*.NOF file the time series are saved with the larger time interval, which is equal to the time step used for the RDI calculation.

## RDI Validation

Some of the parameters in RDI (here meaning both for the rain dependent inflow and the infiltration part) are related to actual physical data. However, the final choice of parameter values must be based on a comparison with historical measured discharges since a number of the parameters have an empirical character.

The available period of the measured discharge data and its resolution in time are of major importance for the credibility of the obtained parameter values. Ideally, for good accuracy, a 3-5 years long time series of measured discharge data with daily values is required for the calibration of the RDI parameters. Several months long time series with higher resolution, i.e. minutes or hours, depending on the size of the area, are needed for the calibration of the surface runoff model. Measured time series with shorter duration are also useful, although not securing optimal parameter values. In such case it is important that the time series represents different hydrological situations, i.e. typical wet period or dry period.

An exact correspondence between simulations and measurements can however not be expected and for areas where precipitation data of worse quality is used, a less accurate calibration result must be accepted. In this case it may be preferable to recall the purpose of the actual model application and concentrate on calibrating yearly volumes, flow peaks or base flows, depending on what kind of analysis is to be performed with the model.

It must be remembered that RDI calculates the precipitation-dependent flow component. When comparing with measured discharge data the total measured discharge therefore has to be reduced with the flow components not being precipitation dependent, e.g. foul flow.

RDI calculates the total generated discharge from a catchment, i.e. overflow within the sub-catchment will also be included in the calculated discharge. Therefore, when comparing with measured peak flows and controlling the water balance (total volume) this has to be taken into consideration.

In principle, the model validation is concerned about comparison of the computed and measured hydrographs. As there are almost an infinite number of possibilities to describe level of agreement between two hydrographs, it is recommended to establish some validation criteria, i.e. a measure for accuracy of the model, relevant for the current application. There are several types of criteria, such as numeric criteria based on single values (e.g. peak discharge, volume, etc.), or more complex numeric criteria based on statistical analysis of the computed and calculated time series. Also, there are different types of visual criteria, based on visual inspection, e.g. comparison of graphic presentations of the calculated and measured duration curves. An important issue is to find the most appropriate criteria for the intended application of the model.

The choice of criteria is important since it may affect the final choice of parameter values and by that the behaviour of the calibrated model. Numerical criteria are, however, limited and therefore a visual comparison between the hydrographs is indispensable.

MIKE URBAN+ supports visual comparison of the calculated time series with any time series of the same type contained in the time series database. E.g., when validating the model, the calculated discharge can be plotted on the same graph with the measured discharge and compared.

In the present version of RDI there is no automatic calculation or evaluation of specific numeric validation criteria as mentioned above. If appropriate, analysis of that type can be conducted so that the calculated time series are exported to a spreadsheet or some other program for further processing and comparison with measured time series.

In the example related to the illustrations, overflow occurs within the model area. RDI can not describe this kind of processes, which complicates the choice of validation criteria.

## Surface runoff model

When simulating storm sewer systems or fully combined systems, usually a good estimation of the area drained by the FRC component (impervious areas, etc.) can be obtained from physical data (maps, etc.). The final model verification of a FRC should however be based upon comparison with measured discharges during rainfall.

To separate the Afrc component (Surface Runoff Model) and the fast part of the SRC component (Surface Runoff Component in RDI), measured discharge data with fairly high resolution in time (hours) is required.



For calibration of the parameters describing the response of the discharge (e.g.  $t_c$  and  $T_{Atype}$  for model A, or M, L and S for model B), a very high resolution in time is usually required, from minutes to hours.

## General hydrological model - RDI

It is not possible to determine the RDI parameters from geophysical measurements, since most of the parameters are of empirical nature. It is therefore necessary that measured discharge from the studied area is available, so that the RDI parameters can be determined by comparison between simulated and measured discharge through the calibration procedure.

The introductory calibration is performed visually by comparing simulated and measured discharge. The final optimization of the parameters is thereafter performed preferably using different numeric and graphical criteria.

The effects of changing each particular parameter are discussed below. Also, the most suitable hydrological periods for calibrating certain parameters are identified, which implies that a certain parameter affects the model behaviour more during periods with specific hydrological conditions. Usually, effects will also be obtained during other periods, why these should also be studied when adjusting a parameter.

The parameters are discussed in the preferable order of adjustment. However, it may be necessary to return to the previous calibration step, as well as repeating the whole process several times. It is recommended, especially for less experienced users, that only one parameter is changed at a time (i.e. for each calculation), so that the effect of the adjustment will appear clearly.

Sometimes, however, the effect of changing one parameter is not sufficient. Then, several parameters controlling similar phenomena can be adjusted together.

In some other cases, undesired secondary effects can be obtained when adjusting certain model parameter. These effects can often be eliminated by simultaneously adjusting other parameters, which do not influence the desired effects, but reduce secondary effects induced by the first parameter.

The following sequence of action is recommended:

- The first step in the RDI calibration is usually to adjust the water balance in the system, i.e. the accuracy between the calculated and measured total volume during the observed period. This is done by correcting the proportion of area,  $Asrc$ . An increase of  $Asrc$  proportionally increases every flow component at each time step.

The total volume generally also contains the runoff from impervious areas (Surface Runoff Model).



- Next, the overland flow coefficient CQOF is adjusted to obtain a correct distribution of volume between overland flow (peak flows) and baseflow. This is done after wet periods and preferably for a period with low evaporation.

A reduction of CQOF reduces the overland flow and increases the infiltration, i.e. induces increase in the baseflow.

The measured flow peaks generally also contain the runoff from impervious areas (Surface Runoff Model).

- CKBF is adjusted against the response of the baseflow, i.e. the build-up and regression of the baseflow. Adjustment against the build-up of baseflow is done during and after wet periods with low evaporation. Adjustment against regression is done during the start of dry periods with high evaporation, preferably when baseflow is the only flow component.

An adjustment of CKBF does not influence the size of the discharged volume studied for a longer period, but displaces the volumes in time.

- CKOF is adjusted against the response, i.e. the shape of the peak flows. This is done during periods with heavy rainfall, preferably after a wet period.

The measured flow peaks generally also contain the runoff from impervious areas (Surface Runoff Model).

- A reduction of Umax reduces the actual evapotranspiration, the process responsible for reduced discharges during period with high potential evaporation. The effect of reducing Umax will be largest for periods preceded by a wet period. Additionally, an increased overland flow is obtained, as well as more water transported to the groundwater storage resulting in an delayed effect of increased baseflow, because of the long response time of baseflow.

An important behaviour of the RDI model is that the surface storage must be filled-up before overland flow and infiltration, respectively, occur. Therefore, during dry periods with high potential evaporation, Umax can be estimated from how much rainfall is required for filling-up the surface storage, i.e. generating overland flow. The same methodology can also be used for the periods with low potential evaporation, but only if the rain event is preceded by a long dry period.

- CKIF is adjusted against the response of interflow during periods with low potential evaporation. A reduction of CKIF will result in a small increase in volume during these periods.



- The relative water content in the unsaturated zone (i.e. root-zone),  $L/L_{\max}$  controls several of the different water transports in the RDI model. Since the storage capacity,  $L_{\max}$ , influences the velocity of the filling of  $L$  towards  $L_{\max}$ ,  $L_{\max}$  is adjusted during periods of heavy filling of the root zone storage. This usually occurs during periods with low potential evaporation preferably in combination with a wet period.

A reduction of  $L_{\max}$  increases the discharge, but it may decrease a little during period with very high potential evaporation.

- The threshold values indicate at which relative water content in the root zone,  $L/L_{\max}$ , overland flow, interflow and baseflow respectively will be generated. Therefore, the threshold values can be estimated from the time of filling the root zone storage when each flow component starts discharging.

The threshold values have no effect during periods when the root zone storage is full,  $L = L_{\max}$ .

An increased threshold value reduces the discharge during dry periods and in the beginning of wet periods, i.e. periods with low relative water content in the root zone storage.

TG is adjusted during periods with heavy filling of the root zone storage, preferably in combination with low potential evaporation and preceded by a dry period. TG is therefore an important parameter for adjusting the increase of the groundwater level in the beginning of wet periods.

TOF is adjusted after a dry period at events with heavy filling of the root zone storage. For example adjustment can be done for events where even larger rainfall volumes does not generate overland flow.

TIF is adjusted after a dry period when filling of the root zone storage, preferably in combination with low potential evaporation. However, TIF is one of the less important parameters.

- The degree-day-coefficient,  $C_{\text{snow}}$  can be estimated from analysis of the relation between temperature, water content in the snow storage and measured discharge. When temperature is below zero, the precipitation is stored in the snow storage. When temperature is above zero the content in the snow storage is emptied into the surface storage, where the velocity of emptying is controlled by  $C_{\text{snow}}$ . An increase of  $C_{\text{snow}}$  increases the emptying procedure.

This process should be addressed now and then during the whole calibration procedure. Otherwise, there is a risk that a snow-melting phenomenon is attempted to be described through adjusting other parameters.



- The Carea coefficient establishes the ratio of groundwater catchment and surface catchment (per Default, the two surfaces are equal). By changing the ratio, the ratio between the baseflow and other runoff components is correspondingly changed.

The Default values of the remaining RDI parameters: Sy (specific yield of the groundwater reservoir), GWLmin (minimum groundwater depth), GWLBF0 (maximum groundwater depth causing baseflow) and GWLFL1 (groundwater depth for unit capillary flux) are adjusted only in exceptional cases. Therefore, these parameters have been included into the RDI parameter set dialog in a separate box. The effects of changing the Default values should be well understood prior to adjustment.

Since the variation of water contents in the surface and root zone storage controls many of the other processes, they should be studied continuously throughout the calibration procedure.

Monthly and yearly values for the different processes, e.g. precipitation volume, real evaporation and total discharge, are written to an ASCII file, NAMSTAT.TXT after every RDI calculation. It is recommended that the content of this file is studied now and then during the calibration procedure.

## Overflow within the model area

In cases when overflow occurs in the model area, e.g. when simulating the discharge to the treatment plant, this has to be considered when calibrating the peak flows during rainfall. RDI calculates the total generated discharge in the catchment area and is therefore not able to describe hydraulic processes like e.g. overflow (loss of water). Calibration of parameters affecting the volume in the peak flows should therefore be performed for rain events when overflow is unlikely to occur. Model parameters affecting the response of the discharge for rain events when overflow occur can be calibrated against the peak flows base or width.

A well-calibrated RDI model can therefore be used for a rough estimation of overflow volume by studying the difference between calculated and measured discharge for heavy peak flows. The credibility for such estimation is however strongly affected by the quality of measured precipitation and discharge time series.

## Non-precipitation dependent flow components

RDI calculates the precipitation dependent flow component. Therefore, both for calibration and validation, other flow components should be treated outside RDI.

Examples of non-precipitation dependent flow components are foul flow and sea water leaking into the sewer system.





The foul flow is preferably estimated through daily values from produced water volumes weighted with yearly charged water volumes. This will however only give a rough estimate, and departure from this methodology may be necessary, e.g. for areas where a large amount of freshwater is used for irrigation.

The amount of leaking sea water is preferably estimated through an iterative procedure between RDI calculation and studies of the difference between the calculated and measured discharge. Only a rough estimation can be achieved, and less accurate calibration results may have to be accepted.

Specially, during the calibration procedure it is very important that non-hydrological errors are generally kept at the lowest level possible in the flow series used. Otherwise, there is a risk of hydrological interpretations of these errors, and the error transmitting in the model and increasing when simulating extreme hydrological situations. A typical example is a rough resolution in time for the foul flow component. The method described above should give a sufficiently correct description for most cases.

## 4.3 Catchment Connections

In order to transfer the runoff generated on catchment surfaces into the collection network, the model must include information about the connection of the catchment outlet to the collection network. One or multiple catchments can be connected to one node, and a catchment can be connected to multiple nodes.

In order to use Catchments in the context of network modeling, they have to be connected to the network.

MIKE URBAN+ supports the connection of catchments to multiple locations (i.e. nodes or links), as well as separately allocating runoff and catchment discharges to multiple locations.

### 4.3.1 Catchment Connections Overview

An overview of relevant connections to a pipe network for catchments is available in the Catchments Editor Catchment Connections Overview Tab (Catchments|Catchments). It shows a table summarizing the connections of the catchment to the network model. The data dynamically link and refer to records in the Catchment Connections Editor (Catchments|Catchment Connections).

The summary table shows information on the following:

- Location. To which type of network element the catchment is connected, and the ID of the element.



- Catchment Runoff. Percentage of the Catchment Runoff from the catchment entering a location.
- Catchment Discharge. Percentage of the Catchment Discharge from the catchment entering a location.
- Action. Offers options for editing or adding connections for the active catchment.

**Edit.** Opens the Catchment Connections Editor, wherein attributes for the existing catchment connection entry can be modified.

**Add connection.** Adds a connection for the active catchment. The new connection is reflected in the overview table and the Catchment Connections Editor.

Location	Catchment RunOff	PE discharge	Action
Node: C14150801	100,000	100,000	Edit
Total	100,000	100,000	Add connection

Figure 4.24 The Catchments Editor Catchment Connections Overview Tab

### 4.3.2 Catchment Connections Editor

Connect catchments to the pipe network via the Catchment Connections Editor (Catchments|Catchment Connections).

The definition and management of catchment connections is supported both through Editors and by a set of graphical catchment connection tools.



Catchment connections

Identification

Catchment ID: S14150801 ... [Insert] [Delete]

Location

☒ Node Node ID: C14150801 ... [Insert] [Delete]

☐ Entire link Link ID: ... [Insert] [Delete]

☐ Link chainage Chainage start/end: [m] [m]

Catchment load allocation

Load type: Standard

Fraction of catchment runoff: 100 [%]

Fraction of catchment discharge: 100 [%]

ID ALL Clear Show selected Show data errors 1/862 rows

	ID	Catchment ID	Type	Node ID	Link ID	Start chainage [m]	End chainage [m]
1	3453	S14150801	Node	C14150801			
2	3454	S14151901	Node	C14150801			
3	3455	S14152801	Node	C14150801			
4	3456	S14150802	Node	C14150802			
5	3457	S15150001	Node	C14150802			
6	3458	S14154801	Node	C14154801			
7	3459	S14152901	Node	C15152001			
8	3460	S14153901	Node	C15152001			
9	3461	S15151101	Node	C15152001			
10	3462	S15152001	Node	C15152001			

Figure 4.25 The Catchment Connections Editor

Create catchment connections through the 'Insert' button. Multiple connections for a single catchment can be set up.



Table 4.17 The Catchment Connections Editor attributes (Table msm\_CatchCon)

Edit field	Description	Usage	Attribute Table Field
Catchment ID	Unique catchment identifier	Yes	CatchmentID
Location Type radio buttons	Specifies the type of network element to which the catchment is connected. Options are: Node Entire link, or Link chainage	Yes	TypeNo
Node ID	Unique identifier for the connected node	Yes, If Connection Type = Node	NodeID
Link ID	Unique identifier for the connected link	Yes, If Connection Type = Entire link or Link chainage	LinkID
Chainage start/end	Start and end chainages of the connected link	Yes, If Connection Type = Link chainage	StartChainage/EndChainage
Load Type dropdown menu	Parameter that defines how the loads from the catchment are allocated to the pipe network for a connection. Options are: Standard, Wastewater Total, Stormwater Total, Combined Partial, Wastewater Partial, and Stormwater Partial. These different Load Types are further explained in the text below.	Yes	LoadTypeNo
Fraction of Catchment Runoff	Fraction of the catchment stormwater runoff to allocate for the connection	Optional, If Load Type = Combined Partial or Stormwater Partial	RRFraction
Fraction of Catchment Discharge	Fraction of the catchment discharge to allocate for the connection	Optional, If Load Type = Combined Partial and Wastewater Partial	PEFraction



As a catchment can be the source of multiple load types (i.e. stormwater and wastewater), and can be connected to multiple network elements and network types, qualifying a load connection type into clear categories according to pipe network type and connection options is important. These Load Types are described in more detail below:

- **Standard:** This type of load connection applies to combined systems where all the catchment output is connected to a single location. This is the Default type, which corresponds to the MIKE URBAN Classic Single Node connection type.
- **Wastewater Total:** This type of load connection applies to fully separated systems, where the catchment is connected to a single location in the wastewater network.
- **Stormwater Total:** This type of load connection applies to fully separated systems where the catchment is connected to a single location in the stormwater network.
- **Combined Partial:** This type of load connection applies to combined systems where the catchment is connected to multiple locations in a combined network. This is the fully versatile connection type.
- **Wastewater Partial:** This type of connection applies to fully separated systems, where the catchment is connected to multiple locations in a wastewater network.
- **Stormwater Partial:** This type of connection applies to fully separated systems where the catchment is connected to multiple locations in a stormwater network.

The User's choice of Load Type affects the Catchment load allocation Editor fields and the internal data validation.

A facility for data validation checks that for each catchment in the Catchment Connections Editor, the sum of the fractions for Catchment Discharge (i.e. PEFraction) and Runoff Discharge (i.e. RRFraction) is close to 100 ( $99.9 < \text{sum} < 100.1$ ).

For catchments where this sum is not found to be close to 100%, all specified connections will be reported as faulty and marked in red.

## 4.4 Low Impact Development (LID)

Water sensitive urban design (WSUD) represents an approach to land development (or redevelopment) that works with nature to manage stormwater as close to its source as possible. It is also known as Low Impact Development (LID).

Low Impact Development employs principles such as preserving and recreating natural landscape features, minimizing effective imperviousness to create



functional and appealing site drainage that treat stormwater as a resource rather than a waste product.

Many practices have been used to adhere to these principles such as bioretention facilities, rain gardens, vegetated rooftops, rainwater tanks, and permeable pavements. By implementing LID principles and practices, stormwater can be managed in a way that reduces the impact of impervious built-up areas and supports the natural movement of water within an urban ecosystem or catchment.

Applied on a broad scale, LID can maintain or restore a catchment's hydrologic and ecological functions. LID has been characterized as a sustainable stormwater practice.

The ability to assess the benefit of LID practices installed in urban catchments is required by Water Utilities and other stakeholders responsible for the urban drainage. An essential part of this requirement is the ability to model the various LID practices at both hydrological screening level and at a detailed hydraulic level in order to evaluate the effect of installing LID practices as parts of a stormwater drainage system.

This chapter describes the implementation and development of model support of various LID structures in MIKE URBAN+.

The modelling of LID practices is divided into 2 main approaches:

- Modelling of LID at screening level - catchment-based approach
- Detailed hydraulic modelling of individual LID structures - drainage network based approach.

This method will provide the User with the option of detailed modelling of individual LID structures hydraulically connected to the stormwater pipe network. This approach is based on the concept of soakaway nodes.

In this Chapter, the MIKE URBAN+ implementation of LID at the screening level - the catchment-based approach - is explained.

The catchment-based methods implemented in MIKE URBAN+ are dominantly based on research published by US EPA, adapted appropriately to the MIKE URBAN+ modelling concept of urban hydrology. In the US, the term Low Impact Development Systems (LIDS) is used for WSUD and the LID concept provides the Users with an overall method for evaluating the various LID controls such as bioretention cells, rain gardens, green roofs, infiltration trenches, permeable pavements, rain barrels/rainwater tanks and vegetative swales.

A user-defined number of LID controls can be deployed and assessed for each individual catchment. This catchment-based approach is used to size



the required infiltration or rainwater harvest by subtraction of flow from the calculated runoff within each catchment.

Please be aware that modelling of LID practices in MIKE URBAN+ is allowed for the Kinematic Wave runoff model (Model B) and runs with the MIKE 1D engine, exclusively.

LIDs are low impact development structures designed to capture or reduce surface runoff from the collecting area by means of a combination of detention, infiltration and evapotranspiration. Low Impact Development controls are conceptual objects that are not displayed on the map visualization of the urban catchment model. Once deployed, they are considered as properties of a given sub-catchment. MIKE URBAN+ can model seven types of LIDs:

1. Bioretention Cells
2. Infiltration Trenches
3. Porous Pavement
4. Rain Barrels
5. Vegetative Swales
6. Rain Garden
7. Green Roof

Bioretention cells, infiltration trenches, and porous pavement systems can have optional underdrain systems in their gravel storage beds to convey storage runoff off the site rather than infiltrate it all. They can also have an impermeable floor of liner that prevents infiltration into the native soil. Infiltration trenches and porous pavement systems can also be subject to a decrease in hydraulic conductivity over time due to clogging.

While some LID practices can also provide important pollutant reduction, the current LID implementation in MIKE URBAN+ can only be used to model the LIDS' quantitative hydrologic performance.

#### 4.4.1 Bioretention Cells

*Bioretention Cells* are terrain depressions that comprise of selected types of vegetation, resistant to the extended periods of high moisture and extreme levels of nutrient concentrations (Nitrogen and Phosphorus) found in stormwater runoff, grown in an engineered soil mixture above a gravel drainage bed. They provide storage, infiltration and evaporation of both direct rainfall and runoff captured from the collecting area surrounding the cell. Rain gardens, street planters, and green roofs are all different types of bioretention cells.

The different structural layers of this feature are:

- Surface

- Soil
- Storage
- Drain (underdrain)

These are illustrated in Figure 4.26. There are one or several relevant hydrological processes associated with each layer.

In the surface occur surface storage, surface infiltration, the collecting area run-on, surface evaporation and overflow.

In the soil layer occur percolation (vertical water movement to the storage layer), evapotranspiration (loss due to the plant root action) and storage in the soil's voids.

In the storage layer, stormwater provided by the percolation through the soil layer is detained in the storage layer's voids. Infiltration (leakage) to the native soil through the storage bottom, controlled by the characteristics of the surrounding soil, restores the storage capacity.

An optional underdrain may be included to empty the storage. The underdrain is activated (with the specified capacity) when the water level in the storage reaches the offset level.

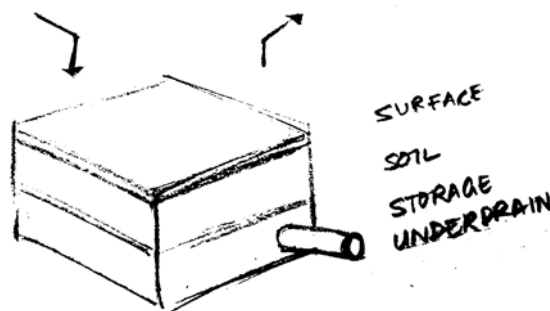


Figure 4.26 Bioretention cell structure layers

## 4.4.2 Infiltration Trenches

*Infiltration Trenches* are storage cells filled with gravel that capture runoff from upstream impervious areas. They provide storage capacity and the possibility for captured runoff to infiltrate the soil underneath.

Figure 4.27 illustrates an infiltration trench structure showing the following components:

- Surface
- Storage





- Drain (optional underdrain)

The processes simulated for the infiltration trench are similar as for bioretention cells, except for the missing soil layer; stormwater from the surface enters the storage directly, i.e. without detention in the soil layer.

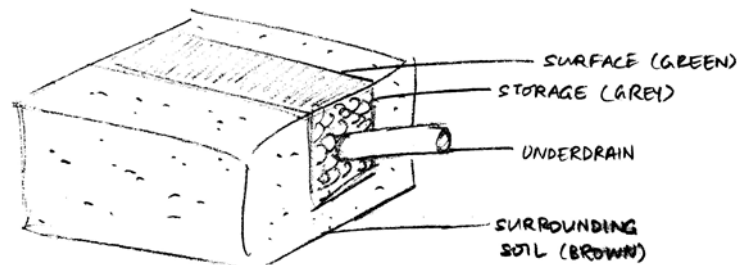


Figure 4.27 Infiltration trench structure layers

#### 4.4.3 Porous Pavement

*Porous Pavement* systems are excavated areas filled with gravel and paved over with a porous concrete or asphalt mix. Porous pavements are implemented in places where the surface has to provide a firm support for vehicle traffic, such as streets and parking lots.

Normally, all rainfall will immediately pass through the pavement into the gravel storage layer below where it can infiltrate at natural rates into the native soil.

Figure 4.28 shows a porous pavement structure, which has the following components:

- Surface
- Pavement material
- Storage
- Drain (underdrain)

Essentially, hydraulic functionality of the porous pavement is similar to that of the bioretention cell, except that the soil layer (and vegetation) are replaced by some porous asphalt or concrete.

Some types of porous pavements may be subject to clogging by fine sediment particles, which reduces their infiltration capacity.

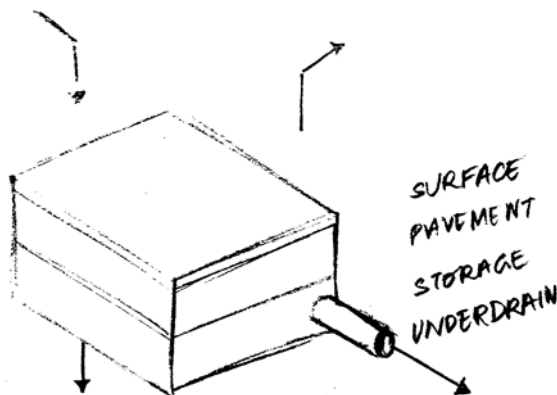


Figure 4.28 Porous Pavement structure layers

#### 4.4.4 Rain Barrels

*Rain Barrels* are containers that collect roof runoff during storm events and can either release or re-use the rain water during dry periods.

A rain barrel includes:

- Storage (with total porosity, i.e. empty volume)
- Drain (underdrain)

The processes simulated include water detention in the storage, overflow and drainage (i.e. storage recovery). The action of the underdrain is timed; the time offset between the end of rain and the drain activation can be specified. This feature allows for the simulation of rainwater reuse for garden watering, which normally takes place several hours or days after the rain has stopped.

A conceptual sketch of a rain barrel is presented in Figure 4.29.

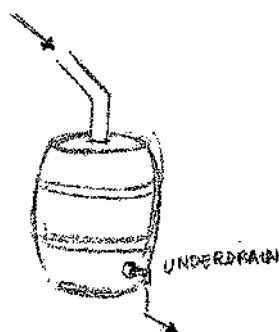


Figure 4.29 Rain Barrel



#### 4.4.5 Vegetative Swales

*Vegetative Swales* are waterways or depressed areas with sloping sides covered with grass and other vegetation. They slow down the conveyance of collected runoff and allow it more time to infiltrate to inherent soil beneath it. The only relevant layers regarding vegetative swales are:

- Surface (and surrounding soil)

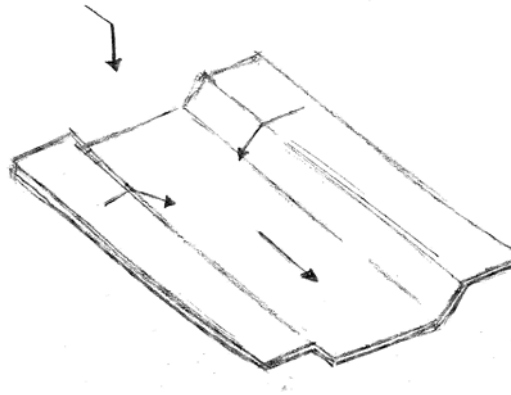


Figure 4.30 Vegetative Swale layer structure

#### 4.4.6 Rain Garden

*Rain Garden* is a simplified form of bioretention cell, which takes advantage of rainfall and stormwater runoff in its design, simultaneously contributing to the reduction of runoff volume and pollutants released from the site. Typically, it is designed as a small garden with selected types of vegetation resistant to the extended periods of high moisture and extreme levels of nutrient concentrations (Nitrogen and Phosphorus) found in stormwater runoff.

The different layers comprising rain gardens are presented in Figure 4.31. These include:

- Surface
- Soil layers

Surface storage, surface infiltration, the collecting area run-on, surface evaporation, and overflow occur on the surface.

In the soil layer occur storage in the soil's voids, evapotranspiration (loss due to the plant root action) and infiltration (leakage) to the native surrounding soil through the bottom. The infiltration is controlled by the characteristics of the surrounding soil.

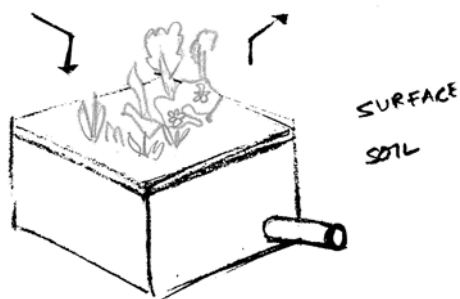


Figure 4.31 Rain Garden process layers

#### 4.4.7 Green Roof

*Green Roofs* are structural components that reduce the negative effects of urbanization on water quality and rainfall runoff by absorbing or detaining, and filtering runoff. They are built of a planted lightweight soil media and a drainage layer, and have the following components:

- Surface
- Soil
- Drainage Mat

Green Roofs may be designed with intensive or extensive vegetation cover. Intensive green roofs are heavy, with soil media layers larger than 15 cm. Extensive green roofs may include a soil layer as thin as 3 cm, affecting the choice of vegetative cover.

Green roofs are equipped with a drainage layer called a drainage mat placed beneath the soil media. The purpose of the drainage mat is to conduct the surplus water percolated through the soil layer from the roof to the drainage system.

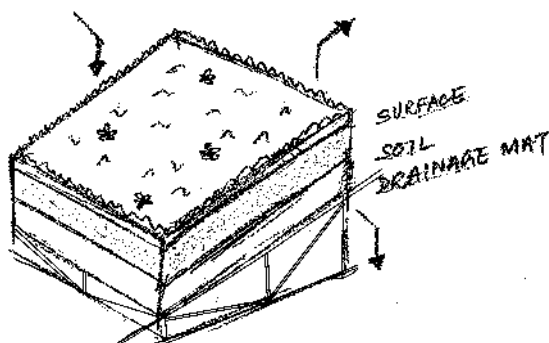


Figure 4.32 Green roof process layers



#### 4.4.8 LID Properties Editor

The MIKE URBAN+ LID Properties editor organizes the data input for the different layers and functional elements of LID structures. The input data is organized into the following group and tabs:

- **Identification:** This group provides unique identification of the specified LID and definition of its type. Each individual LID is generic and is specified per unit area. As such, it can be replicated and placed in any sub-catchment of the study area (i.e. deployed) with different actual sizes and in any number of instances.
- **Tabs:** Surface, Soil, Pavement, Storage, Drain, and Drainage Mat. These tabs represent different layers and functional elements defining the structure of the LID. The properties of each layer and functional element, which constitute the actual LID type, are entered in these tabs. Only the relevant data fields for a LID type are activated and available for data input.

#### Identification

Table 4.18 The LID Properties Identification Group (Table msm\_LIDcontrol)

Edit field	Description	Used or required by simulations	Field name in data structure
ID	ID of LID	Yes	MUID
Type	Type of LID 1:Bioretention Cell 2:Porous Pavement 3:Infiltration Trench 4:Rain Barrel 5: Vegetative Swale 6:Rain Garden 7:Green Roof	Yes	LIDTypeNo

#### LID Properties

Figure 4.33 through Figure 4.38 illustrate the six tabs containing the data for various functional elements of LID structures. The corresponding parameter attributes in the msm\_LIDcontrol database table are summarised in subsequent tables divided by component following the tabs.

##### Surface

A Surface component is used for the following LID structures:

- Bioretention Cell



- Porous Pavement
- Infiltration Trench
- Vegetative Swale
- Rain Garden
- Green Roof

LID properties

Identification

ID:  Type:

Insert Delete

**Surface** Soil Pavement Storage Drain Drainage mat

Storage depth:  [mm] Surface roughness:  [ $m^{1/3}/s$ ]

Vegetative cover:  Surface slope:  [%]

Swale side slope:  [%]

ID	Type	Storage depth [mm]	Vegetative cover	Surface roughness [ $m^{1/3}/s$ ]
1	Bioretention_1	Bio Retention Cell	0,1	1

Figure 4.33 The LID Properties Editor Surface Tab



Table 4.19 LID Properties Surface tab attributes (Table msm\_LIDcontrol)

Edit field	Description	Used or required by simulations	Field name in datastructure
Storage Depth	When confining walls or berms are present, this is the maximum depth to which water can pond above the surface before overflow occurs. For LIDs that experience ponding it is the height of any surface depression storage. For swales, it is the height of its trapezoidal cross section.	Yes If LIDTypeNo = (1,2,3,5)	StorHt
Vegetative Cover	The fraction of the storage area above the surface that is filled with vegetation (0 = no vegetation, 1 = no storage available). NOTE: for infiltration trench, vegetative cover is typically non-existent	Yes If LIDTypeNo = (1,2,3,5)	VegFrac
Swale Side Slope	Slope (run over rise) of the sidewalls of a vegetative swale's cross section. Used for the calculation of the stored volume and wetted width. This value is ignored for other types of LIDs	Yes If LIDTypeNo=5	Xslope



Table 4.19 LID Properties Surface tab attributes (Table msm\_LIDcontrol)

Edit field	Description	Used or required by simulations	Field name in datastructure
Surface Roughness	Manning's n or M (used in combination with surface slope and width) for routing of overflow from the surface of bioretention cell, rain garden, infiltration trench, porous pavement and for flow routing in vegetative swale (see Table 4.25 for typical values). If specified zero (for all types except vegetative swale), no routing of the overflow is applied	Yes If LIDTypeNo = (1,2,3,5 and 6)	Rough
Surface Slope	Slope (used in combination with surface roughness and width) for routing of overflow from the surface of bioretention cell, rain garden, infiltration trench, porous pavement and for flow routing in vegetative swale. If specified zero (for all types except vegetative swale), no routing of the overflow is applied	Yes If LIDTypeNo = (1,2,3,5 and 6)	Slope

### Soil

A Soil component is used for the following LID structures:

- Bioretention Cell
- Rain Garden
- Green Roof





LID properties

Identification

ID: Bioretention\_1 Type: Bio Retention Cell

Insert Delete

Surface **Soil** Pavement Storage Drain Drainage mat

Geometry

Thickness: 100 [mm]  
 Porosity: 0,5  
 Field capacity: 0,2  
 Wilting point: 0,1

Flow

☒ Capacity based  
 Leakage capacity: 1,8E9 [mm/h]  
 Infiltration capacity: 1,8E8 [mm/h]  
☐ Conductivity based  
 Conductivity: 50 [mm/h]  
 Conductivity slope: 10  
 Suction head: 10 [mm]

ID: ALL Clear Show selected Show data errors 1/1 rows, 0 selected

ID	Type	Storage depth [mm]	Vegetative cover	Surface roughness [m^(1/3)/s]	Sur
1	Bioretention_1 Bio Retention Cell	0,1	1	10	

Figure 4.34 The LID Properties Editor Soil Tab

Table 4.20 LID Properties Soil tab attributes (Table msm\_LIDcontrol)

Edit field	Description	Used or required by simulations	Field name in datastructure
Thickness	Thickness of the soil layer. Typical values range from 450 to 900 mm for rain gardens, street planters and other types of land-based bioretention units, but only 75 to 150 mm for green roofs	Yes If LIDTypeNo = (1, 6, 7)	SThick
Porosity	Volume of pore space relative to total volume of soil (as a fraction)	Yes If LIDTypeNo = (1, 6, 7)	Por



Table 4.20 LID Properties Soil tab attributes (Table msm\_LIDcontrol)

Edit field	Description	Used or required by simulations	Field name in datastructure
Field Capacity	Volume of pore water relative to total volume held in the soil after excess water has drained away and the rate of downward movement has decreased (as a fraction). Vertical percolation of water through the soil occurs only when field capacity level is reached or exceeded.	Yes If LIDTypeNo = (1, 6, 7)	FC
Wilting Point	Volume of pore water relative to total volume for a well-dried soil where only bound water remains (as a fraction). The moisture content of the soil cannot fall below this limit and wilting point cannot be higher than the Field Capacity level.	Yes If LIDTypeNo = (1, 6, 7)	WP
Leakage Capacity	The rate of water leaving the soil layer into storage. It is characteristic of the soil layer. Leakage starts when soil storage exceeds field capacity, continues at all times while soil storage is above the field capacity.	Yes If LIDTypeNo = (1, 6, 7) AND Flow-Method = 1 (Capacity-based)	LeakageCapacity



Table 4.20 LID Properties Soil tab attributes (Table msm\_LIDcontrol)

Edit field	Description	Used or required by simulations	Field name in datastructure
Infiltration Capacity	The rate of water moving from surface into the soil. It is characteristics of the surface and the uppermost soil layer (equivalent to Horton's initial infiltration capacity). Infiltration takes place at all times during a rain event and after, as long as there is water available as rainfall, as run on or as water stored in the surface.	Yes If LIDTypeNo = (1, 6, 7)	InfiltrationCapacity
Conductivity	Hydraulic conductivity for the fully saturated soil. This is equivalent to leakage capacity	Yes If LIDTypeNo = (1, 6, 7) AND Flow-Method = 2 (conductivity based))	Ksat
Conductivity Slope	Slope of the curve of log (conductivity) versus soil moisture content (dimensionless). Typical values range from 5 for sands to 15 for silty clay	Yes If LIDTypeNo = (1, 6, 7) AND Flow-Method = 2 (Conductivity-based)	Kcoeff
Suction Head	The average value of soil capillary suction along the wetting front. This is the same parameter as used in the Green-Ampt infiltration model	Yes If LIDTypeNo = (1, 6, 7) AND Flow-Method = 2 (Conductivity-based)	Suct

### Pavement

A pavement component is used for the following LID type:

- Porous Pavement

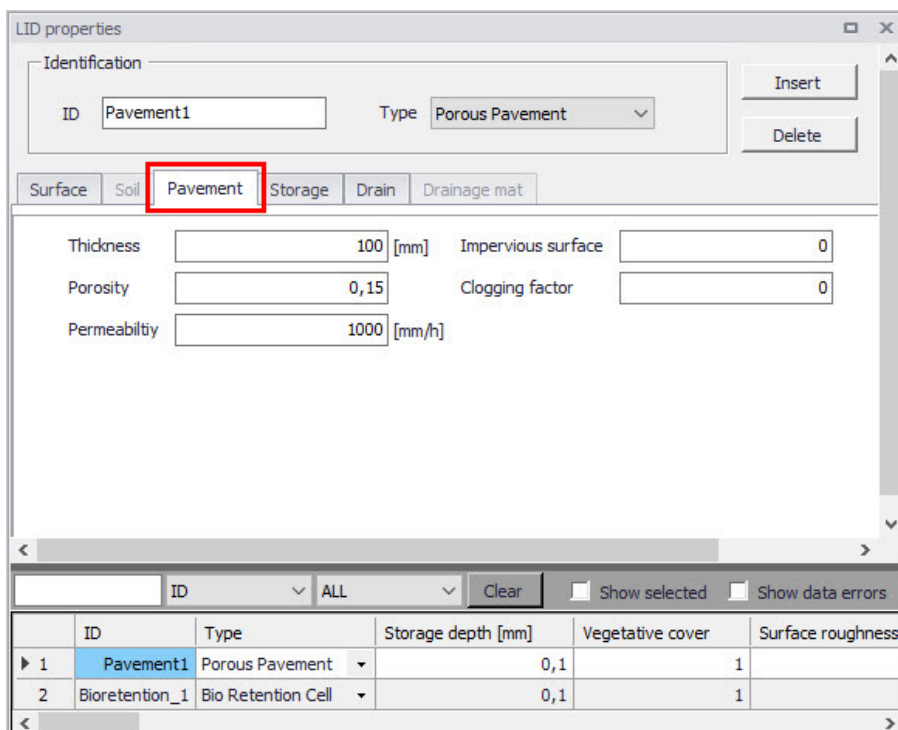


Figure 4.35 The LID Properties Editor Pavement Tab

Table 4.21 LID Properties Pavement tab attributes (Table msm\_LIDcontrol)

Edit field	Description	Used or required by simulations	Field name in data-structure
Thickness	Thickness of the pavement. Typical values are 100 to 150 mm	Yes If LIDTypeNo = 2	PThick
Porosity	The ratio (expressed as a fraction) of the volume of the pores or interstices of a material to the total volume of the pavement. Typical values range from 0.11 to 0.17 for pavements Note that porosity = void ratio/(1 + void ratio).	Yes If LIDTypeNo =2	PVPorosity



Table 4.21 LID Properties Pavement tab attributes (Table msm\_LIDcontrol)

Edit field	Description	Used or required by simulations	Field name in data-structure
Permeability	Permeability of concrete or asphalt used in continuous systems or hydraulic conductivity of the fill material (gravel or sand) used in modular systems. Permeability of new porous concrete or asphalt is high (>2450 mm/h), but over time the fine particles in the runoff tend to clog the pavement, reducing the permeability of the structure.	Yes If LIDTypeNo = 2	Perm
Impervious Surface	Ratio of impervious paver material to total area for modular systems; 0 for continuous porous pavement systems	Yes If LIDTypeNo = 2	FracImp
Clogging Factor	Voids that are clogged due to fine particles accumulation, as a fraction of total voids area. Use a value of 0 to ignore clogging. Max. value = 1.	Yes If LIDTypeNo = 2	PVClog

### Storage

A Storage component is used for the following LID structures:

- Bioretention Cell
- Porous Pavement
- Infiltration Trench
- Rain Barrel



LID properties

Identification

ID:  Type:

Insert  
Delete

Surface Soil Pavement **Storage** Drain Drainage mat

Height:  [mm] Conductivity:  [mm/h]  
Porosity:  Clogging factor:

< >

ID  Clear ☐ Show selected ☐ Show data errors

	ID	Type	Storage depth [mm]	Vegetative cover	Surface roughness
1	Pavement1	Porous Pavement	0,1	1	
▶ 2	Bioretention_1	Bio Retention Cell	0,1	1	

< >

Figure 4.36 The LID Properties Editor Storage Tab



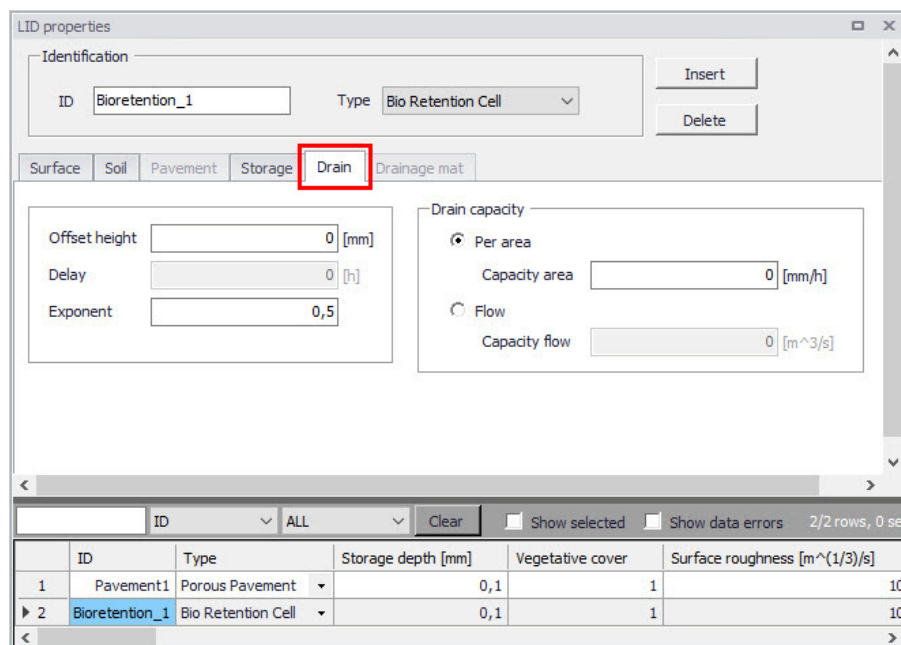
Table 4.22 The LID Properties Storage tab attributes (Table msm\_LIDcontrol)

Edit field	Description	Used or required by simulations	Field name in datastructure
Height	The height of the storage layer in case of bioretention cell, porous pavement and infiltration trench; the height of a rain barrel (mm or inches). Crushed stone and gravel layers are usually 150 to 450 mm thick while rain barrels vary in height from 600 mm upwards.	Yes If LIDTypeNo = (1,2,3,4)	Height
Porosity	The ratio of the volume of the pores or interstices of a material to the total volume of the layer. Typical values range from 0.30 to 0.45 for gravel beds. Note that porosity = void ratio/(1 +void ratio).	Yes If LIDTypeNo = (1,2,3)	SVPorosity
Conductivity	The maximum rate at which water infiltrates to the surrounding soil through the bottom of the freshly constructed storage layer.	Yes If LIDTypeNo = (1, 2, 3)	Filt
Clogging Factor	Volume of voids that are clogged due to fine particles accumulation. Use a value of 0 to ignore clogging.	Yes If LIDTypeNo = (1,2,3)	SVclog

## Drain

A Drain component is used for the following LID structures:

- Bioretention Cell
- Porous Pavement
- Infiltration Trench
- Rain Barrel



The screenshot shows the 'LID properties' window with the 'Drain' tab selected. The 'Identification' section shows ID 'Bioretention\_1' and Type 'Bio Retention Cell'. The 'Drain' tab contains fields for 'Offset height' (0 [mm]), 'Delay' (0 [h]), 'Exponent' (0,5), and 'Drain capacity' (Per area, Capacity area 0 [mm/h]). Below the form is a table with columns: ID, Type, Storage depth [mm], Vegetative cover, and Surface roughness [m^(1/3)/s]. The table contains two rows: '1 Pavement1 Porous Pavement' and '2 Bioretention\_1 Bio Retention Cell'.

ID	Type	Storage depth [mm]	Vegetative cover	Surface roughness [m^(1/3)/s]
1	Pavement1 Porous Pavement	0,1	1	10
2	Bioretention_1 Bio Retention Cell	0,1	1	10

Figure 4.37 The LID Properties Editor Drain Tab

Table 4.23 The LID Properties Drain tab attributes (Table msm\_LIDcontrol)

Edit field	Description	Used or required by simulations	Field name in datastructure
Offset Height	Height of any underdrain piping above the bottom of a storage layer or rain barrel	Yes If LIDTypeNo = (1,2,3,4)	HOffset
Delay	The number of dry weather hours that must elapse before the drain in a rain barrel is activated	Yes If LIDTypeNo = 4	Delay





Table 4.23 The LID Properties Drain tab attributes (Table msm\_LIDcontrol)

Edit field	Description	Used or required by simulations	Field name in datastructure
Exponent	Exponent n that determines the rate of flow through the underdrain as a function of height of stored water above the drain height.	Yes If LIDTypeNo = (1,2,3,4)	Expon
Capacity Area	Coefficient that determines the rate of flow through the underdrain as a function of height of stored water above the drain bottom. Expressed in terms of flow capacity per area.	Yes If LIDTypeNo = (1,2,3,4) AND Drain Capacity = Per Area	DrainCapacityArea
Capacity Flow	Coefficient that determines the rate of flow through the underdrain as a function of height of stored water above the drain bottom. Expressed in terms of flow capacity.	Yes If LIDTypeNo = (1,2,3,4) AND Drain Capacity = Flow	DrainCapacityFlow

### Drainage Mat

A Drainage Mat component is used for the following LID structure:

- Green Roof



LID properties

Identification

ID:  Type:

Surface Soil Pavement Storage Drain **Drainage mat**

Thickness:  [mm]

Porosity:

Roughness:  [ $m^{1/3}/s$ ]

< >

ID:  ALL  ☐ Show selected ☐ Show data errors

	ID	Type	Storage depth [mm]	Vegetative cover	Surface roughness
1	Pavement1	Porous Pavement	0,1	1	
2	GreenRoof1	Green Roof	0,1	1	
3	Bioretention_1	Bio Retention Cell	0,1	1	

< >

Figure 4.38 The LID Properties Editor Drainage Mat Tab

Table 4.24 The LID Properties Drainage Mat tab attributes (Table msm\_LIDcontrol)

Edit field	Description	Used or required by simulations	Field name in datastructure
Thickness	The thickness of the mat or plate. It typically ranges between 25 to 50 mm	Yes If LIDTypeNo = 7	DMThick



Table 4.24 The LID Properties Drainage Mat tab attributes (Table msm\_LIDcontrol)

Edit field	Description	Used or required by simulations	Field name in datastructure
Porosity	The ratio of void volume to total volume in the mat. It typically ranges from 0.5 to 0.6	Yes If LIDTypeNo = 7	DMVPorosity
Roughness	Manning's number, used to compute the horizontal flow rate of drained water through the mat. In absence of standard product specifications provided by manufacturers, the roughness must be estimated. Use of n values from 0.1 to 0.4 (M = 2.5 - 10) is suggested.	Yes If LIDTypeNo = 7	DMRough

Table 4.25 shows examples of Manning M values for different types of surfaces. Table 4.26 shows hydraulic conductivity properties for various porous media.

Table 4.25 Manning's M of surface for porous pavement or vegetative swale <sup>a</sup>

Surface type	Manning M
Smooth asphalt	91
Smooth concrete	83
Ordinary concrete lining	77
Good wood	71
Brick with cement mortar	71
Vitrified clay	67
Cast Iron	67
Corrugated metal pipes	42
Cement rubble surface	42
Fallow soils (no residue)	20
Cultivated soils	50 to 20
Residue cover < 20%	17

Table 4.25 Manning's M of surface for porous pavement or vegetative swale <sup>a</sup>

Surface type	Manning M
Residue cover > 20%	6
Range (natural)	8
Short, prairie	7
Dense	4
Bermuda grass	2
Woods	10
Light underbrush	2,5
Dense underbrush	1,25

a. Source: McCuen, R. et al. (1996), Hydrology, FHWA-SA-96-067, Federal Highway Administration, Washington, DC

Table 4.26 Hydraulic conductivity and porosity of unconsolidated porous media <sup>a</sup>

Material	Hydraulic conductivity $K$ (cm/s)	Porosity $\eta$ (%)
Gravel	$10^{-1} - 10^2$	25 - 40
Sand	$10^{-5} - 1$	25 - 40
Silt	$10^{-7} - 10^{-3}$	35 - 50
Clay	$10^{-9} - 10^{-5}$	40 - 70

a. Source: Freeze, R.A., and Cherry, J.A., (1979), Groundwater, Prentice-Hall, Englewood Cliffs, NJ

#### 4.4.9 LID Deployment

The LIDs are assigned to a catchment by means of the LID Deployment Editor. In this Editor, it is possible to specify the size (i.e. area) of the individual LID structure, the size of the catchment's impervious area that is funnelled into it and the number of the current LID units.

The size properties can be specified either directly as surface area, or as a percentage of the catchment's area. The specified total collecting area must not exceed the size of the catchment's impervious area.

Furthermore, level of initial saturation and routing width for overland flow can be specified.

The input data is organized into the following groups:

- Identification
- Deployment Parameters



ID	Catchment ID	LID control ID	Include	Replicate number	Collecting type	Collecting area [m^2]
1	Deploy_1	S14150801	Bioretention_1	<input checked="" type="checkbox"/>	1	Percent of catchment area

Figure 4.39 The LID Deployment Editor

## Identification

Each deployed LID is linked to a LID Deployment ID. I.e. each deployment represents a LID deployed on a single catchment in a specified number of units. For each LID deployment, a result file can be generated containing time series of relevant variables (fluxes and storages). This result file is in the DFS0 time series format.

A full reference of the attributes related to LID deployment is shown in Table 4.27 and Table 4.28.

Table 4.27 The LID Deployment Identification Group (Table msm\_LIDusage)

Edit Field	Description	Used or required by simulations	Field name in data structure
ID	Unique deployment ID	Yes	MUID
Catchment ID	Identification of the associated catchment	Yes	CatchID
LID ID	Identification of the LID structure to be deployed	Yes	LidID
Active checkbox	Option for activating/deactivating deployment of a LID structure	Yes	IncludeNo

Including or excluding a LID is handled by the Active checkbox. This checkbox is checked by Default.



## Deployment Parameters

Table 4.28 The LID Deployment Properties (Table msm\_LIDusage)

Edit Field	Description	Used or required by simulations	Field name in datastructure
Number of Units	Number of replicate LID units deployed within the catchment	Yes	ReplicateNumber
Width	The width of the outflow face of each identical LID unit (meter or feet). This parameter is applied for all control units that use overland flow to transport surface runoff off the unit, being these roofs, pavement, trenches, and swales for the other control types this parameter can be set as 0	Yes (for porous pavement, swales, roofs and trenches)	Width
Area/% of Catchment Area options	Toggle for LID collecting area setting	Yes	CollectingNo
Unit Area	The surface area of each replicate LID unit	Yes If CollectingNo=Area	UnitArea
Collecting Area	A LID practice is connected to a tributary area whose runoff is treated by the unit. This area includes the LID practice area itself.	Yes If CollectingNo=Area	CollectingArea
% Unit Area	The surface area of each replicate LID unit, expressed as a percentage of the total catchment area	Yes If CollectingNo=% of Catchment Area	UnitAreaPercent
% Collecting Area	The tributary area connected to the LID unit presented as a percentage of the catchment	Yes If CollectingNo=% of Catchment Area	CollectingAreaPercent
Surface	Initial water content of the surface layer	Yes	InitSatSurface



Table 4.28 The LID Deployment Properties (Table msm\_LIDusage)

Edit Field	Description	Used or required by simulations	Field name in datastructure
Soil/Pavement	The degree to which the unit's soil is initially filled with water (0% saturation corresponds to the wilting point moisture).	Yes	InitSatSoil
Storage	Initial water content of the storage layer.	Yes	InitSatStorage

## LID Deployment Result File

Optionally, for each LID structure deployment, a DFS0 time series file can be created. This file includes time series of relevant variables inside the LID structure in terms of inflow, flow between layers, storage levels in various layers and output from the structure to the native soil.

If the User does not activate this option, the only visible outputs from the run-off simulation including LIDs are the changed (reduced) runoff hydrographs, caused by infiltration loss and storage in the LID structure, and the LID summary table in the simulation summary file.

The contents of the DFS0 file depends on the actual LID type. In Figure 4.40, an example of the DFS0 file for porous pavement is presented. Thirteen columns contain time series for the processes occurring inside the porous pavement.

**NOTE: The flow inside the LID structure and the drain flow are reported as intensities based on the LID area. In cases where the collecting area is bigger than the LID area, the reported intensities will not be comparable with rainfall and evapotranspiration intensities, which are given as the model boundary conditions. In order to make the comparison possible, the reported flow intensities must be scaled down by the ratio between the LID area and the collecting area.**



	1	2	3	4	5	6	7	8	9	10	11	12	13
	Time	Inflow [mm/h]	Rain [mm/h]	Evaporation [mm/h]	Infiltration [mm/h]	SurfaceFlow [mm/h]	DrainFlow [mm/h]	SurfaceDepth [m]	PavementMoisture [l]	StorageDepth [m]	SurfaceToPavement [mm/h]	PavementToStorage [mm/h]	MassChecksum [m³/s]
1	07-05-1994 16:36:00.000	0	1.2	0	0	0	0	0	0	4.444444e-005	1.2	1.2	1.734722e-018
2	07-05-1994 16:37:00.000	0	1.2	0	1.2	0	0	0	0	4.444444e-005	1.2	1.2	5.20417e-018
3	07-05-1994 16:38:00.000	0	1.2	0	1.2	0	0	0	0	4.444444e-005	1.2	1.2	5.20417e-018
4	07-05-1994 16:39:00.000	0	1.2	0	1.2	0	0	0	0	4.444444e-005	1.2	1.2	5.20417e-018
5	07-05-1994 16:40:00.000	0	1.2	0	1.2	0	0	0	0	4.444444e-005	1.2	1.2	5.20417e-018
6	07-05-1994 16:41:00.000	0	4.8	0	1.2	0	0	0	0	0.0001777778	4.8	4.8	1.214386e-017
7	07-05-1994 16:42:00.000	0	4.8	0	4.8	0	0	0	0	0.0001777778	4.8	4.8	1.905196e-017
8	07-05-1994 16:43:00.000	0	4.8	0	4.8	0	0	0	0	0.0001777778	4.8	4.8	1.905196e-017
9	07-05-1994 16:44:00.000	0	4.8	0	4.8	0	0	0	0	0.0001777778	4.8	4.8	1.905196e-017
10	07-05-1994 16:45:00.000	0	4.8	0	4.8	0	0	0	0	0.0001777778	4.8	4.8	1.905196e-017
11	07-05-1994 16:46:00.000	0	4.8	0	4.8	0	0	0	0	0.0001777778	4.8	4.8	1.905196e-017
12	07-05-1994 16:47:00.000	0.2571431	4.8	0	4.8	0	0	0	0	0.0001873016	5.057143	5.057143	2.602005e-017
13	07-05-1994 16:48:00.000	2.057143	4.8	0	5.057143	0	0	0	0	0.0002336683	6.857143	6.857143	3.869984e-017
14	07-05-1994 16:49:00.000	2.057143	4.8	0	6.857143	0	0	0	0	0.0002336683	6.857143	6.857143	3.869984e-017
15	07-05-1994 16:50:00.000	2.057143	4.8	0	6.857143	0	0	0	0	0.0002336683	6.857143	6.857143	6.761422e-017
16	07-05-1994 16:51:00.000	2.057143	0.2	0	6.857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.397028e-017
17	07-05-1994 16:52:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
18	07-05-1994 16:53:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
19	07-05-1994 16:54:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
20	07-05-1994 16:55:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
21	07-05-1994 16:56:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
22	07-05-1994 16:57:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
23	07-05-1994 16:58:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
24	07-05-1994 16:59:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
25	07-05-1994 17:00:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
26	07-05-1994 17:01:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
27	07-05-1994 17:02:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
28	07-05-1994 17:03:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
29	07-05-1994 17:04:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
30	07-05-1994 17:05:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
31	07-05-1994 17:06:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
32	07-05-1994 17:07:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
33	07-05-1994 17:08:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
34	07-05-1994 17:09:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
35	07-05-1994 17:10:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
36	07-05-1994 17:11:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
37	07-05-1994 17:12:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
38	07-05-1994 17:13:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
39	07-05-1994 17:14:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
40	07-05-1994 17:15:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
41	07-05-1994 17:16:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
42	07-05-1994 17:17:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
43	07-05-1994 17:18:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
44	07-05-1994 17:19:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
45	07-05-1994 17:20:00.000	0.00571429	0.2	0	0.2857143	0	0	0	0	1.058201e-005	0.2857143	0.2857143	7.879728e-017
46	07-05-1994 17:21:00.000	17.48571	40.8	0	0.2857143	0	0	0	0	0.00215873	58.28571	58.28571	3.010419e-016

Figure 4.40 Example of a result report DFS0 file per deployment (a porous pavement control)

- Time:** calendar time for the simulated time steps.
- Inflow (mm/h):** inflow to the LID unit given as a multiple of the rain intensity and the collecting area outside LID/LID area. It is the run-on from the collecting area outside the LID and rain on top of the LID unit. The run on represents the net rain on the impervious collecting area, i.e. with initial losses subtracted.
- Rain (mm/h):** input rain for the catchment containing the LID unit. This rain loads the LID area directly.
- Evaporation (mm/h):** this is a given parameter specified by the User by means of boundary conditions valid for the catchment as well as for the LID unit.
- Infiltration (mm/h):** infiltration from the LID unit to the surrounding native soil.
- Surface flow (mm/h):** surface water flow. Represents overland flow for vegetative swale; overflow for other LID controls
- Drain flow (mm/h):** water flow through the drain.
- Surface depth (m):** accumulated water on the surface expressed as the water height on the surface. Maximum value is the specified surface storage height.
- Soil moisture (l):** presented as a fraction, relative to the total volume of the soil layer. Corresponds to the water that is held in the spaces between soil particles. Maximum soil moisture (i.e. full saturation) is equivalent to the specified soil porosity.





10. **Pavement moisture()**: presented as a fraction, relative to the total volume of the porous pavement layer. Corresponds to the water that is held in the pavement's voids. Maximum pavement moisture (i.e. full saturation) is equivalent to the specified pavement porosity.
11. **Storage depth (m)**: accumulated water in the storage layer expressed as the water height in the storage. Maximum value is the storage height.
12. **Surface to soil (mm/h)**: infiltration from the surface layer to the soil layer expressed in mm/h.
13. **Surface to pavement (mm/h)**: infiltration from the surface layer to the pavement layer expressed in mm/h.
14. **Soil to storage (mm/h)**: flow from the soil layer to the storage layer expressed in mm/h.
15. **Pavement to storage (mm/h)**: flow from the pavement layer to the storage layer mm/h.
16. **MassChecksum (m<sup>3</sup>)**: regards to the error check in the mass water balance per time step computed, a low value in the order of 1\*E-015 indicates an accurate internal flow estimation.

## LID Simulation Summary

The LID simulation summary is provided as part of the overall simulation summary HTML file. The summary table reports the volume balance for each LID deployment (see example in Figure 4.41).

Ts	Inflow/runoff [m <sup>3</sup> /s]	Rain [m <sup>3</sup> /s]	Evaporation [m <sup>3</sup> /s]	Infiltration [m <sup>3</sup> /s]	Surface runoff [m <sup>3</sup> /s]	Drain Outflow [m <sup>3</sup> /s]	Initial Storage [m <sup>3</sup> ]	Final Storage [m <sup>3</sup> ]
Green_roof3	6,006	19,83	0,000	6,006	0,000	0,000	0,000	19,83
Vegetative_swale1	17,26	1,983	0,000	19,24	0,003	0,000	0,000	0,000
Vegetative_swale2	17,26	1,983	0,000	19,24	0,004	0,000	0,000	0,000
Vegetative_swale3	17,26	1,983	0,000	19,24	0,001	0,000	0,000	0,000
Bio_retention1	17,26	1,983	0,000	2,256	1,595	10,20	0,000	4,520
Bio_retention2	17,26	1,983	0,000	10,66	0,075	0,000	0,000	7,911
Bio_retention3	17,26	1,983	0,000	11,08	0,000	0,000	0,000	8,242
Bio_retention4	17,26	1,983	0,000	10,82	0,000	0,000	0,000	8,421
Bio_retention5	17,26	1,983	0,000	10,82	0,000	0,000	0,000	8,421
Rain_garden1	17,26	1,983	0,000	11,74	0,000	0,000	0,000	7,526
Rain_garden2	17,26	1,983	0,000	11,74	0,000	0,000	0,000	7,526
Rain_garden3	17,26	1,983	0,000	11,74	0,000	0,000	0,000	7,526
Porous_pavement1	6,006	19,83	0,000	19,83	0,000	0,000	0,000	0,000
Porous_pavement2	6,006	19,83	0,000	19,83	0,000	0,000	0,000	0,000
Porous_pavement4	6,006	19,83	0,000	19,83	0,000	0,000	0,000	0,000
Porous_pavement3	6,006	19,83	0,000	19,83	0,000	0,000	0,000	0,000
Rain_barrel2	19,18	3,900	0,000	6,006	9,177	0,000	0,000	1,000
Rain_barrel1	19,18	3,900	0,000	6,006	9,177	0,000	0,000	9,392
Infiltration_trench1	6,006	19,83	0,000	19,83	0,000	0,000	0,000	0,000
Rain_barrel3	19,18	3,900	0,000	6,006	9,177	0,000	0,000	9,392
Infiltration_trench3	6,006	19,83	0,000	19,83	0,000	0,000	0,000	0,000
Infiltration_trench2	6,006	19,83	0,000	19,83	0,000	0,000	0,000	0,000
Green_roof1	6,006	19,83	0,000	6,006	0,000	0,000	0,000	19,83
Green_roof2	6,006	19,83	0,000	6,006	0,000	0,000	0,000	19,83
<b>Total</b>	<b>264,6</b>	<b>222,1</b>	<b>0,000</b>	<b>289,7</b>	<b>29,08</b>	<b>20,42</b>	<b>0,000</b>	<b>146,8</b>

Figure 4.41 Example of a LID simulation summary





## 5 Modelling Stormwater Quality (SWQ)

### 5.1 Introduction

#### SWQ - A model associated with urban catchments and rainfall-runoff modelling

The importance of wide-ranging and yet efficient modelling of stormwater quality on urban catchments and the transport of polluted stormwater in the urban drainage networks is growing with increased focus on local handling of stormwater, drainage network separation, stormwater treatment prior to release to recipients, as well as untreated stormwater overflows.

Stormwater pollution associated with urban catchment surfaces includes dissolved matter and suspended particles originating from:

- Soil erosion
- Erosion of construction materials (roofs, roads)
- Air borne pollution (e.g. industrial emissions particles)
- Local biological pollution related to humans and wildlife (various waste, birds droppings)
- Traffic debris
- Etc.

MIKE URBAN+ SWQ simulates stormwater quality as a special model associated with urban catchments and stormwater runoff and infiltration. This is illustrated in Figure 5.1.

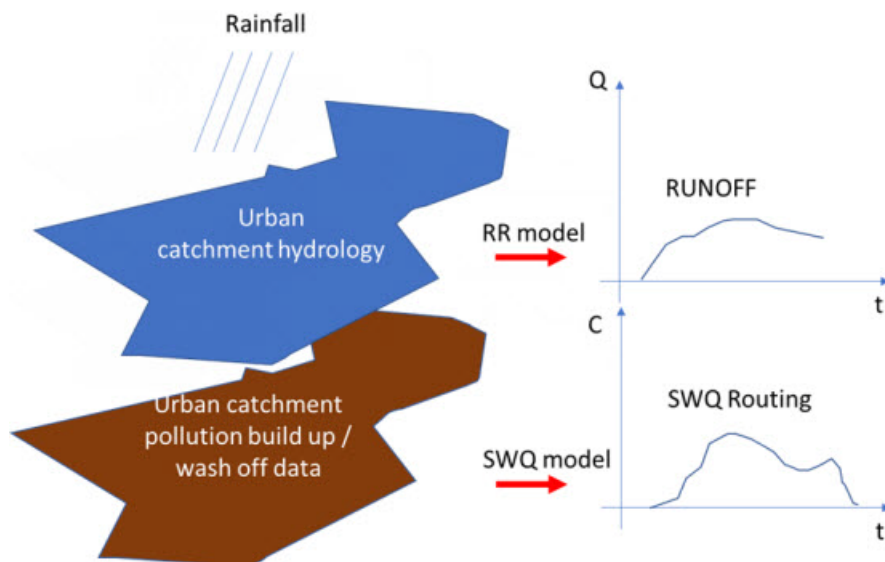


Figure 5.1 Rainfall-runoff and SWQ models act simultaneously on an urban catchment. Both models are driven by the rainfall and by the model parameters controlling the quantities and dynamics of runoff and surface pollution, respectively, being routed towards the catchment outlet.

## Spatial and temporal variation of pollution in urban catchments

### Model catchments vs. spatial distribution of surface pollution

The amount of surface pollution on urban catchments varies both in space and time, governed by types of pollutants, types of catchment surface and its uses. This variation needs to be captured as correctly as possible in the simulation model in order to achieve realistic model results.

The urban drainage model area is typically delineated into a number of sub-catchments, with delineation determined by the drainage network layout, topography or even administrative limits (parcels, urban districts, etc.).

Sometimes, the sub-catchment delineation is done by a simple division (e.g. Thiessen polygons), i.e. is based on purely geometrical reasoning. Only in rare cases, such delineations are appropriate for efficient characterisation of surface pollution loads generated on such sub-catchments.

Therefore, model sub-catchments would typically include different surfaces, such as building roofs made of different material, roads with various traffic intensity and with different paving, green areas with different vegetation, etc.).

Each of these surfaces may have different usage as well. This means that a single model catchment may be a source of various pollutants, differing by:



- Pollutant type:
  - Organic pollution
  - Chemicals
  - Microplastic
  - Heavy metals
  - Etc.
- Pollutant origin and build-up/wash-off mechanism:
  - Airborne (wind, smog)
  - Area use (traffic, people, animals, local industry)
  - Erosion of surface materials (metal roofs, asbestos, PAH...)
  - Soil erosion
- Attachment to surface sediments:
  - Particulate suspended, attached to surface sediments
  - Particulate suspended, on its own
  - Dissolved

These differences get manifested in various pollutants' quantities and their different behaviour on the catchment surface in dry weather (build-up) and when exposed to rainfall (wash-off). The following simple examples illustrate a typical situation.

A catchment has a total area of 2.1 ha. From the point of view of surface pollution, three types of surfaces may be distinguished: building roofs (15% or 0.315 ha), roads (10% or 0.21 ha) and the remaining 75% (or 1.575 ha) is green area. Each of these surfaces may be a source of various pollutants by itself and is exposed to build-up of exogenous pollution by different intensity and dynamics, depending on the surface exposure to external impacts. Further, these pollutants may behave differently in terms of wash-off by action of rainfall.

A MIKE URBAN+ model may contain many - often thousands - of such catchments.

### Decomposing catchments to pollution-related layers

In order to capture such situation correctly and efficiently in the model, the catchment (i.e. each sub-catchment in the model) is decomposed to a number of stacked, geographically identical catchments. In the described case, the catchment is represented by three layers, each one representing one of the three surface types. This is illustrated in the following figure:

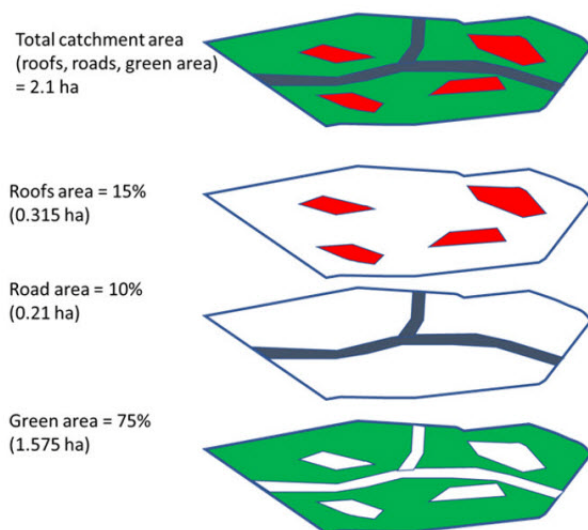


Figure 5.2 A catchment decomposed to three layers, each representing one type of catchment surface.

The upper-most polygon represents the actual catchment. In the model, this catchment is represented by the three polygons below, representing roofs, roads and green areas, respectively.

These three model catchments may inherit the hydrological parameters and connections to the network, but these can also be modified to facilitate a better description of behaviour of the various surface types in the actual catchment.

In any case, the layered catchments will differ by the actual drainage area, which corresponds to the actual area of respective type of surface in the given physical catchment. The sum of the contributing areas for the three sub-catchments must equal to the actual contributing area for the catchment.

### Modelling SWQ from multiple surface types as special type of boundary conditions

Surface pollution loads are defined as special types of boundary conditions to the catchments model (SWQ boundary conditions), similarly as rainfall is specified as a boundary for a precipitation-runoff model. Specifying surface pollution loads as boundary conditions, independent of rainfall boundary conditions, is necessary because spatial distributions of rainfall and of surface pollution are fully independent. Treating rainfall and surface pollution through independent boundary conditions implies that the rainfall and surface pollution can each be modelled with its own geographical distribution.

Since every SWQ boundary condition is associated with one definition of geographical location (i.e. reference to one or more catchments: All, List or Individual), and with any number of WQ boundary properties - one for any given pollutant component, each type of catchment surface must be



described by a separate SWQ boundary condition. I.e. as many surface types user wants to simulate, as many stacked catchment layers and SWQ boundary conditions shall be specified.

Each of these boundary conditions shall be connected to a sub-set of catchments representing certain type of surface and would include as many WQ boundary properties as there are pollutant components associated with that type of surface - each with its own quantities (i.e. temporal variation) method.

## 5.2 SWQ Model Setup

SWQ model setup includes the following components:

- Urban catchments with hydrological parameters for the applied precipitation-runoff model
- Rainfall boundary condition (any type of uniform or spatially distributed rain (dfs0 or dfs2))
- WQ component(s) and/or ST fraction(s)
- SWQ Global data
- SWQ local parameters (applies for Build-up/wash-off and EMC methods only)
- SWQ boundary conditions (Surface and/or RDI): multiple boundary conditions are specified in case when spatial differentiation of SWQ loads is analyzed, e.g. case of different catchment surface types or land uses
- SWQ Boundary properties: for each SWQ boundary condition properties have to be defined for each pollutant component and/or sediment fractions.
- SWQ Output definition
- Simulation setup

In the following sections, SWQ-specific model setup is presented in full detail.

Finally, the workflow sequence is briefly described in Section 5.7.

General issues (urban catchments, rainfall boundary conditions, WQ components, ST fractions, Output definition and Simulation setup) are described elsewhere in the MU+ Collection System User Guide.

## 5.3 SWQ Global Data

Model parameters included in SWQ Global data (see Figure 5.3) apply for entire model and for SWQ advanced methods only.



Figure 5.3 SWQ Global Data Editor

An overview of SWQ Global Data editor attributes is provided in Table 5.1.

Table 5.1 Overview of the SWQ Global Data editor attributes (Table msm\_SWQGlobalData)

Edit Field	Description	Usage	Attribute Table Field
Initial ADWP	Duration of antecedent dry weather period before the start of the simulation [hours]	Build-up /Wash-off and EMC methods	ADWPIni
Event threshold	Peak rainfall intensity in a rainfall event, used as a minimum threshold to include the rainfall event in the SQW computation	EMC method	EventThreshold
Min ADWP	Any two rain intervals separated by a dry interval are considered as the continuous rain event if the dry interval between the two wet-weather periods is less than the specified ADWPmin	EMC method	ADWPMin

## 5.4 SWQ Methods

Similarly as hydrological processes and runoff from urban catchments can be simulated by various runoff models, SWQ supports several methods for simulating processes related to stormwater quality. The available methods are:





1. Simple concentration
2. Table concentration
3. Build-up/Wash-off
4. Event mean concentration (EMC)

**Method 1** (Simple concentration) applies a pollutant concentration directly to the runoff from a catchment. The applied concentration can be specified as constant or based on an arbitrary time series.

**Method 2** (Table concentration) applies a tabulated concentration of pollutant specified as a tabulated function, based on the runoff intensity (i.e. specific runoff).

Note that Method 1 and Method 2 do not consider availability of pollutants. In other words, these methods assume unlimited supply of pollutants on the catchment surface. As such, they should be applied with care and only in appropriate cases.

**Method 3.** (Build-up/Wash-off) simulates the build-up of pollutants or sediments on the catchment surface and wash-off of this pollution by mechanical action of rainfall events. This method is mass-conservative, i.e. the amount of pollutant washed-off from the catchment surface is limited by the build-up process. This method is appropriate for simulating first flush.

**Method 4.** (EMC) assumes that the concentration of pollutant in runoff is constant throughout rainfall event. The method simulates the build-up of pollutants or sediments on the catchment surface in the same way as Method 3, but the rain-dependent wash-off process is replaced by a calculated event-mean concentration. This method is mass-conservative, i.e. EMC or amount of pollutant washed-off from the catchment surface is limited by the build-up process.

Both Method 3 and Method 4 are appropriate for simulating multiple, consecutive rainfalls, e.g. in connection with LTS. These methods are also referenced as SWQ advanced methods.

## SWQ Advanced Methods

SWQ advanced methods include Build-up/Wash-off and Event-mean Concentration (EMC) methods.

In addition to SWQ global data, computations in these methods are driven by user-specified sets of parameters (SWQ local data), which may be associated with each SWQ boundary property separately. This means that different behaviour of each pollutant and each catchment surface type, in terms of pollutant quantities and build-up/wash-off mechanisms, can be simulated.

Parameter set for modelling SWQ using advanced methods are specified through the SWQ Advanced Methods Editor (Figure 5.4).

SWQ advanced methods

Identification

ID:  Surface load type:  Method:

Surface loads:

Surface load:

Attached pollutants: ☒

Attached pollutants

1/2 rows, 0 selected

Pollutant ID	RS ratio [%]	Attached pollutant
1	BOD	100
2		100

SWQ advanced methods

ID	Method	Method	WQ Component	Sediment attached	Max. EMC [mg/l]	Buildup method	Buildup rate
1	Dust_build_up	EMC	Sediment	<input checked="" type="checkbox"/>	500	Linear	
2	Traffic_debris_buildup	EMC	Pollutant	<input type="checkbox"/>	1000	Linear	

Figure 5.4 The SWQ Advanced Methods Editor

The different parts tabs of the editor are described in succeeding sections below.

### 5.4.1 Identification

The main properties of the SWQ parameter set are defined in the Identification box. Any SWQ parameter set may refer either to a pollutant component or to a sediment fraction (with or without pollutants attached). Also, the set will apply for one of the two SWQ advanced methods only (Build-up/Wash-off or EMC).

SWQ advanced methods

Identification

ID:  Surface load type:  Method:

Figure 5.5 Identification box in the SWQ Advanced Methods Editor

An overview of database attributes and their usage is found in Table 5.2 below.



Table 5.2 SWQ Advanced Methods Identification box attributes (Table msm\_SWQPollutant)

Edit Field	Description	Usage	Attribute Table Field
ID	Unique name (identifier) for SWQ local parameter set	Build-up/Wash-off and EMC methods	MUID
Surface load type	1 = Pollutant component 2 = Sediment fraction	Build-up/Wash-off and EMC methods	TypeNo
Method	Choice of SWQ computation method 1 = EMC 2 = Build-Up/Wash-Off	Build-up/Wash-off and EMC methods	MethodNo

### 5.4.2 Surface Loads

The Surface Loads tab (see Figure 5.6) specifies the pollutant component (or sediment fraction) associated with actual SWQ parameter set.

SWQ advanced methods

Identification

ID:  Surface load type:  Method:

Insert Delete

Surface loads: Build-up / Wash-off EMC

Surface load:

Attached pollutants: ☐

Attached pollutants

Insert Delete 0/0 rows, 0 selected

Pollutant ID	RS ratio [%]
Attached pollutant	

Figure 5.6 Surface Loads Tab in the SWQ Advanced Methods Editor

A description of attributes in the Surface loads tab and their usage is found in Table 5.3 below.



Table 5.3 SWQ Advanced Methods editor Surface Loads tab attributes (Table msm\_SWQPollutant)

Edit Field	Description	Usage	Attribute Table Field
Surface Load	Choice of pollutant component (or sediment fraction)	Build-up/Wash-off and EMC methods	ComponentID
Attached pollutants	0 = No pollutants attached (default) 1 = Pollutants attached to sediments	Build-up/Wash-off and EMC methods, TypeNo = 2 (sediment fraction)	SedimentAttachNo

If the actual parameter set relates to a sediment fraction, pollutants may (optionally) be attached to the sediments through inputs in the editor's secondary grid (database table msm\_SWQAttachedPollutant (see Figure 5.7).

Attached pollutant	
Pollutant ID	RS ratio [%]
1 BOD	100
2	100

Figure 5.7 The Attached Pollutants secondary grid in the Surface Loads Tab

The amount of the sediment-attached pollutants is specified as a fraction (percentage) of the sediment mass. The total of the attached pollutants shall not exceed 100%.

When surface load is specified as a pollutant component, the model output is directed into the SWQ pollutants output, which may be used as input into the network advection-dispersion simulation (directly in case of simultaneous catchment and network simulation, or as a WQ boundary property to the run-off load into the network model).

When surface load is specified as a sediment fraction, the model output is directed into the SWQ sediments output, which may be used as input into the network sediment transport simulation (directly in case of simultaneous



catchment and network simulation, or as an ST boundary property to the run-off load into the network model).

Attached pollutants (if any) are directed into the SWQ pollutants output, similarly as in case of a pollutant surface load. The mass of pollutants is calculated as a specified fraction of sediment mass.

A description of attributes in the Attached Pollutants secondary grid (table msm\_SWQAttachedPollutant) and their usage is found in Table 5.4 below.

Table 5.4 Overview of the Attached Pollutants secondary grid attributes (Table msm\_SWQAttachedPollutant)

Edit Field	Description	Usage	Attribute Table Field
PollutantID	Duration of antecedent dry weather period before the start of the simulation [hours]	Build-up/Wash-off and EMC methods, SedimentAttachNo =1	PollutantID
RSRatio	Peak rainfall intensity in a rainfall event, used as a minimum threshold to include the rainfall event in the SQW computation	Build-up/Wash-off and EMC methods, SedimentAttachNo =1	PSRatio

### 5.4.3 Build-Up/Wash-Off

The Build-up/Wash-off tab (see Figure 5.9) provides the local parameters for the Build-up/Wash-off method.

Build-up parameters are:

**Method:** Linear or Exponential. During dry weather periods pollution or sediments accumulate on the surface of urban catchments. The most common formulations for this process are to assume that the build-up is a linear or an exponential function of time. The choice between the two formulations is not straightforward due to insufficient experimental results.

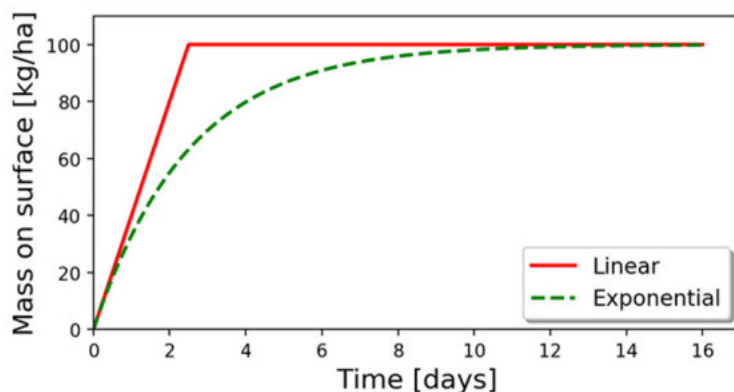
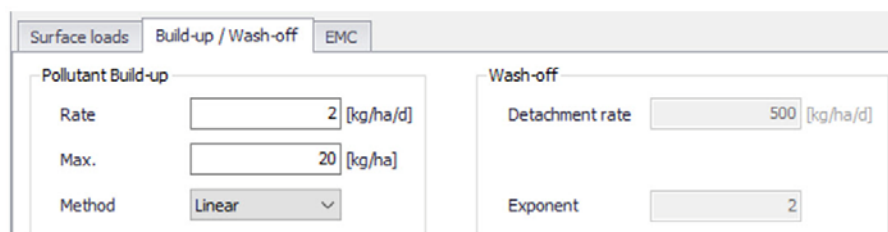


Figure 5.8 Illustration of the linear and the exponential build-up function. For details of mathematical formulation, see MIKE 1D Reference Manual.

**Rate:** Linear build-up rate of the pollutant component (or sediment fraction) on the catchment surface, given as mass per unit area per unit of time.

**Max:** Maximum possible amount of pollution (or sediment) on the catchment surface. This represents an equilibrium situation, when removal rate is equal to build-up rate.



Parameter	Value	Unit
Rate	2	[kg/ha/d]
Max.	20	[kg/ha]
Method	Linear	
Detachment rate	500	[kg/ha/d]
Exponent	2	

Figure 5.9 The Build-Up/Wash-Off Tab in the SWQ Advanced Methods Editor

Wash-off parameters are related to the applied wash-off formula, which is based on the assumption that the wash-off is exponentially related to the rain intensity.

**Detachment rate:** Wash-off (detachment) rate at rainfall intensity 25.4 mm/hour (1 inch/hour). This is a calibration factor for the wash-off process: smaller values apply for pollutants firmly attached the catchment surface, higher values apply for loose particles.

**Exponent:** Default value is 2, which implies that the wash-off is proportional to the kinetic energy of the rain drops.

A description of attributes in the Build-up/Wash-off tab and their usage is found in Table 5.5 below.



Table 5.5 Overview of the SWQ Advanced Methods Build-up/Wash-off tab attributes (Table msm\_SWQPollutant)

Edit Field	Description	Usage	Attribute Table Field
Pollutant Build-Up/Rate	Linear build-up rate of pollutant (sediment) on the catchment surface ( $\text{ML}^{-2}\text{T}^{-1}$ )	Build-up /Wash-off and EMC methods	BuildUpRate
Pollutant Build-Up/Max.	Maximum amount of pollutant (sediment) on the catchment surface per unit area ( $\text{ML}^{-2}$ )	Build-up /Wash-off and EMC methods	MaxBuildUp
Pollutant Build-Up/Method	1 = Linear 2 = Exponential	Build-up /Wash-off and EMC methods	BuildUpTypeNo
Wash-Off/Detachment Rate	Pollutant (sediment) detachment rate at rainfall intensity 25.4 mm/hour (1 inch/ hour)	Build-up /Wash-off method	DetachRate
Wash-Off/Exponent	Default value is 2. Larger values increase the wash off non-linear dependency on the rainfall intensity. Value 1 implies a linear dependency	Build-up /Wash-off method	WashOffExp

#### 5.4.4 EMC

The EMC tab (see Figure 5.10) provides a single local parameter for the EMC (Event Mean Concentration) method.

Figure 5.10 The EMC Tab in the SWQ Advanced Methods Editor

**Max. EMC:** Is the maximum possible concentration of the pollutant component (or sediment fraction) in the runoff leaving the catchment.

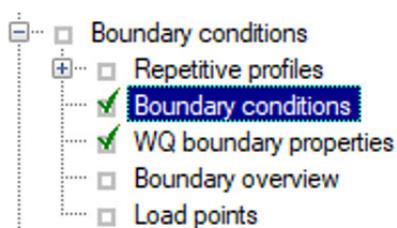


The primary role of this parameter is to prevent unrealistic results i.e. very high values of pollutant EMC in case of long ADWP and/or high build-up rates during small rain events. In such cases, Max. EMC will prevent the full removal of pollutants by a small rain.

Table 5.6 Overview of the SWQ Advanced Methods EMC tab attributes (Table msm\_SWQPollutant)

Edit Field	Description	Usage	Attribute Table Field
Max. EMC	Maximum event mean concentration; used to prevent unrealistically high concentrations and full wash-off by a minor rainfall	EMC method	MaxEMC

## 5.5 Boundary Conditions for SWQ



SWQ boundary conditions define domain of validity for the actual boundary condition (surface runoff or RDII) and the boundary condition spatial extent.





Boundary conditions

Identification

ID:  Type:

☒ Apply Catchment Loads

Spatial extent: ☐ All ☒ List ☐ Individual ☐ Geo-coded ☐ Data source location ☐ Grid distributed weights

Temporal Variation: ☐ Limited interval

roof\_catchments  1: Domestic WW

[m]  [m]

Description

ID:   ☐ Show selected ☐ Show data errors 3/5 rows, 0 select

ID	Boundary type	Group No	Apply Boundary	Load type	Connection
1	Rain Rainfall	Catchment Loads	<input checked="" type="checkbox"/>		All
2	WaterLevel120 Outlet water level	Outlet Levels	<input checked="" type="checkbox"/>		Individual
3	Roofs_pollution Stormwater loads(surface)	Catchment Loads	<input checked="" type="checkbox"/>		List
4	Roads_pollution Stormwater loads(surface)	Catchment Loads	<input checked="" type="checkbox"/>		List
5	Infiltration_pollution Stormwater loads(RDII)	Catchment Loads	<input checked="" type="checkbox"/>		List

Figure 5.11 The Boundary Conditions Editor showing Types relevant for SWQ

### 5.5.1 SWQ Boundary Condition Types

SWQ boundary conditions are of the following types (see Figure 5.11):

- Stormwater Loads (Surface). This type applies for WQ in surface runoff.
- Stormwater Loads (RDII). This type applies for WQ in RDII flows.

Table 5.7 provides an overview of the SWQ methods that are applicable under the two types of stormwater loads (surface runoff and RDII), i.e. with the two types of SWQ boundary conditions.



**Table 5.7** Overview of applicable SWQ boundary condition types and SWQ methods for various hydrological models and their combinations. All surface runoff models support all four SWQ methods, while RDI supports only Method 1 (Simple Concentration) and Method 2 (Tabulated concentration).

Hydrological model/combination	SWQ Boundary condition and SWQ methods	
	Stormwater loads (surface)	Stormwater loads (RDI)
Time-Area	Methods 1, 2, 3, 4	-
Time-Area + RDI	Methods 1, 2, 3, 4	-
Kinematic Wave	Methods 1, 2, 3, 4	-
Kinematic Wave + RDI	Methods 1, 2, 3, 4	Methods 1 ,2
Linear Reservoir (C1)	Methods 1, 2, 3, 4	-
Linear Reservoir (C1) + RDI	Methods 1, 2, 3, 4	Methods 1 ,2
Linear Reservoir (C2)	Methods 1, 2, 3, 4	-
Linear Reservoir (C2) + RDI	Methods 1, 2, 3, 4	Methods 1 ,2
UHM	Methods 1, 2, 3, 4	-
UHM + RDI	Methods 1, 2, 3, 4	Methods 1 ,2
RDI (solo)	-	Methods 1 ,2

## 5.5.2 Spatial Extent

As any other boundary condition, SWQ Boundary Conditions may be specified as uniform for the entire model (i.e. associated with all model catchments), or as spatially distributed through selections of catchments and/or individual catchments.

Figure 5.12 illustrates definition of spatial extent based on a list (selection). Note that selections may refer to different geographical areas as well as to different catchments layers.



Boundary conditions

Identification

ID:  Type:

☒ Apply ☐ Catchment Loads

Spatial extent Temporal Variation Limited interval Scaling factor Distributed Weights Description

☐ All

☒ List

☐ Individual

☐ Geo-coded  (Load category)

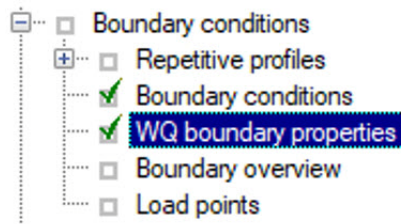
☐ Data source location X  [m] Y  [m]

☐ Grid distributed weights

Figure 5.12 Example of a Stormwater Loads (Surface) boundary condition with spatial extent defined by a list (selection) of catchments (roof\_catchments)

## 5.6 WQ Boundary Properties for SWQ

SWQ quantities and computation methods for various pollutants associated with an SWQ Boundary Condition are specified in the WQ Boundary Properties Editor.





WQ boundary properties

☒ Boundary condition selector:  
Roofs\_pollution ...

Spatial extent: Listroof\_catchments  
Temporal variation: Constant, Value:  
Description:

Identification  
ID: Dust\_on\_roofs Type: Pollutant concentration

Insert  
Delete

Water quality Temporal Variation Scaling factor Description

WQ component: BOD ...  
Sediment fraction: ...

Type: Pollutant  
Decay constant: 0  
Initial condition: 0

ID	WQBoundary type	Trap component ID	Trap fraction ID	Variation No
1 Dust_on_roofs	Pollutant concentration	BOD		Constant
2 T_runoff	Temperature	T		Constant

Figure 5.13 The WQ Boundary Properties Editor with an example SWQ boundary water quality item (i.e. Roofs pollution with dust)

Normally, one SWQ boundary property should be specified for each pollutant included in an SWQ boundary condition.

Definition of WQ boundary properties follows the same workflow as any other WQ boundary property. For details, see descriptions under the Boundary Conditions Chapter in the manual.

In addition, WQ boundary properties for SWQ include two special types of Temporal variations:

- Table concentration (supports application of SWQ table concentration method)
- SWQ advanced (supports application of SWQ advanced methods: Build-up/Wash-off and EMC).

Definition of WQ boundary properties in the WQ Boundary Properties Editor for all SWQ methods is described in the following sections.

### 5.6.1 Boundary Condition Selector

Figure 5.14 The Boundary Condition Selector is the step in specifying WQ boundary properties for SWQ

The wanted SWQ boundary condition item to be associated with a water quality boundary property is selected in the Boundary Condition Selector on top of WQ Boundary Properties editor.

### 5.6.2 Identification

Figure 5.15 Identification information for the WQ boundary property for SWQ

After inserting a new WQ boundary property, it shall be given a proper name (identifier) and a correct (water quality) type shall be selected.

For easier identification, the property name should reflect its contents, i.e. which pollutant (or sediment) and which model area it describes.

Type is selected among available choices filtered according to currently specified WQ components.



### 5.6.3 Water Quality

Water quality | Temporal Variation | Scaling factor | Description

WQ component: BOD ...

Sediment fraction: ...

Type: Pollutant

Decay constant: 0

Initial condition: 0

Figure 5.16 The Water Quality Tab in the WQ Boundary Properties Editor. Used to define pollutant component (or sediment fraction) associated with the current WQ boundary property.

Depending on the specified (water quality) type, the user selects the relevant WQ component or sediment fraction.

### 5.6.4 Temporal Variation

Water quality | Temporal Variation | Scaling factor | Description

Constant: Value: 100 [mg/l] Gradual start up: From: Time:

Cycle: Value: Pattern:

Time series: File name: TS\_datafile\_conc.dfb Time series ID: Zinc\_conc Data type: Concentration

Table concentration: Table ID: Zinc\_concentrations SWQ ID: Dust\_build\_up

SWQ Advanced: Dust\_build\_up

Figure 5.17 The Temporal Variation Tab in the WQ Boundary Properties Editor

In the context of SWQ, definition of temporal variation for WQ boundary property is closely connected to the choice of SWQ method, as summarized in the overview in Table 5.8.



Table 5.8 Overview of relation between Temporal Variation and SWQ Methods

Temporal Variation	SWQ Method			
	Method 1 (Simple concentration)	Method 2 (Table concentration)	Method 3 (Build-up/ Wash-off)	Method 4 (EMC)
Constant	Yes	-	-	-
Cyclic	-	-	-	-
Time series	Yes	-	-	-
Table concentration	-	Yes	-	-
SWQ advanced	-	-	Yes	Yes

## Method 1: Simple Concentration (Constant)

The screenshot shows the 'Temporal Variation' tab in a software interface. The 'Constant' radio button is selected, highlighted by a red arrow. The 'Value' field is set to 100 [mg/l]. There is an unchecked checkbox for 'Gradual start up'. Below it are 'From' and 'Time' fields. To the right, the 'Cyclic' and 'Time series' radio buttons are unselected. The 'Cyclic' section has 'Value' and 'Pattern' fields. The 'Time series' section has 'File name', 'Time series ID', and 'Data type' fields.

Figure 5.18 Definition of constant SWQ concentration

A constant value of any WQ component (e.g. concentration, temperature, etc.) is assigned to runoff.



## Method 1: Simple Concentration (Time series)

Water quality Temporal Variation Scaling factor Description

☐ Constant ☐ Cyclic ☒ Time series

Value  [mg/l]  
☐ Gradual start up  
From  [mg/l]  
Time  [min]

Value  [mg/l]  
Pattern  ...

File name  ...  
Time series ID   
Data type

Figure 5.19 Time series of values of any property is assigned to runoff. In absence of measured data, time series typically reflect an estimate of seasonal variations.

Application of time series values for SWQ boundary properties implies knowledge or estimates of historical variations of any WQ component, e.g. in the context of a WQ model calibration.

## Method 2: Table Concentration

Water quality Temporal Variation Scaling factor Description

☐ Constant ☐ Cyclic ☐ Time series ☒ Table concentration

Value  [mg/l]  
☐ Gradual start up  
From  [mg/l]  
Time  [min]

Value  [mg/l]  
Pattern  ...

File name  ...  
Time series ID   
Data type

Table ID  ...

Figure 5.20 Table Concentration applies to the SWQ Table Concentration method

A tabular function of the type Runoff pollutants is selected and associated with the WQ boundary property. It establishes a fixed relation between the runoff intensity (specific runoff) and the value of WQ component, e.g. pollutant concentration.

## Methods 3 (Build-up/Wash-off) and 4 (EMC): Advanced Methods

☐ Constant ☐ Cyclic ☐ Time series ☐ Table concentration ☒ SWQ Advanced

Value  [mg/l]  
☐ Gradual start up  
From  [mg/l]  
Time  [min]

Value  [mg/l]  
Pattern  ...

File name  ...  
Time series ID   
Data type

Table ID  ...

SWQ ID  ...

Figure 5.21 SWQ Advanced is chosen when SWQ Method 3 (Build-up/Wash-off) or Method 4 (Event Mean Concentration) is applied





After selecting SWQ advanced, the user must choose one among previously specified SWQ parameter sets for the pollutant or sediment fraction associated with the current WQ boundary property.

The SWQ parameter sets are related to one of the two SWQ advanced methods and contain a definition of the parameters for the chosen method. The actual parameters can be looked up in the SWQ Advanced Methods editor.

## 5.7 Workflow

Modelling of SWQ is summarised through description of a workflow.

At the outset, it is assumed that a functional MU+ model including one or more catchments is available.

### Prepare layered catchments (optional)

If the analysis includes various types of surfaces, and if the catchments delineation does not reflect the surface types, the original sub-catchments shall be cloned into layers. All layers of catchments shall be connected to the network identically. Drainage area for all catchments representing one physical catchment shall be specified. The sum of the drainage area for a catchment must be equal to the full contributing catchment area.

### Specify rainfall boundary

A rainfall boundary condition series shall be specified. A single rainfall time series may be associated with all catchments in the model, or the rainfall can be spatially distributed by specifying multiple rain gauges or RADAR rainfall data.

### Specify WQ components and sediment fractions

To be included in SWQ computation, any WQ component and/or sediment fraction must be defined in respective editors (WQ Components editor or Sediment Fractions editor, respectively).

### Activate SWQ module

Make sure that the Stormwater Runoff WQ (SWQ) module is activated (General Settings | Modules). This will provide access to all relevant editors.

### Consider appropriate SWQ method

As shown in Table 5.7, the applicability of the SWQ methods depends on the runoff component, i.e. choice of the runoff model.

Also, not all of the available SWQ methods are applicable to all types of pollutants/sediments. E.g. external pollutants are best simulated by mass-conservative methods (i.e. Methods 3 and 4).

### Review Global SWQ parameters

If one of the advanced SWQ methods is to be applied, review and adjust SWQ global parameters (in the SWQ Global Data editor).



### Specify SWQ parameters sets

If one of the advanced SWQ methods is to be applied in the SWQ computation for any of the pollutants or sediment fractions, SWQ parameter sets must be specified for such pollutants or sediment fractions.

Note that several parameter sets may be specified for any pollutant or sediment fraction - each for one type of catchment surface.

### Specify SWQ boundary conditions

For each type of catchment surface and for each runoff component, a separate boundary condition can be specified as one of the two available SWQ boundary types. Association of the boundary condition with model sub-catchments representing a specific type of surface is achieved by specifying appropriate selection list.

### Specify SWQ boundary WQ properties

For each of the specified SWQ boundary conditions, a number of WQ properties can be specified. Normally, one WQ property is defined for each pollutant (or sediment fraction) assumed to be present on the actual catchment surface type and in the actual runoff component. For details, refer to Section 5.6..

### Set up a runoff simulation with SWQ

The SWQ setup is included in the runoff simulation simply by ticking the Storm Water Quality (SWQ) checkbox in the General tab of the Simulation Setup editor.

The screenshot shows the 'Simulation setup' dialog box with the 'General' tab selected. In the 'Simulation Type' section, the 'Rainfall-Runoff (RR)' and 'Storm Water Quality (SWQ)' checkboxes are checked. A red arrow points to the 'SWQ' checkbox. The 'Simulation Period' section shows the 'Start' time as 01/05/2008 18:16:00, the 'Duration' as 200 0 0 0 [dddd][hh][mm][ss], and the 'End' time as 17/11/2008 18:16:00. The 'Description' field is empty.

Figure 5.22 Example simulation setup for a model including Rainfall-Runoff and SWQ. Note that SWQ can only run in association with a Rainfall-Runoff simulation.



MU+ will automatically include relevant output files. The Default output files can be replaced or complemented by user-specified output files.

Simulation setup

Identification

ID: RR\_1 ☒ Active project Insert Copy

Scenario: Base Delete RUN

General Catchments HD AD and WQ **Results**

Output folder

☒ Save results in default folder

☐ Save results in this folder ...

Collection System Summary Edit summary

Project outputs							
ID	Type	Format	Save every		Default save period	Start saving	End saving
1	Default_Surface_runoff	Surface runoff	.resId	60 seconds	<input checked="" type="checkbox"/>	26/02/2019 12:01:26	26/02/2019 14:01:26
2	Default_Storm_water_quality	Storm water quality	.resId	10 seconds	<input checked="" type="checkbox"/>	26/02/2019 12:01:26	26/02/2019 14:01:26

Figure 5.23 Default output is automatically provided by the system



## 6 Boundary Conditions

In broad terms, a model boundary condition can be defined as an external interference, which forces the behaviour of the computed variables within the model domain.

A great part of the boundary conditions represent various types of water loads (rainfall, infiltration, wastewater...). The main characteristic of these 'load' boundary conditions is that they contain a 'transport medium' - water. Water can transport other material (dissolved pollutants, oxygen, sediments), heat (temperature) and organisms (bacteria and parasites), as well as various other properties, such as pH, conductivity, turbidity, etc. Properties of 'water load' boundary conditions (expressed as concentrations, mass flow, temperature, etc.) are also, in strict terms, boundary conditions for e.g. pollution transport model (Advection-Dispersion). However, these are not treated as separate boundary conditions, but items inseparably associated with the water loads. E.g. a lateral inflow is a water load boundary condition for the hydrodynamic process in the network (defined as discharge item), while the temperature, concentration, etc. associated to this particular inflow are specified as pollutant items of that "load" boundary condition. Effectively, pollutant items of that "load" boundary conditions to the AD process in the network.

Boundary conditions other than water loads are 'simple' in a sense that they are fully defined by the boundary condition variable itself, i.e. no additional item is possible to be associated with them. These are water levels, air temperature, evapotranspiration, etc.

In the following the terminology used is:

- **Boundary condition:** it is defined by its type and model connectivity.
- **Boundary item:** per definition, it is a property inseparably associated with a boundary condition. A boundary item is fully defined by its type, temporal variation and quantity/quality. Through the link to a boundary condition to which it belongs, connection of a boundary item to a model is ensured.

The variable which defines a boundary condition is a default item of the boundary condition.

There are presently 4 sub-fields under Boundary Conditions:

- Boundary conditions (hydraulic and hydrological loads)
- Water Quality boundary properties (if WQ module is active)
- Load points
- Repetitive profiles

Additionally there is a tool for visualizing the boundary conditions in the model named *Boundary Overview*.

## 6.1 Hydraulic boundary conditions

The hydraulic boundary conditions tab allows the modeller to control the loads included and applied to the model.

In order to include a boundary in a simulation the “Apply” box must be checked.

In Figure 6.1 it is shown the ‘Insert’ button, which inserts a new boundary condition to the database. There are 16 boundary condition types:

- Rainfall
- Air temperature
- Evapotranspiration
- Catchment discharge
- Catchment discharge per area
- Catchment discharge per PE
- Load point discharge
- Load point discharge per unit.
- Inflow to node
- Inflow to link
- Inflow from result file
- Outlet water level
- Exfiltration from node
- Exfiltration from link
- Stormwater loads (surface)
- Stormwater loads (RDI)

Figure 6.1 Hydraulic boundary condition types



### 6.1.1 Catchment boundary conditions

Types of variables associated with catchment boundary conditions are:

- Air temperature
- Evapotranspiration
- Rainfall
- Catchment discharge
- Stormwater loads

Any number of each boundary conditions types can be specified.

**Air Temperature** is a boundary condition of the type 'air temperature', and always has a temperature (constant or a time series) associated as a default item. This type of boundary condition is used for snow melt calculations.

**Evapotranspiration** is a boundary condition of the type 'evapotranspiration', and always has potential evapotranspiration (constant or a time series) associated as a default item. This type of boundary is used for RDI hydrological calculations. The dfs0 file needs to be of the type 'Evapotranspiration'. Delete values will be considered equal to 0.0.

**Rainfall** is a boundary condition of the type 'rainfall', and always has rainfall (constant or a time series) associated as a default item. This type of boundary is used for precipitation-runoff hydrological calculations. When using a time series the dfs0-file needs to be one of the following Item Types: 'Rainfall Intensity', 'Rainfall' or 'Rainfall Depth'. Delete values will be considered equal to 0.0.

**Catchment discharge** is a boundary condition of the type 'catchment load', and always has discharge (constant, cyclic or a time series) associated as a default item. This type of boundary represents various kinds of hydraulic loads, such as area-based or PE-based dry weather loads, area-based infiltration, etc. The discharge can be associated with any pollutant, sediment or temperature item (constant, cyclic or a time series). In the example above, the default item (Resident WW flow) is associated with pollutants BOD, NH4 and Temperature.

The following describes the work-flow to define a boundary condition for a catchment.

As the first action after inserting a new boundary conditions, a proper name (ID) must be specified. It is recommended to use a descriptive ID.

Next, a type of boundary connection must be selected, among Rainfall, Air temperature, Evapotranspiration and Catchment Discharge.

The **Spatial Extend** determines the connection type of the catchments for which this boundary condition applies. 'Individual' applies for a single catch-



ment, and requires a specification of the catchment ID. 'List' applies for a set of catchments, contained in the catchment selection list. 'All' applies to all catchments.

### 6.1.2 Network boundary conditions

Types of variables associated with network (i.e node/grid point) boundary conditions are:

- Water level
- Flow (discharge) - incl. WQ and sediment properties

The discharge boundary conditions are termed as **Network Loads**. The water level boundary conditions are termed as "Outlet levels" and can only be linked to "Outlet" type nodes.

Network Loads represent all kinds of hydraulic loads, such as DWF point-inflows, individual lateral inflows, infiltration, storm runoff, etc. This type of boundary condition always has discharge (constant, cyclic or a time series) associated as a default item. The discharge can be associated with any pollutant, sediment or temperature item (constant, cyclic or a time series).

Any number of network loads can be specified, independently on the location point.

Only one water level boundary condition is allowed at each network outlet. If nothing is specified for an outlet, the model assumes a constant water level equal to the outlet invert level. I.e. a free outlet is assumed.

This type of boundary condition always has water level (constant or a time series) associated as a default item.





Boundary conditions

Identification

ID:  Type:

☒ Apply

Spatial extent: ☐ All ☐ List ☐ Individual ☐ Geo-coded ☐ Data source location ☐ Grid distributed weights

(Load category)

X  [m] Y  [m]

ID	Boundary type	Group No	Apply Boundary	Connection type
1	BC1 Rainfall	Catchment Loads	<input checked="" type="checkbox"/>	Individual
2	Exfiltration from node	Network Loads	<input checked="" type="checkbox"/>	Individual
3	WaterLevel120 Outlet water level	Outlet Levels	<input checked="" type="checkbox"/>	Individual
4	Network loads input file - Runoff_1	Inflow from result file	<input checked="" type="checkbox"/>	All

Figure 6.2 Hydraulic Boundary Conditions Dialog

In MIKE URBAN+ there is a single boundary condition editor for all types of loads.

The following describes how to define an boundary condition for the network. This could e.g. be a discharge entering a manhole or pipe infiltration.

As the first action after inserting a new boundary condition, a proper name (ID) must be specified. We recommend that you use a descriptive ID.

### 6.1.3 Spatial extent

The **Spatial Extent** enables the modeller to define the distribution of the boundary conditions. The distribution ranges from 'All' (catchment based), Individual (specified locations), 'Lists' a selection of elements, 'Geo-coded' locations and "Grid distributed weights".

The application of 'All' can be applied to applied to catchment boundaries ('Catchment discharge', 'Catchment discharge per area' and 'Catchment discharge per PE') and meteorological boundaries ('Rainfall', 'Air Temperature' and 'Evapotranspiration')



Selection list can be used to assign boundary conditions. **Lists** can be used to assign catchment boundaries, meteorological boundaries, inflows to nodes and links, as well as exfiltration to nodes and links. **List** applies for a set of node or links, contained in a defined selection, selections can be saved and modified in the **Selection Manager**.

'**Individual**' applies for a single node or pipe, and requires a specification of the Node ID or Link ID.

Similarly to the lists, boundaries can be assigned to individual locations. In addition to catchment boundaries, meteorological boundaries, inflows to nodes and links, exfiltration to nodes and links, outlet water levels.

If a load is connected to a link, it will be uniformly distributed over all computational grid H-points along the link.

For a node - either an inflow hydrograph can be specified or an infiltration boundary can be specified. If the 'Infiltration' option is chosen the boundary items page allows to specify a positive or negative rate. So either infiltration to the node or loss of water from the node to the surrounding ground can be used.

The loss can be defined for any type of node, but it is primarily intended for use with basins or nodes with geometry representing small ponds. The infiltration can be defined as a constant rate (velocity) which is multiplied by the actual wet area in the node. Note that the rate value should be given as a negative value for specifying a loss of water from the network model. Applying a positive value will result in water being added to the node.

**Geo-coded** applies for **Load points** (typically DWF) geo-coded to the network nodes. User can select which one of the geo-coded load categories applies for this boundary condition.

**Geo-coding** can be used to assign 'loads', either load point discharge, or load point per unit. Further information regarding the Geo-coding of loads is discussed specifically under the 'Load Points' help section.

Grid distributed weights, gridded distributed weights can be used to assign spatially varying rainfall data. The application of 2D radar data directly in the urban drainage model using our DHI's *dfs2* format files as input for runoff computations. MIKE 1D will automatically distribute the rainfall to individual catchments and apply it to the runoff computation.

### Visualization of boundaries

The different loads are visualized in the map by means of the "Show in map" button.



### 6.1.4 Temporal variation

The temporal variation is essentially the function of time, related to the condition. The temporal variations which can be applied to a boundary condition are; 'Constant', 'Cyclic' or 'Time Series'.

The temporal variation of a boundary condition can be assigned with a constant, cyclic or a time series temporal variation.

The 3 temporal variations are quite explanatory. Dependent on the boundary condition type, the units are representative units and automatically updated.

If a cyclic temporal variation is variation is to be applied, a pattern is also needed. The help section for 'Repetitive profiles' provides a more detailed description of the design and application patterns and profiles.

The Time-series temporal variation requires a compatible time series file for input. The standard time-series file format is '.DFS0'. The help file for the time series editor provides more detailed information on the types of time series file available, and how they are produced.

For the grid distributed weights spatial extent the temporal variation input file must be of the dfs2 format, files of type "2D Grid file"

### 6.1.5 Limited interval

The limited interval function allows the a specific time definition of when the boundary item is applied.

If a limited validity interval is to be applied to a boundary, then check 'Use limited validity'. It is then necessary to define the start and end date & time of the validity period.

### 6.1.6 Scaling factor

The Scaling factor tab is used to apply a scale factor for the hydraulic load. This can be used to add a climate factor.

### 6.1.7 Distributed weights

In the Distributed Weights tab it is possible to check the distributed weights per catchment and adjust if desired. All catchments connected to the grid (spatially weight distribution) will be presented in the dialogue. Catchments might be presented in several entries if multiple grid points cover its entirety.

There are two text fields which will display the most important data for the loaded boundary condition selected; grid file name and item type.



In the grid all relevant information about data connected to catchments as well as the connected grid points (coordinates i and j) and the engine calculated weight percentage covering the catchment per grid point. These percentages fractions should add up to a 100 per cent for each catchment.

The grid is dynamic and visualises the selected boundary condition data, the grid allows to insert new connecting grid point by right clicking on the dialogue.

The compute button allows the user to compute the weights for either all catchments or a selection of catchments, as well as for the new added grid points (not updated).

Boundary conditions

Identification

ID: RainBC Type: Rainfall

☒ Apply Catchment Loads

Insert Delete

Spatial extent Temporal Variation Limited interval Scaling factor Distributed Weights Description

C:\Users\fit\Desktop\2DBase\_1\_RAINF H Water Depth

Catchment ID	I	J	Weight
imp1	234	131	0,000262398320650...
imp1	234	132	0,000262398320650...
imp1	234	133	0,000262398320650...
imp1	235	111	0,000262398320650...
imp1	235	112	0,000262398320650...

... All Compute

There are atchments not fully covered by the grid file: imp1, perv1

ID: ALL Clear Show selected Show data errors 1/2 rows, 0 select

ID	Boundary type	Group No	Apply Boundary	Load type
1 RainBC Rainfall	Catchment Loads	<input checked="" type="checkbox"/>	Storm Runoff	
2 Network loads input file - Runoff_1 Inflow from result file	Network Loads	<input checked="" type="checkbox"/>		

Figure 6.3 Distributed weights boundary condition

## 6.1.8 Description

It is possible to provide a description of the boundary condition and load type using the Description tab.



## 6.2 Water Quality Boundary Condition Properties

This editor is only available if Water Quality module is active. It allows for water quality components such as chemicals, sediment and water age to be added to a hydraulic boundary condition.

### 6.2.1 Water quality

A Water Quality boundary condition must be connected to a Hydraulic boundary condition. A hydraulic boundary condition can be used with a hydraulic load set to 0 to only add a Pollutant Load or Sediment Load. The **Boundary condition selector** check allows to choose between available Hydraulic Boundary condition IDs.

Figure 6.4 The Water quality tab in the Water Quality editor.

If the checkbox is not marked, all Water Quality Boundary Conditions are shown. If the box is checked, only WQ Boundary conditions for the selected Hydraulic Boundary Condition in that editor are shown and can be manipulated for in this editor. In that case, any existing WQ Boundary conditions for other Hydraulic boundary conditions will still be used but are hidden.

The Insert and Delete button adds and removes WQ Boundary conditions. Any new items added will be automatically connected to the selected Hydraulic Boundary Condition. Each WQ Boundary Condition will be used for one type of Water Quality Component.



A name (ID) and type is given to the WQ Boundary Condition. The available types are:

### Pollutant

The pollutant will be added with the concentration specified on the Temporal Variation tab.

### Microorganism

The component is added as a micro-organism load, used for bacteria and pathogens.

### Temperature

The component represents the temperature, the unit will be adjust according to the unit system specified for the model

### pH

The component is related to the water pH, a measure of how acid or basic the water is.

### Salinity

The component will reflects the measure of salts dissolved in water,

### Water Age

This option allows for water with specified age to enter the network.

### Water Blend

This option allows for water with specified mixing ratio to enter the network.

### Other Type of AD component

Selects the type of AD Component. A type of water contaminant must be pre-defined in the Water Quality AD components dialogue.

## 6.2.2 Temporal Variation

Figure 6.5 Temporal variation tab in Water Quality editor.



A water quality boundary condition can have a different temporal variation than the hydraulic boundary condition it is connected to. It can be constant, cyclic, a time series temporal variation, table concentration and SWQ.

Dependent on the water quality type, the units are representative and automatically updated.

If a cyclic temporal variation is to be applied, a pattern is also needed.

The Time-series temporal variation requires a compatible time series file for input. The standard time-series file format is '.DFS0'.

The table concentration allows to specify a variation of pollutant loads based on a runoff -concentration varying relation.

The temporal variation can also be defined through a Storm Water Quality method, build-up/ wash-off or EMC, for more details please refer to the Water Quality Module.

### 6.2.3 Scaling factor

The scaling factor allows to add a global factor to the load. The Default value is 1.

WQ boundary properties

☒ Boundary condition selector: Nework\_load ...

Spatial extent: All

Temporal variation: Time series, File path: CS\_1Ba

Description:

Identification

ID: BOD\_dissolved Type: Temperature

Insert Delete

Water quality Temporal Variation **Scaling factor** Description

Scale factor: 1

Figure 6.6 Scaling factor tab in Water Quality editor.



### 6.2.4 Description

The Description tab allows the user to add text data to the specific WQ boundary condition.

WQ boundary properties

☒ Boundary condition selector: Network\_load ...

Spatial extent: All

Temporal variation: Time series, File path: CS\_1Ba

Description:

Identification

ID: BOD\_dissolved Type: Pollutant concentration

Insert

Delete

Water quality Temporal Variation Scaling factor Description

Description: BOD dissolved network global load

Figure 6.7 Description tab in Water Quality editor.

## 6.3 Load Point

The allocation of geographically determined load points to the nodes and, or links of a collection system model is defined through the Load Points section. The load points are geographical point features, typically representing a categorised wastewater load, such as domestic wastewater, commercial / industrial wastewater and infiltration.

It is possible to modify the additional categories to provide a tailored coding system to replicate the water loadings of the catchment.

The loads can be include into the model database through manual insertion and importation.





**Load points**

**Identification**

ID:  X:  [m] Y:  [m]

**Geometry** | Load point connection | Description

Load category: **1: Domestic WW** (selected)

Flow: **1: Domestic WW** [m<sup>3</sup>/d]

Units: **10** [0]

ID	Load category	Load flow [m <sup>3</sup> /d]	Load units [0]	Load
1: Load_Point_1	1: Domestic WW	86400	10	Nod

Figure 6.8 Load points grid

There are 3 sub-tabs within the 'Load point' tab, 'Geometry', 'Load point connection' and 'Description'.

### 6.3.1 Geometry

Within the Geometry, the load can be categorised and the flow and units can be quantified.

The number of units regards to the "Load point discharge per unit" when the spatial extent is defined as "Geo-coded". The load discharge is specified through "Load flow (m<sup>3</sup>/s)".

### 6.3.2 Load point connection

Load points can be connected to the model network through nodes and links, each load will be coupled to a single network element.



Load points

Identification

ID  X  [m]

Y  [m]

Geometry Load point connection Description

☒ Node  ...

☐ Link  ...

Start  [m] End  [m]

ID	X coordinate [m]	Y coordinate [m]	Load category	Load flow [m <sup>3</sup> /d]	Load units [0]
1 Load_Point_1	-686976,627153363	-1056061,31730978	1: Domestic WW	86400	10

Figure 6.9 Load point connection

The connections can be made via the asset ID Selector (grid selection) or by map selection.

If using a link connection for the Load point, it is possible to defined the chain-age start and end points.

### 6.3.3 Description

The description tab enables the modeller to record load point information.



Load points

Identification

ID  X  [m] Y  [m]

Geometry Load point connection Description

Description

Data source

Asset ID

Owner

Location

Date

< ID ALL Clear ☐ Show selected ☐ Show data errors 1/1 row

	ID	X coordinate [m]	Y coordinate [m]	Load category	Load flow [m <sup>3</sup> /d]	Load unit
1	Load_Point_1	-686976,627153363	-1056061,31730978	1: Domestic WW	86400	

Figure 6.10 Load point description tab

## 6.4 Repetitive Profiles

The 'Repetitive Profile Editors' can be used for generating dimensionless, cyclic time series ('repetitive profiles') with a fixed time resolution of one hour. E.g., it can be applied for defining diurnal profiles that can describe the Dry Weather Flow (DWF) from a specific catchment. An unlimited number of repetitive profiles can be applied to different groups of catchments. For example, an industrial area will have a different dry weather flow (DWF) description to rural or residential area. DWF profiling may also vary according to the time of week and holidays.

There are four discrete parts forming the repetitive profiles:

- Diurnal patterns- used for specifying diurnal patterns
- Cyclic profiles - used for coupling of individual diurnal patterns with profile calendar definition
- Profiles calendars - used for coupling of individual diurnal patterns with profiles calendar definition
- Special days - used for specifying days that are to be considered as exceptions to the calendar (e.g. the 1st of January)

### 6.4.1 Diurnal patterns

A diurnal pattern consists of the pattern ID, a Delta T (minutes) and non-dimensional coefficients.

Figure 6.11 shows an example of a diurnal pattern editor. A new pattern is created by using the 'Insert' button. It is then required to define the Delta T value (minutes). The DeltaT value represents the interval distribution for the pattern. For example, a DeltaT value of 60min returns 24 hourly intervals. a DeltaT value of 240 will return 6 x 4 hour intervals.

The 'Distribute' button creates the intervals determined by the DeltaT value assigned. The dimensionless coefficient is inserted under the 'Multiplier' column.

The 'Normalize' button adjusts the multiplier values so that the sum of them is equal to 1, but the relative weightings are maintained.

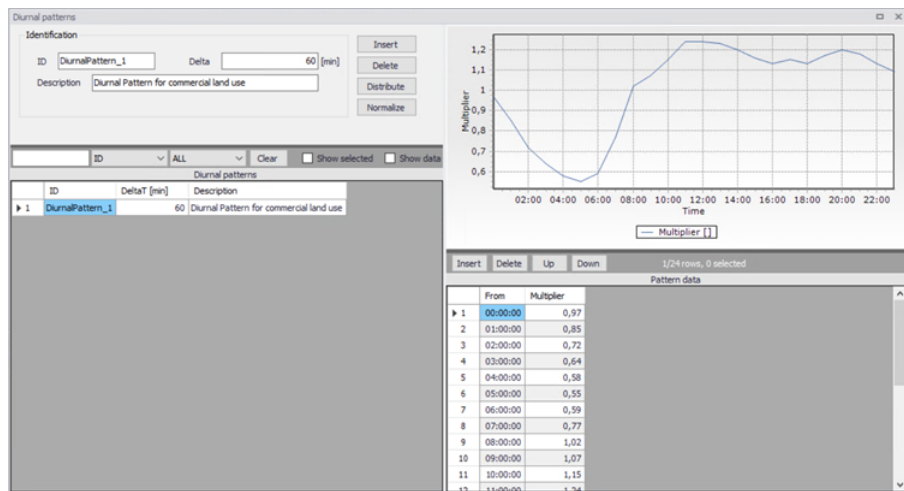


Figure 6.11 Diurnal pattern editor

### 6.4.2 Cyclic profiles

A cyclic profile links a diurnal pattern with the relevant calendar definition.

Each cyclic profile requires an ID with a defined 'Diurnal Pattern' and 'Calendar'. In addition, the profile requires input regarding the interpolation of the pattern, either by 'linear interpolation', or 'no interpolation'. No interpolation will apply a step function between the diurnal pattern values.

Figure 6.12 shows the Cyclic Profile editor. The visualisation shows at a glance how the profile will look (monthly or weekly) with the diurnal pattern



coupled to the selected profile calendar. The Cyclic Profile example shows a 'Residential' diurnal profile with a 'Weekday' profile calendar.

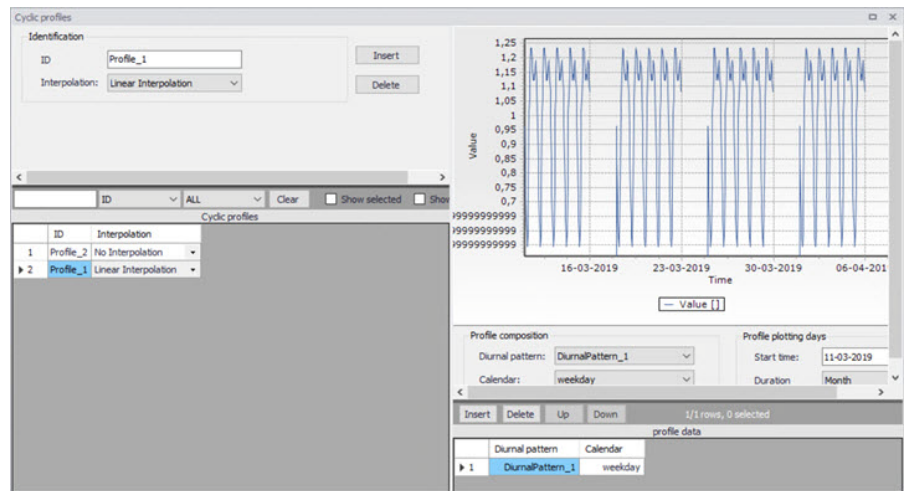


Figure 6.12 Cyclic Profile

### 6.4.3 Profiles calendar

The purpose of the profiles calendar is to specify when the diurnal patterns are to be applied, e.g, only during summer, only February, only on weekdays, only on each first in the month, etc.

Profile calendars specify when the diurnal profile pattern is to be applied, and can be defined in three primary formats, Weekdays, Dates and Months.

There is scope to apply multiple calendar formats to create very specific calendar formats, if required.



Profile calendars

Identification

ID

Weekdays Dates Months

☒ Weekdays

☐ Monday

☐ Tuesday

☐ Wednesday

☐ Thursday

☐ Friday

☒ Saturday

☒ Sunday

ID   ☐ Show selected ☐ Show data errors 1/2 rows, 0 se

	ID	Week days	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sun
▶ 1	weekends	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
2	weekday	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	

Figure 6.13 Profiles calendar weekdays



Profile calendars

Identification

ID:

Weekdays Dates Months

☒ Dates

<input checked="" type="checkbox"/> 1	<input checked="" type="checkbox"/> 8	<input checked="" type="checkbox"/> 15	<input checked="" type="checkbox"/> 22	<input checked="" type="checkbox"/> 29
<input checked="" type="checkbox"/> 2	<input checked="" type="checkbox"/> 9	<input checked="" type="checkbox"/> 16	<input checked="" type="checkbox"/> 23	<input checked="" type="checkbox"/> 30
<input checked="" type="checkbox"/> 3	<input checked="" type="checkbox"/> 10	<input checked="" type="checkbox"/> 17	<input checked="" type="checkbox"/> 24	<input checked="" type="checkbox"/> 31
<input checked="" type="checkbox"/> 4	<input checked="" type="checkbox"/> 11	<input checked="" type="checkbox"/> 18	<input checked="" type="checkbox"/> 25	
<input checked="" type="checkbox"/> 5	<input checked="" type="checkbox"/> 12	<input checked="" type="checkbox"/> 19	<input checked="" type="checkbox"/> 26	
<input checked="" type="checkbox"/> 6	<input checked="" type="checkbox"/> 13	<input checked="" type="checkbox"/> 20	<input checked="" type="checkbox"/> 27	
<input checked="" type="checkbox"/> 7	<input checked="" type="checkbox"/> 14	<input checked="" type="checkbox"/> 21	<input checked="" type="checkbox"/> 28	

ID  
☐ Show selected ☐ Show data errors 1/2 rows, 0 se

	ID	Week days	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
▶ 1	weekends	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
2	weekday	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	

Figure 6.14 Profile calendars dates

Profile calendars

Identification

ID: weekends

Insert

Delete

Weekdays | Dates | Months

☒ Months

☒ January ☒ July

☒ February ☒ August

☒ March ☒ September

☒ April ☒ October

☒ May ☒ November

☒ June ☒ December

ID: ALL Clear ☐ Show selected ☐ Show data errors 1/2 rows, 0 se

ID	Week days	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1 weekends	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
2 weekday	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure 6.15 Profile calendar months

## 6.4.4 Special days

The 'Special days' is used for the specification of individual days that should be considered differently than it is given by the profiles calendar.

For example, the 1st January (the New Year day) falls on a different day each year. Typically, holiday days diurnal profiles are more representative of Weekends. The 'special days' function can be used to assign the 1st January with a weekend diurnal pattern.

The special days have two categories, 'Unique date' and 'Every year'. An example of this is Easter day. The date of Easter varies each year, so the 'Unique date' would be more applicable.





Special days

Identification

ID:

☒ Unique date (selected) ☐ Every year

Date:  Use as:

ID	Unique date	Use as	Date	
1	Special_Day_1	Unique Date	Sunday	25-04-2019

Figure 6.16 Special Days

The date calendar allows the user to select the desired date for a special day. The “Unique date (selected)” and “Every year” checkbox are used to specify the recurrence. Finally “Use as” allows the user to assign the variation pattern, weekday and weekend.

## 6.5 Boundary Overview

It is possible to visualize the time frame variation of all boundary conditions included in the model by means of the boundary overview dialog.

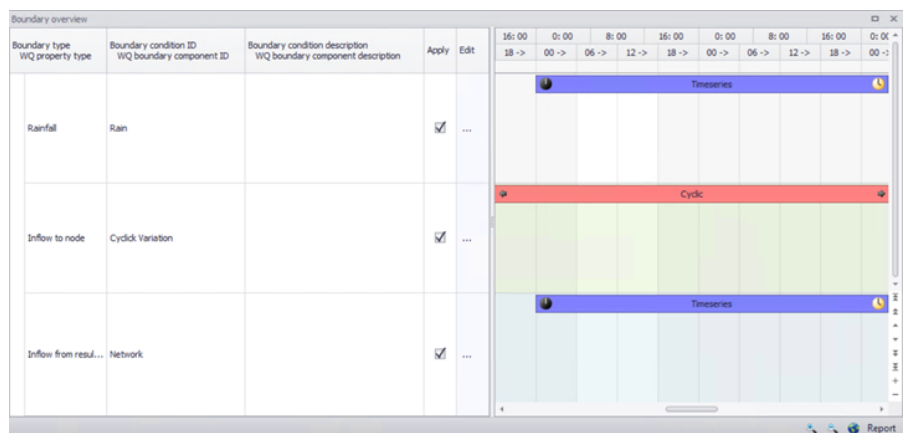


Figure 6.17 Boundary overview



The overview allow the user to apply boundary conditions and lead the user to the editor by clicking on “Edit”. The right side of the panel shows the time frame of the boundary condition.



## 7 Tables

The Tables Section in MIKE URBAN+ holds data for the following tabular data types:

- Curves and Relations
- Materials
- Outlet Head Loss
- On Grade Captures

### 7.1 Curves and Relations

In Tables|Curves and Relations (Figure 7.1), a number of tabular data used in other data dialogs are specified. These different types of tabular data are:

- Capacity Curve QH (used for Pumps)
- Capacity Curve QdH (used for Pumps)
- Pump Acceleration Curve (used for Pumps)
- Regulation Qmax(H)
- Regulation Qmax(dH)
- QH Relation (when specifying a QH relation for a node)
- Valve Rating Curve
- Time-Area Curve (used in Time-Area runoff model)
- Removal Efficiency (used for the efficiency curve for removal weirs)
- DQ Relation (used for Curb Inlets)
- QQ Relation (used for Curb Inlets and On Grade Captures)
- Capacity Curve QdH & Power
- Runoff Pollutants (used for SWQ)
- Basin Geometry (used for Basins)
- RTC (used for RTC Action Set Points)
- RTC Time (used for RTC Action Set Points)
- Undefined (general placeholder)

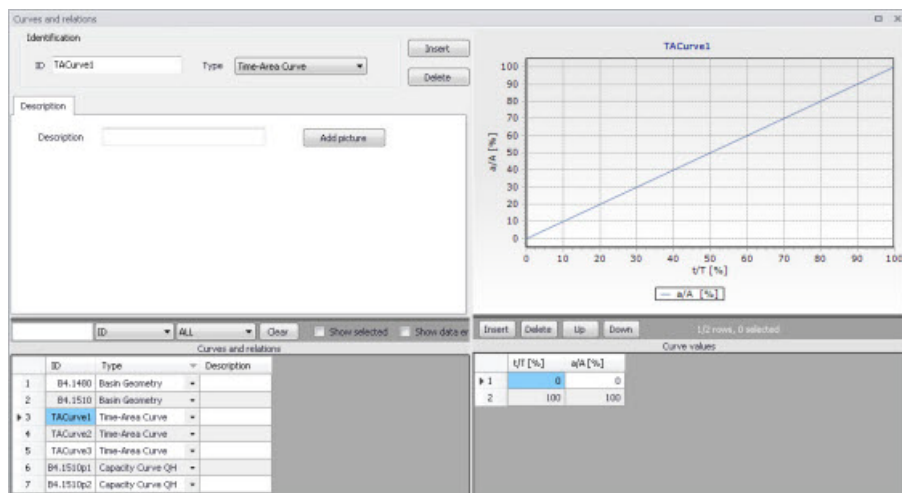


Figure 7.1 Curves and Relations Editor

There are 3 pre-defined Time-Area Curves in the database (TACurve1, TACurve2 and TACurve3), which should not be deleted.

Additional curves and relations are inserted under the Curves and Relations list (i.e. the primary table on the lower left corner of the editor) using the 'Insert' button at the top of the editor (Figure 7.2).

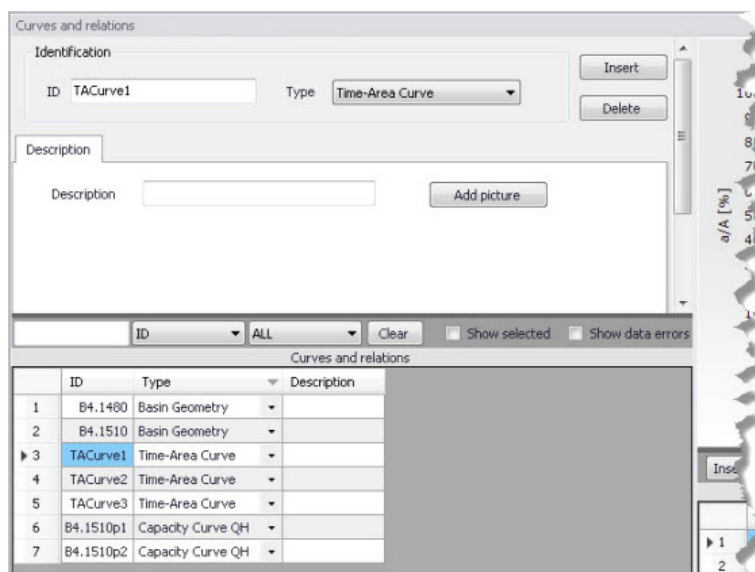


Figure 7.2 Primary table with the Curves and Relations list on the lower left side of the Curves and Relations Editor



After inserting a new tabular data item, define the corresponding data values under the Curve Values table (i.e. secondary table to the right of primary table) (Figure 7.3). Secondary table parameters/columns that should be filled vary depending on the curve and relation type.

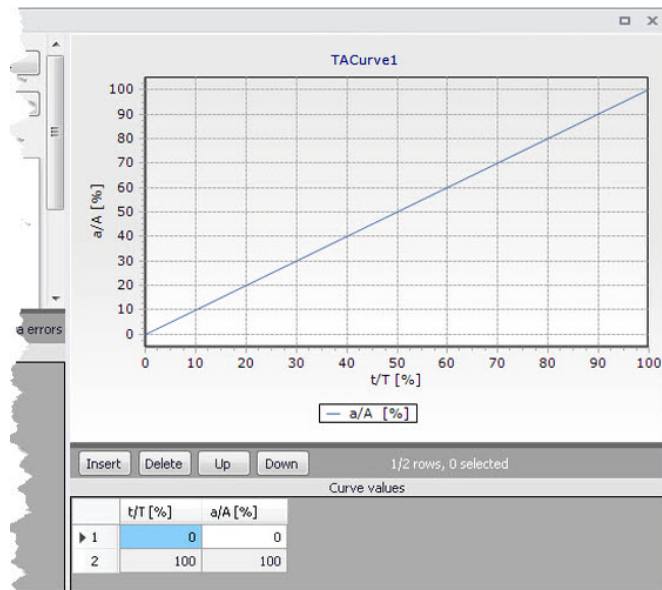


Figure 7.3 Secondary table containing Curves Values on the lower right side of the Curves and Relations Editor. Also shown is the tabular data plot above the secondary Curve Values table.

A plot of the tabular data is also shown on the upper right corner of the editor (Figure 7.3).

Table 7.1 Overview of Curves and Relations Editor attributes (Table ms\_Tab)

Edit field	Description	Used or required by simulations	Field name in datastructure
ID	Tabular data identifier	Yes	MUID
Type	Dropdown menu for selecting tabular data type	Yes	TypeNo
Description	User's descriptive information on the tabular data	Optional	Description



### 7.1.1 Capacity Curves

It is possible to define two types of capacity curves in MIKE URBAN+; both are used to define pump operation.

The capacity curve can be a 'Capacity Curve QH' relation (for screw pumps) or 'Capacity Curve QdH' relation (for differential head pumps).

'H' is the absolute water level in the pump's wet well (i.e. From Node), and 'dH' is the water level difference between the (downstream) 'To Node' and (upstream) 'From Node' locations.

If an offset is specified, this will be added to the capacity curve relation.

Also note that one may specify a pump capacity curve with energy consumption (i.e. Capacity Curve QdH & Power).

### 7.1.2 Pump Acceleration Curve

Pumps may be RTC controlled. For PID-controlled RTC pumps, the acceleration of a pump can be specified as dependent on the actual flow. This pump acceleration curve is then specified as a number of 'dQ, dQ/dt' values.

### 7.1.3 Regulation Curves $Q_{\max}(H)$ and $Q_{\max}(dH)$

The regulation curves  $Q_{\max}(H)$  and  $Q_{\max}(dH)$  are used in the regulation of the maximum discharge in links. The regulation can either be a maximum discharge as a function of the water level in a user-specified node, or a maximum discharge as a function of the water level difference between two user-specified nodes.

### 7.1.4 QH Relation

QH relations can be used for outlets. Using a QH relation in an outlet means that you specify the discharge out of the outlet based on the water level in the outlet.

### 7.1.5 Valve Rating Curve

A valve is a functional relation between two nodes of a sewer network. The valve rating curve specifies the relationship between the valve opening (%) and resistance (k).



### 7.1.6 Time-Area Curve

The Time-Area curve is used in the Time-Area runoff model. A Time-Area curve represents the percentage contributing part of the catchment surface as a function of time.

MIKE URBAN+ comes with three default Time-Area curves - TACurve1, TACurve2 and TACurve3 - applicable for rectangular, divergent and convergent catchments, respectively.

One can define other Time-Area curves. Each Time-Area value table must start with a pair of values (0,0) and must end with a pair of values representing the whole catchment contribution. MIKE URBAN+ maintains T-A curves in percent (%), and the last pair of values in the table must be (100,100).

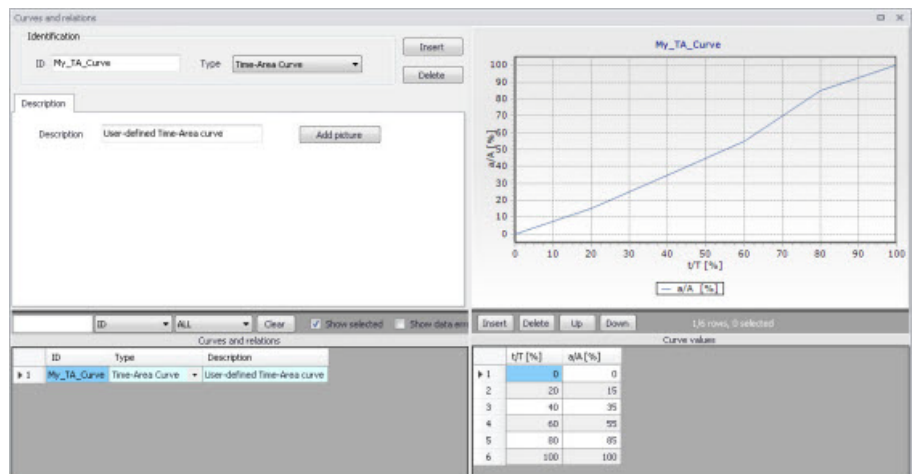


Figure 7.4 Example of user-defined Time-Area curve

### 7.1.7 Removal Efficiency

There are three methods available for the removal of sediments in weirs. In one of these methods you specify the relation between discharge towards the weir and the removal efficiency, i.e. the efficiency curve. The removal efficiency is hence a function of  $Q$  and the efficiency (dimensionless 1/1).

### 7.1.8 Curb Inlet DQ and QQ Relations

Two curve types can be specified for two different types of Curb Inlets:

- DQ Relation (depth-discharge relation specified in the Curb Inlets dialog)
- QQ Relation (Qapproach-Qcapture relation specified in the On Grade Captures editor)

The DQ relation specifies the depth-based capacity curve for a SAG Type Curb Inlet. Values must be monotonously increasing in depth and discharge and starting at (0,0). For depths in excess of the maximum value specified in the last row of the table, the last corresponding discharge value is used.

The QQ relation specifies the relationship between approach flow in the overland flow network ( $Q_{app}$ ) and the captured flow at the connection node for an On Grade Type Curb Inlet ( $Q_{cap}$ ). Values must be monotonously increasing and starting at (0,0). For approach discharges in excess of the maximum value specified in the last row of the table, the last corresponding capture discharge value is used.

### 7.1.9 Capacity Curve QdH & Power

If specific power consumption in relation to pump levels is known, it is possible to include this in the model using the 'Capacity Curve QdH & Power' curve type.

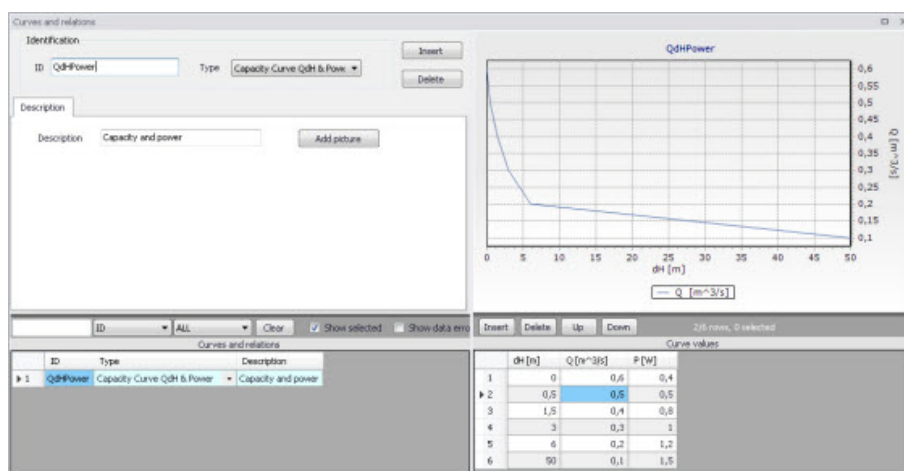


Figure 7.5 Pump capacity curve including power consumption

After the simulation with a 'Capacity Curve QdH & Power' the summary will contain information on the power consumption during the simulation period.

### 7.1.10 Runoff Pollutants

This type of table is used in surface water quality (SWQ) boundary conditions as a way to define the Temporal Variation of surface stormwater loads as well as RDI stormwater loads.

The table serves as a lookup table for the boundary condition, where corresponding concentration values are determined based on runoff intensity. The





tabular data set shall contain values for runoff intensity (i.e. the runoff divided by the total catchment area) and corresponding concentrations.

### 7.1.11 Basin Geometry

Basin geometries are tabulated area-elevation functions. One specifies values for the parameters  $H$ ,  $A_c$ , and  $A_s$ .

$A_c$  is the cross-section area perpendicular to the main flow direction in the basin, which is used to calculate the velocity.  $A_s$  is the surface area of the basin (used to calculate the volume). Both parameters are specified as functions of the water level,  $H$ , in the basin.

The  $H$ -column for the basin geometry can start at any value, e.g. 0 for interpretation of  $H$  as depth in the basin. MIKE URBAN+ associates the first  $H$ -value to the bottom level of the node. This means that the same geometry can be reused in several places in the model.

The maximum level before flooding at a basin is either the highest  $H$  value of the geometry or the ground level. If the top of the basin geometry is below the ground level, the specified basin geometry is extended with additional points to allow for flooding.

### 7.1.12 RTC

RTC tables are lookup tables defining the functional relation between an actual input value (e.g. sensor reading or difference between sensor readings, etc.) and the set point value (or setting). The tabulated values are linearly interpolated between defined relations.

### 7.1.13 RTC Time

RTC Time tables are lookup tables explicitly defining the set-point value (or setting) for particular time periods (i.e. date/time). The tabulated values are linearly interpolated between defined values.

### 7.1.14 Undefined Type

The Undefined table type is an extra generic type of table used as a placeholder for potential future functionality.

## 7.2 Materials

In MIKE URBAN+, a link is characterised by material, which determines the Manning friction coefficient (Manning), the Colebrook-White coefficient (EQ Roughness), or Hazen-Williams coefficient (H-W Coefficient) for the conduit.



It is optional to use either the default roughness values for specific materials or local values.

Specification of the different kind of materials and roughness coefficients is done through the Materials editor (Tables | Materials).

	ID	Manning [m <sup>1/3</sup> /s]	EQ rough [m]	HW coefficient	Description
▶ 1	Cement Mortar	77	0,001	120	
2	Ceramics	70	0,0025	110	
3	Concrete (Normal)	75	0,0015	120	
4	Concrete (Rough)	68	0,003	100	
5	Concrete (Smooth)	85	0,0005	140	
6	Iron (cast)	70	0,0025	120	
7	Iron (wrought)	65	0,0035	100	
8	Plastic	80	0,001	140	
9	Stone	80	0,001	130	

Figure 7.6 Materials Editor

MIKE URBAN+ has the following pre-defined Material types with friction loss properties:

- Cement Mortar
- Ceramics
- Concrete (Normal)
- Concrete (Rough)
- Concrete (Smooth)
- Iron (cast)



- Iron (wrought)
- Plastic
- Stone

Table 7.2 Overview of the Materials Editor attributes (Table ms\_Material)

Edit field	Description	Used or required by simulations	Field name in datastructure
ID	Material type ID	Yes	MUID
Manning	Manning roughness value	Yes If 'Manning Explicit' or 'Manning Implicit' is used	Manning
EQ Roughness	Equivalent roughness	Yes If 'Colebrook-White' formulation is used	EQRough
H-W Coefficient	Hazen-Williams roughness coefficient	Yes If 'Hazen-Williams' is used	HWCoeff
Description	User's descriptive information on the material	Optional	Description

## 7.3 Outlet Head Loss

MIKE URBAN+ models outlet head losses at nodes. The general flow equations are valid only for continuous conduits, where the only resistance to flow is bottom and sidewall friction. Hydraulic conditions in nodes, i.e. at manholes and structures, serve as boundary conditions in the computation of flows in conduits. In turn, hydraulic conditions in a node depend on the flows in the inlet and outlet conduits.

These hydraulic conditions, expressed in terms of the energy conservation principle, are calculated as water levels and velocity heads. The calculation is based on the mass continuity and formulation of more or less advanced energy relation between the node and the neighbouring links, including energy losses caused by local flow disturbances at different locations in the node.

The following parameters constitute a definition of head loss calculation option in MIKE URBAN+:

### Computation Method

Three different methods are available:



- **Classic.** This is a simplified computational model for energy losses in junctions based on F.A. Engelund's energy loss formulae. The total head loss comprises of node inlet loss and node outlet loss, including losses due to change in flow direction, due to change in elevation, and due to contraction, if relevant.
- **Mean Energy Approach.** This is an alternative solution which fully ignores the energy loss at the inlet. For a flow-through manhole, this means that the energy level in the manhole is set equal as at the downstream end of the inlet pipe. For manholes with multiple inlets, the energy level is calculated as the weighted average of the inlet flows (i.e. large flows contribute most to the energy level). In this formulation, the total loss at the manhole is concentrated computationally at the outlet, and can be fully controlled by the user.
- **No Head Losses.** This option ignores all local losses. Regardless of the shape of the outlets, geometrical set-up of the junction and distribution of flows among inlet and outlet conduits, water levels in the junction and the outlet conduit are set equal as if there is no change of geometry and flow conditions between the junction and outlet conduit. This means that this option should be applied only where there is no change in cross section. Inconsistent results may be generated if inappropriately applied. This option is recommended for an artificial node/junction along a straight section of conduit, where no losses actually occur.

Further details on the various head loss computation methods mentioned above are found in the MIKE 1D Reference Manual.

## Effective Node Area

This parameter is only relevant for the Classic head loss computational method. In all other cases, the default total wetted node area is applied. The following choices are available:

- **Full Node Area.** Calculated as product of diameter and water depth for manholes and read from the basin geometry table ( $A_c$ ) for basins. Typically results in overestimate of local loss in a node.
- **Calculated Effective Area.** The effective area in a manhole is calculated based on an empirical formula (see Section 4.6.2 'Headloss calculation for inflowing water' section in the MIKE 1D Reference Manual). This results in a significantly smaller area than full wetted area and, consequently, with a more realistic flow calculation.
- **Reduced Calculated Effective Area.** The effective area in a manhole is further reduced to 50% of the calculated effective area.

## Loss Coefficient

The available loss coefficient types distinguish three different interpretations of the specified head loss coefficient.



- **Km.** Interprets the specified value as the outlet 'shape' coefficient Km (see Equation (4.17) in MIKE 1D Reference Manual).
- **Contraction HLC.** Interprets the specified value as the outlet 'contraction' coefficient  $\zeta_{\text{contr}(j)}$  (see Equation (4.17) in MIKE 1D Reference Manual). This means that the model ignores the geometrical relations between the node and the outlet links (outlet shape), and applies the specified value directly as the  $\zeta_{\text{contr}}$ . The contraction losses in the outlet links are then computed by multiplying the velocity head in the respective link by the  $\zeta_{\text{contr}}$ . The total head loss for an outlet link is computed as a sum of the contraction, direction and elevation loss.
- **Total HLC.** Interprets the specified value as the total outlet head loss. This means that the model completely ignores the geometry of the node/links, and applies the specified value (Total HLC) directly as the  $\zeta_{\text{out}}$ , the same for all outlet links at the node. The total head losses in the outlet links are then computed by multiplying the velocity head in the respective link by the specified  $\zeta_{\text{out}}$ .

Changes to outlet head loss parameter sets used for Nodes are made via the Outlet Head Loss editor (Tables|Outlet Head Loss). Figure 7.7 also lists five pre-defined head loss parameter sets in MIKE URBAN+.

ID	ID	Method	Coefficient type	Coefficient	Effect area
1	Flow-Through Manhole	Classic	Km	0,25	Calculated Eff. Area
2	MOUSE Classic(Engelund)	Classic	Km	0,25	Full Node Area
3	MOUSE Classic(Engelund)_Modified	Classic	Km	0,25	Full Node Area
4	No Cross Section Changes	No Head Losses	Km	0	
5	Weighted Inlet Energy	Mean Energy Approach	Km	0,25	Full Node Area

Figure 7.7 Outlet Head Loss Editor



Table 7.3 Outlet head loss parameter set Editor attributes (Table msm\_LossPar)

Edit field	Description	Used or required by simulations	Field name in datastructure
Head Loss ID	Unique head loss parameter set identifier	Yes	MUID
Method	Dropdown menu to select head loss calculation method for parameter set: - Classic - No Head Losses - Mean Energy Approach	Yes	OutletShapeNo
Effective Node Area	Choice of method for the calculation of wetted area: - Full Node Area - Calculated Eff. Area - Reduced Calculated Eff. Area	Yes If Method = Classic	EffAreaNo
Loss Coefficient [dropdown menu]	Definition of the interpretation of the head loss coefficient: - Km - Contraction HLC - Total HLC	Yes If Method = Classic or Mean Energy Approach	CoeffNo
[Field next to Loss Coefficient dropdown menu]	Value for the loss coefficient	Yes If Method = Classic or Mean Energy Approach	Coeff

## 7.4 On Grade Captures

On Grade Captures tabular data are used as hydraulic properties for On Grade Curb Inlets describing the transfer capacity of connections. The On Grade Captures editor allows the user to group together QQ relations (tabular Curves and Relations data) that comprise a single On Grade Curb Inlet geometry (collective of QQ relations defining the capture rate as a proportion of approach flow). The transfer capacity for an On Grade Curb Inlet is dependent on the approach slope in the overland flow network, and a number of QQ relations can apply for a single curb inlet.

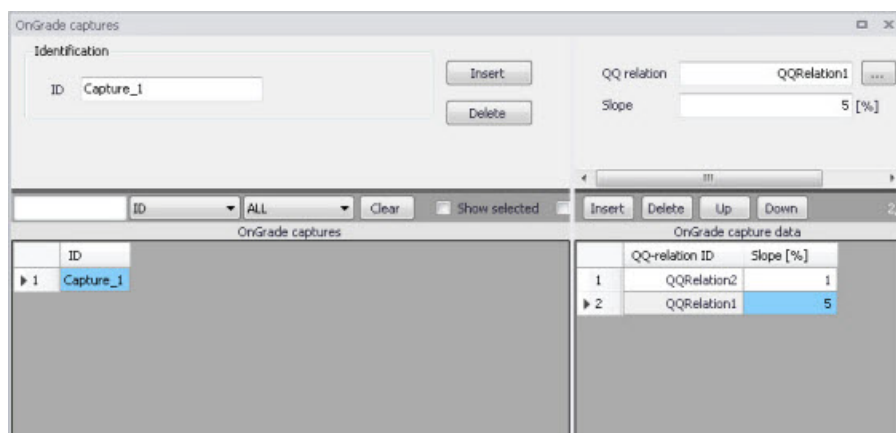


Figure 7.8 On Grade Captures Editor

For calculated or user-defined slopes in the Curb Inlet dialog that are outside the range of slopes specified in the On Grade Captures table, the closest slope curve will be used. For intermediate calculated or user-defined slopes (lying between slope curves in the On Grade Captures table), linear interpolation is applied.

In the case of an On Grade Curb Inlet capacity that is not dependent on slope of the overland flow network, the user needs to define the On Grade Capture with a single QQ relation. *Note: In this case, the calculated or user-defined slope in the Curb Inlet dialog for On Grade Type will be ignored.*







## 8 Real Time Control

The MIKE URBAN+ Control module features advanced Real Time Control (RTC) simulation capabilities for urban drainage and sewer systems. It can describe various controllable devices and makes the definition of complex operational logic for interdependent regulators fully transparent and time efficient. The following controllable devices can be specified:

- Pump
- Weir
- Gate in rectangular orifice (Blade moves from top to bottom)
- Weir in rectangular orifice (Blade moves the bottom to top)
- Valve

The devices may be specified as directly controlled or PID-controlled, with control function evaluation based on a global system analysis. Each regulator or pump operates under the control logic encapsulated into a set of simple logical rules and control functions.

The MIKE 1D Control Module employs an algorithm that reads arbitrary input, not necessarily limited to states of the network itself, and sets the state of the simulation. Network state conditions include measurable and derived hydraulic and water quality variables (e.g. water level, flow, pollutant concentration, level difference), device status (e.g. gate position, pump ON/OFF) and the current control function.

The control functions range from the simplest constants for the operational variables (e.g. constant weir crest setting or constant flow setpoint) to dynamic controlled variables set in a continuous functional relation with any of the measurable variables in the system (e.g. CSO discharge setpoint as a function of flow concentration or a pump START/STOP levels as functions of water level at a strategic location in the system).

### 8.1 RTC in Urban Drainage and Sewer Systems

Real time control (RTC) is an active control and operation of flow regulators based on real-time information about the system state.

RTC is feasible where it proves that flexible redistribution of water in space and time contributes to the fulfilment of the specified operational objectives based on economically- and technically-sound solutions. Accordingly, application of RTC to urban drainage and sewer systems may be relevant:

- Where the system has substantial transport, storage or treatment capacity not effectively used under passive system operation;

- Where typical rainfall patterns over the catchment area exhibit high degrees of spatial variability resulting in some parts of the system becoming overloaded whilst others are underutilised;
- Where the urban wastewater system includes treatment processes whose performance is amenable to active, short term control;
- Where the assimilative capacity of the receiving waters is variable over time.

Usually, RTC is implemented as an integral part of a rehabilitation/upgrade scheme also involving significant civil upgrading works to increase the transport, treatment or assimilative capacity of the urban wastewater system. In such circumstances, the role of RTC is to optimise the operation of both the new and the existing facilities, thereby maximising the benefit in performance terms. Where the overall objective is to achieve compliance with specified performance targets, RTC serves to minimise the scale and extent of the necessary works.

## 8.2 Architecture of RTC Systems

An RTC system includes **sensors/monitors**, which generate measurement values characterising states of the system. To be useful for RTC, the measurements must be available with relatively insignificant time lag (delay). The sensors must be accurate and reliable.

The active control is performed by **regulators** - controllable movable devices (weirs, gates and valves) and pumps. Regulators may take various forms and sizes, and the regulation may be continuous within the functional range, step-wise, or discontinuous (e.g. ON/OFF, OPEN/CLOSED). The regulators may be powered mechanically, hydraulically or pneumatically.

Controllers on the basis of a pre-programmed operational strategy determine the regulator movements (the **control actions**). The operational strategy may consist of two parts: the control action(s) and, if more control actions are specified, the control logic (**conditions**) responsible for the selection of an appropriate control action. A control action establishes a relation between a **control variable** and a **controlled variable**. A controlled variable can be a regulator setting (e.g. gate position, pump START/STOP level) or some of the flow variables (e.g. water level, flow).

In the latter case, the control decisions are derived by evaluating (comparing) the current value of the controlled flow variable and the pre-defined **setpoint** value. The control algorithm is based on the numerical solution of the “continuous control problem” equation and is usually termed as **PID** (Proportional-Integral-Differential) control. The actuation signal for the regulator is generated by a PID controller, which usually appears as part of the operational strategy programmed in a Programmable Logical Controller (**PLC**).



Selection of a controlled variable is, however, subject to limits set by the variable's "controllability". Therefore, a controlled variable is usually selected among the flow variables (flow, water level), preferably in the vicinity of the regulator. As a controlled variable becomes more distant from the regulator, it becomes more difficult to control due to time lags, diffusion and uncontrollable interference. Control of relatively distant controlled variables is difficult and often cannot give satisfactory results.

When a regulator setting is used as a controlled variable, the control algorithm is reduced to an explicit functional relation between the control variable and the regulator setting, which controls the system response indirectly. This is much simpler than PID control, but in turn, the control results are in many cases inherently inexact and only a rough flow control can be achieved. This type of control is most suitable for regulators of the ON/OFF (or OPEN/CLOSE) type, while the application to continuously controllable regulators should be carefully considered.

If the operational strategy is based on conditions local to the regulated device (for example the ON/OFF-control of a pump based on the water level in a wet well) it is called **local control**. A PLC receives signals (measurements) from local sensors and sends the control decisions (actuation signals) to the regulators. The usual situation for a sewer system is to have a number of local controllers associated with pumps.

If the operational logic is based on global conditions, it is then called **global control**. In such a situation, a **global controller** is required. A global controller is a computer program that makes the overall system state analysis in real time and provides additional input to the local controllers, which overrides or supplements the local logic with e.g. actuator signals, or by modified setpoint values.

An additional component needed is then a data transmission system to transfer data between sensors, controllers and the global controller. In connection with the global controller function, an RTC system is usually equipped with the data management and storage facilities (databases) and the user interface. This is usually termed as SCADA (Supervisory Control And Data Acquisition) system.

The global control can also be extended to include forecast data in addition to real-time data, which is then called predictive RTC. The most comprehensive way to obtain forecast data is to include a model in the control system. Predictive control brings additional benefits in relatively inert systems, i.e. where the response time of an operational variable is long compared to the change of relevant disturbance (external input or control action).

## 8.3 MU+ Control vs. Real Life

MU+ RTC simulates reactive local and global RTC systems in urban drainage and sewer networks. The software implementation is inherently a conceptual-



isation of real life, of which the user must be fully aware. Some conceptualisations applied in MU+ RTC are listed below.

- The program does not distinguish explicitly between local and global RTC. Per default, all elements of a modelled RTC system are assumed available for global control.
- Sensors are specified as operational devices with definition of sensor type and position in the sewer network. Sensors with multiple functionality must be specified individually.
- When devices (weirs, gates and pumps) are specified as controllable in the MU+ interface, a number of Regulation parameters about the behaviour of the structure is required to describe e.g. the allowed change rates for the state of the structure.
- The actual controllers are not specified explicitly as physical devices, but their function (i.e. operational logic as a combination of operational conditions and control actions) is associated with the respective devices.
- MU+ RTC uses sampling and actuation (control loop) frequency identical to the simulation time step.
- Sensor readings are simulated as perfectly accurate and with 100% availability.
- Low-level logic of the pump START/STOP operation is built into the program and is controlled by the START and STOP levels.
- The PID control algorithm is built into the program and is controlled by the PID constants and by factors for weighting the terms of the numerical solution of the control equation.

## 8.4 Sensors

A sensor is a device positioned somewhere in the system providing information on the actual value of a monitored variable.

A sensor can only monitor one variable. If more variables are measured at the same location, a corresponding number of sensors has to be described.

	ID	Type	Location type	Node ID	Link ID	Weir ID	Orifice ID	Valve ID
1	Level_02	External	Node	Node_02				
2	Level_12	Concentration	Node	Node_12				
3	Gate	Weir/Gate Position	Gate				Orifice_1	

Figure 8.1 The Sensors Editor showing an example setup for an External sensor

Table 8.1 Overview of the Sensors editor attributes (Table msm\_RTCensor)

Edit field	Description	Used or required by simulations	Field name in data structure
ID	Sensor unique identifier	Yes	MUID
Type	Type of parameter measured by the sensor	Yes	TypeNo
WQ Component	Measured water quality component	Yes If Type = Concentration or Mass flux	ComponentID
Location/Type	Location type	Yes	LocationNo
Location/ID	Location ID	Yes	_LocationID (prefix varies with location type)



Table 8.1 Overview of the Sensors editor attributes (Table msm\_RTCSensor)

Edit field	Description	Used or required by simulations	Field name in data structure
Time Series File	Path to external time series file defining sensor values	Yes If Type = External	TSFileName
Time Series Item	Item name for the selected data series from the time series file	Yes If Type = External	TSItemName
Description	Free text description of the sensor	Optional	Description

### Sensor ID

Each sensor needs a unique ID, which can be used to access the sensor information from other dialogs.

### Type

This parameter defines the type of variable measured by the sensor. The options are:

- Level
- Discharge
- Surface Runoff
- Concentration
- Mass Flux
- Weir/Gate Position
- Pump ON/OFF
- Action Active
- Action Active Time
- Valve Opening
- External (external time series file)

### WQ Component

The measured water quality component for the 'Concentration' and 'Mass Flux' sensor types.

### Location Type and Location

Depending on the sensor type, there could be one or more location types for a sensor (Table 8.2).

Define the location type and then specify the corresponding location ID. Note that a 'location' may be only indirectly related to a physical location, such as for 'Action Active' and 'External' sensors.



### Time Series File and Item

For an 'External' sensor type, an external time series file, which will be used for sensor values, must be defined. Select the appropriate time series Item to use when loading the time series file.

**Table 8.2** Overview of available Location Types for each Sensor Type

Sensor Type	Location Type						
	Node	Link	Weir	Gate	Pump	Action	Valve
Level	Yes	Yes	-	-	-	-	-
Discharge	Yes	-	-	-	-	-	-
Surface Runoff	Yes	Yes	-	-	-	-	-
Concentration	Yes	Yes	Yes	Yes	Yes	-	-
Mass Flux	-	Yes	Yes	Yes	Yes	-	-
Weir/Gate Position	-	-	Yes	Yes		-	-
Pump ON/OFF	-	-	-	-	Yes	-	-
Action Active	-	-	-	-	-	Yes	-
Action Active Time	-	-	-	-	-	Yes	-
Valve Opening	-	-	-	-	-	-	Yes
External	-	-	-	-	-	-	-

## 8.5 RTC Settings

Define controllable devices and the respective control settings on the RTC Settings editor (Figure 8.2).

The main parts of the RTC Settings editor are:

- An overview table of controllable devices (lower left side of the editor)
- The Rules editor (in the Rules tab)
- Other data tabs for controllable devices (i.e. Type and Description tabs)
- The Actions editor (right side of the editor)

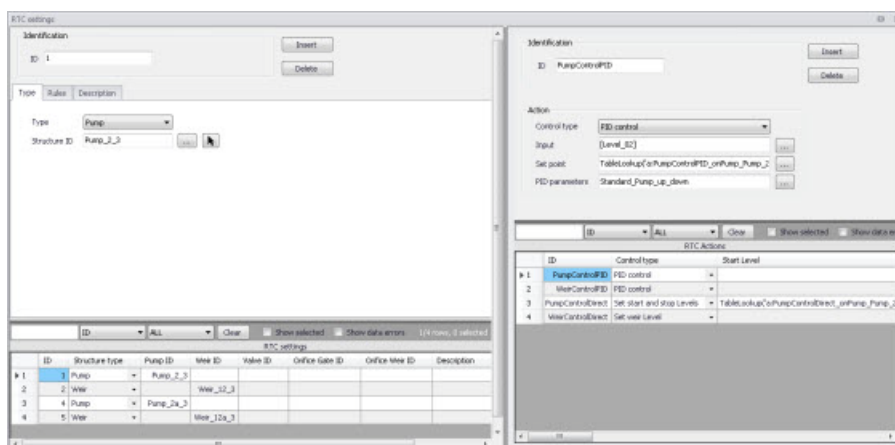
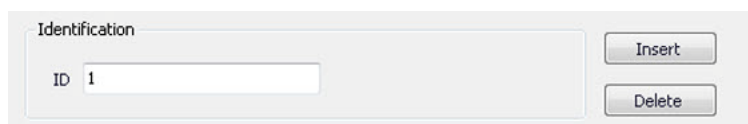


Figure 8.2 The RTC Settings Editor

The operational control rules for controllable devices are specified in this editor. The control is specified as a set of rules linking logical conditions and control actions. The rules are evaluated sequentially following the rules list sequence.

### 8.5.1 Identification

Specify the ID of RTC settings configurations in the Identification group box on the RTC Settings editor.



Use the 'Insert' button to add RTC configurations in the project. A summary of RTC settings is shown in the overview table on the bottom left part of the editor.

### 8.5.2 Type

Define the type of controlled device for which to apply RTC settings in the Type tab on the editor.





Figure 8.3 The Type Tab in the RTC Settings Editor

The Type identifies the device which is controlled. The available device types are 'Pump', 'Weir', 'Gate in rectangular orifice', 'Weir in rectangular orifice' and 'Valve' (see Figure 8.4).

Controlled devices require that the related structures have been previously defined in the relevant Network data dialogs (see succeeding sections and Figure 8.5 to Figure 8.8).

An orifice should first be defined in the model (Network | Orifices) for 'Gate in rectangular orifice' and 'Weir in rectangular orifice' controllable devices. The 'RTC Settings' dialog is used to add either a movable gate or a movable weir to the orifice.

Note that a 'Weir in rectangular orifice' device requires predefining an orifice in the Network model, and not an ordinary weir.

Also, the difference between a 'Gate in rectangular orifice' and 'Weir in rectangular orifice' is that the gate blade edge moves downwards from the top of the orifice (to the bottom), while the weir blade edge moves upwards from the bottom of the orifice.

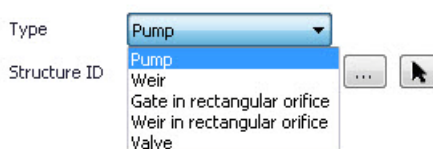


Figure 8.4 The different device types



When the device 'Type' has been selected the specific parameters for the configuration of the device can be defined in the RTC Settings tab.

## Pumps

Specify RTC settings for RTC pumps in the Regulation tab on the Pumps Editor (Network | Pumps).

The screenshot shows the 'Pumps' editor window with the 'Regulation' tab selected. The 'Identification' section at the top shows 'ID: 01CC232p1', 'From node: 01CC232', and 'To node:'. Below this are tabs for 'Geometry', 'Capacity', 'Regulation', and 'Description'. In the 'Regulation' tab, the 'Use regulation' checkbox is checked. Under 'Variable speed', the 'Wetwell Setpoint' is set to '[m]'. The 'RTC' section is active, showing 'Constant speed' and 'Variable speed' options. The 'Variable speed' option is selected, with 'Max start level' set to 0,272 [m], 'Min stop level' set to 0,222 [m], 'Min time ON' set to 5 [min], and 'Min time OFF' set to 5 [min].

Figure 8.5 Control data specific for pumps in the Pumps Editor Regulation Tab

### Max Start Level

The maximum START level for the pump. If exceeded, the pump is unconditionally switched ON.

### Min Stop Level

The minimum STOP level for the pump. If a lower level occurs, the pump is unconditionally switched OFF.

### Min Time ON

The minimum time the pump has to be ON before it can stop.

### Min Time OFF

The minimum time the pump has to be OFF before it can start again.

## Valves

For controlled valves, specify RTC settings in the Regulation tab on the Valves Editor (Network | Valves).



Figure 8.6 Control data specific for valves in the Valves Editor Regulation Tab

### Max Opening

The maximum opening of the valve in percentage.

### Min Opening

The minimum opening of the valve in percentage.

### Max Speed

The maximum velocity for movement of the valve in percentage/sec.

## Weirs

For controlled weirs, specify RTC settings in the Regulation tab on the Weirs Editor (Network | Weirs).

Figure 8.7 Control data specific for weirs in the Weirs Editor Regulation Tab

### Max Level

The maximum elevation of the movable weir crest.

### Min Level

The minimum elevation of the movable weir crest. The fixed weir crest level is not used for an RTC weir.

### Max Speed Up

The maximum velocity for movement of the weir in upward direction.

### Max Speed Down

The maximum velocity for movement of the weir in downward direction.

## Orifices with weirs and gates

If the device type is either 'Gate in rectangular orifice' or 'Weir in rectangular orifice', specify RTC settings in the Regulation tab on the Orifices Editor (Network | Orifices).

The screenshot shows the 'Orifices' dialog box with the 'Regulation' tab selected. The 'Identification' section shows 'ID: 20CC132o1', 'From node: 20CC132', and 'To node: 20CC132X'. The 'Regulation' section has a 'Non return flap' checkbox (unchecked) and a 'Controlled through Real Time Control' checkbox (checked). Below this is a 'Controlled' button. The 'Control data' section contains four input fields: 'Max level' (1,43 [m]), 'Min level' (0,43 [m]), 'Max speed up' (0,01), and 'Max speed down' (0,01).

Figure 8.8 Control data specific for orifices in the Orifices Editor Regulation Tab

### Max Level

The maximum elevation of the movable gate/weir.

### Min Level

The minimum elevation of the movable gate/weir.

### Max Speed Up

The maximum velocity for movement of the gate/weir in upward direction.

### Max Speed Down

The maximum velocity for movement of the gate/weir in downward direction.

## Difference between weir and weir in orifice

It is possible to define weirs in two different ways. One way is through the 'Weir' dialog, which we will refer to as an 'ordinary weir'. The second way is to use the combination of an orifice and the controllable device type 'Weir in rectangular orifice'.

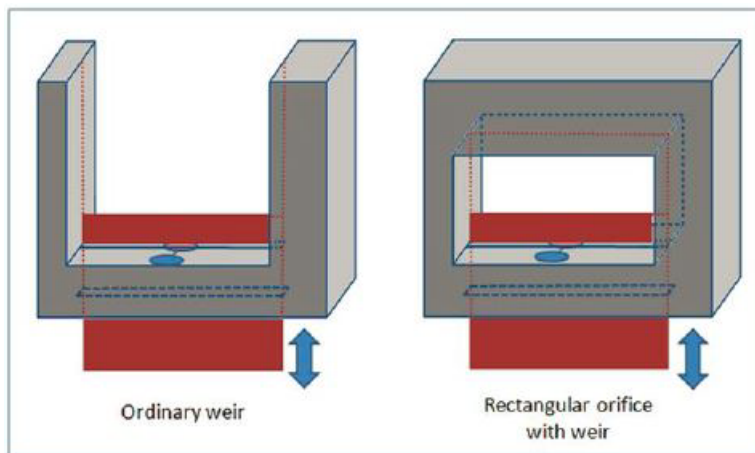


Figure 8.9 Difference between ordinary weir and a weir in rectangular orifice

The main difference is that the 'Weir in rectangular orifice' can close the orifice completely while the ordinary weir is always open upwards. It has no ceiling and in principle the flow can always pass over the weir if the water level is higher than the weir crest level.

For the 'Weir in rectangular orifice', once the weir fully closes the orifice then no flow will pass the weir even if the water level is above the crest level.

### 8.5.3 Actions

A control Action is a functional relation between input from one or two sensors and the setpoint or the setting for the controlled device.

Actions are defined in the Actions dialog located on the right side of the RTC Settings editor. Additional parameters for Actions must be defined depending on the Action Control Type specified.

Identification

ID

Insert

Delete

Action

Control type

Input

Set point

PID parameters

RTC Actions

ID	Control type	Start Level
1	PumpControlPID	PID control
2	WeirControlPID	PID control
3	PumpControlDirect	Set start and stop Levels
4	WeirControlDirect	Set weir Level

Figure 8.10 The Actions dialog on the RTC Settings Editor

An overview of the Action dialog parameter attributes is shown in Table 8.3 below.

Table 8.3 Overview of the Actions dialog attributes (Table msm\_RTCAction)

Edit field	Description	Used or required by simulations	Field name in data structure
ID	Unique ID for the Action used to access the action from other dialogs	Yes	MUID
Control Type	The Action type	Yes	ControlTypeNo
Start Level	Pump start level	Yes If Control Type = Set start and stop levels	StartLevel



Table 8.3 Overview of the Actions dialog attributes (Table msm\_RTCAction)

Edit field	Description	Used or required by simulations	Field name in data structure
Stop Level	Pump stop level	Yes If Control Type = Set start and stop levels	StopLevel
Input	The parameter to control (at the Set-point location)	Yes If Control Type = PID Control	PIDInput
Setpoint	Target value for PID-controlled parameter	Yes If Control Type = PID Control	PIDSetPoint
PID Parameters	Parameters for PID control action	Yes If Control Type = PID Control	PID
Weir Level	Desired weir blade edge level	Yes If Control Type = Set weir level	WeirLevel
Position	Desired gate blade edge level	Yes If Control Type = Set gate position	GatePosition
Opening	Desired % valve opening	Yes If Control Type = Set valve opening	ValveOpening

### Control Type

This field holds information on the type of control the Action describes, as well as the applicability of the action with respect to a device type. For example, a 'Set valve opening' Action would be related to a controllable valve.

The available control Action types are:

- Direct setting:
  - Set start and stop levels
  - Set weir level
  - Set gate position
  - Open
  - Close
  - Set valve opening
- PID control (at a setpoint)

If a direct setting is used, the action specifies information on e.g. start- and stop levels for pumps, or the wanted position for gates or weirs. If PID control is applied, the action specifies a setpoint (for flow or level) anywhere in the system.



## Input

For a PID control action, the Input parameter is the parameter being evaluated against the setpoint (i.e. target) value at the setpoint for the controlled device.

The Expression editor may be used to define the Input. Note that a Double data type is expected from the evaluation of the input expression.

The input may involve two sensors e.g. if the flow is regulated as a function of the difference between two level sensor values.

## Setpoint

The setpoint value (i.e. target) for a PID control action. The Expression editor may be used to define the Setpoint. Note that a Double data type is expected from the evaluation of the setpoint expression.

A functional relation may also be defined under 'Setpoint'. The functional relation (i.e. of type RTC or RTC Time) should first be defined on the Curves and Relations editor (Tables | Curves and Relations) (see Tables Chapter in this User Guide for more details on Curves and Relations).

Identification

ID: WeirControlPID

Insert

Delete

Action

Control type: PID control

Input: [Level\_12]

Set point: TableLookup('a:WeirControlPID\_onWeir\_Weir\_12\_'

PID parameters: Standard\_Weir\_up\_up

RTC Actions

	ID	Control type	Start Level	Stop Level	Parameters ID	PID input
▶ 1	WeirControlPID	PID control			Standard_Weir_up_up	[Level_12]

Figure 8.11 Example PID Control Action

In this example, the weir level (at Weir\_12\_3) shall be modified by controlling the water level at setpoint location [Level\_12] (see Figure 8.12).





Control of the water level at [Level\_12] shall be according to the RTC lookup table (a:WeirControlDirect\_onWeir\_Weir\_12a\_3) (see Figure 8.13). The lookup table provides corresponding setpoint values for [Level\_12] according to water level readings at another reference sensor [Level\_A] (Figure 8.13). The TableLookup function syntax for the expression is TableLookup ('Table MUID',reference sensor).

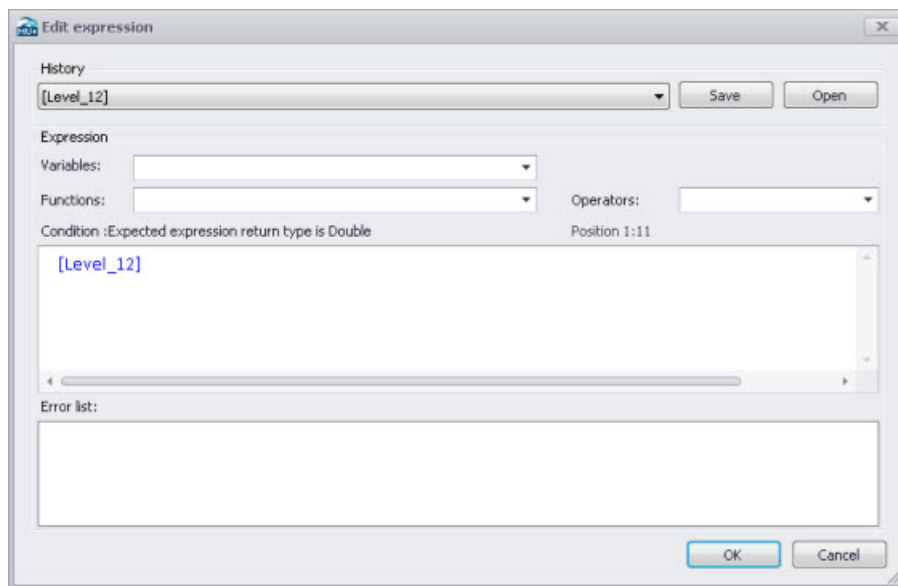


Figure 8.12 Example Input expression in Expression Editor

Initially, one may start with the Variables dropdown menu in the Expression editor when building expressions for Input. The Variables dropdown offers predefined variables, such as Sensors.

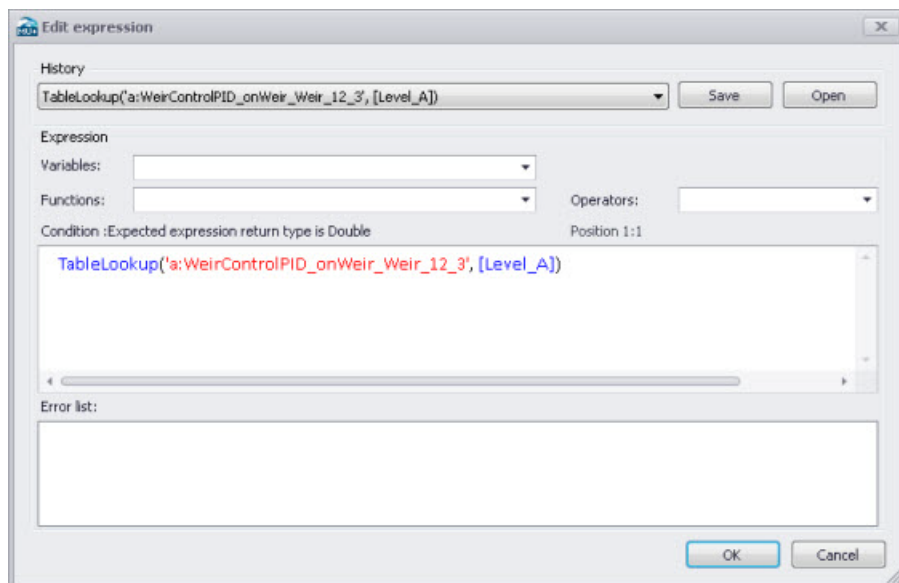


Figure 8.13 Example Setpoint expression in Expression Editor

Functions and Operators may also be used to define more complex expressions for both Input (e.g. difference between 2 sensors) and Setpoint (e.g. TableLookup).

## 8.5.4 Rules

Control rules are specified in the Rules tab on the RTC Settings editor.

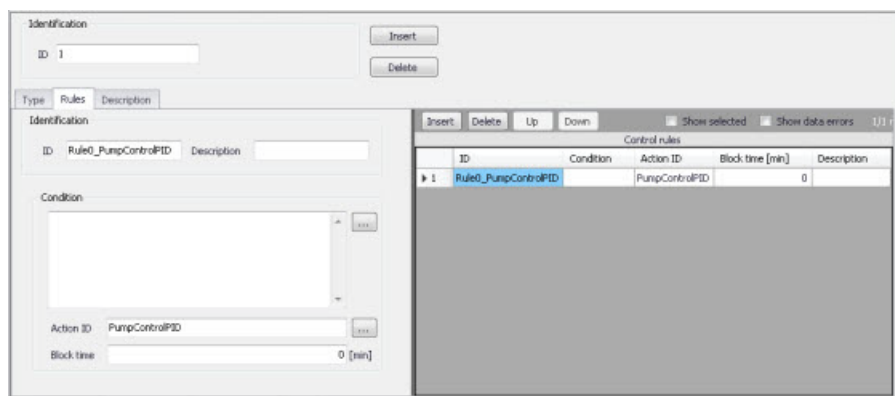


Figure 8.14 The Rules Tab on the RTC Settings Editor

An overview of the Rules tab parameters is shown in Table 8.4.



Table 8.4 Overview of the Rules Tab attributes in the RTC Settings editor (Table msm\_RTCRule)

Edit field	Description	Used or required by simulations	Field name in data structure
ID	Unique identifier for the rule	Yes	MUID
Description	Free text description	Optional	Description
Condition	Input box for the Condition Expression	Yes	Condition
Action ID	Id of the Action item corresponding to a Condition for a control rule	Yes	ActionID
Block Time	The period over which the system is locked to a certain rule after it is activated	Yes	BlockTime
Control Rules secondary grid	Table listing control rules made up of Condition-Action combinations	Yes	-

### Control rules secondary grid

Create rules for a device under the Control Rules secondary grid in the Rules tab (Figure 8.15). Add a new rule using the 'Insert' button above the table.

Insert		Delete		Up		Down		<input type="checkbox"/> Show selected		<input type="checkbox"/> Show data errors		1/1	
Control rules													
	ID	Condition		Action ID		Block time [min]		Description					
▶ 1	Rule0_PumpControlPID			PumpControlPID		0							

Figure 8.15 The Control Rules secondary grid in the Rules tab

Rules are combinations of Conditions and Actions.

Any number of rules can be specified to control the device. The statements are sequentially evaluated starting from the top. This means that appropriate sequence of rules is essential for the achievement of the desired control logic.

Use the 'Up' and 'Down' buttons above the secondary grid to modify the order of the Rules.

Evaluation of a logical condition belonging to a rule as 'TRUE', leads to the selection of the specified control action. If a logical conditions is 'FALSE', the evaluation proceeds to the next rule on the list.

If no logical condition is specified, the rule is unconditionally evaluated as 'TRUE'. This implies that the last rule in the sequence must not include any logical conditions in order to ensure a selection of a 'Default' control action if all specified conditions are found 'FALSE'.

### Condition

A logical condition demarcates the boundaries of a certain operational situation in the controlled system. This frame consists of an arbitrary number of independent logical tests on the various operational variables, where the relation of the actual value (or state) of the variable (provided by a sensor) is tested against the specified threshold (limit) value (or state). The individual tests are evaluated as TRUE or FALSE, with the outcome depending on the actual variable value (or state), the threshold and the specified operator.

A condition is specified as a mathematical expression in the Condition input box in the editor (Figure 8.16).

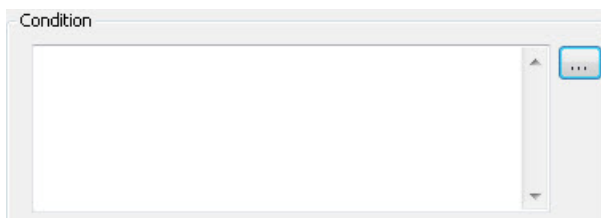


Figure 8.16 The Condition input box in the Rules Tab

The implementation of mathematical expressions in MIKE URBAN+ is very general, supporting a comprehensive set of mathematical functions and operators. Click on the ellipsis button to the right of the Condition input box to launch the Expression editor.

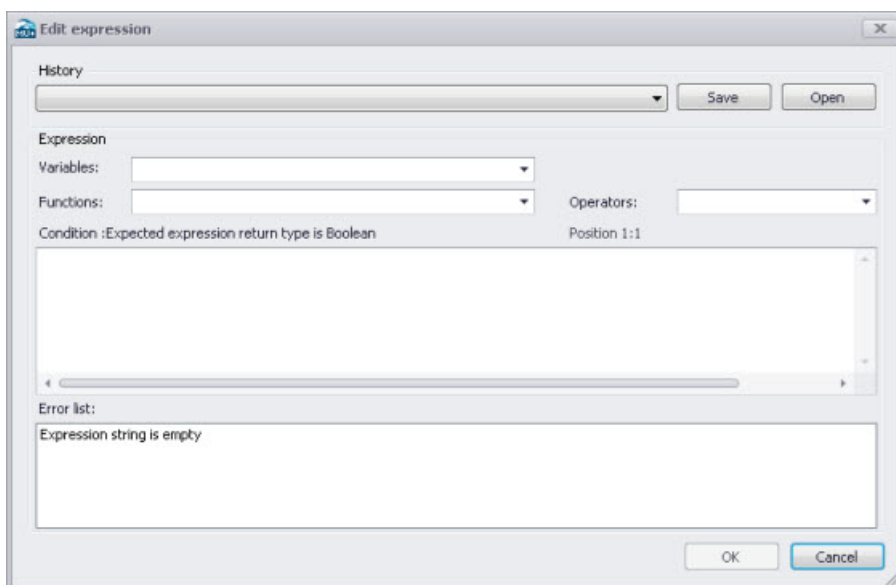


Figure 8.17 The Expression Editor

Mathematical expressions are formulas or expressions trees. The formulas support the standard mathematical functions like sine, cosine, abs, power etc. On top of these standard mathematical functions, a number of specific MIKE 1D engine control functions are available.

Note that a Boolean data type (i.e. TRUE, FALSE) is expected from the evaluation of the expression for Conditions.

### Action ID

The corresponding control Action for a given Condition. Options are taken from the Action dialog on the right side of the RTC Settings editor. The choice of the controllable device determines relevant control actions.

### Block Time

The Block Time ensures that a certain rule is applied for a minimum period. This means that the system is locked to a certain rule in a period equal to the block time after it is activated.

Some notes when specifying rules are:

- All control actions used to control a specific device must be of the same function type – corresponding to the specified device Type and Control Type.
- For PID control, all control actions must refer to the same setpoint sensor (i.e. Input). Changing the setpoint sensor during simulation is not allowed.
- For time dependent control (Setpoint = RTC Time lookup table) only ONE rule can be specified. The menu allows more rules to be inserted, but only the first one will be used during the simulation.
- When starting a simulation, the system checks if these conditions are fulfilled and in the case of any violation, the simulation will not start.

## 8.5.5 Description

One may include a description of RTC settings items in the Description tab of the editor. An image file (e.g. of the controlled device) may also be added using the 'Add picture' button.

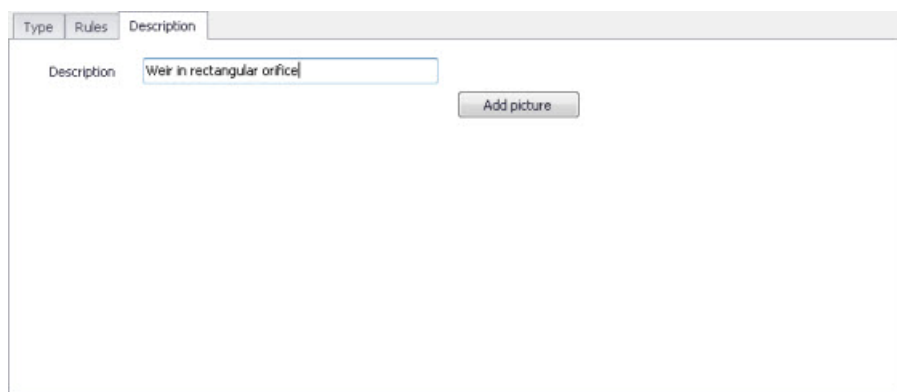


Figure 8.18 The Description Tab in the RTC Settings Editor



## 8.6 PID Settings

This editor is used to define the functions for PID (Proportional Integral Differential) control. RTC includes the possibilities for PID control of weirs, gates, pumps, and valves. Independently of the choice of the controlled variable, the PID algorithm adjusts the settings of the regulator according to the current error between the specified setpoint and the actual value of the controlled variable.

The following settings/outputs can be used as means of flow control:

- Weirs: weir crest level setting
- Gates: level of the bottom lip of the gate setting
- Pumps: pump discharge
- Valves: opening of the valve

A single PID set can be used to regulate any of these parameters.

ID	Proportionality [()]	Integration [h]	Derivation [h]	Alpha 1	Alpha 2	Alpha 3
1 Standard_Pump_up_up	1	0,08333333	0,000222222	1	1	1
2 Standard_Pump_up_down	-1	0,08333333	0,000222222	1	1	1
3 Standard_Weir_up_up	1	0,08333333	0,000222222	1	0,7	1
4 Standard_Weir_up_down	-1	0,08333333	0,000222222	1	0,7	1
5 Standard_Gate_up_up	1	0,08333333	0,000222222	1	0,7	1
6 Standard_Gate_up_down	-1	0,08333333	0,000222222	1	0,7	1

Figure 8.19 The PID Settings Editor

### ID

Each set of PID settings is identified with a unique ID. This is how the PID parameter set is accessed from other dialogs.

### Proportionality Factor, Integration Time, and Derivation Time

The 3 main parameters for the PID control. These parameters are further discussed in Section 8.6.1 below.



### Alpha-1, Alpha-2 and Alpha-3

Weighting factors for time level  $n$ ,  $n-1$  and  $n-2$ . These parameters are further discussed in Section 8.6.1 below.

## 8.6.1 Calibration of the PID Constants

Tuning of the PID constants ( $T_i$ ,  $T_d$  and  $K$ ) is not a straightforward task. Understanding the theoretical background and the numerical solution of the control equation would be beneficial in this process.

The following values may be used as a guide:

### Typical values of the PID constants and weighting factors

Table 8.5 below shows suggestions for initial values for PID constants.

Table 8.5 Summary of typical values for PID constants and weighing factors

Parameters	Pumps	Gates	Weirs
$T_i$	300 sec.		
$T_d$	0.8 sec.		
$K$ (Setpoint downstream of device)	1	1	-1
$K$ (Setpoint upstream of device)	-1	-1	1
Alpha-1	1	1	1
Alpha-2	1	0.7	0.7
Alpha-3	1	1	1

NOTE: The sign on the  $K$ -factor is very important. If it is wrong it will cause the control function not to work at all since the device will typically move to one of the extreme positions and stay there until the end of the simulation.

Figure 8.20 to Figure 8.22 show examples of how the actual variable (flow or water level) can fluctuate around the setpoint as a consequence of PID constants values. Each figure has three different graphs depending on whether the constant is too high, too low, or adequate.



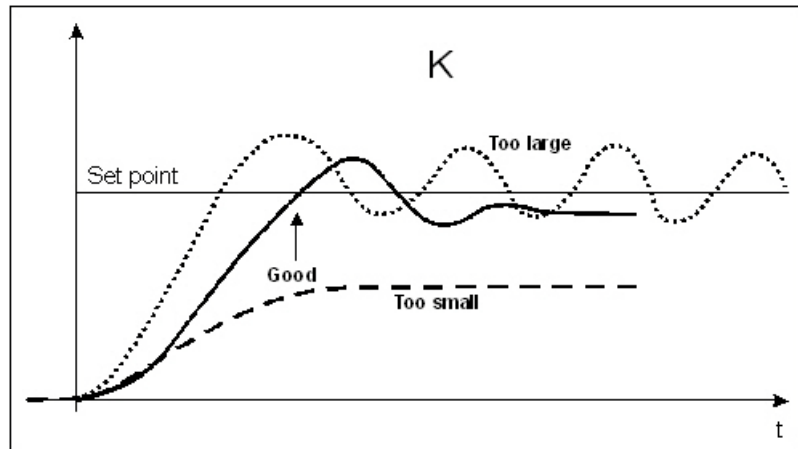


Figure 8.20 Fluctuations around the setpoint depending on the size of the proportionality factor,  $K$

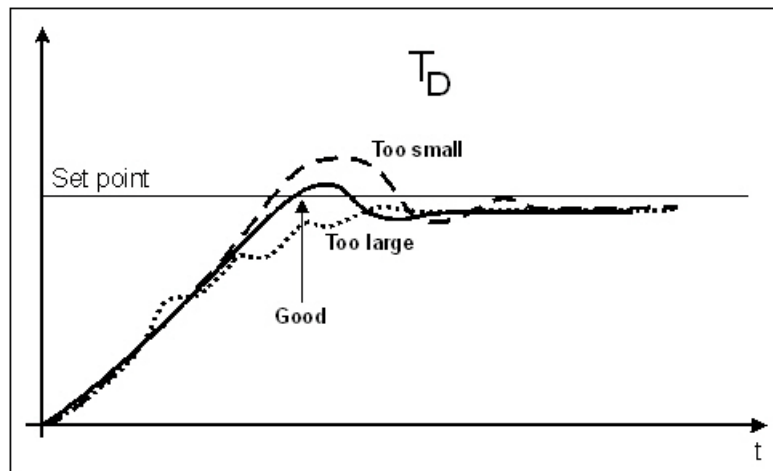


Figure 8.21 Fluctuations around the setpoint depending on the size of the derivation time,  $T_D$

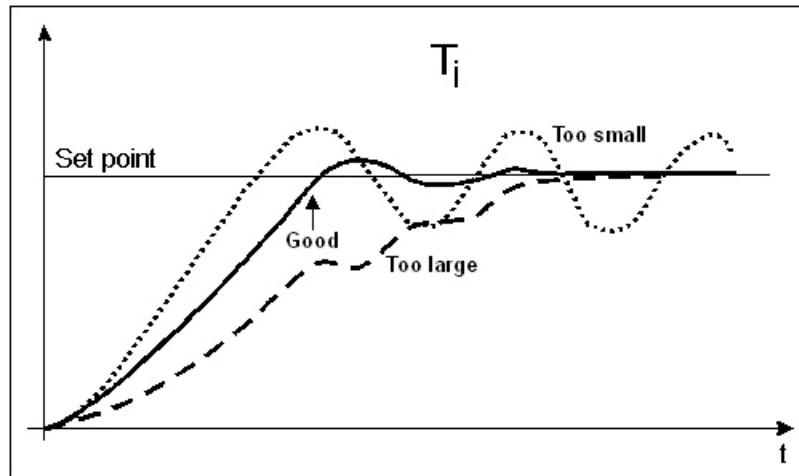


Figure 8.22 Fluctuations around the setpoint depending on the size of the integration time,  $T_i$



## 8.7 RTC Computations

An RTC simulation is started from the usual Simulation Setup editor (Simulation Specifications | Simulation Setup).

RTC computations are performed if the 'Real time control (RTC)' module is active on the Modules editor (General Settings | Modules) (Figure 8.23.).

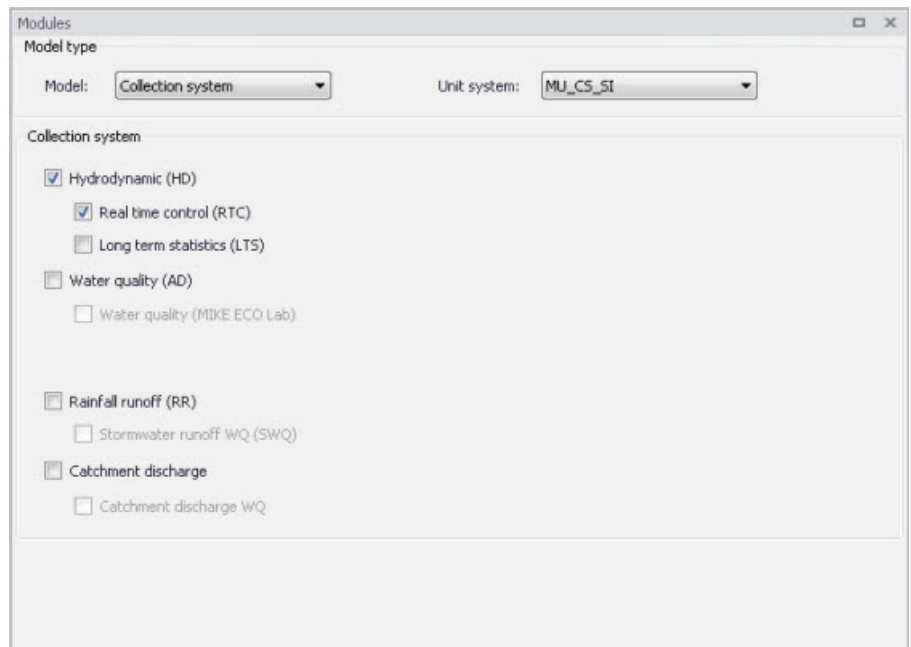


Figure 8.23 Activate the Real Time Control (RTC) module on the Modules Editor



## 9 Long-Term Statistics (LTS)

The Long-Term Statistics (LTS) module performs a time-efficient simulation of wastewater collection and urban drainage systems exposed to intermittent hydrological inputs over long, continuous historical periods and the computation of relevant statistics for the operational variables (instantaneous and accumulated) of interest.

LTS features an easy way to convert a usual simulation covering a long historical period (typically 10 - 30 years) into a discontinuous series of relevant hydrological events and to define various event-based and annual statistics for the selected variables. By these means, the long-term simulation becomes feasible even for large models, as both the simulation time and the amount of the generated output data gets significantly reduced, compared to a continuous simulation over the same historical period.

Based on the specified criteria, the system automatically selects the periods for dynamic pipe flow simulations during wet weather. This reduces the simulation time significantly, while preserving the accuracy in the simulation of relevant dynamic effects in the system - CSOs, surcharges, pollution emissions, etc.

Running LTS simulations with the existing drainage system configuration and with the planned upgrades, impacts of the planned investments (e.g. new sewers, retention tanks, control schemes) on system performance can be reliably tested and evaluated based on the computed operational statistics.

This allows the user to diagnose the current operation of the system and to develop the optimal rehabilitation/upgrade strategy, e.g. for satisfying the requirements of environmental regulations.

Statistics on maximum water levels, discharges from weirs, pollution emissions, etc. generated by simulating long continuous periods subject to impact of recorded historical rainfalls is particularly useful for the evaluation of the simulated system functionality. Statistics are used to compare the effects of various mitigation measures in the planned rehabilitation process, the performance of various control strategies, the cost-benefit efficiency of the planned investments, as well as to determine whether the functionality of the sewer system is compliant with legislative requirements.

The functionality of urban drainage systems is often subject to requirements like:

- Flooding on terrain must not happen more frequently than once in every T-years.
- Flooding of basements must not happen more frequently than once in every T-years.



- Discharge from CSO weirs to receiving waters must not happen more frequently than  $n$  times per year.
- Total volume from CSOs must not exceed a certain threshold amount per year.

LTS answers these and other similar questions and is thereby an essential simulation tool for reliable assessment of drainage system performance.

Statistics on some operational variables are only reliable if the simulated number of independent events is sufficiently large, i.e. if the simulated historical period is sufficiently long. This, in turn, may imply very long simulation times (if 'normal' computing hardware is applied) and thereby spoil the feasibility of the analysis.

However, use of dynamic simulation for the hydraulic and pollution transport analysis of drainage networks is only beneficial in periods of high-flow dynamics. Otherwise, simpler and much faster simulation tools can be used with a similar level of accuracy. Since high-flow dynamics in urban drainage networks are normally associated with rainfall events, the dynamically simulated periods can be reduced to include wet weather periods only, i.e. only a few percent of the historical period included in the analysis.

The fundamental principle behind the LTS concept is therefore the ability to reduce the simulation time without losing significant information. LTS can, based on the user-specified criteria, eliminate the irrelevant periods from the simulated series and to limit the dynamic simulations to a series of disconnected events instead of the entire simulation period.

## 9.1 Data Input

### 9.1.1 LTS Job List

LTS Job list specifies intervals within the LTS simulation period that are relevant for dynamic network simulation. Duration of each job (i.e. simulation event) is defined by its START time and END time.

A job list is generated by the LTS computational engine on the basis of model setup and boundary files, the simulation period (specified in the Simulation Setup Editor, General Tab), optionally the LTS initiation hot start file(s) and user-specified job list criteria.

The job list is written into an ASCII file, recognizable by the extension \*.JLF.

The job list file includes the following information:

- General information on the actual simulation setup
- List of relevant boundary conditions



- Overview over job list criteria
- Job list events, defined by
  - Start time
  - End time
  - Hot start file name and hot start time
  - Triggering job list criteria
- Job List Summary

### 9.1.2 Job List Criteria

Job list criteria are defined as hydraulic loads thresholds on the network, including dry weather flow (i.e. wastewater), rainfall and other loads, with the purpose of identifying and delimiting wet weather periods relevant for dynamic (network) simulation. Each job list criterion consist of a job START criterion and a job STOP criterion.

Job START criterion selects rainfall events to be included in the LTS job list, by comparing the inflow generated by all hydraulic loads to the specified part of the model (location) with the specified start-threshold value: if the threshold is exceeded continuously for at least the specified duration, the event is included in the job list. The simulation event start time is set at exactly the beginning of the identified rainfall event.

The location can be specified as an individual node, part of the system defined by a selection list or the system as the whole (General).

The START threshold value should be specified as an estimate of the hydraulic load peak just below the load that is likely to cause the operational effects of interest (e.g. overflows, inundations, activation of retention basins, etc.). By these means, many small, potentially irrelevant rainfall events are eliminated from the LTS simulation, making it feasible and time-efficient. Anyway, the specified threshold should be set sufficiently low to ensure that none of the relevant events is omitted from the simulation.

"Duration" is included in the evaluation to avoid inclusion of very short events that, despite a relatively high peak, are not likely to cause significant hydraulic effects in the system.

If multiple job list criteria are specified and activated, at least one active START criterion must be fulfilled for the event to be included in the job list.

Job STOP criterion defines the anticipated end of dynamic simulation (i.e. end-time of the simulation event). The end-time is set by comparing the inflow generated by all hydraulic loads to the specified part of the model with the specified end-threshold value: simulation end-time is set at the time when the load falls below the specified threshold and remains lower than the threshold continuously for at least the specified duration.



The simulation event end time may be extended by (optional) runtime stop criteria.

"Duration" ensures that very short drops in inflow are ignored, i.e. that the inflow load has definitely dropped below the threshold. Also, appropriately set "duration" may secure that the time offset between the actual hydraulic load and its effects in the system is included in the dynamic simulation. In the large systems including significant volumes, this offset may be quite long (e.g. emptying of a large retention basin may take many hours or even days). In such cases, instead of attempting to capture this by setting a long duration for the job list stop criterium, runtime criteria should be applied.

If multiple job list criteria are specified and activated, all active STOP criteria must be fulfilled at the simulation event end-time.

Figure 9.1 The Job List Criteria Editor.  
LTS simulation requires definition of at least one set of job list criteria

Table 9.1 Job List Criteria editor attributes (Table msm\_LTSJobListCriteria)

Edit field	Description	Used or required by simulation	Field name in data structure
ID	Job list criteria identifier. Up to 40 characters and case sensitive.	Yes	MUID
Type	Controls the type of criterion to be specified. In this version only "Total Inflow" can be selected	Yes	ConditionNo





Table 9.1 Job List Criteria editor attributes (Table msm\_LTSJobListCriteria)

Edit field	Description	Used or required by simulation	Field name in data structure
Apply checkbox	Checkbox for activating or deactivating a Job list criteria	Yes	ApplyNo
Location Type	For the criteria of type 'Total Inflow', it must be specified for which part of the system the inflow must be evaluated. 'Location type' can be: 'General' (the whole system), 'List' (a list of elements), or 'Individual' (a single node)	Yes	LocationNo
Location	For the types 'List' and 'Individual', additional information must be specified in the 'Location' field. For the 'List', a Selection List must be specified. For 'Individual', a single node name must be types or selected from the node list.	Yes, except LocationNo=1 (General)	LocationID
Job Start Threshold	Defines the threshold that must be exceeded in order to evaluate the job start criterion as true.	Yes	StartValue



Table 9.1 Job List Criteria editor attributes (Table msm\_LTSJobListCriteria)

Edit field	Description	Used or required by simulation	Field name in data structure
Job Start Duration	Criteria of type 'Total Inflow' can optionally be extended by specifying the duration of a continuous period in which the threshold must be exceeded in order to evaluate the criterion as true. The Default duration is zero.	Yes	StartTime
Job Stop Threshold	Defines the lower threshold that must be achieved in order to evaluate the job stop criterion as true.	Yes	StopValue
Job Stop Duration	Specifies the duration of a continuous period in which the stopping threshold must be fulfilled in order to evaluate the stop criterion as true. The Default duration is zero.	Yes	StopTime

### 9.1.3 Initial Conditions for Simulated Events

Appropriate initial conditions for the individual LTS simulation events are essential for achieving realistic statistics in hydrodynamic LTS simulations.

LTS provides two different methods for initializing the network model: The network model can either be initialized in an empty state before each job (Default), or a set of hot start files can be provided. If the latter option is used, then the specific hot start file used for a simulation event is selected based on the actual hydrological inflow to the system at the start of the event.

When applying the 'Empty system' method, the model will for all simulated events be initiated as empty, similarly as in a normal network simulation without hot start. This option is valid only for storm drainage systems where there is no water in the system during dry periods. It is not recommended to use this option in any other situation.



The method with hot start accounts for the correct initial conditions related both to the amount of infiltration and DWF load at the simulation event start time.

If a set of hot start files is provided, each hot start file must be associated with an inflow interval for total hydrological inflows. This interval is the "validity interval", meaning that the specified hot start file is valid (i.e. the file will be used) for all simulation events in the Job List where the total hydrological inflow (i.e. inflow generated by any of the hydrological models) to the network at the beginning of the actual simulation event is within that interval.

Note that for the surface runoff models, the hydrological inflows will be zero at the beginning of the simulation event in most cases. This implies that correct initial conditions may be achieved with only one hot start file, covering any possible inflow, defined as the inflow interval including zero inflow (e.g. from 0 m<sup>3</sup>/s to 10 m<sup>3</sup>/s). This hot start file is created by simulating the system loaded by any recurring (typically wastewater) loads, over at least one day.

In model setups including continuous hydrological models (RDI), multiple hot start files are needed in order to cover different infiltration levels that may occur at the start of a simulation event. E.g. if it is known that infiltration may vary between zero and 2 m<sup>3</sup>/s, a set of 4 hot start files may be prepared, covering the following infiltration intervals: 0 -> 0.5 m<sup>3</sup>/s, 0.5 -> 1.0 m<sup>3</sup>/s, 1.0 -> 1.5 m<sup>3</sup>/s, 1.5 -> 2.0 m<sup>3</sup>/s. These files are created by simulating the system loaded by any recurring (typically wastewater) loads and constant infiltration loads of 0.25 m<sup>3</sup>/s, 0.75 m<sup>3</sup>/s, 1.25 m<sup>3</sup>/s and 1.75 m<sup>3</sup>/s, over at least one day. The infiltration loads should be distributed proportionally to the catchment area.

If the total inflow to the system at the beginning of job is outside of all specified validity intervals provided for the hot start files, the system will be initialized with the hot start file that is the closest to the actual inflow.

In order to account for diurnal inflow variations, the time-of-day at which the values from the hot start file should be used is set equal to the simulation event start time. However, the hot start date must be provided by the user. This is because the hot start file may cover two or more days, including the system filling phase. The date specified for the hot start must relate to the day following the completion of the filling phase.



Figure 9.2 Initial Conditions Editor

Table 9.2 Initial Conditions editor attributes (Table msm\_LTSInit)

Edit field	Description	Used or required by simulation	Field name in data structure
Empty System/Use Hotstart radio button	Radio buttons for selecting the initial conditions mode	Yes	-
Hotstart File	Specifies a hot start file to be used for the system initialization in association with the specified range of total inflows (excluding DWF) detected at the beginning of certain job.	Yes, if Hotstart	HotStartFilename
From	Defines a lower threshold for total inflow intervals (excluding DWF) used at the start of each job in the Job List to evaluate what hot start parameters to use.	Yes, if Hotstart	InitFrom



Table 9.2 Initial Conditions editor attributes (Table msm\_LTSInit)

Edit field	Description	Used or required by simulation	Field name in data structure
To	Defines an upper threshold for total inflow intervals (excluding DWF) used at the start of each job in the Job List to evaluate what hot start parameters to use.	Yes, if Hotstart	InitTo
Date	Specifies the date in the hot start file to be used in the search for the hot start conditions associated with the specified range of total inflows (excluding DWF) detected at the beginning of a job.	Yes, if Hotstart	InitDate

#### 9.1.4 Generating and editing Job Lists

A Job List is created based on the Job List Criteria, simulation input files, simulation period (specified in the Simulation Setup Editor, General Tab) and, optionally, the LTS initiation hot start file.

A Job List is created using the Create Job List function in the Simulation Setup Editor (Simulation Setup | LTS Tab).

The simulation periods for individual events in the resulting Job List represent the minimum simulation time (i.e. preliminary), which may be extended during run time when evaluating the Run Time Criteria.



	ID	Scenario	Active Project	Catchments	Runoff(RR)	Stormwater runoff WQ (SWQ)	Catchment
1	Simulation_15	Base	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
2	Rainfall_CDS_1_year	Base	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	

Figure 9.3 Generate Job List option in the Simulation Setup Editor LTS Tab

There is no dedicated dialog available for reviewing and editing job list files. Instead, Windows Notepad is used. Alternatively, any ASCII editor can be used.



```

Sirius_LTSfeature_1_CD0001_area2Base.MJL - Notepad
File Edit Format View Help
// Created      : 2019-09-5 10:9:54
// DLL          : C:\Program Files (x86)\DHI\MIKE URBAN\2019\bin\x64\pfs2004.DLL
// Version      : 18.0.0.13246

[MIKE1D_JOB_LIST]
[SIMULATION_SETUP]
  Simulation_ID = 'Sirius_LTSfeature_1_CD0001_area2'
  Scenario_ID = 'Base'
  Simulation_start = 1933, 7, 22, 16, 31, 0
  Simulation_end = 1934, 5, 19, 14, 50, 0
  Live_catchments = true
EndSect // SIMULATION_SETUP

[BOUNDARY_CONDITIONS]
  Catchment_source_boundaries = 'Catch_discharge'
  Global_source_boundaries = 'Rainfall'
EndSect // BOUNDARY_CONDITIONS

[LTS_SETUP]
[INITIAL_CONDITIONS]
  Hotstart1 = 'Hot_startLTSBase.res1d', 0.005, 0.01, '2019-01-01 00:00:00'
EndSect // INITIAL_CONDITIONS

[JOB_START_CRITERIA]
  JL_Criterium_2 = 0.1, '00:05:00', 'SingleNode'
  JL_Criterium_1 = 0.15, '00:03:00', 'SingleNode'
EndSect // JOB_START_CRITERIA

[JOB_STOP_CRITERIA]
  JL_Criterium_2 = 0.02, '00:10:00', 'SingleNode'
  JL_Criterium_1 = 0.02, '00:10:00', 'SingleNode'
EndSect // JOB_STOP_CRITERIA

EndSect // LTS_SETUP

[SIMULATION_EVENT]
  Simulation_start = '1933-07-22 16:31:00'
  Simulation_end = '1933-07-22 18:49:00'
  Simulation_end_no_duration = '1933-07-22 18:39:00'
  Hotstart_file = 'Hot_startLTSBase.res1d'
  Hotstart_time = '2019-01-01 16:31:00'
  Hotstart_hydrological_inflow = 0.0
  Duration = '02:18:00'
  Job_number = 1
  Job_start_criterion = 'JL_Criterium_1'
  Job_stop_criterion = 'JL_Criterium_2'
EndSect // SIMULATION_EVENT

[SIMULATION_EVENT]

```

Figure 9.4 Example Job List file

Optionally, the Job List file can be edited before starting the LTS calculation.

A job list file includes several info sections:

- SIMULATION\_SETUP
- BOUNDARY\_CONDITIONS
- LTS\_SETUP



- SUMMARY

Actual simulation events are defined in sections "SIMULATION\_EVENT" (one section for each event). See example:

```
[SIMULATION_EVENT]
  Simulation_sTart = '1933-07-22 16:31:00'
  Simulation_end = '1933-07-22 18:49:00'
  Simulation_end_no_duration = '1933-07-22 18:39:00'
  Hotstart_file = 'Hot_startLTSBase.resld'
  Hotstart_time = '2019-01-01 16:31:00'
  Hotstart_hydrological_inflow = 0.0
  Duration = '02:18:00'
  Job_number = 1
  Job_start_criterion = 'JL_Criterium_1'
  Job_stop_criterion = 'JL_Criterium_2'
  DtMin = 10.0
  DtMax = 10.0
EndSect // SIMULATION_EVENT
```

Some of the parameters in the simulation event definition may be edited:

**Simulation\_start:** defines start time of the simulation event,

**Simulation\_end:** defines end time of the simulation event,

**Simulation\_end\_no\_duration:** defines end time of the simulation event, without "duration". This is of relevance when run-time criteria are included, i.e. defines the time when evaluation of run-time criteria commences.

**Hotstart\_file:** name of the hot start file for the actual simulation event

**Hotstart\_time:** hot start time for the actual simulation event

**DtMin:** minimum time step [s] for network simulation in the actual simulation event

**DtMax:** maximum time step [s] for network simulation in the actual simulation event

The remaining parameters are for information only, and editing would not affect the simulation.

### 9.1.5 Run Time Stop Criteria

The simulation event end time may optionally be subject to further evaluation and possible extension by a set of Run Time Criteria during the simulation.





Run time Criteria are founded on the evaluation of the operational variables within the network itself, which can potentially extend the simulation beyond the end time defined in the Job List. Since the Run Time Criteria are evaluated during the simulation, it is not possible to determine the exact duration of the dynamic simulation in advance.

LTS Run Time Stop Criteria define threshold values to be evaluated during computations (i.e. run time) in order to determine the earliest time at which the simulation can be stopped without missing important information in the closing phase of the simulated event. This may include e.g. emptying of retention basins and, generally, return of the system to dry weather situation.

The following types of Run Time Stop criteria are available:

- **Outflow - Inflow**

The threshold value represents an absolute value of a difference between the total inflow into the system and the total outflow from the system. During rain events, this difference is relatively big due to the dynamic effects in the network: outflows are normally attenuated and delayed in the network. In dry weather, this difference is typically very small and relates to the attenuation and transport time of diurnally varying wastewater loads.

This criteria is defined for the entire system only (Location = General). It is used to identify return of the system to dry weather situation.

- **Outflow**

The threshold value represents outflow from the system at a specified location. The location can be specified as general, list and individual, separately for various types of outlets (outlets, pumps, weirs, orifices, valves).

This criterium can be used to identify return of the system to dry weather situation, end of overflow, end of pumping from a retention basin, etc.

- **Total volume**

The threshold value represents volume of water contained in the model elements specified as location. The location can be specified as general, list and individual.

Knowing the water volume in the specified location in dry weather situation, this criterium can be used to identify return of the system to dry weather situation, completed emptying of a basin, etc.

- **Filling degree**

The threshold value represents the filling degree (fraction of full system volume) of entire system.



This criterium can be used to identify return of the system to dry weather situation, end of overflow, etc.

- Depth

This threshold represents water depth in a node specified as location. If location is specified as List of nodes, then the highest depth in all included nodes is evaluated against the specified threshold.

This criterium can be used to identify completed emptying of a retention basin.

- Local flow

This threshold represents flow at a specified individual conduit (link) or structure (weir, orifice, pump, valve) anywhere in the system, i.e. not limited to outlets.

The "Duration", associated with each run time criteria, ensures that the criterium has been fulfilled continuously over the specified duration, and that it is not just a short instance in oscillating or varying variable.

The Run Time Stop Criteria for the event being simulated are evaluated throughout the simulation. As soon as some of run time criterium is fulfilled, the time counter for the specified duration is activated. The simulation will stop only after all active run time criteria are fulfilled, but never before the "Simulation\_end" time specified in the job list.

For better understanding, figures below illustrate possible situations.

In the depicted example, three active job list criteria are specified (JL1, JL2 and JL3), each with different "duration" parameter. During job list generation, the LTS engine has determined the simulation start time (equal for all three criteria, if the rainfall event exceeds the thresholds specified for all three criteria). Also, the simulation end times are determined for each criterium. The latest of the three "simulation end" times (JL2) is selected and written in the job list.

During the simulation, the three run time criteria (RT, RT2 and RT3) are continuously evaluated. Whenever one of the run time thresholds has been achieved, the duration counter for that criterium is activated. The simulation continues at least until the "simulation\_end". If at that time there are any run time criteria still not fulfilled (including the specified duration), the simulation will continue until all run time criteria are satisfied.

In example 1 (Figure 9.5), when the simulation reaches the "job list simulation end", the run time criterium RT2 is still not fulfilled for the specified "duration". Therefore, the simulation continues beyond the "job list simulation end" and stop only after RT2 criterium has been satisfied.



### EXAMPLE 1: RUNTIME CRITERIA EXTEND THE SIMULATION TIME

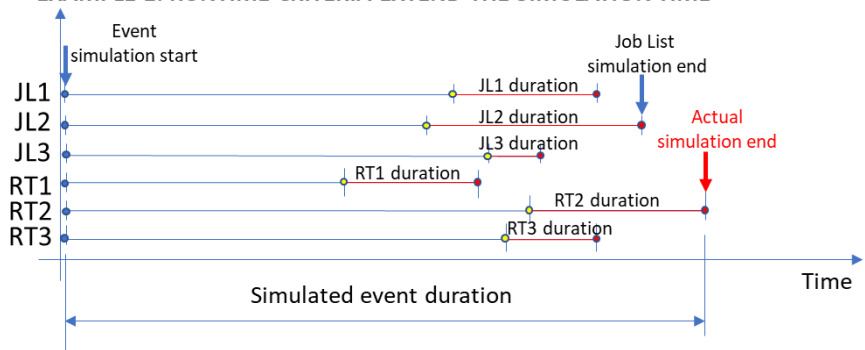


Figure 9.5 Run Time criterium RT2 extends the simulation end time determined by job list.

In example 2 (Figure 9.6), all the run time criteria (including duration) have been satisfied before the simulation reaches the "job list simulation end". Therefore, the simulation ends at the "job list simulation end".

### EXAMPLE 2: RUNTIME CRITERIA DO NOT EXTEND THE SIMULATION TIME

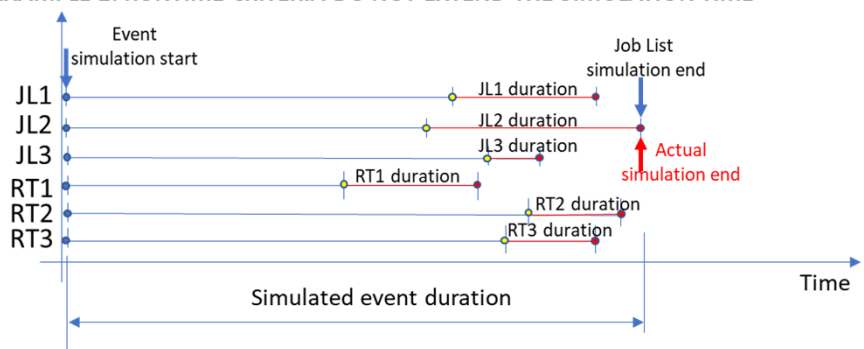


Figure 9.6 Run time criteria do not affect the "job list simulation end"



Run time stop criteria

Identification

ID:  Type:

☒ Apply

Location

Location type:  Location:  ...

Stop Criterium

Threshold:  [m<sup>3</sup>/s]  
Duration:  [h]

Insert  
Delete

ID:  ALL  ☐ Show selected ☐ Show data errors 1/1 rows, 0 :

	ID	Apply	Type	Location type	Location	Threshold	Duration [h]
▶ 1	Outlet	<input checked="" type="checkbox"/>	Outflow	General		0,05	0,01666667

Figure 9.7 The Run Time Stop Criteria Editor



Table 9.3 Run Time Stop Criteria database attributes (Table msm\_LTSTRunS)

Edit field	Description	Used or required by simulation	Field name in data structure
ID	Unique name for a Run Time Stop criterion Each criterion is identified with a unique identifier, which is used as a reference in the evaluation matrix.	Yes	MUID
Type	Controls the type of criterion to be specified: - Inflow-Outflow (difference between inflow and outflow), - Outflow (total outflow), - Total Volume (total volume stored in the system), - Filling degree (filling degree in the system), - Depth, - Local flow	Yes	ConditionNo
Apply checkbox	Checkbox for activating or deactivating a Run Time Stop Criteria set	Yes	ApplyNo



Table 9.3 Run Time Stop Criteria database attributes (Table msm\_LTSSRunS)

Edit field	Description	Used or required by simulation	Field name in data structure
Location Type	Defines for which part of the system the run time stop criteria must be evaluated. Location type can be: <ul style="list-style-type: none"><li>- General (the whole system),</li><li>- List (a list of elements),</li><li>- Node,</li><li>- Outlet,</li><li>- Weir,</li><li>- Orifice,</li><li>- Pump,</li><li>- Valve,</li><li>- Link</li></ul>	Yes	LocationNo
Location	For the 'List' Location Type, a Selection List must be specified. For individual element location types, a single element ID must be specified or selected from the element list.	Yes, Except for Location Type = General	LocationID
Threshold	The residual value of the variable defined by the 'Type' that must be achieved in order to evaluate the criterion as true	Yes	StopValue
Duration	A period in which the parameter value must be below the threshold in order to evaluate the criterion as true.	Yes	StopTime

### 9.1.6 LTS Global Parameters - Event Definitions

In terms of events statistics, MU+ LTS distinguishes events associated with extremes (maxima) of instantaneous variables (e.g. water level, discharge,



mass transport), and intermittent (i.e. discontinuous) events where accumulated values (e.g. volume, pollution mass) and durations are calculated.

In order to perform statistical analysis on extreme events (maxima), MU+ LTS analyses the respective time series and identifies independent extreme events. For instantaneous variables (e.g. water level, discharge, concentration, etc.), the event identification must consider time between consecutive extreme events and the "depth" of the local minima in order to eliminate dependent maxima and "noise" caused by numerical instabilities, a nearby pump action, etc. In other words, MU+ LTS applies two interevent criteria to identify independent extreme events:

1. Interevent time criterion  $dT_c$ : Two successive events (i.e. peak occurrences) are considered independent if the time between the two events is larger than  $dT_c$ . This parameter is considered for all statistics of instantaneous values, i.e. level, flow, velocity, and concentration.
2. Interevent level criterion  $p_c$  ( $0 < p_c < 1$ ): Two successive events are independent if the level between the events is smaller than  $p_c$  times the lower of the two events. This is a threshold for the ratio between the lowest minimum value between two peaks and the lower peak.

MU+ LTS considers two successive events as independent only if both criteria (1) and (2) are fulfilled. This means that two peaks are independent if the time between them is longer than  $dT_c$  AND if the lowest minimum between the two peaks is smaller than the value of the smaller peak multiplied with  $p_c$ .

Both for peak statistics and for accumulated flow statistics, two events are always considered as independent if the computation has been stopped in between by the specified stop criteria. Thus, specification of a very long  $dT$  - longer than any individual event to be simulated would result in the number of peak values and the number of accumulated discharges and duration corresponding exactly to the number of simulated events.

Each MU+ LTS simulation job contains at least one statistical event. In some cases, several events may be identified within one MU+ LTS Job.

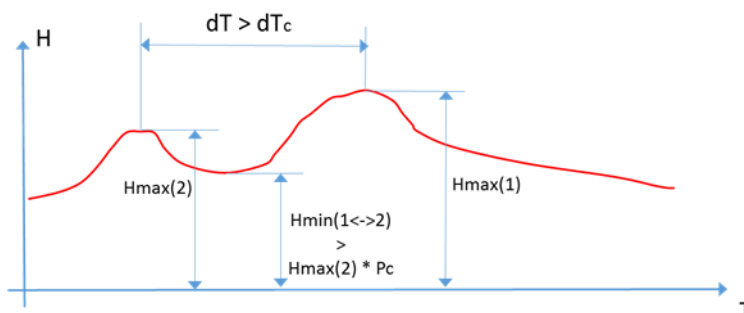
The interevent time criterion  $dT_c$  is user-specified through the LTS Global Parameters editor, separately for instantaneous (Q, H, v, C) and accumulated (V, T, M) values. The interevent level criterion  $p_c$  is also specified through the LTS Global Parameters editor.

Note that the default value 0.75 only removes "noise" of relatively small amplitude as well as prevents false extremes in case of a flat time series. Application of smaller values would reduce the number of identified independent events.

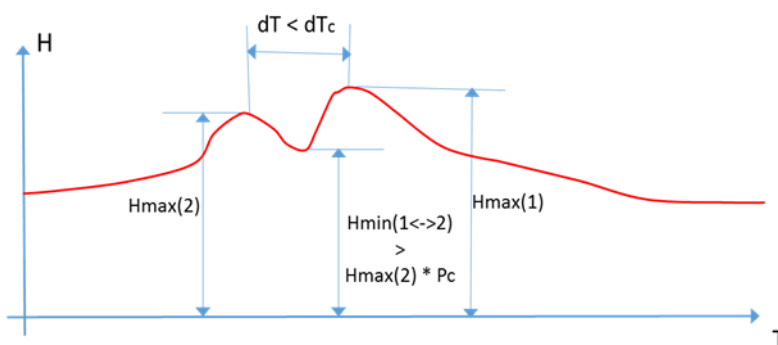
Note that for some variables (e.g. discharge) the specified  $p_c$  applies for the actual value of the variable. In other cases, e.g. water levels,  $p_c$  is applied on

local water depth, i.e. water level subtracted local invert level. In principle, all variables are offset so that the minimum possible local value is zero.

Definition of independent extreme events for instantaneous variables is illustrated in several examples below.



**Figure 9.8** The two water level (i.e. depth) peaks in the time series are grouped under one event. The higher of the two depth peaks is clearly one extreme event in the current simulation. The other peak ( $H_{max}(2)$ ) is also a candidate for extreme depth event, because it occurs before the highest peak longer than the specified  $dT_c$  criterion. But evaluation of the level criterion is negative - the "bottom" between the two peaks is higher than the specified criterion  $p_c$ . Therefore,  $H_{max}(2)$  is not considered a separate, independent event and is considered as belonging to the same event leading to the true peak  $H_{max}(1)$ .



**Figure 9.9** The two water level (i.e. depth) peaks in the time series are grouped under one event. The higher of the two peaks is clearly one extreme event in the current simulation. The other peak ( $H_{max}(2)$ ) is also a candidate for extreme depth event, but evaluation of both criteria is negative - this peak occurs too close to the highest peak and the "bottom" between the two peaks is higher than the specified criterion  $p_c$ . Therefore,  $H_{max}(2)$  is excluded as a separate, independent event. Rather, it is considered as belonging to the same event leading to the true peak  $H_{max}(1)$ .



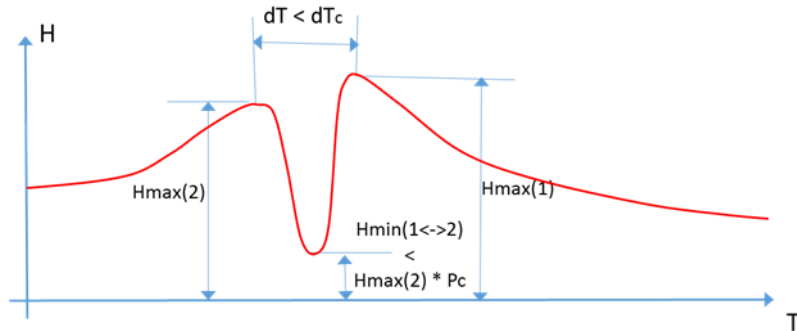


Figure 9.10 The two water level (i.e. depth) peaks in the time series are grouped under one event. The higher of the two depths ( $H_{\max(1)}$ ) is clearly an extreme event in the current simulation. The other peak ( $H_{\max(2)}$ ) is also a candidate for extreme depth event, but evaluation of  $dT_c$  criterion is negative - this peak occurs too close to the highest peak. Therefore,  $H_{\max(2)}$  is excluded as a separate, independent event and is considered as belonging to the same event leading to the true peak  $H_{\max(1)}$ .

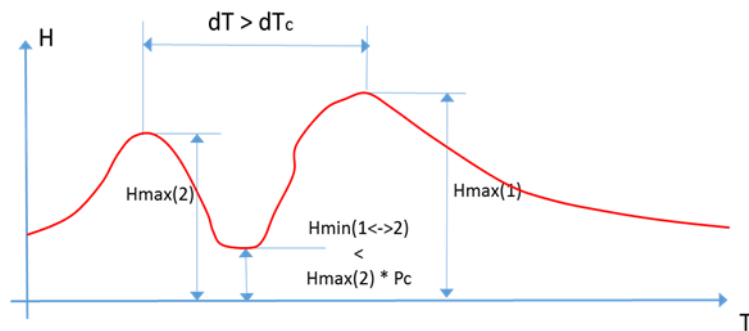


Figure 9.11 The two water level (i.e. depth) peaks in the time series are identified as two separate events. The higher of the two peaks ( $H_{\max(1)}$ ) is clearly an extreme event in the current simulation. The other peak ( $H_{\max(2)}$ ) is also a candidate for extreme depth event. Both criteria are evaluated positively - this peak occurs long time before the highest peak ( $dT > dT_c$ ) and the "bottom" between the two peaks is lower than the specified criterion  $p_c$ . Therefore,  $H_{\max(2)}$  is also identified as a separate, independent event.

To identify intermittent events and statistics on accumulated variables (e.g. volume, duration, and mass), only the interevent time criterion  $dT_c$  applies. Consecutive independent events are separated by time intervals longer than  $dT_c$ , where the underlying instantaneous variable (e.g. discharge for volume, mass transport for mass) is below the specified threshold (default value for the threshold is zero). E.g. two overflow events (i.e. overflow spills) are considered as independent overflow events if there is zero flow between them for a time longer than  $dT_c$ .

A threshold value other than zero is relevant for inherently continuous variables, e.g. discharge in pipes: even if the pipe is empty, due to the requirements of the algorithm, a small "numeric" discharge in the pipe will be reported. In order to consider such periods as "dry", the user may want to specify a small discharge threshold other than zero.

This feature is offered via the 'LTS\_DISCHARGE\_THRESHOLD' parameter in the CS Engine Configuration dialog accessed through the Simulation menu ribbon.

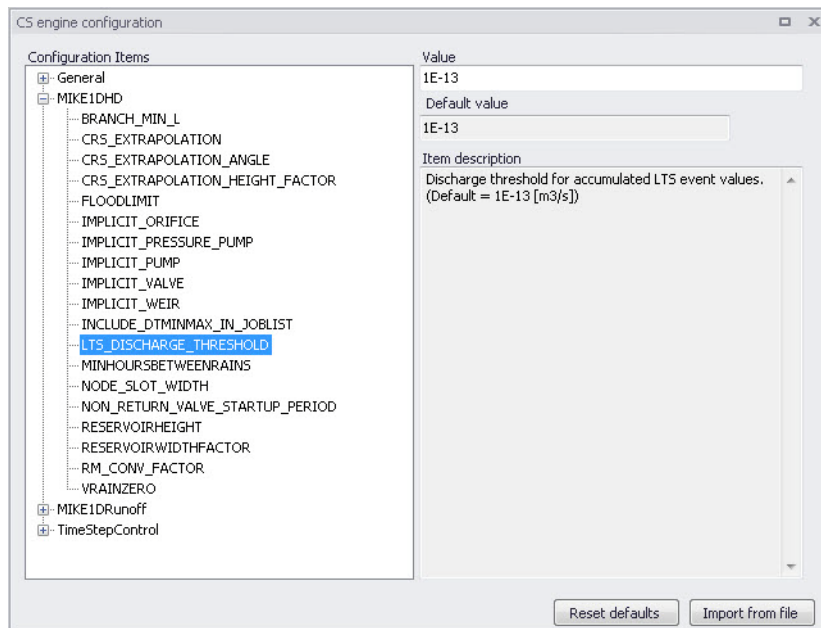


Figure 9.12 The CS Engine Configuration dialog

Override the Default value of 1E-13 for the parameter by specifying a value in the Value input box.

Examples of identifying independent events are shown in Figure 9.13.

For some statistics parameters, the number of events during a long LTS computation can be very high and the statistics result file size can grow rapidly.

Therefore, the statistical computation can be limited to a specified number of highest events, i.e. only the limited number of most significant events is included into the calculation. This is possible if the purpose of statistical calculation is to focus only on extreme events. In such a case, all insignificant events may be eliminated from the statistics as "irrelevant".

The maximum number of events must be specified within the range 1-5000.



The main parameters which control the event definition for various types of statistics are specified in the LTS Global Parameters editor (Figure 9.14).

This editor also includes parameters for controlling the LTS outputs:

- Number of events to save: limits the saved results to the specified number of the most significant (i.e. the largest) events
- Discharge and emissions statistics frequency: allows for switching between Monthly and Yearly statistic.
- Continuous DWF TS save frequency: specifies saving frequency for continuous LTS TS outputs for intervals between dynamic simulations.

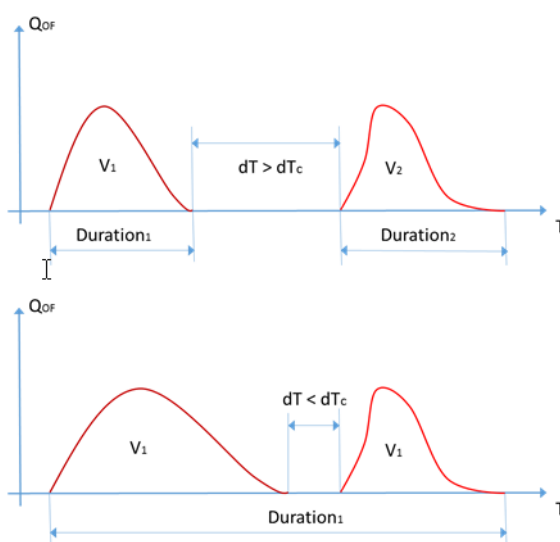


Figure 9.13 This example illustrates simulated sewer overflows occurring as two spills separated by a time period with zero flow. In the upper graph, the two spills are separated by  $dT$  which is longer than the specified  $dT_c$ . In this case, MU+ LTS considers the two spills as two independent overflow events and calculates their volumes and durations separately. In the lower graph, the second spill starts shortly after the first one has stopped, i.e. within time interval shorter than  $dT_c$ . In this case, MU+ LTS considers both spills as one overflow event (probably caused by the same meteorological event) and calculates the total volume and duration.



LTS Global parameters

Independent event criteria for instantaneous variables statistics (Q, H, v, C,...)

Interevent dT

Interevent p

Independent event criterion for accumulated values (V,T,M)

Interevent dT

Output

Number of events to save

Discharge and emissions statistics frequency

Figure 9.14 The LTS Global Parameters Editor

Table 9.4 LTS Global Parameters table attributes (Table msm\_LTSResult)

Edit field	Description	Used or required by simulation	Field name in data structure
Interevent dT (For instantaneous variables statistics)	Interevent time criterion or minimum time interval between two peaks to consider them as independent	Yes	Dth
Interevent p (For instantaneous variables statistics)	Interevent level criterion or threshold for ration between the lowest minimum value between two peaks and the lower peak	Yes	Pc
Interevent dT (For accumulated variables statistics)	Interevent time criterion or minimum time interval between two events to consider them as independent	Yes	DtQV
Number of events to save	Number of largest events to save in the statistics results (1-5000)	Yes	EventLimit
Discharge and emissions statistics frequency	Choice between monthly and yearly chronological statistics	Yes	StatFrequencyNo



## 9.2 LTS outputs

A MIKE URBAN+ LTS simulation generates result files containing timeseries and various event-based and annual statistics.

LTS outputs are defined as any other model results, i.e. by specifying the wanted result files and their contents under result specification. The specified results are then included in the actual simulation setup, as required.

LTS outputs may take the following forms:

- "Standard" TS result outputs
- Extreme event statistics (instantaneous and accumulated)
- Chronological statistics (monthly and yearly)
- Continuous TS outputs

### 9.2.1 Standard TS result files

Standard TS result files with default or user-specified contents may be specified as part of an LTS simulations. These are actually "normal" result files, generated by the catchment and network models.

Common for all these files is that due to long simulation periods, they tend to be quite large and care should be taken to keep the size of such LTS outputs within reasonable limits.

The default MIKE 1D result files (\*.RES1D), where the computed time series for default result items are saved for entire model, may become extremely large in long-term simulations if the saving frequency is high. On the other hand, too coarse time resolution in a result file might make the saved results useless. Consequently, for simulations covering long periods, a user-specified result file with carefully defined contents will usually be of major interest.

The user-specified result file will only contain selected result items at locations of interest. This makes it especially practical for keeping LTS results sufficiently resolved and the default result file potentially unnecessary. Detailed information on the specification of the contents of user-specified result files is provided in the Result Specifications Chapter.

- Runoff result file  
Strictly speaking, runoff result files are not specific for LTS. A fundamental difference compared to runoff results in other types of analysis is the length of the simulation periods and, consequently, size of the file. In the context of LTS simulations, runoff result files may be used as input for job list generation and/or as boundary condition for LTS simulation. Due to highly dynamic character of surface runoff, the runoff result saving frequency must remain high during rainfall. During dry weather periods, the



simulation time step and saving frequency is automatically changed to much longer "DWF" time step.

RDI model is per definition continuous, so the results will be saved continuously for the entire simulation period.

Inevitably, models many sub-catchments and long simulation periods will generate extremely large runoff result files (and, optionally, SWQ result files). If accompanied with surface pollution result files with multiple pollutants, this may become a serious problem. In order to avoid this, alternative workflow for the job list creation and LTS simulation are available (see the description of simulation workflows further ahead).

- Catchment discharge result file

Similarly, as runoff result file, in context of LTS simulations, catchment discharge result files may be used as input for job list generation and/or as boundary condition for LTS simulation. Catchment discharge normally represent slowly chaining flows (diurnal wastewater and constant infiltration, where the simulation time step and result saving frequency can be low (e.g. 1 hour) without any significant loss of accuracy. However, catchment discharge is present continuously during the simulation period. This means that models with many sub-catchments and long simulation periods will generate extremely large catchment discharge result files (and, optionally, CD WQ result files). In order to avoid this, alternative workflow for the job list creation and LTS simulation are available (see the description of simulation workflows further ahead).

- Network result file

When generated by LTS simulation, network result files contain time series the specified result items for the entire model domain or for the specified locations of interest. The time series are discontinuous, i.e. results are only available during the dynamic simulation. Due to normally high result saving frequency, these results may become very large unless the specified contents is user-specified, focused to really needed results.

## 9.2.2 Statistics Result File

When running any simulation over a longer period, information on operational statistics is of major interest rather than on the raw time series. MIKE 1D LTS can save additional result files (\*.RES1D) containing various statistics (event-based and annual) over the individual computed time series and the system performance as a whole:

- LTS Event-based Extremes Statistics (instantaneous and accumulated)

These result files contain ranked extreme values for the included result items and for the specified locations. The result items represent either extremes (peaks) of instantaneous variables (e.g. water level, discharge,



concentration) and/or accumulated values of cumulative variables (e.g. volume, mass, duration) for the statistical events identified as described elsewhere in this document. Such results are typically desired for overflows, water levels, pumps operations, etc.

- LTS Chronological Statistics (monthly and yearly)  
These result files contain accumulated (monthly or yearly) cumulative variables for the specified locations in the system, sorted chronologically. Such results are typically desired for overflows and pollution emissions, pumps operations, etc.

The statistics are computed according to user specifications.

The technical background for statistical computations and the process of specifying which statistical results to save are further described in the following sections below.

### 9.2.3 Specification of Statistics and Result Files

LTS statistical results are stored in statistical result files (\*.RES1D). As a bonus, an \*.ERF file is also generated, which can be loaded in MIKE View for presentation and statistics report generation.

It is possible to combine LTS hydrodynamic simulations with pollution transport (AD) calculations. In this way, one can estimate statistics on annual or event-based pollutant loads.

The contents of the statistical result file (result items and locations) must be specified prior to an LTS simulation. Content statistics is defined through the Result Files dialog (Result Specifications| Result Files).

There are two types of LTS statistics results:

1. LTS Extreme Statistics. These are divided in two sub-types:
  - Instantaneous values statistics. Represent instantaneous extreme (peak) values. These include:
    - Max water level. Saves ranked peak water levels.
    - Max flow. Saves ranked peak flows.
    - Max velocity. Saves ranked peak flow velocities.
    - Max concentration. Saves ranked peak concentrations for all simulated pollutants.
  - Accumulated values statistics. Represent accumulated values during events.
    - Event volume. Saves ranked event-accumulated discharge.
    - Event mass. Saves ranked event-accumulated mass for all simulated pollutants
    - Event duration. Saves ranked event duration.



2. LTS Chronological Statistics. These have the following two sub-types:
  - Individual chronological statistics. These may include accumulated discharge and pollutant mass transport in individual pipes, weirs, pumps, orifices, outlets, valves, and spilling nodes. Individual statistics imply multiple item values per file.
    - Accumulated volume. Saves individual accumulated yearly/monthly discharge in chronological order.
    - Accumulated mass transport. Save individual accumulated yearly/monthly mass flux for all simulated pollutants in chronological order.
  - Global accumulated statistics of discharges and emissions. These include accumulated discharge and pollutant mass transport for ALL outlets and weirs, pumps, orifices, valves discharging out of the system, and all spilling nodes, as well as TOTAL accumulated discharge and pollutant mass transport out of the system. Global statistics imply one (i.e. TOTAL) item value per file.
    - Total accumulated volume. Saves chronological total accumulated yearly/monthly discharge.
    - Total emission. Saves chronological total accumulated yearly/monthly mass flux for all simulated pollutants.

LTS statistics result items are specified in the LTS HD Items and LTS AD Items tabs in the Result Files editor. Available statistics results items are presented in Figure 9.15, Figure 9.16, Figure 9.17 and Figure 9.18.





Result files

Identification

ID:  Model type:  Insert

Content type:  Format:  Copy

Delete

Location LTS HD Items LTS AD Items

☐ Max water level

☐ Max flow (grid points)

☐ Max flow (spilling nodes)

☐ Max flow (surcharging nodes)

☐ Max velocity (grid points)

☐ Event volume (grid points)

☐ Event volume (spilling nodes)

☐ Event volume (surcharging nodes)

☐ Event volume (soakaway exfiltration)

☐ Event duration (grid points)

☐ Event duration (spilling nodes)

☐ Event duration (surcharging nodes)

Result files

ID	Model type
10	Default_LTS_extreme_statistics

Result selections

ID	Location type	Subset type
1	NET_LTSC_Copy	Save all

Figure 9.15 LTS HD Items for event-based extreme statistics in the Result Files Editor

Result files

Identification

ID:  Model type:  Insert

Content type:  Format:  Copy

Delete

Location LTS HD Items LTS AD Items

☐ Max concentration

☐ Event load (grid points)

☐ Event load (spilling nodes)

☐ Event load (surcharging nodes)

☐ Event load (soakaway exfiltration)

Result files

ID	Model type
10	Default_LTS_extreme_statistics

Result selections

ID	Location type	Subset type
1	NET_LTSC_Copy	Save all

Figure 9.16 LTS AD Items for event-based extreme statistics in the Result Files Editor



Result files

Identification

ID: Default\_LTS\_chronological\_statis Model type: Network

Content type: LTS chronological statistics Format: .res1d

Insert Copy Delete

Save all LTS HD Items LTS AD Items

☒ Total accumulated volume (out of the system)  
☒ Total accumulated volume (outlet pipes)  
☒ Total accumulated volume (pumps out of the system)  
☒ Total accumulated volume (weirs out of the system)  
☒ Total accumulated volume (orifices out of the system)  
☐ Total accumulated volume (valves out of the system)  
☐ Total accumulated volume (spilling nodes)  
☐ Accumulated spilled volume (spilling nodes)  
☐ Accumulated surcharge volume (nodes)  
☐ Accumulated exfiltration volume (soakways)  
☐ Accumulated volume (discharge)

Result files

ID	Model type	Conte
4	Default_LTS_chronological_s...	Network LTS ch

Result selections

ID	Location type	Subset type	Indivi
1	NET_LTSC	Save all	Selection Node

Figure 9.17 LTS HD Items for annual/monthly statistics in the Result Files Editor

Result files

Identification

ID: Default\_LTS\_chronological\_statis Model type: Network

Content type: LTS chronological statistics Format: .res1d

Insert Copy Delete

Save all LTS HD Items LTS AD Items

☐ Total emission  
☐ Total emission (outlet pipes)  
☐ Total emission (pumps)  
☐ Total emission (weirs)  
☐ Total emission (orifices)  
☐ Total emission (valves)  
☐ Total emission (spilling nodes)  
☐ Accumulated spilled mass (spilling nodes)  
☐ Accumulated surcharge mass (nodes)  
☐ Accumulated exfiltration mass (soakways)  
☐ Accumulated mass transport

Result files

ID	Model type	Conte
4	Default_LTS_chronological_s...	Network LTS ch

Result selections

ID	Location type	Subset type	Indivi
1	NET_LTSC	Save all	Selection Node

Figure 9.18 LTS AD Items for annual/monthly statistics in the Result Files Editor



## 9.2.4 Applicability of LTS statistics to various types of model elements

LTS statistics output is defined by the result item type and by location. Availability of certain statistics at a specific location depends on the compatibility of the location and item type, and on the actual implementation status. A complete overview of the currently available statistics is provided in Table 9.5, Table 9.6 and Table 9.7.

**Table 9.5** Statistics result types in nodes (Manholes, Basins and Soakaways)

Result Type	Node (Manhole, Basin)	Spilling nodes (Cover Type = Spilling)	Surcharged nodes (WL > GL)	Soakaways
Max water level	Yes	Yes	Yes	Yes
Max flow		Yes	Yes	Yes
Event volume		Yes	Yes	Yes
Event duration		Yes	Yes	Yes
Max concentration	Yes	Yes		Yes
Event load		Yes		Yes
Total accumulated volume		Yes		
Accumulated volume		Yes		
Total emission		Yes		
Accumulated mass		Yes		

**Table 9.6** Statistics result types in links (Links and Outlet pipes)

Result Type	Link (Grid point)	Outlet (Outlet pipe)
Max water level	Yes	Yes
Max flow	Yes	Yes
Max velocity	Yes	
Event volume	Yes	Yes
Event duration	Yes	Yes
Max concentration	Yes	Yes
Event load	Yes	Yes
Total accumulated volume		Yes
Accumulated volume		Yes
Total emission		Yes
Accumulated mass		Yes



Table 9.7 Statistics results in outflow structures (Pumps, Weirs, Orifices, and Valves leading out of the system)

Result Type	Pump	Weir	Orifice	Valve
Max flow	Yes	Yes	Yes	Yes
Event volume	Yes	Yes	Yes	Yes
Event duration	Yes	Yes	Yes	Yes
Max concentration	Yes	Yes	Yes	Yes
Event load	Yes	Yes	Yes	Yes
Total accumulated volume	Yes	Yes	Yes	Yes
Accumulated volume	Yes	Yes	Yes	Yes
Total emission	Yes	Yes	Yes	Yes
Accumulated mass	Yes	Yes	Yes	Yes

### 9.2.5 Specifying location for LTS statistics results

LTS statistics outputs are per definition user-specified. For such (non-Default) results it must be specified for which location(s) the desired results are to be saved.

As for "normal" result files, the location type for LTS statistics can be either 'Save all' (the whole system), 'Save subset' (Selection), 'Save individual' (Location ID), or 'Save within polygon'.

If 'Save subset' or 'Save individual' is selected, supplementary information on the selection list or element ID should be specified.

Additionally, for LTS statistics some pre-defined groups can be specified as subsets, such as:

- Pipes and canals
- Manholes
- Pumps
- Weirs
- Orifices
- Valves
- Outlet nodes
- Basins
- Soakaways

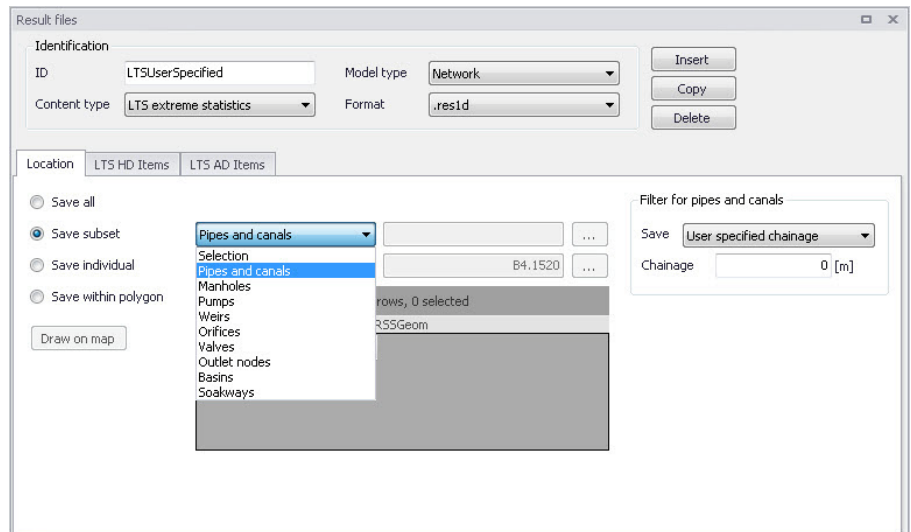


Figure 9.19 Pre-defined result location subset groups

For pipes and canals, the location for saving results can be specified as:

- All grid points
- Upstream grid point
- Downstream grid point
- Both upstream and downstream grid points
- Middle grid point
- User-specified chainage. Specify the chainage in the Chainage input box.

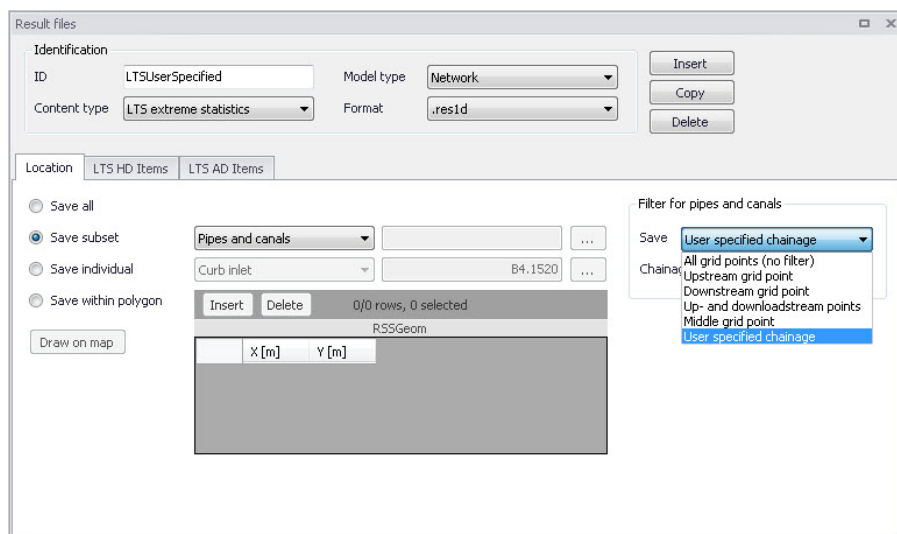


Figure 9.20 Grid point selector for result locations in pipes and canals

For chronological (annual/yearly) LTS statistics, the result items themselves define a subset of the model. E.g. result items "Total accumulated volume (weirs out of system)" contains statistics for accumulated volume of all weirs discharging out of the system. This filtering works jointly with the initially specified location, so that separate results of the same type can be achieved for various parts of the system. E.g. if definition of "Location" only includes weirs discharging into one of several recipients in the model area, the "Total accumulated volume (weirs out of system)" will be calculated and summed up for these weirs only.

If the same LTS statistics result type is used more than once (e.g. that the results from the above example are created for all local recipients separately and for the entire system), these need to be saved in separate result files.

## 9.2.6 Continuous LTS TS Outputs

Per definition, LTS network simulations generate discontinuous time series, with results available during dynamic simulation only. In the time intervals between events that are simulated dynamically, the variables values are set to zero.

At some locations in a modelled system it is advantageous to study a complete time series, also including the intervals between the dynamically simulated events. A typical example is the inflow to a WWTP.

MU LTS allows for the specification of any number of locations (links) in the system where such continuous discharge time series is generated by the system.



A continuous time series in the specified link is constructed by concatenation of the network simulation results during events and the sum of all hydraulic loads (boundaries) contributing to the flow in the specified link during inter-event periods. Obviously, the flows inserted in the inter-event periods are not hydraulically correct, but only an approximation. Volumes of the inserted flows are correct, but the peak amplitudes and timings inherently include an error, as the transport time and hydraulic diffusion in the network are not accounted for.

The contributing loads are user-defined by specifying the "Location" - a set of nodes and links located upstream the specified link. All loads (boundary conditions defined as runoff input, catchment discharge, load point, lateral inflows, infiltration) associated with the included model elements will be included automatically.

Accurate definition of the model elements contributing to the flows in the specified link is solely the modeler's responsibility - the model does not check if the listed elements really contribute to the specified link discharge.

The continuous time series are saved in a network result files with the contents type "LTS continuous". As for any other LTS result file, there is no default configuration available. This means that when a continuous TS output is wanted, LTS result file with continuous output TS must be created and configured "from scratch", and finally included in the actual LTS simulation setup.

The following parameters define LTS continuous result file:

File name:	user-specified
Model Type	Network
Content type:	LTS continuous
Format	res1d or dfs0
Location (contributing to the system):	Save all Save selection Save within polygon
Location (LTS continuous output in pipe of canal):	Any link
HD items	Discharge

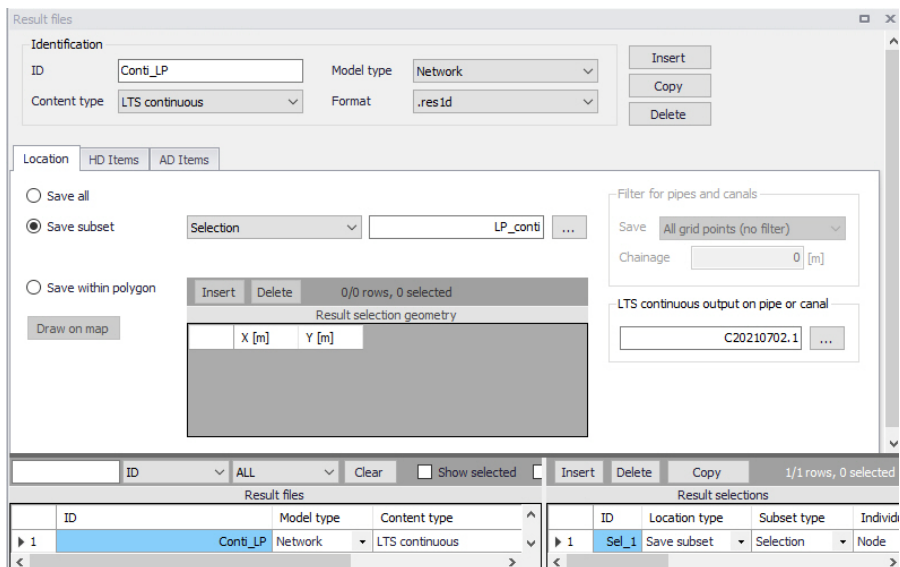


Figure 9.21 Continuous LTS TS output definition

The continuous LTS TS outputs are saved with two different frequencies:

- During dynamic simulation: user-specified save frequency in "Simulation setup | Results (Default: 60 seconds)
- Inter-event intervals: user-specified save frequency in "LTS Global parameters | Continuous DWF TS save frequency" (Default = 1 hour)

## 9.3 LTS Computations

### 9.3.1 Starting an LTS computation

LTS computations are started from the Simulation Setup editor with the Long-Term Statistics (LTS) module activated in the General Tab.





Simulation setup

Identification

ID: TutorLTS ☒ Active project

Scenario: Base

Insert Copy

Delete RUN

General Catchments HD LTS Results

Simulation Type

- ☒ Catchments
  - ☒ Rainfall-Runoff (RR)
  - ☐ Storm Water Quality (SWQ)
  - ☒ Catchment Discharge (CD)
  - ☐ CD Water Quality
- ☒ Network (HD)
  - ☒ Long-Term Simulation (LTS)
  - ☒ Pollution Transport (AD)
  - ☐ MIKE ECO Lab (WQ)
  - ☐ Sediment Transport (ST)
  - ☐ 2D Overland

Simulation Period

Start: 03/01/1936 01:26:00

Duration: 30 0 0 0 [dddd][hh][mm][ss]

End: 02/02/1936 01:26:00

Boundary Info.

Set max. time

Description

Simulation setup

ID	Scenario	Active Project	Catchments	Runoff(RR)	Stormwater runoff WQ (SWQ)	Catchment Discharge
1	TutorLTS	Base	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure 9.22 LTS computation activation in the Simulation Setup dialog General Tab

9.3.2 Generating job list files

Activating the LTS module activates the Generate Job List functionality in the LTS Tab for generating a Job List file.

Simulation setup

Identification

ID: TutorLTS ☒ Active project

Scenario: Base

Buttons: Insert, Copy, Delete, RUN

Tabs: General, Catchments, HD, LTS, Results

LTS Job List

TutorLTSBase.MJL ... Edit Generate Job List

Simulation setup

1/1 rows, 0 selected

ID	Scenario	Active Project	Catchments	Runoff(RR)	Stormwater runoff WQ (SWQ)	Catchment Discharge
1	TutorLTS	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure 9.23 LTS Tab in the Simulation Setup dialog

### 9.3.3 Automatic recovery of a failed LTS simulation

An LTS simulation includes many - possibly thousands - simulation events. Depending on the size of the model, complexity and the number of the requested statistical outputs, such a simulation may represent a significant computational job. With usually available hardware, a single LTS run may take hours, days or even weeks. This sets the requirements for a stable a safe completion of such simulations very high, to avoid repetitions and delays.

Likelihood for a successful completion of a simulation improves with the application of a conservatively short time steps, at the expense of the overall longer simulation time.

Anyway, it happens occasionally that one of the simulation jobs in the LTS simulation fails. In such a case, LTS will recover automatically by repeating the failed simulation with a reduced time step.

Time step for a repeated simulation is calculated as a fraction of the time step applied in the just failed simulation. This is controlled by the parameter `LTS_FAILED_JOB_TIME_STEP_REDUCTION_FACTOR`, found under "Simulation | CS Engine configuration".



The system will reduce the time step and repeat the simulation as many times as specified in `LTS_FAILED_JOB_MAX_REDO_COUNT`, also found under "Simulation | CS Engine configuration".

Any repetition due to a failed simulation will be reported in the simulation log.

If the repeated simulation was successful, the LTS computation will continue regularly.

If the simulation still fails after the maximum number of redo attempts was tried, this event will be excluded from any specified output and the LTS computation will continue regularly.

Any exclusion of a simulation event due to the simulation failure will be reported in the simulation log.

## 9.4 LTS Statistics Presentation

LTS results are saved in \*.RES1D format. Due to specific contents and requirements for LTS result presentation, \*.RES1D files containing LTS results are flagged to distinguish them from regular \*.RES1D files containing ordinary result time series.

Essentially, there are two types of LTS result files:

1. Files containing extreme statistics (ranked extreme values) for specified variables and locations.
2. Files containing chronological yearly or monthly accumulated statistics for specified variables and locations.

### 9.4.1 Displaying Yearly/Monthly Statistics Bar Charts

Annual/monthly statistics may be displayed as bar charts.

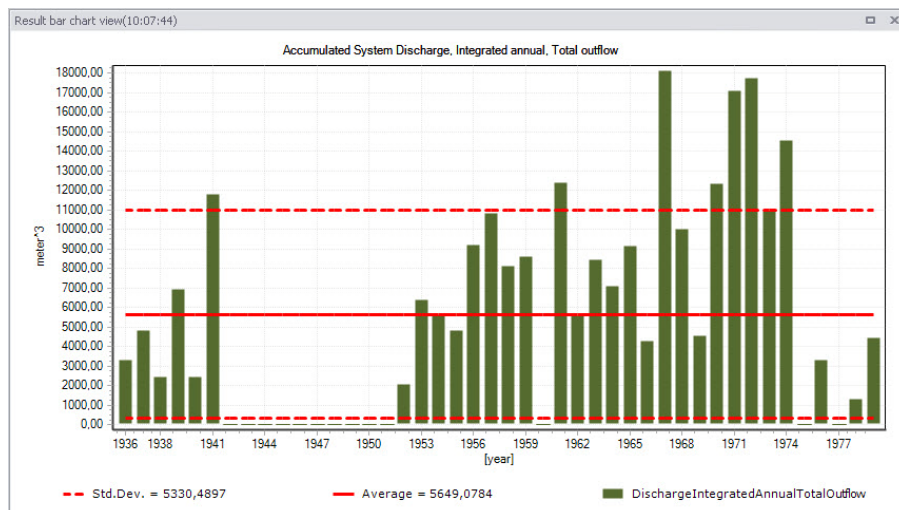


Figure 9.24 Chronological yearly statistics displayed as bar chart.

X-axis: Year axis. Yearly values are shown in case of yearly statistics. In case of monthly statistics, major tick marks are shown for years and minor tick marks for months.

Y-axis: Values axis showing with units according to type of variable for accumulated values.

Statistical information: The graph also displays the average annual/monthly accumulated (or duration) values, as well as standard deviation values plotted as line series on the graph.

The chart appearance (e.g. bar colours) may be customized.

## 9.4.2 Displaying Extreme Events Statistics Probability Plots

Extreme events statistics are displayed as probability plots.

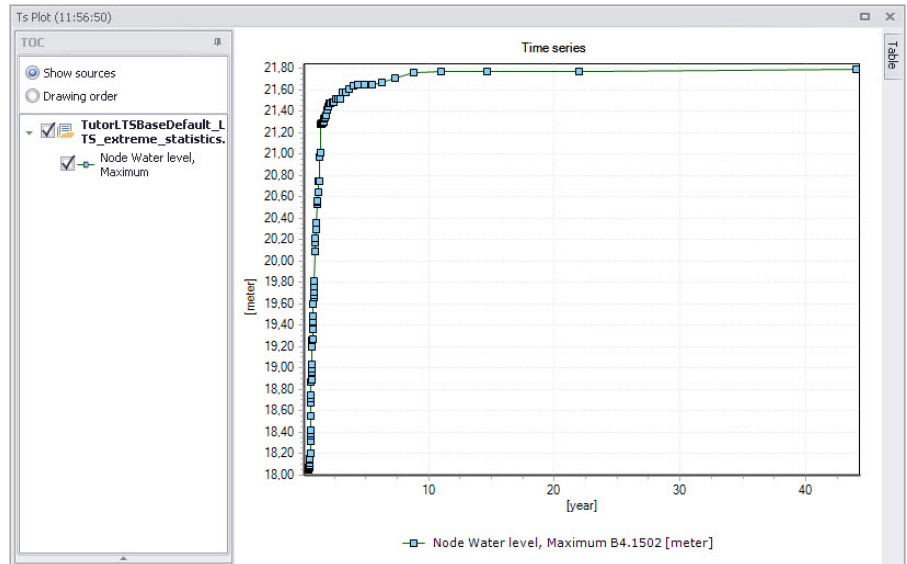


Figure 9.25 Probability plot shows ranked extreme values in reverse order (from smallest to largest, plotted against approximated recurrence interval (calculated as simulation period divided by rank).

X-axis: Recurrence interval in years.

Y-axis: Value units are displayed according to the type of variable plotted.

The user can modify plot data series colors, line thickness, marker type, etc.

### 9.4.3 User-specified "Observation Period"

"Observation Period" is calculated as the difference between the simulation end date/time and start date/time by Default. But sometimes, the simulated period is not continuously covered by boundary data and therefore these "empty" intervals do not contribute to the statistics.

In the bar chart example in Figure 9.24, the period between 1943 and 1952 (ten years) is not covered by rainfall data and no statistics are available for these years. In some of the other years, there are no reported results in the graph, but this is due to the actual simulations, and not due to the absence of boundary data.

To compensate for missing intervals (i.e. to calculate the exceedance frequency with the correct time base), the default "Observation Period" can be overwritten by a user-specified value:

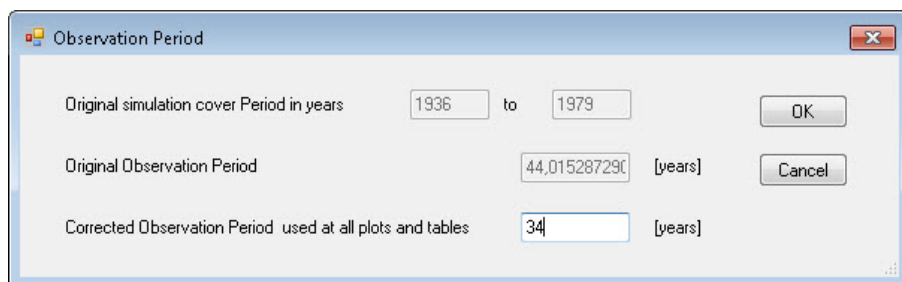


Figure 9.26 LTS Observation Period dialog

The Observation Period dialog is accessed via the “LTS user period” button in the Result Time Series window that appears when loading a result file. The option is only available for LTS extreme events statistics results.

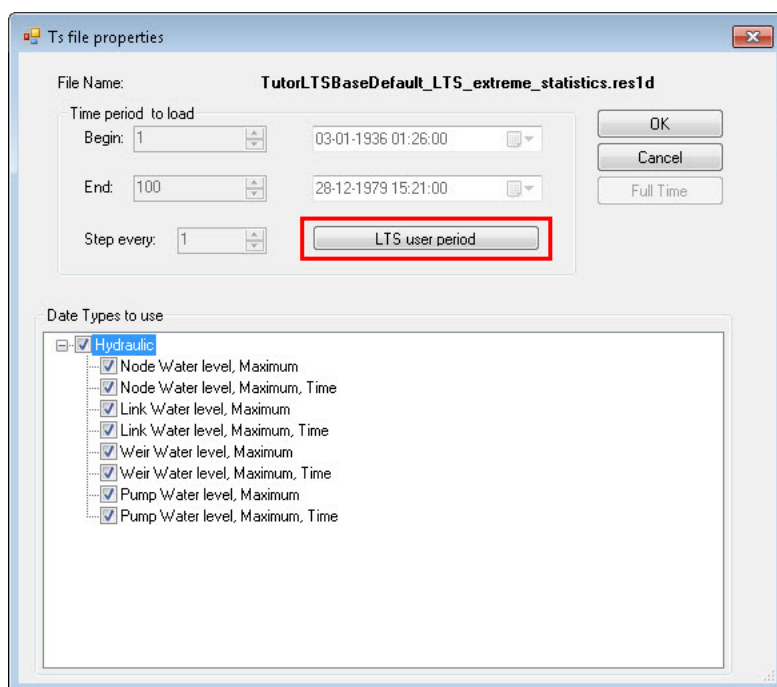


Figure 9.27 The LTS User Period button in the Timeseries File Properties window that appears when loading LTS extreme events statistics results

#### 9.4.4 Displaying Extreme Events Statistics in Longitudinal Profiles

Recurrence intervals of exceedance for selected variables may be displayed along a longitudinal profile.

**Profile plot**

The plot displays water levels (m) on the y-axis (ranging from 16 to 22) against distance (m) on the x-axis (ranging from 0 to 1000). The plot is divided into segments by vertical dashed lines at specific distances: 0, 210, 301.5, 264, 150, and 60 meters.

**Legend:**

- 20 year [m]
- 10 year [m]
- 3 year [m]
- 1 year [m]
- Ground Level [m]
- Bottom Level [m]
- Bottom Level (open CR5) [m]
- Bottom Level (open CR5, right levee) [m]
- Bottom Level (open CR5, left levee) [m]
- Node Level [m]

**Node Labels:**

- B4.1502
- B4.1501
- B4.1500
- B4.1490
- B4.1485
- B4.1480

**Link Labels:**

- B4.1502I1
- B4.1501I1
- B4.1500I1
- B4.1490I1
- B4.1485I1

**Length [m]:**

- 210,00
- 301,50
- 264,00
- 150,00
- 60,00

**Y-axis Labels:**

- 16
- 16,5
- 17
- 17,5
- 18
- 18,5
- 19
- 19,5
- 20
- 20,5
- 21
- 21,5
- 22

**X-axis Labels:**

- 0
- 100
- 200
- 300
- 400
- 500
- 600
- 700
- 800
- 900
- 1000

Exceedance values for the following variables are available for plotting along a profile:

- Maximum water level (grid points and nodes)
- Max flow (grid points, pumps, orifices, weirs, valves)
- Max velocity (grid points)
- Max concentration (grid points, pumps, orifices, weirs, valves, nodes)

#### 9.4.5 Calculating exceedance values for specified recurrence intervals

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The program calculates exceedance values by linear interpolation between the first available shorter recurrence interval and the first longer recurrence interval (see example below):

Number of years simulated: 15

Index (rank)	Recurrence int.	Hmax
1	15.0000	7.50
2	7.5000	7.20
3	5.0000	7.00
4	3.7500	6.70
5	3.0000	6.40
6	2.5000	6.30
7	2.1429	6.15
8	1.8750	6.10
9	1.6667	6.05
10	1.5000	6.00
11	1.3636	5.99
12	1.2500	5.97
13	1.1538	5.80
14	1.0714	5.70
15	1.0000	5.65
16	0.9375	5.50
17	0.8824	5.40
18	0.8333	5.30
19	0.7895	5.35
20	0.7500	5.34

Exceedance value for 10 years recurrence interval is calculated as (i.e. interpolation between values for the 7.5 and 15 recurrence intervals):

$$H_{\max}(10y) = 7.20 + (10-7.5)/(15-7.5)*(7.5-7.2) = 7.30$$

#### 9.4.6 Displaying Extreme Events Statistics on the Map

MU+ can present the following results as layers on the map:

- Maximum water level exceedance in nodes and grid points for specified recurrence intervals. The values are presented in all nodes and grid points where "Max water level" statistics are available. Results in nodes are shown as point symbols, and results in grid points as line symbols.
- Maximum discharge exceedance in grid points, weirs, pumps, orifices and valves for specified recurrence intervals. The values are presented in all locations where max. discharge statistics are available. Results are shown as line symbols.



Ground levels for nodes are taken from node data. Ground levels for grid points are interpolated from the neighboring nodes.

- Recurrence interval for Maximum water level exceedance of critical level in nodes. The recurrence interval is calculated similarly as described in the previous section (i.e. by linear interpolation). The values are presented in all nodes where "Max water level" statistics and "Critical level" data are available.

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- Recurrence interval for Maximum flow exceedance of Manning discharge (i.e. full-flow discharge) in grid points. The recurrence interval is calculated similarly as described in the previous section (by linear interpolation). The values are presented in all grid points where "Max flow" statistics are available.

Manning discharge for grid points (i.e. for links) are taken from the link data in the LTS result file.

### 9.4.7 Generating Reports on LTS Statistics

MU+ generates LTS statistics reports for the following:

1. **Summary report on extreme events statistics.** This report contains tables summarizing all calculated statistics in the file, i.e. for all individual locations, variables and statistics types. Can be generated only for result files with LTS extreme events statistics.
2. **Detailed report on extreme events statistics.** This report contains tables detailing all calculated statistics in the file, i.e. for all individual locations, variables and statistics types. Can be generated only for result files with LTS extreme events statistics.
3. **Report on chronological (yearly/monthly) statistics.** This report shall contain tables with all calculated yearly/monthly statistics for all individual locations and variables (volumes, accumulated mass, durations, number of events). Can only be generated for Chronological results (with yearly/monthly statistics).

#### Summary report on extreme events statistics

This report includes some or all of the tables listed below. The tables included depend on the actual contents of the LTS result file and user selection.

The following fields (columns) are included in the tables:

- **MUID:** Location ID (always)
- **Position:** Distance of the grid point from upstream node (Optional, only for location type = Link)
- **GL:** Node ground level (Optional, only for some types of statistics in nodes)
- **T\_GL:** Recurrence interval for exceedance of node ground level (Optional, only for some types of statistics in nodes)
- **H\_crit:** Node critical level (Optional, only for some types of statistics in nodes)
- **T\_Hcrit:** Recurrence interval for exceedance of node critical level (Optional, only for some types of statistics in nodes)



- **Q\_full:** Link's full-flowing Q (Manning Q) (Optional, only for discharge statistics in links)
- **T\_Qfull:** Recurrence interval for exceedance of link's Q\_full (Optional, only for discharge statistics in links)
- **T\_spill:** Recurrence interval for occurrence of spill in a spilling node (Optional, only for some types of statistics in spilling nodes)
- **T\_surgecharge:** Recurrence interval for occurrence of surgecharge in nodes (Optional, only for some types of statistics in spilling nodes)
- **1year:** Exceedance of variable value for recurrence interval 1 year (For LTS simulations longer than 1 year)
- **2year:** Exceedance of variable value for recurrence interval 2 years (For LTS simulations longer than 2 years)
- **5year:** Exceedance of variable value for recurrence interval 5 years (For LTS simulations longer than 5 years)
- **10year:** Exceedance of variable value for recurrence interval 10 years (For LTS simulations longer than 10 years)
- **20year:** Exceedance of variable value for recurrence interval 20 years (For LTS simulations longer than 20 years)
- **50year:** Exceedance of variable value for recurrence interval 50 years (For LTS simulations longer than 50 years)
- **100year:** Exceedance of variable value for recurrence interval 100 years (For LTS simulations longer than 100 years)

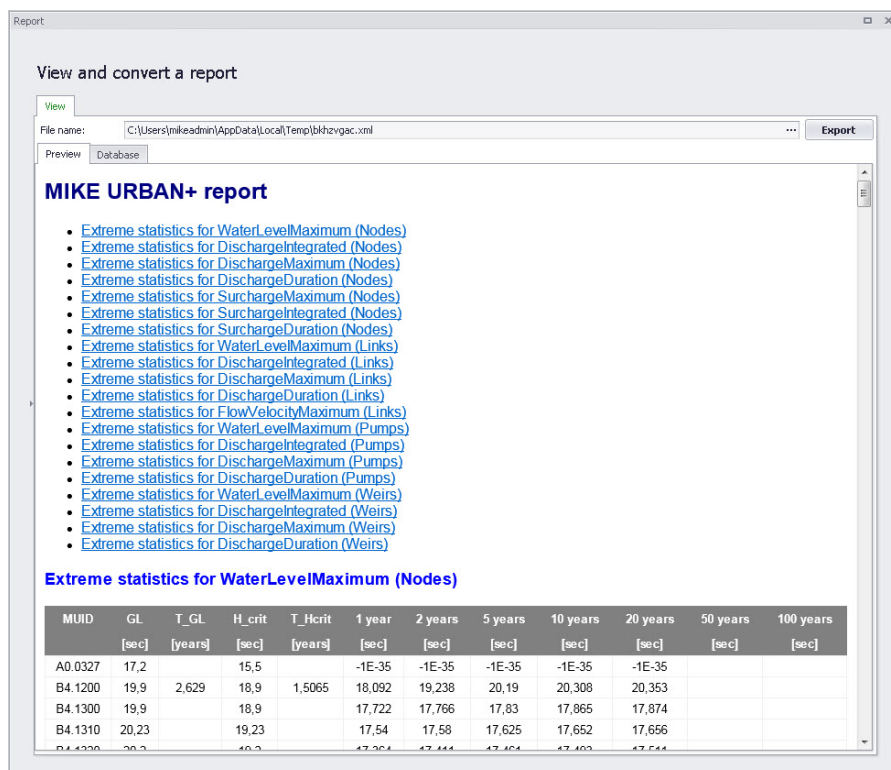


Figure 9.30 Example report on extreme statistics for water level in nodes

## Detailed report on extreme events statistics

This report provides full detail of all extreme events statistics available in the LTS result file. The total number of tables corresponds to the number of available statistics types multiplied by the actual number of locations for each type of statistics.

The header of the report document has a list of hyperlinks for available statistics.

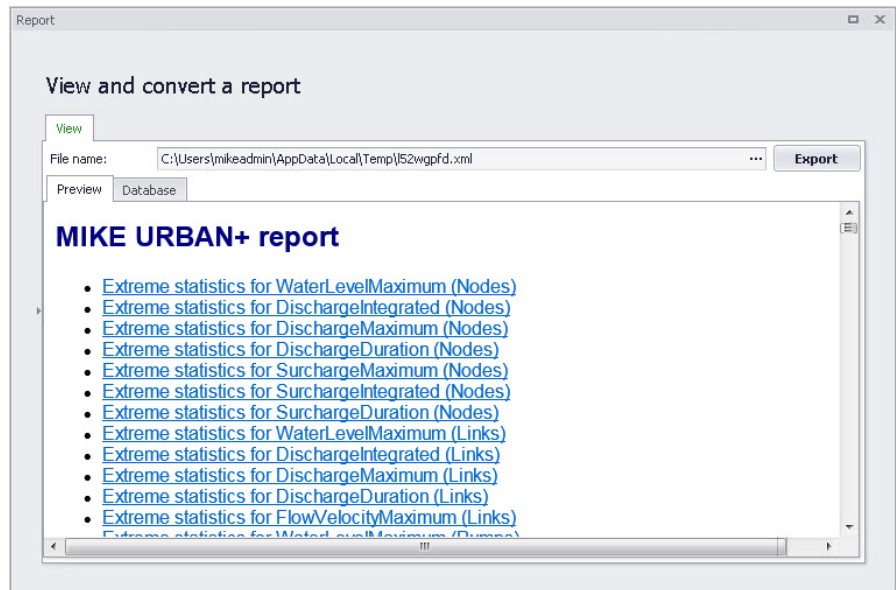


Figure 9.31 Report header hyperlinks

## Report on chronological (yearly/monthly) statistics

This report includes tables according to the actual contents of the LTS chronological (yearly/monthly) statistics result file and user selections.

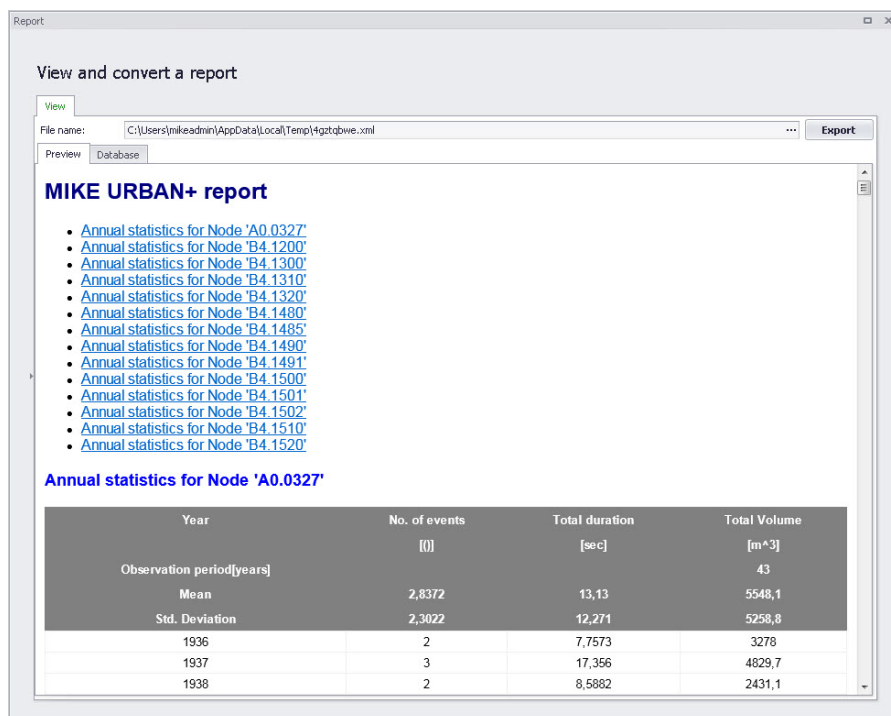


Figure 9.32 Report on chronological statistics

The number of tables in the report is a multiple of the number of included (and selected) table types and locations.

The following fields are included in the tables:

- **Year:** (Always) Actual year. The first row in the table contains the first year of simulation, and the last row contains the last year of the simulation. Intermediate rows contain the simulated years in growing order.
- **Month:** (Optional, only if monthly statistics). Actual month. The first row in the table contains the first month of simulation, and the last row contains the last month of the simulation. Intermediate rows contain the simulated months in growing order, repeating from 1 to 12 each year.
- **No. of events:** (Optional, only for individual locations). Count of events identified in the current year/month.
- **Total Duration:** (Optional, only for individual locations). Accumulated duration of all events in the current year/month.
- **Total Volume:** (Optional, if volume statistics are available and selected for this type of location). Accumulated volume for all events in the current year/month.



- **Total mass (Component xx):** (Optional, if pollutant mass statistics are available and selected for this type of location). Accumulated pollutant mass for all events in the current year/month. NOTE: This column shall be repeated for each AD component included in the simulation.

## 9.5 LTS Workflows

Setting up and running LTS simulations is a modelling task that requires a thorough understanding of the LTS concepts and solid modelling skills. The following descriptions of the complete workflows and advices on individual steps complement the technical information provided in the previous chapters.

A typical LTS workflow includes the following steps:

- Preparation of an LTS model setup
  - Set-up and calibration of a collection system model (catchments + network)
  - Choice of the simulation period, preparation of the LTS catchment boundary time series and definition of the LTS catchment model boundary condition
  - Definition of job list criteria
  - Definition of runtime stop criteria (optional)
  - Preparation of hot start files and definition of initial conditions for LTS simulation events (optional)
  - Review and modification (optional) of LTS global parameters
  - Definition of LTS outputs
    - "Standard" result outputs
    - Extreme event statistics (instantaneous and accumulated)
    - Chronological statistics (monthly and yearly)
    - Continuous TS outputs
- Setting-up and execution of an LTS simulation
  - Set-up and execution of the catchment model simulation (runoff and catchment discharge)
  - Creating a job list
  - Set-up and execution of the network LTS simulation

- Review, analysis and presentation of LTS results

The steps in the LTS workflow are described in the following chapters.

## 9.5.1 Preparation of an LTS setup

### Set-up and calibration of a collection system model

This step is identical as for any other collection system model. I.e. the model shall be set-up and calibrated, following a good modelling practice and calibration principles.

The model stability shall be tested by simulating high-intensity rainfall events (historical or synthetic) so that an appropriate simulation time step for the LTS simulation can be determined: a shorter time step contributes to the simulation stability but may compromise the simulation efficiency.

### Choice of the simulation period, preparation of the LTS catchment boundary time series and definition of the LTS catchment model boundary condition

An LTS simulation normally covers long historical periods, ranging from several years to several decades (10-30 years). Duration of the simulation period may be limited by the purpose of the LTS study and, often, by the limited availability of reliable historical rainfall time series. A longer simulation period is to be preferred, as it creates a better foundation for the statistical analysis.

The applied rainfall time series should be as complete as possible. Application of a time series with frequent drop-out events may generate misleading statistical results.

If the rainfall time series includes events known to be recorded incorrectly or if such events have been removed from the time series, they should be replaced by correctly recorded rainfall at the given time at a nearby rain gauge (if available).

Any selected rainfall time series (one or several) shall be included as the catchment model rainfall boundary condition. If the hydrological simulation includes RDI model, then the potential evapotranspiration time series for the model area, covering the LTS simulation period shall also be provided as boundary condition. Similarly, where relevant, air temperature time series must be provided to support the simulation of snow accumulation/snow melt processes.

### Definition of job list criteria

At least one job list criterium shall be specified. Otherwise, any number of job list criteria may be specified.

The specified START threshold shall be defined so that any event of relevance for the actual analysis is included in the LTS job list. A too high threshold value may cause important loss of information (i.e. exclusion of events that contribute to the statistics. On the other hand, a too low threshold means





inclusion of many, potentially insignificant events in the LTS job list, which may compromise the efficiency of the LTS simulation.

A good guideline for the threshold value may be intensity of specific runoff ( $LT^{-1}$ ), i.e. runoff per unit area. E.g. if it is known that overflows are likely to occur if the specific runoff exceeds certain intensity, the threshold may be calculated based on the total catchment area connected to the specified location.

"Duration" depends greatly on the specified location (size of the connected catchments). Small catchments may generate very short runoff peaks associated with spikes in recorded rainfall. Specifying a longer "duration" may eliminate such events from the LTS simulation.

The specified END threshold should reflect a situation when the inflow is low enough to be considered as insignificant for the processes of interest. Usually, it can be defined as a fraction of the START threshold (e.g. 10%). To ensure that the delayed hydraulic effects in the network are included in the simulation, appropriate "Duration" is specified. This depends on the size of the system, emptying time of the retention basins, etc.

Note that a better and a more precise way to control the END of the event simulation is by means of runtime criteria.

### Definition of runtime stop criteria (optional)

It is recommended to apply run time stop criteria, as this is much more precise method to control the end of the event simulation than job list stop criteria. Precisely specified runtime stop criteria will result in the shortest total simulation time, without any loss of important information due to prematurely ending event simulations.

### Preparation of hot start files and definition of initial conditions for LTS simulation events (optional)

Realistic initial conditions for the LTS simulation must be provided in order to achieve correct results. The following cases should be considered:

- Storm drainage system loaded by a surface runoff model  
It is assumed that the system is empty in dry weather. The runoff model generates intermittent runoff loads associated with rainfall events.  
Appropriate initial conditions for such a setup are "empty system", i.e. no hot start file is required.
- Wastewater and/or combined drainage system with some dry weather loads and runoff loads generated by a surface runoff model  
In dry weather, the system carries dry weather loads, typically wastewater. At the beginning of rainfall event, hydrological load is zero.

Appropriate initial conditions for such a setup is with a single hot start file, created with dry weather loads only. The hot start file shall include at least one day of dry weather flows, excluding the filling phase. This can be achieved either running the DWF hot start simulation over two or several days, until a fully stationary (repetitive) situation is established.

- Wastewater and/or combined drainage system with some dry weather loads and runoff loads generated by RDI runoff model (continuous infiltration)

In dry weather, the system carries dry weather loads, typically wastewater, and some infiltration load. At the beginning of rainfall event, the hydrological load (i.e. infiltration) may have a different scale, depending on previous hydrological events, season, etc.

Appropriate initial conditions for such a setup are established with several hot start files, created with dry weather loads and a constant infiltration component. The hot start files shall cover the expected range of possible infiltration in uniform intervals. The hot start files shall include at least one day of dry weather flows, excluding the filling phase. This can be achieved either running the DWF hot start simulation over two or several days, until a fully stationary (repetitive) situation is established.

When a hot start file (or files) is/are prepared, initial conditions for the LTS event simulations shall be specified in the dedicated "LTS initial conditions editor".

## Review and modification (optional) of LTS global parameters

Default values for LTS global parameters represent a reasonable choice for the most case. It is, however, a good idea to review the global parameters and consider modifications, if it deems appropriate for the actual LTS setup.

## Definition of LTS outputs

Depending on the specific requirements, LTS output files should be specified and included in the actual simulation setup.

### 9.5.2 Setting up and executing LTS simulations

After the LTS model has been set-up according the previous steps, the LTS simulation itself must be set-up and executed.

Several alternative workflows for running LTS simulations are available. These are described and commented in the following.

#### "Classic" LTS workflow

Running LTS simulation in a "Classic" LTS workflow includes three steps as described and illustrated below.



- STEP 1: Running runoff and catchment discharge (optional) simulation. This a "normal" catchment simulation, except that it runs over long historical periods.
  - Rainfall boundary condition(s) and, optionally, evapo-transpiration, temperature and SWQ boundary condition(s) must be specified for the entire simulation period and activated.
  - Catchment discharge boundary condition(s) (optional dry weather flow) must be specified for entire simulation period and activated.
  - Set-up a catchment simulation with runoff and catchment discharge (optional) included. Simulation must include at least the period to be included in the LTS simulation.
  - Define adequate simulation time step for runoff and catchment discharge simulations
  - Result files for runoff and catchment discharge shall be included in the simulation. They must include results for all catchments, saved with the frequency enough to resolve the simulated dynamics. For surface runoff, saving frequency is typically 60-300 seconds, for RDI 1- 12 hours and for catchment discharge 1 hour.
  - Start the catchment model simulation by pressing "RUN"

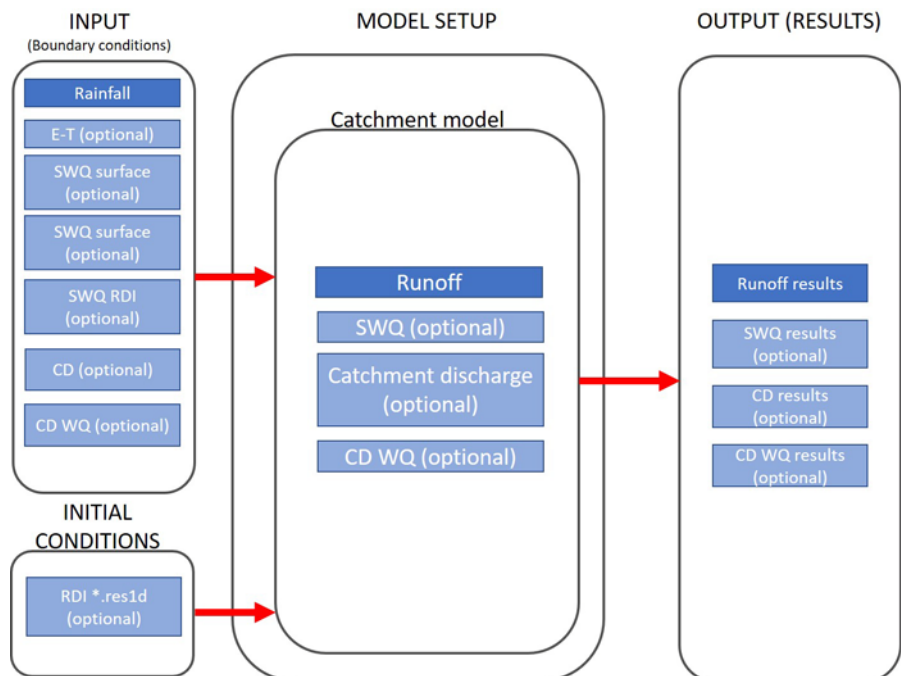


Figure 9.33 "Classic" workflow - STEP1

- STEP 2: Create job list
  - Set-up a network simulation and include LTS. The simulation period shall extend over the wanted historical period (inside the available rainfall boundary data).
  - Create and activate boundary conditions of the type "inflow from file" with simulated runoff and catchment discharge
  - In the HD TAB of the simulation setup editor define the network model simulation time step. Make sure that the specified time step is adequate for the actual model
  - In the LTS TAB of the simulation setup editor press "create job list" button. This will initiate the job list creation process. A job list file \*.jlf will be created in the actual project directory. The file's name includes the actual simulation job name.
  - Upon completed job list creation, load the job list file into the simulation setup by opening the file browser (...) and picking the \*.jlf file. Open the file to review and (optionally) manually modify its contents (e.g. change time step for some known extreme event). Make sure that all included boundary conditions are OK. Pay attention to the reported overall number of simulation jobs (event) and total duration of the simulation. If this deviate significantly from expectation, review and modify the job list criteria and repeat job list creation. Finally, close and save (optionally) the \*.jlf file.

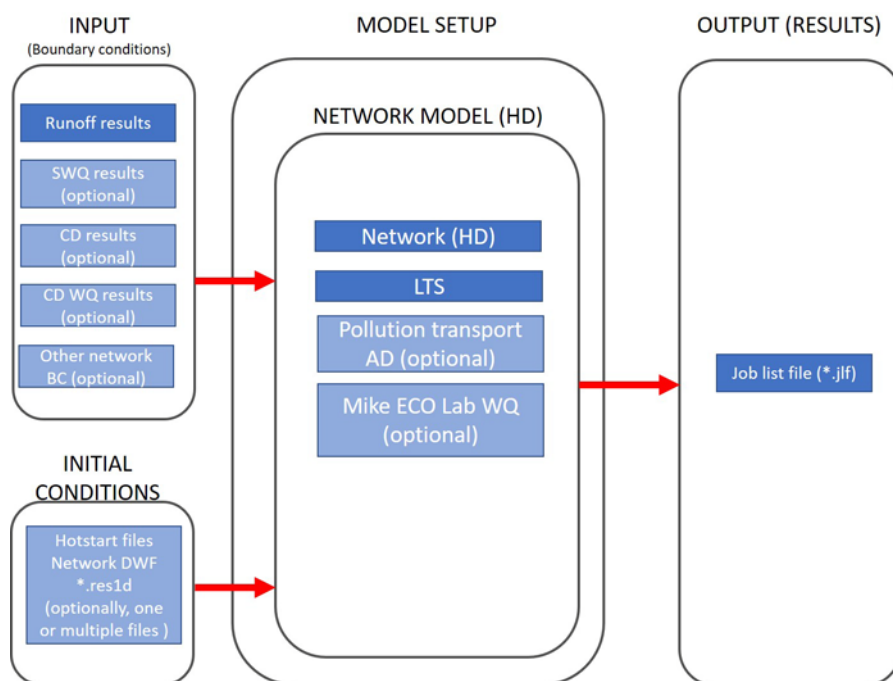


Figure 9.34 "Classic" workflow - STEP2



- STEP 3: Running LTS network simulation
  - Include the wanted output files in the simulation setup. All LTS outputs (except ASCII version for computed statistics \*.ERF) are optional. The output will typically include LTS extreme statistics and LTS chronological statistics. LTS continuous output and "standard" network result files may be added if such outputs are wanted.
  - Start the network LTS simulation by pressing "RUN". Depending on the size of the model, length of the simulation period, number of specified statistics and the available hardware, this simulation may take a long time.

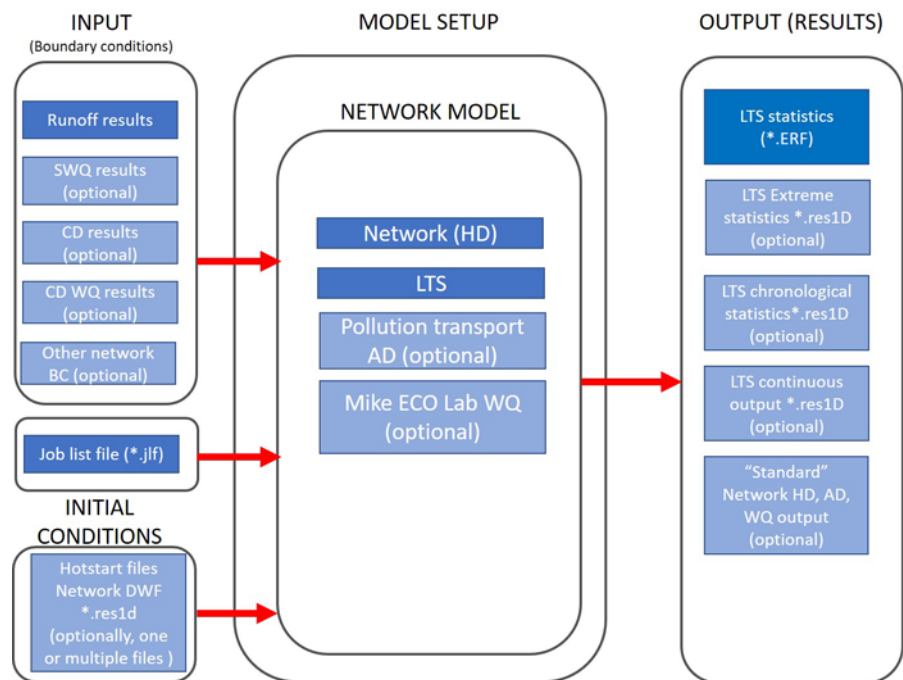


Figure 9.35 "Classic" workflow - STEP3

Disadvantage of this workflow is its inefficiency and generation of large intermediate result files (runoff and catchment discharge) with the sole purpose to provide input to the network LTS simulation.

## Integrated 2-step LTS workflow

This workflow includes two steps as described and illustrated below.

- STEP 1: Create job list "on the fly" i.e. simultaneously with runoff and catchment discharge simulations



- Set-up an integrated catchment & network simulation, including runoff and catchment discharge, as well as LTS. The simulation period shall extend over the wanted historical period (inside the available rainfall boundary data).
- Define adequate simulation time step for runoff and catchment discharge simulations
- In the HD TAB of the simulation setup editor define the network model simulation time step. Make sure that the specified time step is adequate for the actual model
- Rainfall boundary condition(s) and, optionally, evapotranspiration, temperature and SWQ boundary condition(s) must be specified for the entire simulation period and activated.
- Catchment discharge boundary condition(s) (if dry weather flow included) must be specified for entire simulation period and activated.
- Any existing network boundary condition (inflow from file) representing runoff and/or catchment discharge shall be de-activated or removed.
- No result files should be specified, as we want to avoid large intermediate result files. However, if wanted, result files for runoff and catchment discharge can be included in the simulation.
- In the LTS TAB of the simulation setup editor press "create job list" button. This will initiate the job list creation process. A job list file \*.jlf will be created in the actual project directory. The file's name includes the actual simulation job name.
- Upon completed job list creation, load the job list file into the simulation setup by opening the file browser (...) and picking the \*.jlf file. Open the file to review and (optionally) manually modify its contents. Make sure that all included boundary conditions are ok. Pay attention to the reported overall number of simulation jobs (event) and total duration of the simulation. If these outcome deviates significantly from expectation, review and modify the job list criteria and repeat job list creation. Finally, close and save (optionally) the \*.jlf file.

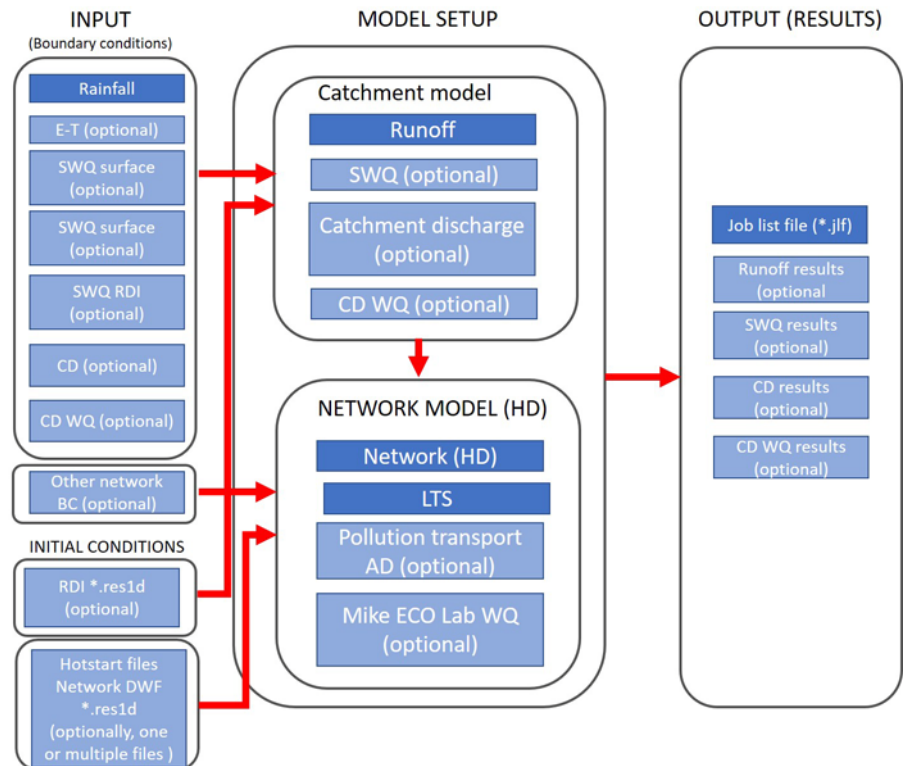


Figure 9.36 2-step integrated simulation workflow - STEP1

- STEP 2: Running integrated LTS catchment and network simulation
  - Include the wanted output files in the simulation setup. These will typically include LTS extreme statistics and LTS chronological statistics. Optionally, LTS continuous output and "standard" network result files may be added.
  - Start the integrated catchment and network LTS simulation by pressing "RUN". Depending on the size of the model, length of the simulation period, number of specified statistics and the available hardware, this simulation may take a long time.

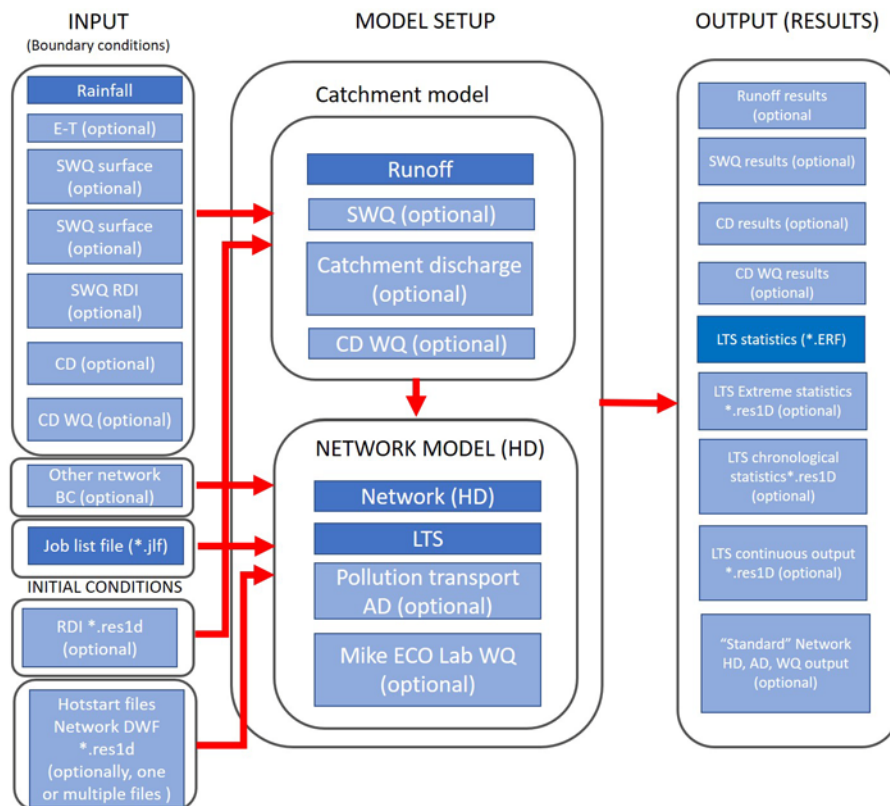


Figure 9.37 2-step integrated simulation workflow - STEP2

Advantage of this LTS workflow is its relative simplicity and avoiding creation of large runoff and catchment discharge result files.

### Integrated simulation single step LTS workflow

This workflow executes the LTS simulation in a single step as follows:

- Set-up an integrated catchment & network simulation, including runoff and catchment discharge, as well as LTS. The simulation period shall extend over the wanted historical period (inside the available rainfall boundary data).
- In the "Catchments" TAB of the simulation editor, define adequate simulation time step for runoff and catchment discharge simulations
- In the "HD" TAB of the simulation setup editor define the network model simulation time step. Make sure that the specified time step is adequate for the actual model
- In the "LTS" TAB of the simulation setup editor, make sure that the job list file field is empty.





- Rainfall boundary condition(s) and, optionally, evapotranspiration and temperature boundary condition(s) must be specified for the entire simulation period and activated.
- Catchment discharge boundary condition(s) (dry weather flow) must be specified for entire simulation period and activated.
- Any network boundary condition (inflow from file) representing runoff and/or catchment discharge shall be ad-activated or removed.
- Include the wanted LTS output files in the simulation setup. These will typically include LTS extreme statistics and LTS chronological statistics. Optionally, LTS continuous output and "standard" network result files may be added
- No result files for the runoff and catchment discharge models should be specified. However, if wanted, result files for runoff and catchment discharge can be included in the simulation.
- Start the integrated catchment and network LTS simulation by pressing "RUN". Starting an LTS simulation without specified job list file, will trigger the single-step LTS simulation. Depending on the size of the model, length of the simulation period, number of specified statistics and the available hardware, this simulation may take a long time. This simulation will create a job list "on the fly" and apply it for the LTS network simulation.

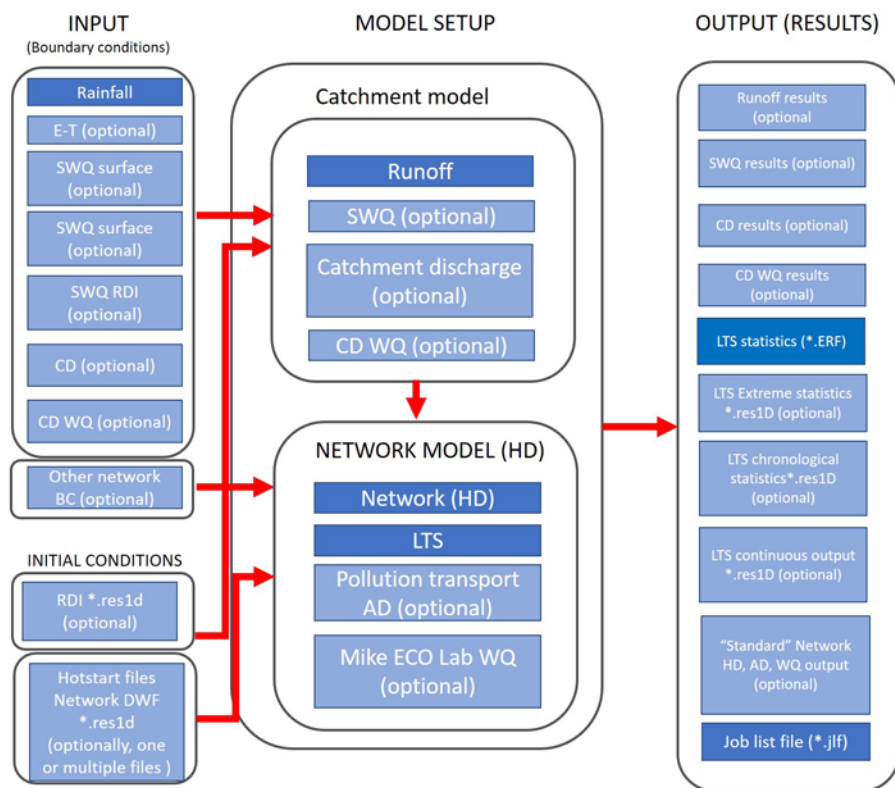


Figure 9.38 Single step integrated simulation workflow - STEP2

This workflow is the simplest and most efficient. Disadvantage is that it does not allow for review and optional editing of the job list file. Therefore, it is recommended for relatively simple LTS setups or for repeated LTS simulation with minor modifications of the LTS setup.

## 9.6 Controlling the LTS computations

In addition to data and parameters supplied through the general model setup and LTS editors, several engine parameters are available for controlling and adjusting the default performance of the LTS computation.

These parameters can be accessed through "CS engine configuration" dialog

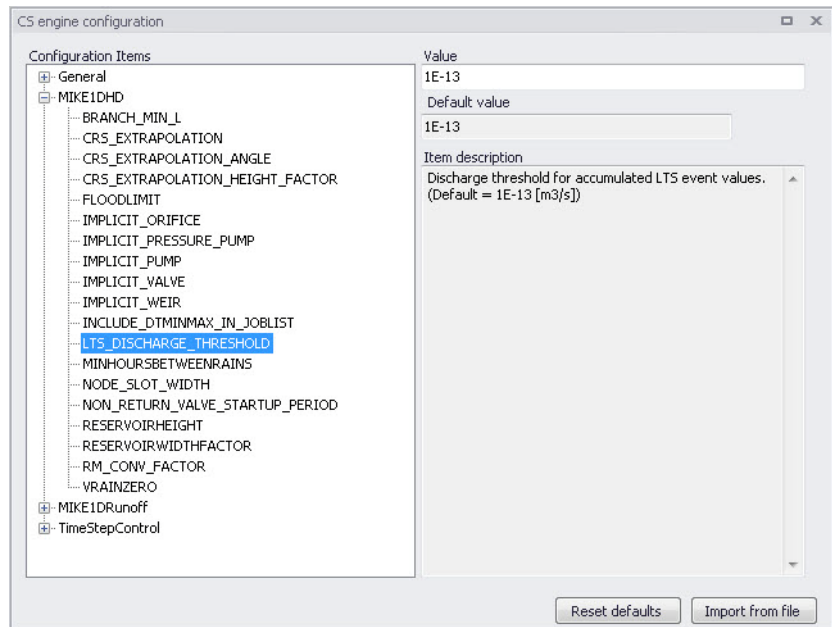


Figure 9.39 LTS engine parameters can be modified through "CS engine configuration"

### 9.6.1 INCLUDE\_DTMINMAX\_IN\_JOBLIST

When value of INCLUDE\_DTMINMAX\_IN\_JOBLIST is "ON", the job list generator will include lines with minimum and maximum timestep in each simulation event definition (see example below):

```
[SIMULATION_EVENT]
Simulation_start = '1933-07-22 16:31:00'
Simulation_end = '1933-07-22 18:49:00'
Simulation_end_no_duration = '1933-07-22 18:39:00'
Hotstart_file = 'Hot_startLTSBase.res1d'
Hotstart_time = '2019-01-01 16:31:00'
Hotstart_hydrological_inflow = 0.0
Duration = '02:18:00'
Job_number = 1
Job_start_criterion = 'JL_Criterium_1'
Job_stop_criterion = 'JL_Criterium_2'
DtMin = 10.0
DtMax = 10.0
EndSect // SIMULATION_EVENT
```



By "manually" editing these parameters for individual simulation events, user can ensure that e.g. a particularly difficult rain event is simulated with shorter time steps than generally specified.

Possible values:      ON (writes DTmin and DTmax in the job list)  
                             OFF (does not write DTmin and DTmax in the job list)

Default value:        OFF

## 9.6.2 LTS\_DISCHARGE\_THRESHOLD

This parameter controls the definition of statistical intermittent events for accumulated variables (discharge, mass transport) in network conduits.

Per definition, discharge and mass transport events (duration, volume and accumulated mass) are delimited by the events start time and end time.

Due to "numerical water" in empty conduits, discharge and, possibly, mass transport is never zero during a simulation. Accordingly, without a specified threshold discharge (or specified very low, i.e. smaller than expected "numerical" discharge), every simulated accumulated event in a conduit would have duration equal to the simulation period, and the accumulated volume and/or mass would include numerical water and mass. The two consecutive discharge events, even they are sufficiently separated ( $dT > \text{Interevent } dT$ ) would be reported as a single event. The effect of correctly/incorrectly specified LTS\_DISCHARGE\_THRESHOLD is illustrated in Figure 9.40:

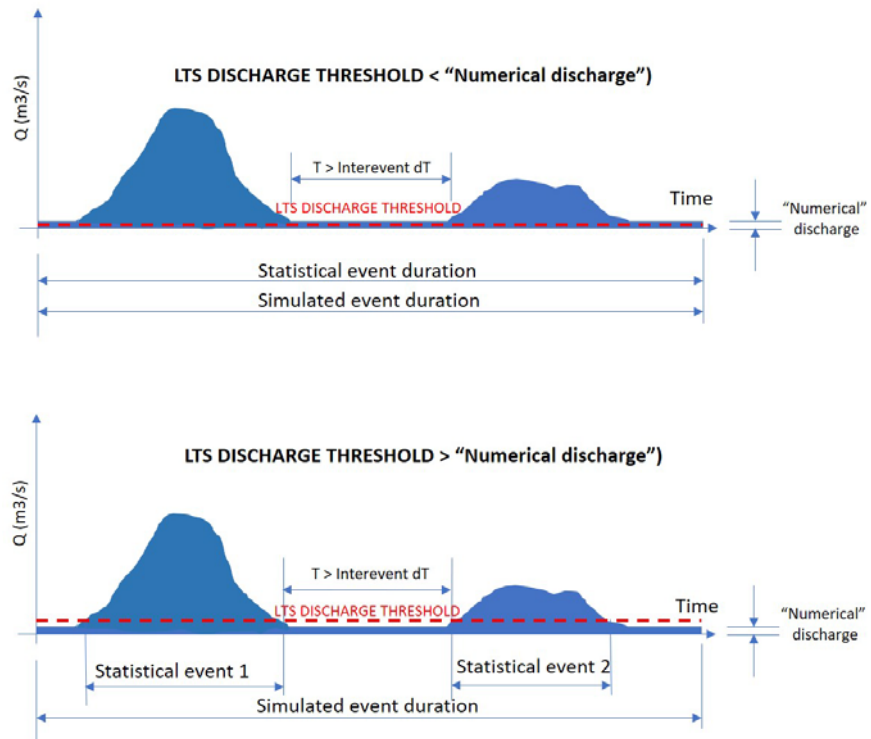


Figure 9.40 LTS discharge threshold

Possible values: any positive value

Default value: 10-13 [ $\text{m}^3/\text{s}$ ]

### 9.6.3 LTS\_FAILED\_JOB\_MAX\_REDO\_COUNT

This parameter is related to the automatic recovery of failed jobs during an LTS simulation. It specifies how many times a failed job may be re-simulated with a shorter time step.

Possible values: 0, 1, 2, 3, 4, 5...

Default value: 1

Note: Time step for an LTS simulation should be specified so to ensure a stable and accurate simulation of the most intensive events included in the LTS simulation. Re-simulating accidentally failed jobs with a shorter time step should be considered as exception.



#### 9.6.4 LTS\_FAILED\_JOB\_TIME\_STEP\_REDUCTION\_FACTOR

Likewise LTS\_FAILED\_JOB\_MAX\_REDO\_COUNT, this parameter is related to the automatic recovery of failed jobs during an LTS simulation. It specifies how much the simulation time step shall be reduced in the following attempt to simulate a failed job..

Possible values:  $0 < \text{LTS\_FAILED\_JOB\_TIME\_STEP\_REDUCTION\_FACTOR} < 1..$

Default value: 0.5

#### 9.6.5 LTS\_JOBLIST\_CREATOR\_TYPE (0/1)

This parameter controls the process of job list creation, with focus on speed or accuracy.

Choice of possible values (0 or 1) has the following effects:

- **LTS\_JOBLIST\_CREATOR\_TYPE = 0**  
Calculates the inflows used by job list criteria only when it is raining. This effectively skips potential jobs where boundary inflow other than rainfall satisfies a job start condition, but there is no active rain. This contributes to the job list creation efficiency, as wet periods typically represent a smaller part of the simulated period.
- **LTS\_JOBLIST\_CREATOR\_TYPE = 1**  
Calculates the inflow continuously, i.e. also during periods without rainfall. This option is relevant in cases when the model includes significant intermittent inflows which are not directly related to the local rainfall. This slows down the process of job list creation.

Possible values: 0 (calculates inflow only during rain)  
1 (calculate inflows continuously)

Default value: 0

#### 9.6.6 LTS\_JOB\_LIST\_DFS0 (Off/On)

When this parameter is set to "On", the LTS job list creation process generates a \*JobStartEnd.dfs0 file containing the following time series items:

Job ON/OFF (): 1 (job = ON); 0 (job = OFF)

Duration (hours): Simulation job duration



An example of such file shown in figure below:

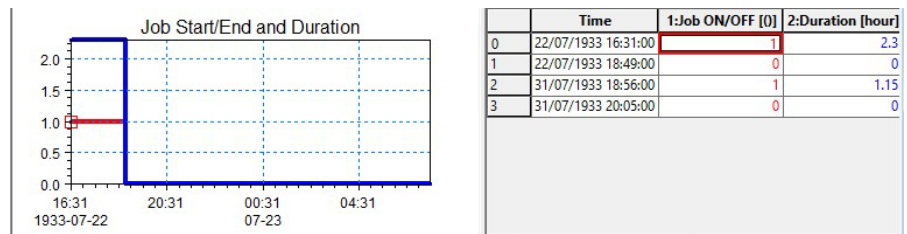


Figure 9.41 Example of dfs0 file containing time series of job activity and duration

Possible values: On (create \*.JobStartEnd.dfs0 file)  
Off (do not create \*.JobStartEnd.dfs0 file)

Default value: Off

### 9.6.7 LTS\_JOB\_LIST\_INFLOW\_TIMESERIES (Off/On)

When this parameter is set to "On", the LTS job list creation process generates a \*BaseJobCriteriaInflow.dfs0 file containing the time series of inflows into the system, used in the evaluation of job list criteria. I.e. the file includes as many time series as there are job list criteria in the actual LTS setup.

The time series are created by summing up all inflows (catchment discharges, runoff, infiltration, any other lateral inflow) connected to the specific location (Individual), part of the system (List, defined by a selection) or to the whole system (General).

Figure 9.42 below illustrates example with two job list criteria. The time series are intermittent, i.e. only contain inflow discharges for the period during the simulation jobs.

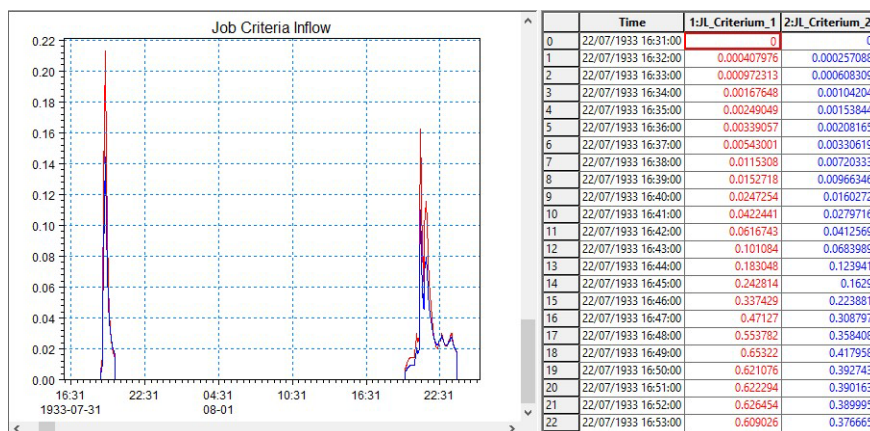


Figure 9.42 Example of dfs0 file with inflow time series associated with two job list criteria

Possible values: On (create \*.BaseJobCriteriaInflow.dfs0 file)  
Off (do not create \*.BaseJobCriteriaInflow.dfs0 file)

Default value: Off

## 9.6.8 LTS\_TIME\_BEFORE\_JOB\_CATCHMENT\_DISCHARGE

This parameter controls the running of catchment discharge model in the dry periods between simulated events, during a "live" run of catchment and network model in an LTS simulation.

When running the catchment discharge model (typically generating wastewater inputs to the network) and the network model simultaneously in an LTS simulation, the catchment discharge model may be set to run only during the network simulation, or it can be specified to start running several days before the start time of the network simulation. Ultimately, the catchment discharge model can be set to run continuously.

Purpose of stopping the catchment discharge simulation between LTS simulation events is to minimize the simulation time and size of the catchment discharge result file. As catchment discharge establishes instantaneously,





default setting is "0", i.e. the catchment discharge simulation will start exactly at the same time as the network simulation.

Possible values:	-1	catchment discharge simulation runs continuously between events
	0	catchment discharge simulation starts at the same time as network simulation
	N (1,2,3,...)	catchment discharge simulation starts N days before the network model simulation
Default value:	0	

### 9.6.9 LTS\_TIME\_BEFORE\_JOB\_NAM

This parameter controls the running of RDII (NAM) hydrological model in the dry periods between simulated events, during a "live" run of catchment and network model in an LTS simulation.

When running the RDII hydrological model (generating continuous hydrological inputs to the network) and the network model simultaneously in an LTS simulation, the RDII model may be set to start running a number of days before the network simulation or, ultimately, the RDII model can be set to run continuously. The latter option is preferred, because RDII model simulates slow hydrological processes and only a continuous simulation between LTS events ensures correct results..

Possible values:	-1	RDII simulation runs continuously between events
	0	RDII simulation starts at the same time as network simulation
	N (1,2,3,...)	RDII simulation starts N days before the network model simulation
Default value:	1	

### 9.6.10 LTS\_TIME\_BEFORE\_JOB\_SURFACE

This parameter controls the running of any surface runoff model in the dry periods between the simulated events, during a "live" run of catchment and network model in an LTS simulation.

When running a surface runoff model (typically generating storm runoff inflows to the network) and the network model simultaneously in an LTS simulation, a surface runoff model may be set to run only during the network sim-



ulation, or it can be specified to start running a number of days before the start time of the network simulation. Ultimately, the surface runoff model can be set to run continuously.

Purpose of stopping a surface runoff simulation between LTS simulation events is to minimize the simulation time and size of the runoff result file. However, this must be done with a due care to avoid incorrect simulation. Models involving processes which depend on significant "hydrological memory" (e.g. infiltration) may need to be run before the actual start of the network simulation, in order to capture the effects of small rainfall events not included in the LTS job list. .

Possible values:	-1	Surface runoff simulation runs continuously between LTS events
	0	Surface runoff simulation starts at the same time as network simulation
	N (1,2,3,...)	Surface runoff simulation starts N days before the network model simulation
Default value:	1	

### 9.6.11 MINHOURSBETWEENRAINS

This parameter allows to consider consecutive recorded rainfalls, separated by relatively short dry intervals, as one continuous rainfall event. This may affect the start time of an LTS job (it is set to the rainfall start time) in cases when a rainfall event included in the LTS job list is preceded by a small, low-intensity rainfall. This is illustrated in figures below.

If the preceding small rainfall is separated from a large rainfall event by a **dry interval longer than the specified MINHOURSBETWEENRAINS**, the two rainfalls are considered as two separate events. The small rainfall is ignored as it generates the inflow to the system smaller than the threshold specified by any of the job list START criteria. The big rainfall is included in the job list (it exceeds the threshold discharge for the time longer than the specified duration, for at least one of the job list START criteria. The start time for the simulation is set to the start of the big rainfall event.

The end of the job list event is set to the time when the inflow drops below the specified threshold for the time longer than the specified duration, for all specified job list STOP criteria.

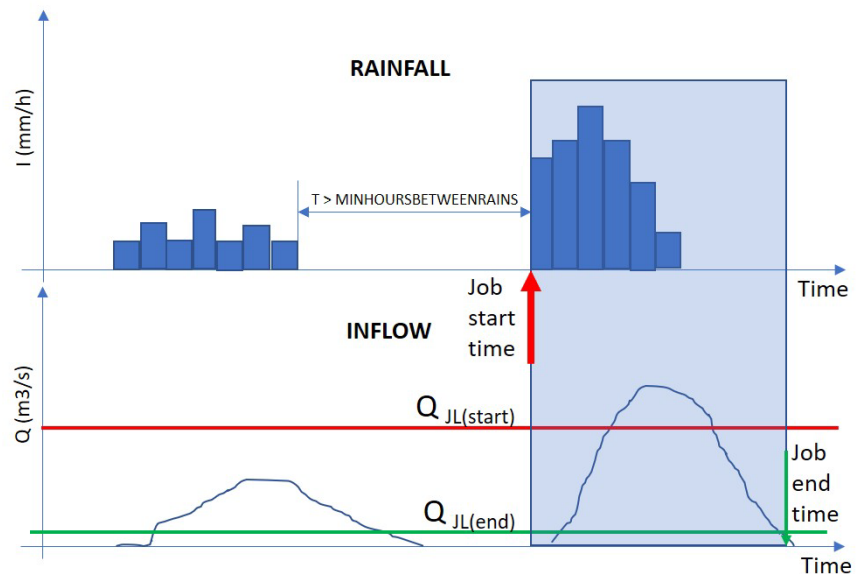


Figure 9.43 Definition of event start for rainfall events separated by a long dry interval

If the preceding small rainfall is separated from a large rainfall event by a **dry interval shorter than the specified MINHOURS BETWEEN RAINS**, the two rainfalls are considered as one continuous event. The small rainfall is included in the simulation, as it is treated as part of the big event. The joint rainfall event is included in the job list (it exceeds the threshold discharge for the time longer than the specified duration, for at least one of the job list START criteria). The start time for the simulation is set to the start of the joint rainfall event, effectively at the beginning of the small rainfall.

The end of the job list event remains unaffected, it is set to the time when the inflow drops below the specified threshold for the time longer than the specified duration, for all specified job list STOP criteria.

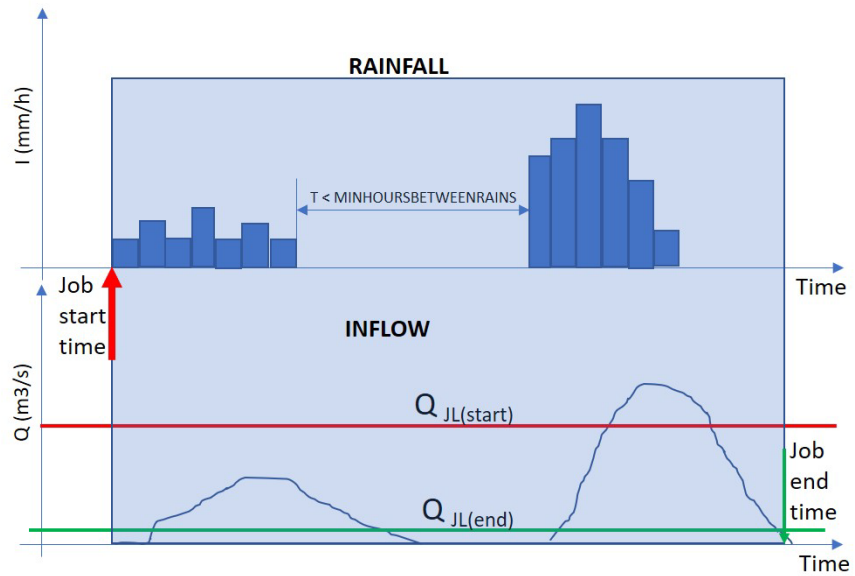


Figure 9.44 Definition of event start for rainfall events separated by a short dry interval



## 10 Water Quality

MIKE URBAN+ provides several modules for the simulation of and water quality for both urban catchments surfaces and sewer systems. Since pollutants are carried by sediment, sediment transport process and water quality in sewer systems are closely interconnected. This is important for understanding phenomena like the first flush effect, which can only be simulated with a description of the temporal and spatial distribution of sediment deposits on the catchment surface and in the sewer system. MIKE URBAN+ can model these complex mechanism using Surface Water Quality (check catchments module), Advection-Dispersion (AD), and the MIKE ECO Lab engine to solve Biological Processes equations.

### 10.1 Advection-Dispersion (AD)

Advection-Dispersion (AD) simulates the transport of dissolved substances and suspended fine sediments in the network. Conservative materials as well as those that are subject to a linear decay can be simulated. The computed pipe flow discharges, water levels, and cross-sectional flow areas are used in the AD computation. The solution of the advection-dispersion equation is obtained using an implicit, finite-difference scheme which has negligible numerical dispersion. Concentration profiles with very steep fronts can be accurately modelled. The computed results can be displayed as longitudinal concentration profiles and pollutants graphs, which could be used at the inflow to a sewage treatment plant or an overflow structure. The AD can be linked to Long Term Statistics modelling capacities to provide long-term simulation of pollutant transport.

The option to simulate water age and blend in percentages between two sources can be done with the AD module.

The Advection-Dispersion model can be used for calculation of the transport of dissolved or suspended substances, age of water, blend in percent between two sources, and for modelling of water temperature variation within the sewer network. The model is based on the one-dimensional transport equations for dissolved material. The equations reflect two transport mechanisms: the advective (or convective) transport with the mean flow velocity and the dispersive transport due to concentration gradients in the water. The transport equations are solved by use of an implicit finite difference scheme, which is fully time and space centred, in order to minimize the numerical dispersion. The main assumptions of the model are:

- The considered substance is completely mixed over the cross-sections. This implies that a source/sink term is considered to mix instantaneously over the cross-section.
- The substance is conservative or subject to a first order reaction (linear decay).



- Fick's diffusion law can be applied, i.e. the dispersive transport is proportional to the concentration gradient.

Special considerations have been given to the transport at manholes and other structures.

The Advection-Dispersion model requires two types of data: time series of concentrations at the model boundaries and data for full definition of the components to be modelled, e.g. initial concentrations, dispersion coefficients and decay rates.

## Water Quality (WQ) Components

Each of the WQ components (substances) to be included in the Advection-Dispersion computations must be specified in this section shown in the WQ Components dialog. Naming of component is absolutely flexible, and no 'reserved' or 'standard' component names are prescribed.

	ID	Type
1	Component_1	Pollutant
2	Component_2	Pollutant
3	Component_3	Pollutant

Figure 10.1 Water Quality Components

The specified pollution components can be declared as 'Pollutant', 'Microorganism', 'Temperature', 'pH', 'Salinity', 'Water Age', 'Water Blend' and 'Other'. This categorization is needed for correct handling of units: mass per volume (pollutants, other), counts per volume (bacteria), water age in hours, water blend in %, and degrees (temperature). When working with water-quality model, this categorization is further supplemented with other parameters, in order to apply the components in the WQ model properly. Practically, each of the specified components can be connected to a 'standard' component in the WQ module. By these means the WQ module 'knows' how to treat each component.



For each component, specification of an initial condition and decay coefficient can be specified. The decay coefficient cannot be given for water age and water blend type. If the specification of the initial concentration for a certain component has been omitted, a zero concentration is automatically applied.

Water blend concentration must always be given as a number between 0 and 100 percent, and the sum of the two blend components must add up to 100 percent.

Advection-Dispersion initial conditions for pollutants, water blend, water age and temperature can be specified under 'AD Initial conditions'.

Figure 10.2 AD Initial Conditions

The initial conditions are specified for individual nodes. The initial conditions in the connected conduits is calculated by linear interpolation of the concentrations specified in the upstream and downstream nodes.

By defining decay constants, non-conservative components can be specified. For such non-conservative component the concentration is assumed to decay according to the first order expression:

$$\frac{dC}{dt} = KC \quad (10.1)$$

where:

K = the decay coefficient (h<sup>-1</sup>)



C = the concentration

The decay constant is defined as an uniform decay over the entire model.

The AD model can be run with the components specifications only. In this case all model specific parameters (decay constant, dispersion coefficient, initial concentration) as well as boundary conditions are set to zero.

Please note that the sum of the two blend components must always add up to 100.

## AD Dispersion

The dispersion coefficient is specified as a function of the flow velocity. The function is given as:

$$D = au^b \quad (10.2)$$

where:

D = the dispersion coefficient (m<sup>2</sup>/s),

a = the dispersion factor,

u = the flow velocity (m/s),

b = a dimensionless exponent.

If the exponent is set equal to zero, then the dispersion coefficient is constant and independent of the flow velocity. The unit for the dispersion factor will then be m<sup>2</sup>/s. If the exponent is 1, i.e. the dispersion coefficient is a linear function of the flow velocity, then the unit of the dispersion factor will be meter, and the dispersion factor will in this case be equal to what is generally termed the dispersivity. It is possible to specify values of the minimum and the maximum dispersion coefficients, in order to limit the range of the dispersion coefficient calculated during the simulation.





Figure 10.3 AD Dispersion

The dispersion coefficient can be given either globally or locally.

The global description will be used at all locations except for those pipes where local conditions have been specified in the menu.

The dispersion coefficients specified locally, 'override' the global specification

## 10.2 Biological Processes (BP)

Biological processes can be modelled through MIKE ECO Lab, it simulates the reaction processes in multi-compound systems, including degradation of organic matter, bacterial fate, exchange of oxygen with the atmosphere and oxygen demand from eroded sewer sediments. This allows realistic analysis of complex phenomena related to water quality in sewer systems. Biological Processes includes diurnal variation of foul flow discharges and user-specified concentrations of foul flow components. The sediment types included in the interaction with BP are foul flow organic sediments, fine and coarse mineral in-pipe sediments originating from catchment runoff, potholes, and stilling basins. BP can account for:

- Decay of BOD/COD in biofilm and water phase
- Hydrolysis of suspended matter
- Growth of suspended biomass
- Oxygen consumption from decay of BOD/COD, biofilm, and erosion of sediment



- Re-aeration
- Bacterial fate
- Interaction with sediments for nutrients and metals

## 10.3 Water Quality (MIKE ECO Lab Template)

Hydrodynamic and advection-dispersion (transport) simulations can be coupled with MIKE ECO Lab for efficient and versatile simulation of water quality processes in sewer systems. This option opens for practically unlimited range of processes to be simulated, as long as these can be described by a consistent model.

MIKE ECO Lab is a highly flexible and open framework for formulation of water quality models. MIKE ECO Lab utilises a concept of templates where water quality models are defined transparently: Complete contents of the pre-defined templates supplied by the MU installation is accessible for review and can be modified without any need to involve the software vendor. Also, completely new templates can be developed by the user.

The MIKE URBAN+ installation includes two pre-defined water quality templates that can be applied “as is” - or they can be adjusted by the user to conform to the specific project requirements.

A MIKE ECO Lab template is an ASCII file which can be accessed and edited by the MIKE ECO Lab editor. Note that MIKE ECO Lab is part of MIKE Zero and it is necessary to install MIKE Zero and acquire a license for MIKE ECO Lab in order to use MIKE ECO Lab with MIKE URBAN+.

Please consult the MIKE Zero ECO Lab documentation on how to create or modify model templates, i.e. how to work with the MIKE ECO Lab editor.

MIKE ECO Lab implementation in MIKE URBAN+ is limited to coupling the existing MIKE ECO Lab templates for MIKE URBAN+ with the hydrodynamic and transport model and to editing the MIKE ECO Lab model constants during calibration.

A simulation job with the coupled HD/AD and MIKE ECO Lab model is set up and launched from within MIKE URBAN+ in a usual way.

MIKE ECO Lab in MIKE URBAN+ is supported by a set of four MIKE ECO Lab editors in MIKE URBAN+:

- Templates and Assignments
- State Variables
- Forcings
- Constants



These four editors and the database tables behind them are described below.

MIKE ECO Lab templates

Identification

ID:  ☒ Apply

Template file | Connections | Description

Template:

Summary

State variables:  Constants:

Forcings:  Auxiliary variables:

Processes:  Delivered output:

1/1 rows, 0 selected

ID	Apply	Template	File name
1 ECOLAB_template_1	<input checked="" type="checkbox"/>	MIKE URBAN Classic WQ	C:\Program Files (x86)\DHI\MIKE URBAN\2019\Templates\ECO...

Figure 10.4 MIKE ECO Lab Templates



Table 10.1 Field description for MIKE ECO Lab Templates editor

Edit field label	Database field	Description
ECO Lab Template ID	msm_EcoLabTemplate.MUID	User-specified template ID
Description	msm_EcoLabTemplate.Description	Free text description of the template
ECO Lab name	msm_EcoLabTemplate.TemplatePath	Path/filename of the MIKE ECO Lab template
Connection type	msm_EcoLabTemplate.ConnectionType	1 = All 2 = Individual 3 = List
Node	msm_EcoLabTemplate.NodeID	Individual node assignment
Link	msm_EcoLabTemplate.LinkID	Individual link assignment
List	msm_EcoLabTemplate.ListName	Path/filename of the *.MUS file for the template assignment

Pressing <Import> button after the template has been already loaded (imported) into MIKE URBAN+ will re-load the template and any associations of the MIKE ECO Lab state variables with MIKE URBAN+ AD components, as well as any modifications of the MIKE ECO Lab constants will be lost.

### 10.3.1 MIKE ECO Lab State Variables

This editor is used for coupling MIKE URBAN+ AD components to MIKE ECO Lab state variables and for possible reconciliation of differences in units used in MIKE URBAN+ and in MIKE ECO Lab, respectively. The data for this editor is stored in the msm\_EcoLab.Component MU database table.

In MIKE URBAN+ database table msm\_ADComponent there should be an entry for every MIKE ECO Lab state variable defined in the MIKE ECO Lab template. This means that all MIKE ECO Lab state variables are subject to both AD transport mechanisms and to MIKE ECO Lab transformations.

AD components must be specified by the user. These AD components must represent exactly the same constituents as those in the MIKE ECO Lab template, but their names can be freely defined. The specified initial values for the AD components will be applied in the computation. Initial (default) values for the MIKE ECO Lab state variables defined in the template will be ignored.



The import operation described in the MIKE ECO Lab Templates and Assignments section will automatically create the required entries in this table. The user must couple each of these MIKE ECO Lab state variables (components) to the relevant AD component.

The 'Conversion Factor' entry (default value 1, i.e. no conversion) can be set different from 1.0 if the units for the AD components and MIKE ECO Lab state variables are different. Please note that the AD components require a specific unit while MIKE ECO Lab does not require a specific unit for a specific component type.

	ID	MIKE ECO Lab	State variable	WQ component	Conversion factor	Description
1	ECOLAB_Component_8	ECOLAB_template_1	DO	DO	1	
2	ECOLAB_Component_9	ECOLAB_template_1	BOD_dis	BOD_Diss	1	
3	ECOLAB_Component_10	ECOLAB_template_1	BOD_susp	BOD_susp	1	
4	ECOLAB_Component_11	ECOLAB_template_1	ColiF	ColiF	1	
5	ECOLAB_Component_12	ECOLAB_template_1	ColiT	ColiT	1	
6	ECOLAB_Component_13	ECOLAB_template_1	Strep	Strep	1	
7	ECOLAB_Component_14	ECOLAB_template_1	Temperature	Temperature	1	

Figure 10.5 MIKE ECO Lab State Variables

Table 10.2 Field description for MIKE ECO Lab State Variables editor

Edit field label	Database field	Description
Component ID	msm_EcoLabComponent.ComponentID	MIKE ECO Lab state variable identifier
MIKE ECO Lab Template	msm_EcoLabComponent.TempID	MIKE URBAN+ name of the template the component belongs to



Table 10.2 Field description for MIKE ECO Lab State Variables editor

Edit field label	Database field	Description
WQ Component ID	msm_EcoLabComponent.ADComponentID	MU AD component which is coupled to the MIKE ECO Lab state variable
Conversion factor	msm_EcoLabComponent.ConvFactor	Conversion factor for possible units conversion between MU and MIKE ECO Lab

Please note that the only active fields in this editor are those for coupling the MU+ AD components with MIKE ECO Lab state variables, and for specification of the conversion factor.

The <Delete> button has a functionality limited to very special applications, deleting a state variable would destroy the MIKE ECO Lab template functionality, with unpredictable consequences.

### 10.3.2 MIKE ECO Lab Forcings

Forcings are external variables associated with computational points (i.e. are spatially fixed), constant or variable in time, which affect some of the processes on the state variables.

Forcings are “Built-In” or “User-Defined”, “Built-in” means that forcings are provided by the hydraulic model through coupling with MIKE ECO Lab. “User Defined” forcings must be provided by the user, either as constant values or as time series (dfs0 file name and item in the file).

This editor is used for setting the User Defined forcings associated with the loaded MIKE ECO Lab templates. Built-In forcings are also imported into MIKE URBAN, but specification of their values as constants or time series would not have any effect on the MIKE ECO Lab computations.

The data table in MIKE URBAN database containing MIKE ECO Lab forcings is msm\_EcoLabForcing. The database records are created automatically during the template import. The table contains as many forcings as there are in the MIKE ECO Lab template.



ID	MIKE ECO Lab	Forcing ID	TS type	Value	File name	Item	Description
1	7	ECOLAB_template_1	u	Constant	0,2		
2	8	ECOLAB_template_1	dm	Constant	8		
3	9	ECOLAB_template_1	slope	Constant	0		
4	10	ECOLAB_template_1	volume	Constant	200000		
5	11	ECOLAB_template_1	ABiofilm	Constant	100000		
6	12	ECOLAB_template_1	SED_Eroded	Constant	0		

Figure 10.6 MIKE ECO Lab Forcings

Table 10.3 Field description for MIKE ECO Lab Forcings editor

Edit field label	Database field	Description
Forcing ID	msm_EcoLabForcing.ForcingID	MIKE ECO Lab forcing identifier
MIKE ECO Lab Template	msm_EcoLabForcing.TemplateID	MIKE URBAN name of the template the forcing belongs to
Value	msm_EcoLabForcing.DefaultValue	Constant value for the forcing
File	msm_EcoLabForcing.FileName	Path/filename for dfs0 time series file containing forcing TS data
Item	msm_EcoLabForcing.ItemLabel	dfs0 item reference

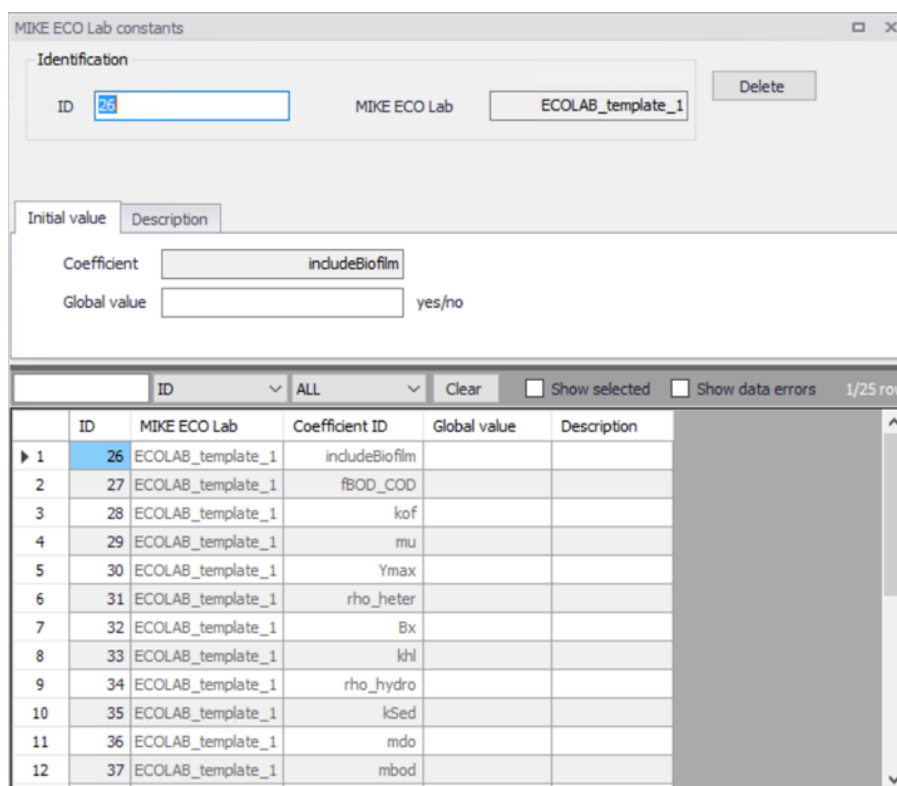
Please note that the only active fields are those for the specification of the forcing's constant value or the reference to dfs0 TS file. The remaining fields are read-only.

The <Delete> button has a functionality limited to very special applications. Deleting a forcing would destroy the MIKE ECO Lab template functionality, with unpredictable consequences.

### 10.3.3 MIKE ECO Lab Constants

This editor is used for setting the values of constants used in the MIKE ECO Lab template, typically in relation to the model calibration.

The data table in MIKE URBAN+ database containing MIKE ECO Lab constants is msm\_EcoLabCoeff. The database records are created automatically during the template import. The table contains as many constants as there are in the MIKE ECO Lab template.



	ID	MIKE ECO Lab	Coefficient ID	Global value	Description
1	26	ECOLAB_template_1	includeBiofilm		
2	27	ECOLAB_template_1	fBOD_COD		
3	28	ECOLAB_template_1	kof		
4	29	ECOLAB_template_1	mu		
5	30	ECOLAB_template_1	Ymax		
6	31	ECOLAB_template_1	rho_heter		
7	32	ECOLAB_template_1	Bx		
8	33	ECOLAB_template_1	khl		
9	34	ECOLAB_template_1	rho_hydro		
10	35	ECOLAB_template_1	kSed		
11	36	ECOLAB_template_1	mdo		
12	37	ECOLAB_template_1	mbod		

Figure 10.7 MIKE ECO Lab Constants





Table 10.4 Field description for MIKE ECO Lab Constants editor

Edit field label	Database field	Description
Coefficient	msm_EcoLabCoeff.CoeffID	MIKE ECO Lab constant identifier
MIKE ECO Lab Template	msm_EcoLabCoeff.TemplateID	MIKE URBAN name of the template the constant belongs to
Description	msm_EcoLabCoeff.Description	Free text description of the template coefficient
Global Value	msm_EcoLabCoeff.CoeffValue	Value of the constant

Please note that the only active field in the one containing the constant value. The remaining fields are read-only.

The <Delete> button has a functionality limited to very special applications, deleting a constant would destroy the MIKE ECO Lab template functionality, with unpredictable consequences.

### 10.3.4 Running MIKE ECO Lab simulation

To run a MIKE ECO Lab simulation, the network model must be prepared in consistency with the MIKE ECO Lab template which is to be simulated. This means that it should contain at least those AD components which are to be coupled with MIKE ECO Lab state variables.

Further, the wanted MIKE ECO Lab template should be imported to MIKE URBAN+. Possible unit inconsistencies must be considered and resolved by providing proper conversion factors. Values of the constant should be reviewed and modified, as appropriate. User-defined forcings should be specified, either as constants or as time series.

The network simulation with MIKE ECO Lab is activated by checking “Transport (AD)” and “ECO Lab” checkboxes, as shown in Figure 10.8. Default integration method (EULER) can be applied in most cases.

The simulation will result in three files containing all the hydrodynamic information (\*.res1d), advection and dispersion results for the state variables (\*AD.res1D) and the auxiliary variables, processes and derived outputs included in the MIKE ECO Lab results file (ADEL.res1D).



Simulation setup

Identification

ID:  ☒ Active project

Scenario:

Insert Copy Delete RUN

General Catchments HD AD and WQ Results

Simulation Type

☐ Catchments

☒ Rainfall-Runoff (RR)

☐ Storm Water Quality (SWQ)

☐ Catchment Discharge (CD)

☐ CD Water Quality

☒ Network (HD)

☐ Long-Term Simulation (LTS)

☒ Pollution Transport (AD)

☒ MIKE ECO Lab (WQ)

Simulation Period

Start:

Duration:     [dddd][hh][mm][ss]

End:

Description

ID Scenario Active Project Catchments Runoff(RR) Stormwater runoff WQ (SWQ) Catchment D

1	teste_2	Base	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
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Figure 10.8 MIKE ECO Lab Check

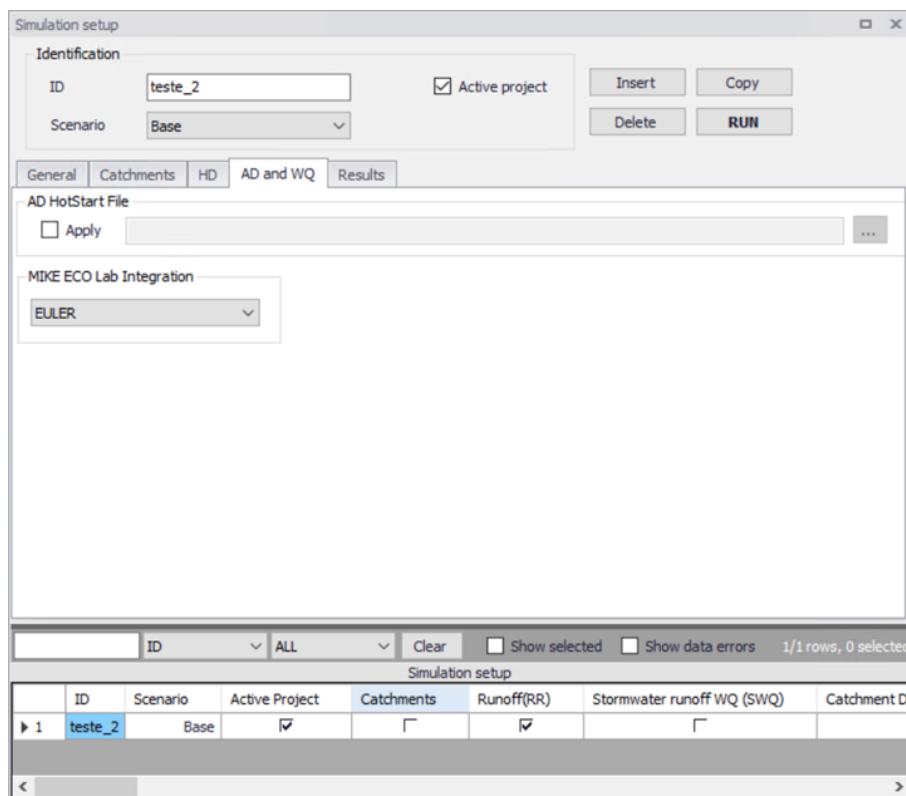


Figure 10.9 MIKE ECO Lab Integration Method

### 10.3.5 The Sediment Transport Models

The sediment transport models in MIKE URBAN+ can be divided into two groups:

- Explicit models
- Morphological models

The main difference between the two model types is that in the explicit models the bed levels are fixed during the simulation. In the morphological models the bed levels / sediment deposits are updated dynamically during the simulation.

#### The Explicit Sediment Transport Models

In the explicit sediment transport models the bed level is fixed throughout the simulation and the only feed-back from the sediment transport computations to the hydrodynamics is established via the Manning number. The sediment transport capacity is calculated in time and space as an explicit function of the corresponding hydrodynamic flow parameters, i.e. the model calculates a

potential sediment transport and no sediment is moved around in the system. The explicit models are in general used to:

- Investigate the hydraulic capacity in pipes with sediment deposits
- Calculation of the sediment transport at locations where the bed levels changes are insignificant during a simulation

## The Morphological Models

The morphological models are:

- Morphological model for uniform sediment
- Morphological model for non-uniform sediment

In the morphological models the sediment transport continuity equation is solved, based on the corresponding values of the hydrodynamic parameters (i.e. discharge, water levels, etc). The feedback to the hydrodynamic module is established through dynamically changed flow area and flow resistance number.

The morphological model for uniform sediment uses one grain diameter at each point in the sewer system to calculate the sediment transport. In the morphological model for non-uniform sediment it is possible to calculate the sediment transport from a range of grain diameters. For the transport of fine organic particles some of the non-uniform sediment fractions can be chosen to be transported by use of the Advection-Dispersion transport formulation instead of the non-cohesive sediment transport formula, as the transport of particles transported in suspension is better described by used of the advection-dispersion equation. The fractions transported by the advection-dispersion module are still included in the morphological calculation, but the description of erosion/deposition is changed.

### 10.3.6 The Transport Formulae - Short Description

The following four non-cohesive sediment transport formulae are implemented in ST:

- Engelund - Hansen
- Ackers - White
- Engelund - Fredsøe - Deigaard
- van Rijn

Short descriptions of the sediment transport formulae are given below. No general guidelines can be given for the preference of one formulation over another, as the applicability of each depends on a number of factors.

All these formulae demonstrate that the sediment transport is a highly non-linear function of the flow velocity: depending on the formulation, the sedi-



ment transport is proportional to the velocity raised to the power from 3 to 5. Hence, the user should be very careful in the description of the hydrodynamics in the model setup.

### The Ackers-White formulae

The formulae determine directly the total sediment transport. The formulae are semi-empirical, based partly on dimensional analysis and partly on physical arguments.

### The Engelund-Hansen formula

The formula determines the total sediment transport directly. It has been derived from consideration of the work done by the flow on the sediment being transported. Originally, the formula was derived for a dune covered bed, but it was found applicable to the upper regimes (plane bed and anti-dunes) as well.

### The Engelund-Fredsøe-Deigaard formulae

The formulae calculate the total transport as the sum of the bed load transport and the suspended transport. The sediment transport is calculated from the skin friction, i.e. the shear stress acting on the surface of the bed. In this formulae it is possible to describe the development of sand dunes in pipes and hence include the resulting friction into the computations. The total bed resistance is then calculated as the sum of a contribution from the skin friction acting on the dune and an expansion loss behind the dune.

### The van Rijn formulae

In the van Rijn sediment transport formulae the sediment transport is divided into bed load and suspended load. The bed load is calculated from the saltation height, the particle velocity and the bed load concentration. The bed load computations follow the approach of Bagnold (1973), which assumes that the motion of the bed load particles is dominated by the gravity forces. When the bed shear velocity exceeds the fall velocity sediment is transported in suspension.

The suspended load is calculated as the depth integration of the local concentration and flow velocity. The method uses the reference concentration computed from the bed load transport. The formula has been verified for particles in the range 200 - 2000 mm. The verification based on 600 data sets, showed that 77% of the predicted bed load rates were within 0.5 and 2 times the observed values, van Rijn (1984a). The verification for the suspended load, using 800 data sets showed that 76% of the predicted values were within 0.5 and 2 times the observed values, van Rijn (1984b).



### 10.3.7 The Flow Resistance in Sewer Systems with Sediment Deposits

The hydraulic resistance in the sewer originates from the pipe wall and from the sediment deposits on the bottom of the sewer. The resistance from the sediment deposits consists of two contributions, one part originates from the grain friction and the other part originates from the expansion loss behind the bed forms. The dimensions of the bed forms are determined by the sediment transport and the flow, the resistance from the bed forms can be described through sediment transport formulae.

The average shear stress in a pipe with sediment deposits is calculated from the Einstein side-wall elimination procedure. The calculation is based on the pipe roughness and the bed shear stress calculated from the sediment.



## 11 Sediment Transport (ST)

Urban drainage networks are exposed to sediment loads carried by wastewater and/or by stormwater runoff. Such sediment loads may vary strongly both in space and time, as well as they may include a variety of particle types, ranging from large pieces of solid waste, street litter, sand and gravel from construction sites and unpaved areas, wind-borne dust, traffic debris, as well as small organic particles originating from wastewater. These sediments, if present in forms and quantities larger than the self-cleansing capacity of the sewer can handle, may create significant operational problems, such as reduced hydraulic capacity, increased overflows and full blockages of sewer pipes. These problems are typically associated with higher operational costs.

Modelling sediments in urban drainage networks does not belong to main-stream modelling work. However, the sediment modelling may be motivated by the wish to understand and eliminate existing or anticipated sediments-related problems, or by the need to document compliance with design criteria in terms of self-maintaining the sediment-free network.

MIKE URBAN+ ST provides a modelling platform for such analyses. Current implementation of sediment transport modelling in MIKE URBAN+ is a truncated version of a full-scale sediment transport model developed for river sediment modelling applications. Scientific background for the implemented solutions can be found in the document MIKE1D\_Reference\_Manual, Sediment Transport (ST).

Inevitably, keeping the modelling apparatus reasonably simple and practically applicable requires some conceptualization of the complex reality. In MIKE URBAN+ this is achieved by limiting the number of model parameters and computational options to those most important ones. The following are examples of simplifications and conceptualization in MIKE URBAN+:

- Various sediment fractions are distinguished by the median grain size ( $D_{50}$ ), relative density and the applied transport mechanism. Typically, the sewer sediments are represented by one coarse fraction ( $D_{50} \geq 0.1$  mm) and one fine fraction ( $D_{50} < 0.1$  mm).
- Transport of the coarse fraction is preferably computed as non-cohesive transport, using one of the available sediment transport formulae.
- Transport of the fine fraction is preferably computed as cohesive transport, with advection-dispersion transport mechanism.

A detailed description of the ST editors and work flows is provided in the following paragraphs.

## 11.1 Types of Sediment Transport Analyses

Two types of sediment transport analyses are supported by MIKE URBAN+ ST:

- Hydraulic effects of fixed bed sediment deposits (so called explicit ST model)
- Morphological analysis

The main differences between the two analysis types are that in the explicit models the bed levels are fixed during the simulation and any sediment boundary conditions are ignored, while in the morphological models the bed levels / sediment deposits are updated dynamically during the simulation (erosion/deposition) due supply of sediments through the model's boundary condition and transport of sediments in the network.

### 11.1.1 The explicit sediment transport model

In the explicit sediment transport analyses the bed level is fixed throughout the simulation and the only feed-backs from the sediment transport computations to the hydrodynamics are established via the reduced cross-section area and flow resistance (Manning number).

The flow resistance in a conduit with sediment deposits is calculated as a weighted average of the Manning number for the horizontal sediment bed and the wetted conduit walls. The Manning number of sediment deposits can be provided either directly or computed automatically, based on the specified sediment fractions grain sizes.

No sediment is moved around in the system and any active sediment boundary condition is ignored.

The explicit ST models are in drainage systems modelling used to:

- investigate the hydraulic capacity in pipes with sediment deposits, i.e. document changes of hydraulic capacity and overflow volume and frequency due to sediment deposits and their removal;
- calculate and map bottom shear stress under representation hydraulic conditions. Result of this analysis may e.g. be used for planning of preventing maintenance (sediment removal) and identification of sedimentation-prone locations.

### 11.1.2 The morphological analyses

In the morphological models the sediment transport continuity equation is solved, based on the corresponding values of the hydrodynamic parameters (i.e. discharge, water levels, etc.). The feedback to the hydrodynamic module





is established through dynamically changed flow area and flow resistance (Manning number).

The morphological ST model in MIKE URBAN+ allows for calculation of sediment transport for any number of specified sediment fractions, i.e. to perform the analysis for non-uniform sediments. However, it is recommended to limit the analysis to two representative fractions - coarse and fine fraction. More complex setups become increasingly difficult to verify and analyse.

The transport of the coarse fraction is modelled by one of four non-cohesive sediment transport formulae:

- Engelund - Hansen
- Ackers - White
- Engelund - Fredsøe - Deigaard
- van Rijn

Short descriptions of the sediment transport formulae are given in the following paragraphs. No general guidelines can be given for the preference of any one formulation over the another, as this may be guided by the modeller's preference.

The transport of the fine fraction (D50 less than 0.1 mm) should preferably be modelled by the Advection-Dispersion transport formulation instead of the non-cohesive sediment transport formula, as the transport of particles transported in suspension is better described by used of the advection-dispersion equation. The fractions transported by the advection-dispersion module are still included in the morphological calculation, but the description of erosion/deposition is changed.

Note, that the morphological models require sediment supply boundary conditions at the model inflow boundaries. At inflow boundaries with no sediment, zero sediment load is assumed.

## 11.2 The Transport Formulae - Short Description

The implemented formulae demonstrate that the sediment transport is a highly non-linear function of the flow velocity: depending on the formulation, the sediment transport is proportional to the velocity raised to the power from 3 to 5. Obviously, a correct description of the hydrodynamics in the model setup is an essential prerequisite for a meaningful and accurate simulation of sediment transport.



### 11.2.1 The Ackers-White formulae

The formulae determine directly the total sediment transport. The formulae are semi-empirical, based partly on dimensional analysis and partly on physical arguments.

### 11.2.2 The Engelund-Hansen formula

The formula determines the total sediment transport directly. It has been derived from consideration of the work done by the flow on the sediment being transported. Originally, the formula was derived for a dune covered bed, but it was found applicable to the upper regimes (plane bed and anti-dunes) as well.

### 11.2.3 The Engelund-Fredsøe-Deigaard formulae

The formulae calculate the total transport as the sum of the bed load transport and the suspended transport. The sediment transport is calculated from the skin friction, i.e. the shear stress acting on the surface of the bed. In this formulae it is possible to describe the development of sand dunes in pipes and hence include the resulting friction into the computations. The total bed resistance is then calculated as the sum of a contribution from the skin friction acting on the dune and an expansion loss behind the dune.

### 11.2.4 The van Rijn formulae

In the van Rijn sediment transport formulae the sediment transport is divided into bed load and suspended load. The bed load is calculated from the saltation height, the particle velocity and the bed load concentration. The bed load computations follow the approach of Bagnold (1973), which assumes that the motion of the bed load particles is dominated by the gravity forces. When the bed shear velocity exceeds the fall velocity sediment is transported in suspension.

The suspended load is calculated as the depth integration of the local concentration and flow velocity. The method uses the reference concentration computed from the bed load transport. The formula has been verified for particles in the range 200 - 2000  $\mu\text{m}$ . The verification based on 600 data sets, showed that 77% of the predicted bed load rates were within 0.5 and 2 times the observed values, van Rijn (1984a). The verification for the suspended load, using 800 data sets showed that 76% of the predicted values were within 0.5 and 2 times the observed values, van Rijn (1984b).

## 11.3 Main Parameters of a Sediment Transport Model (Editor "ST Model")

Setting up a sediment transport model commences in the "ST Model" editor, where the model's main parameters are specified. These parameters are valid for entire model area and for all simulation jobs in the current MU+ project.

### 11.3.1 Selecting type of sediment transport analysis

The wanted type of the ST analysis type is selected in the "ST Model" editor (File | Sediment Transport | ST Model).

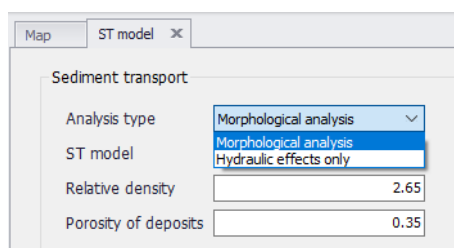


Figure 11.1 Selecting the type of ST analysis

The selected analysis determines the type of results which may be saved as the ST simulation output. Outputs of "Hydraulic effects only" are limited to items: "Bed level", "Manning number" and "Bed shear stress".

When morphological analysis is selected, the preferred transport formula can be selected in the field "ST Model".

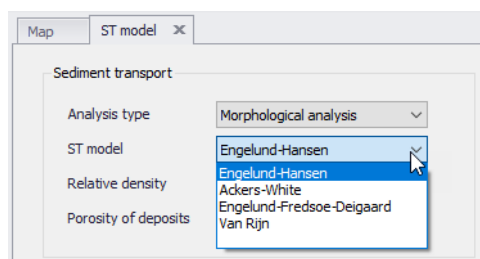


Figure 11.2 Selecting type of ST transport formula

The global sediment parameters (relative density and porosity of sediment deposits) apply for the sediments in the model as the whole and are valid for the entire geographical scope of the model. These parameters are specified in the "ST Model" editor (Setup | Sediment Transport | ST Model).

As they are only relevant for morphological analysis, the default values can be modified only when "Morphological analysis" is selected.



"ST Model" editor fields are described in Table 11.1.

Table 11.1 "ST Model" editor data fields

Edit field	Description	Unit SI	Unit US
Analysis type	Choice between two types of analysis: - Morphological analysis (default) - Hydraulic effects only	-	-
ST Model	Choice between four sediment transport formulae: - Engelund-Hansen - Ackers - White - Engelund - Fredsøe - Deigaard - van Rijn	-	-
Relative density	Density of all sediments in the model, relative to water	-	-
Porosity of deposits	Fraction of sediment deposits volume filled with pores	-	-

## 11.4 Specifying Sediment Fractions (Editor "Sediment fractions")

Any number of individual sediment fractions can be specified (at least one). Sediment fractions are inserted and edited in the "Sediment fractions" editor (Setup | Sediment Transport | Sediment fractions).

Figure 11.3 The "Sediment fractions" editor



Sediment fraction editor fields are described in Table 11.2.

Table 11.2 "Sediment fraction editor data fields"

Edit field	Description	Unit SI	Unit US
ID	Unique identified of a sediment fraction	-	-
Transport mode	Determines the transport mechanism for the sediment fraction: ST Model = transport as non-cohesive sediments by the specified transport formula. Recommended for grain sizes > 0.1 mm AD Model = transport as cohesive sediments suspended in water, with deposition and erosion. Recommended for fine sediments with grain sizes ≤ 0.1 mm	-	-
Grain size	Median grain size (D50) for the sediment fraction	mm	in
Pct. of total sediment volume	Percent of total sediment volume. Sum for all fraction shall be 100%	%	%
Fall velocity mode	Specified: user-specified fall velocity Computed: fall velocity computed by Rubey formula (1933), based on sediment fraction grain size, sediment relative density and water viscosity (at 20 deg.C)	cm/s	In/s
Erodibility coeff.	Determines the rate of erosion when bottom shear stress exceeds critical value for erosion (only for AD transport mode)	g/m <sup>2</sup> /s	g/m <sup>2</sup> /s
Tau crit. (deposition)	The maximum value of bottom shear stress at which sedimentation of the actual fraction will occur (only for AD transport mode)	N/m <sup>2</sup>	N/m <sup>2</sup>
Tau crit. (erosion)	The minimum value of bottom shear stress at which erosion of the actual fraction will occur (only for AD transport mode)	N/m <sup>2</sup>	N/m <sup>2</sup>



## 11.5 The Flow Resistance and Initial Sediment (Editor "Initial sediment depths and friction")

### 11.5.1 The flow resistance due to sediment deposits in sewers

The hydraulic resistance in the sewer originates from the pipe wall and from the sediment deposits on the bottom of the sewer. In general, the flow resistance from the sediment deposits consists of two contributions: one part originates from the grain friction and the other part originates from the expansion loss behind the bed forms (ripples, dunes, etc.). In MIKE URBAN+ ST, only the flow resistance from the sediment grains is calculated.

The flow resistance of the horizontal sediment bed can be specified explicitly (as Manning number) or it can be calculated based on the sediment grain size and bed shear stress. Both methods can be applied globally (i.e. for entire model) and for individual conduits. Any local definition overrides the global specification.

The average shear stress in a pipe with sediment deposits is calculated from the Einstein side-wall elimination procedure. The calculation is based on the pipe roughness and the bed shear stress calculated from the sediment deposits.

### 11.5.2 Initial sediment depths

Specification of initial sediment depths in the model's links is important in two cases:

- In morphological analysis, as correct initial conditions, e.g. according to the observed situation
- In hydraulic effects analysis, as a fixed-bed sediment deposits, representing e.g. observed situation or assumed sedimentation scenario

The specified sediment depth is assumed uniform along entire link.

### 11.5.3 "Initial sediment depths and friction" editor

Initial sediment depths and sediment deposits friction are defined in the "Initial sediments depths and friction" editor (Setup | Sediment Transport | Initial sediment depths and friction).

Initial sediment depths and friction can be specified globally (for all links in a model), or specifically for individual links or selection of links. The local definitions override the global definition.



Figure 11.4 The "Initial sediment depths and friction" editor

"Initial sediment depths and friction" editor fields are described in Table 11.3..

Table 11.3 "Initial dediment depths and friction" editor data fields

Edit field	Description	Unit SI	Unit US
Global data - Sediment depth	Uniform sediment depth in all model's conduits	m	ft
Global data - Manning type	Determines the model-wide method for the definition of sediment deposits flow resistance:  Specified = Manning number (M) value for sediment deposits is specified directly Computed = Manning number (M) value for sediment deposits is calculated, based on grain size and shear stress		
Global data - Manning value	Model wide directly specified Manning number (M) for sediment deposits		
Link ID	Identifier of a single link where local sediment depth and/or friction definition method, and (optionally) Manning number is to be specified. This definition overrides the global and "List" definition		
List	Selection of links where local sediment depth and/or friction definition method, and (optionally) Manning number is to be specified. This definition overrides the global definition		
Sediment depth	Uniform sediment depth in specified conduits (links)	m	ft



Table 11.3 “Initial dediment depths and friction” editor data fields

Edit field	Description	Unit SI	Unit US
Manning type	Determines the method for the definition of sediment deposits flow resistance in specific links:  Specified = Manning number (M) value for sediment deposits is specified directly Computed = Manning number (M) value for sediment deposits is calculated, based on grain size and shear stress		
Manning value	Directly specified Manning number (M) for sediment deposits in specific links		

## 11.6 Removal of Non-cohesive Sediments in Basins (Editor "Sediment removal in basins")

Basins act as "sediment traps" because the water flow kinetic energy and turbulence (hence, dynamic forces acting on sediments) are much lower than in the conduits. Sedimentation in basins may in some cases be an unwanted side-effect and an operational problem (need for frequent sediment removal), while in other cases it may be deliberately designed to induce sedimentation.

MIKE URBAN+ ST does not simulate sedimentation in basins: both non-cohesive (ST) and cohesive (AD) sediment transport continues unaffected through basins (actually, through any node in the model).

However, effect of basins on sediment transport (non-cohesive sediments transport only) may be emulated by defining a sediment removal efficiency in individual basins. This function simply removes the specified fraction of the inflowing non-cohesive (ST transport) sediments.

Cohesive sediments (AD transport) are not affected by this function.

Removal of non-cohesive sediment in basins is defined in the "Sediment removal in basins" editor (Setup | Sediment Transport | Sediment removal in basins).





Figure 11.5 The "Sediment removal in basins" editor

"Sediment removal in basins" editor fields are described in Table 11.4..

Table 11.4 "Sediment removal in basins" editor data fields

Edit field	Description	Unit SI	Unit US
ID	Unique identifier of sediment removal definition	-	-
Basin ID	Identifier of actual basin	-	-
Removal coefficient	Fraction of inflowing non-cohesive sediment to be removed in the actual basin	-	-

The sediment removed in basins can be reported in ST output file for each basin individually as sediment and mass transport (instantaneous and accumulated) for each ST fractions separately and for total sediment transport.

## 11.7 Removal of non-cohesive sediments in weirs

Weirs act as efficient barriers for non-cohesive sediment transport, as the weir crest levels are normally significantly higher than the conduit's invert. This means that significant part of non-cohesive sediment cannot be transported over weirs.

MIKE URBAN+ ST simulates effect of weirs on sediment transport (non-cohesive sediments transport only) by defining a constant sediment removal efficiency or removal efficiency as function of weir discharge. This function simply removes the specified fraction of the non-cohesive (ST transport) sediments from the weir flow.

Removal of non-cohesive sediment in weirs is defined in the "Sediment removal in weirs" editor (Setup | Sediment Transport | Sediment removal in weirs).



Figure 11.6 The "Sediment removal in weirs" editor

"Sediment removal in weirs" editor fields are described in Table 11.5..

Table 11.5 "Sediment removal in weirs" editor data fields

Edit field	Description	Unit SI	Unit US
ID	Unique identifier of sediment removal in weirs definition	-	-
Weir ID	Identifier of actual weir	-	-
Method	Constant efficiency: sediments removal by efficiency factor  Efficiency (flow): sediment removal efficiency specified as function of weir flow	-	-
Efficiency factor	Fraction of non-cohesive sediment to be removed from the actual weir flow (only with "Constant efficiency")		
Efficiency function	Reference to a tabular function of type "Removal efficiency" (only with "Efficiency(flow)")		

The sediment removed in weirs can be reported in ST output file for each weir individually as sediment and mass transport (instantaneous and accumulated) for each ST fractions separately and for total sediment transport.

## 11.8 Sediment transport boundary conditions

Sediment transport boundary conditions are only relevant for morphological analysis. For "Hydraulic effects only" type of analysis, no sediment boundary conditions are needed. Any active sediment boundary conditions are ignored in the sediment transport analysis is specified as "Hydraulic effects only".



Sediment transport boundary conditions may be specified at any inflow boundary in the model (upstream boundary) and at outlet water level boundaries (downstream boundary).

Sediment inflows to a drainage model can be specified either in association with catchment model or with network model, defined as "WQ boundary properties" for the any hydraulic or SWQ boundary conditions.

The sediment boundary (only for AD transport) can also be specified in association with outlet water level boundary for a network model.

For most of boundary condition types, the sediment boundary properties are specified directly as sediment concentration in the inflowing water ( $\text{ML}^{-3}$ ). For SWQ boundaries, sediments inflows are defined either as a tabular function (specific runoff vs. sediment concentration) or are calculated by SWQ advanced methods (BuildUp/WashOff and EMC).

A schematic overview over the possible types of sediment boundary conditions is presented in Table 11.6.

Note that when running an integrated simulation (Catchment + Network simultaneously), sediment outputs from the catchment model are automatically transferred to the network model at the locations of catchments connections to the network model. If the simulations of catchment and network models are run separately in a sequence, the catchment model's sediment outputs must be specified as WQ boundary properties of the corresponding hydraulic boundary conditions to the network model.

**Table 11.6**    Overview over possible sediment boundary conditions.



	Boundary condition type	WQ boundary property (for each sediment fraction)				
		Constant	Cydic	Time series /result file	Table concentration	SWQ advanced
Catchment model	Catchment discharge	YES, sediment concentration	YES, sediment concentration	YES, sediment concentration	NO	NO
	Catchment discharge per PE					
	Catchment discharge per area		NO		YES, sediment concentration as function of runoff intensity	YES, SWQ calculation
	Stormwater loads (surface)					
	Stormwater loads (RDII)					
Network model	Inflow to node	YES, sediment concentration	YES, sediment concentration	YES, sediment concentration	NO	NO
	Inflow to link					
	Inflow from result file					
	Exfiltration from node	NO	NO	NO		
	Exfiltration from link					
	Outlet water level	YES, sediment concentration, AD transport only	YES, sediment concentration, AD transport only	YES, sediment concentration, AD transport only		

## 11.9 Sediment transport outputs

Per default, MIKE URBAN+ ST generates an output file "Default\_Network\_ST" with basic contents, including Total sediment transport and sediment transport per fraction.

This default contents can be expanded to include a full range of relevant results: sediment transport (instantaneous and accumulated), mass transport (instantaneous and accumulated), bed level, bed shear stress, Manning number.

Overview of possible outputs is presented in Figure 11.7.



Result files

Identification

ID:  Model type:  Insert

Content type:  Format:  Copy

Delete

Save all HD Items AD Items **ST Items** ECO Lab

Basic items

- ☒ Total sediment transport
- ☒ Sediment transport (per fraction)

Additional items

- ☒ Bottom level
- ☒ Bed shear stress
- ☒ Dimensionless bed shear stress
- ☒ Manning number
- ☒ Total mass transport
- ☒ Mass transport (per fraction)
- ☒ Total accumulated mass transport
- ☒ Accumulated mass transport (per fraction)
- ☒ Total accumulated sediment transport
- ☒ Accumulated sediment transport (per fraction)
- ☒ Suspended sediment concentration (per fraction)
- ☒ Total Bed load removal
- ☒ Bed load removal (per fraction)
- ☒ Total accumulated bed load removal
- ☒ Accumulated bed load removal (per fraction)
- ☒ Mass balance (per fraction)

Figure 11.7 The output items for sediment transport model

## 11.10 Sediment Transport Modelling Work Flows

Several typical work flows in modelling sediment transport are presented below.

### 11.10.1 Analysis of hydraulic effects of sediment deposits

This analysis focusses on the hydraulic effects (changes in flow capacity, overflows, surcharge, etc.) as consequence of fixed bed sediment deposits in the network.

**Step1:** Prepare a stable and well-calibrated drainage network model, loaded with representative hydraulic inflows

**Step 2:** Set the "Sediment transport | ST Model" analysis type to "Hydraulic ef-fects only".

**Step 3:** Specify at least one sediment fraction (Sediment transport | Sediment fractions). Fractions' basic properties (grain size and percent of total sediments) are only relevant if sediment flow resistance (Manning number) is specified as "Computed" (see Step 5). Fall velocity is not relevant for the specified type of analysis.



**Step 4:** Specify initial sediment depths (fixed-bed sediment depths), globally and, optionally, locally. The local sediment depth specifications override global specification.

**Step 5:** Specify flow resistance for sediment deposits, globally and, optionally, locally. The local Manning number specifications override global specification.

**Step 6:** Outputs. Review the contents of the default output file for sediment transport (Default\_Network\_ST) and include the wanted output items. Note that this type of analysis generates only result items "Bottom level", "Bottom shear stress", and "Manning number". Alternatively, make a copy of default network result file, change its contents type to "Mixed contents" and add the wanted ST result items.

**Step 7:** Set up ST simulation. Create a simulation job, including "Network (HD)" and "Sediment transport (ST)". Set appropriate simulation period, simulation time step and hot-start file (optionally).

**Step 8:** Review output files to be generated and set appropriate result saving frequency

**Step 9:** Run a simulation

**Step 10:** Review results

### 11.10.2 Analysis of wastewater sediments transport in a drainage network

This is a morphological analysis of sedimentation in a wastewater collection network. The analysis includes sediment loads from wastewater inflows generated on urban catchments, and their transport, sedimentation and erosion in the sewer network.

**Step1:** Prepare a stable and well-calibrated drainage network model, loaded with representative hydraulic inflows, defined as "Catchment discharge", representing wastewater generated by population in the catchments. Wastewater load is defined by quantity and diurnal variation.

**Step 2:** Set the "Sediment transport | ST Model" analysis type to "Morphological analysis". Choose the ST formula and review basic sediments properties (relative density and porosity of deposits).

**Step 3:** Specify at least one sediment fraction (Sediment transport | Sediment fractions) and review/modify its properties.

**Step 4:** Specify initial sediment depths, globally and, optionally, locally. The local sediment depth specifications override global specification.



**Step 5:** Specify flow resistance for sediment deposits, globally and, optionally, locally. The local Manning number specifications override global specification.

**Step 6:** Specify WQ Boundary properties for the wastewater boundary condition, as sediment concentration in wastewater, separately for each sediment fraction. The concentration may be given as a constant or as diurnal variation.

**Step 7:** Outputs. Review the contents of the default output file for sediment transport (Default\_Network\_ST) and include the wanted output items. Alternatively, make a copy of default network result file, change its contents type to "Mixed contents" and add the wanted ST result items.

**Step 8:** Set up ST simulation. Create a simulation job, including "Catchments | Catchment discharge | Catchment discharge WQ" and "Network (HD) | Sediment transport (ST)".

Set appropriate simulation period, simulation time step for catchment discharge and for network simulation, and hot-start file for the network model (optionally).

**Step 9:** Review output files to be generated and set appropriate result saving frequency.

**Step 10:** Run a simulation

**Step 11:** Review results

### 11.10.3 Analysis of stormwater sediments buildup/washoff ("first flush") and sediment transport in a drainage network

This is a morphological analysis of sedimentation in a wastewater collection network. The analysis includes sediment loads from storm runoff, generated on urban catchments, and their transport, sedimentation and erosion in the sewer network

**Step 1:** Prepare a stable and well-calibrated drainage network model, loaded with representative rainfall, defined as "Rainfall" boundary condition.

**Step 2:** Set the "Sediment transport | ST Model" analysis type to "Morphological analysis". Choose the ST formula and review basic sediments properties (relative density and porosity of deposits).

**Step 3:** Specify at least one sediment fraction (Sediment transport | Sediment fractions) and review/modify its properties.

**Step 4:** Specify initial sediment depths, globally and, optionally, locally. The local sediment depth specifications override global specification.



**Step 5:** Specify flow resistance for sediment deposits, globally and, optionally, locally. The local Manning number specifications override global specification.

**Step 6:** Define buildup/washoff parameters for the specified sediment fractions or the model's catchments

**Step 7:** Define SWQ boundary condition (Stormwater loads (surface) and its WQ properties, based on SWQ advanced method "BuildUp Washoff".

**Step 8:** Outputs. Review the contents of the default output file for sediment transport (Default\_Network\_ST) and include the wanted output items. Alternatively, make a copy of default network result file, change its contents type to "Mixed contents" and add the wanted ST result items.

**Step 9:** Set up ST simulation. Create a simulation job, including "Catchments | Rainfall-Runoff (RR) | Storm water quality (SWQ)" and "Network (HD) | Sediment transport (ST)".

Set appropriate simulation period, simulation time step for runoff and for network simulation, and hot-start file for the network model (optionally).

**Step 10:** Review output files to be generated and set appropriate result saving frequency

**Step 11:** Run a simulation

**Step 12:** Review results





## 12 Calibrations

Model calibration is important to ensure that model predictions represent the actual hydraulic and water quality conditions in the system. Calibration of the model is important when model results are to be used for decisions regarding remedial actions, augmentation works, forecasting, etc.

Calibration is primarily focused on reproducing the observed hydraulics and water quality behaviour of the system in terms of flow depth/pressure, flow discharges and velocities. The model calibration should include comparisons between model simulation results and field measurements for, but not limited to, the following:

- Flow
- Water level / Pressure / Hydraulic head
- Velocity
- Water mass balance
- Contaminant concentrations
- Contaminant migration rates
- Degradations rates

Usually these comparisons are presented in maps, tables or graphs. The calibration results need to be evaluated by the modeller using engineering professional judgement. There are no universally accepted 'goodness of fit' criteria that can be applied in all cases. However it is important that the user makes every attempt to minimize the difference between model simulations and measured field data.

The model calibration procedure is supported in MIKE URBAN+ wherein calibration plots of simulated and measured value can be set up and visually compared. Also, statistical analysis can be performed to determine the goodness of fit in MIKE URBAN+. The calibration plots and statistics are written to a report as documentation and for further report processing.

### 12.1 Measurement Stations

Measurement stations, representing locations of flow gauges, pressure meters, and the like, can be defined in MIKE URBAN+. It is possible to graphically add a measurement station on the map as well as directly on the editor (Calibrations | Measurement Stations) (Figure 12.1).

	ID	X coordinate [m]	Y coordinate [m]	Location type	Location ID	Chainage
1	Station_1	708822,886005698	6165044,98065347	Nodes	Olsbaek_5225	Downstream
2	Station_2	711477,237785518	6166506,63159307	Nodes	KystRender_960	Downstream

Figure 12.1 The Measurement Stations Editor

The stations can be viewed on the Map providing the user an overview of monitoring locations. Additional information such as an image and description may be provided for a station.

Graphically add a station on the map using the 'Create' layer editing tool, specifying 'Measurement stations' as the Target layer. As with other point layers, the 'Create', 'Edit', and 'Delete' tools are available for measurement stations.

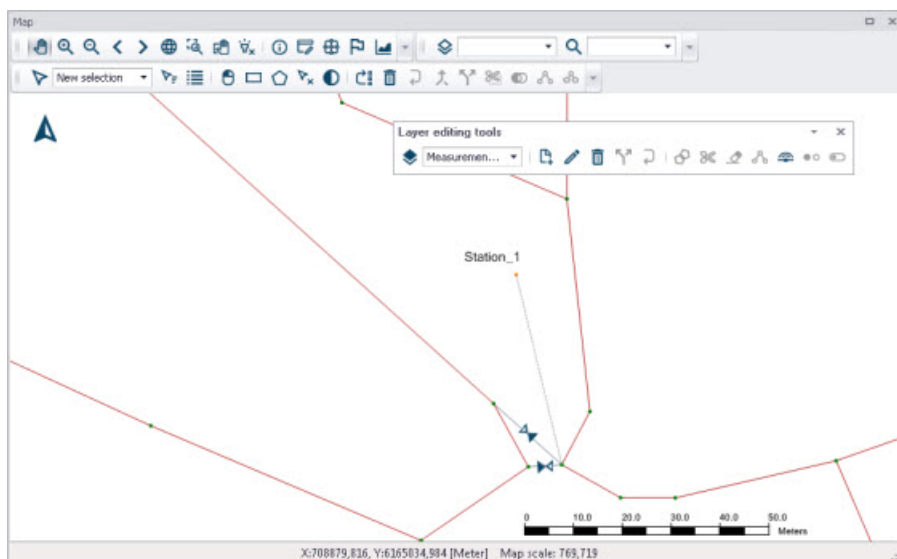


Figure 12.2 Graphically add or edit Measurement Stations on the Map using Layer Editing Tools. The example shows the creation of 'Station\_1' on the map.

The various parts of the Measurement Stations editor are described in succeeding sections.

### 12.1.1 Identification

The Identification group box holds information on the measurement station ID and location. Use the 'Insert' button to add new measurement stations in the Editor.

 The screenshot shows the 'Identification' group box in the Measurement Stations Editor. It contains an 'ID' field with the value 'Station\_2'. To the right, there are two input fields for coordinates: 'X:' with the value '711477,237785518 [m]' and 'Y:' with the value '6166506,63159307 [m]'. At the bottom right of the group box are two buttons: 'Insert' and 'Delete'.

Figure 12.3 The Identification group box on the Measurement Stations Editor

### 12.1.2 Model Connection

The stations need to be associated (i.e. geocoded) with elements of the model network to link the measurement station with a modelling result item.

Associate measurement stations with specific model elements in the Model Connection tab on the Measurement Stations Editor (Figure 12.4).

Figure 12.4 The Model Connection Tab on the Measurement Stations Editor

### Model Element Type

Define the model element type to be associated with a measurement station by selecting an element type from the dropdown menu. Model element types that may be linked to stations are:

- Nodes
- Pipes and Canals
- Pumps
- Weirs
- Orifices
- Valves
- Curb Inlets

### Model Element ID

Define the ID for the particular model element to associate with a station.

Use the ellipsis button to select the ID from a list.

Use the cursor button to graphically select the element on the Map.

### Chainage

For stations connected to links, there is an option to specify the chainage or computational grid point of the connection - either Upstream, Middle or Downstream of the link.

Note that connections lines between stations and the network are displayed on the map after model connections are specified for stations. Also, on the Map View, the 'Connect station' tool is available from the 'Layer editing tools' toolbar for connecting stations to network elements.



### 12.1.3 Measurements

Define time series for externally measured data for a station in the Measurements Tab on the Measurement Stations editor (Figure 12.5).

Add an external time series item via the secondary grid in the tab by specifying the time series file location under the 'File' column. A plots of a specified time series is shown to the right of the secondary grid.

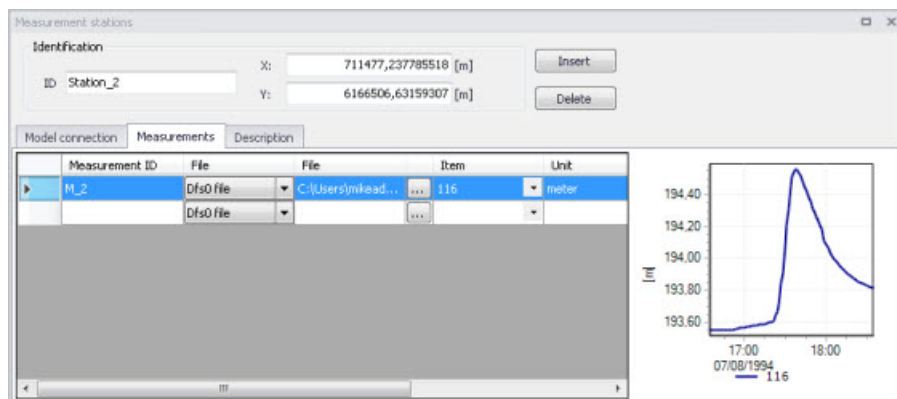


Figure 12.5 The Measurements Tab on the Measurement Stations Editor

The Measurements secondary grid has the following data columns:

#### Measurement ID

The unique identifier for the measurement time series.

#### File

Measurement time series data may be in .DAT or .DFS0 file formats.

#### Item

The item to use from the time series file.

#### Unit

Displays the units for the selected time series item.

#### Start

Displays the start date and time for the time series.

#### End

Displays the end date and time for the time series.

#### Action (Edit)

Launches the Plots and Statistics Editor wherein comparisons of the measured data with simulation results may be configured.



### 12.1.4 Description

The Description tab allows the modeller to add descriptive information for the Measurement Station. An image may also be added using the 'Add picture' button.

The screenshot shows the 'Measurement stations' dialog box with the 'Description' tab selected. The 'Identification' section contains fields for ID (Station\_2), X (711477,237785518 [m]), and Y (6166506,63159307 [m]), with 'Insert' and 'Delete' buttons. The 'Description' section has a list of fields: Description (Basin), Data source (Utility), Asset ID (Basin 1), Status (4: Inserted), Network type (3: Combined), Bottom level (0 [m]), and Model (1: Overall). An 'Add picture' button is located to the right of the Description field.

Figure 12.6 The Description Tab on the Measurement Stations Editor

Table 12.1 below shows an overview of the various parameters on the Measurement Stations Editor.

Table 12.1 Overview of the Measurement Stations editor attributes (Table m\_Station)

Edit field	Description	Used or required	Field name in data structure
ID	Station identified	Yes	MUID
X	X coordinate of the station	Yes	-
Y	Y coordinate of the station	Yes	-
Model Element Type	Type of connected model element	Yes	LocationType
Model Element ID	ID if connected model element	Yes	LocationID
Chainage	Model element grid point associated with measurements	Yes If Model Element Type = Pipes and canals	Chainage



Table 12.1 Overview of the Measurement Stations editor attributes (Table m\_Station)

Edit field	Description	Used or required	Field name in data structure
Description	Free text description of the measurement station	Optional	Description
Data Source	Source of data	Optional	DataSource
Asset ID	Station ID in asset database	Optional	AssetName
Status	Information on data status	Optional	Element_S
Network Type	Information on the type of network	Optional	NetTypeNo
Bottom Level	Bottom level at measurement point	Optional	BottomLevel
Model	Model group under which the station is categorised	Optional	SubModelNo

## 12.2 Plots and Statistics

The Plots and Statistics dialog allows the user to compare measured data with simulation results at measurement stations.

Set up a calibration plot on the Plots and Statistics Editor (Figure 12.7), where a reference file with observation data is loaded and compared to a result file. Multiple plot and statistics setups may be created for a project.

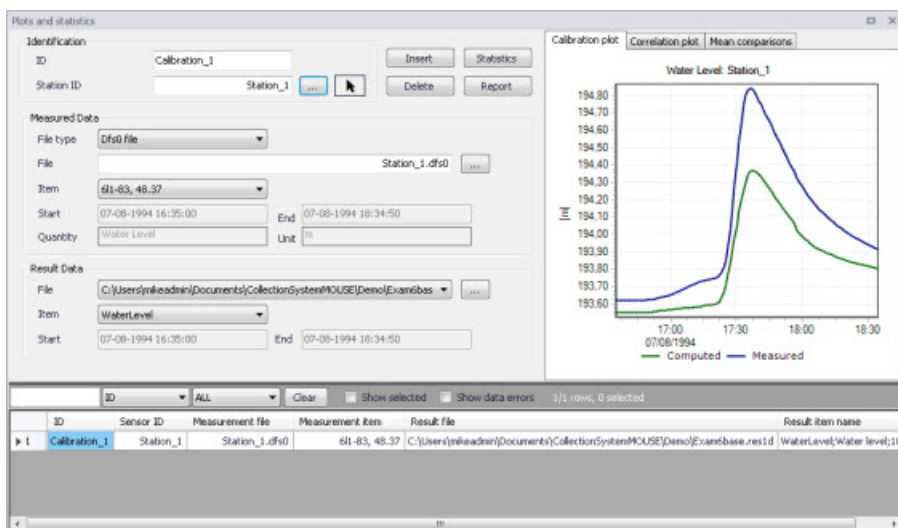


Figure 12.7 The Plots and Statistics dialog

The user can opt to plot a correlation plot, presenting the deviation of simulated results from observed data.

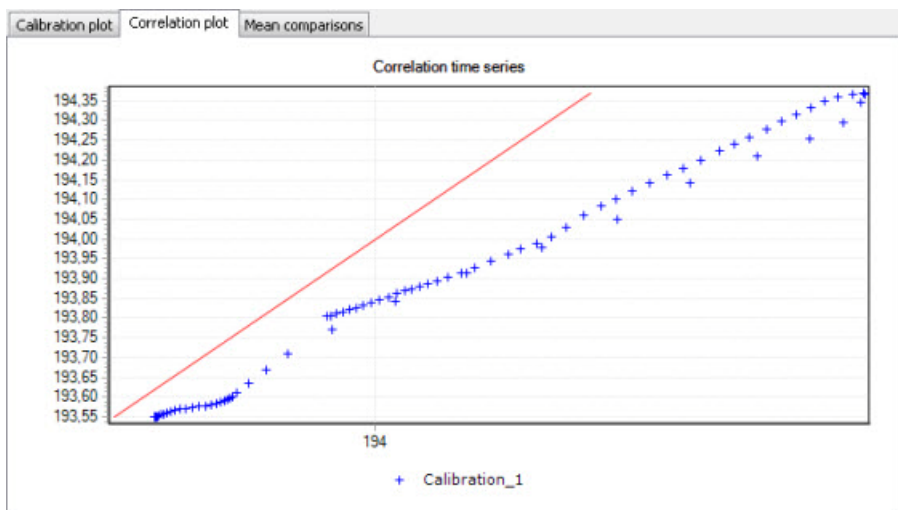


Figure 12.8 Example correlation plot

Below is an example of a mean comparison plot wherein the mean value for simulated results is compared to the mean value for measured data.



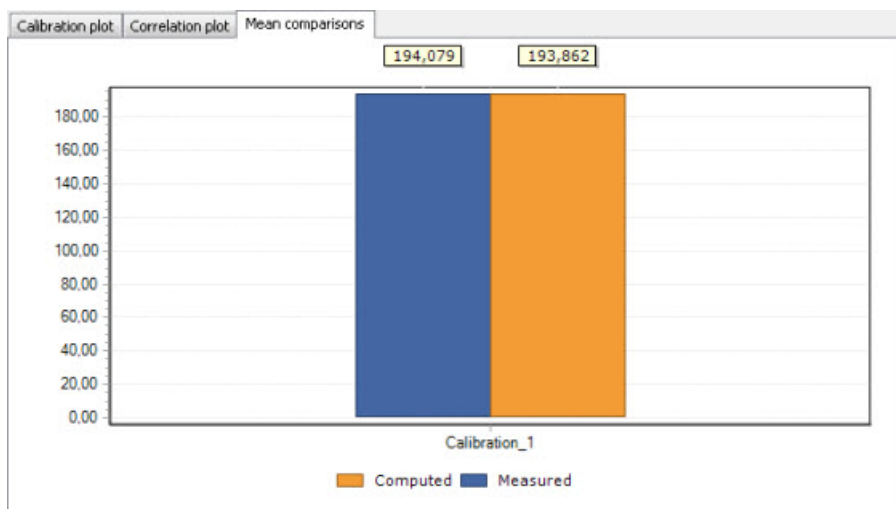


Figure 12.9 Example mean comparison plot

Table 12.2 Overview of the Plot and Statistics editor attributes (Table m\_Measurement)

Edit field	Description	Used or required	Field name in data structure
ID	Each time a record is added an automatic ID is given of the form: Calibration_1, Calibration_i.... This may be changed to something more descriptive	Yes	m_Measurement.MUID
Station ID	The ID of the Measurement Station	Yes	m_Measurement.StationID
File Type	Measurement time series data may be in .DAT or .DFS0 file formats.	Yes	-
Measured Data File	External file name and path - this is where the measured time series is linked to the measurement station	Yes	TSFileName



Table 12.2 Overview of the Plot and Statistics editor attributes (Table m\_Measurement)

Edit field	Description	Used or required	Field name in data structure
Measured Data Item	Display of item in the measured time series	Yes	TSItemName
Measured Data Start	Auto filled with the time series file start time. Used to control the Start time for comparison	Yes	-
Measured Data End	Auto filled with the time series file end time. Used to control the End time for comparison	Yes	-
Measured Data Quantity	Displays item name for selected item from measurement time series	Yes	-
Measured Data Unit	Displays units used for selected item from measurement time series	Yes	-
Result Data File	Result file name and path	Yes	ResFileName
Result Data Item	The result file item being compared to measurements	Yes	ResItemName
Result Data Start	Display of simulated result time series start date and time	Yes	-
Result Data End	Display of simulated result time series end date and time	Yes	-

The following button functionalities are available on the Plots and Statistics dialog:

#### Insert

Inserts a new Plot and Statistics item.



### Delete

Deletes the active Plot and Statistics item.

### Statistics

Displays various statistics parameter values, such as Mean error and RMS error, used for evaluating the comparison between simulated values and measurements.

### Report

Option for exporting a report in various file formats about the time series comparisons.





## 13 Result Specifications

MIKE URBAN+ allows flexible generation of model simulation result files and summaries. Various result file setups may be specified in the Result Specifications section, which may then be used in a simulation as needed by the user.

Result files obtained from simulations may be customised with respect to the number of result files generated, file types, spatial extent of saved results, and types of result items included in the files.

In MIKE URBAN+, **one result file** may be set up to contain **multiple result sets** comprised of **various location-item combinations** (see Sections 13.1.4 and 'User-specified results').

Result file and custom network summary specifications are defined under the following editors:

- **Result Files.** Result files obtained from simulations may be customised with respect to the number of result files generated, file types, spatial extent of saved results, and types of parameters included in the files.
- **Network Summary.** Basic HTML summaries for network simulations may be extended by adding supplementary tables to the summary.

### 13.1 Result Files

The Result Files editor (Figure 13.1) provides a facility for viewing and specifying result file setups in a project. The types or results available depend on the active Modules for the project (General Settings | Modules).

Result setups are a mix of Default and User-specified results.

#### Default results

The editor is initially filled with Default result setups. A Default set is shown for each active Module in the project. These records are distinguished by the "Default\_" prefix in their IDs.

The following table shows an overview of the various Default result files that are possible in MIKE URBAN+.

Table 13.1 Overview of possible Default result files in MU+

Default ID	Model Type	Format	Content Type
Default_Surface_runoff	Catchments	.RES1D	Surface runoff
Default_RDII	Catchments	.RES1D	RDII



Table 13.1 Overview of possible Default result files in MU+

Default ID	Model Type	Format	Content Type
Default_Storm_water_quality	Catchments	.RES1D	Storm water quality
Default_Storm_water_sediments	Catchments	.RES1D	Storm water sediments
Default_LIDs	Catchments	.DFS0 (currently hard-coded)	LIDs
Default_Catchment_discharge	Catchments	.RES1D	Catchment discharge
Default_Catchment_discharge_quality	Catchments	.RES1D	Catchment discharge quality
Default_Network_HD	Network	.RES1D	Hydrodynamic
Default_Network_RTC	Network	.RES1D	Real time control
Default_Network_AD	Network	.RES1D	Pollution transport
Default_Network_-_MIKE_ECOLab	Network	.RES1D	MIKE ECO Lab
Default_LTS_extreme_statistics	Network	.RES1D	LTS extreme statistics
Default_LTS_chronological_statistics	Network	.RES1D	LTS chronological statistics
Default_2D_overland	2D Overland	DFSU / DFS2	2D area
Default_2D_overland_AD	2D Overland	DFSU / DFS2	2D area, AD
Default_2D_-_Flood_statistics	2D Overland	DFSU / DFS2	2D flood statistics
Default_2D_Volume_balance	2D Overland	DFS0	Volume balance

Default result sets include results in all model elements, saving values for the basic calculation parameters.

Default result sets may be modified with respect to:

- File format: .RES1D or .DFS0 file format.
- Result items: Calculated parameters to be included in the file. Only basic result items are initially included in Default result setups.



Note that the saving locations may not be modified for Default results, and results will always be saved in all elements.

Also note that for some content types, only one file format is allowed and cannot be changed.

## User-specified results

The user may also define custom result file setups according to their modelling needs.

The following properties may be customised for user-specified results:

- File format
- Location: Spatial extent or network elements for which results are saved in the file.
- Result items: Calculated parameters to be included in the file.

Note that **multiple result sets comprised of various location-item combinations may be specified for one user-specified result file** (see Section 12.1.4 for more details).



ID	Model type	Content type
1	Catchments	Surface runoff
2	Catchments	RDII
3	Catchments	Storm water quality
4	Catchments	Storm water sediments
5	Catchments	LIDs
6	Catchments	Catchment discharge
7	Catchments	Catchment discharge quality
8	Network	Hydrodynamic
9	Network	Pollution transport
10	Network	Sediment transport
11	Catchments	Mixed catchment
12	Network	Mixed content

ID	Location type	Subset type	Individual type
1	Save all	Selection	Node

Figure 13.1 The Result Files Editor

The various data tabs and components of the Result Files editor are described in succeeding sections.

### 13.1.1 Identification

The Identification group box on the Result Files editor contains general information on a result file item.

ID	Model type	Content type	Format
Default_Network_HD	Network	Hydrodynamic	.res1d

Figure 13.2 The Identification group box on the Result Files Editor





## Model Type

Each result file item is categorised based on the type of model from which it is generated. The model may either be a Catchment model, a Network model (comprising CS network and/or River network) or a 2D Overland model.

## Content Type

This parameter characterises result files according to the calculation modules, and filters the available result items that may be included in the result file setup. The available categories depend on the selected Model Type for a result file setup.

Note that there are also “mixed content” types, which allow flexibility in terms of mixing result items across various active computational modules in one result file setup (See Section 13.1.4).

Content Type can be:

- For ‘Catchments’ Model Type:
  - Mixed catchment contents. Content type for which result items across various active catchment model-related computational modules may be included.
  - Surface runoff
  - RDII
  - Storm water quality
  - Storm water sediments
  - LIDs
  - Catchment discharge
  - Catchment discharge quality
- For ‘Network’ Model Type:
  - Mixed content. Content type for which result items across various active network model-related computational modules may be included (e.g. HD, AD, ST, and MIKE ECO Lab).
  - Hydrodynamic
  - Real time control. If the ‘Real Time Control (RTC)’ module is active.
  - Pollution transport. If the ‘Water Quality (AD)’ module is active.
  - MIKE ECO Lab. If the ‘Water Quality (MIKE ECO Lab)’ module is active.
  - LTS extreme statistics. If the ‘Long Term Statistics (LTS)’ module is active.
  - LTS chronological statistics. If the ‘Long Term Statistics (LTS)’ module is active.
- For ‘2D Overland’ Model Type:
  - 2D area: a map result file containing instantaneous results at regular time intervals
  - 2D flood statistics: a map result file containing a single time step with statistical results (e.g. maximum values over time)



- Time series: time series results from one or more cells from the 2D domain
- Volume balance: a time series providing total volumes over the 2D domain
- Section discharge: a time series providing the total discharge computed through a cross section
- 2D area, AD: a map result file containing instantaneous water quality results at regular time intervals
- Time series, AD: time series of water quality results from one or more cells from the 2D domain

### Format

Some result files may be saved in various file formats.

An overview of the Identification group attributes in the Result Files editor is shown in Table 13.2 below.

Table 13.2 Overview of the Identification group box attributes (Table msm\_RS)

Edit field	Description	Used or required by simulations	Field name in datastructure
ID	Unique identifier for the result file setup	Yes	MUID
Model Type	Categorises the model used to generate the result file as either: - Catchment model, or - Network model	Yes	ModelTypeNo
Content Type	The type of result set under which the result file item falls under. Lists of possible content types are shown below.	Yes	ContentTypeNo
Format	The file format for the generated result file is either: - .RES1D - .DFS0 - DFSU - DFS2	Yes	FormatNo

The buttons to the right of the Identification group box control the data rows in the left overview table in the Result Files editor.



### 'Insert' button

Adds a new result item in the Result Files table.

### 'Copy' button

Creates a copy of an active result file item. The ID of the copied item is set the same as the original item's ID plus the suffix '\_Copy'.

### 'Delete' button

Deletes the current selected rows from the left overview table in the editor.

## 13.1.2 Location

The flexibility in results-saving in MIKE URBAN+ extends to possibilities for selecting elements or specifying locations for which to save results in the file.

Result locations may be defined for user-specified result files, but not for Default results. Note that Default result files will always save results in all model elements (i.e. 'Save all' option).

Result saving locations are specified in the Location tab in the Result Files editor (Figure 13.3).

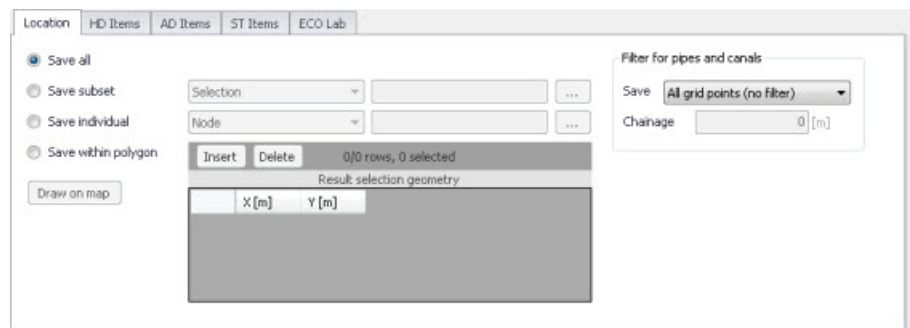


Figure 13.3 The Location Tab in the Result Files Editor



Table 13.3 Overview of the Location tab attributes in the Result Files editor (Table msm\_RSS)

Edit field	Description	Used or required by simulations	Field name in datastructure
[Location radio buttons]	Radio button for selection result saving location: - Save all - Save subset - Save individual - Save within polygon	Yes	SelectionNo
[Save Subset dropdown menu]	Dropdown menu for selecting the type of subset	If Location = Save subset	SubsetNo
[Selection list input box]	Input box for a Selection List	If Location = Save subset and Subset = Selection	SelectionListID
[Save Individual dropdown menu]	Dropdown menu for selecting the type of model element for which to save results	If Location = Save individual	IndividualNo
[Element input box]	Input box for an element selection	If Location = Save individual	ElementID
Save [Filter for Pipes and Canals]	Option for selecting the calculation grid point(s) along pipes and canals for which to save results	Yes If Model Type = Network, and results are saved in Pipes and Canals	GridPointNo
Chainage [Filter for Pipes and Canals]	Input box for specifying the chainage (i.e. distance from upstream node) of grid point along the pipe or canal for which to save results	Yes If Model Type = Network, results are saved in Pipes and Canals, and Save = User-specified chainage	Chainage



## Save all

This option saves results in all model elements. All Default result files (see Default results section, page 367) use this option, which may not be modified. Also note that this option is not available when results are saved in .DFS0 format (see Format section).

## Save subset

This option offers a dropdown list of possible subset groups for which to save results. The list varies according to Model Type associated with the results. A selection list must be defined (Figure 13.4) when the subset is a 'Selection'.

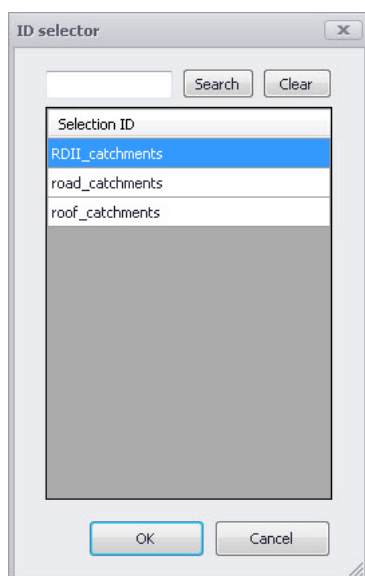


Figure 13.4 Selection lists in the ID Selector window

## Save individual

This option offers a dropdown list of model elements for which to save results. The list varies according to the Model Type associated with the results. An element ID must be defined for the selected model element.

## Save within polygon

Results from only the network elements or the 2D domain elements within a specified polygon are saved in the file. The polygon is characterised by vertex XY coordinates defined in the secondary grid on the Location tab (Figure 13.5).

Figure 13.5 The Result Selection Geometry secondary grid in the Location Tab

The location polygon may be defined by:

- Defining values in the secondary table.  
Polygon vertex locations are added and removed from the table using the 'Insert' and 'Delete' buttons at the top of the secondary grid.
- Drawing the polygon on the map using the 'Draw on map' button to the left of the table.  
Use the 'Draw on map' button to define a new polygon on the map. The 'Draw on map' button activates the Map view (Figure 12.5). Draw a polygon on the map by defining vertex locations. Double-click on the map to finish the polygon editing. The polygon coordinates are then shown in the secondary table in the Location tab of the Result Files editor.

The 'Draw on map' button is renamed 'Edit on map' as soon as a polygon has been defined and the secondary table is filled.

Note that the location polygon is shown on the Map only while drawing. The polygon is no longer shown on the map once the polygon has been drawn.

When the polygon already exists (i.e. when the Location tab secondary table is not empty), the 'Edit on map' button allows for editing the existing polygon. The Map is shown, where polygon vertices may be moved, deleted, or added.

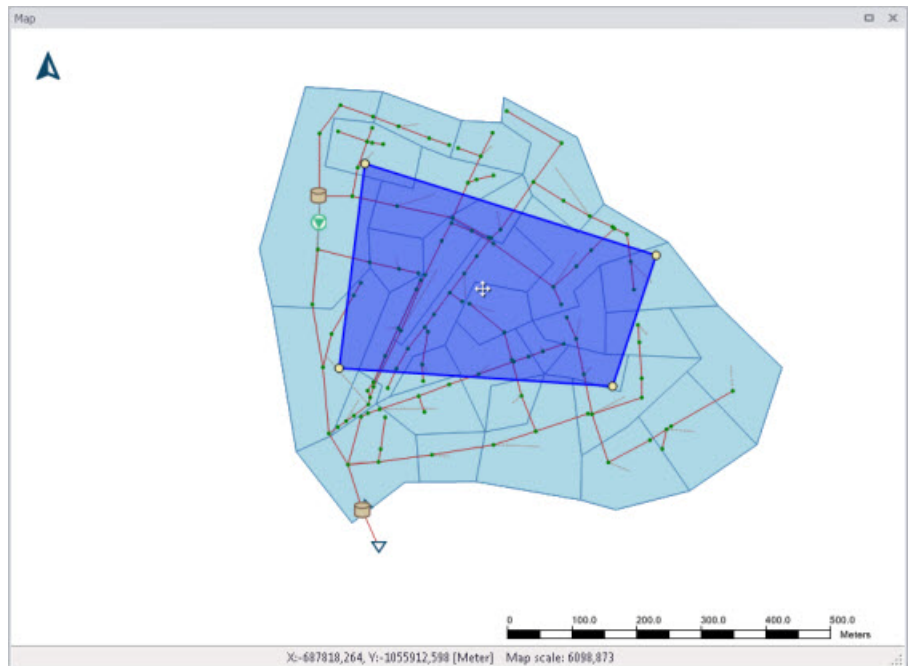


Figure 13.6 Defining a result location polygon on the Map

## Coordinates

For 2D time series data, the X and Y coordinates of the time series must be specified in the table. When multiple coordinates are specified for the same result file, each location will be saved as an individual item in this file. For each time series, the raw results for the 2D domain element in which the coordinates fall will be saved.

For a 2D section discharge result file, coordinates must be specified for the start and end of the cross section line, through which the discharge will be computed.

## Defining saving grid points

The Filter for Pipes and Canals group box is shown on the right side of the Location tab when the result is from a network model (i.e. Model Type = Network).

This section is used to select grid points along pipes and canals for which results are saved in the result file.



Filter for pipes and canals

Save

Chainage  [m]

The 'Save' dropdown list offers the following options:

- All grid points (no filter)
- Upstream grid point
- Downstream grid point
- Up- and downstream points
- Middle grid point
- User specified chainage. If 'User specified chainage' is selected, specify the grid point location for which results are saved in the 'Chainage' field below. Results are saved for the grid point closest to specified chainage value.

### 13.1.3 Items

Tabs in the Result Files editor are used to select items that will be stored in the result file. Different tabs are shown depending on the Model Type and active project Modules.

Note that customising Items related to LIDs is currently not available. Also, modifying items related to MIKE ECO Lab results is done in the MIKE ECO Lab template (.ECOLAB) and not the MU+ interface.



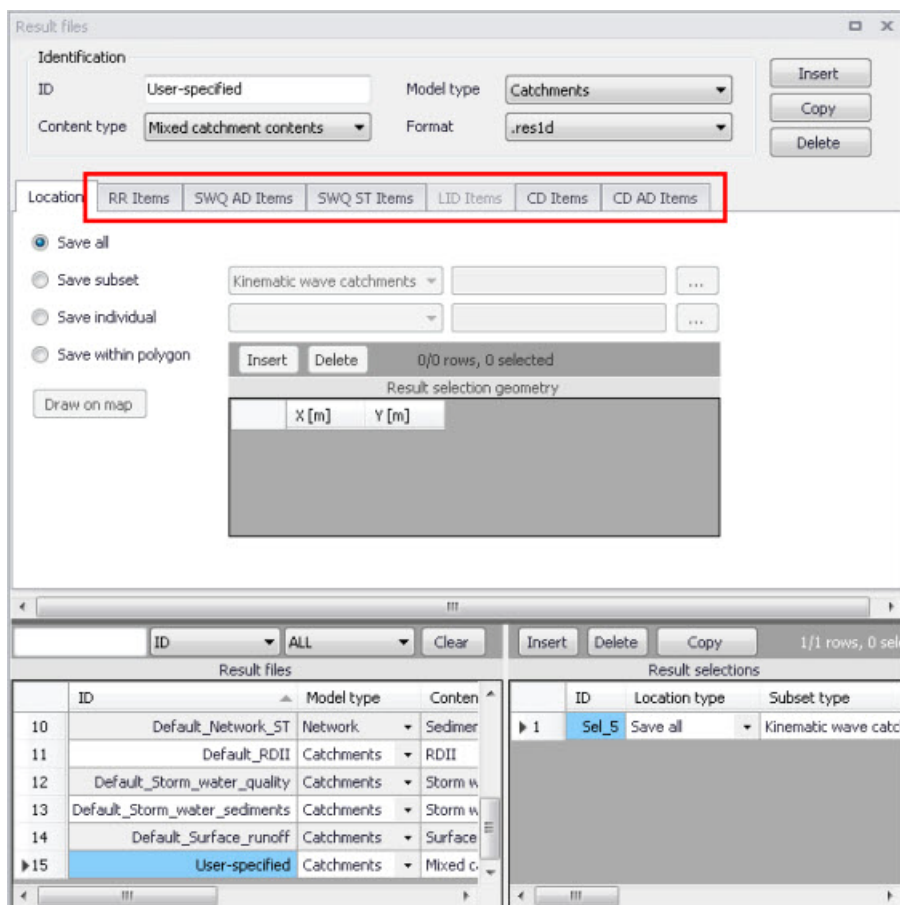


Figure 13.7 Item Tabs in the Result Files Editor. This figure shows available tabs for results from Catchment models.

Each tab shows items related to a computation Module, and the items are categorised as:

- Basic items. Primary result parameters for a simulated process.
- Additional items. Additional result items that provide greater detail on the simulated processes for the system.

The following sections describe the various result items available in MIKE URBAN+.

## RR Items (Surface runoff and RDII)

These are catchment rainfall-runoff modelling result items. RDII result items are also selected from the RR Items tab (i.e. Additional items).

Table 13.4 summarises items that may be saved in surface runoff result files.

Result files

Identification

ID: Default\_Surface\_runoff

Model type: Catchments

Content type: Surface runoff

Format: .res1d

Buttons: Insert, Copy, Delete

Tabs: Save all, **RR Items**, SWQ AD Items, SWQ ST Items, LID Items, CD Items, CD AD Items

Basic Items

- ☒ Total runoff
- ☒ Net rainfall

Additional Items

- ☐ Actual rainfall
- ☐ Actual evaporation
- ☐ Total infiltration
- ☐ Total Loss
- ☐ RDI: Overland flow
- ☐ RDI: Interflow routed from second reservoir
- ☐ RDI: Base flow
- ☐ RDI: Interflow and base flow
- ☐ RDI: Rootzone storage
- ☐ RDI: Surface storage

Figure 13.8 The RR Items Tab in the Result Files Editor. The 'Total runoff' and 'Net rainfall' items are initially included in Default Surface Runoff results.



Table 13.4 Overview of Surface Runoff result items in the RR Items Tab

Basic Items	Additional Items
Total runoff Net rainfall	Actual rainfall Actual evaporation Total infiltration RDI: Overland flow (Default RDII) RDI: Interflow routed from second reservoir (Default RDII) RDI: Base flow (Default RDII) RDI: Interflow and base flow (Default RDII) RDI: Rootzone storage (Default RDII) RDI: Surface storage (Default RDII) RDI: Groundwater depth (Default RDII) RDI: Infiltration to groundwater (Default RDII) RDI: Overland first reservoir flow, from first to second reservoir (Default RDII) RDI: Interflow first reservoir flow, from first to second reservoir (Default RDII) RDI: Capillary flux (Default RDII) RDI: Overland first reservoir storage (Default RDII) RDI: Overland second reservoir storage (Default RDII) RDI: Lower base flow (Default RDII) SnowStorage (Default RDII) RDI: Snow ZoneTemperature (Default RDII) RDI: Snow ZoneRainfall (Default RDII) RDI: Snow ZoneWaterRetention (Default RDII) RDI: Snow ZoneMeltingCoefficient (Default RDII) RDI: Snow ZoneAreaCoverage (Default RDII) RDI: Snow ZoneMeltingWater (Default RDII) TimeArea: InitialLossStorage UHM: Excess Rainfall KW Runoff [ImperviousSteep, Flat] KW Runoff [PerviousSmall, Medium, Large] KW Depth [ImperviousSteep, Flat] KW Depth [PerviousSmall, Medium, Large] KW WettingLoss [PerviousSmall, Medium, Large] KW WettingLoss [ImperviousFlat] KW StorageLoss [ImperviousFlat] KW StorageLoss [PerviousSmall, Medium, Large] KW Infiltration [PerviousSmall, Medium, Large] KW InfiltrationPotential [PerviousSmall, Medium, Large]

## SWQ AD Items (Stormwater quality)

These are results related to the modelling of water quality of stormwater from catchments.

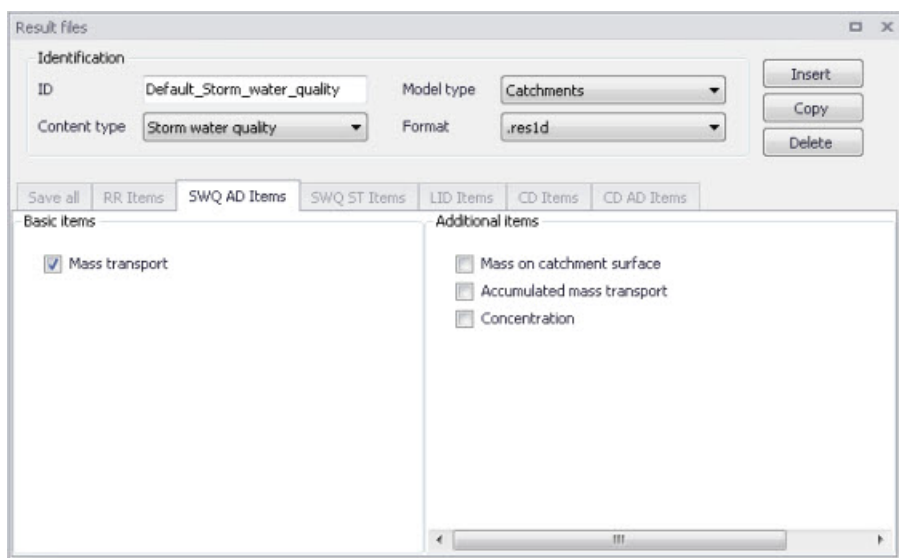


Figure 13.9 The SWQ AD Items Tab in the Result Files Editor. The 'Mass transport' item is initially included in Default Stormwater Quality results.

Table 13.5 Overview of Stormwater Quality result items in the SWQ AD Items Tab

Basic Items	Additional Items
Mass transport	Mass on catchment surface Accumulated mass transport Concentration

## SWQ ST Items (Stormwater sediments)

These are results related to the modelling of sediment transport with stormwater over catchments.

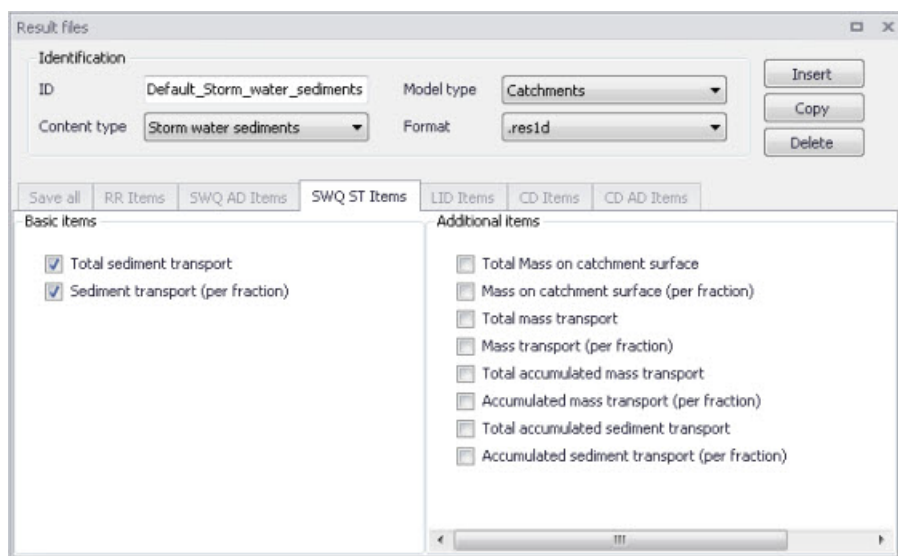


Figure 13.10 The SWQ ST Items Tab in the Result Files Editor. The 'Total sediment transport' and 'Sediment transport (per fraction)' items are initially included in Default Stormwater Sediments results.

Table 13.6 Overview of Stormwater Sediments Transport result items in the SWQ ST Items Tab

Basic Items	Additional Items
Total sediment transport Sediment transport (per fraction)	Total Mass on catchment surface Mass on catchment surface (per fraction) Total mass transport Mass transport (per fraction) Total accumulated mass transport Accumulated mass transport (per fraction) Total accumulated sediment transport Accumulated sediment transport (per fraction)

## LID Items

It is currently not possible to customise result items for LID results in MIKE URBAN+. All result items are saved by Default. Table 13.7 shows the LID result items from a catchment model saved in .DFS0 format.

Table 13.7 Overview of LID result items

Basic Items	Additional Items
Rain Inflow Surface Flow Drain Flow Infiltration	Evaporation Surface Depth Soil Moisture Storage Depth Surface to Soil Soil to Storage Drain Storage Depth (Green Roof) Soil to Drain Storage (Green Roof) Pavement Moisture (Porous pavement) Surface to pavement (Porous pavement) Pavement to Storage (Porous pavement) Mass Checksum

Please refer to the ‘LID Deployment Result File’ section under the ‘Rainfall-Runoff Modelling’ chapter in this Collection System User Guide for more details on the LID result items listed above.

## CD Items (Catchment discharge)

Catchment discharge consists of person equivalent (PE)-based or area-based inflows from catchments (e.g. wastewater inflows).

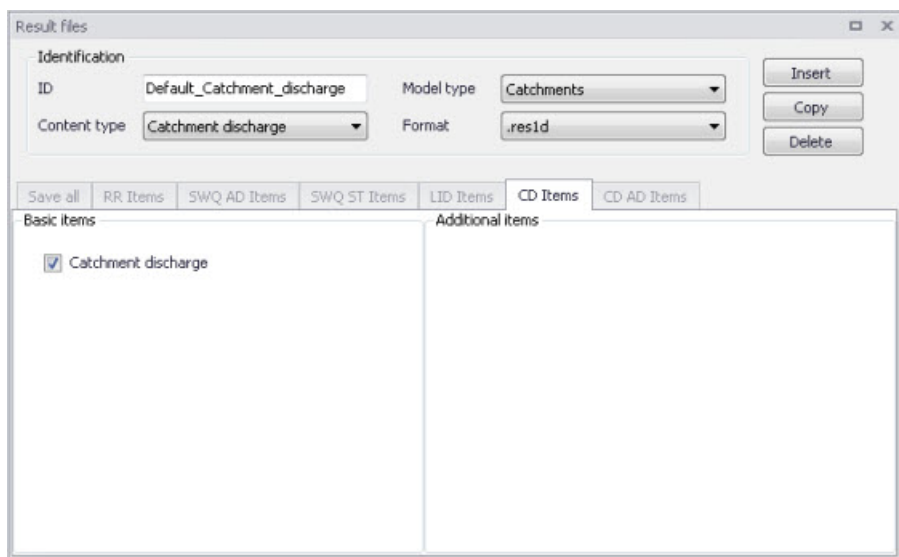


Figure 13.11 The CD Items Tab in the Result Files Editor. The ‘Catchment discharge’ item is initially included in Default Catchment Discharge results.



### CD AD Items (Catchment discharge quality)

These are computational items related to the modelling of pollutant transport with catchment discharge.

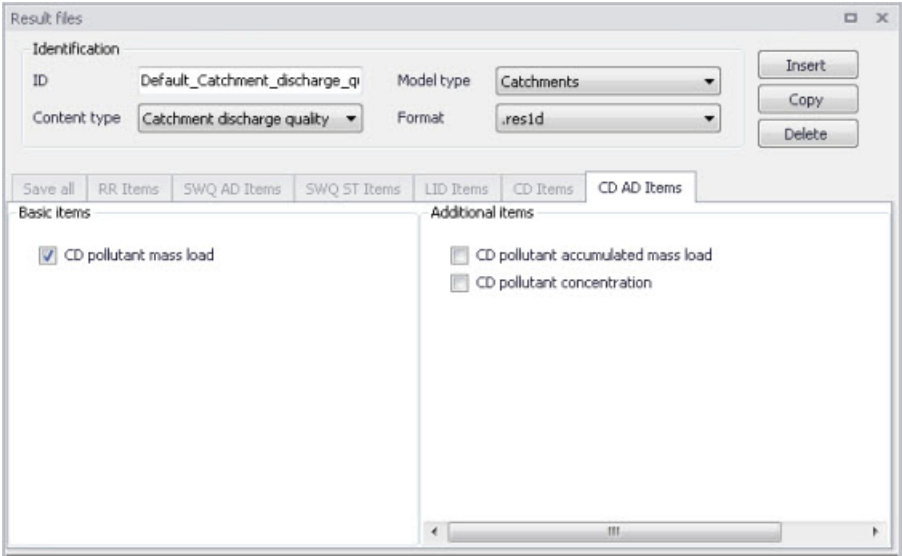


Figure 13.12 The CD AD Items Tab in the Result Files Editor. The ‘CD pollutant mass load’ item is initially included in Default Catchment Discharge Quality results.

Table 13.8 Overview of Catchment Discharge Quality result items in the CD AD Items Tab

Basic Items	Additional Items
CD pollutant mass load	CD pollutant accumulated mass load CD pollutant concentration

### HD Items (Hydrodynamic and RTC)

These are result items related to hydrodynamic calculations in the sewer network.

RTC (Real Time Control) result items are also selected from the HD Items tab. The Additional Items RTC setpoint value, RTC pump start level, and RTC pump stop level are always saved for RTC results as they are essential in case the result file is also used for hotstart.

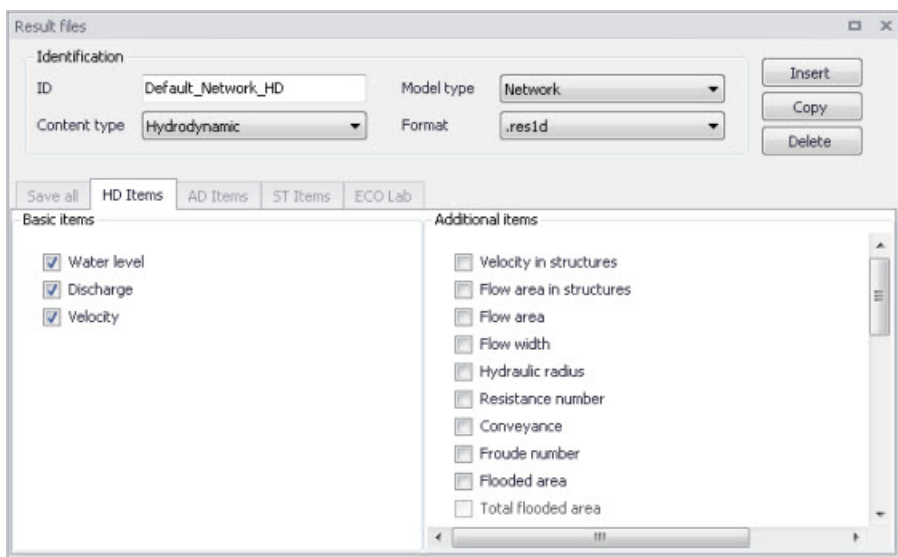


Figure 13.13 The HD Items Tab in the Result Files Editor. The 'Water level', 'Discharge' and 'Velocity' items are initially included in Default Hydrodynamic results.





Table 13.9 Overview of Hydrodynamic and RTC result items in the HD Items Tab

Basic Items	Additional Items
Water level Discharge Velocity	Velocity in structures Flow area in structures Flow area Flow width Hydraulic radius Resistance number Conveyance Froude number Flooded area Volume Water volume above ground Water flow rate to node volume above ground Simulation time step Number of tries for current time step Water level slope Energy level Energy level slope Bed shear stress Gate level Weir crest level Valve position RTC setpoint value RTC pump start level RTC pump stop level Pump active Infiltration rate

### AD Items (Pollution transport)

These are result items related to the modelling of the transport of pollutants in the sewer network.

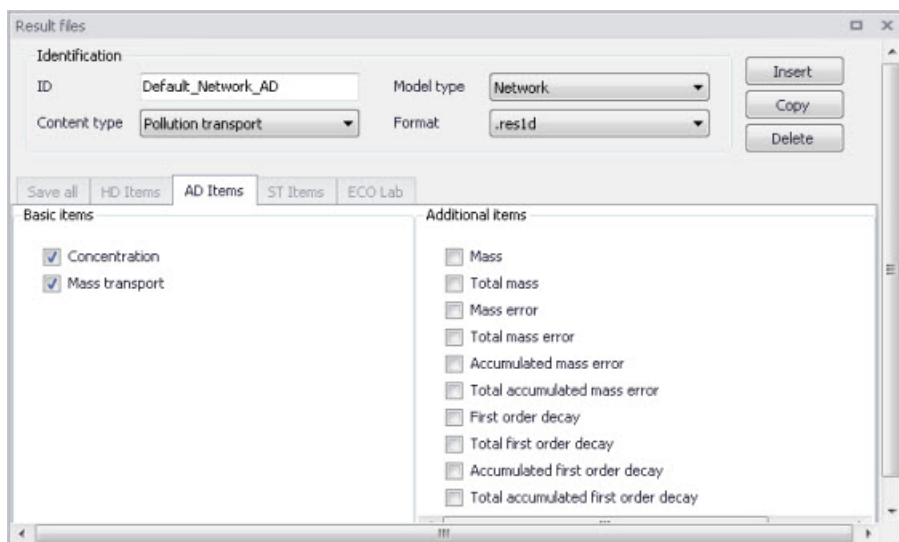


Figure 13.14 The AD Items Tab in the Result Files Editor. The 'Concentration' and 'Mass transport' items are initially included in Default Pollution Transport results.

Table 13.10 Overview of pollution transport items in the AD Items tab

Basic Items	Additional Items
Concentration Mass transport	Mass Total mass Mass error Total mass error Accumulated mass error Total accumulated mass error First order decay Total first order decay Accumulated first order decay Total accumulated first order decay

## ECO Lab (MIKE ECO Lab water quality)

The result items from network water quality modelling using MIKE ECO Lab depend on the State Variables, Auxiliary Variables, Processes and Derived Outputs indicated in the MIKE ECO Lab template used in the simulation (Figure 13.15).

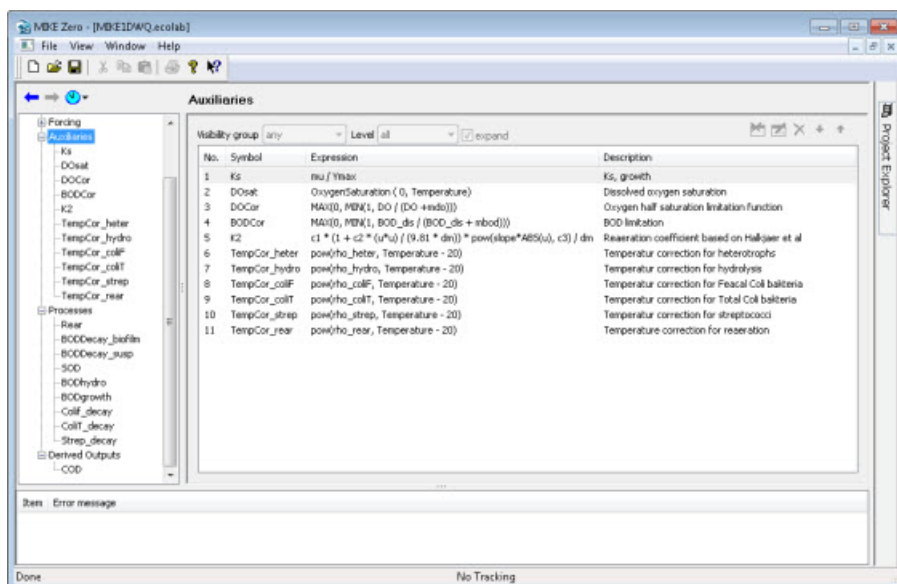


Figure 13.15 Example MIKE ECO Lab template (\*.ECOLAB) showing the Auxiliaries, Processes, and Derived Outputs sections

Customising ECO Lab result items is done in the MIKE ECO Lab template that is eventually loaded into MU+, and not in the MU+ interface.

The MIKE ECO Lab simulation will result in three files containing all the hydrodynamic information (.RES1D), advection-dispersion results for the state variables (\*AD.RES1D), and derived outputs, selected auxiliary variables, processes and derived outputs included in the MIKE ECO Lab results file (ADEL.RES1D).

Refer to the 'Water Quality' chapter in this Collection System User Guide for details on using MIKE ECO Lab templates in MIKE URBAN+.

## LTS HD Items (LTS extreme and chronological statistics)

These are LTS statistics results related to LTS hydrodynamic modelling in sewer networks.

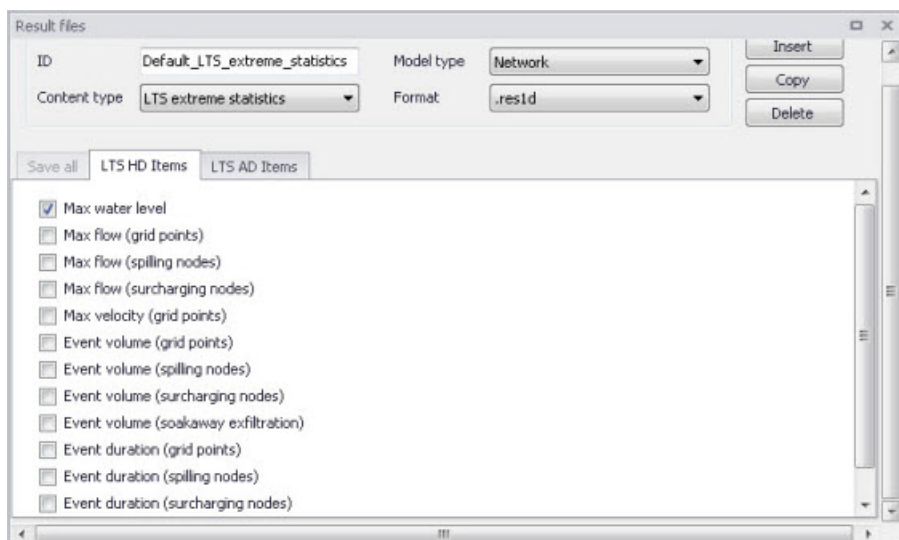


Figure 13.16 The LTS HD Items Tab in the Result Files Editor. The figure shows pre-selected items for Default LTS Extreme Statistics results.

Table 13.11 Overview of items in the LTS HD Items Tab related to LTS Extreme and Chronological Statistics Results

Extreme Statistics	Chronological Statistics
Max water level	Total accumulated volume (out of the system)
Max flow (grid points)	Total accumulated volume (outlet pipes)
Max flow (spilling nodes)	Total accumulated volume (pumps out of the system)
Max flow (surcharging nodes)	Total accumulated volume (weirs out of the system)
Max velocity (grid points)	Total accumulated volume (orifices out of the system)
Event volume (grid points)	Total accumulated volume (valves out of the system)
Event volume (spilling nodes)	Total accumulated volume (spilling nodes)
Event volume (surcharging nodes)	Accumulated spilled volume (spilling nodes)
Event volume (soakaway exfiltration)	Accumulated surcharge volume (nodes)
Event duration (grid points)	Accumulated exfiltration volume (soakaways)
Event duration (spilling nodes)	Accumulated volume (discharge)
Event duration (surcharging nodes)	
Event duration (soakaway exfiltration)	



LTS AD Items (LTS extreme and chronological statistics)

These are LTS statistics results related to LTS modelling of pollution transport in sewer networks.

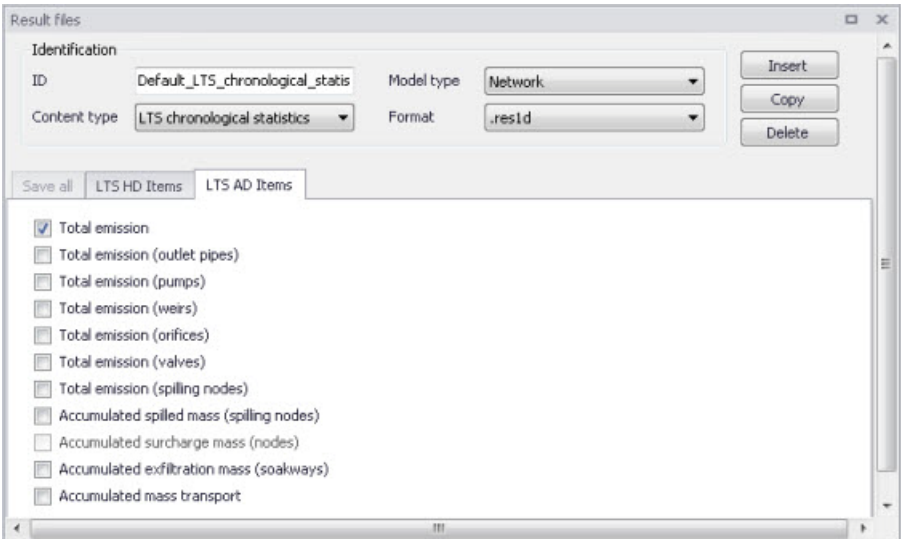


Figure 13.17 The LTS AD Items Tab in the Result Files Editor. The figure shows pre-selected items for Default LTS Chronological Statistics results.

Table 13.12 Overview of items in the LTS AD Items Tab related to LTS Extreme and Chronological Statistics Results

Extreme Statistics	Chronological Statistics
Max concentration	Total emission
Event load (grid points)	Total emission (outlet pipes)
Event load (spilling nodes)	Total emission (pumps)
Event load (surcharging nodes)	Total emission (weirs)
Event load (soakaway exfiltration)	Total emission (orifices)
	Total emission (valves)
	Total emission (spilling nodes)
	Accumulated spilled mass (spilling nodes)
	Accumulated surcharge mass (nodes)
	Accumulated exfiltration mass (soakways)
	Accumulated mass transport



### 13.1.4 Combining various result items in one file

MIKE URBAN+ offers high flexibility in configuring result files obtained from simulations. The secondary table (Figure 13.18) in the Result Files editor is used to specify different combinations of items and locations for user-specified result setups.

User-specified results (i.e. non-Default) may be configured to contain different result sets with varying combinations of:

- Location
- Items. Items may be from the same Content Type or from across different (active) Content Types.

Result files

Identification

ID: User-specified Model type: Network Content type: Mixed content Format: .res1d

Location: HD Items AD Items ST Items ECO Lab

Save all Save subset Save individual Save within polygon

Filter for pipes and canals: Save All grid points (no filter) Change: 0 [m]

Result selection geometry

	X [m]	Y [m]
1	-687950,6	-1056398
2	-687819,9	-1056194
3	-687579,1	-1056349
4	-687585,3	-1056509

Result files

ID	Model type	Content type	Format	
1	User-specified	Network	Mixed content	.res1d

Result selections

ID	Location type	Subset type	Individual type	
1	Selection1	Save subset	Pipes and canals	Node
2	Selection2	Save individual	Manholes	Node
3	Selection3	Save within polygon	Selection	Node

Figure 13.18 The secondary table in the Result Files Editor

The example shown in Figure 13.18 is a 'Network' result file setup that has 'Mixed content' and includes 3 Location-Items combinations in one .RES1D result file. Result items from across content types (i.e. active modules) may also be saved in one file. Use Content Type = 'Mixed content' for the result file setup to allow this option (see example in Figure 13.18).



The Location-Item combinations are in the example are summarised in the table below:

**Table 13.13** Example Location-Items combinations from across content types that may be combined in one Mixed Content User-Specified result file

Result	Location	Items
Selection1	Save subset = Pipes and canals	HD Items = Water level, Velocity
Selection2	Save individual = Node 7	AD Items = Concentration
Selection3	Save within polygon	HD Items = Discharge

The content of the secondary table is controlled with the following buttons:

**'Insert' button**

Creates a new item in the table, with Default properties.

**'Delete' button**

Deletes the current selected rows from the secondary table.

**'Copy' button**

Creates a copy of the active row.

## 13.2 Network Summary

The basic contents of HTML summaries generated at the end of simulations may be customised in MIKE URBAN+. Various Network Summary configurations may be defined through the Network Summary editor (Result Specifications | Network Summary) (see Figure 13.20). These configurations may then be invoked in the Simulations Setup editor when running Network (HD) simulations.

The basic HTML summary shows information on the simulation, overall results summary, and boundary inputs. Adding a network summary configuration will extend the basic summary with the 'HD Results Summary' section (Figure 13.19).

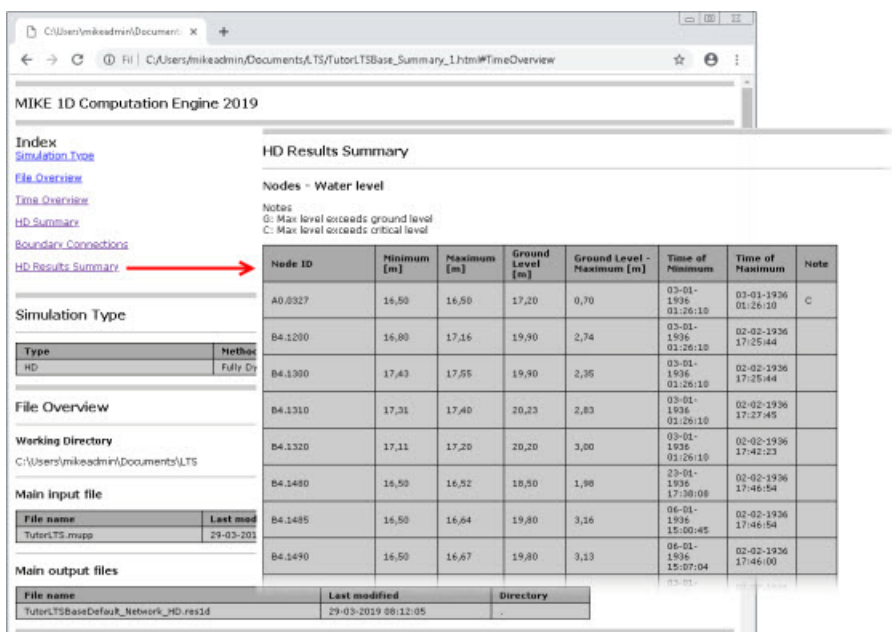


Figure 13.19 Example network simulation HTML summary augmented with an additional HD result summary table for Nodes.

Additional items may be activated for each network summary setup in the editor. The Network Summary editor is organized into the following groups:

- Identification
- Tables with min, max and accumulated values for
- Summary of input data
- Use selection to reduce summary tables

Activate the various options on the editor to customise additional contents for the network simulation HTML summary. An overview of the various options in the editor is shown in Table 13.14.



Figure 13.20 The Network Summary Editor

Table 13.14 Overview of the Network Summary editor attributes (Table msm\_Html-Summary)

Edit field	Description	Used or required by simulations	Field name in datastructure
ID	ID of summary- user specified	Yes	MUID
Nodes checkbox	Activate to include tables with min, max and accumulated values in the summary	Optional	SummaryNodeNo
Weirs and orifices checkbox	Activate to include tables with min, max and accumulated values in the summary	Optional	SummaryWeirNo



Table 13.14 Overview of the Network Summary editor attributes (Table msm\_Html-Summary)

Edit field	Description	Used or required by simulations	Field name in datastructure
Pumps checkbox	Activate to include tables with min, max and accumulated values in the summary	Optional	SummaryPumpNo
Links and structures checkbox	Activate to include tables with min, max and accumulated values in the summary	Optional	SummaryLinkNo
Grid points, water levels checkbox	Activate to include tables with min, max and accumulated values in the summary	Optional	SummaryLinkLevelNo
Grid points, discharge checkbox	Activate to include tables with min, max and accumulated values in the summary	Optional	SummaryLinkDischargeNo
Links, velocity checkbox	Activate to include tables with min, max and accumulated values in the summary	Optional	SummaryLinkVelocityNo
Summary of input data, Links and structures checkbox	Activate to include a summary of input data in the HTML summary	Optional	SummaryLinkInputNo
Node selection file checkbox	Activate to specify nodes for which to include tables with min, max and accumulated values in the summary	Optional	NodeSelectionNo
Node selection input box	Input box for specifying the Node selection list	Yes If NodeSelectionNo=1	NodeSelection-Name



Table 13.14 Overview of the Network Summary editor attributes (Table msm\_Html-Summary)

Edit field	Description	Used or required by simulations	Field name in datastructure
Link selection file checkbox	Activate to specify links for which to include tables with min, max and accumulated values in the summary	Optional	LinkSelectionNo
Link selection input box	Input box for specifying the link selection list	Yes If LinkSelectionNo=1	LinkSelectionName

Use the following button functions on the editor to add or remove network summary setups for the project:

**‘Insert’ button**

Adds a new Network Summary setup in the editor.

**‘Delete’ button**

Removes the active/selected Network Summary setup from the editor.





## 14 Scenarios

The water distribution and wastewater collection data models are commonly used for the system performance analysis and in the planning process. The complexity of the involved systems, the various uncertainties about the future conditions and usually huge costs associated with maintenance, rehabilitation and development necessitate a thorough investigation of alternative system configurations in a search for the technically feasible, environmentally sound and economically efficient solution. These alternative configurations - scenarios - may differ by the system's physical layout, loading conditions, operational strategies, etc. Various projects, such as development of a Sewerage Master Plan, Wastewater Transportation Strategy, an Overflow Abatement Strategy, etc. would typically result in a large number of scenarios, either representing alternative system configurations at a given time and/or representing the system at various development stages. Test of each scenario against the prescribed legislation or the standards of service that the authorities provide requires a numerical model on its own.

These scenarios are always related to each other through the common origin ('Base') and the differences typically epitomize a smaller part of the total data. Moreover, scenarios representing a development of the system through time are subject to the dependencies propagating along with the timeline. Analysis of the scenarios as separate projects creates major inconveniences, such as:

- Large number of models, even when differences between them are minor
- Missing the efficient overview over the entire set of solutions
- Inability to maintain the existing dependencies between the individual scenarios automatically. Thus, the updating of the models with additional information requires editing of multiple files to change the same element, e.g. if a pipe diameter is found to have been incorrectly registered in the GIS database, it will have to be updated multiple times in each of the scenario project files.

### 14.1 What are Scenarios

The MIKE URBAN+ Scenarios is a user interface for a set of MIKE URBAN+ features, enabling the definition, organisation management and reporting of alternative scenarios, such as:

- Augmentation of existing trunk sewer mains;
- Increased wastewater loading from increased population;
- Increased water demands from increased population;
- Alternative design loads, e.g. rainfall-runoff of different return period;
- Alternative alignment of sewer and storm mains;



- Building of a new sewer trunk and water supply mains in order to cater for a new development area within the same MIKE URBAN+ project.

## 14.2 Design of the MIKE URBAN+ Scenario Manager

The MIKE URBAN+ Scenario group is based on the concept of Data Groups, Alternatives and Scenarios. In this context, a Data Group is a set of database tables which form a meaningful set. E.g. all database tables containing collection system network data belong to the data group 'Network Data'. Every database table relevant for the scenario manager is included in one of the Data Groups.

Each Data Group can appear in the MIKE URBAN project in any number of Alternatives. The initial alternative is named with a default name 'Base'. Any further alternative is created upon user request and gets a user-specified name. The Alternatives for a certain data group are organised in a tree-like structure, where dependencies propagate along the branches -from the 'parent' to all the 'heirs' i.e. 'children'.

A scenario represents a complete set of consistent data, featuring the system configuration for a given situation. In other words, a scenario contains one alternative of each Data Group. Actually, individual alternatives are used as building blocks for constructing scenarios. A moderate number of data groups (eight for collection system and nine for water distribution) allows for a manageable structure of scenarios, while ensuring the high level of flexibility.

The initial scenario is named with a default name 'Base', and consists of the 'Base' alternative of each data group. Any further scenario is created upon user request and gets a user-specified name. The scenarios are organised in a tree-like structure of 'parents' and 'children'.

### Alternatives

The alternatives represent the components of the scenarios. The various alternatives contain the actual data belonging to a certain data group. Actually, each subsequent alternative only contains the information on the differences relative to its immediate 'parent', while the rest of data is inherited from the 'parent' through the principles of inheritance.

Grouping of various alternatives belonging to different data groups into scenarios is sometimes subject to limitations, because the data groups have not been formed on the basis of data independency, but rather following the logical data grouping. E.g. the alternative of the 'Catchment connections' CS data group, which specifies a catchment connection to node 'A', cannot be used with the alternative of the 'Network data' data group where node 'A' has been renamed or deleted. Obviously, the catchment would remain disconnected.



## Collection System Alternatives

For Collection Systems, the scenarios are composed of the following data groups:

- Network
- Loads and Boundary
- Catchment & Hydrological
- WQ
- Operational RTC
- LTS
- Profiles and Curves

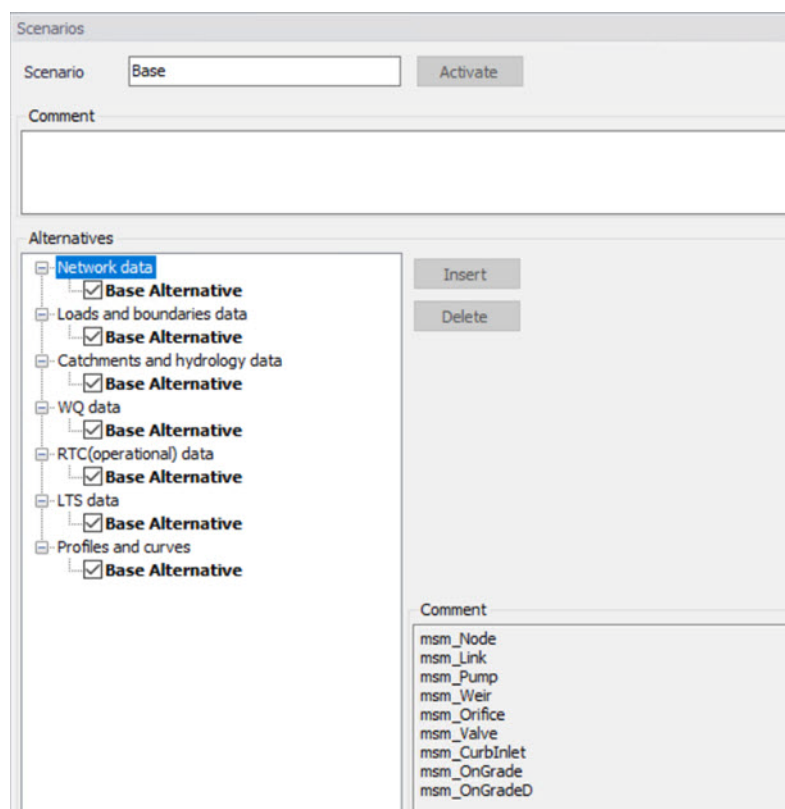


Figure 14.1 Scenarios Alternatives for Collection System

## Water Distribution Alternatives

For Water Distribution Systems input data can be grouped the following way, corresponding to the different types of available alternatives:



- Network
- Water Demands
- Control
- Water Quality
- Pattern and Curves

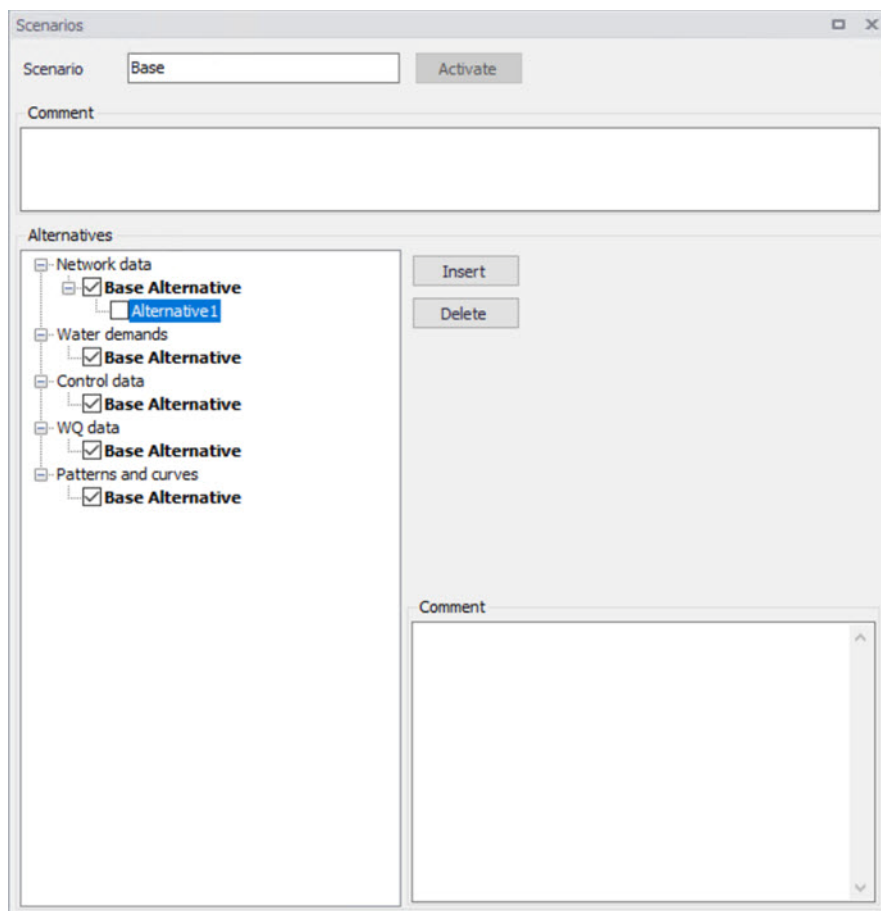


Figure 14.2 Scenarios Alternatives for Water Distribution

## Inheritance principles

With the inheritance from 'parent' alternatives to 'child' alternatives, some specific items must be kept in mind.





- Making a change to an alternative will affect all descendent ('child') alternatives of that alternative. This means that it will impact all the scenarios where either the alternative or the children of that alternative are applied. This also ensures that if one value needs updating it will be updated in all the scenarios where the alternative is applied (e.g. if a pipe diameter is found to have been incorrectly registered in the GIS data during the course of a project then the pipe diameter can be changed one place only, regardless of the number of scenarios and alternatives that reference to this alternative).
- The chain of inheritance for a certain data record stops where any change (or delete) of that element has occurred in earlier work. E.g. if a bottom level of a node 'A' has been edited in some child alternative, some later update of the bottom level in 'Base' will only propagate through the alternative tree until the alternative containing the old change.
- Adding an element (e.g. a node) in the 'parent' with an ID that already exists in one or more of its descendants ('children') will overwrite the content of the 'child' element
- If adding an element (e.g. pump/link) in the parent that cannot be added to all the children (because some parts may have been deleted/changed there), the element is added where possible and omitted elsewhere.

## 14.3 Managing Scenarios and Alternatives

The Scenario Manager has two parts:

- The Scenario part
- The Alternatives part

The scenario part is for creating, editing and managing scenarios, while the alternatives part is for creating, editing and managing alternatives.

Under Scenarios in the tree view one can “right-click” to get the option of creating a new child scenario.

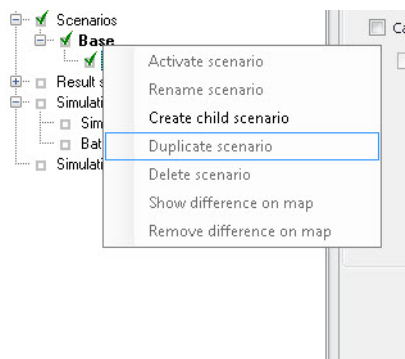


Figure 14.3 Create a new child scenario

Right-clicking on a child scenario enables the options to activate, rename, duplicate, delete, create a new child scenario and visualize the differences in the map.

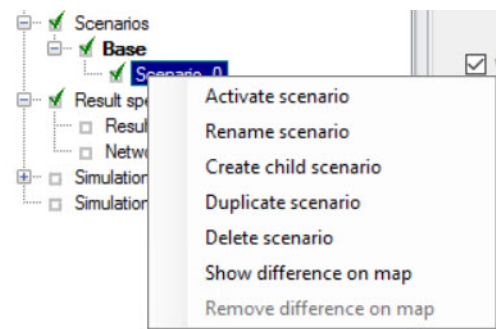


Figure 14.4 Management of child scenarios

## Scenarios

The scenario part is used for creating, editing, and managing scenarios. Per default there will one built-in scenario, i.e. the Base scenario. The Base scenario cannot be edited or deleted. An unlimited number of additional scenarios can then be added to cover the various 'What if' scenarios.

### Create a Child Scenario

This option adds a scenario that is a child of the highlighted (not to be confused with the active/current scenario), i.e. to begin with the alternatives of a new scenario will be that of the highlighted scenario. A name for the new scenario is suggested by default. The name can be changed through the option of Rename scenario or by editing directly in the ID field in the Scenario editor.

### Remove

The remove option will delete the highlighted scenario. The Base scenario cannot be deleted. Note that deleting a scenario will not delete any data as



the alternatives hold the data (the scenarios just refer to alternatives). The comments for the scenario being deleted, however, will also be deleted.

### Rename

The rename option will make the scenario name active so it can be easily renamed.

### Activate

The activate button will load the scenario, i.e. the project data is manipulated so that all editors contain the appropriate data. Depending on the size of the project this may take some time.

### Alternatives

Alternatives can be edited only if the appropriate scenario is made active. Alternatives can, however, be added regardless of the active scenario. When a scenario is loaded, the project data is manipulated so that all editors contain the appropriate data.

Alternatives can be activated, inserted and deleted in the editor through the visual buttons.

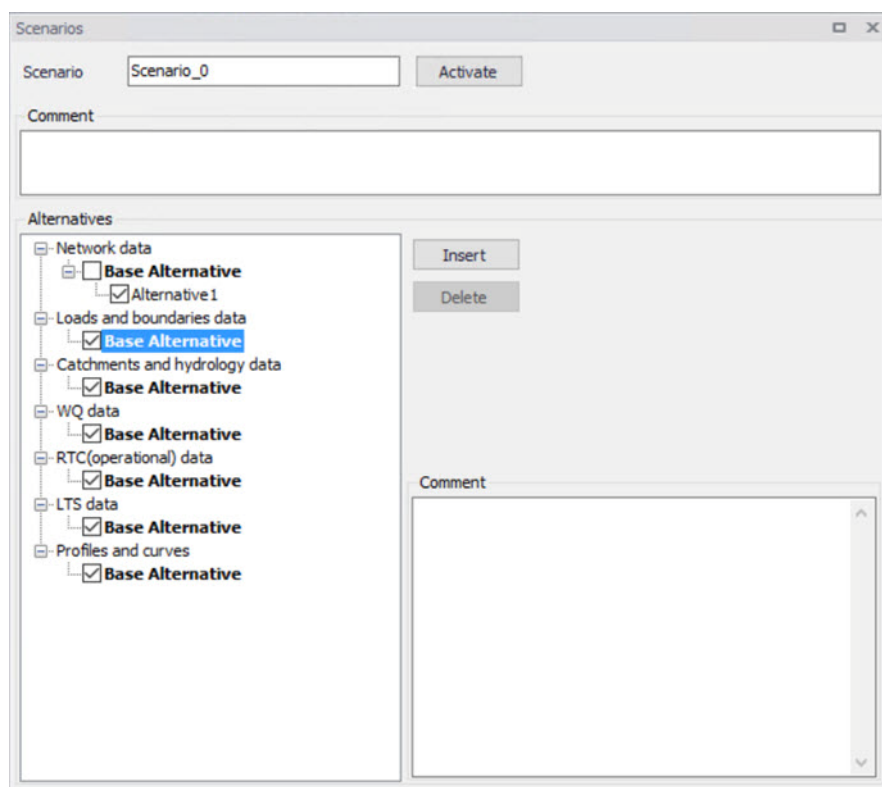


Figure 14.5 Alternative options



## 14.4 How to Start Working with Scenarios

### Creating alternatives and scenarios

- Right click on Scenario in the Tree view
- Create a child scenario
- Select the alternative group that you wish to add an alternative to and press the 'Insert' button
- You can now rename it and/or continue to make alternatives
- Select the alternative and click on Activate

The activated scenario is displayed in bold font. Equally, all the alternatives belonging to the active scenario, are displayed in bold in the 'Alternatives' page.

Both the data tables, the graphics and any MIKE URBAN+ tools work **ONLY** with the data belonging to the currently active scenario. Access to the data belonging to other scenarios is not possible through MIKE URBAN+ interface.

## 15 Simulation Validation

MIKE URBAN+ employs automatic validation, checking for data errors as one navigates through the various editors. However, one may also collectively check the consistency of the MIKE URBAN+ project data through Simulation Validation.

Run model validation through the Simulation Validation window (Figure 15.1).

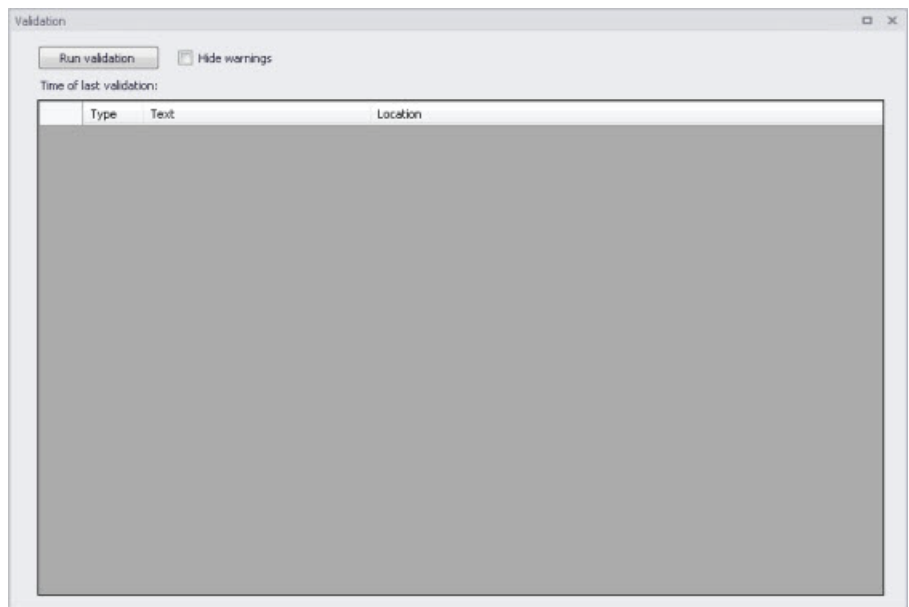


Figure 15.1 The Simulation Validation window

Data validation is performed depending on the active modelling mode and modules in the MIKE URBAN+ project.

### Run Validation

Run data validation by clicking on the 'Run validation' button on the window.

The validation time depends on the database size, number of active modules and number of errors found.

An error log is shown at the end of the validation.

### Time of Last Validation

The date and time of when validation was last performed for the project is displayed on the window.

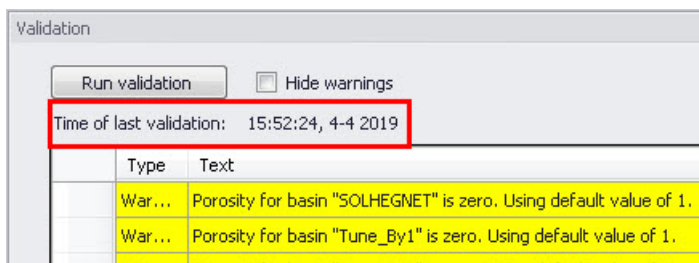


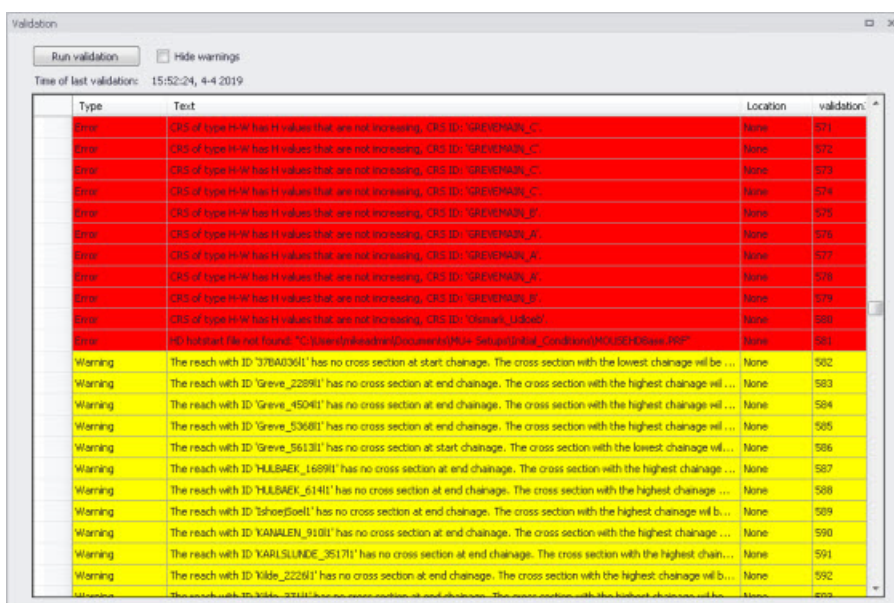
Figure 15.2 Time of last validation displayed

## Hide warnings

Activate the 'Hide warnings' option to only show Errors and not Warnings in the Error Log.

## The Error Log

The error log is a list of detected errors and warnings.



The Error Log indicates whether an item is an Error (highlighted in red) or a Warning (highlighted in yellow).

A description of the warning or error is also included under the 'Text' column on the list. The description usually indicates the data type or editor in which the error should be corrected.

The total number of detected errors and warnings is also indicated beside the Simulation Validation section on the setup tree after validation.

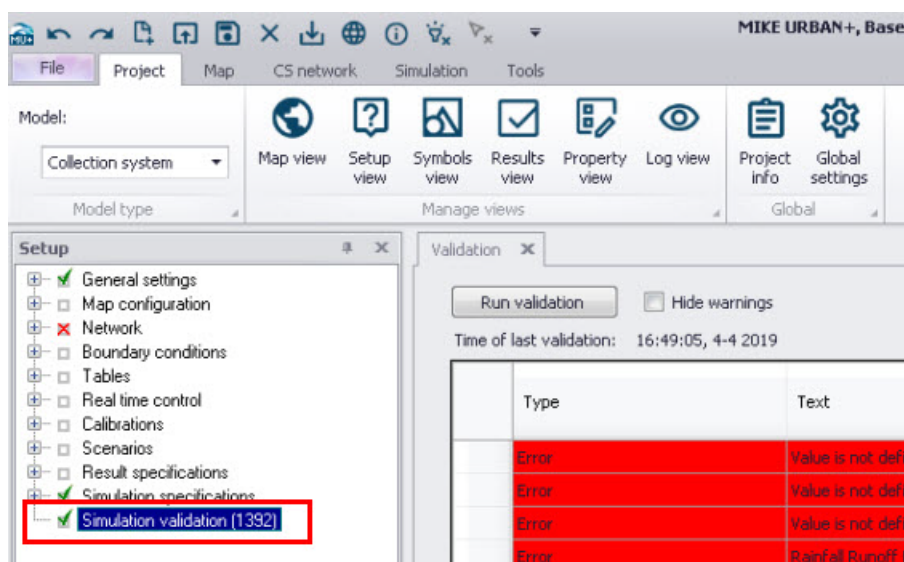


Figure 15.3 1392 errors and warnings were detected after validation







## 16 Simulation Specifications

MIKE URBAN+ simulations are started from the Simulation Specifications section. This section includes the following menus:

- **Simulation Setup.** Where various combinations of different types of simulations may be setup and run.
- **Batch Simulation.** Controls batch simulations involving the automatic sequential launch of several simulation jobs.

### 16.1 Simulation Setup

The Simulation Setup editor has several tabs, which are shown depending on the active Modules for the project:

- **General.** Includes general parameters, such as definition of the simulation period, selection of simulation types, and free text description of the simulation setup.
- **Catchments.** Includes parameters specific for Runoff simulation.
- **HD.** Includes parameters specific for HD simulation.
- **AD and WQ.** Includes parameters specific for network AD simulation and MIKE ECO Lab.
- **LTS.** Includes parameters specific for Network LTS simulation.
- **Results.** Includes specification of results (output) to be generated by the simulation.



Figure 16.1 The Simulation Setup Editor

The Identification group at the top and the scrollable grid table at the bottom of the editor are common across all tabs.

Table 16.1 Overview of the Simulation Setup Identification data group (Table msm\_Project)

Edit field	Description	Used or required by simulations	Field name in datastructure
ID	User-specified ID of simulation. ID will be reflected in the name of result files	Yes	MUID



Table 16.1 Overview of the Simulation Setup Identification data group (Table msm\_Project)

Edit field	Description	Used or required by simulations	Field name in datastructure
Scenario	Dropdown menu for selecting ID of Scenario for the simulation	Yes	ScenarioName
Active Project checkbox	Defines a simulation setup as "in the tray", i.e. as the one chosen among simulation setups to be used when extracting data by external application, e.g. MIKE Flood, and for running directly from the Simulation toolbar. Only one job at a time may be set as "Active".	Yes	ActiveProject

The following buttons are also located at the top of the editor with the Identification group:

#### **‘Insert’ button**

Inserts a new record in the Simulation Setup editor with a default unique MUID.

#### **‘Copy’ button**

Duplicates an existing (currently active) simulation setup record.

#### **‘Delete’ button**

Deletes a currently active simulation record.

#### **‘RUN’ button**

Triggers export of the currently active simulation job and execution of the simulation.

### 16.1.1 General

The General tab includes parameters relevant for the entire simulation setup. The following parameters are specified in the General tab:

- Simulation type
- Simulation period



- Description

Figure 16.2 The Simulation Setup Editor General tab

An overview of the editor fields and corresponding database attributes is provided in Table 16.2 below.

Table 16.2 Overview of the Simulation Setup General tab attributes (Table msm\_Project)

Edit field	Description	Used or required by simulations	Field name in datastructure
Catchments	Activates catchment-related simulation types	Yes	CatchmentComputationNo
Rainfall-Runoff (RR)	Activates runoff simulation	Yes	RRComputationNo
Storm Water Quality (SWQ)	Activates SWQ simulation	Yes	SWQComputationNo
Catchment Discharge (CD)	Activates catchment discharge computations	Yes	CDComputationNo
CD Water Quality	Activates water quality computations for catchment discharges	Yes	CDWQComputationNo
CS Network (HD)	Activates CS Network HD simulation	Yes	HDComputationNo
Long Term Simulation (LTS)	Activates LTS simulation	Yes	LTSComputationNo
Water quality (AD)	Activates Network AD simulation	Yes	ADComputationNo



Table 16.2 Overview of the Simulation Setup General tab attributes (Table msm\_Project)

Edit field	Description	Used or required by simulations	Field name in datastructure
MIKE ECO Lab (WQ)	Activates Network ECO Lab simulation	Yes	ELComputationNo
Sediment Transport (ST)	Activates CS network sediment transport simulation	Yes	STComputationNo
Rivers (HD)	Activates River network HD simulation	Yes	RiverHDComputationNo
2D overland (HD)	Activates 2D overland HD simulation	Yes	M2DComputationNo
Water quality (AD)	Activates 2D overland AD simulation	Yes	M2DADComputationNo
MIKE HYDRO River	Activates coupling to MIKE HYDRO River. HD coupling is always activated. AD coupling is activated if AD module is activated for another simulation module.	Yes	MHRiverComputationNo
Start	Specifies start date and time for the simulation.	Yes	ComputationBegin
Duration	Displays the duration of the simulation in days, hours, minutes and seconds. Automatically adjusted based on Start and End time/date. May be edited, adjusting End date/time accordingly.	Yes	-

Table 16.2 Overview of the Simulation Setup General tab attributes (Table msm\_Project)

Edit field	Description	Used or required by simulations	Field name in datastructure
End	Specifies end date and time for the simulation. Adjusted automatically according to user's specification of duration.	Yes	ComputationEnd
Description	Free text description of the simulation setup	Optional	Description

### 'Boundary Info.' button

The Boundary Info. button opens the Boundary Overview window with a horizontal bar chart showing time extent of all active boundary conditions from all included modules.

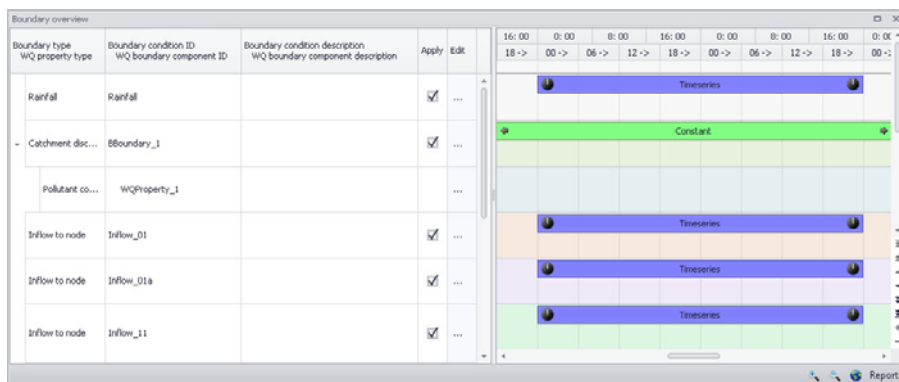


Figure 16.3 The Boundary Overview appears when pressing the 'Boundary Info.' button

### 'Set max. time' button

The 'Set max. time' button sets the maximum simulation time by filling in the start and end times of the simulation. The start time of a simulation is considered the latest start time of all boundaries. Likewise the end time for the simulation is considered the earliest end time of all boundaries.

Each boundary contains a number of items which can cover different parts of the simulation.

If a limited validity interval is specified for a boundary condition, this specifies the start and end time. If a validity is not specified, only items specified as



timeseries have a start and end time. If either a constant or cyclic value is given without validity interval, the item is not included in the evaluation.

### 16.1.2 Catchments

The following parameters can be specified on the Catchments tab:

- Surface runoff model simulation time step
- RDII simulation time step
- Catchment discharge simulation time step
- RDII hotstart specification
- Additional parameters specification

Figure 16.4 The Simulation Setup Catchments Tab

Table 16.3 The Simulation Setup Catchments tab attributes (Table msm\_Project)

Edit field	Description	Used or required by simulations	Field name in datastructure
Time-Area	Fixed time step for Time-Area runoff model	Yes if at least one catchment is set for simulation with Time-Area model	TSDt
Kin. Wave	Fixed time step for Kinematic Wave runoff model	Yes if at least one catchment is set for simulation with Kinematic Wave model	KWDt



Table 16.3 The Simulation Setup Catchments tab attributes (Table msm\_Project)

Edit field	Description	Used or required by simulations	Field name in datastructure
UHM	Time step for UHM model	Yes if at least one catchment is set for simulation with UHM runoff model	UHMDt
Wet weather	Time step during wet periods	Yes if at least one catchment is set for simulation with Linear Reservoir runoff model	DtWetPeriod
Dry weather	Time step during dry periods	Yes if at least one catchment is set for simulation with Linear Reservoir runoff model	DtDryPeriod
RDII	RDII slow runoff component time step. The fast runoff component time step is the corresponding surface runoff model time step.	Yes if at least one catchment is set for simulation with RDI runoff model	SRCDt
Catchment Discharge	Time step for catchment discharge	Yes if Catchment Discharge simulation active	CDDt
RDII Hotstart Apply checkbox	If this checkbox is ticked, a hotstart file for RDII must be specified.	Optional	RDIHotStartNo
Additional Parameters Apply checkbox	If this checkbox is ticked, an *.ADP file for the runoff simulation can be specified	Optional	ADPRunoffFileNo

The additional parameter file (\*.ADP file) is a separate file with additional settings for the simulation. Please refer to the separate documentation on this file for further information.





### 16.1.3 HD

For a network (CS network and/or river network) simulation, the tab holds parameters specific to the hydrodynamic simulation setup:

- Fixed simulation time step, or
- Adaptive simulation time step settings
- Network initial condition type
- Additional parameters

For a simulation including 2D overland, the time step parameters are changed to:

- A fixed simulation time step, used by the network simulation. This time step is also used to determine the saving frequency of 2D overland result files, and to synchronize the HD and AD modules for the 2D overland simulation.
- Adaptive time step settings, applying only to the 2D overland simulation.

The tab is active if a hydrodynamic (HD) module is activated and if relevant data exist in the project (e.g. if at least 1 conduit is specified).

The screenshot shows the 'HD' tab selected in the 'Simulation Setup Editor'. The 'Time Step' section has two radio buttons: 'Fixed' (selected) and 'Adaptive'. The 'Fixed' option has a text box with '10 [sec]'. The 'Adaptive' option has three text boxes: 'Minimum' with '10 [sec]', 'Maximum' with '10 [sec]', and 'Max. increase factor' with '1,3'. The 'Network HotStart File' section has a checkbox 'Apply' (unchecked), a text box, and a 'HotStart time' dropdown set to '01/01/2005 00:00:00'. The 'Additional Parameters' section has a checkbox 'Apply' (unchecked) and a text box.

Figure 16.5 HD Tab of the Simulation Setup Editor



Table 16.4 The Simulation Setup HD tab attributes (Table msm\_Project)

Edit field	Description	Used or required by simulations	Field name in datastructure
Fixed/Adaptive radio buttons	Toggles between alternative time step type	Yes	HDTimeStepType
Fixed	Specifies a fixed time step for the network simulation	Yes if Fixed time step type or if including 2D overland	HDDtFixed
Minimum	Specifies a minimum time step for network or 2D overland model	Yes if Adaptive time step type or if including 2D overland	HDDtMin
Maximum	Specifies a maximum time step for network or 2D overland model	Yes if Adaptive time step type or if including 2D overland	HDDtMax
Max. Increase Factor	Specifies maximum increase factor for adaptive time step for network model	Yes if Adaptive time step type	HDDtIncreaseFactor
Max. CFL number	Specifies the expected maximum CFL number in the simulation, to control the adaptive 2D overland time step	Yes if including 2D overland	M2DHDMaxCFL
Network initial conditions type	Specifies if the network (CS and/or river) is initially empty, or using user-defined initial conditions	Yes if including CS network or River network simulation	HDInitCondTypeNo
Initial conditions ID	Specifies the ID of the set of initial conditions, defined in the 'Initial conditions' page	Yes if user-specified type	HDInitCondID
Additional Parameters Apply checkbox	Activates *.ADP file with network-relevant input. Define *.ADP file name and path if activated.	Optional	ADPNetworkFileNo



The additional parameter file (\*.ADP file) is a separate file with additional settings for the simulation. Please refer to the separate documentation on this file for further information.

### 16.1.4 AD and WQ

The "AD and WQ" TAB includes parameters specific for the Network AD and MIKE ECO Lab (WQ) simulation setup. The tab is available if the Water Quality (AD) module is activated in the project, and if at least 1 AD component is specified; otherwise it is hidden.

Figure 16.6 The Simulation Setup AD and WQ Tab

Table 16.5 The Simulation Setup AD and WQ tab attributes (Table msm\_Project)

Edit field	Description	Used or required by simulations	Field name in datastructure
Minimum	Specifies a minimum time step for 2D overland model	Yes if including 2D overland	M2DADDtMin
Maximum	Specifies a maximum time step for 2D overland model	Yes if including 2D overland	M2DADDtMax
Max. CFL number	Specifies the expected maximum CFL number in the AD simulation, to control the adaptive 2D overland AD time step	Yes if including 2D overland	M2DADMaxCFL
AD Hotstart File Apply checkbox	Checkbox activates hotstart for network AD computations	Optional	ADHotStartFileNo



Table 16.5 The Simulation Setup AD and WQ tab attributes (Table msm\_Project)

Edit field	Description	Used or required by simulations	Field name in datastructure
[Parameter beside the AD Hotstart File Apply checkbox]	The Network AD hotstart file name and path	Yes if AD Hotstart File = Apply	ADHotStatrFile-Name
MIKE ECO Lab Integration	Specified ECOLab integration method	Yes If Simulation Type = MIKE ECO Lab (WQ)	ELIntegrationNo

Note that the hotstart date/time for the AD hotstart is the same as the Network HD hotstart date/time (i.e. HD hotstart must be active if AD hotstart is used).

### 16.1.5 LTS

The LTS tab includes parameters specific for Network LTS simulations. The tab is shown if the Long Term Statistics (LTS) module is activated in the project and if at least 1 Job List Criterion is specified.

Figure 16.7 The Simulation Setup Editor LTS Tab



Table 16.6 Simulation Setup LTS tab attributes (Table msm\_Project)

Edit field	Description	Used or required by simulations	Field name in datastructure
LTS Job List	Defines the Job List *.MJL file name and path to be used in the LTS simulation	Yes If Simulation Type = Long Term Simulation (LTS)	MJLFileName

The LTS tab also has buttons for the following functions:

#### **‘Edit’ button**

Opens the specified Job List file (\*.MJL) in text editor. If the Job List File dialog is empty, or the specified file does not exist or is empty, the ‘Edit’ button opens an empty ASCII file.

#### **‘Generate Job List’ button**

Starts a Job List generation process. This is a special form of simulation where the output is a Job List file (\*.MJL).

More details on Job List generation and editing are found in the Long Term Statistics (LTS) User Manual.

## 16.1.6 Results

The Results tab includes parameters for defining output from a simulation setup.

Multiple result files may be specified for each simulation setup.



Simulation setup

Identification

ID: TutorLTS ☒ Active project

Scenario: Base

Buttons: Insert, Copy, Delete, RUN

Tabs: General, Catchments, HD, AD and WQ, LTS, Results

Output folder

☐ Save results in default folder

☒ Save results in this folder: C:\Users\mikeadmin\Documents\LTS\Custom\_Folder

Collection System Summary

Sum\_TutorLTS

Project outputs

	ID	Type	Format	Save every
▶ 1	AD	Pollution transport	.res1d	60 sec
2	Default_LTS_chronological_statistics	LTS chronological statistics	.res1d	60 sec
3	Default_LTS_extreme_statistics	LTS extreme statistics	.res1d	60 sec
4	Default_Network_HD	Hydrodynamic	.res1d	60 sec
5	Default_Network_RTC	Real time control	.res1d	60 sec
6	Default_Network_AD	Pollution transport	.res1d	60 sec
7	HD	Hydrodynamic	.res1d	60 sec

Result files

Simulation setup

ID	Scenario	Active Project	Catchments	Runoff(RR)	Stormwater runoff WQ (SWQ)	Catchment Disc
▶ 1	TutorLTS	Base	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

Figure 16.8 Results Tab of the Simulation Setup Editor showing multiple result items

Table 16.7 Overview of Simulation Setup Results tab attributes (Table msm\_Project)

Edit field	Description	Used or required by simulations	Field name in datastructure
Save Results in Default Folder/Save Results in this Folder [Output Folder radio buttons]	Toggles between Default folder and user-specified folder for output file location	Yes	HDOuputNo
[Input box beside 'Save Results in this Folder' option]	Contains the path for user-specified output destination folder	Yes if 'Save Results in this Folder' activated	HDFolderPath



Table 16.7 Overview of Simulation Setup Results tab attributes (Table msm\_Project)

Edit field	Description	Used or required by simulations	Field name in datastructure
Collection System Summary dropdown menu	Specifies a MIKE1D simulation summary. User selects from the list of available summaries. Only one network summary per simulation job is possible.	Yes if including a network simulation	SummaryID
Edit Summary button	Opens the Network Summary editor with the current summary in focus. Allows for editing summary contents. If user has specified a non-existing summary ID, program automatically creates a new summary record with default contents and opens the summary editor with the new summary in focus.	Yes	-

A secondary grid in the Simulation Setup Results tab displays a list of the output files selected for the simulation setup (Figure 16.9). The grid retrieves the information from the Result Files editor (Result Specifications| Result Files).

Project outputs								Result files	
ID	Type	Format	Save every	Default save period	Start saving	End saving			
1	HD Hydrodynamic	.res1d	60 seconds	<input checked="" type="checkbox"/>	03-01-1936 ...	28-12-1979 ...			
2	Default_Network_...	.res1d	60 seconds	<input checked="" type="checkbox"/>	03-01-1936 ...	28-12-1979 ...			
3	Default_Network_...	.res1d	60 seconds	<input checked="" type="checkbox"/>	03-01-1936 ...	28-12-1979 ...			
4	Default_Network_...	.res1d	60 seconds	<input checked="" type="checkbox"/>	03-01-1936 ...	28-12-1979 ...			
5	Default_LTS_extre...	.res1d	60 seconds	<input checked="" type="checkbox"/>	03-01-1936 ...	28-12-1979 ...			
6	Default_LTS_chro...	.res1d	60 seconds	<input checked="" type="checkbox"/>	03-01-1936 ...	28-12-1979 ...			
7	AD Pollution trans...	.res1d	60 seconds	<input checked="" type="checkbox"/>	03-01-1936 ...	28-12-1979 ...			

Figure 16.9 The Project Outputs secondary grid in the Results Tab

The list of outputs is controlled by the user using functional buttons to the right of the grid.



The user selects output definitions to include from among those available in the project associated with the modules included in the simulation (and specified in the Result Files editor). The options are filtered according to the contents of the actual simulation.

The list will include at least one "Default" result file definition for each module (Runoff, Network HD, etc.) containing the most usual results for the entire model domain (e.g. runoff for all catchments, discharges and water levels for all model elements, etc.). The list of result file definitions may be extended by "user-specified" output definitions.

An overview of the attributes of the Project Outputs secondary grid is shown in Table 16.8 below.

**Table 16.8** Overview of the Project Outputs secondary grid attributes (Table `mism_ProjectOutput`)

Edit field	Description	Used or required by simulations	Field name in datastructure
ID	MUID of the selected output file definition	Yes	OutputID
Type	Shows type and default contents of the output file (read only)	Yes	ContentsTypeNo
Format	Shows the file format (read only)	Yes	FormatNo
Save Every	Specifies results saving frequency	Yes	DtSave
[Column to the right of 'Save Every' column]	Specified unit for result saving frequency	Yes	DtSaveUnitNo
Default Save Period checkbox	Specify to save results for the entire simulation (check), or for user-specified period only (uncheck)	Yes	DefaultSavePeriodNo
Start Saving	Defines start date and time for saving results	Yes if user-specified save period	SaveStartDate
End Saving	Defines end date and time for saving results	if user-specified save period	SaveEndDate





The following functional buttons are available for controlling the list of outputs in the Project Outputs secondary grid:

**‘Include’ button**

Opens a list of all relevant output definitions for the simulation and allows the user to choose those which are to be added to the list.

**‘Include all’ button**

Fills the list with all relevant pre-defined output definitions found in the database. Relevance is determined by the modules included in the simulation. If the list is not empty, it only adds those outputs which are not already in the list.

**‘Edit’ button**

Opens the Result Files editor with the current output in focus.

**‘Remove’ button**

Removes selected output(s) from the list.

**‘Use Default Period’ button**

This function finds the full period available for an output item. The information is reflected in the Start Saving and End Saving secondary grid attributes. This tool may be used in defining user-specified saving periods to ensure they fall within valid periods.

## 16.2 Hotstart Files

**What is hotstart?**

Hotstart is a facility that enables application of initial conditions for a simulation other than the default initial conditions. Default initial conditions are empty network and uniform concentrations of pollutants in the pipe flow model, or initial values of hydrological state variables in the RDII hydrological model.

**What is a hotstart file?**

Hotstart initial conditions represent the state of the system as recorded in a previously generated result file at a specified time -- the so-called hotstart file.

Relevant information from a hotstart file for a network simulation includes:

- Water levels and pollutant concentrations in nodes of the system
- Water levels, discharges and pollutant concentrations in grid points of the network
- Pumps, weirs, orifices (gates) and valves flows and pollutant concentrations
- Position of controllable weirs, gates and valves (if RTC is applied)



For the RDII model, relevant information in the hotstart file includes all relevant hydrological state variables, such as surface storage, groundwater depth, etc.

It is recommended that a hotstart file for a network simulation is generated from exactly the same model setup as the model used in a hotstarted simulation run.

Only information available in the hotstart file are used to initialize a simulation; any missing information from the hotstart file (e.g. because of newly-added elements) are not interpolated/extrapolated from available hotstart values during initialization.

### Why and when is hotstart relevant?

Hot start files can be used for the following purposes:

- To avoid potential numerical instabilities that occasionally take place under Dynamic Wave computations during the initial phase of the simulation.
- To create a realistic initial condition for a simulation. This typically implies levying a set of constant base flows (for a natural channel network) or a set of dry weather sanitary flows (for a sewer network) over some start-up period of time. The resulting hotstart file from this run is then used to initialize a subsequent run where the inflows of real interest are imposed.
- To divide long continuous simulations into shorter simulation periods. Here are the initial conditions for each subsequent simulation period set as the end of the previous simulation period.

### Specification of the hotstart

Hotstart options are set in the Catchments, HD, and AD and WQ tabs in the Simulation Setup editor.

For the RDII runoff model, the only parameter needed is the Hotstart Filename. The system automatically detects the values of the relevant variables at the simulation start time and initiates the actual simulation run accordingly.

For the pipe flow model (HD), the following parameters are needed:

- Hotstart Filename: This is the name of an existing result file from which initial conditions for the simulation will be loaded.
- Hotstart Time: The date and time at which the initial conditions are taken from the hotstart file. The selected hotstart time must be within the hotstart file time coverage.

For the Pollution Transport (AD) hotstart, the model is initiated from the AD Hotstart File. It uses the same Hotstart Time specified for the HD hotstart as it is expected that the HD and AD hotstart files are consistent with each other (i.e. from the same simulation run).



## 16.3 Batch Simulation

If you need to run more simulations sequentially, you can choose to do so by including these to a batch simulation. This is done through the Batch Simulation editor.

The Batch Simulation editor includes functionalities allowing control and execution of batch simulations.

The 'Batch Run' button executes all simulations that have the 'Include to batch' flag set in the sequence that they are specified in the grid table. This means that multiple simulations and scenarios can be simulated in batch without user interaction.

	Include to batch	ID	Scenario	Active Project	Catchments	Runoff(RR)	Stormwater runoff W
1	<input checked="" type="checkbox"/>	TutorLTS	Base	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

Figure 16.10 The Batch Simulation Editor

The Batch Simulation editor manages the same data from the Simulation Setup editor. The grid table shows the same entries as the grid in the Simulation Setup editor, but built-in tools allow reordering and filtering of simulation job records for batch execution.



Table 16.9 Overview of Batch Simulation editor fields (Table msm\_Project)

Edit field	Description	Used or required by simulations	Field name in datastructure
ID	ID of the simulation setup	Yes	MUID
Scenario	Scenario for the simulation setup	Yes	ScenarioName
Add to Batch checkbox	Option for including a simulation setup to batch	Yes	IncludeToBatchNo

The following functionalities are available on the editor:

#### Move Up

Moves the active record one position up in the grid.

#### Move Down

Moves the active record one position down in the grid.

#### Move To Top

Moves the active record to the top of the table.

#### Move To End

Moves the active record to the bottom of the table.

#### 'All jobs' and 'Batch jobs only' radio buttons

This filters the list of simulation jobs displayed in the table. A complete list of simulation jobs (i.e. All jobs) is shown by Default, but the display can be reduced to show only those jobs included in the batch (i.e. Batch jobs only).

#### 'Batch Run' button

This starts a batch job execution following the sequence of the simulation jobs on the list. Each consecutive job must wait until the previous job has been fully completed. All user prompts are suppressed during the batch job execution, i.e. the simulations are automatically executed without user prompts.



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