Centre de recherche sur l'environnement alpin (CREALP)

HydroCosmos SA

RS MINERVE

RS MINERVE - User Manual

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Centre de recherche sur l'environnement alpin (CREALP)

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Foreword

RS MINERVE is a software for the simulation of free surface run-off flow formation and propagation. It models complex hydrological and hydraulic networks according to a semi-distributed conceptual scheme. In addition to particular hydrological processes such as snowmelt, glacier melt, surface and underground flow, hydraulic control elements (e.g. gates, spillways, diversions, junctions, turbines and pumps) are also included.

The global analysis of a hydrologic-hydraulic network is essential in numerous decision-making situations such as the management or planning of water resources, the optimization of hydropower plant operations, the design and regulation of spillways or the development of appropriate flood protection concepts. RS MINERVE makes such analyses accessible to a broad public through its user-friendly interface and its valuable possibilities. In addition, thanks to its modular framework, the software can be developed and adapted to specific needs or issues.

RS MINERVE contains different hydrological models for **rainfall-runoff, such as GSM**, **SOCONT**, **SAC-SMA**, **GR4J** and **HBV**. The combination of hydraulic structure models (reservoirs, turbines, spillways,…) can also reproduce complex hydropower schemes. In addition, a **hydropower model** computes the net height and the linear pressure losses, providing energy production values and total income based on the turbine performance and on the sale price of energy. A **consumption model** calculates water deficits for consumptive uses of cities, industries and/or agriculture. A **structure efficiency model** computes discharge losses in a structure such a canal or a pipe by considering a simple efficiency coefficient.

The **Expert module**, specifically created for research or complex studies, enables in-depth evaluation of hydrologic and hydraulic results. **Time-slice simulation** facilitates the analysis of large data sets without overloading the computer memory. **Scenario simulation** introduced the possibility of simulating multiple weather scenarios or several sets of parameters and initial conditions to study the variability and sensitivity of the model results. The **automatic calibration** with different algorithms, such as the SCE-UA, calculates the best set of hydrological parameters depending on a user-defined objective function.

RS MINERVE program is **freely distributed** to interested users. Several projects and theses have used and are using this program for study basins in Switzerland, Spain, Peru, Brazil France and Nepal. In addition to the research center **CREALP** and the engineering office **HydroCosmos SA**, which currently develop RS MINERVE, two universities (**Ecole Polytechnique Fédérale de Lausanne** and **Universitat Politècnica de València**) collaborate to improve RS MINERVE and use it to support postgraduate courses in Civil Engineering and Environmental Sciences.

Chapter 1. Introduction

RS MINERVE is based on the same concept than Routing System II, earlier software developed at the Laboratory of Hydraulic Constructions (LCH) at the Ecole Polytechnique Fédérale de Lausanne (EPFL) (Dubois et al., 2000; García Hernández et al., 2007) and used since 2002 in different projects and theses, such as by Jordan (2007) or Claude (2011).

The software presented hereafter, RS MINERVE, is currently developed by the CREALP and HydroCosmos SA, with the collaboration of the previously mentioned LCH as well as the Universitat Politècnica de València (UPV). It has also been used since 2011 in numerous projects and theses (e.g. García Hernández, 2011).

This first chapter contains the structure of the manual, the procedure to install and update RS MINERVE and the overview of the RS MINERVE interface.

1.1. Document structure

The manual is composed of nine main chapters:

1. Introduction
2. Rainfall-runoff modelling
3. Hydraulic infrastructures modelling
4. Database
5. GIS
6. Hydrological-hydraulic simulation
7. Expert module
8. Examples of application

In the different chapters, actions to be done by the user are presented in blue.

After the bibliography, the appendix presents in detail the different parameters and initial conditions of the hydrological models available in RS MINERVE. In addition to this User's manual, the reader can also find all model equations and file descriptions in the technical manual (García Hernández et al., 2020)

1.2. Installation procedure

Proceed as follows to install RS MINERVE on your computer (requires Windows 7 or later versions of Windows):

- Visit the CREALP website: https://www.crealp.ch/fr/accueil/outils-services/logiciels/rs-minerve/telechargement-rsm.html
- Click on *Download page: RS MINERVE*
- Save the file, double-click on RSMinerve-install.exe (in the Internet browser *Downloads* frame) and follow the installation procedure.

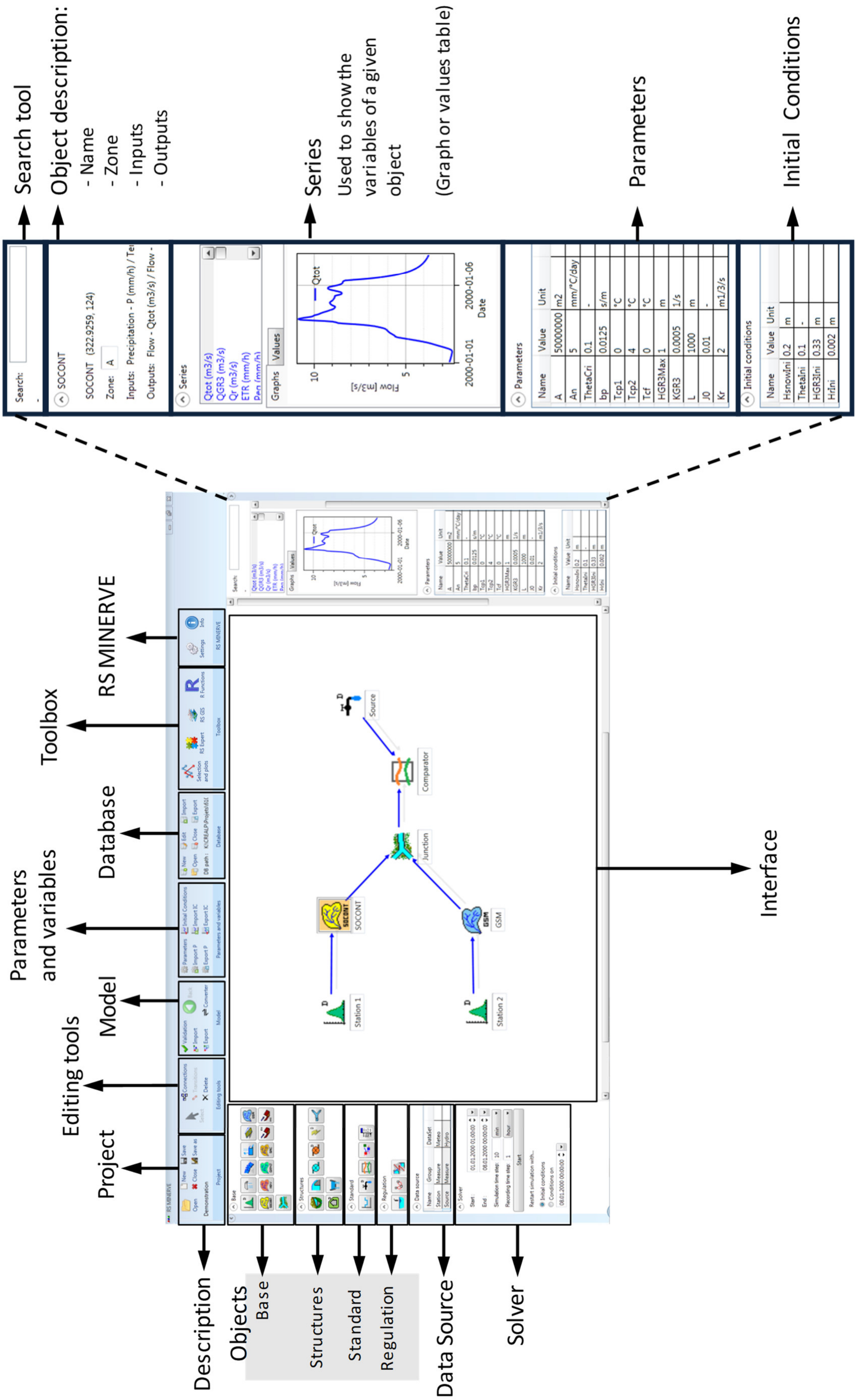


Figure 1 Structure of the RS MINERVE main interface

1.3. Updates

When RS MINERVE is opened and if an Internet connection is available, RS MINERVE connects to the server to check if a new version is available. If this is the case, the user is invited to install the new version by accepting the update.

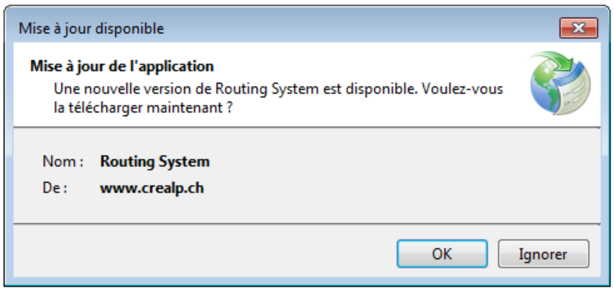


Figure 2 Installation of updates

1.4. Uninstallation procedure

To uninstall RS MINERVE, use the conventional uninstallation procedure in Windows.

1.5. The Model interface

The structure of the RS MINERVE main window and the different frames composing it are presented in Figure 1.

The *Interface* frame (Figure 1) in the middle of the RS MINERVE interface allows the visualization of the model network.

Interaction within the *Interface* is possible with the mouse.

- Use the scroll wheel to zoom in / zoom out
- Press the scroll wheel and move the mouse to move the interface window
- Left click on an object (Figure 3 (b)) -> Select the object and move it in the interface
- Double-click on an object (the object is highlighted, Figure 3 (c)) -> Display the *Object description, Series* and other corresponding frames (in the right part).

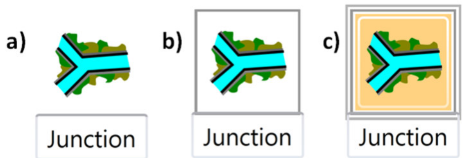


Figure 3 Example of an unselected object (a), after a left click (b) and after a double-click (c)

1.6. The Search tool

To facilitate navigation in the main window, the *Search* tool (right-frame) allows the user to enter the name of an object. All corresponding names are listed and a click on the correct one opens the parent model and highlights the corresponding object.

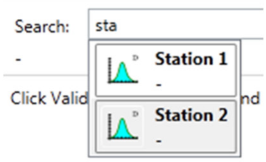


Figure 4 The Search tool

1.7. Settings

The user can access to the settings in the RS MINERVE frame (Figure 5) and can change the following values:

- The units of inputs, parameters and state variables of RS MINERVE (Precipitation, Temperature, Length, Height,…)
- The interpolation method for meteorological values:
  - Thiessen polygons: for using the nearest meteorological station
  - Shepard method: for values depending on inverse distance weighting
- The Potential Evapotranspiration (ETP) method used in the hydrological model. The ETP can be directly taken from Database, or computed with one of the following methods:
  - Turc
  - McGuinness
  - Oudin
  - Uniform ETP

Any change is directly applied to the current model. In addition, the user can also save the current settings as default settings for new models.

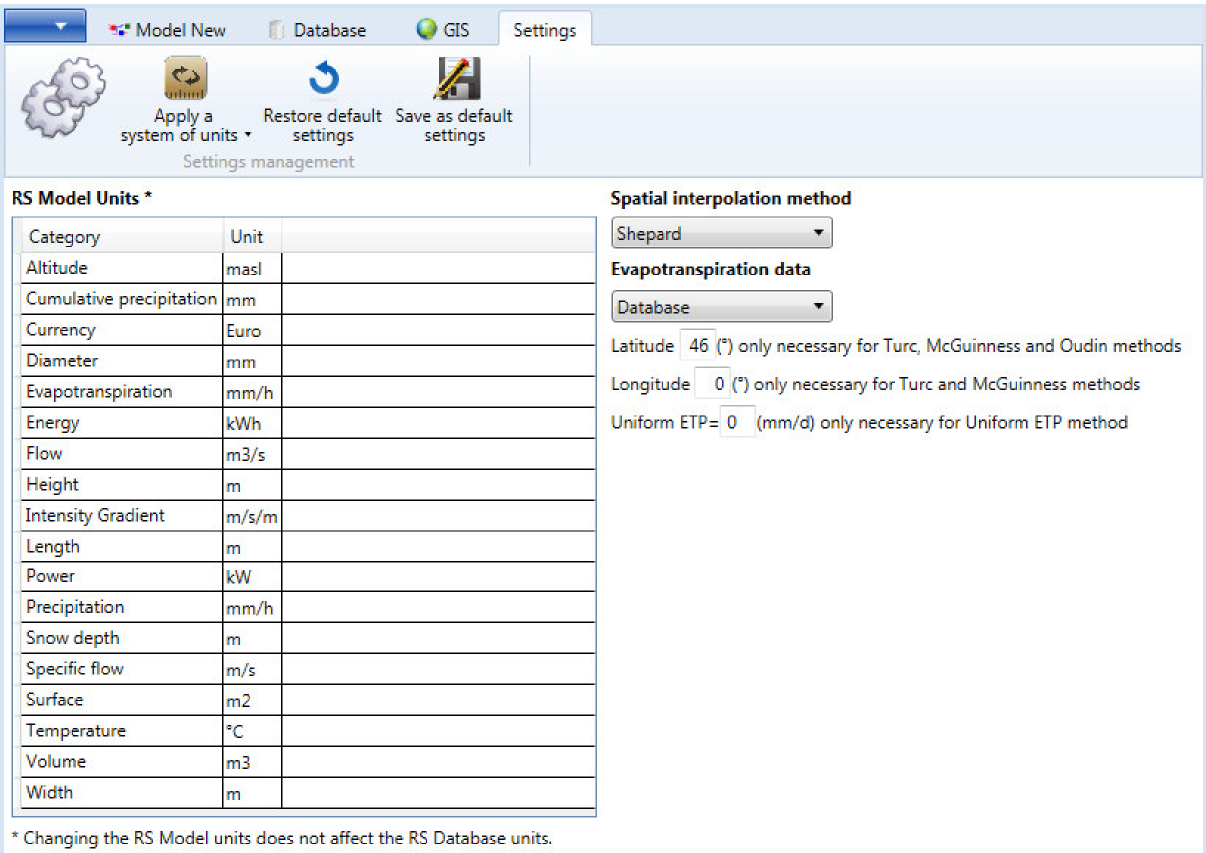


Figure 5 RS MINERVE Settings tab

1.8. List of keyboard shortcuts and mouse actions

The user can use a list of keyboard shortcuts (Table 1) as well as a list of mouse actions over the graphics (Table 2).

Table 1 List of keyboard shortcuts

Ctrl + N	New Project
Ctrl + O	Open Project
Ctrl + S	Save Project
Ctrl + Shift + S	Save as Project
Ctrl + W	Close Project
F5	Start Simulation
Shift + F5	Stop Simulation
Esc	Back (go to hierarchical higher level),
	Cancel object selection (when object type selected in Objects frame)
Space	Switch between *Select* and *Connections*
Ctrl + Space	Switch between *Select* and *Transitions* (in a Regulation object only)
Ctrl	To select more than one object or series

Table 2 List of mouse actions in graphics

Over the axes	
Left click	-
Right click and move the mouse	Displace the current view
Move the scroll wheel	Zoom in / zoom out
Click on scroll wheel and move the mouse	Select the zoom zone
Double click on scroll wheel	Back to default zoom
Over the time series plot	
Left click	Date and value of the nearest series point
Right click and move the mouse	Displace the current view
Move the scroll wheel	Zoom in / zoom out
Click on scroll wheel and move the mouse	Select the zoom zone
Double click on scroll wheel	Back to default zoom

Chapter 2. Rainfall-runoff modelling

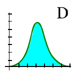
RS MINERVE is an object-oriented modeling software. The different processes are modeled with equation-based objects, presented hereafter in Chapters 2.1 (*Base objects*) and 2.2 (*Standard objects*). *Hydraulic infrastructures* and *Regulation* objects are presented in Chapter 6.

The implemented hydrological models (Snow-SD, SWMM and GSM-SOCONT) have been developed within the framework of different research projects, namely CRUEX (Bérod, 1994), SWURVE (Schaefli & al., 2005) and MINERVE [1] (Hamdi & al., 2003, 2005).

The hydrological models HBV (Bergström 1976, 1992), GR4J (Perrin et al., 2003) and SAC (Burnash, 1995) are also included in the software RS MINERVE for extending the hydrological modeling possibilities.

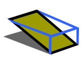
2.1. Hydrology

The *Base objects* are mostly composed of the hydro-meteorological objects. For more details, see the Technical Manual.



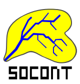
Virtual weather station - It calculates the local meteorological conditions (precipitation (P), temperature (T) and potential evapotranspiration (ETP)) based on observed or forecasted data from the database and based on Thiessen or Shepard interpolations. In addition, the ETP can be also calculated either with a constant value or from one of the different equations proposed by Turc (1955, 1961), McGuinness et Bordne (1972) or Oudin (2004). The method can be selected in the Settings (see chapter 1.6). For more details, please refer to the Technical Manual of RS MINERVE.

Snow-SD - Simulates the time evolution of the snow pack based on temperature (T) and precipitation (P). The output is an equivalent precipitation (P_{eq}) and the snow height (H) proposed as input to other models such as *SAC-SMA or GR4J*.

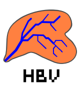


Runoff (SWMM) - The runoff-based hydrograph is calculated with this object from a net rainfall (i_{Net}).

GSM (Glacial Snow Melt) - The GSM object combines Snow and Glacier models.



SOCONT (SOil CONTribution) - The SOCONT object combines the Snow, Infiltration (GR3) and Runoff (SWMM) models.



HBV - This integrated rainfall-runoff model is based on the HBV model. Using a precipitation (P), a temperature (T) and a potential evapotranspiration (ETP) as inputs, it produces a total discharge (Q_{tot}) composed of a run-off flow (Q_r), an interflow (Q_u) and a baseflow (Q_l).

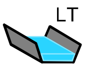
[1] MINERVE: Modélisation des Intempéries de Nature Extrême du Rhône Valaisan et de leurs Effets (Modeling of Rhone extreme floods in Valais and their consequences).

GR4J - This object is based on the GR4J model, containing 4 parameters. Using an equivalent precipitation (P_{eq}) and a potential evapotransipration (ETP) as inputs, an outflow is calculated.

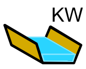
SAC - The SAC-SMA (Sacramento-Soil Moisture Account) object uses an equivalent precipitation (P_{eq}) and a potential evapotranspiration (ETP) as inputs and provides an outflow at the outlet of the sub-basin.

2.2. Rivers

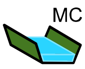
Different *Rivers objects* are proposed by RS MINERVE:



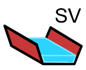
Lag-Time **-** The Lag-Time river calculates a river transition based on a lag-time but does not produce any attenuation of the flow.



Kinematic Wave - The flow is transferred based on the Kinematic wave equations.



Muskingum-Cunge - The flow is transferred based on the Muskingum-Cunge (1969, 1991) equations.

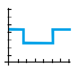


St-Venant - The flow is transferred based on the St-Venant equations.

2.3. Standard

The *Standard objects* are complementary but generally necessary for feeding, structuring and calibrating the model.

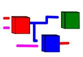
Junction - This object allows calculating the addition of different flow inputs (also coming from hydraulic infrastructures).



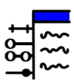
Time series - Data can be provided to the model as time series (time in seconds). Data of any type (Flow, Temperature, Precipitation, ETP,...) can be directly transferred to other objects.

Source - Data can be also loaded from a database. *Sources* are mostly used to define flow time series for turbine or pump flow and as reference flow for calibration (with a *Comparator* object).

Comparator - This object is used to compare the results of a simulation with a reference data coming from another object, generally a *Source*. Both objects are connected to the *Comparator* for results comparison.



Submodel - A combination of objects can be saved as a submodel and integrated as such in a model.



Group Interface - It allows transferring the input or output variables between different hierarchical levels.

For hydraulic infrastructures objects and regulation objects, please refer to Chapter 6.

2.4. Creation of a hydrological model

The steps to create a hydrological model for a natural basin (without hydraulic infrastructures) are presented in this chapter.

To create the model

- Open RS MINERVE.
- Click on the type of object to be added (*Objects* frame, Figure 1). With the pencil, click in the *Interface* to add the object. Repeat the operation for all objects. If the wrong object is selected in the *Objects* frame, use the *Esc* key to cancel.
- Select *Connections* in the *Editing tools* frame (Figure 1) or press the *space* key to switch, interconnect the objects with blue arrows in the sense of flow and select the variables(s) concerned by the connections in the pop-ups (Figure 6). [2]
- Choose *Select* in the *Editing tools* frame or press the *space* key to switch.
- By clicking on each object separately,
  - Rename the objects.
  - Modify their fixed parameters (such as coordinates for the Station and surface for main hydrological objects) in the *Parameters* frame (Figure 1). See Appendix 1 for a complete list of parameters and initial conditions.
  - Define the *Zone* of each object in the *Object* frame (Figure 1). [3]
    Use "Tab" to validate the *Zone* number.

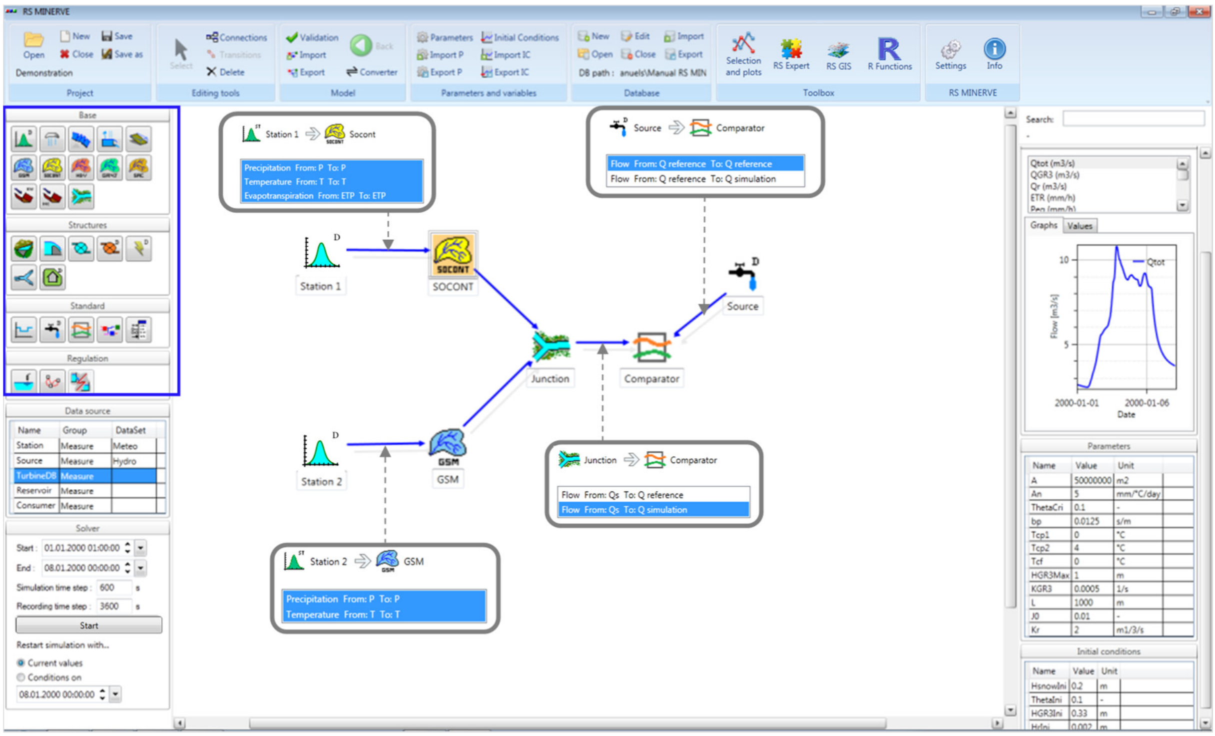


Figure 6 Example of a simple model

[2] In absence of water flow, connect arrows in the sense of information transfer.
[3] The concept of *Zones* allows the modification of a parameter or initial condition to all the objects contained in the selected zone(s) by attributing a unique value.

To define the *Parameters* of the model objects:

- Click on *Parameters* in the *Parameters and Variables* frame (Figure 1).
- Select an *Object type* and a *Zone Id* in the *Selection* frame (Figure 7). Use *Ctrl* to select more than one Zone ID.
- In the *Parameters management* frame (Figure 8, left), the parameters of the selected object type are listed. Parameters with identical value in all objects of the selected zone(s) are checked by default. The objects contained in the zone(s) and their respective parameter values are displayed in the *Objects list* (Figure 8, right).
- Define the parameters to be calibrated, i.e. uniformly modified, by checking and unchecking the parameters in the *Parameters management* frame (the [x] column, Figure 8, left).
- Modify in the *Parameters management* frame the values of the *Parameters* to be calibrated and click on *Apply selected changes*. (Alternatively, individually modify the values of each object in the *Objects* list (Figure 8, right)).
- Repeat the procedure for all object types in each zone.

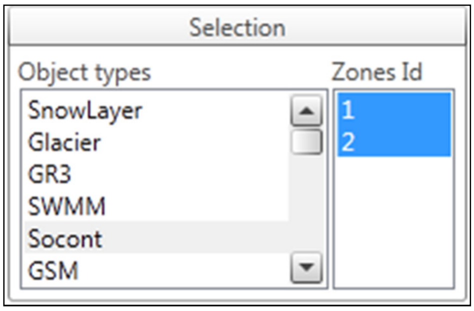


Figure 7 Selection frame

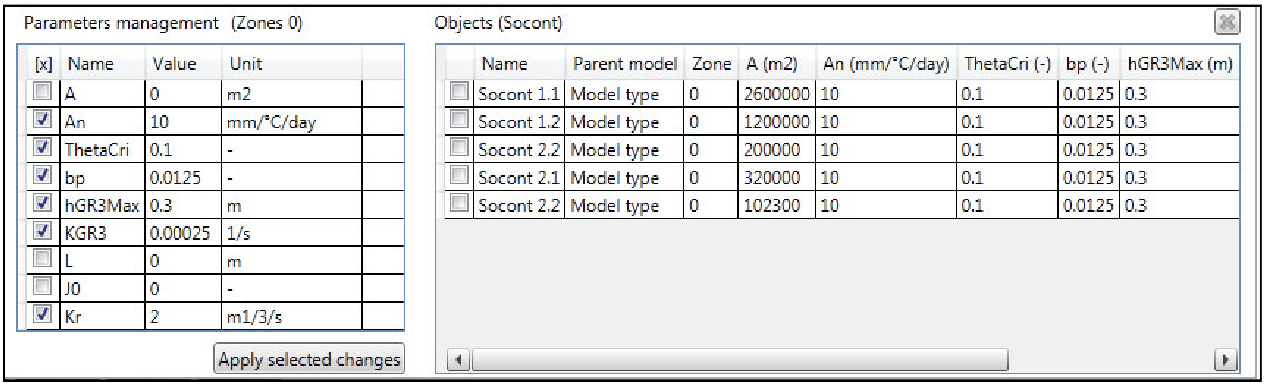


Figure 8 Left: Parameters management frame; Right: Objects of the selected zone(s) and their parameters

To define the *Initial Conditions*:

- Click on *Initial Conditions* in the *Parameters and Variables* frame (Figure 1).
- Proceed in a similar way than for the *Parameters* definition to modify all the *Initial Conditions*.

Initial conditions are generally not known precisely. Approximated values can be entered to improve the simulation results. Final conditions of a previous simulation ending at the start time of the period of interest can be used as current initial conditions to improve the results.

To save the project:

- Click on *Save* in the *Project* frame (Figure 1).
- Define the file name and save.

2.5. Exportation of a submodel

Combinations of objects can be exported and later imported as *Submodel* objects in a complete model. This allows the structuration of the model by organizing it in different hierarchical levels.

- Add a *Group Interface* to the combination of objects to be exported. [4]
- Link the output object of the model (*Junction* in Figure 9) to the *Group Interface*. Select the link(s) to be created in the pop-up (*Flow* in the example of Figure 9). [5]

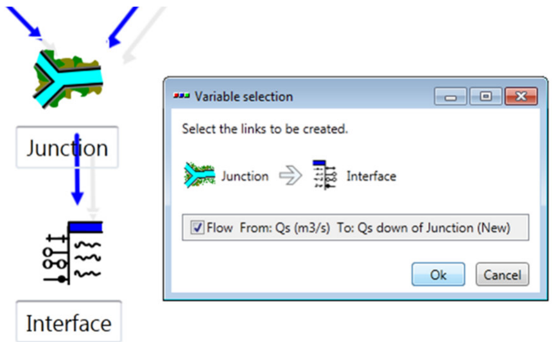


Figure 9 Addition of a *Group Interface* to the combination of objects to be exported as submodel

- Export the active model with the *Export* button in the *Model* frame (Figure 1). [6]
- Create a new project with the *New* button in the *Project* frame. [7]
- Import the *Submodel* with the *Import* button in the *Model* frame.
- Open the *Submodel* with a right-click on it. The model previously created appears.
- Return to the upper hierarchical level with the *Back* button (*Model* frame) or by pressing the *Esc* button.
- Add a *Junction* object and link the *Submodel* to the new *Junction* (Figure 10). In the example of Figure 10, the flow of the new *Junction* now corresponds to the flow of the *Junction* in the *Submodel*.

[4] Group Interfaces are required to assemble a submodel with the upper hierarchical level. It allows transferring the input and/or output variables.

[5] If only one link can be created, it is selected by default. If more than one link is possible, none is selected.

[6] During the exportation, only the elements contained in the active hierarchical level, including all the submodels and objects, are considered. Hierarchically higher elements are not exported.

[7] Or, alternatively, open a project with Project -> Open.

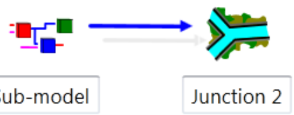


Figure 10 Link the *Submodel* to a *Junction*

At the same time, if a *Submodel* receives also an input from upstream, a second *Group Interface* has to be added in the *Submodel* and linked to the object receiving the incoming variables. *Group Interfaces* can support more than one variable as input and/or as output.

Submodels can also be created by adding an empty *Submodel* object [8] and then adding the adequate objects in the *Submodel* (opened with a right-click). In a similar way, objects can be added to or deleted from imported *Submodels*.

Modifying the *Zone* of a *Submodel* modifies the zone of all the objects contained in the *Submodel*.

2.6. Model conversion

The conversion between different hydrological models is possible with the button “Converter” of the Model Properties frame (Figure 11).

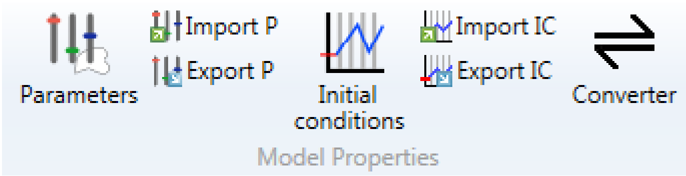


Figure 11 Model frame

The model conversion is direct for all hydrological model as presented in Table 3. For achieving the conversion, initial and final hydrological model types are selected. Then, the zone(s) and the object(s) to convert are chosen (Figure 12).

In the current version, only the parameter A (Surface) is transferred to the new model. All other parameters are fixed to the by default values of each model.

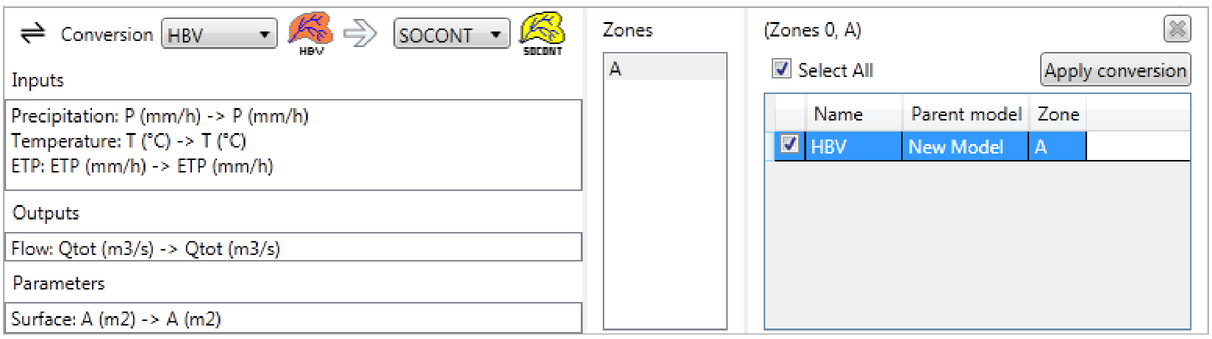


Figure 12 Example of a conversion between HBV and SOCONT

If the converted model does not need all inputs, a message informs that one of the inputs is deleted, as presented in Figure 13 for the input *Temperature*.

[8] By selecting *Submodel* in the *Standard objects* frame and adding the object in the *Interface*.

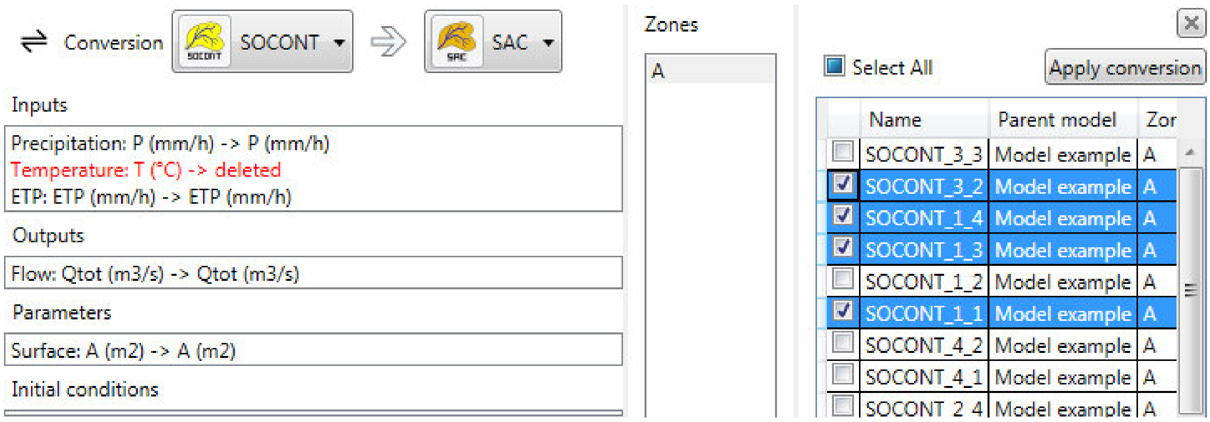


Figure 13 Example of a conversion between a model HBV and SAC, where the input Temperature is deleted

Finally, if the converted model needs more inputs than the original one, a message informs that one or several inputs need to be added, as presented in Figure 14 for the input *Temperature*. In that case, this/these input(s) is/are added between the station and the model (If the data comes from several *Stations* or *Time Series*, the user needs to link himself and to select the correct inputs among all possibilities).

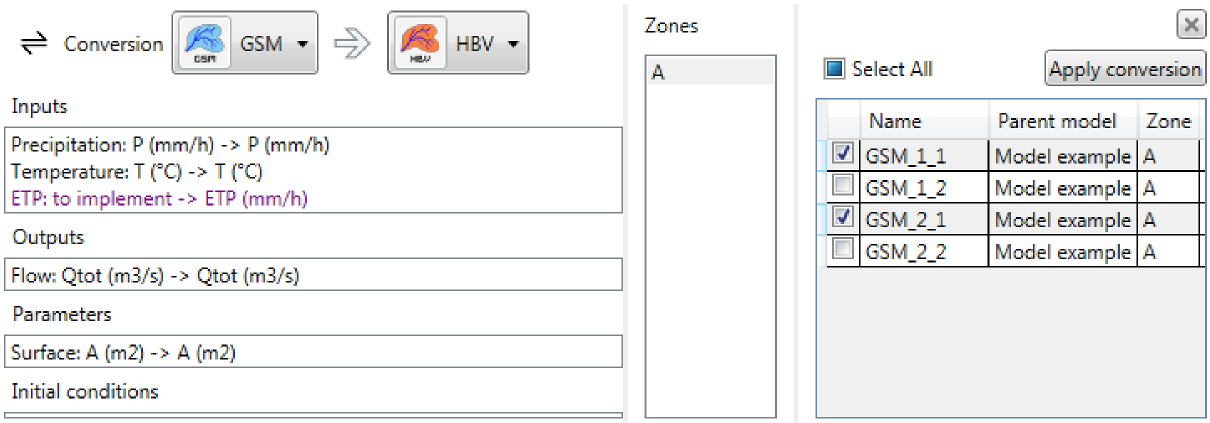


Figure 14 Example of a conversion between a model SAC and HBV, where the input Temperature has to be implemented by the user

Regarding the outputs, the total discharge (Qtot or Q depending on the model) is directly linked to the downstream object after the conversion.

If any other discharge is linked downstream, e.g. the Qr in the SOCONT model to a junction, the link is deleted after conversion.

Table 3 Conversions between objects

Object	Inputs		Object	Inputs
SWMM	P	→	**GSM**	P and T
			SOCONT	P, T, ETP
			HBV	P, T, ETP
			GR4J	P and ETP
			SAC	P and ETP
GSM	P and T	→	**SWMM**	P
			SOCONT	P, T and ETP
			HBV	P, T and ETP
			GR4J	P and ETP
			SAC	P and ETP
SOCONT	P, T and ETP	→	**SWMM**	P
			GSM	P and T
			HBV	P, T and ETP
			GR4J	P and ETP
			SAC	P and ETP
HBV	P, T and ETP	→	**SWMM**	P
			GSM	P and T
			SOCONT	P, T and ETP
			GR4J	P and ETP
			SAC	P and ETP
GR4J	P and ETP	→	**SWMM**	P
			GSM	P and T
			SOCONT	P, T and ETP
			HBV	P, T and ETP
			SAC	P and ETP
SAC	P and ETP	→	**SWMM**	P
			GSM	P and T
			SOCONT	P, T and ETP
			HBV	P, T and ETP
			GR4J	P and ETP

2.7. Single sub-basin parametrization

The parametrization (or calibration) process aims to progressively improve the model to fit the simulated data to the reference data (e.g. the observations) by iteratively adjusting the object's parameters.

To proceed to the optimal parametrization (or calibration), observed data are required as comparison basis for the simulated data. Sites of measure stations generally define outlets of sub-basins since they represent the location of comparison (simulated data vs. observed data). [9]

For simplicity, division into zones generally respects the sub-basin's division. However, this is not compulsory and a zone can correspond to several sub-basins or one sub-basin can be divided into several zones. In this subchapter, it is assumed that the sub-basin is composed of a single zone.

Model's performance evaluation

Before adjusting the parameters, the current performance of the model is evaluated.

- Click on the *Comparator* object which has been added and connected as presented in Figure 6.
- In the *Series* frame (Figure 15), select $Q_{reference}$ and $Q_{simulation}$ (use *Ctrl* to select both).
- Visualize the actual results:
    - In the *Series frame*, both curves are plotted together under *Graphs*.
    - In the *Comparator* frame, seven performance indicators are provided (read the Technical Manual for more information).
        - Nash coefficient
        - Nash-ln coefficient
        - Pearson Correlation Coefficient
        - Kling-Gupta Efficiency
        - Bias Score
        - Relative Root Mean Square Error
        - Relative Volume Bias
        - Normalized Peak Error

Manual parameters adjustment

Based on the current model's performance, object's parameters can be adjusted to improve the next run's performance.

- Click on *Parameters* in the *Parameters and variables* frame (Figure 15).
- Select in the *Selection* frame (Figure 15) the type of object to be modified and the corresponding zone. See Chapter 2 for complete procedure.
- Modify the selection (checks) of parameters in the *Parameters Management* frame to select only the ones to be calibrated (i.e. to be uniformly modified).
- Modify the values of the selected parameters and click on *Apply selected changes*. Parameters are modified in the listed objects.
- Proceed in a similar way for all object types.

[9] Other factors are also considered during the basin division such as reservoir locations or river junctions.

- Modify also the initial conditions to fit better the reference data.

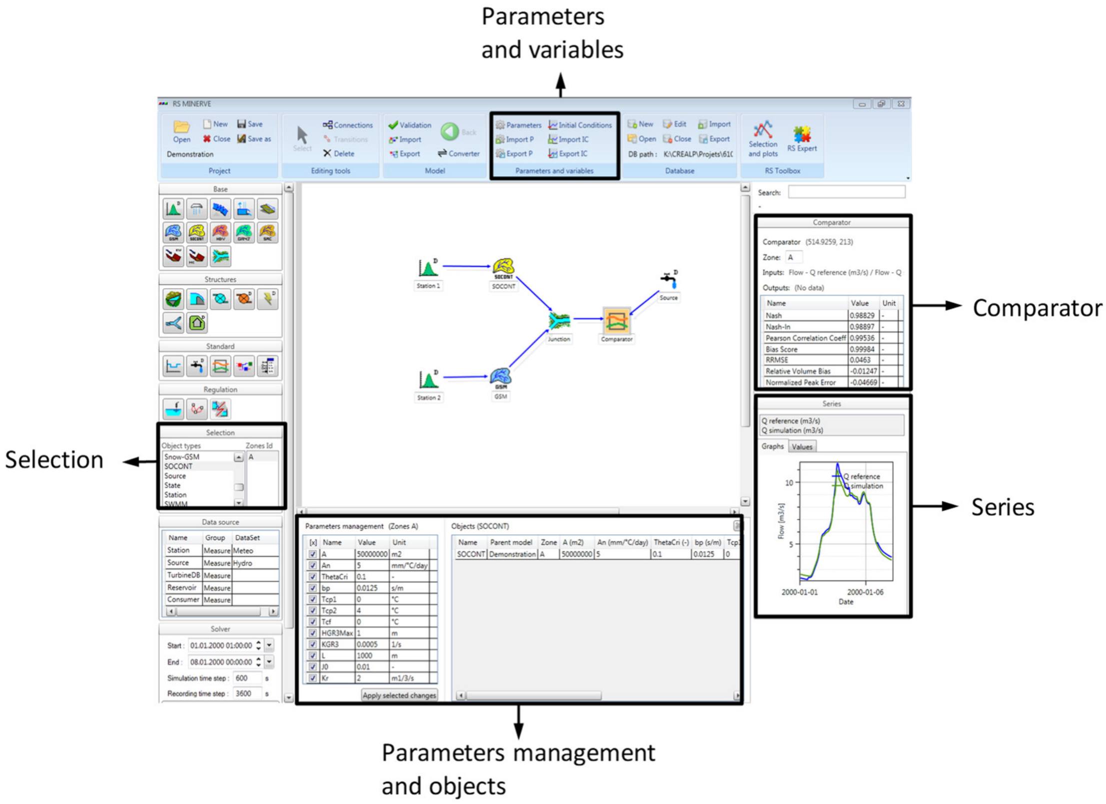


Figure 15 Frames used for the parametrization

- After running the model, analyze the results in the comparator and modify again the parameters when necessary.

The procedure is iterative until the simulation results are considered sufficiently satisfying for a specified zone.

Parameters and *Initial conditions* can be exported to be, later, imported again. Use *Export P* and *Import P* for the parameters and *Export IC* and *Import IC* for the initial conditions in the *Parameters and variables* frame (Figure 15). The parameters or initial conditions can be saved as .txt file or also as .xlsx file with one sheet per object type.

Automatic parameters adjustment

An automatic calibration can be also achieved thanks to a specific tool developed in the Expert module. Please the chapter 7.1 for more information.

2.8. Complete basin parametrization

When a basin is composed of many sub-basins, the parametrization has to be progressively achieved from upstream to downstream in the basin. By proceeding as such, contributions from the upstream calibrated sub-basin(s) are considered as input(s) to the downstream sub-basin on which the parametrization is performed. Parameters are modified for the concerned sub-basin to obtain the best possible results at the outlet of the sub-basin. The calibration module (Chapter 7.1) can realize multiple parametrizations for calibrating these complex basins from upstream to downstream.

Depending on the quality of the simulation results, inputs from upstream sub-basins can be replaced in the parametrization process by observed data at the entrance of the sub-basin being calibrated.

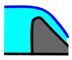
Chapter 3. Hydraulic infrastructures modelling

Chapters 1 to 5 have presented the different steps to create a hydrological model without any hydraulic infrastructures. Chapter 6 explains how infrastructures like reservoirs, turbines or spillways are implemented in RS MINERVE.

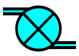
Hydraulic infrastructures are listed in Chapter 6.1 and objects used for automatic regulation are presented in Chapter 6.2.

3.1. Infrastructures

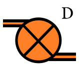
Reservoir - Water level and volume evolution are simulated based on a "Level-Volume" relation and an initial reservoir level.



HQ - Based on a level-discharge relation, it allows integration of level-based outflows to reservoirs (such as spillways, gates, orifices,…).

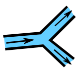


Turbine - It calculates the turbine or pump flow from a reservoir, based on a *Wanted Discharge* defined in the same object by a time-discharge series.



TurbineDB - The TurbineDB object works as the *Turbine* object but is directly based on data provided by the database. It is equivalent to the combination of a turbine and a source.

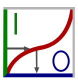
Hydropower - This object calculates the power and the revenue, normally produced by a turbine, depending on the discharge and on the reservoir level.



Diversion - This object is used to simulate the separation of flow based on an "Inflow - Diverted flow" relation. It can be used as a hydrological object but is mostly used as a hydraulic function.

Consumer - This object simulates the consumed discharge of a user (e.g.: a village or an agricultural field) based on a series from a database or from a uniform demand.

Structure efficiency – This object computes effects of discharge losses in a structure like a canal or a pipe based on an efficiency coefficient.



Planner - This is a control system consisting of the definition of a set of management rules, based on conditions. This object allows you to manage the regulation of reservoirs, turbines, bottom outlets, etc.

3.2. Addition of a Hydropower scheme

This chapter presents a general example for the construction of a hydropower scheme, including a reservoir with a hydropower plant, a turbine and a spillway.

Addition of a reservoir

To add a reservoir:

- Select the object *Reservoir* in the Infras*tructures objects* frame (Figure 16) and add it in the *Interface*.
- Link the output of the upstream sub-basin (object *Junction* in Figure 16) to the *Reservoir*.

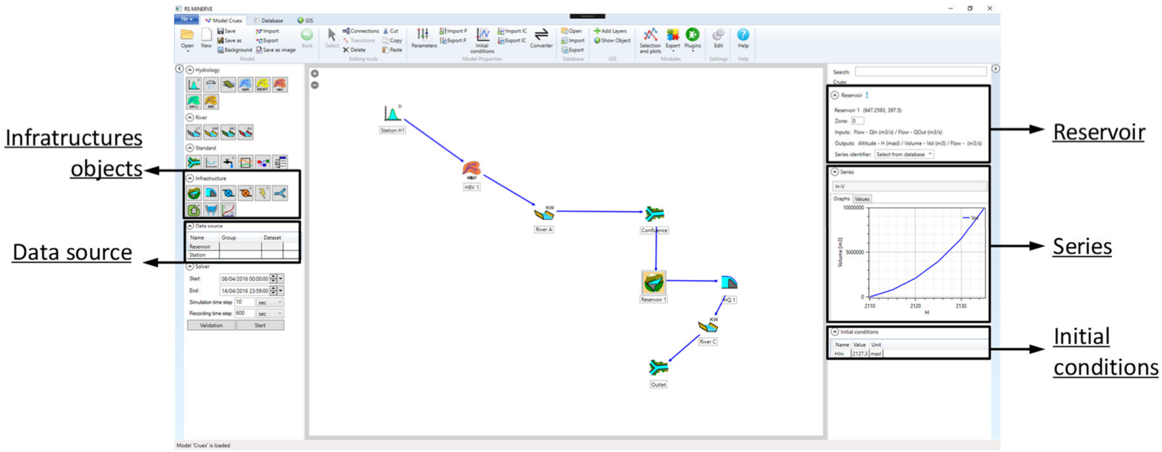


Figure 16 A regular model with a reservoir

- Double-click on the *Reservoir* object. The *Reservoir*, *Series* and *Initial Conditions* frames are opened (Figure 16).
- In the *Series* frame, select the *H-V* series and open the *Values* tab.
- By default, the table is empty. Insert the corresponding Height-Volume (*H-V*) relation for the reservoir.
- Define an initial water elevation (*HIni*) in the *Initial conditions* frame.

Alternatively to the last point to define the initial water elevation of the *Reservoir*, a time series can be saved in the database with a sensor of Category *Altitude* and Unit *masl*. For each simulation, RS MINERVE will then search and interpolate the initial condition from the added time series. To link the *Reservoir* with the sensor, first select in the *Data Source* frame the corresponding *Group* and *Dataset*.

Then, in the *Reservoir* frame (right part), click on the *Select station from Database* button and define the correct station in the *Station* drop-down list (only stations containing a sensor with appropriate units are listed). The value in the *Initial conditions* frame will change after every simulation to the value interpolated from the time series.

Once a reservoir is implemented, outputs of the reservoir have to be defined. Water from a reservoir can be exited through different ways. A combination of *Turbine* (or *TurbineDB*) and *Hydropower* objects are used to simulate the use of water for hydropower production.

Regulations are generally used to automatize the operation of *Turbine* and *TurbineDB* objects. Finally, *HQ* objects generate discharges based on elevation-discharge relations. [10]

All these objects can be used independently and cumulatively. For example, several turbines can be placed in parallel with one or several *TurbineDB*(s), *HQ* object(s) and/or *Regulation*(s). None of them is imperative.

Addition of a TurbineDB object

The *TurbineDB* object is based on data from a database. Thus, before adding a *TurbineDB*, data have to be added to the database

- Open a database (see Chapter 3) and create a station with a sensor of category *Flow.* Modify the description and insert data for the *TurbineDB* outflow in the *Values* tab.

The *TurbineDB* object is then added.

- Select the object *TurbineDB* in the *Structures objects* frame (Figure 16) and add it in the *Interface*. Add also a *Junction* to which outflow(s) from the *Reservoir* will be linked to.
- Switch to *Connections* (*Editing Tools* frame-> *Connections* or use the *space* key) and link the *Reservoir* to the *TurbineDB* object and the *TurbineDB* object to the *Junction* (Figure 17).

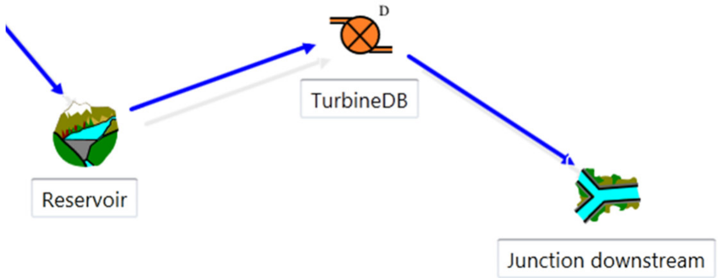


Figure 17 Addition of a *TurbineDB* and a junction

- In the *Data Source* frame (Figure 16), select for the line *HPP* [11] the *Group* and *DataSet* corresponding to the sensor created in the database.
- Double-click on the *TurbineDB* object to open the *TurbineDB* frame (right-side). Then, click on the *Select station from Database* button and define the corresponding station in the *Station* drop-down list. The link between the *TurbineDB* object and the database is now operational.
- In the *Parameters* frame (Figure 18), user can define the reservoir water altitude to start (H_{on}) or stop (H_{off}) the turbine. If the value is equal to zero, the turbine operation will be independent of the reservoir altitude.
- In the *Initial conditions* frame (Figure 18), user must define the initial turbine status when the water altitude is initially between H_{on} and H_{off}. 'Zero' (0) means starting the simulation with the turbine OFF and 'one' (1) means starting with the turbine ON.

[10] As outputs from the *Reservoir* are defined by downstream objects, output flows (Qs) are considered as an *Input* to the *Reservoir* in terms of information flow. The corresponding water is thereby withdrawn from the stored volume. This implies that at least one output flow has to be defined to validate the model (See [13]).
[11] Short for HydroPower Plant, which includes the *TurbineDB* and the *Hydropower* objects.

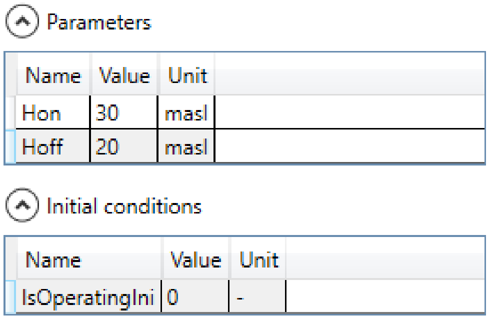


Figure 18 Parameters and initial conditions of turbine.

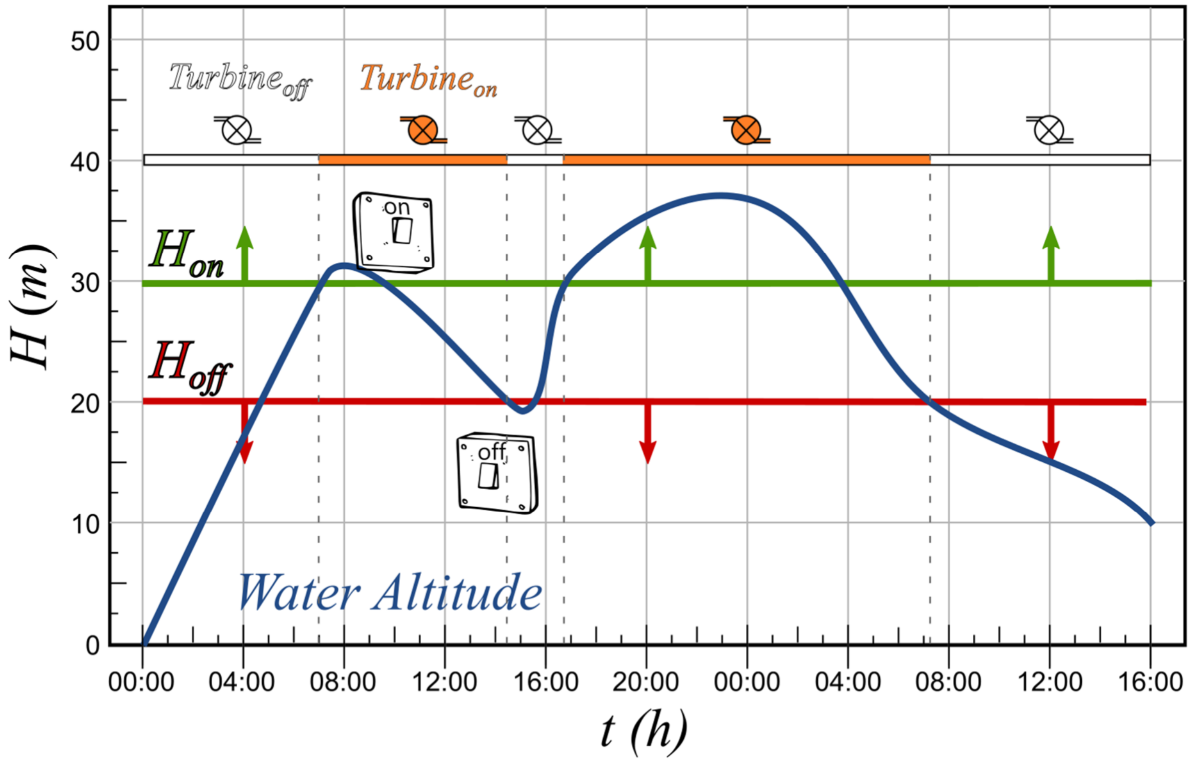


Figure 19 Example of turbine operation

Once these parameters specified, the *TurbineDB* object is ready for use.

Addition of a Hydropower object

The *Hydropower* object calculates the power and the revenue produced by the discharge of the turbine from the reservoir. The results depend on the discharge and on the reservoir water level.

- Select the object *Hydropower* in the *Structures objects* frame (Figure 16) and add it in the *Interface* (Figure 20).

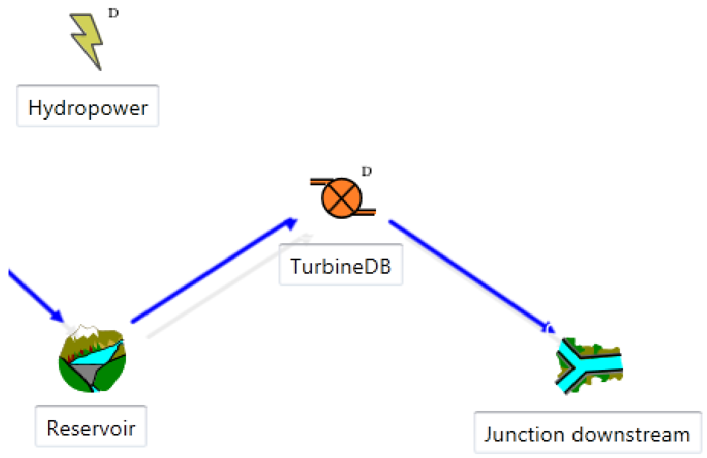


Figure 20 Addition of a *Hydropower* object

As the power produced in the hydropower plant depends on the water level in the reservoir and on the discharge of the turbine, these two variables (water level and discharge) must be transferred to the Hydropower object as follows (Figure 21):

- Link the *TurbineDB* to the *Hydropower* object so the discharge variable can be transferred to the *Hydropower* object.
- The water level information will be automatically transferred from the *Reservoir* to the *Hydropower* object through the *TurbineDB* object.

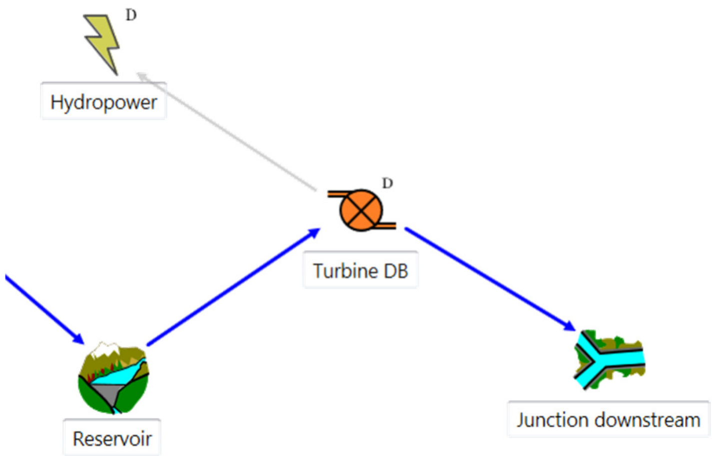


Figure 21 Links between the *Hydropower* object and the *Reservoir* and *TurbineDB* information

- Double-click on the *Hydropower* object to open its frame (right-side). Then, click on the *Select station from Database* button and define the corresponding station which contains the "Electricity price" series in the *Station* drop-down list. The link between the *Hydropower* object and the database is now operational.
- In the *Series* frame, select the Q-η (discharge-efficiency) series and open the Values tab. Insert data for the Q-η relation (manually or copied from a spreadsheet).
- In the *Parameters* frame, introduce the features of the hydropower plant. In particular the following parameters must be specified: the hydropower plant altitude (Zcentral) in masl; the length of the pipe (L) in m; the diameter of the pipe (D) in m; the Roughness (K) in m; the kinematic viscosity (ν) in m^2/s; and the default price of electricity, only used if no data exists in the database.

The *Hydropower* object is ready for use.

Addition of an HQ object

HQ objects are used to define level-discharge relations to implement structures such as spillways, orifices or sluice gates. For illustration purpose, an *HQ* object is used as a spillway in the following procedure.

- Select the *HQ* object in the *Structures objects* frame (Figure 16) and add it in the *Interface*.
- Link the *Reservoir* to the *HQ* object and the *HQ* object to the *Junction* (Figure 22).

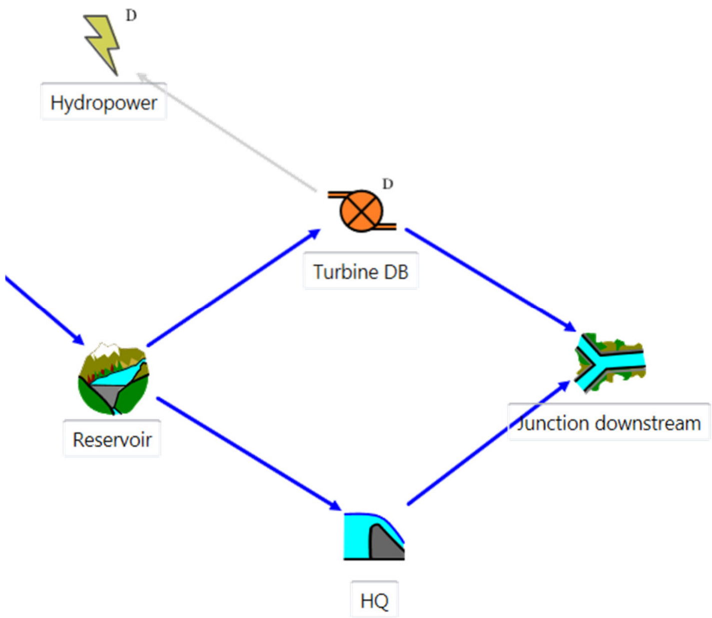


Figure 22 Addition of a spillway

- Double-click on the *HQ* object. In the *Series* frame, select the *H-Q* series and open the *Values* tab. Insert data for the *H-Q* relation (manually or copied from a spreadsheet).

The *HQ* object is ready for use.

Simulation with implemented structures

Several structures can be added in parallel as illustrated in Figure 22. When all objects are created, the model linked to the database and validated, start the simulation (Chapter 4.1). Discharges through the different objects can then be visualized by clicking on each object (Chapter 4.1) or within the *Selection and Plots* module (Chapter 4.2).

It is **important** to remember that discharges generated by *HQ* objects are defined by the water level in the reservoir. Below a certain level, no discharge is produced. This is not the case of the *TurbineDB* objects that withdraws from the reservoir the discharges defined in the database, without checking if water is available or not in the reservoir. This might result in a negative volume in the reservoir (a warning is generated in the *Simulation report*). In order to generate discharges only when the water is actually available, *Regulation* objects are necessary.

3.3. Implementation of a planner

The planner object represents a control system that allows the definition of a set of management rules based on conditions. This object allows regulating the operation of reservoirs, turbines and hydropower models in RS MINERVE.

Each rule is defined using one or more conditions (that can be combined), temporary restrictions (specific dates, hours, days of the week, or months of the year) and an expected output. The conditions and the temporary restrictions define the rule to be applied (and corresponding output). The input values for the conditions can be defined in different ways: directly taken from the variable of some object of the full model (e.g., a specific reservoir), its own input or depending on the state of another rule defined in the same planner. The output can be generated from a predefined series of values, through the database, as one of the three possible inputs of the planner object or by setting a specific value. Furthermore, the output values can be modified by applying a multiplier and/or additive coefficient(s). A planner can be connected from all objects and to all objects except to stations, time series and sources (Figure 23).

Once we have simulated the model, the planner shows at what times each defined rule has been applied. With all these options, the planner object is an efficient tool for managing complex systems.

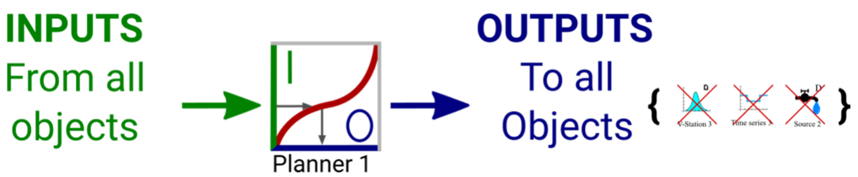


Figure 23 Inputs and outputs for a *Planner object.*

Planner

The first part of the Planner window (right frame) shows basic information about the object (Figure 24).

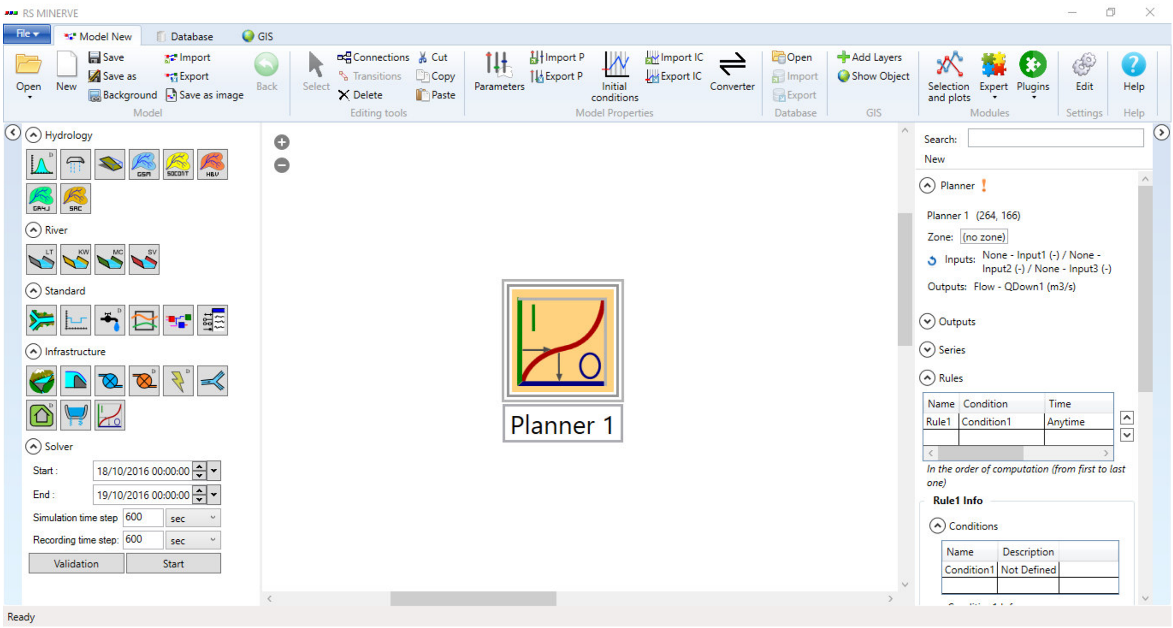


Figure 24 *Planner* object principal window.

To know if the planner is correctly connected in the model, the exclamation mark should be green; if it is not, the exclamation mark will be orange and the object will be isolated and not calculated (Figure 25). In that case, it will indicate what part of the planner element is not correctly defined.

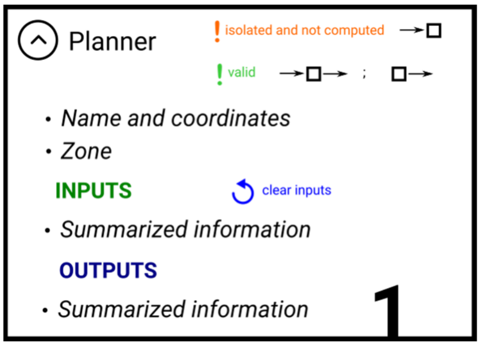


Figure 25 Planner section.

- Click on the blue circular arrow ("Clear variable") to reset inputs information after connections are removed.

Figure 26 shows an example with one Input (Altitude) and two outputs (Qdown1 , Qdown2):

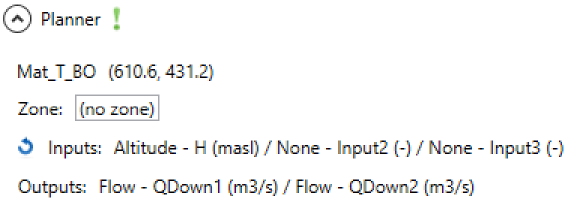


Figure 26 Planner section example.

Outputs

The second part allows the user to add or delete outputs for the object (Figure 27). The number of outputs for a planner object is not limited.

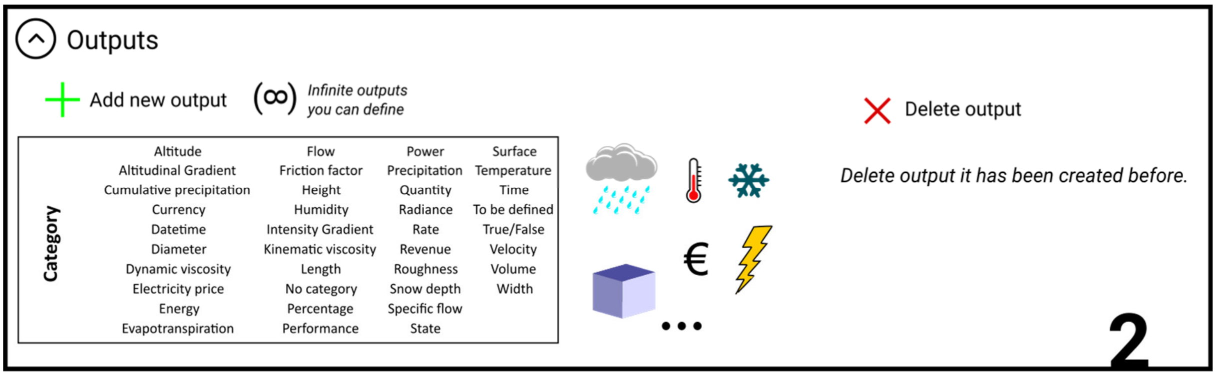


Figure 27 Outputs section.

- To add a new output, choose the category and then push the "Add new output" button (green cross).
- To delete an output, choose the output and push the "Delete output" button (red cross).

Series

The third part shows the series that can be used by the planner object (Figure 28). The user can define new series linking different variable types. It's also possible to delete the existing series. As in the output section, the number of series for one planner object is not limited.

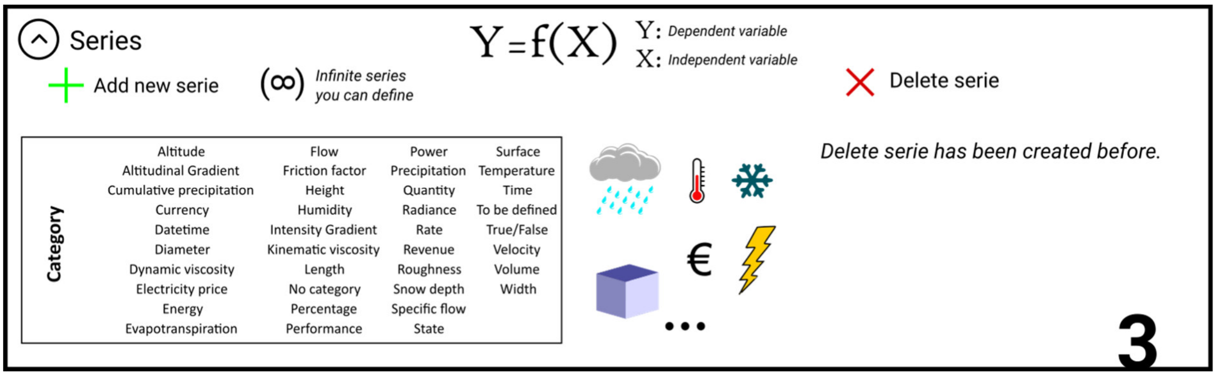


Figure 28 Series section.

- To add a new series, choose the category and select the independent variable, then push the "Add new series" button (green cross).
- To delete a series, choose it and push the "Delete series" button (red cross).

Rules

The fourth part shows basic information about the rules for the management of the object (Figure 29). This part is divided into four sections: *Conditions*, *Time*, *Output generation* and *Initial rule state*. The rules' listing in the table defines the order in which those rules will be applied.

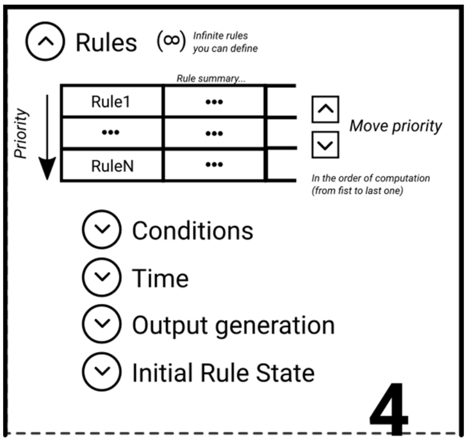


Figure 29 Rules section.

- To move the rule in the table you can use the up and down arrows.

Example is shown in Figure 30. It shows summary information about the rules.

Rules

Name	Condition	Time	Output	Initial State
Normal Turbine	[>MaxLevel OR [>MinLevel AND <MaxLevel AND ThisRule]]	Full Period; Start hour: 08:00:00;	From Value: 20; Output: 1*QDown1 (m3/s) + 0	On
Preventive Turbine	[Hreservoir AND Qinflow]	Anytime	From Value: 20; Output: 1*QDown1 (m3/s) + 0	On
No Normal Turbine	<MinLevel	Anytime	From Value: 0; Output: 1*QDown1 (m3/s) + 0	On
No Turbine	[[Qvisp OR [QvispMin AND ThisRule]] AND MatTurbine]	Anytime	From Value: 0; Output: 1*QDown1 (m3/s) + 0	On

In the order of computation (from first to last one)

Figure 30 Rules section *example.*

In the *Conditions* section, the user can define stand-alone or combined conditions (Figure 31). To define the condition, it's possible to use the planner's inputs, the results of any object or the states of other rules (Figure 32). The "always satisfied" option allows defining a condition as always true.

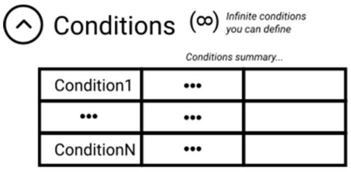


Figure 31 Conditions (Rules) section.

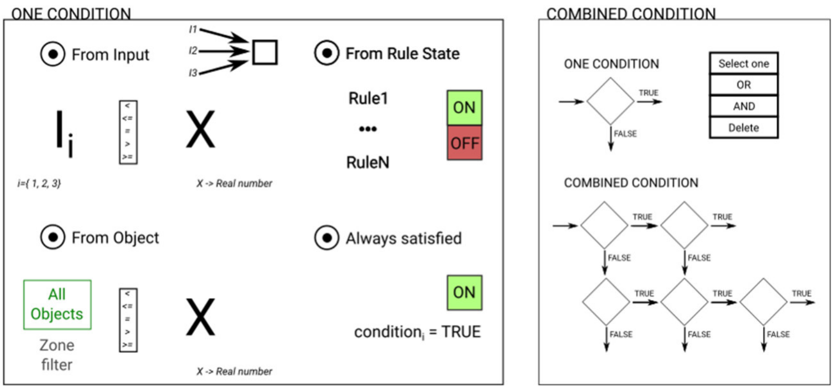


Figure 32 Example of stand-alone and combined conditions.

- Once one or more rules are defined, the user can create combined conditions using operators between conditions (AND, OR …).
- The number of conditions is not limited.

Figure 33 shows an example, with some stand-alone conditions and combined conditions. At the end, it shows summarize information about the combined conditions (violet, as a simplified expression with names, and blue as expanded expression with descriptions).

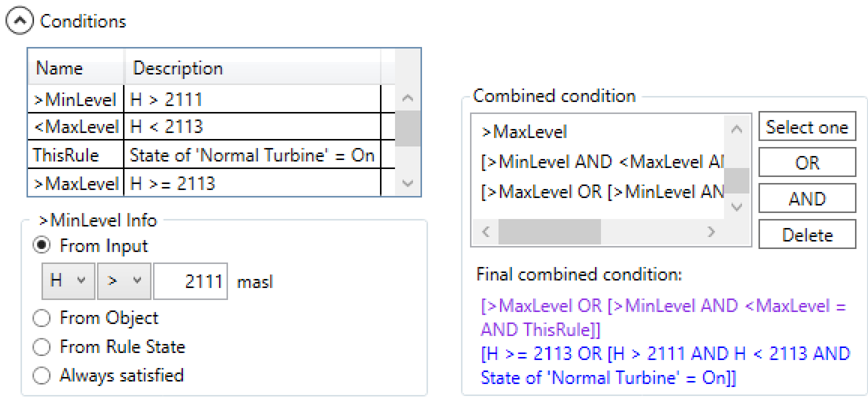


Figure 33 Conditions (Rules) section example.

In the *Time* section, the user can define a time schedule to turn on or off the rule depending on the time (Figure 34).

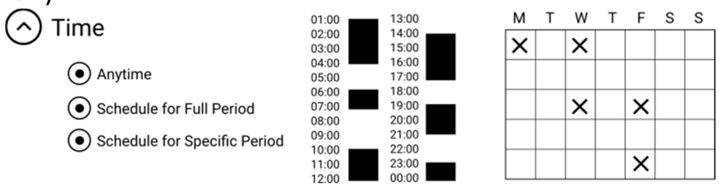


Figure 34 Time (Rules) section.

Figure 35 shows an example with a schedule to start and stop the rules.

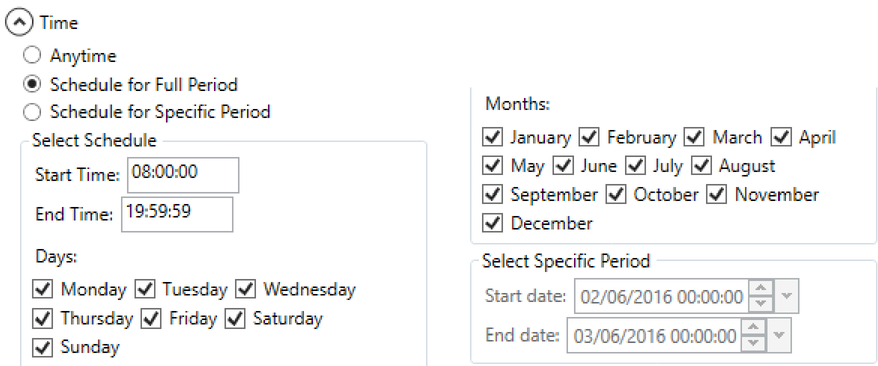


Figure 35 Time (Rules) section example.

In the *Output generation* section, the user can define how to create the output (Figure 36).

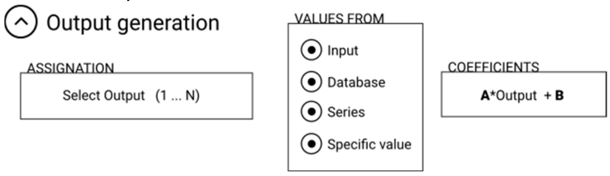


Figure 36 Output generation (Rules) section.

An example is shown in Figure 37 with a specific value (19 m^3/s) for the output (Qdown1).

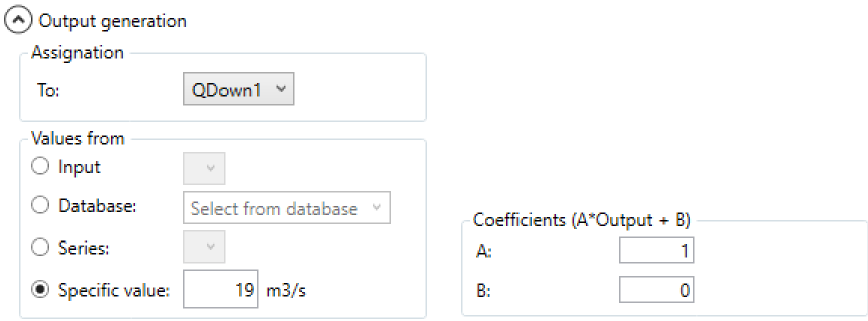


Figure 37 Output generation (Rules) section example.

In the last section, *Initial Rule State*, the user can define the initial rule state for the planner object at the beginning of the simulation (Figure 38).

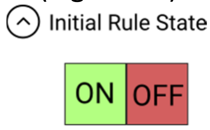


Figure 38 Initial Rule State (Rules) section.

Simulation with the planner implemented

Once the planner object is properly implemented, the user can start the simulation. Results can be visualized by double-clicking on the object or by using the *Selection and Plots* module (Figure 39).

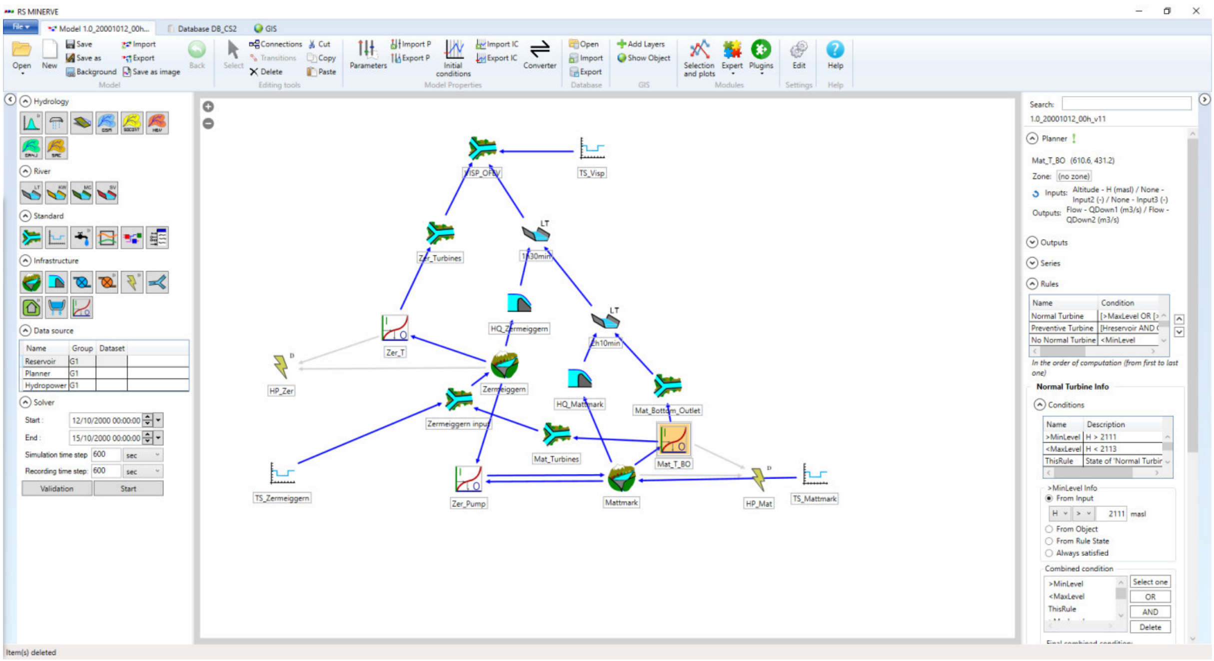


Figure 39 A complete example of a model with planner objects.

Chapter 4. Database

The different input data as well as exported results are managed within a database. The *Database* tab is used to create or edit the database linked to the active model.

4.1. The Database tab

The *Database* tab appears when a database is created (*New)* or opened for edition (*Open* and then *Edit*).

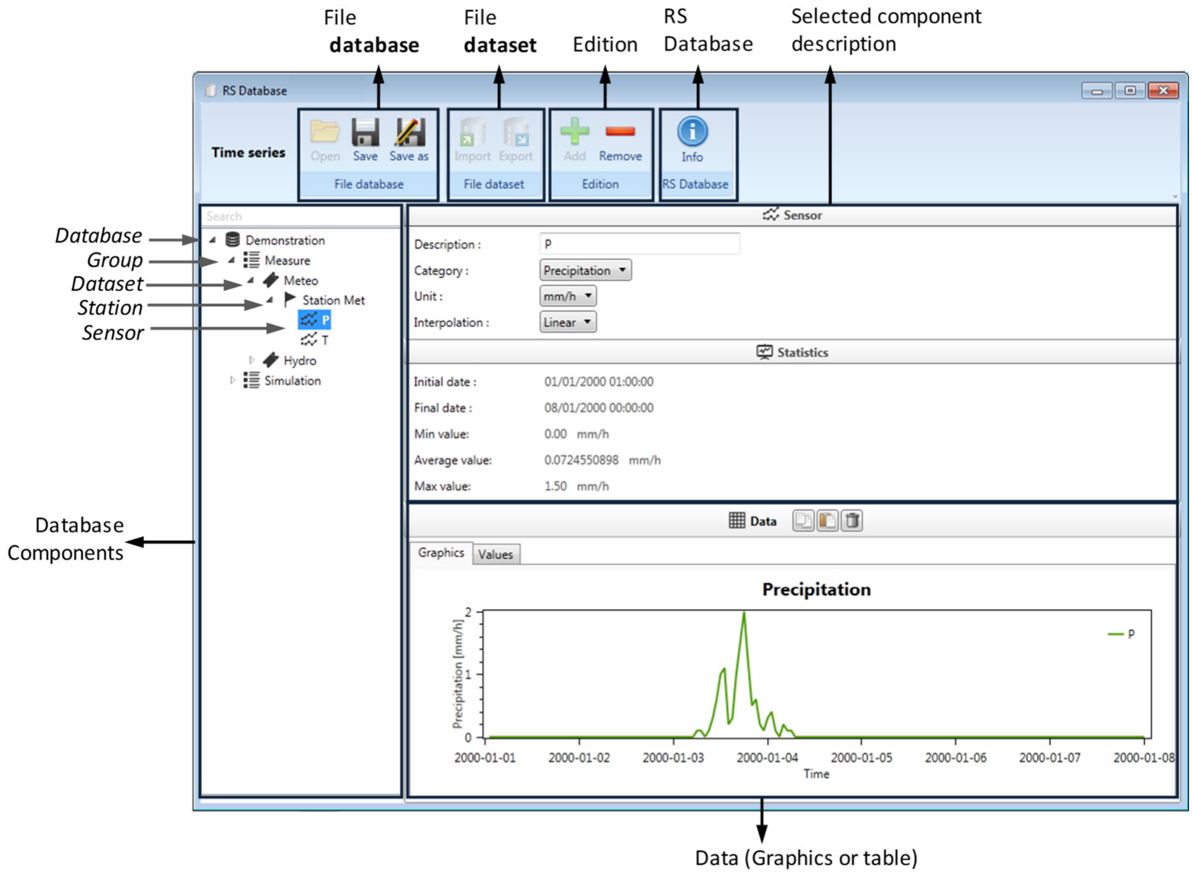


Figure 40 The *Database* tab

The database structure is organized in five hierarchical levels, listed hereafter.

- **Database** Description of the database, complete set of data
  - **Group** Separation based on category of data (Measures, Forecasts, Simulations,…)[12]
    - **Dataset** Set of data of common type (Meteo data, Flow data,…) 9
      - **Station** Information about the station (name and coordinates)
        - **Sensor** Description of the sensor (name, units and data)

[12] Definition and use of *Groups* and *Datasets* can also be done in a different way by the user.

4.2. Creation of a database

The creation of a new database can be achieved following next steps:

- Click on *New* in the *Database* frame (Figure 1) and save the new database. The *Database tab* is opened (Figure 40).
- Create the components of the different hierarchical levels of your database by using the *Add* button (*Edition* frame).
- For the stations, give an adequate name and enter the coordinates.
- For each sensor:
  - Define the *Description* (name), *Category, Unit and Interpolation* method.
  - Select the "Values" tab and add the data with the *Paste* button (after copying them from any spreadsheet program).
- Save the database.

The data can be managed (exported or imported) as database or as dataset.

To manage a **database**, proceed as follows:

- To save a database: Click on the *Database* component -> *File database -> Save as.*
- To load another database: Remove the current database and click on *Open* in the *Database* frame to open the new database.

To manage a **dataset**, perform as follows:

- To export a dataset: Click on the Dataset component -> *File Dataset -> Save*
- To import a dataset: Click on a Group component -> *File Dataset -> Import*

If a dataset contained in a database is also stored separetely as a dataset (not only in the database), both have to be saved (*File database -> Save; File dataset -> Save*) to properly modify all the files!

4.3. Data format

For copying series values in a sensor, two columns are necessary. The first column contains the data in one of these formats:

- dd.mm.yyyy
- dd.mm.yyyy hh:mm
- dd.mm.yyyy hh:mm:ss

The second column contains the values of the series (example in Figure 41).

31.01.2000 07:00	10.3
31.01.2000 08:00	11.1
31.01.2000 09:00	11.6
31.01.2000 10:00	12.4

Figure 41 Example of data format to use in the sensors

4.4. Connection of a database to a model

Once the database is created, links between the model and the database have to be implemented. The *Data source* frame (Figure 42, left), located in the main interface and available only when a database is opened, is used for this purpose.

- Define for the *Station* and the *Source* the corresponding *Group* and *DataSet*.
- For the *Source* objects, define in the *Object description* frame the correct station under the *Select from database* button (Figure 42, right). [13]

The name of the station appears under *Station identifier* and is stored in the model when the model is saved.

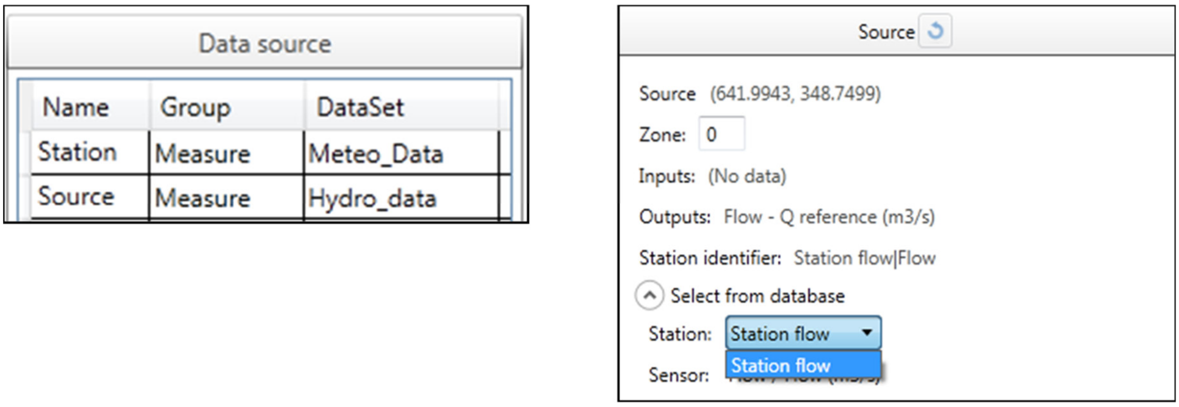


Figure 42 Left: The Data Source frame; Right: Definition of the station for objects Source

Interaction between the database and the active model

Modifications of the database in *Database tab* (without saving them!) are taken into account during simulations of the active model. However, when the database is closed, only saved changes will be applied to the database. Therefore, proper saving of the modifications is recommended.

[13] Source objects have to be linked to another object to define the type of output (and corresponding units) before the link to the station can be defined.

Chapter 5. GIS

The GIS module allows the user to manage and process geospatial data. In this chapter, the GIS interface and its different tools are presented.

5.1. GIS interface

To start GIS:

- Click on *GIS* section in the main frame (Figure 1). The *GIS* tab is shown in Figure 43.

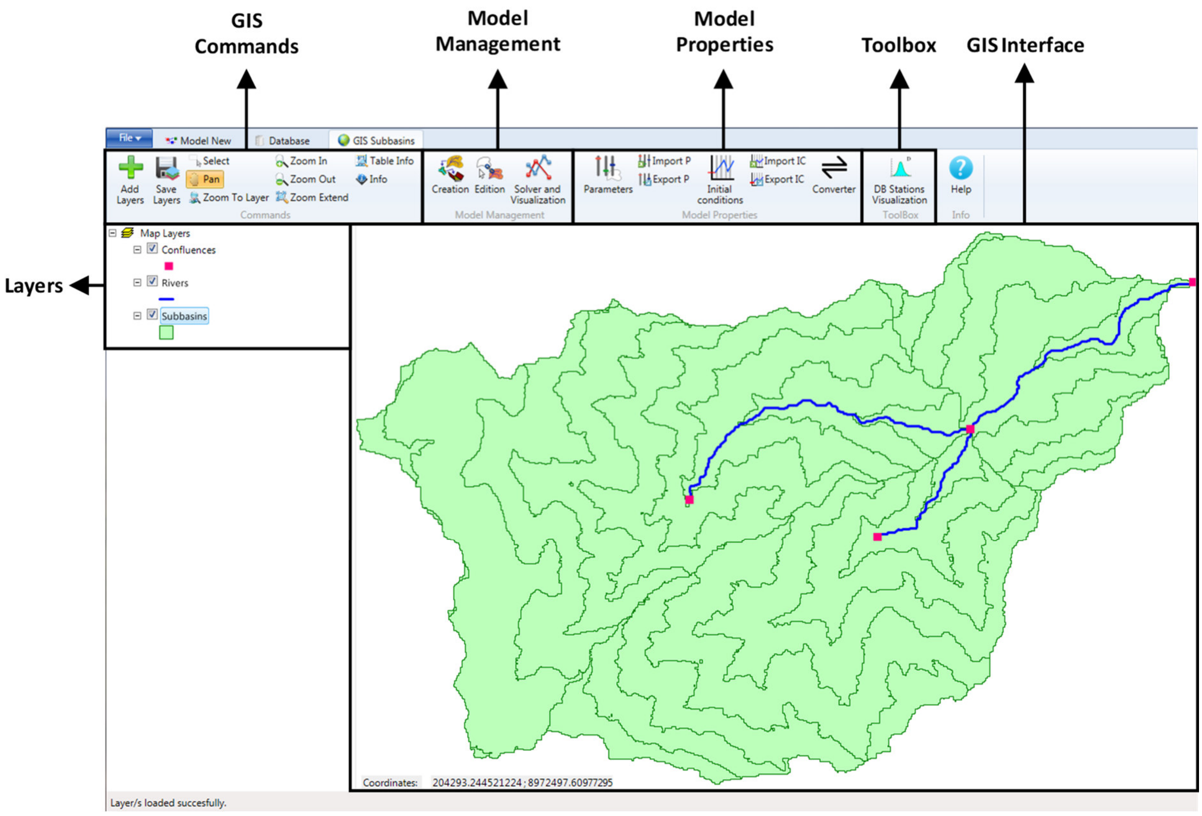


Figure 43 Interface of the GIS tool

5.2. GIS Commands

Importation of new layers

To add geospatial data in the GIS Interface,

- Click on the *Add layers* button in the GIS Commands tab (Figure 43).
- Move up/down the different layers and use the check boxes to display or not the layers.

> ! The file path of the shapefile is added to the hydrological model (.rsm) , not the whole shapefile.

Tools for interaction in the interface

 Select features by rectangle

 Pan

 Zoom in

 Zoom out

 Zoom to layer extent

 Zoom to global extent

 View attribute table of selected layer

 View information on selected feature

5.3. Automatic Model *Creation*

The *Creation* tool in the *Model Management* frame automatizes the creation of hydrological models based on the GIS layers where the hydrological objects, the confluences and their links are defined. This tool connects the objects (which represent the different subbasins) with their corresponding downstream junctions (that represent the outlets of each subbasin); theses junctions with the downstream rivers that transport the discharges generated in the subbasins; and finally these rivers with the outlet downstream junctions.

The structure of the GIS layers has to be edited under the following format:

- The subbasins layer must contain an attribute column with the ID of the downstream junctions (the outlets of each subbasin).
- The junctions layer must contain an attribute column with the ID of the downstream rivers that will transport the discharges. Also, one of the attribute columns must correspond with the ID indicated in the subbasins and the rivers layers.
- The rivers layer must contain an attribute column with the ID of the downstream outlet junctions.

Once the different layers have been added to the interface, it is possible to use *Creation*:

- Click *Creation* in the *Model Management* frame.

A *Configuration* area with three parts –*Subbasins*, *Junctions* and *Rivers*– as well as an attribute table (for the selected layer) should appear below the GIS interface (Figure 44).

- In the *Subbasins* part, select the name of the layer that contains the subbasins information (*Layer name*), the attribute that contains the basins name (*Basins name*) and the ID of the downstream junctions to be linked to the subbasins (*Junctions ID*). You can create submodels based on Basins ID, by choosing the corresponding ID field.
- In the *Junctions* part, select the name of the layer that contains the junctions information (*Layer name*), the attribute that contains the junctions name (*Junctions name*), the ID field of the junctions that will be linked to the downstream rivers (*Junctions ID*), and the ID field of the rivers that will be linked (*Rivers ID*).
- If you want to create river sections, choose the option in the *Rivers* part (*Create rivers*), select the name of the layer that contains the rivers information (*Layer name*), the attribute that contains the rivers name (*Rivers name*), the ID field of the rivers that will be linked to the downstream junctions (*Rivers ID*), and the ID field of the downstream junctions that will be linked (*Junctions ID*).
- In the *Allocate SubBasins Type*, select the different subbasins entities aggregated per type by holding Ctrl while clicking (Step 5 in Figure 44). Choose the type of object to create (like SOCONT or GSM) and click *Allocate Subbasins*.
- In the *Allocate Rivers Type*, select the different rivers entities aggregated per type by holding Ctrl while clicking (Step 6 in Figure 44). Choose the type of object to create (like Kinematic Wave) and click *Allocate Rivers*.
- Click *Create Model* to create all the objects and their links defined in the GIS layers.

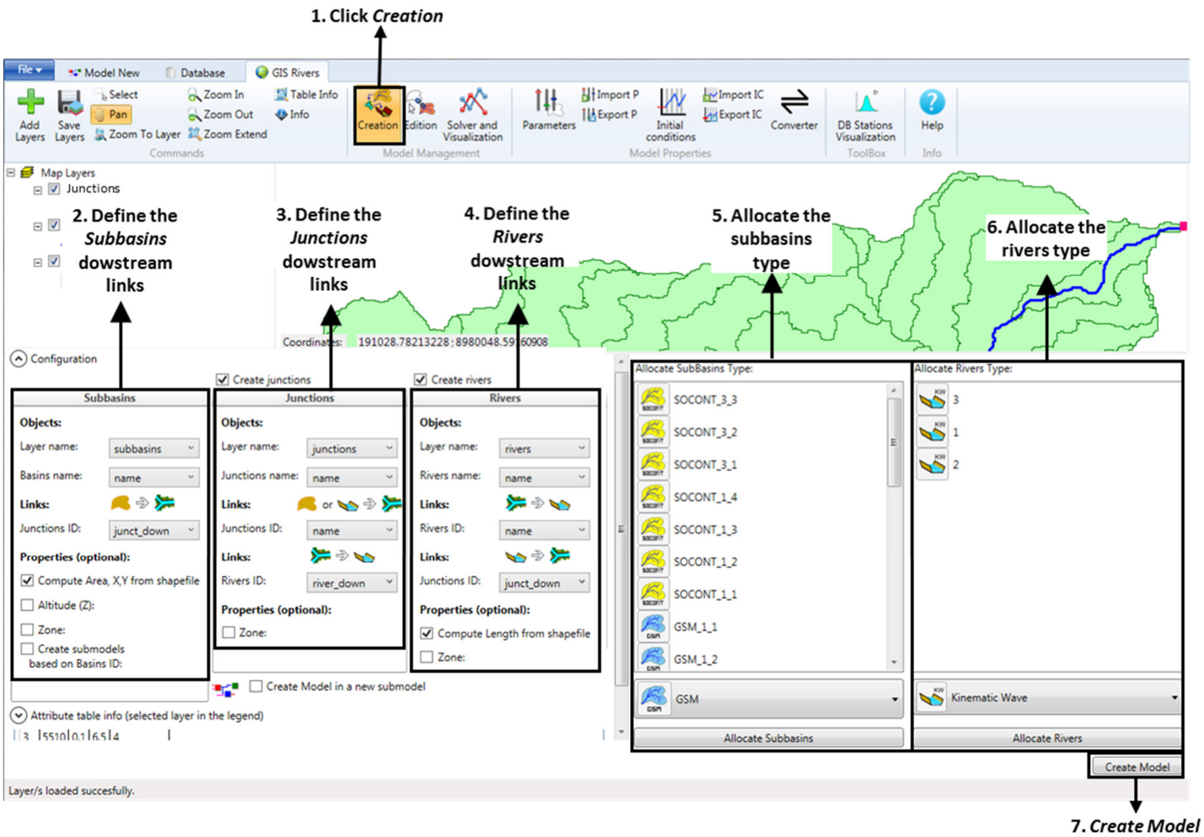


Figure 44 Model Creation interface in the GIS

> ! The *Creation* tool defines automatically the parameters Surface, X and Y of the objects; the definition of the Z parameter is optional using the option *Altitude (Z)*. For the definition of the rest of parameters, please use the *Edition* tool.

If you use the default layers names, the program will load automatically the specific fields. The names are shown in the Figure 45.

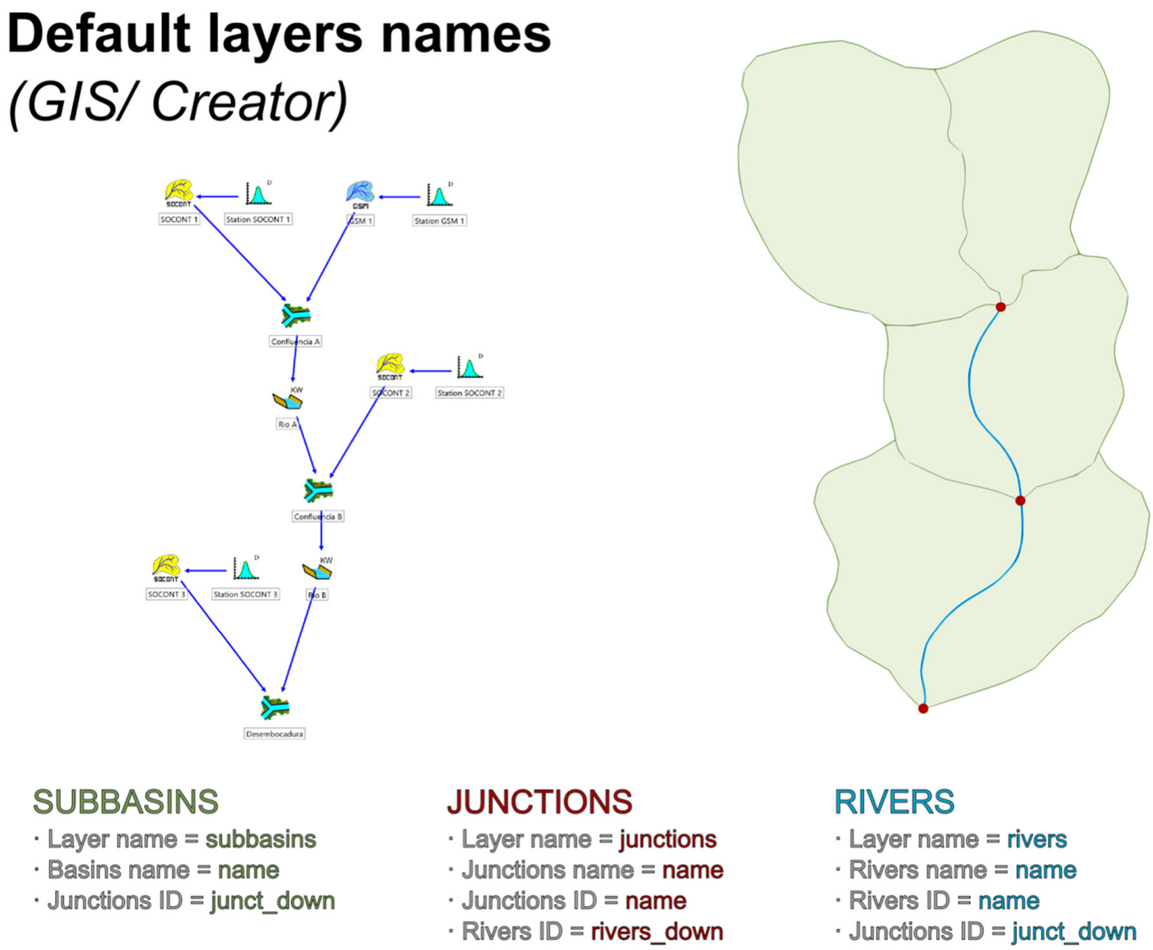


Figure 45. Default layers names to autofill fields.

5.4. Model *Edition*

With the *Edition* tool in the *Model Management* frame, the user can manually edit existing objects and links, create new ones, or remove some of them.

Once the GIS layers have been added and/or the hydrological objects have been created,

- Select the layer on the left side of the GIS tab.
- Click *Edition* in the *Model Management* frame.

An attribute table (for the selected entities) as well as an action area with three tabs should appear below the GIS interface (Figure 46),

- Select features of the selected layer in order to bring them up in the attribute table (use the *Select All* button to select all features).

- In the action area, select in the drop-down menu a Field Name (layer attribute) that should be used to identify features.

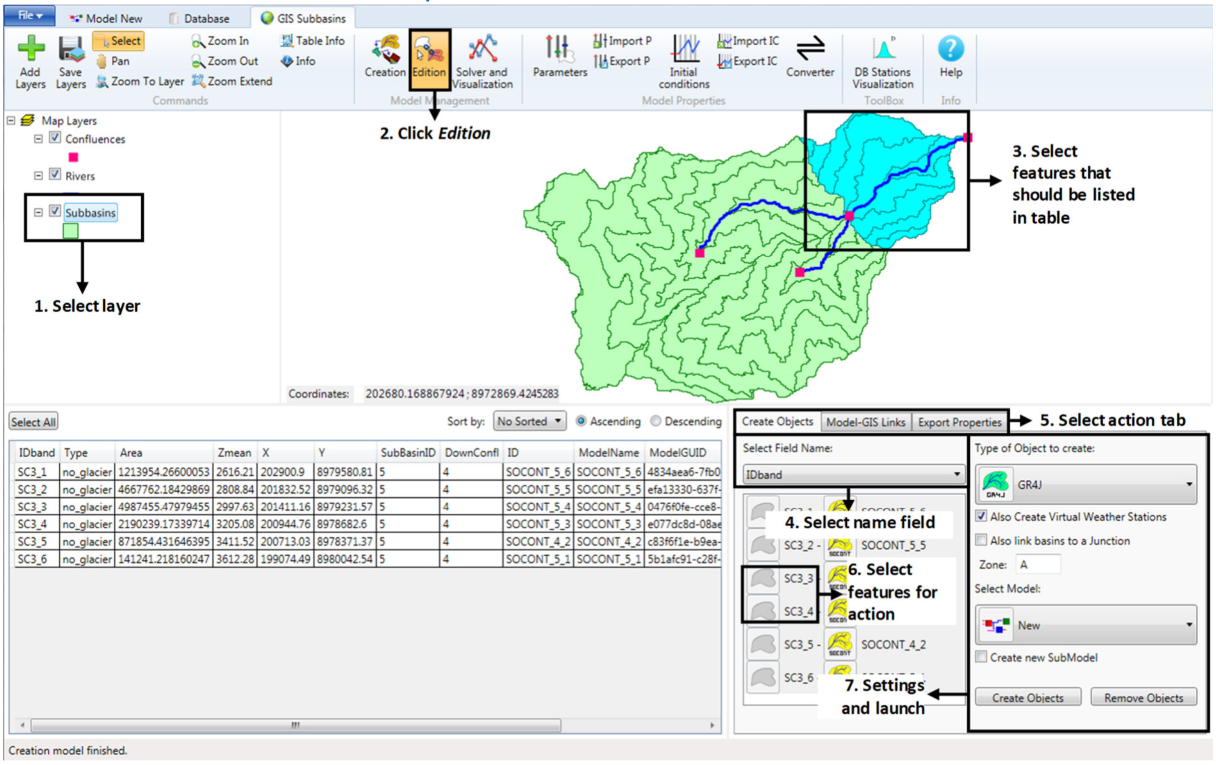


Figure 46 Model Edition interface in the GIS and its workflow

The three tabs offer you the possibility of the following actions:

- **Create Objects**: Create model objects from GIS features.
- **Model-GIS Links**: Link GIS features to existing model objects.
- **Export Properties**: Export feature properties to properties (parameters) of model objects.

Create Objects

In the following example, we are going to generate a sub-model of the subcatchment highlighted in blue in Figure 46, which has both normal and glacial elevation bands.

- Select the *Create Objects action tab*
- Select all non-glacial features by holding Ctrl while clicking (Step 3 in Figure 46). Using the sorting tool for the attribute table might help to order the objects.
- Under *Type of Object to create*, select a non-glacial basin model (like SOCONT).
- Put a check on *Also Create Virtual Weather Stations*. Now, a virtual weather station will be created for and linked to each created object.
- Put a check on *Also link basins to a Junction*. Now, all created objects will be linked to a single newly created junction.
- Under *Select Model*, select the model in which you wish to place the newly created objects. In our case, this is the parent model.
- Put a check on *Create new Submodel* and give it a name. Now, a submodel will be created and contain all the newly created objects.
- Click *Create Objects*.

Once the creation process is finished, a message is displayed and object icons are displayed next to each of the features, to indicate that the features and the objects have been linked (Figure 47).

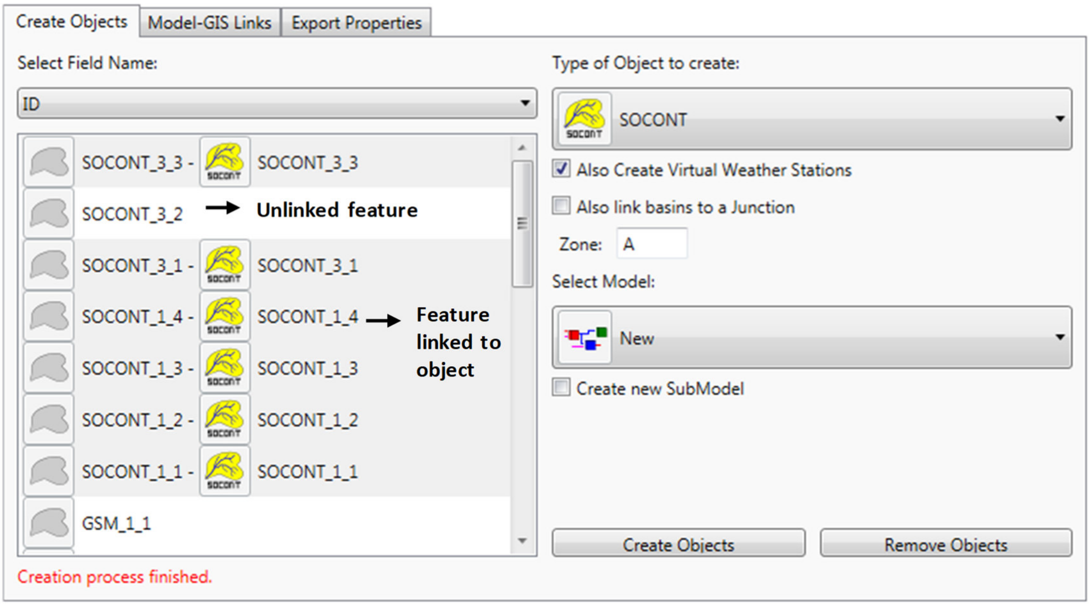


Figure 47 Object creation process completed

We then create the glacial objects:

- Select glacial features by holding Ctrl while clicking (Step 3 in Figure 46).
- Under *Type of Object to create*, select a glacial basin model (like GSM).
- Put a check on *Also Create Virtual Weather Stations*. Now, a virtual weather station will be created for and linked to each created object.
- Put a check on *Also link basins to a Junction*. Now, all created objects will be linked to another single newly created junction.
- Under *Select Model*, select the model in which you wish to place all newly created objects. In our case, this is the model that was previously created.
- Remove the check from *Create new Submodel*, since we created our submodel in the last step.
- Click *Create Objects*.

If we now view the hydraulic submodel that was created we see that all the SOCONT and GSM objects were created and linked to both a junction and a virtual station (Figure 48).

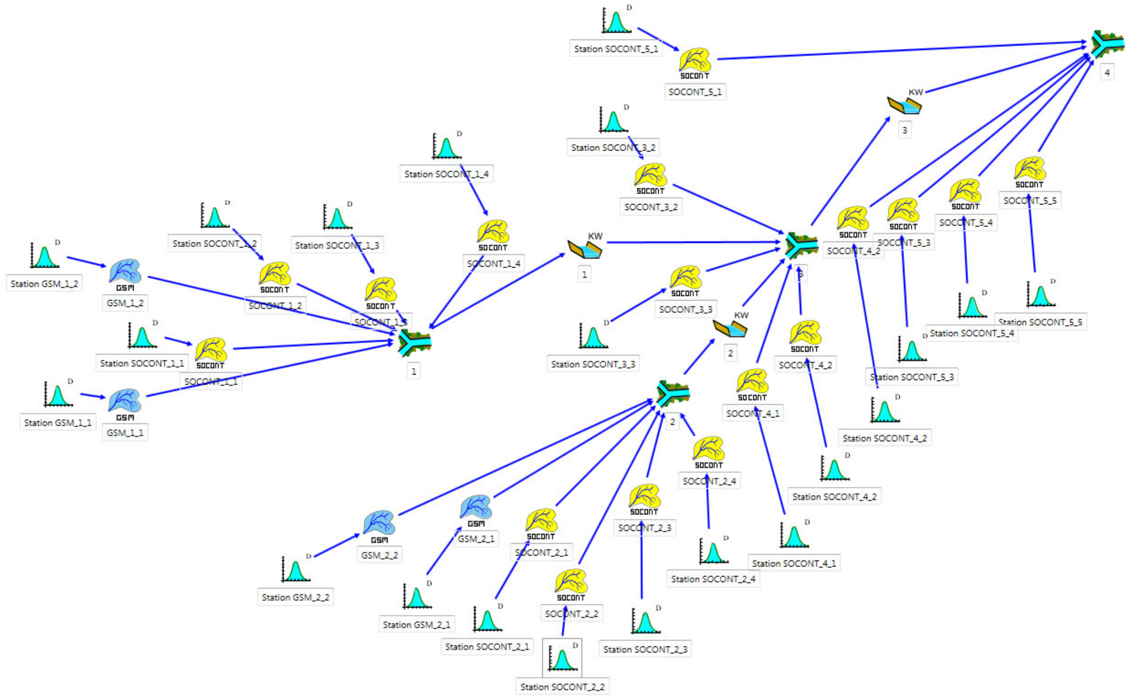


Figure 48 Automatically generated objects

It is still necessary to link the junctions to a group interface and define certain properties of the basins (area) and virtual stations (coordinates) in order for the submodel to be complete. In *Export Properties*, we see how these properties can be exported by bulk from the linked shapefile features.

Model-GIS Links

It is important that model objects be linked with GIS features for two reasons. First, it allows properties to be efficiently exported from the features to the object (see next section). Second, it allows model simulation results to be viewed in the GIS (See Figure 51).

In the following, we explain how to remove and create a link between a feature and an existing model object.

Link creation

To create a link,

- Select an unlinked feature in the link viewer.
- Select a model object in the right-hand list.
- Click the *link* icon situated below the *Auto-Link* button.

Link removal

To remove a link,

- Select the link you wish to remove in the link viewer on left side of Figure 49.
- Click the *unlink* icon situated below the *Auto-Link* button.

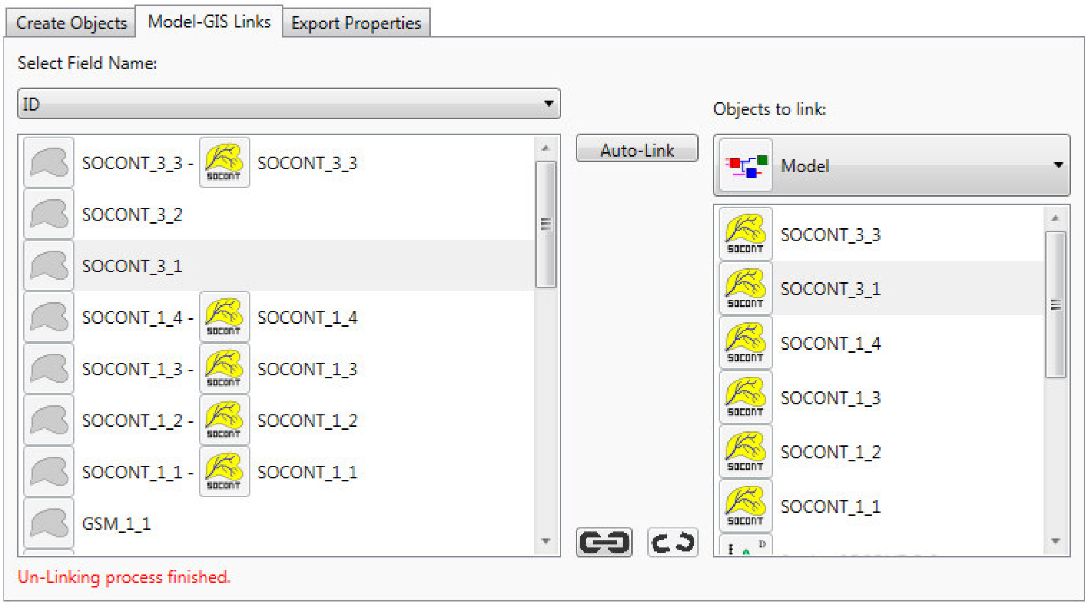


Figure 49 Linking and unlinking elements. Here, the two unlinked elements are ready to be linked.

Auto-linking objects

If the object names match the Field Name displayed in the link viewer, then you can use the *Auto-Link* button to match and link the elements automatically.

Export Properties

Properties can be exported from a linked feature directly to the basin model or to its associated virtual weather station. There are two properties that you will definitely want to export from the GIS to the hydraulic model: Basin area and the coordinates of the virtual weather station of each basin.

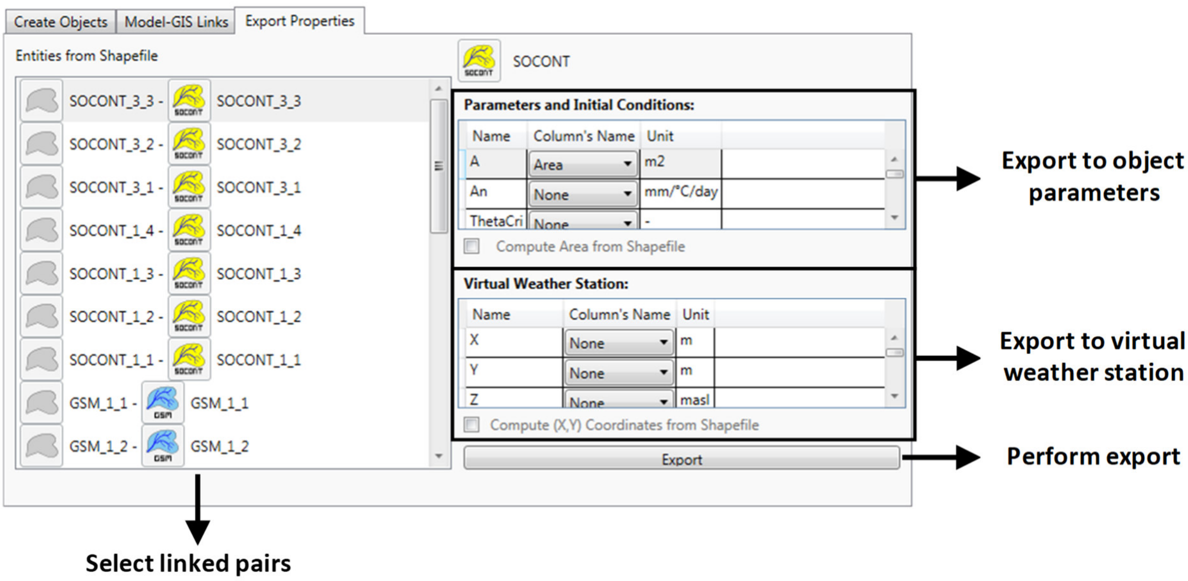


Figure 50 Exporting feature attributes to model objects

Export pre-calculated feature attributes

In order to use a feature attribute as a model parameter value,

- Select a linked pair of elements in the *Export Properties* tab.
- Navigate to the model parameter that you wish to change, and in the drop-down list, select the attribute of the linked feature that should be used.

Compute properties from the shapefile

The area of a basin, as well as average X and Y coordinates, can be calculated directly from the feature itself instead of using a pre-calculated feature attribute. In order to do that,

- Select a linked pair of elements in the *Export Properties* tab.
- To compute the area for the different sub-basins, select *Compute Area from Shapefile*.
- To compute the centre of gravity for the virtual weather station, select *Compute (X,Y) Coordinates from Shapefile*.

The action can be performed on multiple pairs at the same time, but only pairs of objects of the same type (i.e. only pairs of SOCONT objects). The action cannot be applied to different object types at the same time because different object types have different sets of parameters.

5.5. Hydro Model Visualization

The *Model Visualization* module lets you visualize and edit model information from within the GIS interface. There are three tabs for interaction:

- **Object Info**: view and edit model object parameters.
- **Solver**: run a simulation.
- **Spatial View**: Change the colours of GIS features based on values from linked objects.

> ! Shapefile features must be linked to a model object to display information.

Spatial View

The Spatial View (Figure 51) allows you to visualize results, parameters, or initial conditions at each of the objects.

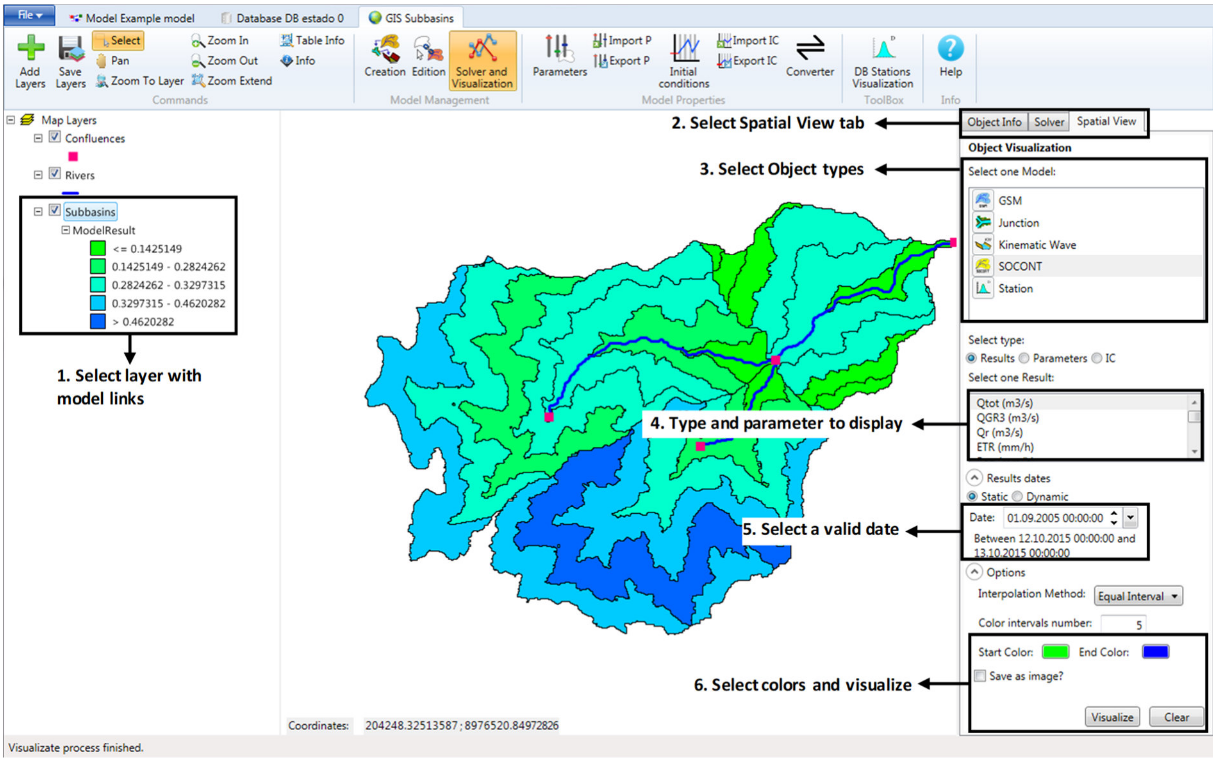


Figure 51 Hydro Model Visualization: interface workflow in the Spatial View

In order to perform a visualization,

- Select the layer that you wish to visualize. Features from this layer must be linked with model objects.
- Select the *Spatial View* tab.
- Select the object types that you wish to visualize. Multiple selections can be made, but different object types must share a parameter in order to be displayed.
- Select the parameter type from either *Results, Parameters, or Initial Conditions*.
- Select the parameter that you wish to display.
- If you are viewing simulation results, select the date for which results should be displayed.
- Optional: change color settings.
- Click on *Visualize*.

5.6. DB Stations Visualization

The *DB Stations Visualization* tool allows spatial representation of the stations contained in a database or a dataset.

The stations are represented directly in the GIS interface. The coordinates are taken from the X, Y and Z coordinates from the position of the stations.

Data requirements

The input is composed of a dataset or a database (RS MINERVE format).

Procedure

The steps to plot in GIS the stations' location are presented hereafter.

- In GIS, click on the *DB Stations Visualization* button (*Toolbox* frame).
- Select the dataset or the database to be considered.

A new layer of points is created and displayed in the GIS interface (Figure 52). The user can posteriorly save the layer.

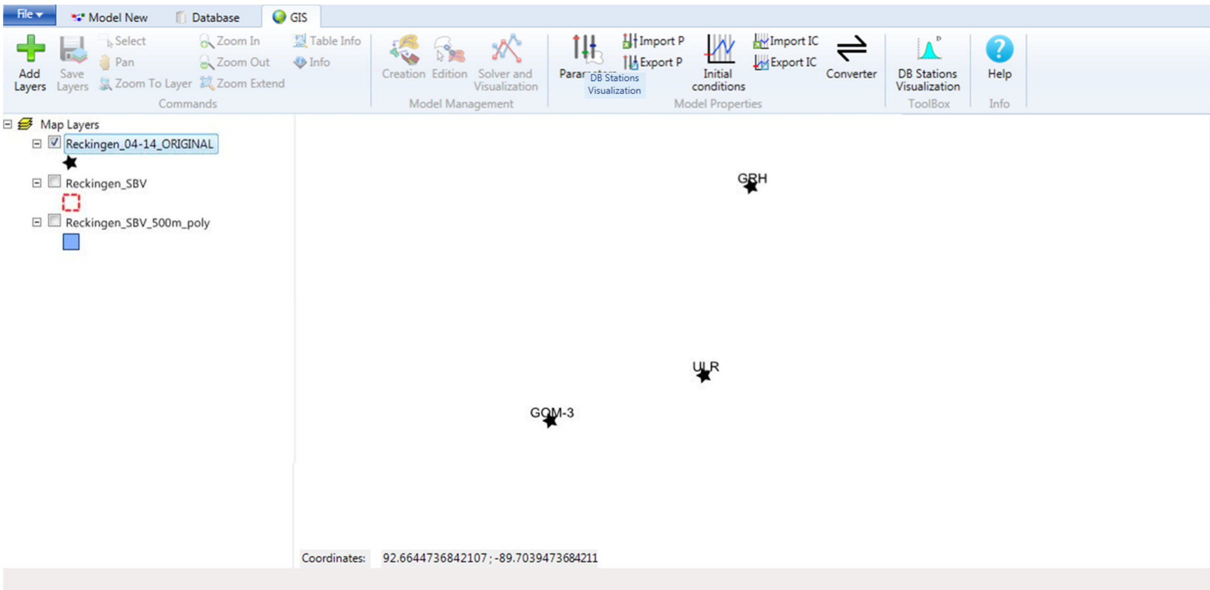


Figure 52 Visualization of stations' location in GIS

Chapter 6. Hydrological-hydraulic simulation

6.1. Run a model

Before solving a model, its validity has to be verified.

- Click on the *Validation* button. A *Pre-Simulation* report is generated (right-frame).
  In case of **Fatal error(s)**: Correct your model consequently. [14]
  In case of **Warning(s)**: Proceed to adequate modifications if required.
  In case of **Note(s)**: Consider the message(s) and go ahead.
- In the *Solver* window (Figure 1), define the simulation period, simulation time step and recording time step (Figure 53).

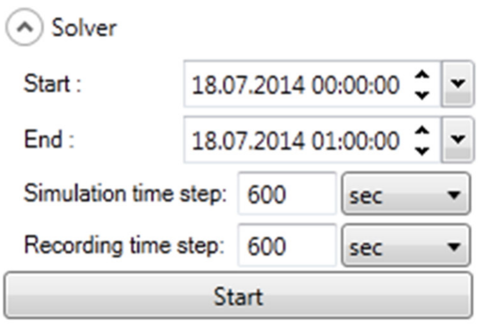


Figure 53 The *Solver* window

The time interval for the simulation time step and recording time step can be modified accordingly to Table 4.

Table 4 Possible time intervals for simulation and recording time steps

Simulation time step	Recording time step
• Seconds	• Seconds
• Minutes	• Minutes
• Hour	• Hour
• Day	• Day
	• Month

- Click on *Start*. At the end of the computation, a *Post-Simulation report* (right frame) provides a summary of the simulation with potential warning(s).

- Visualize the obtained results by selecting each object in the *Interface* and using the *Graphs* tool in the *Object* frame (Figure 1). Select the variable(s) of interest in the list (use *Ctrl* to select more than one series).

[14] During the *Validation* process, the model is verified. In particular, a *Fatal error* is generated for each missing required object's input (absence of interconnection from upstream).

6.2. Results visualization with the *Selection and Plots*

A combination of results can be visualized in the *Selection and Plots* module.

- Click on *Selection and plots* in the *Toolbox* frame (Figure 1). A new tab is opened.

In the *Objects and variables* frame (Figure 54), all the variables are listed by objects.

- Check in the *Objects and variables* frame the variable(s) to draw. [15]
- Click on *Plot* to plot the listed series. [16]
- Give a name to the active selection in the *Selections list*.
- Export the selection using *Selections* frame -> *Export*. [17]
- Import a selection using *Selections* frame -> *Import*.

A second selection appears in the *Selections list*. Different selections can be defined and saved for the exploitation and analysis of the results.

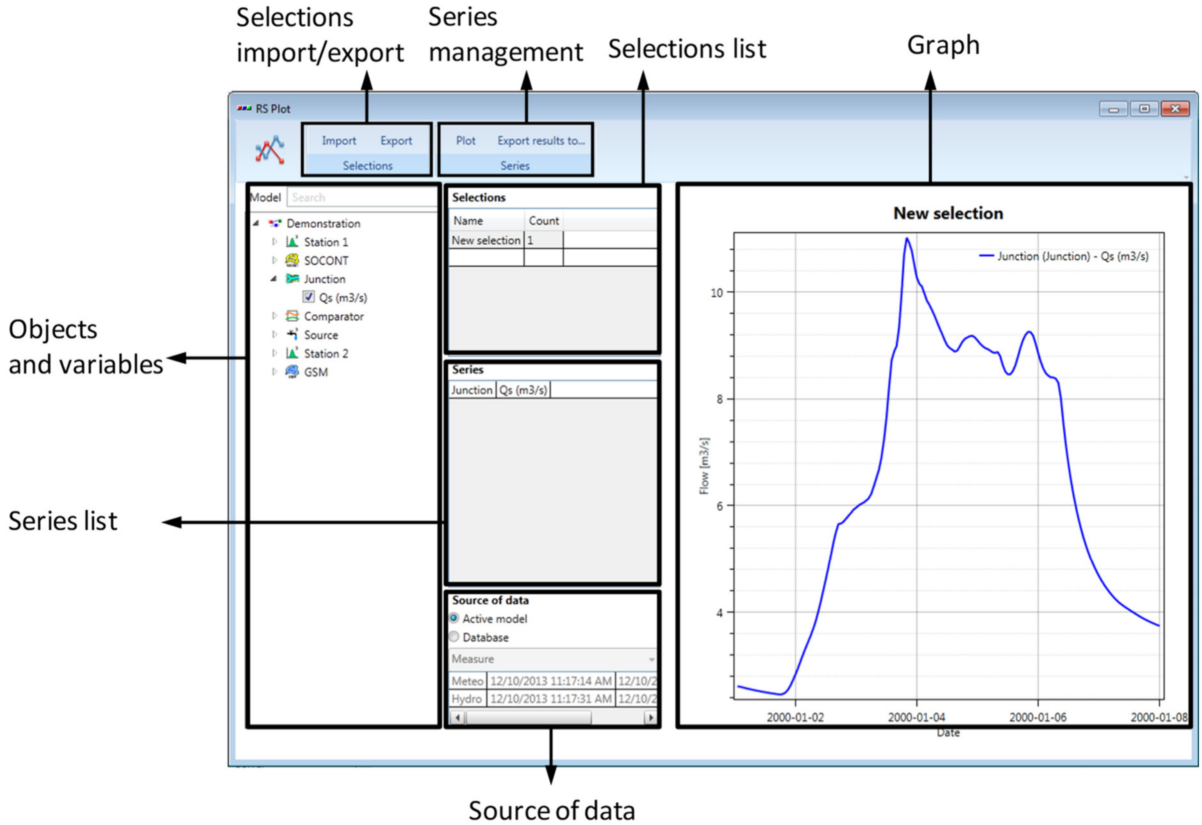


Figure 54 The *Selection and Plots interface*

[15] Variables of two different units can be drawn simultaneously (second axis).
[16] Use the mouse to visualize data values (press left button), move (press right button), zoom (press scroll-wheel) or fit to view (double-click on scroll-wheel). Zoom and fit to view can be also realised onto the axes.
[17] Selections are saved in a text file with the *.chk format.

6.3. Export / Import of results to a database

Results of a simulation can be saved to the *database* as a dataset of time series.

- Select *Export* in the *Database* frame (Figure 1) in the RS MINERVE main window.
- Define the name of the dataset and choose between:
    - Add the dataset to an existing Group.
    - Create a new Group.
- Export with *OK*. [18]

You can now visualize your results in the database (cf. Chapter 3). Once exported, results can be imported into the model. Importing a dataset of series replaces the current time series (results of a simulation) of all concerned objects.

- Select *Import* in the *Database* frame.
- Select the *Group* and the *Dataset* of time series to import and click *Ok*.

Exported results can also be visualized in the *Selection and Plots* module.

- Open *Selection and Plots* module (*Module* frame -> Selection and plots).
- In the Source of data, check the *Database* source (Figure 54), then select in the combo the Group containing the dataset of time series.
- Select the dataset of time series to be drawn.
- Click on *Plot* in the *Series* frame.

[18] By activating *Only selected series*, only the series corresponding to the last active *Selection* in the *Selection and Plots* are exported.

Chapter 7. Expert module

In this chapter, the four plugins of the Expert module are presented:

- Automatic calibration of hydrological model parameters;
- Stochastic simulation
- Time-slices simulation;
- Scenario simulation.

7.1. Calibrator

The complexity of a hydrological model calibration increases with the number of parameters to calibrate. The search for optimal values of calibration parameters can be made manually to a reasonable number of parameters. But in general, for large basins including hundreds or thousands of parameters, it is essential to have an automatic calibration tool.

In RS MINERVE, an automatic calibration can be realized in the *Calibrator* tool (Figure 55).

- Click on *Expert* module and then on the Calibrator tool (Figure 55).

Calibration configuration

Different types of calibration can be achieved for an optimization:

- Regular calibration: One or more zones with a unique downstream gauged station, calibrated with the same parameters for all zones.
- Calibration per zone: One or more zones with a unique downstream gauged station, calibrated with different parameters per zones.
- Regional calibration: One or more zones with several downstream gauged station, calibrated with the same parameters for all zones.

The creation of a new calibration configuration can be realized following next steps (corresponding to the black boxes in the Figure 55):

- In the *Selection* frame (Figure 55), select the object types to calibrate: press simultaneously *Ctrl* on keyboard and left click on the object types. Then define the corresponding zone(s) by clicking on the Zone Id number(s).
  All the objects corresponding to the selected object types and zone(s) appear in the *Models* frame (Figure 55). The correspondent parameters are shown in the *Parameters* frame (Figure 55).
- In the *Parameters* frame (Figure 55), select the parameters to calibrate. For each of them, define their minimum and maximum possible values (*Min* and *Max* columns) and the value to be used for the first iteration of the calibration (*From model*, *Defined* value or *Random* value).
- If more than one zone has been selected (*Selection* frame), a column *Values per zone* appears in the table. For the parameter(s) selected for calibration, a box appears in this column. If the box is checked, the calibration for the parameter will consider a different value for each zone. If not, the same value will be considered for all zones in the concerned calibration.

  Parameters can be imported in the model by clicking on Import P in the *Parameters import/export* frame (Figure 55).

In the *Comparators* frame (Figure 55), select the comparator(s) whose the observed variables (discharges or heights) will be used for the calibration (press simultaneously *Ctrl* on keyboard and left click on the comparators name to select more than one). If more than one comparator is selected, all will be taken into account in the objective function with the same weight.

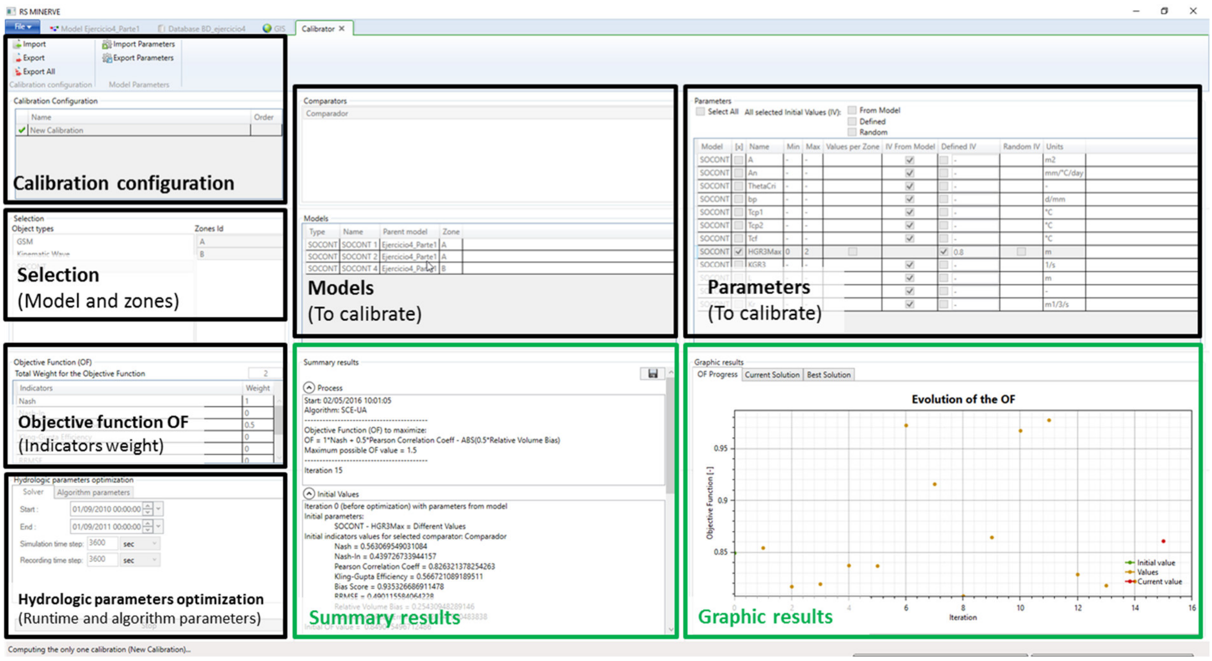


Figure 55 Interface of the Hydrological calibration module (in black: configuration; in green: results)

- Define the weight of each indicator to determine the objective function in the *Objective Functions* (OF) frame. Its total weight appears in the cell at the top of the frame.
- In the *Solver* tab of the *Hydrologic parameters optimization* frame (Figure 55), specify the calibration period and both *Simulation* and *Recording* time steps (Figure 56). The *warm up period* parameter defined for each comparator will be taken into account to initialize the state variables (as explained in the Technical manual).

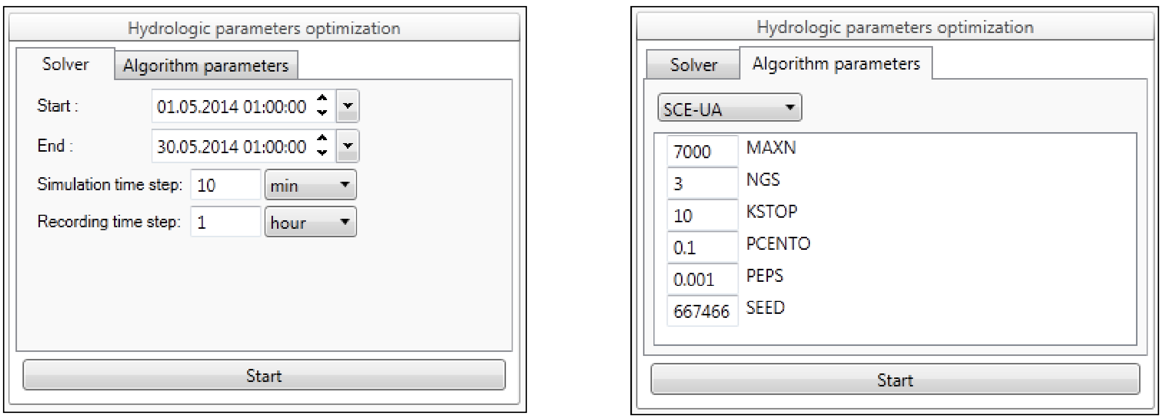


Figure 56 Calibration solver: both runtime (left) and algorithm properties (right)

In the *Algorithm parameters* tab of this same frame, define the algorithm type (SCE-UA in the example of Figure 56) and the corresponding parameters.

Three different algorithms (Shuffled Complex Evolution – University of Arizona - SCE-UA and Uniform Adaptive Monte Carlo - UAMC and Coupled Latin Hypercube and Rosenbrock - CLHR) are available in the actual version. For more information, see RS MINERVE – Technical Manual.

The mouse fly above of each parameter name shows their description.

- Click on Export in the *Calibration Configuration* frame (Figure 55) to save the current calibration configuration. If you want to save the configuration for all the calibrations click on Export All. The produced file can be imported for the next calibration test.

To import an existing configuration, click on Import in the *Calibration Configuration* frame (Figure 55) and load the file.

Calibration start/stop

- Click on Start in the *Hydrologic parameters optimization* frame to launch the calibration.
  If the calibration configuration is valid, a « Start » message with the current date appears in the *Process* tab in the *Summary Results* frame. Otherwise, a red error message is displayed at the bottom of the *Solver* tab and describes the problem to resolve.
- To stop the calibration, click on Stop in the *Hydrologic parameters optimization* frame. It takes a moment to stop until the current simulation ends.

Calibration results

After each simulation during the calibration, the following results are showed in the *Summary Results* frame (Figure 55 and Figure 57):

- The Objective Function (OF), with its maximum possible value.
- The results of the simulation before optimization with initial parameters, initial indicators values and initial OF value.
- The results of the current iteration with its parameters values and the respective indicators values and OF value.
- The best result, with related parameters and OF value.

These results can be exported at all times by saving with the Save button located in the same frame or by copying then pasting the text in a file.

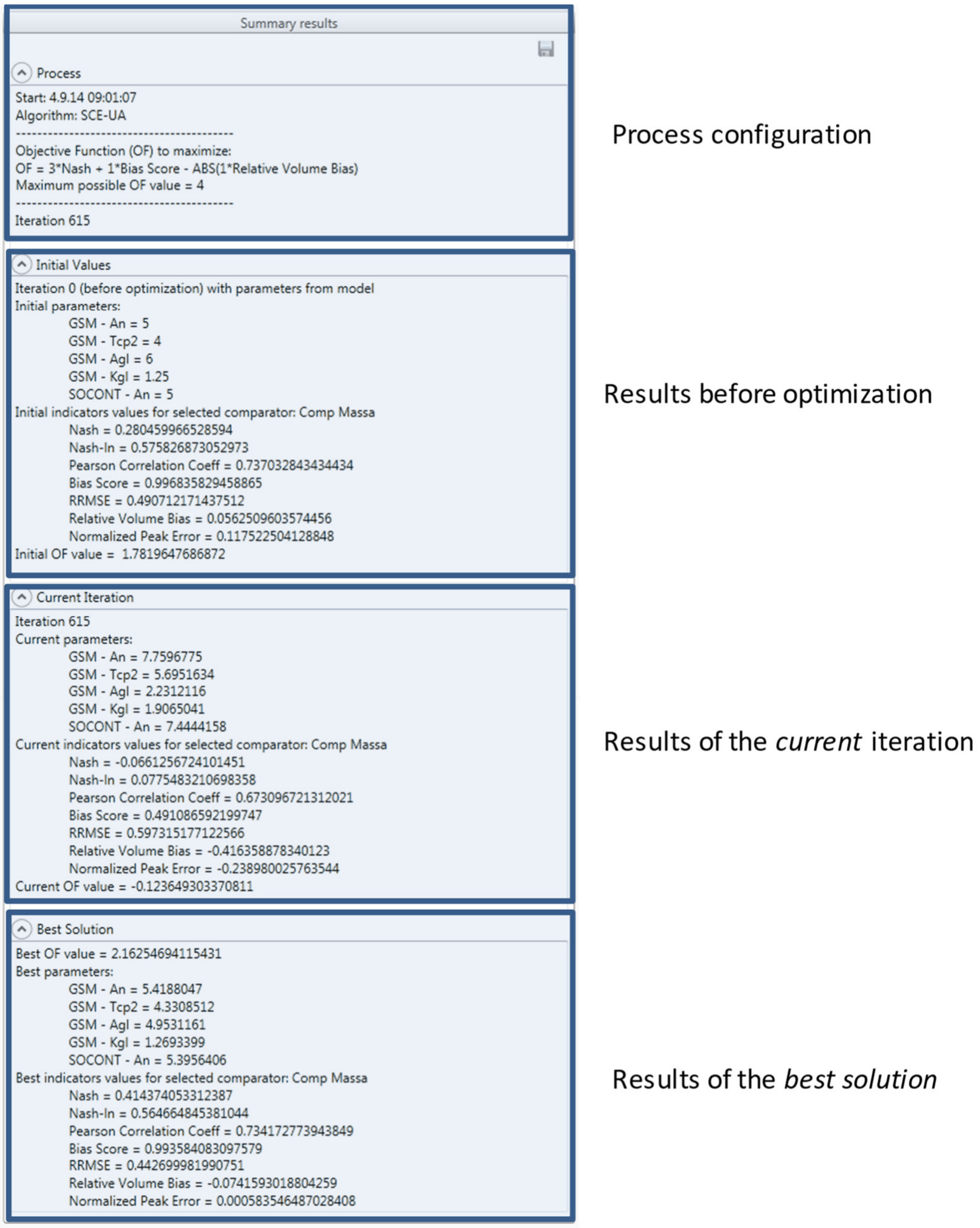


Figure 57 Textual results of the calibration in progress

If more than one comparator has been selected in the *Comparators* frame, the Objective Function is equal to the sum of the objective functions obtained at each compactor.

The results of the calibration in progress can also be visualized as graphic form in the *Graphic Results* frame (Figure 55 and Figure 58):

- The *OF Progress* tab shows the temporal evolution of the Objective Function (OF), with Initial value in green, current value in red and all other values in orange. The activation of the mouse wheel on vertical axis allows to zoom on the OF values of interest.
- The *Comparator* tab allows following the progression of the current simulated variable (discharges or heights) with respect to the observed one. If more than one comparator had been selected for the calibration in the *Comparators* frame, the

comparator to show can be modified by clicking on the one of interest in the same frame.

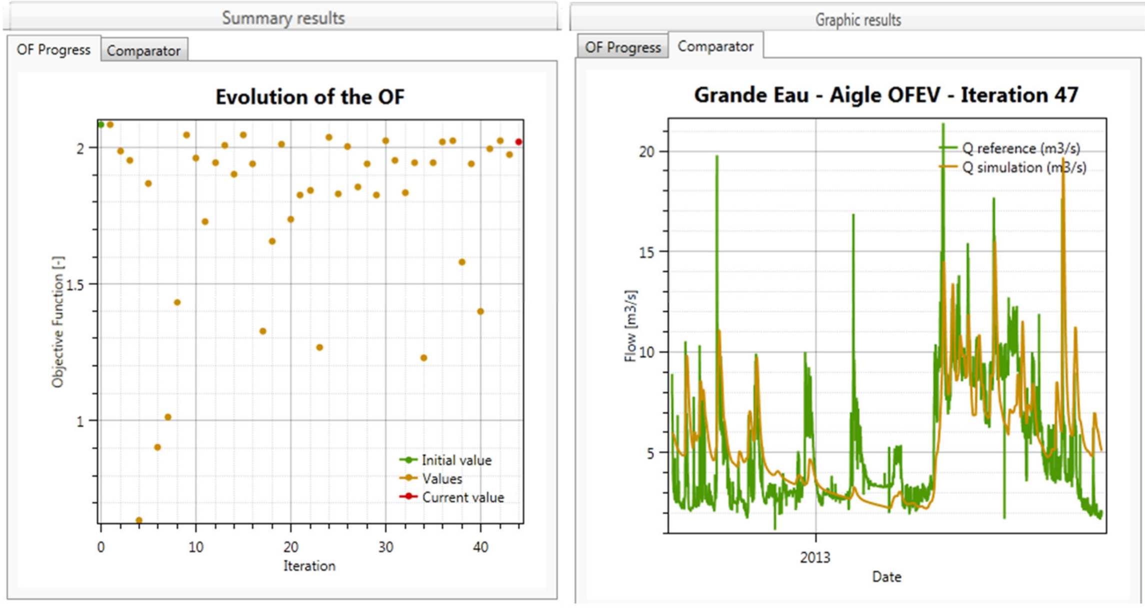


Figure 58 Graphic results of the calibration in progress. Evolution of the Objective function (left) and hydrograph of both observed and current simulated discharge (right).

At the end of the calibration:

- The parameters obtained for the best *Objective Function* value are applied in the current model. If the model is saved, the parameters are stored; if not, the hydrological model keeps the initial parameter values.
- The parameters can be also exported in a file by clicking on 

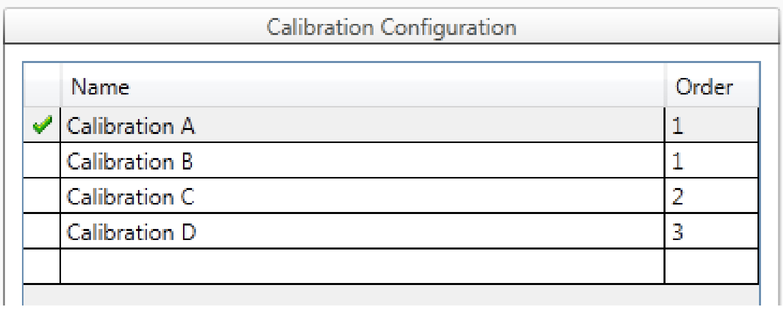
 in the *Parameters import/export* frame (Figure 55).

Multiple calibration

Additionally, in combination with all possible optimizations, multiple calibrations can be achieved:

- Unconnected basins calibration: several independent basins can be calibrated if the same "order" is provided for all of them.
- Upstream-downstream basins calibration: Different dependent basins can be calibrated from upstream to downstream ("order" grows up from upstream to downstream).

Parallel and series calibration can be combined for a complex basin as presented in example of the Figure 59, where two unconnected basins are calibrated in Calibration A and Calibration B, then a downstream basin is calibrated in Calibration C and, finally, a more downstream basin is calibrated in Calibration D.



Calibration Configuration

	Name	Order
✔	Calibration A	1
	Calibration B	1
	Calibration C	2
	Calibration D	3

Figure 59 Example of a calibration with two unconnected basins and two basins upstream

7.2. Scenario simulation

To evaluate the model sensitivity (i.e. the simulated flows) to the Initial Conditions, to the parameters and also to the meteorological inputs, it is necessary to run a lot of simulations to test different sets of values. But for the user it is very tedious to launch these many scenarios simulations.

In RS MINERVE, scenario's simulations can be realized in the *Scenario simulation* tool.

- Click on the *Expert module* in the *Toolbox* frame (Figure 1) and then on the *Scenario simulation* (Figure 60).

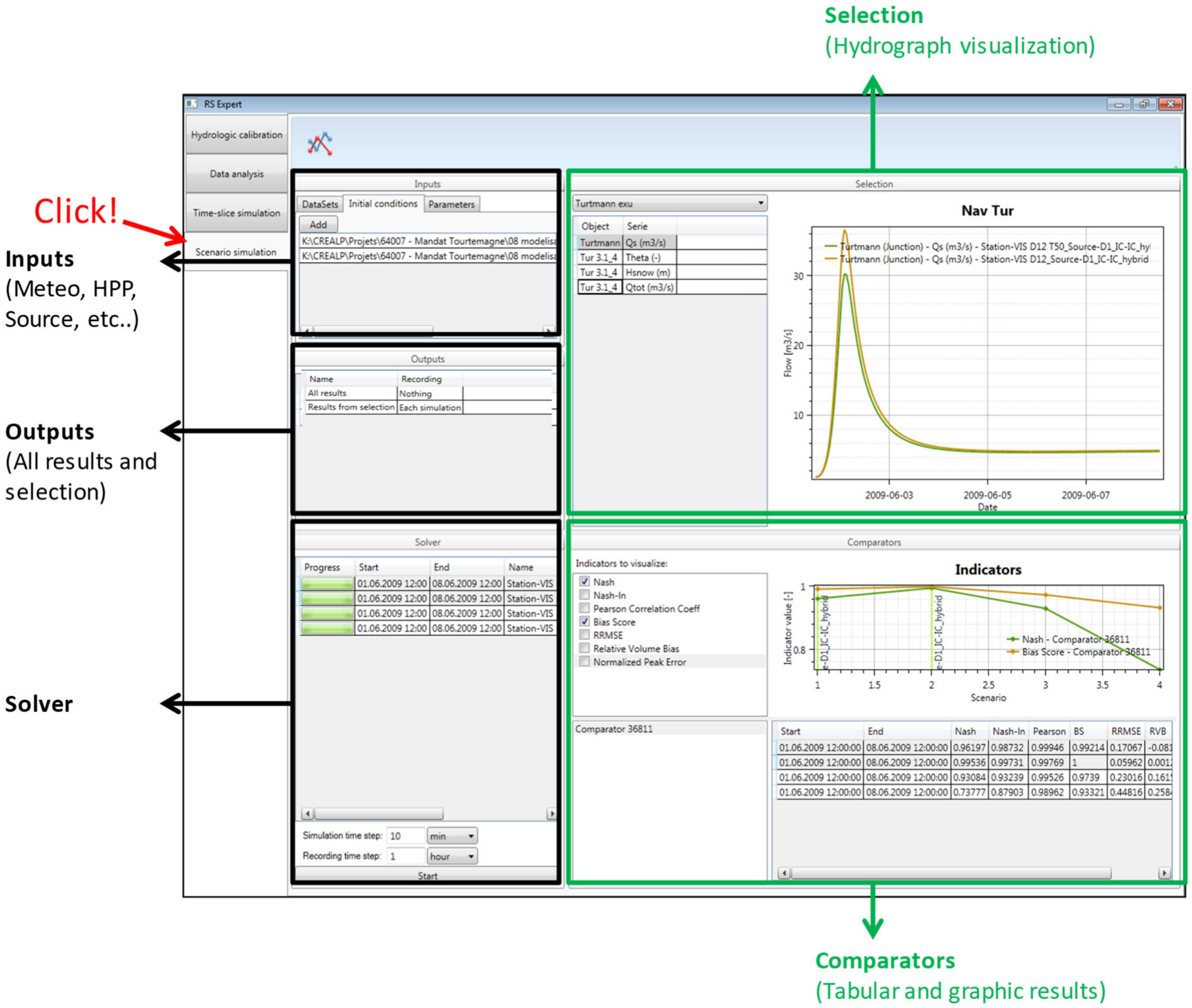


Figure 60 Interface of the Scenario simulation module (in black: configuration; in green: results)

Scenarios configuration

A scenario is composed of a combination of input datasets (one for each type of *Input data*), a set of initial conditions and a set of parameters. Except the dataset for the *Station* input (meteorological inputs) when the model contains at least one *Virtual weather station*, all other inputs are optional. Initial conditions and parameters can be provided as text or worksheet files.

All possible combinations composed of every input type with at least one dataset or input file are proposed, but the user can erase undesired simulations.

The creation of a new scenarios configuration can be achieved following next steps (corresponding to the black boxes in the Figure 68):

- In the *Inputs* frame (Figure 60), click on the *DataSets* tab (Figure 61). Select the dataset(s) to be used as data sources for the different *Inputs*: Station, TurbineDB, Source, Reservoir and Consumer (only object types existing in the model are listed). For example, for the *Station* data source, click on *Station* in the left part, search the corresponding dataset name(s) in the right part and check it/them.

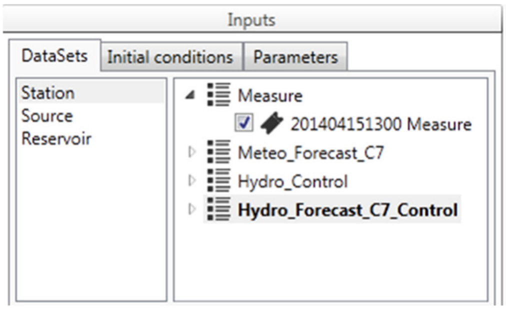


Figure 61 *Inputs* frame in the Scenario simulation tool

- Click on the Initial conditions tab (Figure 61). If you want to add initial conditions (IC) file(s), click on Add and import the desired IC files. The selected ones are listed in the *Inputs* frame.
- Click on the Parameters tab (Figure 61). If you want to add parameters file(s), click on Add and import the desired parameters files. The selected ones are listed in the *Inputs* frame.
- In the *Selection* frame (Figure 60), choose the *model selection* to be used.
- Then, select the object's series to be displayed.

The *model selection* is also used for the results exportation.

- In the *Outputs* frame (Figure 60), define the outputs to be recorded: *All results* (all the simulation results of the model) and/or *Results from selection* (which considers only the above selected model selection). For each one, it is possible to record:
    - *Each simulation:* one dataset will be produced by time-slice (see *Simulation period* in *Solver frame* at Figure 60);
    - *Combined simulations*: only one dataset will be produced for all the period;
    - *Nothing:* no dataset will be produced*;*
- In the *Solver* frame (Figure 60), specify:
    - Both *Simulation* and *Recording* time steps;

The period of each scenario simulation will only correspond to the period covered by all the datasets composing the scenario. If the covered periods for a scenario do not overlap for more than one time step, a gray progress bar is displayed (since simulation cannot be achieved).

The name of the output file of each scenario is composed by merging the names of all the datasets used for the scenario. The input type of each dataset (e.g. Station, Source) is added before the name of each dataset (e.g. "*Station*-Datameteo_Source-Datasource…")

Scenario simulation start/stop

- Click on Start in the *Solver* frame to launch the time-slice simulation.

  If the model is valid, the simulation starts. Succes of each scenario is presented with a green progress bar (Figure 62). If the current scenario is not valid, the RS MINERVE error is displayed and a gray progress bas is shown (Figure 69, right).

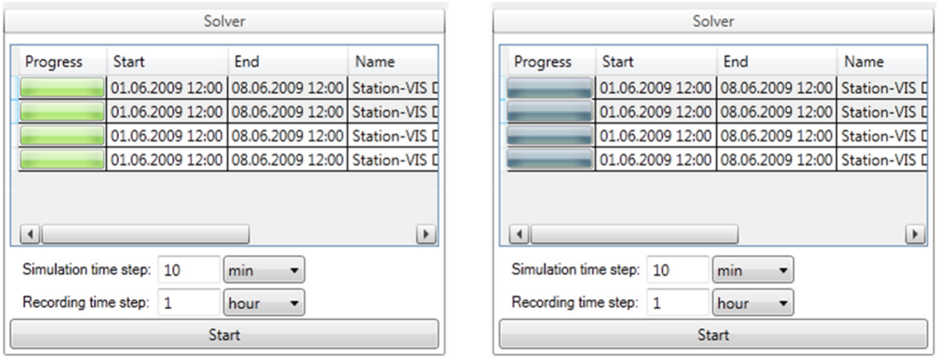


Figure 62 Progress state after succes (left) and failure (right) of the simulation

- Click on Stop in the *Solver* frame if necessary to stop the simulation. All results until that moment are saved.

Scenarios results

After simulation of each scenario, following components are showed:

- In the *Selection* frame: the temporal evolution of the selected object's series;
- In the *Comparators* frame: the values of indicators checked at the top left of the frame (*Indicators to visualize*).These values are displayed as graphical and tabular forms and correspond to the comparator selected in the bottom left of the *Comparator* frame;

During the simulation, you can change all the objects or all indicators or all comparators to visualize by clicking on or checking them. The tabular results of indicators can be exported at all times by copying then pasting the text in a file.

At the end of the scenario simulation, the outputs datasets are available in the same repository than those of the database.

7.3. Stochastic simulation

This tool is capable of generating a set of simulations based on different parameters or initial conditions with values located in a defined user interval. For each element of the model, simulated hydrographs, corresponding statistics (mean, median, quartiles, minimum and maximum values), and related set of parameters for each simulation are provided. This module has implemented 4 types of probability distributions, uniform, normal, log normal and exponential. Also, it is possible to define a custom probability distribution with a txt file, to get more information go to the Technical Manual.

Sometimes the complexity of a hydrological model requires a sensitivity analysis to collect a set of simulations. The possibility to analysis the results of a model depending of a range parameter is really useful to know the variability of the model. This module generates a lot of information, all the results simulations, generated parameter series and finally a statistic results.

In RS MINERVE, an automatic stochastic simulation can be realized in the *Hydrological calibration* tool (Figure 63).

- Click on *Expert* module and then on the Stochastic Simulation (Figure 63).

Stochastic configuration

The creation of a new Stochastic simulation configuration can be realized following next steps (corresponding to the black boxes in the Figure 63):

- In the *Selection* frame (Figure 63), select the object types to simulate: press simultaneously *Ctrl* on keyboard and left click on the object types. Then define the corresponding zone(s) by clicking on the Zone Id number(s).
  All the objects corresponding to the selected object types and zone(s) appear in the *Models* frame (Figure 63). The correspondent parameters are shown in the *Parameters* frame (Figure 63).
- In the *Parameters* frame (Figure 63), select the range parameters to simulate. For each of them, define their minimum and maximum possible values (*Min* and *Max* columns) and the probability distribution to be used in the simulation (*Uniform, normal, log normal, exponential and user defined*). To get more information go to the Technical Manual.
- If more than one zone has been selected (*Selection* frame), a column *Values per zone* appears in the table. For the parameter(s) selected for simulation, a box appears in this column. If the box is checked, the simulation for the parameter will consider a different value for each zone. If not, the same value will be considered for all zones in the concerned simulation.

  Parameters can be imported in the model by clicking on 

 in the *Parameters import/export* frame (Figure 63).

In the *Selection plot* frame (Figure 63), select the result(s) that will be used for the simulation (press simultaneously *Ctrl* on keyboard and left click on the selection name to select more than one). It is necessary to define previously a plot to run the stochastic simulation.

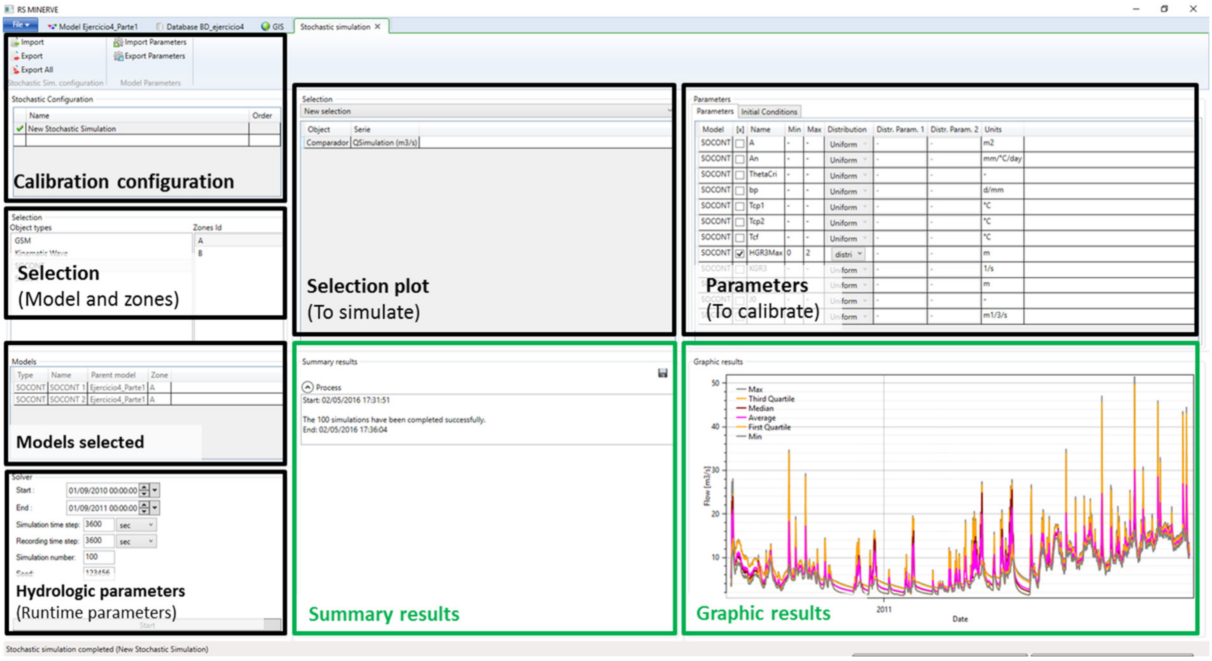


Figure 63. Interface of the Stochastic simulation module (in black: configuration; in green: results)

- In the *Solver* tab of the *Hydrologic parameters* frame (Figure 63), specify the simulation period and both *Simulation* and *Recording* time steps.
- Click on Export in the *Summary results* frame (Figure 63) to save the current stochastic configuration. If you want to save the configuration for all the simulations click on Export All. The produced file can be imported for the next simulation test.

To import an existing configuration, click on Import in the *Simulation Configuration* frame (Figure 63) and load the file.

Stochastic start/stop

- Click on Start in the *Hydrologic parameters* frame to launch the simulation.
  If the simulation configuration is valid, a « Start » message with the current date appears in the *Process* tab in the *Summary Results* frame. Otherwise, a red error message is displayed at the bottom of the *Solver* tab and describes the problem to resolve.
- Click on Stop in the *Hydrologic parameters* frame to stop the simulation. It takes a moment to stop until the current simulation ends.

Stochastic results

After each simulation during the calibration, the following results are showed in the *Summary Results* frame (Figure 64):

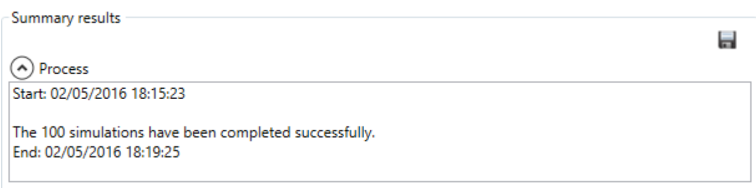


Figure 64 Textual results of the stochastic simulation.

These results can be exported at all times by saving with the Save button.

This action save three CSV files with all the numerical simulation information.

- First file, (*.csv) contains all the simulations results for the defined period of time (Figure 65L).
- Second file, (* - Statistical.csv) contains the statistical values for simulations results for the defined period of time (Max, Q(75%), Median, Average, Q(25%) and Min) (Figure 65R).
- Third file, (* - P&IC.csv) contains the parameters values with a defined probability distribution (Figure 66).

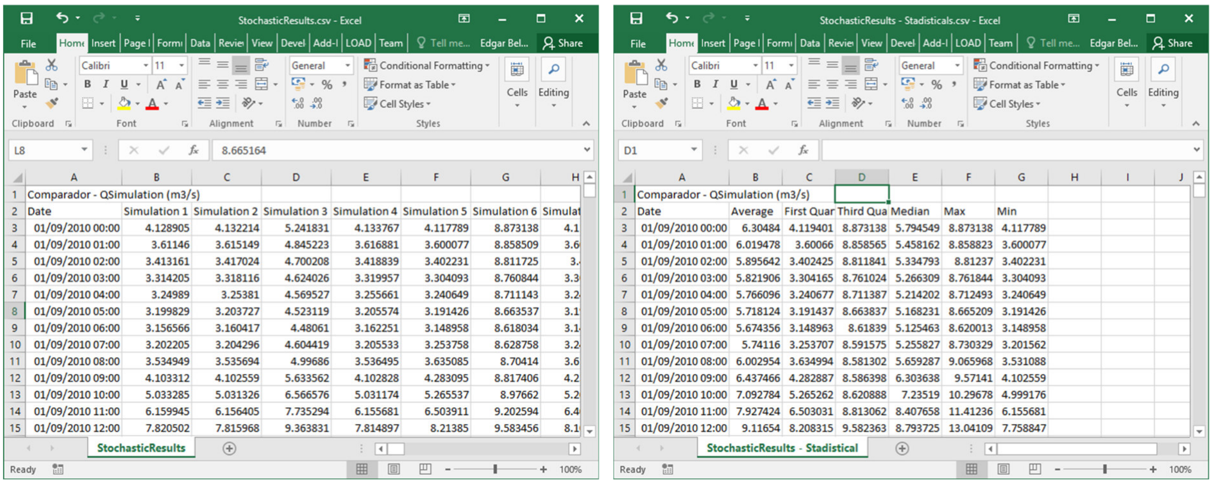


Figure 65 Numerical results for the stochastic simulation. All the simulation iterations (left). Statistical results (right).

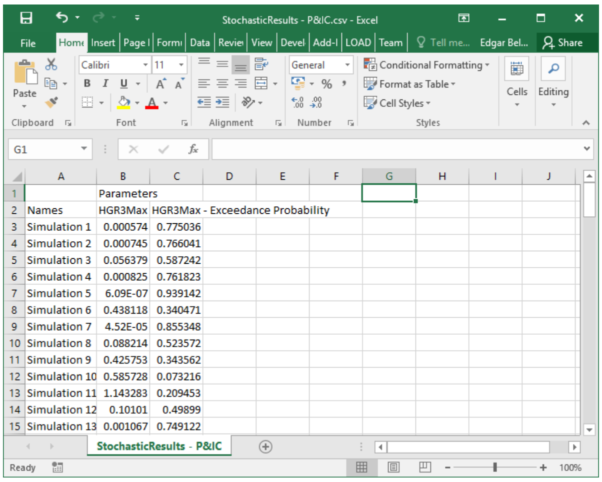


Figure 66 Parameters values with a defined probability distribution.

Finally, the Figure 67 shows the statistical graphical results for the defined period of time.

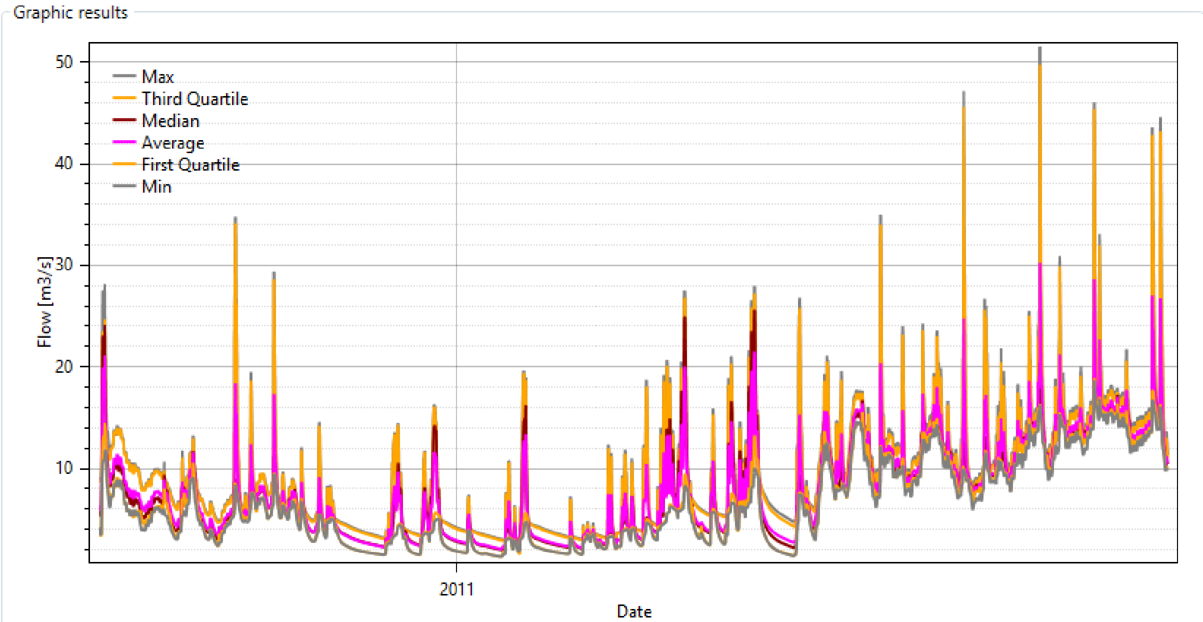


Figure 67 Graphic results of the stochastic simulation, statistical series plots.

7.4. Time-slice simulation

The computation duration logically increases with the model complexity but also with the simulation period length. Thus, simulations on long periods with short time steps and a complex model can become inappropriate for user's computer performance. In this case, it is necessary to clip the simulation period in time-slices.

In RS MINERVE, a time-slice simulation can be realized in the *Time-slice simulation* tool.

- Click on *Expert* module and then in the *Time-slice simulation* tool (Figure 68).

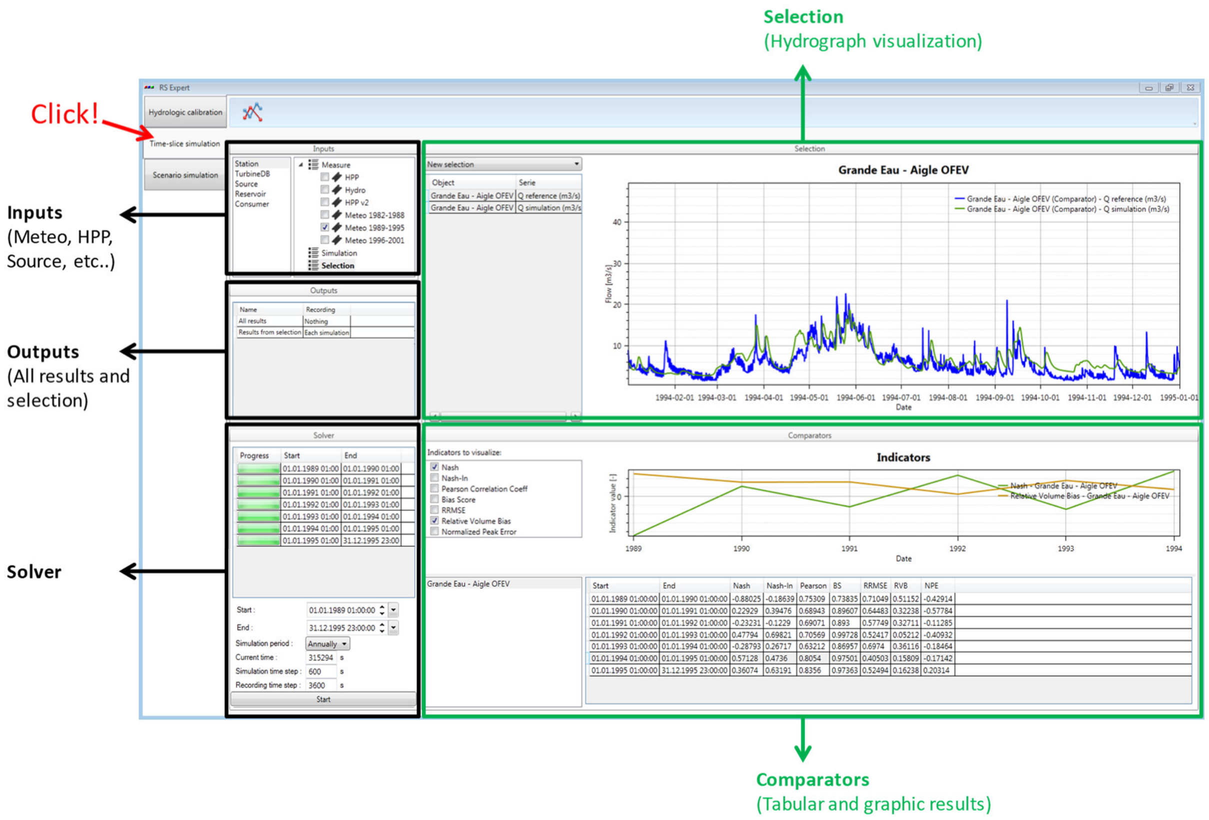


Figure 68 Interface of the Time-slice simulation tool (in black: configuration; in green: results)

Time-slice configuration

The creation of a new time-slice configuration can be achieved following next steps (corresponding to the black boxes in the Figure 68):

- In the *Inputs* frame (Figure 68), select the dataset(s) for each data source (Station, TurbineDB, Source, etc...). For example, for the *Data Source* of *Station* objects: click on *Station,* search the corresponding dataset name(s) and check it.

  More than one dataset can be checked for each type of input. If a period of the simulation is covered by more than one dataset, the dataset starting first is used

- In the *Selection* frame (Figure 68), choose the *model selection* to be used.
- Then, select the object's series to be displayed.

  The *model selection* is also used for the results exportation.

- In the *Outputs* frame (Figure 68), define the outputs to be recorded: *All results* (all the simulation results of the model) and/or *Results from selection* (which considers only the above selected model selection). For each one, it is possible to record:
  - *Each simulation:* one dataset will be produced by time-slice (see *Simulation period* in *Solver frame* at Figure 68);
  - *Combined simulations*: only one dataset will be produced for all the period;
  - *Nothing:* no dataset will be produced*;*
- In the *Solver* frame (Figure 68), specify:
  - The entire simulation period: *Start* and *End* dates.

    By default, the maximum possible period to be simulated is proposed. It corresponds to the maximum period covered by the datasets in each object type for which at least one dataset is selected. Manual modification can only shrink the extent of the simulation period.

- The time-slice or *Simulation period: annually, monthly, etc…;*
- Both *Simulation* and *Recording* time steps.

Time-slice simulation start/stop

- Click on Start in the *Solver* frame to launch the time-slice simulation.

  If the model is valid, the simulation starts. In addition, succes of each time-slice is presented with a green progress bar (Figure 69, left). If one time-slice cannot be achieved, the RS MINERVE error window is displayed and a gray progress bar is shown (Figure 69, right).

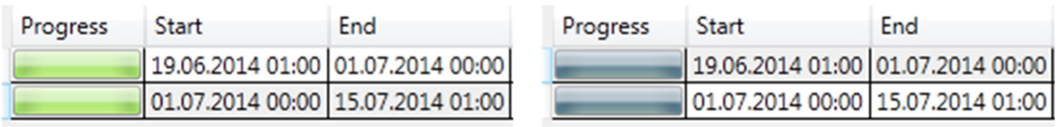


Figure 69 Progress state after success (left) and failure (right) of the simulation

- Click on Stop in the *Solver* frame if necessary to stop the simulation. All results until that moment are saved

Time-slice results

After each computation of each time-slice, next components are showed:

- In the *Solver* frame, the progress bar of each time-slice;
- In the S*election* frame, the series of the components selected in the object list for the last computed time-slice.
- In the Comparators frame: the values of the indicators checked under *Indicators to visualize* for the selected comparators are graphically shown in the top part of the frame and in tabular form in the bottom part of the same frame (Figure 70).

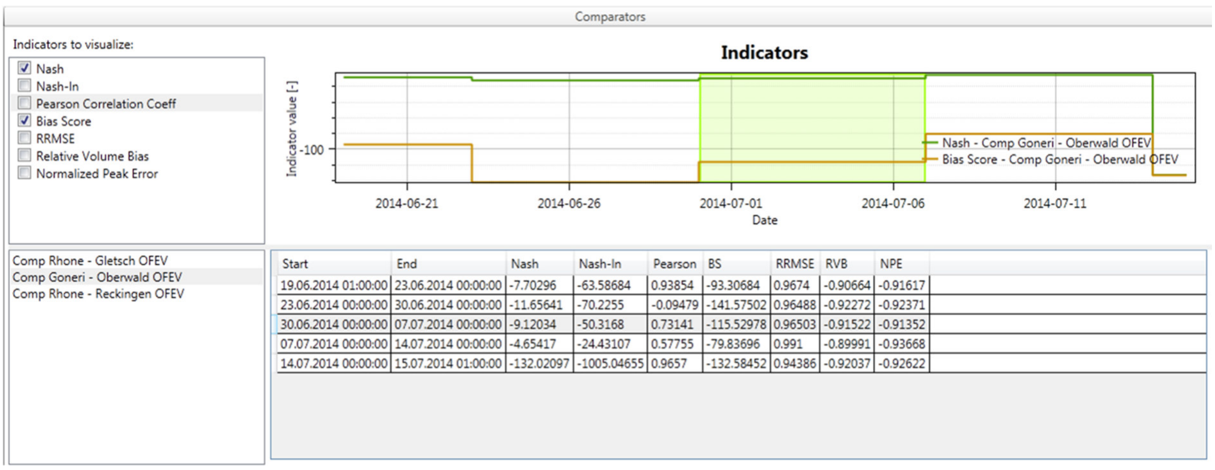


Figure 70 Visualization of indicators at the different comparators

Objects selection in the *Selection* frame as well as indicators and comparators to consider in the *Comparators* frame can be modified during the Time-slice simulation.

The tabular results of indicators can be exported at any time by copying them and pasting the text in a file.

At the end of the time-slice simulation, the outputs datasets are available in the same repository than those of the database.

7.5. Optimizator

In RS MINERVE, an automatic optimization of the Planner's conditions and rules can be performed with the *Optimizator* tool (Figure 71).

- Click on *Expert* module and then on the Optimizator tool (Figure 71).

Optimization configuration

The definition of a new optimization configuration can be carried out following the next steps (corresponding to the black boxes in Figure 71):

- In the *Selection* frame (Figure 71), select the Zones to be considered and the Planners objects to which the optimization should be applied to: press *Ctrl* and click to select multiple Zones or Planners.
  Once the Zones and Planner objects selected, all the possible "output generation" parameters and the "conditions" parameters that can be optimized appear in the *Parameters to optimize* frame (Figure 71).
- In the *Parameters to optimize* frame (Figure 71), select the parameters to optimize in both tabs (Output generation and Conditions). For each one, define its minimum and maximum possible values.

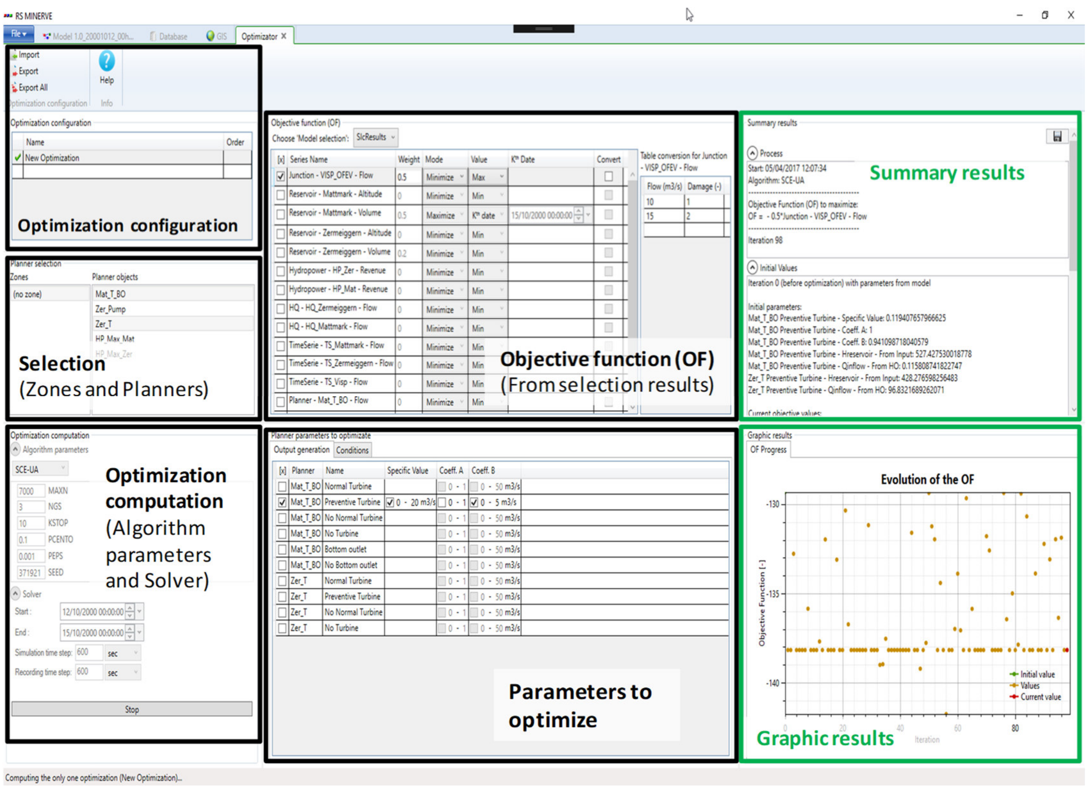


Figure 71 Interface of the Planner optimization module (in black: configuration; in green: results)

- Choose the 'Model selection' (from those defined in *Selection and plots* module) in the *Objective Function* (OF) frame (Figure 71). The available series of this selection appear in the table below.
- Select the series to take into account in the objective function. For each selection, specify its weight, the optimization type (maximize or minimize) and the value we want to maximize/minimize (the maximum value of the series, the minimum value, the average or the value for a specific K date).
- If the option "Kth date" is selected for the Value to optimize, the user has to define a specific date in the "Kth Date" column.
- A conversion from discharge to damages can be applied to the flow series selected. This could be used to optimize damages instead of discharges. For this purpose, the user can create a conversion curve adding at least two points in the "Table conversion" on the right. When the points are added, the Convert option for this result can be enabled.
- In the *Solver* section of the *Optimization computation* frame, specify the optimization period and both the *Simulation* and *Recording* time steps (Figure 71).

  In the *Algorithm parameters* section of the same frame, define the optimization algorithm to be used (e.g., SCE-UA in Figure 71) and its corresponding parameters. Three different algorithms are available: Shuffled Complex Evolution – University of Arizona - SCE-UA; Uniform Adaptive Monte Carlo – UAMC; Coupled Latin Hypercube with Rosenbrock - CLHR. For more information about their basic essentials, please refer to the RS MINERVE – Technical Manual.

  Hover the mouse over each parameter to display a short description.
- To save the current optimization configuration (optional), click on Export in the *Optimization Configuration* frame (Figure 71). If you want to save the configuration for all the optimizations, click on Export All. The resulting file can be imported for the next optimization.

  To import an existing optimization, click on Import in the *Optimization Configuration* frame (Figure 71) and load the file.

Optimization start/stop

- Click on Start in the *Optimization computation* frame to launch the optimization.
  If the optimization configuration is valid, a « Start » message with the current date appears in the *Process* tab of the *Summary Results* frame. Otherwise, a red error message is displayed at the bottom of the *Solver* section with a description of the problem.
- To stop the process, click on Stop in the *Optimization computation* frame. It takes a moment to stop until the ongoing simulation ends.

Optimization results

During the optimization running, the following results are displayed in the *Summary Results* frame (Figure 71 and Figure 72):

- The Objective Function (OF), with its maximum possible value.

- The results of the simulation before the optimization with the initial Planner parameters and the initial OF value.
- The results of the current iteration with its Planner parameters values and the respective values of the OF value.
- The best result, with related parameters and OF value.

The results can be exported for all iterations at the end of the process with the Save button located in the same frame. The summary results can also be copy -pasted the text in a file.

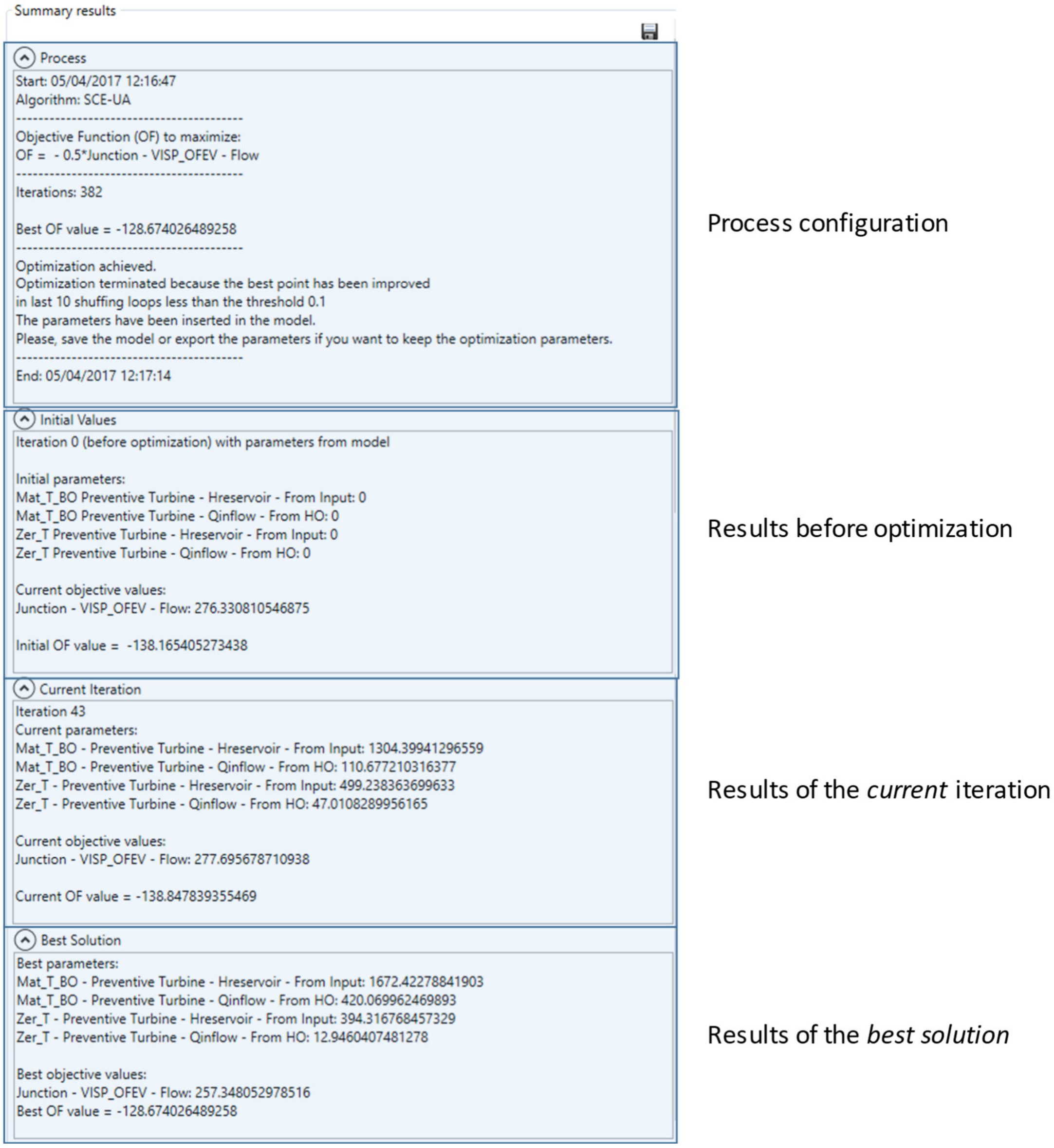


Figure 72 Textual results of the optimization in progress

The results of the optimization in progress are also displayed graphically in the *Graphic Results* frame (Figure 71):

- The *OF Progress* tab shows the evolution of the Objective Function (OF), with its Initial value in green, the current value in red and all other values in orange. The activation of the mouse wheel on the vertical axis allows to zoom on the OF values of interest.

At the end of the optimization:

- The Planner parameters obtained at the end of the optimization process are applied to the model. If the model is saved, the parameters are stored; if not, the Planner objects keep the initial (unoptimized) parameters.

Chapter 8. Plugins

Needs and requests in terms of hydrological and hydraulic modelling differ a lot among users. This is why sometimes, tools need to be developped for specific applications. To answer these particular requests, a plugin module has been developped to enable integration of additional tools into RS MINERVE.

8.1. Options for the integration of plugins

Plugins are additional tools integrated in RS MINERVE. They are developed by the RS MINERVE Group on request of users of the RS MINERVE community that are willing to fund their developments. Depending on their wish to share or not the developed plugin, three different possibilities exist:

- **Integration in RS MINERVE**: The plugin is directly integrated in RS MINERVE and therefore available to all users at installation.
- **Plugin available for download on a website**: The founder can decide that the plugin should not be part of RS MINERVE but freely available for download on a webpage (CREALP website or company website).
- **Private plugin**: The funder can decide not to share the plugin.

8.2. Plugin Manager (under development)

The Plugin manager will allow integration of plugins not yet available in RS MINERVE (available for download on a webpage). This part is still under development. However, plugins can already be used trough addition of dll files. In case of questions, please contact the RS MINERVE Group trough the email contact indicated on the Plugin Manager.

8.3. Plugins documentation

The documentation of the plugin is specific to each plugin and not part of the official User's and Technical manuals of RS MINERVE.

Chapter 9. Examples of application

In this chapter, some examples of application are presented in order to deepen the knowledge of the program. These basic examples are designated to facilitate the learning of the program RS MINERVE. The examples are organized according to the degree of difficulty.

The use of RS MINERVE in case studies has demonstrated the capacity of the program to correctly reproduce the real behavior of river basins. In addition, the program facilitates the search of different scenarios of operation while optimizing complex systems in a satisfactorily way.

This chapter contains three examples with didactic aims:

- Example 1 – Simple basin with only runoff.
- Example 2 - Combined full basin with meteorological stations.
- Example 3 - Equipped basin with a hydropower scheme.
- Example 4 – Automatic calibration of a model

9.1. Example 1 – Simple basin with only runoff

In the first example the objective is to model the production of a net rain-flow of three impermeable basins, then the propagation of two hydrographs, the implementing of three inflows at a confluence and finally their propagation to the model outlet (Figure 73).

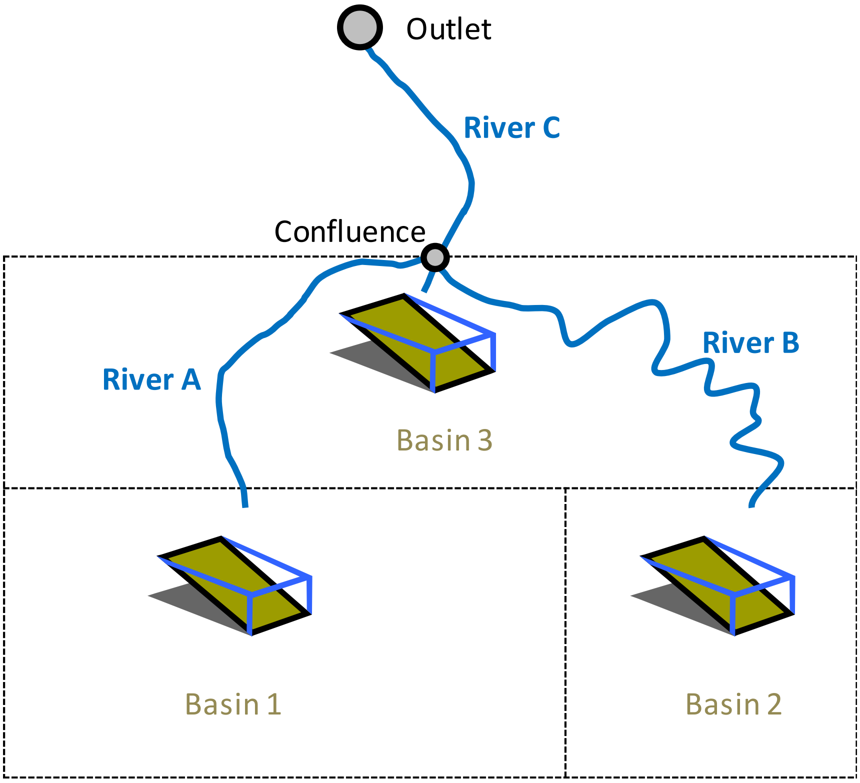


Figure 73 Model scheme

The three impermeable surfaces are supposed to be located in the same region, thus receiving an identical precipitation. Each surface has its own outlet into different rivers (A and B) which are joined later on in a single final river (C) before flowing into the outlet of the model. The parameters and the state variables of the three surfaces, of the three rivers and the precipitation data are provided in Table 5. The three rivers are modeled with the kinematic wave model.

Objective of Example 1

The requested result is the hydrograph at the model outlet during 24 hours, after the beginning of the precipitation, as well as the peak discharge and the peak time.

The simulation parameters are:

- Simulation time step = 600 s;
- Recording time step = 600 s.

A uniform and null ETP is assumed for this example (the user can check the selected ETP method in the RS MINERVE settings).

Table 5 Characteristics of the objects

Precipitation

time (h)	rainfall (mm/h)
0	0
1	1.08
2	1.44
3	1.80
4	2.88
5	5.40
6	8.28
7	9.97
8	6.84
9	5.04
10	3.24
11	2.63
12	1.44
13	0.72
14	0

SWMM 1

Parameters and initial conditions	Values	Units
A	1.00E+07	m^2
L	1500	m
JO	0.1	-
K	1.9	$m^{1/3}/s$
Hini	0	m

SWMM 2

Parameters and initial conditions	Values	Units
A	4.00E+06	m^2
L	3000	m
JO	0.05	-
K	1.5	$m^{1/3}/s$
Hini	0	m

SWMM 3

Parameters and initial conditions	Values	Units
A	8.00E+06	m^2
L	2500	m
JO	0.02	-
K	1.3	$m^{1/3}/s$
Hini	0	m

River A

Parameters and initial conditions	Values	Units
L	3000	m
BO	6	m
m	1	-
JO	0.001	-
K	30	$m^{1/3}/s$
N	1	-
Qini	0	m^3/s

River B

Parameters and initial conditions	Values	Units
L	4000	m
BO	4	m
m	1	-
JO	0.005	-
K	30	$m^{1/3}/s$
N	1	-
Qini	0	m^3/s

River C

Parameters and initial conditions	Values	Units
L	2000	m
BO	7	m
m	1	-
JO	0.001	-
K	30	$m^{1/3}/s$
N	1	-
Qini	0	m^3/s

Resolution of Example 1

This first example is a simplified representation of the reality. Despite of that, it allows the familiarization with the concept of *RS MINERVE* and to know more about its hydrological objects.

At first, the object "Time Series"  is introduced. Clicking once on its icon in the *Objects frame*, a pen appears. You can then click in the graphic interface for creating the object in the position you want. Next, the three run-off surfaces are created by means of the object "SWMM" . The three rivers are introduced by selecting the model "Kinematic Wave" . The model built-up will be finished with the introduction of the two objects "Junction" .

The graphical interface at this stage is presented in Figure 74.

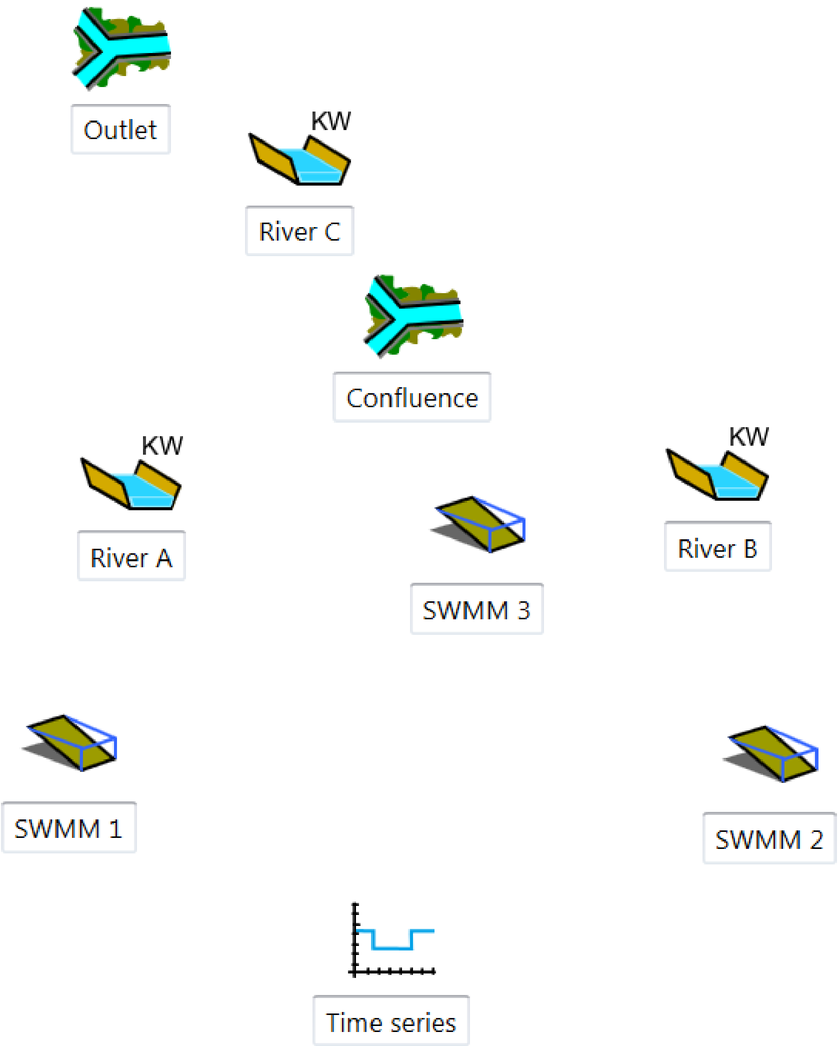


Figure 74 Graphic interface of Routing System II with the new objects

After creating the new objects, topological links or connections have to be established. To do so, it is sufficient to press once the space bar of the keyboard to pass in "connections" mode. In Editing tools, the Connections button is then automatically pressed (Figure 75). Flying over each objet, the curser presented before as an arrow now appears as a cross. Next, click from the object "Time Series" to the object "SWMM 1", thus creating a topological link.

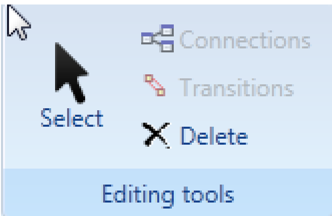


Figure 75 Editing tools frame in Connections mode

The others objects are connected in the same way. Press again the space bar of the keyboard to return to selection mode. The construction of all the model objects and the resulting topologic links is thus achieved as presented in Figure 76 and it only remains the introduction of the parameters.

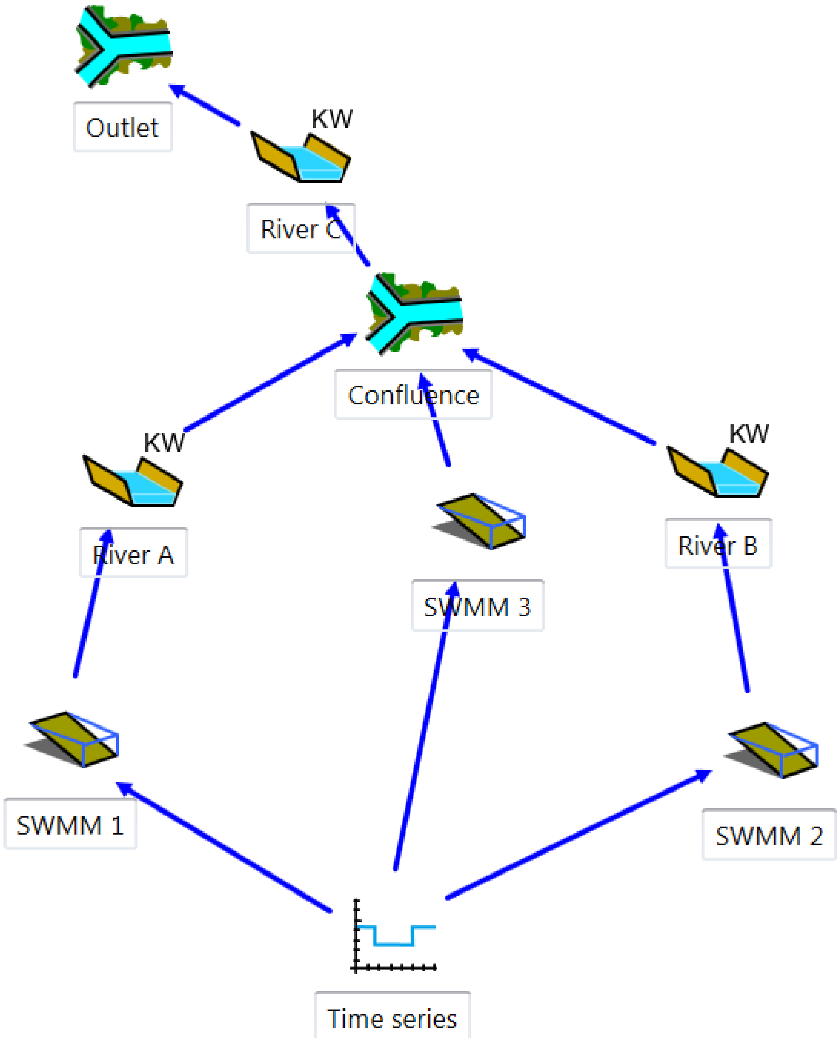


Figure 76 Topologic links between the different objects from the model

By double clicking on the links just created (blue arrows), the information transferred between « Time Series » and the three run-off surfaces as well as that between all other objects from up- to downstream is verified (Figure 76).

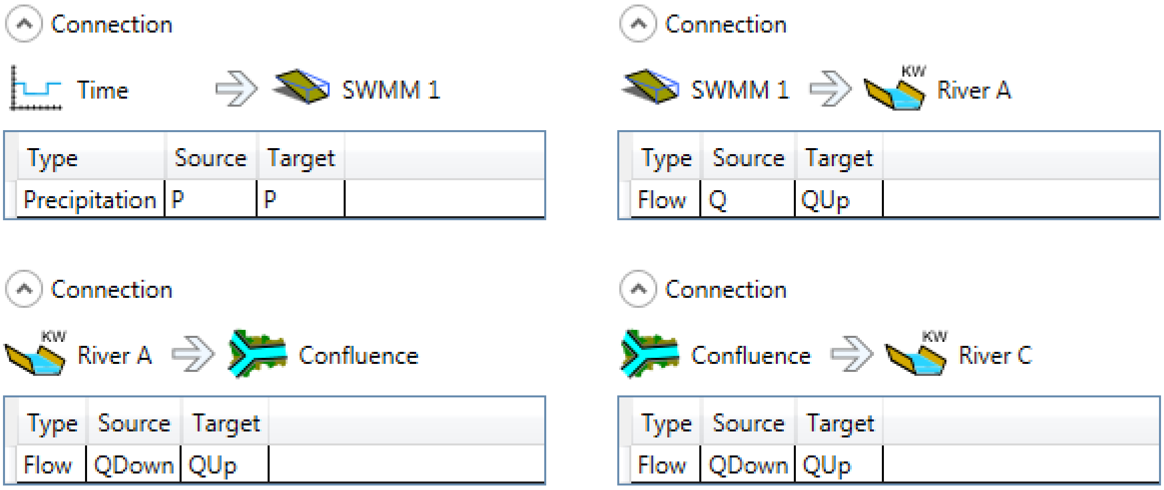
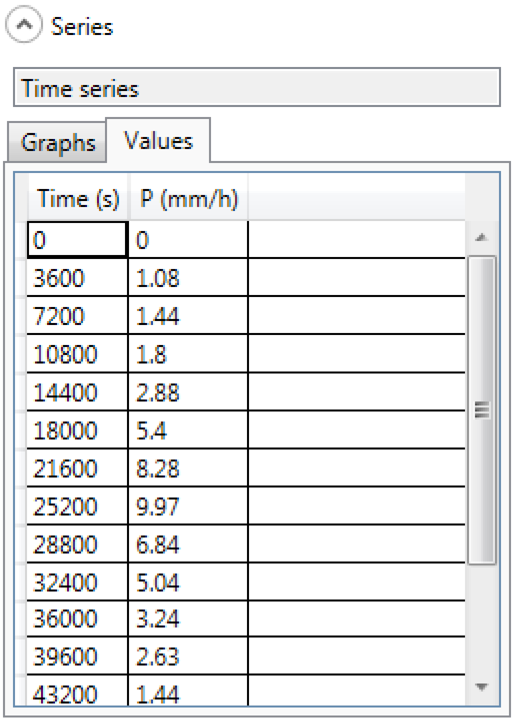


Figure 77 Examples of different connections of the presented model

In clicking double on the Time Series object, the associated frame is opened on the right of the screen and the values "*Time (s) - P (mm/h)*" are introduced (Figure 78).



Time (s)	P (mm/h)
0	0
3600	1.08
7200	1.44
10800	1.8
14400	2.88
18000	5.4
21600	8.28
25200	9.97
28800	6.84
32400	5.04
36000	3.24
39600	2.63
43200	1.44

Figure 78 Values of the "Time series"

Next, for each SWMM object (), the respective parameters (values available in Table 5) are defined by double clicking on every object and introducing them by the help of the both Parameters and Initial conditions frames. The parameters of the Rivers are introduced in the same way (Figure 79).

Parameters

Name	Value	Unit
A	10000000	m2
L	1500	m
J0	0.1	-
K	1.9	m1/3/s

Initial conditions

Name	Value	Unit
HIni	0	m

Parameters

Name	Value	Unit
L	3000	m
B0	6	m
m	1	-
J0	0.001	-
K	30	m1/3/s
N	1	-

Initial conditions

Name	Value	Unit
QIni	0	m3/s

Figure 79 Parameters and initial conditions frames of SWMM 1 (left) and of River A (right)

The date parameters of the simulation are modified in Solver frame on the left of the screen (Figure 80) before the calculation. For both dates « Start » and « End » an arbitrary date is proposed, but the « End » date has to finish 24 hours later than « Start » date. The “Simulation time step” and the “Recording time step” have a value of 600 s.

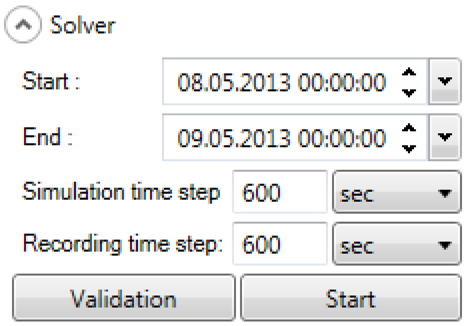


Figure 80 Solver frame

Constructed final model can be now saved clicking in the button and giving a name to the file (e.g. “Example1.rsm”). This way the model could be loaded later to do new simulations (Figure 81).

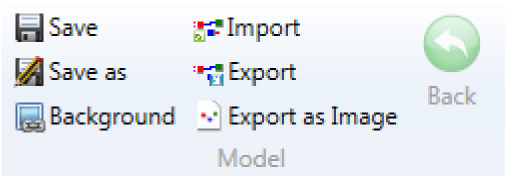


Figure 81 Project frame.

Before running calculation, a pre-simulation validation of the model parameterization can be made in clicking in the button Validation (Solver frame). Its report is summarized on the right of the interface.

Finally, the simulation is initiated by clicking on the button Start in the Solver frame.

Results of Example 1

In order to access to the calculation results for each object it has to be clicked two times on any of them. For example, clicking double on the object Outlet, its dialog box is opened on the right and the simulated hydrograph, being the objective of the Example 1, is shown (Figure 82).

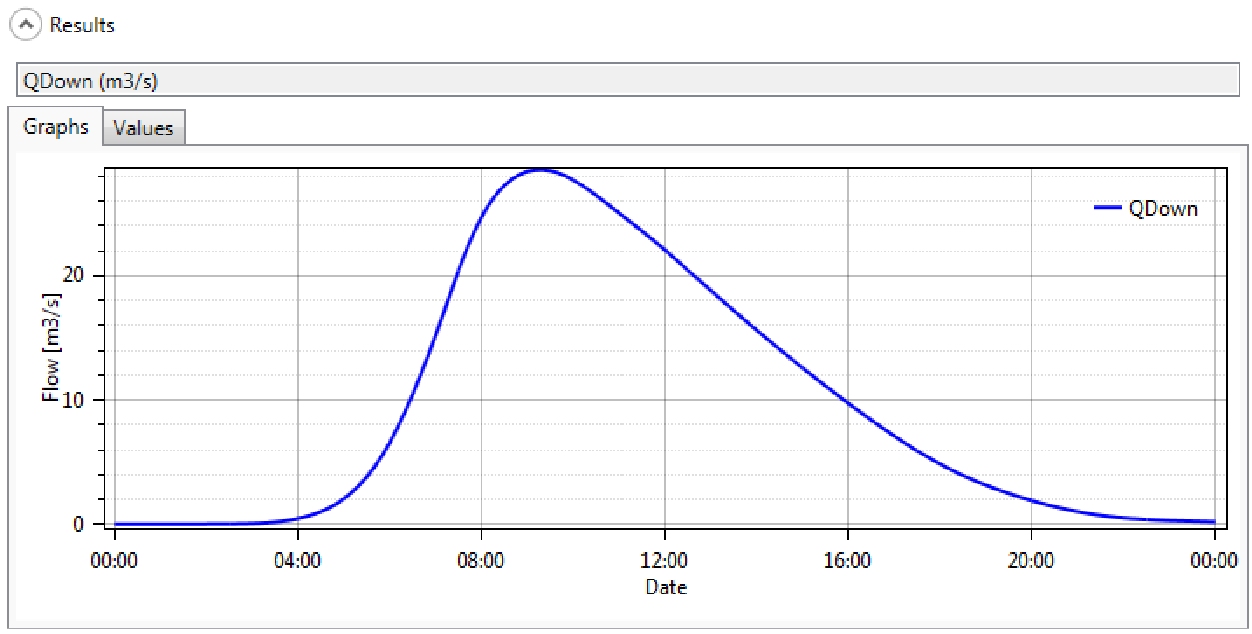
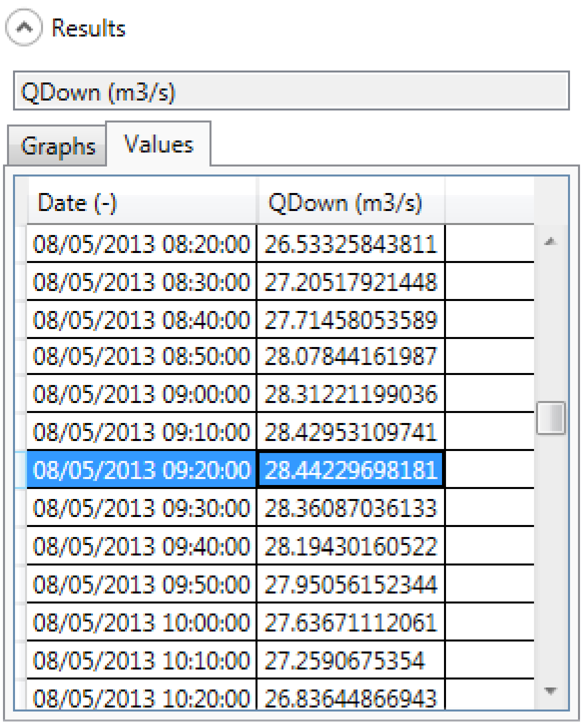


Figure 82 Results of the simulation in the outlet of the model

If we check the values (Figure 83), we can found that the maximal discharge (28.442 m^3/s) arrives at 09:20 (assuming the simulation starts at 00:00).



Date (-)	QDown (m3/s)
08/05/2013 08:20:00	26.53325843811
08/05/2013 08:30:00	27.20517921448
08/05/2013 08:40:00	27.71458053589
08/05/2013 08:50:00	28.07844161987
08/05/2013 09:00:00	28.31221199036
08/05/2013 09:10:00	28.42953109741
08/05/2013 09:20:00	28.44229698181
08/05/2013 09:30:00	28.36087036133
08/05/2013 09:40:00	28.19430160522
08/05/2013 09:50:00	27.95056152344
08/05/2013 10:00:00	27.63671112061
08/05/2013 10:10:00	27.2590675354
08/05/2013 10:20:00	26.83644866943

Figure 83 Discharge values at outlet

9.2. Example 2 – Combined full basin with meteorological stations

The hydrological system proposed by the Example 2 includes four hydrological models of production, a GSM and three HBV models as well as the rivers of the basin. The discharge production in the sub-basins area is based on given precipitations and temperatures from a database.

This expected model is represented in Figure 84.

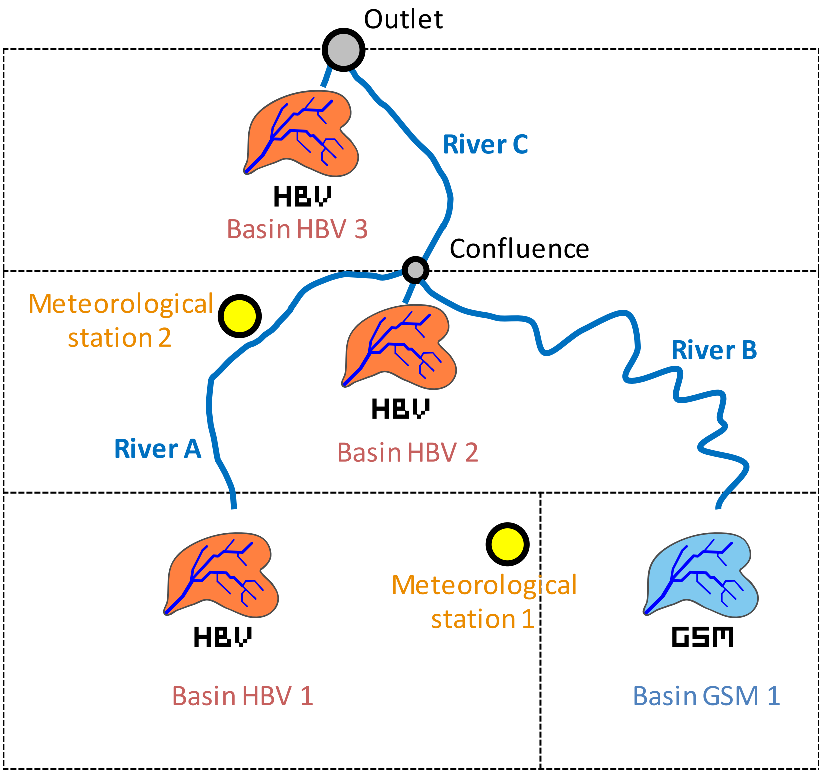


Figure 84 Model scheme

The parameters of the objects are provided in Table 6 and the precipitation and temperature data are in the database « Database manual».

Objective of Example 2

The objective of this example is to determine the hydrograph in the outlet of the system during the period between the 08.05.2013 00:00 and the 15.05.2013 00:00, the peak discharge and the peak time, as well as the discharge created at the outlet of each sub-basin.

The simulation parameters are:

- Simulation time step = 600 s;
- Recording time step = 600 s.

A uniform and null ETP is assumed for this example (the user can check the selected ETP method in the RS MINERVE settings).

Table 6 Characteristics of the objects

Virtual Weather Station G1 (for GSM 1)

Parameters and initial conditions	Values	Units
X	606482	m
Y	101777	m
Z	3035	m
Search Radius	10000	m
No. min. of stations	1	-
Gradient P	0	1/m
Gradient T	-0.0065	C/m
Gradient ETP	0	1/m
Coeff P	1	-
Coeff T	0	-
Coeff ETP	1	-

Virtual Weather Station H1 (for HBV 1)

Parameters and initial conditions	Values	Units
X	603679	m
Y	102025	m
Z	2889	m
Search Radius	10000	m
No. min. of stations	1	-
Gradient P	0	1/m
Gradient T	-0.0065	C/m
Gradient ETP	0	1/m
Coeff P	1	-
Coeff T	0	-
Coeff ETP	1	-

GSM 1

Parameters and initial conditions	Values	Units
A	4.00E+06	m2
An	6	mm/°C/day
ThetaCri	0.1	-
bp	0.0125	s/m
Tcp1	0	°C
Tcp2	6	°C
Tcf	0	°C
Agl	7	mm/°C/day
Tcg	0	°C
Kgl	1.4	1/d
Ksn	1.7	1/d
SWEIni	0.2	m
ThetaIni	0	-
QsnowIni	0.1	m3/s
QglacierIni	0	m3/s

HBV 1

Parameters and initial conditions	Values	Units
A	1.00E+07	m2
CFMax	6	mm/°C/day
CFR	1	-
CWH	0.1	-
TT	2	°C
TTInt	2	°C
TTSM	0	°C
Beta	2.5	-
FC	0.25	m
PWP	0.325	m
SUMax	0.05	m
Kr	0.25	1/day
Ku	0.15	1/day
Kl	0.05	1/day
Kperc	0.15	1/day
SWEIni	0.02	m
WHIni	0	-
HumIni	0.23	m
SUIni	0.05	m
SLIni	0.15	m

Table 7 Characteristics of the objects

Virtual Weather Station H2 (for HBV 2)

Parameters and initial conditions	Values	Units
X	604908	m
Y	103668	m
Z	2406	m
Search Radius	10000	m
No. min. of stations	1	-
Gradient P	0	1/m
Gradient T	-0.0065	C/m
Gradient ETP	0	1/m
Coeff P	1	-
Coeff T	0	-
Coeff ETP	1	-

Virtual Weather Station H3 (for HBV 3)

Parameters and initial conditions	Values	Units
X	604837	m
Y	105120	m
Z	1947	m
Search Radius	10000	m
No. min. of stations	1	-
Gradient P	0	1/m
Gradient T	-0.0065	C/m
Gradient ETP	0	1/m
Coeff P	1	-
Coeff T	0	-
Coeff ETP	1	-

HBV 2

Parameters and initial conditions	Values	Units
A	8.00E+06	m2
CFMax	7	mm/°C/day
CFR	1	-
CWH	0.1	-
TT	2	°C
TTInt	2	°C
TTSM	0	°C
Beta	2.3	-
FC	0.275	m
PWP	0.36	m
SUMax	0.055	m
Kr	0.3	1/day
Ku	0.1	1/day
Kl	0.05	1/day
Kperc	0.15	1/day
SWEIni	0.01	m
WHIni	0	-
HumIni	0.2	m
SUIni	0.01	m
SLIni	0.1	m

HBV 3

Parameters and initial conditions	Values	Units
A	9.00E+06	m2
CFMax	7	mm/°C/day
CFR	1	-
CWH	0.1	-
TT	2	°C
TTInt	2	°C
TTSM	0	°C
Beta	2.3	-
FC	0.28	m
PWP	0.37	m
SUMax	0.06	m
Kr	0.35	1/day
Ku	0.1	1/day
Kl	0.05	1/day
Kperc	0.15	1/day
SWEIni	0	m
WHIni	0	-
HumIni	0.22	m
SUIni	0.02	m
SLIni	0.1	m

Table 8 Characteristics of the objects

River A

Parameters and initial conditions	Values	Units
Lenght (L)	3000	m
bed width (BO)	6	m
Side bank rel. (m)	1	-
Slope (JO)	0.001	-
Strickler (K)	30	$m^{1/3}/s$
Sections (N)	1	-
Initial discharge (Qini)	0	m^3/s

River B

Parameters and initial conditions	Values	Units
Lenght (L)	4000	m
bed width (BO)	4	m
Side bank rel. (m)	1	-
Slope (JO)	0.005	-
Strickler (K)	30	$m^{1/3}/s$
Sections (N)	1	-
Initial discharge (Qini)	0	m^3/s

River C

Parameters and initial conditions	Values	Units
Lenght (L)	2000	m
bed width (BO)	7	m
Side bank rel. (m)	1	-
Slope (JO)	0.001	-
Strickler (K)	30	$m^{1/3}/s$
Sections (N)	1	-
Initial discharge (Qini)	0	m^3/s

Besides, two meteorological real stations are included in the data base

Table 9 Characteristics of the meteorological real stations

Meteorological Station 1 (Database)

Parameters and initial conditions	Values	Units
X	605709	m
Y	102143	m
Z	2756	m

Meteorological Station 2 (Database)

Parameters and initial conditions	Values	Units
X	604002	m
Y	103517	m
Z	2387	m

Resolution of Example 2

First of all, the subcatchment with HBV and GSM models will be set up. Then, the three rivers (with Kinematic Wave) and the two junctions are also added as presented in Figure 84 (more details are given in Example 1 for model construction, including the link between each object and their parameterization).

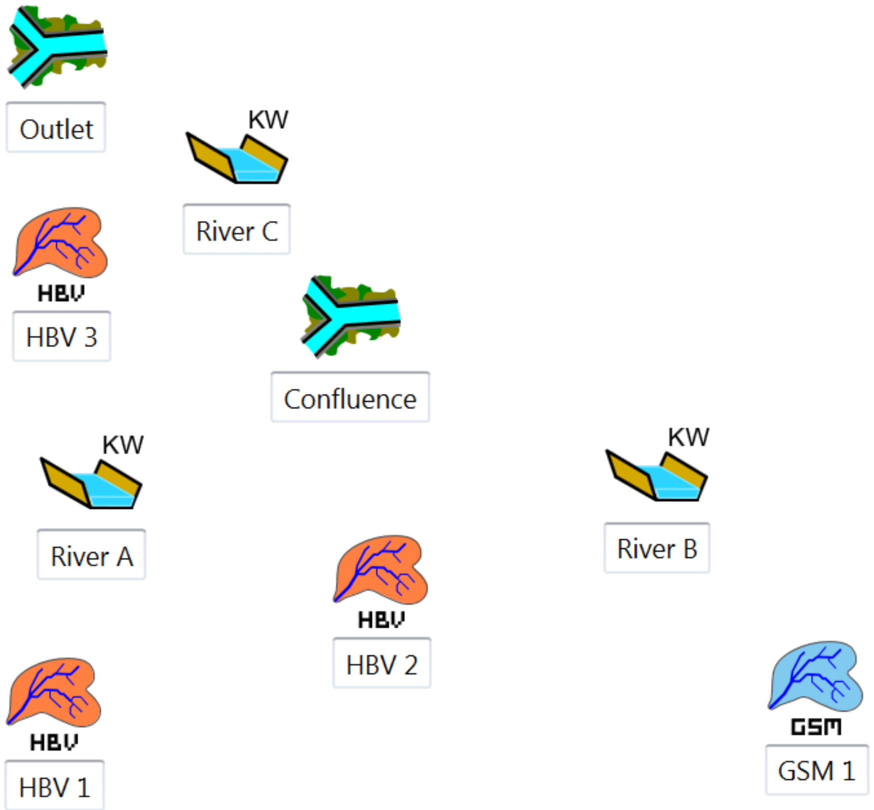


Figure 85 Topologic links between the different objects

After that, the models are linked from upstream to downstream and the relations created can be visualized by double clicking on each blue arrow (Figure 86, Figure 87, Figure 88).

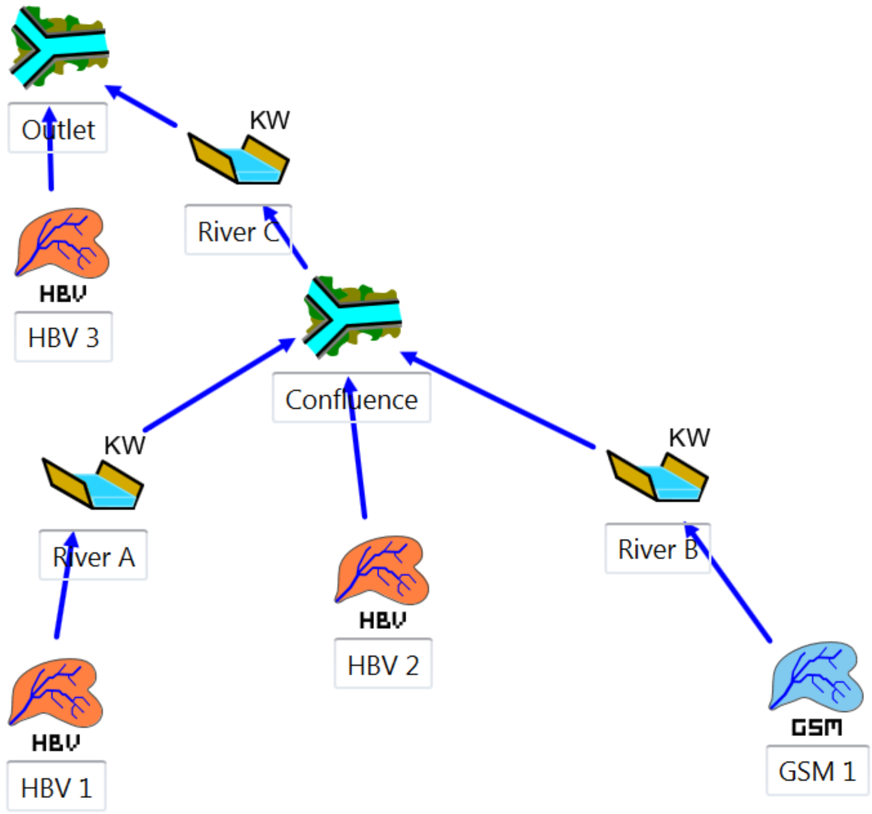


Figure 86 Relations between the objects

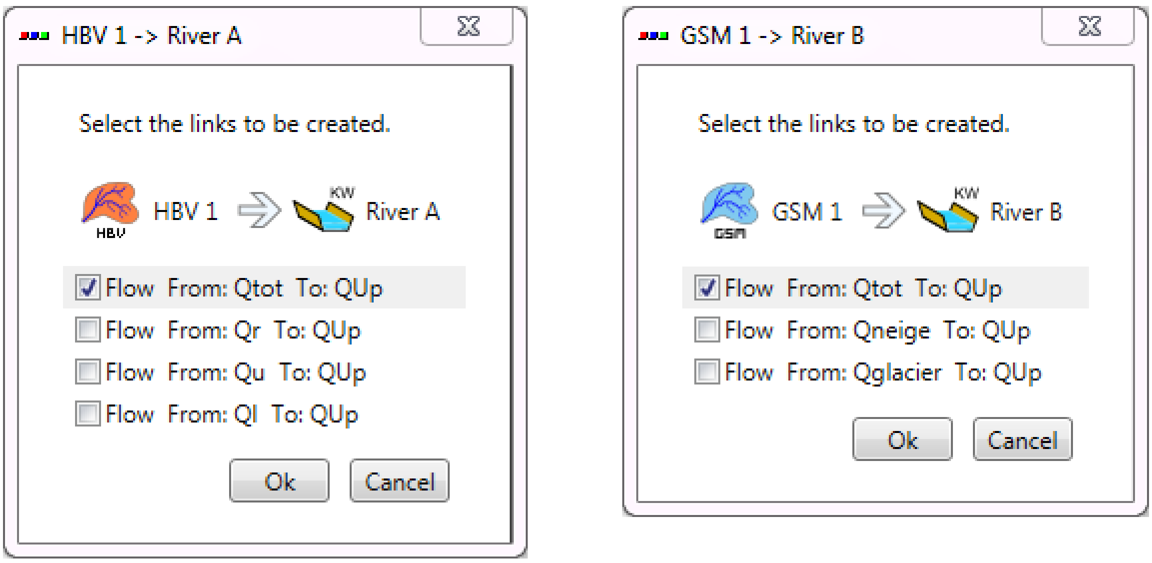


Figure 87 Possible outputs transfers between objects

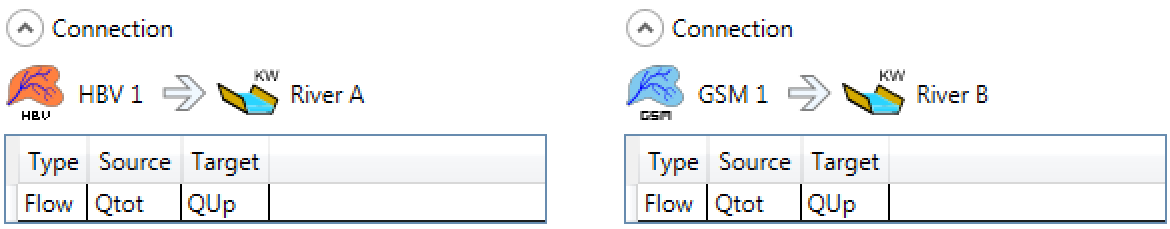


Figure 88 Connections between objects

The parameters associated to each object are then introduced (values available in previous tables). The result is presented for both HBV 1 and GSM 1 models in Figure 89.

Parameters

Name	Value	Unit
A	10000000	m2
CFMax	6	mm/°C/day
CFR	1	-
CWH	0.1	-
TT	2	°C
TTInt	2	°C
TTSM	0	°C
Beta	2.5	-
FC	250	mm
PWP	325	mm
SUMax	50	mm
Kr	0.25	1/d
Ku	0.15	1/d
Kl	0.05	1/d
Kperc	0.15	1/d

Initial conditions

Name	Value	Unit
HsnowIni	0.02	m
WHIni	0	-
HumIni	0.23	m
SUIni	0.05	m
SLIni	0.15	m

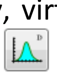
Parameters

Name	Value	Unit
A	4000000	m2
An	6	mm/°C/day
ThetaCri	0.1	-
bp	0.0125	s/m
Tcp1	0	°C
Tcp2	6	°C
Tcf	0	°C
Agl	7	mm/°C/day
Tcg	0	°C
Kgl	1.4	1/d
Ksn	1.7	1/d

Initial conditions

Name	Value	Unit
HsnowIni	0.2	m
ThetaIni	0	-
QsnowIni	0.1	m3/s
QglacierIni	0	m3/s

Figure 89 Parameters of the HBV 1 model (left) and the GSM 1 model (right)

Secondly, virtual weather stations are inserted. For its accomplishment, 4 Virtual Weather Stations  are created and connected according to the Figure 90. The topology of the relations created in this case is detailed in Figure 91. Then the parameters are introduced (Figure 92) with the available values presented previously.

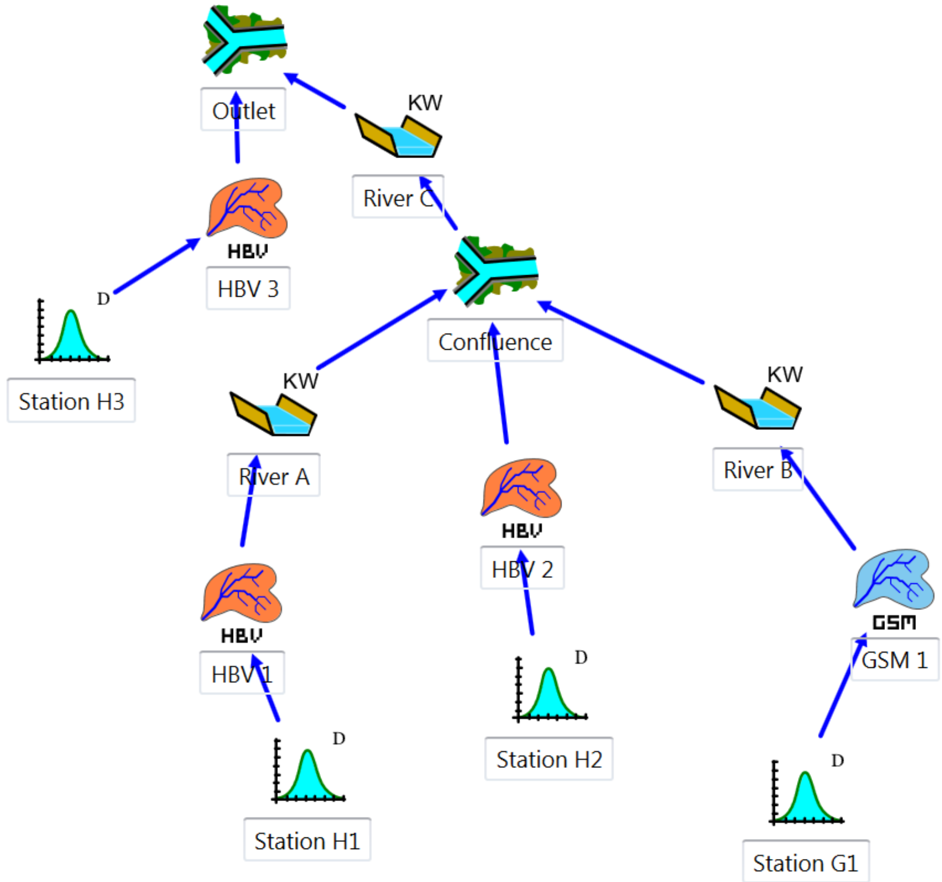
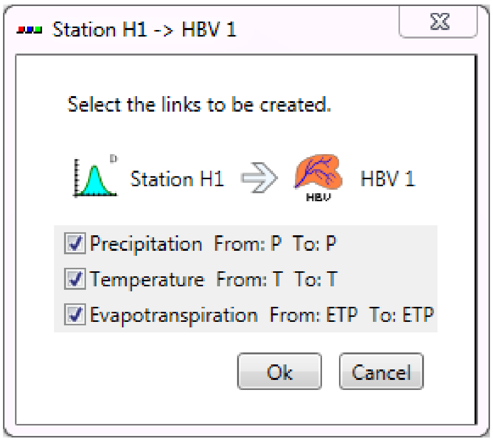
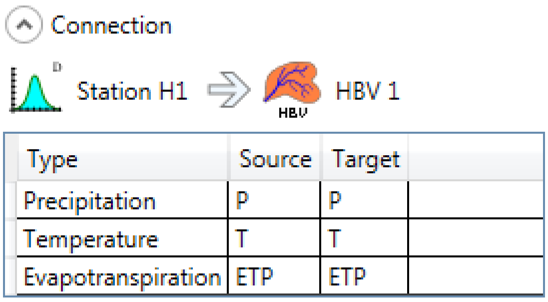
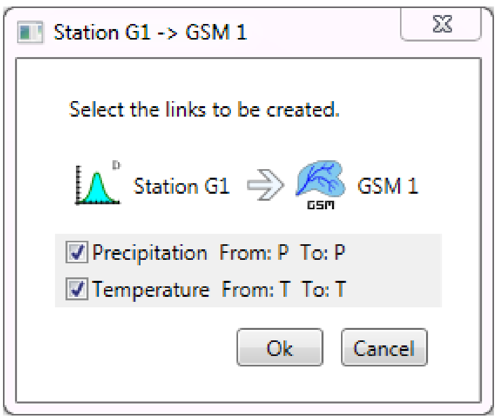


Figure 90 Topology of the full model: production, transfer then transport







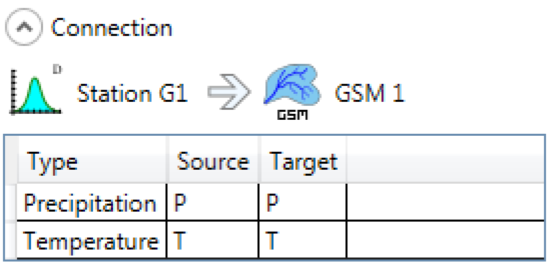


Figure 91 Topologic links between the different objects

Parameters

Name	Value	Unit
X	603679	m
Y	102025	m
Z	2889	masl
Search Radius	10000	m
No. min. of stations	1	-
Gradient P	0	m/s/m
Gradient T	-0.0065	C/m
Gradient ETP	0	m/s/m
Coeff P	1	-
Coeff T	0	-
Coeff ETP	1	-

Figure 92 Parameters of the Virtual Weather Station H1 (for HBV 1)

Constructed model can be now saved clicking in the button and giving a name to the .rsm file (e.g. “Example2.rsm”).

Next, the meteorological data have to be loaded: the dialog box of the database is opened clicking in (Figure 93) for loading the corresponding database file (“Database manual.dbx”).

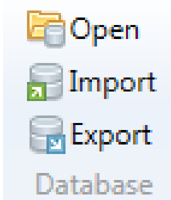


Figure 93 Database frame

The user can click on the Database tab to visualize or modify the series of the database (Figure 94).

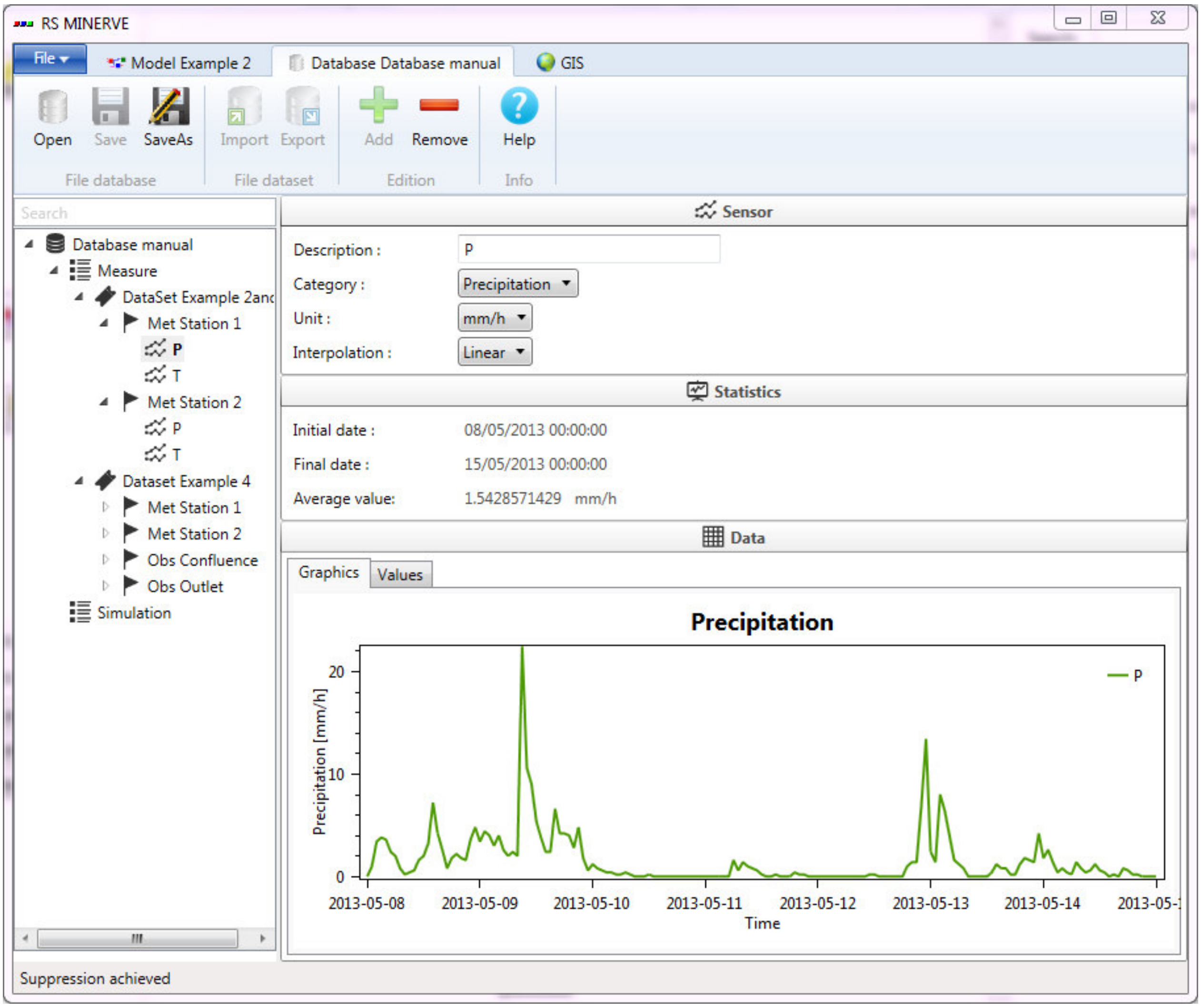


Figure 94 Database of the model

Once the database loaded, the user can connect the database to the hydrological model. For achieving this purpose, the user has to choose the correct data source in the corresponding frame (Figure 95): the group “Measure” and the dataset “DataSet Example 2and3” for the current example. Since no source, *TurbineDB*, reservoir or consumer objects exist in the model, it is not necessary to fill up their data sources.

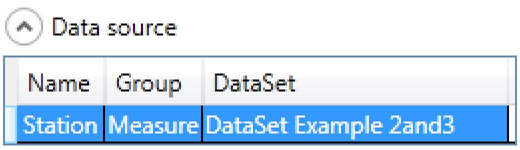


Figure 95 Data source used for connecting the model to the database

Finally, and after achieve a simulation, the weight of each meteorological real station can be checked by clicking at one Virtual Weather station of the hydrological model (Figure 96).

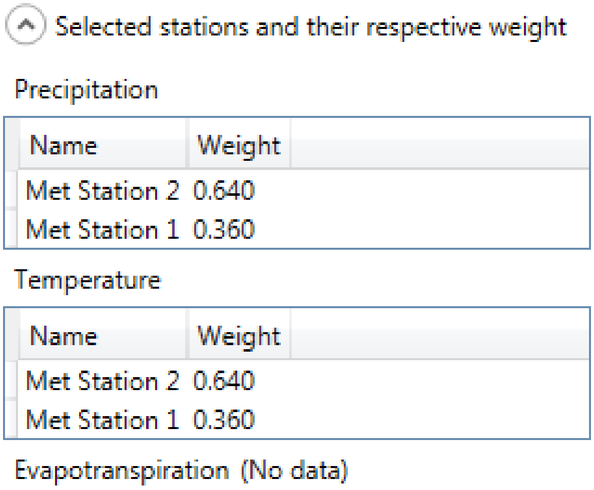


Figure 96 Weight of each meteorological station for the Virtual Weather Station H1

The pre-simulation validation (

) allows to valid the model. If the message: "Model 'Example 2' is valid" appears, the simulation can be started by clicking in the button Start.

Results of Example 2

Once finished the calculation, the hydrograph in the outlet of the system, among others, can be visualized (Figure 97).

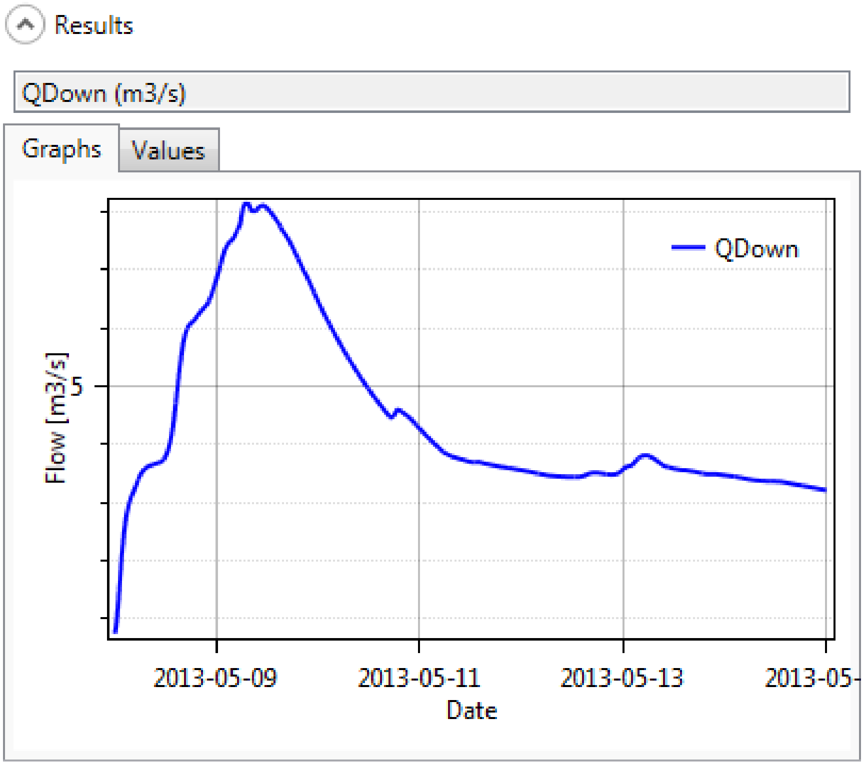
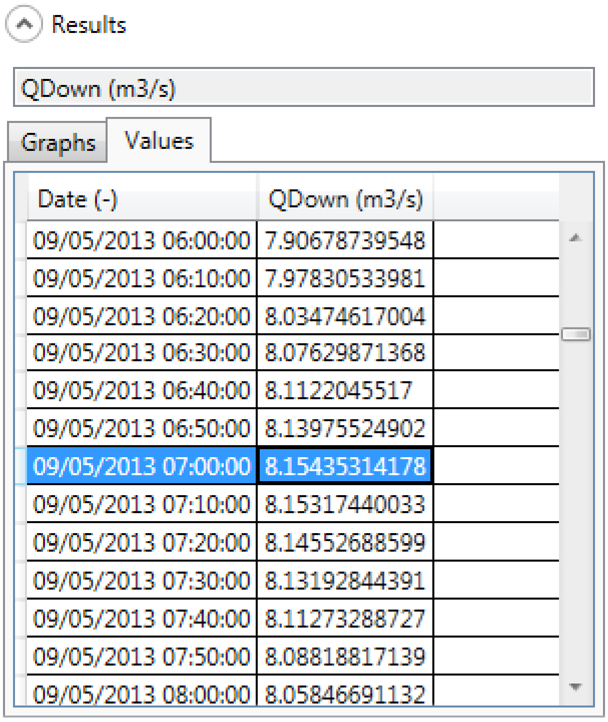


Figure 97 Hydrograph in the outlet of the system

If we check the values (Figure 98), we can found that the maximal discharge arrives on May the 9th, 2013 at 07:00 and the discharge value is 8.154 m³/s.



Date (-)	QDown (m3/s)
09/05/2013 06:00:00	7.90678739548
09/05/2013 06:10:00	7.97830533981
09/05/2013 06:20:00	8.03474617004
09/05/2013 06:30:00	8.07629871368
09/05/2013 06:40:00	8.1122045517
09/05/2013 06:50:00	8.13975524902
09/05/2013 07:00:00	8.15435314178
09/05/2013 07:10:00	8.15317440033
09/05/2013 07:20:00	8.14552688599
09/05/2013 07:30:00	8.13192844391
09/05/2013 07:40:00	8.11273288727
09/05/2013 07:50:00	8.08818817139
09/05/2013 08:00:00	8.05846691132

Figure 98 Discharge values at outlet

All the simulated variables of the model (including the discharge in each sub-basin outlet) can be visualized (Figure 99 and Figure 100) clicking on the "Selection and plots" frame and in selecting the series to draw as presented in chapter 4.2. Finally you can export the selection results in excel format clicking in "Export results to…" in the series frame.

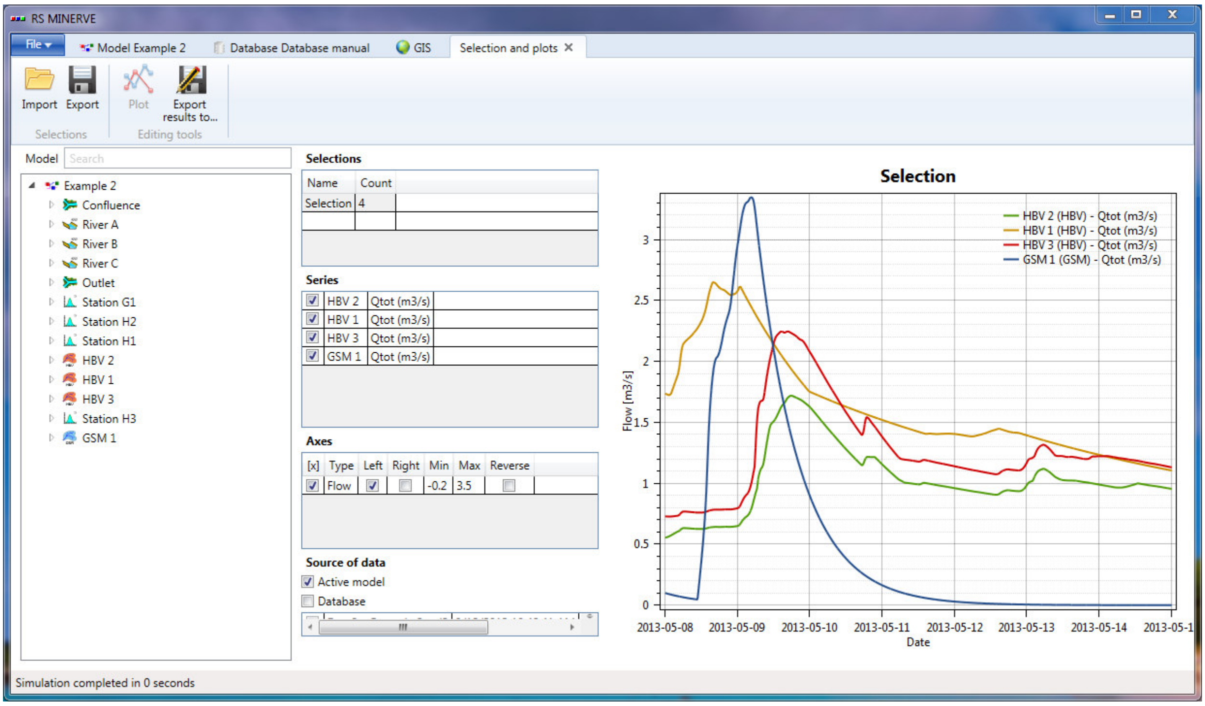


Figure 99 *Selection and Plots* with the hydrographs at the outlet for each sub-basin of the system

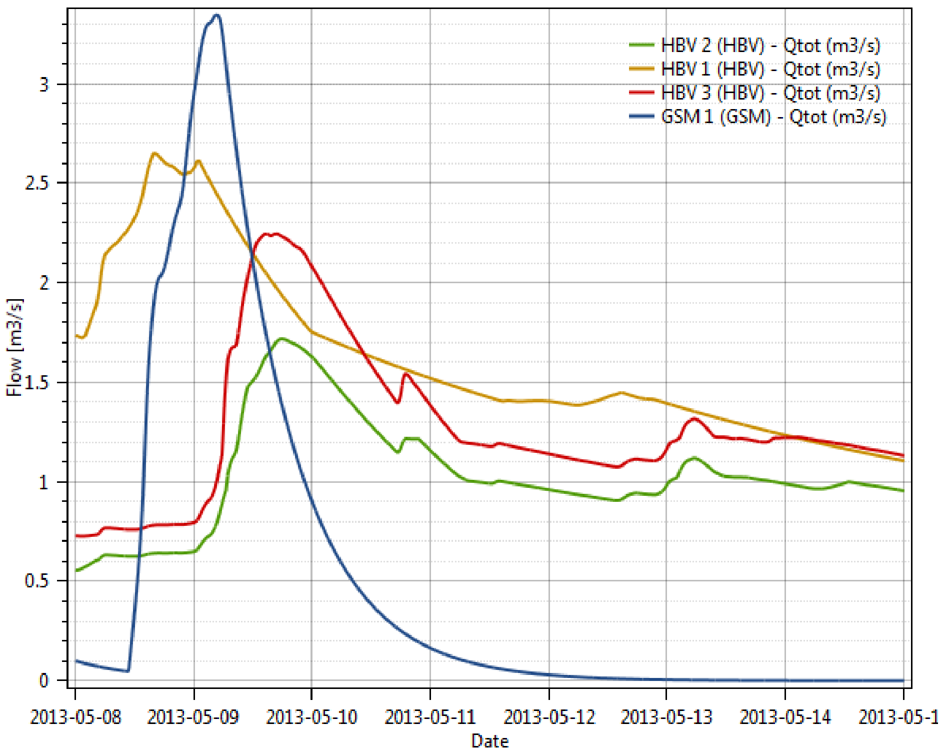


Figure 100 Hydrographs at the outlet for each sub-basin of the system

9.3. Example 3 – Equipped basin with a hydropower scheme

This example, allows showing the potential of RS MINERVE for equipped basins. The model starts with the previous model built in Example 2 and adds a hydropower scheme as well as a supplementary basin with an intake. The complete model is presented in Figure 101.

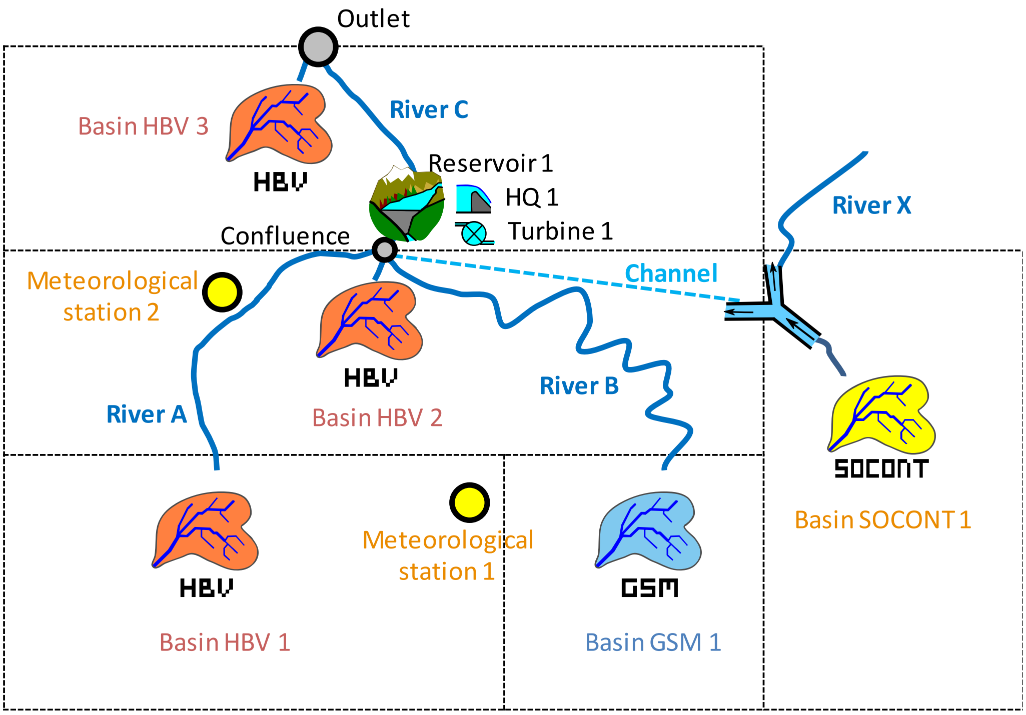


Figure 101 Model scheme

HBV 1, HBV 2 and GSM 1 basins flow through the Reservoir 1. Intake located downstream of a SOCONT model provides supplementary discharge up to 2 m^3/s. It is assumed that the propagation in the channel is insignificant and thus it is not necessary to include it in the model (in other case, we could built it with the Reach Kinematic object).

The reservoir includes a turbine and a spillway. The turbine generates electricity as long as it is possible for a capacity of 1 m^3/s. These two reservoir outflows flow in the River C up the outlet, where they are joined by the production of HBV 3 sub-basin. All the parameters of the different objects are provided in Table 10. The temperature and precipitation data are in the database « Database manual ». A uniform and null ETP is assumed for this example (the user can check the selected ETP method in the RS MINERVE settings).

Objective of Example 3

Part A

The wanted result for this example is the inflow in the reservoir, the spillway discharge and the hydrograph in the outlet of the model for the period between the 08.05.2013 00:00 and the 15.05.2013 00:00 (as well as the peak discharge and the peak time).

Part B

Second issue aims to know if the reservoir could be managed in order to reduce the peak in the outlet of the system. The objective of this extension is to implement a facility to release water for preventive purposes.

Table 10 Characteristics of the objects

Virtual Weather Station S1 (for SOCONT 1)

Parameters and initial conditions	Values	Units
X	608017	m
Y	102861	m
Z	2796	m
Search Radius	10000	m
No. min. of stations	1	-
Gradient P	0	1/m
Gradient T	-0.0065	C/m
Gradient ETP	0	1/m
Coeff P	1	-
Coeff T	0	-
Coeff ETP	1	-

SOCONT 1

Parameters and initial conditions	Values	Units
A	8000000	m2
An	7	mm/°C/day
ThetaCri	0.1	-
Bp	0.0125	s/m
Tcp1	0	°C
Tcp2	4	°C
Tcf	0	°C
HGR3Max	0.3	m
KGR3	0.005	1/s
L	800	m
J0	0.01	-
Kr	2	$m^{1/3}/s$
SWEIni	0.1	m
ThetaIni	0	-
HGR3Ini	0.1	m
HrIni	0	m

Table 11 Characteristics of the objects

Reservoir 1

H (m a.s.l.)	Vol (m^3)
2110	0
2115	7.92E+05
2120	2.09E+06
2125	3.96E+06
2130	6.48E+06
2135	9.90E+06

Parameters	Values	Units
Hini	2127.3	masl

Spillway 1 (with HQ)

H (m a.s.l.)	Q (m^3)
2128	0
2129	10
2130	30
2132	100
2135	250

Turbine 1

Time (s)	Q (m^3/s)
0	1
3.00E+06	1

Diversion 1

Qup (m3/s)	Qdiverted (m3/s)
0	0
2	2
10	2

Additionally, initial discharge (Qini) of River C is in this case 1 m^3/s.

Resolution of Example 3 – Part A

In the first place, the model of the Example 2 is opened. The connection between the "Confluence" and the River C is erased and objects Virtual Weather Station , SOCONT , Reservoir , Spillway , Turbine and Junction are added, as presented in Figure 102.

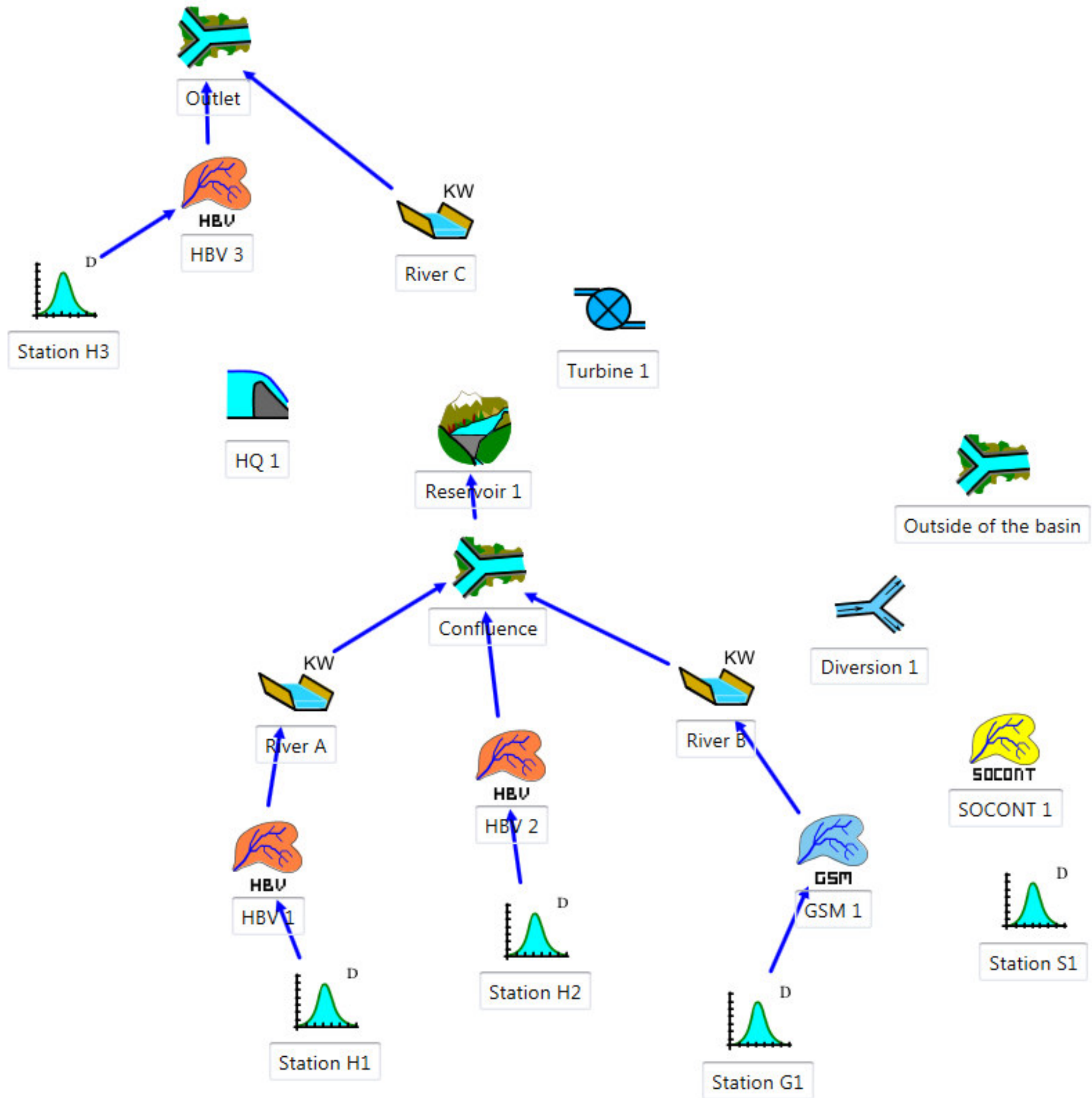


Figure 102 Construction of the Example 3 model on the basis of Example 2

New objects are always linked from upstream to downstream (e.g.: SOCONT 1 to Diversion 1, Diversion 1 to Confluence (Qdiverted) and to Outside of the Basin (Qdown), Reservoir 1 to HQ 1, Reservoir 1 to Turbine 1, Turbine 1 to River C, etc). After creating the links (Figure 103), the news relations can be visualized by double clicking on each blue arrow (Figure 104 and Figure 105).

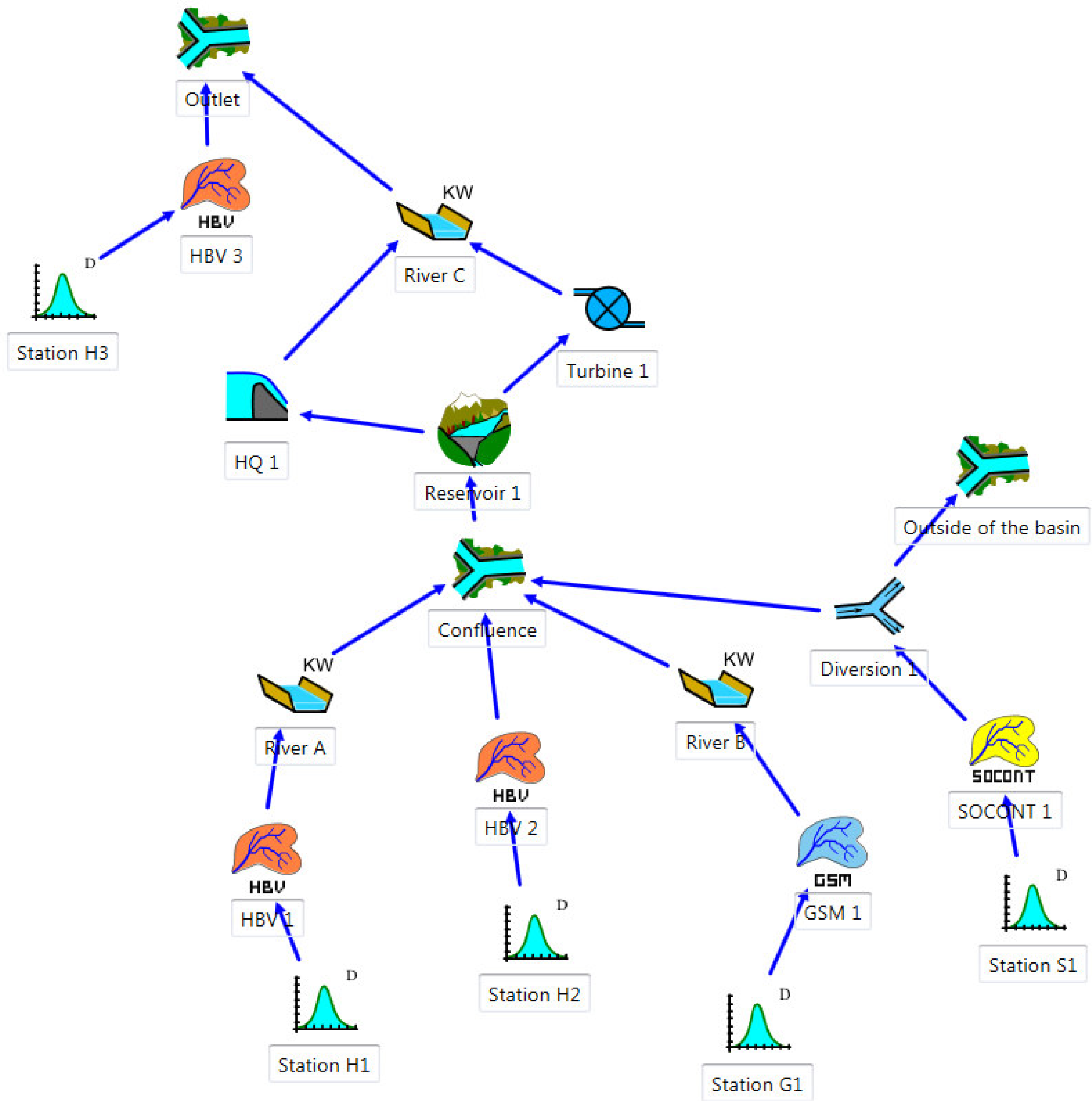


Figure 103 Typology of the new model

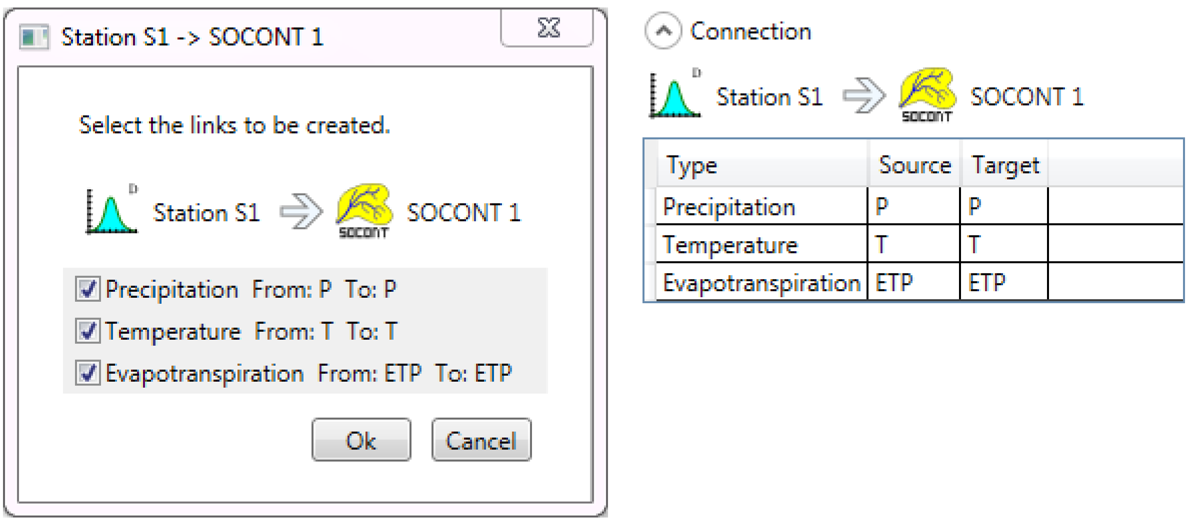


Figure 104 Relations for Virtual Weather Station S1 and SOCONT 1 objects

Reservoir relations

Connection

Reservoir 1 ⇨ HQ 1

Type	Source	Target
Altitude	H	H

Connection

HQ 1 ⇨ River C

Type	Source	Target
Flow	Q	QUp

HQ 1 ⇨ Reservoir 1

Type	Source	Target
Flow	Q	QOut

Turbine relations

Connection

Reservoir 1 ⇨ Turbine 1

Type	Source	Target
Altitude	H	H

Connection

Turbine 1 ⇨ River C

Type	Source	Target
Flow	Qturbine	QUp

Turbine 1 ⇨ Reservoir 1

Type	Source	Target
Flow	Qturbine	QOut

Intake relations

Connection

SOCONT 1 ⇨ Diversion 1

Type	Source	Target
Flow	Qtot	QUp

Connection

Diversion 1 ⇨ Outside of the basin

Type	Source	Target
Flow	QDown	QUp

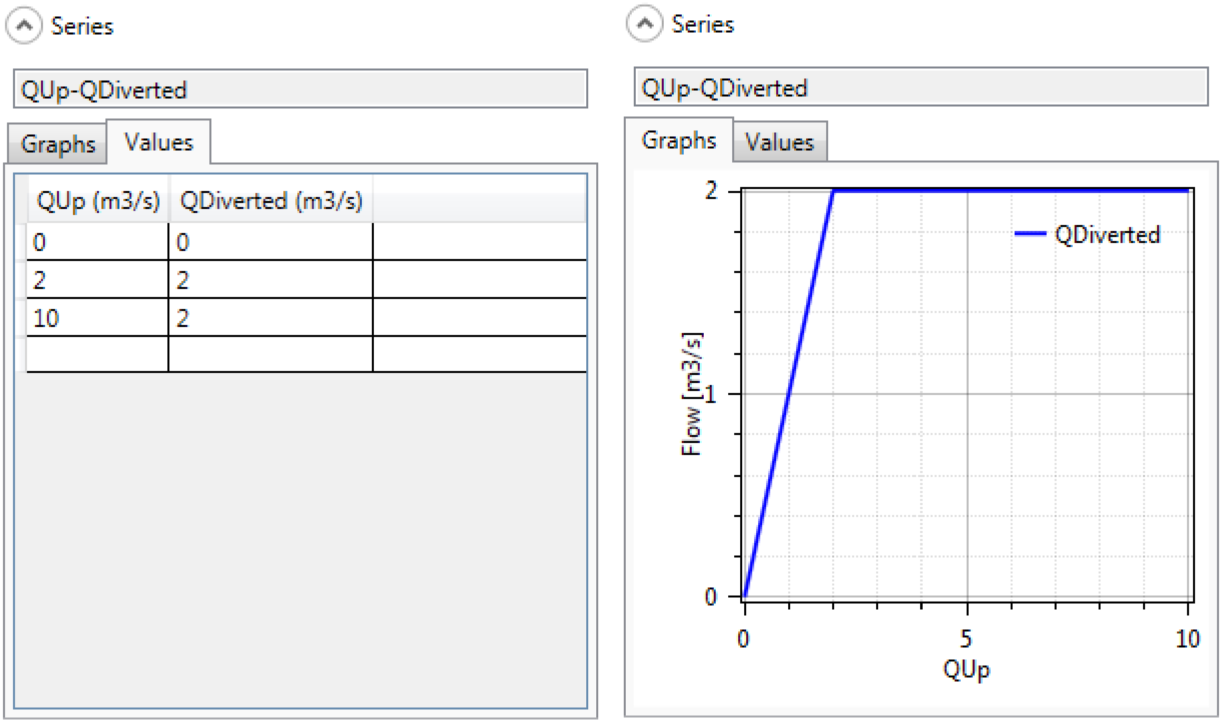
Connection

Diversion 1 ⇨ Confluence

Type	Source	Target
Flow	QDiverted	QUp

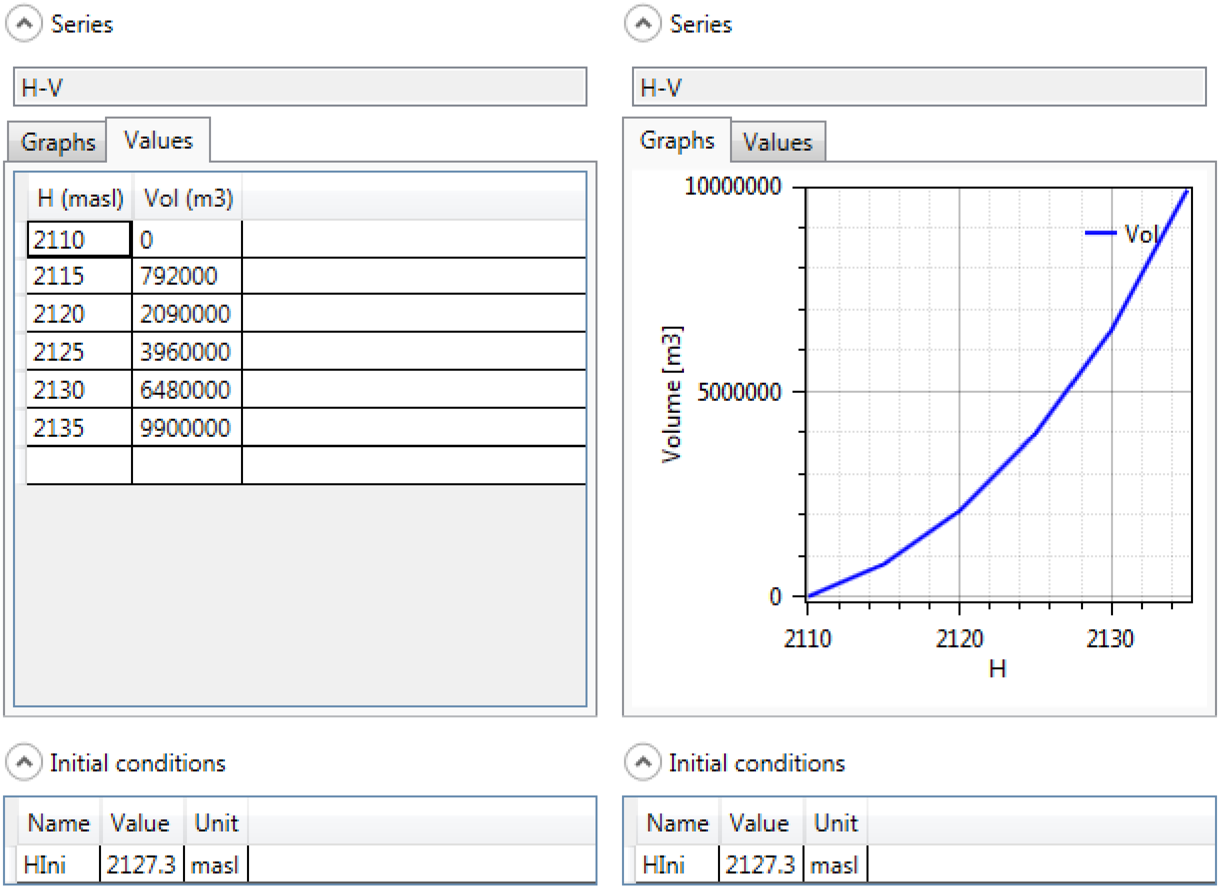
Figure 105 Connections between objects

The introduced parameters of new objects Diversion 1, Reservoir 1, HQ 1 and Turbine 1 are presented in Figure 106 to Figure 109.



QUp (m3/s)	QDiverted (m3/s)
0	0
2	2
10	2

Figure 106 Relation Qup-Qdiverted introduced in the Diversion 1



H (masl)	Vol (m3)
2110	0
2115	792000
2120	2090000
2125	3960000
2130	6480000
2135	9900000

Name	Value	Unit
HIni	2127.3	masl

Name	Value	Unit
HIni	2127.3	masl

Figure 107 Relation H-V of the Reservoir 1

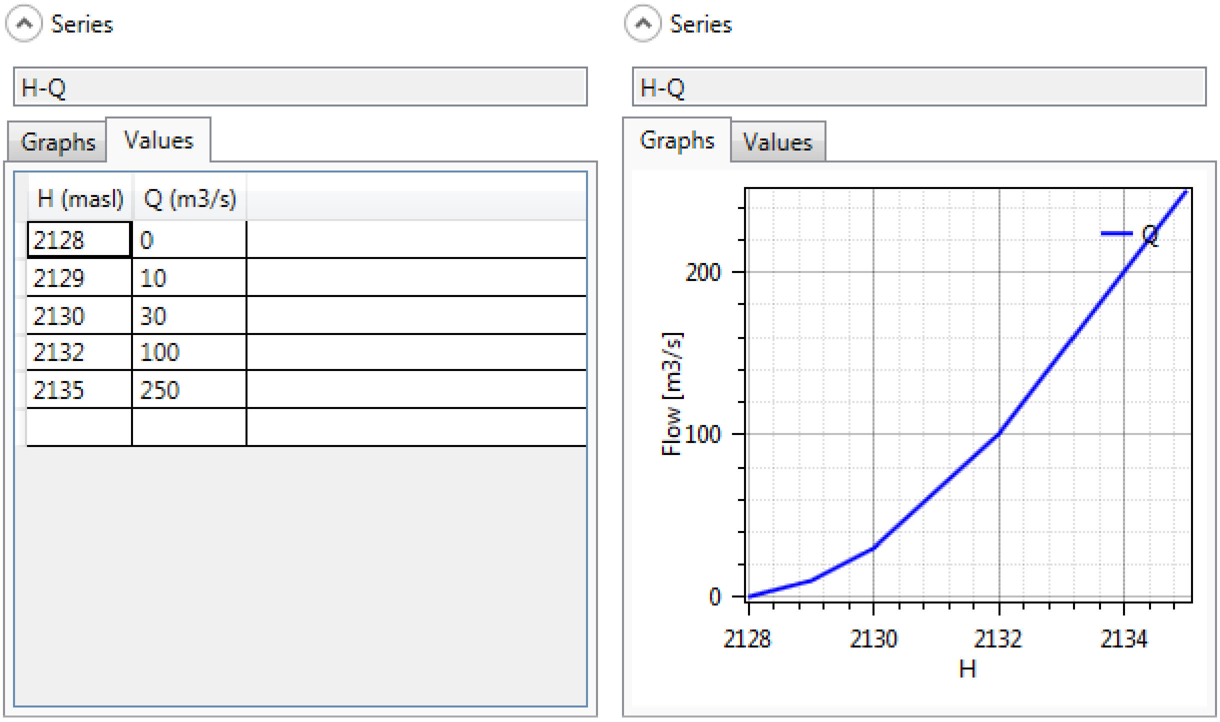


Figure 108 Relation H-Q of the HQ 1

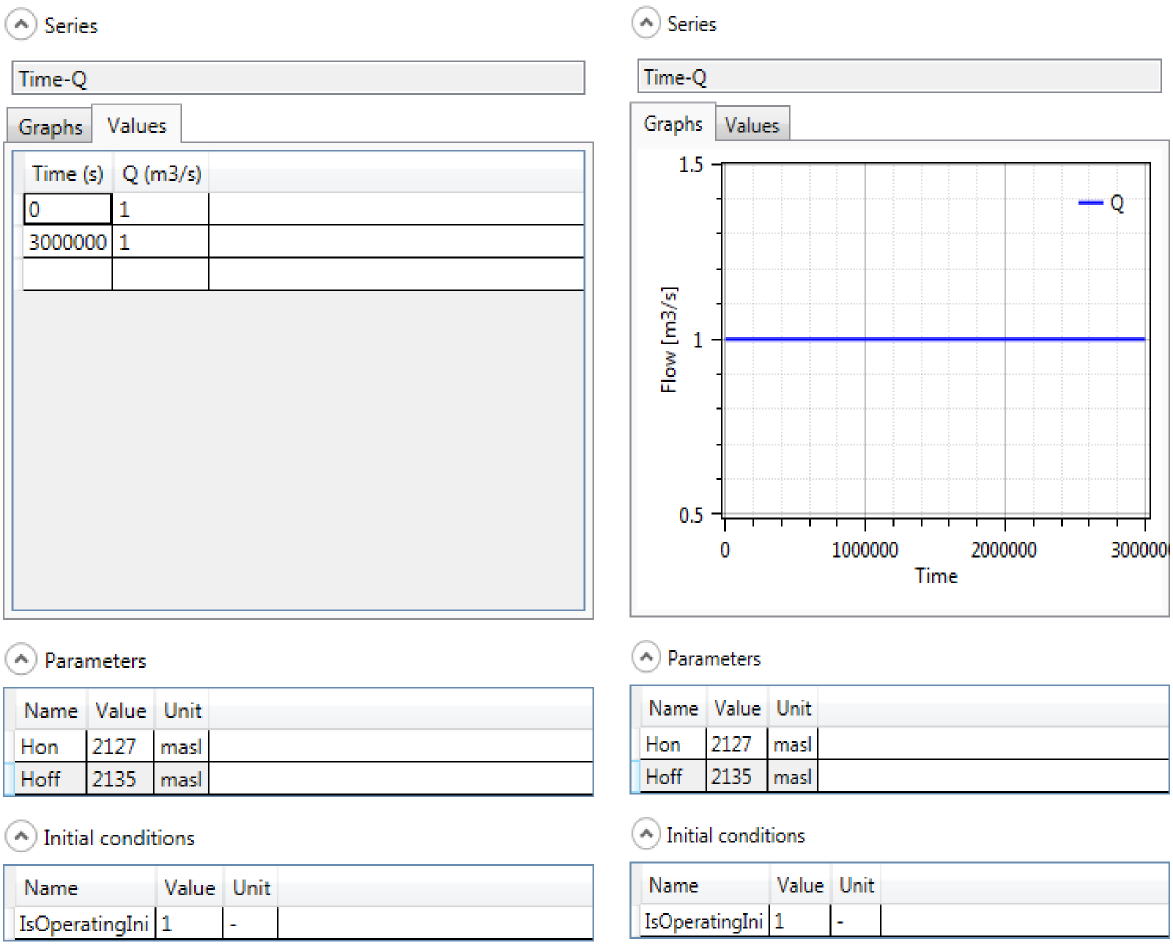


Figure 109 Discharge of the Turbine 1

As shown in Figure 109, the thresholds in the level of the reservoir to start (2127 masl) and to stop (2110 masl) the turbine cycle, as well as the first suggested value for the turbine cycle (1 = turbine) have to be introduced.

Once the construction finished, it can be saved clicking in the button and giving a name to the .rsm file (e.g. “Example3.rsm”).

Before starting the calculation, the meteorological data have to be loaded: the dialog box of the database is opened clicking in Open for loading the corresponding database file (“Database manual”). The user can click on the Database tab to visualize or modify the series of the database (Figure 94).

Once the database loaded, the user can connect the database to the hydrological model. For achieving this purpose, the user has to choose the correct data source in the corresponding frame (Figure 110): the group “Measure” and the dataset “DataSet Example 2and3” for the current example. It is not necessary to fill up the data sources of the reservoir as it will take the default value for the simulation.

Data source

Name	Group	Dataset
Station	Measure	DataSet Example 2and3
Reservoir		

Figure 110 Data source used for connecting the model to the database

Finally, the necessary parameters of the simulation are chosen in the menu Solver frame according to the propose dates in the wording. The other values (time intervals) stay as indicate in the program, being 600 s in both cases.

If the pre-simulation validation allows to valid the model (with the message: “Model ‘Example 3’ is valid”), the simulation can be initiated clicking in the button Start.

Results of Example 3 – Part A

All the results can be visualized by double clicking in the corresponding object. Figure 111 presents the hydrograph at the system outlet.

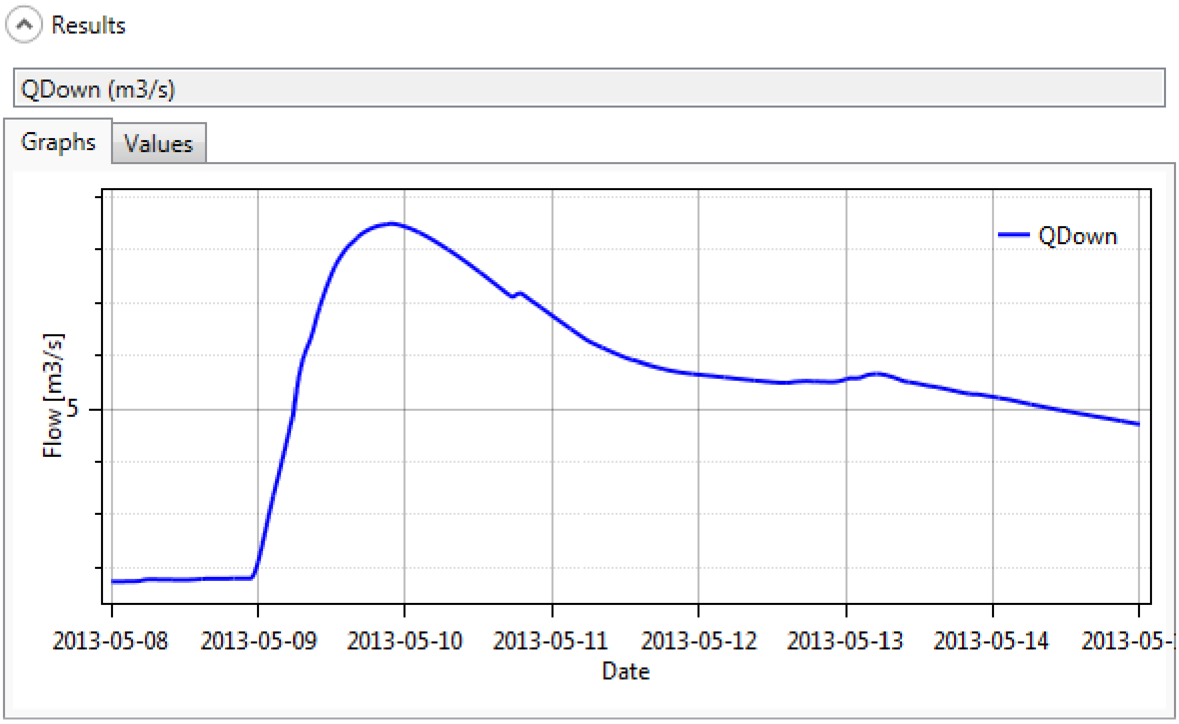


Figure 111 Outlet hydrograph

The peak discharge arrives on May the 9th, 2013 at 21:40 and the peak discharge is equal to 8.482 m^3/s.

To summarize the simulated balance of Reservoir 1, an analysis of inputs/outputs in the Reservoir 1 is realized with the “Selection and plots” module. The inflow into the Reservoir 1 (Confluence), the spillway discharge (HQ 1), the turbine flow (Turbine 1), the total flow at the downstream of the reservoir (River C, Qup) and the reservoir level evolution (Reservoir 1) are presented in Figure 112. Despite the turbine, the reservoir level reached its maximal fill rating with an overflow which lasted several days. At the end of the simulation, the reservoir level comes around 90 cm above the initial level.

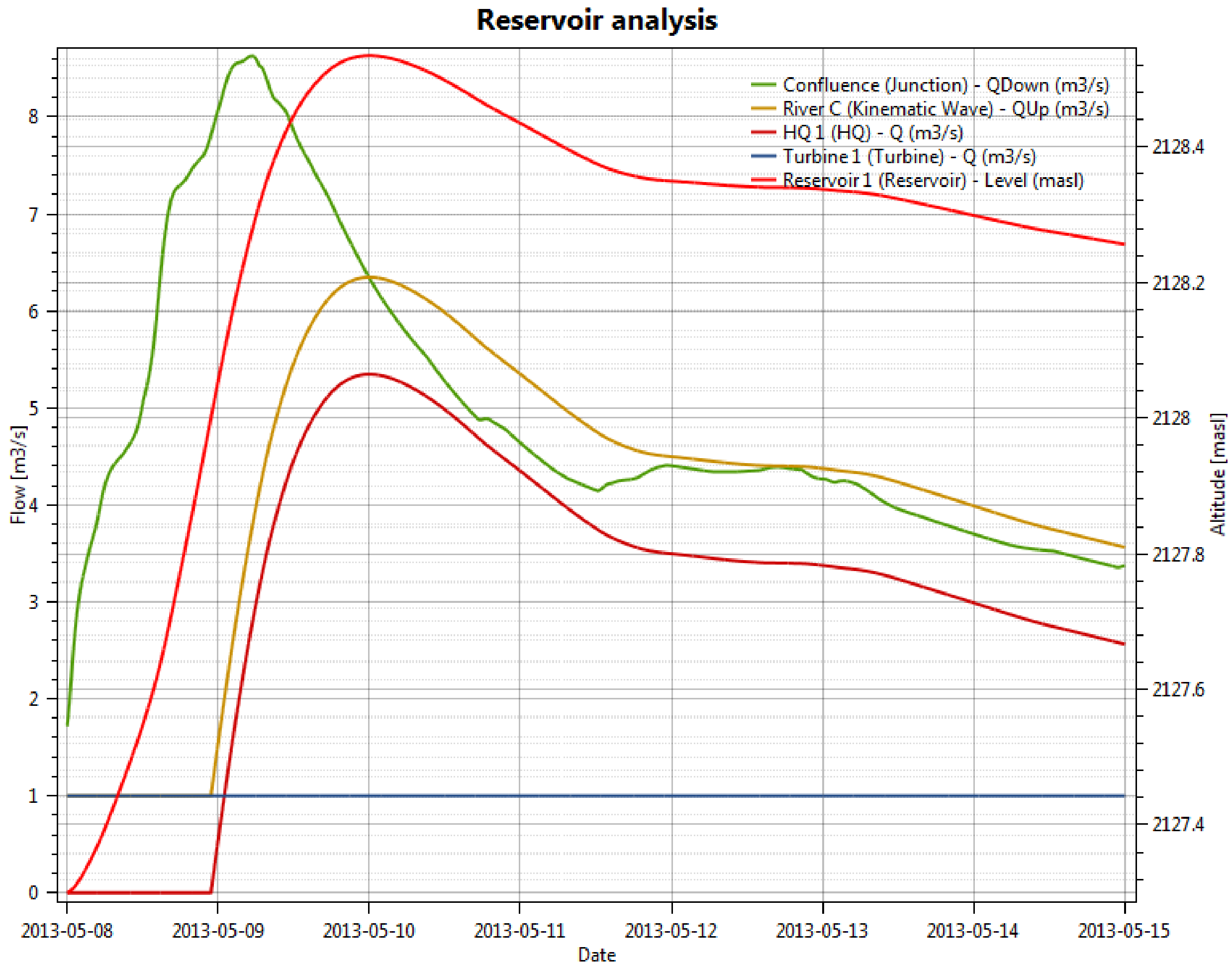


Figure 112 Flows balance of the reservoir

Resolution of Example 3 – Part B

In order to create an outlet or a facility for releases, one way is to define a turbine connected to the reservoir (Figure 113). We create a new turbine (Turbine 2) and make the connections from the reservoir to the new turbine and from the turbine to River C. Also we create a time series element connected to the new turbine where we will define the releases from the reservoirs.

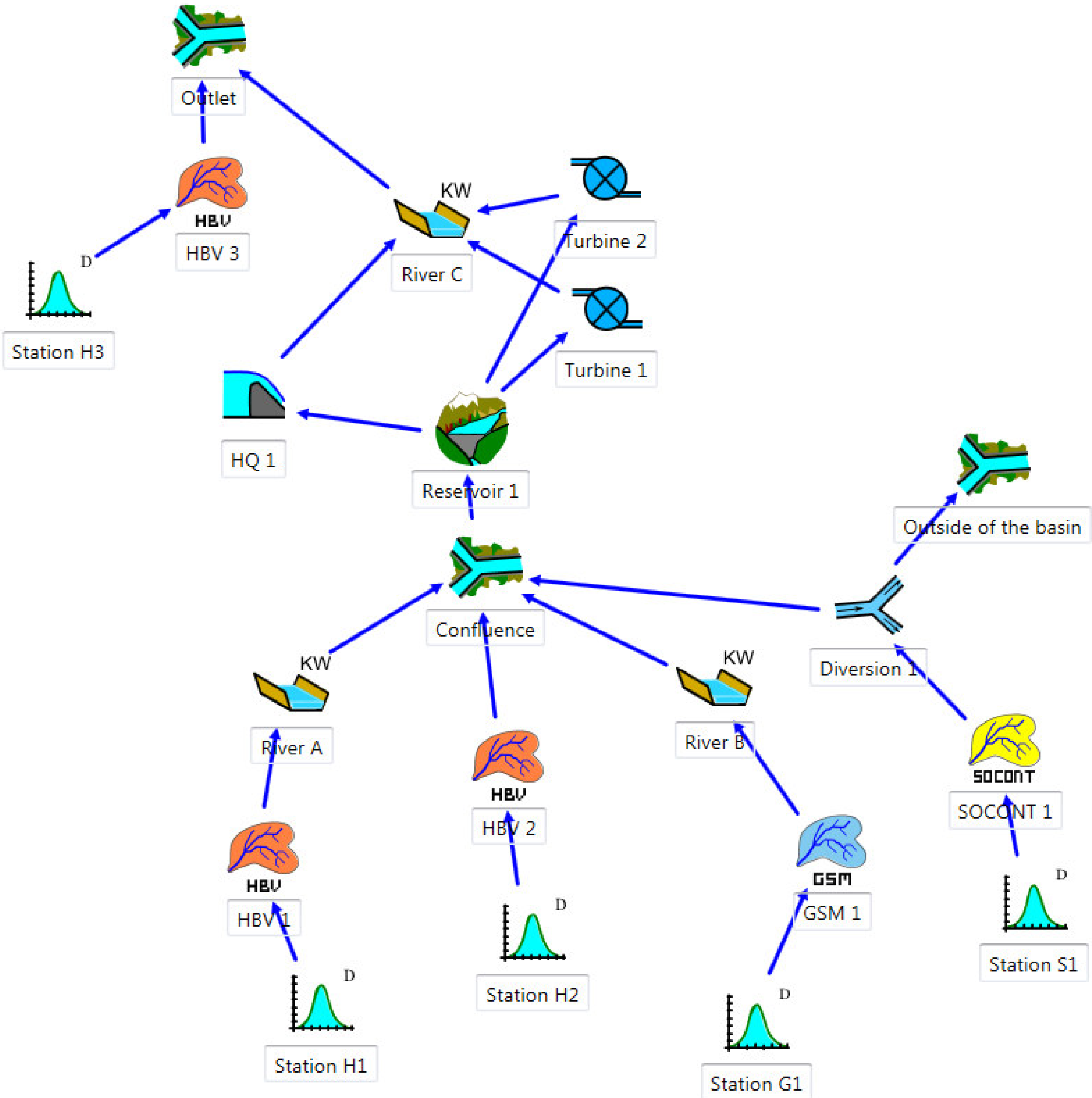


Figure 113 Typology of the model including the new release

Notice that actually the new turbine is representing a sluice of the reservoir.

Once the model has been adapted we have to define the preventive releases in the corresponding Turbine 2. Analyzing the results of the example one can think that preventive release should start near 13h00 of first day and finish eleven hours later.

As in the time series we have to define time in seconds (0 seconds corresponds to the start time of the simulation), the start is at 46800 s and the end at 86400 s. Moreover, it is considered that the release must take place only when the level in the reservoir exceeds 2128 masl, and stops when it is under 2125 masl.

The value of the releases depends on the capacity of the sluice and the decision of the manager. In this case, a discharge of 5 m^3/s is defined, as presented in Figure 114.

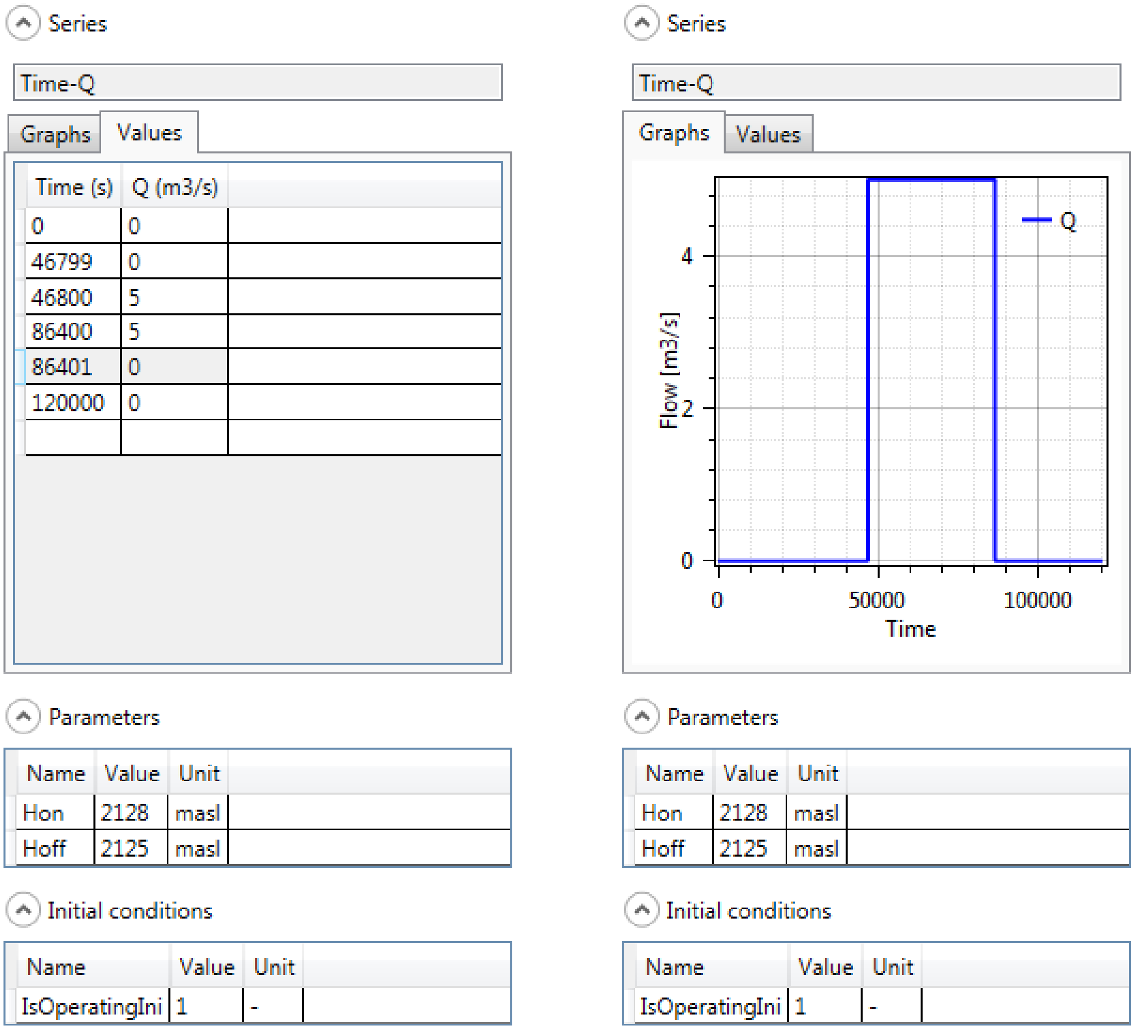


Figure 114 Proposed release from the Turbine 2

New objects are linked as before, from upstream to downstream, obtaining same relations, as presented in Figure 115.

"Turbine 2" relations

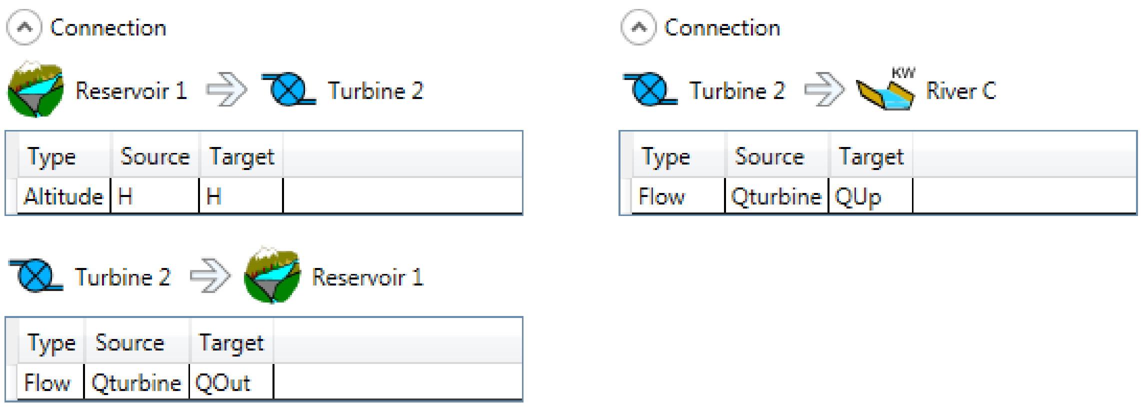


Figure 115 Connections between objects

Results of Example 3 – Part B

In the following figure we can see the new flows of the outlet and other variables. As it can be seen the peak is reduced to less than 8 m^3/s due to the preventive releases at the outlet of the model (Figure 116). Moreover, with the extra releases, we have created a first artificial peak.

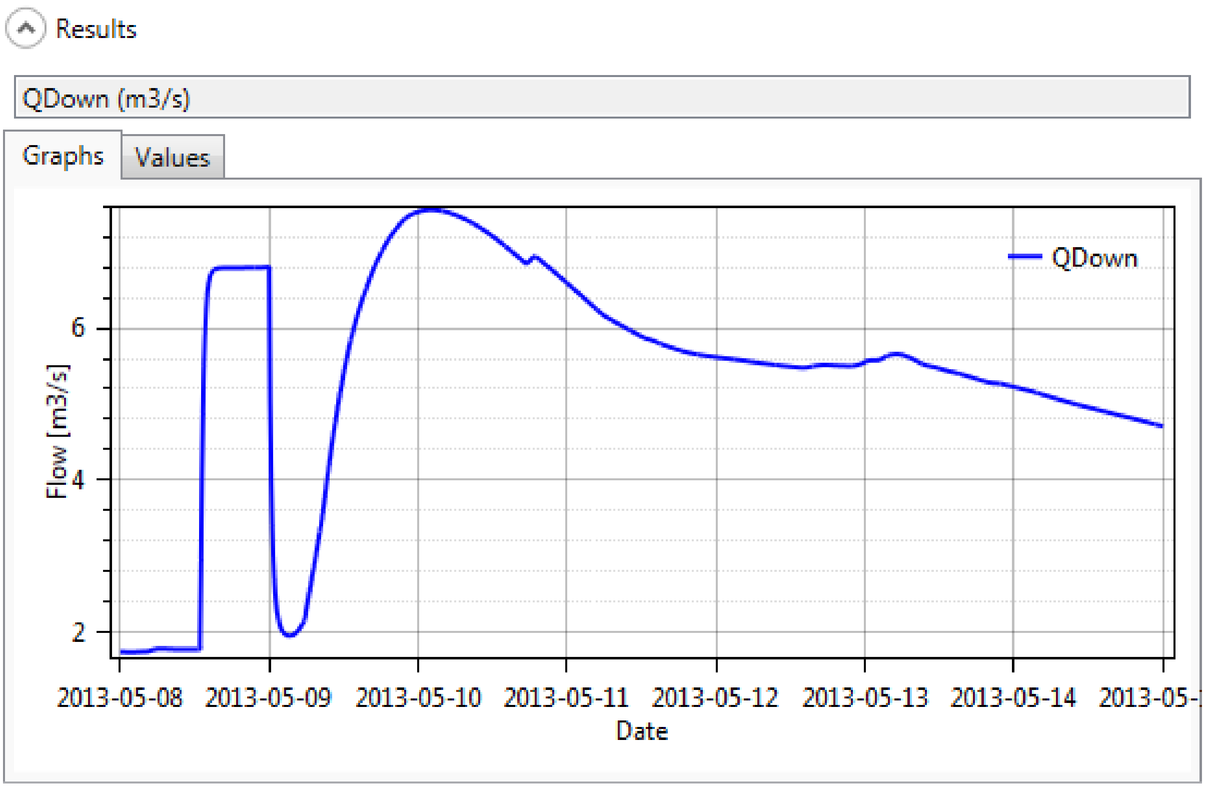


Figure 116 Outlet hydrograph after the addition of the new release. Peak discharge of 7.552 m^3/s arrives now on May the 10th, 2013 at 02:10.

Maximum water level on the reservoir, 2128.4731 m a.s.l., is at this case smaller than without the extra release of Part A (maximum water level of the part A was 2128.467 m a.s.l.).

To compared this results with the results of Part A, same results are presented, i.e., an analysis of inputs/outputs in the Reservoir 1. The inflow into the Reservoir 1 (Confluence), the spillway discharge (HQ 1), the turbine flows (Turbine 1 and Turbine 2), the total flow at the downstream of the reservoir (River C, Qup) and the reservoir level evolution (Reservoir 1) are presented in Figure 117.

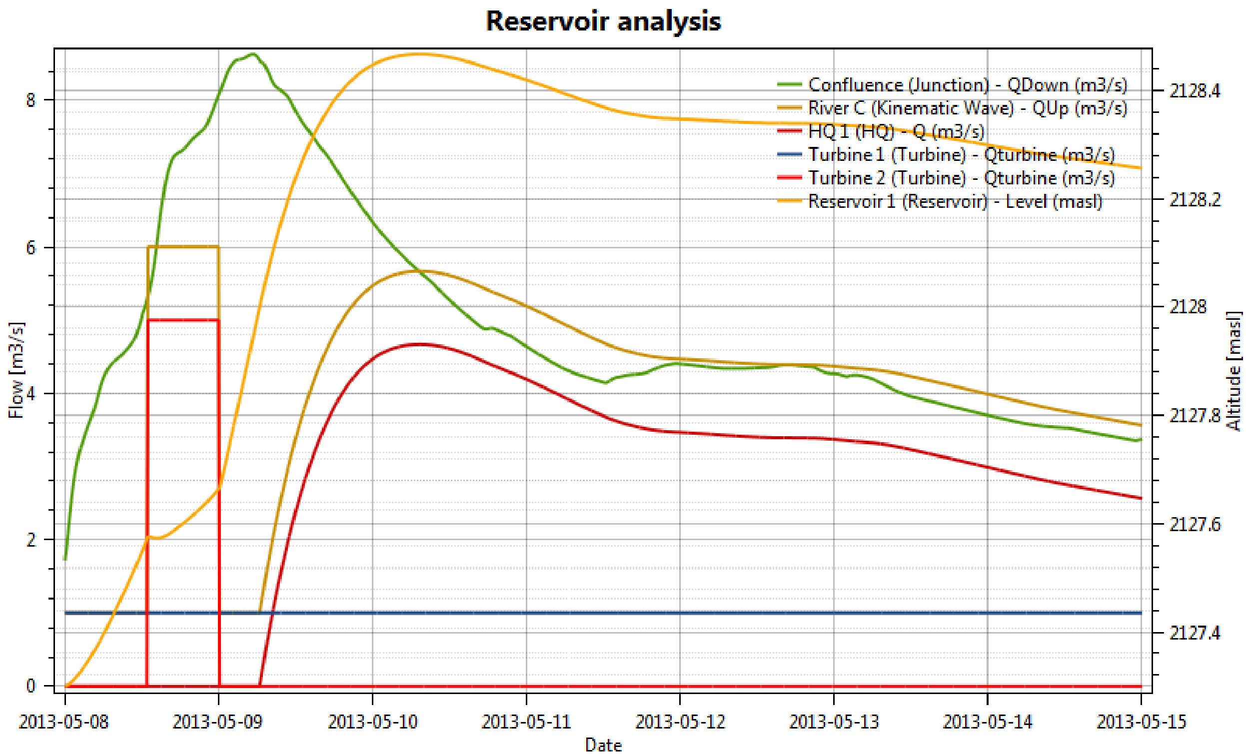


Figure 117 Flows balance of the reservoir and hydrographs at main control points

Although the objective has achieved, many issues emerge from the management of the reservoir. How much water do we have to release? Are we aggravating the situation downstream? How much energy will we lose if the flood is not as important as expected? And so on.

9.4. Example 4 – Automatic calibration of a model

This example allows an introduction to the use of the tool of hydrologic calibration in Expert module. The model starts with the previous model built in Example 2, with the same parameters. The calibration will be based on the comparison between observed and simulated discharges. Through this example (Figure 118), five parameters are calibrated. Two parameters are calibrated for the GSM object and three for the HBV model:

- GSM-An, the degree-day snowmelt coefficient;
- GSM-Agl, the Degree-day icemelt coefficient;
- HBV-FC, the maximum soil storage capacity;
- HBV-SUMax, the upper reservoir water level threshold;
- HBV-Kr, the near surface flow storage coefficient.

The range of values for the calibration can be defined based on the values given as regular range in Appendix 1. The temperatures, the precipitations and the outflow observed are in the database "Database manual". A uniform and null ETP is assumed for this example (the user can check the selected ETP method in the RS MINERVE Settings).

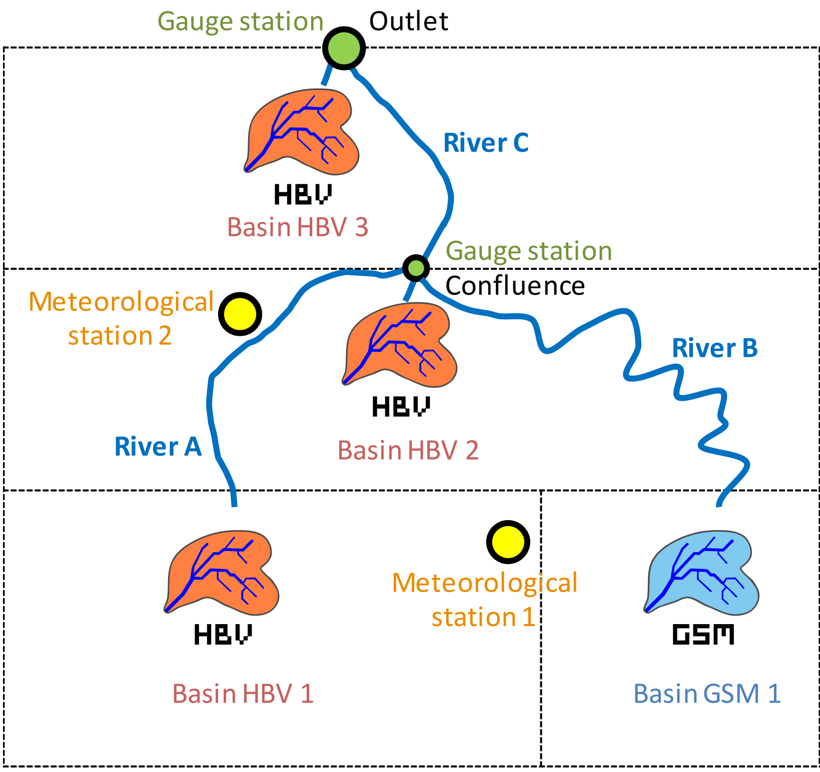


Figure 118 Model scheme

Objective of Example 4

The wanted result is the new values for the calibrated parameters of the GSM and HBV models after the automatic calibration. For the calibration, observed and simulated data are compared at the confluence point and at the outlet for a period between the 01.09.2011 00:00 and the 31.08.2012 00:00. In this example, the calibration uses an Objective Function (OF) with a weight of four for the Nash indicator, two for the Pearson Correlation Coeff indicator, four for the Relative Volume Bias indicator and zero for the other indicators. The “Simulation time step” and the “Recording time step” are fixed to 600 s.

Resolution of Example 4

For the calibration, it is necessary to add two source objects  to have a reference flows (observed discharges) at the confluence point and at the outlet. Two comparators objects  are also necessary to compare the results of the simulation with the reference data (observations) coming from the source object.

The Confluence and the Source 1 are connected to the comparator 1. The Outlet and the Source 2 are connected to the Comparator 2. The relations created can be visualized by double clicking on each blue arrow (Figure 119, Figure 120, Figure 121).

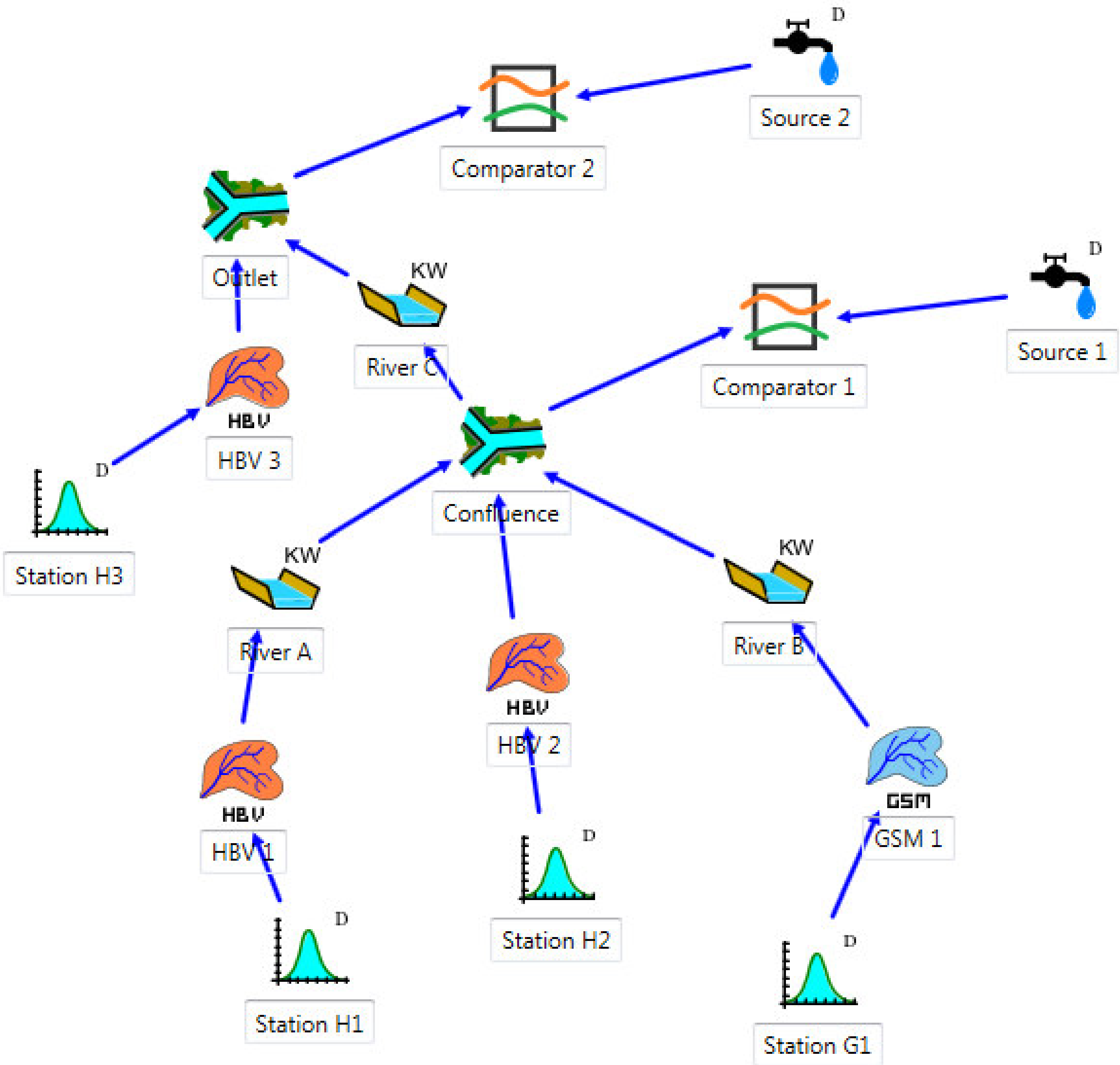


Figure 119 Topologic links between the different objects

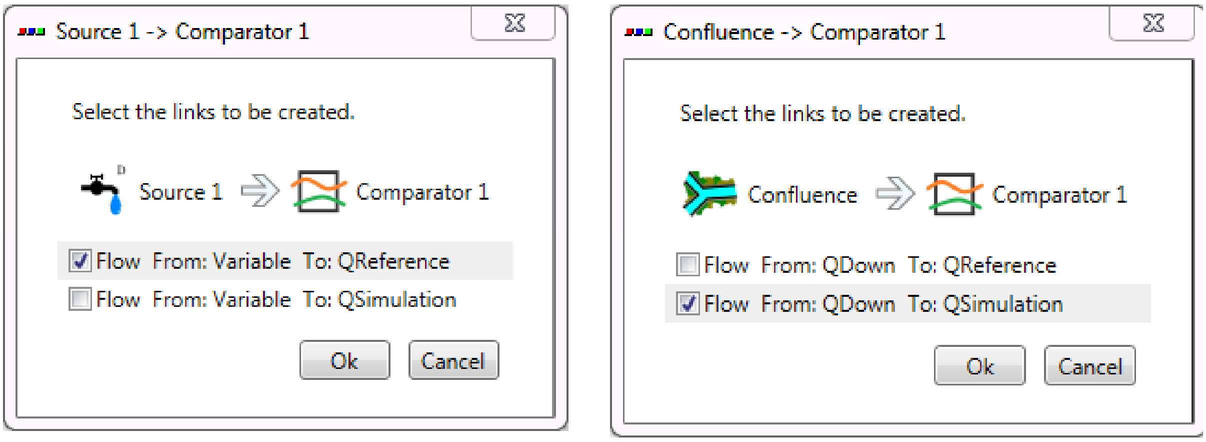


Figure 120 Possible outputs transfers between objects

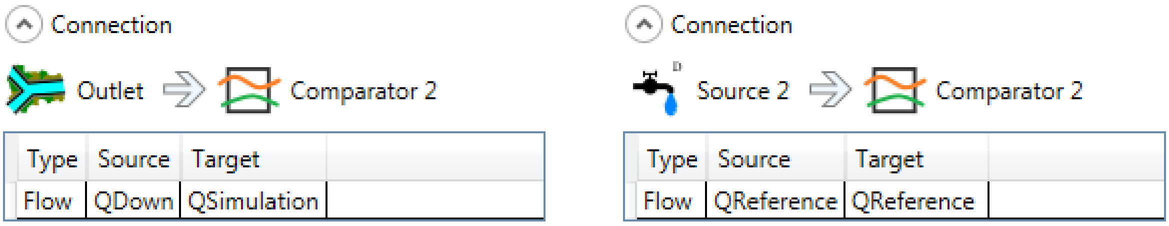


Figure 121 Connections between objects

Constructed model can be now saved clicking in the button and giving a name to the .rsm file (e.g. “Example4.rsm”).

Next, the meteorological data have to be loaded: the dialog box of the database is opened clicking in (Figure 122) for loading the corresponding database file (“Database manual.dbx”).

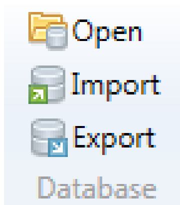


Figure 122 Database frame

The user can visualize or modify the database (Figure 123).

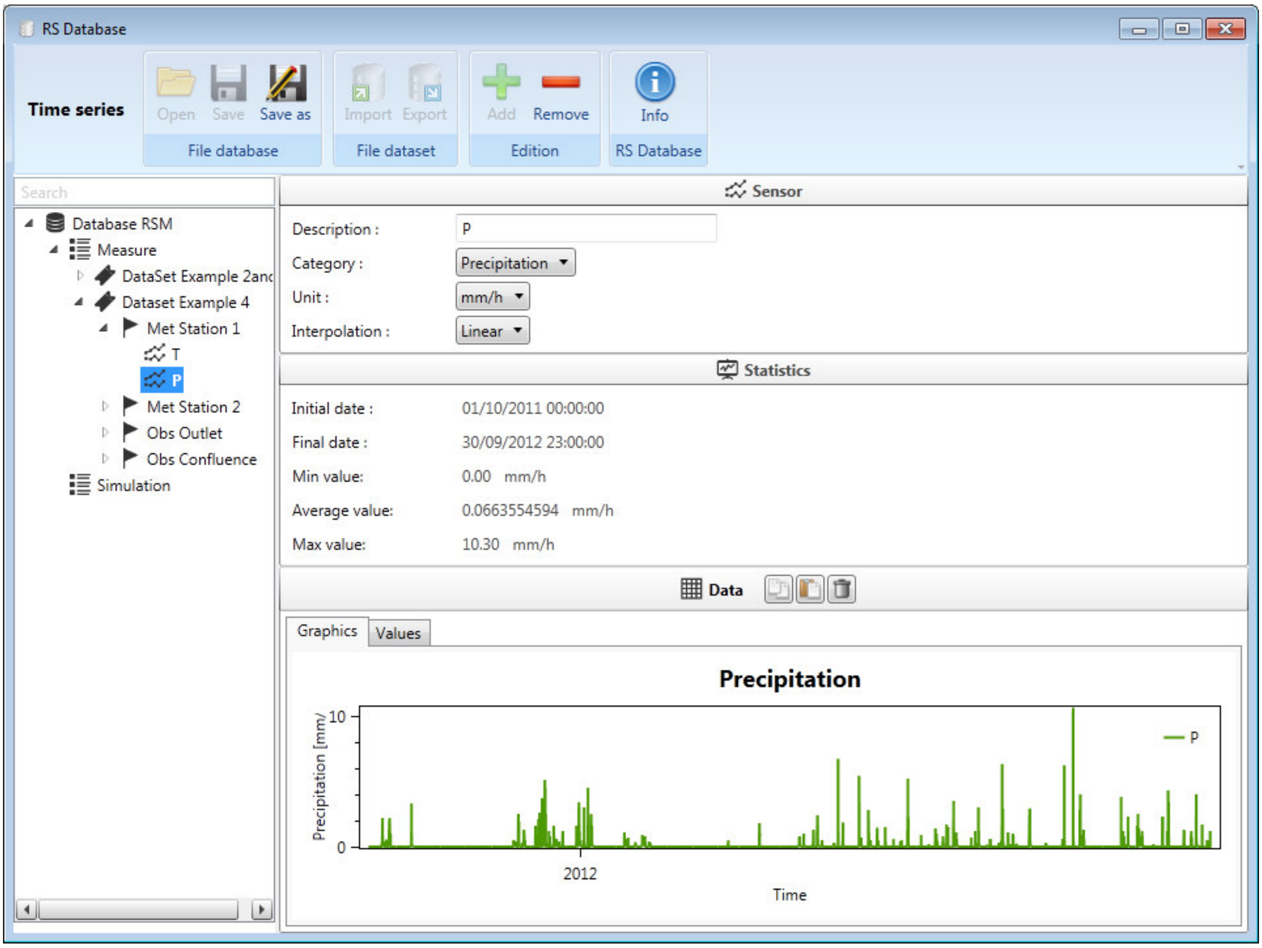
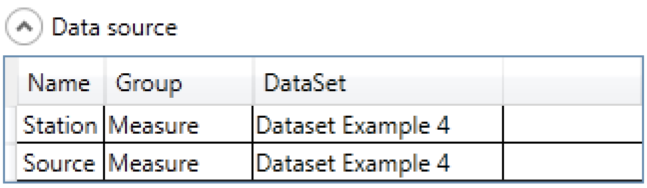


Figure 123 Database of the model

Once the database is loaded, the user can connect the database to the hydrological model. For achieving this purpose, the user has to choose the correct data source in the corresponding frame (Figure 124): the group “Measure” and the dataset “DataSet Example 4” for the current example.



Data source

Name	Group	DataSet	
Station	Measure	Dataset Example 4	
Source	Measure	Dataset Example 4	

Figure 124 Data source used for connecting the model to the database

Then, the user has to choose the series identifier for each Source object (the series of the database which contains the observed discharges) as shown in Figure 125.

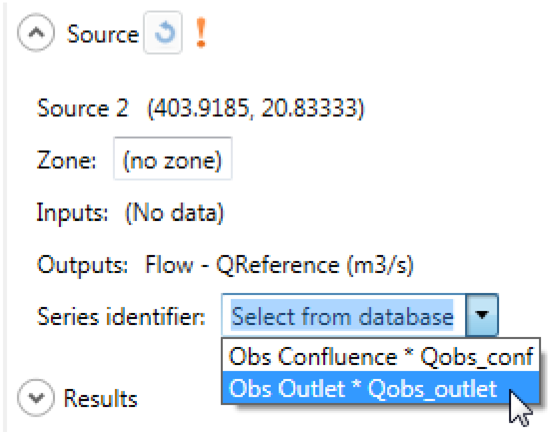


Figure 125 Series identifier for the "Source 2" object.

In order to clarify the use of the Calibrator tool, the different objects of the model will be aggregated in 2 zones:

- Zone 1: all the objects upstream the "Confluence" object (including the "Confluence").
- Zone 2: the rest of the objects of the model.

For that, the user has to double-click on each objects of the Zone 1 and change the Zone form 0 (default) to 1 as shown in Figure 126. The user will proceed similarly for the Zone 2.

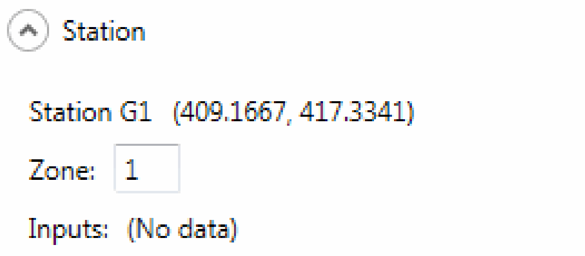


Figure 126 Change of the Zone of the "Station G1" object.

Finally, the module of hydrologic calibration can be launched by clicking on Expert → Calibrator in the *Modules* frame (Figure 127).

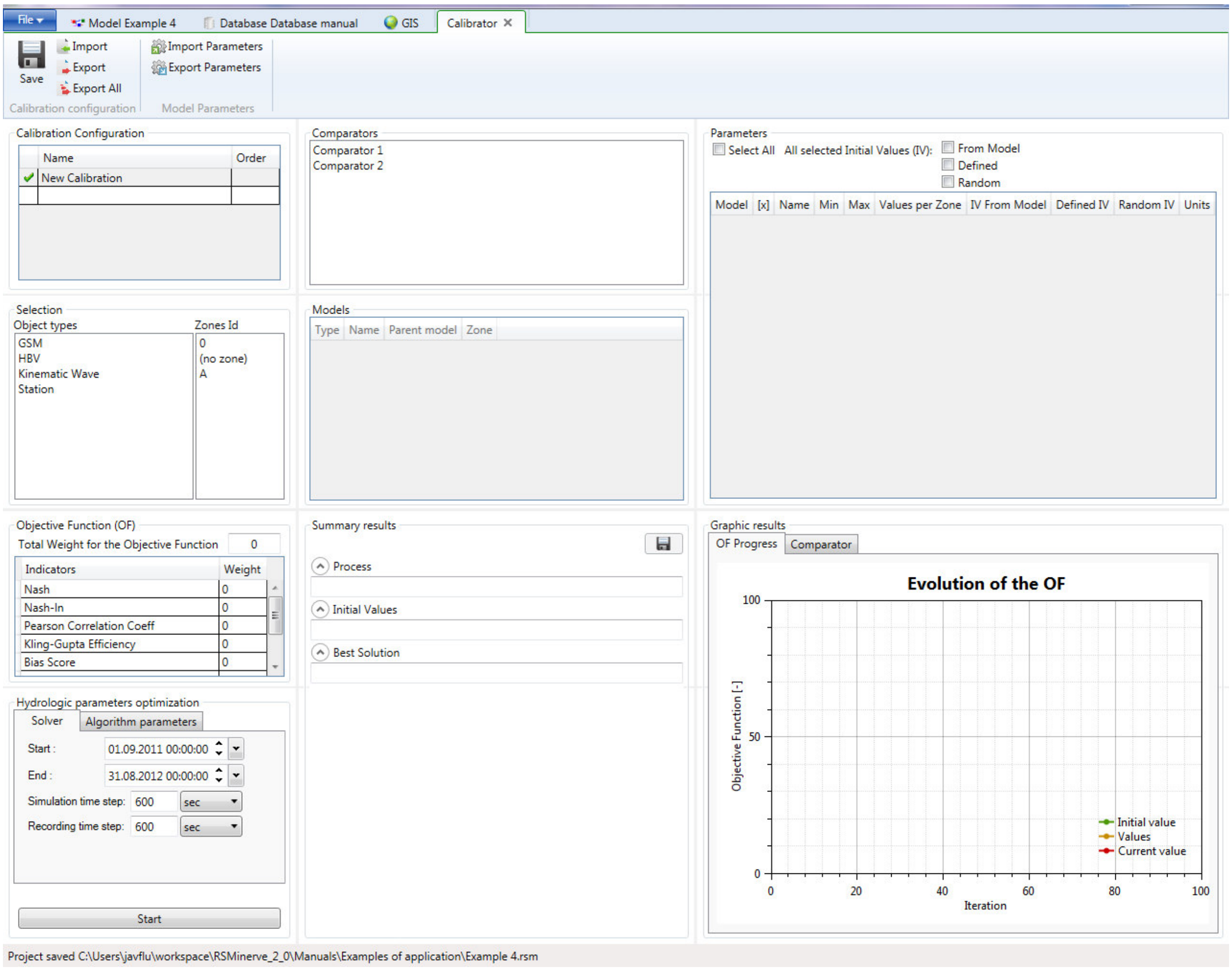


Figure 127 Interface of the Calibrator tool

Two calibration configurations can be created, one for each zone of the model (Figure 128). Give the order 1 to the calibration of Zone 1 (this one will be executed first) and order 2 to the calibration of Zone 2 (this one will be executed next).

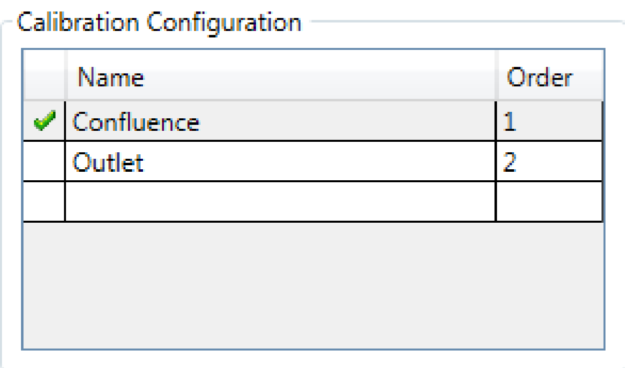


Figure 128 Creation of the calibration configurations

For each calibration configuration, in the Selection frame the HBV and GSM objects types are selected with the corresponding zone (Figure 129).

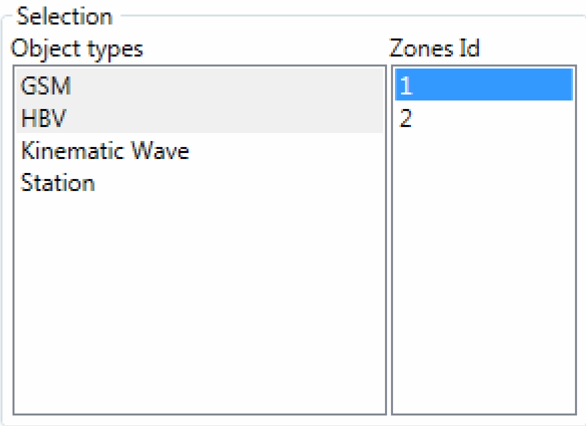
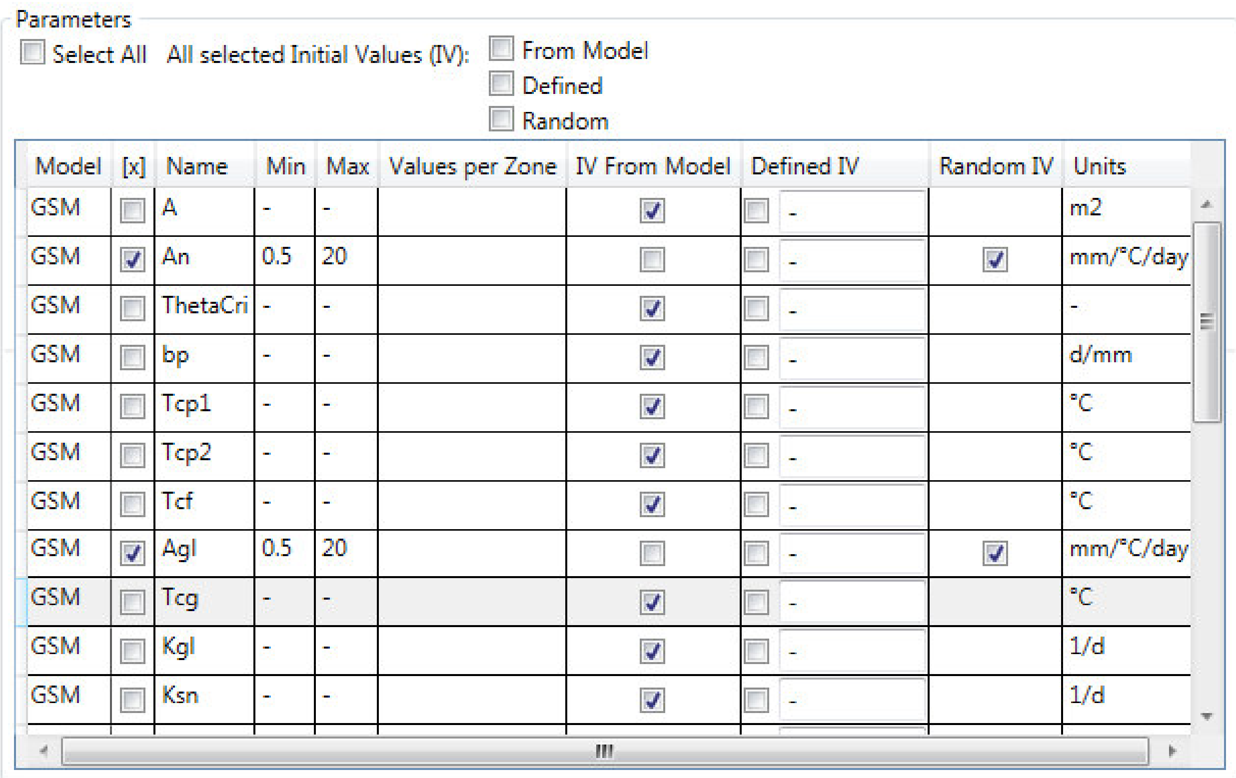


Figure 129 Selection of objects and zones to calibrate, for the “Confluence” calibration configuration.

The parameters to calibrate are checked in the Parameters frame (Figure 130). For each of them, the minimum and maximum values are:

- GSM-An: 0.5 – 10
- GSM-Agl: 0.5 – 10
- HBV-FC: 0.05 – 0.65
- HBV-SUMax: 0 – 0.1
- HBV-Kr: 0.05 – 0.5

The source of the initial values is selected as random for the parameters to calibrate and from model for the others.


Parameters
☐ Select All All selected Initial Values (IV): ☐ From Model ☐ Defined ☐ Random

Model	[x]	Name	Min	Max	Values per Zone	IV From Model	Defined IV	Random IV	Units
GSM	☐	A	-	-		☑	☐ -		m2
GSM	☑	An	0.5	20		☐	☐ -	☑	mm/°C/day
GSM	☐	ThetaCri	-	-		☑	☐ -		-
GSM	☐	bp	-	-		☑	☐ -		d/mm
GSM	☐	Tcp1	-	-		☑	☐ -		°C
GSM	☐	Tcp2	-	-		☑	☐ -		°C
GSM	☐	Tcf	-	-		☑	☐ -		°C
GSM	☑	Agl	0.5	20		☐	☐ -	☑	mm/°C/day
GSM	☐	Tcg	-	-		☑	☐ -		°C
GSM	☐	Kgl	-	-		☑	☐ -		1/d
GSM	☐	Ksn	-	-		☑	☐ -		1/d

Figure 130 Definition of the parameters to calibrate

In the Comparators frame, select alternatively the comparator whose the observed discharges will be used for the calibration of the corresponding zone (Comparator 1 for the first calibration configuration, and Comparator 2 for the second one).

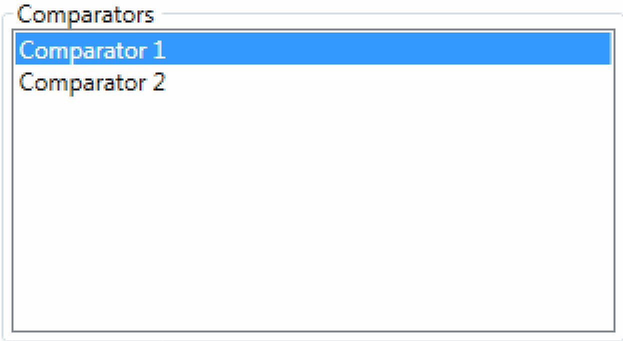
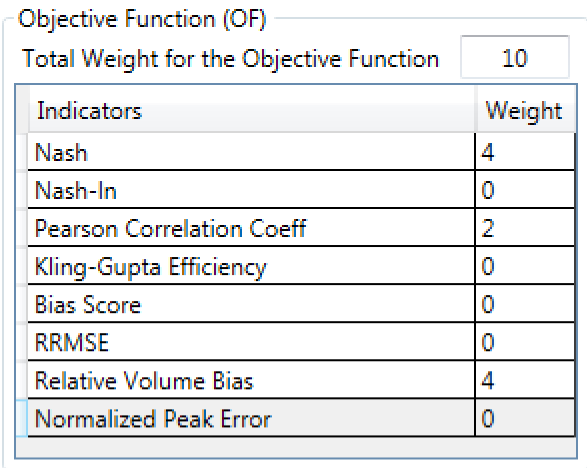


Figure 131 Selection of comparators

In the Objective Function (OF) frame the weight of the Nash and Relative Volume Bias coefficient are settled to 4 and the weight of the Pearson relative coefficient is 2. The other coefficients are all settled to zero (Figure 132). The default algorithm parameters are used.



Objective Function (OF)

Total Weight for the Objective Function 10

Indicators	Weight
Nash	4
Nash-ln	0
Pearson Correlation Coeff	2
Kling-Gupta Efficiency	0
Bias Score	0
RRMSE	0
Relative Volume Bias	4
Normalized Peak Error	0

Figure 132 Weight of each indicator to determine the objective function

After specifying the calibration period in the Solver tab of the Hydrologic parameters optimization frame, the calibration configuration can be saved and then started.

At the end of the calibrations the final parameters obtained are collected in the current model. If the model is saved, the parameters are stored; if not, the hydrological model keeps preliminary parameters.

Results of Example 4

Once the calculation is finished (after approximately 1'300 iterations for the confluence calibration and 400 iteration for the outlet calibration), the best values obtained for the parameters can be visualized in the Summary results frame. From a maximum possible value of the Objective Function (OF) of 6, the best score provided by the algorithm is 5.448 and 5.560 for the confluence calibration and the outlet calibration, respectively.

Hereafter (Table 12 and Table 13) the results of the calibration (since the algorithm contains the random calculations, it is possible to obtain a similar but not exactly the same result).

Table 12 Calibrated parameters

	Initial Parameter		Best Parameter	
	Confluence	Outlet	Confluence	Outlet
GSM - An	6	-	0.761	-
GSM – Agl	7	-	0.500	-
HBV – FC	Different values	0.275	0.126	0.534
HBV – SUMax	Different values	0.0055	0.100	0.0781
HBV – Kr	Different values	0.3	0.281	0.152

Table 13 Performance indicators

	Initial Performance		Final Performance	
	Confluence	Outlet	Confluence	Outlet
Nash	-26.38	0.87	0.89	0.91
Nash-ln	-2.67	0.81	0.80	0.84
Pearson Correlation Coeff.	0.57	0.95	0.95	0.96
Kling-Gupta Efficiency	-2.20	0.91	0.94	0.95
Bias Score	-9.03	0.99	1	1
RRMSE	3.95	0.26	0.25	0.22
Relative Volume Bias	3.17	0.07	2E-5	-6E-7
Normalized Peak Error	0.63	0.001	-0.02	-0.005
OF	-117.06	5.12	5.45	5.56

The simulation fits pretty well the outflow observed (Figure 133). Thus, the new parameters after the calibration can be kept by saving the model.

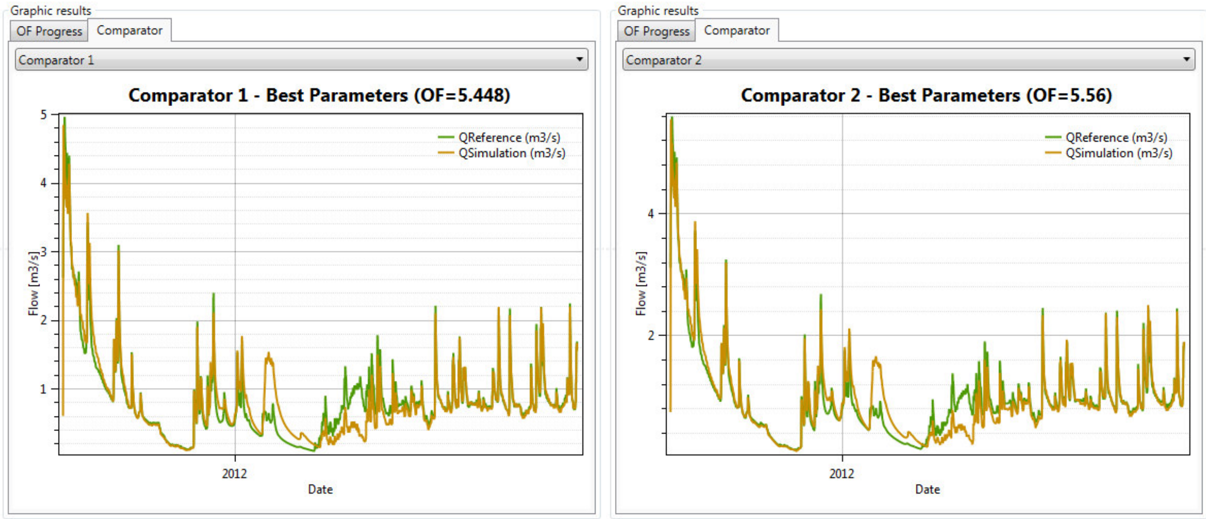


Figure 133 Graphic results of the calibration. Hydrograph of both observed and current simulated discharge

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Appendix: List of parameters and initial conditions

Table A1.1 List of parameters and initial conditions for meteorological stations and reaches

Object	Name	Units	Description	Regular Range
Station	X, Y, Z	-	Coordinates of the virtual weather station	-
	Search radius	m	Search radius of weather stations	>0
	Gradient P	1/m	Precipitation gradient	- [a]
	Gradient T	°C/m	Temperature gradient	-0.007 to -0.004
	Gradient ETP	1/m	Potential evapotranspiration gradient	- [a]
	Coeff. P,		Multiplying correction coefficient	0.5 to 2
	Coeff.T,		Adding correction coefficient	-2 to 2
	Coeff. ETP	-	Multiplying correction coefficient	0.5 to 2
Reach	L	m	Length	>0
	B0	m	Width of the channel base	>0
	m	-	Side bank relation coeff. (1H/mV)	0.1 to 1
	J0	-	Slope	>0
	K	$m^{1/3}/s$	Strickler coefficient	10 to 90
	N	-	Number of sections (St. Venant only)	>0
	QIni	m^3/s	Initial discharge	-

[a] The precipitation and potential evapotranspiration gradients are function of the local conditions. Their regular ranges have to be estimated for each studied case.

Table A1.2 List of parameters and initial conditions for Snow-SD, SWMM, GSM and SOCONT objects

Object	Name	Units	Description	Regular Range
Snow-SD	S	mm/°C/day	Reference degree-day snowmelt coefficient	0.5 to 20
	SInt	mm/°C/day	Degree-day snowmelt interval	0 to 4
	SMin	mm/°C/d	Minimal degree-day snowmelt coefficient	≥0
	SPh	d	Phase shift of the sinusoidal function	1 to 365
	ThetaCri	-	Critical relative water content of the snow pack	0.1
	bp	day/mm	Melt coeff. due to liquid precipitation	0.0125
	CFR	-	Refreezing factor	0.05-1
	T_{cp1}	°C	Minimum critical temperature for liquid precipitation	0
	T_{cp2}	°C	Maximum critical temperature for solid precipitation	6
	T_{cf}	°C	Critical snowmelt temperature	0
	SWEIni	m	Initial snow water equivalent height	-
	ThetaIni	-	Initial relative water content in the snow pack	-
GSM	A	m^2	Surface of infiltration	>0
	S	mm/°C/day	Reference degree-day snowmelt coefficient	0.5 to 20
	SInt	mm/°C/day	Degree-day snowmelt interval	0 to 4
	SMin	mm/°C/d	Minimal degree-day snowmelt coefficient	≥0
	Sph	d	Phase shift of the sinusoidal function	1 to 365
	ThetaCri	-	Critical relative water content of the snow pack	0.1
	bp	day/mm	Melt coeff. due to liquid precipitation	0.0125
	CFR	-	Refreezing factor	0.05-1
	G	mm/°C/day	Degree-day icemelt coefficient	0.5 to 20
	GInt	mm/°C/d	Degree-day glacier melt interval	0 to 4
	GMin	mm/°C/d	Minimal degree-day glacier melt coefficient	≥0
	Kgl	1/d	Release coeff. of icemelt reservoir	0.1 to 5
	Ksn	1/d	Release coeff. of snowmelt reservoir	0.1 to 5
	T_{cp1}	°C	Minimum critical temperature for liquid precipitation	0
	T_{cp2}	°C	Maximum critical temperature for solid precipitation	6
	T_{cf}	°C	Critical snowmelt temperature	0
	T_{cg}	°C	Critical glacier melt temperature	0
	SWEIni	m	Initial snow water equivalent height	-
	QsnowIni	m^3/s	Initial outflow of linear snow reservoir	-
	QglacierIni	m^3/s	Initial outflow of linear glacier reservoir	-
	ThetaIni	-	Initial relative water content in the snow pack	-

Object	Name	Units	Description	Regular Range
SOCONT	A	m^2	Surface of infiltration	>0
	S	mm/°C/day	Reference degree-day snowmelt coefficient	0.5 to 20
	SInt	mm/°C/day	Degree-day snowmelt interval	0 to 4
	SMin	mm/°C/d	Minimal degree-day snowmelt coefficient	≥0
	Sph	d	Phase shift of the sinusoidal function	1 to 365
	ThetaCri	-	Critical relative water content of the snow pack	0.1
	bp	day/mm	Melt coeff. due to liquid precipitation	0.0125
	CFR	-	Refreezing factor	0.05-1
	HGR3Max	m	Maximum height of infiltration reservoir	0 to 2
	KGR3	1/s	Release coeff. of infiltration reservoir	0.00025 to 0.1
	L	m	Width of the plane	>0
	J0	-	Runoff slope	>0
	Kr	$m^{1/3}/s$	Strickler coefficient	0.1 to 90
	SWEIni	m	Initial snow water equivalent height	-
	HGR3Ini	m	Initial level in infiltration reservoir	-
	HrIni	m	Initial runoff water level downstream of the surface	-
	ThetaIni	-	Initial relative water content in the snow pack	-
SWMM	A	m^2	Surface of runoff	>0
	L	m	Length of the plane	>0
	J0	-	Runoff slope	>0
	K	$m^{1/3}/s$	Strickler coefficient	0.1 to 90
	HIni	m	Initial water level downstream of the surface	-

Table A1.3 List of parameters and initial conditions for HBV and GR4J objects

Object	Name	Units	Description	Regular Range
HBV	A	m^2	Surface of the basin	>0
	CFMax	mm/°C/day	Melting factor	0.5 to 20
	CFR	-	Refreezing factor	0.05
	CWH	-	Critical relative water content of the snow pack	0.1
	TT	°C	Threshold temperature of rain/snow	0 to 3
	TTInt	°C	Temperature interval for rain/snow mixing	0 to 3
	TTSM	°C	Threshold temperature for snow melt	0
	Beta	-	Model parameter (shape coeff.)	1 to 5
	FC	m	Maximum soil storage capacity	0.05 to 0.65
	PWP	-	Soil permanent wilting point threshold	0.03 to 1
	SUMax	m	Upper reservoir water level threshold	0 to 0.10
	Kr	1/d	Near surface flow storage coeff.	0.05 to 0.5
	Ku	1/d	Interflow storage coeff.	0.01 to 0.4
	Kl	1/d	Baseflow storage coeff.	0 to 0.15
	Kperc	1/d	Percolation storage coeff.	0 to 0.8
	SWEIni	m	Initial snow water equivalent height	-
	WHIni	-	Initial relative water content in the snow pack	-
	HIni	m	Initial humidity	-
	SUIni	m	Initial upper reservoir water level	-
	SLIni	m	Initial lower reservoir water level	-
GR4J	A	m^2	Surface of the basin	>0
	X1	m	Capacity of production store	0.1 to 1.2
	X2	m	Water exchange coefficient	-0.005 to 0.003
	X3	m	Capacity of routing store	0.02 to 0.3
	X4	d	UH time base	1.1 to 2.9
	SIni	m	Initial water content in the production reservoir	-
	RIni	m	Initial water level in the routing reservoir	-

Table A1.4 List of parameters and initial conditions for the SAC-SMA object

Object	Name	Units	Description	Regular Range
SAC-SMA	A	m^2	Surface of the basin	>0
	Adimp	-	Maximum fraction of an additional impervious area due to saturation	0 to 0.2
	Pctim	-	Permanent impervious area fraction	0 to 0.05
	Riva	-	Riparian vegetarian area fraction	0 to 0.2
	UztwMax	m	The upper zone tension water capacity	0.01 to 0.15
	UzfwMax	m	The upper zone free water capacity	0.005 to 0.10
	Uzk	1/d	Interflow depletion rate from the upper zone free water storage	0.10 to 0.75
	Zperc	-	Ratio of maximum and minimum percolation rates	10 to 350
	Rexp	-	Shape parameter of the percolation curve	1 to 4
	Pfree	-	Percolation fraction that goes directly to the lower zone free water storages	0 to0.6
	LztwMax	m	The lower zone tension water capacity	0.05 to 0.40
	LzfpMax	m	The lower zone primary free water capacity	0.03 to 0.80
	LzfsMax	m	The lower zone supplemental free water capacity	0.01 to 0.40
	Rserv	-	Fraction of lower zone free water not transferable to lower zone	0 to 1
	Lzpk	1/d	Depletion rate of the lower zone primary free water storage	0.001 to 0.03
	Lzsk	1/d	Depletion rate of the lower zone supplemental free water storage	0.02 to 0.3
	Side	-	Ratio of deep percolation from lower zone free water storages	0 to 0.5
	AdimIni	m	Initial tension water content of the ADIMP area	-
	UztwIni	m	Initial upper zone tension water content	-
	UzfwIni	m	Initial upper zone free water content	-
	LztwIni	m	Initial lower zone tension water content	-
	LzfpIni	m	Initial lower zone free supplemental content	-
	LzfsIni	m	Initial lower zone free primary content	-

Table A1.5 List of parameters and initial conditions for structures objects

Object	Name	Units	Description	Regular Range
Reservoir	H-V (paired data)	-	Level - Volume relation	-
	Hini	masl	Initial level in the reservoir	-
HQ	H-Q (paired data)	-	Level - Spill flow relation	-
Turbine				
Hydropower	Q-η (paired data)	m^3/s - %	Discharge-Performance relation	-
	$Z_{central}$	masl	Hydropower plant altitude	10-1’000
	L	m	Length of the pipe	10-10’000
	D	m	Diameter of the pipe	0.1-5
	K	m	Roughness of the pipe	0.002-1
	ν	m^2/s	Kinematic viscosity	$0,6*10^{-6}$ -$1.5*10^{-6}$
	Default Price	euro/Kwh	Default price, only used if no data exists in the database	0.05-0.5
Diversion	Q_{up}-$Q_{diverted}$ (paired data)	-	Inflow - Diverted flow relation	-
Consumer	Default QDemand	m^3/s	Default demand of consummation, only used if no data exists in the database	-
Structure efficiency	Efficiency	-	Efficiency coefficient of the structure	-

Table A1.6 List of parameters and initial conditions for structures objects

Object	Name	Units	Description	Regular Range
Time Series	Series (paired data)	s - (depending on the series)	Time – Value series	-

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