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The hydrological model HYDROTEL
USER Manual
-
Beginner

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Context

Welcome to the user guide for HYDROTEL. This guide is designed to help you navigate and utilize the features of an existing project. It is not intended for advanced users who wish to create a project from scratch, but rather for those who are new to the software or are looking to understand its functionalities within an existing project.

Getting Started

Before diving into the details, let's ensure you have everything you need to begin exploring the project:

- Access: Make sure you have the necessary permissions to access the project. If you are unsure, contact your project administrator or manager.
- Software Installation: Ensure that the software is installed on your system. If not, you only need to copy paste the necessary files in your chosen directory and create a desktop shortcut for ease of use.
- License: Make sure your license is activated and the language is set to English. If you do not have a license, contact Alain N Rousseau at alain.rousseau@inrs.ca.

Symbols and signs

The following symbols are used throughout this whole document to draw the reader's attention to crucial points.

MUST NOT DO

HELP

INFORMATION

QUICK TIPS

CONTENT

1 HYDROTEL structure

Spatially, HYDROTEL is a distributed hydrological model. This means that the calculations performed by the model are done on a set of computational elements distributed within a watershed. This approach allows for better consideration of the spatial variability of the physiographic characteristics of the watershed (topography, land use, soil types, etc.) and the meteorological systems that affect it. **Temporally**, HYDROTEL is a model that operates continuously, as opposed to an event-based model. Finally, the various hydrological processes occurring within a watershed between rainfall or snowmelt events and river flows are considered in HYDROTEL as **sub-models**. These dimensions of HYDROTEL's simulation structure are further discussed in the following sections.

1.1 Spatial simulation structure

PHYSITEL, the specialized GIS, was used to prepare the watershed database, enabling the determination of the spatial flow structure within this watershed. This structure needs to be finalized, that is: for each Relatively Homogeneous Hydrological Unit (RHHU), hydrological processes are initially influenced by land use, such as types of vegetation, and the presence of impermeable surfaces like outcrop, roads, urban, or industrial areas. Using images obtained by remote sensing, the percentage of each land use class within each RHHU is estimated. Furthermore, it is important to consider the spatial distribution of soil types in a watershed, which can vary from sands to clays, including outcrop areas. These soils can also vary in thickness above the bedrock. To simplify, only one dominant soil type has been chosen for each RHHU. However, if there is significant spatial variation in soil types, this must be considered when discretizing the RHHUs.

All physiographic data mentioned above constitute the database for a to be modelled using HYDROTEL. Without altering the spatial data, in HYDROTEL, it is possible to group RHHUs. Since a watershed is typically divided into several hundreds or even thousands of UHRHs, it is impractical to assign individual values for certain physiographic, meteorological variables and sub-model parameters to each UHRH. The main reason for this is that users usually lack sufficiently detailed information about the watershed to assign satisfactory values at this level. In such cases, it may be acceptable to provide them identical values across the entire watershed. However, HYDROTEL provides a compromise. Users can group UHRHs based on their knowledge of land use and soil types within the watershed, and then assign values for certain physiographic, meteorological variables, and sub-model parameters specific to each of these groups of UHRHs. This concept is further explained in the user guide.

1.2 Temporal simulation structure

HYDROTEL conducts continuous simulations, starting and ending at specific dates and times. Within each simulation period, HYDROTEL provides simulation results at each time step, which may be 1, 2, 3, 4, 6, 8, 12, and 24 hours.

Meteorological and hydrological input data must be known for time intervals that do not exceed the duration of the simulation time step. Data known at finer time intervals are integrated over the simulation time step scale. It is important to note that while some sub-models may use internal calculation steps smaller than HYDROTEL's external simulation time step for numerical stability, the flow of data between sub-models occurs only once per external simulation time step.

In this context, it is important to consider the following example. If HYDROTEL is configured with a 24-hour time step, but meteorological data are known at an hourly interval, the hourly rainfall amounts will be added together to calculate daily totals. These summed or integrated values will then be used in the simulation sub-models. However, if a sub-model such as the vertical water balance model needs to use a two-hour internal time step for numerical reasons, the rainfall used for the calculations will be the 24-hour integrated rainfall divided by 12, not the hourly data. To maintain the temporal detail of hourly data, the model should be used with an external simulation time step that is hourly.

1.3 Sub models and hydrological processes

HYDROTEL divides the simulation of hydrological processes into six main sub-models: meteorological data interpolation, snow cover evolution, potential evapotranspiration, vertical water balance, surface runoff, and flow through the hydrographic network. Also, HYDROTEL includes internal process to account for wetlands (isolated and riparian) that can be activated or not.

For each hydrological process, HYDROTEL offers a choice between one or several algorithms (Table 1) suited to the availability of input data. For example, if only precipitation and temperature data from a single station are available for a given watershed, and no database provides information on the distribution of soil types, the model can be used with minimal options, such as Thiessen polygons, the degree-day method, the Thornthwaite equation or the Hydro-Québec equation, the vertical water balance using the CEQUEAU algorithm, etc.Alternatively, if a watershed is well-documented with data, particularly in terms of meteorological data and knowledge of soil distribution, more comprehensive sub-models can be used, such as the weighted average of the inverse distance to the three nearest stations, the mixed thermal energy balance degree-day method, the Penman-Monteith equation, the vertical water balance with three soil layers, etc.

Let us now establish the connection between hydrological processes, RHHUs, and river segments of the hydrographic network. The first four processes (meteorological data interpolation, snow cover evolution, potential evapotranspiration, and vertical water balance) are simulated at the level of each RHHU. The same applies to the fluxes between them. Surface runoff is simulated by initially producing a geomorphological unit hydrograph specific to each RHHU, generated by the flow of a reference water depth from cell to cell within this computational unit. It is important to note that the flows between the algorithms that simulate the first five hydrological processes are carried out at the level of the UHRHs. Thus, the sub-model that calculates surface runoff receives, at each time step and at the RHHU level, a water depth that it distributes over time based on the previously estimated geomorphological unit hydrograph from the specific internal flow structure within the RHHU. Finally, flow through the hydrographic network is simulated for each network segments. The inputs for each segment come from the upstream segment and the lateral contributions from the connected RHHUs. As a complement the isolated wetland module is simulated at the level of each RHHU, and riparian wetland module is simulated at the level of each associated river segments.

Table 1: Modeled hydrological processes and available algorithms.

Hydrological processes	Algorithms
1. Weather data interpolation	1.1 Thiesssen polygons
	1.2 Weighted average of the three nearest stations
2. Snow cover evolution	2.1 Modified degree day
	2.2 Band degree day
3. Soil temperature / Frost depth	3.1 Rankinen (2004)
	3.2 Thorsen (2010)
4. Glacier melt	4.1 Glacier degree day
5. Potential evapotranspiration	5.1 Hydro-Québec
	5.2 McGuinness (1972)
	5.3 Penman (1948)
	5.4 Linacre (1977)
	5.5 Thornthwaite (1948)
	5.6 Priestley-Taylor (1972)
	5.7 Penman-Monteith (Monteith 1965)
6. Vertical water balance	6.1 BV3C
	6.2 CEQUEAU
7. Flow towards the hydrographic network	7.1 Kinematic wave
8. Flow in the hydrographic network	8.1 Modified kinematic wave
9. Wetlands	9.1 Isolated / Riparian

2 Navigating the project

2.1 Opening an existing project

Once HYDROTEL is launched, navigating through the graphical user interface is straightforward. From the bar menu, accessible options are very limited. You will find the commands/action items to create a project, open a project, a database, or exit. To open a project, simply click on "Open" as displayed in Figure 1 to display Figure 2.

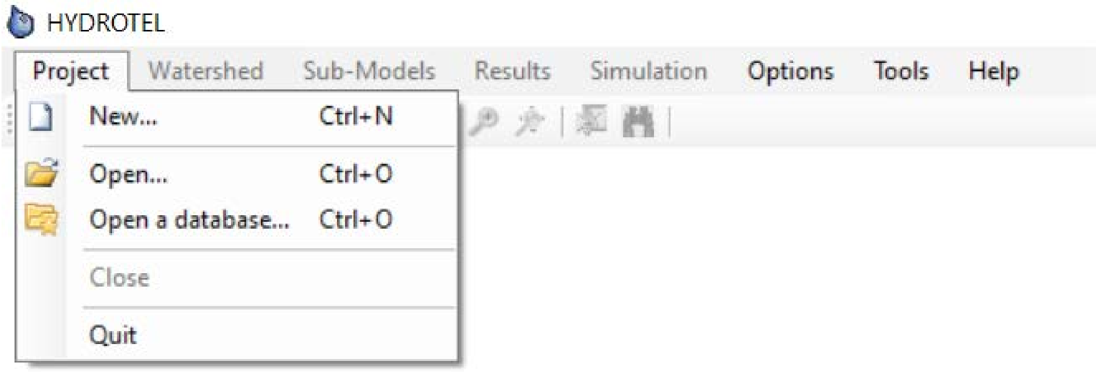


Figure 1: HYDROTEL menu bar, "Project" menu

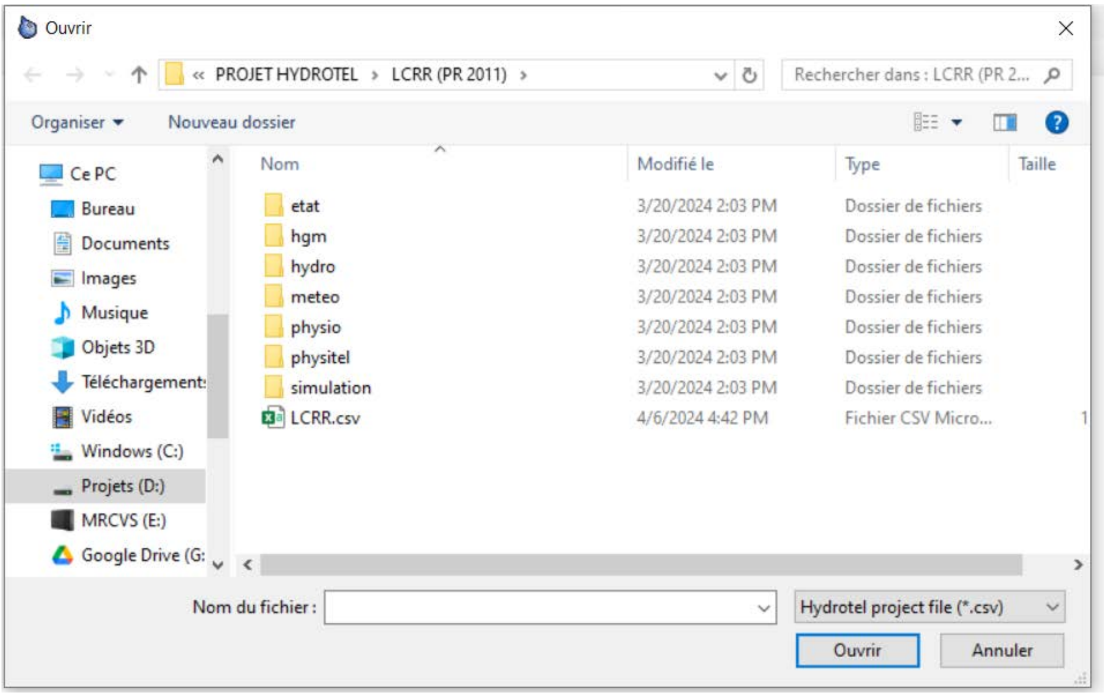


Figure 2:Dialog box to open a HYDROTEL project

This dialog box allows you to navigate through the computer's folders and locate the existing HYDROTEL project. The graphic interface of an open project appears in Figure 3.

HYDROTEL projects are identified using a .csv file extension

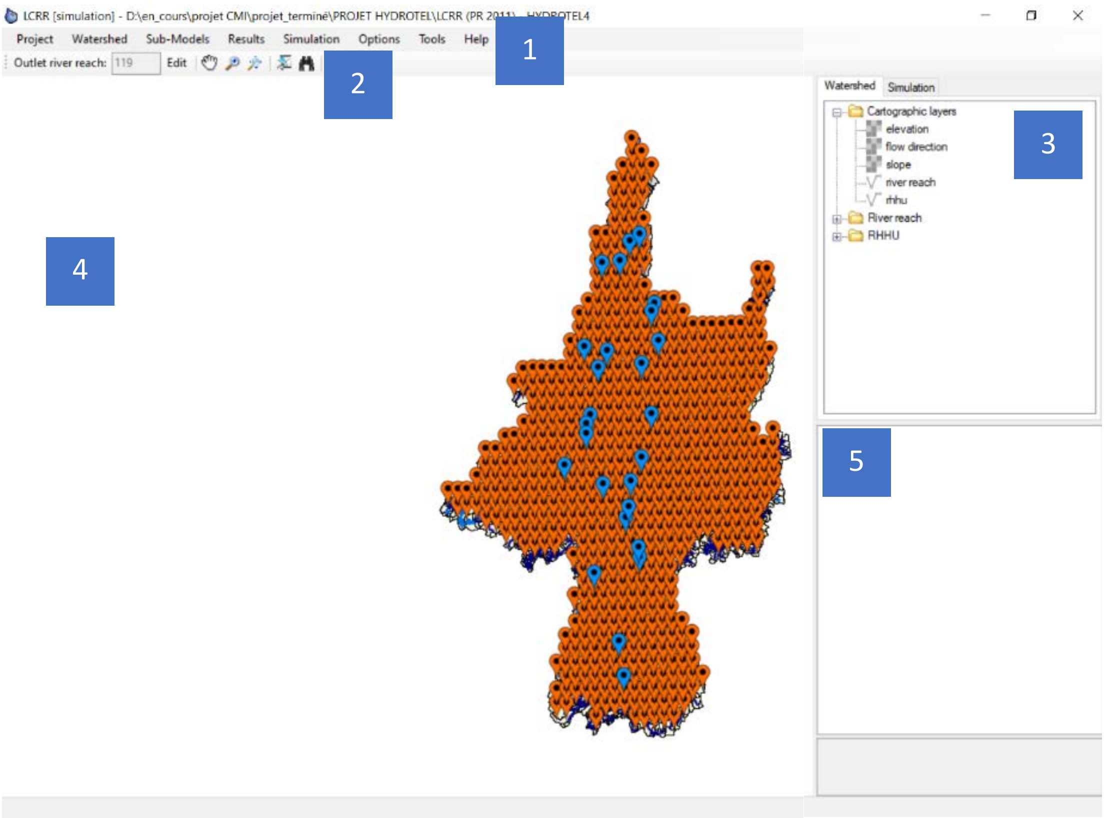


Figure 3: HYDROTEL graphic interface for an open project

The interface is divided into the bar menu (1), navigation icons (2), input data window (3), and main display window (4) and detailed geographic information window (5).

2.2 Navigation options

The navigation options (2) accessible through icons are standard. A zoom in of this zone is provided in Figure 4.

Figure 4: Project navigation icons

From left to right, the "outlet river reach" identifies the downstream reach used for computation. If it is not the current outlet of the overall project, only the upstream part will be considered during the simulations. The following icons are made to let you navigate the map (hand), zoom in, or to the extent of the project, select a reach or RHHU in the main window, or select a reach or RHHU using its identification number.

Icons are only active if a project is open; display is dynamic.

Hovering over an icon menu displays its function in a tooltip.

2.3 Geographic input data

The top right-side panel from Figure 3 presents the project's watershed geographic input data as illustrated in Figure 5.

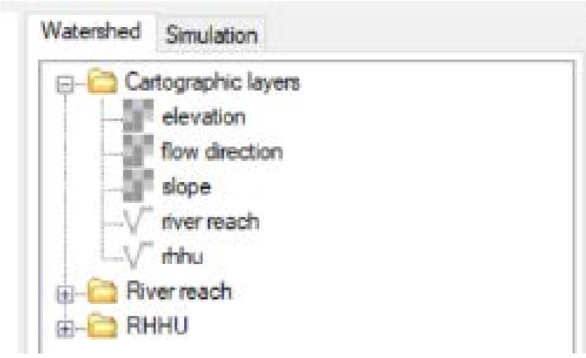


Figure 5: Side panel, watershed geographic input data

These input data include the cartographic layers constructed using PHYSITEL, that is elevation, flow direction, slope, river network segmentation (i.e., reach) and RHHU. They can be displayed by double clicking. The reader can also refer to the PHYSTEL user manual for more detailed information. The river reach and RHHU folder simply contain a list of all reaches and RHHUs sorted according to their identification number starting from 1 to the number of reaches and hydrological units used in the current project. By double-clicking on the identification number, the object properties are displayed in the detailed geographic information window.

2.4 Main display window

The main display window shows the entire watershed (by default) as in Figure 6. The user can zoom in or out using the navigation icons or the mouse scroll wheel.

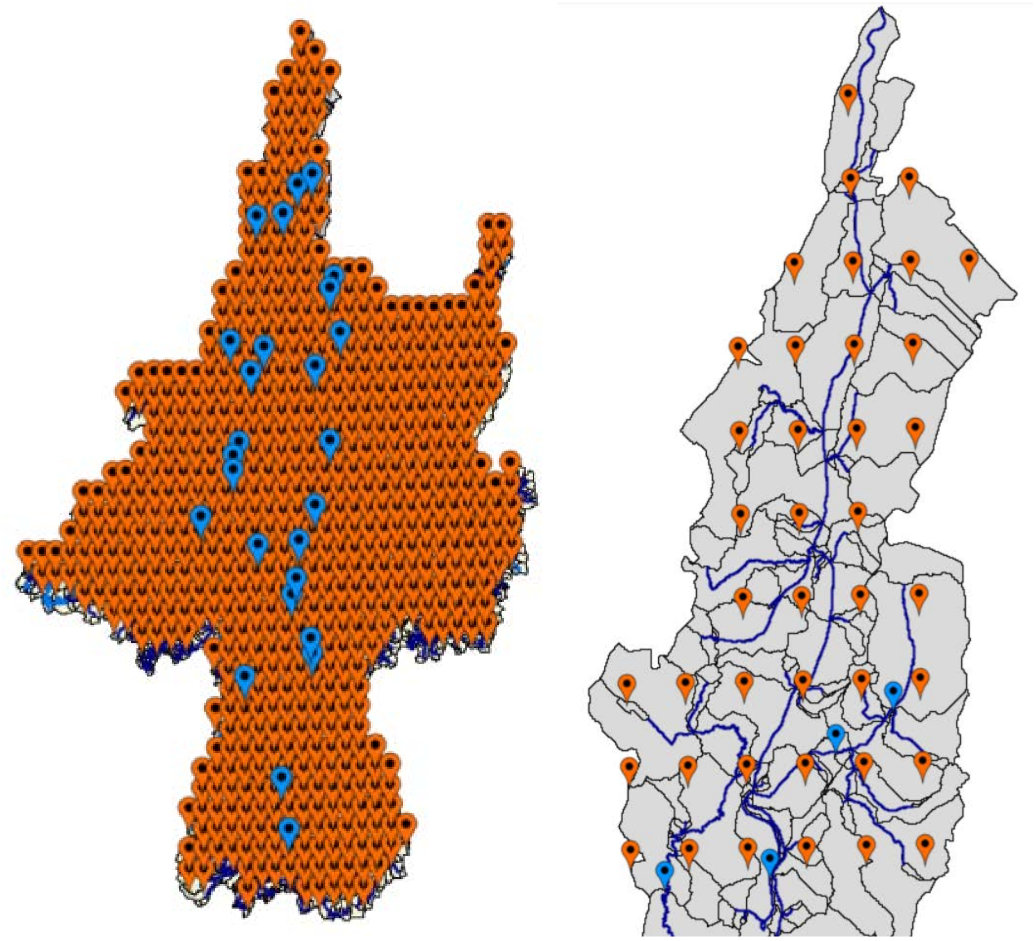


Figure 6: Watershed displayed within the main window (left) and zoom-in on the Northmost part of the watershed (right)

Blue and red pins localize the hydrometric and meteorological stations, respectively. The hydrographic network is represented by a network of blue interconnected lines while black lines show the RHHU delineations. The RHHUs displayed in grey are outside of the contributive area to the outlet reach (reach 119 in this set up). When RRHUs are within the drainage area, they appear in yellow as shown in Figure 7. Orange is reserved for the outlet currently considered, which is the Lake Champlain in this case.

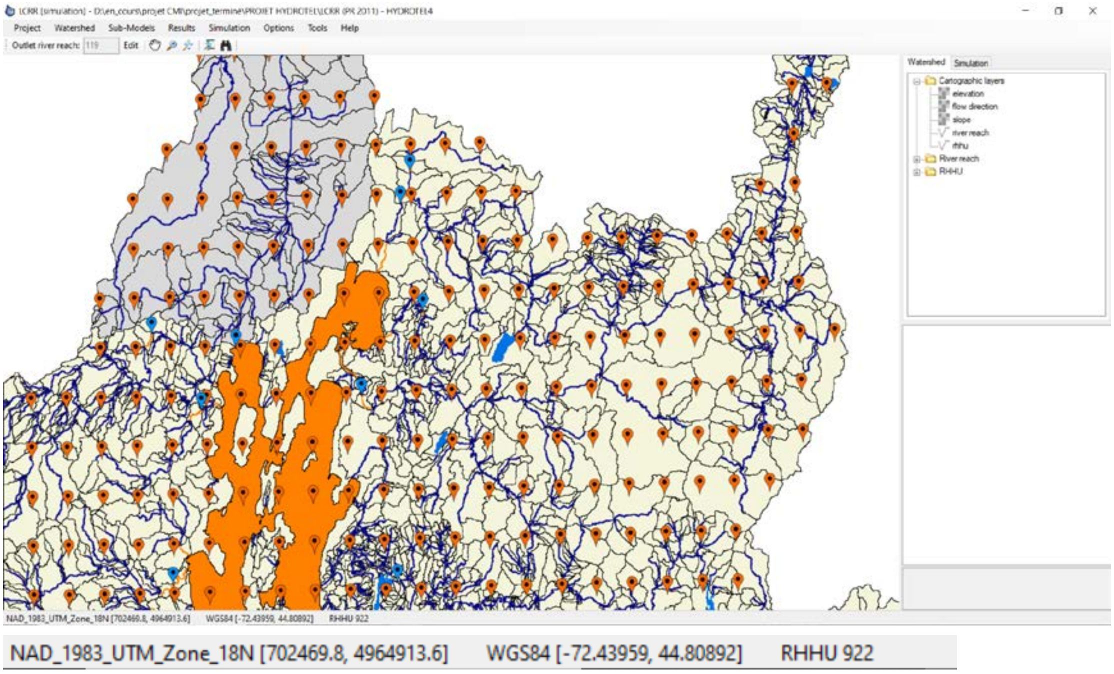


Figure 7: Main display window, discriminating between areas included within the current project's computation area.

Modifying the outlet reach can help decrease computation times as it allows the user not to model the whole system, but only part of it.

In the current project the outlet should not be placed downstream of Lake Champlain because of lake modeling accuracy and proper hydrologic model usage.

2.5 Detailed geographic information window

Selections within the main window are linked to the detailed geographic information window (5) as well as position in the geodesic system of use which is displayed at the bottom of the main window as shown in the zoomed-in portion at the bottom of Figure 7.

2.5.1 Reach selection and hydrometric stations connection

Selecting a reach within the main display window, as shown in Figure 8, will highlight all RHHUs upstream of that reach in light blue.

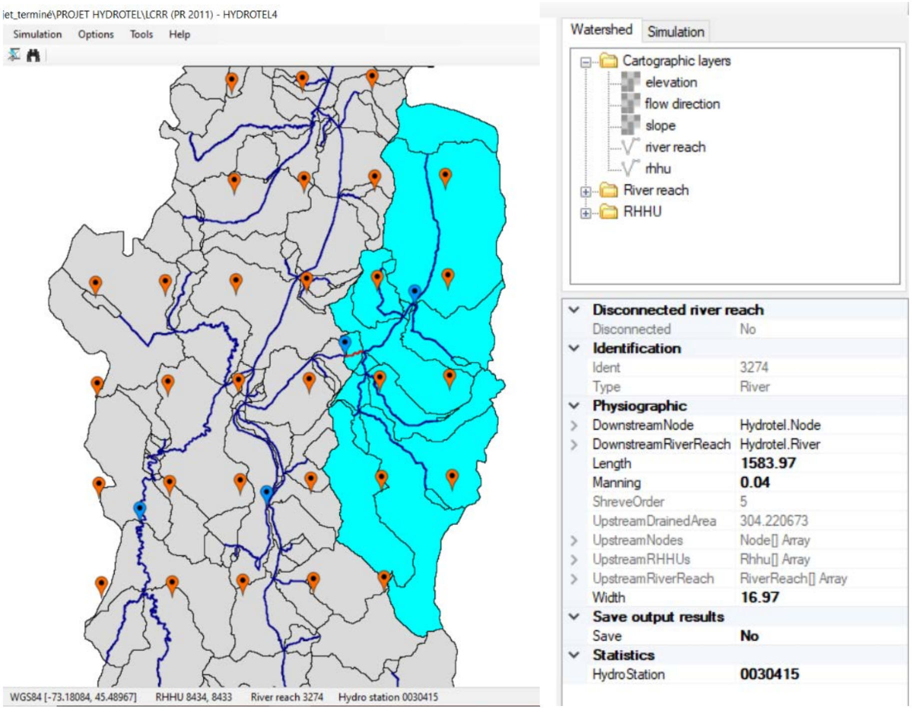


Figure 8: Selecting a river reach within the main display window in HYDROTEL

The detailed geographic information windows displays all information available for the specific reach selected that is whether the reach is connected to the overall hydrographic network, its identification and type (Figure 8, Ident: 3274, and type River), its physiographic properties, including its length (Figure 8, 1583.97 m), associated Manning coefficient (Figure 8, 0.04), Strahler order (Figure 8, 5), its upstream drained area (Figure 8, 304.220673 km^2) and its width (Figure 8, 16.97 m). It also indicates to the user whether the output results are specifically saved for this reach (Figure 8, no), and if a hydrometric station is associated with it (Figure 8, Hydrometric station 0030415 is associated with river reach 3274, but results are not saved). On the contrary, Figure 10 shows the detailed information of river reach 2331 which is associated with hydrometric station 420000 and which results are specifically saved.

To make it more efficient to access the list of the overall saved results, the user can access the Results menu, click on selected river reaches as shown in Figure 9 to make Figure 10 appear. It lists all river reaches for which results are saved and whether they are associated with a hydrometric station or not.

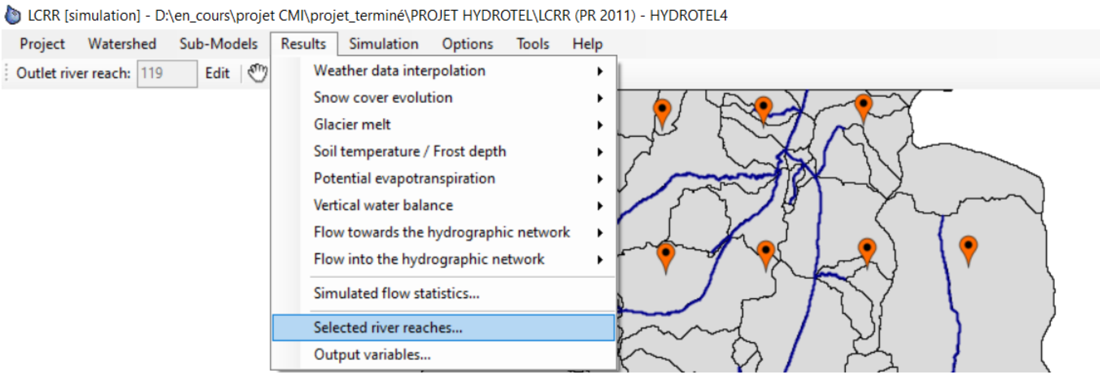


Figure 9: Accessing the list of all selected river reached for results saving in HYDROTEL

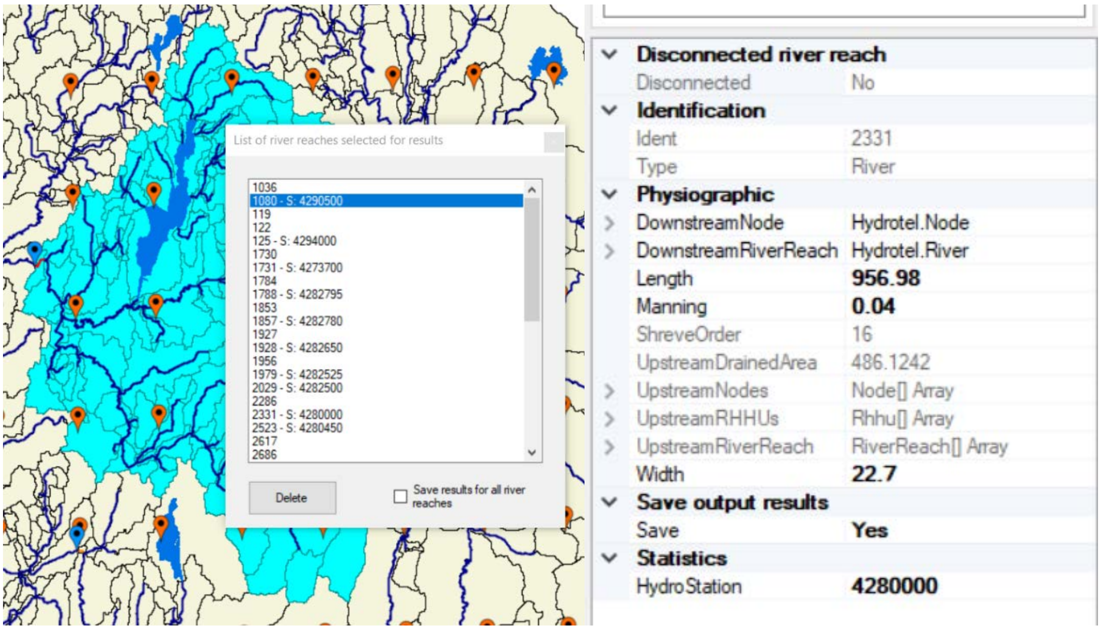


Figure 10: List of river reaches selected for results and whether they are associated with a hydrometric station in HYDROTEL

2.5.2 RHHU information

Like the reach information, the user can select a RHHU in the main display window and access its detailed information as shown in Figure 11

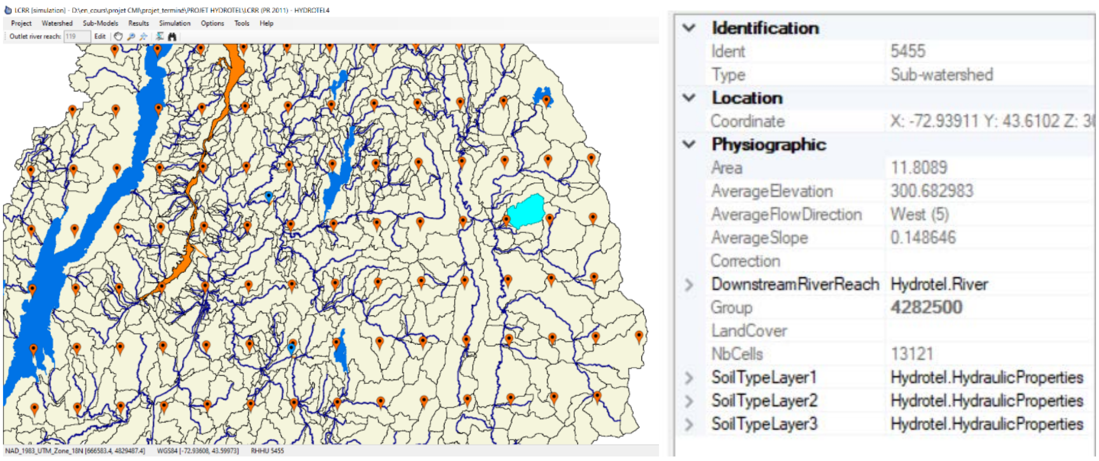


Figure 11: Accessing a RHHU detailed information in the main display window of HYDROTEL

The detailed geographic information windows displays all information available for the selected RHHU that is its identification and type (Figure 11, Ident: 3274, and type sub-watershed), centroid location (Figure 11, X=…,Y=, Z=), and physiographic properties including its area (Figure 11, 11.8089 km^2), average elevation (Figure 11,300.68 m), average flow direction (Figure 11,West) and slope (Figure 11, 0.15). It also indicates to users whether the RHHU is included in a subwatershed group (Figure 11, group 4282500), the number of base cells it is comprised of (Figure 11, 13121), and gives access to the hydraulic properties of its dominant Soil type (Figure 11, layers 1 to 3).

3 Input data

All input data are accessible via the project folders as shown in Figure 12. They include the "hydro", "meteo" and "physitel" folders. The latter contains all information computed and formatted for HYDROTEL by PHYSITEL. The list of files is available in Figure 13. The reader can refer to the PHYSITEL user manual for more information. As even the beginner users might need to update the content of the "hydro" and "meteo" folders, more details are provided in the following sections.

Figure 12: List of folders created for the HYDROTEL project structure.

> projet CMI > projet_terminé > PROJET HYDROTEL > LCRR (PR 2011) > physitel

Nom	Modifié le	Type	Taille
altitude.tif	4/6/2024 4:46 PM	Fichier TIF	263,008 Ko
lacs.dbf	3/20/2024 2:03 PM	Fichier DBF	1 Ko
lacs.prj	3/20/2024 2:03 PM	Fichier PRJ	1 Ko
lacs.shp	3/20/2024 2:03 PM	Fichier SHP	684 Ko
lacs.shx	3/20/2024 2:03 PM	Fichier SHX	1 Ko
ListUhrhAmont.csv	3/20/2024 2:03 PM	Fichier CSV Micros...	3,095 Ko
noeuds.nds	3/20/2024 2:03 PM	Fichier NDS	161 Ko
occupation_sol.cla	3/20/2024 2:03 PM	Fichier CLA	459 Ko
occupation_sol.csv	3/20/2024 2:03 PM	Fichier CSV Micros...	1 Ko
occupation_sol.tif	3/20/2024 2:03 PM	Fichier TIF	246,804 Ko
orientation.tif	3/20/2024 2:03 PM	Fichier TIF	246,804 Ko
pente.tif	3/20/2024 2:03 PM	Fichier TIF	246,804 Ko
point.rdx	3/20/2024 2:03 PM	Fichier RDX	27,871 Ko
proprietehydrolique.sol	3/20/2024 2:03 PM	Fichier SOL	2 Ko
rivieres.dbf	3/20/2024 2:03 PM	Fichier DBF	35 Ko
rivieres.prj	3/20/2024 2:03 PM	Fichier PRJ	1 Ko
rivieres.shp	3/20/2024 2:03 PM	Fichier SHP	4,611 Ko
rivieres.shx	3/20/2024 2:03 PM	Fichier SHX	26 Ko
troncon.trl	4/6/2024 5:06 PM	Fichier TRL	168 Ko
type_sol.cla	3/20/2024 2:03 PM	Fichier CLA	67 Ko
type_sol.tif	3/20/2024 2:03 PM	Fichier TIF	246,804 Ko
uhrh.csv	3/20/2024 2:03 PM	Fichier CSV Micros...	597 Ko
uhrh.dbf	3/20/2024 2:03 PM	Fichier DBF	108 Ko
uhrh.prj	3/20/2024 2:03 PM	Fichier PRJ	1 Ko
uhrh.shp	3/20/2024 2:03 PM	Fichier SHP	26,103 Ko
uhrh.shx	3/20/2024 2:03 PM	Fichier SHX	79 Ko
uhrh.tif	3/20/2024 2:03 PM	Fichier TIF	246,804 Ko

Figure 13: Physitel file list for a HYDROTEL project

3.1 Hydrometric station data (folder hydro)

The hydro folder contains data relative to the hydrometric stations of the watershed (Figure 14). Files are of two types, ".hyd" and ".sth". ".hyd" files contain hydrometric station data as shown in Figure 15, including dates and flows. The ".sth" contains the location of each hydrometric station as shown in Figure 16.

> projet CMI > projet_terminé > PROJET HYDROTEL > LCRR (PR 2011) > hydro

Nom	Modifié le	Type	Taille
0030401.hyd	3/20/2024 2:03 PM	Fichier HYD	611 Ko
0030415.hyd	3/20/2024 2:03 PM	Fichier HYD	316 Ko
0030421.hyd	3/20/2024 2:03 PM	Fichier HYD	276 Ko
0030423.hyd	3/20/2024 2:03 PM	Fichier HYD	140 Ko
0030424.hyd	3/20/2024 2:03 PM	Fichier HYD	125 Ko
0030425.hyd	3/20/2024 2:03 PM	Fichier HYD	123 Ko
0030429.hyd	3/20/2024 2:03 PM	Fichier HYD	92 Ko
4271500.hyd	3/20/2024 2:03 PM	Fichier HYD	461 Ko
4271815.hyd	3/20/2024 2:03 PM	Fichier HYD	162 Ko
4273500.hyd	3/20/2024 2:03 PM	Fichier HYD	455 Ko
4273700.hyd	3/20/2024 2:03 PM	Fichier HYD	396 Ko
4273800.hyd	3/20/2024 2:03 PM	Fichier HYD	151 Ko
4275500.hyd	3/20/2024 2:03 PM	Fichier HYD	466 Ko
4276500.hyd	3/20/2024 2:03 PM	Fichier HYD	461 Ko
4276842.hyd	3/20/2024 2:03 PM	Fichier HYD	162 Ko
4280000.hyd	3/20/2024 2:03 PM	Fichier HYD	439 Ko
4280450.hyd	3/20/2024 2:03 PM	Fichier HYD	164 Ko
4282500.hyd	3/20/2024 2:03 PM	Fichier HYD	453 Ko
4282525.hyd	3/20/2024 2:03 PM	Fichier HYD	163 Ko
4282650.hyd	3/20/2024 2:03 PM	Fichier HYD	162 Ko
4282780.hyd	3/20/2024 2:03 PM	Fichier HYD	162 Ko
4282795.hyd	3/20/2024 2:03 PM	Fichier HYD	162 Ko
4290500.hyd	3/20/2024 2:03 PM	Fichier HYD	458 Ko
4292500.hyd	3/20/2024 2:03 PM	Fichier HYD	456 Ko
4294000.hyd	3/20/2024 2:03 PM	Fichier HYD	170 Ko
APPORTS.hyd	3/20/2024 2:03 PM	Fichier HYD	1 Ko
station.sth	3/20/2024 2:03 PM	Fichier STH	2 Ko

Figure 14:Hydro file list for a HYDROTEL project

```
1	24
01/03/1990	10.7038
02/03/1990	13.6487
03/03/1990	13.4505
04/03/1990	9.8259
05/03/1990	5.9748
06/03/1990	5.3519
07/03/1990	3.9360
08/03/1990	4.0776
09/03/1990	4.3891
10/03/1990	6.0032
11/03/1990	13.5637
12/03/1990	11.0719
13/03/1990	15.4893
14/03/1990	14.6398
15/03/1990	7.6172
16/03/1990	6.1164
17/03/1990	6.1447
18/03/1990	8.8915
19/03/1990	5.2386
20/03/1990	6.8243
21/03/1990	9.9392
22/03/1990	7.9570
23/03/1990	11.6665
24/03/1990	7.8154
25/03/1990	5.8333
26/03/1990	5.0970
```

Normal text file | length : 165,880 lines : 8,708 | Ln : 1 C

Figure 15:.hyd file structure

Regarding the ".hyd" file structure shown in Figure 15, the reader should know that the first line indicates the HYDROTEL internal time step, 24 hr in this case. Separators are tabulations (could be spaces also), dates follow the DD/MM/YYYY format.

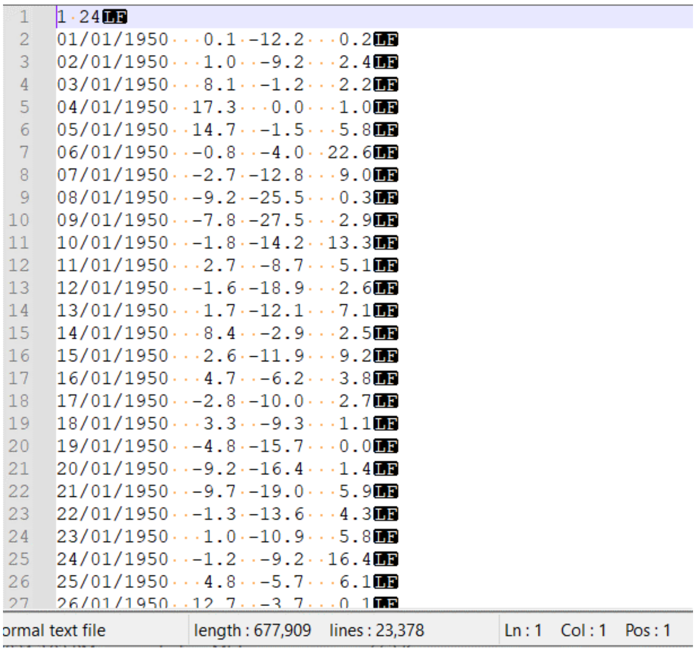
```
1   2
2   26
3   Produit par Physitel version 3.3.0.12
4   4271500 618157 4984044 53.2 3 @5 hydro
5   4271815 625135 4973311 36.4 3 @5 hydro
6   4273500 621165 4948725 53.0 3 @5 hydro
7   4273700 619380 4944062 70.2 3 @5 hydro
8   4273800 619363 4938969 74.4 3 @5 hydro
9   4275500 608008 4922906 154.8 3 @5 hydro
10  4276500 627947 4912927 47.9 3 @5 hydro
11  4276842 623298 4866634 67.3 3 @5 hydro
12  4280000 636191 4831516 44.6 3 @5 hydro
13  4280450 638799 4813761 97.5 3 @5 hydro
14  4282500 646821 4874954 107.6 3 @5 hydro
15  4282525 646478 4880348 84.3 3 @5 hydro
16  4282650 639882 4895361 46.1 3 @5 hydro
17  4282780 641402 4901073 50.4 3 @5 hydro
18  4282795 642086 4914516 47.9 3 @5 hydro
19  4290500 647986 4926748 74.7 3 @5 hydro
20  4292500 652718 4949117 95.0 3 @5 hydro
21  4294000 647686 4975396 38.8 3 @5 hydro
22  0030421 627528 5027598 29.9 3 @5 hydro
23  0030415 641758 5039048 20.0 3 @5 hydro
24  0030423 654511 5006866 47.9 3 @5 hydro
25  0030424 653200 5002418 39.9 3 @5 hydro
26  0030425 656301 4987303 59.3 3 @5 hydro
27  0030429 646583 5042617 27.3 3 @5 hydro
Normal text file    length : 1,088    lines : 30    Ln : 1    Col : 1    Pos : 1
```

Figure 16:.sth file structure

Regarding the ".sth" file structure shown in Figure 16, the reader should know that the first line depends on the geodetic reference system used, in this case the NAD83 datum. The second line informs the program that 26 stations are included within the file. Starting at line 4, the columns represent the station name, its X, Y, Z coordinates and a code 3@5 hydro indicating data are stored within a folder (code 3), whose name is comprised of 5 characters and is called "hydro". Separators are spaces (could be tabulations).

3.2 Meteorological station data (folder meteo)

The meteo folder contains data relative to the meteorological stations (or gridded data points) of the watershed. Files are of two types, ".met" and ".stm". ".met" files contain meteorological station data as shown in Figure 17, including dates, maximum and minimum temperatures, as well as total precipitations. The ".stm" file contains the location of each meteorological station as shown in Figure 18.

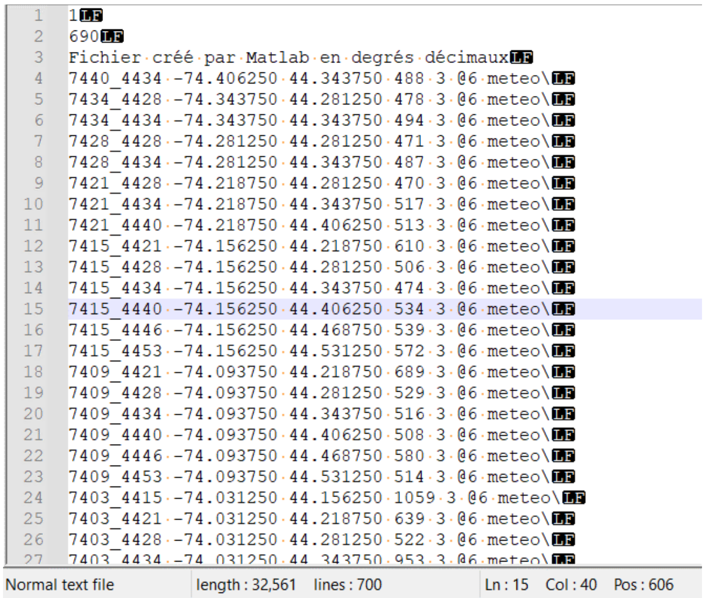


```
1 24
01/01/1950   0.1 -12.2   0.2
02/01/1950   1.0  -9.2   2.4
03/01/1950   8.1  -1.2   2.2
04/01/1950  17.3   0.0   1.0
05/01/1950  14.7  -1.5   5.8
06/01/1950  -0.8  -4.0  22.6
07/01/1950  -2.7 -12.8   9.0
08/01/1950  -9.2 -25.5   0.3
09/01/1950  -7.8 -27.5   2.9
10/01/1950  -1.8 -14.2  13.3
11/01/1950   2.7  -8.7   5.1
12/01/1950  -1.6 -18.9   2.6
13/01/1950   1.7 -12.1   7.1
14/01/1950   8.4  -2.9   2.5
15/01/1950   2.6 -11.9   9.2
16/01/1950   4.7  -6.2   3.8
17/01/1950  -2.8 -10.0   2.7
18/01/1950   3.3  -9.3   1.1
19/01/1950  -4.8 -15.7   0.0
20/01/1950  -9.2 -16.4   1.4
21/01/1950  -9.7 -19.0   5.9
22/01/1950  -1.3 -13.6   4.3
23/01/1950   1.0 -10.9   5.8
24/01/1950  -1.2  -9.2  16.4
25/01/1950   4.8  -5.7   6.1
```

ormal text file length : 677,909 lines : 23,378 Ln : 1 Col : 1 Pos : 1

Figure 17: met file structure

The ".met" file structure is equivalent to that of the hydrometric station data files (.hyd). The first line indicates the HYDROTEL internal time step, 24 hr in this case. Separators are tabulations (could be spaces also), dates follow the DD/MM/YYYY format. Data columns include the maximum and minimum temperatures as well as the total precipitation.



```
1
690
Fichier créé par Matlab en degrés décimaux
7440_4434 -74.406250 44.343750 488 3 @6 meteo\
7434_4428 -74.343750 44.281250 478 3 @6 meteo\
7434_4434 -74.343750 44.343750 494 3 @6 meteo\
7428_4428 -74.281250 44.281250 471 3 @6 meteo\
7428_4434 -74.281250 44.343750 487 3 @6 meteo\
7421_4428 -74.218750 44.281250 470 3 @6 meteo\
7421_4434 -74.218750 44.343750 517 3 @6 meteo\
7421_4440 -74.218750 44.406250 513 3 @6 meteo\
7415_4421 -74.156250 44.218750 610 3 @6 meteo\
7415_4428 -74.156250 44.281250 506 3 @6 meteo\
7415_4434 -74.156250 44.343750 474 3 @6 meteo\
7415_4440 -74.156250 44.406250 534 3 @6 meteo\
7415_4446 -74.156250 44.468750 539 3 @6 meteo\
7415_4453 -74.156250 44.531250 572 3 @6 meteo\
7409_4421 -74.093750 44.218750 689 3 @6 meteo\
7409_4428 -74.093750 44.281250 529 3 @6 meteo\
7409_4434 -74.093750 44.343750 516 3 @6 meteo\
7409_4440 -74.093750 44.406250 508 3 @6 meteo\
7409_4446 -74.093750 44.468750 580 3 @6 meteo\
7409_4453 -74.093750 44.531250 514 3 @6 meteo\
7403_4415 -74.031250 44.156250 1059 3 @6 meteo\
7403_4421 -74.031250 44.218750 639 3 @6 meteo\
7403_4428 -74.031250 44.281250 522 3 @6 meteo\
```

Normal text file length : 32,561 lines : 700 Ln : 15 Col : 40 Pos : 606

Figure 18: stm file structure

The ".stm" file is equivalent to that of the hydrometric station location files (.sth). It follows the same structure and lists all meteorological station locations (690 stations) as shown in Figure 18.

Note that for the LCRR HYDROTEL project is driven by gridded meteorological conditions from 1950 to 2013 (690 grid points located within the watershed limits – data from Livneh et al., 2015)

4 Computation

This section aims at explaining the setup used in the current HYDROTEL project for the user to be able to modify some of the most basic parameters. Advanced information, including calibration parameters will not be delved into. Most simulation parameters can be accessed via the simulation menu as shown in Figure 19.

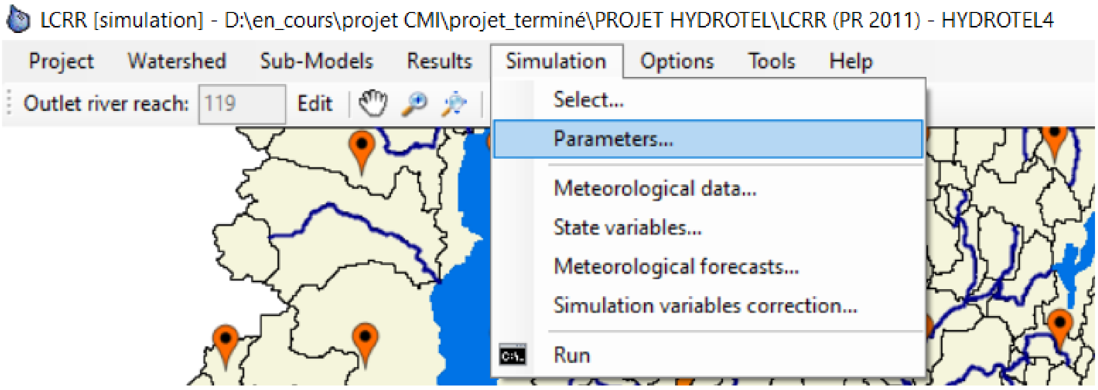


Figure 19:Simulation menu in HYDRTOTEL

Select options are mainly used by advanced user to navigate and create new and independent simulation

4.1 Main options for setting up a HYDROTEL simulation

The simulation parameters are shown in Figure 20. They include the temporal parameters (1), some miscellaneous options (2), the sub-model choices (3), the wetland computational options (4).

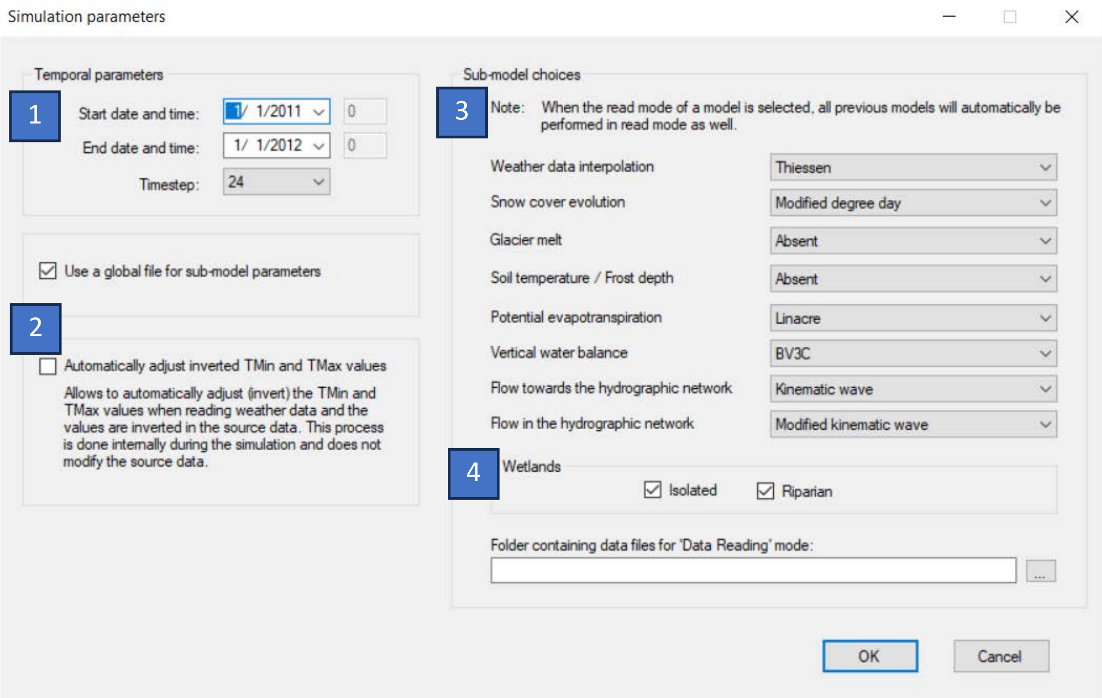


Figure 20:HYDROTEL simulation parameters, main computational options

4.1.1 Temporal parameters

Temporal parameters, shown in Figure 21, include the start and end date of the simulation period as well as the internal time step.

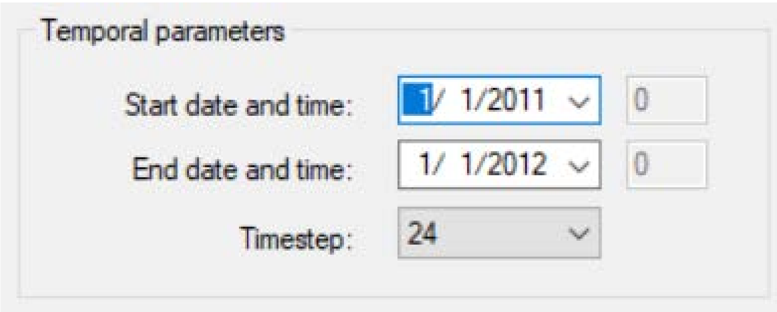


Figure 21: HYDROTEL simulation parameters, Temporal parameters

Temporal parameter must always refer to a period supported by meteorological data.

4.1.2 Miscellaneous options

The miscellaneous options, shown in Figure 22, include the optional use of a global file for sub-model parameters, this enables the grouping of all sub-models into one master .csv file instead of having to deal with multiple files. The second option is helpful for adjusting inverted TMin and TMax values from meteorological stations.

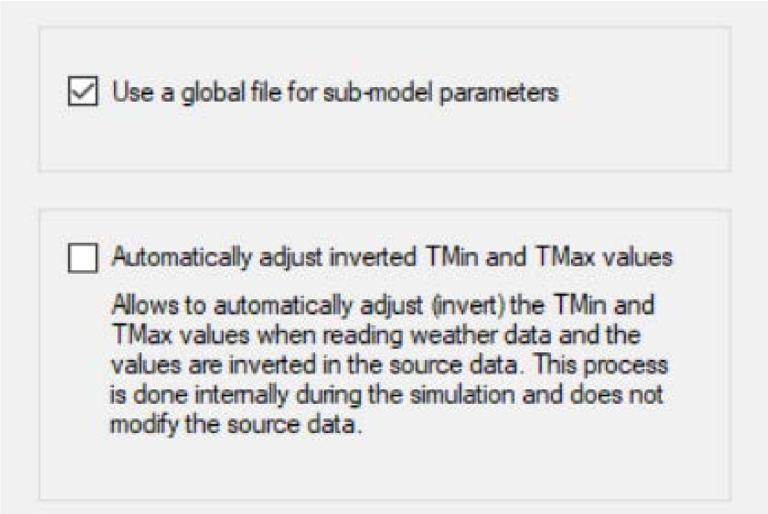


Figure 22: HYDROTEL simulation parameters, Miscellaneaous parameters

Do note modify the global file option, this is reserved for advanced users only.

4.1.3 Sub-models choices

The sub-model choices section, shown in Figure 23, allows the user to specify the computational models (i.e., algorithms) to be used (as presented in Table 1). As a beginner user, we do not recommend making any modifications.

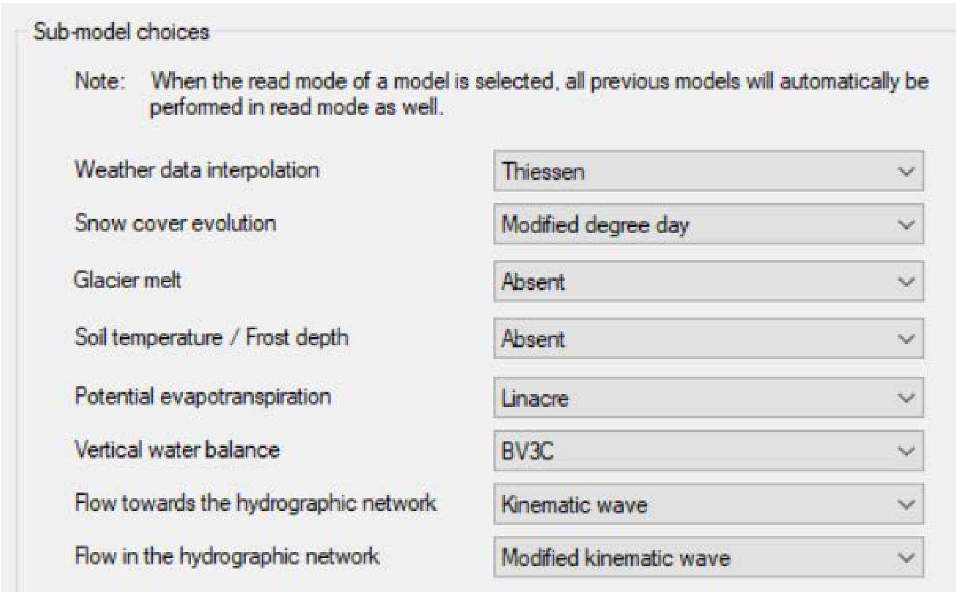


Figure 23: HYDROTEL simulation parameters, Sub-models selection

Modifying the sub-models' algorithms will result in default parameters being used, which will nullify the project calibration

4.1.4 Wetland options

The wetland options, shown in Figure 24, enable the user to enable/disable the consideration of wetlands during a simulation.

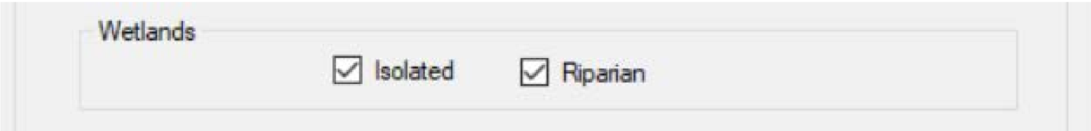


Figure 24: HYDROTEL simulation parameters, wetland consideration

Enabling/disabling the wetland consideration is used to assess the impact of wetlands (and their typology) on river flows or other internal hydrological processes. This is especially useful for restoration projects.

4.2 Starting the simulation

The run item from the simulation menu presented in Figure 19 allows the user to access the dialogue box presented in Figure 25 thus allowing to show/hide the simulation progress.

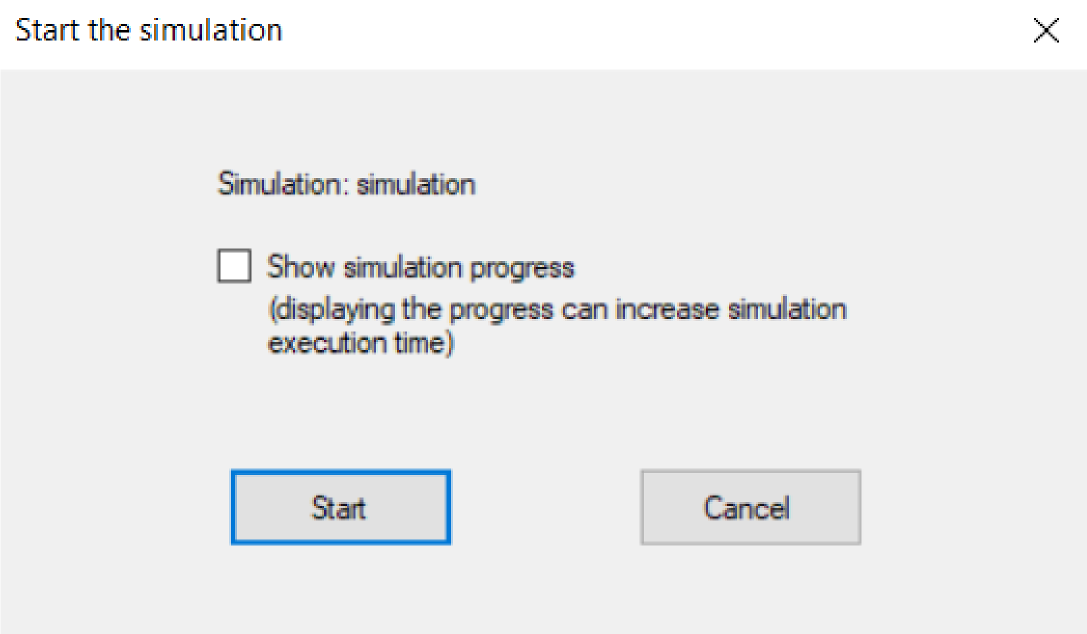


Figure 25:Starting the simulation, dialogue box

4.3 Spatial structure, RHHU grouping

The watershed menu, shown in Figure 27 allows the user to display the current RHHU groupings used to make the attribution of physiographic and sub-model parameters tailored to the actual knowledge of land use and soil types in the watershed. These groupings are also used in conjunction with hydrometric stations to allow for a more refined spatial calibration.

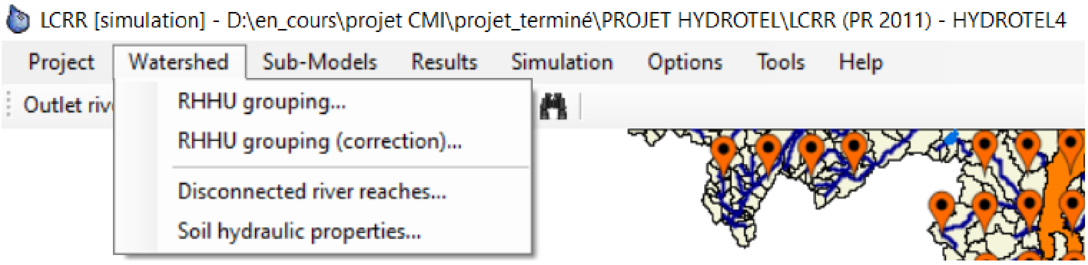


Figure 26: Watershed menu in HYDROTEL

Figure 27and Figure 28 show the RHHU groups associated with the LCRR basin, and the group named 4282795 after the ID number of the hydrometric station located downstream.

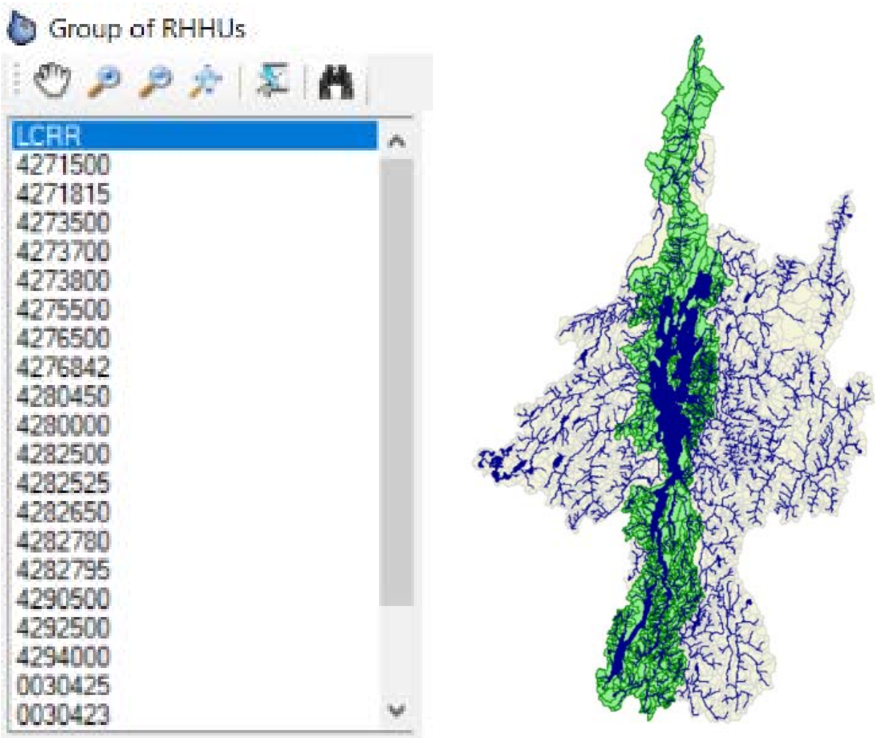


Figure 27:RHHU grouping options, window overview.

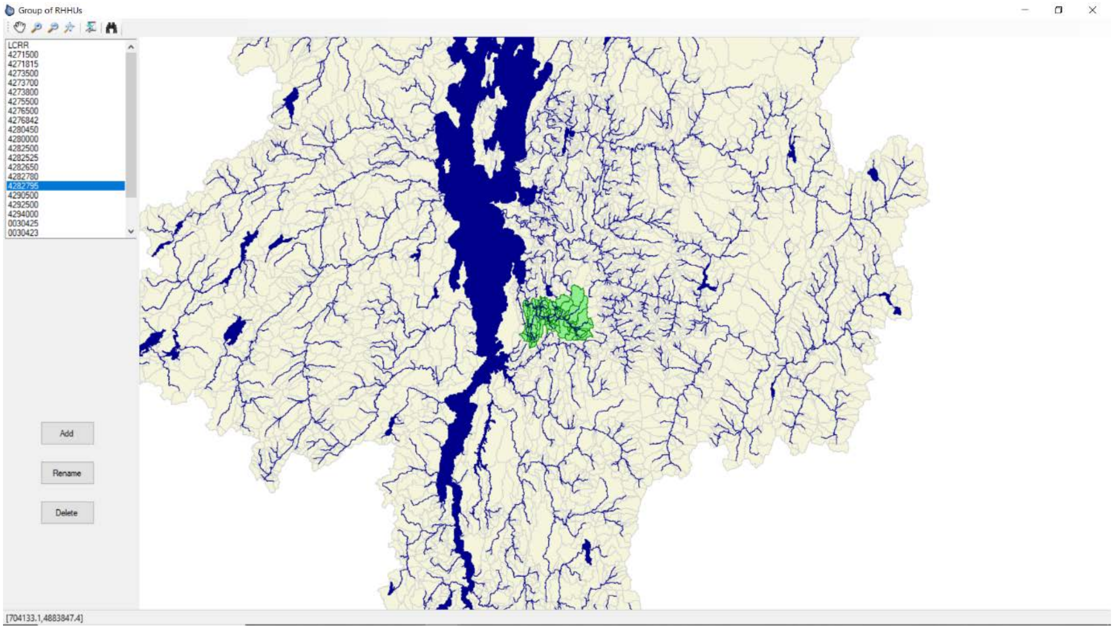


Figure 28: RHHU grouping delineation, RHHU group 4282795

Adding new hydrometric stations is one of the most common ways to discretize the watershed calibration further. When some new data are available, grouping RHHUs together within their specific contributive area helps updating the calibration in the proper geographic area.

4.4 Sub-model modifications

The menu Sub-models allows access to all the algorithm parameters used in each HYDROTEL sub-model as shown in Figure 29. For example, Weather data interpolation can be computed using either the Thiessen polygons, the three nearest station weighted mean, or a regular grid. As a reminder, Figure 30 shows where the actual algorithm choice needs to me made by the user.

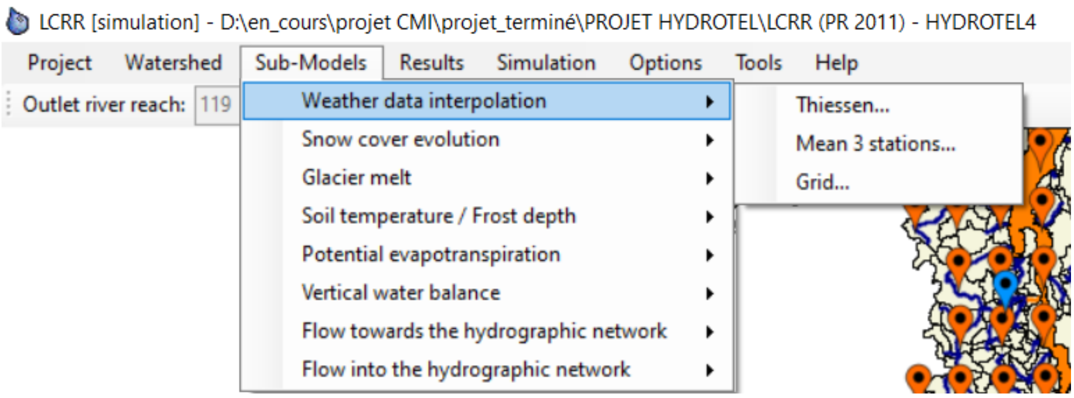


Figure 29:Sub-Models menu in HYDROTEL

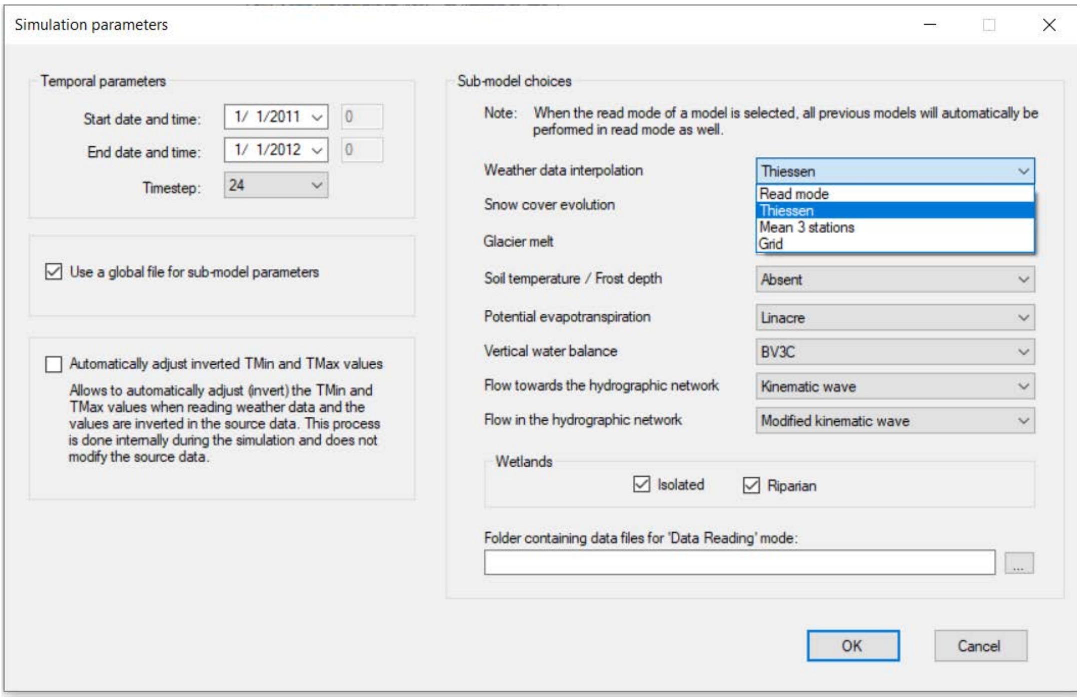


Figure 30: Sub model selection for HYDROTEL computations

We strongly recommend that beginner users refrain from switching algorithms and stick to navigating the model and its parameters.

5 Results

Modeling results can be accessed one of two ways: via the graphic interface using the Results menu, or via the HYDROTEL project folders, editing or copying the .csv files directly.

To be able to access specific results, these need to be saved using the Output variables sub-menu within the Results menu as shown in Figure 31 and Figure 32.

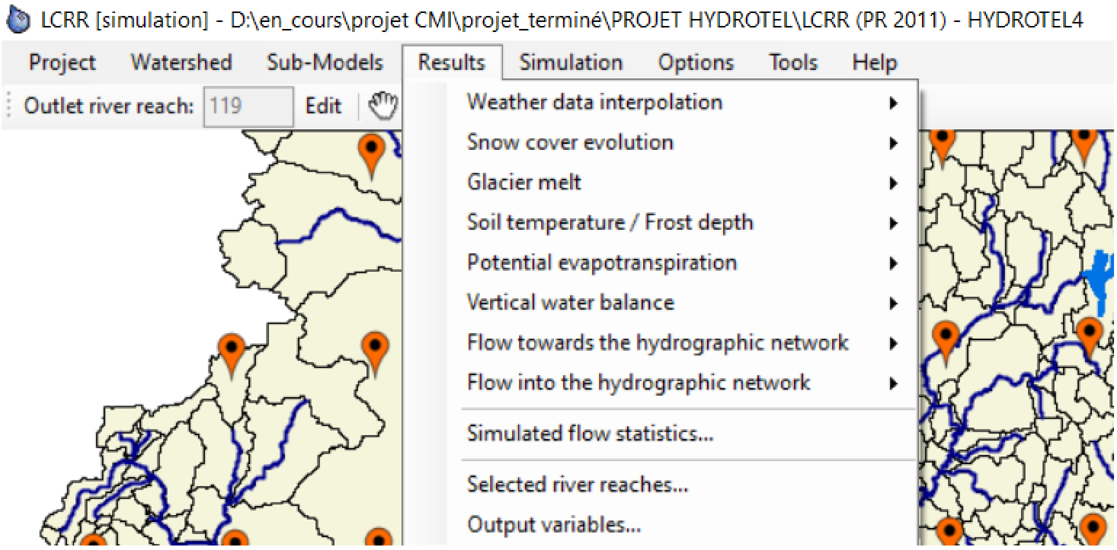


Figure 31:Results menu in HYDROTEL

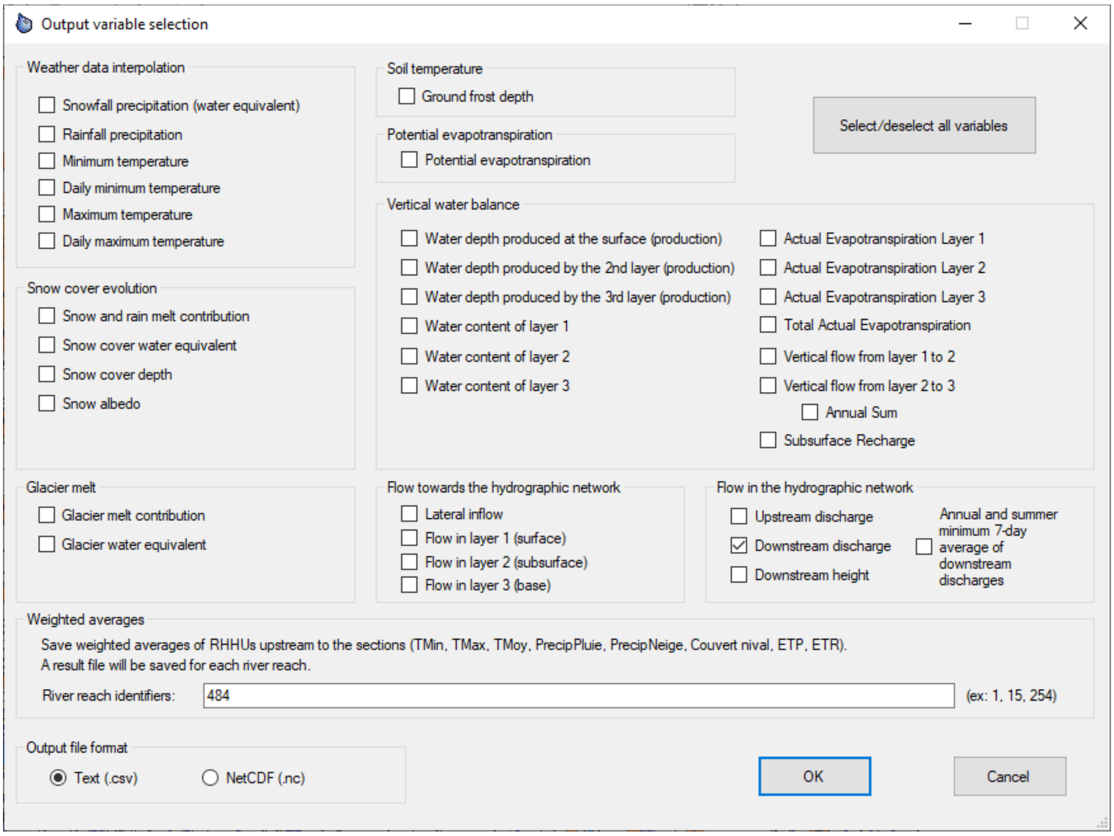


Figure 32: Output variable selection window

As Figure 32 clearly illustrates only the hydrographic network flows are saved within this project. This is why attempting to access any other result will display an error message.

5.1 Graphical user interface

If/when specific results are enabled to be saved by the user using the output variable selection window presented in Figure 32, the graphical interface allows to access all results and internal variables from each of the selected sub-models using charts or tables: weather data interpolation, snow cover evolution, glacier melt, soil temperature / frost depth, potential evapotranspiration, vertical water balance, flow towards the hydrographic network, flow into the hydrographic network. Figure 33, Figure 34, Figure 35, Figure 36, Figure 37, Figure 38, Figure 39 and Figure 40 respectively show the available internal sub-model variables.

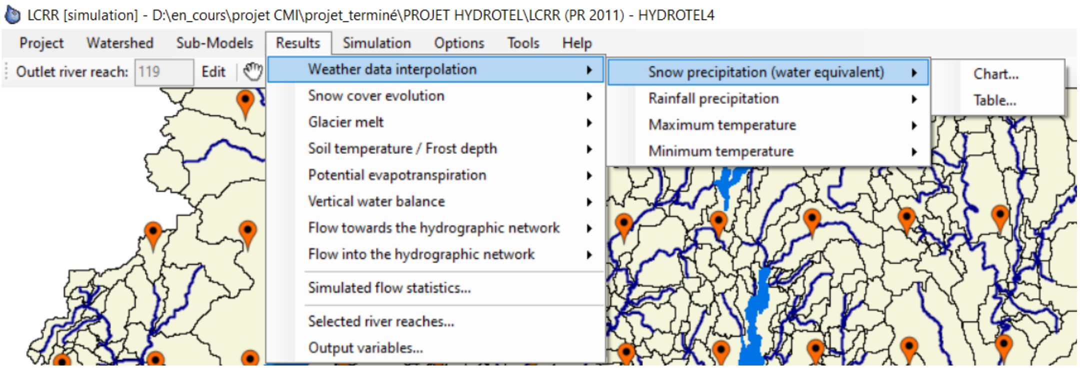


Figure 33: Accessing snow precipitation results in HYDROTEL.

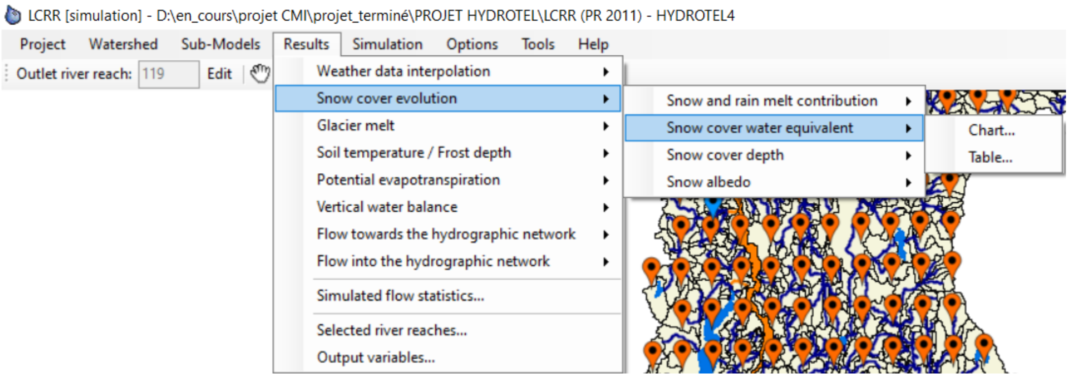


Figure 34: Accessing snow cover water equivalent results in HYDROTEL.

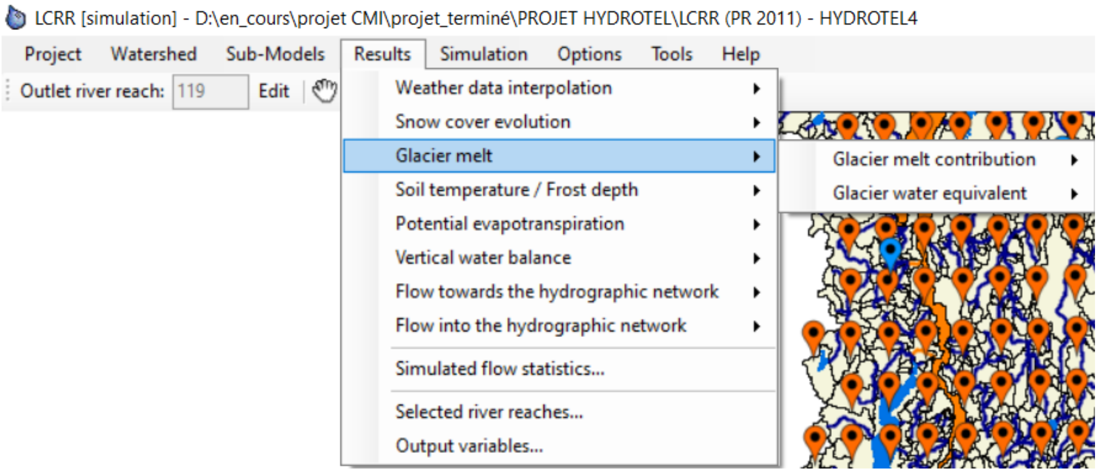


Figure 35: Accessing glacier melt results in HYDROTEL.

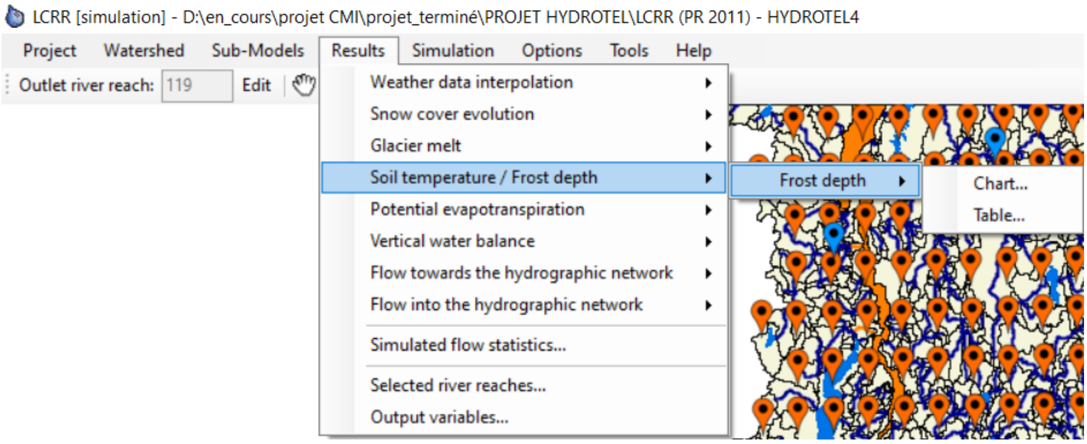


Figure 36: Accessing soil temperature/frost depth results in HYDROTEL.

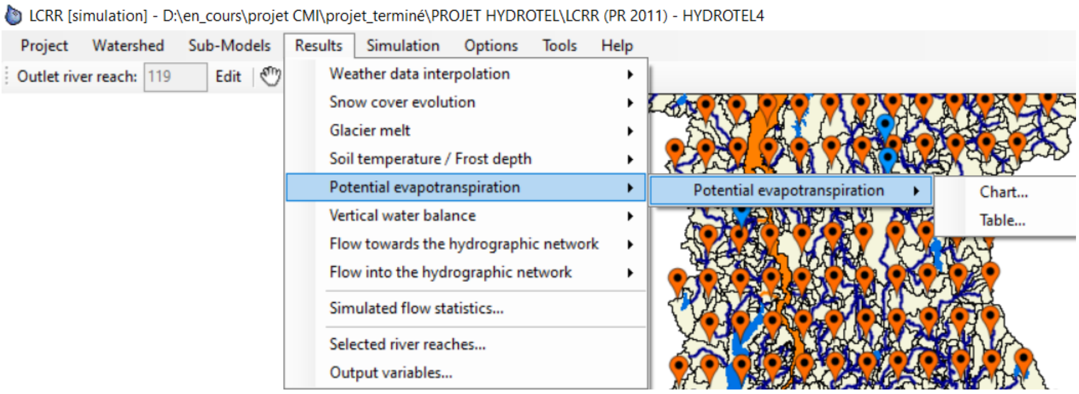


Figure 37: Accessing potential evapotranspiration results in HYDROTEL.

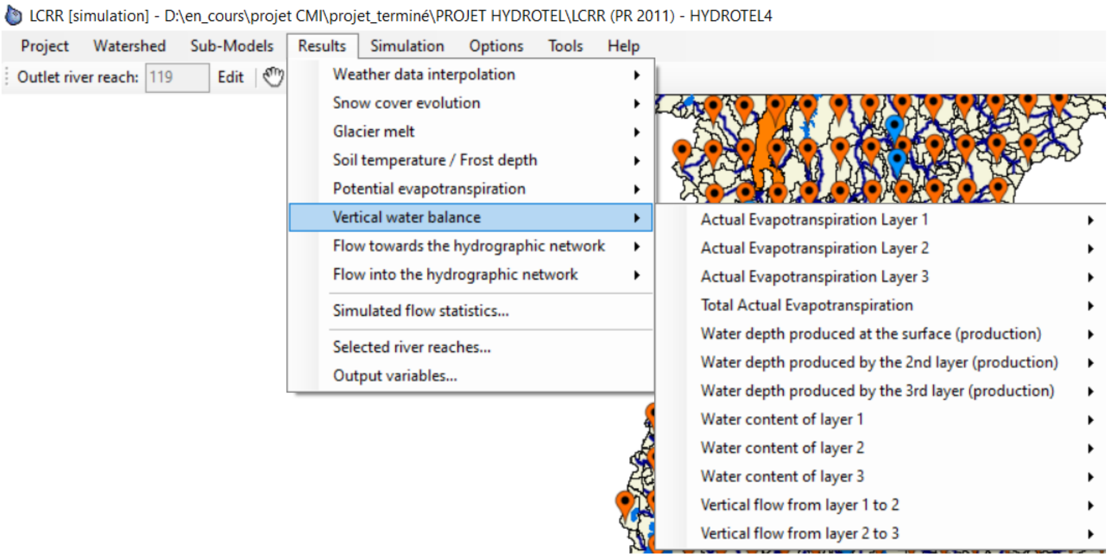


Figure 38: Accessing vertical water balance results in HYDROTEL.

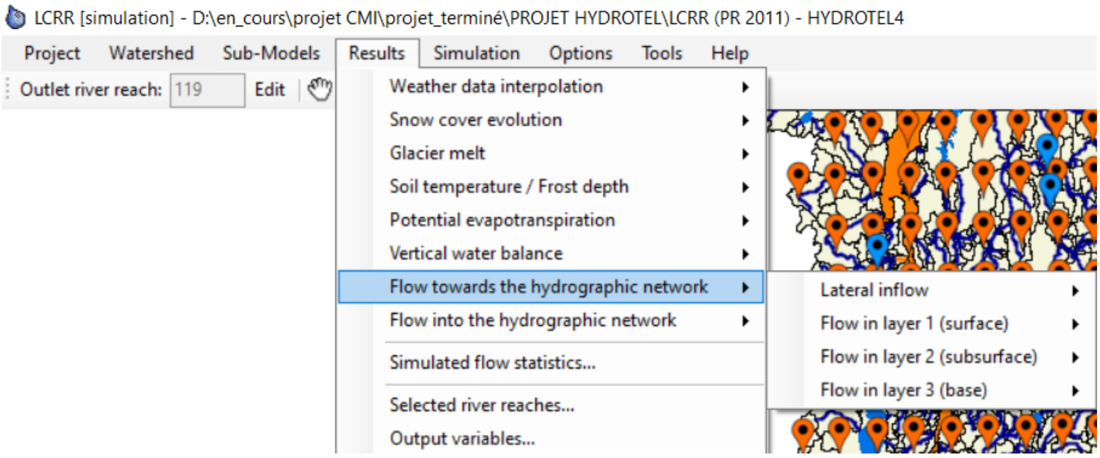


Figure 39: Accessing runoff results in HYDROTEL.

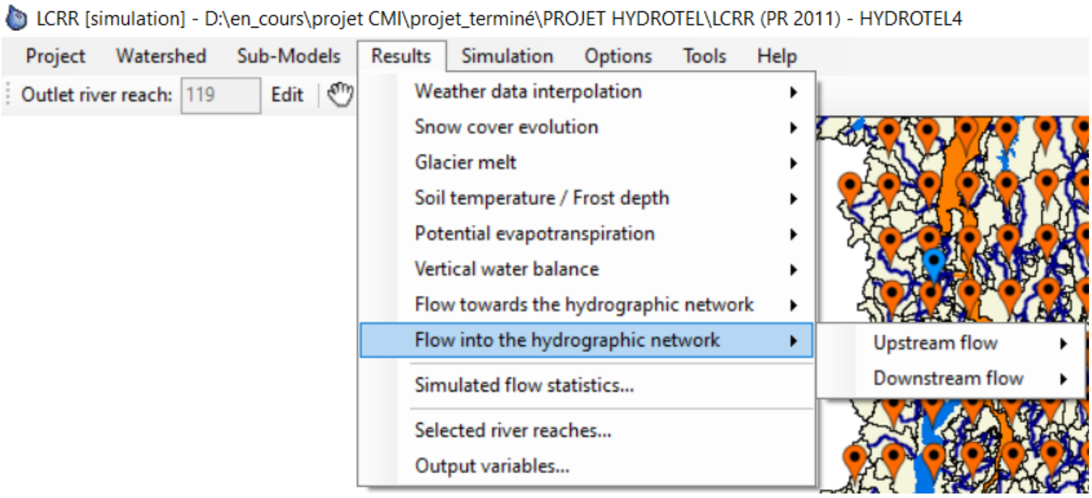


Figure 40: Accessing River flow results in HYDROTEL.

The graphical user interface lets you access flow statistics and simulated flows using the menu shown in Figure 33. Statistics are presented in Figure 41 in various subsections: the river reach selection window (1), the statistics for the chart period (2), the statistics for the overall period (3), the main flow display window (4), and the calibration assistance section (5).

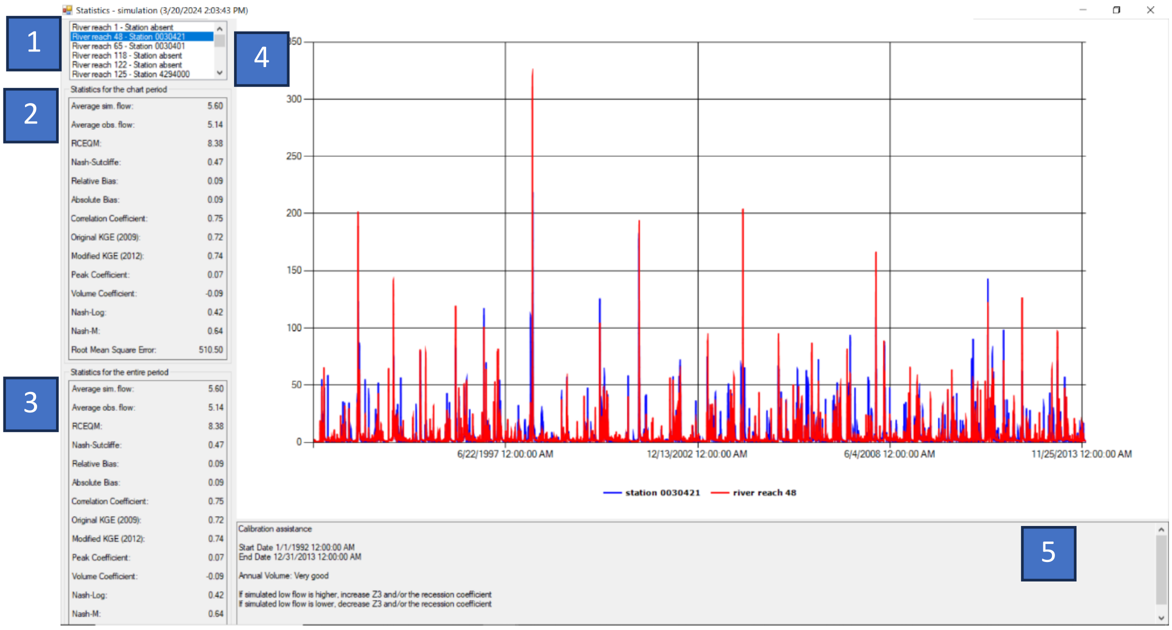


Figure 41: Simulated flow statistics, window overview

Figure 42 displays the river reach selection section that lets the user choose which river reach flow results to display in the main display window (4).

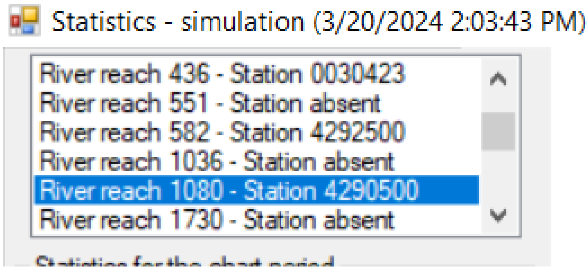


Figure 42: Simulated flow statistics, river reach selection

It is interesting to note that river reaches associated with hydrometric station will enable displaying both the modeled and observed flow data. Statistics are only provided for river reaches associated with a hydrometric station.

Figure 43 displays the statistics for the chart period (2) and the statistics for the overall period (3). They are the same since we displayed the entire period within the main window (4). To select a specific time period, drag the mouse cursor over the period of interest while holding the left click. These statistics show the calibration performance attained at each reach associated with a hydrometric station. In this case Figure 43 exhibits really good results for river reach 1080, station 429050000 with Nash-Stucliffe value close to 0.7, KGE values above 0.8 and Nash-log values above 0.82. The calibration assistance section (5) shown in Figure 45 supports this performance, stating that the annual volume representation is very good and giving some advice for possibly modifying some of the BV3C (vertical water balance module) parameters (for advanced user only). Finally, Figure 44 displays modeled flows in red, observed flows in blue. Their behavior is extremely similar which demonstrates that a proper calibration of this reach was achieved.

Statistics for the chart period

Average sim. flow:	56.95
Average obs. flow:	57.29
RCEQM:	38.11
Nash-Sutcliffe:	0.68
Relative Bias:	-0.01
Absolute Bias:	0.01
Correlation Coefficient:	0.84
Original KGE (2009):	0.84
Modified KGE (2012):	0.84
Peak Coefficient:	0.03
Volume Coefficient:	0.01
Nash-Log:	0.82
Nash-M:	0.71
Root Mean Square Error:	39.95

Statistics for the entire period

Average sim. flow:	56.95
Average obs. flow:	57.29
RCEQM:	38.11
Nash-Sutcliffe:	0.68
Relative Bias:	-0.01
Absolute Bias:	0.01
Correlation Coefficient:	0.84
Original KGE (2009):	0.84
Modified KGE (2012):	0.84
Peak Coefficient:	0.03
Volume Coefficient:	0.01
Nash-Log:	0.82
Nash-M:	0.71

Figure 43: Simulated flow statistics, statistics windows for the chart period and entire period at river reach 1080

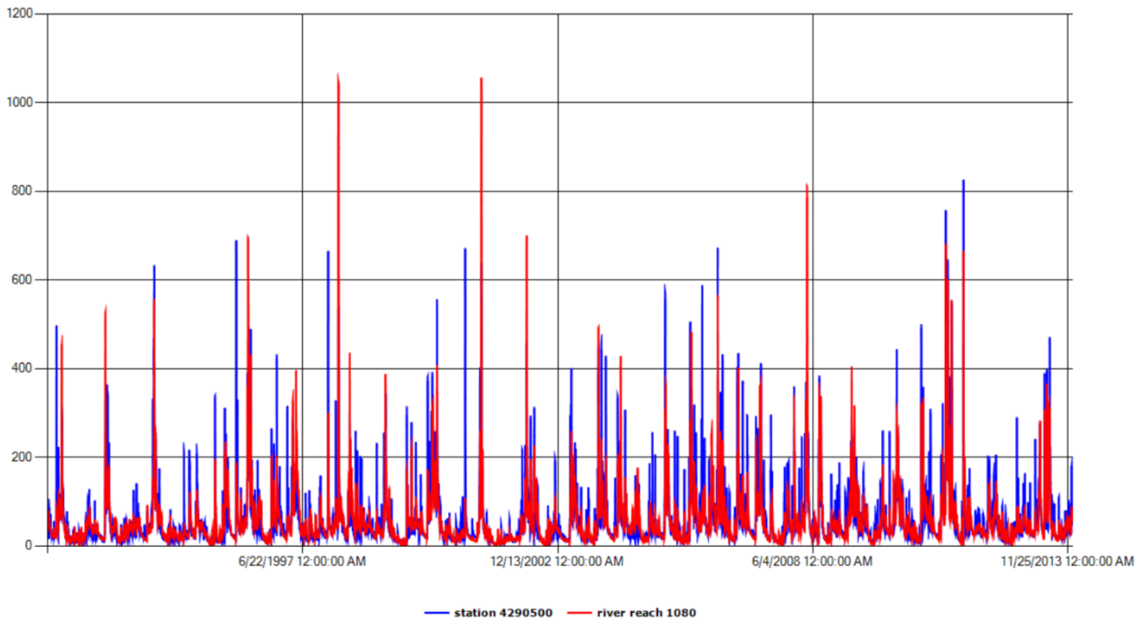


Figure 44: Simulated flow statistics, modeled and observed flows for river reach 1080 – Station 4290500

Calibration assistance

Start Date 1/1/1992 12:00:00 AM
End Date 12/31/2013 12:00:00 AM

Annual Volume: Very good

If simulated low flow is higher, increase Z3 and/or the recession coefficient
If simulated low flow is lower, decrease Z3 and/or the recession coefficient

Figure 45: Simulation flow statistics, calibration assistance window

5.2 Accessing detailed results database

If/when users needs to access actual model results, they then need to locate and edit the results files. They are located in the simulation-“simulation name” folders of the HYDROTEL folder architecture as shown in Figure 46.

> projet CMI > projet_terminé > PROJET HYDROTEL > LCRR (PR 2011) > simulation > simulation

Nom	Modifié le	Type	Taille
resultat	3/20/2024 2:03 PM	Dossier de fichiers	
degre_jour_modifie_glacier.csv	3/20/2024 2:03 PM	Fichier CSV Micros...	298 Ko
milieux_humides_isoles.csv	3/20/2024 2:03 PM	Fichier CSV Micros...	261 Ko
milieux_humides_riverains.csv	3/20/2024 2:03 PM	Fichier CSV Micros...	223 Ko
output.csv	4/6/2024 5:06 PM	Fichier CSV Micros...	1 Ko
parametres_sous_modeles.csv	4/6/2024 5:06 PM	Fichier CSV Micros...	13 Ko
simulation.csv	4/6/2024 5:06 PM	Fichier CSV Micros...	3 Ko
simulation.gsb	4/6/2024 5:05 PM	Fichier GSB	70 Ko
stats.txt	4/6/2024 5:06 PM	Document texte	1 Ko
troncons_stations.csv	4/6/2024 5:06 PM	Fichier CSV Micros...	1 Ko

Figure 46:Accessing the detailed result files.

This results folder (resultat) includes all saved data during the model computation (Figure 47,downstream flows at selected reaches, weighted means meteorological condition for river reach number 484 upstream watershed, observed and simulated flows at saved hydrometric locations, flow statistics). They are given as .csv files and use a common structure.

> projet CMI > projet_terminé > PROJET HYDROTEL > LCRR (PR 2011) > simulation > simulation > resultat

Nom	Modifié le	Type	Taille
debit_aval.csv	3/20/2024 2:03 PM	Fichier CSV Micros...	3,636 Ko
moyennes-ponderees-troncon484.csv	3/20/2024 2:03 PM	Fichier CSV Micros...	385 Ko
obs-sim-flows.csv	3/20/2024 2:03 PM	Fichier CSV Micros...	5,382 Ko
stats.csv	3/20/2024 2:03 PM	Fichier CSV Micros...	5,328 Ko
wetland_isole.csv	3/20/2024 2:03 PM	Fichier CSV Micros...	0 Ko
wetland_riverain.csv	3/20/2024 2:03 PM	Fichier CSV Micros...	0 Ko

Figure 47:Result files available for the current HYDROTEL project

We strongly recommend the users to copy-paste any results file to be edited outside of the current HYDROTEL results folder.

No results have been saved for isolated and riparian wetlands, resulting in empty csv files

The common file structure is standard. It uses “;” as separator and usually include a header line describing the column headers. Figure 48 shows a portion of the weighted area at river reach 484 file where data include the date, time, minimum temperature, maximum temperature, average temperature, rainfall, snowfall, Snow water equivalent (EEN) and potential evapotranspiration from 01-01-1992 to 31-12-2013 for RHHU upstream or river reach 484, that is RHHUs 1349, 1350 and 1351.

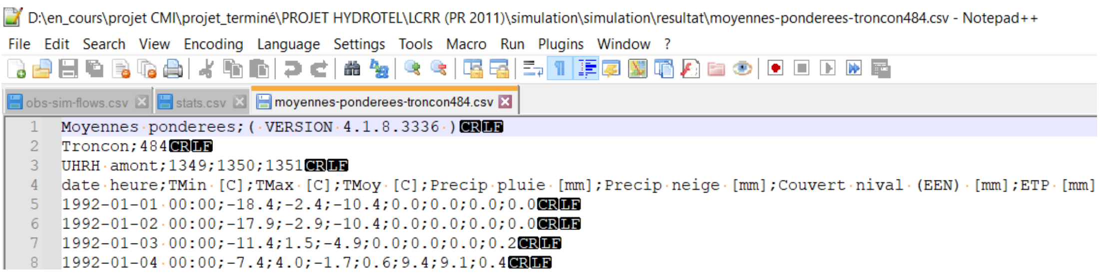
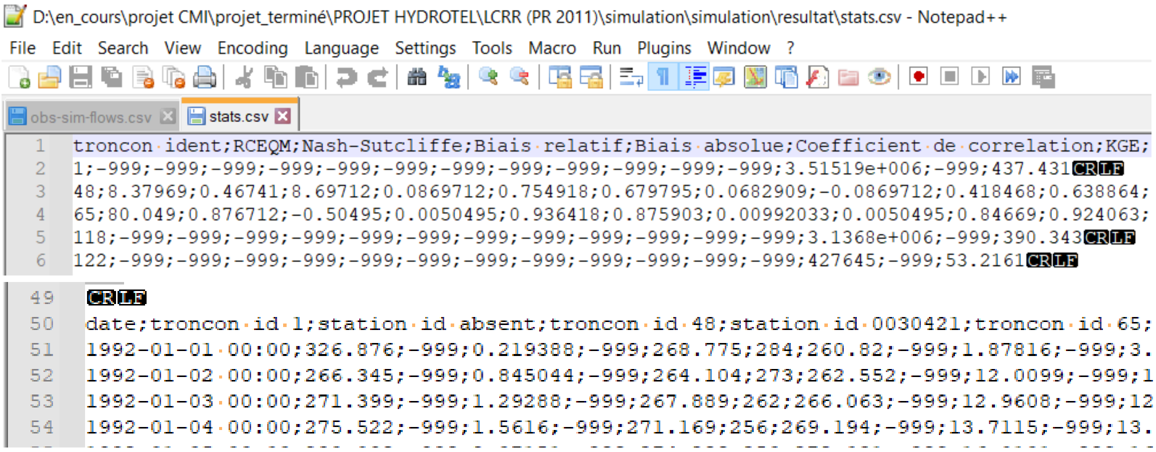


Figure 48: Weighted means upstream of river reach 484 .csv file.

Figure 49 shows a portion of the flow statistics file, including the river reach identification number, the RCEQM (root mean squared error), the Nash-Sutcliffe, the relative bias, the absolute bias, the correlation coefficient, the KGE, the peak factor, the volume coefficient, the Nash-log, the Nash-M., the mean squared deviation, the summation of observed values, the summation of modeled values, the mean of observations and the mean of modeled flows for each of the 47 selected reaches (1, 48, 65, 118, 122, 125, 400, 412, 432, 434, 436, 551, 582, 1036, 1080, 1730, 1731, 1784, 1788, 1853, 1857, 1927, 1928, 1956, 1979, 2029, 2286, 2331, 2525, 2617, 2686, 2690, 2734, 2735, 2801, 2809, 2966, 2967, 2982, 2983, 3118, 3127, 3131, 3141, 3149, 1274, 3280). These flow statistics are followed by the observed and modeled flow values for each of the reaches from 1992-01-01 to 2013-12-31 to let the user compute its own metrics as needed.



D:\en_cours\projet CMI\projet_terminé\PROJET HYDROTEL\LCRR (PR 2011)\simulation\simulation\resultat\stats.csv - Notepad++

File Edit Search View Encoding Language Settings Tools Macro Run Plugins Window ?

obs-sim-flows.csv stats.csv

```
1  troncon ident;RCEQM;Nash-Sutcliffe;Biais relatif;Biais absolue;Coefficient de correlation;KGE;
2  1;-999;-999;-999;-999;-999;-999;-999;-999;-999;-999;-999;-999;3.51519e+006;-999;437.431CRLF
3  48;8.37969;0.46741;8.69712;0.0869712;0.754918;0.679795;0.0682909;-0.0869712;0.418468;0.638864;
4  65;80.049;0.876712;-0.50495;0.0050495;0.936418;0.875903;0.00992033;0.0050495;0.84669;0.924063;
5  118;-999;-999;-999;-999;-999;-999;-999;-999;-999;-999;-999;-999;3.1368e+006;-999;390.343CRLF
6  122;-999;-999;-999;-999;-999;-999;-999;-999;-999;-999;-999;-999;427645;-999;53.2161CRLF

49 CRLF
50 date;troncon id 1;station id absent;troncon id 48;station id 0030421;troncon id 65;
51 1992-01-01 00:00;326.876;-999;0.219388;-999;268.775;284;260.82;-999;1.87816;-999;3.
52 1992-01-02 00:00;266.345;-999;0.845044;-999;264.104;273;262.552;-999;12.0099;-999;1
53 1992-01-03 00:00;271.399;-999;1.29288;-999;267.889;262;266.063;-999;12.9608;-999;12
54 1992-01-04 00:00;275.522;-999;1.5616;-999;271.169;256;269.194;-999;13.7115;-999;13.
```

Figure 49: flow statistics .csv file.

Note that re-starting the simulation will account for changes in simulation parameters and will end up overwriting the corresponding results. Advanced users can prevent such overwriting procedure by using simulations creation and selection tool.