River Network Toolkit Manual

June 18

Introduction

RivTool is an innovative software that integrates river network information with environmental data. Designed to be a straightforward and user-friendly software it facilitates: (1) obtaining information that characterises the network based only on its topographic structure; and (2) by linking environmental data to freshwater networks acquire new data through mathematical calculations that account for the hierarchical nature of these systems. The software is table driven and was developed to work with two distinct basic units: segment and sub-basin.

Disclaimer – Terms & Conditions

The current version is continuously under testing and improvement. Also, we are continuously improving existing features and correcting minor details, please make sure you have the latest version.

The River Network Toolkit is a free software, provided "as-is" and does not come with any warranty or guarantee of any kind. It may be used at your own risk and authors will not be held responsible for its incorrect installation and/or use.

All comments, suggestions and questions may be sent to info@rivtoolkit.com.

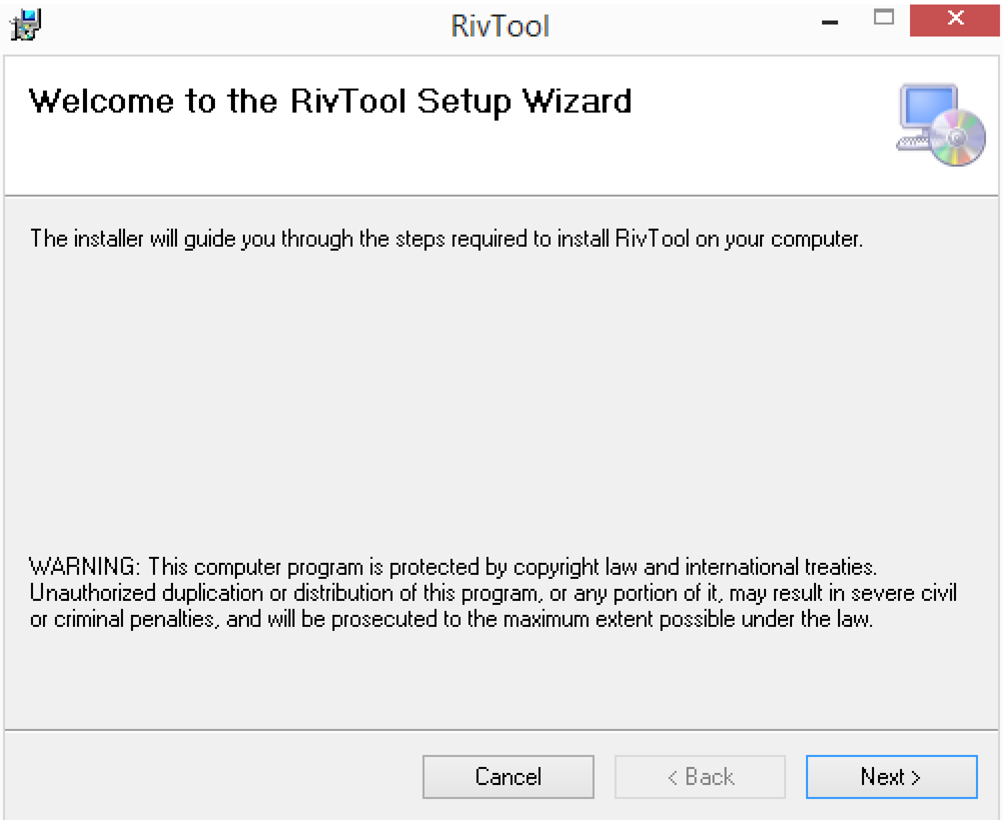
System

Requirements

- RivTool runs under Microsoft .NET framework 4.5.2. If you don’t have this installed, the setup will download and install it automatically.
- It has a version for 32-bit systems and another for 64-bit systems. We recommend using a 64-bit system due to the increased memory addressability. Users with 32-bit systems might run into out-of-memory problems when using large input files.
- We recommend 4GB RAM or higher. Be aware that a 32-bit system only uses a maximum of 3GB RAM.
- To achieve a faster calculation, the tool uses parallel processing. This type of processing uses all available processor resources. With this in mind, we recommend a 2-core computer or higher.

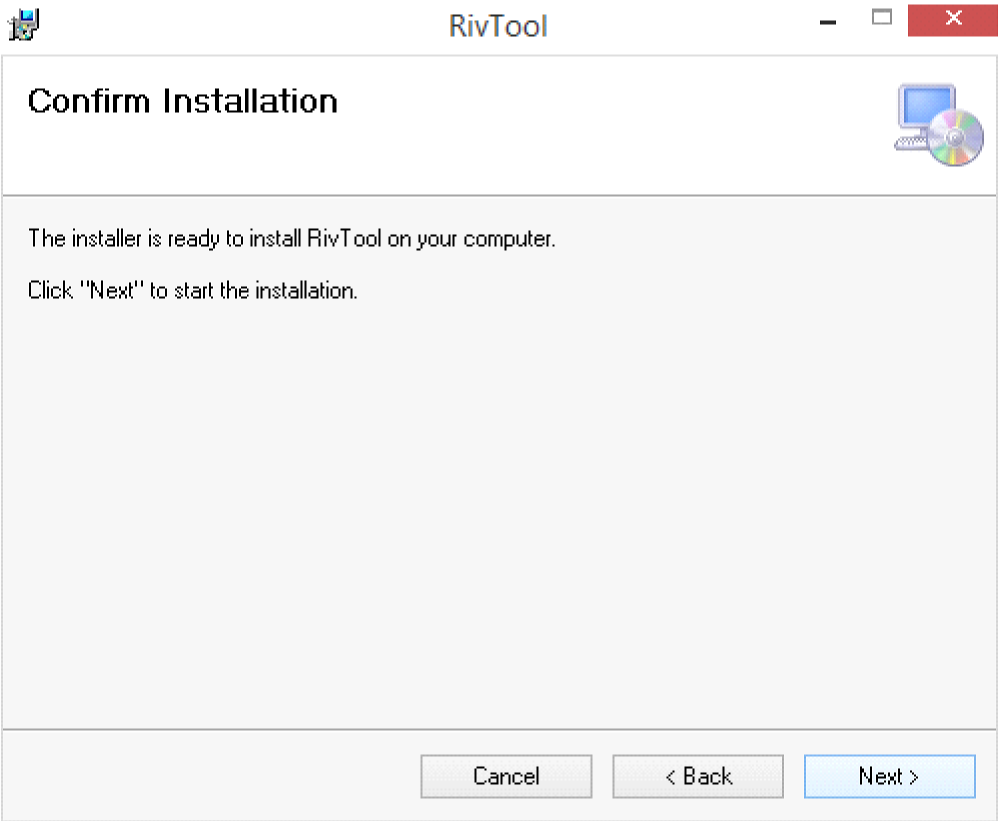
Installation procedure

RivTool is very easy to install. After you download the setup file – RivTool.msi – please execute and proceed with the installation.

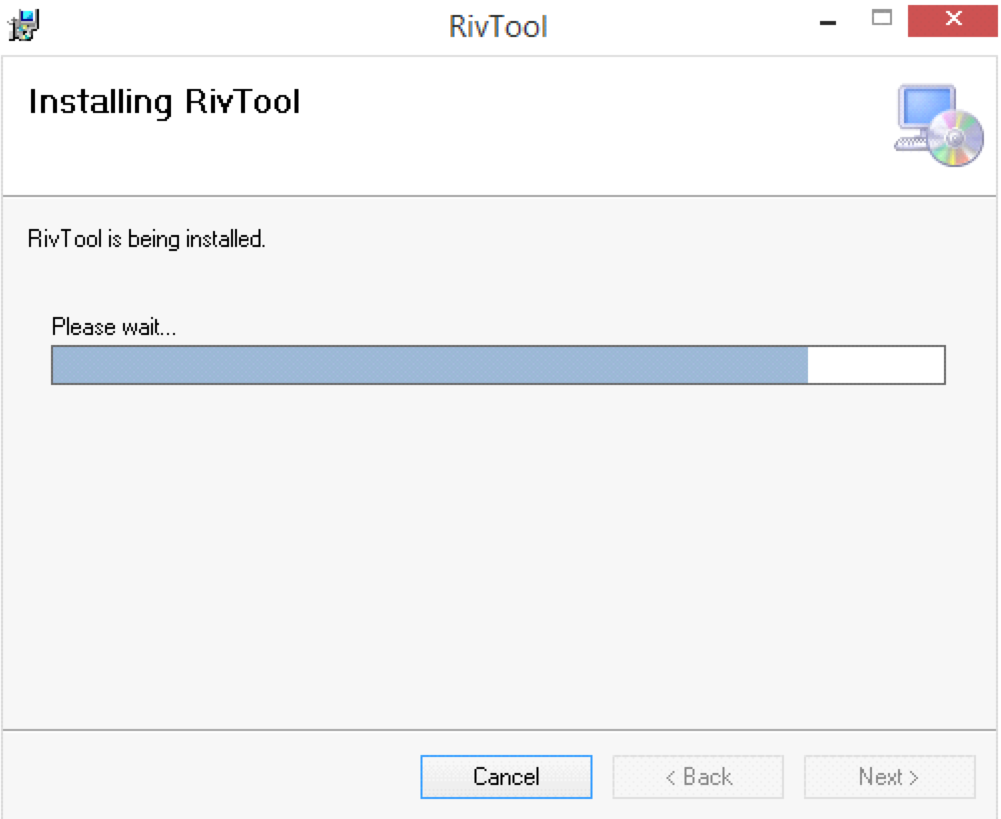


Click 

button to proceed with the setup.



Click  button to confirm the installation process and the setup will finish.



When the installation finishes, a desktop icon will be created as well as a shortcut folder in your Windows start menu.

Upgrading procedure

After downloading the new version of RivTool and before installing it please uninstall the previous release.

The workspace folder will <u>not be erased</u>, but just for safe keeping please <u>backup your workspace environment</u>.

Folder structure

RivTool

- fns *(functions images)*
- Help *(help documents)*
- Images *(images used in the application)*
- Library *(library files folder)*
    - Data *(data files)*
        - CCM *(CCM data files)*
            - Segments *(CCM data files)*
            - Sub-basins *(CCM data files)*
        - ECRINS *(ECRINS data files)*
            - Segments *(CCM data files)*
    - Label *(label files)*
        - CCM *(CCM label files)*
            - Segments *(CCM label files)*
            - Sub-basins *(CCM label files)*
        - ECRINS *(ECRINS label files)*
            - Segments *(CCM label files)*
    - Main Rivers *(main river source files)*
        - CCM *(CCM network files)*
        - ECRINS *(ECRINS network files)*
    - Networks *(network files)*
        - Segments *(CCM network files)*
            - CCM *(CCM network files)*
                - Basins *(CCM network files)*
                - Countries *(CCM network files)*
                    - Portugal *(CCM network files)*
            - ECRINS *(ECRINS network files)*
                - Basins *(ECRINS network files)*
        - Sub-basins *(ECRINS network files)*
            - CCM *(CCM network files)*
                - Main River segments excluded from sub-basins *(CCM network files)*
                    - Basins *(CCM network files)*
                - Main River segments included in sub-basins *(CCM network files)*
                    - Basins *(CCM network files)*
            - ECRINS *(ECRINS network files)*
                - Main River segments excluded from sub-basins *(ECRINS network files)*
                    - Basins *(ECRINS network files)*

        - Main River segments included in sub-basins *(ECRINS network files)*
            - Basins *(ECRINS network files)*

- Templates *(templates folder containing examples)*
- Workspaces *(workspaces folder)*
    - Default *(default workspace folder – all exports and saved data will be sent to this folder)*

RivTool Interface

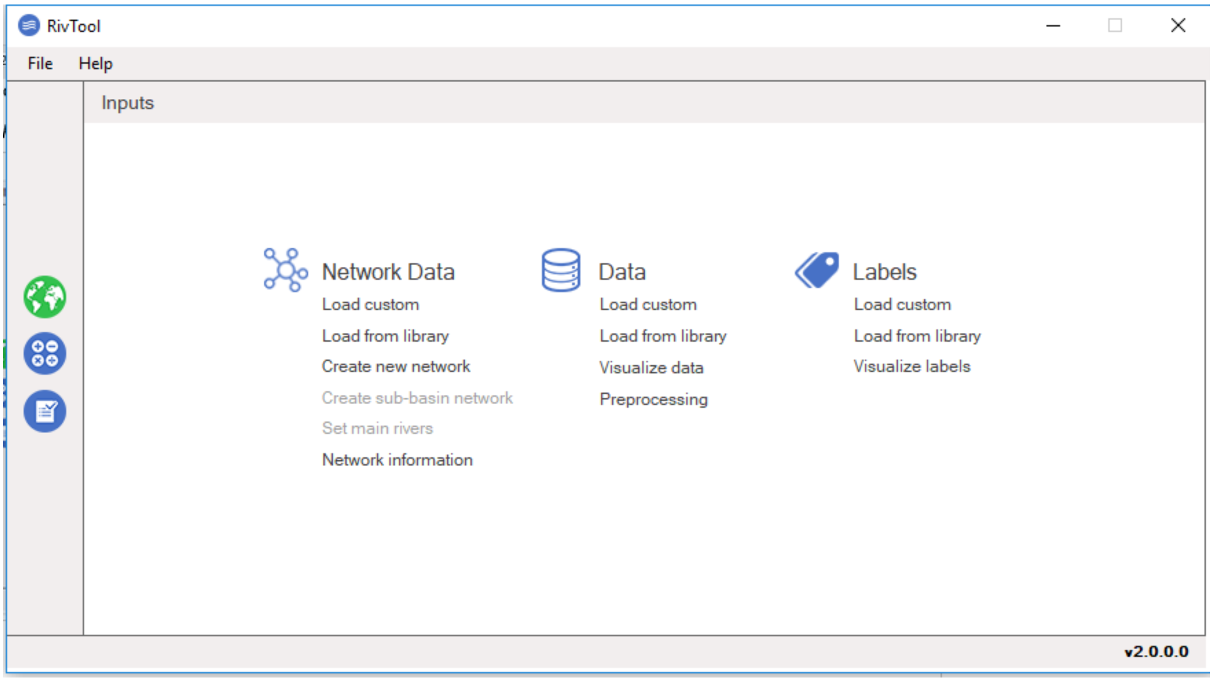
There are 5 main interfaces for the software:

1. **Inputs**

   This area is for inputting network, network settings, data variables and label variables.

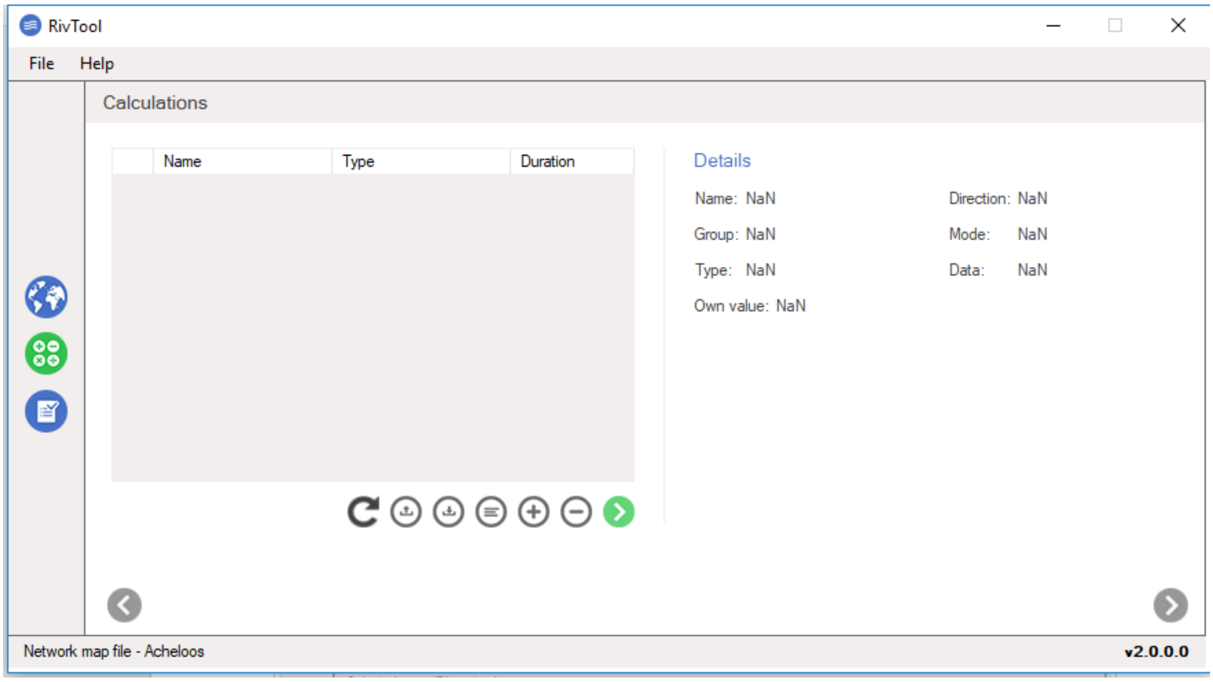
   Here you can choose the network(s), set the main river(s), pre-process landscape/environmental data to comply with RivTool data input requirements, load data and labels that you want to use in the calculations.

   You can also create your custom map, segments or sub-basins, based on a custom segments file (check *Help -> Templates* for the map file template).



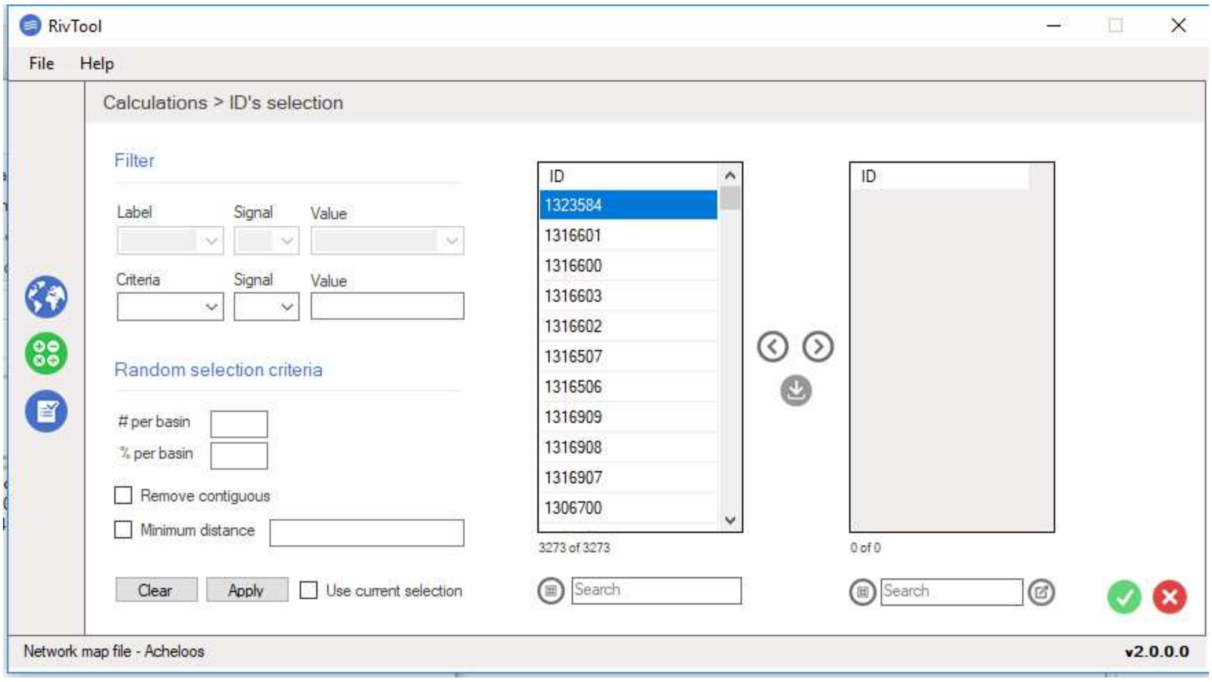
2. Calculations

This area gives access to the interface of the calculations' editor and the interface of selection of segments. Also, in this window, after choosing and defining the calculations, it is possible to visualise the calculations chosen and their specifications.



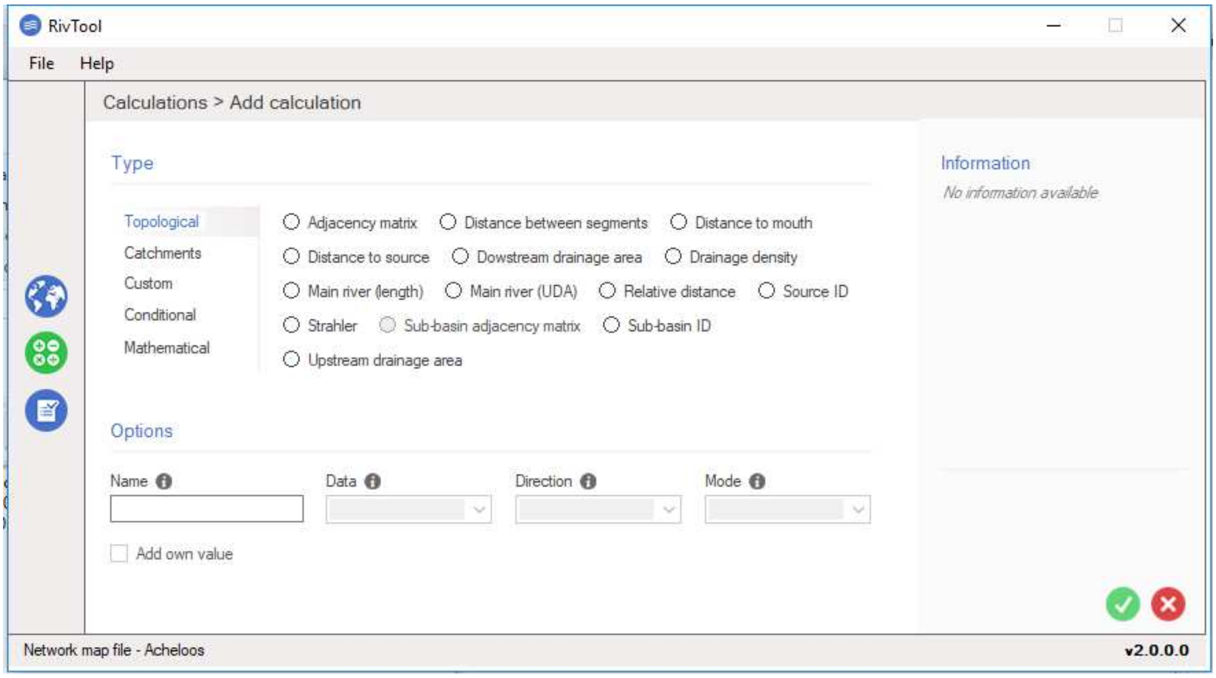
3. Segments selection

This area is for the selection of the unit of analysis ID's. Here you can choose which ID's you want to use in your calculations. Several methods for segment selection are available and, by default, all segments will be used.



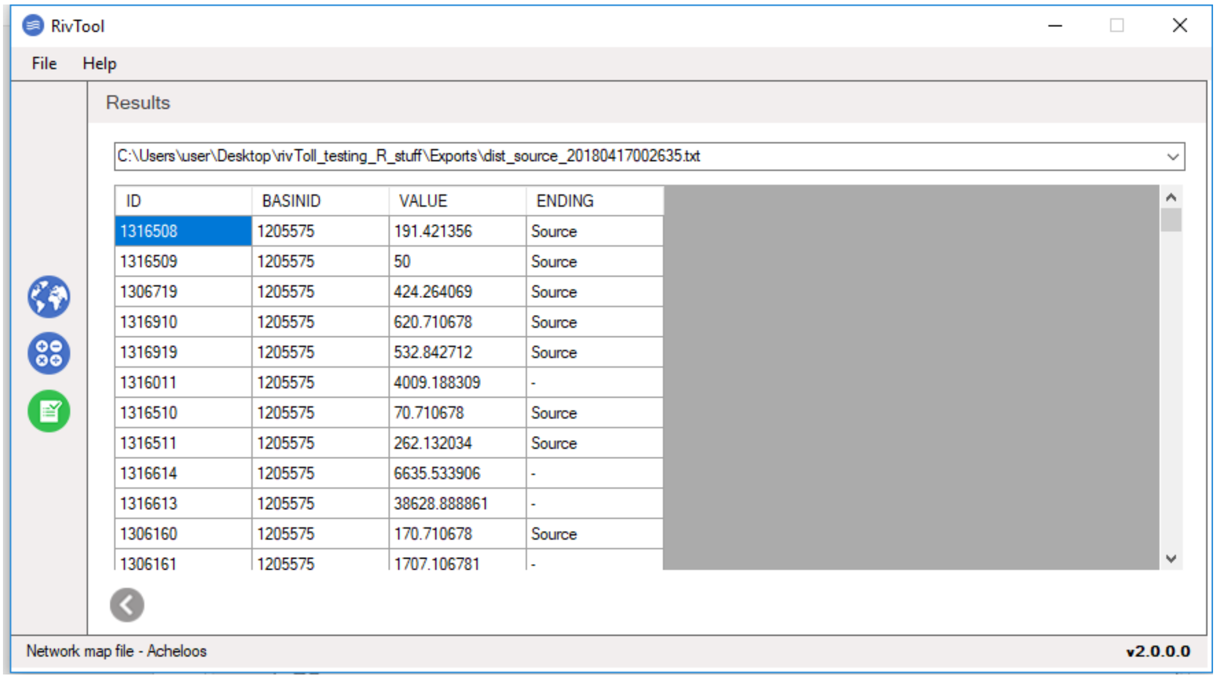
4. **Calculations editor**

Here you can add and edit calculations that will be executed using the selected units of analysis of the network.



5. **Results**

This area is for results display purposes. Here you will find all calculation results. You can then analyse and export the results into separate files or all in one export file.



Templates

Map creation input file

The software provides the possibility of creating a custom network from a user-provided file. The file should contain 4 fields:

1. The ID of the segment or the sub-basin
2. The ID of the Basin where it belongs

3. The ID of the downstream adjacent segment or sub-basin (also called the nextdown ID)
4. Primary catchment area of the segment or sub-basin area
5. The length of each segment or the sum of the length of all segments in a sub-basin
6. The Name of the River (optional)

Fields should be separated by a comma (,) while decimal values are indicated by using a dot (.) Finally, in this file, all fields should have a header.

Example:

Segment_ID,Basin_ID,Next_down_ID,Area,Length
30844,4,30843,20000,300.00
30845,4,30925,1200.56,1589.94
30842,4,30866,10000,665.68
30843,4,30912,50000,1972.79
52870,2,52966,150000.42,1189.9

Main River Sources

The software allows the user to define the source of the main river for every basin. By default, it will consider the source of the main river as the most distant from the river mouth. In this setting, a library file can be used or a user-provided file. It should contain 2 fields:

1. The ID of the Basin
2. The ID of the main river source segment for the respective basin. Obligatorily this has to be a source segment.

Fields should be separated by a comma (,). In this file, all fields should have a header.

Example:

Basin_ID,Main_river_source_ID
130749,255566
129537,250975
129742,252129
130834,267432
129778,270310

Data file

The user can provide custom data for any network but this file must provide information for every segment/sub-basin present in the network map it intends to use.

The file has 1 mandatory field, after which data fields intended to be used in RivTool can be added:

1. The ID of the segment or the sub-basin
2. Data for variable 1
3. Data for variable 2

N. Data for variable N

Fields should be separated by a comma (,) while decimal values are indicated by using a dot (.). Finally, in this file, all fields should have a header.

Example:

Segment_ID,Strahler,Temperature,Precipitation,slope,Forest
30844,4,21,300.00,1.0,35
30845,4,10,1589.94,1.6,65
52875,6,20,300.00,2.9,25
52873,7,21,1065.68,1.8,90
52870,2,27,1189.94,3.0,10

Label file

The user can provide custom label data for any network but this file must provide information for every segment/sub-basin present in the network map it intends to use. Label should be text fields.

The file has 1 mandatory field, after which data fields intended to be used in RivTool can be added:

1. The ID of the segment or the sub-basin
2. Label 1
3. Label 2

N. Label N

Fields should be separated by a comma (,) while decimal values are indicated by using a dot (.). Finally, in this file, all fields should have a header.

Example:

Segment_ID,Basin,Sub-basin,Ocean,Land_use,Climate_type
30844,Nemunas,Neris,Baltic,Pasture,Continental
30845,Danube,Inn,Black,Forest,Alpine
52877,Tagus,Jarama,Atlantic,Urban,Mediterranean
52875,Nemunas,Shchara,Baltic,Urban,Continental
52870,Tagus,Zezere,Atlantic,Forest,Mediterranean

Segment list file

When choosing the segments or sub-basin IDs to be used in the calculation the user can provide a file with these IDs. The file should be a simple list of the IDs of the segments/sub-basins to be used in the calculation.

Example:

30844
30845
52875
52873
52870

Data Preprocessing

Users can create data inputs tables from raster information using the preprocessing option of the Data Inputs. There are 4 functionalities available: Resample, Calculation using multiple rasters, Zonal Statistics and Missing Data Patch. The first 3 options use internal R software computation.

Resample rasters

Allows users to resample one or a set of raster using the following functions:

```
resampleRaster <- function(path_to_raster, x, y,
                           method, output_raster_name){
  original_raster <- raster (path_to_raster)
    new_raster <- disaggregate (original_raster, fact=c(x,y),
                               method = method,
                               filename = output_raster_name)
}

resampleRasters <- function(path_to_rasters, x, y, method){
  raster_list <- list.files(path=path_to_rasters, full.names=TRUE)

  for (i in 1:length(raster_list)){
    resampleRaster(raster_list[i], x, y, method,
                   paste(format(Sys.time(), "%d%m%y_%H%M%OS_"),
                         "resampled_", basename(raster_list[i])))
  }
}
```

Calculation using multiple rasters

Allows users to perform mathematical calculations using multiple rasters using the following function:

```
calcMultipleRasters <- function(path_to_rasters,
                               define_function,
                               output_raster_name){
  raster_list <- list.files(path_to_rasters,full.names=TRUE)
  raster_stack <- stack(raster_list)

  beginCluster(detectCores())
  calc_output <- calc(raster_stack,
                      fun = define_function,
                      na.rm = T,
                      filename = paste(format(Sys.time(),
                                              "%d%m%y_%H%M%OS_"),
                                       output_raster_name, ".tif"))
  endCluster()
}
```

Zonal Statistics

Allows users to perform zonal statistics using one or several rasters and polygon shapefile using the following function:

```
zonalStatistics <- function(path_to_zone_polygon,
                            layer_name, path_to_rasters,
                            define_function, is_mean,
                            method, output_zonal_stats_name){
    file_extension <- get.file.extension(path_to_zone_polygon)

    if (file_extension == ".shp") {
        zone_polygon_name <- tools::file_path_sans_ext(basename(path_to_zone_polygon))
        zone_polygon <- shapefile(path_to_zone_polygon)
    } else if(file_extension == ".gdb") {
        subset(ogrDrivers(), grepl("GDB", name))
        zone_polygon <- readOGR(dsn=path_to_zone_polygon,layer=layer_name)
    }

    raster_list <- list.files(path=path_to_rasters, full.names=TRUE)
    raster_stack <- stack(raster_list)

    zonal_stats_output <- extract(
        raster_stack,
        zone_polygon,
        fun = define_function,
        method = method,
        small = TRUE,
        weights = is_mean,
        normalizeWeights = FALSE,
        cellnumbers=TRUE,
        sp=TRUE,
        na.rm = TRUE,
        df=TRUE)

    write.csv(zonal_stats_output,
              file = paste(format(Sys.time(), "%d%m%y_%H%M%OS_"),
                           output_zonal_stats_name, ".csv"))
}
```

Missing Data Patch

Geographic differences between shapefiles and raster files will lead to missing values in the zonal statistics procedure (eg, small differences between coastal limits in the shapefiles and the last pixel of the raster with information in the coastal area often leads to zones with no information). This means that the produced table from the zonal statistics procedure will lack some data and thus possibly preventing the rivtool from using it as a data input. This functionality will fill these information gaps using data from adjacent river segments. For each segment with missing data, rivtool will perform the weighted average using the data from the adjacent segments. Because this problem may affect multiple adjacent segments, rivtool will start the calculation for those segments with a higher number of adjacent segments with pre-existing information.

Functions

All functions require the completing of the field "*Name*". The alphanumeric characters introduced in this field will be used to name the output table to be created after performing the calculation. Nearly all functions also require the user to choose, in the "*Data*" dropdown box which variable from the environmental data will be used to perform the calculation. The "add own value" checkbox gives the user the possibility of choosing if they want to consider the segment/sub-basin for which the calculation is being performed as part of this calculation.

Type

Topological

Functions that only depend on the topological structure of the network data.

Catchments

Functions that retrieve descriptive information about basins or sub-basins.

Custom

Ready-to-use functions mostly without the need for configuration. Most of these retrieve common relevant information searched when dealing with freshwater systems.

Conditional

Functions where a condition before calculation has to be imposed.

Mathematical

Ordinary mathematical calculations that are performed using both network and environmental data. These functions require the specification of a few options:

- **Direction**: Establishes the direction to indicate which segments or sub-basins will be included in the calculations. Downstream will use segments/sub-basins that are downstream of a considered segment/sub-basin. Upstream will use segment/sub-basin that is upstream of a considered segment/sub-basin.
- **Mode:** Given a direction, this option will establish which of these segments/sub-basins will be used to perform the calculations. Path establishes that only segments/sub-basins in the shortest path towards mouth (when the direction is downstream) or towards the respective source (when the direction is upstream) will be used in calculations. Relatives establish that all segments/sub-basins downstream or upstream (depending on the established direction) of a given segment/sub-basin will be used in calculations.

Function Descriptions

Type	Function	Description	Unit of Analysis	Units
Topological	Adjacency matrix	Identifies the IDs of contiguous units of analysis of a given unit.	Segment and sub-basin	-
Topological	Distance between segments	Distance along the river between the midpoints of a given set of segments.	Segment	meters (m)
Topological	Distance to mouth	Distance from the midpoint of a given segment to the mouth of the river.	Segment	m
Topological	Distance to source	Distance from the midpoint of a given segment to its correspondent river source.	Segment	m
Topological	Downstream drainage area (DDA)	Downstream drainage area of a given unit.	Segment and sub-basin	m^2
Topological	Drainage density	Ratio between the length and the primary catchment of a unit, when using segments. Ration between the sum of the units lengths and the sum of primary catchments' area when using sub-basins.	Segment and sub-basin	-
Topological	Main river (length)	Identifies the segments that belong to the main river course of a basin based on the longest path between source and mouth.	Segment	-
Topological	Main river (UDA)	Identifies the segments that belong to the main river course of a basin based on the largest upstream drainage area.	Segment	-
Topological	Relative distance	Indicates the relative distance of a segment to the mouth considering the full distance between the mouth and the correspondent river source for that segment. For more information about the application of this descriptor see Imbert, H. et al. (2008).	Segment	Proportion
Topological	Source ID	Identifies the ID of the correspondent source for a given unit.	Segment and sub-basin	-
Topological	Strahler	Calculates the Strahler stream order for every segment. For more information see Strahler, A. N. (1952) and Strahler, A. N. (1957).	Segment	-
Topological	Sub-basin ID	Considering the main river course established, identifies the natural sub-basins to which a given segment belongs. It establishes the ID of the sub-basin using the ID of the first main river segment after the mouth of the tributary. The maximum Strahler number of the sub-basin is equal to the one from the last segment of the sub-basin river.	Segment	-
Topological	Upstream drainage area (UDA)	Upstream drainage area of a given unit.	Segment and sub-basin	Km^2
Catchments	Basin drainage density	Ratio between the sum of the length of all segments and the drainage area of a basin.	Basin (inputs: Segment or sub-basin)	Km^{-1}
Catchments	Basin stats	Summary statistics about each basin using segments as an analysis unit (check the manual for more detail).	Basin (inputs: segments)	several
Catchments	Basin stats (sub-basins)	Summary statistics about each basin using sub-basins as an analysis unit (check the manual for more detail).	Basin (inputs: sub-basins)	several
Catchments	Bifurcation ratio	Average of the ratios between the number of segments of one Strahler order (n) and those of the next-higher Strahler order (n+1) in a basin.	Basin (inputs: segments)	-
Catchments	Total mouth segments	Number of mouth segments per basin.	Basin (inputs: segments)	-
Catchments	Total source segments	Number of source segments per basin.	Basin (inputs: segments)	-
Custom (also in Topological)	Drainage density	Ratio between the length and the primary catchment of a unit, when using segments. Ration between the sum of the units lengths and the sum of primary catchments' area when using sub-basins (same as in the Topological type).	Segment and sub-basin	-
Custom	Occupancy in DDA	Area covered by the chosen variable (e.g. forest, crop) in the downstream drainage area of a given unit.	Segment and sub-basin	dependent on selected variable
Custom	Occupancy in UDA	Area covered by the chosen variable (e.g. forest, crop) in the upstream drainage area of a given unit.	Segment and sub-basin	dependent on selected variable
Custom (also in Topological)	Relative distance	Indicates the relative distance of a specific ID to the mouth considering the full distance between the mouth and the correspondent river source for that ID. For more information about the application of this descriptor see Imbert, H. et al. (2008) (same as in the Topological type).	Segment	proportion
Custom	Relative occupancy in DDA	Area covered by the chosen variable (e.g. forest, crop) in the DDA of a given unit divided by the total area of the DDA.	Segment and sub-basin	proportion
Custom	Relative occupancy in primary catchment	Area covered by the chosen variable (e.g. forest, crop) in the primary catchment of a given unit divided by the total area of primary drainage catchment.	Segment and sub-basin	proportion
Custom (also in Topological)	Strahler	Calculates the Strahler stream order for every segment. For more information see Strahler, A. N. (1952) and Strahler, A. N. (1957) (same as in the Topological type).	Segment	-
Custom	Stream Power	Calculates for each segment the rate of potential energy expenditure over a reach (Gordon, N. D. et al. 2004), i.e., Stream Power per river segment. Calculation according to Gordon, N. D. et al. (2004) and using the computation formulas described in Logez, M. et al. (2012).	Segment	$kg\ m^2\ s^{-3}\ km$
Custom (also in Topological)	UDA	Upstream drainage area of a given unit (same as in the Topological type).	Segment and sub-basin	Km^2

Type	Function	Description	Unit of Analysis	Units
Conditional	Conditional sub-basin Strahler	Starting from the output of the "Sub-basin ID" function, aggregates the segments for which the Strahler number is lower than the established threshold to the one immediately downstream that fulfils this condition. If there is no sub-basin below that matches the condition, it will look for one immediately upstream. If no sub-basin has a Strahler number equal or larger than the threshold, then all units of analysis of the basin are considered to be in the same sub-basin (in this case the sub-basin corresponds to the total basin).	Segment	-
Mathematical	Average	Arithmetic mean considering the values of a given variable for all considered units in the calculation.	Segment and sub-basin	dependent on selected variable
Mathematical	Count	Number of units given the direction and mode chosen.	Segment and sub-basin	
Mathematical	Max	Maximum value of a given variable for all considered units in the calculation.	Segment and sub-basin	dependent on selected variable
Mathematical	Min	Minimum value of a given variable for all considered units in the calculation.	Segment and sub-basin	dependent on selected variable
Mathematical	Range	Range of values of a given variable for all considered units in the calculation.	Segment and sub-basin	dependent on selected variable
Mathematical	Standard deviation	Standard deviation considering the values of a given variable for all considered units in the calculation.	Segment and sub-basin	dependent on selected variable
Mathematical	Standard error	Standard error considering the values of a given variable for all considered units in the calculation.	Segment and sub-basin	dependent on selected variable
Mathematical	Sum	Retrieves the sum of all the values of a given variable for all considered units in the calculation.	Segment and sub-basin	dependent on selected variable
Mathematical	Variance	Variance considering the values of a given variable for all considered units in the calculation.	Segment and sub-basin	dependent on selected variable
Mathematical	Weighted Average	Area or length weighted arithmetic mean considering the values of a given variable for all considered units in the calculation.	Segment and sub-basin	dependent on selected variable

Formulas and detailed Functions

Basin Stats

The calculations performed by this function using a network of segments includes:

- Total segments
- Total sources
- Total mouths
- Total major river segments
- Total minor river segments
- Total sub-basins
- Maximum segment length
- Minimum segment length
- Main river length
- Drainage density
- Bifurcation ratio

The calculations performed by this function using a network of sub-basins includes:

- Total number of sub-basins
- Maximum water courses length
- Minimum water courses length
- Average water courses length

- Maximum sub-basins area
- Minimum sub-basins area
- Average sub-basins area
- Drainage density

Bifurcation Ratio

Average of the ratios between the number of segments of one strahler order (n) and those of the next-higher strahler order (n+1) in a basin.

$$Bifurcation\,ratio = \sum_{n}^{i} \frac{strahler\ order_n}{strahler\ order_{n-1}}$$

Drainage Density

Ratio between the length and the primary catchment of a unit, when using segments. Ratio between the sum of the units lengths and the sum of primary catchments' area when using sub-basins.

$$Drainage\ Density\ = \frac{length}{area}$$

Relative Distance

Indicates the relative distance of a segment to the mouth considering the full distance between the mouth and the correspondent river source for that segment. For more information about the application of this descriptor see Imbert et al. (2008).

$$RelativeDist = \frac{Distance\ to\ mouth}{Distance\ to\ Mouth + Distance\ to\ respective\ source}$$

Stream Power

Calculates for each segment the rate of potential energy expenditure over a reach (Gordon et al. 2004), i.e., Stream Power per river segment. Calculation according to Gordon et al. (2004) and using the computation formulas described in Logez et al. (2012)

$$STP = \rho\ g\ Q\ S$$

P – density of water

g – gravitational acceleration

Q – annual discharge

S – slope

$$Q = \frac{MAR \times UDA}{31536}$$

MAR – Mean annual run-off

UDA – Upstream drainage area

$$MAR = P - PET$$

P – Mean annual precipitation

PET – Annual potential evapotranspiration

$$PET = \frac{P}{\sqrt{0.9 + (\frac{P}{L})^2}}$$

$$L = 300 + 25T + 0.05T^2$$

L – Temperature factor derived from mean annual temperature

The software allows you to perform this function using the temperature, precipitation and drainage values calculated for the segment drainage area (SDA) or the upstream drainage area (UDA). These work independently, i.e., you may have temperature data for the UDA and precipitation data for SDA. If you have discharge values for every segment you may directly calculate the Stream Power of the segment without using the UDA or SDA drop-down boxes.

Libraries

Networks

Catchment Characterisation and Modelling v2.1 (CCM2)

All basins included in the CCM2 have a network data file, and there is one file that includes all basins. Please check Vogt et al. (2007) for more information.

European Catchments and Rivers Network System – ECRINS/ Managing Aquatic Ecosystems and Resources under Multiple Stress (MARS)

Only basins with more than 50 km^2 were included. There is one file for each basin and a file that includes all basins. Please check EEC (2012) and MARS (2015) for more information.

Main River Sources

CCM2

Main river sources for CCM2 were established for 794 basins using the “MAINRIVERS” and the “NAMEDRIVERS” CCM2 layers. We also cross-checked these layers with ArcBruTile v0.7 layers to verify and/or confirm river sources. Please check Vogt et al. (2007) for more information about the CCM2 layers used. For ECRINS (666 basins) we used the information created for CCM2 and cross-checked again with ArcBruTile v0.7 layers to verify and/or confirm river sources.

Variables

CCM2

All data variables included in the segments and primary catchment layers of the CCM2 are available. Please check Vogt et al. (2007) for more information and detail about the aforementioned variables.

ECRINS/MARS

Two label files are included, one with labels related to the biogeographic regions and other with the Corine Land Cover information present in the MARS geodatabase. Please check MARS (2015) for more information.

Labels

CCM2

The basin name and the field “Sea_CD” were included as label data. For those basins where the name was not available, the basin ID was used concatenated with the word “Basin”. For the “Sea_CD” field we concatenated every value with the letter “a” to make it a text field. Please check Vogt et al. (2007) for more information and detail about the aforementioned fields.

ECRINS/MARS

Two data files are included, one with variables characterising the segments and respective drainage areas and other related with the River Basin Districts (RBDs) and their subunits (RBDSUs) (EEA 2017). Please check MARS (2015), EEA (2017) and EEA (2016) for more information.

Troubleshooting

Please make sure to read the manual and check the template files to correctly use the River Network Toolkit. Since we are continuously improving and correcting minor details, please make sure you have the latest version.

All comments, suggestions and questions may be sent to river.network.toolkit@gmail.com.

How to reference RivTool

For this please contact the authors via the email info@rivtoolkit.com.

References

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