The HortonMachine - A tutorial for the processing of the digital terrain data.

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Chapter 1. Introduction

This tutorial contains the description of the usage of some commands for the hydro-geomorphological analysis or river basins with the HortonMachine library. The purpose of this manual is to introduce hydro-geomorphologic terrain analysis in gvSIG using the HortonMachine toolbox.

The guide is not comprehensive in documenting the use and functionality of all the HortonMachine library. Rather, it is intended as a short introduction to guide a user through the initial steps of running some of the more important functions required to delineate a stream network and to evaluate some main hydrological quantities and indexes. The complete documentation on the use of each HortonMachine tool is given directly in the Graphical Interface of the command. This software is developed at HydroloGIS in Bolzano (Italy) for hydrologic digital elevation model analysis, watershed delineation and LiDAR data analysis and may be obtained from here.

In this tutorial, you will perform the following tasks:

- preliminary operations
- principal characteristics of topography
  - pit remove
  - gradient
  - aspect
  - curvatures
- derived characteristics of topography
  - D8 flow directions
  - D8 contributing area
  - D8-LAD and D8-LTD flow direction
  - D8-LAD and D8-LTD total contributing area
  - stream extraction by threshold
  - slope
- watershed delineation
  - extract basin
  - networkAttributesBuilder
  - distance to outlet
  - rescaled distance
- hillslope analysis
  - H2CD (Hillslope to Channel Distance)
  - topographic classes
  - hillsope numbering

- hydro-geomorphology tools
    - ab
    - topographic index
    - peakflow
    - shalstab

The Flanginec watershed located in the north of Italy, in the province of Trento, is used as example.

More information about the modules and the implemented algorithms are available in e-book The Horton Machine.

1.1. The HortonMachine library

The entire HortonMachine library is divided into 7 different sections:

- **Basin:** set of tools to evaluate some characteristics and indexes of the basin.
    - BasinShape
    - RescaledDistance
    - TopIndex
- **DEM Manipulation:** set of tools for basic preliminary analysis on Digital Terrain Models (DTM).
    - Markoutlets
    - Pitfiller
    - Wateroutlet
- **Geomporphology:** set of tools for evaluating the main geomorphological attributes of a basin.
    - Ab
    - Aspect
    - Curvatures
    - DrainDir
    - FlowDirections
    - Gc
    - Gradient
    - Nabla
    - Slope
    - Tca3d
- **Hillslope**: set of tools for evaluating the main characteristics of the hillslopes of a basin and perform a classification based on geomorphological properties.
    - DownSlopeConnectivity

    - H2cA
    - H2cd
    - Tc
- **Hydro-Geomorphology**: set of tools and models for hydrological and geomorphological analysis of river basins.
    - Hillshade
    - Insolation
    - Peakflow
    - Shalstab
    - Skyview
    - LWRecruitment (package of different tools)
- **Network**: set of tools to analyse some properties of the stream network.
    - DistanceToOutlet
    - ExtractNetwork
    - HackLength
    - Magnitudo
    - NetDiff
    - NetNumbering
    - NetworkAttributesBuilder
- **Statistics**: set of tools for statistical analysis on raster maps.
    - Cb
    - SumDownstream

1.2. Preliminary operations

In the following sections we illustrate some HortonMachine basic hydro-geomorphological functions starting from a DTM in ascii grid format and leading you running the further commands.

First of all download the Flanginec example data zip file from http://[INSERT LINK]. This data was extracted from the open LiDAR derived DTM dataset of the Province of Trento. Data is in UTM-WGS84 coordinate reference system with code *EPSG: 32632*.

Before starting to work on the data, you have to prepare a dedicated *Project* and *View* in gvSIG in same projection of the given DTM. Please do the following preliminary operations:

1. open gvSIG
2. select the default view in the *Project* view and select the *Properties* button
3. select the button to define the *Current Projection*
4. the first time you open this menu you will probably see nothing in the recent tab, please click

on the drop-down menu and select the *EPSG* item

5. in the search box write the code *32632* and then select the resulting row
6. select *OK* to set this projection to the *View*
7. select *OK* again to close the properties window.

The most important step is to choose the right projection (EPSG code) in the properties of the *View* as shown in Figure "Set the projection of the View in gvSIG with the coordinate reference system of the available data (steps 1 - 4)." and "Set the projection of the View in gvSIG with the coordinate reference system of the available data (steps 5 - 7).".

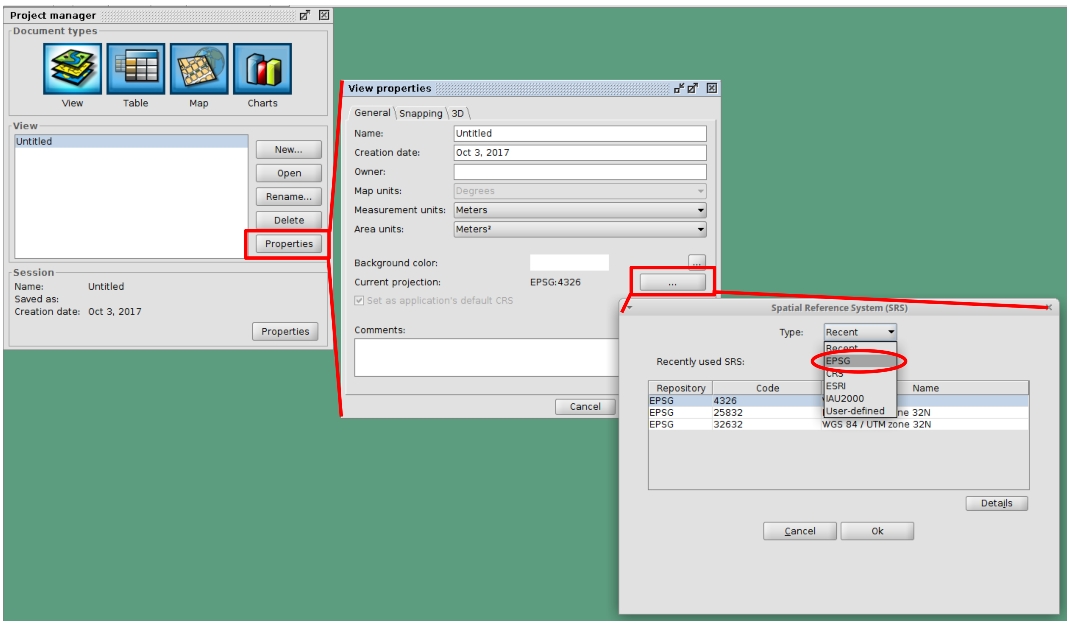


Figure 1. Set the projection of the View in gvSIG with the coordinate reference system of the available data (steps 1 - 4).

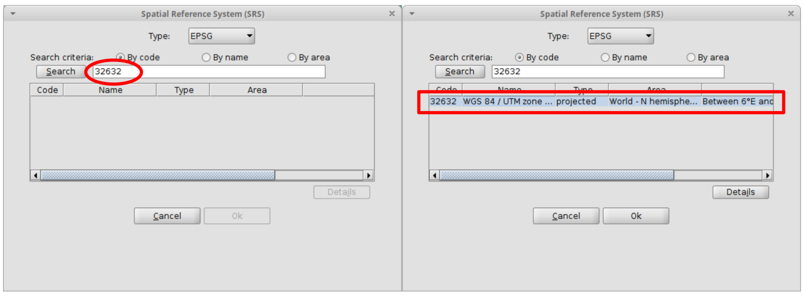


Figure 2. Set the projection of the View in gvSIG with the coordinate reference system of the available data (steps 5 - 7).

Projected data should be used when working with HortonMachine because the tools use grid dimensions (cell size) in their length and slope calculations and these will be incorrect if they are not consistent in E-W and N-S directions and in the same units as the vertical units of the DEM (typically meters).

Use your favorite *File Manager* or command line tool to extract all from the zip file. Enter the *DTM* folder and load all the *.asc* files into gvSIG. After loading all the data in the *View* you can zoom to all layers simply selecting this icon from the main toolbar . The data will look like in Figure "Import of the test dataset in gvSIG, zoom to all layers." where you can distinguish the different tiles and the distribution of the elevations inside each one. It is possible to use gvSIG tools to personalize the style of the maps using the *Color table* or the *Single Band Raster Styler* items of the menu of the map (to access it just select the map in the *View* and right click with mouse, see Figure "Access to the menu of the map for styling the raster.").

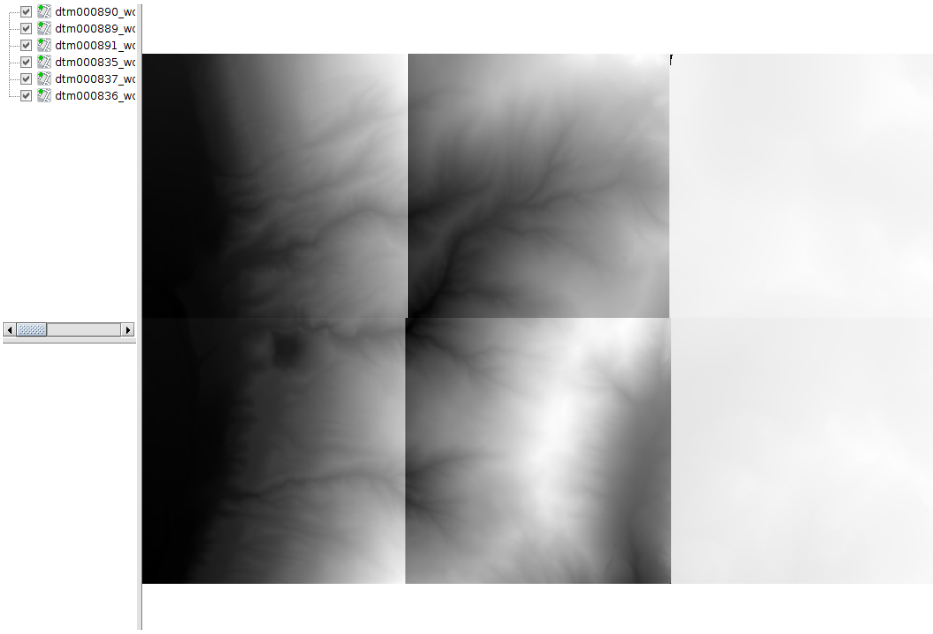


Figure 3. Import of the test dataset in gvSIG, zoom to all layers.

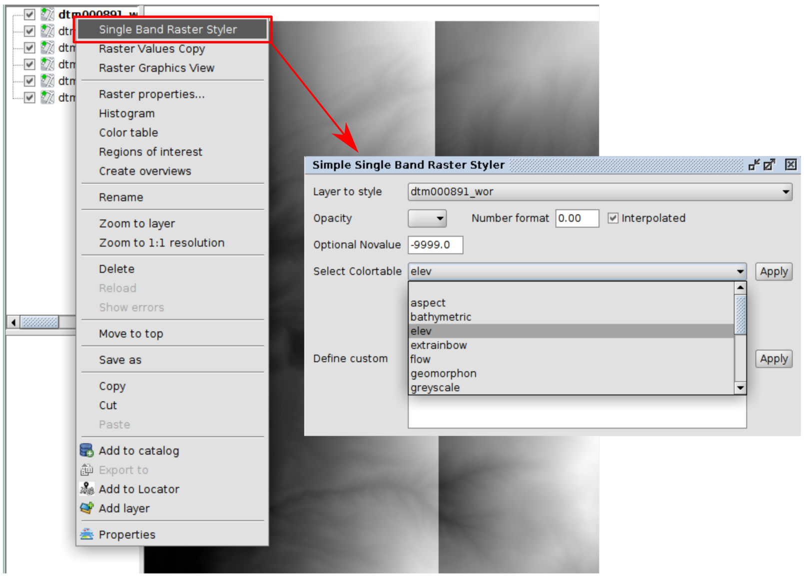


Figure 4. Access to the menu of the map for styling the raster.

Before proceeding with the analysis with the HortonMachine it is necessary to merge all the tiles in one single map. This operation can be done using the **Mosaic12** tools contained in the *Spatial Toolbox* of gvSIG. To access the *Spatial Toolbox* which contains also all the HortonMachine tools you have to select the **HMachine** item of the main menu bar and then access **Spatial Toolbox** as shown in Figure "Access to the *Spatial Toolbox* from the main menu of gvSIG.".

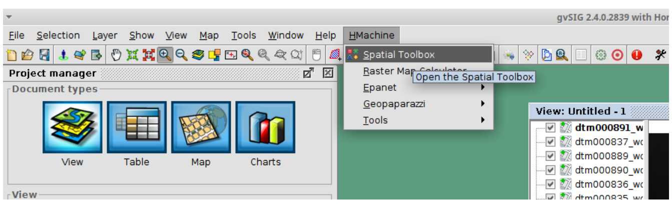


Figure 5. Access to the Spatial Toolbox from the main menu of gvSIG.

The first time you open the *Spatial toolbox* you have to specify two important parameters used for running the modules:

- the memory usage: **Heap [MB]** which depends on the available RAM of you computer and of the operating system
- if loading also the experimental modules or not **Load Experimental** which is selected by default
- if running the modules in **Debug** mode to see all the debug information in the output console, this option is usually not flagged even if there is the need to send the debug information to the developers for solving some bugs.

Once set these options, they will be considered for all the future running of the *Spatial toolbox*, at any time it will be possible to change them.

1.2.1. Join raster tiles: Mosaic12

Mosaic12 joins raster tiles, this module can be used for patching maximum 12 raster maps. It is possible to specify the type of interpolation to use:

- nearest neightbour
- bilinear
- bicubic

In our example we have 6 raster tiles to join in one single DTM for the area, please insert the names of the different maps in the first 6 items and specify the *nearest neightbour* as type of interpolation. Finally you have to specify the path and the name of the resulting raster map. In our example we start with *.asc* files and we will create the complete DTM in *.tiff*.

> All the tools of the *Spatial toolbox* need to specify the extention of the resulting maps (vector and rasters). Supported formats are **shp, tiff, asc**.

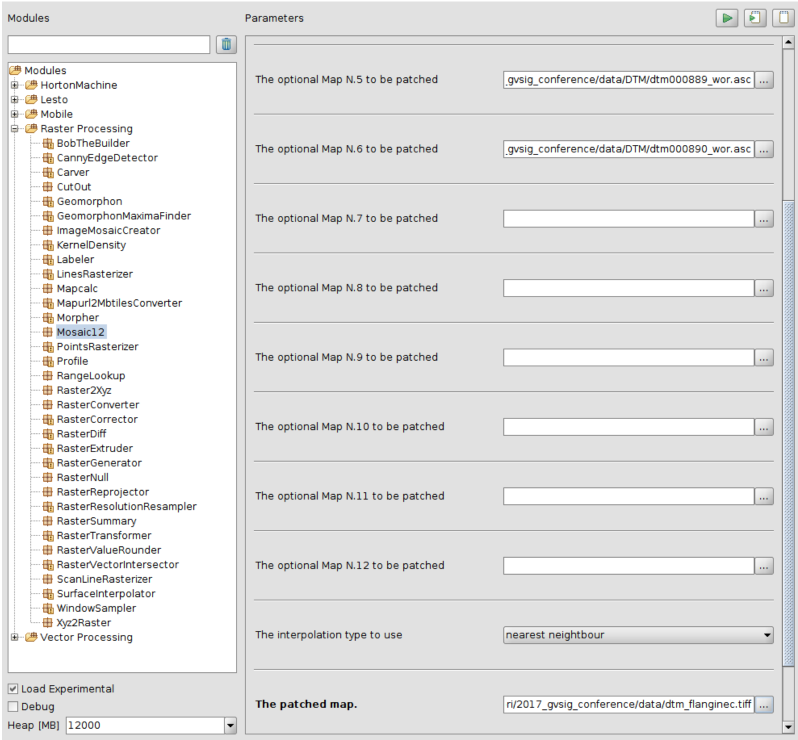


Figure 6. Main window of the Spatial Toolbox of gvSIG containing the Horton Machine library.

To run the module select the  icon at the top right of the *Spatial toolbox* window. All the information regarding the running process will be shown in the **Console Log** which will be displayed in the main gvSIG window.

The *Console Log* has to be closed manually after the operations to avoid to have lots of opened windows.

The output of the *Mosaic12* module is a unique raster layer in *tiff* format as shown in Figure "Output of the module *Mosaic12*.". You can style this layer also with the *elev* raster color map available in the *Single Band Raster styler* menu of the map (see Figure "Output of the module *Mosaic12* styled with *elev* color map for rasters.").

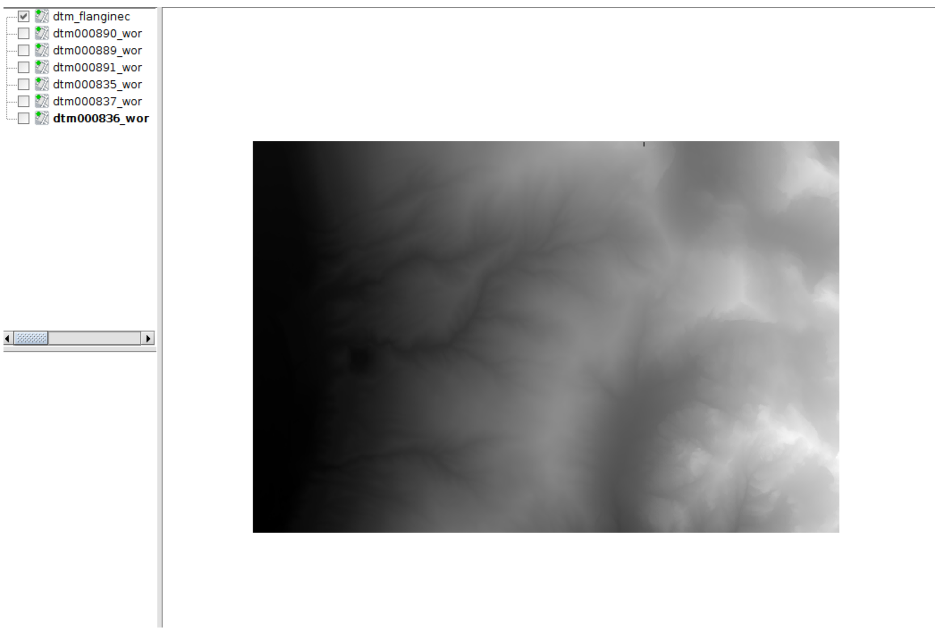


Figure 7. Output of the module Mosaic12.

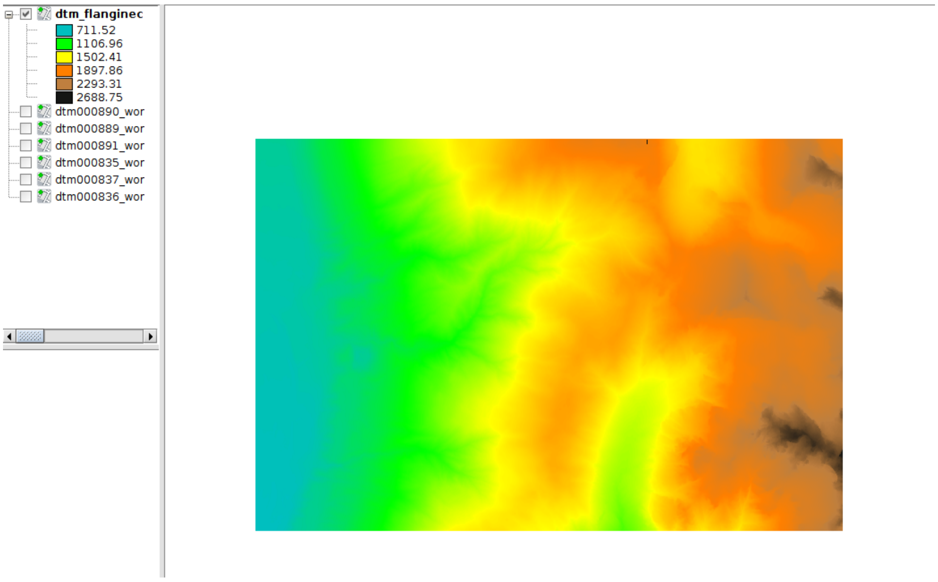


Figure 8. Output of the module Mosaic12 styled with elev color map for rasters.

Now it is possible to *Delete* all the original layers from the *View* (Figure "Access to the menu of the map to *Delete* single layers from the *View*."). These layers will disappear from the map view but they will still be saved on your original folder, the data will not be deleted using this operation. All the further operations will be performed starting from the DTM complete *dtm_flanginec.tiff*.

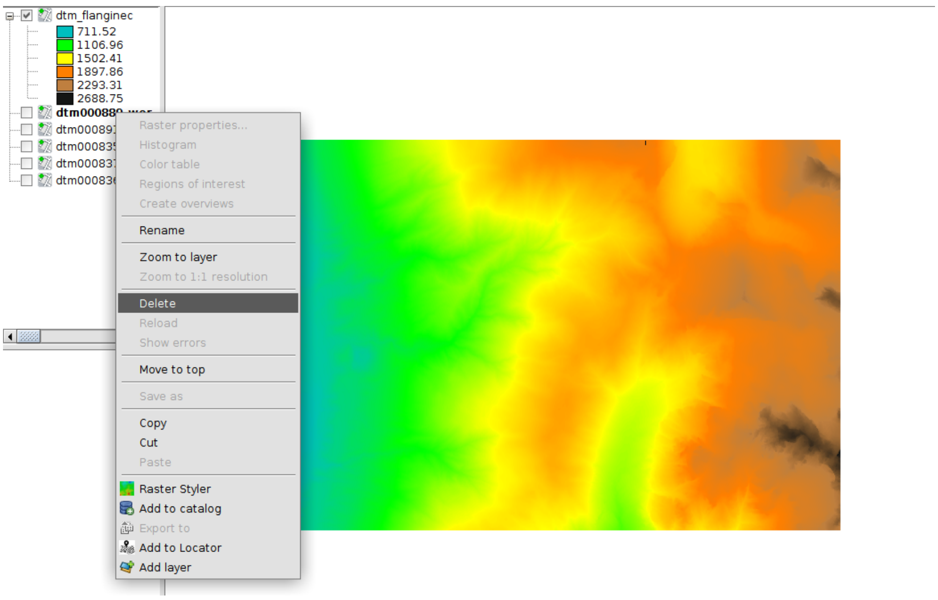


Figure 9. Access to the menu of the map to Delete single layers from the View.

Chapter 2. Principal characteristics of topography

The hydro-geomorphological approach to digital data starts with some basic topographic analysis to hydrologically correct the digital terrain model (DTM) like the pit filling (*Pitfiller*), the delineation of drainage directions (*Flowdirections* and *Draindir*) and finally the river network extraction (*ExtractNetwork*).

2.1. Pitfiller

The first function to use is the pit remove. Pits are grid cells surrounded by higher terrain that do not drain. *Pitfiller* creates a hydrologically correct DEM by raising the elevation of pits to the point where they overflow their confining points and can drain to the edge of the domain. To execute the command, once opened the *Spatial Toolbox* from the main menu bar, enter the sections

HortonMachine → DEM Manipulation

and select the **Pitfiller** entry (Figure "Access to the *DEM Manipulation* section of the *HortonMachine*").

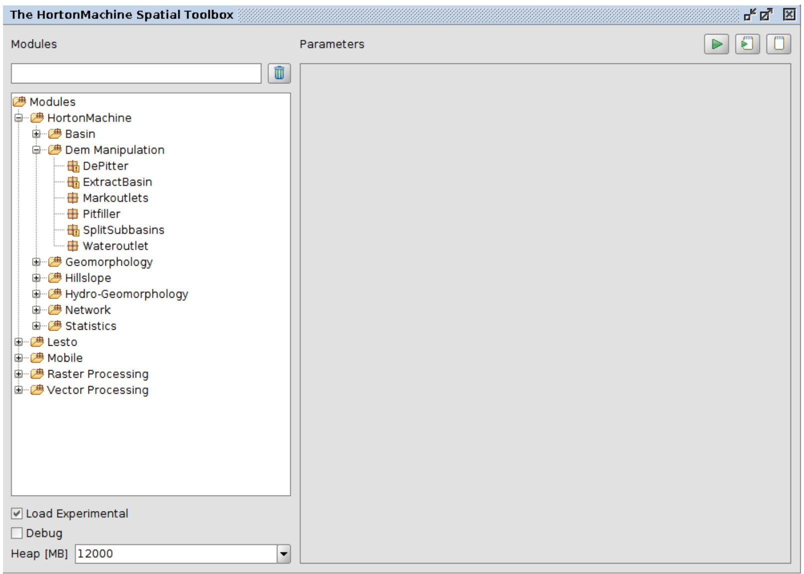


Figure 10. Access to the DEM Manipulation section of the HortonMachine

When you select the module to run from the list on the left side of the Spatial Toolbox window, it will automatically show the graphical interface of the command on the right side of the same window. Here you have to fill the requested fields (input, output and parameters). The type and supported extentions for each element are specified in the file locator window as *type of file*, please specify one of the suggested for the output maps.

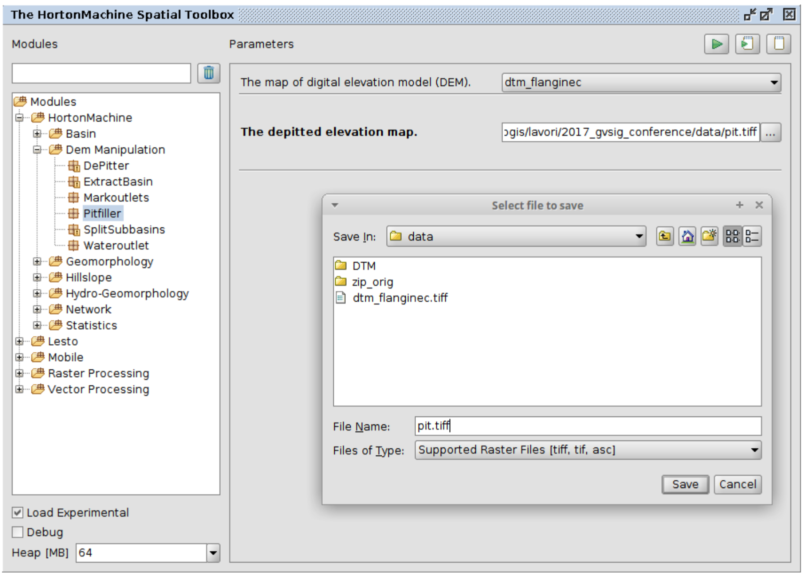


Figure 11. Execution of the Pitfiller command

Once filled all the required information run the model using the play  icon. The Spatial Toolbox will automatically open a *Console* where all the progress information and in general the *Log* of the execution of the command will displayed (Figure "*Console Log* of the *Pitfiller* command."). When the process is finished the output map will be automatically loaded and displayed in the active *View*. You can style this layer using the *Single Band Raster Styler* tool and the *elev* color ramp as in Figure "Output of the *Pitfiller* command: DTM without pits.".

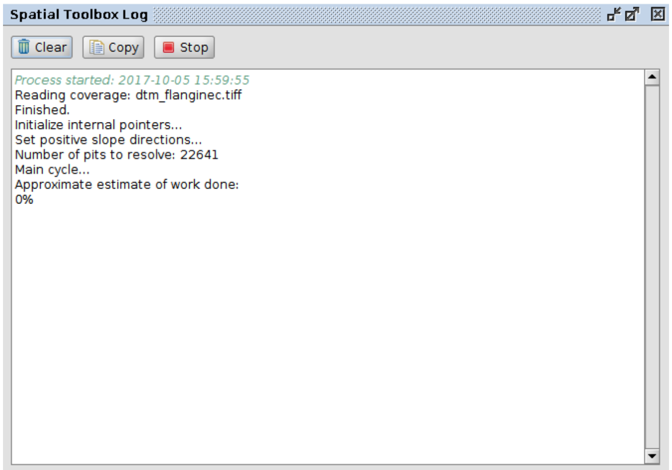


Figure 12. Console Log of the Pitfiller command.

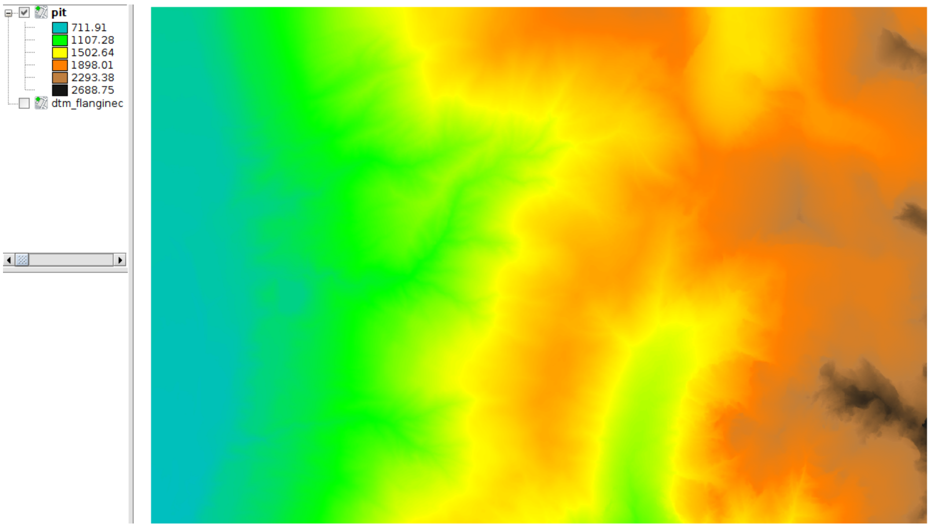


Figure 13. Output of the Pitfiller command: DTM without pits.

The pitfilling process is continuosly iterative over the map so it will take a lot of time to run if you have big regions and high resolution data.

2.2. DePitter

The HortonMachine contains a second model for depitting a DTM, this second module is faster than the original *Pitfiller* but it is still under testing because it has some problems in resolving big flat areas (lakes). If you want to test it, you can find it in the same section as *Pitfiller*:

HortonMachine → DEM Manipulation

with the name *DePitter*. The *DePitter* creates in output two raster maps, the map of the depitted DTM and the map with the flow directions following the D8 algorithm (Figure "Execution of the *DePitter* command."). The output maps are shown in Figure "Output of the *DePitter* command: DTM without pits and flow directions.", the map of flow directions uses the same conventions as specified for the *FlowDirections* command.

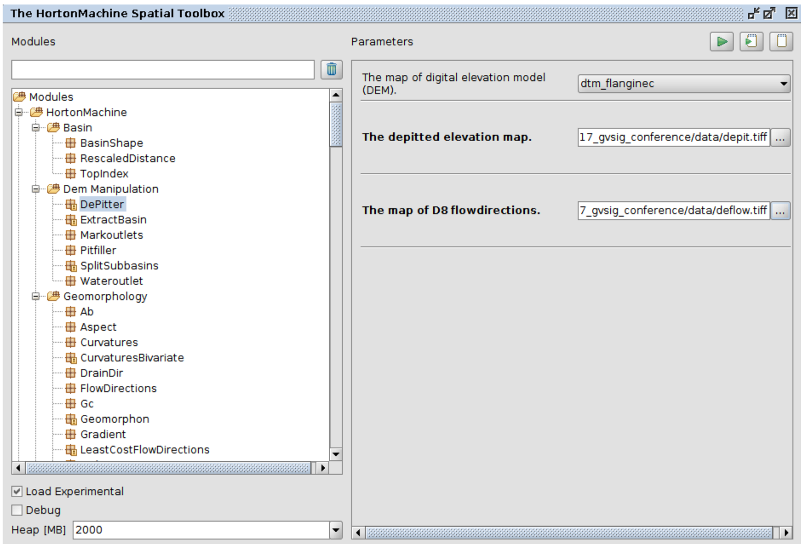


Figure 14. Execution of the DePitter command.

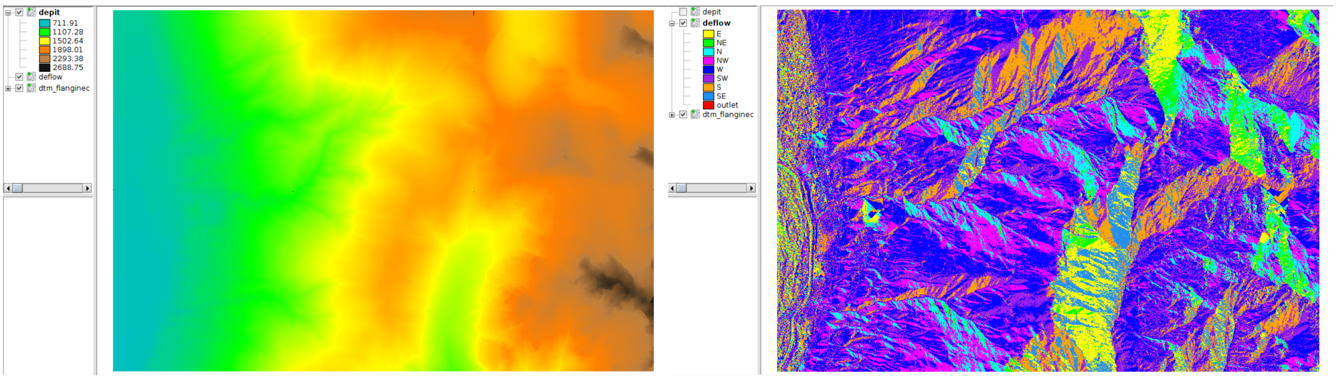


Figure 15. Output of the DePitter command: DTM without pits and flow directions.

2.3. Gradient

The slope distribution is relevant from many points of view. Since the main motive-power of the hydrologic flows on the Earth's surface and in the soil directly below is gravity, the surface gradient identifies, in first approximation, the water flow directions and contributes to the determination of their speed.

The gradient, contrarily to the slope, does not use the drainage directions. It calculates the module of the local gradient which in reality is a vectorial quantity oriented in the direction starting from the minimal up to the maximal potential.

To execute the command you have to access the section

HortonMachine → Geomorphology

and select the entry **Gradient**.

The required inputs are the elevation map, which can be the original DTM or the DTM depitted and two additional parameters:

- the formula to use for calculating the gradient: finite difference (default value), Horn and Evans
- the values to write in the map: the tangent of the angle (default choice) or the angle in degrees

And the output is the map of the gradient.

Figure "Execution of the *Gradient* command." shows the graphical user interface for the *Gradient* command on the test data and Figure "Output of the *Gradient* command: map with the local gradient." shows the output map of the gradient for the area.

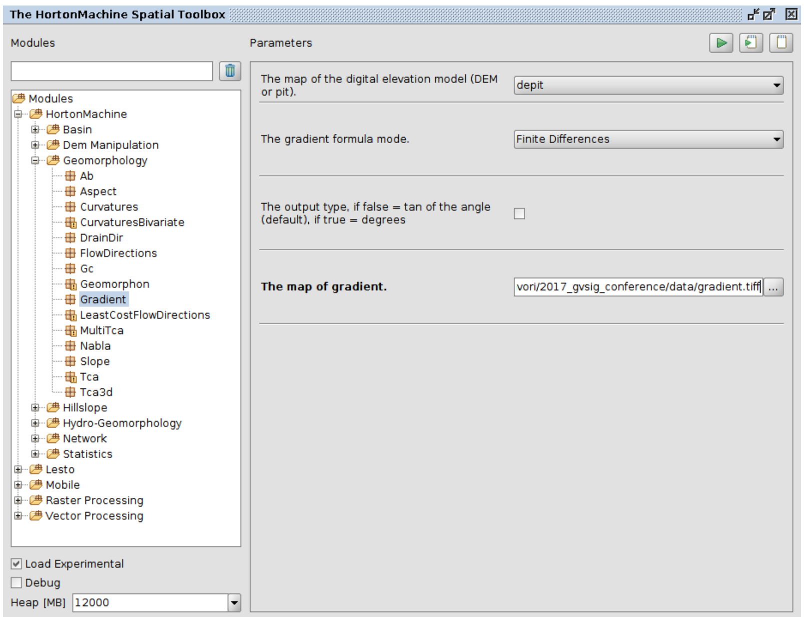


Figure 16. Execution of the Gradient command.

The **slope** color table is usually used to render the map of gradient as in the illustrations of this tutorial.

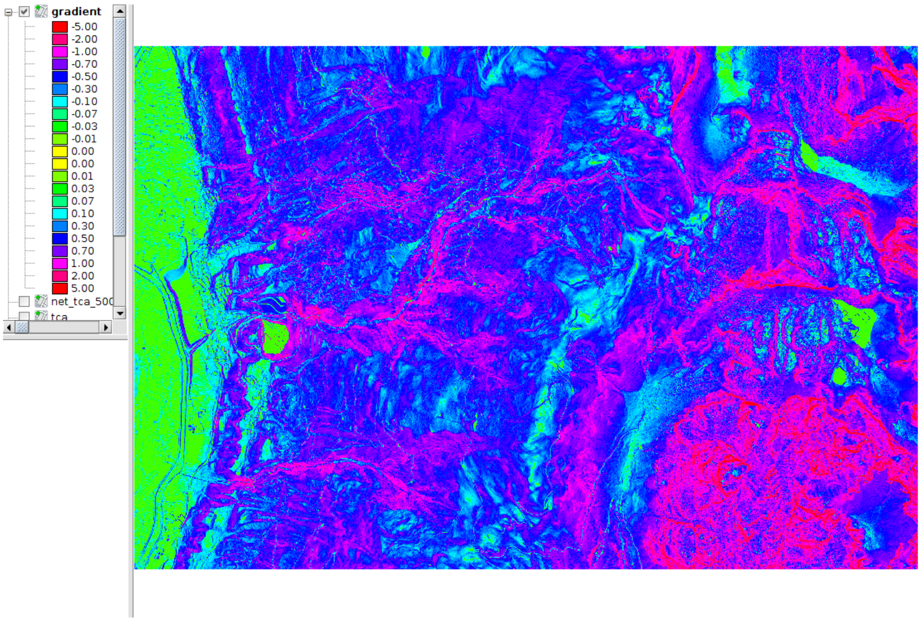


Figure 17. Output of the Gradient command: map with the local gradient.

2.4. Aspect

Aspect estimates the aspect as the inclination angle of the gradient by considering a reference system which puts the zero towards the east and the rotation angle anticlockwise. It differs from the drainage directions in which it is given in radians and it is a continuous function while drainage direction returns a number between 1 and 10. The aspect is 0 in the the east direction and increase anticlockwise.

To execute the command you have to access the section

HortonMachine → Geomorphology

and select the entry **Aspect**.

The module requires in input the map of the elevation, which can be the original DTM or the DTM depitted. The output is the map of the aspect.

There is the possibility to specify two additional parameters:

- the possibility to have in the output map values in degrees instead of radians
- the possibility to round the output values (especially in case of degrees).

Figure "Execution of the *Aspect* command." shows the graphical user interface for the *Aspect* command on the test data using the output map of *DePitter*. Figure "Output of the *Aspect* command: map with aspect." shows the output map of the aspect.

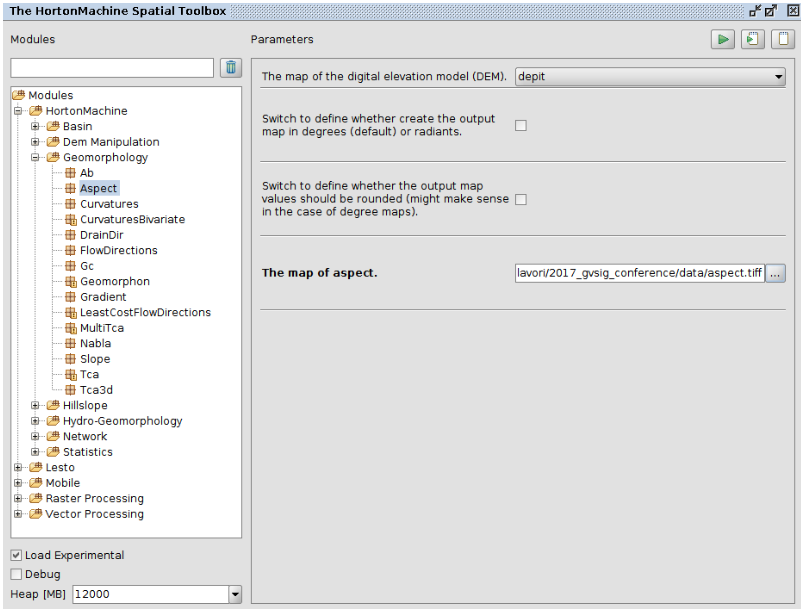


Figure 18. Execution of the Aspect command.

The **aspect** scale is best to render aspect values as in the illustrations of this tutorial.

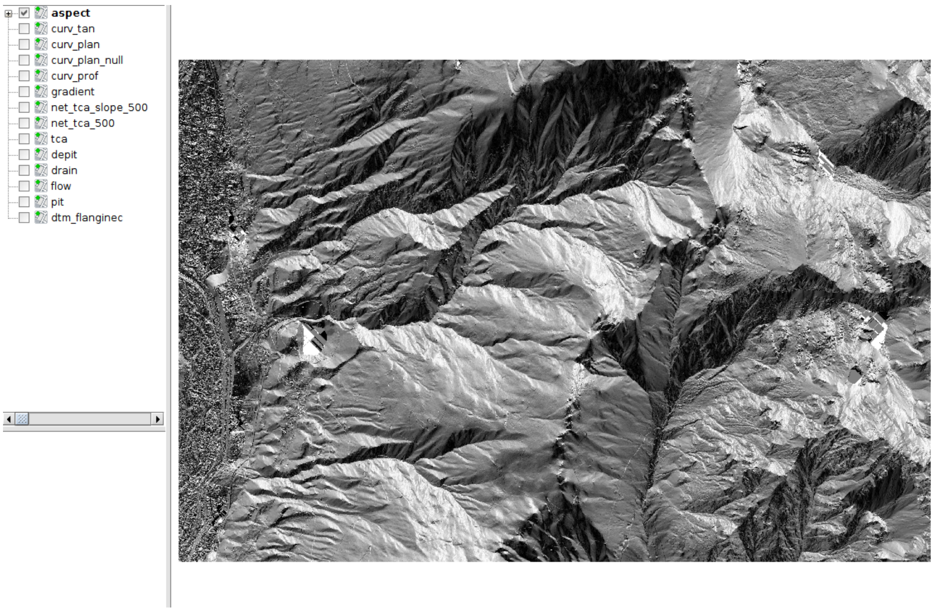


Figure 19. Output of the Aspect command: map with aspect.

2.5. Curvatures

It estimates the longitudinal (or profile), normal and planar curvatures for each site through a finite difference schema. The longitudinal curvature represent the deviation of the gradient along the flow (it is negative if the gradient increase), the normal and planar curvatures are locally proportional to each other and measure the convergence/divergence of the flow (the curvature is positive for convergent flow).

To execute the command you have to access the section

HortonMachine → Geomorphology

and select the entry **Curvatures**.

The module requires as inputs only the elevation map, which can be the original DTM or the DTM depitted. The output is the map of the gradient.

Figure "Execution of the *Curvature* command." shows the graphical user interface for the *Curvatures* command on the test data using the depitted DTM output of *DePitter*. Figure "Output of the *Curvature* command: map with the local profile (longitudinal), planar and tangential (normal) curvature." shows the output maps of the profile (longitudinal), planar and tangential (normal) curvature.

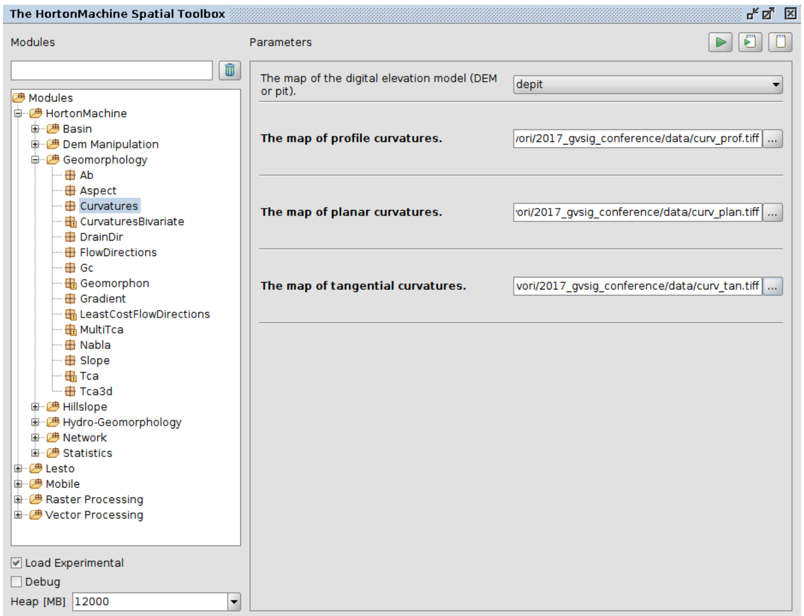


Figure 20. Execution of the Curvature command.

The **extrainbow** color table is usually used to render the map of curvatures as in the illustration of this tutorial. In some cases the maps of curvatures (especially the one of planar curvatures) have some outliers which makes the choice of the color map intervals very hard. In these cases it is recommended to delete the outliers using the *Raster Map Calculator* and then proceed in styling the map.

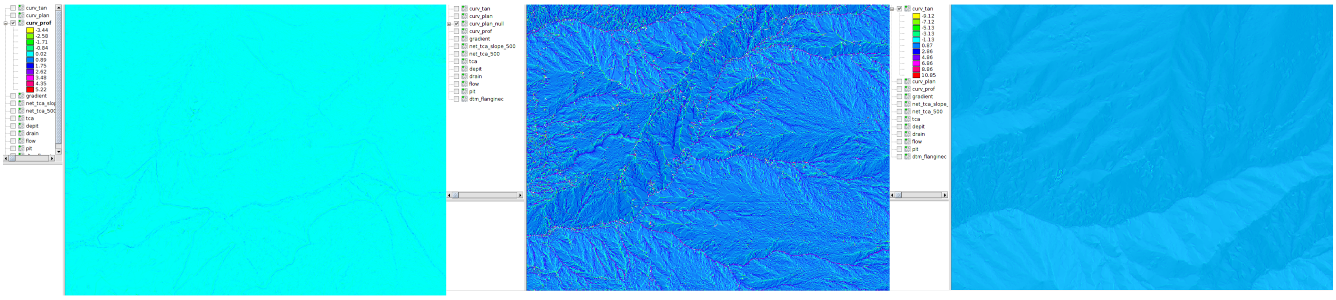


Figure 21. Output of the Curvature command: map with the local profile (longitudinal), planar and tangential (normal) curvature.

Chapter 3. Derived characteristics of topography

The hydro-geomorphological approach to digital data starts with some basic topographic analysis to hydrologically correct the digital terrain model (DTM) like the pit filling (*Pitfiller*), the delineation of drainage directions (*Flowdirections* and *Draindir*) and finally the river network extraction (*ExtractNetwork*).

3.1. FlowDirections

The next operation is to understand how the water flows over the surface with relation to the topography. This operation has important implications on the calculation of drainage areas and other quantities required for the description of a drainage system. The earliest and simplest method for specifying drainage directions is to assign a pointer from each DEM cell to one of its eight neighbors, either adjacent or diagonal in the direction of the steepest downward slope. This method is commonly known as D8 (eight drainage directions).

The function to run is *FlowDirections*. To execute the command you have to access the section

HortonMachine → Geomorphology

and select the entry **DrainDir**.

This takes as input the hydrologically correct elevation grid (output of the *Pitfiller* module) and outputs the D8 flow direction for each grid cell (Figure "Execution of the *FlowDirections* command.").

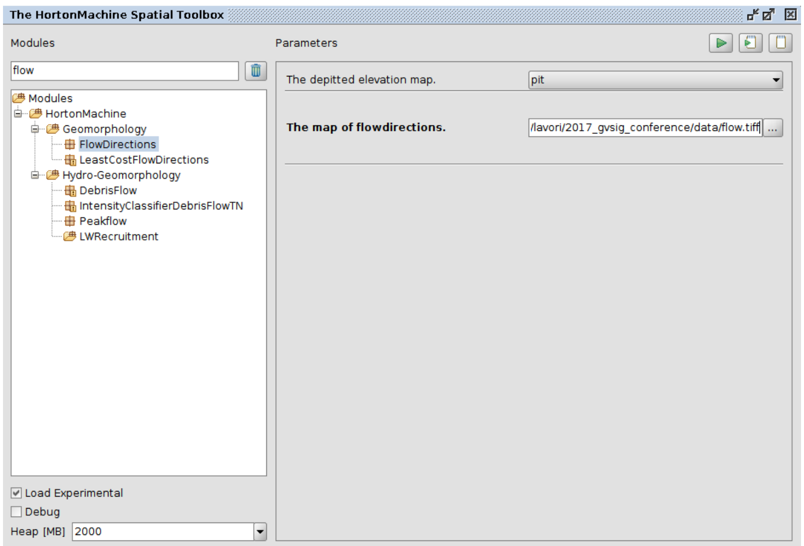


Figure 22. Execution of the FlowDirections command.

The resulting D8 flow direction grid uses an encoding of the direction of steepest descent from each grid cell following a convention based on the numbers from 1 to 8, starting with 1 in the *east* direction (Figure "Schema of the convention adopted for the drainage directions.") .

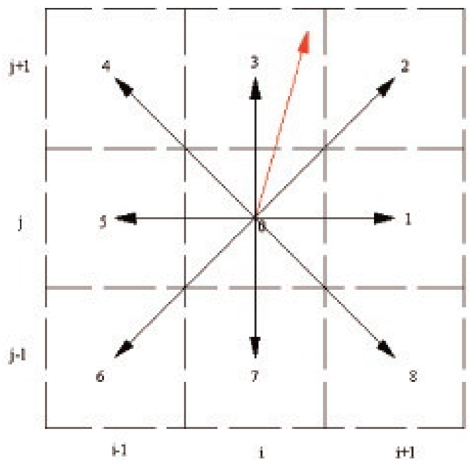


Figure 23. Schema of the convention adopted for the drainage directions.

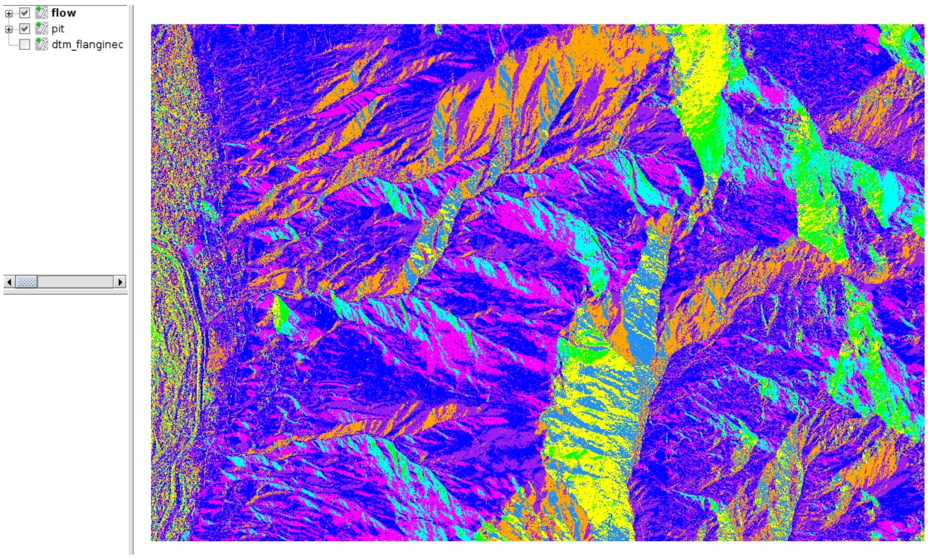


Figure 24. Output of the FlowDirections command: map with numbers representing the flow directions following the D8 method

The D8 approach is characterized by two major restrictions:

1. the drainage direction from each cell is restricted to eight possibilities
2. drainage area which originates over a two dimensional cell is treated as a point-source and is projected downslope by a line.

To overcome these two restrictions different alternative methods have been developed but in the HortonMachine only one variations on D8 method has been fully implemented so far (See *DrainDir*).

3.2. DrainDir

Using the ”pure” D8 method for the drainage direction estimation causes an effect of deviation from the real direction identified by the gradients. Some authors claim that, in nature, there is also a dispersive effect due to the subgrid variation of the gradients along the finite size of pixels, but this effect is usually negligible in most of the real cases.

Joining the eight neighbors with the central pixels, eight triangle are created and the gradient vector is inside one of them. The gradient vector deviates from the side of the triangle which represent two choices for a possible direction in the traditional D8 method. The D8 method choose the direction among the two which is closer to the real gradient direction.

The deviation of the sides from the gradient can be expressed in two ways. We can consider the angle between the aspect and the sides or the distance between the center of the pixel and the line along the gradients. The first criterion implemented, *D8- LAD* (least angular deviation), minimize the total angular deviation, the second criterion, *D8-LTD* (least trasversal deviation), minimizes the total deviation length. Both the method gives a drainage direction for any DEM cell. Besides, they can provide the estimation of the total deviation from the gradients, just cumulating the angular or the linear deviation going from the higher pixel downhill.

The core of the new method (Orlandini) is to to redirect the D8 drainage direction if use the total deviation (either angular or linear) is larger than an assigned threshold value .

- λ = 0 the deviation’s counter has no memory and the pixel up-hill do not influence the choice.
- λ = 1 the total deviation is entirely recorded.

For the D8-LAD λ = 0 is equivalent to use the steepest descent method.

The function containing the module to correct the original D8 flow directions is *DrainDir*. To execute the command you have to access the section

HortonMachine → Geomorphology

and select the entry **DrainDir**.

The mandatory input are the hydrologically correct elevation grid (output of the *Pitfiller* module) and the map of the D8 flow directions that has to be corrected (output of *FlowDirections* or *DePitter*) and outputs the map of the corrected flow direction for each grid cell and the map of the total contributing areas. Figure "Execution of the *DrainDir* command." shows the graphical user interface for the *DrainDir* command on the test data using the output map of *DePitter*. Figure "Output of the *DrainDir* command: corrected flow directions and total contributing areas." shows the outputs of the module: the map of corrected drainage directions and the map of the total contributing areas.

There is the possibility to specify some other optional inputs like:

1. the map containing the drainage directions along fixed network (considered only in case of LTD method): in case you choose to fix the extracted network on a path different from the one automatically extracted from the DTM

2. the λ parameter representing the direction correction factor which must be a value in the range 0 - 1
3. the method choosen: LAD (angular deviation - default value) and LTD (trasversal distance).

> Remember that in the case of fixed flow calculation the total contributing areas have to be recalculated afterwards because the output in this case has previously been calculated on the original flow directions without the fixed network.

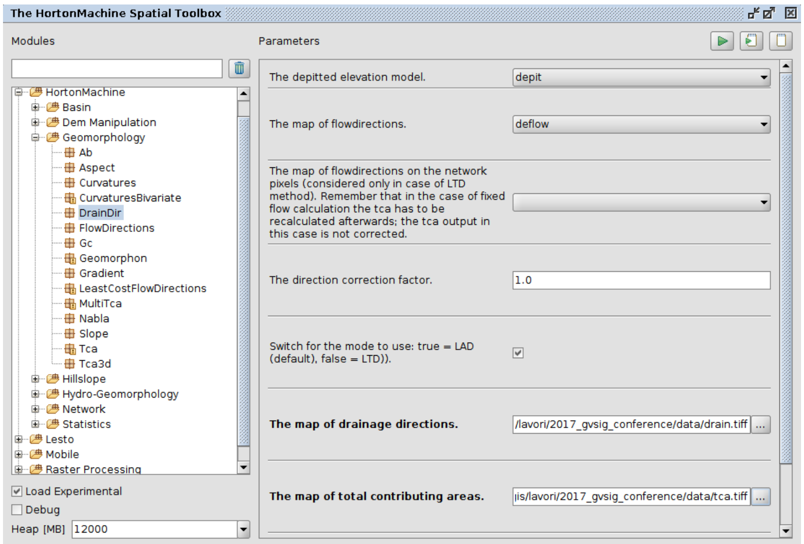


Figure 25. Execution of the DrainDir command.

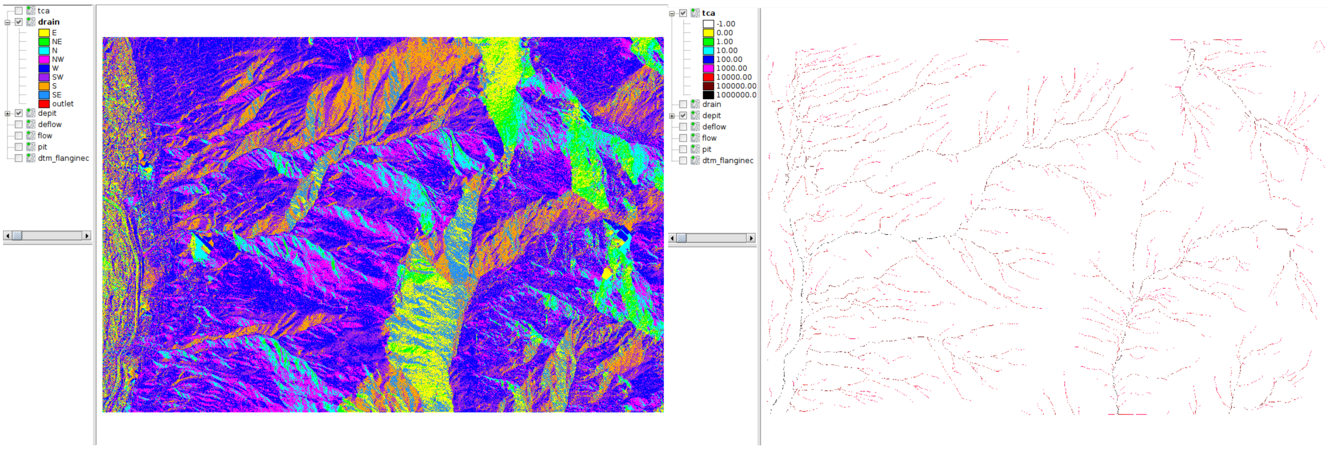


Figure 26. Output of the DrainDir command: corrected flow directions and total contributing areas.

3.3. TCA

The upslope catchment (or simply contributing) areas represent the planar projection of the areas afferent to a point in the basin. Once the drainage directions have been defined, it is possible to calculate, for each site, the total drainage area afferent to it, indicated as *TCA* (Total Contributing Area).

TCA counts the number of grid cells draining through (out of) each grid cell based on the map of the flow directions. This module is used only if you want to work with the original D8 flow directions and when you work with the corrected drainage directions with a fixed network. The map of the *TCA* is automatically extracted when running the *DrainDir* command to correct the drainage directions.

To execute the command you have to access the section

HortonMachine → Geomorphology

and select the entry **Tca**.

The module requires in input the map of the flow directions for which you want to calculate the total contributing areas and creates in output the map of the total contributing area in each grid cell as number of grid cells draining through it and, in case of problems, a vector layer containing the loops not resolved by the algorithm. Figure "Execution of the *Tca* command." shows the graphical user interface for the *Tca* command on the test data using the output map of *FlowDirections*. Figure "Output of the *Tca* command: map with total contributing areas." shows the output map of the total contributing areas.

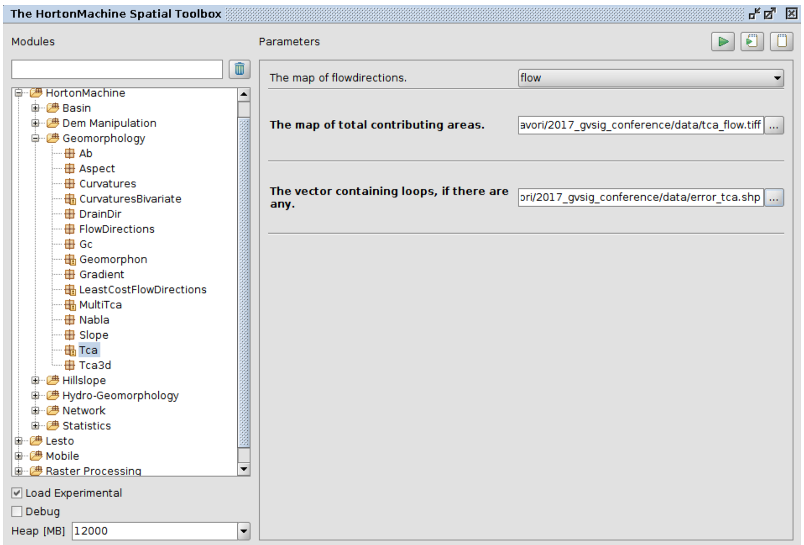


Figure 27. Execution of the Tca command.

A logarithmic scale is often best to render contributing area values as in the illustration of this tutorial.

Figure 28. Output of the Tca command: map with total contributing areas.

The **Tca3D** module is similar to the *Tca* but it estimates the real draining area and not only its projection on the plane as the TCA does.

3.4. Slope

Slope estimates the slope in every site by following the drainage directions. Differently from the gradients, slope calculates the drop between each pixel and the adjacent points placed underneath and it divides the result by the pixel length or by the length of the pixel diagonal, according to the cases. The greatest value is the one chosen as slope.

To execute the command you have to access the section

HortonMachine → Geomorphology

and select the entry **Slope**.

The module requires in input the map of the elevation depitted (output of *DePitter*) and the map of the flow directions (output of *DrainDir*). The output is the map of the slope in each pixel.

There is the possibility to specify if eventually negative values will be set to the minimum positive value or maintain them as negative.

Figure "Execution of the *Slope* command." shows the graphical user interface for the *Slope* command on the test data using the output map of *DePitter* and of the *DrainDir*. Figure "Output of the *Slope* command: map with slope." shows the output map of the slope.

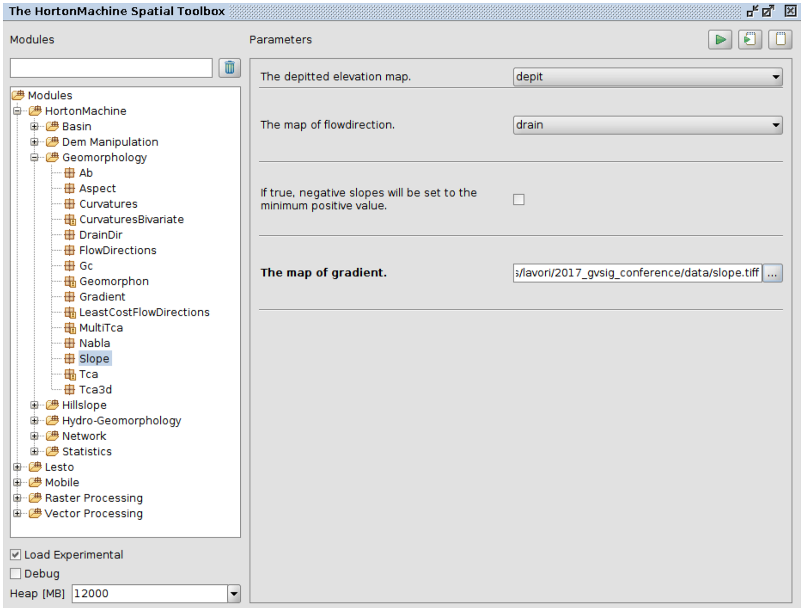


Figure 29. Execution of the Slope command.

The **slope** scale is best to render slope values as in the illustrations of this tutorial.

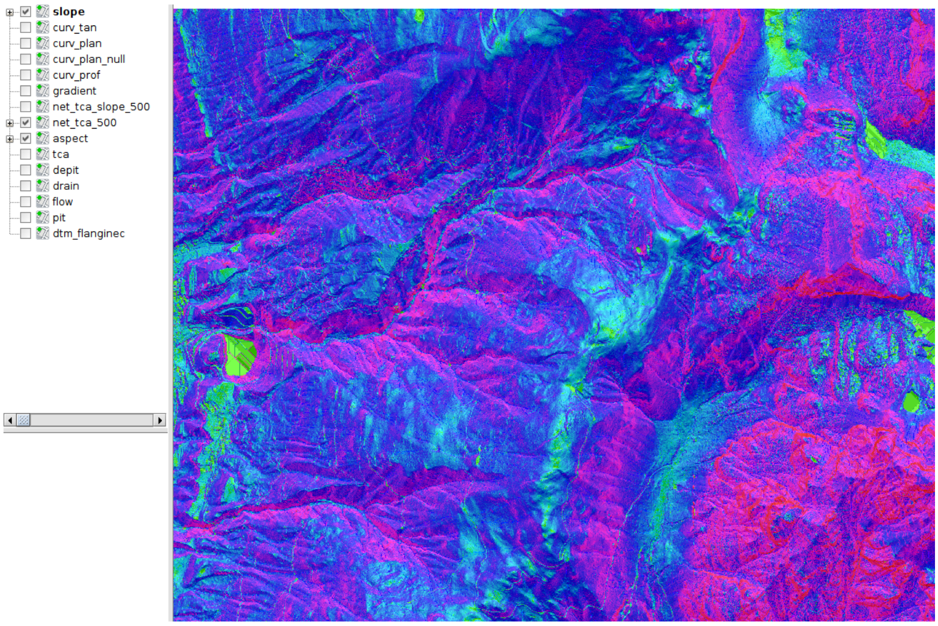


Figure 30. Output of the Slope command: map with slope.

3.5. ExtractNetwork

It extracts the channel network from the drainage directions in three possible ways:

1. by using a threshold value on the contributing areas: only the pixels with contributing area greater than the threshold are considered channel heads
2. by using a threshold value on the product of two quantities, for example the contributing areas and the slopes (equivalent of a threshold on the stress tangential to the bottom: this requires the additional input map of slopes calculated with **Gradient**
3. by using a threshold value on the contributing areas only in convergent sites: the extracted network pixels have to show a convergent morphology: this requires the additional input map with the topographic classes **Tc**.

Once individuated the beginning of the channel incision, the points downstream are considered as canalized.

To execute the command you have to access the section

HortonMachine → **Network**

and select the entry **ExtractNetwork**.

3.5.1. Extracting the network using the contributing areas

The network is extracted by fixing a threshold on the total contributing areas or on the magnitudo (output of the **Magnitudo** command). Using this mode all the pixels with contributing area greater than the threshold are considered channel. The choice of the threshold value depends on the characteristics of the soil and on the resolution of the input maps. It is reccommended to do some tests using different values of the threshold on the TCA and compare the resulting network with the real. This is the default *Thresholding mode* **Only Tca**.

Figure "Execution of the *Gradient* command." shows the graphical user interface for the *ExtractNetwork* command on the test data using the output map of *DrainDir* and a threshold value of TCA of 500 pixels considering the resolution of the input map of 2 m. Figure "Output of the *Gradient* command: map with the local gradient." shows the output map of the extracted stream network for the entire area.

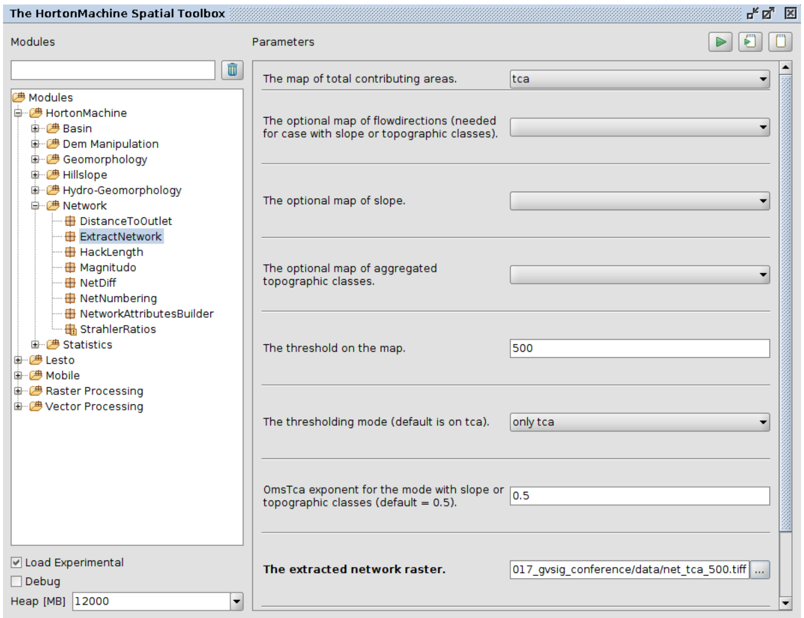


Figure 31. Execution of the ExtractNetwork command considering a threshold on TCA.

The **net** color table is usually used to render the extracted network map as in the illustrations of this tutorial.

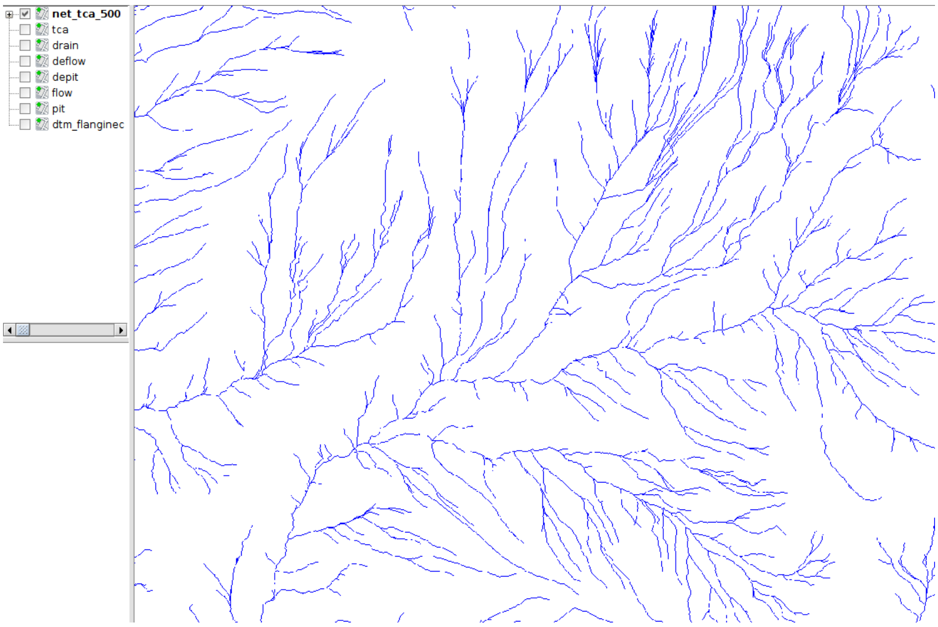


Figure 32. Output of the ExtractNetwork command with a threshold on TCA: a zoom of the map of the extracted stream network.

3.5.2. Extracting the network using the contributing areas and the slopes

The network is extracted by fixing a threshold on the product of two quantities, for example, the contributing areas and the slope. First of all you need to calculate the map of slopes using the function **Gradient**.

It is possible to proceed with the network extraction by fixing a threshold on the product of the *TCA* and *Gradient*. Figure "Execution of the *ExtractNetwork* command considering a threshold on TCA and slope." shows the graphical user interface for the *ExtractNetwork* command on the test data using both the output maps of *DrainDir* (total contributing areas and drainage directions), the map of slope obtained with the *Gradient* module and a threshold value on the product between contributing areas and slope of 500, also in this case considering the resolution of the input map of 2 m. The choice of the threshold value depends on the characteristics of the soil and on the resolution of the input maps. It is reccommended to do some tests using different values of the threshold on the TCA and compare the resulting network with the real one. Remember to specify the *Thresholding mode* by selecting the **Tca and slope** from the dropdown menu.

Figure "Output of the *ExtractNetwork* command with a threshold on TCA and slope: the map of the extracted stream network." shows the output map of the extracted stream network with this mode for the entire area. As you can see the resulting network is quite different (less branched) from the one extracted on the same are and using the same value of threshold with the previous mode.

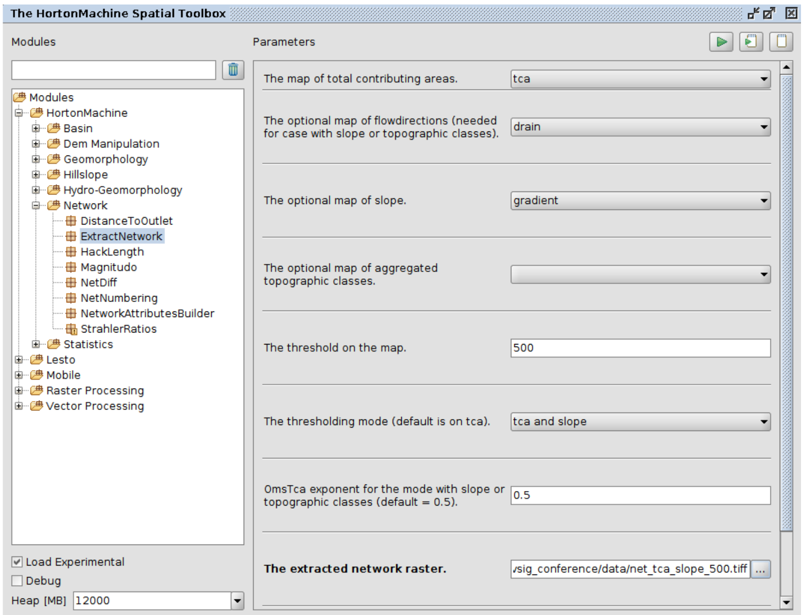


Figure 33. Execution of the ExtractNetwork command considering a threshold on TCA and slope.

The **net** color table is usually used to render the extracted network map as in the illustrations of this tutorial.

Figure 34. Output of the ExtractNetwork command with a threshold on TCA and slope: the map of the extracted stream network.

3.5.3. Extracting the network using the curvatures

The network is extracted by fixing a threshold on the product of the total contributing areas and slope but only in convergent sites. To execute this operation first of all you need to calculate the map of curvatures using the function **Curvatures** and then you have to distinguish the different topographic classes (concave, convex and planar sites) with the command *Tc*.

It is possible to proceed with the network extraction by fixing a threshold on the product of *TCA* and *Slope* and considering only the concave sites from the *Tc* map of the 3 aggregated topographic classes. Figure "Execution of the *ExtractNetwork* command considering a threshold on TCA in concave sites." shows the graphical user interface for the *ExtractNetwork* command on the test data using the map of TCA output of *DrainDir* and the map of aggregated topographic classes obtained with the *Tc* module and a threshold value on the total contributing areas of 500, also in this case considering the resolution of the input map of 2 m. Remember to specify the *Thresholding mode* by selecting the **Tca in convergent sites** from the dropdown menu. The choice of the threshold value depends on the characteristics of the soil and on the resolution of the input maps. It is reccommended to do some tests using different values of the threshold on the TCA and compare the resulting network with the real. Figure "Output of the *ExtractNetwork* command with a threshold on TCA in concave sites: the map of the extracted stream network." shows the output map of the extracted stream network with this mode for the entire area.

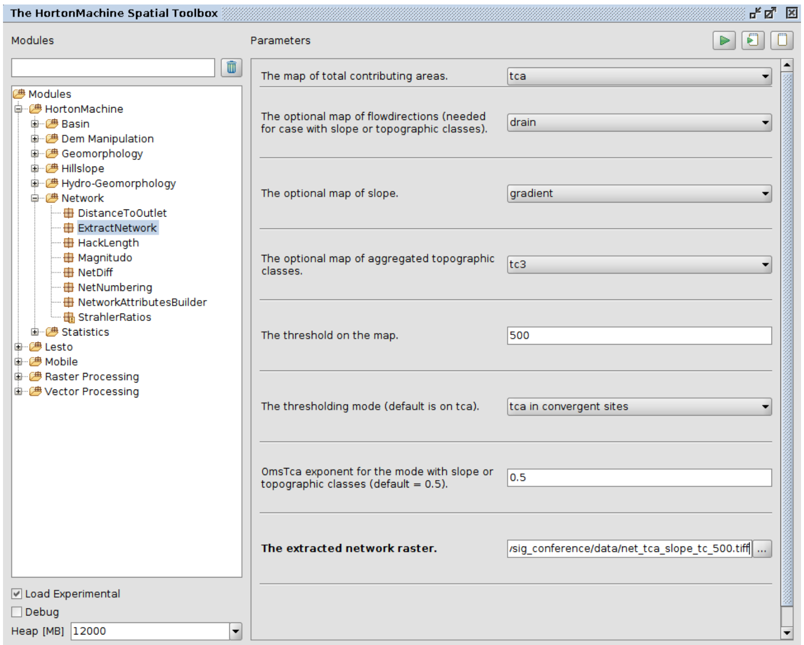


Figure 35. Execution of the ExtractNetwork command considering a threshold on TCA in concave sites.

The **net** color table is usually used to render the extracted network map as in the illustrations of this tutorial.

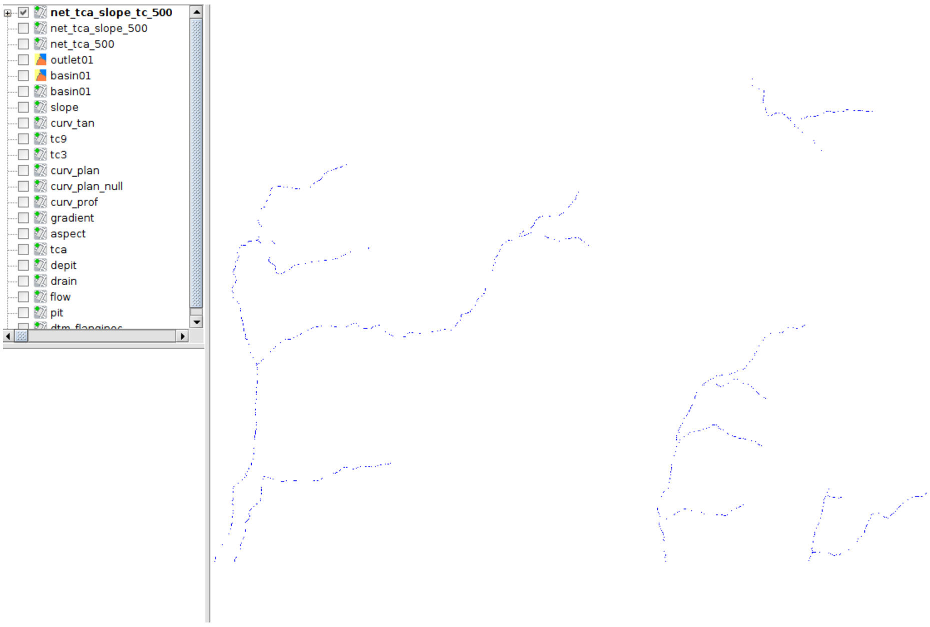


Figure 36. Output of the ExtractNetwork command with a threshold on TCA in concave sites: the map of the extracted stream network.

Chapter 4. Watershed delineation

Once the stream network is available it is possible to extract a water basin which represents only one part of the whole area of the DTM. Further analysis will be made only on the selected basin in order to prepare all the data for the evaluation of the stability of the hillslopes and the maximum discharges.

4.1. ExtractBasin

ExtractBasin extracts a watershed from a map of flow directions given the position of the outlet.

To execute the command you have to access the section

HortonMachine → Dem Manipulation

and select the entry **ExtractBasin**.

The module requires in input the coordinates of the basin outlet, the map of the flow directions (output of *DrainDir*) and, optionally, the map of the stream network (output of *ExtractNetwork*). The output maps are the raster with the mask of the basin and the vector maps of the point of the basin outlet and the boundaries of the extracted basin.

There is the possibility to specify a map of the stream network to force the program to snap to a link of the network and therefore it is necessary to specify the buffer for the operation of snapping. An additional parameter to specify gives the possibility to smooth the boundaries of the output vector map of the extracted basin in order to have a nice representation of the polygon without following the pixels.

The coordinates of the basin outlet can be specified in two ways:

- by entering the coordinates in the relative boxes
- by clicking on the position of the outlet in the *View*, in this case you can see the coordinates changing automatically when clicking on different points.

> the basin should be representative of the area draining into a point of the river network, for this it is highly reccommended to select a point of the extracted network. Please take care of visualize the stream river and zoom on the area where you want to place the basin outlet. To help you in this operation the command supports the automatic snapping on a given extracted network.

Figure "[horton02_29]" shows the graphical user interface for the *ExtractBasin* command on the test data using the output map of *DrainDir* and visualizing the network extracted with *ExtractNetwork*. Figure "[horton02_30]" shows the output map of the mask of the extracted basin.

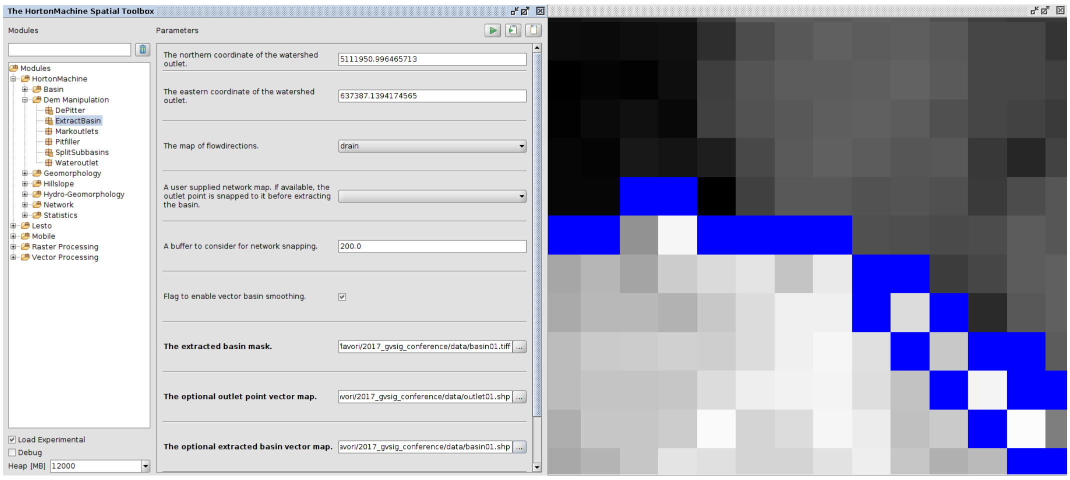


Figure 37. Execution of the ExtractBasin command.

> The **slope** scale is best to render slope values as in the illustrations of this tutorial.

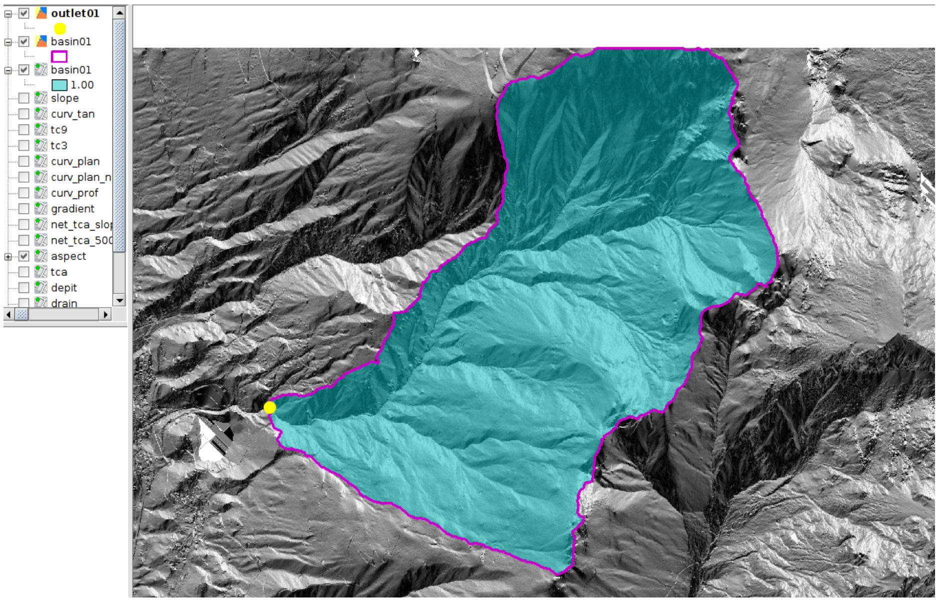


Figure 38. Output of the ExtractBasin command: maps with the raster mask of the basin, the vector maps of the outlet points and boundaries of the basin.

> Please take care to read the messages contained in the *Log View* in particular for this module because there could be important information about the process. For example in this case the messages are two:

1. the extracted basin touches the boundaries of the map and therefore it will be not complete
2. the program couldn't do the smoothing of the output polygon of the extracted basin.

We can proceed now with some analysis on the extracted basin. The first operation to do is to cut the available maps that we calculated in the previous chapters on the mask of the basin.

> It is reccommended to cut the maps on the region of the extracted basin instead of running all the commands again to be sure that all the resulting maps cover exactly the same region. Maps with different areas will create problems doing some further analysis on the extracted basin. This problem could occur with modules that need to consider all the 8 surrounding cells. In this case, the cells at the boundaries could not be elaborated because they miss one or more vaules, therefore in the output map these cells will be put to NOVALUE. An example of a module which will have such a problem is *FlowDirections*.

In this tutorial we will proceed to cut only the maps that we will use for further analysis and in particular:

- the map of the depitted DTM output from *DePitter*
- the map of drainage directions and the relative total contributing areas output of *DrainDir*
- the maps of slopes output of *Gradient* and *Slope*
- the map of the planar curvatures output fo *Curvatures*
- the map of the extracted network output of *ExtractNetwork*, in this case we choose to go on with the network extracted using only the threshold on the TCA.

There are two ways to do the cutting:

1. through the *Raster Map Calculator* using a formula based on a *IF* statement
2. using the ad-hoc command *CutOut* of the Spatial Toolbox.

Here we will describe only the second option because it is easier and faster, for the use of the *Raster Map Calculator* you can refer to the available documentation.

4.2. CutOut

CutOut is a module for raster thresholding and masking. It gives the possibility to:

- cut a raster on the valid area (cells) of an other given raster which is called **mask**.
- extract the areas of a raster map where the values are upper or lower to a given threshold
- extract the mask area or the inverse (negative).

To execute the command you have to open the *Spatial Toolbox* and access the section

Raster Processing

and select the entry **CutOut**.

In this tutorial we will use the standard mode, which means to extract the data of the map that have to be processed on the mask area without thresholds. The command requires two maps in input:

- the raster map that have to be processed (in this case cut)
- the raster map to use as mask (the extracted basin mask).

And the output is the original map cut on the mask area (the basin area), which means that the output map is a map containing the same values of the original map inside the area of the mask and NODATA outside.

Figure "Execution of the *CutOut* command." shows the graphical user interface for the *CutOut* command for the map of the depitted DTM output map of *DePitter* using the extracted basin as mask output of *ExtractBasin*. Figure "Output of the *CutOut* command: map of the depitted DTM cut on the basin area." shows the output map of the depitted DTM on the area of the extracted basin.

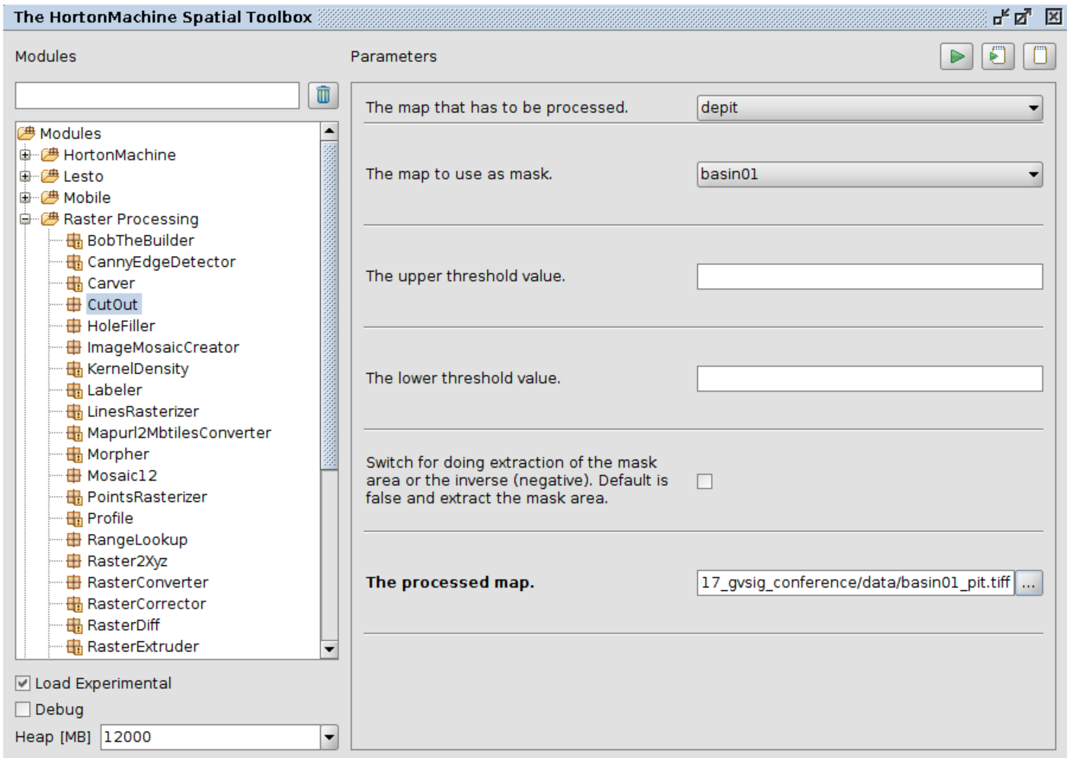


Figure 39. Execution of the CutOut command.

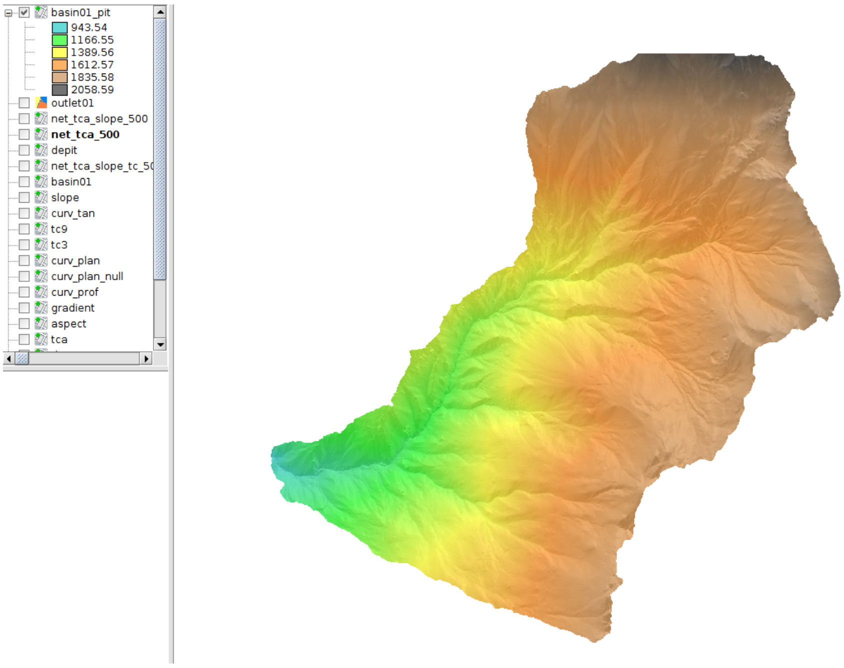


Figure 40. Output of the CutOut command: map of the depitted DTM cut on the basin area.

The same operation has to be done for the other following maps:

- the map of drainage directions and the relative total contributing areas output of *DrainDir*
- the maps of slopes output of *Gradient* and *Slope*
- the map of the planar curvatures output fo *Curvatures*
- the map of the extracted network output of *ExtractNetwork*, in this case we choose to go on with the network extracted using only the threshold on the TCA.

Just change the map that has to be processed and the name of the output map in the GUI of the command. The output maps are displayed in Figures "Output of the *CutOut* command: map of the drainage directions cut on the basin area." - "Output of the *CutOut* command: map of the total contributing areas cut on the basin area." - "Output of the *CutOut* command: map of the gradient cut on the basin area." - "Output of the *CutOut* command: map of the slope cut on the basin area." - "Output of the *CutOut* command: map of the planar curvatures cut on the basin area.".

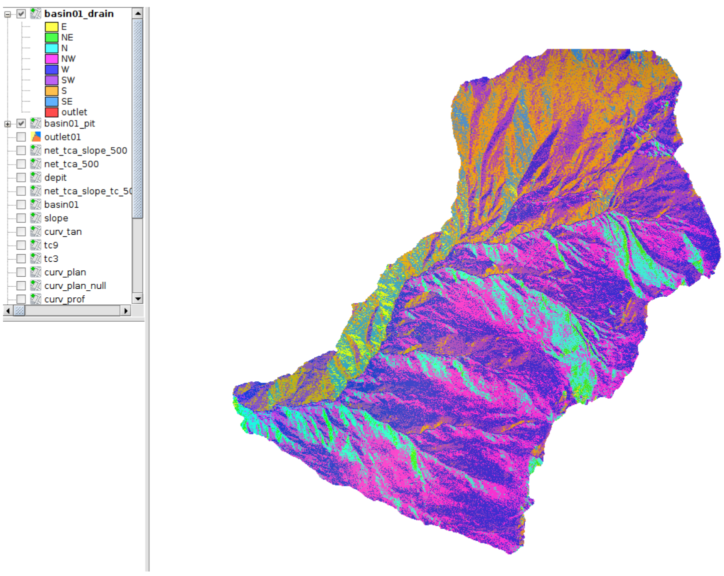


Figure 41. Output of the CutOut command: map of the drainage directions cut on the basin area.

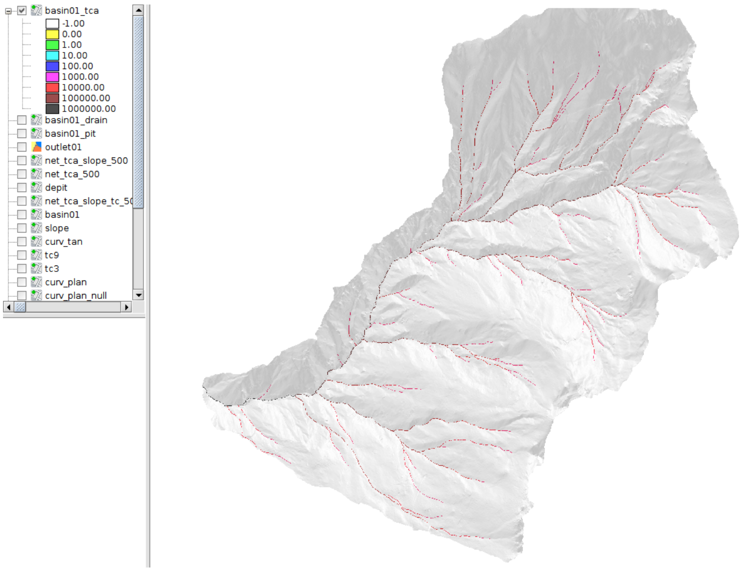


Figure 42. Output of the CutOut command: map of the total contributing areas cut on the basin area.

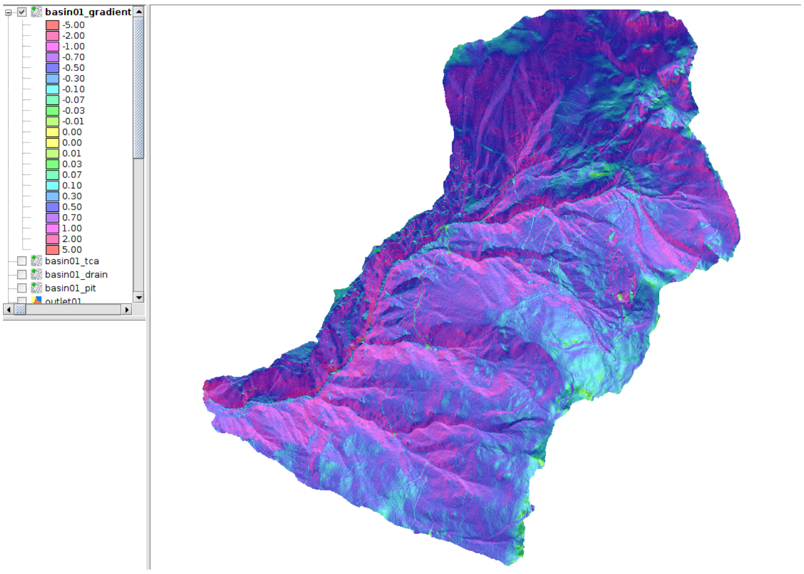


Figure 43. Output of the CutOut command: map of the gradient cut on the basin area.

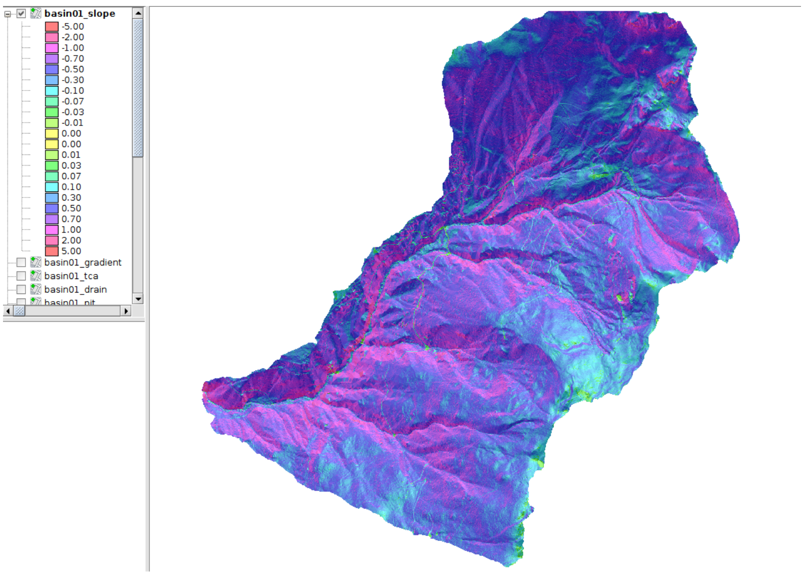


Figure 44. Output of the CutOut command: map of the slope cut on the basin area.

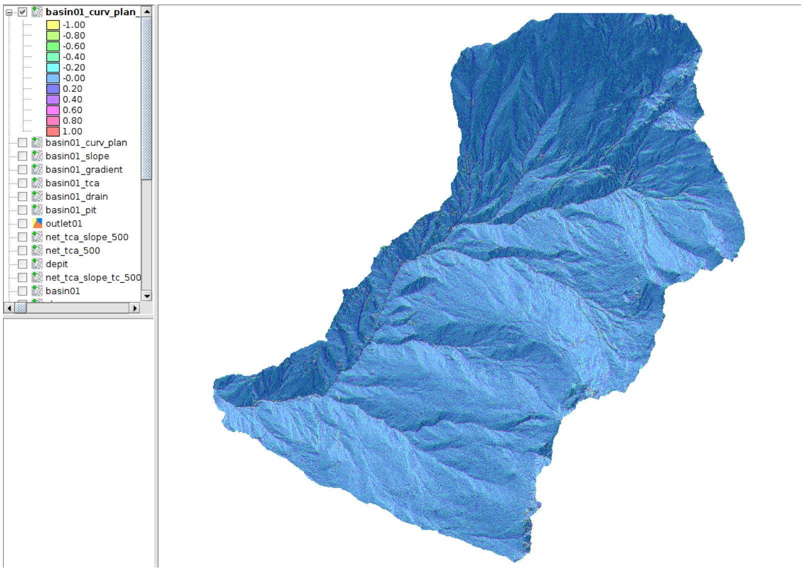


Figure 45. Output of the CutOut command: map of the planar curvatures cut on the basin area.

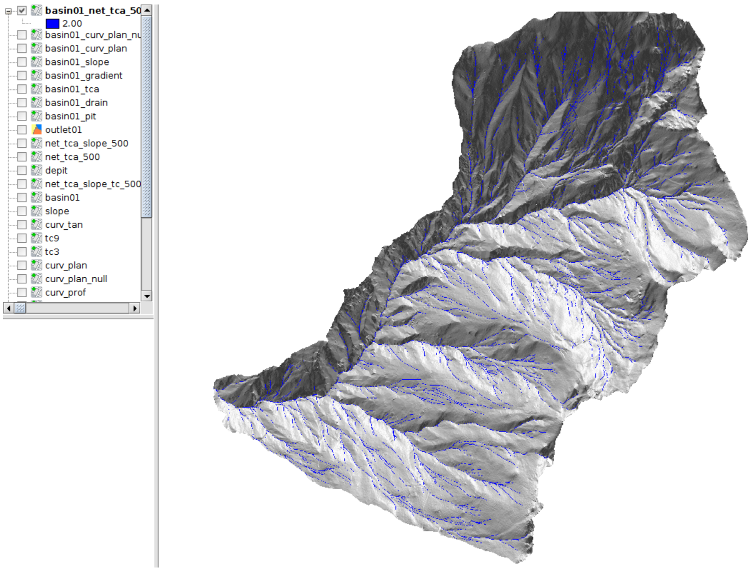


Figure 46. Output of the CutOut command: map of the extracted network cut on the basin area.

4.3. NetworkAttributesBuilder

NetworkAttributesBuilder extracts network attributes and the vector network based on a raster network and additional attributes raster maps.

To execute the command you have to access the section

HortonMachine → **Network**

and select the entry **NetworkAttributesBuilder**.

The module requires in input:

- the map (raster) of the extracted network (output from *ExtractNetwork*) cut on the current basin
- the map of the flow directions and total contributing areas (output of *DrainDir*) cut on the current basin

The output maps are the vector map of the stream network (same detail as the input raster map) with additional attributes and the raster map of the network numbering of Hack (see The Horton Manual for more details on this map). To create the map with the Hack numbering you have to check the box *Flag to also create the hack map*.

The attributes contained in the vector map of the network are:

- the Hack numbering
- the Strahler numbering
- the Pfafstetter enumeration.

Figure "Execution of the *NetworkAttributesBuilder* command." shows the graphical user interface for the *NetworkAttributesBuilder* command on the test data using the outputs map of *ExtractNetwork* (only with a threshold on TCA) and *DrainDir* and with the option to create also the raster map of Hack numbering. Figure "Output of the *NetworkAttributesBuilder* command: vector map with the stream network with the associated attrubutes table." shows the output vector map of the network with the associated attribute table and Figure "Output of the *NetworkAttributesBuilder* command: raster map of Hack numbering." the raster map of Hack numbering.

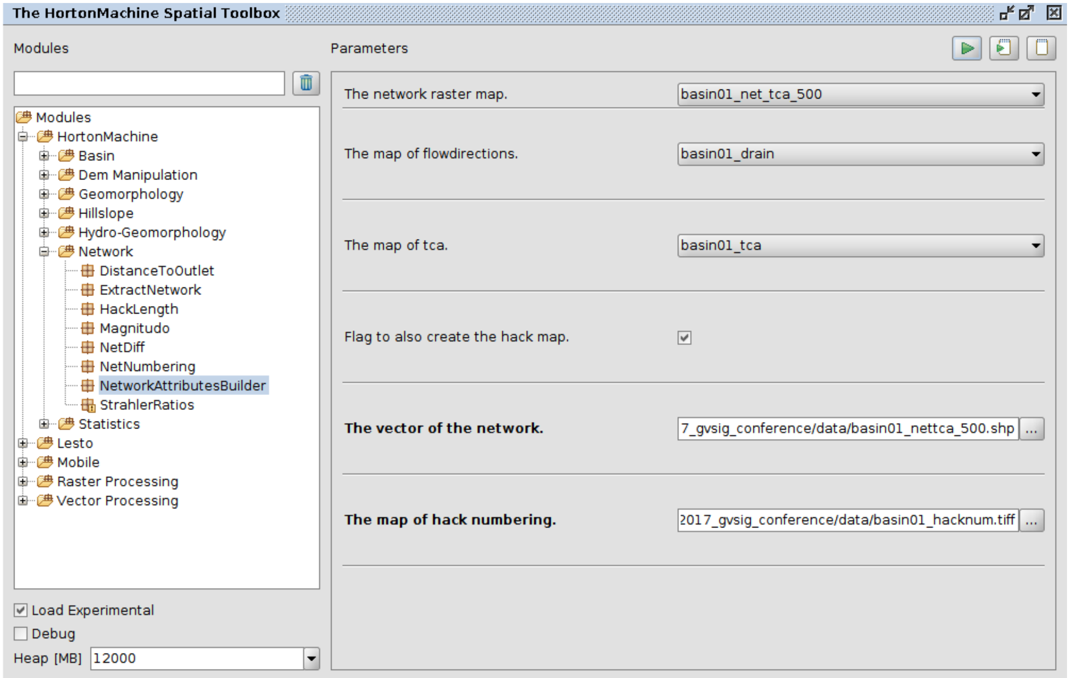


Figure 47. Execution of the NetworkAttributesBuilder command.

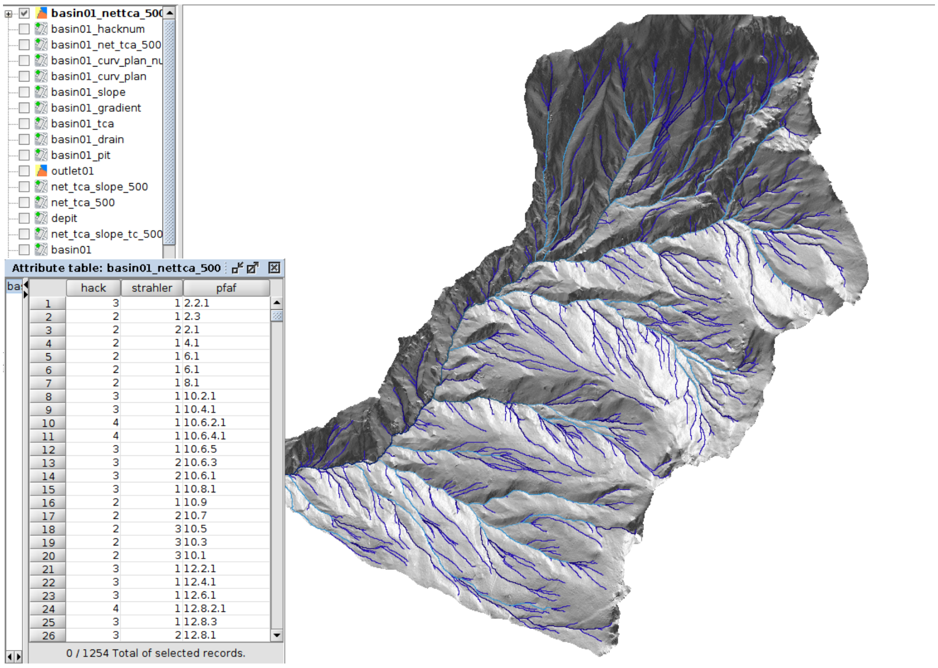


Figure 48. Output of the NetworkAttributesBuilder command: vector map with the stream network with the associated attrubutes table.

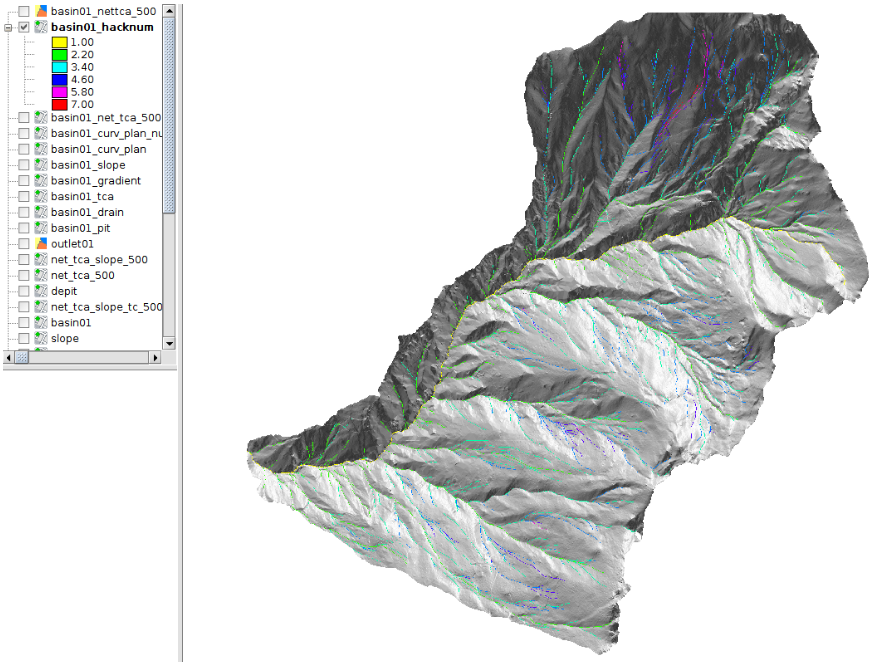


Figure 49. Output of the NetworkAttributesBuilder command: raster map of Hack numbering.

4.4. DistanceToOutlet

DistanceToOutlet calculates the projection on the plane of the distance of each pixel from the basin outlet, measured along the drainage directions. By aggregating the matrix so obtained, we get the so called width function. The program can work in two different ways: it can calculate the distance from the outlet either in pixel number (0: topological distance mode), or in meters (1: simple distance mode).

To execute the command you have to access the section

HortonMachine → Network

and select the entry **DistanceToOutlet**.

The module requires in input:

- the map of the elevation depitted (output from *DePitter*), if this map is not provided the model will work in 2D mode
- the map of the flow directions (output of *DrainDir*)

The output map is the raster map with the distance from each pixel to the outlet of the basin following the flow directions (minimum steepest path).

There is the possibility to specify if the output map will be in meters (simple mode) or in number of pixels (topological mode).

Figure "Execution of the *DistanceToOutlet* command." shows the graphical user interface for the *DistanceToOutlet* command on the test data using the outputs map of *DePitter* and *DrainDir* and with the option to create the raster map in meters. Figure "Output of the *DistanceToOutlet* command: map with the distance in meters from each pixel to the basin outlet." shows the output map of the distance for each pixel to the basin outlet.

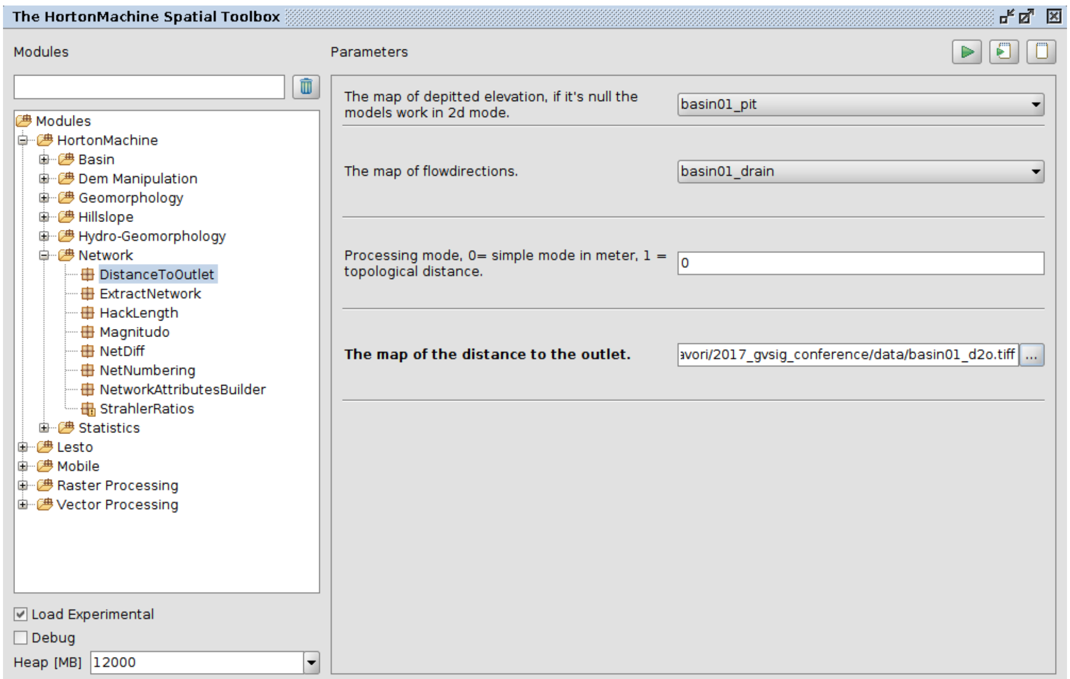


Figure 50. Execution of the DistanceToOutlet command.

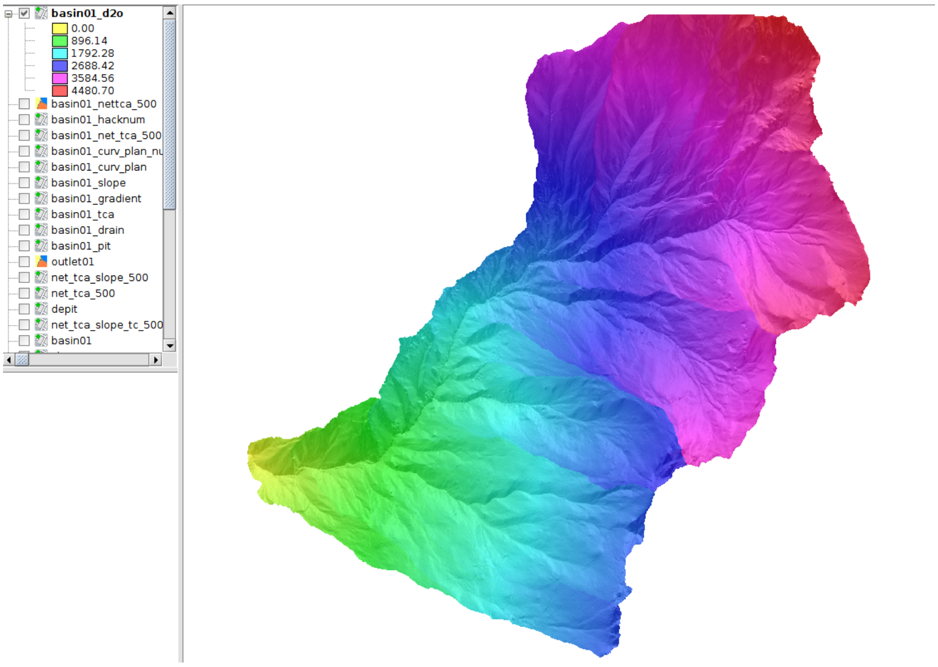


Figure 51. Output of the DistanceToOutlet command: map with the distance in meters from each pixel to the basin outlet.

4.5. RescaledDistance

RescaledDistance calculates the rescaled distance of each pixel from the outlet. The module considers the total distance to the outlet split in two different components: the distance along the channels and the distance in the hillslopes. The two components can have different weights if a value of the *Ratio between the velocity in the channel and in the hillslope* different from 1 is specified.

To execute the command you have to access the section

HortonMachine → **Basin**

and select the entry **RescaledDistance**.

The module requires in input:

- the map of the flow directions (output of *DrainDir*)
- the map of the extracted network (output of *ExtractNetwork*)
- the map of the elevation depitted (output from *DePitter*), if you want to calculate the 3D distance, otherwise the model will work in 2D mode (default mode).

The value of the ratio between the velocity in the channel and in the hillslope is also required as mandatory input. The default value is zero, this means that the distance in the hillslopes will not be considered in the evaluation of the total distance to outlet. Reasonable values are from 1 to 1000 depending on the geology of the hillslopes and on the geometry of the sections of the network.

The output map is the raster map with the rescaled distance from each pixel to the outlet of the basin following the flow directions (minimum steepest path).

This module is usually used to prepare the input data for the semi distributed hydrological model *Peakflow* also integrated in the Horton Machine library. It represents the base component for the evalutation of the width function.

Figure "Execution of the *RescaledDistance* command." shows the graphical user interface for the *RescaledDistance* command on the test data using the outputs map of *DrainDir* and *DePitter* in 2D mode and with a ratio between the distance on the network and on the hillsope of 10. Figure "Output of the *RescaledDistance* command: map with the rescaled distance in meters from each pixel to the basin outlet using a ratio between the celerity in the channels and in the hillslopes of 10." and Figure "Output of the *RescaledDistance* command: map with the rescaled distance in meters from each pixel to the basin outlet using a ratio between the celerity in the channels and in the hillslopes of 100." shows the output map of the rescaled distance for each pixel to the basin outlet considering the ratio of 10 and 100.

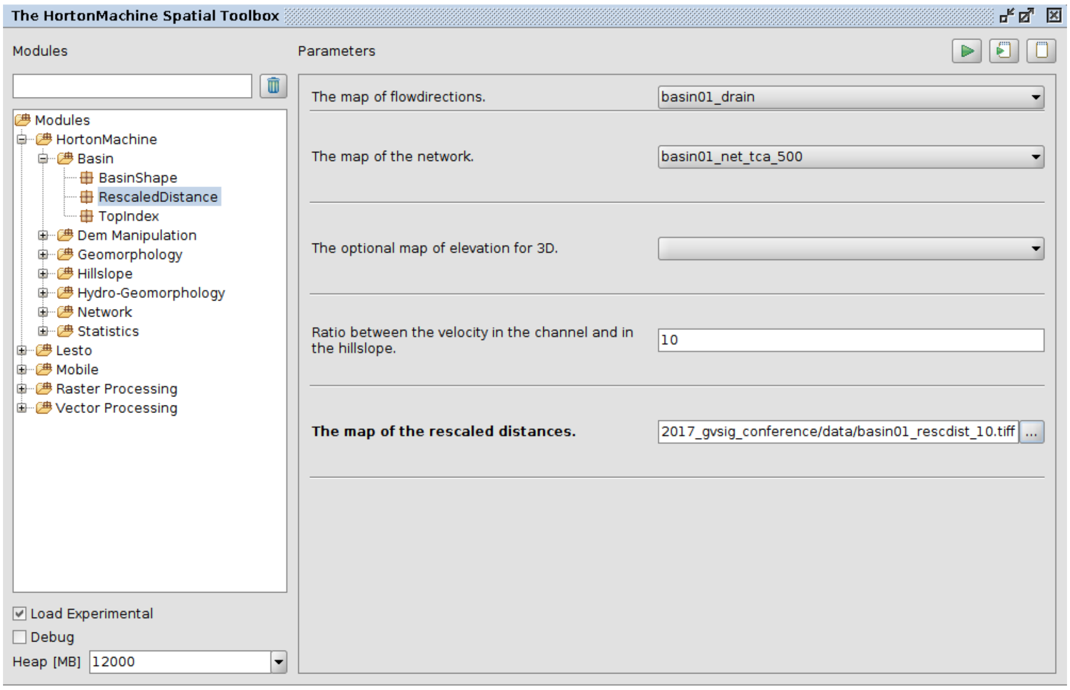


Figure 52. Execution of the RescaledDistance command.

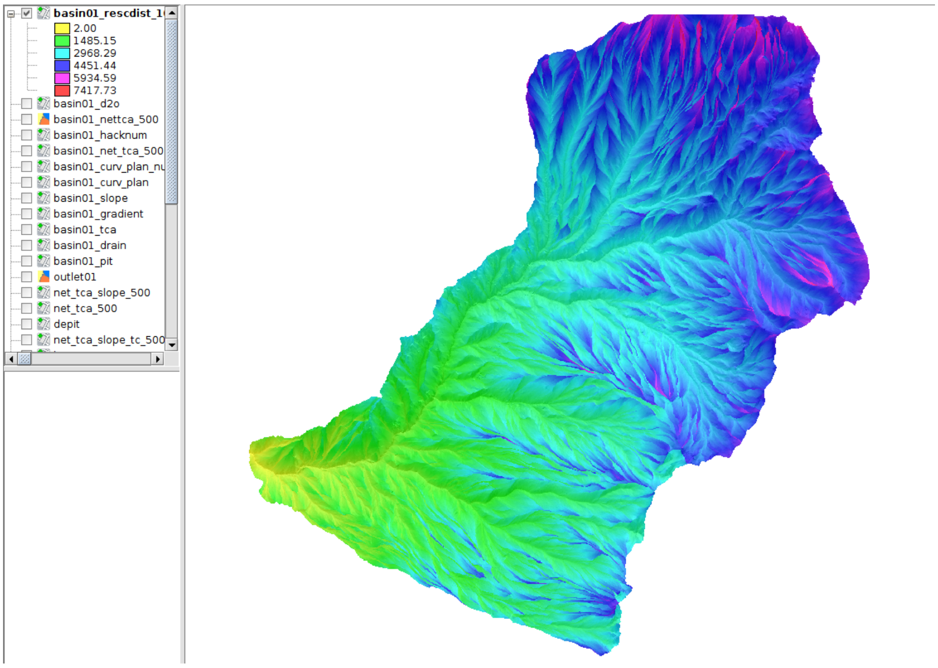


Figure 53. Output of the RescaledDistance command: map with the rescaled distance in meters from each pixel to the basin outlet using a ratio between the celerity in the channels and in the hillslopes of 10.

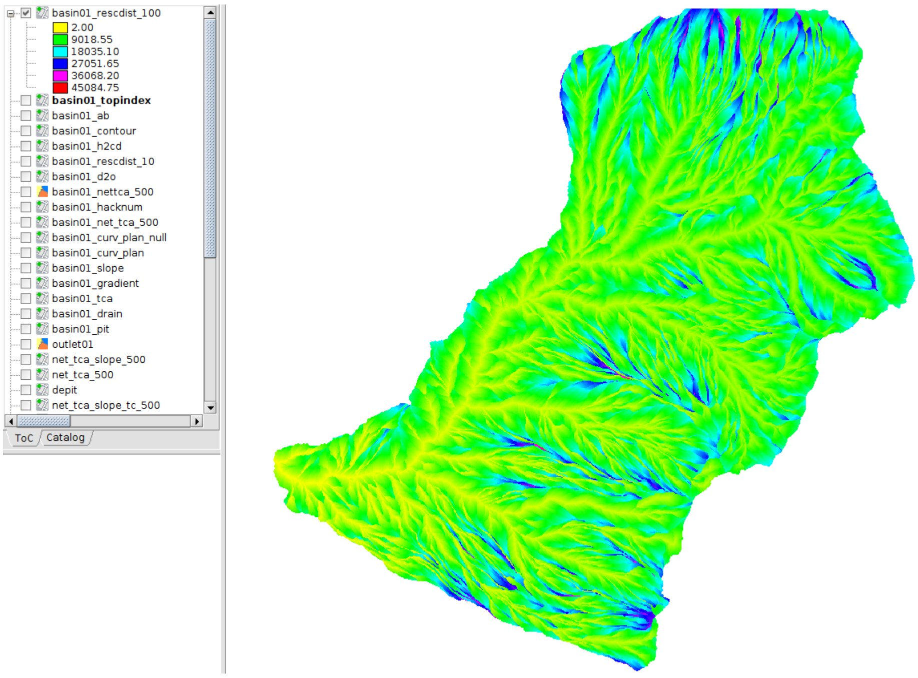


Figure 54. Output of the RescaledDistance command: map with the rescaled distance in meters from each pixel to the basin outlet using a ratio between the celerity in the channels and in the hillslopes of 100.

Chapter 5. Hillslope analysis

5.1. H2cd

H2cd is for *Hillsopes To Channel Distance* and it calculates for each hillslope pixel its distance from the river networks, following the steepest descent (the drainage directions). The program can work in two different ways: it can calculate the distance from the outlet either in number of pixels (0: topological distance mode), or in meters (1: simple distance mode).

To execute the command you have to access the section

HortonMachine → Hillsope

and select the entry **H2cd**.

The module requires in input:

- the map of the flow directions (output of *DrainDir*)
- the map of the extracted network (output of *ExtractNetwork*)
- the map of the elevation depitted (output from *DePitter*), if you want to calculate the 3D distance only if you want the results in meters. If this map is not specified the model will work in 2D mode (default mode).

There is the possibility to specify if the output map will be in meters (simple mode) or in number of pixels (topological mode).

Figure "Execution of the *H2cd* command." shows the graphical user interface for the *H2cd* command on the test data using the outputs map of *ExtractNetwork* (only with a threshold on TCA) and *DrainDir* in 2D mode. Figure "Output of the *H2cd* command: vector map with the stream network with the associated attrubutes table." shows the output map of the distance for each pixel to the network.

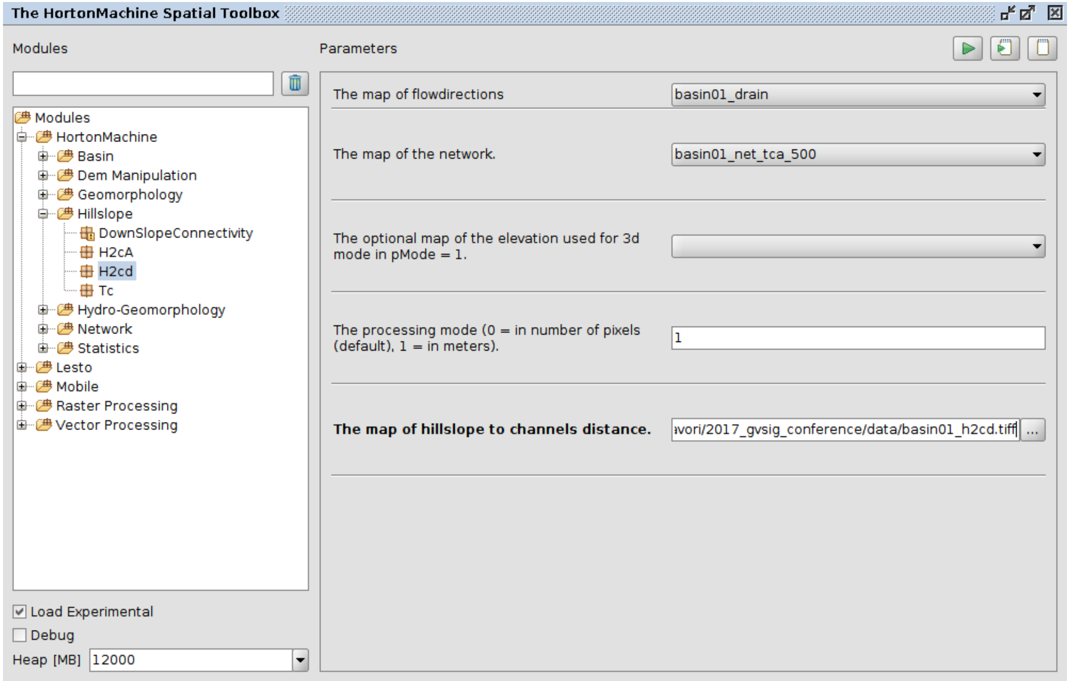


Figure 55. Execution of the H2cd command.

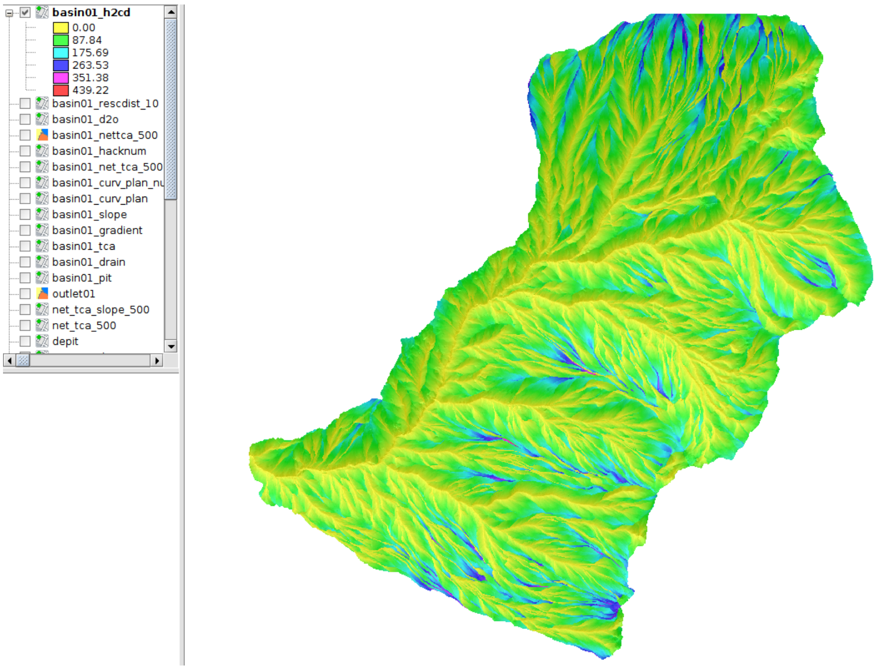


Figure 56. Output of the H2cd command: vector map with the stream network with the associated attrubutes table.

5.2. Net(Hillslope)Numbering

NetNumbering assigns numbers to the network links and to their relative hillslopes. The algorithm start from the channel heads which are numbered first. Then, starting again from each source, the drainage direction are followed till a junction is found. If the link downhill the junction was already numbered, a new source is chosen. Otherwise the network is scanned downstream ad a new number is attributed to the link's pixels. At the same time the subbasin relative to each link is extracted and numnered the same as the referencing link. The module can also be used also to split the links in subpieces, for example:

- where a monitoring point or any other interesting thing is located, in this case the user has to provide the vector map of the monitoring points where to split the links and the name of the attribute field containing the ID of the points
- where the contributing area is greater than a thresold, in this case the user has to insert the threshold value of TCA.

To execute the command you have to access the section

HortonMachine → Network

and select the entry **Netnumbering**.

The module requires in input:

- the map of the flow directions (output of *DrainDir*)
- the map of the total contributing area (output of *DrainDir* or *TCA*)
- the map of the extracted network (output of *ExtractNetwork*)
- the optional vector map of the monitoring points where you want to split the network and subbasins at those points.

In the non standard execution of the tool, two more parameters have to be specified:

1. the name of the node ID field in mode 2: in the monitoring points vector layer
2. the threshold value on TCA map.

The output maps are the raster maps of the numbered network and associated subbasins.

Figure "Execution of the *NetNumbering* command." shows the graphical user interface for the *NetNumbering* command on the test data using the outputs map of *ExtractNetwork* (only with a threshold on TCA) and *DrainDir* in 2D mode. Figure "Output of the *NetNumbering* command: raster map of the numbered network." and "Output of the *NetNumbering* command: raster map of the numbered subbasins." show the output maps of the numbered network and corresponding subbasins.

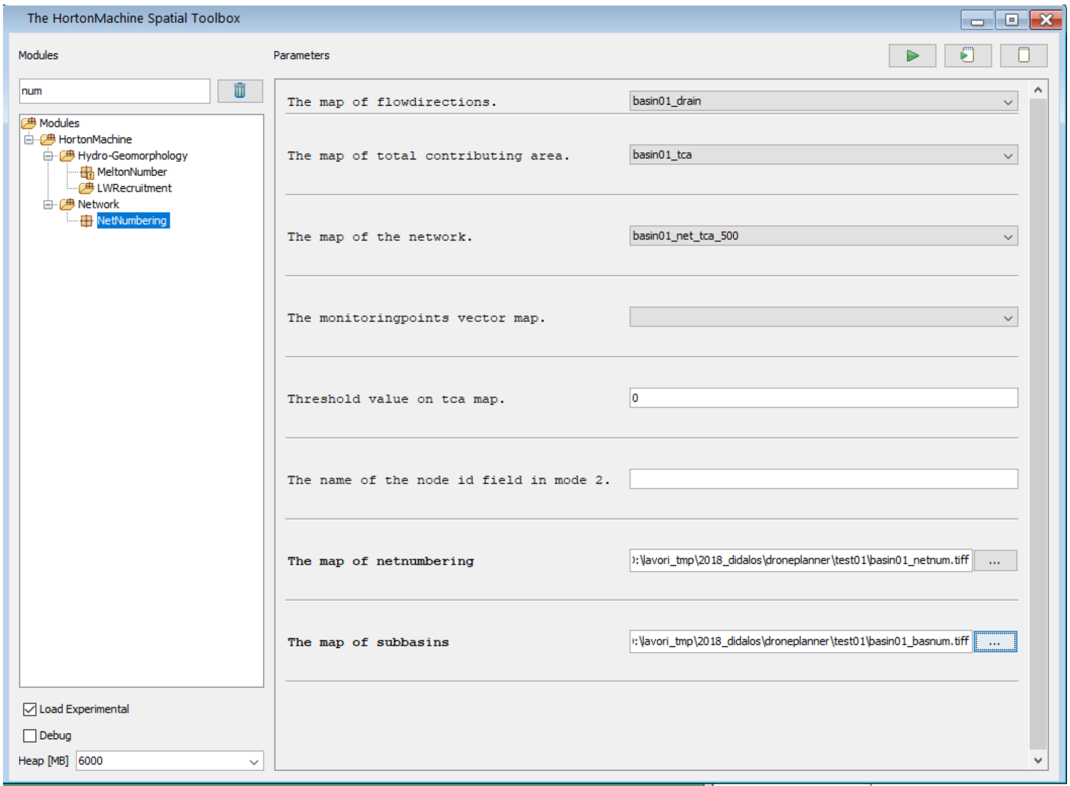


Figure 57. Execution of the NetNumbering command.

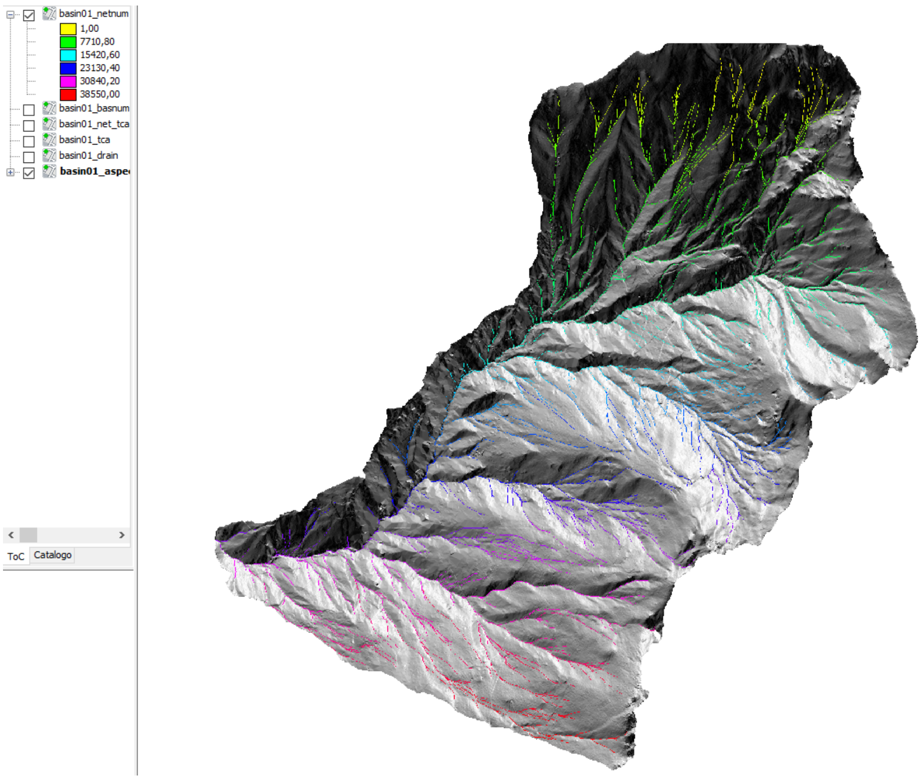


Figure 58. Output of the NetNumbering command: raster map of the numbered network.

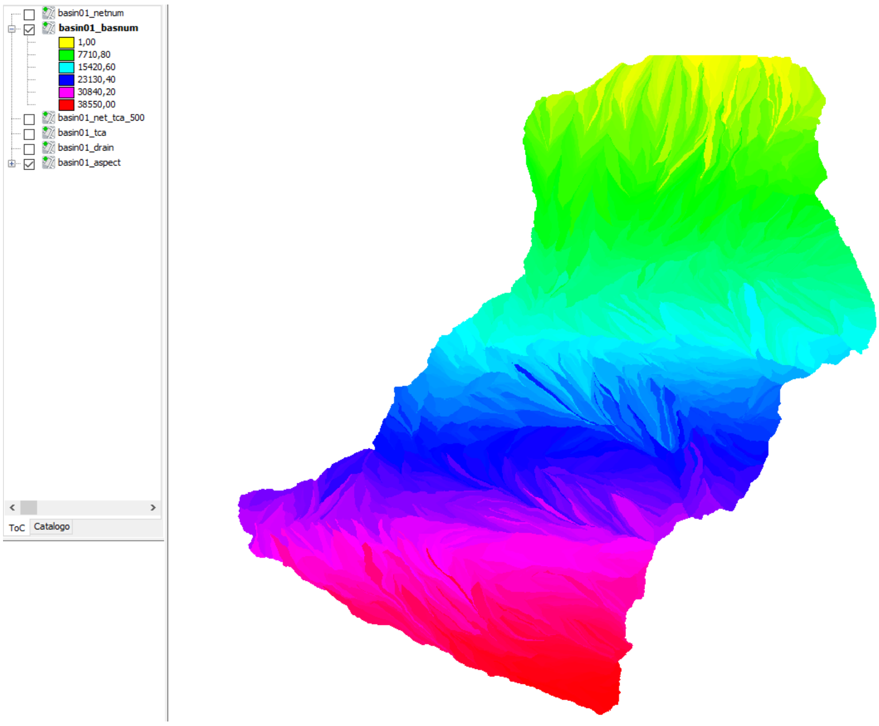


Figure 59. Output of the NetNumbering command: raster map of the numbered subbasins.

5.3. SplitSubbasis

SplitSubbasins labels the subbasins of a basin. Given the Hack's number of the channel network, the subbasins up to a selected order are labeled. If the Hack order 2 is specified as iput parameter, the subbasins of Hack order 1 and 2 and the network of the same order are extracted.

To execute the command you have to access the section

HortonMachine→ DemManipulation

and select the entry **SplitSubbasins**.

The module requires in input:

- the map of the flow directions (output of *DrainDir*)
- the map of Hack numbering of the network (output of *Hacklength*)
- the maximum Hack order to consider for basin split.

The output maps are the raster maps of the numbered network and associated subbasins.

Figure "Execution of the *SplitSubbasins* command." shows the graphical user interface for the *SplitSubbasins* command on the test data using the outputs map of *DrainDir* in 2D mode and *HackLength*. Figure "Output of the *SplitSubbasins* command: raster map of the numbered network." and "Output of the *SplitSubbasins* command: raster map of the numbered subbasins." show the output maps of the numbered network and corresponding subbasins.

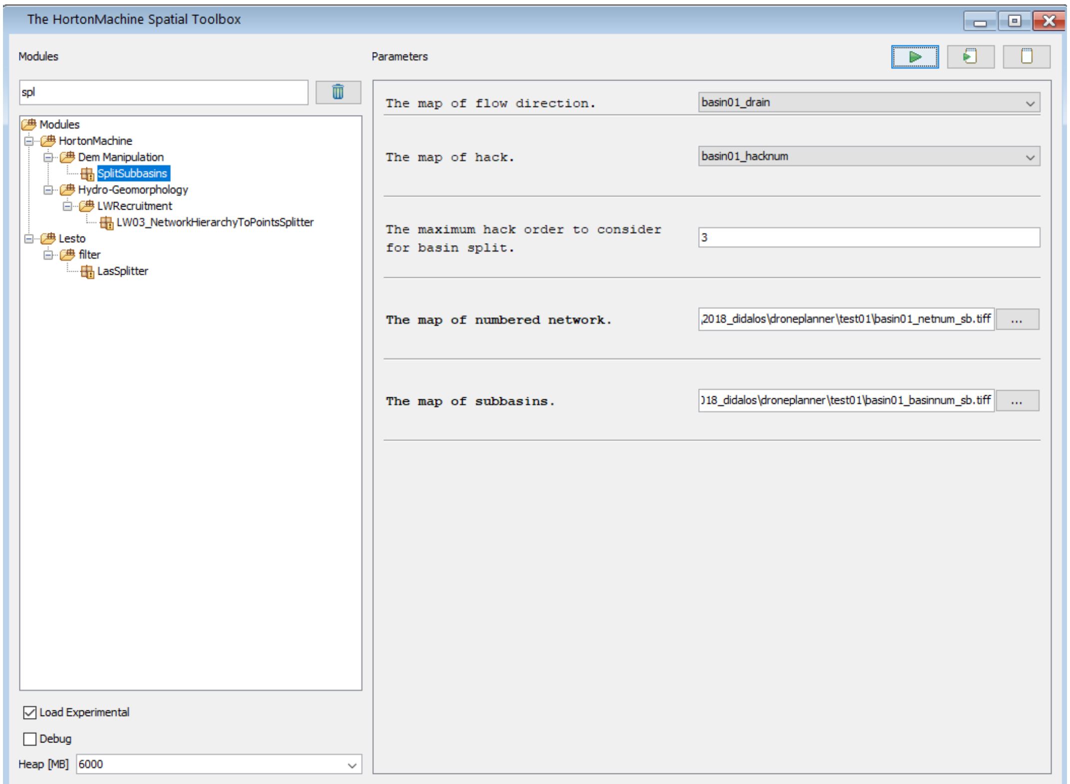


Figure 60. Execution of the SplitSubbasins command.

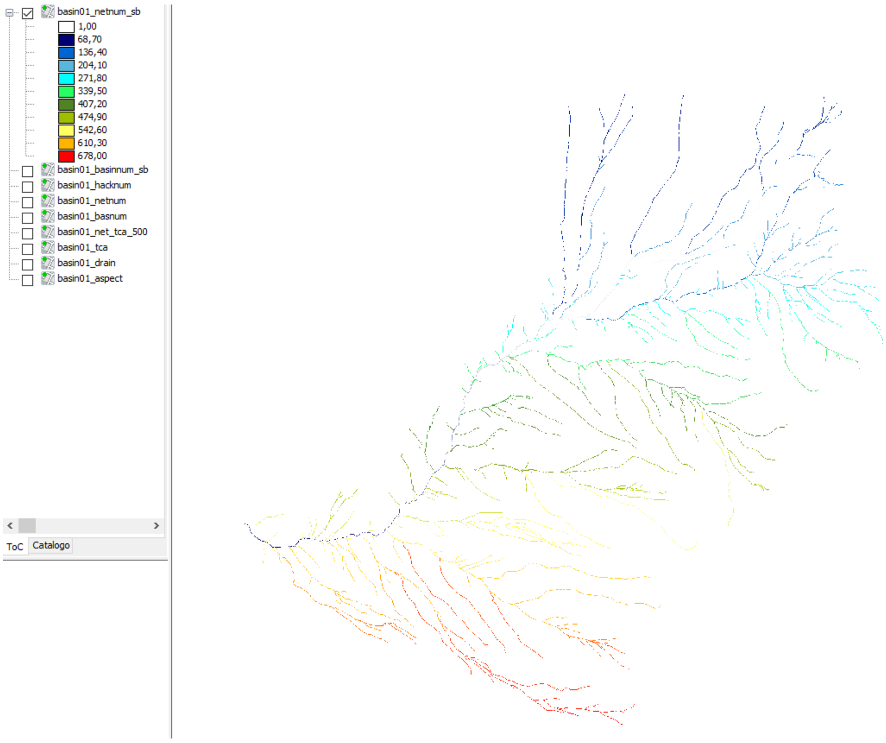


Figure 61. Output of the SplitSubbasins command: raster map of the numbered network.

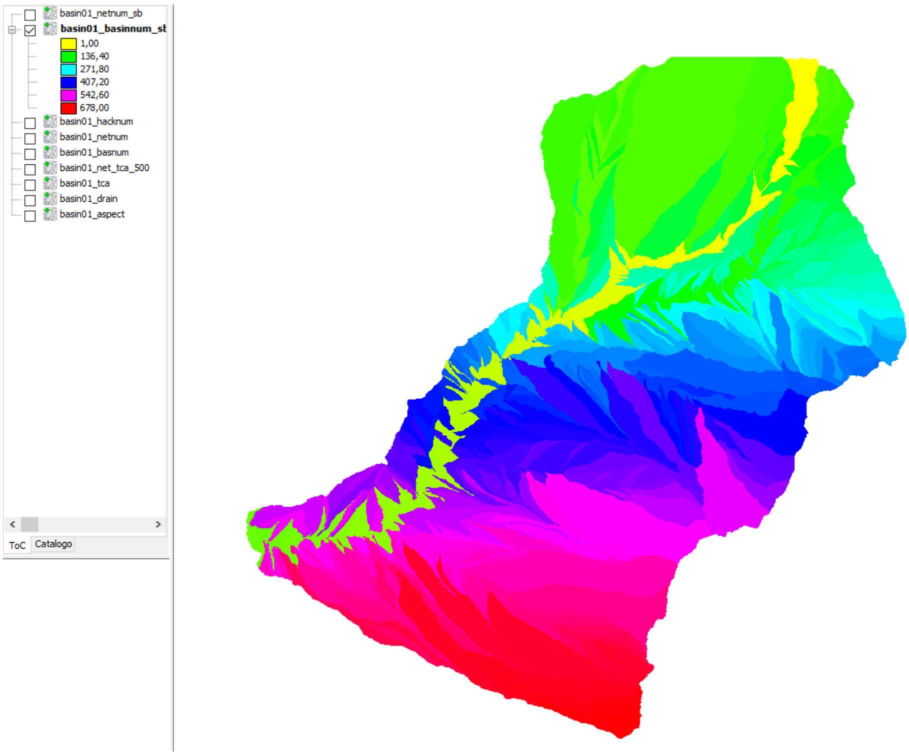


Figure 62. Output of the SplitSubbasins command: raster map of the numbered subbasins.

5.4. Tc

Topographic Classes *Tc* subdivides the sites of a basin in the 9 topographic classes identified by the normal (tangential) and transversal (longitudinal) curvatures. The program produces two different output matrixes, one with the 9 classes schematized conventionally in the following way:

- 10 → planar -planar sites
- 20 → convex-planar sites
- 30 → concave- planar sites
- 40 → planar- convex sites
- 50 → convex-convex sites
- 60 → concave-convex sites
- 70 → planar-concave sites
- 80 → convex-concave sites
- 90 → concave-concave sites.

The second output file contains an aggregation of these classes in the three fundamentals, indexed as follows:

- 15 → concave sites (classes 30, 70, 90)
- 25 → planar sites (class 10)
- 35 → convex sites (classes 20, 40, 50, 60, 80).

The required inputs maps are the maps of the profile (longitudinal) and tangential (normal) curvatures and two additional parameters which have to be ”calibrated” for each basin:

- the threshold value for the longitudinal curvatures which define their planarity (i.e. those sites presenting a curvature with absolute value lesser than the threshold)
- the threshold value for the normal curvatures which define their planarity (i.e. those sites presenting a curvature with absolute value lesser than the threshold).

And the outputs are the maps of the topographic classes, one with 9 different classes and the other with 3 different classes (concave, planar and convex sites).

Figure "Execution of the *Tc* command." shows the graphical user interface for the *Tc* command on the test data using the output maps of *Curvatures* and a threshold value of both the longitudinal and normal curvatures of 0.001. Figure "Output of the *Tc* command: maps with topographic classes (9 different and 3 aggregated fundamental)." shows the output maps of the extracted topographic classes.

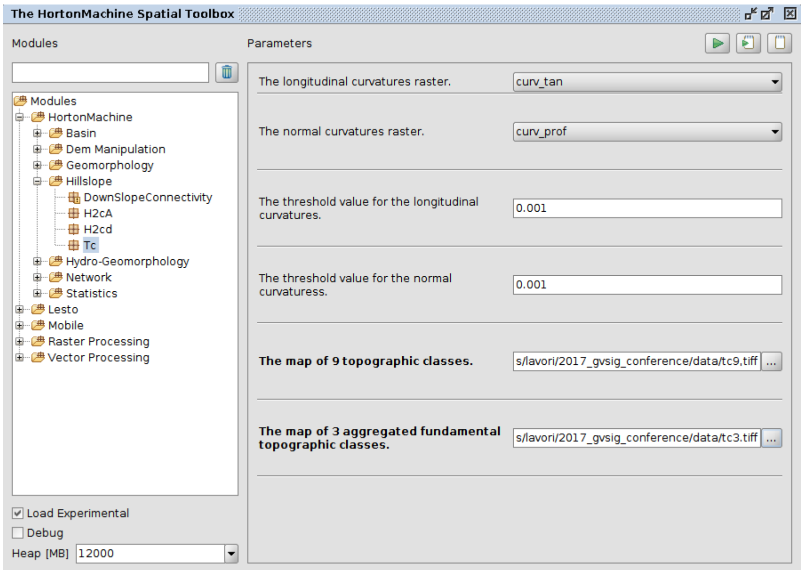


Figure 63. Execution of the Tc command.

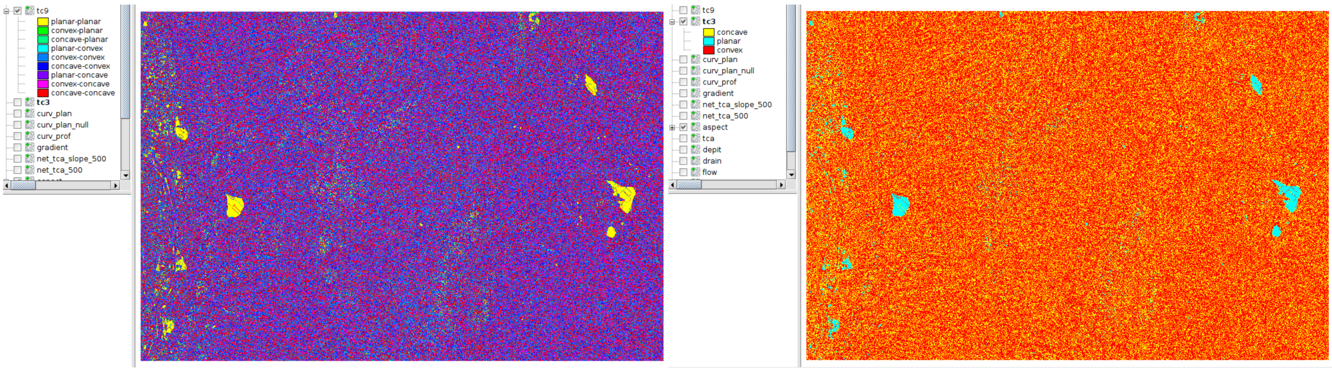


Figure 64. Output of the Tc command: maps with topographic classes (9 different and 3 aggregated fundamental).

Now it is possible to proceed with the network extraction by fixing a threshold on the product of *TCA* and *Slope* and considering only the concave sites from the *Tc* map of the 3 aggregated topographic classes. Figure "Execution of the *ExtractNetwork* command considering a threshold on TCA in concave sites." shows the graphical user interface for the *ExtractNetwork* command on the test data using the map of TCA output of *DrainDir* and the map of aggregated topographic classes obtained with the *Tc* module and a threshold value on the total contributing areas of 500, also in this case considering the resolution of the input map of 2 m. Remember to specify the *Thresholding mode* by selecting the **Tca in convergent sites** from the dropdown menu. The choice of the threshold value depends on the characteristics of the soil and on the resolution of the input maps. It is reccommended to do some tests using different values of the threshold on the TCA and compare the resulting network with the real one. Figure "Output of the *ExtractNetwork* command with a threshold on TCA in concave sites: the map of the extracted stream network." shows the output map of the extracted stream network with this mode for the entire area.

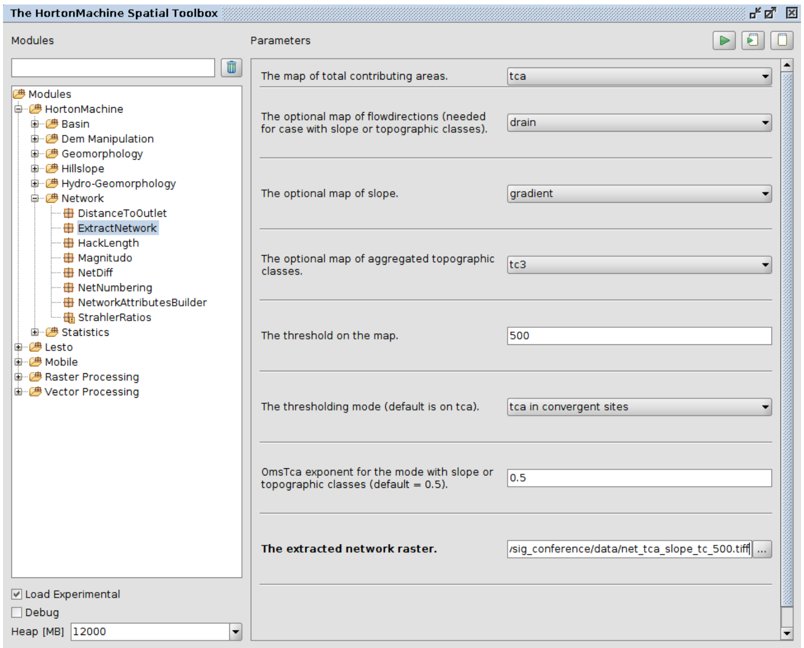


Figure 65. Execution of the ExtractNetwork command considering a threshold on TCA in concave sites.

The **net** color table is usually used to render the extracted network map as in the illustrations of this tutorial.

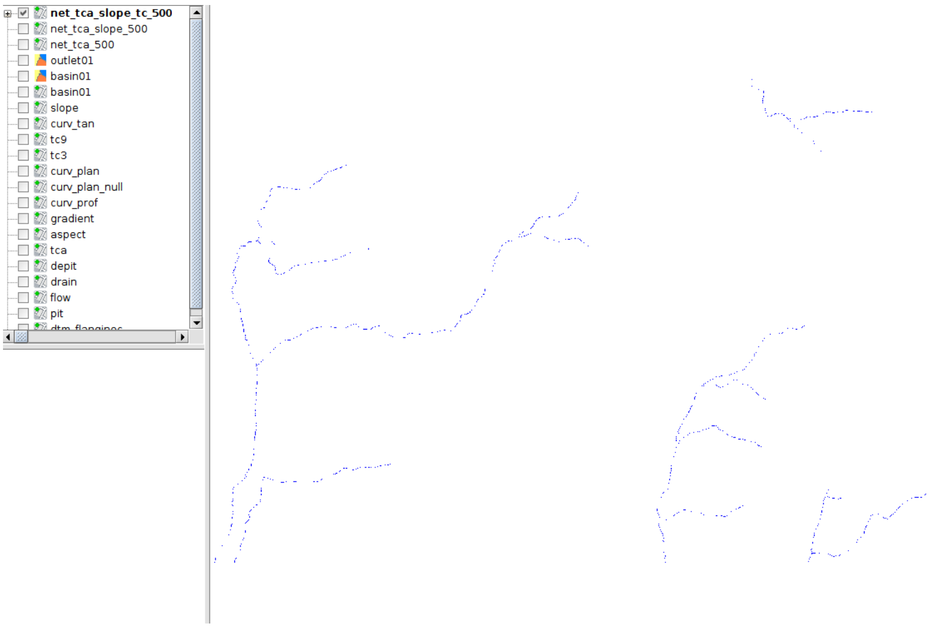


Figure 66. Output of the ExtractNetwork command with a threshold on TCA in concave sites: the map of the extracted stream network.

Chapter 6. Hydro-geomorphology tools

At this point we have all the basic information to proceed with the analysis of the stability of the hillslopes and with the hydrological analysis of the basin for the evaluation of the maximum discharges. First of all we can calculate an important hydrological index representative of the hydro-geomorphological conditions of the basin: the topographic index. The evaluation of this index requires in input a map with the contributing area in each pixel. We can use for this the standard TCA map (output of *DrainDir* or *Tca*), even if it will be better to use an other *HortonMachine* module called *Ab*.

6.1. Ab

Ab (Area per length) calculates the draining area per length unit (A/b), where A is the total upstream area and b is the length of the contour line which is assumed as drained by the A area (Figure "The graphical description of the area A and the length of the contour line b used in the *Ab* command."). The contour length is here be estimated based on curvatures.

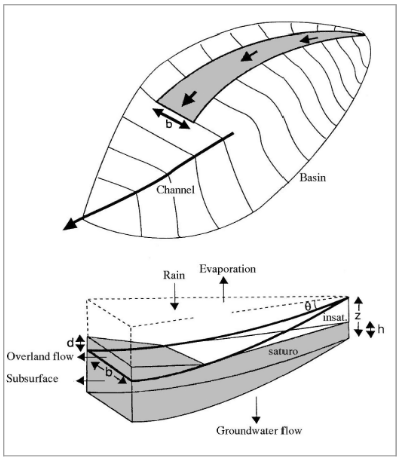


Figure 67. The graphical description of the area A and the length of the contour line b used in the Ab command.

To execute the command you have to access the section

HortonMachine → Geomorphology

and select the entry **Ab**.

The module requires in input:

- the map of the total contributing areas (output of *Ab* or *DrainDir*) cut on the current basin
- the map of the planar curvatures (output of *Curvatures*) cut on the current basin.

The output maps are the maps with the value of the area per length and the map with the contour line (raster).

Figure "Execution of the *Ab* command." shows the graphical user interface for the *Ab* command on the test data using the outputs map of *DrainDir* and *Curvatures*. Figure "Output of the *Ab* command: map of area per length." and Figure "Output of the *Ab* command: zoom on the map of contour lines." shows the output map of the area per length and the map of the contour lines (source *The HORTON machine: a system for DEM analysis. The reference manual*).

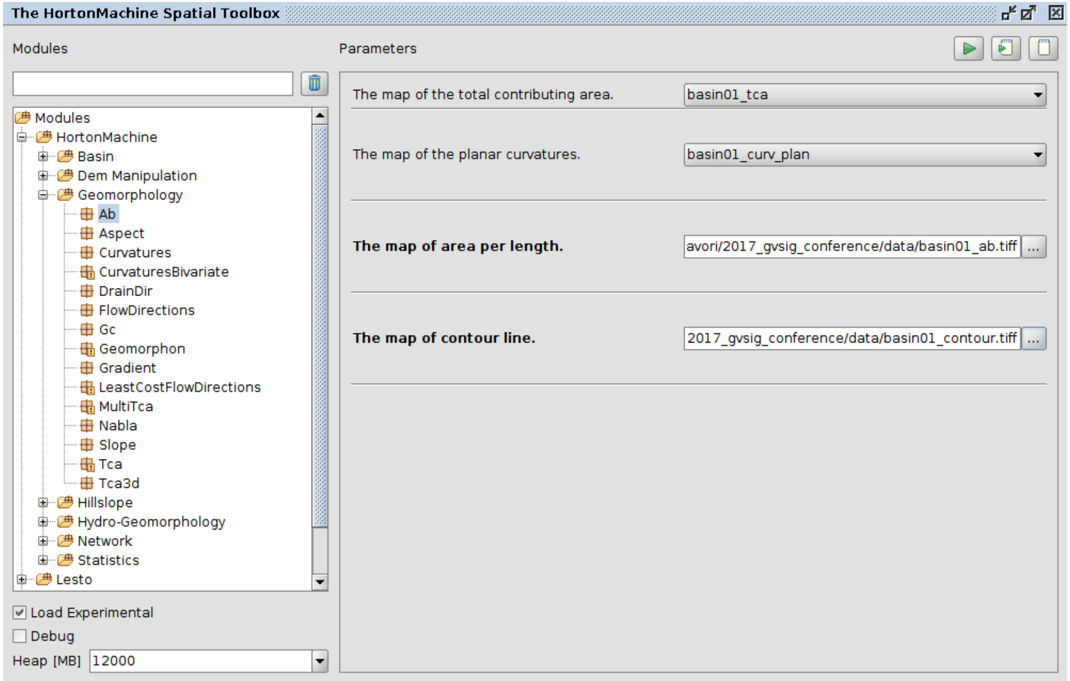


Figure 68. Execution of the Ab command.

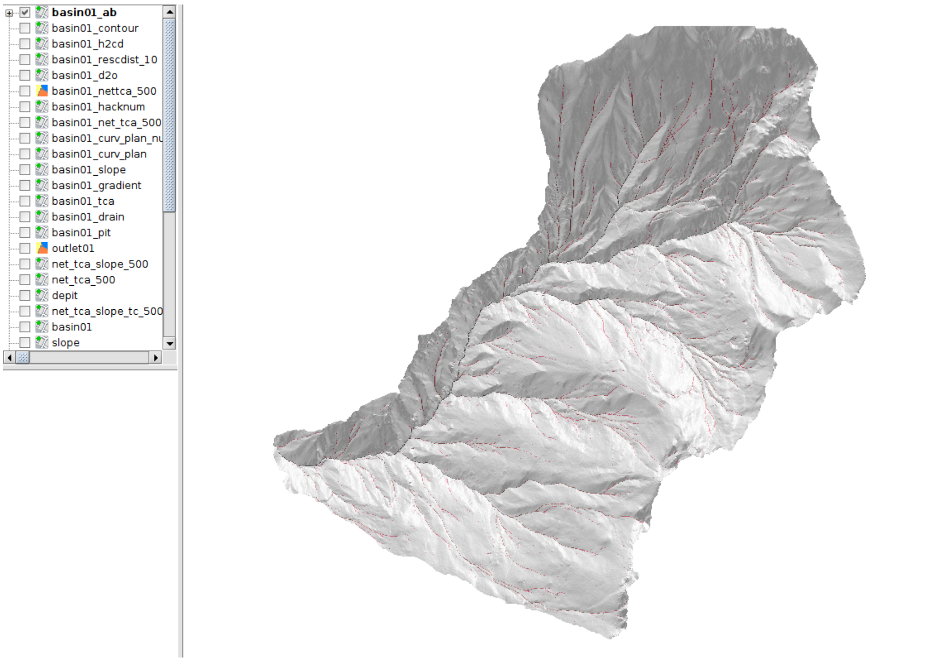


Figure 69. Output of the Ab command: map of area per length.

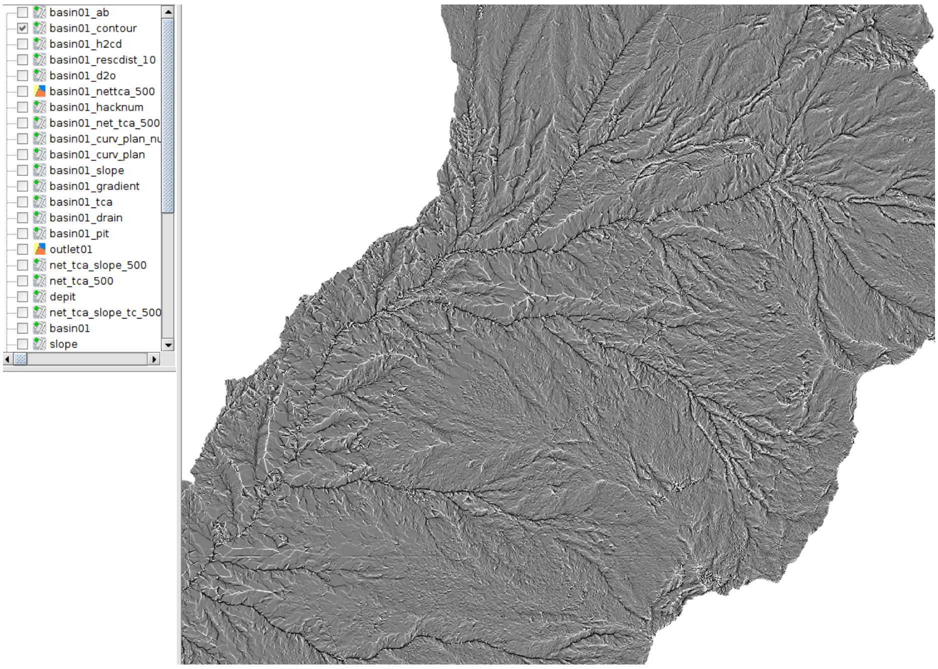


Figure 70. Output of the Ab command: zoom on the map of contour lines.

6.2. TopIndex

TopIndex (topographic index) calculates the topographic index of a basin. It is defined as the mean value over the whole basin of the *logarithm* of the ratio between the contributing area and the slope in each pixel. The topographic index is an index which is necessary to recognize the sites generating dunnian surface flow in a similar way. Sites with higher topographic index become saturated before than sites with lower topographic index.

To execute the command you have to access the section

HortonMachine → **Basin**

and select the entry **TopIndex**.

The module requires in input:

- the map of the total contributing areas (output of *Ab* or *DrainDir*) cut on the current basin
- the map of the slope (output of *Gradient*) cut on the current basin.

The output map is the map with the value of the topographic index in each pixel.

Figure "Execution of the *TopIndex* command." shows the graphical user interface for the *TopIndex* command on the test data using the outputs map of *Ab* and *Gradient*. Figure "Output of the *TopIndex* command: map of the topographic index." shows the output map of the topographic index.

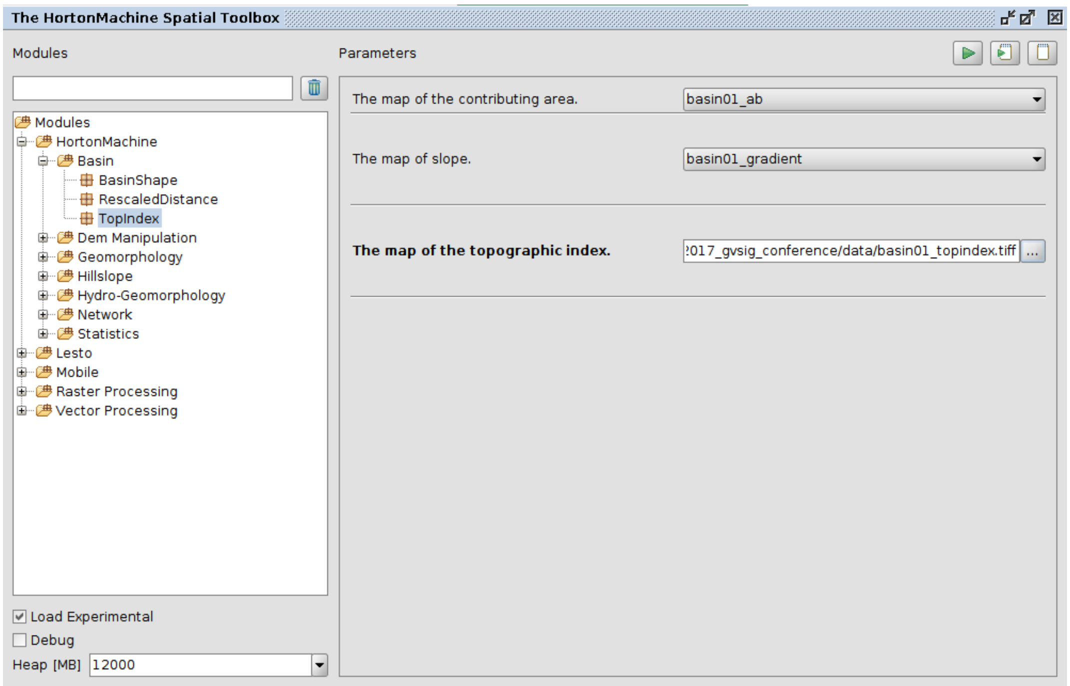


Figure 71. Execution of the TopIndex command.

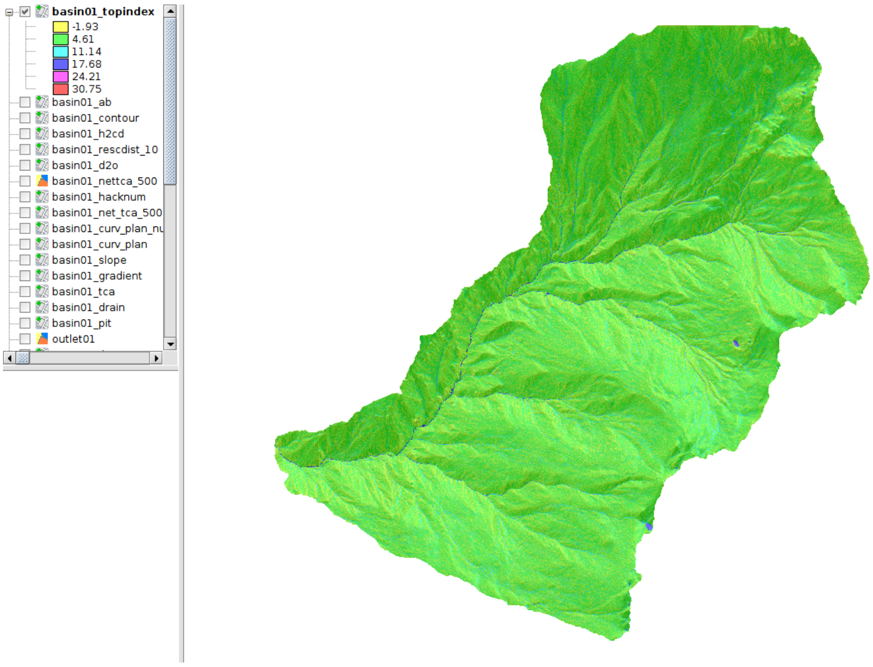


Figure 72. Output of the TopIndex command: map of the topographic index.

6.3. Peakflow

Peakflow is the semi-distributed model integrated in the HortonMachine library, it calculates the maximum discharge and the relative rainfall for a given basin using the GIUH (Geomorphologic Instantaneous Unit Hydrograph) approach. The theory of the model is based on:

- the theory of the Geomorphologic Instantaneous Unit Hydrograph calculated using the width function
- the precipitation hyetographs is constant during the whole event.

The *Peakflow* model considers separately the superficial and subsuperficial fluxes. The runoff is generated through a Dunnian mechanism of saturation from the bottom, this means that the runoff is generated only where the soil is already saturated. In this way the saturated area of the basin is in equilibrium between the superficial and subsuperficial flow, while the non saturated area contributes only in the subsuperficial flow.

To execute the command you have to access the section

HortonMachine → Hydro-Geomorphology

and select the entry **Peakflow**.

The user have to specify the following parameters:

- the parameters of the IDF (Intensity Duration Frequency) rainfall curves (*a* and *n*)
- the CSV file containg a real rainfall event alternatively to the IDF parameters
- the average velocity of the flow in the channels
- the diffusion parameters for the flow in the channels
- the saturation percentage of the basin during the event which generates the maximum discharge
- the ratio between the velocity in the channels and in the hillslopes for superficial and subsuperficial flow: these last parameters are used in the *RescaledDistance* module to generate the superficial and subsuperficial width functions.

The required input maps are:

- the maps representing the superficial and sub-superficial width functions (output of *RescaledDistance*): the width function represents the distribution of the distances from the basin outlet. It is equivalent to the number of pixels at the same distance from the basin outlet measured along the drainage directions starting from the basin outlet. The rescaled width function considers for it also the different velocity of the flow in the channels and in the hillslopes throuhg the coefficient *r*.
- the map of the topindex (output from *Topindex*)
- the map of the saturation (optionally to the constant fixed % of saturation): this map represents a mask of the saturated pixels of the basin when the maximum discharge occurs with the value 1 for saturated pixels and *NODATA* instead.

The model considers a Dunnian mechanism for the generation of the superficial flow (saturation from the bottom), whith the saturated area localized near the stream network. The maximum saturation percentage is equivalent to all the concave area of the basin. The topographic index map is used to extract the area (pixels) corresponding the the fixed saturation percentage. Please consider these information to provide a correct and coherent values of the saturation percentale or alternatively provide your own map of saturation.

Reasonable values of the saturation percentage during a flooding event for a basin are from 40 to 60%. This percentage increases when the dimensions of the basin decrease up to a maximum of the total concave sites of the basin.

Alternatively to the use of statistic precipitations *Peakflow* can work for a real event, in this case a file containing the precipitation has to be provided. The file is a text file *CSV* containg the following parameters:

- date *YYYY-MM-DD HH:MM*
- hour
- measured rainfall in *mm/h* for the given timestep

The file needs a specific header and will be in the following format

```
@T, "rain data"
Author, NAME OF THE AUTHOR
DataSource, DESCRIPTION OF THE DATA SOURCE
DateFormat,yyyy-MM-dd HH:mm

@H,   time,rain
,2000-12-06 00:00,0.01
```

The outputs of the model are:

- the value of the maximum discharge in *m3/s*
- the duration of the precipitation which generates the maximum discharge in *sec*
- the text file *CSV* containg the complete output discharge for the given precipitaion.

This module is usually used to prepare the input data for the semi distributed hydrological model *Peakflow* also integrated in the Horton Machine library. It represents the base component for the evalutation of the width function.

Figure "Execution of the *Peakflow* command." shows the graphical user interface for the *Peakflow* model with the test data using the outputs map of *RescaledDistance* and *TopIndex* and a constant value of the percentage of saturation. Figure "Output of the *Peakflow* command: maximum discharge and precipitation and complete output discharge file." shows the output console of the hydrologic model and the content of the discharge file to be opened in a spreadsheet for visualization and further analysis.

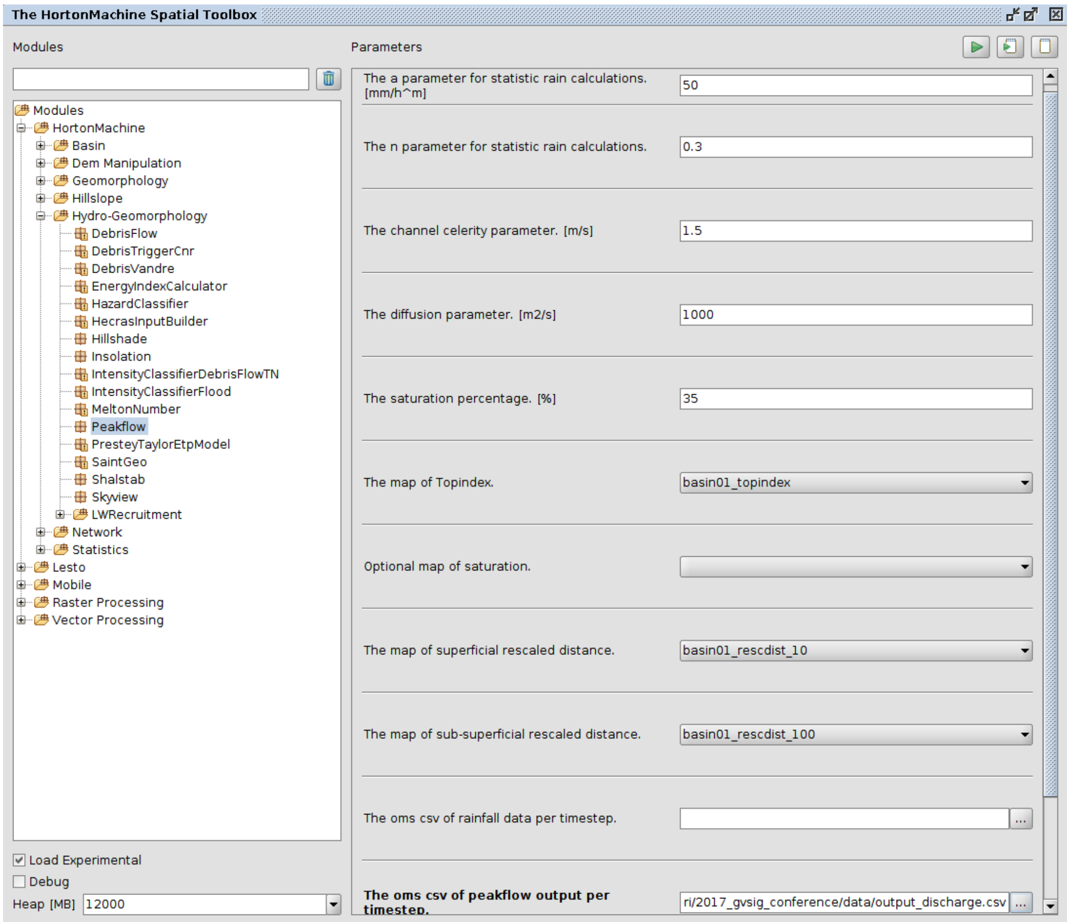
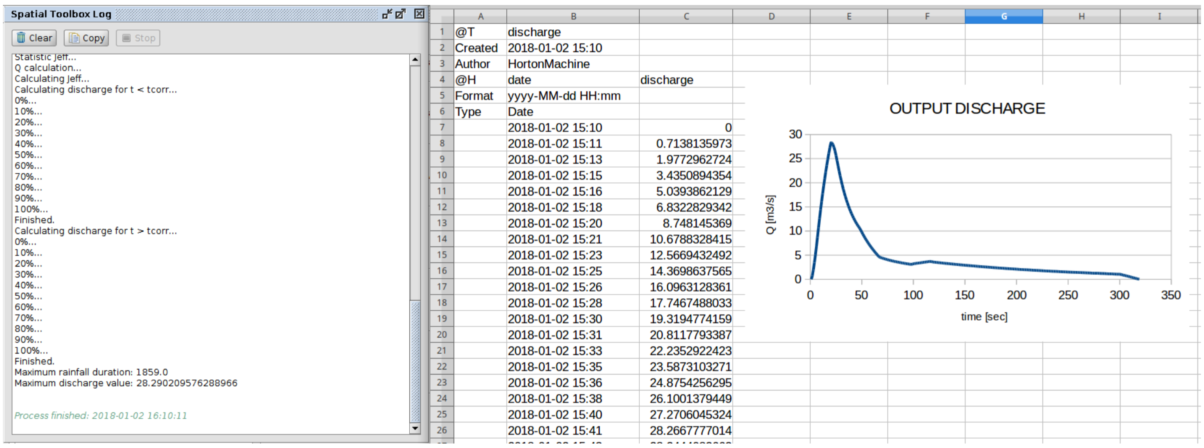


Figure 73. Execution of the Peakflow command.



	A	B	C
1	@T	discharge	
2	Created	2018-01-02 15:10	
3	Author	HortonMachine	
4	@H	date	discharge
5	Format	yyyy-MM-dd HH:mm	
6	Type	Date	
7		2018-01-02 15:10	0
8		2018-01-02 15:11	0.7138135973
9		2018-01-02 15:13	1.9772962724
10		2018-01-02 15:15	3.4350894354
11		2018-01-02 15:16	5.0393862129
12		2018-01-02 15:18	6.8322829342
13		2018-01-02 15:20	8.748145369
14		2018-01-02 15:21	10.6788328415
15		2018-01-02 15:23	12.5669432492
16		2018-01-02 15:25	14.3698637565
17		2018-01-02 15:26	16.0963128361
18		2018-01-02 15:28	17.7467488033
19		2018-01-02 15:30	19.3194774159
20		2018-01-02 15:31	20.8117793387
21		2018-01-02 15:33	22.2352922423
22		2018-01-02 15:35	23.5873103271
23		2018-01-02 15:36	24.8754256295
24		2018-01-02 15:38	26.1001379449
25		2018-01-02 15:40	27.2706045324
26		2018-01-02 15:41	28.2667777014

Figure 74. Output of the Peakflow command: maximum discharge and precipitation and complete output discharge file.

6.4. Shalstab

Shalstab is a version of the Shalstab algorithm developed by Montgomery and Dietrich (1994). The models associates the theories of infinite slope, where the strength of soil share at the discretion of rupture of Mohr Coulomb, with a simplified hydrological model (O'Loughlin, 1986). The resulting equation shows the ratio between the contributing area and the length of the boundary in the point considered as a function of the soil density, the water density, the angular slope, the friction angle, the soil transmissivity and the the effective rain.

To execute the command you have to access the section

HortonMachine → Hydro-Geomorphology

and select the entry **Shalstab**.

The module requires in input:

- the map of the flow slope (output of *Gradient* or *Slope*)
- the map of the total contributing area (output of *TCA* or *Ab*)
- the trasmissivity of the soil in [mm2/day]: this parameter can be a map provided by the user or a constant value
- the tangent of the friction angle of the soil in [ ]: this parameter can be a map provided by the user or a constant value
- the cohesion of the soil in [Pa]: this parameter can be a map provided by the user or a constant value
- the soil depth [m]: this parameter can be a map provided by the user or a constant value
- the effective precipitation [mm/day]: this parameter can be a map provided by the user or a constant value
- the density of the soil as density ratio between the density of the soil and of the water [ ]: this parameter can be a map provided by the user or a constant value
- the maximum value of the slope where we can find soil, for higher values it is considered rock: if nodata is provided herethe soil is considered available everywhere in the basin independently from the slope but based on the input map or considering the constant value.

The output maps are the raster map with the threshold values of precipitation in each pixel which generates instability (*critical discharge*) and the raster map of stability classes containg for each pixel of the basin the stability class based on the given input effective precipitation.

Figure "Execution of the *Shalstab* command." shows the graphical user interface for the *Shalstab* command on the test data using the outputs map of *Gradient* and *Ab* and constant values of the other input parameters. Figure "Output of the *Shalstab* command: map with the critical rainfall." shows the output map of the critical rainfall and Figure "Output of the *Shalstab* command: map with the stability classes corresponding to the input precipitation." shows the output map of the stability classes.

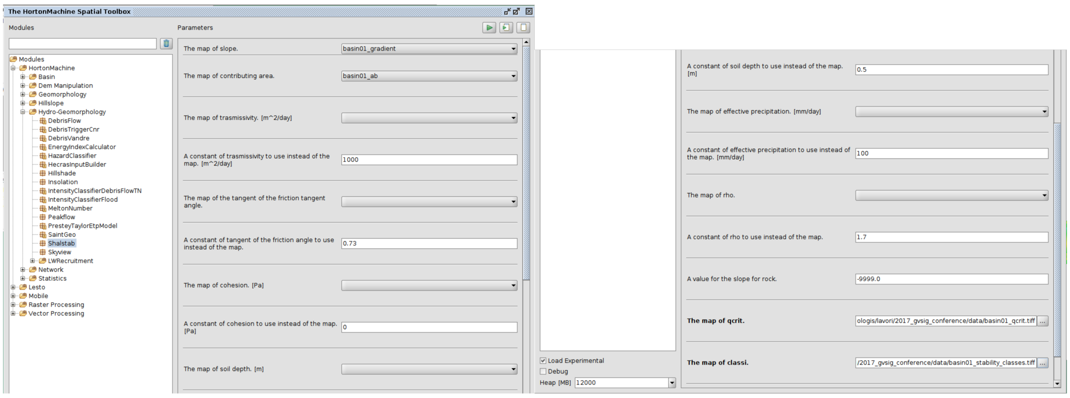


Figure 75. Execution of the Shalstab command.

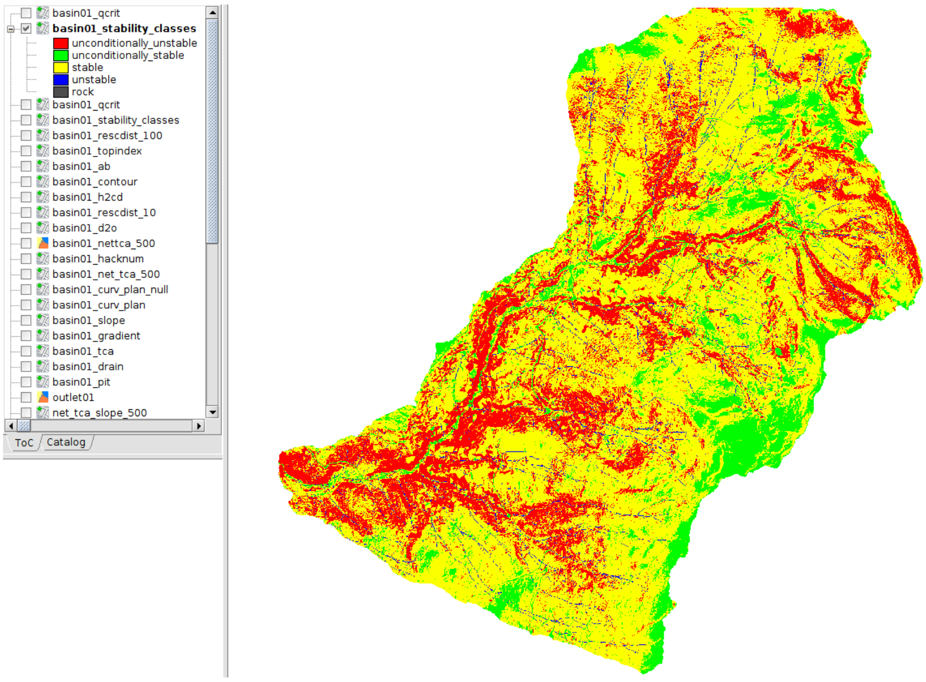


Figure 76. Output of the Shalstab command: map with the critical rainfall.

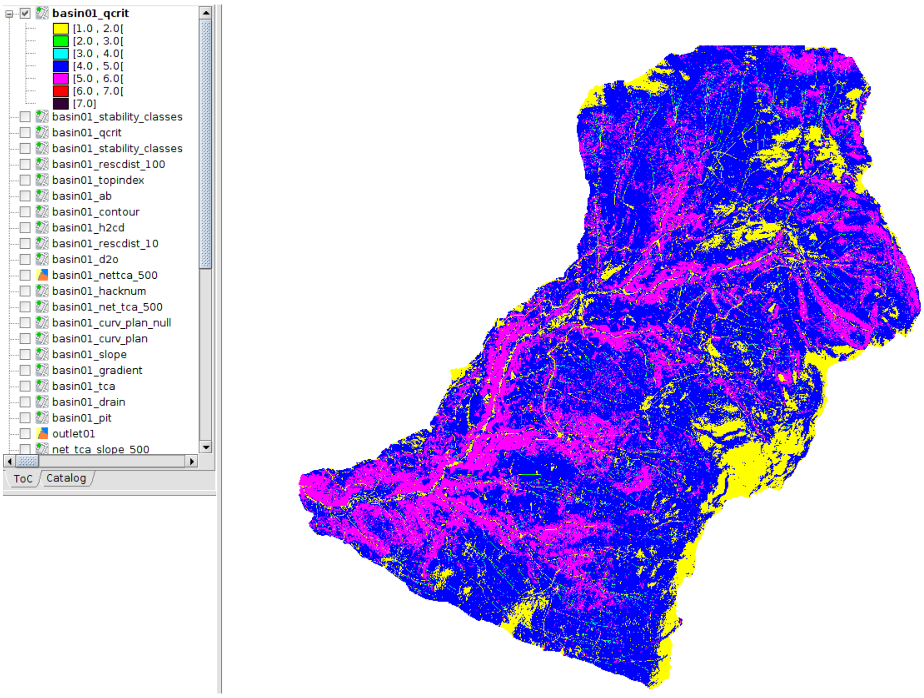


Figure 77. Output of the Shalstab command: map with the stability classes corresponding to the input precipitation.