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QGIS Plugin

Hydrological Analysis Stream Network

Figure 1 Icon for the QGIS plugin "Hydrological Analysis Stream Network

The study of the structure and properties of a watershed's drainage network—encompassing both permanent and ephemeral elements such as rivers, streams, brooks, and artificial channels—forms an essential foundation for modern hydrological analysis. This systematic characterization goes beyond mere morphological description; it provides the fundamental interpretative framework for: 1) understanding hydrological processes at the watershed scale, 2) accurately modelling surface and subsurface water flow, and 3) quantifying hydrological responses to extreme meteorological events.

To achieve optimal results in terms of precision and scientific robustness, this study adopted an **integrated geoprocessing approach**, synergistically leveraging the complementary strengths of algorithms available in the **GRASS GIS** and **SAGA GIS** environments. This hybrid strategy enabled:

• Maximizing reliability through cross-validation of results from different algorithms

• Optimizing performance by using the most efficient and validated tool for each study phase

• Enriching the analysis by combining well-established methodologies from the open-source hydrological community

The systematic integration of GRASS libraries known for stability in basic hydrological derivation algorithms and SAGA libraries excellent for advanced morphometric analysis and DTM pre-

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processing represented the optimal methodological choice to ensure both scientific rigor and the completeness of the results obtained.

Relationship

These elements are not isolated, but form part of a logical processing chain, which is illustrated in Figure 6:

1. **Drainage Directions** are calculated from the **DTM**. This represents, for each cell of the DTM, towards which adjacent cell (among the 8 possible) the water would flow. It is the first and most critical output of hydrological analysis based on a DEM. All other layers (network, basins, indices) are derived from this layer.
2. The **Specific Contributing Area (a)** is derived from the Drainage Directions.
3. By combining a and the local **Slope (β**) from the DEM, the Topographic Index (more precisely, the **Topographic Wetness Index - TWI**) is calculated. This is a central index in hydrological modelling. It quantifies an area's propensity to generate surface runoff or saturation.
   - **a**: Specific contributing area (upstream catchment area per unit contour width). Indicates how much water arrives.
   - **tan(β**): Local slope. Indicates the drainage capacity of the soil.

   The index combines two opposing forces:

   - **Water convergence (a**): The larger 'a' is, the more water arrives at the point, increasing the probability of saturation.
   - **Drainage capacity (tanβ):** The larger 'tanβ' is (steep slope), the faster the water drains away, reducing saturation.

   Therefore, a HIGH value of the index ln(a/tanβ) indicates:

   - **Conditions of potential saturation**: Landscape points where a lot of water converges from upstream ('a' large) on a gentle slope ('tanβ' small).
   - **High probability of generating surface runoff**: When the soil is saturated, even a small amount of additional rainfall cannot infiltrate and generates immediate surface runoff.
   - **Zones of moisture accumulation**: Areas such as valley bottoms, concavities, and foot slopes.

   A LOW value of the index indicates:

   - **Dry conditions**: Locations on steep slopes ('tanβ' large) or ridges ('a' small), where water drains quickly or does not converge.
   - **High infiltration capacity**: The soil tends to remain unsaturated.

   Practical Applications:

   The index is used to map:

   - Areas prone to saturation and waterlogging (wetlands, riparian zones).

- Source areas for surface runoff during rainfall events.
- The spatial variability of soil moisture within a catchment.
- The potential location of erosion processes or mass movements (landslides triggered by saturation).

4. By applying a critical area threshold to the Contributing Area, the **Stream Network** is generated (first as a raster, then vectorised and smoothed).
5. Using the Stream Network as a guide, the main basin is subdivided into **Half Basins** (or sub-basins). These are the drainage areas relative to each segment of the river network. They represent the "tiles" with a homogeneous hydrological response. They are the computational units in many semi-distributed hydrological models (e.g., HEC-HMS, SWAT), allowing for the aggregation of parameters such as land use, soil type, and precipitation.

Workflow Geoprocessing

Step 1: Fill Sinks (Wang & Liu Algorithm)

Aim: To create a hydrologically correct DTM (Digital Terrain Model), without depressions that would artificially block the flow of water.

Raw DTMs (especially LiDAR or high-resolution ones) contain thousands of small depressions, many of which are measurement errors or artefacts, not true endorheic basins. The Wang & Liu algorithm is an efficient and accurate "Fill & Raise" method. It identifies all depressions (sinks). For each depression, it finds the lowest outlet point (spill point) on its boundary. It fills the depression up to the height of the outlet point.

Output: Raster filled DTM

Step 2: Flow Calculation and Stream Delineation

Purpose: To calculate the water flow path and identify the cells that form the river network.

2a. Flow Direction: For each cell of the *filled DTM*, the direction towards the adjacent cell with the steepest downward slope is determined. For this purpose, the GRASS *r. watershed* algorithm was used. GRASS does not limit itself to simple D8 (where for each cell, its elevation is compared to that of its 8 neighbours (D8), slopes are calculated, and the steepest downslope direction is identified). Instead, it uses a flow search algorithm that considers a broader window to determine the flow direction towards the farthest downslope cell, not just the adjacent one.

Output: Drainage direction raster (*flow direction)*

2b. Flow Accumulation: For each cell, the total number of upstream cells that drain into it is calculated. Each cell contributes a value of 1 (or an area value). The result is a map representing the drainage volume.

Output: TWI raster (*flow accumulation*).

2c. Stream Delineation: A contributing area threshold (default 100 m^2) is applied to the flow accumulation raster. Cells with an accumulation value exceeding this threshold are classified as part of the river channel.

Output: Delineate streams raster (*streams*).

Step 3: Raster to Vector Conversion

Purpose: To transform the raster (grid-based) representation of the network into more manageable vector lines (polylines) for GIS analysis and cartography.

Process: The GRASS algorithm (*r.to.vect)* traces lines by following adjacent cells classified as channels in the stream raster.

Output: A vector layer LineString type.

The resulting network has a *stair-case pattern*, as it follows the grid of raster cells. It is geometrically precise but visually and hydraulically unrealistic; therefore, the operation described in Step 4 was performed.

Step 4: Geometry Smoothing

Purpose: To improve the cartographic and hydraulic realism of the vector network by smoothing the right angles. Smoothing is a generalisation operation. The plugin provides two parameters: a smoothing offset (default value 0.25) and a parameter controlling the number of iterations. Smoothing must be applied with moderation to avoid excessively altering the real channel position (e.g., making it crossroads or boundaries). Consequently, both the *raw* version (for analysis) and the *smoothed* version (for visualisation and cartographic representation) have been retained.

All layers generated by the plugin are the analytical building blocks that transform a simple elevation model (DTM) into a functional representation of a landscape's hydrological behaviour, essential for modelling, planning, and risk management.

Software installation

Installation is performed directly from the QGIS plugins section (Figure 2. QGIS Plugins Section) by entering the keyword "Geology" in the search box (Figure 3. Plugin Search and Installation).

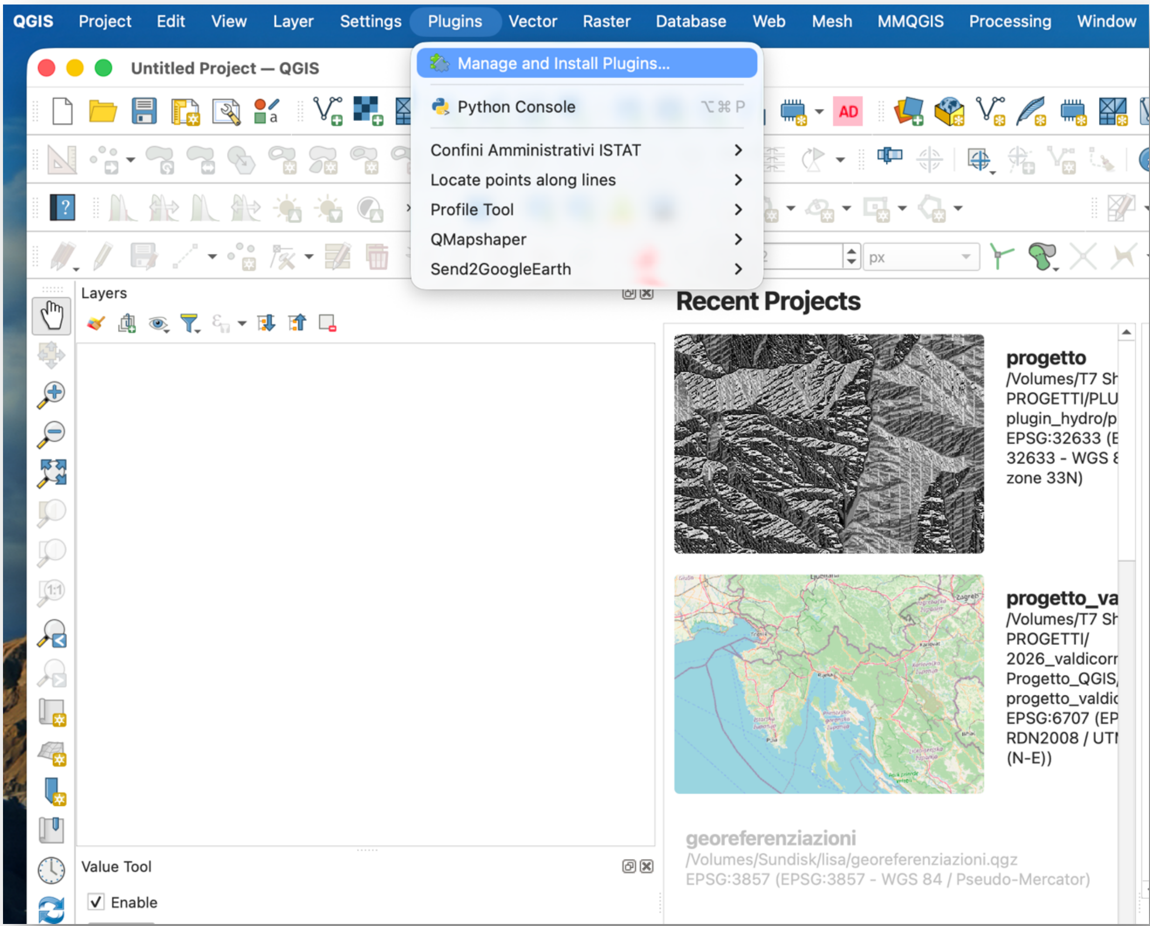

Figure 2. QGIS plugins section

Once installed, the plugin will be available in the Processing Tools section (Figure 4. QGIS Processing Tools Section).

Clicking on the tool will open the interface for selecting input files and configuring the geoprocessing operations (Figure 5. Plugin Input and Output data entry form).

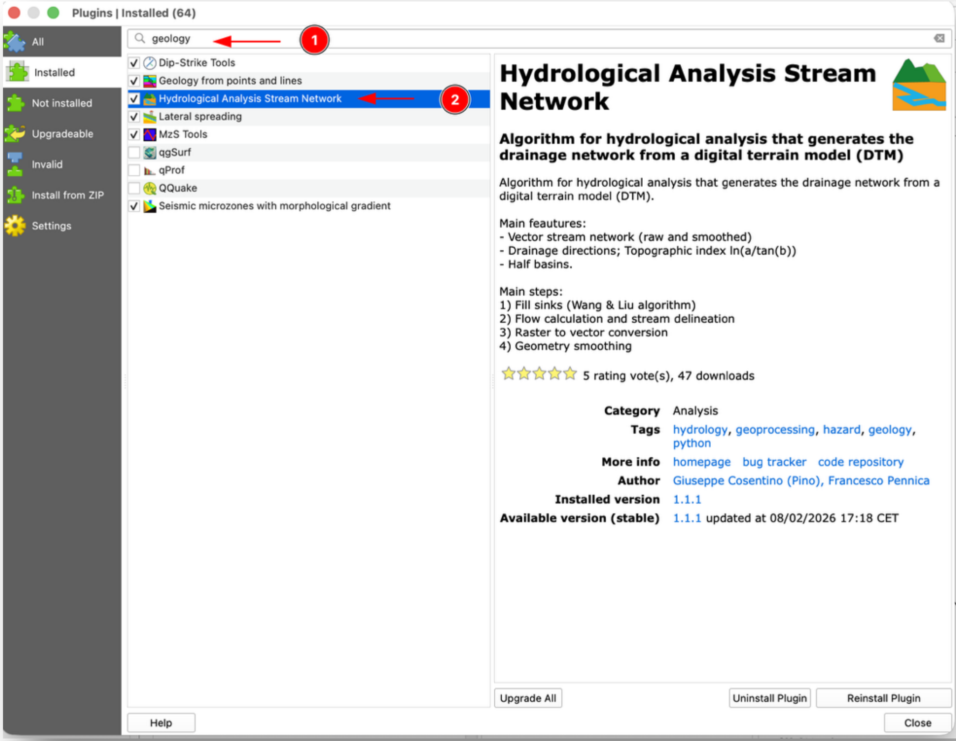

Figure 4. Plugin search and installation

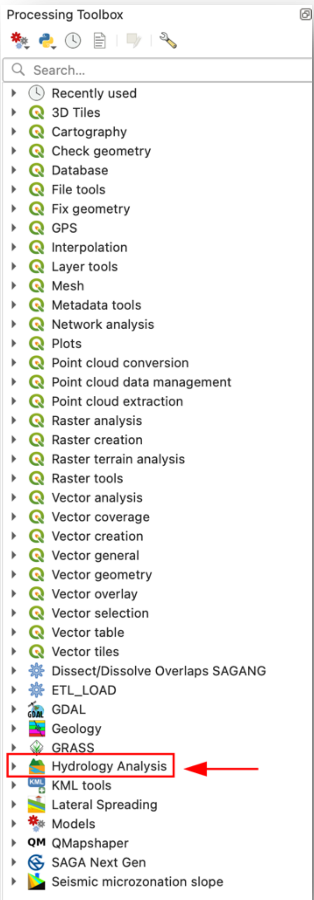

Figure 3. QGIS processing Tools section

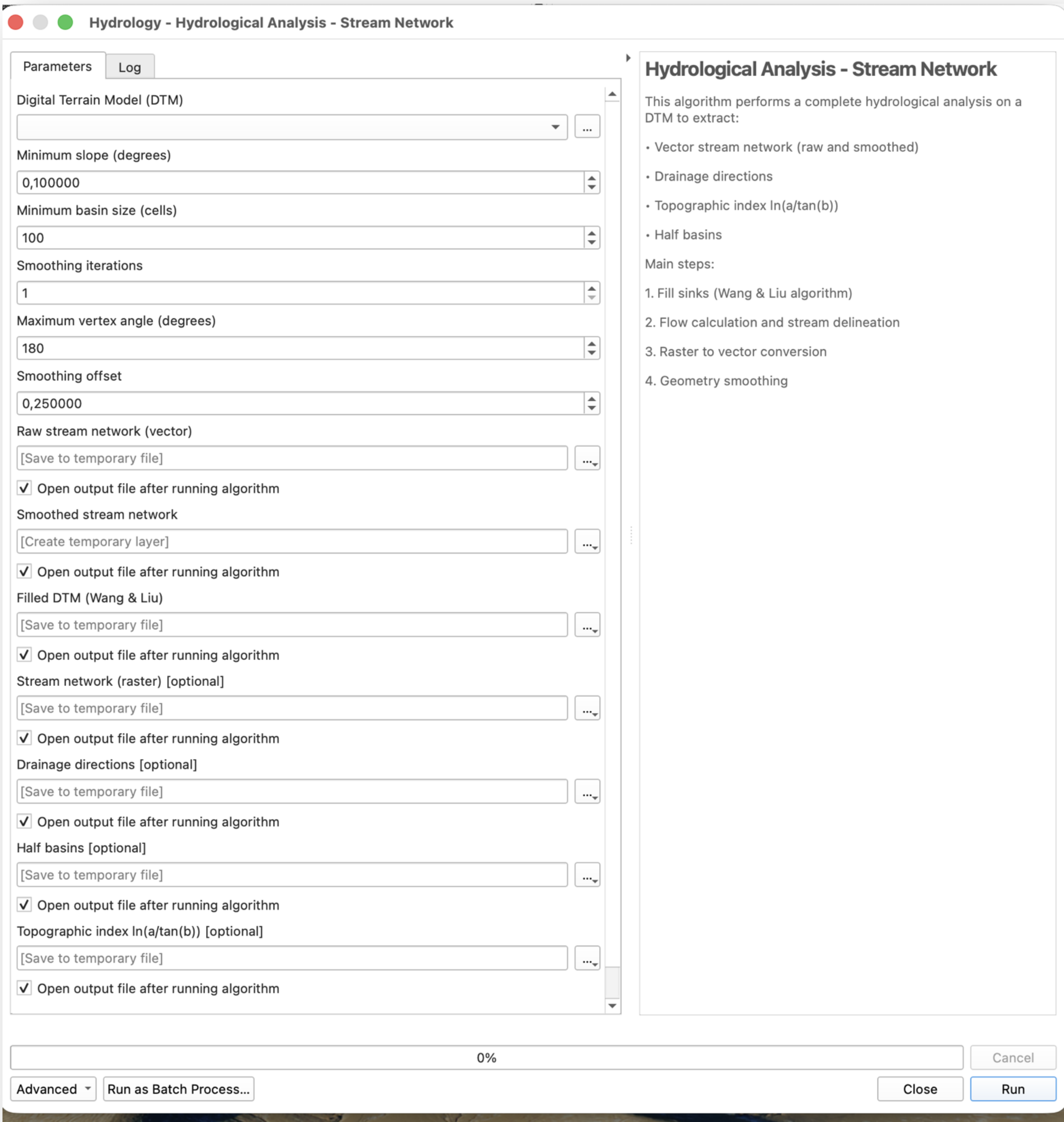

Figure 5. Form plugin for data and parameters input and output files

Schema Plugin

Hydrological Analysis Stream Network - QGIS Plugin

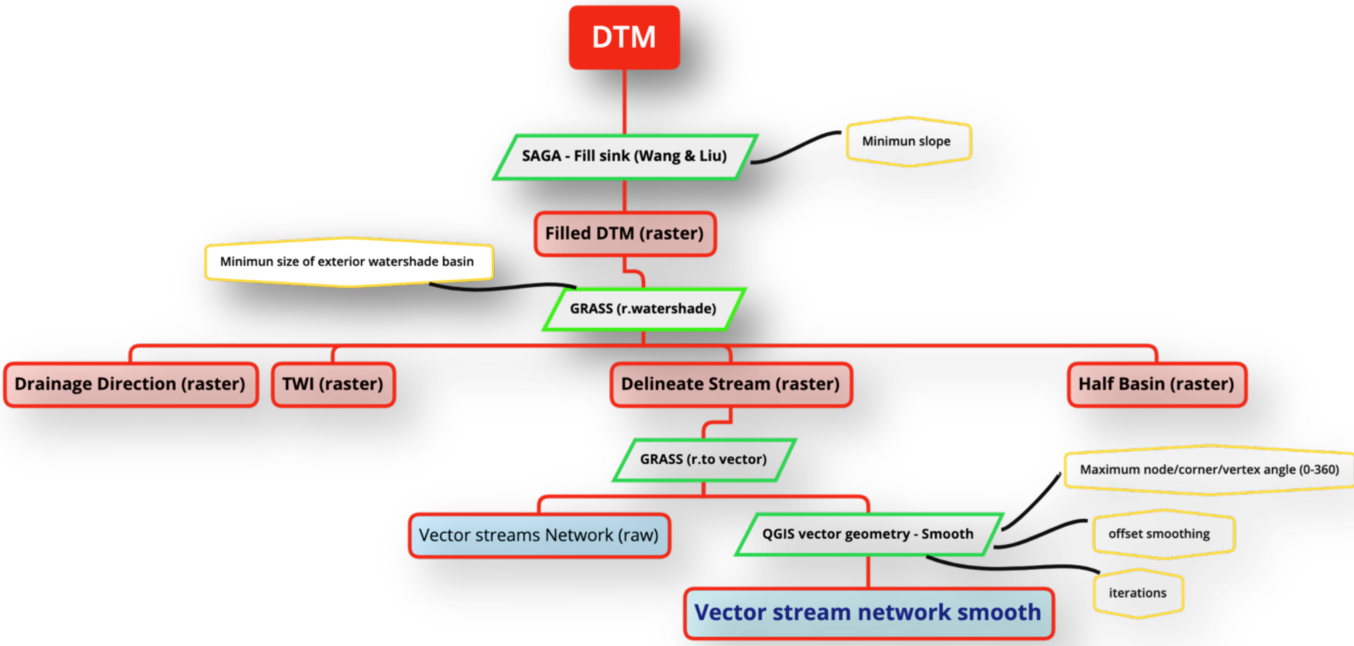

Figure 6- schema plugin