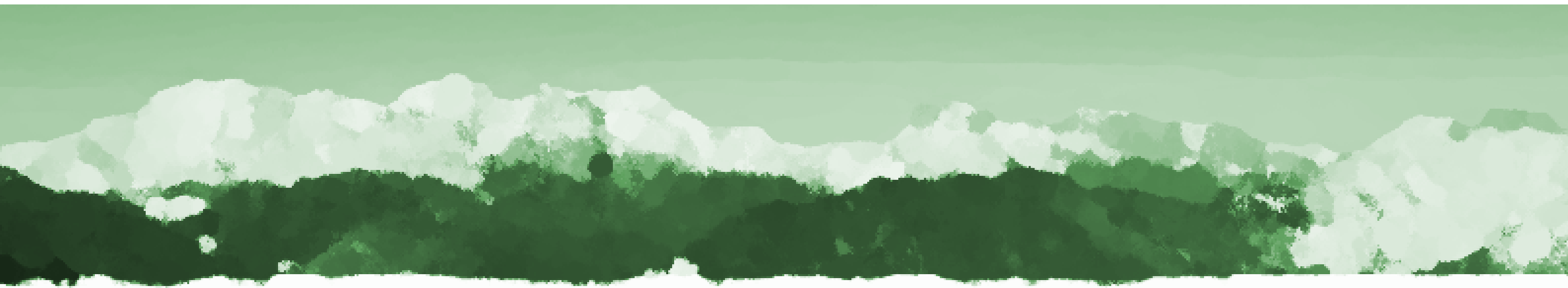
# LWRecruitment&Propagation

*A tutorial on analysis tools developed within the GSoC2014*



# Readme

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# 1. Introduction

This is a short tutorial containing the most important information on the general work-flow of the tools for Large Wood (LW) recruitment from hillslopes and propagation along the network developed within the GSoC2014 program. The new developed tools will be integrated in the *JGrassTools* library and will be directly available in the Spatial Toolbox.

More information about the modules and the installation instructions are available at *www.jgrasstools.org*.

The modules developed are named with the name of the activity that will be done by each module with a prefix containing the number of the order of execution considering the entire work-flow. The developed modules are:

- LW01_ChannelPolygonMerger
- LW02_NetworkAttributesBuilder
- LW03_NetworkHierarchyToPointsSplitter
- LW04_BankfullWidthAnalyzer
- LW05_BridgesDamsWidthAdder
- LW06_SlopeToNetworkAdder
- LW07_NetworkBufferWidthCalculator
- LW08_NetworBufferMergerHolesRemover
- LW09_AreaToNetpointAssociator
- LW10_NetworkPropagator

This tutorial contains a general introduction on the tools with the basic information on licenses and the general work-flow to follow to start form a dataset and obtain the desired results.

## 1.1. Licenses

All the developed modules for Large Wood will be integrated in the *JGrassTools* library and released under free and open source software. You can redistribute it and/or modify it under the terms of the GNU General Public License as published by the Free Software Foundation, either version 3 of the License, or (at your option) any later version.

# 2. General Work-flow

The general work-flow of the tools developed in the *OceanDTM* package is shown in Figure 2.1.

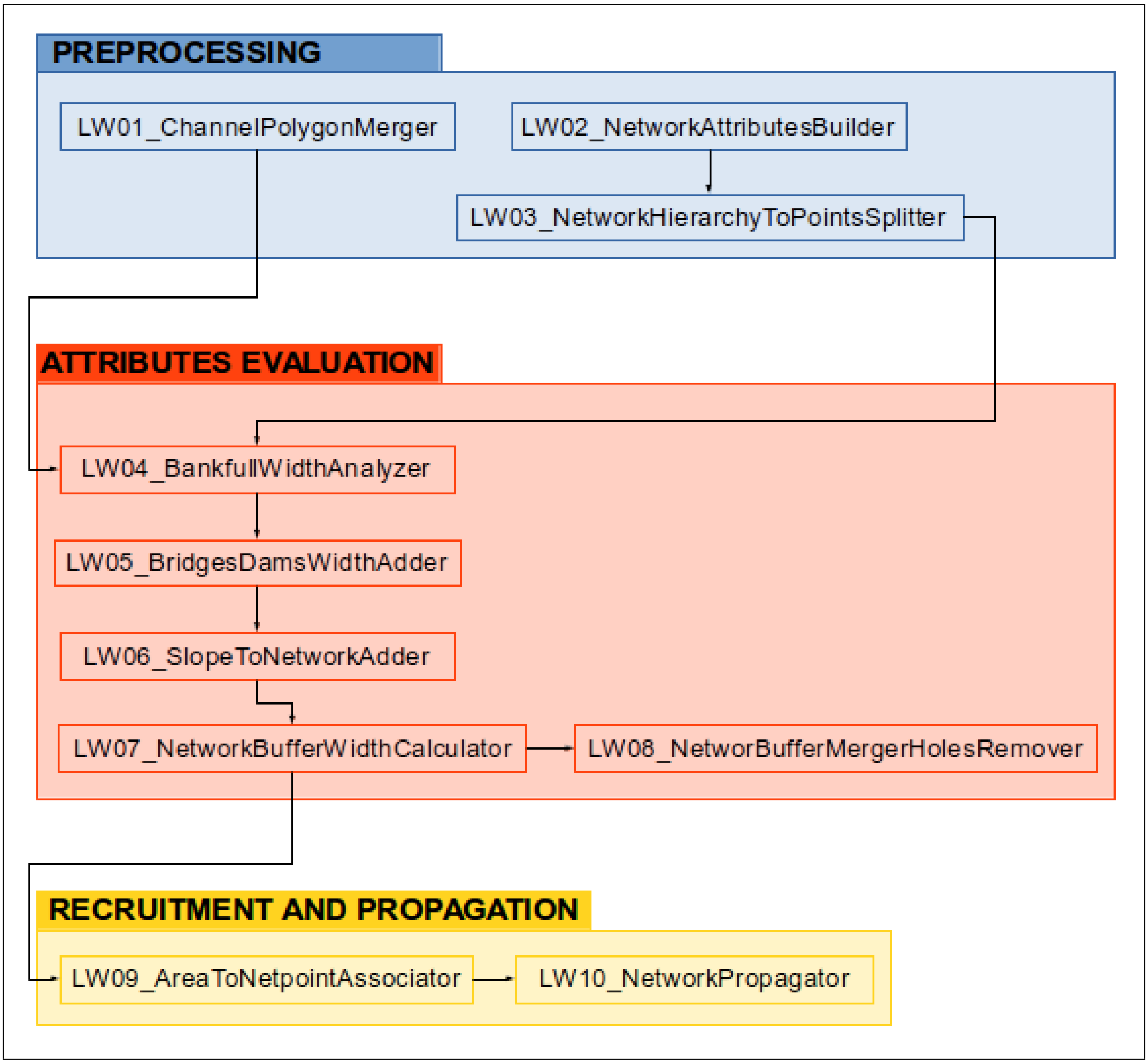



Figure 2.1: *Work-flow of the tools for the evaluation of Large Wood recruitment and propagation.*

The inputs of the algorithms of Large Wood evaluation are:

- digital models of the terrain and vegetation: DTM, DSM, FSV
- DTM derived geomorphology attributes: contributing areas, slope, connectivity, watershed delineation
- extension of the bankfull area: the area covered by water in standard condition of flow
- position and dimensions of bridges and dams: from a field survey or from local cadasters
- superficial geology: rock or erodible deposits.

The overview of the input and output of the set of LW tools is shown in Figure 2.2.

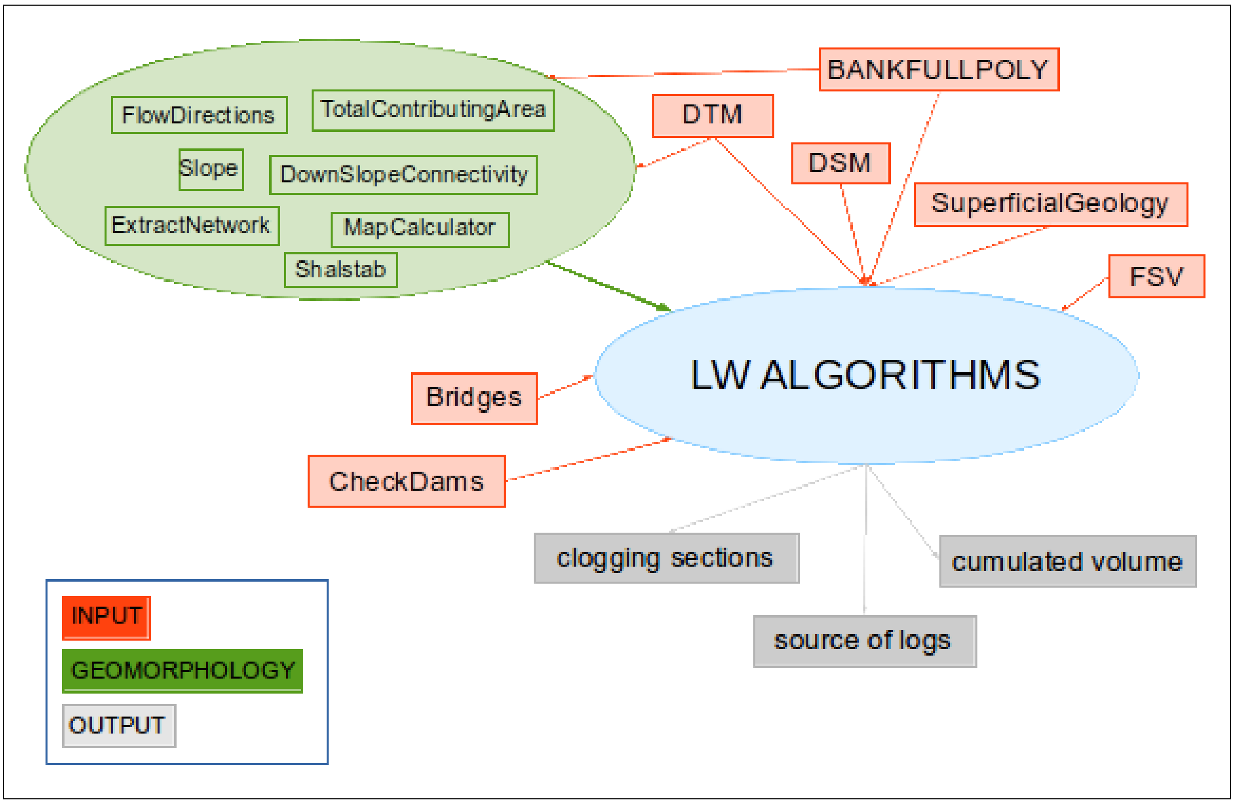



Figure 2.2: *Overview of the input and output of the Large Wood recruitment and propagation tools.*

A detailed description of the different modules is available in the following paragraphs.

# 3. LW01_ChannelPolygonMerger

## 3.1. Description

Merges the adjacent bankfull polygons in a single geometry for further processing.

Bankfull discharge is defined as a flood with high recurrence frequency (2-years flood or the flood that has a 50% probability of occurring in a given year). The bankfull width represents the river width at the bankfull discharge and usually it is estimated using remote sensing data (orthofoto or satellite images) or on field surveys. Usually this layer is manually drawn and may contain overlapping of polygons and polygons with non uniform boundaries

This first module of the preprocessing tools contains an algorithm that validates and cleans the geometries in the bankfull polygon and merges adjacent bankfull polygons into a single geometry without considering any attributes field.

## 3.2. Input layers

- inBankfull: the input polygon layer of the bankfull area.

## 3.3. Output layers

- outBankfull: the output layer with the bankfull polygons validated, cleaned and merged.

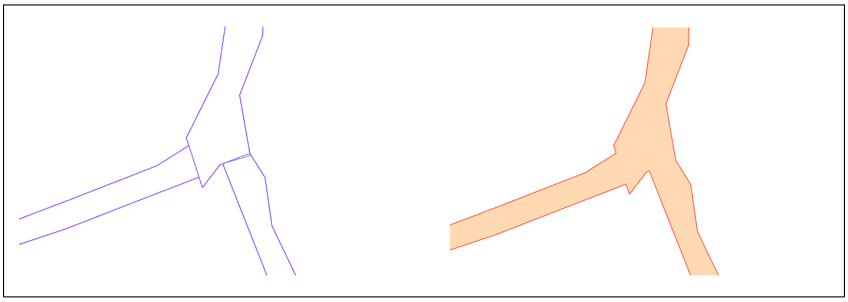


Figure 3.3: Example of the operation of merging bankfull polygons with LW01_ChannelPolygonMerger.

# 4. LW02_NetworkAttributesBuilder

## 4.1. Description

This module is a simple call to the already existing module *NetworkAttributesBuilder* of the **JGrassTools** library, to create the vector of the network with hierarchical attributes based on an input raster network.

The resulting network vector layer contains the stream separated in different features at each confluence. The links are orientated from upstream (startpoint) to downstream (endpoint) and the available attributes are:

- **Strahler enumeration**[1]: the ordering is based on the hierarchy of tributaries and the main channel is not determined. Strahler's stream ordering starts in initial links which assigns order one. It proceeds downstream. At every node it verifies that there are at least 2 equal tributaries with maximum order. If not it continues with highest order, if yes it increases the node's order by 1 and continues downstream with new order.
- **Hack enumeration**: this main stream of the catchment is set to 1, and consequently all its tributaries receive order 2. Their tributaries receive order 3 etc. The order of every stream remains constant up to its initial link
- **Pfafstetter enumeration** (modified version): this system is hierarchal, and watersheds are delineated from junctions on a river network.

Figure 4.4: Different enumeration of the channel network (starting from left): Hack, Strahler and Pfafstetter.

## 4.2. Input layers

- inNet: the input network raster layer
- inFlow: the input map of flow directions
- inTca: the input map of total contributing areas.

## 4.3. Output layers

- outNet: the output vector layer of polylines with the stream network.

[1] http://en.wikipedia.org/wiki/Strahler_number

# 5. LW03_NetworkHierarchyToPointsSplitter

## 5.1. Description

The evaluation of the possibility to clog of a network depends on the width of the bankfull and/or the width of the inundated areas, therefore we need to evaluate those values in each section of the network. To speed up this procedure we decided to use the points along the stream to identifiy each section.

This module extracts each point along the network with the Pfafstetter original attributes of the line stream and an additional attribute referring to the position of the point in the link (progressive distance of each point from the starting node).

## 5.2. Input layers

- inNet: the input hierarcy network vector layer of lines.

## 5.3. Output layers

- outNet: the output network vector layer of points.

The output point layer is the base for all the other elaboration of Large Wood recruitment and propagation along the network and should contain:

- pfaf: the original Pfafstetter enumeration
- linkid: the identifier of the point inside each link, points are numbered progressivly from upstream to downstream in each link.

An example of how it looks the extracted point layer with the attributes table is shown in Figure 5.5.

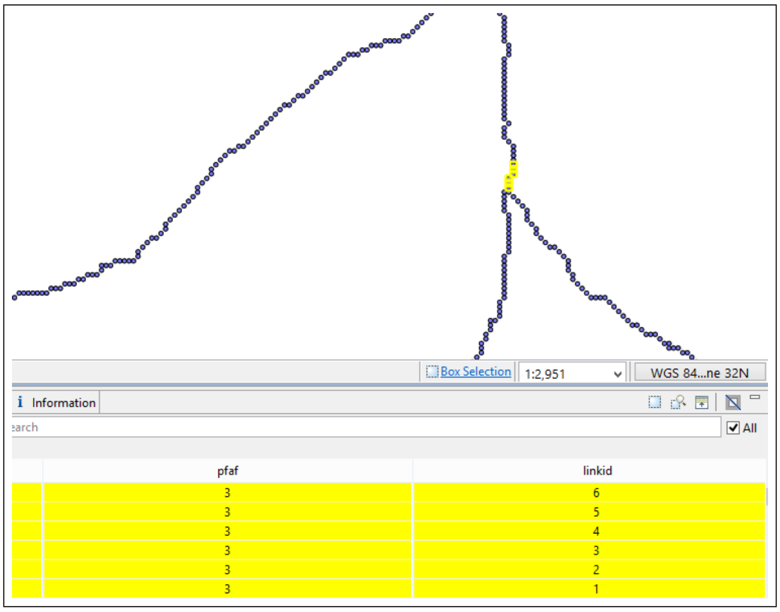



Figure 5.5: *Example of the basic points network layer used in LW modules: map and attributes table.*

# 6. LW04_BankfullWidthAnalyzer

## 6.1. Description

This module extracts the bankfull width for each section of the stream network and adds it as an attribute to the point representing the section. Bankfull width is extracted from the bankfull polygon layer.

The inputs of the model are the DTM extracted network and the digitalized bankfull polygons and they usually have different origins:

- bankfull layer is derived from orthofoto, satellite data or hydraulics models
- network layer is extracted from DTM using geomorphological functions based on elevation and flow directions.

An example of how different are the two information is the following (Figure 5.5):

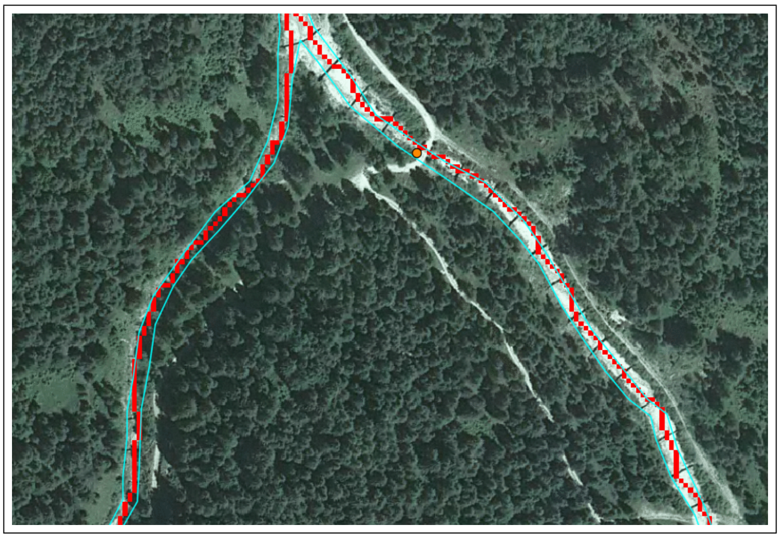


Figure 6.6: *Difference between the extracted network and the digitalized bankfull polygon.*

The different origin of the input data can be a source of problems. In each section there are different situations to consider regarding the position of the extracted network respect to the given polygon:

1. the extracted network is (almost) in the center of the bankfull polygon
2. the extracted network is only tangential to the bankfull polygon
3. the extracted network does not intersect the bankfull polygon.

This module has been developed to handle all these situations in a way that it is possible to assign the bankfull width to a channel section even if there isn't any intersection between the two.

In each point of the network, representing a section, the bankfull width is assigned considering the relative position between the point of the channel and the polygon of the bankfull as the width of the bankfull in the nearest point of channel.

If the channel and the bankfull polygon are too far (maxdist) or if there are others problems in drawing the correspondent section, the point is labelled as problematic and added to the output problem point layer.

## 6.2. Input layers

- inBankfull: the input polygon layer of the bankfull area
- inNetPoints: the input hierarcy network vector layer of lines

## 6.3. Input parameters

1. MAX_DISTANCE_FROM_NETPOINT: the maximum distance that a point can have from the nearest polygon. If the distance is greater, then the netpoint is ignored and labelled as outside the region of interest.

## 6.4. Output layers

- outNetPoints: the output points layer of the network with the additional attribute of bankfull width
- outBankfullSections: the output layer with the sections lines where the bankfull width has been calculated with the two attributes pfaf and linkid to connect each section to the network point
- outProblemPoints: the output points layer highlighting the position of the problematic sections.

Two additional attribute fields are added to the network point layer:

1. w: bankfull width
2. w_from: origin of the bankfull width, for bankfull polygon 0.

The origin of the bankfull width at the end of this module is fixed to a value of 0. This value will be updated in the next module to consider if in the section there are human structures that force the bakfull width to a defined width (mainly bridges or check dams).
An example of the two outputs are in Figure 6.7 and Figure 6.8.

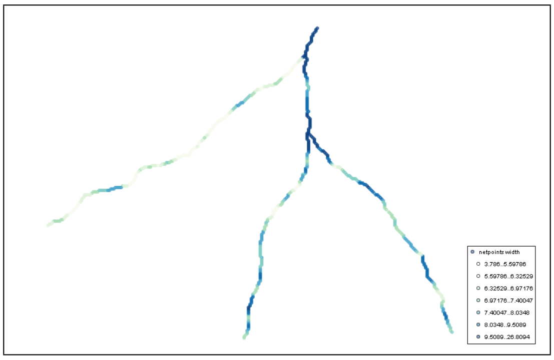



Figure 6.7: *Point layer colored according to the bankfull width.*

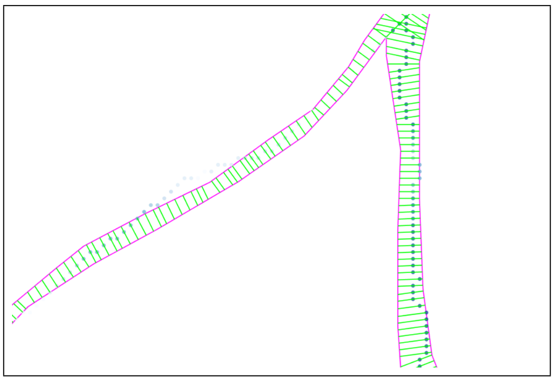


Figure 6.8: *Extracted sections of the bankfull correspondent to each point of the network.*

# 7. LW05_BridgesDamsWidthAdder

## 7.1. Description

This module corrects the bankfull width of the sections of the channels where a bridge or a check dam is found and set the attribute of the origin of the width to the corresponding value.

Human structures like bridges and dams modify the natural evolution of channels width and will be (specialy in the propagation phase) the most probable critical sections. Dams and bridges are georeferenced with GPS or other techniques and they can not overlay perfectly with the network extracted from the DTM. The structures are linked to the nearest section on the network within a predefined maximum distance.

The update of the channel width is calculated differently for dams and bridges:

- *check dams*: a fixed, constant width is used

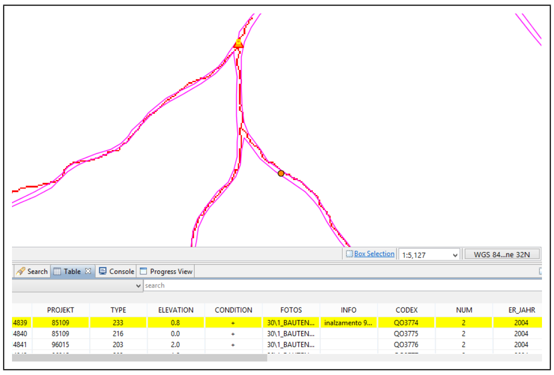


Figure 7.9: *An example of position and attributes table of a layer of check dams.*

- *bridges*: the attribute of the bridges layer containing the length of the bridge is used.

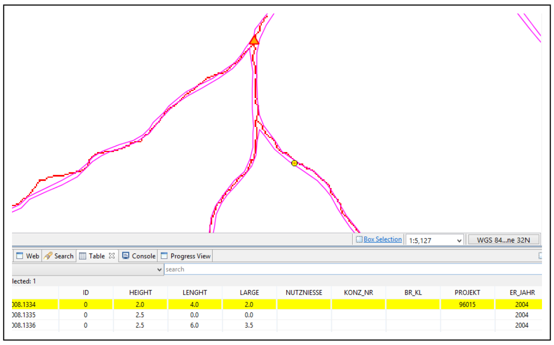


Figure 7.10: *An example of position and attributes table of a layer of bridges.*

If the bridges do not have the information of their length they will not be considered, and they are added to an output layer with all the others problematic bridges. In this way they are easily recognizable and the values can be updated by the user before running the simulation again.

## 7.2. Input layers

- inNetPoints: the input hierarcy network layer of points with the attributes fields of the bankfull width and the origin of that value
- inBridges: the input point layer with the bridges to consider to modify channel width
- inDams: the input point layer with the check dams to consider to modify channel width.

## 7.3. Input parameters

1. bridgeLenghtField: name of the attribute field of the bridges layer to use as width of the channel under the bridge
2. damsOnNetDistance: maximum distance of a dam to be snapped on the network
3. bridgesOnNetDistance: maximum distance of a bridge to be snapped on the network
4. fixedDamsWidth: fixed value of the width assigned to the sections where a check dam is located.

## 7.4. Output layers

- outNetPoints: the output points layer of the network with the bankfull width updated with the information of bridges and dams width
- outProblemBridges: the output layer containing the points of the bridges without information of the width.

The attribute correspondent to the origin of the calculated channel width, *w_from*, can assume three different values:

- 0: width from bankfull polygon
- 1: widht from check dams
- 2: width from bridges.

An example of the modified section width for dams and bridges are shown in Figure 7.11 and Figure 7.12.

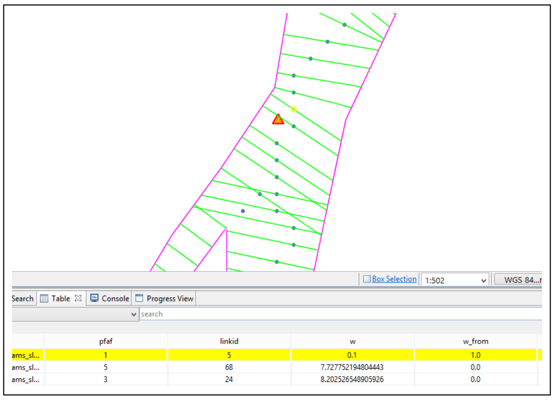


Figure 7.11: *Assingment of the fixed value of channel width in the nearest section of a check dams.*

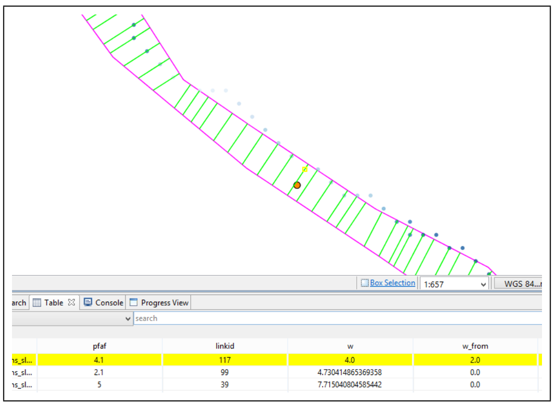


Figure 7.12: *Assingment of the length of the bridge as channel width in the nearest section of a bridges.*

# 8. LW06_SlopeToNetworkAdder

## 8.1. Description

This module adds the attribute of local slope to the input channel point layer.

This is the starting point for the procedure to evaluate the average channel slope in each section considering also the surrounding cells (upstream and downstream). The average slope will be calculated in the next module together with the inundation width which requires almost the same background elaborations on channel points.

## 8.2. Input layers

- inNetPoints: the input hierarcy network layer of points with the information about the bankfull width and the origin of that value
- inSlope: the input slope raster map of the area covered by the network.

## 8.3. Output layers

- outNetPoints: the output points layer of the network with the additional attribute of local slope.

The slope is extracted from the raster layer in the pixel where the each point is placed.

An example of the extracted values of local slope are shown in Figure 8.13.

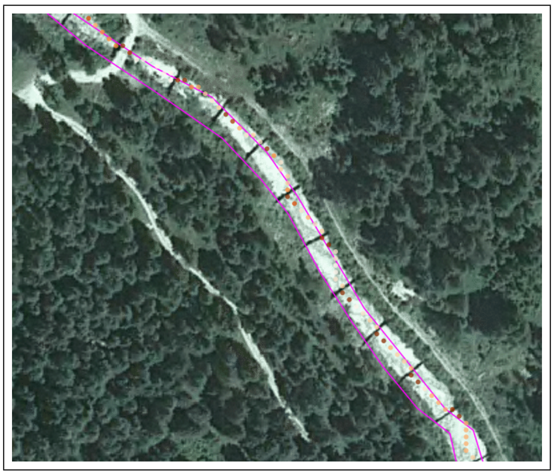


Figure 8.13: *Example of the extracted local slope of the channel sections.*

# 9. LW07_NetworkBufferWidthCalculator

## 9.1. Description

This module calculates the possible areas along the channel network where there is the possibility for the water, during extreme events, to erode and within this process to recruit material from outside the river. The extent of these areas contributing to large wood in the channel are calculated following a power law, where the new width is a function of the bankfull widht and the channel slope. The parameters of the power law should be derived from field observations and so they are added as input parameters.

An experimental power law equation is used to evaluate the possible extended inundated width starting from bankfull width. The increased channel width is calculated on the original channel sections: the bankfull sections are equally extended on both sides to reach the new channel width.

The model allows to constrain the widening depending on expert criteria. For instance, it gives the possibility to input a polygon layer with the surficial geological formation (quaternary deposits). The widening would be constrained to these areas and it would be limited by the presence of rocks. For this reason inundation areas should not be extended where the geological superficial formations is rock:

- the sections that intersect the rock in the baricenter of the bankfull will be left as they are: resulting width is the same as bankfull width
- the sections that intersect the rock on the new calculated vertexes will be cut: resulting width will consider only the areas where possible erodible soil is present.

## 9.2. Input layers

- inNetPoints: the input hierarcy network layer of points with the information about the bankfull width and the local slope
- inGeo: the input polygon layer with the geological superficial geological formations
- inSectWidth: the input line shapefile with the extracted transversal sections (output of LW04_BankfullWidthAnalyzer)

## 9.3. Input parameters

1. prePostCount4Slope: the number of cells upstream and downstream to consider to evaluate the average slope in each section
2. k, n: parameters of the power law for the evaluation of the new width

$$newWidth = width + k * slope^n$$

3. MIN_SLOPE: the value to use for the points of the network where the local slope is zero.

## 9.4. Output layers

- outNetPoints: the output points network layer with the additional attribute of the calculated contributing width and average slope
- outInundationArea: the output polygon layer with the extended contributing areas
- outInundationSections: the output layer with the sections lines corresponding to the extended contributing width.

An example of the calculated extended width considering also the superficial geological formations and the delineation of the extended contributing sections are shown in Figure 9.14 and Figure 9.15.

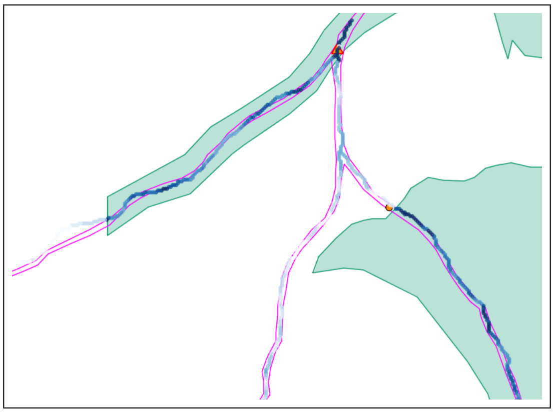


Figure 9.14: *Evaluation of extended contributing width considering superficial geological formations.*

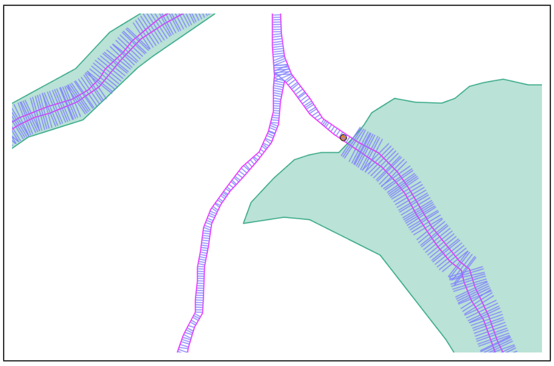


Figure 9.15: *Delineation of extended contributing sections drawn considering superficial geological formations.*

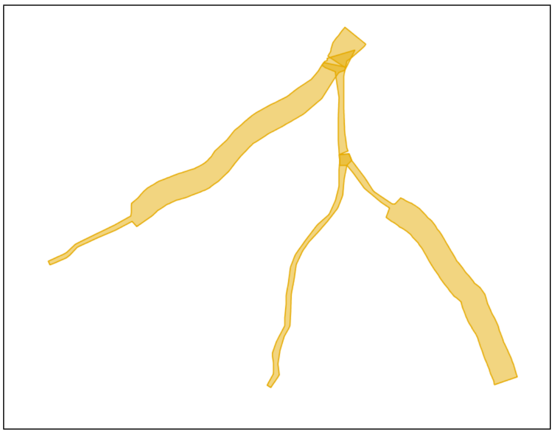


Figure 9.16: *Extracted total inundated area considering superficial geological formations.*

# 10. LW08_NetworBufferMergerHolesRemover

## 10.1. Description

The extracted polygons output of the model *LW07_NetworkBufferWidthCalculator* are disjointed and irregular (see Figure 10.17) and there is the need to merge the inundated polygons and remove the holes in the new geometries. This simple module merges the inundated polygons and cleans the geometries to avoid strange perimeters.

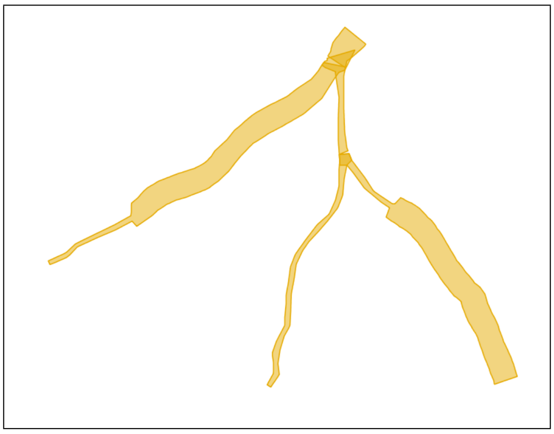


Figure 10.17: *Example of the inundated polygons output of the model LW07_NetworkBufferWidthCalculator.*

## 10.2. Input layers

- inInundationArea: the input layer with the inundation polygons output from *LW07_NetworkBufferWidthCalculator*

## 10.3. Output layers

- outInundationArea: the output polygon layer with the merged, and without holes, inundation polygons.

An example of the result of the merging and cleaning of the polygon layer is shown in Figure 10.18.

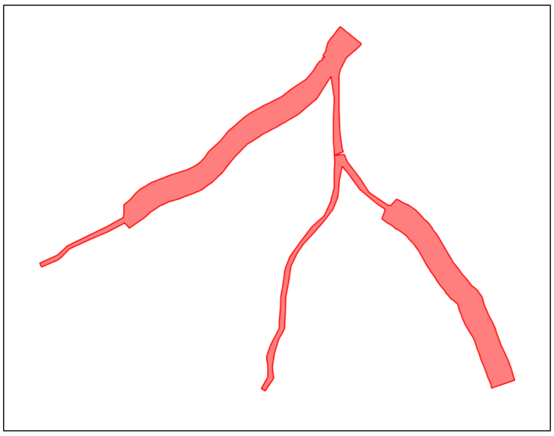


Figure 10.18: *Merged and cleaned inundate polygons.*

# 11. LW09_AreaToNetpointAssociator

## 11.1. Description

This module calculates the median vegetation height and total timber volume of the vegetation coming in the river from unstable and connected areas of the hillsopes in each section.

The steps for the evaluation of the amount of Large Wood coming from the local hillslopes in each section are:

1. evaluation of unstable areas: shalstab model (or any other stability model)
2. evaluation of the downslope component of the connectivity index[3] for each pixel using the results of shalstab as weights in the formula

$$D_{dn} = \Sigma \frac{d_i}{W_i S_i}$$

3. extract the subbasin for each point of the channel network
4. extract the unstable and connected areas for each subbasin:
   - pixels inside the inundated polygon: always connected
   - pixels outside the inundated polygon: connected only if the connectivity index is less than a given threshold
5. extract vegetation height and forest stand volume on unstable connected area
6. assign these attributes to the network points.

In Figure 11.19 the simplified workflow of the module is presented.

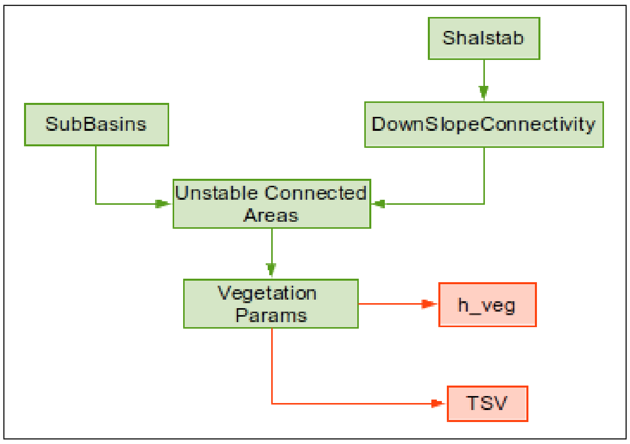



Figure 11.19: *Simplified workflow for the module LW09_AreaToNetpointAssociator.*

### 11.1.1. Shalstab

Large Wood in rivers comes from the unstable area of the local hillslopes. We can use a stability model to evaluate if there are unstable areas for the given precipitation and where they are located. It is possible to use the **Shalstab** stability model of the JGrassTools library[2].

One of the output of Shalstab is the map of the stability classes for the given input precipitation with the current classification:

- 1: unconditionally unstable
- 2: unconditionally stable
- 3: stable
- 4: unstable.

This map is used to derive the map of weights required in the Downslope Connectivity Index, in particular we have to reclassify the map assigning:

- 1 → stable pixels
- 100 → unstable pixels

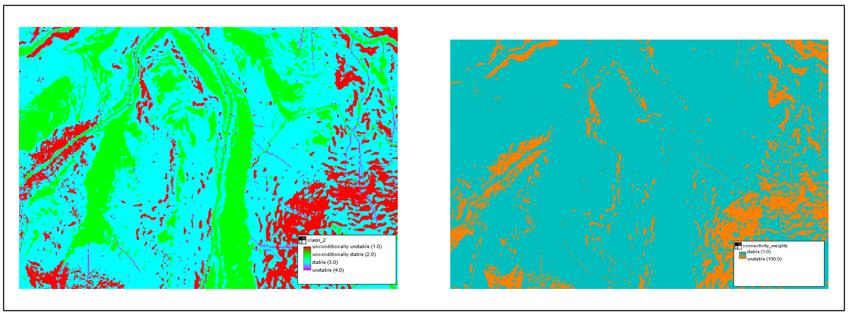


Figure 11.20: Example of the output map of stability classes of the Shalstab model and its classification for the use as weights in the downslope connectivity index.

### 11.1.2. Downslope Connectivity Index

Not all the unstable areas on hillslopes will flow into the rivers mainly because of the distance and the local slope. The Connectivity Index is used to identify which part of the unstable area on the hillslopes can reach the network. Considering the conditions for the movement of the Large Wood, we can use only the downslope component of the Connectivity Index.

The Downslope Connectivity Index module of the JGrassTools library evaluates the downslope component of the connectiviy index considering the flow path length that a particle has to travel to arrive to the nearest point of the network[3].

The input maps are:

1. map of flowdirections
2. map of extracted network
3. map of slope
4. map or constant value of weights.

The output is:

- the map of the Log of the downslope component of the connectivity index.

An example of the resulting map of downslope connectivity index is shown in Figure 11.21.

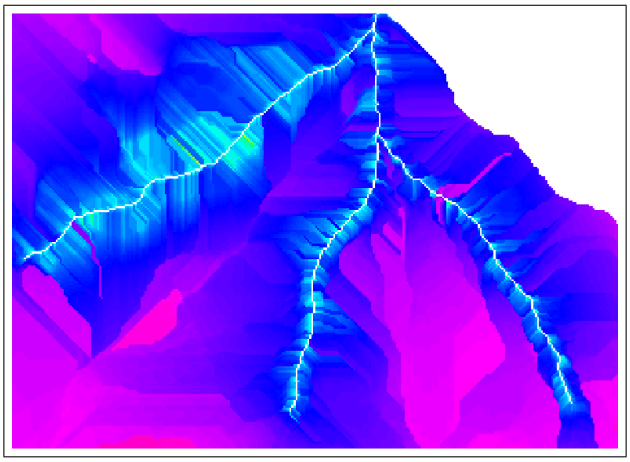


Figure 11.21: *Example of the map of the Downslope Connectivity Index.*

### 11.1.3. Characterization of the vegetation

To evaluate the lenght of the logs and then the possibility to clog the sections we need some maps of the vegetation, in particular:

- height of the trees
- distribution and volume of biomass.

The module extracts the height of the vegetation as the difference between the DSM and the DTM with the possibility to add a threshold on the minimum height to consider, the map of the Forest Stand Volume is required as input and can be derived from different sources (LiDAR data, field surveys, literature, ...).

### 11.1.4. Evaluation of Large Wood recruitment from hillslopes

The module **LW09_AreaToNetpointAssociator** extracts the subbasin closing at each network point and evaluates the main vegetation parameters over the unstable and connected areas inside each basin.

To evaluate the subbasin the module calls the *NetNumbering* algorithm of the JGrassTools library[2]. NetNumbering assigns the number to each network link and splits the relative subbasins. The call to the module is done using the point layer of the network in input to extract the subbasin for each point but only to that point and not taking into account the draining area of the upstream point in the fluvial network.

Using the concept of Downslope Connectivity Index it is possible to first extract the unstable and connected areas inside a basin just fixing a threshold on the value of the Log of the index. In particular unstable and connected areas are those:

- with a value of connectivity lower than a given threshold
- inside the inundated polygon.

The last step of the evaluation of the contribution of hillslopes to the large wood in the network is to calculate the main vegetation parameters, median vegetation height and total timber volume, on the unstable and connected areas of each basin. Those parameters will be added to the output points network layer (Figura 11.22).

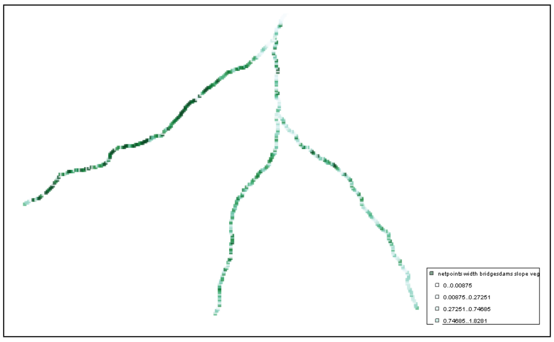



Figure 11.22: *Vegetation parameters added as attributes in the output layer.*

## 11.2. Input layers

- inNetPoints: the input hierarcy network layer of points with the information about the bankfull width and its origin, the local and average slope and the inundated width
- inInundationArea: the input layer with the inundation polygons output from *LW08_NetworBufferMergerHolesRemover*
- inFlow: the input raster map of flow directions
- inTca: the input raster map of Total Contributing Areas
- inNet: the input raster map with the extracted network
- inDtm: the input raster map with the terrain elevations
- inDsm: the input raster map with the surface elevations
- inStand: the input raster map with the total stand volume derived from field surveys
- inSlope: the input raster map with the slopes
- inConnectivity: the input raster map of the downslope connectivity index

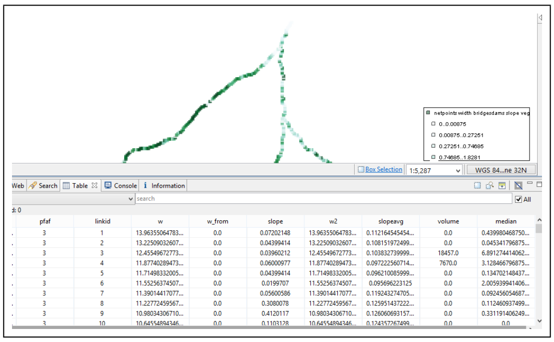
## 11.3. Input parameters

1. connectivityThreshold: threshold value of connectivity map for extracting unstable connected pixels of each basin.

## 11.4. Output layers

- outNetPoints: the output points layer of the network with two additional attributes: total timber volume from the local hillslopes and median of vegetation height
- outNetnum: the output raster map with the enumeration of the network
- outBasins: the output map with the subbasins closing in each section of the network not taking into account the draining area of the upstream point in the fluvial network.

An example of attributes table of resulting layer is shown in Figure 11.23.




| pfaf | linkid | w | w_from | slope | w2 | slopeavg | volume | median |
|---|---|---|---|---|---|---|---|---|
| 3 | 1 | 13.96355064783... | 0.0 | 0.07202148 | 13.96355064783... | 0.112164545454... | 0.0 | 0.439980468750... |
| 3 | 2 | 13.22509032607... | 0.0 | 0.04399414 | 13.22509032607... | 0.108151972499... | 0.0 | 0.045341796875... |
| 3 | 3 | 12.45549672773... | 0.0 | 0.03960212 | 12.45549672773... | 0.103832739999... | 18457.0 | 6.891274414062... |
| 3 | 4 | 11.87740289473... | 0.0 | 0.06000977 | 11.87740289473... | 0.097222560714... | 7670.0 | 3.128466796875... |
| 3 | 5 | 11.71498332005... | 0.0 | 0.04399414 | 11.71498332005... | 0.096210085999... | 0.0 | 0.134702148437... |
| 3 | 6 | 11.55256374507... | 0.0 | 0.0199707 | 11.55256374507... | 0.095696223125 | 0.0 | 2.005939941406... |
| 3 | 7 | 11.39014417077... | 0.0 | 0.05600586 | 11.39014417077... | 0.119243274705... | 0.0 | 0.092456054687... |
| 3 | 8 | 11.22772459567... | 0.0 | 0.3080078 | 11.22772459567... | 0.125951437222... | 0.0 | 0.112460937499... |
| 3 | 9 | 10.98034306710... | 0.0 | 0.4120117 | 10.98034306710... | 0.126060693157... | 0.0 | 0.331191406249... |
| 3 | 10 | 10.64554894346... | 0.0 | 0.1103128 | 10.64554894346... | 0.124357267499... | 0.0 | 0.0 |

Figure 11.23: *Attributes table of the output layer of network points.*

# 12. LW10_NetworkPropagator

## 12.1. Description

Identifies the critical section for the transit of Large Wood in the ginen stream network and identifies the origin of that material.

The algorithm is based on the comparison between the lenght of the logs and the channel width. The logs can have two different origins:

1. **local**: logs coming from the unstable areas of the local hillslope
2. **global**: logs coming from the network upstream.

If median of the length of the logs is greater than the channel width the section is labelled as critical. If the vegetation length of the unstable areas of the local hillslope is greater than the channel width, the section is critical for local conditions, if the vegetation greater is that coming from upstream in the channel network, the section is critical for global conditions.

## 12.2. Input layers

- inNetPoints: the input network points layer with as attributes the vegetation height and total timber volume.

## 12.3. Input parameters

1. FIELD_LINKID: name of the attribute field of the input network layer containing the progressive identification number of the point within each link
2. FIELD_WIDTH: name of the attribute field of the input network layer containing the section width to compare to the vegetation height for defining a section as critical
3. FIELD_MEDIAN: name of the attribute field of the input network layer containing the median value of the height of the vegetation on unstable pixels of the basin closing in the current section.

## 12.4. Output layers

- outNetPoints: the output network points layer with the labelled critical sections.

In the output layer three additional fields will be added:

1. FIELD_ISCRITIC_LOCAL: contains the information about the critical sections for local parameters, values are 0 for non critical sections; 1 for critical sections
2. FIELD_ISCRITIC_GLOBAL: contains the information about the critical section for global parameters, values are 0 for non critical sections; 1 for critical sections
3. FIELD_CRITIC_SOURCE: only for critical sections, it contains the information about the identification number (Pfafstetter number - linkID) of the section from where the vegetation blocked in the current section comes from. For sections that are critical for local conditions this field contains the identification of the same section.

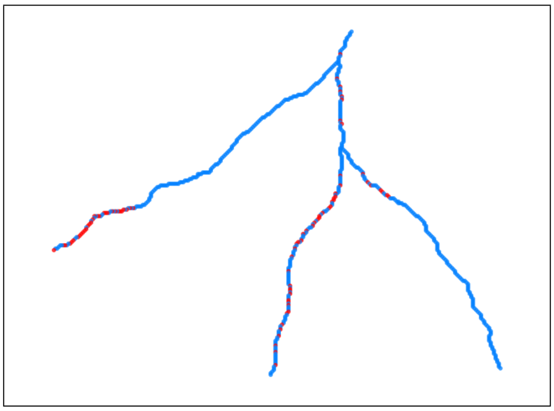


Figure 12.24: *Example of the output network layer with highlited the critical sections.*

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FSV model