GIS-Fuzzy logic large wood recruitment toolbox: Quick User Guide (version August. 2022)

Introduction

Before starting

This toolbox has been developed within the **WoodFlow** (woodflow.wsl.ch) research **project** and aimed to provide a tool to compute recruitable (delivered or supplied) wood volumes at the catchment scale for three different frequency scenarios using available data in Swiss river catchments. The approach was a variation of the model presented by Ruiz-Villanueva et al., (2014).

The model was built for ESRI **ArcGis 10.7** and it is supplied as a **.tbx** file. The tool requires **Spatial Analyst**, **3D Analyst** extensions (Advanced License).

In addition, to compute **stream sinuosity** index (values between 0 and 1) the following **python** tool is required:

https://www.arcgis.com/home/item.html?id=00e708a448b74810a0e805c4a97f9d46

Please, read the documentation of this tool and install it before starting to use the Wood Recruitment Toolbox. This document does not explain how to use ArcGis and assumes that the user is already familiar with the software.

Because the analysis is based on **Fuzzy Logic** the following documents are recommended:

http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/fuzzy-membership.htm

http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/fuzzy-overlay.htm

The toolbox is composed of several steps, but each process can be done independently without using the toolbox, and similar approaches could be followed in other GIS software.

The tool was developed considering available input data in Switzerland; therefore, certain analyses were specific for this type of information (i.e., format, resolution, etc.). However, the Toolbox is flexible and could be adapted to a different type of input data.

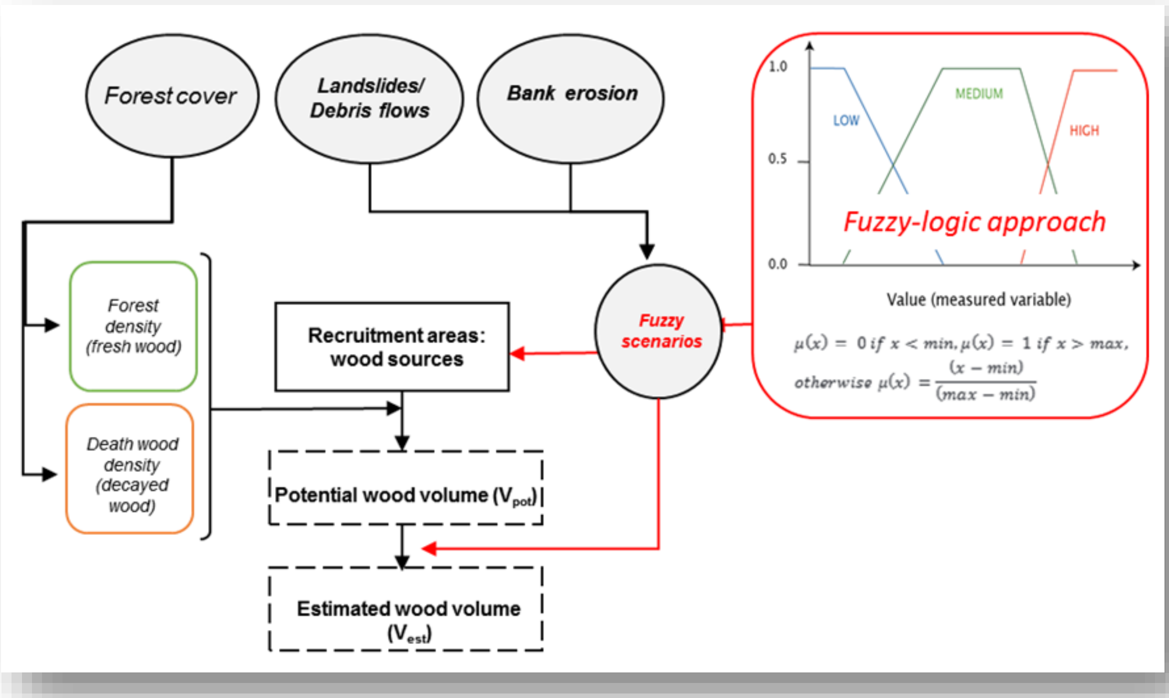
The Wood Recruitment Toolbox works with raster and feature class files and the required input data is as follows:

- The catchment or study area polygon
- Digital elevation model (DEM)
- Forested area polygon
- Forest density raster in m3/ha
- Stream network lines
- Recruitment processes (i.e., landslides and debris flows) affected areas (raster files or feature class shapefiles to be converted to raster)

GENERAL DESCRIPTION

The general approach is divided into three main steps (see the following Figure):

(i) terrain analysis to establish the wood sources, such as areas affected by landslides, debris flows and bank erosion, taking into account different scenarios (based on the process frequency and intensity);
(ii) forest cover and density analysis; and
(iii) estimation of wood volume for each scenario.



The areas affected by the wood supply (recruitment) processes can be modelled using different approaches (e.g., numerical modelling). This information was available in Switzerland, and the Wood Recruitment Toolbox was developed to use this existing data. For the hillslope processes, the affected areas by shallow landslides and debris flows were defined based on linear trajectories provided by the SilvaProtect-CH dataset from Losey and Wehrli (2013). To transform these lines into areas (and to pixels of raster files), the density of the lines is used to classify the terrain into three scenarios: FREQUENT, MEDIUM, and RARE events (named as E"30", E"100", E"300" respectively as they were assumed equivalent to events of approximately 30, 100 and 300 years return period), for high, medium and low-density line respectively. The reasoning is as follows, high trajectories density is assumed to represent the areas more prone to landslides or debris flows, usually of a higher frequency and therefore, lower magnitude. The same is applied to debris flows. The thresholds to classify the three areas are based on 4 natural breaks.

Once the trajectories are converted to pixels, the connectivity between these pixels and the stream network is analysed. Connectivity is established as a function of both the distance to the channel and the slope (Figure below A). The distance (D) is calculated based on the tree height and a toppling coefficient (k=2): $D=k \cdot Ht$ [1]

Trees located in a landslide-prone pixel or in the toppling influence area (defined as a buffer equal two times the mean tree high), may reach the channel if they are were close enough (Euclidean distance < 50 m) or further away but on a steep slope (>40%). In the case of debris flows, all pixels were assumed to be connected to the stream network.

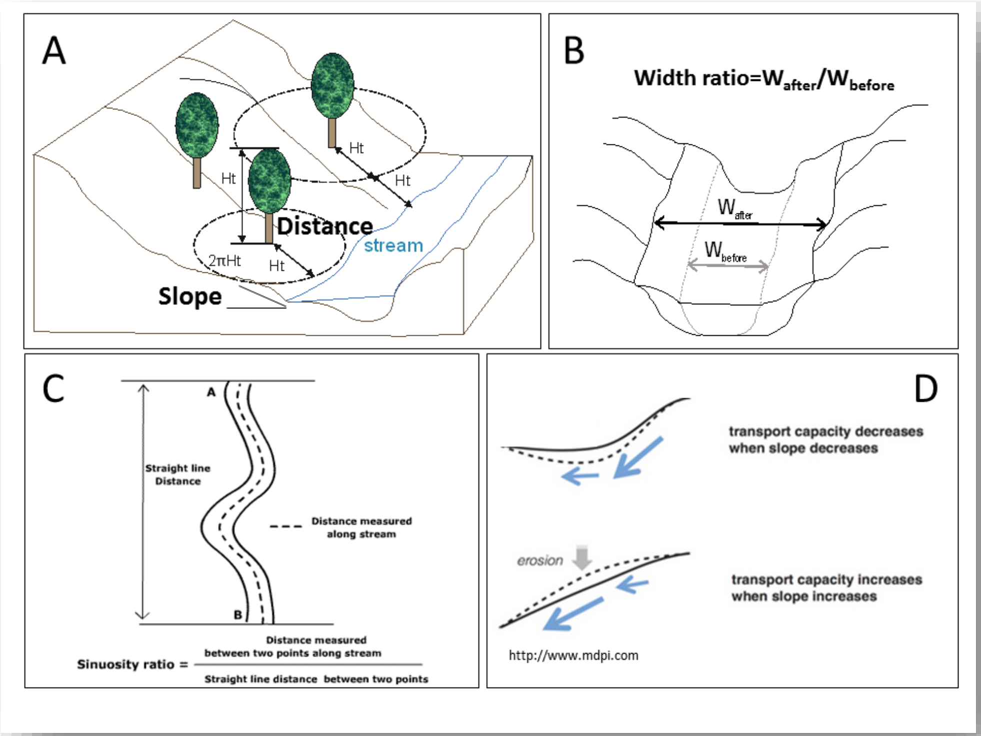
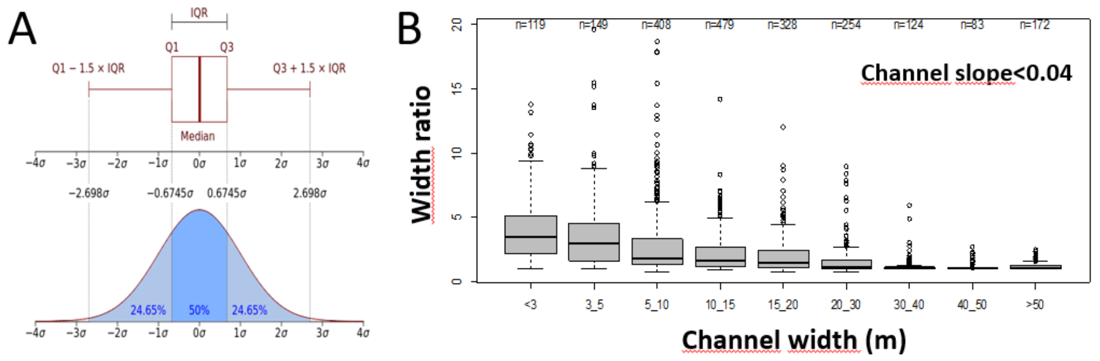


Figure : (A) Variables describing the connectivity between areas affected by landslides and debris flows and the channel network; (B) width ratio used to define areas affected by bank erosion; (C) definition of channel sinuosity; (D) slope used as a proxy for

For bank erosion the process is slightly different as SilvaProtect does not include this process, and there is not available database for the areas affected by bank erosion in Switzerland. Areas potentially affected by bank erosion areas are computed based on channel sinuosity and slope as a proxy for transport capacity (Figure above C and D), the channel with and the width ratio (Figure B). The width ratio gives the potential final channel width due to bank erosion during floods. This width ratio has been calculated analysing a European database, including several rivers and flood events in Switzerland and other 6 countries, and the three scenarios were defined according to the first and third quartile and the median value for different channel width classes (Figure below).



C **FREQ (E"30"), MED (E"100")and RARE (E"300") scenarios**

width/ width ratio	<3	3_5	5_10	10_15	15_20	20_30	30_40	40_50	>50
Freq. (Q1)	1.2	1.1	1.1	1.1	1.1	1	1	1	1
Medium (median)	3	2	2	2	2	1.6	1.3	1.2	1.2
Rare (Q3)	4	3	2.5	2.5	2.2	1.8	1.6	1.5	1.5

Figure : (A) Boxplot and density function showing the quartiles used to define the scenarios; (B) boxplots of width ratio values for different channel width classes for rivers with longitudinal slopes lower than 4%; (C) table showing the final values of width

As the Figure above shows, a width ratio value applies to the different channel width categories for the three scenarios. For example, to define the areas affected by high intensity bank erosion (rare event) and for small channels (< 3 m wide) a width ratio equal to 4 is applied (meaning that the area affected by bank erosion covers a width 4 times the initial channel width), while for very large rivers (> 50 m wide) the width ratio for this scenario is equal to 1.5 (only 1.5 times the initial width). To assign the width ratio the stream network has been reclassified according to the channel width provided by the Ecomorphology database (Sohlenbreite). These reclassifications have been done in ArcGis using the following python code (this code defined the width ratio according to initial width for the FREQUENT scenario (E"30") and was adapted for the other two):

```
def Reclass(GSBREITE):
 if GSBREITE <=3: return 1.2
 elif GSBREITE >3 and GSBREITE <=5: return 1.1
 elif GSBREITE >5 and GSBREITE <=10: return 1.1
 elif GSBREITE >10 and GSBREITE <=15: return 1.1
 elif GSBREITE >15 and GSBREITE <=20: return 1.1
 elif GSBREITE >20 and GSBREITE <=30: return 1
 elif GSBREITE >30 and GSBREITE <=40: return 1
```

```
 elif GSBREITE >40 and GSBREITE <=50: return 1
 elif GSBREITE >50: return 1
 width_low= Reclass( !GSBREITE! )
```

The stream network provided by the ecomorphology database was grouped by the channel width classes as explained above and the width ratio was assigned to estimate the resulted potential erodible width for each stream segment. These buffers were transformed to pixels and the final pixels prone to bank erosion were assigned based on channel sinuosity and gradient. Stream segments characterized with high sinuosity and high gradient were assumed to be more prone to bank erosion.

The described variables (i.e., landslide prone areas, connectivity, debris flow prone areas, bank erosion prone areas, sinuosity and gradient) are transformed to fuzzy sets using the Fuzzy Membership tool in ArcMap 10.1 with a linear membership function. The resulted converted fuzzy variables are combined (e.g., landslides prone pixels and connectivity; sinuosity and gradient) with the Fuzzy Overlay tool. As a result, all pixels are transformed to fuzzy values ranging between 0 and 1, and they are used to compute the volume of wood by multiplying the fuzzy pixel value by the forest density pixel. In case of overlapped pixels, priority was given to areas prone to debris flows, then banks erosion and finally landslides.

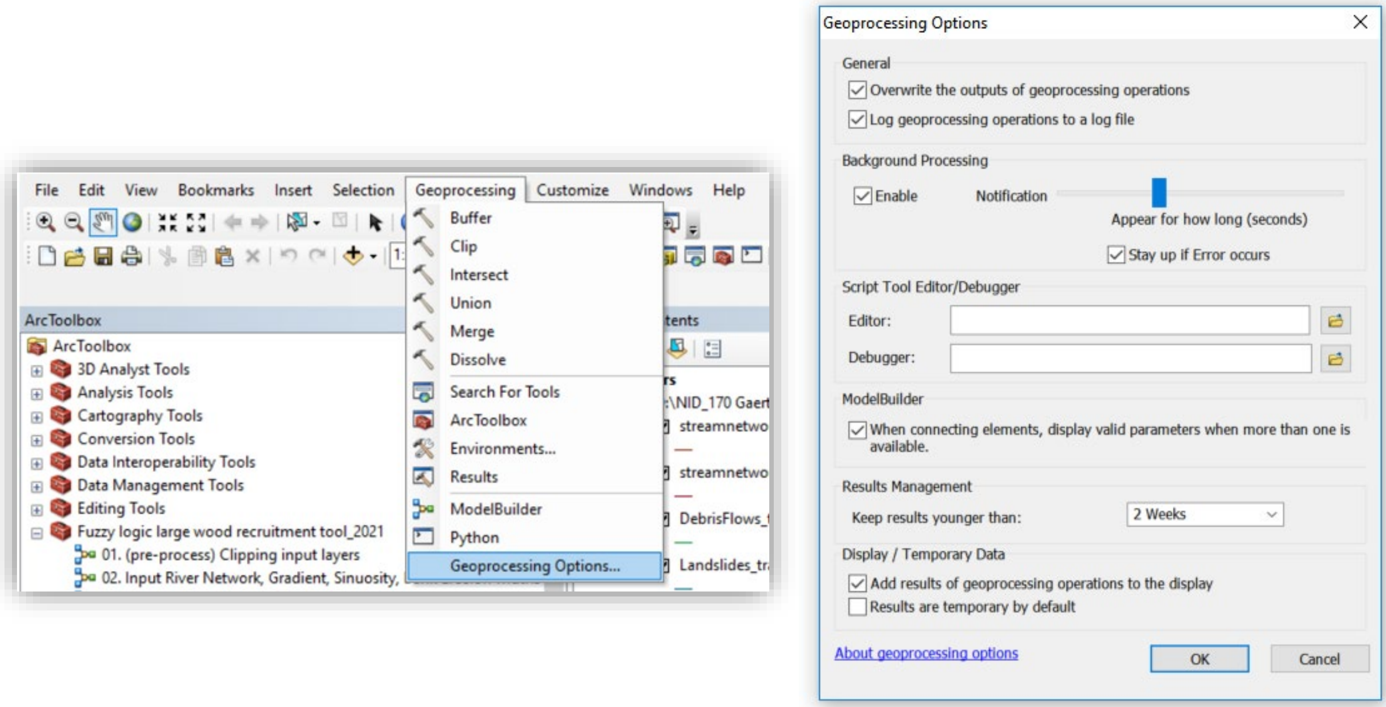
To compute the wood volume estimations a forest density map is required. The stand density of living trees in Swiss forests (in m^3 ha^{-1}) was derived from a nationwide raster map with an original resolution of 25 x 25 m (rescaled to 1 x 1 m), based on digital stereo aerial photographs from 2007 to 2016 (Ginzler et al., 2019). In addition, previously stored instream wood volumes are also included in the calculations. Detailed information on wood loads across the stream network was not available, so based on a literature review by Rickli and Bucher (2006) and Ruiz-Villanueva et al. (2016), volumes of instream wood are assigned to the different streams grouped by stream order (FGA) classes provided in the stream network dataset. The following python code was used:

```
def Reclass(FLOZ):
 if FLOZ <=3: return 0.006
 elif FLOZ >3 and FLOZ <=6: return 0.012
 elif FLOZ >6: return 0.005
 wood_load= Reclass( !FLOZ! )
```

To complete the final computations and to obtain the estimated recruited wood volume 10 steps must be done (Figure 4), and the user has full control on the entire process, step by step. Step 11 can be used to compute the probable maximum recruitable wood volume, which is the total wood volume potentially recruitable computed without considering the volume reduction by the fuzzy functions.

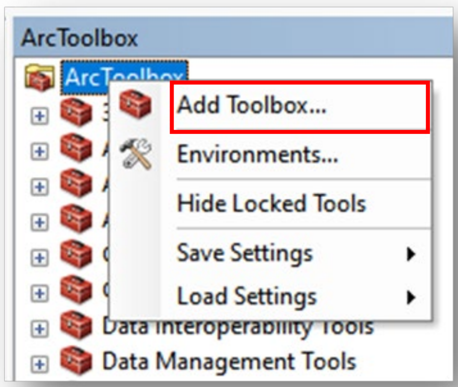
STEP BY STEP

Before starting, set up the Geoprocessing options as shown in the Figure:

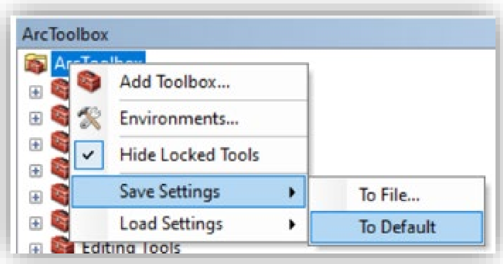


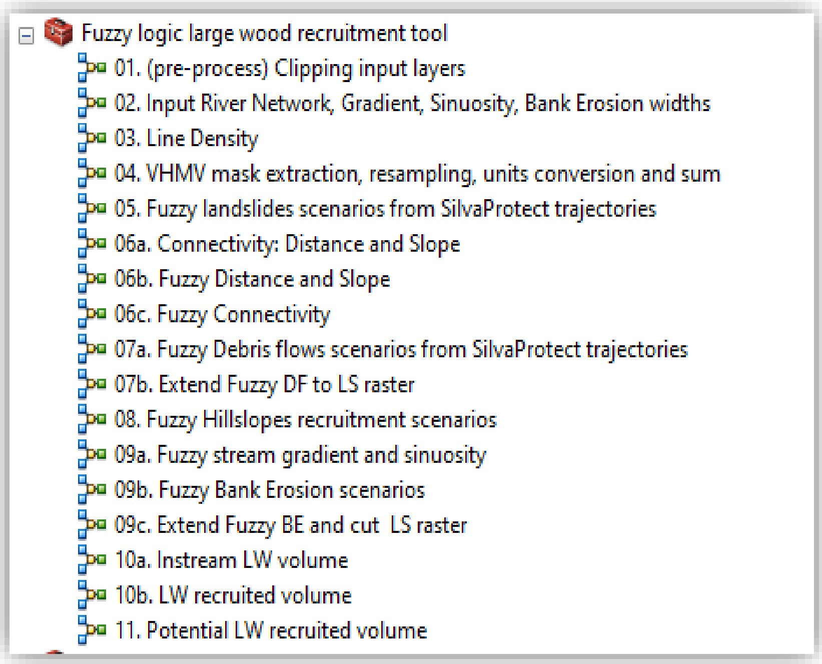
The Toolbox is very intuitive, user friendly and the user needs just to enter the required input data and save the output files, which are used for the following step.

Add the toolbox to the ArcToolbox list:



If you want to add the toolbox "*Fuzzy logic large wood recruitment tool_2021*" to the default setting mode you have to: right click on ArcToolbox > Save Setting > To Default





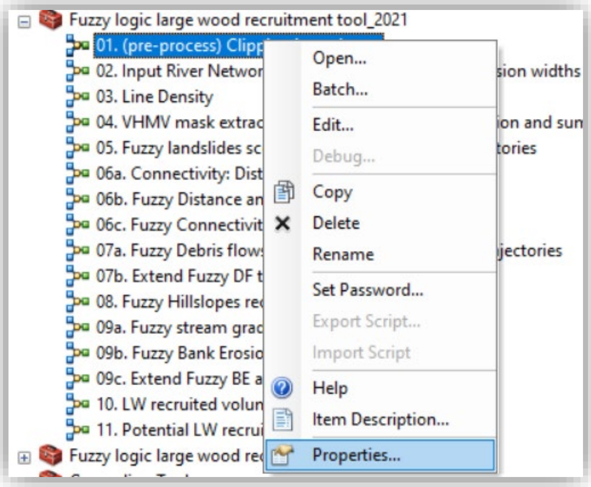
The *Fuzzy logic large wood recruitment tool_2022* appears as in the previous *Figure.*

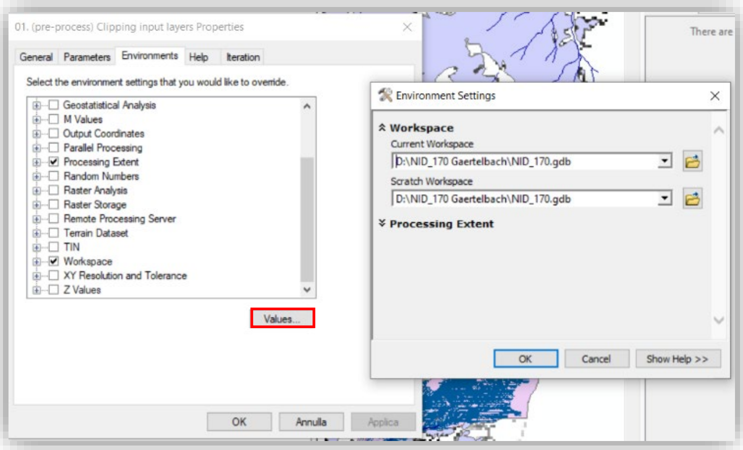
The correct setting of the workspace it is a very important stage, and it must be checked often to ensure that output files are always saved in the correct geodatabase folder. It is important to double check that the workspace and path for input and output files is the right one. Before starting, it is necessary to check that the workspace is set up in the correct *Geodatabase* folder.

File > Map document Properties > Default Geodatabase > > Set the correct folder.

In the following sections, step by step procedures are explained using a case study as an example, the Gaertelbach (NID_170) stream catchment.

For each step, it is important to check that the workspace is set correctly in every single step. The workspace must be the same as the *default geodatabase*.

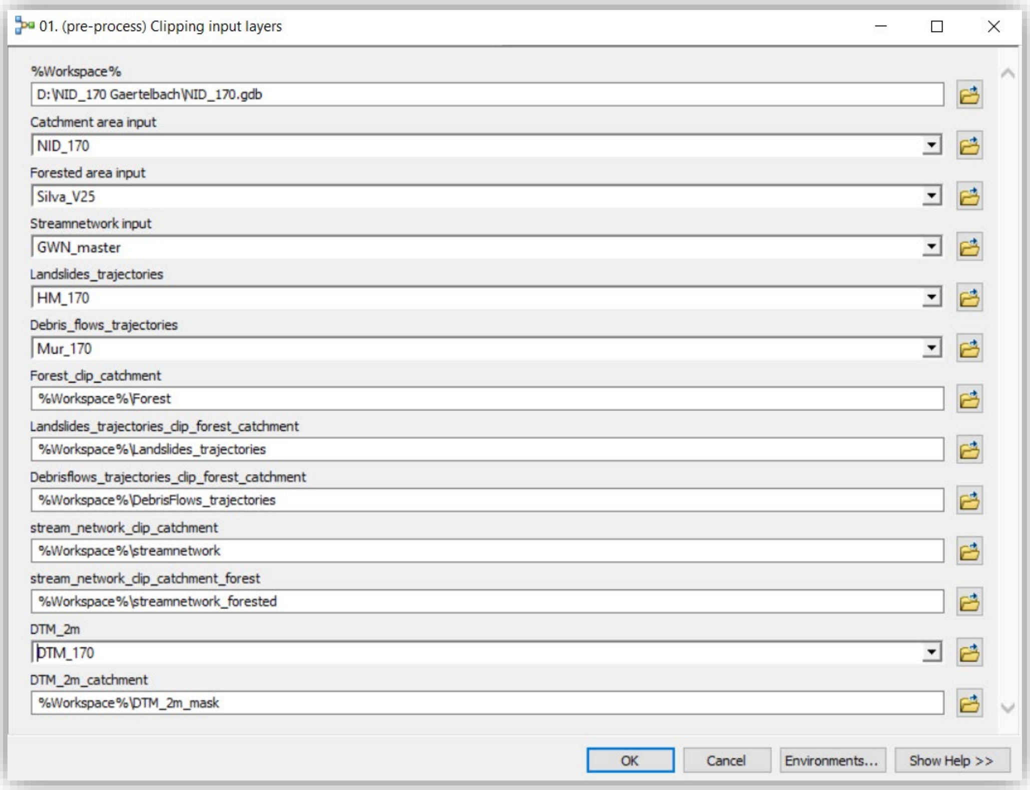




1. Pre-process: clipping input layers

This step applies clipping to the initial input larger datasets (e.g., national stream network, forest cover, etc.) to obtain the input data for the catchment or study area polygon. Check that the workspace is set to the correct folder. It must be the same as the default geodatabase.

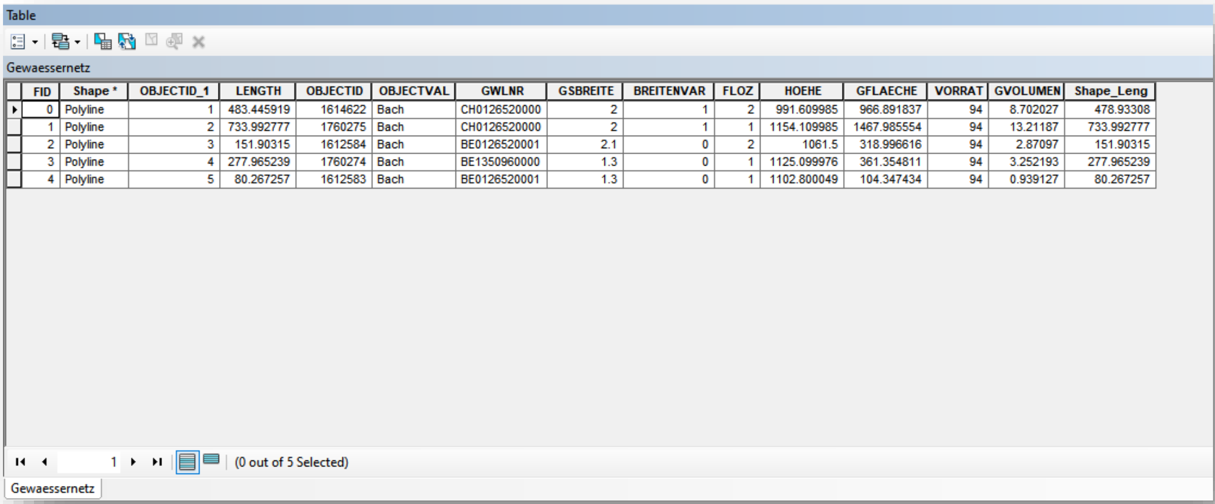
The clipping includes also the SilvaProtect trajectory lines, so this step is only required when using this dataset. If not the clip tool available in the Spatial Analysis could be used.



Use always full path (avoid %Workspace, as sometimes does not find the right workspace) or select the layers in the browser. Do this in all steps (from 1 to 11).

2. *Processing input river network, gradient, sinuosity, bank erosion widths*

Before running this step, it is important to check the attribute table of the stream network feature class to verify that some of the fields exist and the names they have:



Table

Gewaessernetz

FID	Shape *	OBJECTID_1	LENGTH	OBJECTID	OBJECTVAL	GWLNR	GSBREITE	BREITENVAR	FLOZ	HOEHE	GFLAECHE	VORRAT	GVOLUMEN	Shape_Leng
0	Polyline	1	483.445919	1614622	Bach	CH0126520000	2	1	2	991.609985	966.891837	94	8.702027	478.93308
1	Polyline	2	733.992777	1760275	Bach	CH0126520000	2	1	1	1154.109985	1467.985554	94	13.21187	733.992777
2	Polyline	3	151.90315	1612584	Bach	BE0126520001	2.1	0	2	1061.5	318.996616	94	2.87097	151.90315
3	Polyline	4	277.965239	1760274	Bach	BE1350960000	1.3	0	1	1125.099976	361.354811	94	3.252193	277.965239
4	Polyline	5	80.267257	1612583	Bach	BE0126520001	1.3	0	1	1102.800049	104.347434	94	0.939127	80.267257

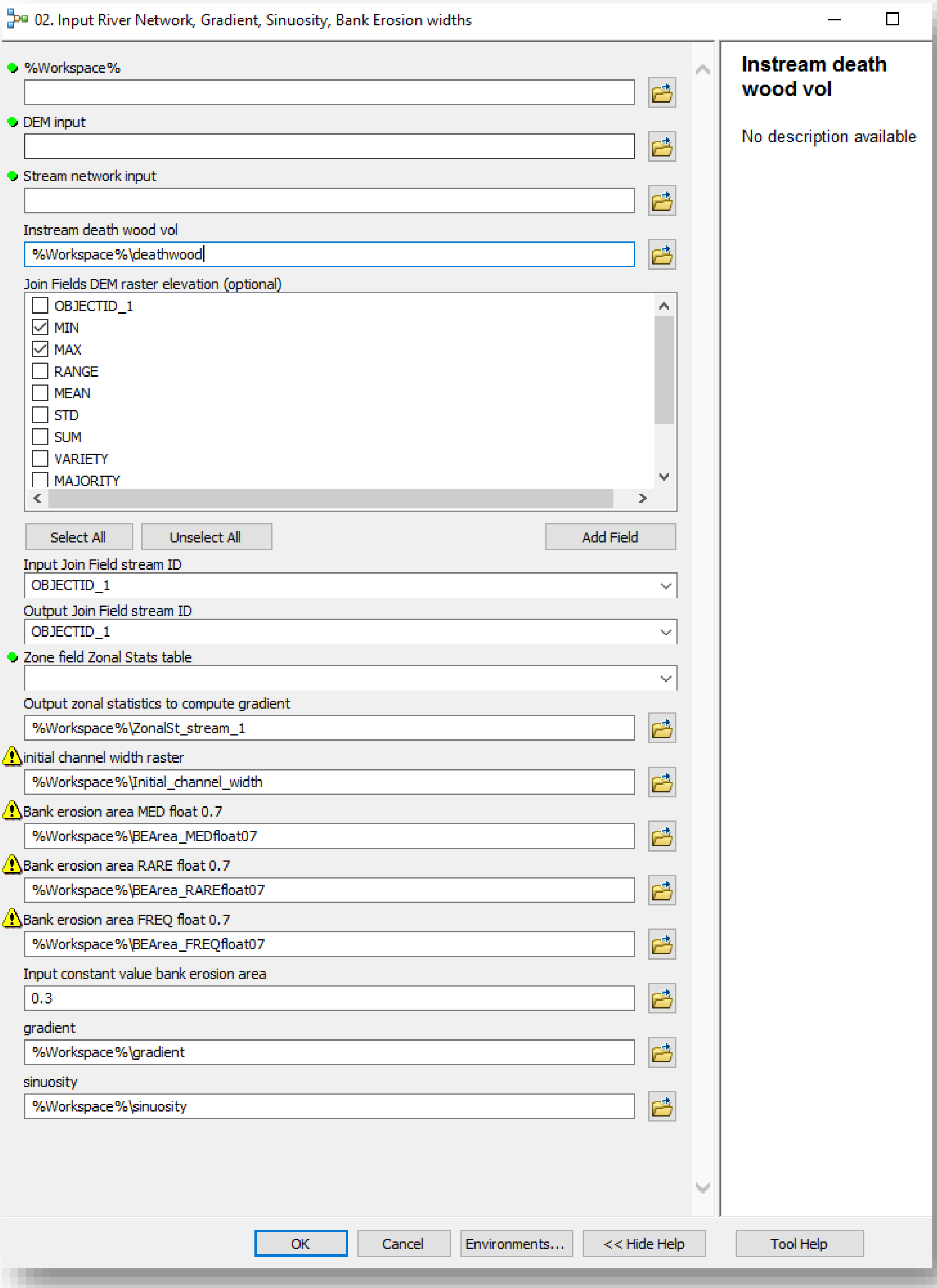
1 (0 out of 5 Selected)

Gewaessernetz

In this step the input stream network is edited to add the variables used for bank erosion (sinuosity and gradient) and the final wood volume calculation (death wood). The river reach gradient is calculated based on the maximum and minimum elevation values provided by the DEM and the longitudinal distance (length) between them by using the Zonal Statistics (Expression: [Max] - [Min]) / [Shape_Length]); the sinuosity is computed using the python tool; the final erodible width is computed based on width ratios as explained above; and the death wood stored in the stream is assigned (field wood_load) according to the stream order which is given by the FLOZ field.

A constant value here in the example equal to 0.7 is used to reduce the final wood volume calculations, assuming that out of the entire erodible area only 70% of it is actually affected by erosion and thus contributes with wood (this is homogeneously reduced from the computed area, and not spatially explicitly distributed). This value can be changed according to the knowledge of the study site.

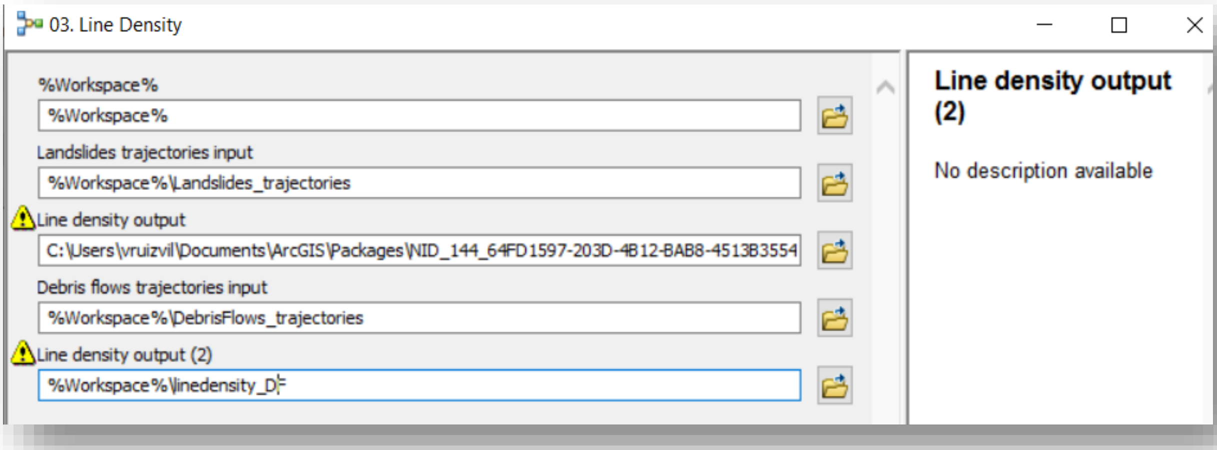
check and correct if needed the join fields raster elevation (e.g., MAX, MIN) and the raster calculator expression to be sure all fields match and exist


02. Input River Network, Gradient, Sinuosity, Bank Erosion widths
%Workspace%
DEM input
Stream network input
Instream death wood vol
%Workspace%\deathwood
Join Fields DEM raster elevation (optional)
OBJECTID_1
MIN
MAX
RANGE
MEAN
STD
SUM
VARIETY
MAJORITY
Select All
Unselect All
Add Field
Input Join Field stream ID
OBJECTID_1
Output Join Field stream ID
OBJECTID_1
Zone field Zonal Stats table
Output zonal statistics to compute gradient
%Workspace%\ZonalSt_stream_1
initial channel width raster
%Workspace%\Initial_channel_width
Bank erosion area MED float 0.7
%Workspace%\BEArea_MEDfloat07
Bank erosion area RARE float 0.7
%Workspace%\BEArea_RAREfloat07
Bank erosion area FREQ float 0.7
%Workspace%\BEArea_FREQfloat07
Input constant value bank erosion area
0.3
gradient
%Workspace%\gradient
sinuosity
%Workspace%\sinuosity
OK
Cancel
Environments...
<< Hide Help
Tool Help
Instream death wood vol
No description available

3. *Line Density*

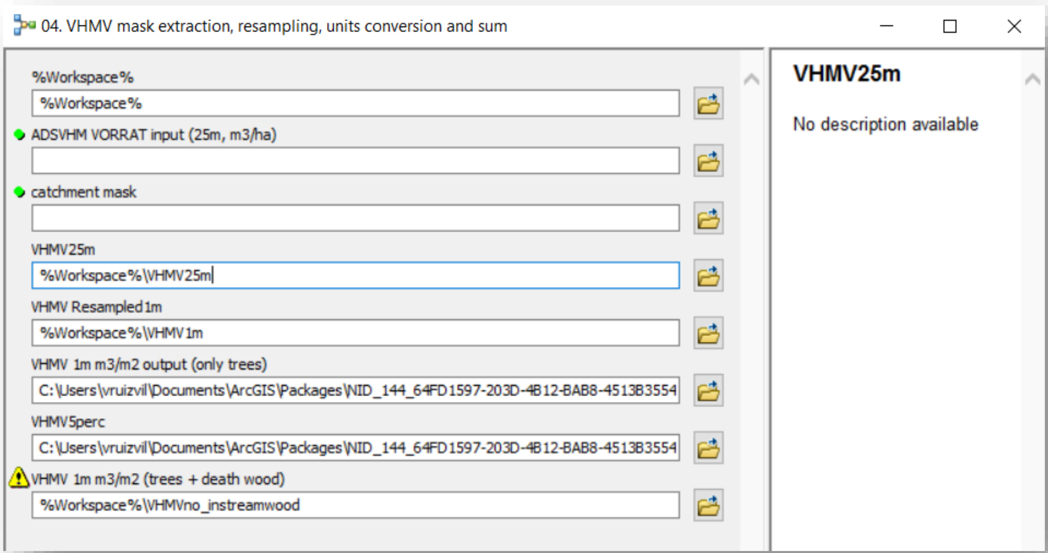
This step computes de line density based on the *Landslides* (LS) and *debris flows* (DF) trajectories to define the three scenarios as explained above.

Line density default parameters: pixel size 2m; Radius= 25m. These values can be changed editing the step in the model builder editor.



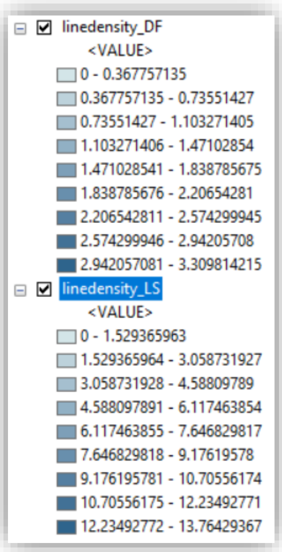
4. *VHMV mask extraction, resampling, units conversion and sum*

In this step the vegetation density is resampled, and the units are converted and forest and wood volumes are sum.

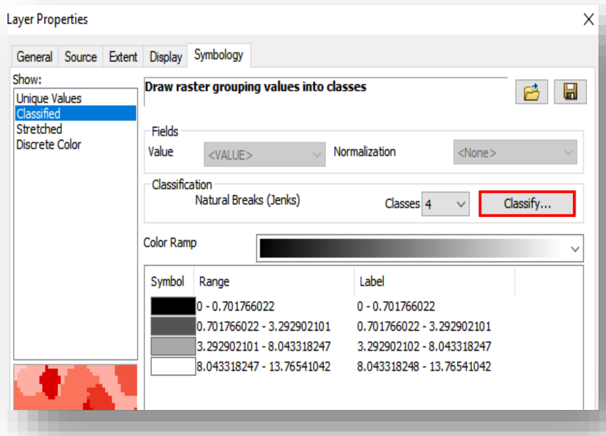


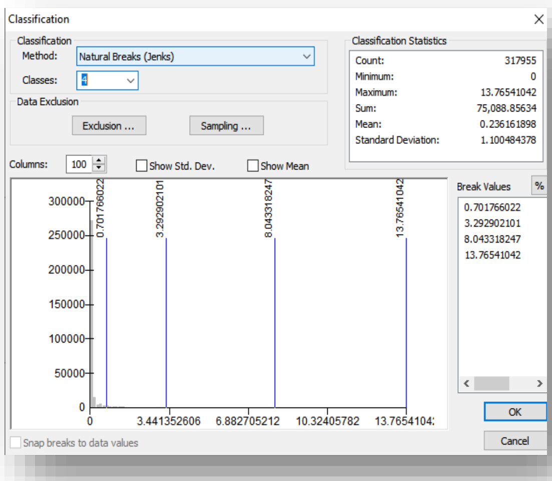
5. Fuzzy landslides scenarios from SilvaProtect trajectories

Once the raster files of line density are obtained, the values to define the scenarios are given by the natural breaks of the raster classification as shown in the figures:

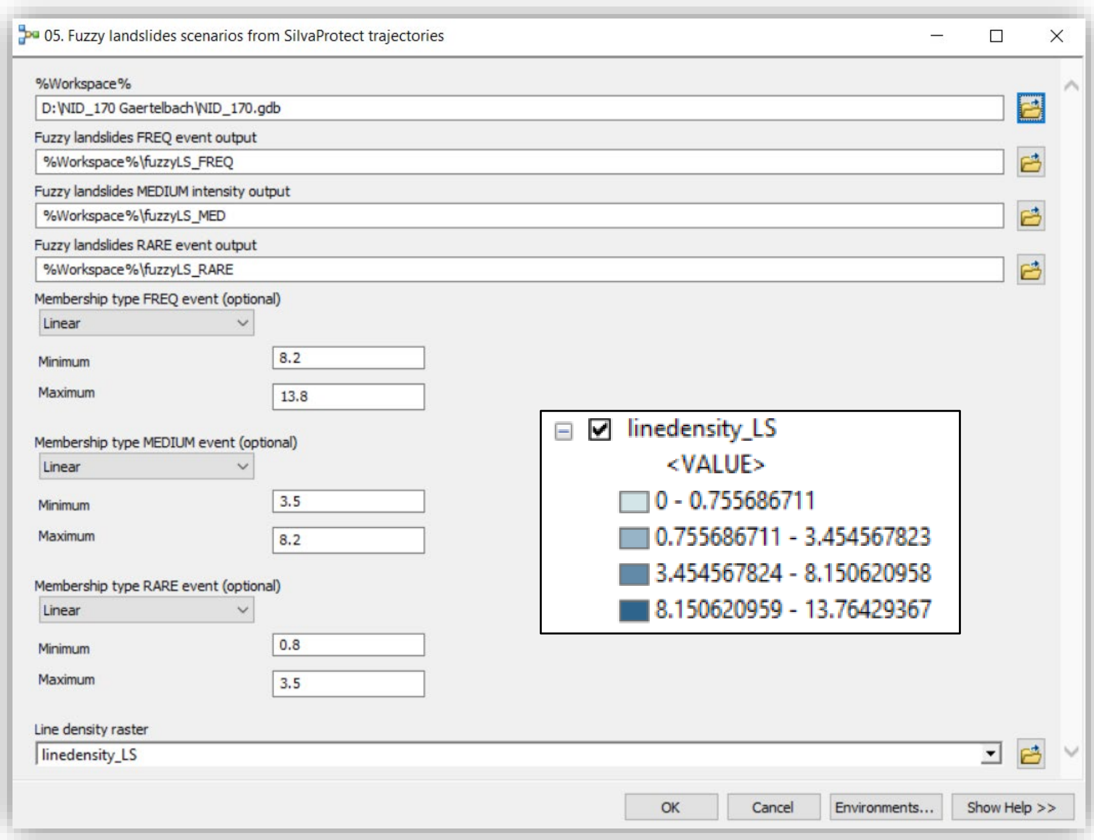


Right click on Linedensity_LS > Properties > Symbology > Classify > Classification Method > Natural Breaks (Jenks) and 4 classes. **The same procedure is needed for the debris flows trajectories.**



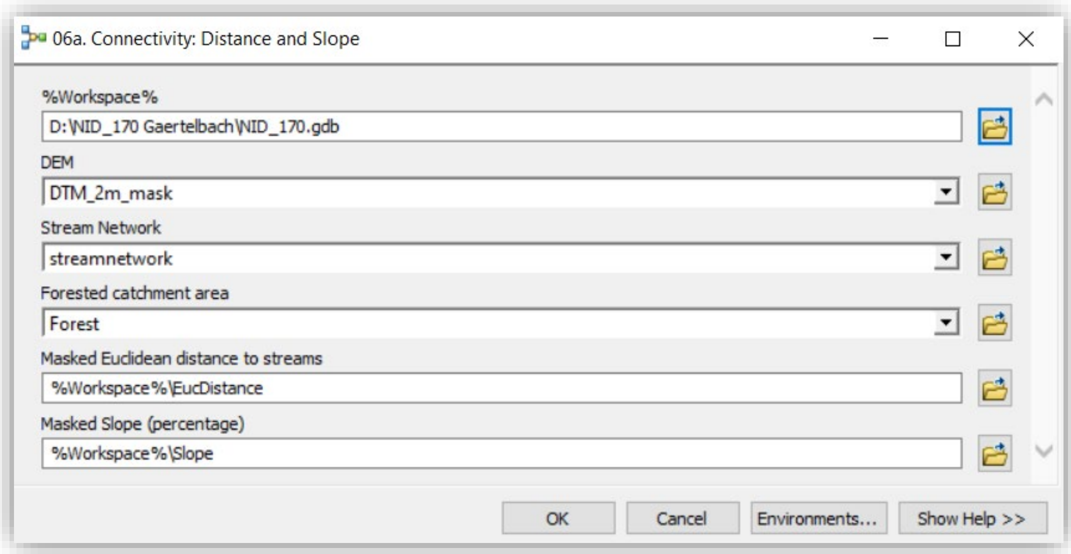


Using the natural breaks values, the fuzzy scenarios for landslides are defined by applying a linear fuzzy membership as shown in the image:



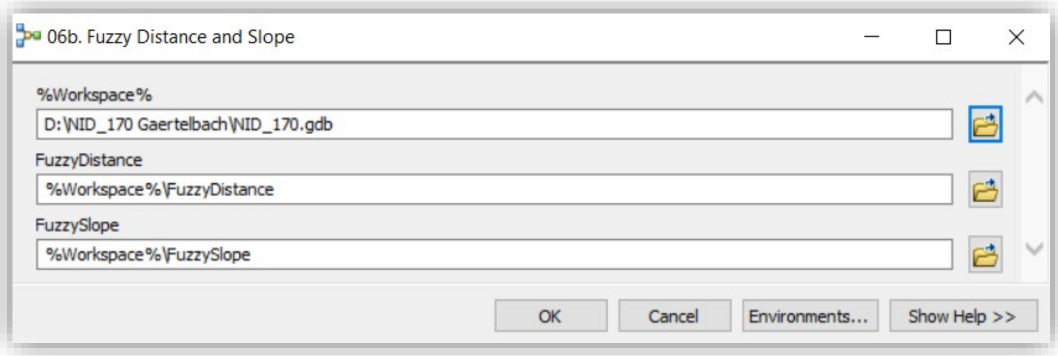
6a. Connectivity: distance and slope

Here the distance and slope between the landslides and debris flows trajectories and the stream network are calculated:



6b. Fuzzy distance and slope

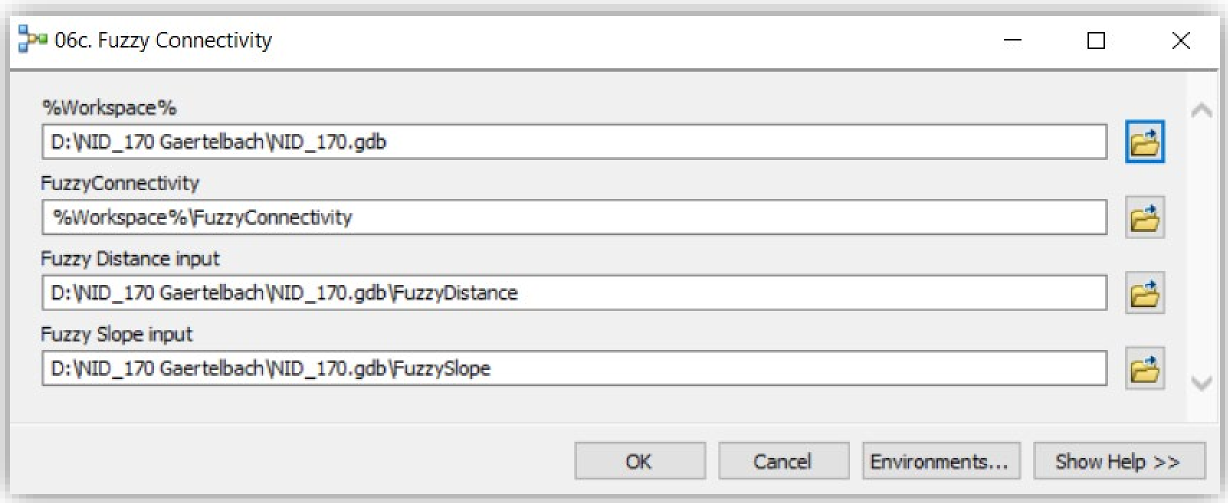
This step use the Fuzzy Membership tool (or editing the model builder tool), with Fuzzy Membership



By default the values are: Lineal: For Distance: min =100, max=50; and for Slope (%): min=90, max=40. They can be changed editing the model builder tool.

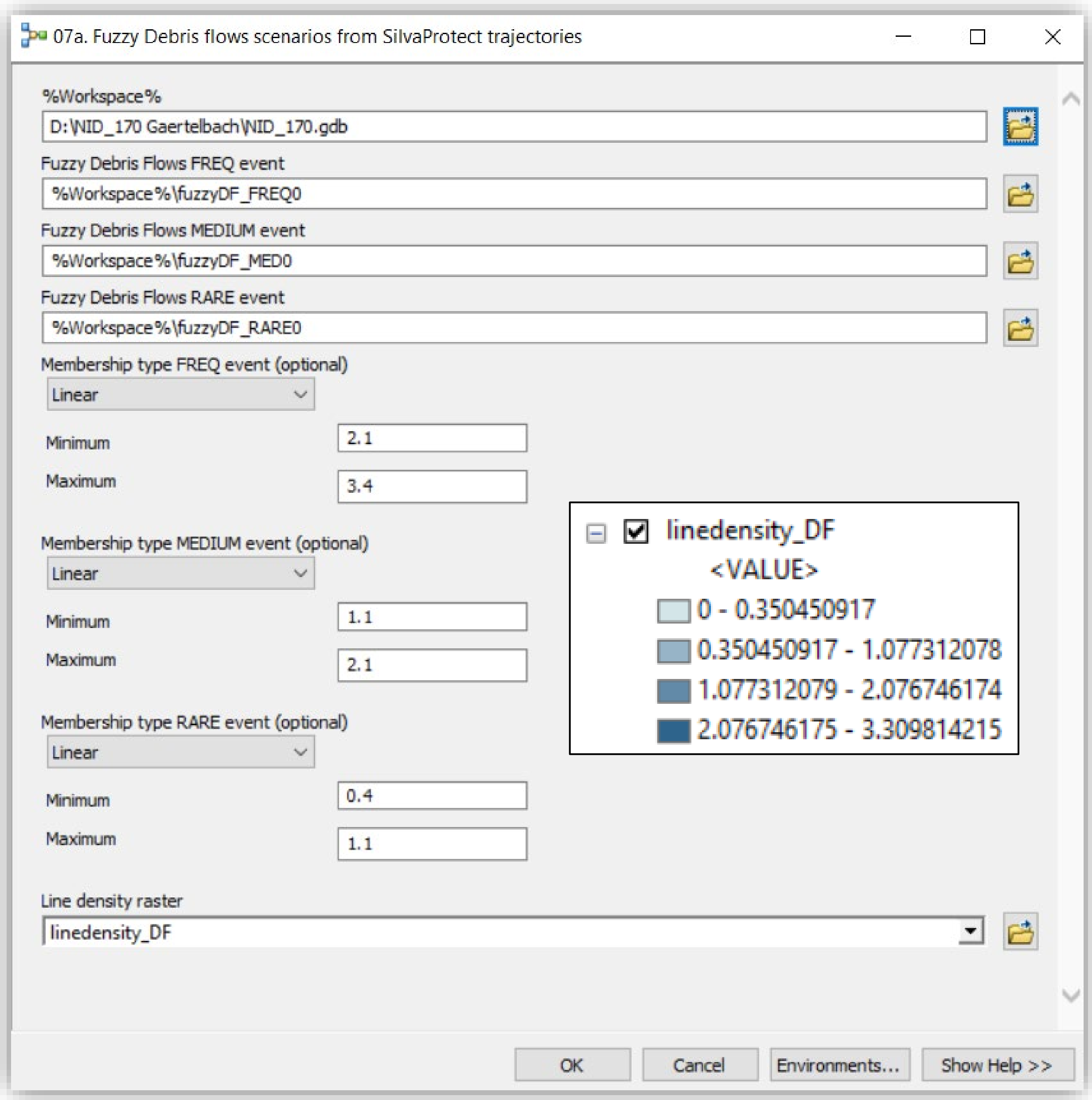
6c. Fuzzy connectivity

This step computes the Fuzzy overlay to calculate the fuzzy connectivity:

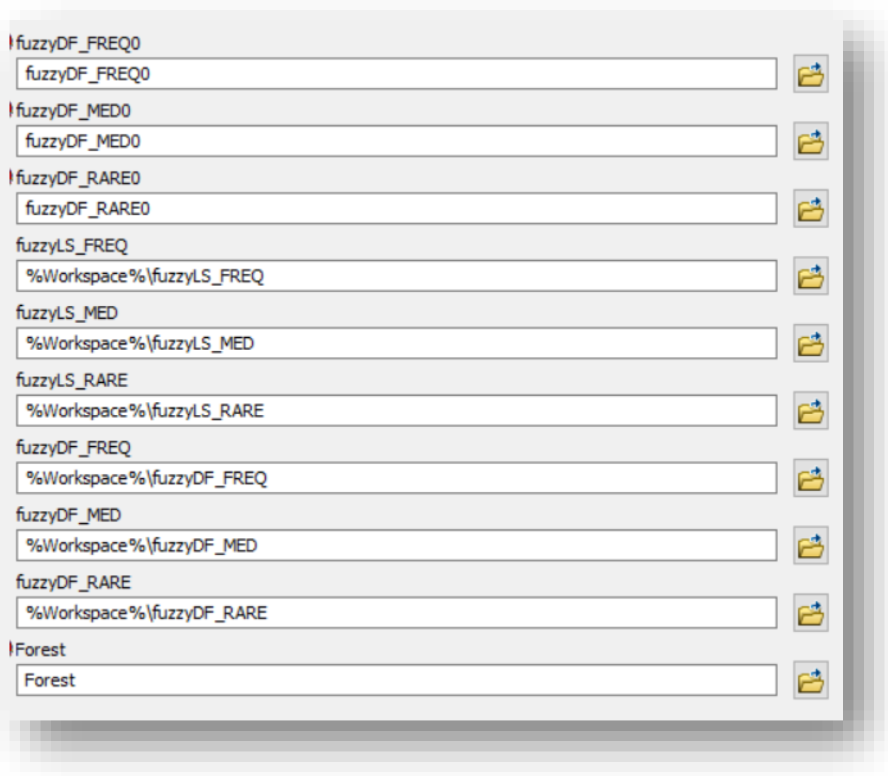


7a. Fuzzy Debris flows scenarios from SilvaProtect trajectories

As done for landslides, here use the 4 natural breaks of the line density file.

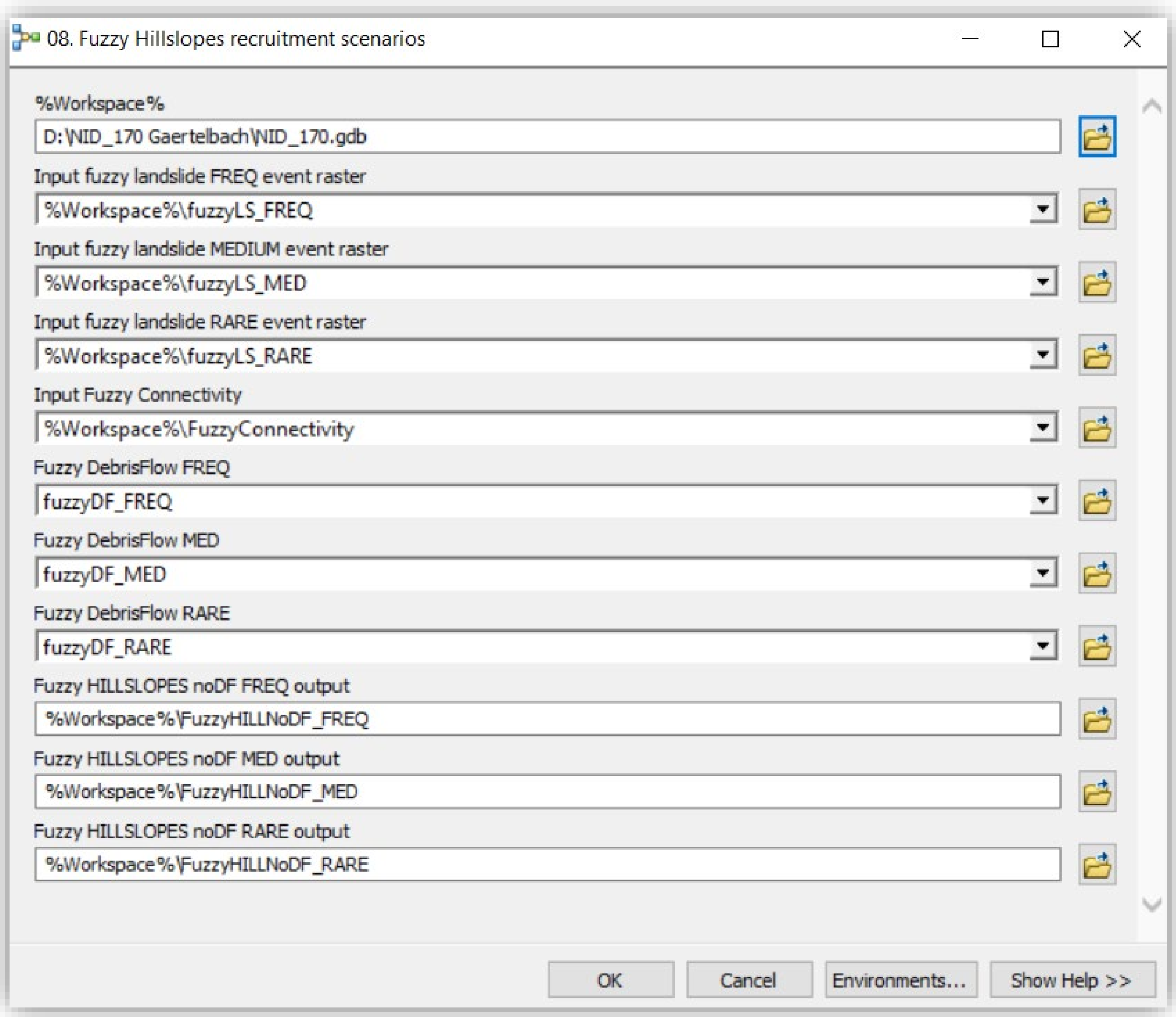


7b. Extent Fuzzy debris flows (DF) to landslide (LS) raster

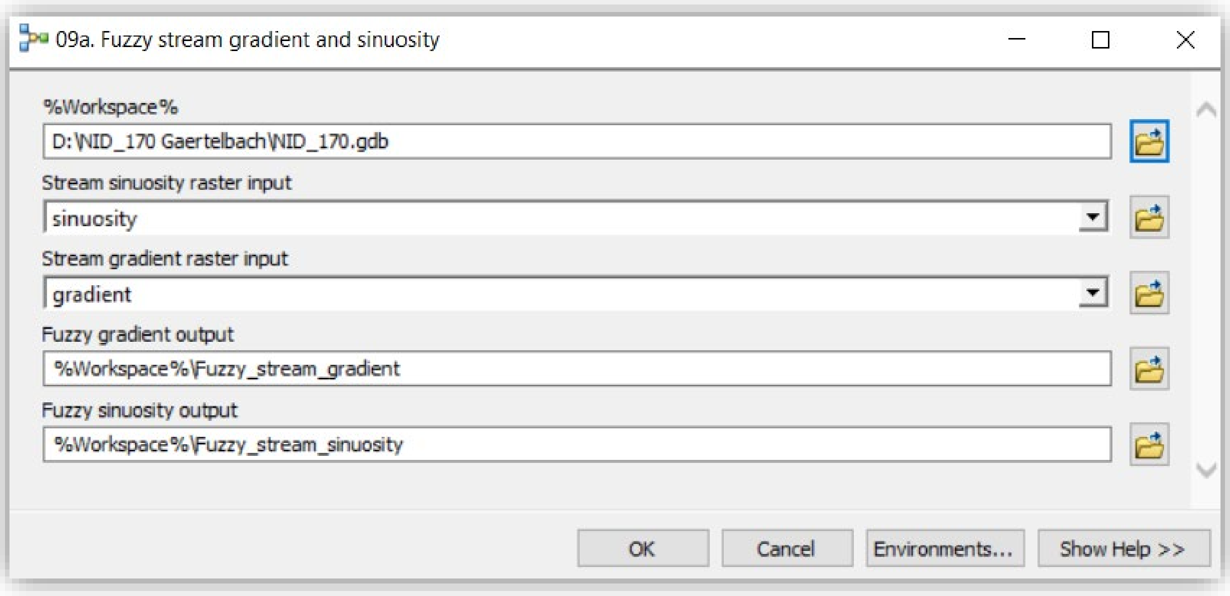


Remember: Use always full path (avoid %Workspace, as sometimes does not find the right workspace) or select the layers in the browser. Do this in all steps (from 1 to 11).

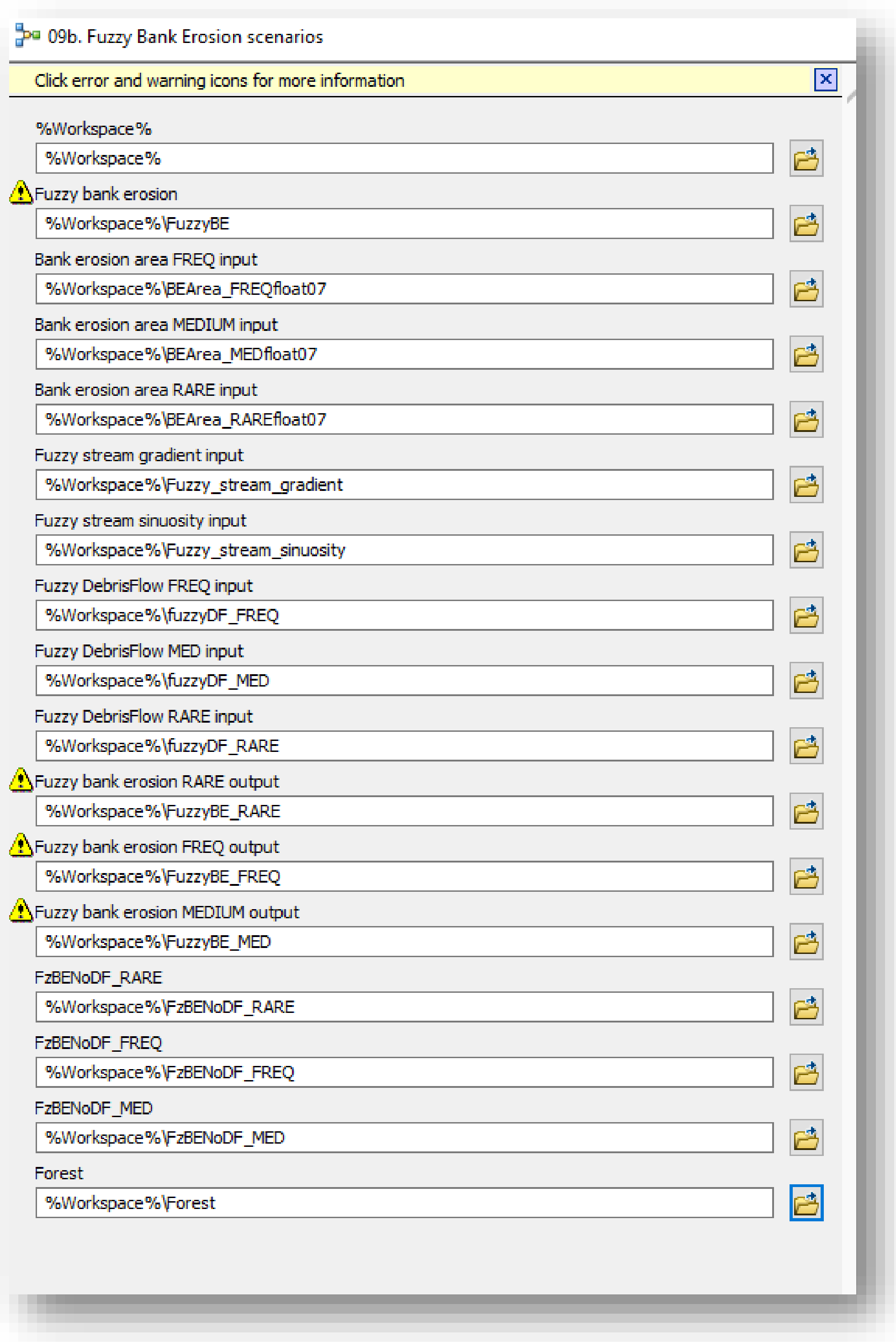
8. Fuzzy Hillslopes recruitment scenario (i.e., landslides connected to the stream network)



9a. Fuzzy stream gradient and sinuosity



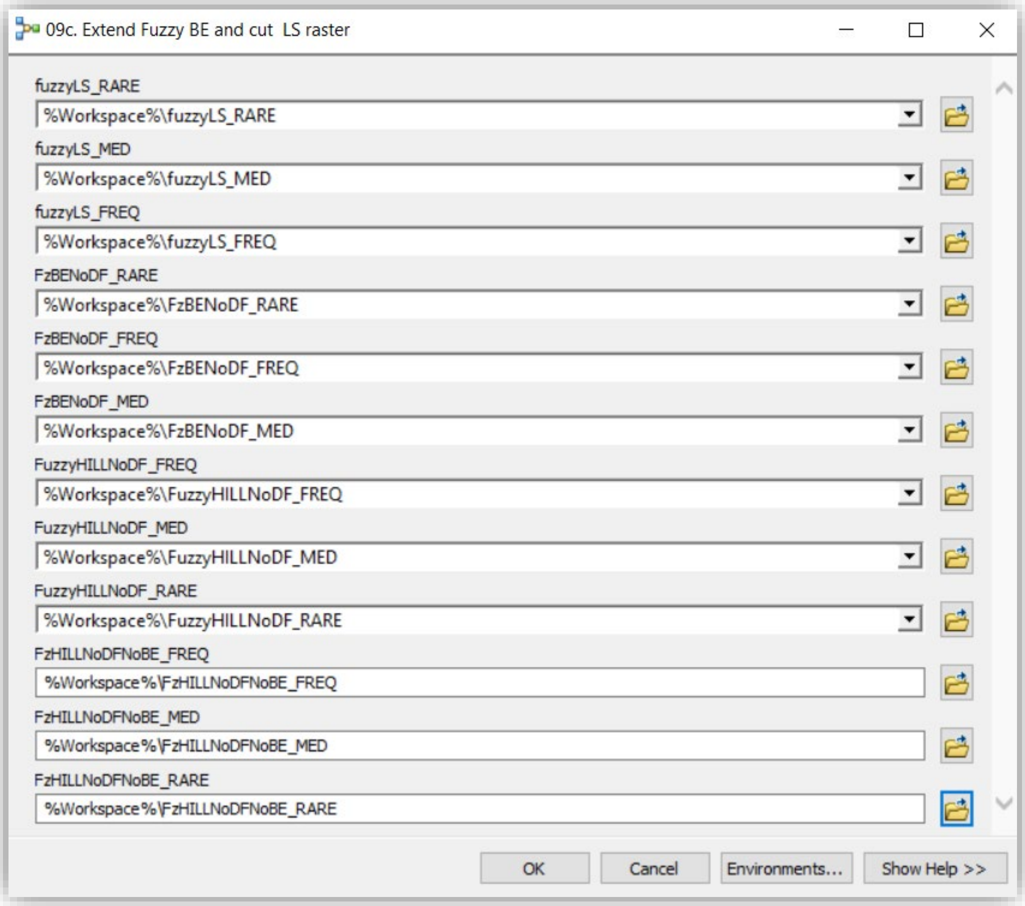
9b. Fuzzy Bank Erosion scenarios



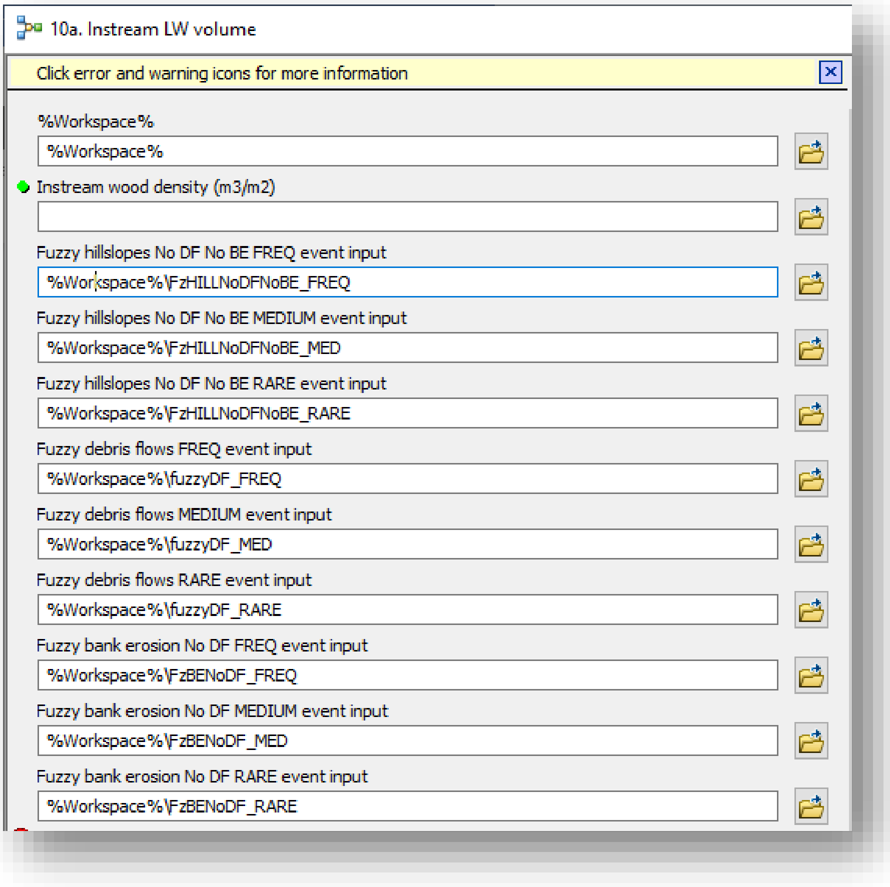
When filling this window with the input layers sometimes an error sign appear, ignore and continue filling all layers. If the error persists, then check the path and location of all input layers.

9c. Extent Fuzzy BE and cut LS raster

This step removes overlapped landslides areas

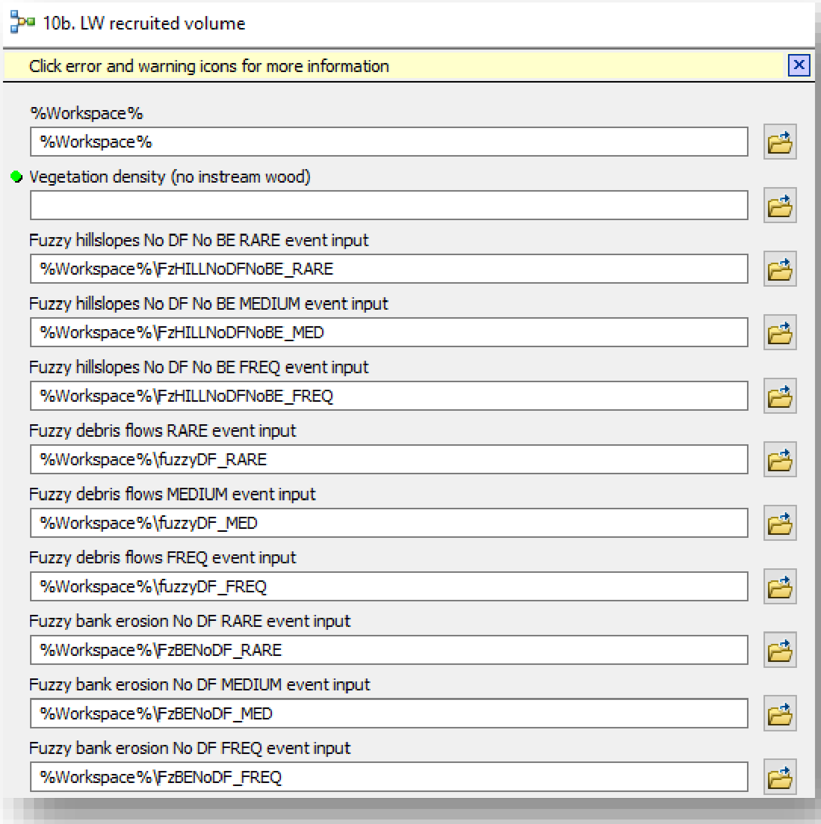


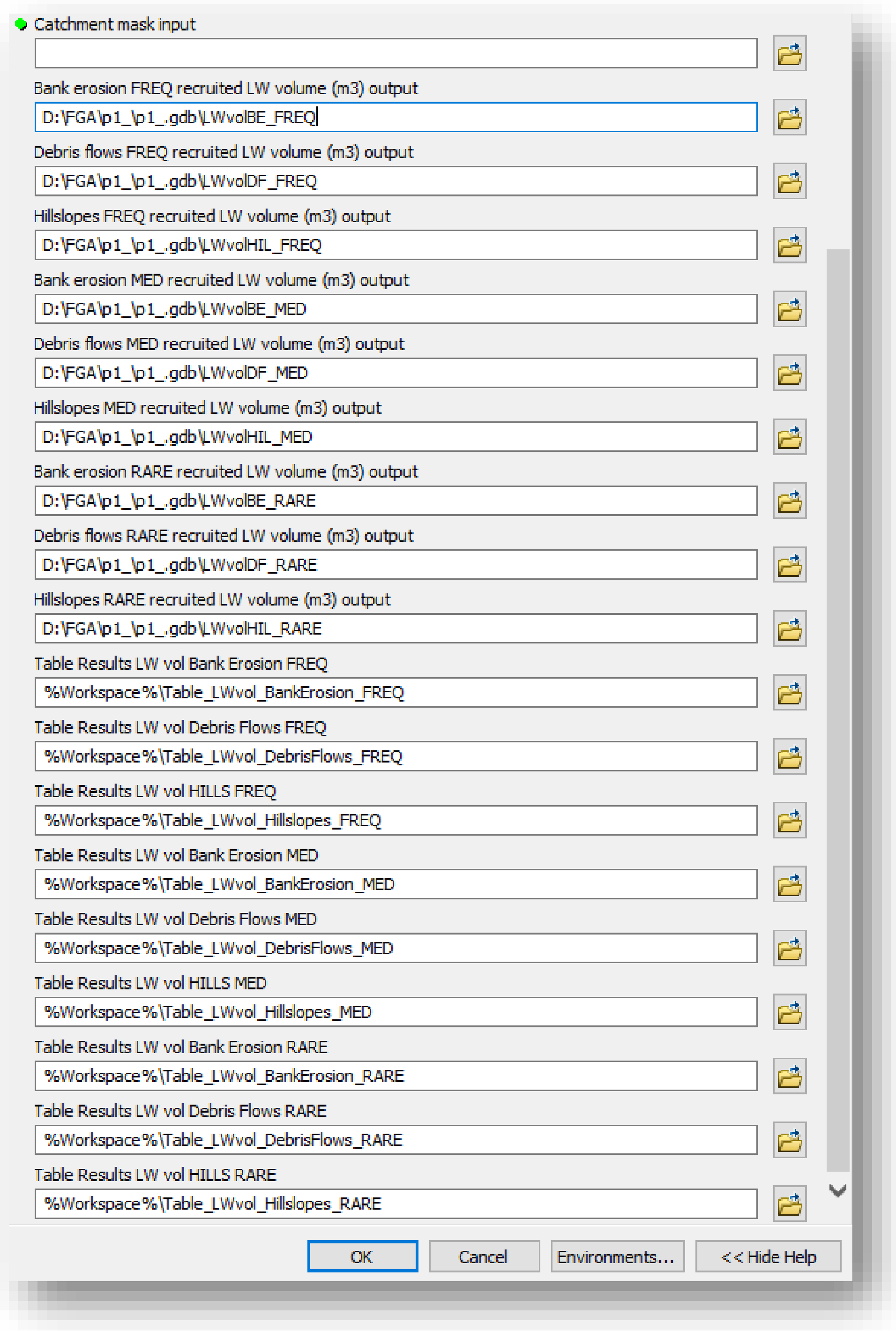
10a. Instream LW volume



Remember: Use always full path (avoid %Workspace, as sometimes does not find the right workspace) or select the layers in the browser. Do this in all steps (from 1 to 11).

10b. LW recruited volume




Catchment mask input
Bank erosion FREQ recruited LW volume (m3) output
D:\FGA\p1_\p1_.gdb\LWvolBE_FREQ
Debris flows FREQ recruited LW volume (m3) output
D:\FGA\p1_\p1_.gdb\LWvolDF_FREQ
Hillslopes FREQ recruited LW volume (m3) output
D:\FGA\p1_\p1_.gdb\LWvolHIL_FREQ
Bank erosion MED recruited LW volume (m3) output
D:\FGA\p1_\p1_.gdb\LWvolBE_MED
Debris flows MED recruited LW volume (m3) output
D:\FGA\p1_\p1_.gdb\LWvolDF_MED
Hillslopes MED recruited LW volume (m3) output
D:\FGA\p1_\p1_.gdb\LWvolHIL_MED
Bank erosion RARE recruited LW volume (m3) output
D:\FGA\p1_\p1_.gdb\LWvolBE_RARE
Debris flows RARE recruited LW volume (m3) output
D:\FGA\p1_\p1_.gdb\LWvolDF_RARE
Hillslopes RARE recruited LW volume (m3) output
D:\FGA\p1_\p1_.gdb\LWvolHIL_RARE
Table Results LW vol Bank Erosion FREQ
%Workspace%\Table_LWvol_BankErosion_FREQ
Table Results LW vol Debris Flows FREQ
%Workspace%\Table_LWvol_DebrisFlows_FREQ
Table Results LW vol HILLS FREQ
%Workspace%\Table_LWvol_Hillslopes_FREQ
Table Results LW vol Bank Erosion MED
%Workspace%\Table_LWvol_BankErosion_MED
Table Results LW vol Debris Flows MED
%Workspace%\Table_LWvol_DebrisFlows_MED
Table Results LW vol HILLS MED
%Workspace%\Table_LWvol_Hillslopes_MED
Table Results LW vol Bank Erosion RARE
%Workspace%\Table_LWvol_BankErosion_RARE
Table Results LW vol Debris Flows RARE
%Workspace%\Table_LWvol_DebrisFlows_RARE
Table Results LW vol HILLS RARE
%Workspace%\Table_LWvol_Hillslopes_RARE
OK
Cancel
Environments...
<< Hide Help

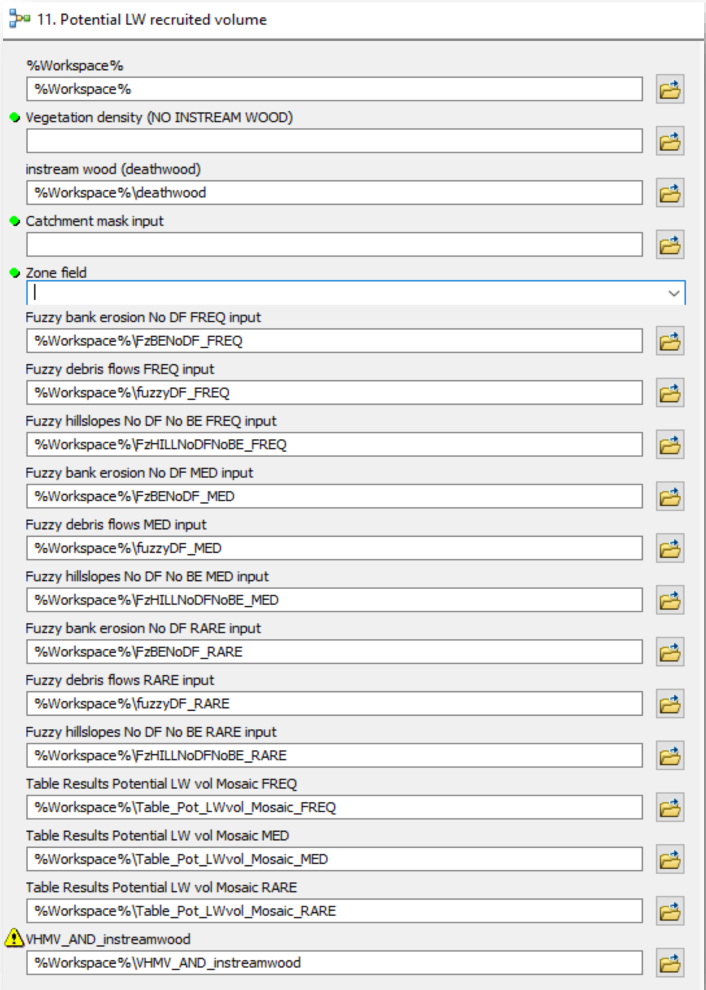
- Table_LWvol_3processes_RARE
- Table_LWvol_3processes_MED
- Table_LWvol_3processes_FREQ
- Table_LWvol_BankErosion_FREQ
- Table_LWvol_DebrisFlows_FREQ
- Table_LWvol_Hillslopes_FREQ
- Table_LWvol_BankErosion_RARE
- Table_LWvol_DebrisFlows_RARE
- Table_LWvol_Hillslopes_RARE
- Table_LWvol_BankErosion_MED
- Table_LWvol_DebrisFlows_MED
- Table_LWvol_Hillslopes_MED

Table_LWvol_DebrisFlows_FREQ

OBJECTID *	OBJECTID_1	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
1	1	221410	221410	0	0.041439	0.041439	0.000484	0.002947	107.106222

Results are provided in tables and in raster layers

11. Potential LW recruited volume



Results are provided in the following tables:

Table_Pot_LWvol_Mosaic_FREQ
Table_Pot_LWvol_Mosaic_MED
Table_Pot_LWvol_Mosaic_RARE

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