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Restoring Ecosystems and Landscapes

Green Development Fund for the SICA region

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region

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Green Development Fund methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration practices in the SICA region
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Content

Introduction

Forest landscape restoration (FLR) is the ongoing process of regaining ecological functionality and enhancing human well-being across deforested or degraded forest landscapes (IUCN, 2023). As an integrated approach which considers entire landscapes and their interacting land uses, diverse inhabitants and varying governance and tenure systems, it has great potential to address climate change and biodiversity loss at the same time while contributing to sustainable development. FLR includes practices like natural regeneration, sustainable agricultural practices and tree planting and aims to generate a range of ecosystem goods and services that benefit multiple stakeholder groups.

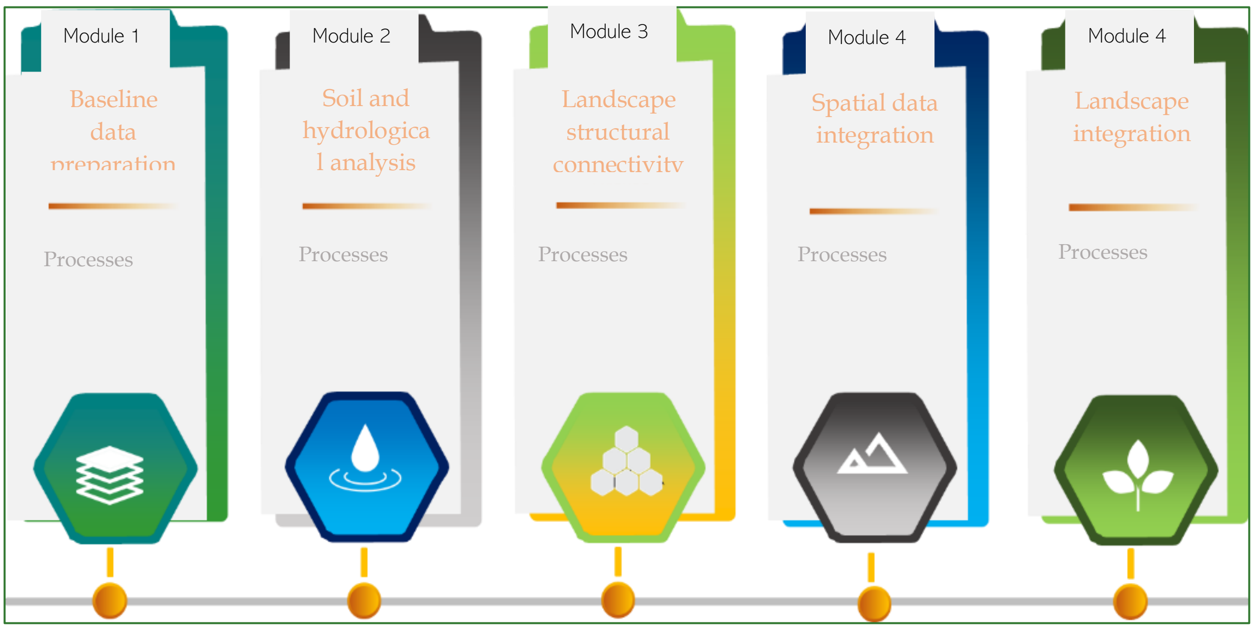
To strengthen FLR globally, Germany initiated the **Bonn Challenge** together with the International Union for Conservation of Nature (IUCN) in 2011. The Bonn Challenge is a global goal to bring 150 million hectares of degraded and deforested landscapes into restoration by 2020 and 350 million hectares by 2030. Commitments, actions and results of the Bonn Challenge have greatly contributed to putting the restoration of forests and other ecosystems at the heart of the global environmental discourse and start the **UN Decade on Ecosystem Restoration (2021-2030)** and the #GenerationRestoration movement.

To successfully implement forward-looking and dynamic FLR for resilient landscapes a reliable planning and monitoring system is indispensable. This includes creating baselines, building a transparent decision system and selecting appropriate indicators for measuring progress and impact.

The Green Development Fund (FDV) developed an approach to create baselines which reflect respective ecosystem condition and ecosystem services before the start of FLR interventions, as well as suitability indices for landscape restoration in the countries of the Central American Integration System (SICA region). To share this approach with the global restoration community the project produced the present "Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region". Although the methodology was applied in SICA it can be replicated in any other country or territory.

Summary of the manual

This document comprises a user manual to develop baselines for ecosystem services and suitability indices for landscape restoration practices. It was developed by the Green Development Fund (FDV) for the monitoring of the implementation of landscape restoration projects in the SICA region. Constructing the baseline and the suitability indices involves a series of steps and processes. They include generating inputs such as base maps, a topographical analysis, a water infiltration analysis, erosion analysis, forest carbon mapping, and calculation of biological connectivity. The results of these analyses can support implementers to identify the restoration practices suitable for the respective landscape.



The proposed methodology uses geoprocessing tools to create a series of digital maps of tree/forest cover, climate data, topographical variables and vegetation indices, among others. This basemap or core mapping data is used to create a series of models to characterise ecosystems and estimate ecosystem services at landscape level, such as water regulation, freshwater supply, erosion control, (forest) carbon sequestration and biological connectivity (as proxy for biodiversity). Combining these indices, the user can estimate an integrated ecosystem services baseline.

This manual offers step-by-step guidance to construct the ecosystem services baseline and the suitability indices for landscape restoration practices by applying different geospatial analyses. This baseline provides spatially explicit information for different types of political-administrative and landscape units that can support territorial planning processes and integrated decision-making for ecosystem restoration. This can improve ecosystem services and enhance the livelihood (sustainable production) of local communities in deforested or deteriorated ecosystems.

Detailed instructions and sources for the graphical and numerical information required for the analysis are provided to ensure successful implementation of the methodology.

Earth Observing Systems

One of the main goals of the Earth Observing System (EOS) is to study the role of land vegetation, soil and climate in medium and large-scale processes with the goal to understand how they interact in a system and change over time. This requires getting an insight into the distribution of vegetation types, as well as their biophysical and structural properties. Remote detection systems provide spatially continuous data that represent land vegetation and patterns within a range of spatial, spectral and time resolutions (Laidler et al., 2008). It has been shown that by applying remote detection data via geospatial analysis, it is possible to:

(i) Provide benchmark data to outline vegetation patterns (Muller et al., 1999).

(ii) Examine vegetation structure (e.g. estimating aboveground biomass) (Epstein et al., 2012).

(iii) Predict CO_2 flow patterns on a variety of spatial scales (Shaver et al., 2007).

Remote sensors and geospatial analyses support the development of biophysical baselines which indicate ecosystem services, such as freshwater supply, carbon sequestration, erosion control and habitat provisioning, among others. These baselines enable the characterization and monitoring of landscapes and ecosystems.

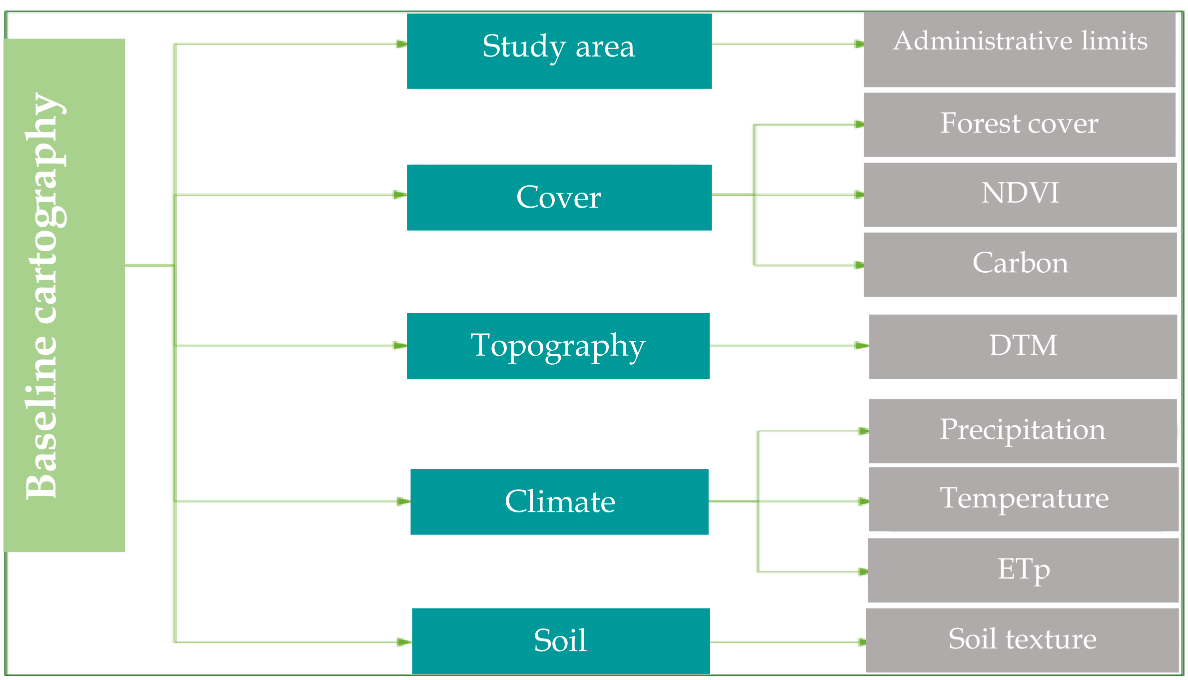
Baseline data preparation

Methodological guide to developing an ecosystem services baseline

Module 1: Baseline data preparation

The first step to develop ecosystem services baselines and landscape suitability indices is the creation of a Basemap (in the following referred to as “input”). To build the Basemap, a series of folders have to be created into which the data will be systematised in accordance with each of the corresponding modules. Each step will be done using ArcMap 10.5 software by ArcGis ESRI©.

Basemaps comprise a set of georeferenced information on the study area that includes administrative limits, tree cover, as well as topographical, climate and soil data.



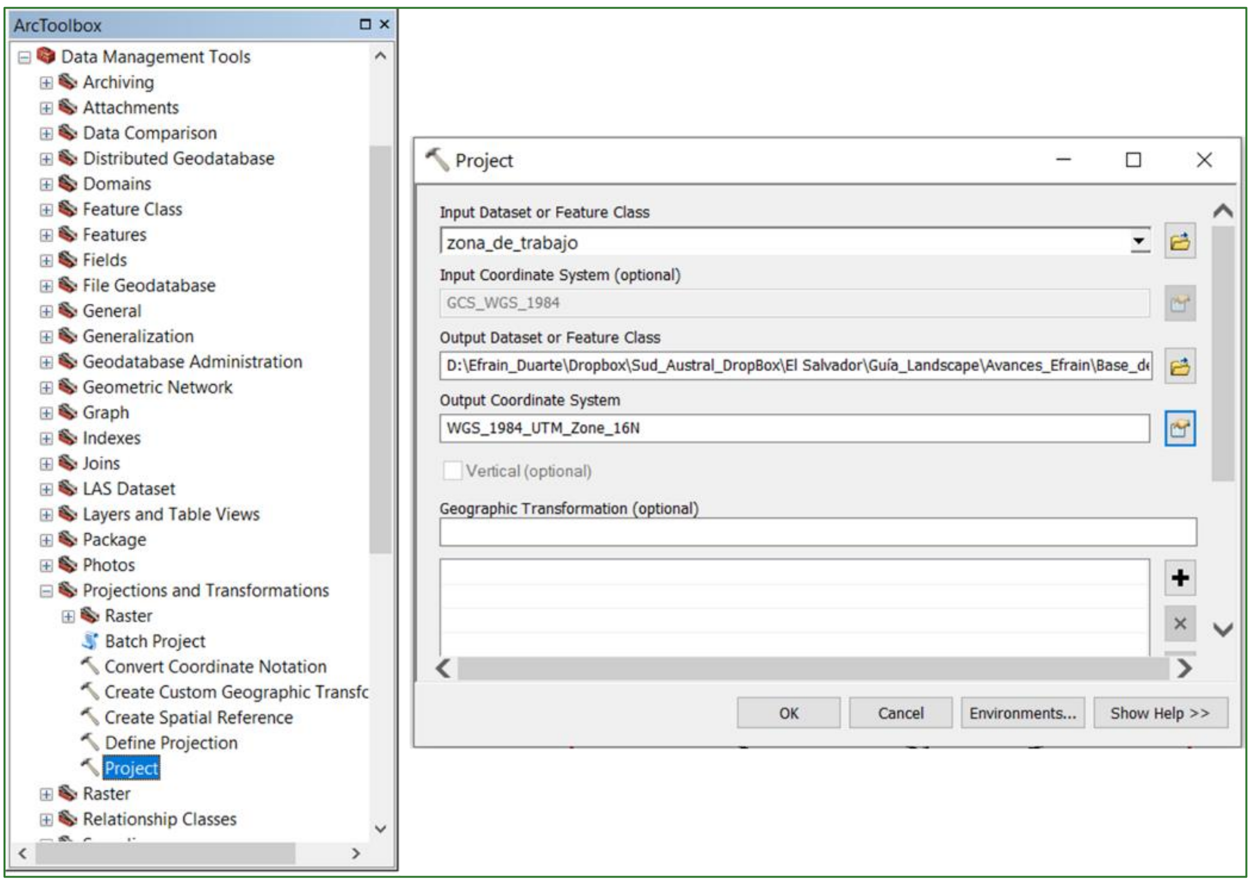
The diagrams in this methodological guide are available in an online GitHub repository by clicking on the following link (Spanish original): https://github.com/guialandscape/Diagramas

Part 1. Projecting the layers onto the country's geodesic system

One of the first steps required to work with geospatial analyses is to project all the mapping inputs onto the same coordinate system. Some of the data downloaded from different online repositories that contain worldwide data offer a series of layers on the geographical coordinate system expressed in longitude and latitude. Accordingly, it is recommended that the data be reprojected onto the specific system used for your country. Generally, this is the Universal Transverse Mercator (UTM), which means the coordinates are expressed in metres. Take the following steps to convert your data to the UTM system.

1. Add the study limit area or any geographical layer you want to convert. If it is in geographical coordinates, reproject it to UTM or the projection system used in your country. Save it in the VECTORES folder and call it **lim_zona_estudio_project.shp.**

   ✓ Data Management Tools/Projections and Transformations/Project

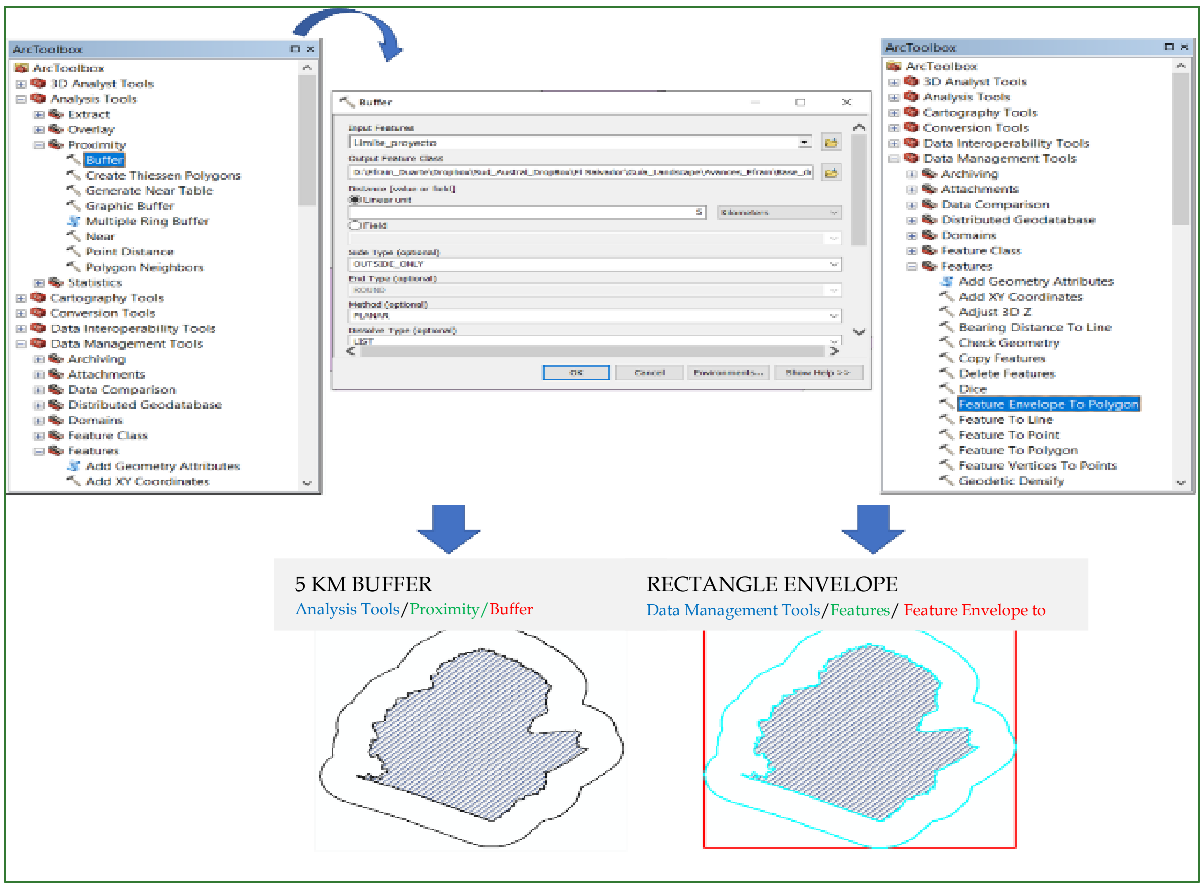


Part 2. Prepare the project area

The project area is the specific area of interest. In the example given in this user manual, the project area of the pilot project in El Salvador is used, which is located on the southern coast in the El Imposible – Barra de Santiago area. The processes to prepare the project area are described below.

2. Create a 5 km buffer area around the project area, then generate a rectangle around the buffer area created, name it **zona_de_trabajo.shp** and save it in a folder called **"VECTORES"**.

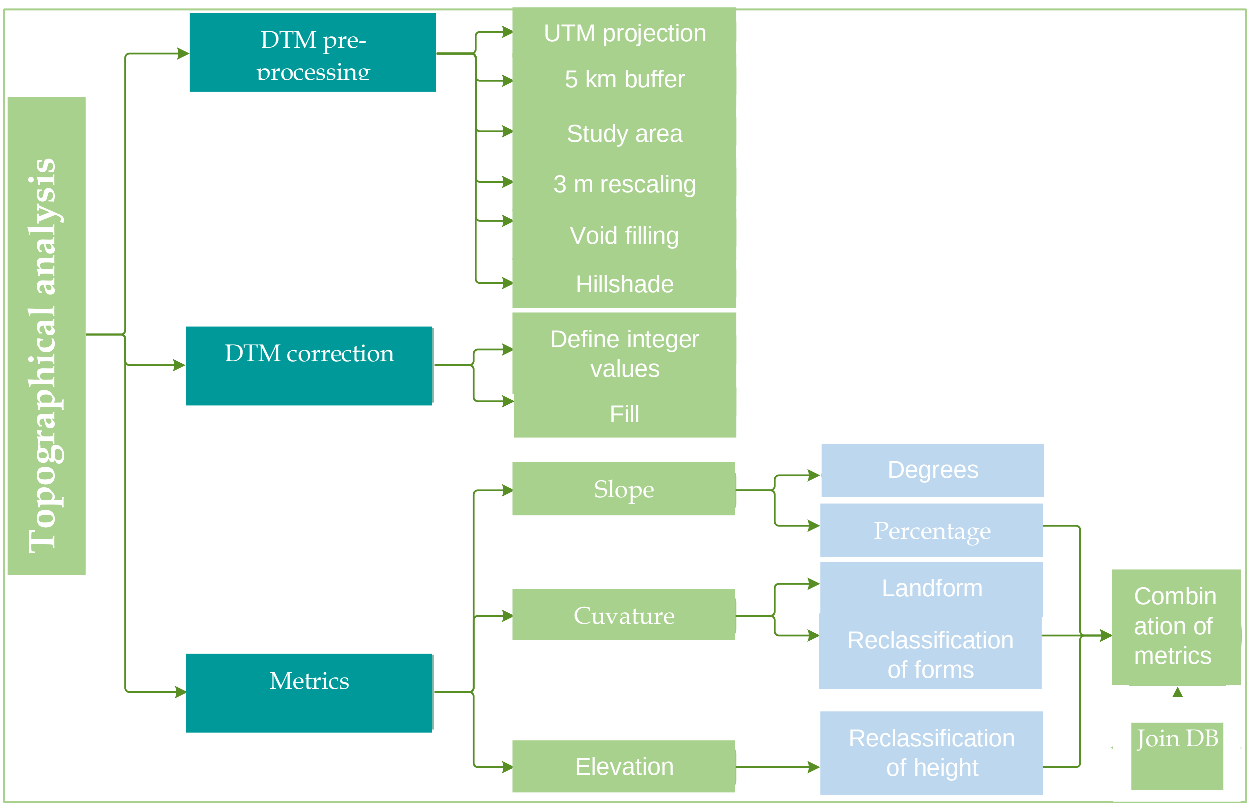
- ✓ ArcToolbox/Analysis Tools/Buffer
- ✓ ArcToolbox/Data Management Tool/Features/Feature Envelope To Polygon



Baseline data: Topography

Baseline data: Topography

In this section, you will analyse the topographical data as part of the baseline data preparation module. Analysing topographical data comprises the pre-processing of the Digital Terrain Model (DTM), and a respective DTM correction. A series of metrics that correspond to the slope, curvature and elevation of the land will be obtained. The data generated in this section will form the basis for the soil and hydrographical analysis later in this methodological guide.

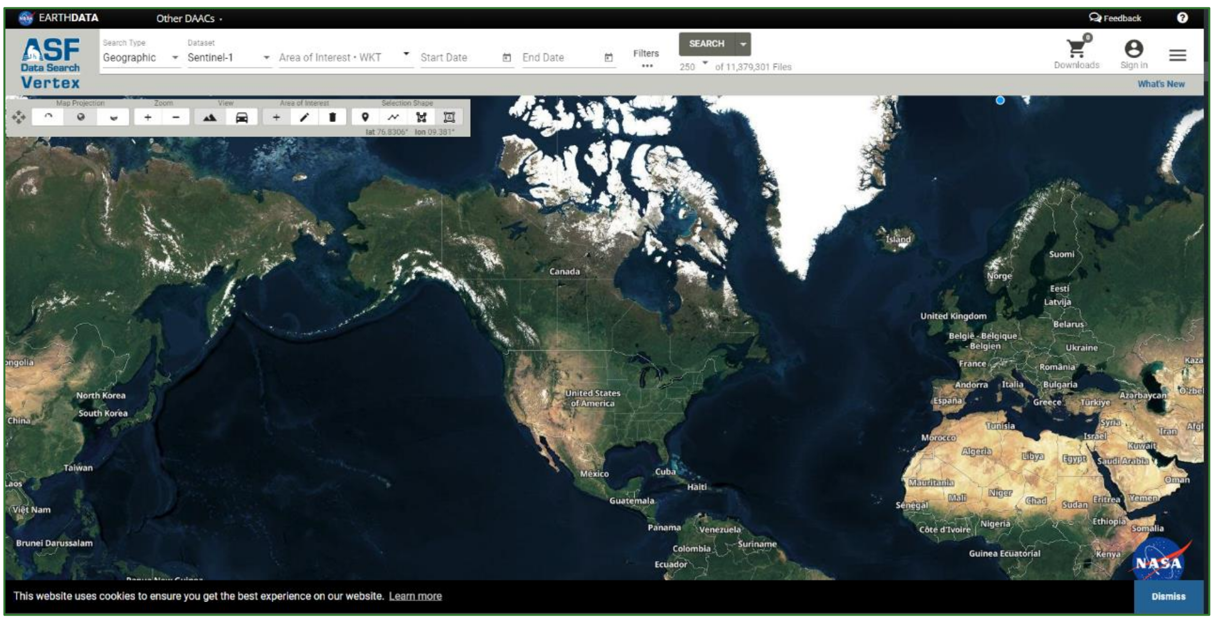


The diagrams in this methodological guide are available in an online GitHub repository by clicking on the following link (Spanish original): https://github.com/guialandscape/Diagramas

Part 3. Preparing the Digital Terrain Model (DTM)

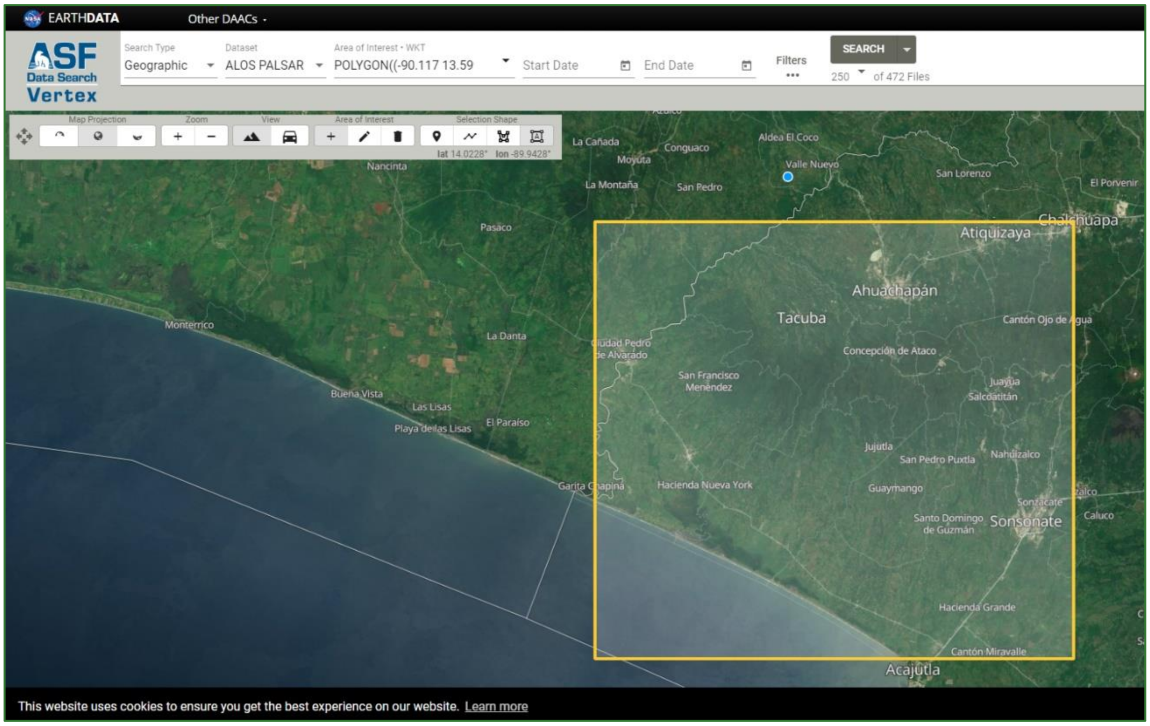
A Digital Terrain Model (DTM) is a numerical data structure that represents the spatial distribution of a quantitative and continuous variable. A DTM is a raster representation that generally refers to an area of land. Resolution (the distance between sample points) mainly determines the accuracy of these data.

1. Follow these steps to download the DTM: Go to the following site: https://search.asf.alaska.edu/#/
   The following window will open:

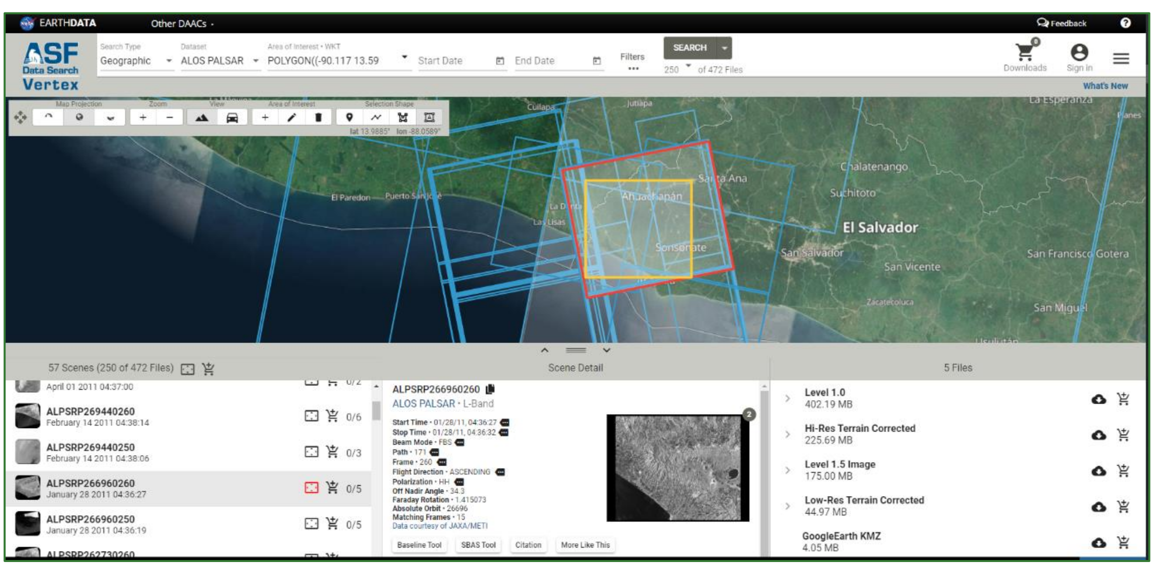


2. Next, select the dataset of interest. Select ALOS PALSAR for this example.

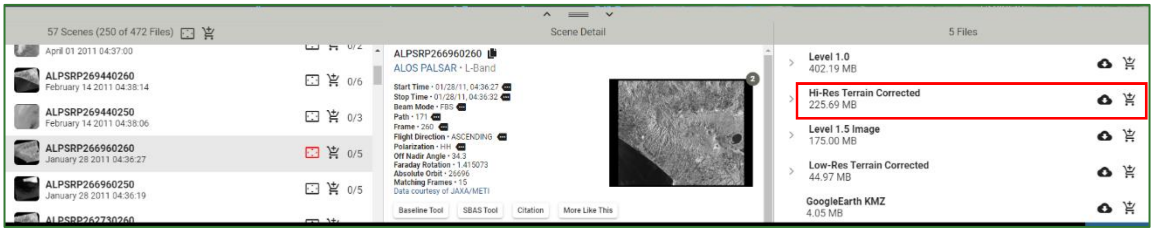
3. After selecting the dataset, you can import the project area or create a polygon using the tool described in the following image:



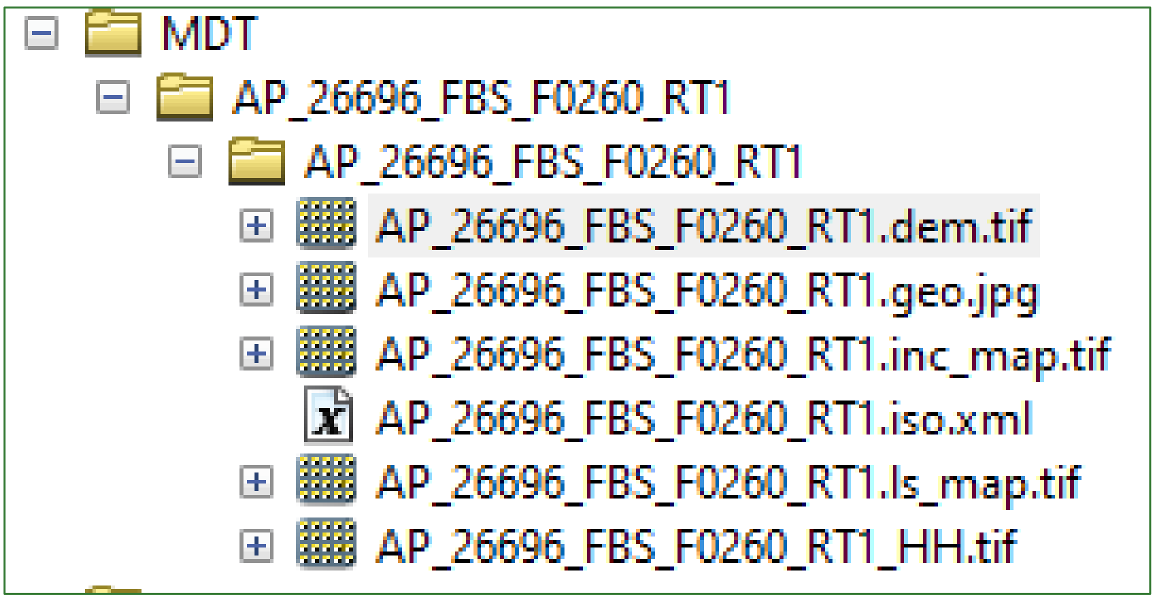
4. Next, click on the SEARCH tab and a group of images available for the study area will be displayed. In this process, try to select a quadrant that includes the whole study area.



5. Select the file called Hi-Res Terrain Corrected to download the DTM. This will be displayed on the right-hand side of the file window. Then click on the download cloud. A compressed file with the previously selected data will be downloaded into your folder. Bear in mind that you must have a user account to download files from the platform.

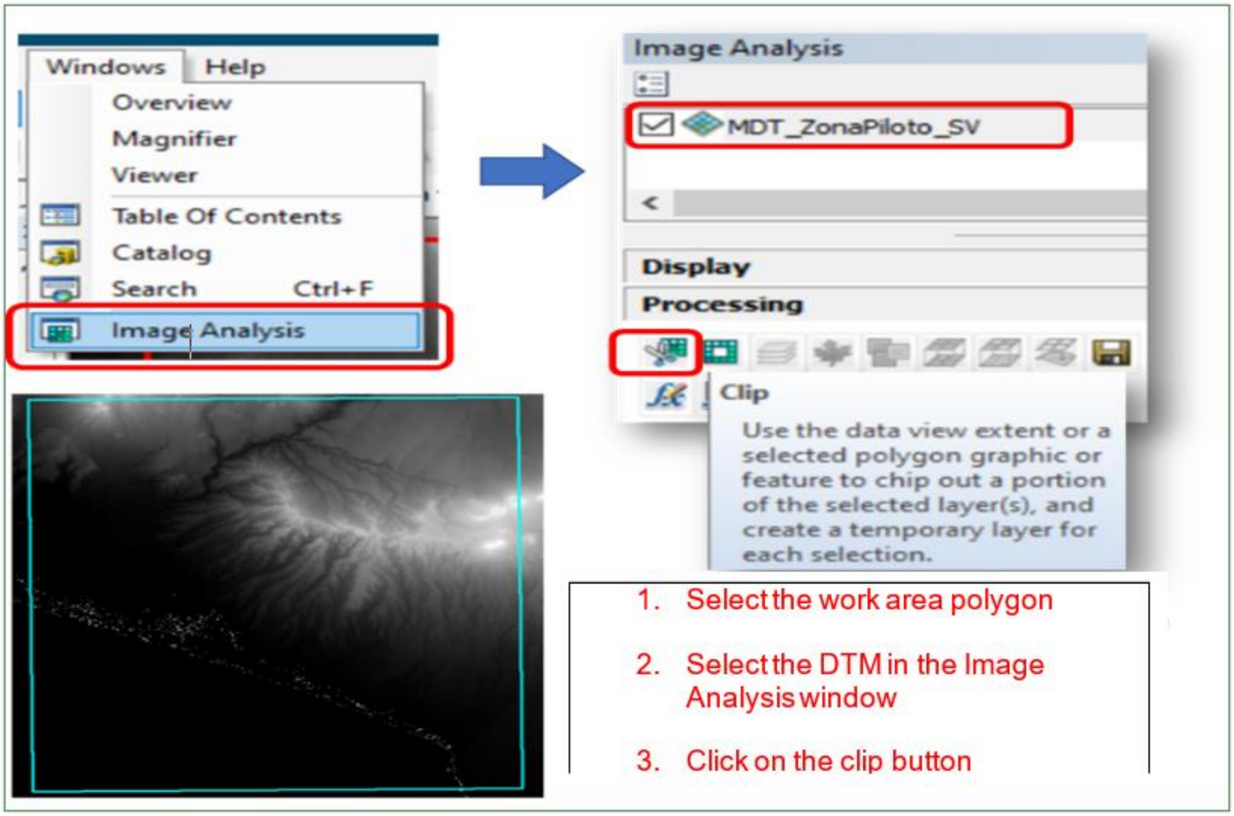


6. After downloading the files, extract them and select the first one called AP_26696_FBS_F0260_RT1.dem.tif.

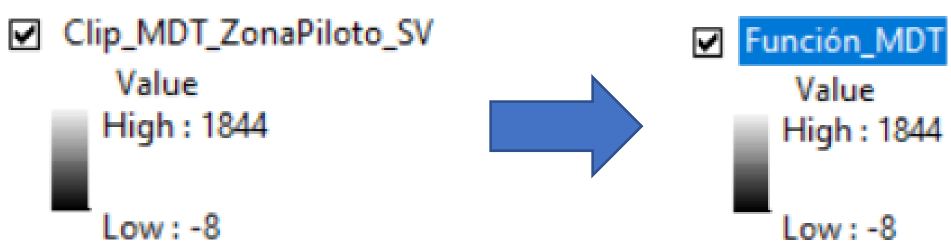


7. Save the DTM in a folder on your computer and name it **RASTER/GLOBAL_DATA\AlosPalsarDEM.**

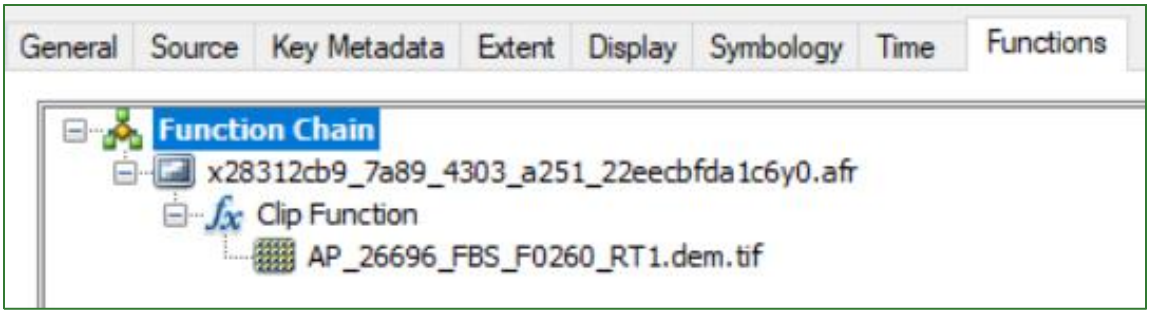
8. Add the MDT saved in the **ASTER/GLOBAL_DATA\AlosPalsarDEM** folder then use the CLIP tool in the Image Analysis window to cut out your work area.



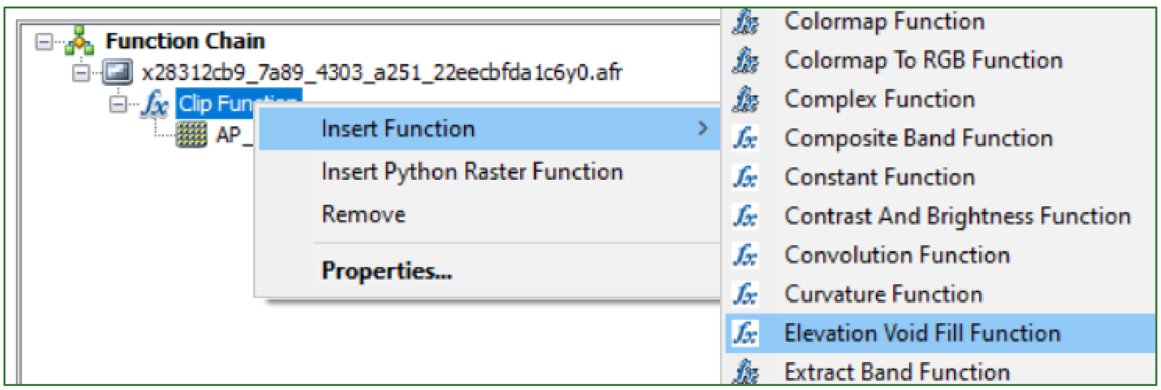
9. Rename the raster created in the previous step (Clip) as **Función_MDT.**

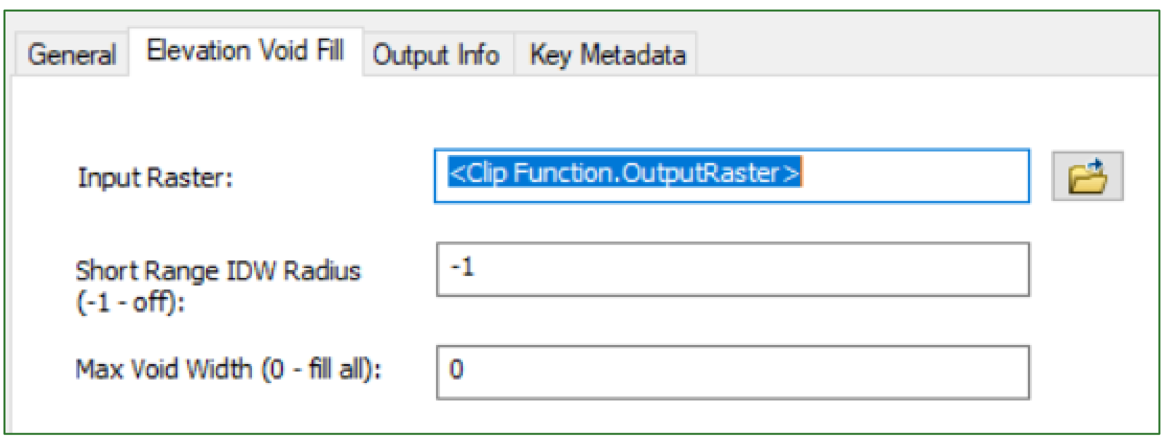


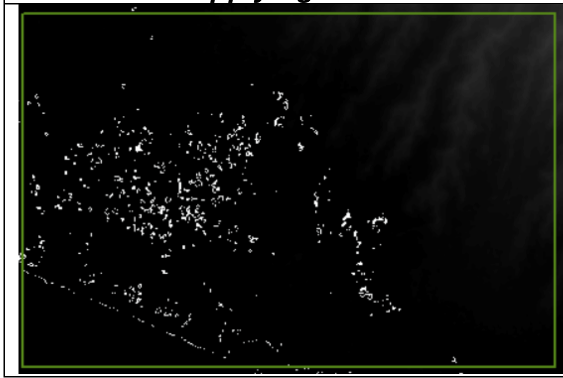
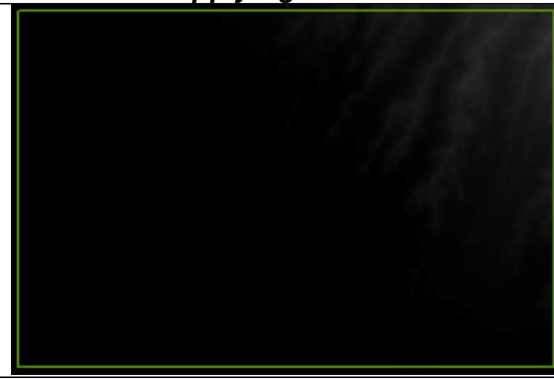
10. Go to the **Función_MDT** raster properties by double clicking on its name and then go to the **Functions** tab.



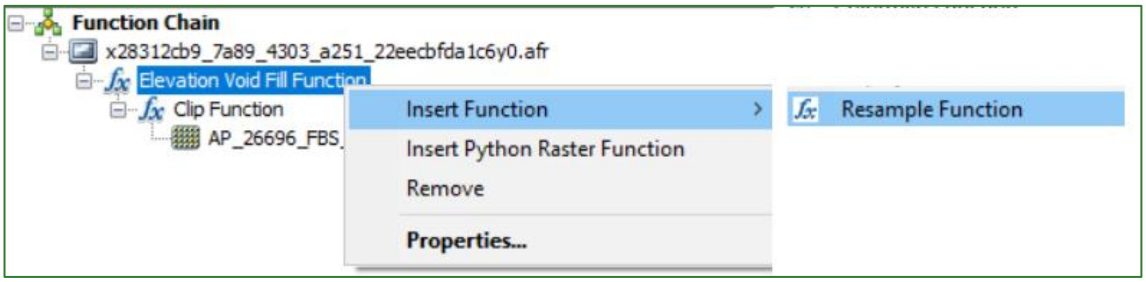
11. Right click on **Clip Function**, then on **Insert Function** and select **Elevation Void Fill Function**. This function will fill the empty DTM values (gaps) using an interpolation procedure.



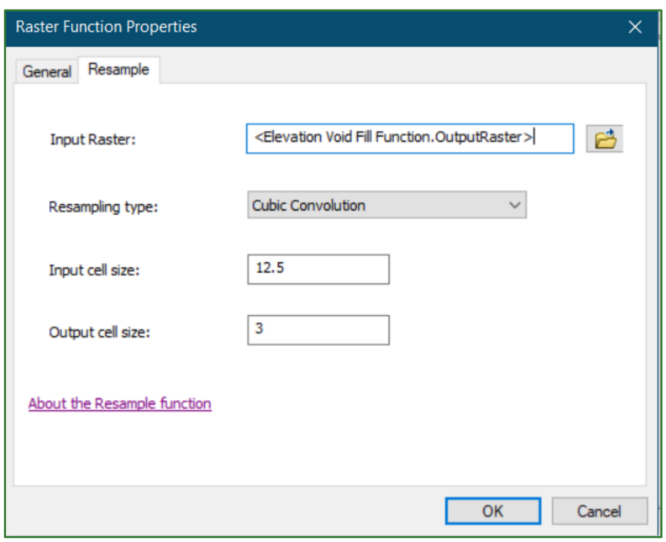


Before applying the function	***After applying the function***
	

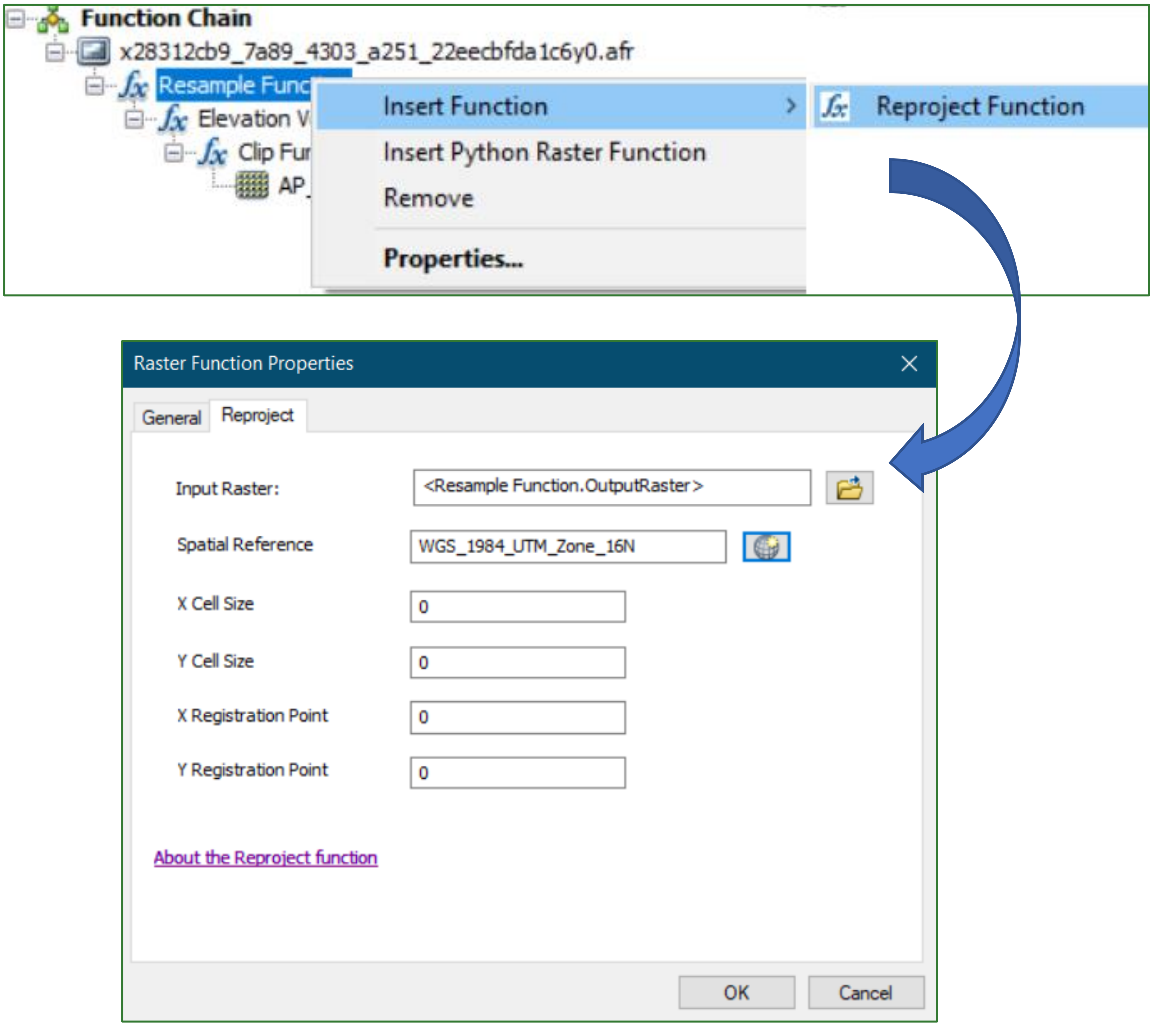
12. Right click on **Elevation Void Fill Function** and insert the **Resample Function**.



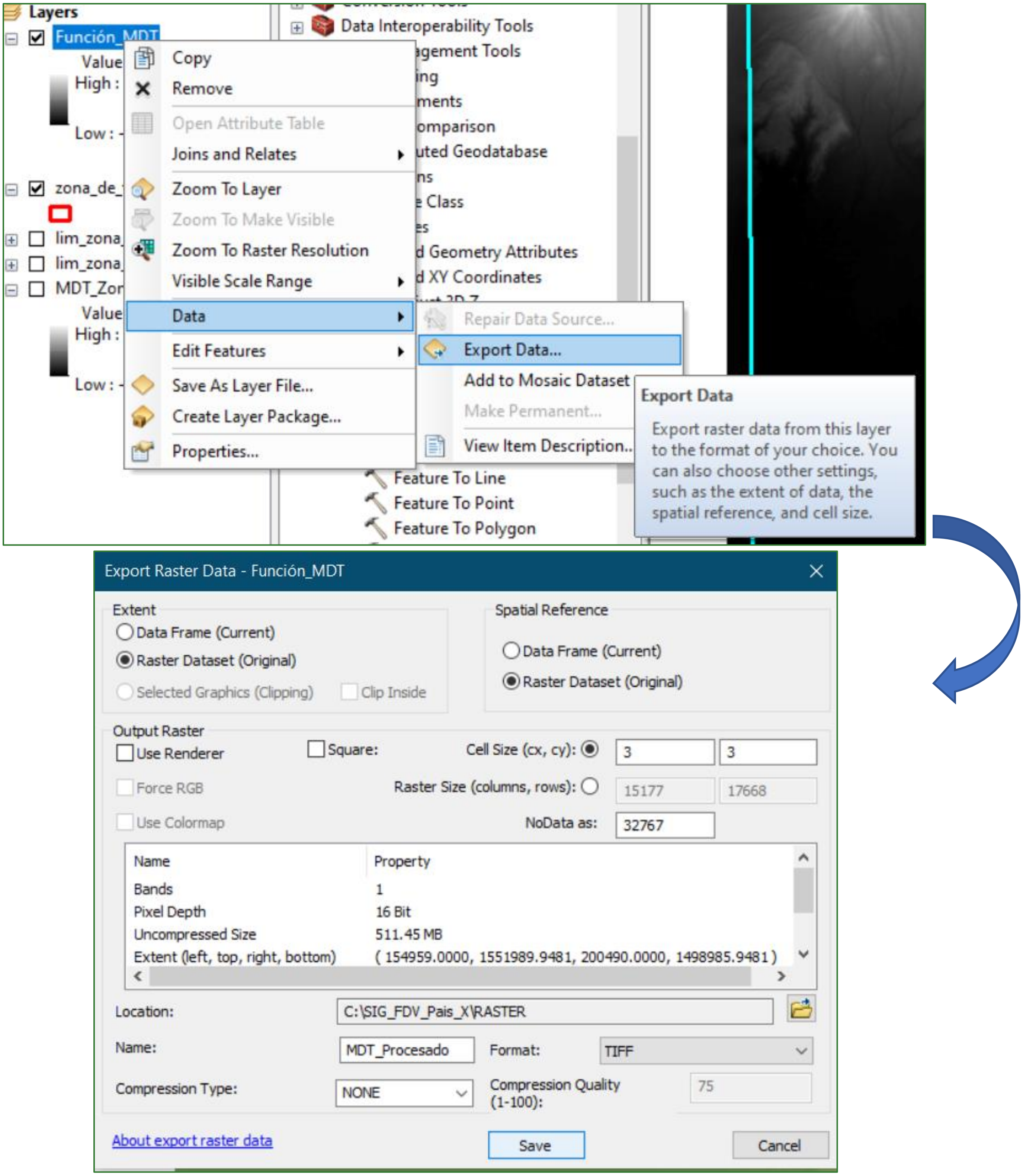
The Input cell size is the original DTM, which is **12.5 m** in this case. The Output cell size for this exercise will be the same as that of the satellite image used to generate the tree cover map (e.g. 3 m). Select **Cubic Convolution** as the interpolation method.



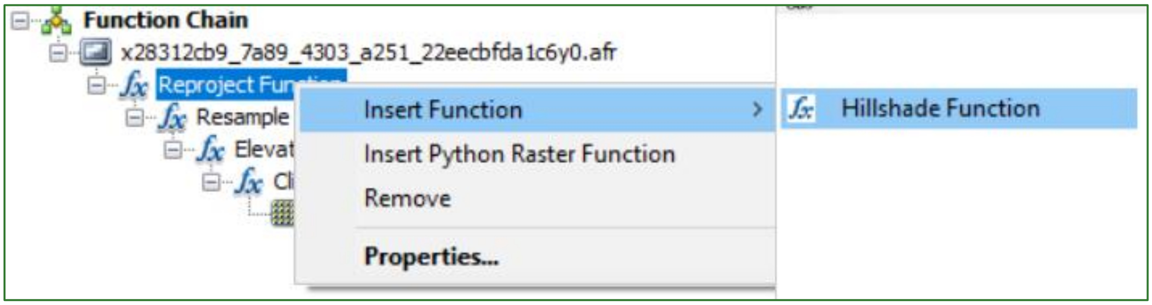
13. Right click on **Resample Function** and insert **Reproject Function.**



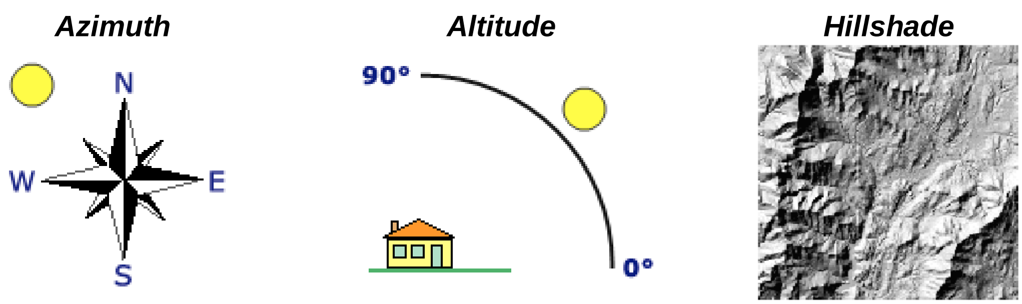
14. Export the **Función MDT** raster, save it in the **RASTER/MDT** folder and name it **MDT_procesado.tif.**

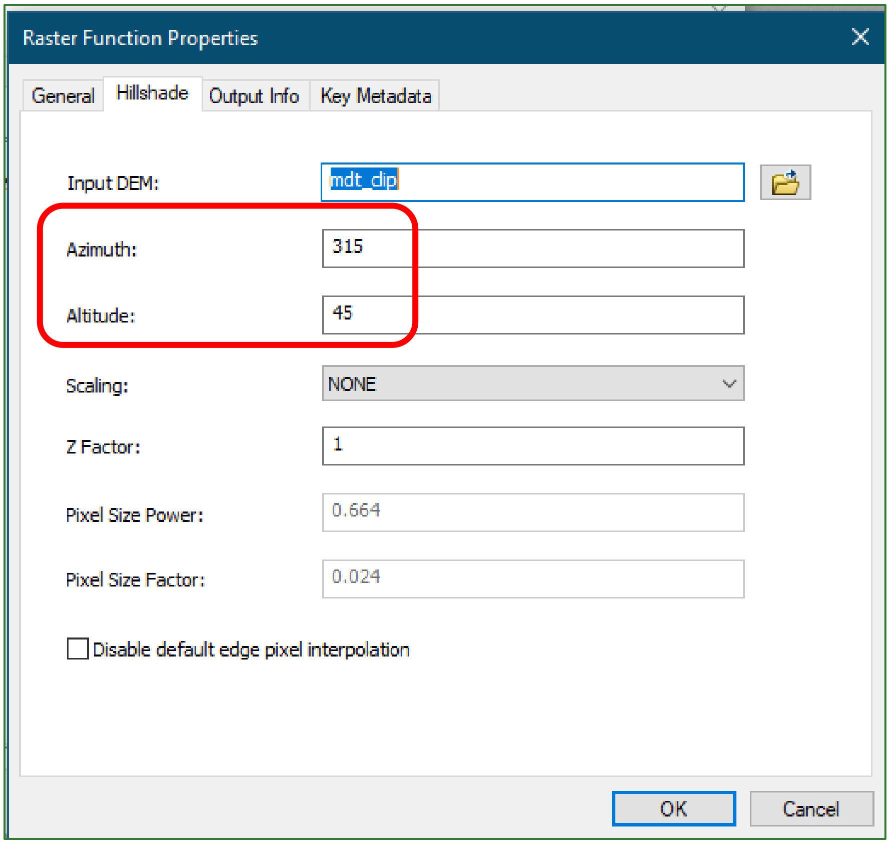


15. Go to the **Función MDT** raster properties again, right click on **Reproject Function** and insert **Hillshade Function.**

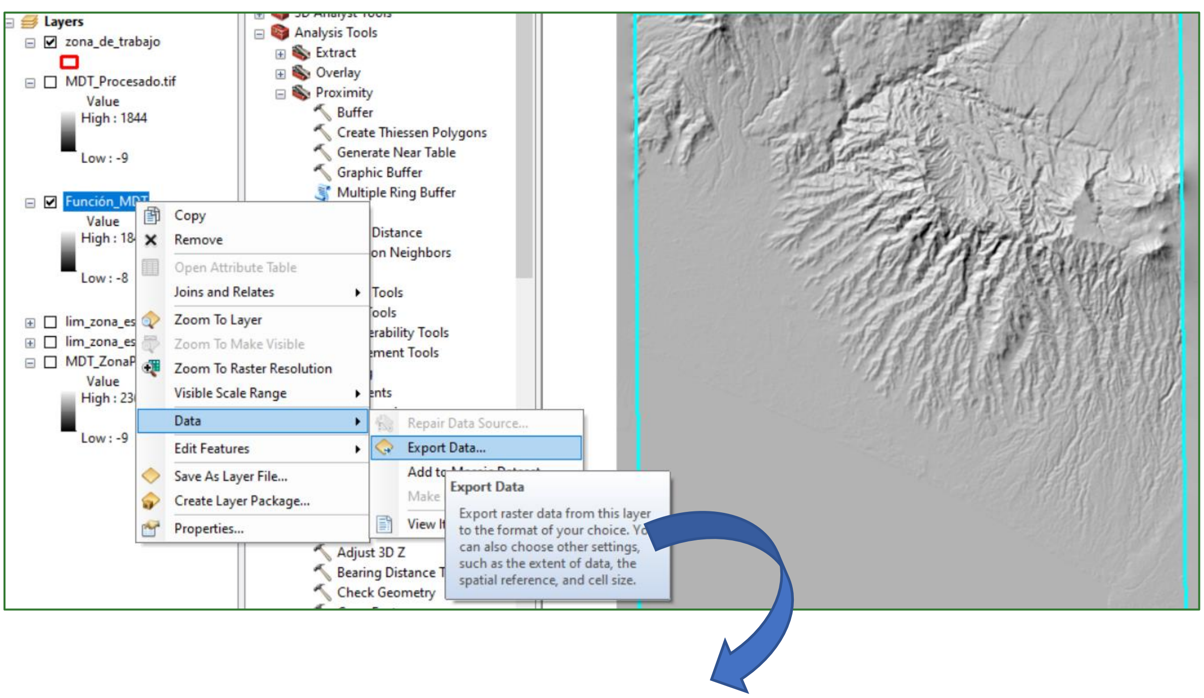


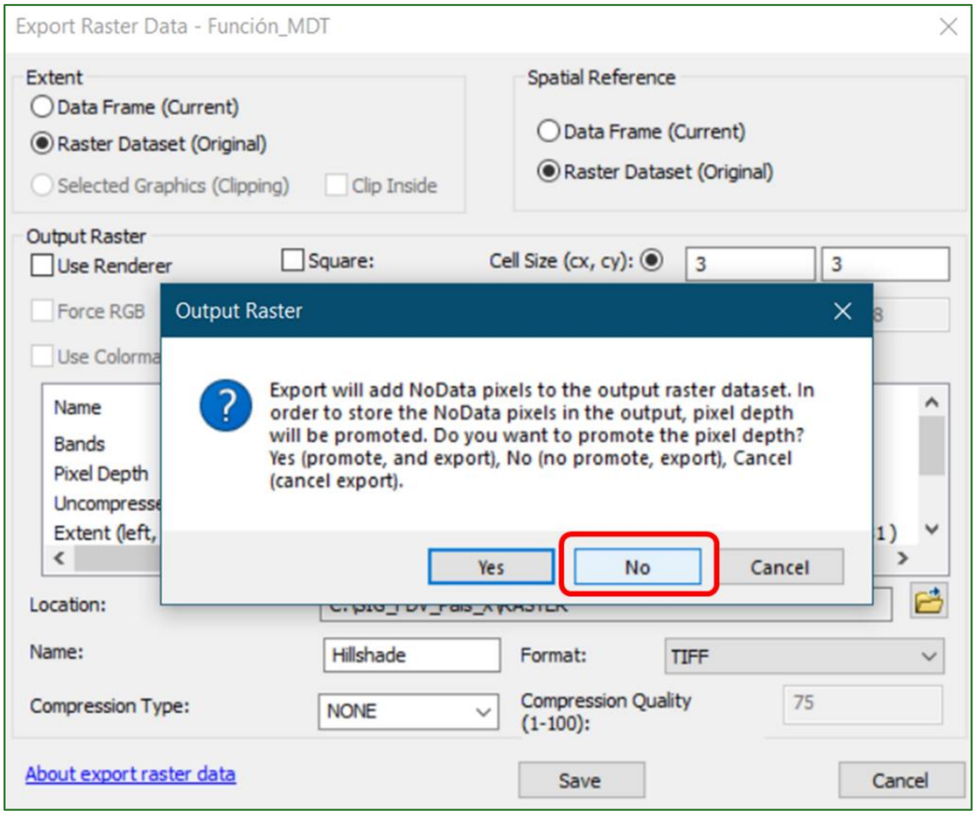
The Hillshade function generates a three-dimensional view of the land taking the sun's position into account.



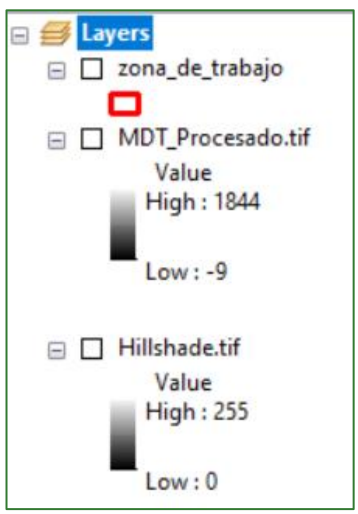


16. Repeat the **Export Data** procedure, save the file and name it **Hillshade.tif** in the **RASTER/MDT** folder.

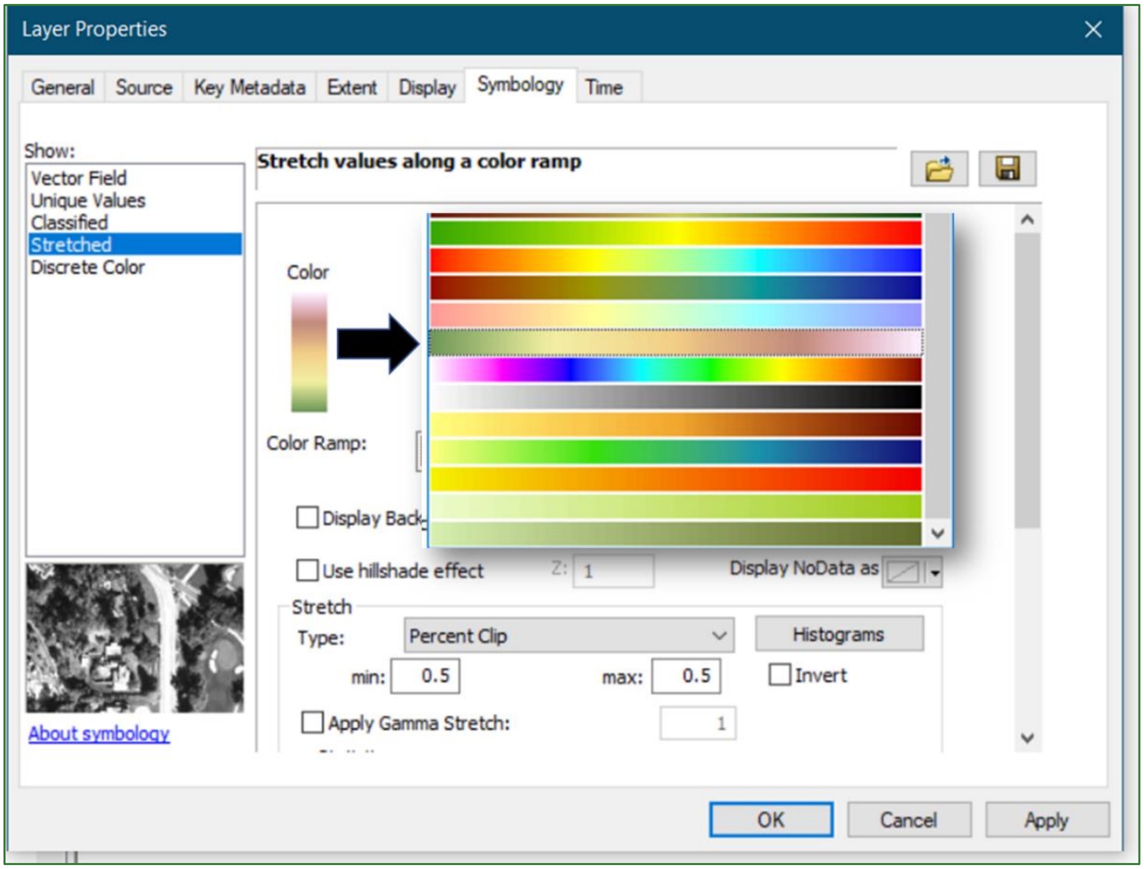




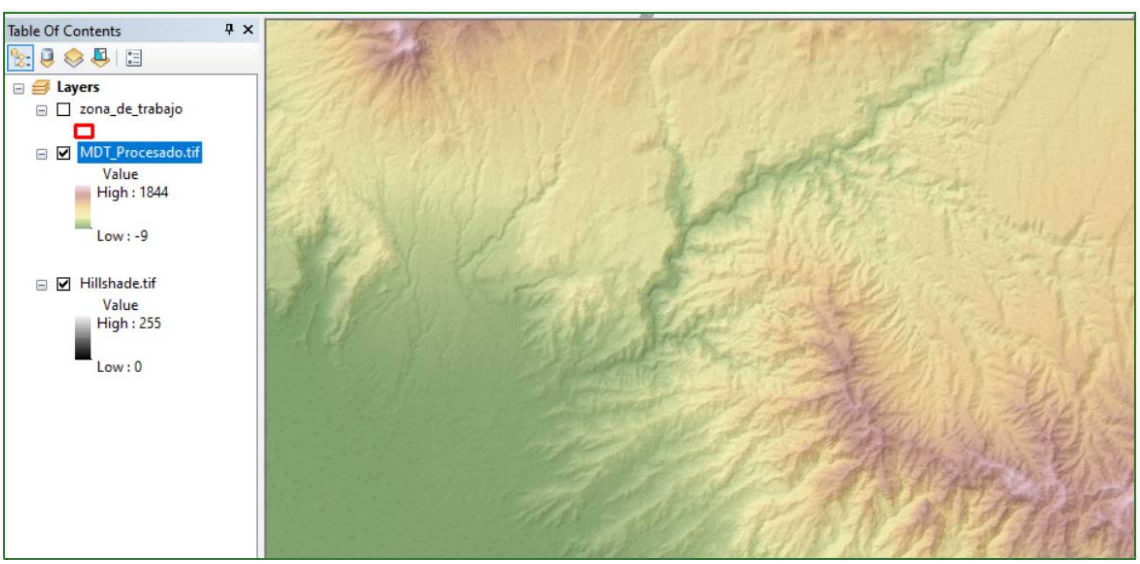
17. Clear the Content Table leaving only the **Hillshade.tif**, **MDT_procesado.tif** and **zona_de_trabajo** files in the order indicated below.



18. Go to the **MDT_procesado** properties by double clicking on its name, going to the **Symbology** tab and assigning the palette shown below.



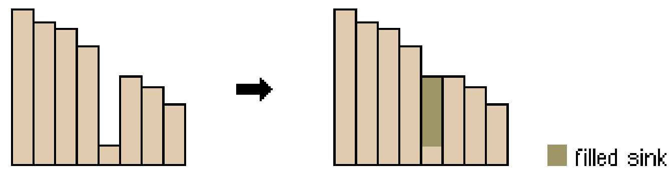
19. Then, in the same **Layer Properties** window, go to the **Display** tab and assign a **transparency of 30%**. This will allow you to view both the elevation ranges and the hillshade relief appearance.



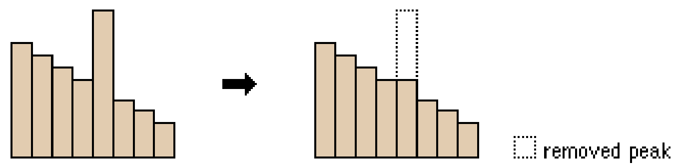
Part 4. Correcting the Digital Terrain Model (DTM)

If the DTM is not corrected, it contains peaks and sinks. These need to be corrected to avoid interruptions in the continuity of the groundwater flows in simulation processes.

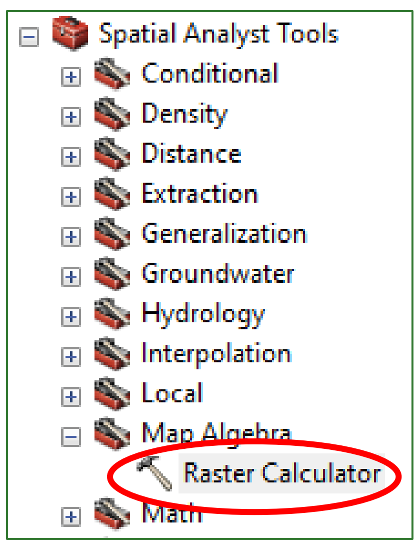
Filling sinks



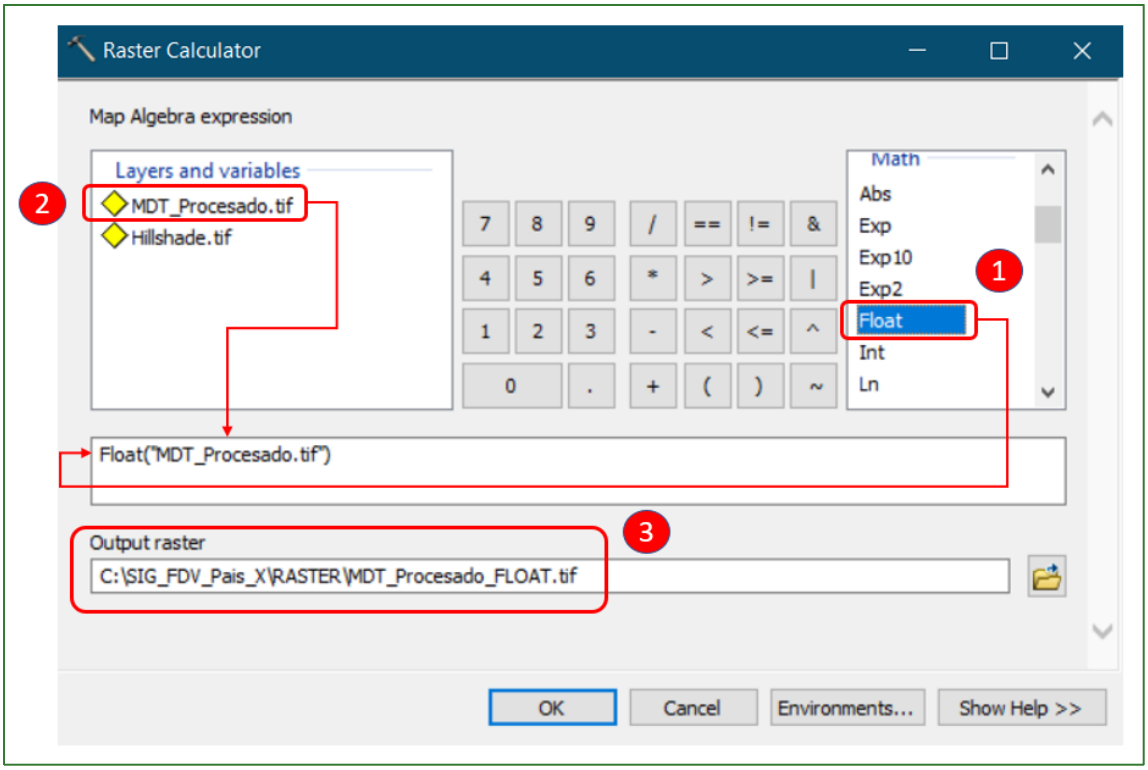
Removing peaks



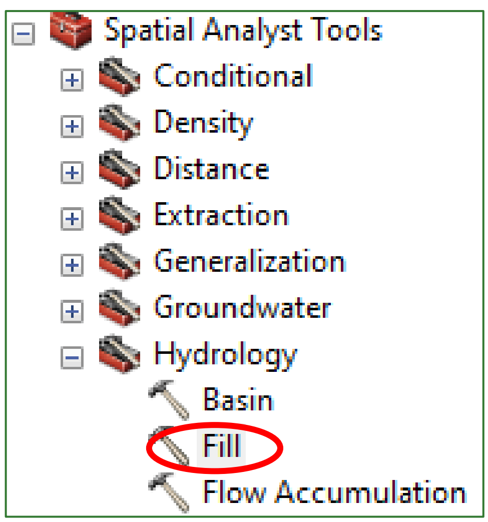
20. Before correcting the DTM, its INTEGER values must be converted to FLOAT values. To do so, use the **"Raster Calculator"** tool located at: **ArcToolBox/Spatial Analyst Tools/Map Algebra/Raster Calculator.**



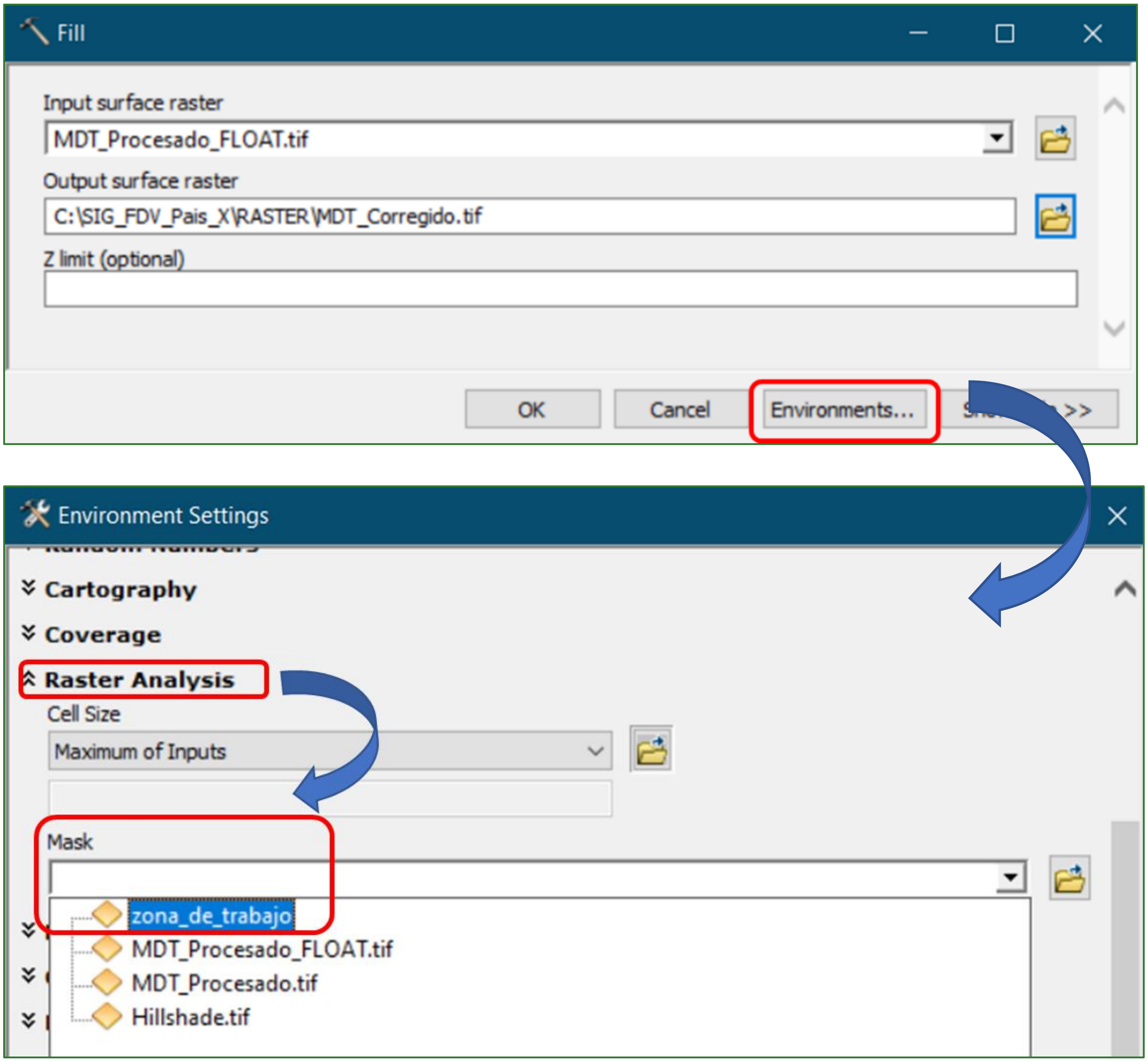
Apply the formula as indicated below: **Float("MDT_Procesado.tif")** assign the name **MDT_proceado_FLOAT.tif** as output and save it in the **RASTER/MDT** folder.



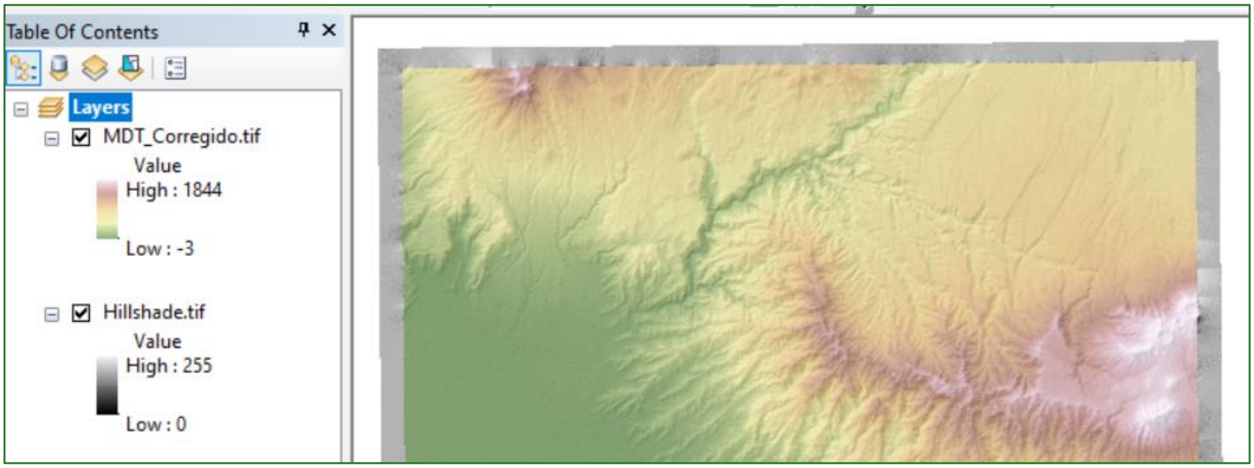
21. You can now use the FILL tool to fill sinks and remove peaks that prevent groundwater flow continuity in the DTM. Use the **"Fill"** tool to do so. This is located at: **ArcToolBox/Spatial Analyst Tools/Hydrology/Fill.**



Select the **MDT_Procesado_FLOAT.tif** as the Input and assign the name **MDT_Corregido.tif** as the Output in the **RASTER/MDT** folder. Use this step to cut out your project area from the output file. To do so, click on the  button and then assign the **zona_de_trabajo.shp** file in the **Raster Analysis/Mask** section.

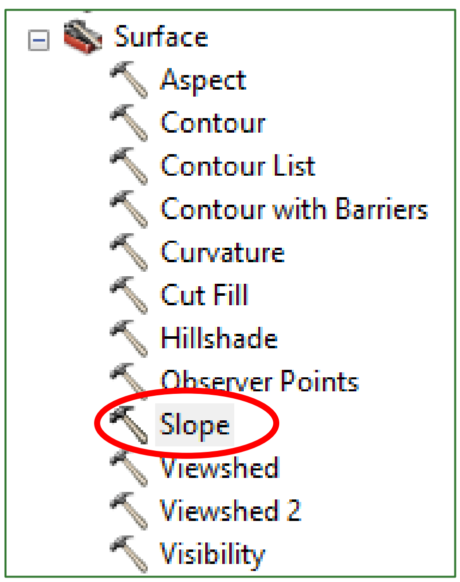


22. Assign a colour palette to the **MDT_corregido.tif** as you did in the previous steps and clear the content table leaving only the **Hillshade.tif** and **MDT_corregido.tif** files.

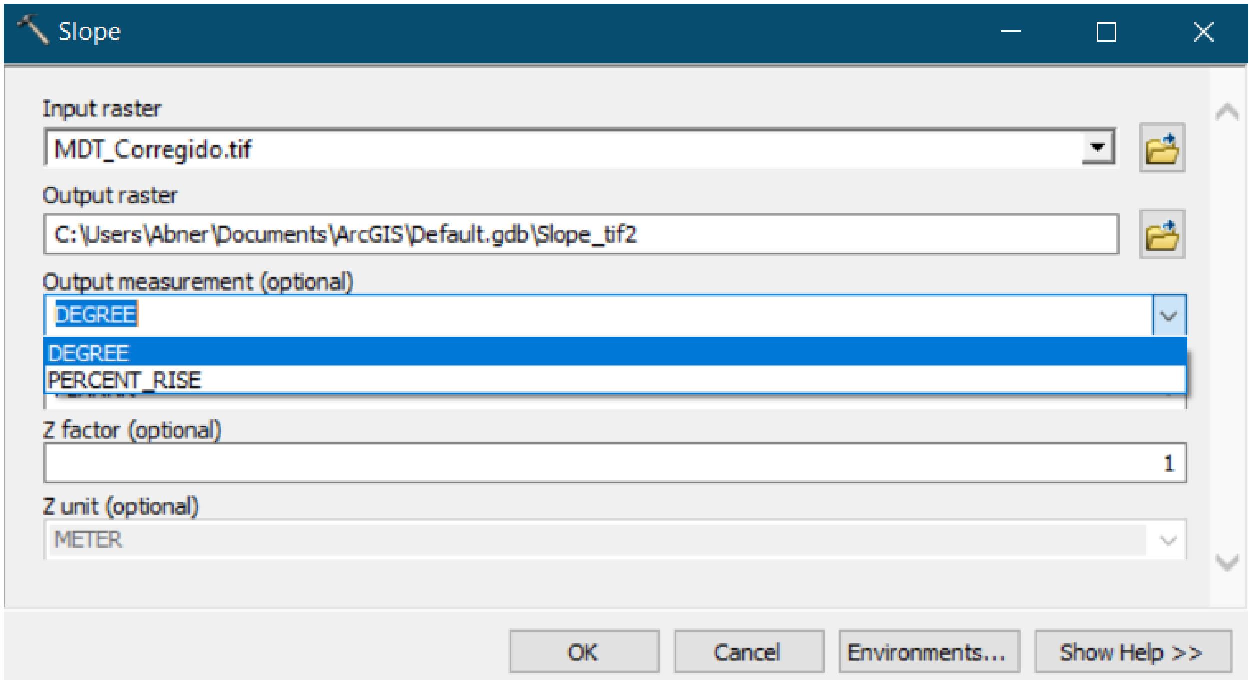


Part 5. Obtaining metrics from the Digital Terrain Model

SLOPE: the maximum slope that exists in the elevation values between each pixel and its neighbouring pixels. The **"Slope"** tool located at **ArcToolBox/Spatial Analyst Tool/Surface/Slope** is used to obtain the slope of the land in the study area.

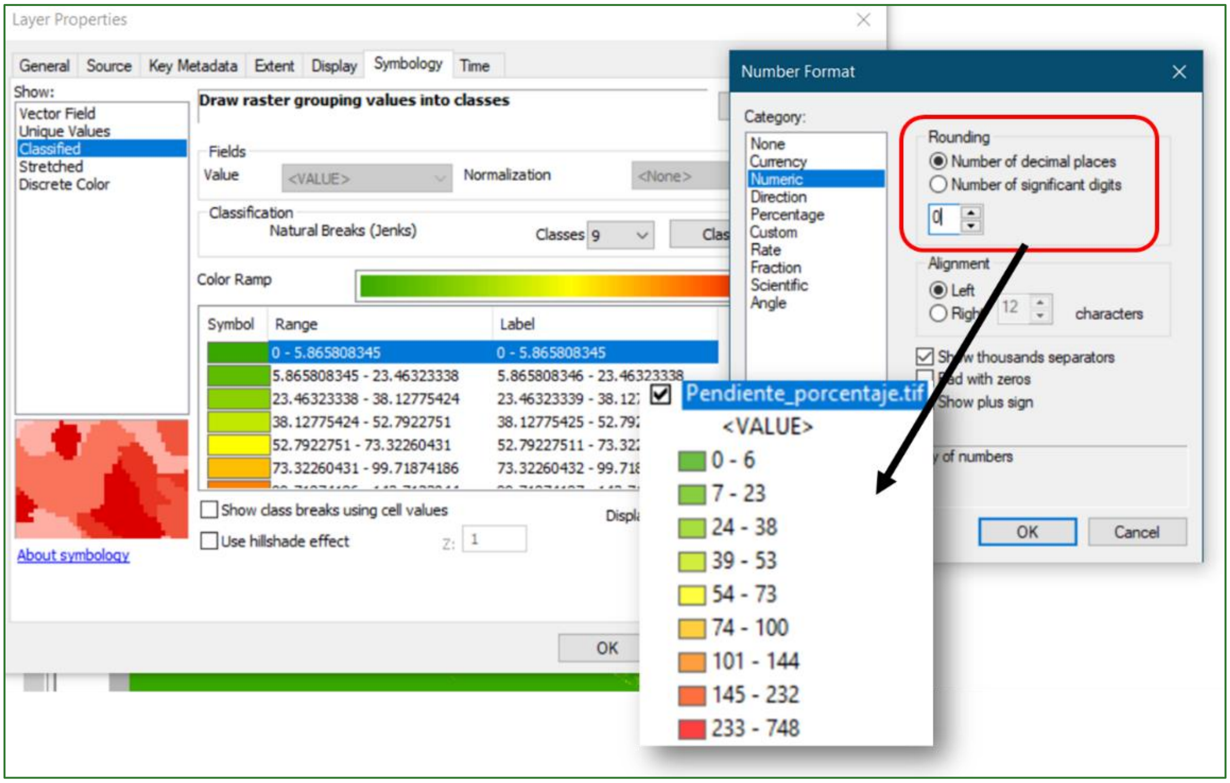


The slope can be calculated in **degrees** or by **percentage**:

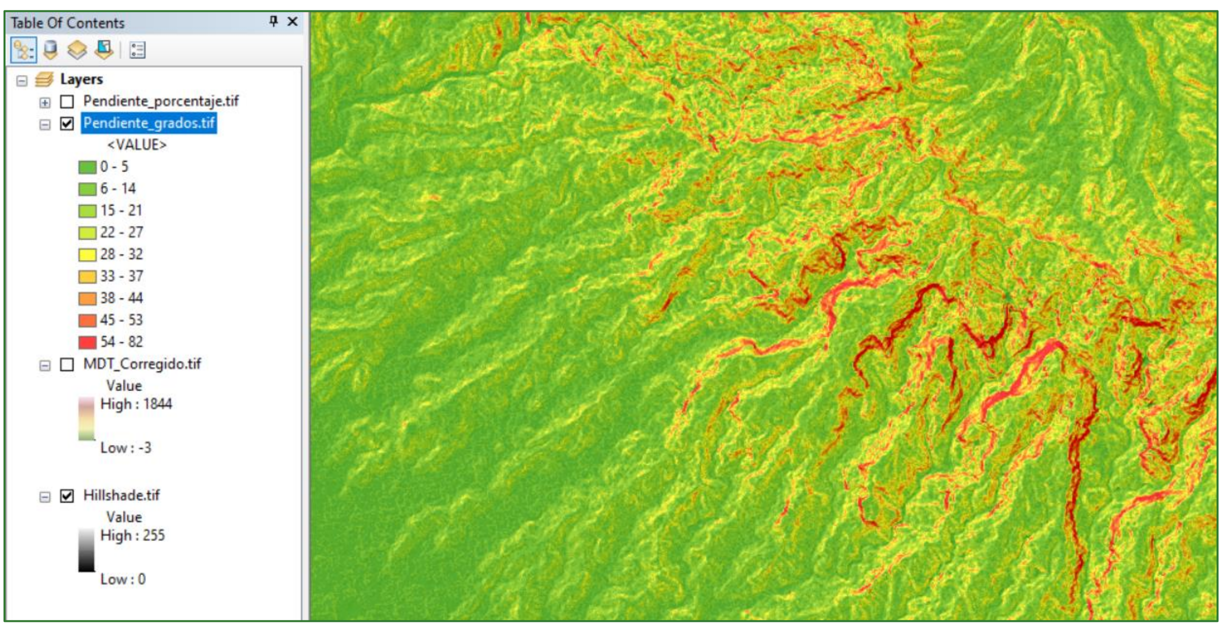


23. Generate the **slope** raster, first in degrees and then as a percentage value, and save them under the names **pendiente_grados.tif** and **pendiente_porcentaje.tif**, respectively, in the **RASTER/MDT** file.

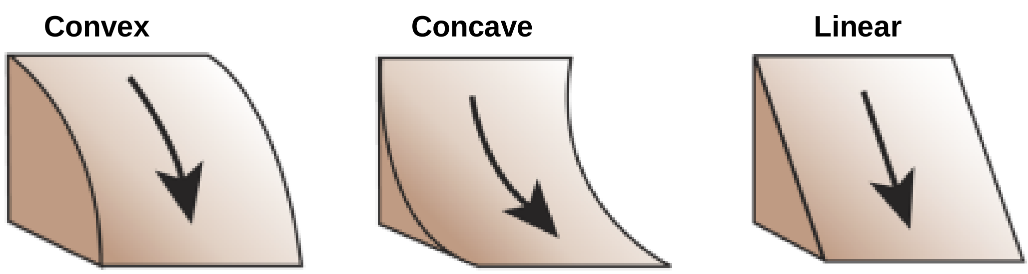
24. You can specify the number of decimals you want to show in the values for a raster key by going to the symbology tab in raster properties, right-clicking on this and selecting the **"Format Labels"** option:



Example of the result of the slope calculation:

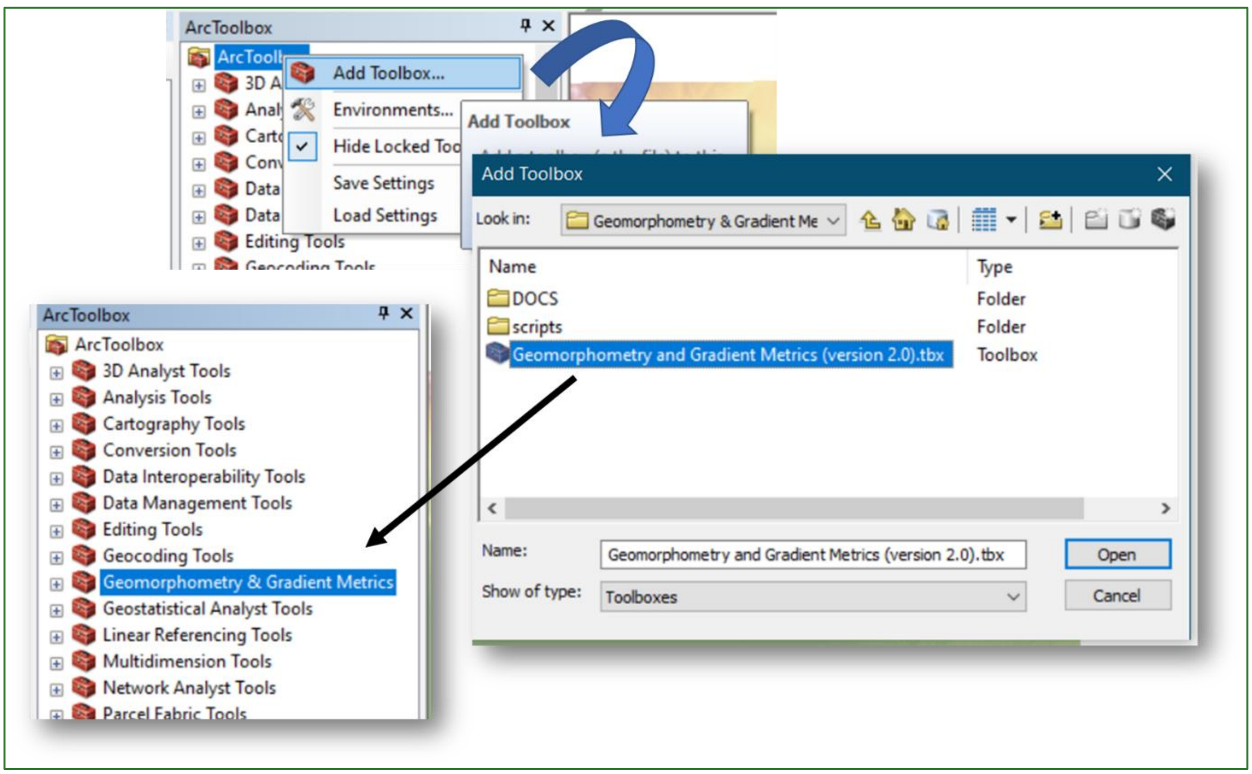


LANDFORM: refers to the concavity or convexity of the surface of the land in the direction of the slope. The calculation of the landform is based on curvature.

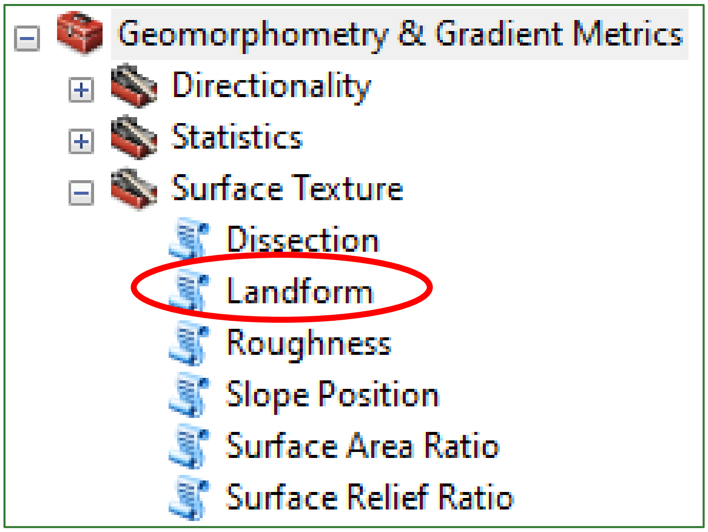


Use the (external) **"Geomorphometry & Gradient Metrics"** tool located in the **SOFTWARE** folder to conduct this procedure.

25. Add the **Geomorphometry & Gradient Metrics** tool to the **ArcToolBox** by following these steps.

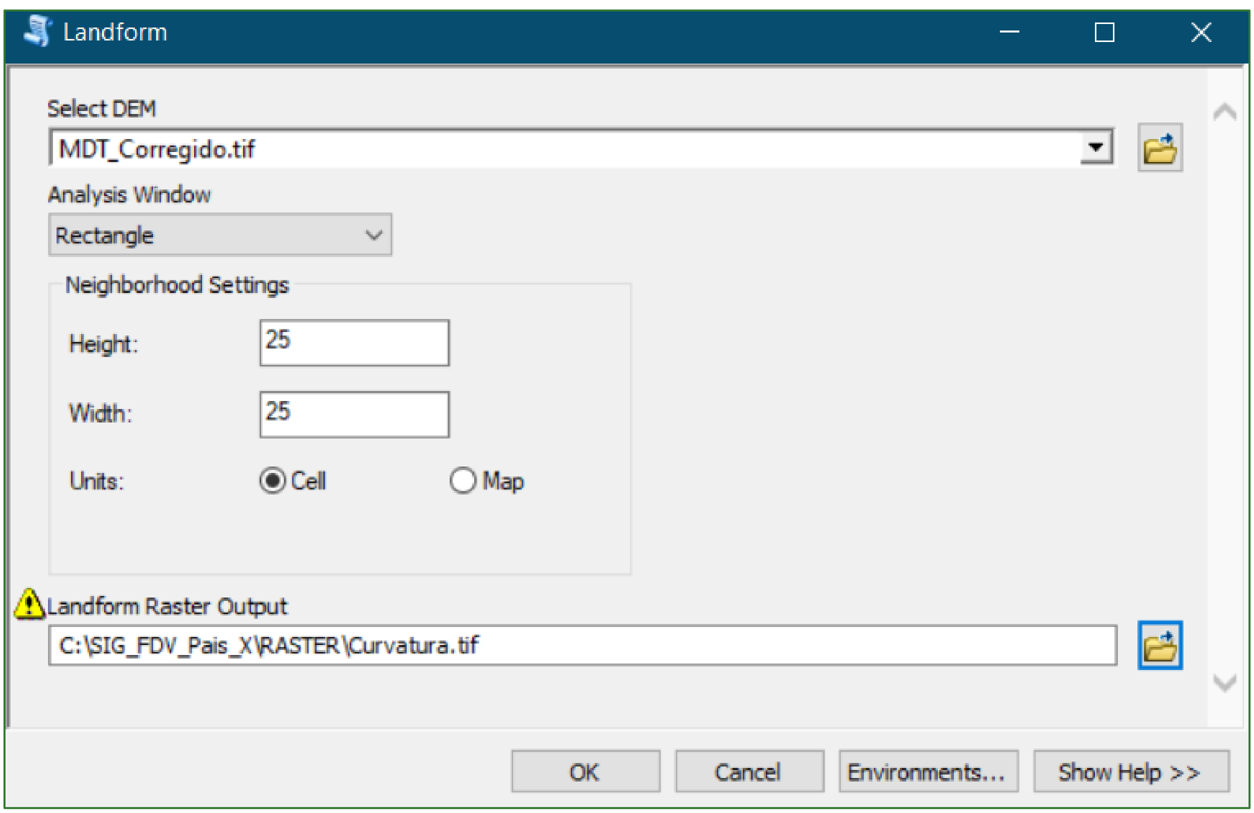


26. In **Geomorphometry & Gradient Metrics**, access the **Surface Texture/Landform** tool.

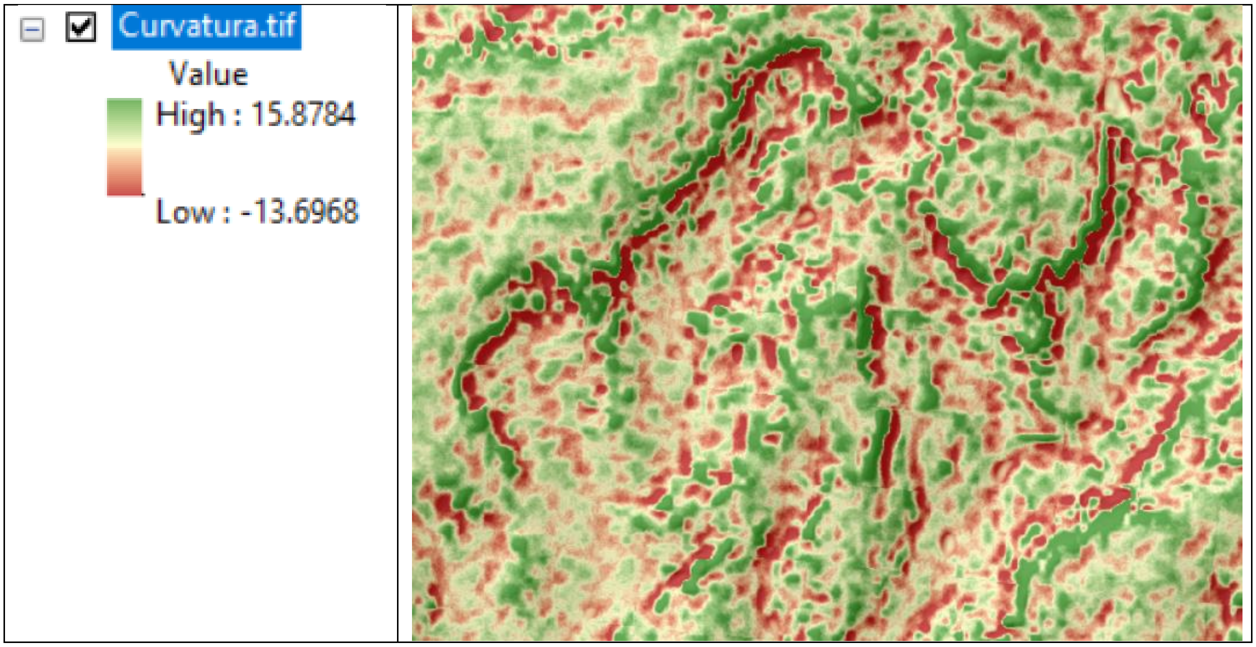


Enter the **MDT_corregido.tif** in Select DEM, assign the name **Curvatura.tif** to the output file and save it in the **RASTER/MDT** folder.

For a 3 m DTM select the **Rectangle** analysis option with a **25 (Cell)** value for both **Height** and **Width.**



Assign a code to the result by selecting a three-colour palette:



General considerations: the Geomorphometry & Gradient Metrics tools in some ArcMap versions may return an error when you are executing them. One way to fix this is to edit the code. Whenever a tool is executed in a script, an ArcGIS licence is required. ArcGIS tool extensions, such as the ArcGIS Spatial Analyst extension, require an additional licence. If the licences required are not available, a tool fails and returns error messages. The way to fix this error is by editing the code, replacing "Available" with "NotLicensed". From then on, the Geomorphometry & Gradient Metrics tool can be executed without any problems. Further details on correcting an extension or tool due to licence availability problems is available at the following link: https://desktop.arcgis.com/en/arcmap/latest/analyze/python/access-to-licensing-and-extensions.htm landform.py: Bloc de notas

Archivo Edición Formato Ver Ayuda

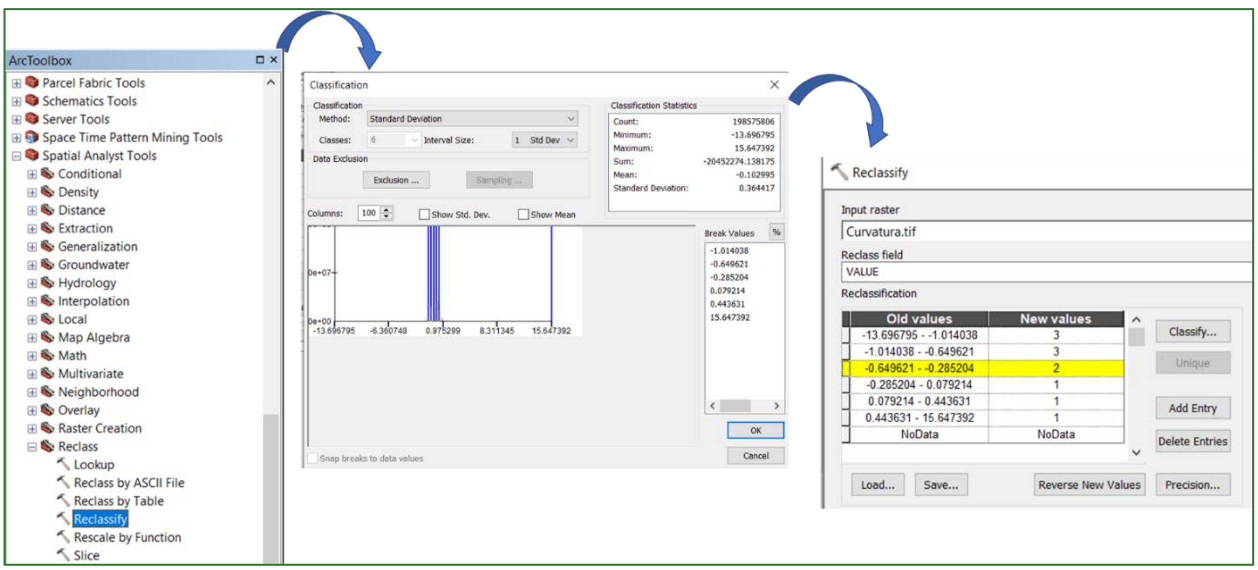
```
#-------------------------------------------------------------------------------
# Name:          Landform.py
# Purpose:
#
# Authors:        Jeff Evans and Jim Oakleaf
#
# Created:       09/09/2014
# Copyright:     (c) Evans and Oakleaf 2014
# Licence:       Attribution-ShareAlike 4.0 International (CC BY-SA 4.0)
#-------------------------------------------------------------------------------



from arcpy import env
from arcpy.sa import *
import os
import geomorph_routines_module

class LicenseError(Exception):
    pass

try:
        #Check for spatial analyst license
    if arcpy.CheckExtension("Spatial") == "Available":
        arcpy.CheckOutExtension("Spatial")
    else:
        raise LicenseError
    #Modeling polygon --- roadless
    inR = arcpy.GetParameterAsText(0)
    r = geomorph_routines_module.checkExt(inR)

    # Set overwrite option
    env.overwriteOutput = True
```

Obtaining landforms and classifying relief

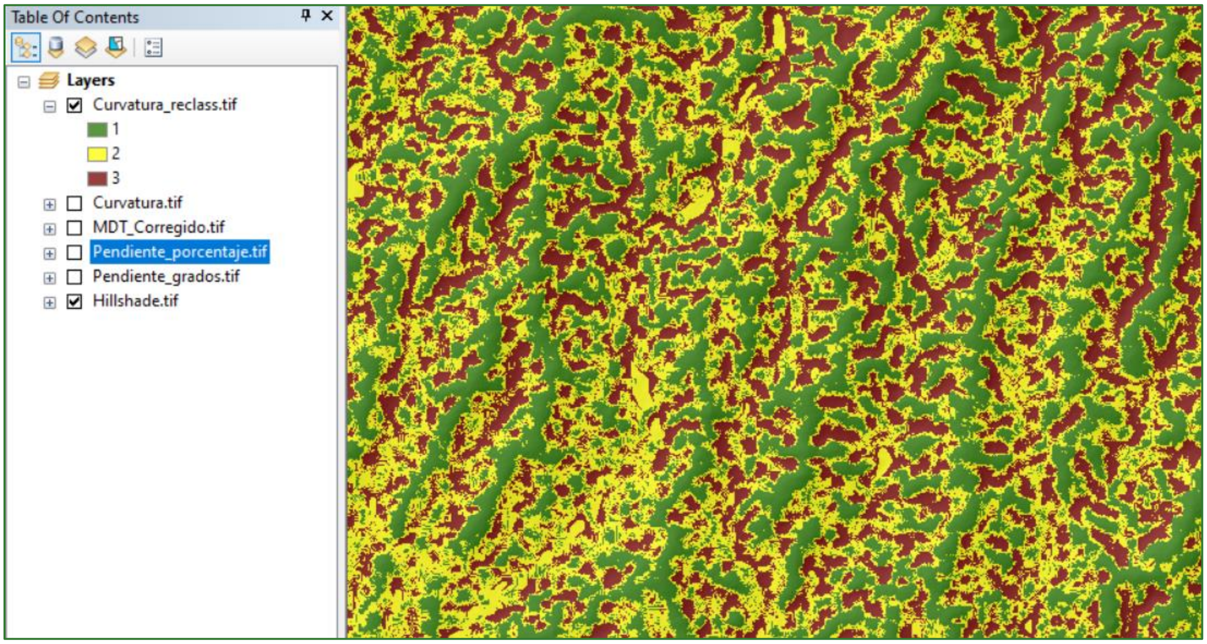
1. As a first step, the **Curvatura.tif** raster file must be reclassified. You do this by using the **"Reclassify"** tool located at **ArcToolBox/Spatial Analyst Tools/Reclass/Reclassify.**

- Enter the raster called **Curvatura.tif** in the Input Raster field.
- Click on the Classify window.
- Reclassify it using the **Standard Deviation** method.
- Click on the Classify... button to apply the reclassification via the **Standard Deviation** method. Assign the **New values** as indicated in the following table. Assign the name **Curvatura_reclass.tif** to the output file in the **RASTER/MDT** folder.
- Assign the values as shown in the following ranges:

Slope	New Value
Lower ranges than the mean range	**3**
Mean range	**2**
Higher ranges than the mean range	**1**

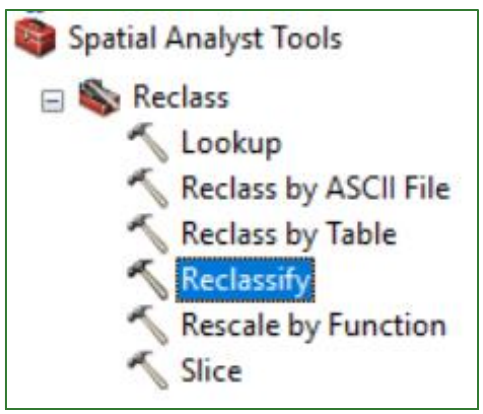


Example of the curvature reclassification result:

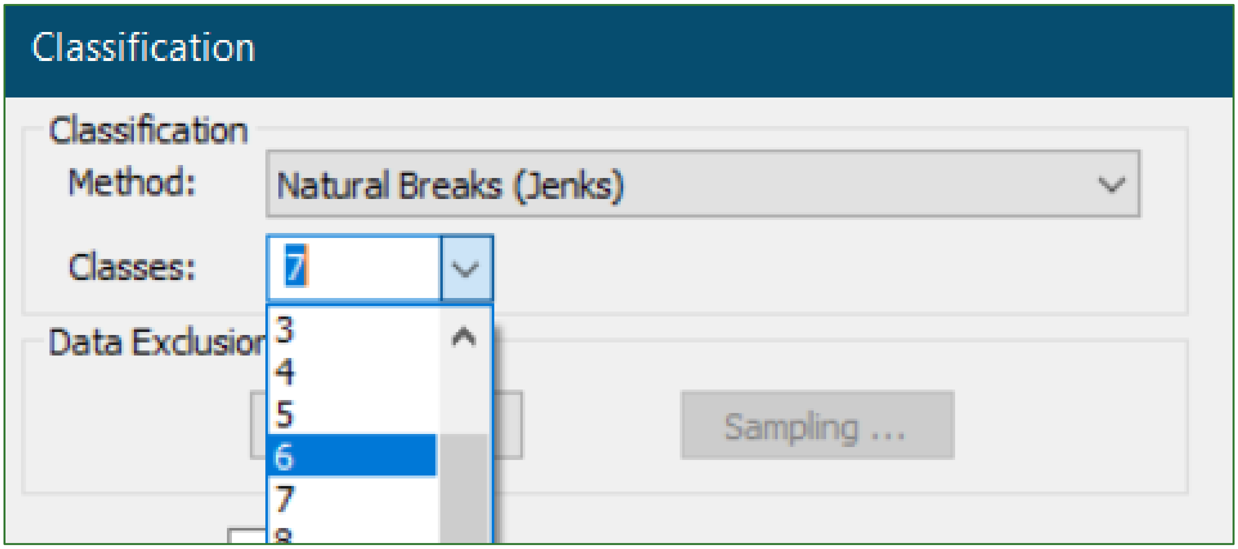


1 = Crest (Convex) 2 = Straight hillside / Plain 3 = Hillside foot (Convex)

Use the reclassification tool to get the **pendiente_porcentaje.tif** and **MDT_Corregido.tif** reclassification rasters, using the ranges in the table shown below.



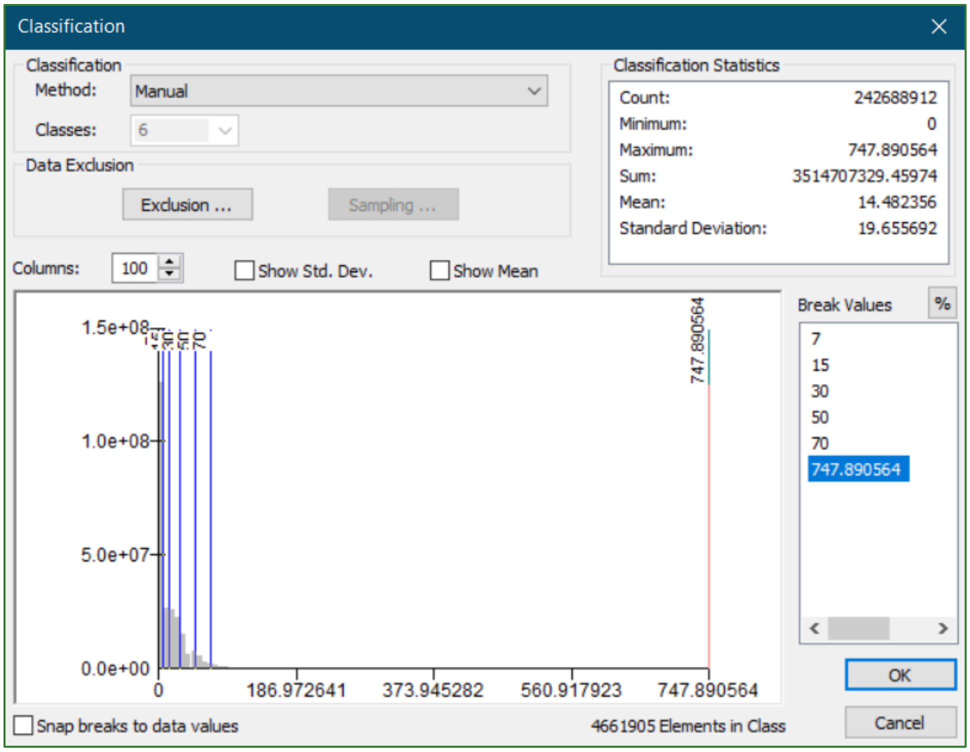
To do so, go to Classify... and assign the classes as indicated in the following table.

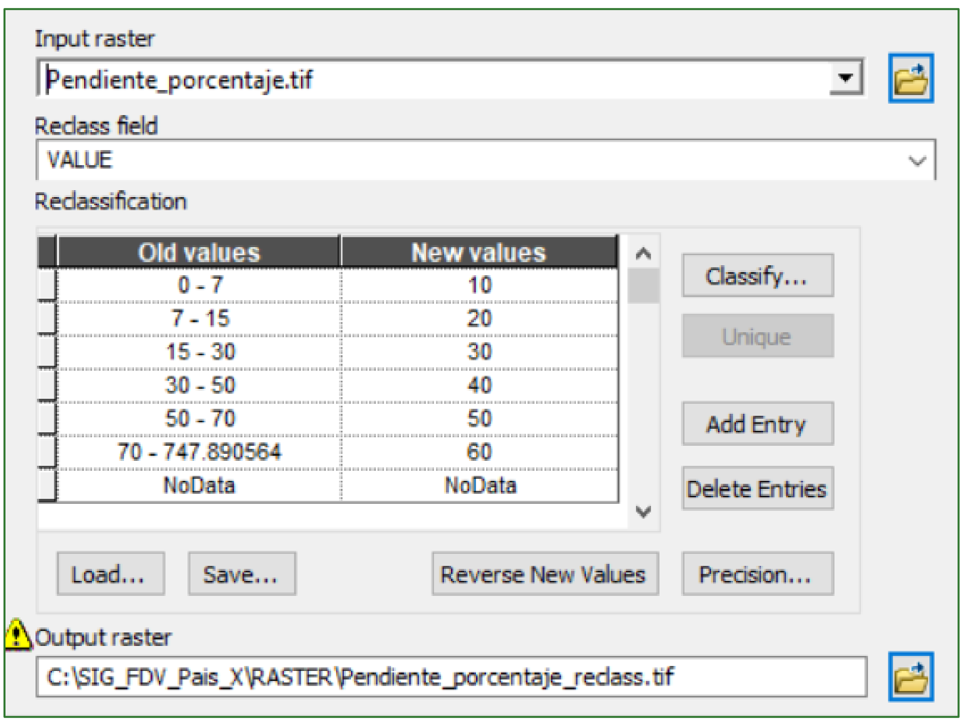


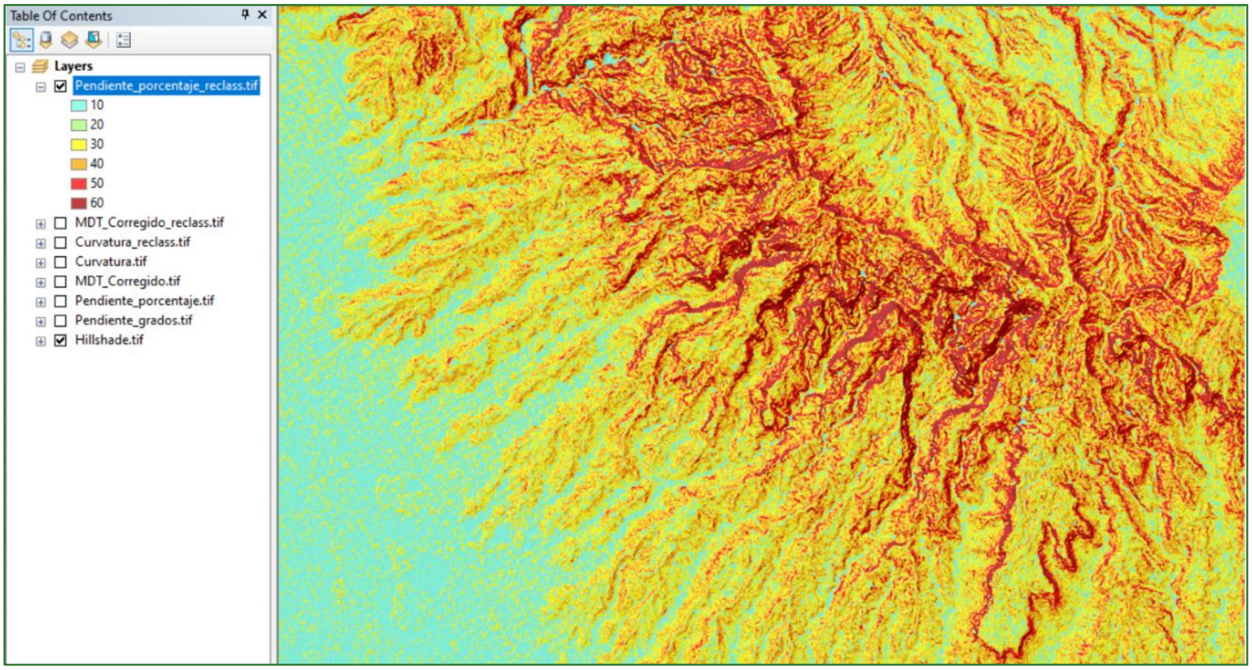
Slope	New Value
0-7%	10
7-15%	20
15-30%	30
30-50%	40
50-70%	50
>70%	60

Altitude	New Value
0-500	100
500-1,000	200
1,000-2,000	300
>2000	400

Assign the name **Pendiente_porcentaje_reclass.tif** to the slope output file in the **RASTER/MDT** folder.

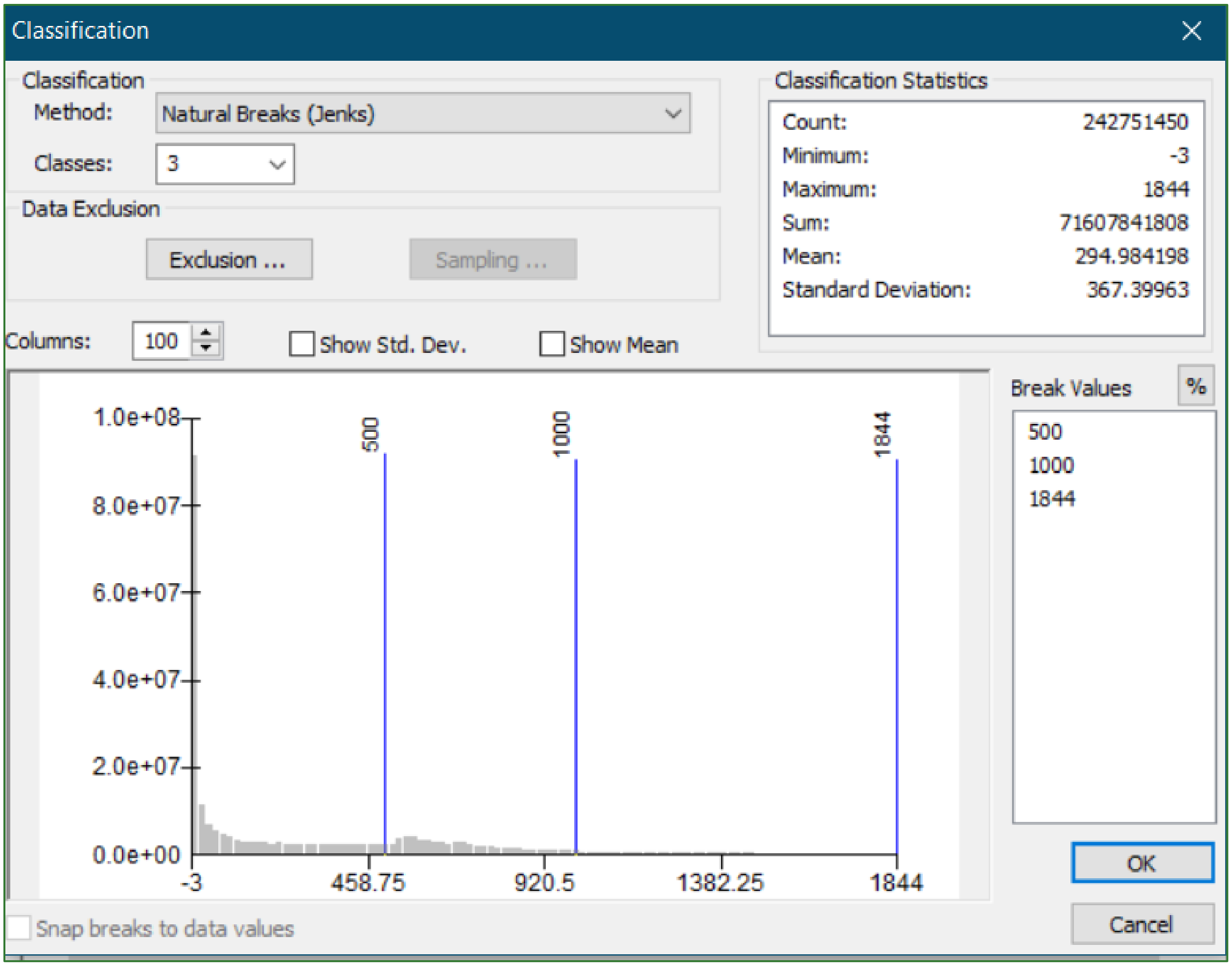

Classification
Classification
Method: Manual
Classes: 6
Data Exclusion
Exclusion ...
Sampling ...
Classification Statistics
Count: 242688912
Minimum: 0
Maximum: 747.890564
Sum: 3514707329.45974
Mean: 14.482356
Standard Deviation: 19.655692
Columns: 100
Show Std. Dev.
Show Mean
Break Values
%
7
15
30
50
70
747.890564
1.5e+08
1.0e+08
5.0e+07
0.0e+00
0
186.972641
373.945282
560.917923
747.890564
OK
Cancel
Snap breaks to data values
4661905 Elements in Class


Input raster
Pendiente_porcentaje.tif
Reclass field
VALUE
Reclassification
Old values
New values
0 - 7
10
7 - 15
20
15 - 30
30
30 - 50
40
50 - 70
50
70 - 747.890564
60
NoData
NoData
Classify...
Unique
Add Entry
Delete Entries
Load...
Save...
Reverse New Values
Precision...
Output raster
C:\SIG_FDV_Pais_X\RASTER\Pendiente_porcentaje_reclass.tif

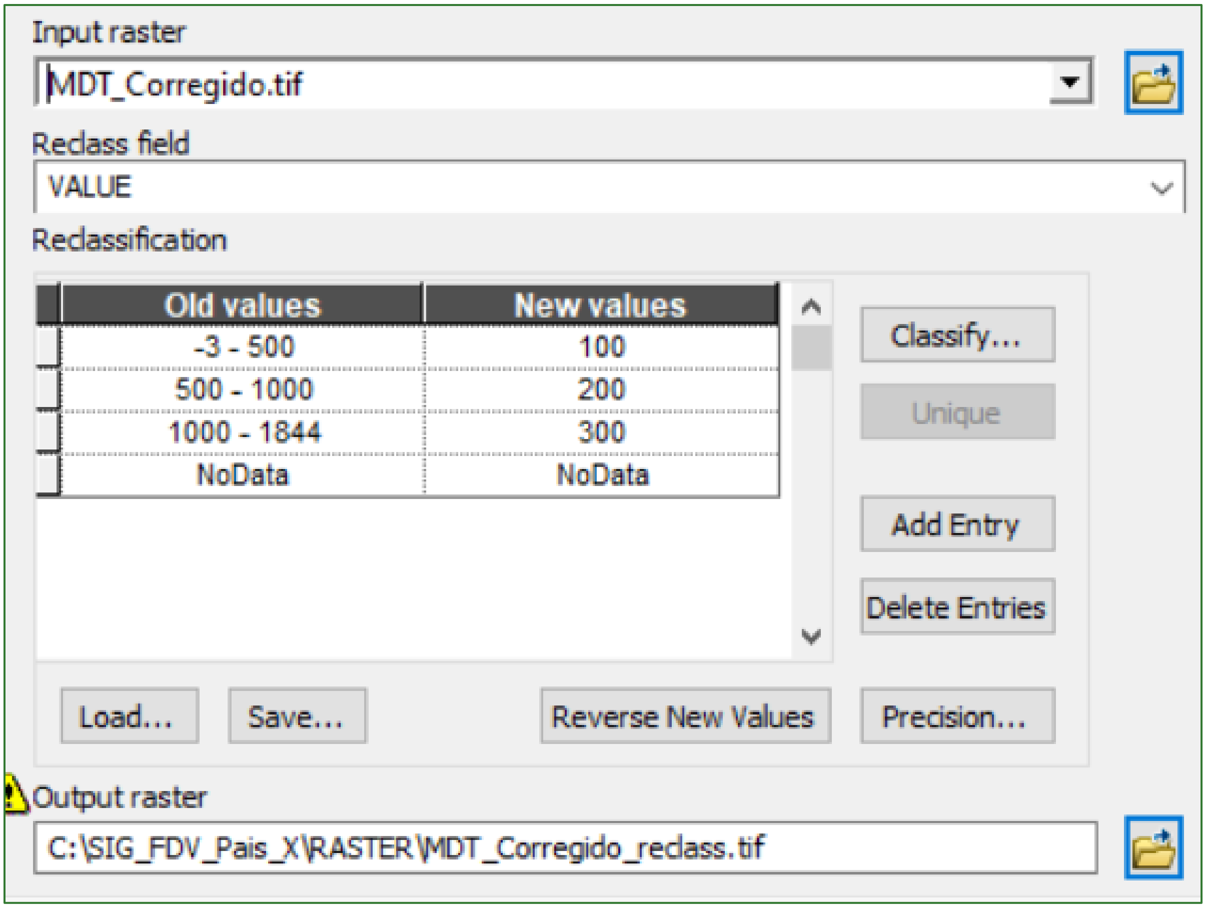


Example of the reclassified slope output:

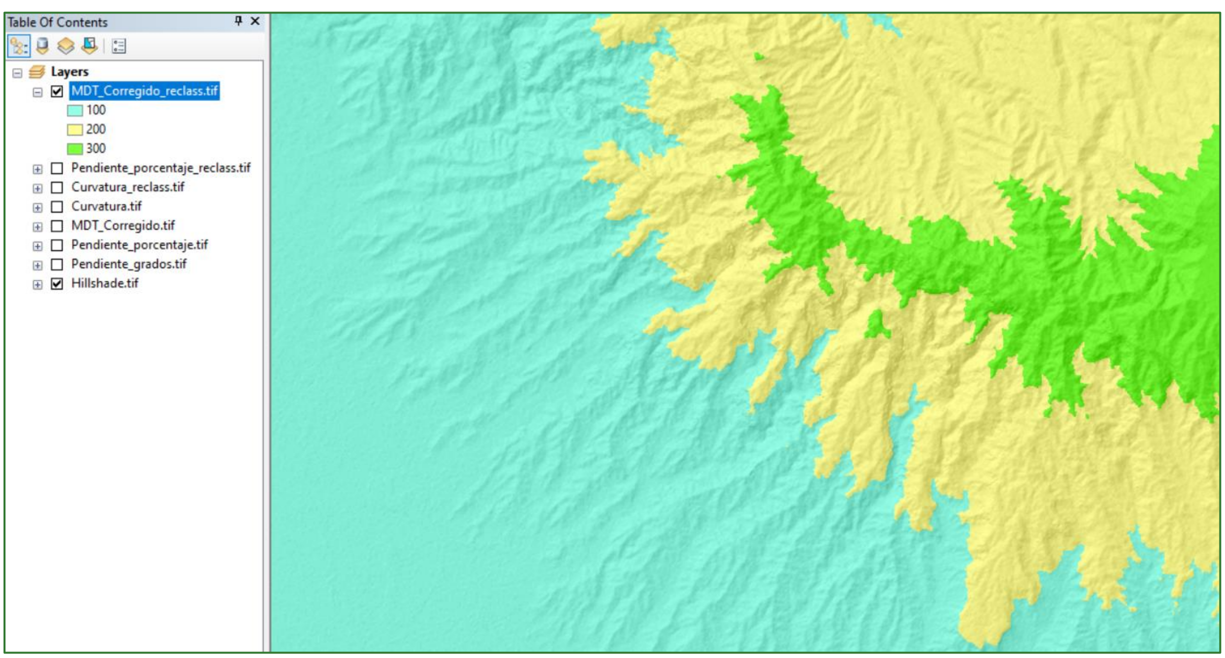
In the case of elevation (MDT), first check the maximum altitude in your study area, thereby defining the number of classes according to the table.



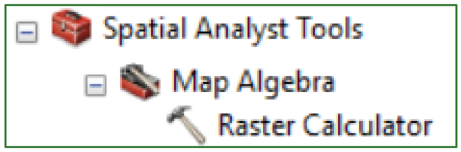
Assign the name **MDT_Corregido_reclass.tif** to the output file in the **RASTER/MDT** folder.



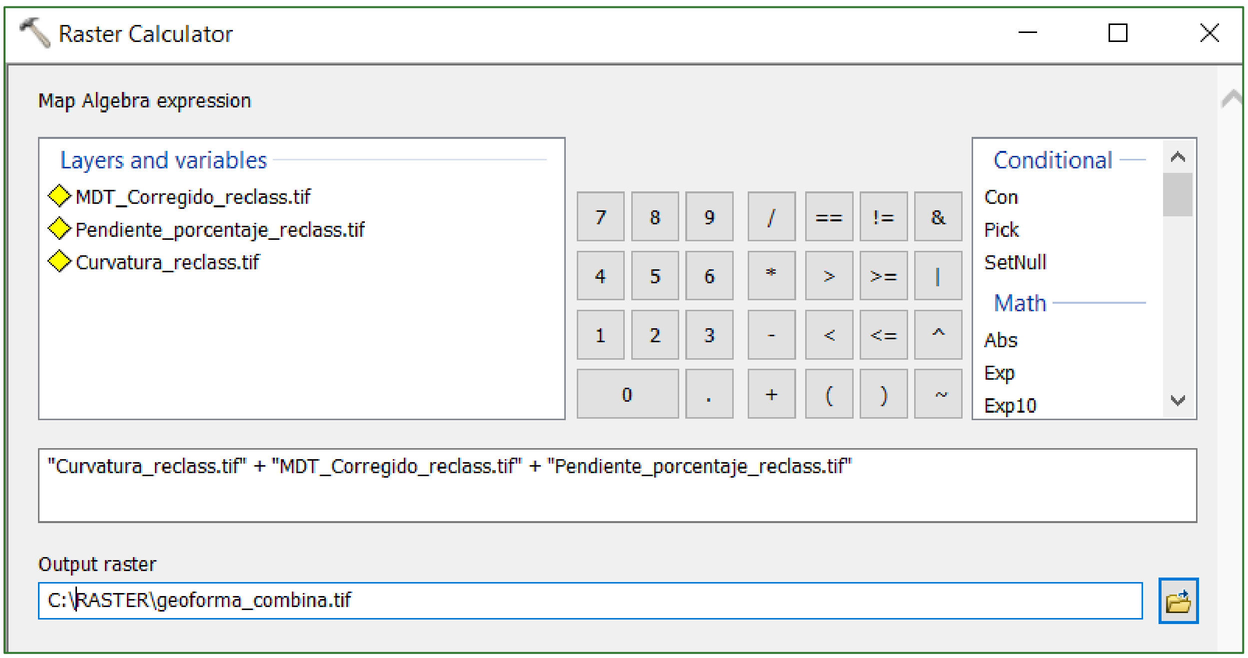
Example of the reclassified DTM output:



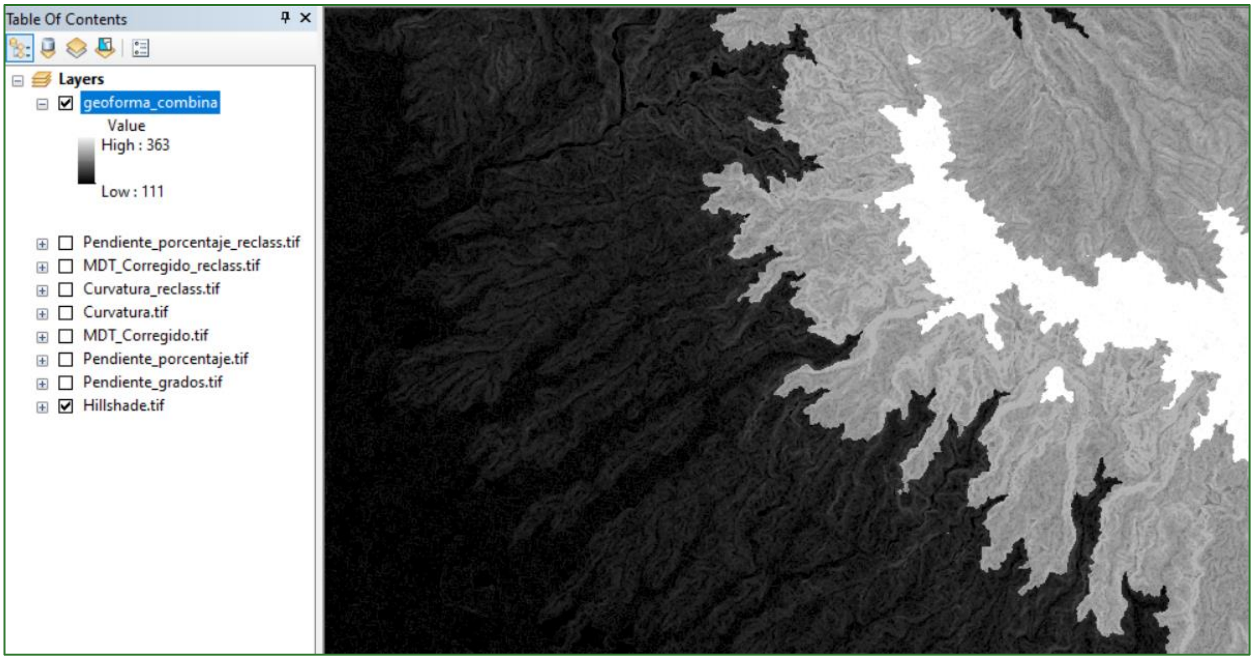
Add up the three reclassified rasters using the map calculator (Raster Calculator). The order of the files is important in this step: **Curvatura_reclass.tif + MDT_Corregido_reclass.tif + Pendiente_porcentaje_reclass.tif.**



Assign the name **geoforma_combina.tif** to the output raster and save it in the **RASTER/MDT** folder.

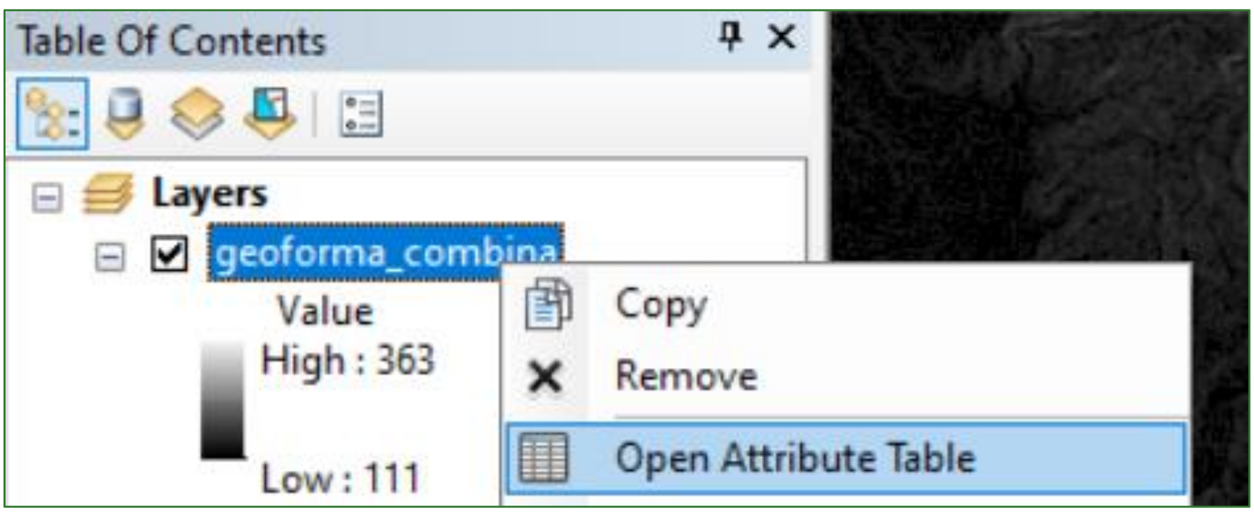


As a result, values are obtained that represent the combination between the slope, altitude and curvature:

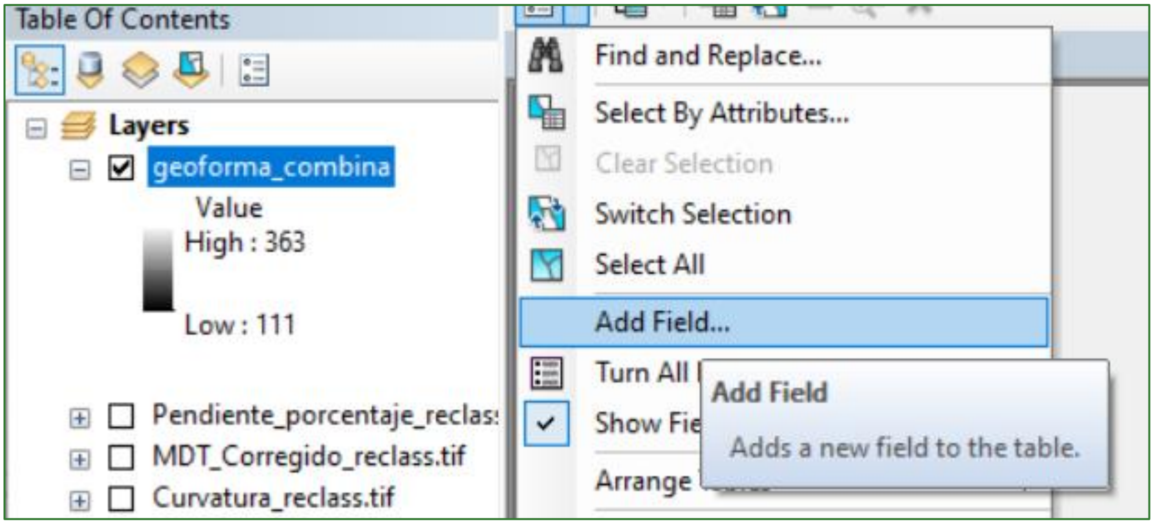


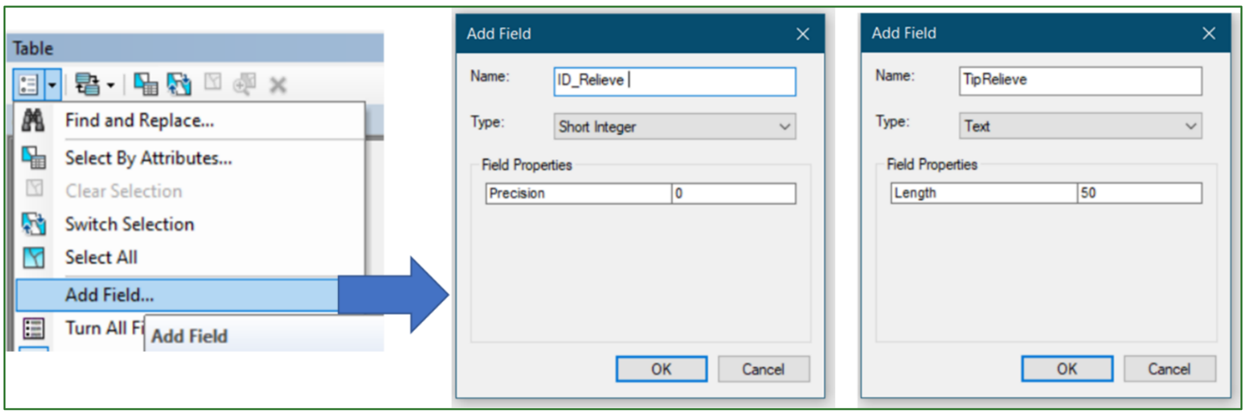
2. In the resulting **geoforma_combina.tif** raster attributes table, add the **ID_Relieve** (numerical field) and **TipRelieve** (text field) fields.

   Right-click on **geoforma_combina.tif** and then on **Open Attribute Table** to go to the attribute table.

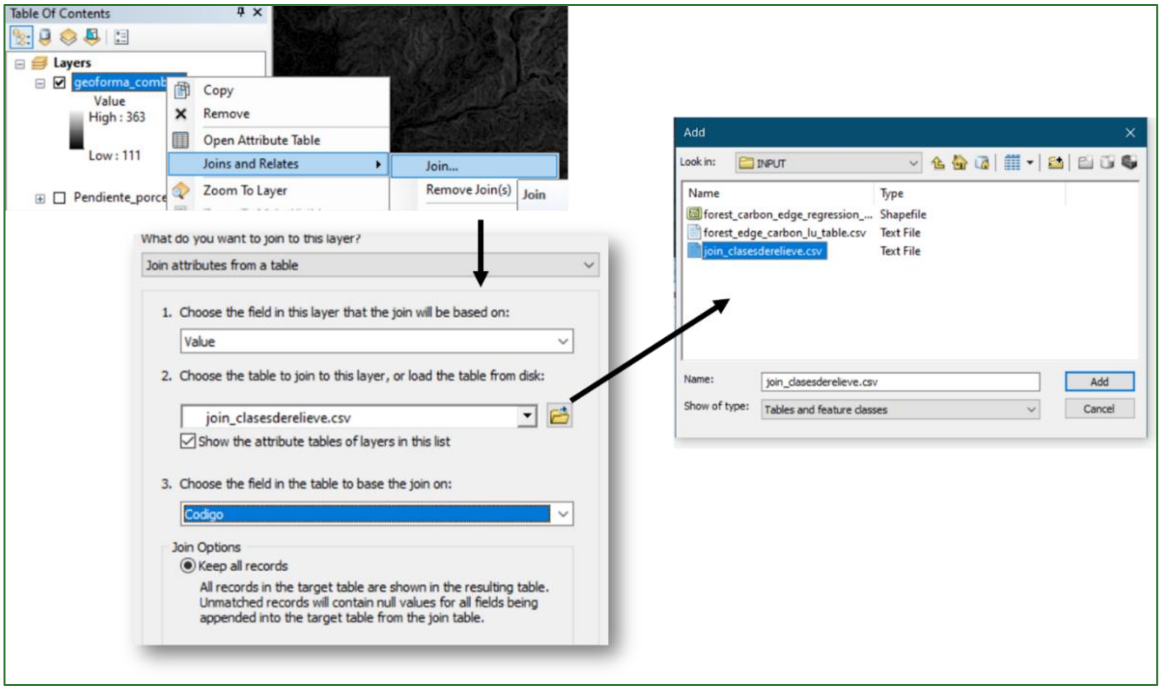


   Click on **Field** to add each field.





3. Create a join between the **geoformas_combina.tif** attribute table and the **"join_clasesderelieve.csv"** table which is available in an online GitHub repository that can be downloaded at the following address: https://github.com/guialandscape/Tablas



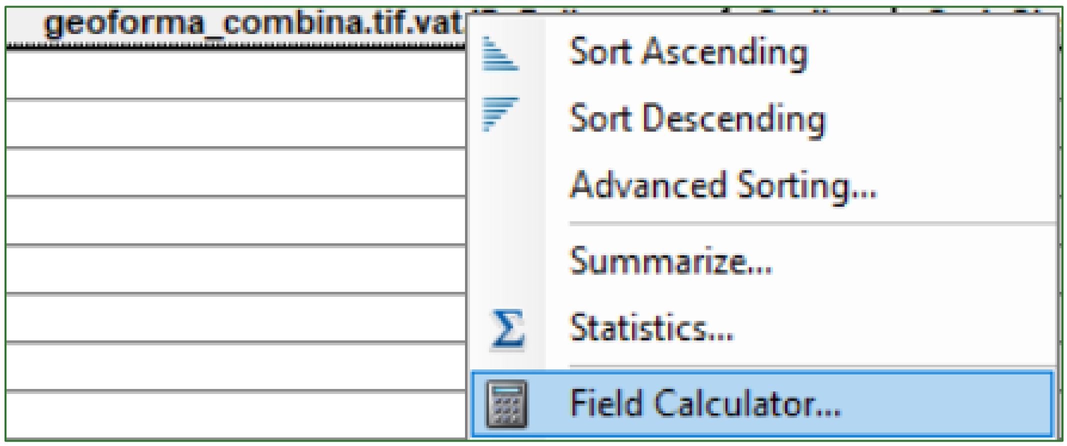
As a result, the following 16 relief categories are transferred to the **geoforma_combina.tif** raster.

			Elevation levels:		**Lowlands**	**Foothill**	**Montane**	**Alpine**
					0-500	**500-1000**	**1000-2000**	**>2000**
Slope			**Shape of the terrain**		100	200	300	400
10	Flat	0-7%	**11**	*Ridge*	1	1	2	2
			12	*Hillside/Plain(hilly)*	1	1	2	2
			13	*Foothill*	1	1	2	2
20	Slightly flat	7-15%	**21**	*Ridge*	3	3	4	4
			22	*Hillside/Plain(hilly)*	3	3	4	4
			23	*Foothill*	3	3	4	4
30	Moderately sloped	15-30%	**31**	*Ridge*	11	12	12	13
			32	*Hillside/Plain(hilly)*	5	7	7	9
			33	*Foothill*	14	15	15	16
40	sloped	30-50%	**41**	*Ridge*	11	12	12	13
			42	*Hillside/Plain(hilly)*	5	7	7	9
			43	*Foothill*	14	15	15	16
50	Steeply sloped	50-70%	**51**	*Ridge*	11	12	12	13
			52	*Hillside/Plain(hilly)*	6	8	8	10
			53	*Foothill*	14	15	15	16
60	Precipitous	>70%	**61**	*Ridge*	11	12	12	13
			62	*Hillside/Plain(hilly)*	6	8	8	10
			63	*Foothill*	14	15	15	16

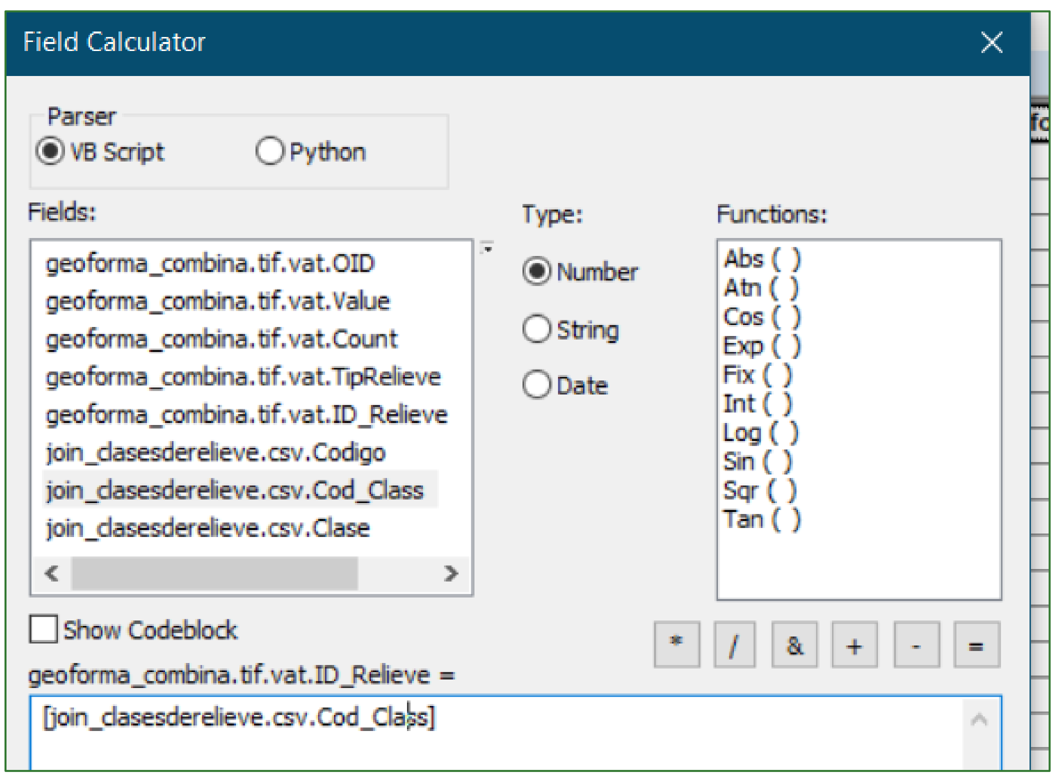
1	Plain (flat)
2	Tableland (flat)
3	Plain (hilly)
4	Tableland (hilly)
5	Lowland sloped hillside
6	Lowland precipitous hillside
7	Medium altitude sloped hillside
8	Medium altitude precipitous hillside
9	High altitude sloped hillside
10	High altitude precipitous hillside
11	Lowland ridge
12	Medium altitude ridge
13	High altitude ridge
14	Lowland foothill
15	Medium altitude foothill
16	High altitude foothill

As the join is only temporary, you must transfer the values from the **join_clasesderelieve.csv** table to the **geoforma_combina.tif** raster fields. To do so, follow these steps:

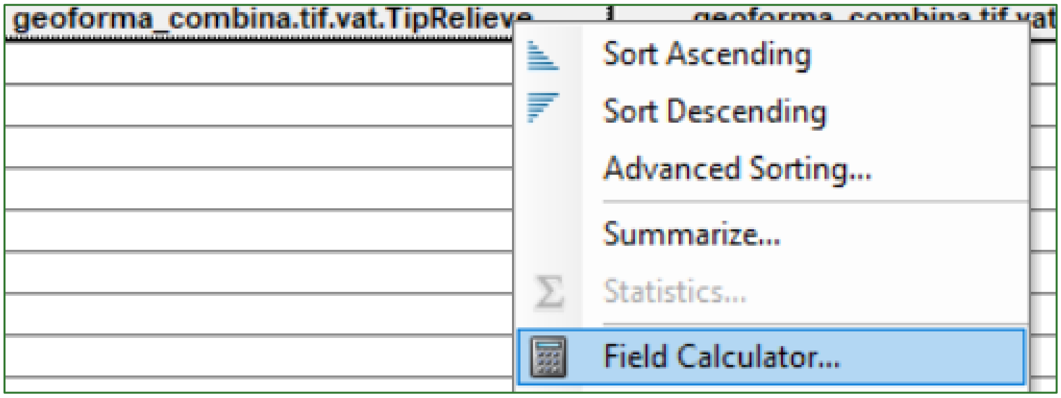
Right-click on the field geoforma_combina.tif.vat.ID_Relieve and select the **Field Calculator** option.



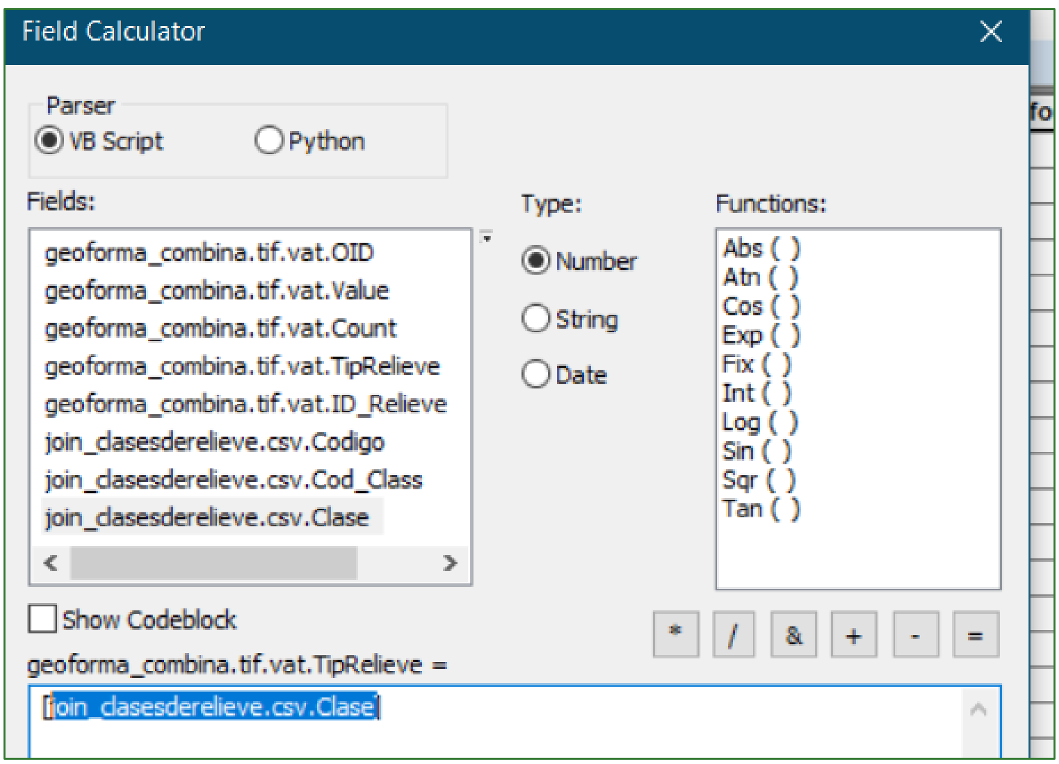
Double-click on **join_clasesderelieve.csv.Cod_Class** in the window that comes up and then on OK.



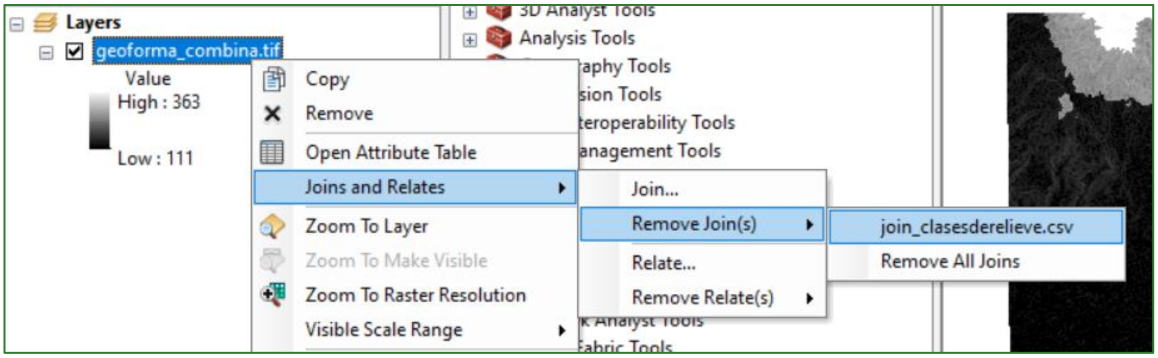
Right-click on the geoforma_combina.tif.vat.TipRelieve field and select the **Field Calculator** option.



Double-click on **join_clasesderelieve.csv.Clase** in the window that comes up and then on OK.

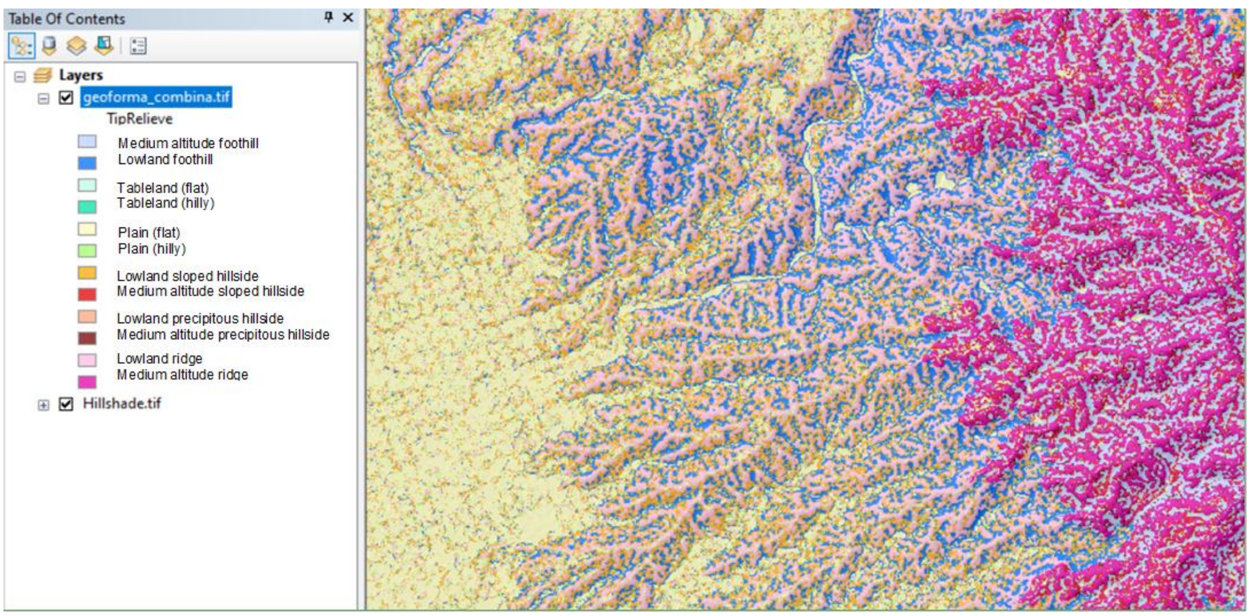


4. Close the table and undo the join by right-clicking on the **geoformas_combina.tif** raster and selecting the **Remove Join** option.



5. Reclassify the raster according to the type of relief. The output is illustrated below:

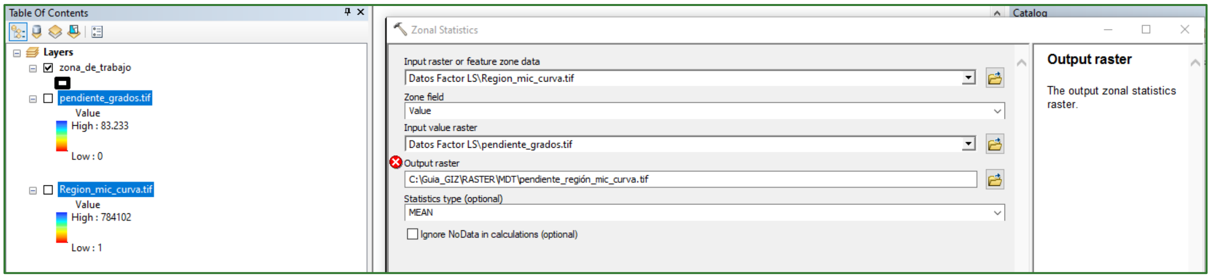
   A layer file with the "Geoforma combina" raster key format can be found in an online GitHub repository named "**geoforma_combina.tif.lyr**", which can be downloaded at the following address: https://github.com/guialandscape/Tablas



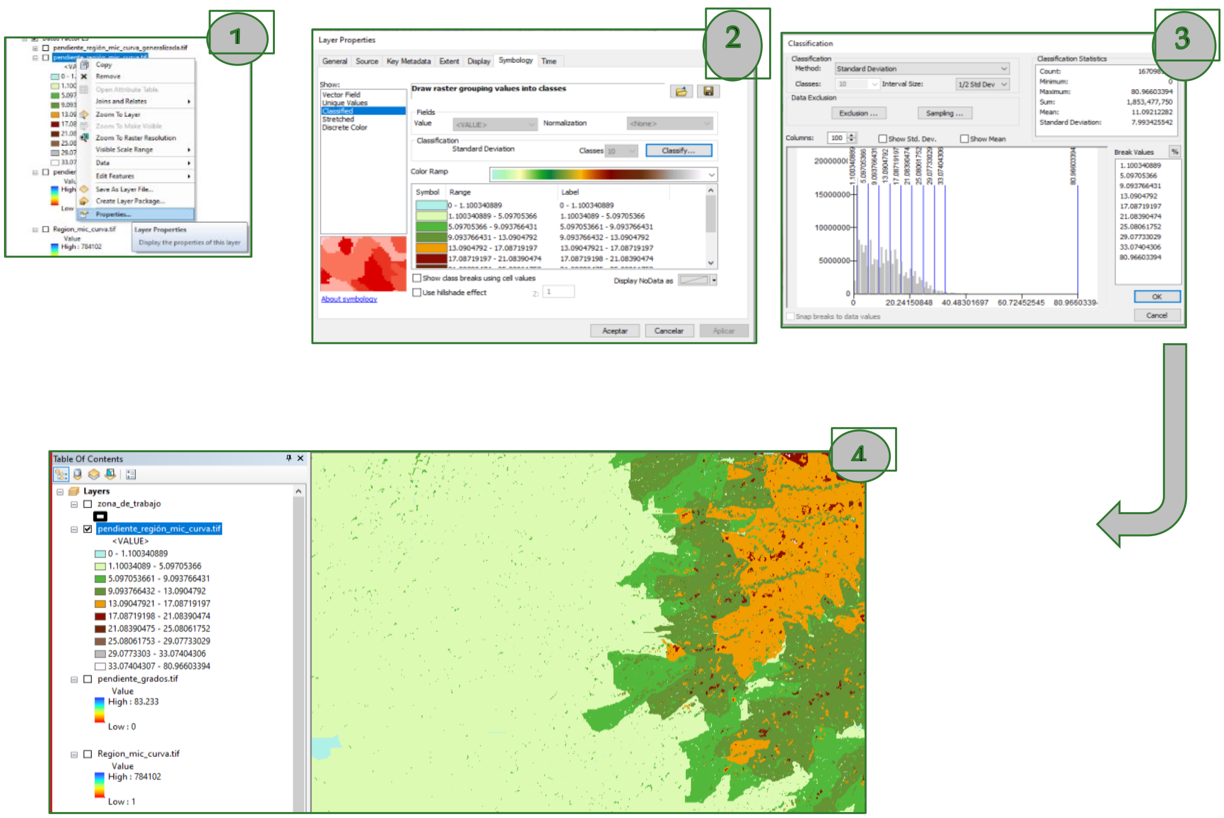
Generalising the slope on planes:

When working with such a detailed pixel size as in this study, some abrupt slope changes come up in flat areas. Accordingly, it is recommended that you:

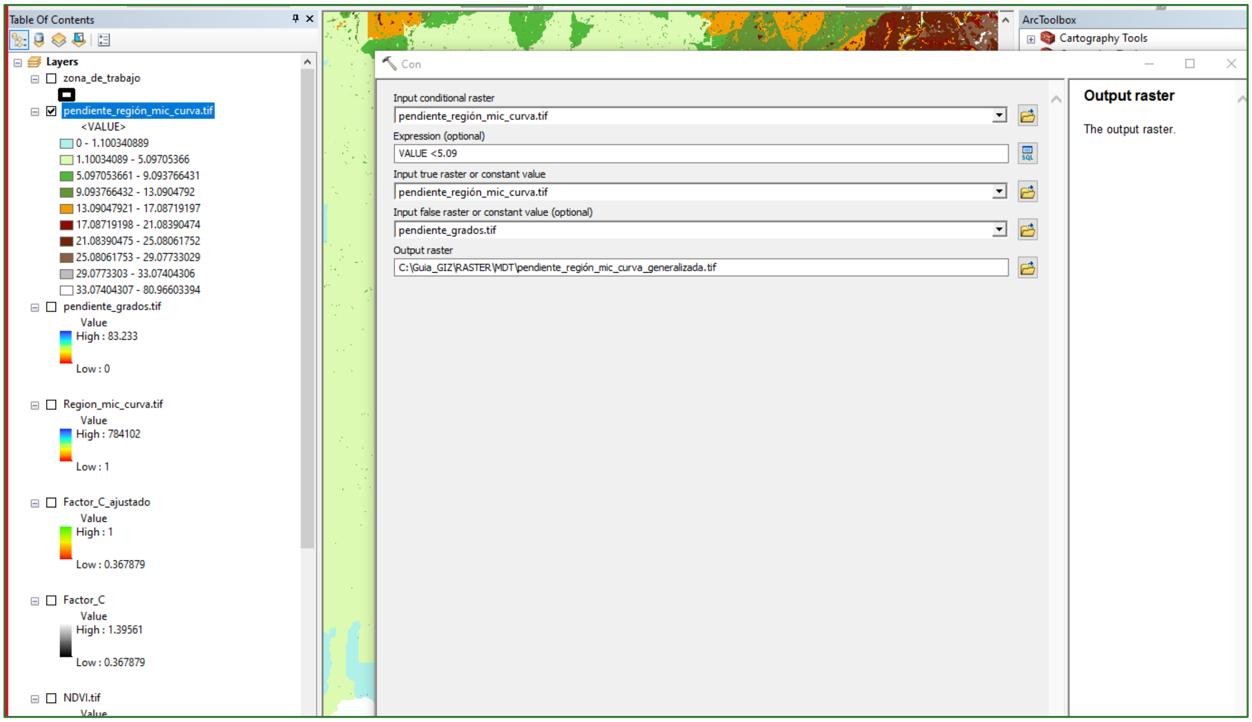
- Generalise these areas by calculating a slope mean for the geomorphological regions defined in the **región_mic_curva.tif** raster located in the **RASTER/MDT** folder.
- Apply zonal statistics using the **pendiente_grados.tif** and **región_mic_curva.tif** layer located in the **RASTER/MDT** folder and save the result in the **RASTER/MDT** folder, naming it **pendiente_region_mic_curva.tif.**



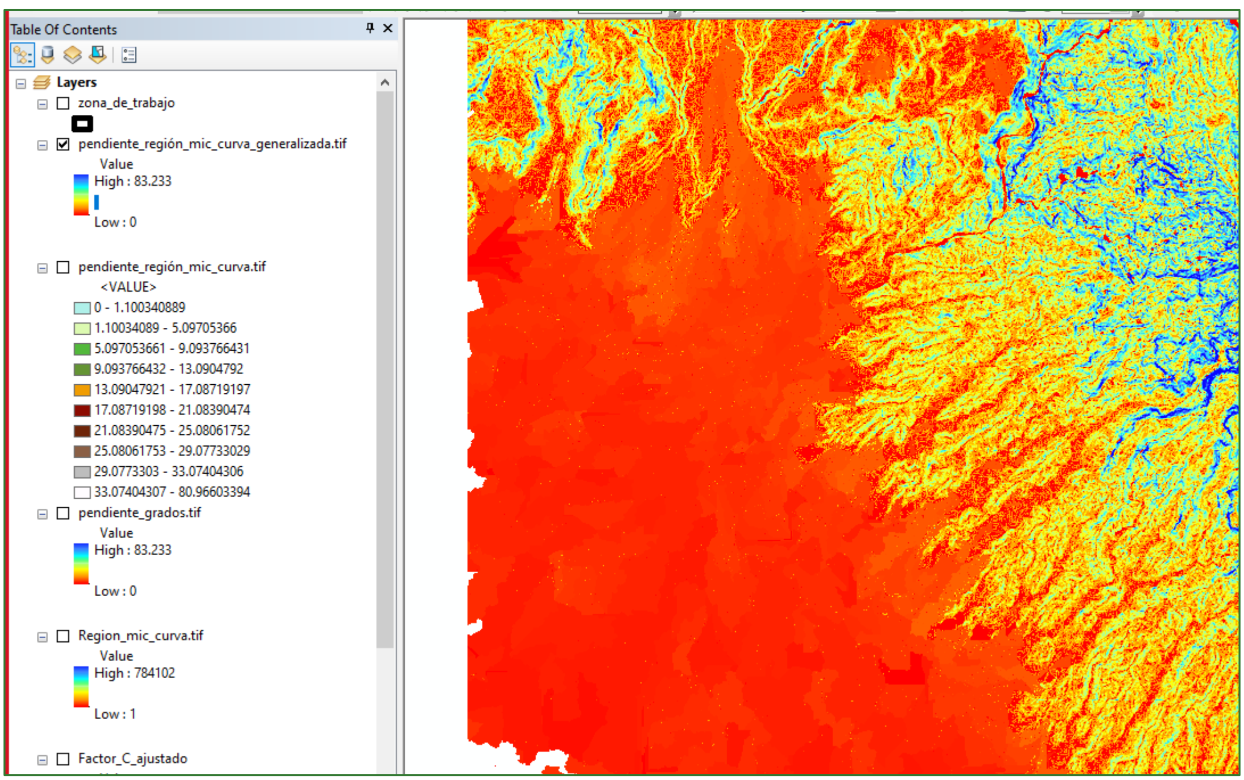
- Visually reclassify the **pendiente_región_mic_curva.tif** raster using ½ standard deviation and identify the lower limit threshold that defines the flat areas.
- You can see that the flat areas are between 1 and 5.



- Next, apply a condition so that all the pixels in the **pendiente_región_mic_curva.tif** raster are located within the lower threshold range in classifying the slopes into ½ standard deviation ranges and take the value of that raster in the **pendientes_grados.tif** layer. You must save the result in the **RASTER/MDT** folder naming it **pendiente_región_mic_curva_generalizada.tif.**



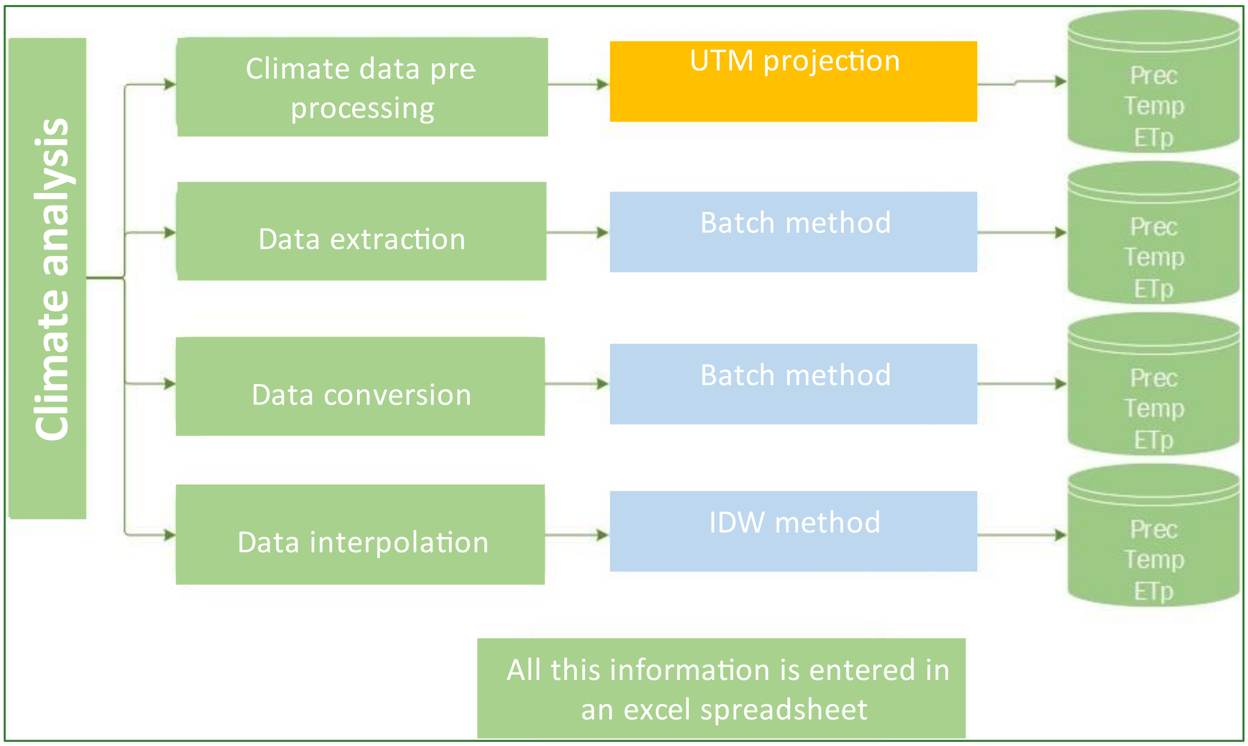
- The output will be displayed as follows:



Baseline data: Climate

Baseline data: Climate

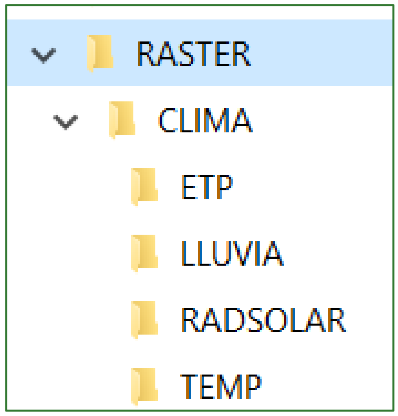
In this section you will carry out an analysis of the climate data as part of the baseline data preparation module. The climate data analysis is based on data on precipitation, temperature, solar radiation and evapotranspiration. The process includes the extraction of data from freely available web servers, as well as the conversion of numerical data into vector data by means of a systematic network of points. It ends with a series of interpolations in which values will be obtained for each one of the climate metrics in the entire project area. The data generated in this section will form the basis for the water erosion analysis covered later in this methodological guide.



The diagrams in this methodological guide are available in an online GitHub repository by clicking on the following link (Spanish original): https://github.com/guialandscape/Diagramas

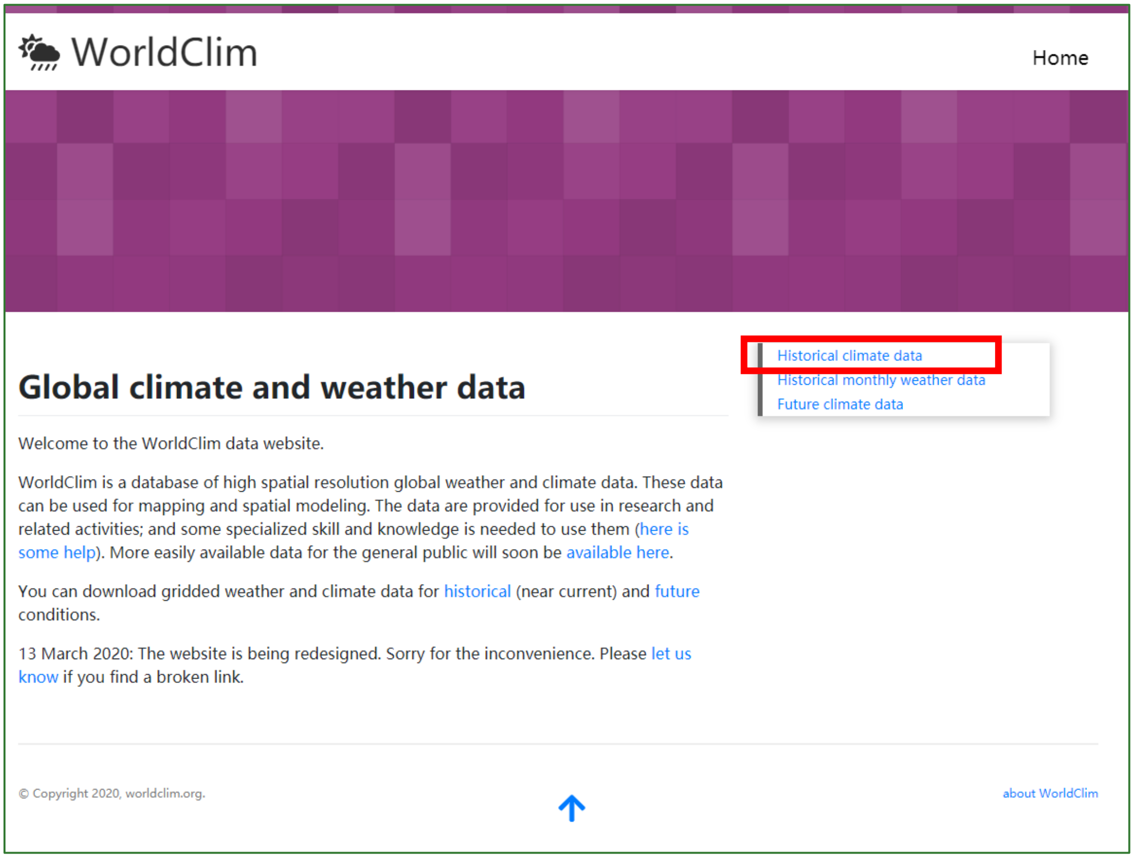
Part 6. Climate data pre-processing

1. Create a subfolder in the RASTER folder and name it CLIMA. Inside this subfolder, create the subfolders: ETP, LLUVIA, TEMP and RADSOLAR. These folders correspond to evapotranspiration (ETP), temperature (TEMP) and solar radiation (RADSOLAR).

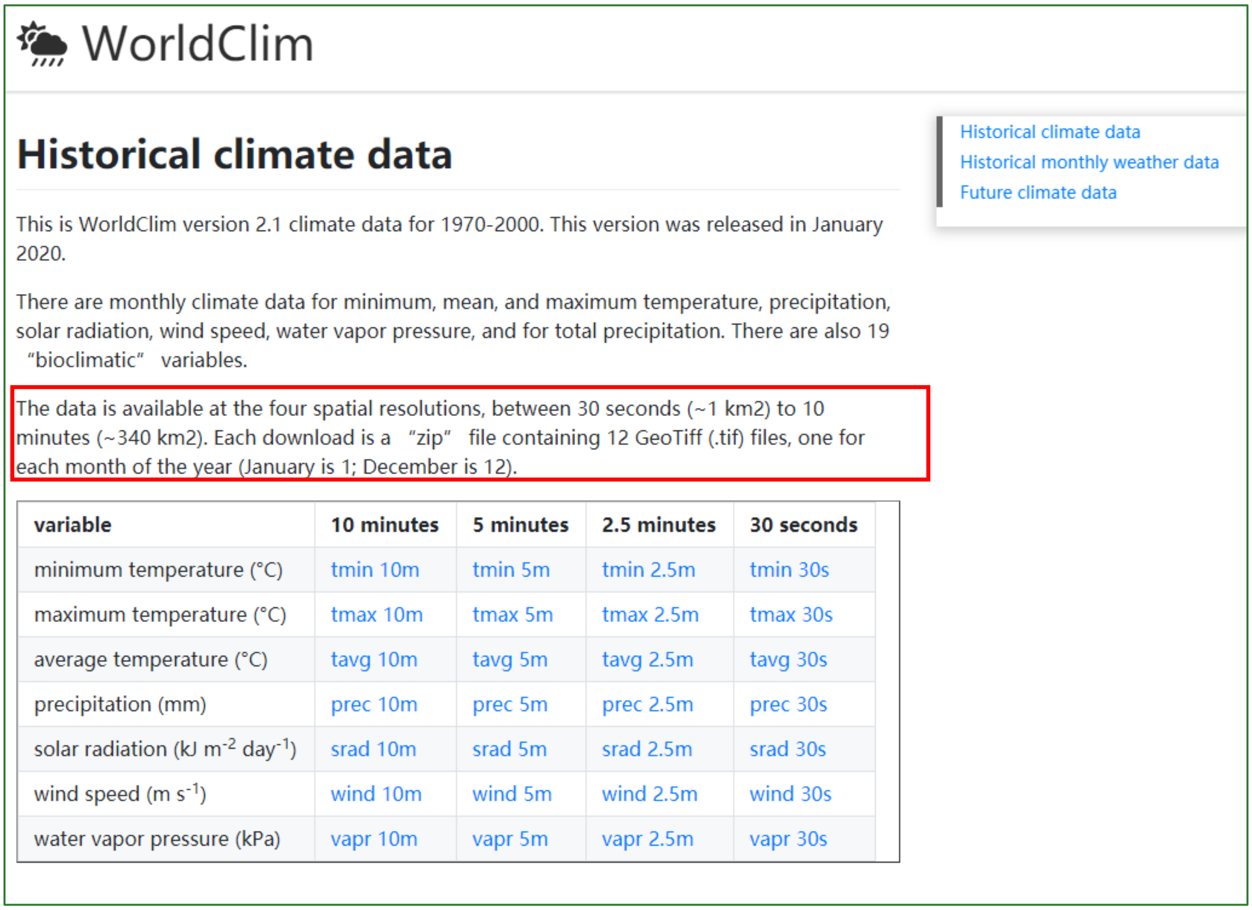


2. After creating the folders, download the precipitation, temperature and solar radiation data from the WorldClim platform (https://worldclim.org/data/index.html)

The following window will come up on screen:



Next, click the Historical climate data tab, which will open the following window:



WorldClim

Historical climate data

Historical monthly weather data

Future climate data

Historical climate data

This is WorldClim version 2.1 climate data for 1970-2000. This version was released in January 2020.

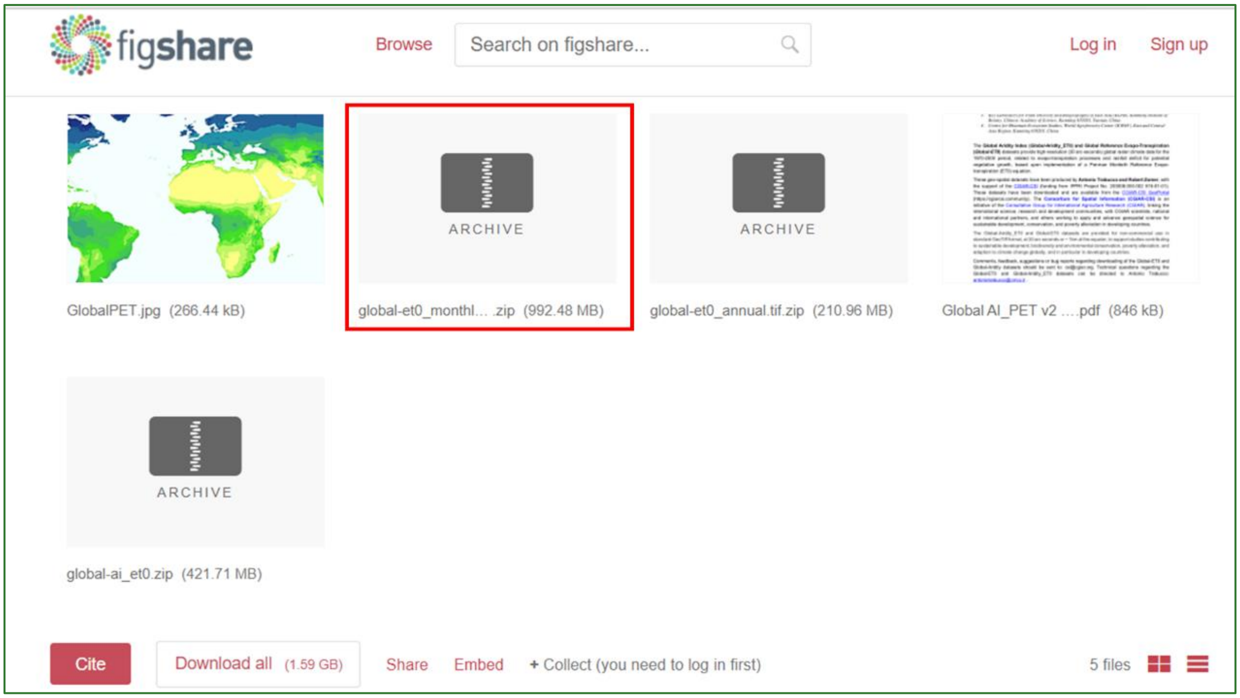
There are monthly climate data for minimum, mean, and maximum temperature, precipitation, solar radiation, wind speed, water vapor pressure, and for total precipitation. There are also 19 "bioclimatic" variables.

The data is available at the four spatial resolutions, between 30 seconds (~1 km2) to 10 minutes (~340 km2). Each download is a "zip" file containing 12 GeoTiff (.tif) files, one for each month of the year (January is 1; December is 12).

variable	10 minutes	5 minutes	2.5 minutes	30 seconds
minimum temperature (°C)	tmin 10m	tmin 5m	tmin 2.5m	tmin 30s
maximum temperature (°C)	tmax 10m	tmax 5m	tmax 2.5m	tmax 30s
average temperature (°C)	tavg 10m	tavg 5m	tavg 2.5m	tavg 30s
precipitation (mm)	prec 10m	prec 5m	prec 2.5m	prec 30s
solar radiation (kJ m^{-2} day^{-1})	srad 10m	srad 5m	srad 2.5m	srad 30s
wind speed (m s^{-1})	wind 10m	wind 5m	wind 2.5m	wind 30s
water vapor pressure (kPa)	vapr 10m	vapr 5m	vapr 2.5m	vapr 30s

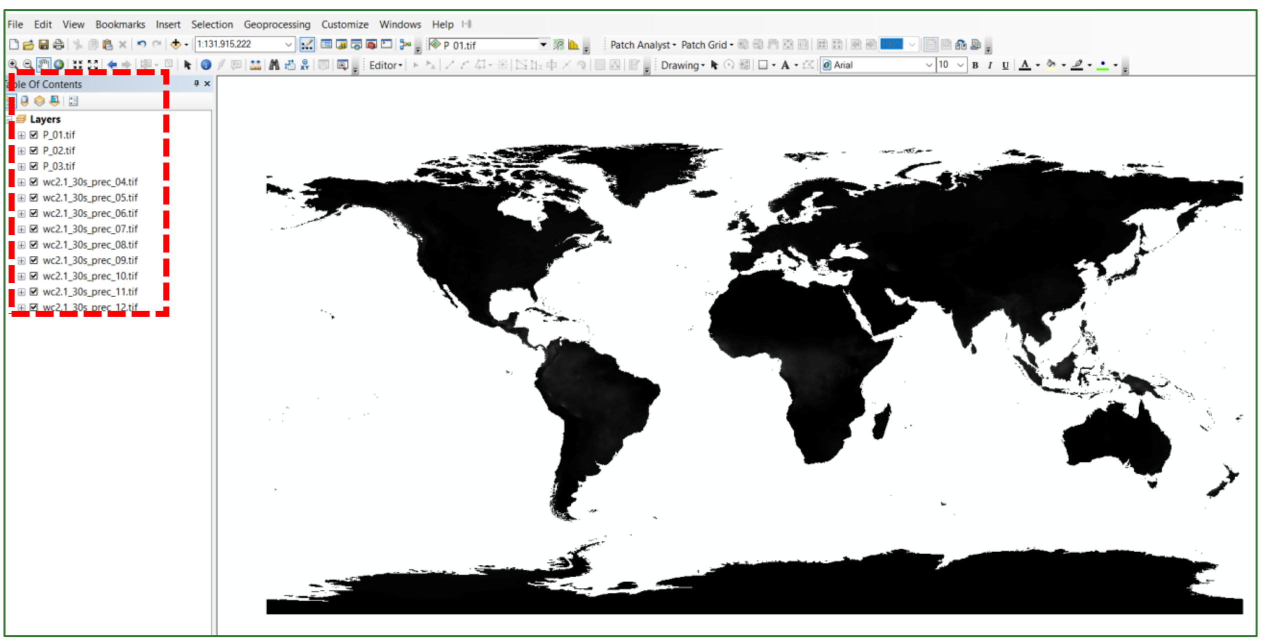
In this step, download the precipitation (mm), temperature (T) and solar radiation (RS) data with the highest resolution (30s ≈ 1 km^2) and save it in the GLOBAL_DATA/WorldClim folder.

3. Evapotranspiration (ETP) data can be downloaded from the following platform https://figshare.com/articles/Global_Aridity_Index_and_Potential_Evapotranspiration_ET0_Climate_Database_v2/7504448/3 and must also be saved in the GLOBAL_DATA/WorldClim folder.

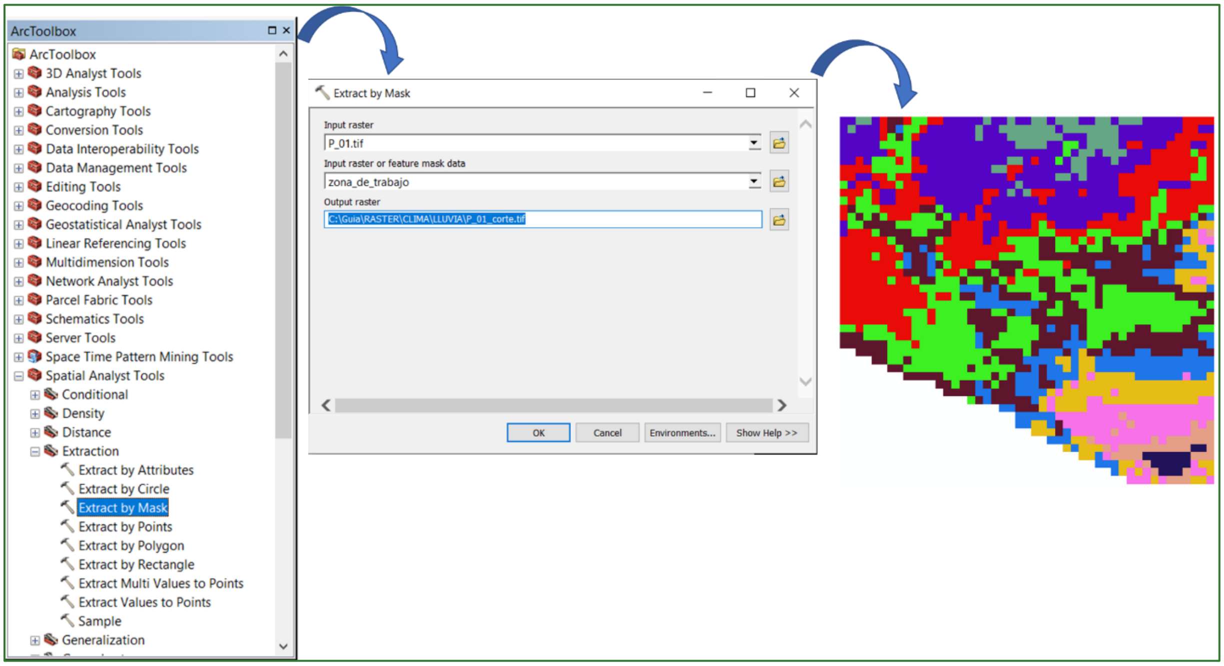


4. Now create a point mesh with annual mean data for climate variables (e.g. precipitation) calculated based on the data you have downloaded above and following these steps:

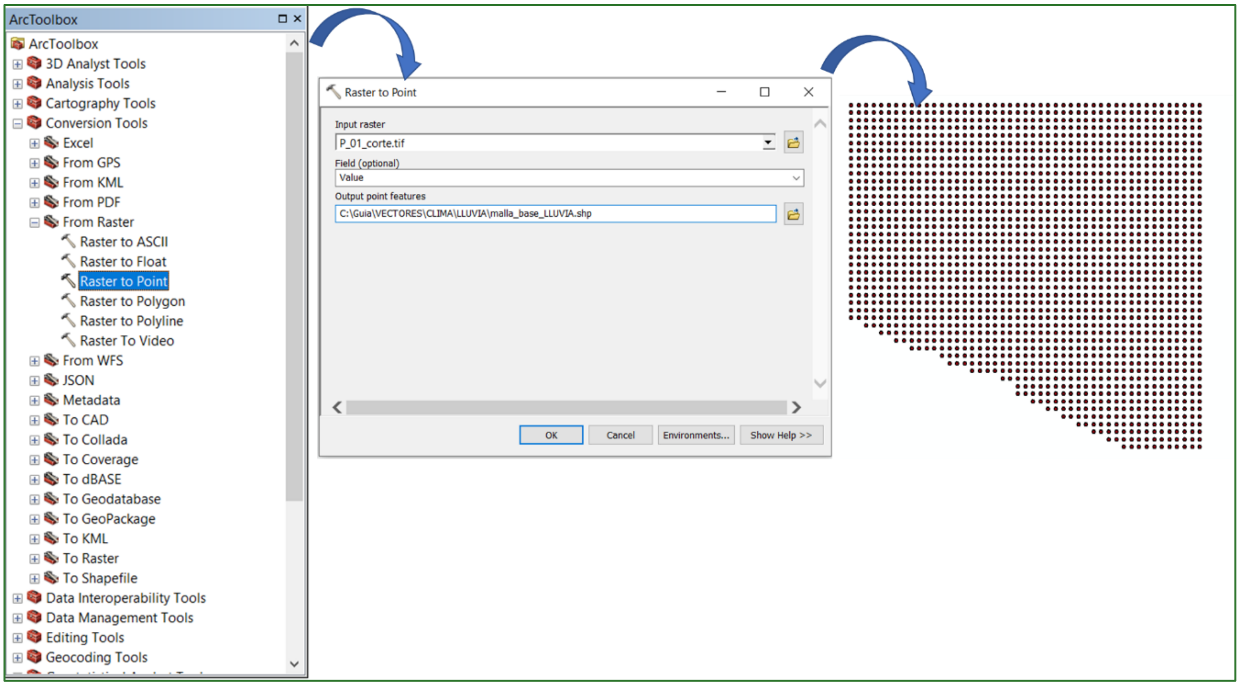
a) Load the monthly precipitation you obtained from WorldClim into ArcMap.
b) Once loaded in ArcMap, rename them as P1, P2, P3 according to the month.



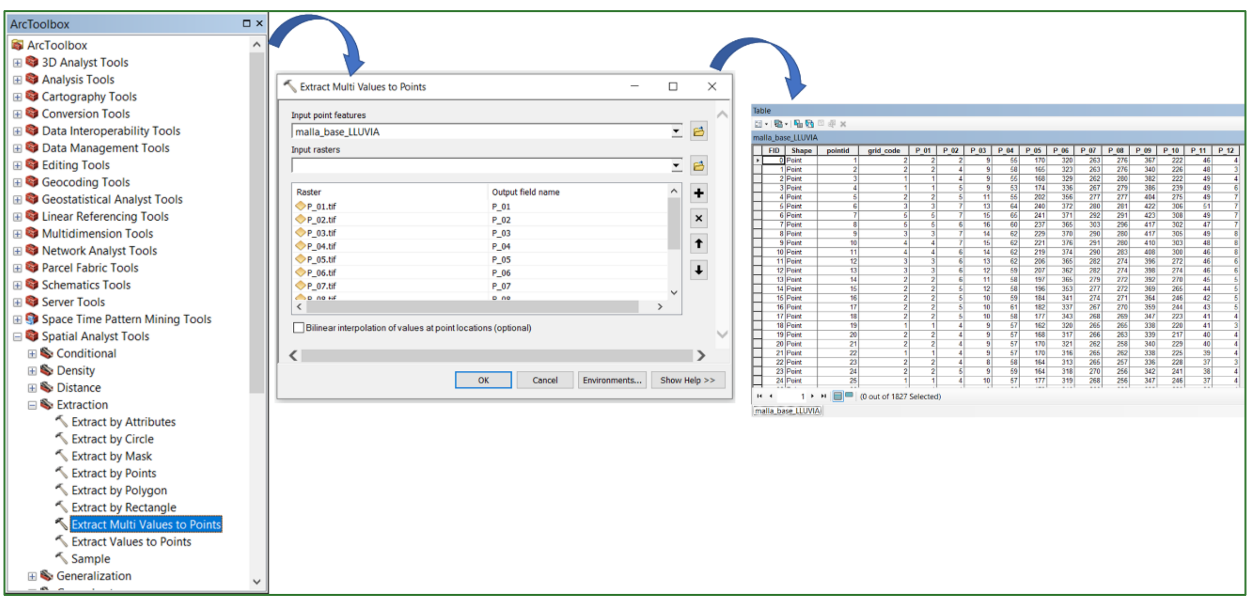
c) Next. cut one of the layers (for instance, P_01) with the study area layer called **zona_de_trabajo.shp**. Use the "Extract by Polygon" tool for this purpose. To this end, go to the **ArcToolBox/Spatial Analyst Tools/Extraction/Extract tool by Mask** and save the layer in the **RASTER\CLIMA\LLUVIA** folder, naming it **P_01_corte.tif.**



d) When you have done this, use the layer you named **P_01_corte.tif** which resulted from the process to generate a point mesh. In this way, each pixel will be converted to a point, resulting in a point mesh with information from the **P_01_corte.tif** raster. Use the "Raster to Point" tool for this procedure, located in: **ArcToolBox/Conversion Tools/From Raster/Raster to Point**. Save the file to the **RASTER\CLIMA\LLUVIA** folder, naming it **malla_base_LLUVIA.shp.**



e) Now carry out the procedure that will link the rain value for the 12 rasters (one per month) to the point mesh generated in the previous step. Use the "**Extract Multi Values To Point**" to do this. This is located in: **ArcToolBox/Spatial Analyst Tools/Extraction/ Extract Multi Values To Point**. Save the file in the **RASTER\CLIMA\LLUVIA** folder, without changing the name (**malla_base_LLUVIA.shp**)



Table

malla_base_LLUVIA

FID	Shape	pointid	grid_code	P_01	P_02	P_03	P_04	P_05	P_06	P_07	P_08	P_09	P_10	P_11	P_12
0	Point	1	2	2	2	9	55	170	320	263	276	367	222	46	4
1	Point	2	2	2	4	9	58	165	323	263	276	340	226	48	3
2	Point	3	1	1	4	9	55	168	329	262	280	382	222	49	4
3	Point	4	1	1	5	9	53	174	336	267	279	386	239	49	6
4	Point	5	2	2	5	11	55	202	356	277	277	404	275	49	7
5	Point	6	3	3	7	13	64	240	372	280	281	422	306	51	7
6	Point	7	5	5	7	15	65	241	371	292	291	423	308	49	7
7	Point	8	5	5	6	16	60	237	365	303	296	417	302	47	7
8	Point	9	3	3	7	14	62	229	370	290	280	417	305	49	8
9	Point	10	4	4	7	15	62	221	376	291	280	410	303	48	8
10	Point	11	4	4	6	14	62	219	374	290	283	408	300	46	8
11	Point	12	3	3	6	13	62	206	365	282	274	396	272	46	6
12	Point	13	3	3	6	12	59	207	362	282	274	398	274	46	6
13	Point	14	2	2	6	11	58	197	365	279	272	392	270	45	5
14	Point	15	2	2	5	12	58	196	353	277	272	369	265	44	5
15	Point	16	2	2	5	10	59	184	341	274	271	364	246	42	5
16	Point	17	2	2	5	10	61	182	337	267	270	359	244	43	5
17	Point	18	2	2	5	10	58	177	343	268	269	347	223	41	4
18	Point	19	1	1	4	9	57	162	320	265	265	338	220	41	3
19	Point	20	2	2	4	9	57	168	317	266	263	339	217	40	4
20	Point	21	2	2	4	9	57	170	321	262	258	340	229	40	4
21	Point	22	1	1	4	9	57	170	316	265	262	338	225	39	4
22	Point	23	2	2	4	8	58	164	313	265	257	336	228	37	3
23	Point	24	2	2	5	9	59	164	318	270	256	342	241	38	4
24	Point	25	1	1	4	10	57	177	319	268	256	347	246	37	4

1 (0 out of 1827 Selected)

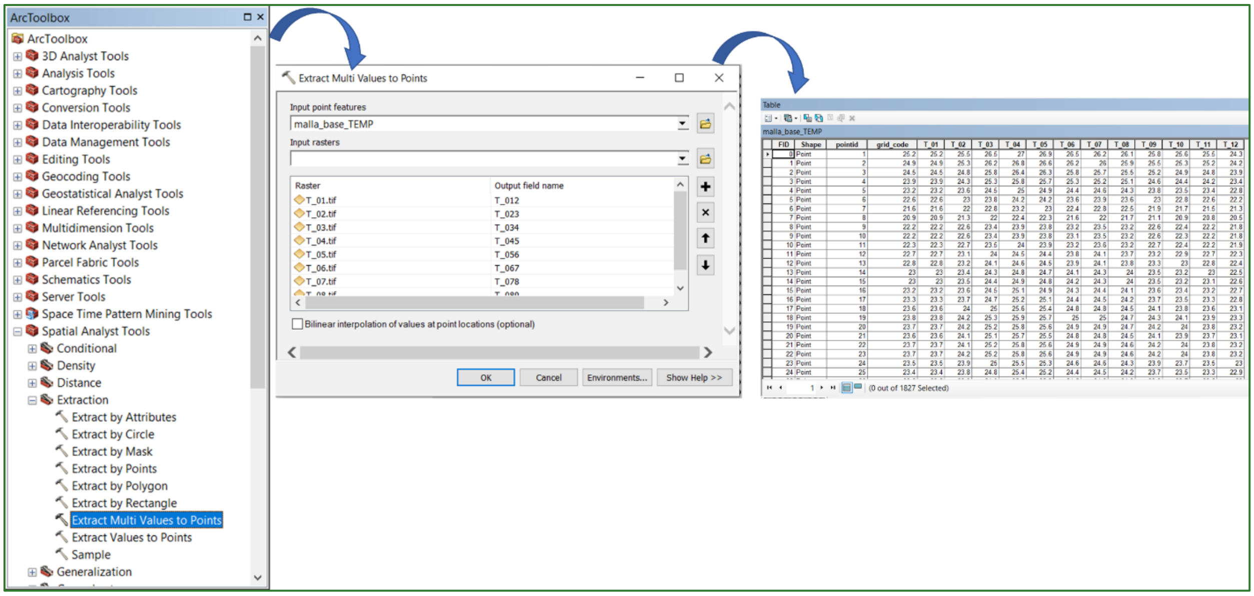
malla_base_LLUVIA

f) You now have a point mesh systematically separated every 1 km with mean monthly precipitation information for each of the 12 months with data from WorldClim. The file is a vector named **malla_base_LLUVIA.shp** and saved in the **RASTER\CLIMA\LLUVIA** folder.

g) Lastly, the point mesh needs to be reprojected onto the coordinate system of your country following the steps given in PART 1, entitled "PART 1. PROJECTING THE COUNTRY'S GEODESIC SYSTEM LAYERS", given herein.

h) The same procedure must be followed for Temperature, Solar Radiation and Evapotranspiration data. A series of figures are provided below regarding the procedure to be followed.

TEMPERATURE: save this in the **RASTER\CLIMA\TEMP** folder, naming it **malla_base_TEMP.shp.**



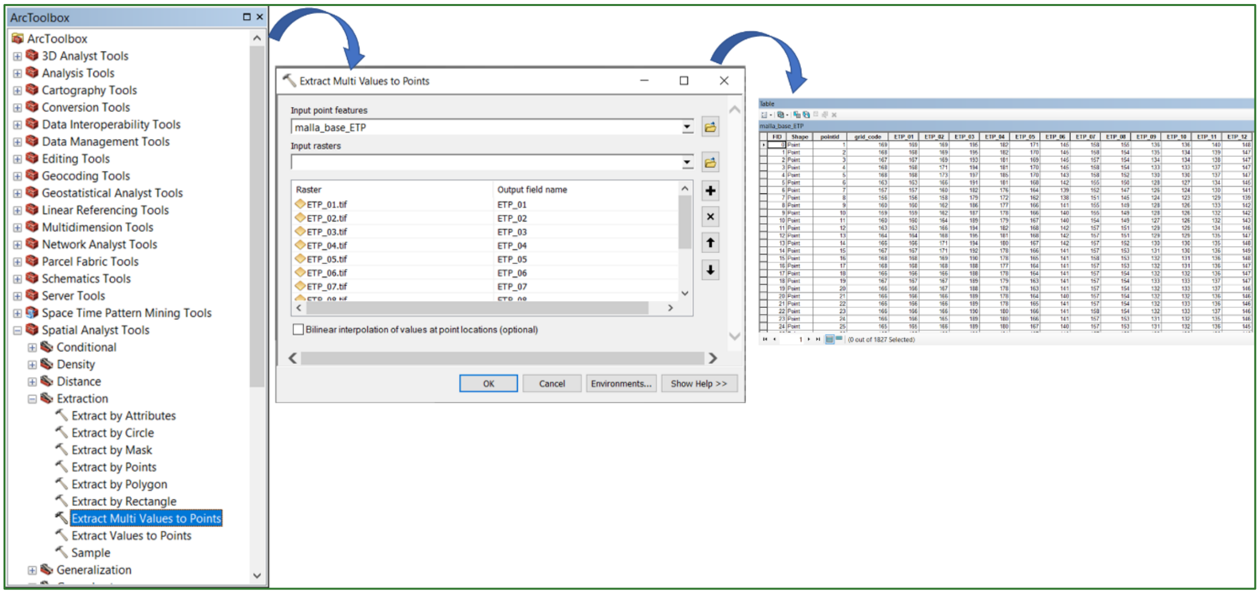
Table

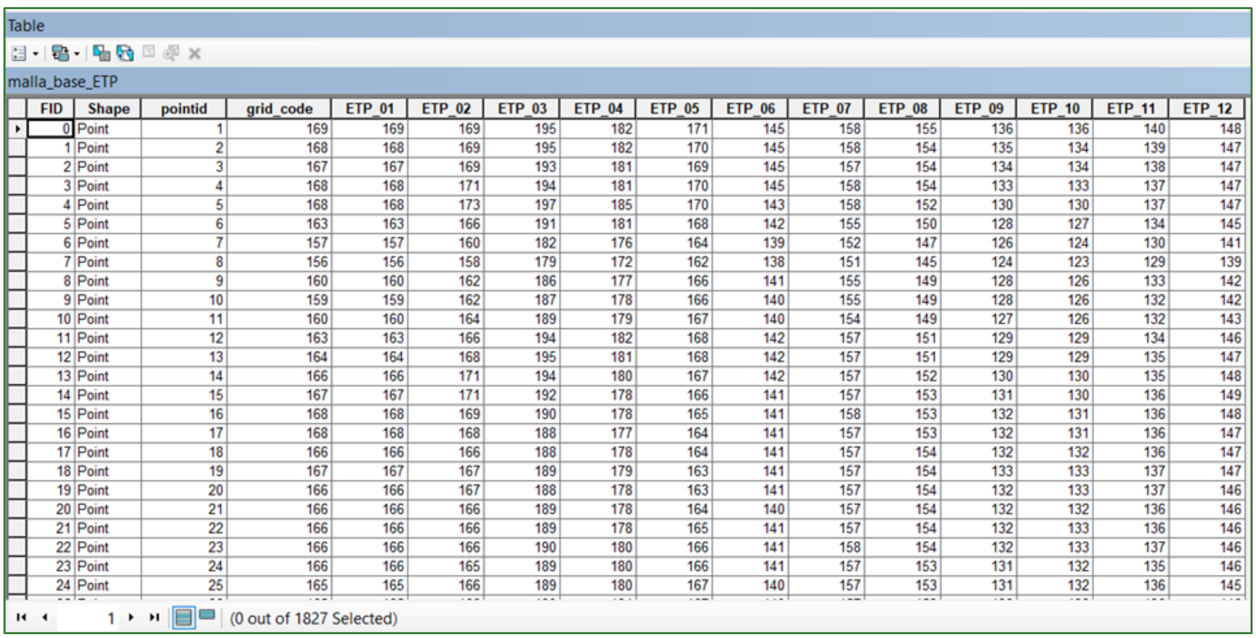
malla_base_TEMP

FID	Shape	pointid	grid_code	T_01	T_02	T_03	T_04	T_05	T_06	T_07	T_08	T_09	T_10	T_11	T_12
0	Point	1	25.2	25.2	25.5	26.5	27	26.9	26.5	26.2	26.1	25.8	25.6	25.5	24.3
1	Point	2	24.9	24.9	25.3	26.2	26.8	26.6	26.2	26	25.9	25.5	25.3	25.2	24.2
2	Point	3	24.5	24.5	24.8	25.8	26.4	26.3	25.8	25.7	25.5	25.2	24.9	24.8	23.9
3	Point	4	23.9	23.9	24.3	25.3	25.8	25.7	25.3	25.2	25.1	24.6	24.4	24.2	23.4
4	Point	5	23.2	23.2	23.6	24.5	25	24.9	24.4	24.6	24.3	23.8	23.5	23.4	22.8
5	Point	6	22.6	22.6	23	23.8	24.2	24.2	23.6	23.9	23.6	23	22.8	22.6	22.2
6	Point	7	21.6	21.6	22	22.8	23.2	23	22.4	22.8	22.5	21.9	21.7	21.5	21.3
7	Point	8	20.9	20.9	21.3	22	22.4	22.3	21.6	22	21.7	21.1	20.9	20.8	20.5
8	Point	9	22.2	22.2	22.6	23.4	23.9	23.8	23.2	23.5	23.2	22.6	22.4	22.2	21.8
9	Point	10	22.2	22.2	22.6	23.4	23.9	23.8	23.1	23.5	23.2	22.6	22.3	22.2	21.8
10	Point	11	22.3	22.3	22.7	23.5	24	23.9	23.2	23.6	23.2	22.7	22.4	22.2	21.9
11	Point	12	22.7	22.7	23.1	24	24.5	24.4	23.8	24.1	23.7	23.2	22.9	22.7	22.3
12	Point	13	22.8	22.8	23.2	24.1	24.6	24.5	23.9	24.1	23.8	23.3	23	22.8	22.4
13	Point	14	23	23	23.4	24.3	24.8	24.7	24.1	24.3	24	23.5	23.2	23	22.5
14	Point	15	23	23	23.5	24.4	24.9	24.8	24.2	24.3	24	23.5	23.2	23.1	22.6
15	Point	16	23.2	23.2	23.6	24.5	25.1	24.9	24.3	24.4	24.1	23.6	23.4	23.2	22.7
16	Point	17	23.3	23.3	23.7	24.7	25.2	25.1	24.4	24.5	24.2	23.7	23.5	23.3	22.8
17	Point	18	23.6	23.6	24	25	25.6	25.4	24.8	24.8	24.5	24.1	23.8	23.6	23.1
18	Point	19	23.8	23.8	24.2	25.3	25.9	25.7	25	25	24.7	24.3	24.1	23.9	23.3
19	Point	20	23.7	23.7	24.2	25.2	25.8	25.6	24.9	24.9	24.7	24.2	24	23.8	23.2
20	Point	21	23.6	23.6	24.1	25.1	25.7	25.5	24.8	24.8	24.5	24.1	23.9	23.7	23.1
21	Point	22	23.7	23.7	24.1	25.2	25.8	25.6	24.9	24.9	24.6	24.2	24	23.8	23.2
22	Point	23	23.7	23.7	24.2	25.2	25.8	25.6	24.9	24.9	24.6	24.2	24	23.8	23.2
23	Point	24	23.5	23.5	23.9	25	25.5	25.3	24.6	24.6	24.3	23.9	23.7	23.5	23
24	Point	25	23.4	23.4	23.8	24.8	25.4	25.2	24.4	24.5	24.2	23.7	23.5	23.3	22.9

1 (0 out of 1827 Selected)

EVAPOTRANSPIRATION: save this in the **RASTER\CLIMA\ETP** folder, naming it **malla_base_ETP.shp.**





Table

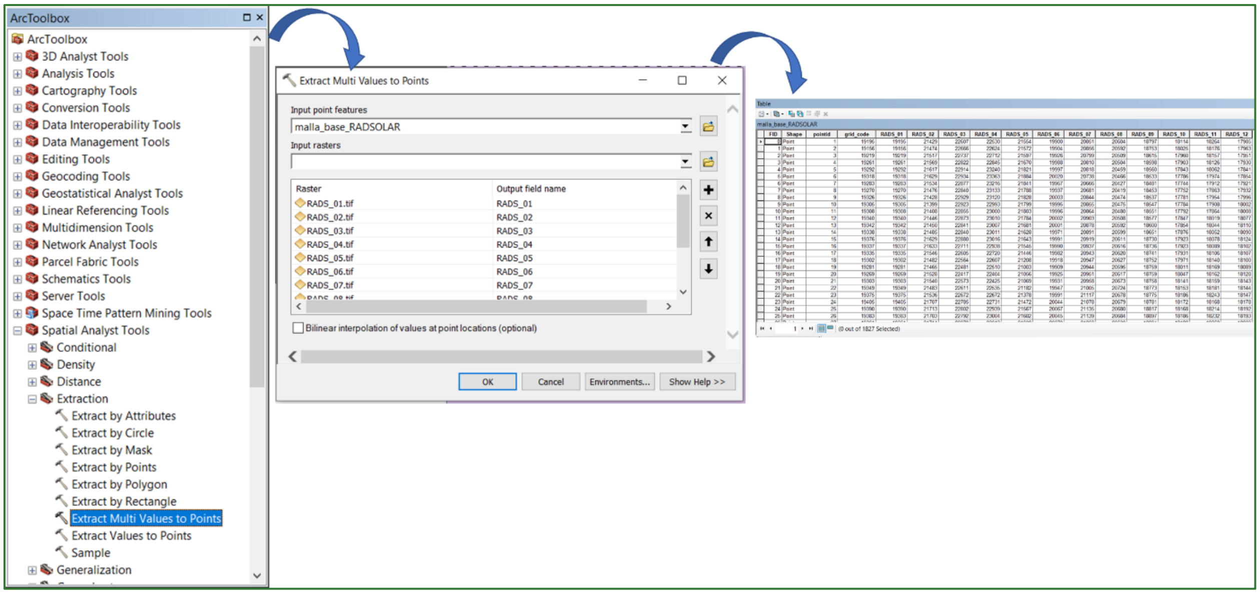
malla_base_ETP

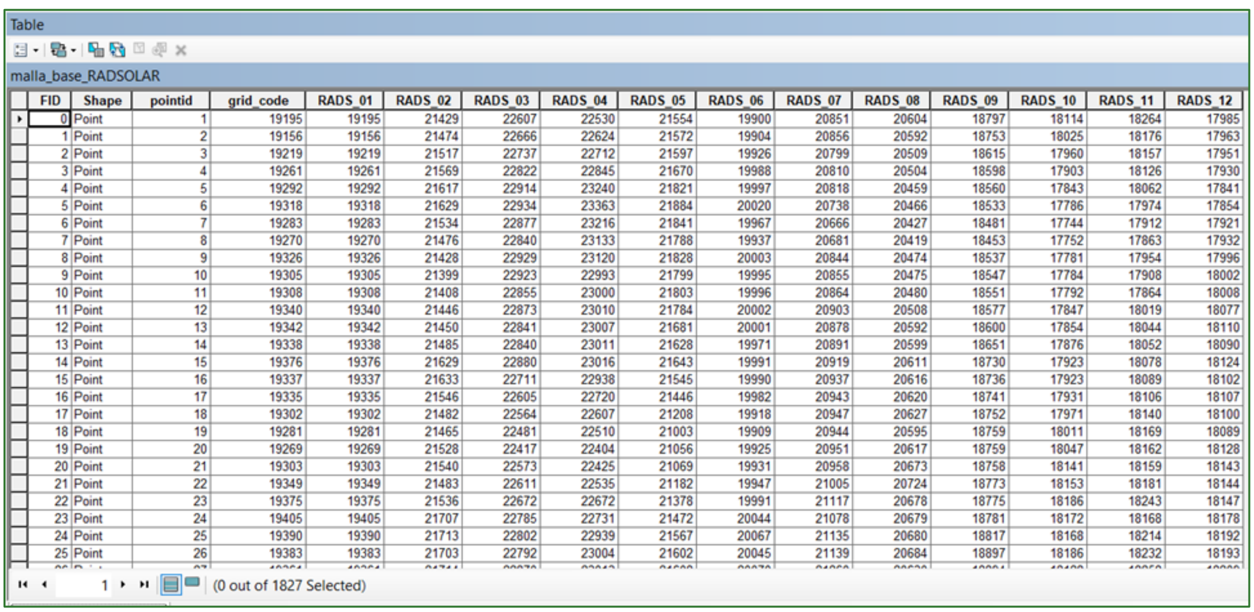
FID	Shape	pointid	grid_code	ETP_01	ETP_02	ETP_03	ETP_04	ETP_05	ETP_06	ETP_07	ETP_08	ETP_09	ETP_10	ETP_11	ETP_12
0	Point	1	169	169	169	195	182	171	145	158	155	136	136	140	148
1	Point	2	168	168	169	195	182	170	145	158	154	135	134	139	147
2	Point	3	167	167	169	193	181	169	145	157	154	134	134	138	147
3	Point	4	168	168	171	194	181	170	145	158	154	133	133	137	147
4	Point	5	168	168	173	197	185	170	143	158	152	130	130	137	147
5	Point	6	163	163	166	191	181	168	142	155	150	128	127	134	145
6	Point	7	157	157	160	182	176	164	139	152	147	126	124	130	141
7	Point	8	156	156	158	179	172	162	138	151	145	124	123	129	139
8	Point	9	160	160	162	186	177	166	141	155	149	128	126	133	142
9	Point	10	159	159	162	187	178	166	140	155	149	128	126	132	142
10	Point	11	160	160	164	189	179	167	140	154	149	127	126	132	143
11	Point	12	163	163	166	194	182	168	142	157	151	129	129	134	146
12	Point	13	164	164	168	195	181	168	142	157	151	129	129	135	147
13	Point	14	166	166	171	194	180	167	142	157	152	130	130	135	148
14	Point	15	167	167	171	192	178	166	141	157	153	131	130	136	149
15	Point	16	168	168	169	190	178	165	141	158	153	132	131	136	148
16	Point	17	168	168	168	188	177	164	141	157	153	132	131	136	147
17	Point	18	166	166	166	188	178	164	141	157	154	132	132	136	147
18	Point	19	167	167	167	189	179	163	141	157	154	133	133	137	147
19	Point	20	166	166	167	188	178	163	141	157	154	132	133	137	146
20	Point	21	166	166	166	189	178	164	140	157	154	132	132	136	146
21	Point	22	166	166	166	189	178	165	141	157	154	132	133	136	146
22	Point	23	166	166	166	190	180	166	141	158	154	132	133	137	146
23	Point	24	166	166	165	189	180	166	141	157	153	131	132	135	146
24	Point	25	165	165	166	189	180	167	140	157	153	131	132	136	145

1 (0 out of 1827 Selected)

SOLAR RADIATION: save it in the **RASTER\CLIMA\RADSOLAR** folder, naming it **malla_base_RADSOLAR.shp.**

N.B.: in the case of solar radiation the fields must be renamed with shorter names (RADS) as indicated below:





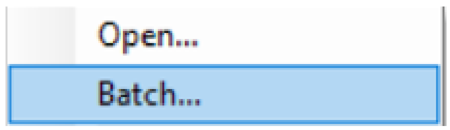
Table

malla_base_RADSOLAR

FID	Shape	pointid	grid_code	RADS_01	RADS_02	RADS_03	RADS_04	RADS_05	RADS_06	RADS_07	RADS_08	RADS_09	RADS_10	RADS_11	RADS_12
0	Point	1	19195	19195	21429	22607	22530	21554	19900	20851	20604	18797	18114	18264	17985
1	Point	2	19156	19156	21474	22666	22624	21572	19904	20856	20592	18753	18025	18176	17963
2	Point	3	19219	19219	21517	22737	22712	21597	19926	20799	20509	18615	17960	18157	17951
3	Point	4	19261	19261	21569	22822	22845	21670	19988	20810	20504	18598	17903	18126	17930
4	Point	5	19292	19292	21617	22914	23240	21821	19997	20818	20459	18560	17843	18062	17841
5	Point	6	19318	19318	21629	22934	23363	21884	20020	20738	20466	18533	17786	17974	17854
6	Point	7	19283	19283	21534	22877	23216	21841	19967	20666	20427	18481	17744	17912	17921
7	Point	8	19270	19270	21476	22840	23133	21788	19937	20681	20419	18453	17752	17863	17932
8	Point	9	19326	19326	21428	22929	23120	21828	20003	20844	20474	18537	17781	17954	17996
9	Point	10	19305	19305	21399	22923	22993	21799	19995	20855	20475	18547	17784	17908	18002
10	Point	11	19308	19308	21408	22855	23000	21803	19996	20864	20480	18551	17792	17864	18008
11	Point	12	19340	19340	21446	22873	23010	21784	20002	20903	20508	18577	17847	18019	18077
12	Point	13	19342	19342	21450	22841	23007	21681	20001	20878	20592	18600	17854	18044	18110
13	Point	14	19338	19338	21485	22840	23011	21628	19971	20891	20599	18651	17876	18052	18090
14	Point	15	19376	19376	21629	22880	23016	21643	19991	20919	20611	18730	17923	18078	18124
15	Point	16	19337	19337	21633	22711	22938	21545	19990	20937	20616	18736	17923	18089	18102
16	Point	17	19335	19335	21546	22605	22720	21446	19982	20943	20620	18741	17931	18106	18107
17	Point	18	19302	19302	21482	22564	22607	21208	19918	20947	20627	18752	17971	18140	18100
18	Point	19	19281	19281	21465	22481	22510	21003	19909	20944	20595	18759	18011	18169	18089
19	Point	20	19269	19269	21528	22417	22404	21056	19925	20951	20617	18759	18047	18162	18128
20	Point	21	19303	19303	21540	22573	22425	21069	19931	20958	20673	18758	18141	18159	18143
21	Point	22	19349	19349	21483	22611	22535	21182	19947	21005	20724	18773	18153	18181	18144
22	Point	23	19375	19375	21536	22672	22672	21378	19991	21117	20678	18775	18186	18243	18147
23	Point	24	19405	19405	21707	22785	22731	21472	20044	21078	20679	18781	18172	18168	18178
24	Point	25	19390	19390	21713	22802	22939	21567	20067	21135	20680	18817	18168	18214	18192
25	Point	26	19383	19383	21703	22792	23004	21602	20045	21139	20684	18897	18186	18232	18193

1 (0 out of 1827 Selected)

5. It is now ready for the interpolations of each of the monthly climate variables for the study area. Use the **Spatial AnalystTools/Interpolation/IDW** tool to do so, but apply the **Batch** procedure explained above.



Follow the instructions to complete each field in the Batch table:

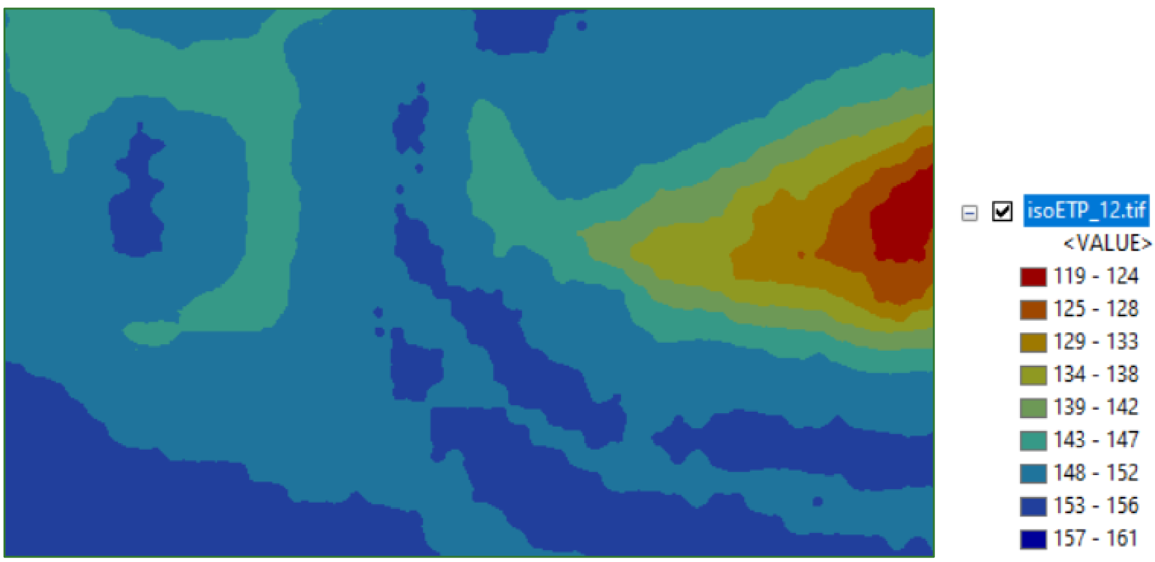
	Input point features	Z value field	Output raster
1	malla_base_ETP	ETP_01	C:\SIG_FDV_Pais_X\RASTER\CLIMA\ETP\iso_ETP_01.tif

Input point features	Select the corresponding climate variable mesh, for example, **malla_base_ETP**
Z value field	Select the field that contains the values for each month, for example: ETP_01 ETP_02 …
Output raster	Enter the raster output name. Use the prefix **iso** before the name of each monthly raster and save it in the RASTER/CLIMA folder: for example, CLIMA\ETP\isoETP_01.tif CLIMA\ETP\isoETP_02.tif …

The ETP Batch table should look as shown below. Follow the same logic for the other variables.

	Input point features	Z value field	Output raster
1	malla_base_ETP	ETP_01	C:\SIG_FDV_Pais_X\RASTER\CLIMA\ETP\iso_ETP_01.tif
2	malla_base_ETP	ETP_02	C:\SIG_FDV_Pais_X\RASTER\CLIMA\ETP\iso_ETP_02.tif
3	malla_base_ETP	ETP_03	C:\SIG_FDV_Pais_X\RASTER\CLIMA\ETP\iso_ETP_03.tif
4	malla_base_ETP	ETP_04	C:\SIG_FDV_Pais_X\RASTER\CLIMA\ETP\iso_ETP_04.tif
5	malla_base_ETP	ETP_05	C:\SIG_FDV_Pais_X\RASTER\CLIMA\ETP\iso_ETP_05.tif
6	malla_base_ETP	ETP_06	C:\SIG_FDV_Pais_X\RASTER\CLIMA\ETP\iso_ETP_06.tif
7	malla_base_ETP	ETP_07	C:\SIG_FDV_Pais_X\RASTER\CLIMA\ETP\iso_ETP_07.tif
8	malla_base_ETP	ETP_08	C:\SIG_FDV_Pais_X\RASTER\CLIMA\ETP\iso_ETP_08.tif
9	malla_base_ETP	ETP_09	C:\SIG_FDV_Pais_X\RASTER\CLIMA\ETP\iso_ETP_09.tif
10	malla_base_ETP	ETP_10	C:\SIG_FDV_Pais_X\RASTER\CLIMA\ETP\iso_ETP_10.tif
11	malla_base_ETP	ETP_11	C:\SIG_FDV_Pais_X\RASTER\CLIMA\ETP\iso_ETP_11.tif
12	malla_base_ETP	ETP_12	C:\SIG_FDV_Pais_X\RASTER\CLIMA\ETP\iso_ETP_12.tif

An example of one of the interpolated rasters is shown below:

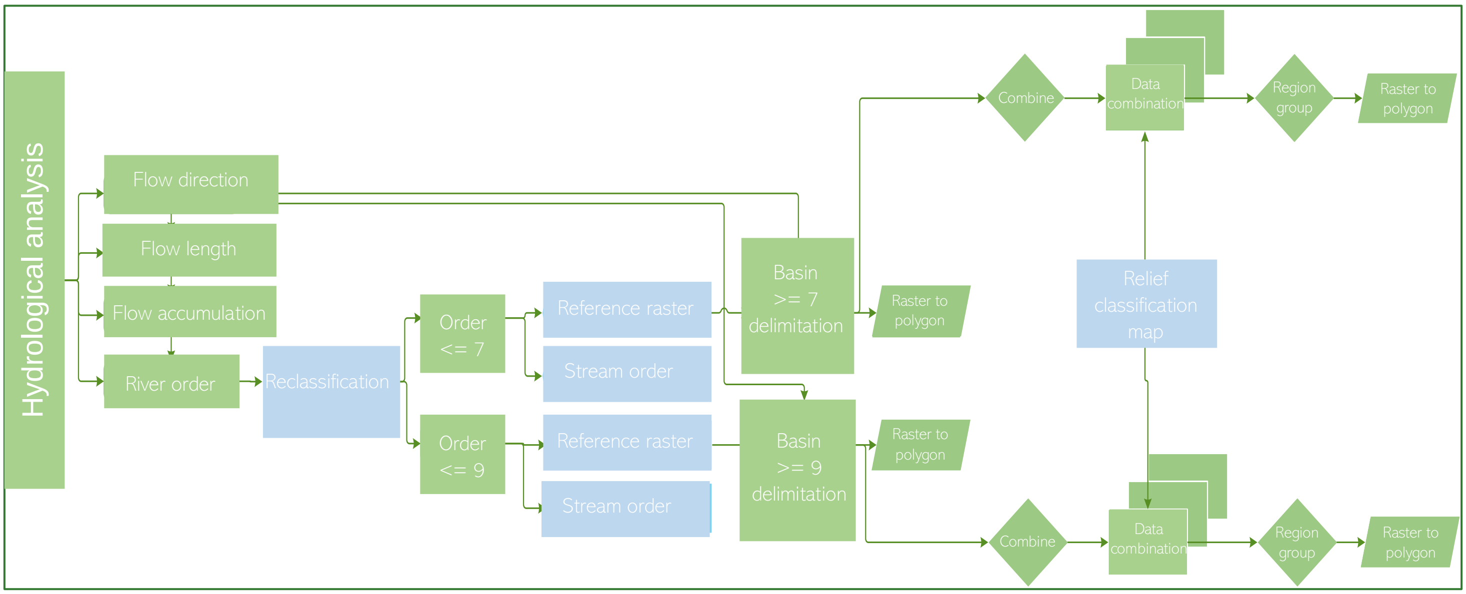


General considerations: in this exercise, data from global information sources are used to work with homogenous data from known sources. If you have information from other, national sources, you can use them by applying the method explained above.

Baseline data: Hydrography

Baseline data: Hydrography

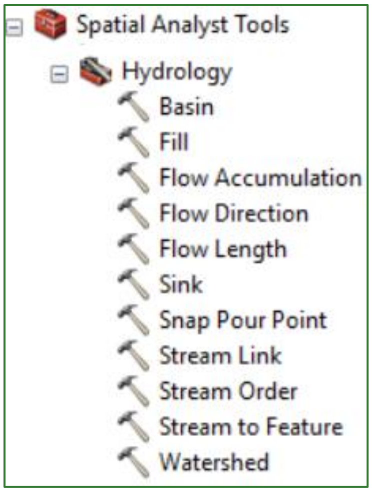
This section shows you how to carry out a hydrological analysis. You will model a series of hydrographic data such as flow, surface runoff and the delimitation of hydrological basins and sub-basins. The data generated in this section will form the basis for the water erosion and infiltration analysis covered later in this methodological guide.



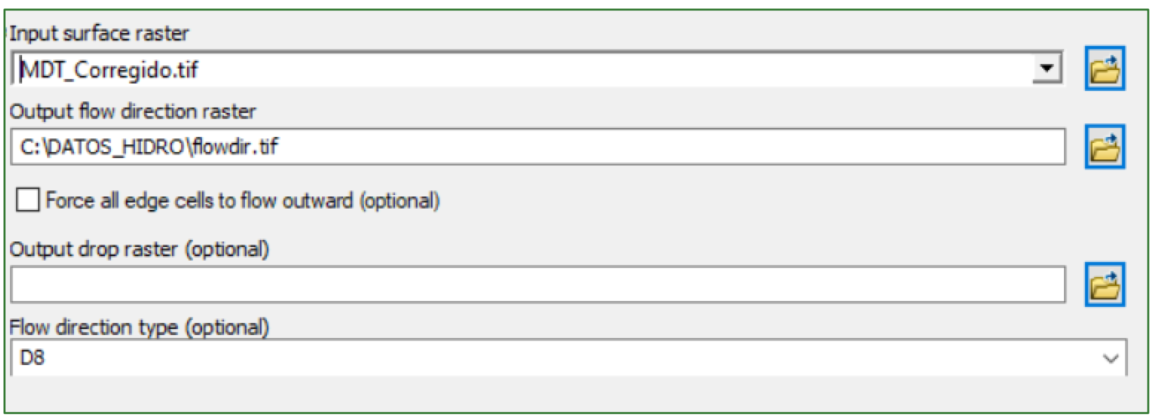
The diagrams in this methodological guide are available in an online GitHub repository by clicking on the following link (Spanish original): https://github.com/guialandscape/Diagramas

Part 7. Preparing hydrographic and micro-basin data

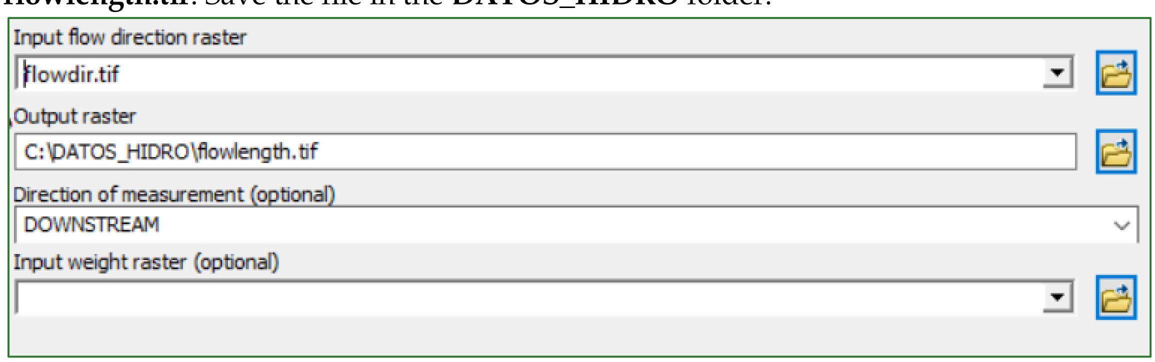
Use the **Hydrology** tool to carry out the processes in this section. You will find the tool in: **ArcToolBox/Spatial Analyst Tools/Hydrology.**



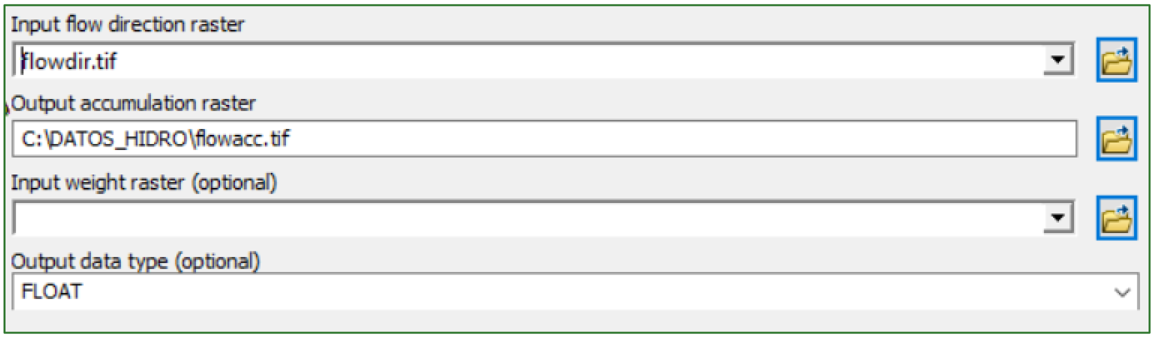
1. As a first step, create the Flow Direction raster using the Flow Direction tool. Use the **MDT_corregido.tif** file as the input file and name the output file **flowdir.tif**, saving it in the **DATOS_HIDRO** folder.



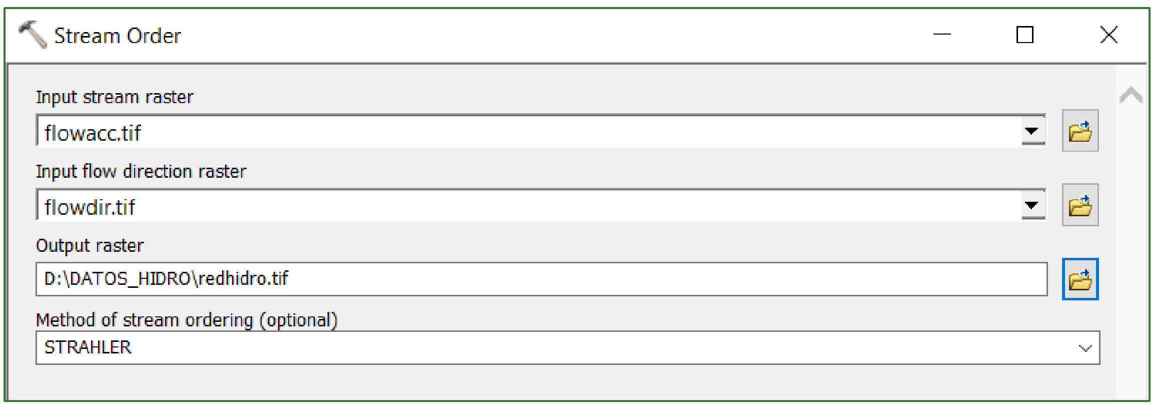
2. Create the Flow Length raster using the Flow Length tool. To do so, use the previously created flow direction file, flowdir.tif, as the input data, and name the output file **flowlength.tif**. Save the file in the **DATOS_HIDRO** folder.



3. Create the Flow Accumulation raster using the **Flow Accumulation** tool. To do so, use the previously created flow direction file, flowdir.tif, as the input data, and name the output file **flowacc.tif**. Save the file in the **DATOS_HIDRO** folder.

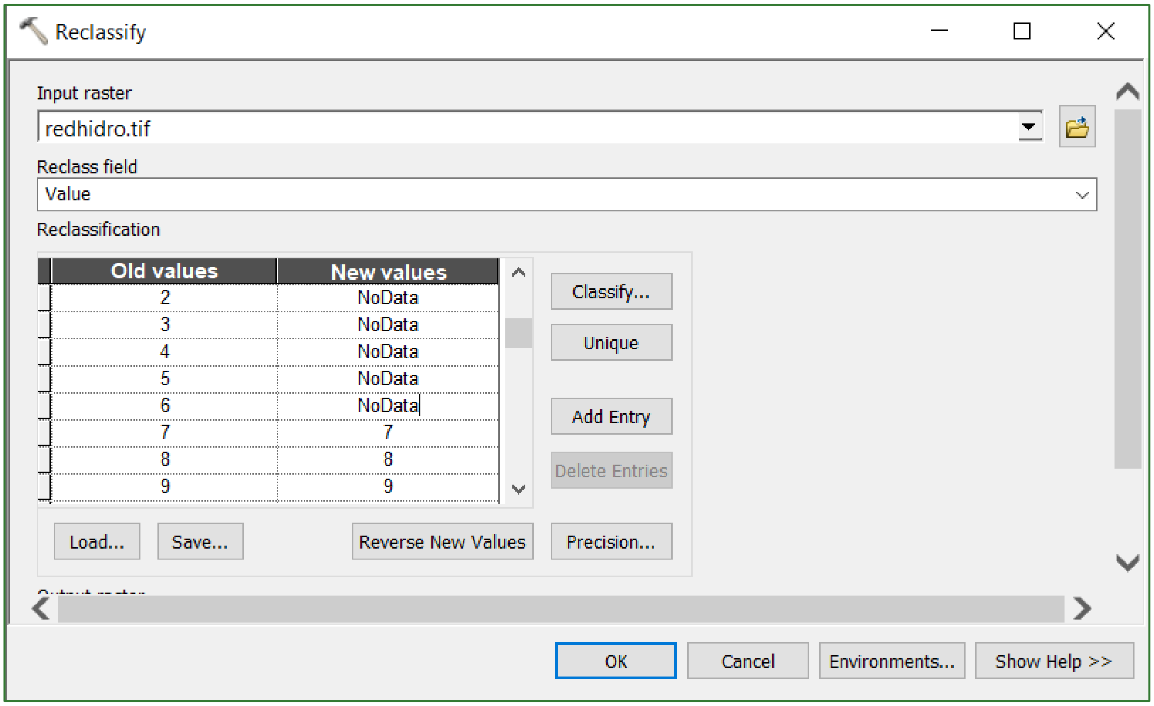


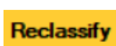
4. Get the Stream Order raster using the **Stream Order** tool. To do so, use the previously created flow accumulation file, **flowacc.tif**, as the input data, and name the output file **rehidro.tif**. Save the file in the **DATOS_HIDRO** folder.



5. Reclassify **redhidro.tif** to get the stream order greater than or equal to order 7 using the **Reclassify** tool. Name the output file **redhidro_orden7.tif** and save it in the **DATOS_HIDRO** folder.

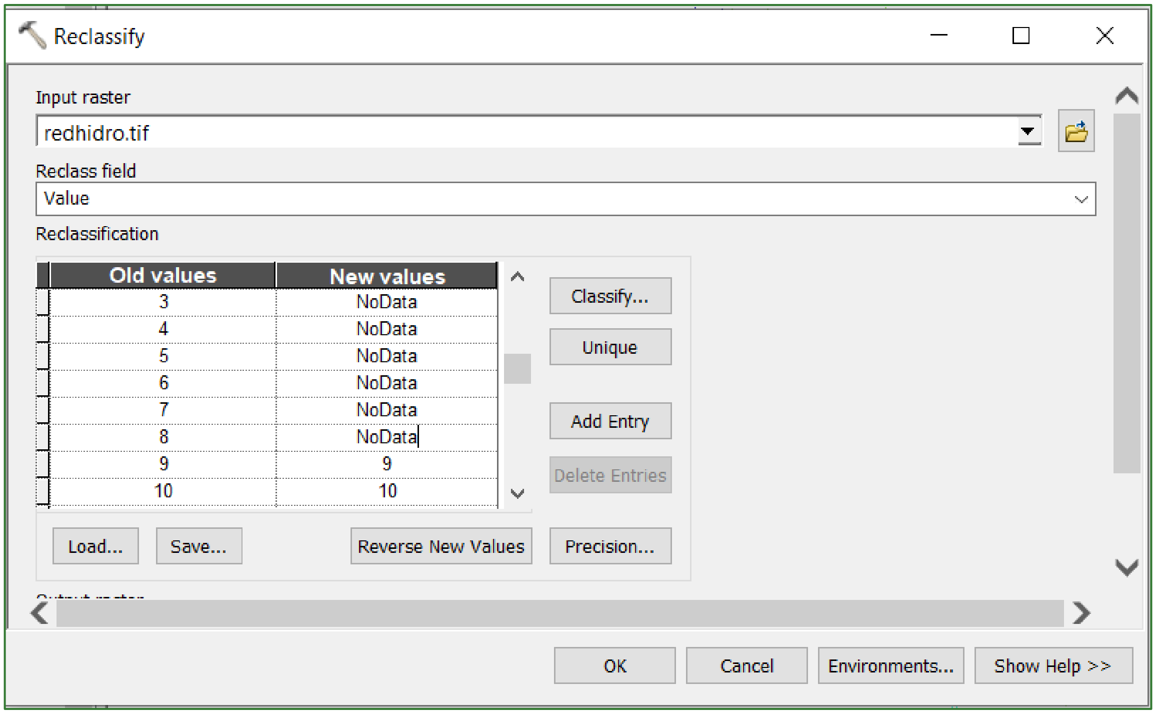
   By using all values equal to or greater than 7 you will maintain their original value, while those under 7 will be assigned the NoData value.



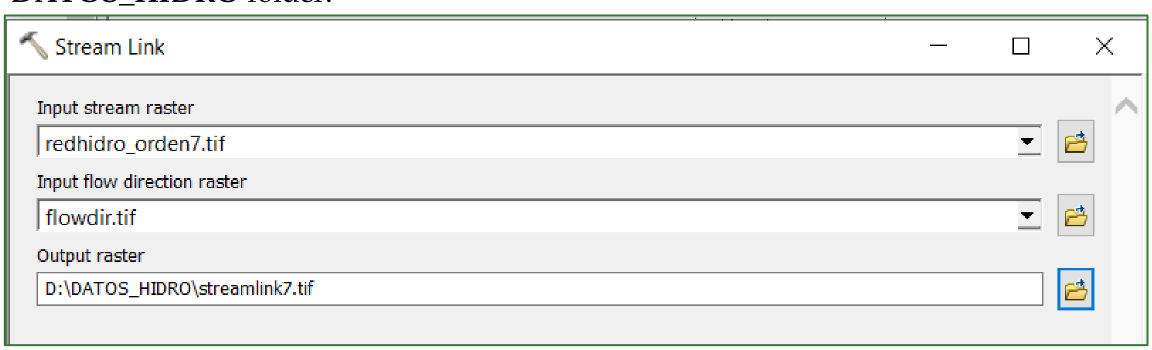
Reclassify **redhidro.tif** to get the stream order greater than or equal to order 9 using the 

tool. Name the output file **redhidro_orden9.tif** and save it in the **DATOS_HIDRO** folder.

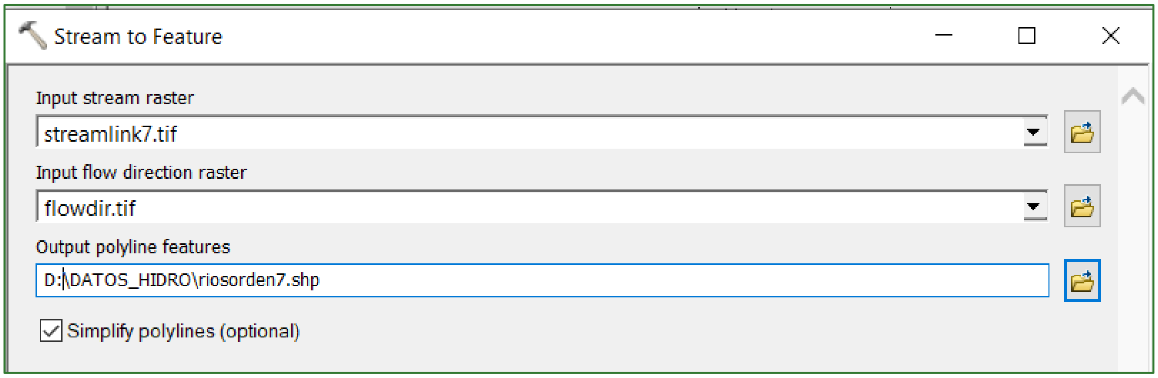
By using all values equal to or greater than 9 you will maintain their original value, while those under 9 will be assigned the NoData value.



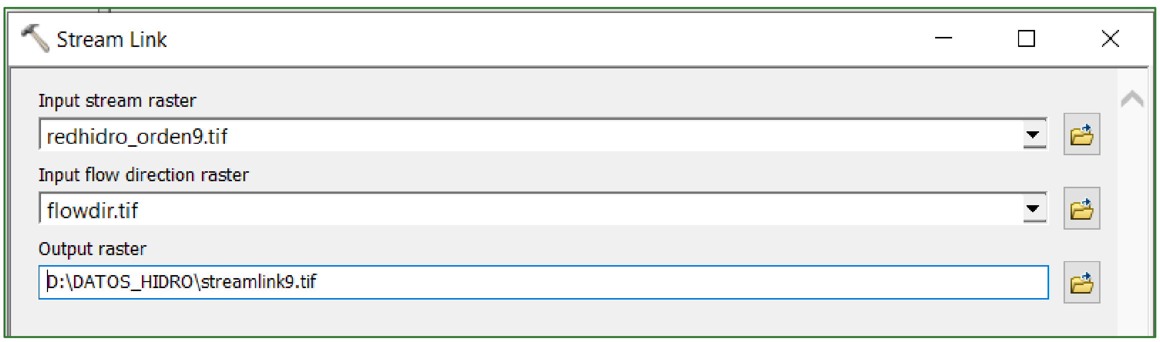
6. Generate the reference raster to delimit the order 7 basin from the **redhidro_orden7.tif** using the **Stream Link** tool. Name the output file **streamlink7.tif** and save it in the **DATOS_HIDRO** folder.



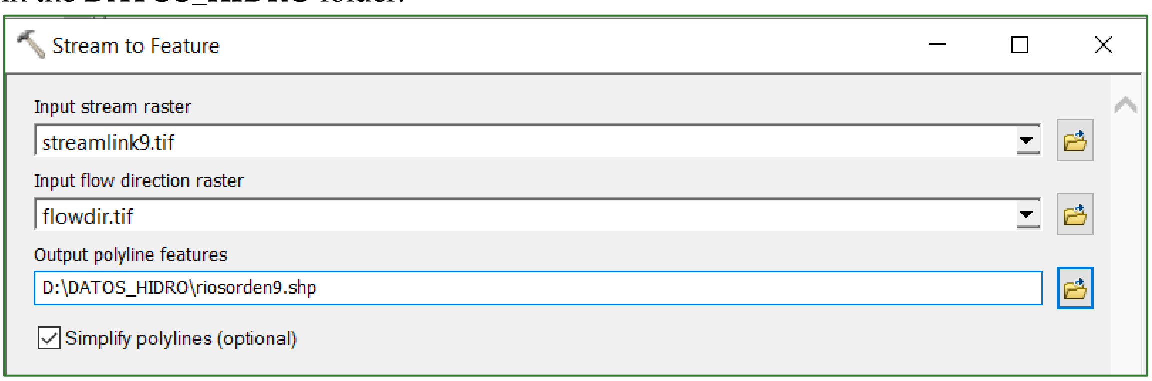
You can take advantage of this step to convert the order 7 stream into a shapefile using the **Stream to Feature** tool. Check the Simplify Polylines box and save the file as **riosorden7.shp** in the **DATOS_HIDRO** folder.



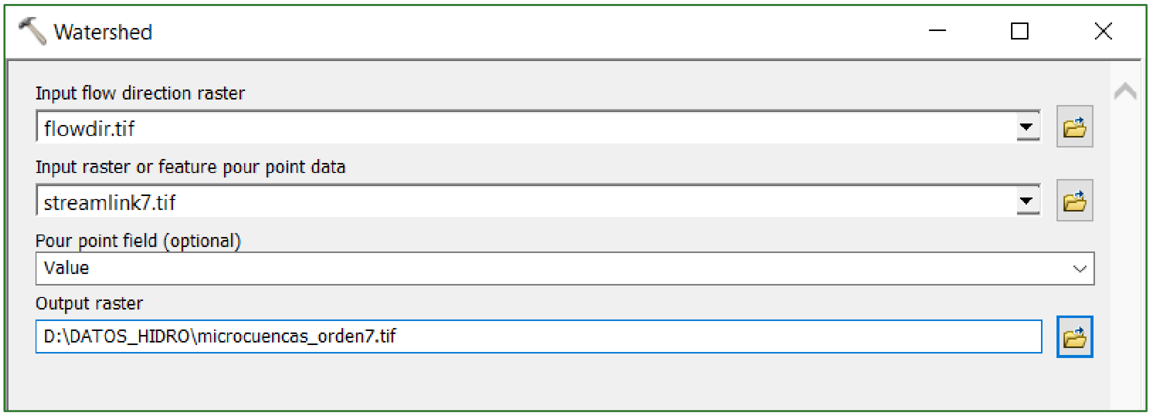
7. Generate the reference raster to delimit the order 9 basin from the **redhidro_orden9.tif** using the Stream Link tool. Name the output file **streamlink9.tif** and save it in the **DATOS_HIDRO** folder.



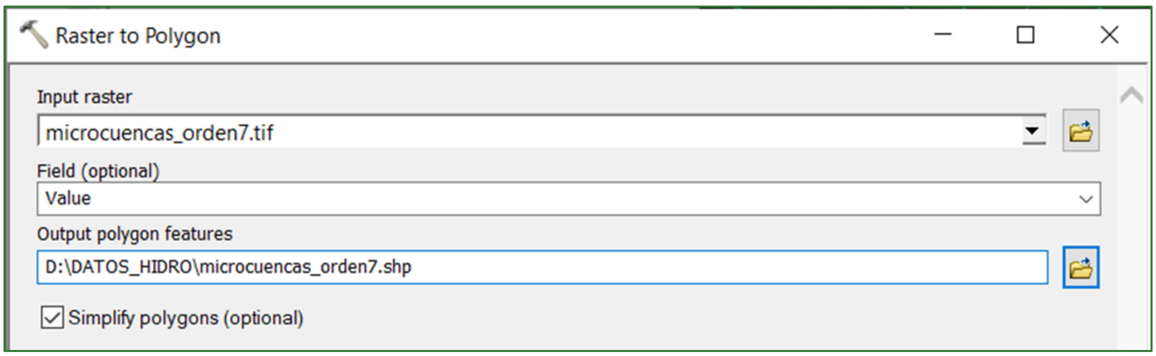
You can take advantage of this step to convert the order 9 stream into a shapefile using the Stream to Feature tool. Check the Simplify Polylines box and save the file as **riosorden9.shp** in the **DATOS_HIDRO** folder.

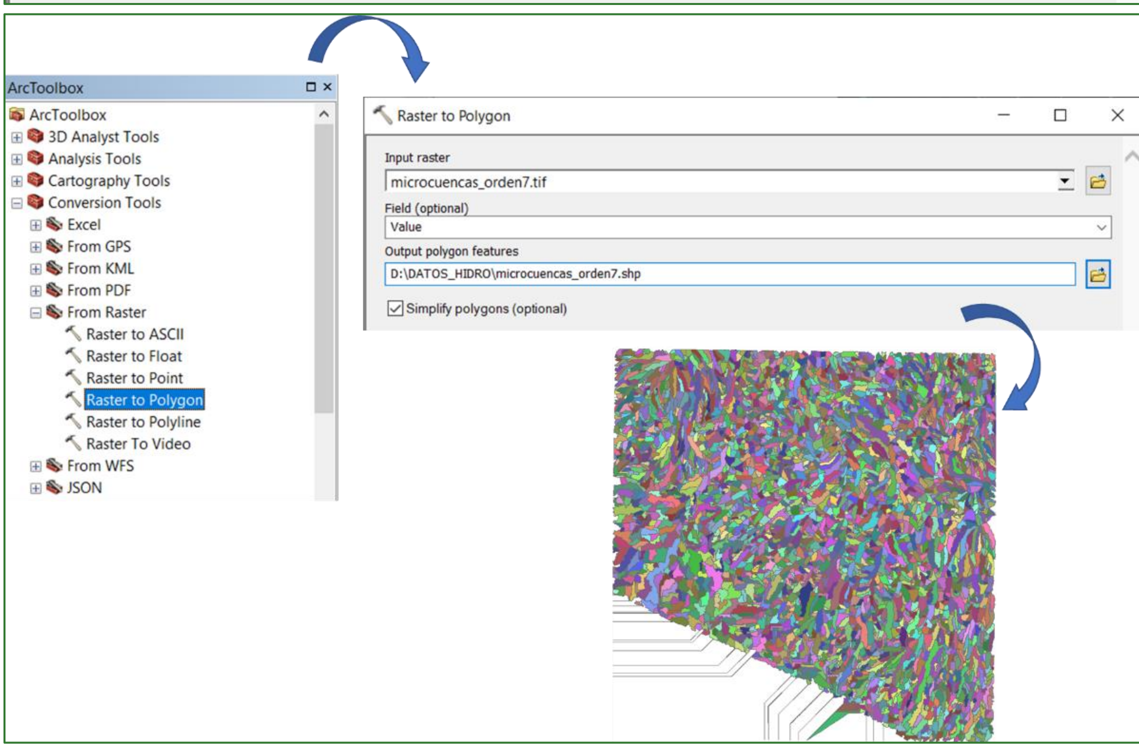


8. Generate order 7 micro-basins with the Watershed tool and save the file as **microcuencas_orden7.tif** in the **DATOS_HIDRO** folder.

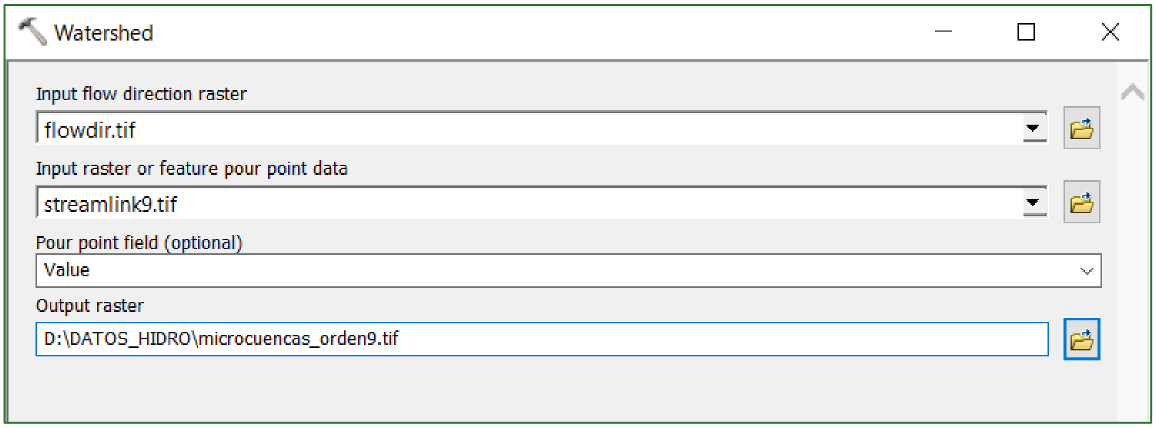


Convert the **microcuencas_orden7.tif** raster into a shapefile using the **Raster to Polygon** tool and save the file as **microcuencas_orden7.shp** in the **DATOS_HIDRO** folder.

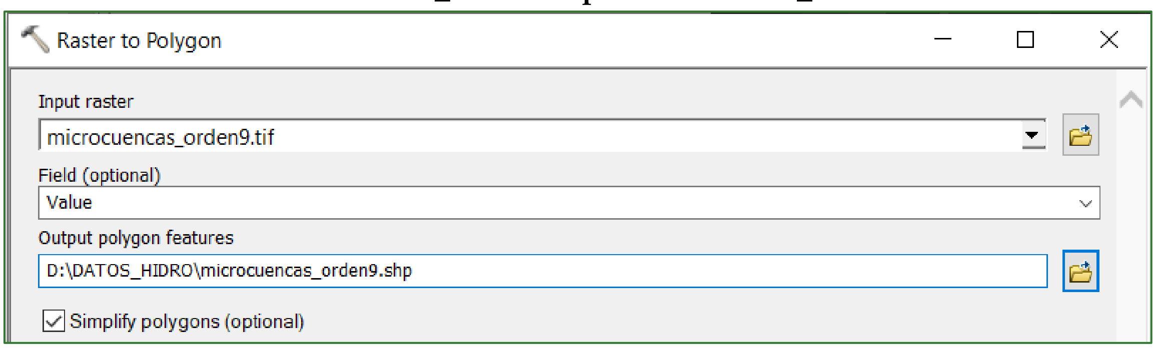


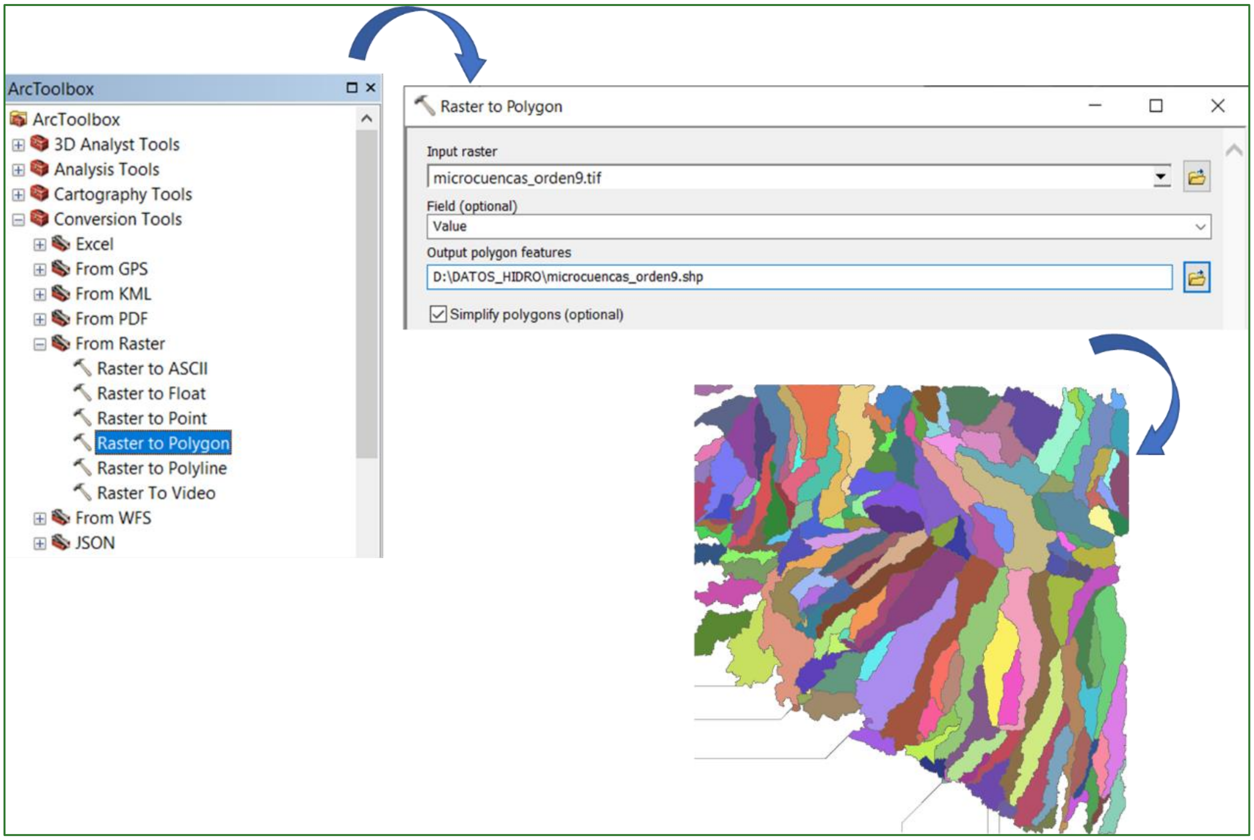


9. Generate the order 9 micro-basins with the **Watershed** tool and save the file as **microcuencas_orden9.tif** in the **DATOS_HIDRO** folder.

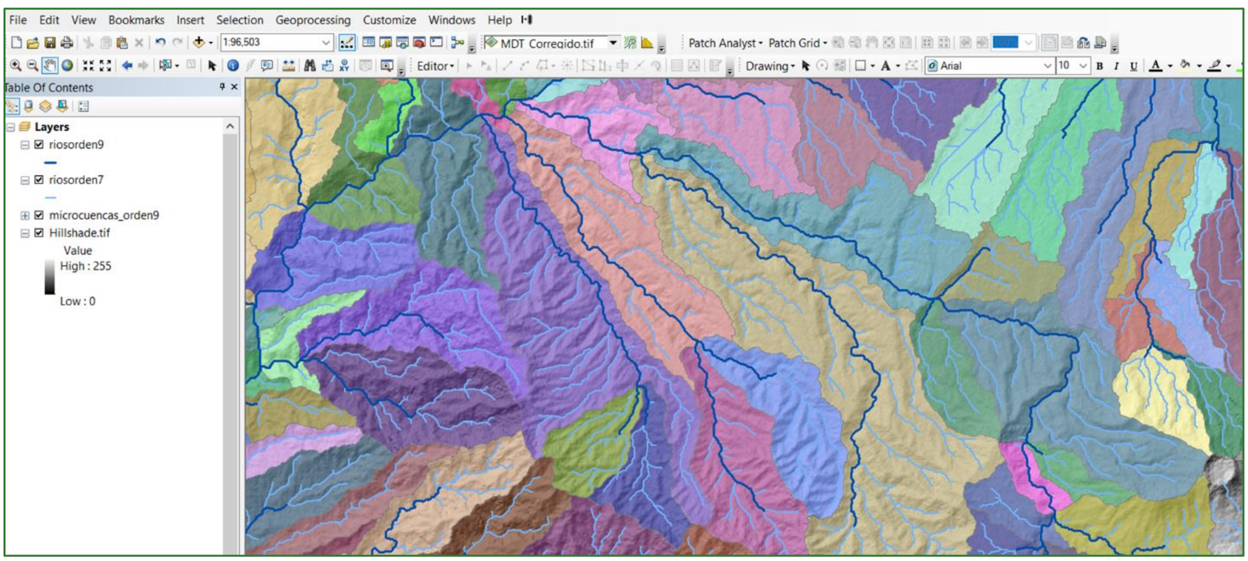


Convert the **microcuencas_orden9.tif** raster into a shapefile using the **Raster to Polygon** tool and save the file as **microcuencas_orden9.shp** in the **DATOS_HIDRO** folder.



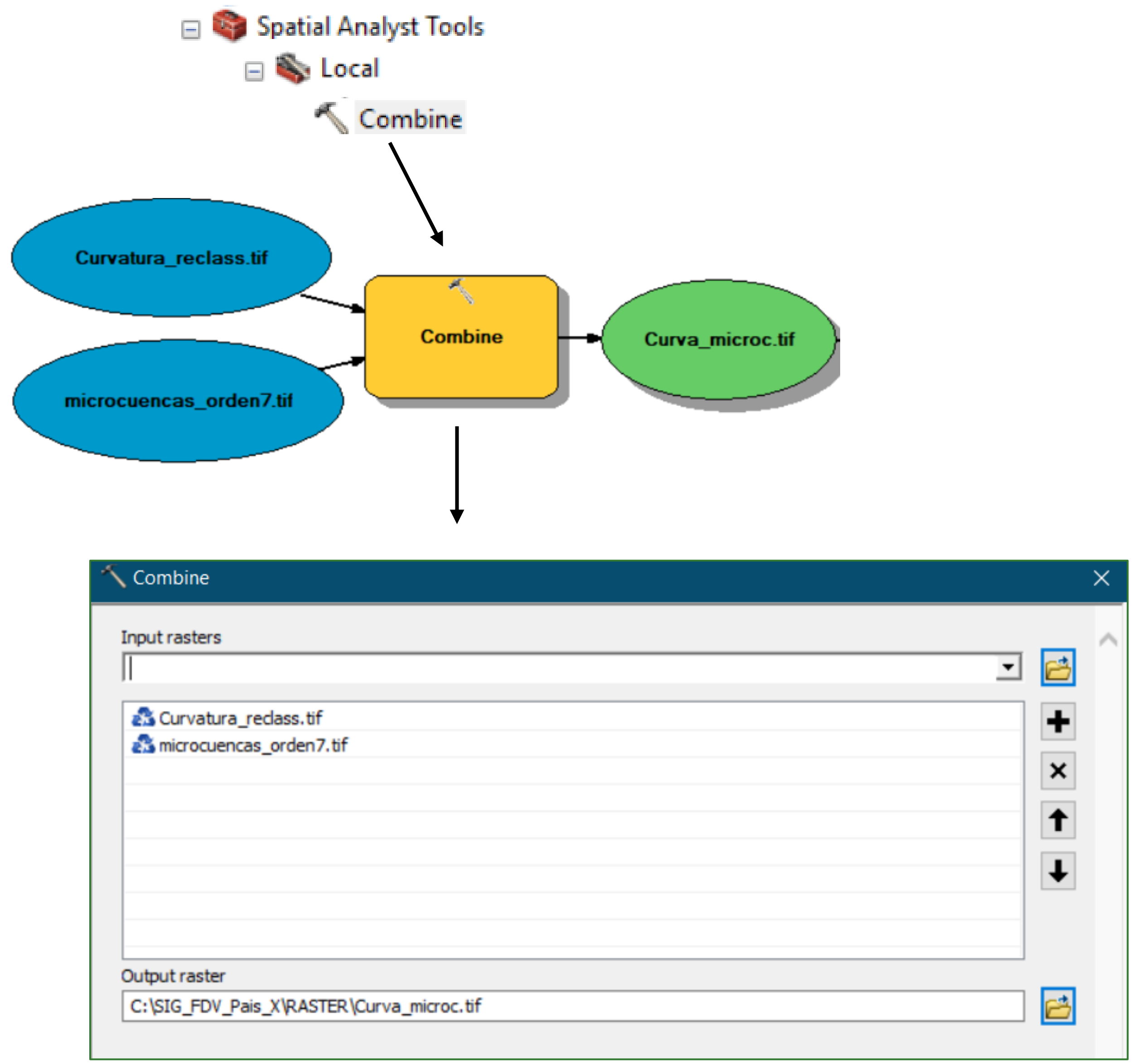


The output from obtaining hydrography and micro-basins should look as follows:



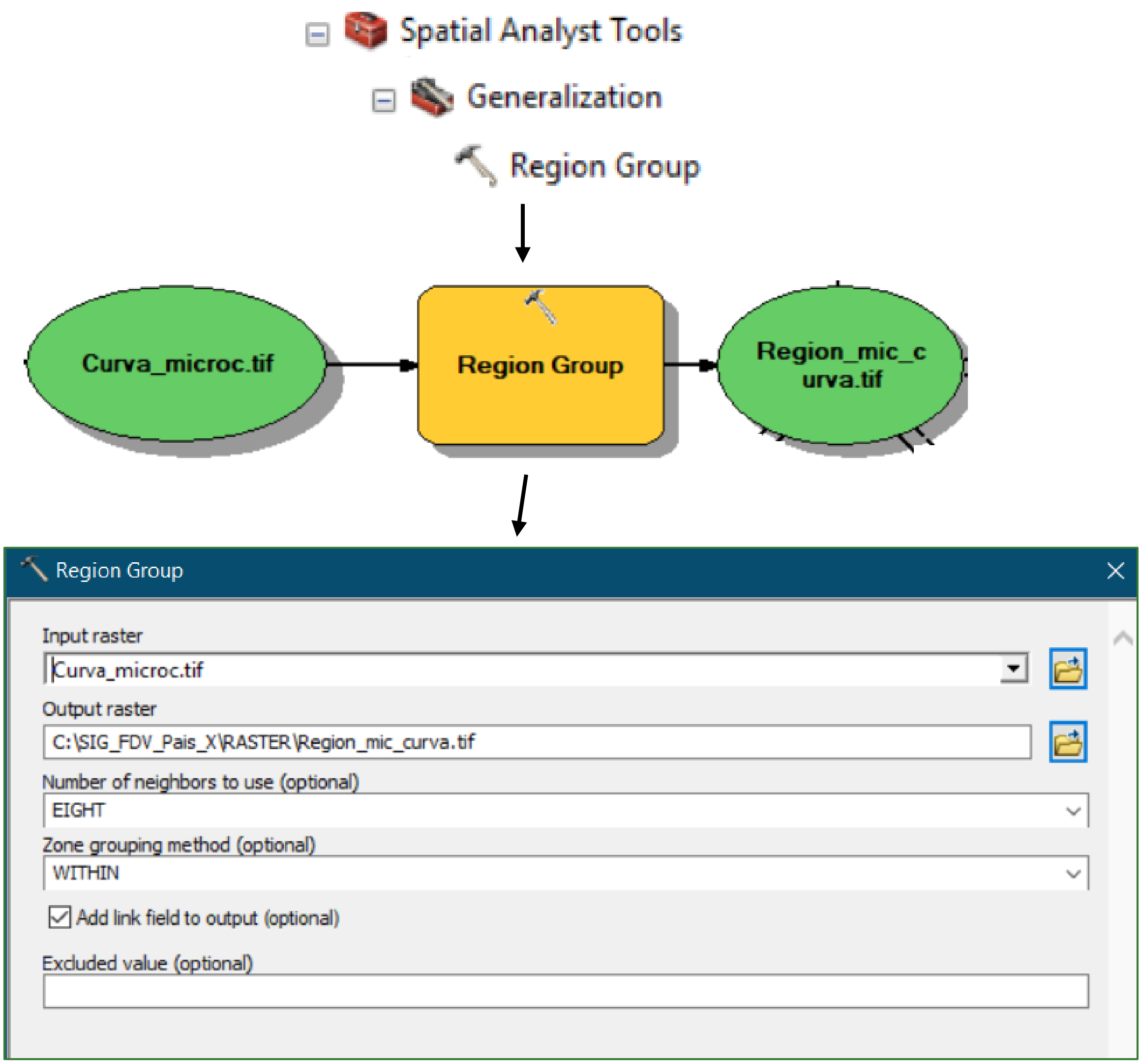
Part 8. Obtaining relief baseline units (region-group)

Combine the **curvatura_reclass.tif** and **microcuencas_orden7.tif** rasters using the **Combine** tool. You must save the output file in the **RASTER/MDT** folder and name it **Curva_micro.tif.**

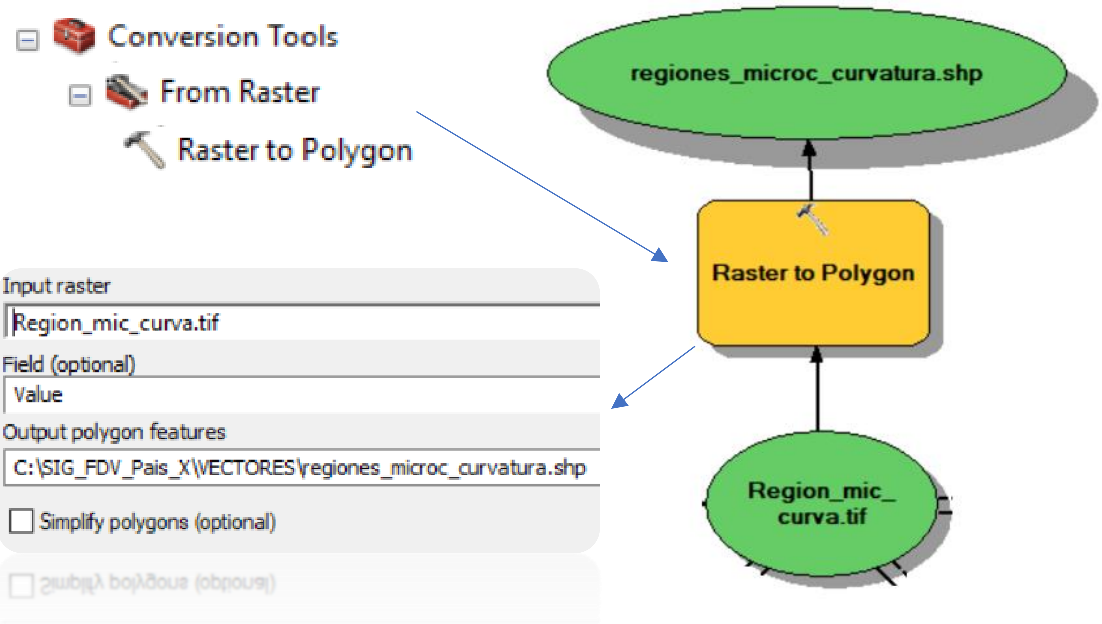


10. Subsequently, apply the **Region Group** tool to the **Curva_micro.tif** file resulting from the previous step. Save the output file in the **RASTER** folder naming this **Region_mic_curva.tif.**

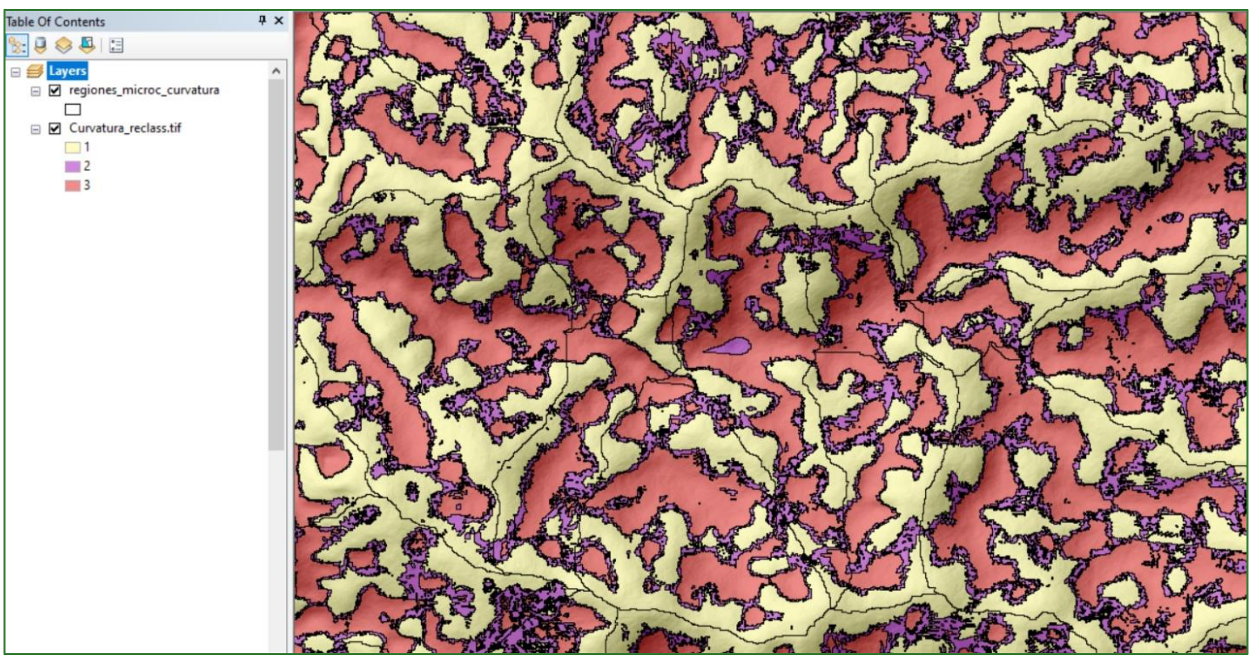
    N.B.: The time it takes to process the **Region_mic_curva.tif** file largely depends on the type of processor your computer has. It is estimated that the process will take from 15 to 20 minutes to complete.



11. Convert the **Region_mic_curva.tif** file resulting from the previous step into a shapefile. Save the output file in the **VECTORES** folder naming it **regiones_microc_curvatura.shp** and then save it in the **RASTER/MDT** folder. This vector file is obtained for purely display purposes and will therefore not be required for subsequent processes.



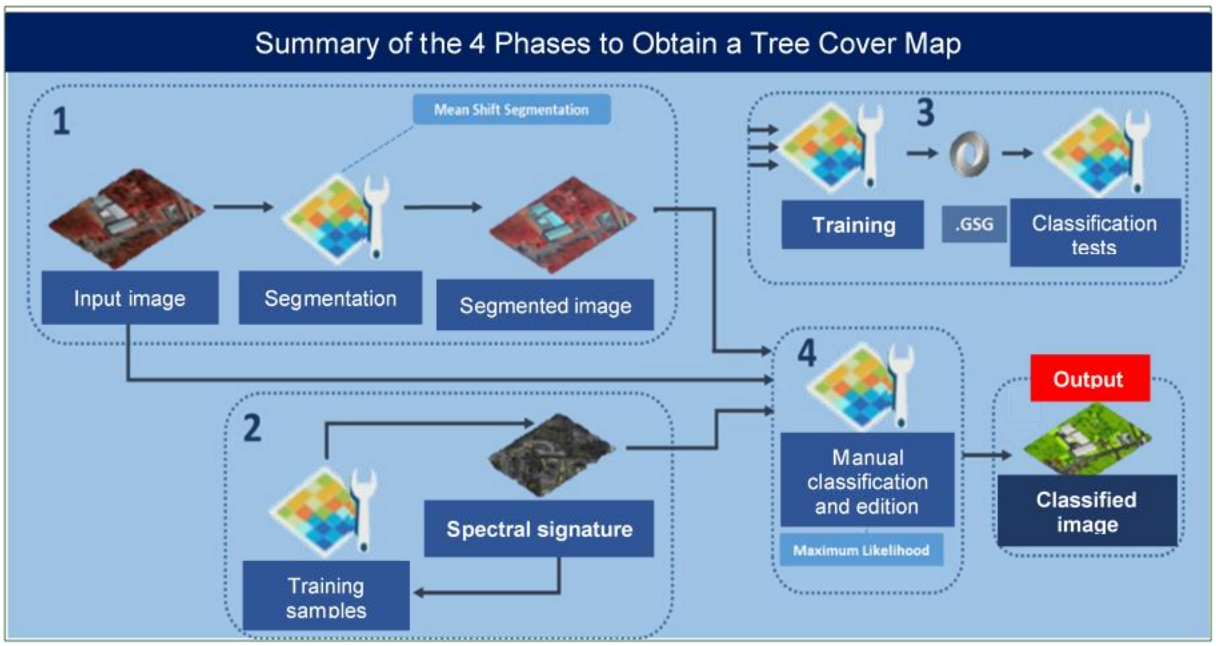
The resulting file should look as follows: **The generated file will be used in Part 12.**



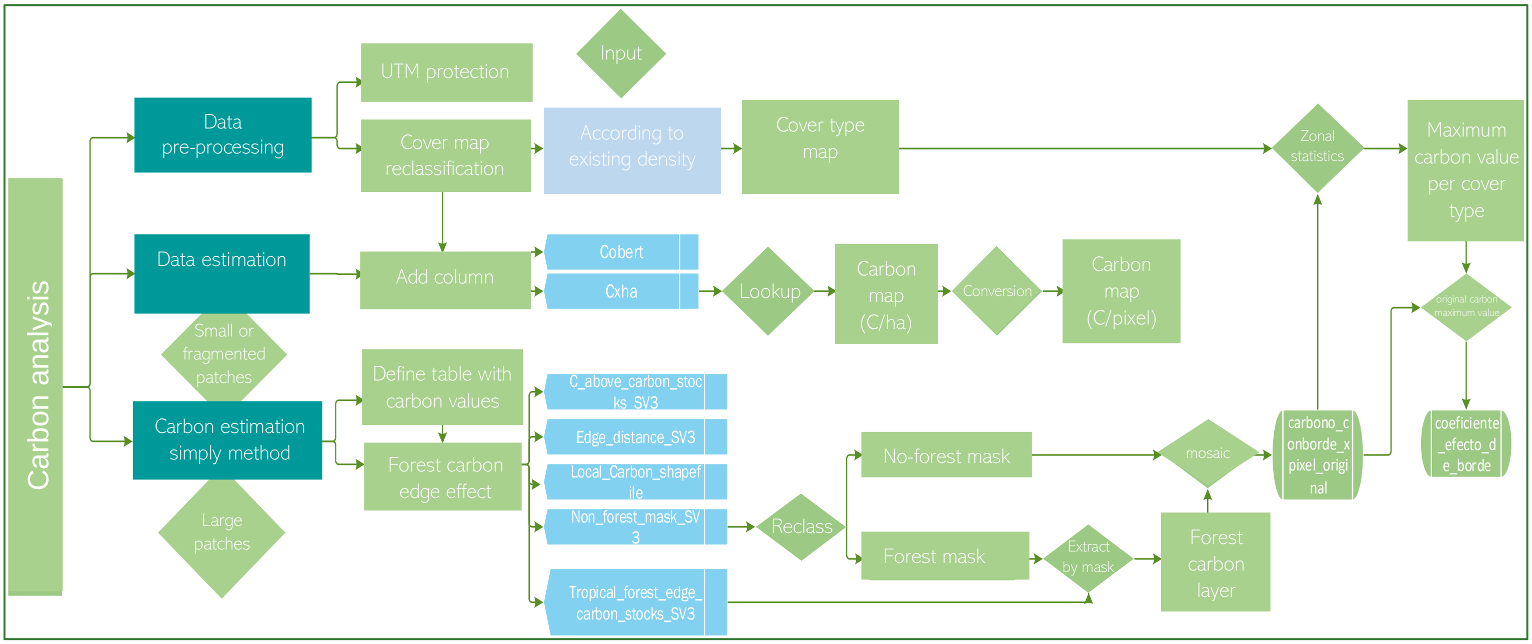
Baseline data: Tree cover, carbon and soil

Baseline data: Tree cover, carbon and soil

In this section you will carry out a series of geo processes to generate a tree cover and forest carbon map. These processes involve generating a satellite image-based mosaic, the creation of spectral signatures and the mapping of tree cover. Based on this map, the carbon stored in tree cover will be estimated using two types of methods. The data generated in this section will form the basis for the biological connectivity and water erosion analysis covered later in this methodological guide.



Module 1: Baseline data preparation



The diagrams in this methodological guide are available in an online GitHub repository by clicking on the following link (Spanish original): https://github.com/guialandscape/Diagramas

Part 9. Obtaining the cover map

Introduction

Remote sensing images and data make it possible to obtain extensive spatial, and time-based, land surface information and are therefore crucial tools to generate the tree cover thematic map. From when the first remote sensor images were taken to the present date, there has been a substantial rise in their application in monitoring tree as well as forest cover (Achard & Hansen, 2013). Indeed, there is an increase in airborne programs that take and distribute image data, as well as processing methods, computational programs and technological resources used to monitor cover.

Generating tree cover thematic maps requires the use of remote sensing along with geographical processing tools over an integrated platform such as a Geographical Information System (GIS).

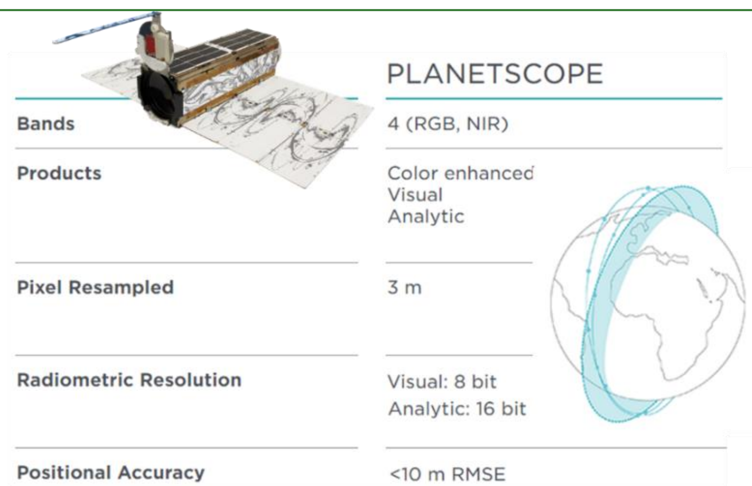
Remote sensing image classification involves a long, and possibly slow workflow as it includes the processing phase prior to the segmentation, selection of training samples, training, classification, quality control and subsequent processing. In many cases the steps must be repeated (depending on the intermediate results, they may require the process to be repeated several times to obtain the best results). Creating an accurate classification map is an intensive process. Users need in-depth knowledge of their input data, the classification scheme, the classification algorithms, the expected results, and the acceptable accuracy.

The main steps to generate a tree cover map by means of classifying Planet satellite images are described below.

Inputs to obtain tree cover

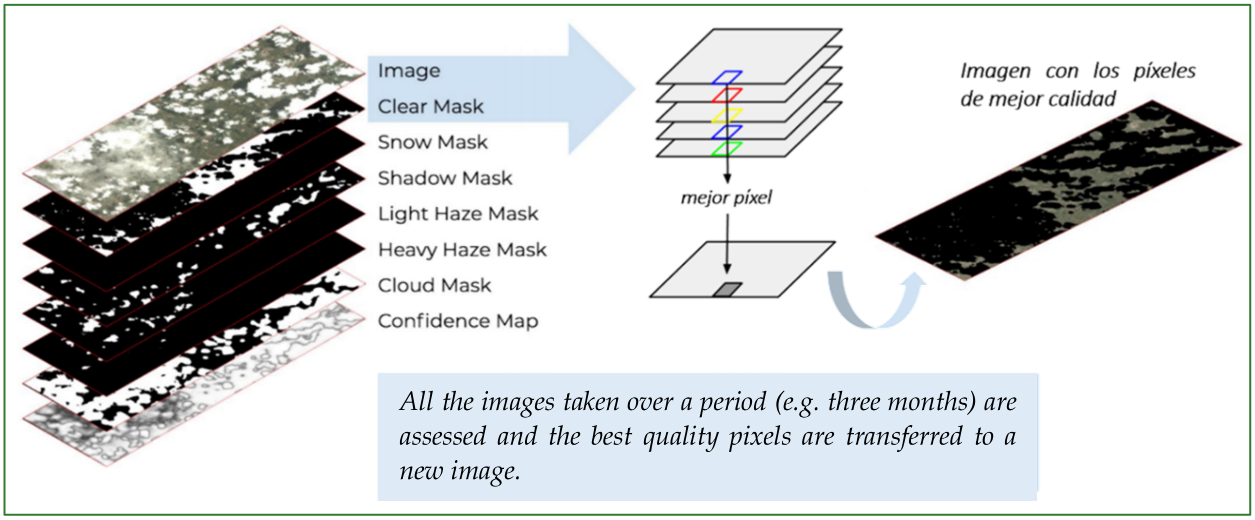
Planet images captured by nanosatellites and with the following characteristics will serve as your input.

120 “Dove” Nanosatellites. Comprising a 30 cm cylinder (“Cubesat” format) with an in-built camera and two solar panels that open out when



PRODUCT: MOSAICS

Best pixels from a period



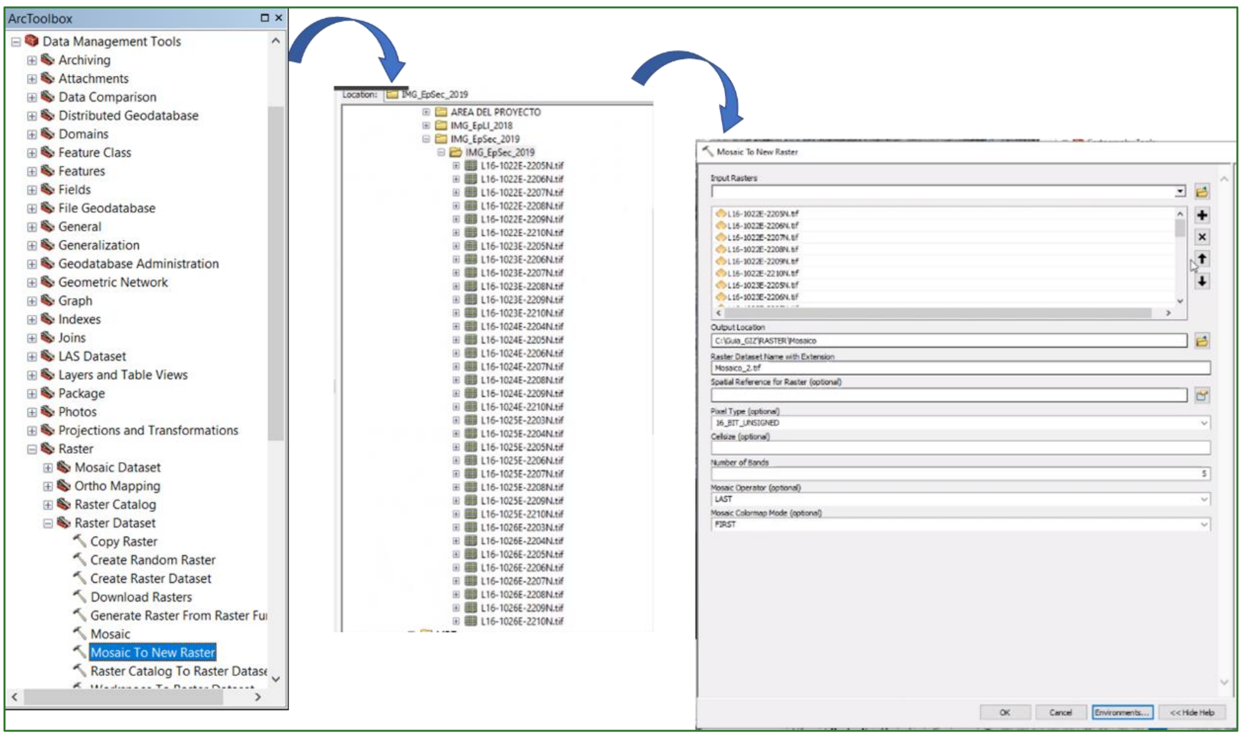
ArcGIS ESRI ArcMap is the programme used to generate the tree cover map. Country experts can choose to use another programme they may prefer once they have learned about the procedure involved and the results obtained. The purpose of this manual is to show the procedure and its output.

Phase 1. Creating a mosaic for the study area from satellite images

Before you start, you need to prepare the file structure by folder: add a new folder, naming it **COBERTURA.**

- Part 1: the process to create a mosaic from satellite images is as follows:
  Use the tool called "**Mosaic to New Raster**" which can be found in **ArcToolBox/Data Management Tools/Raster/Raster Dataset/Mosaic to New Raster.**

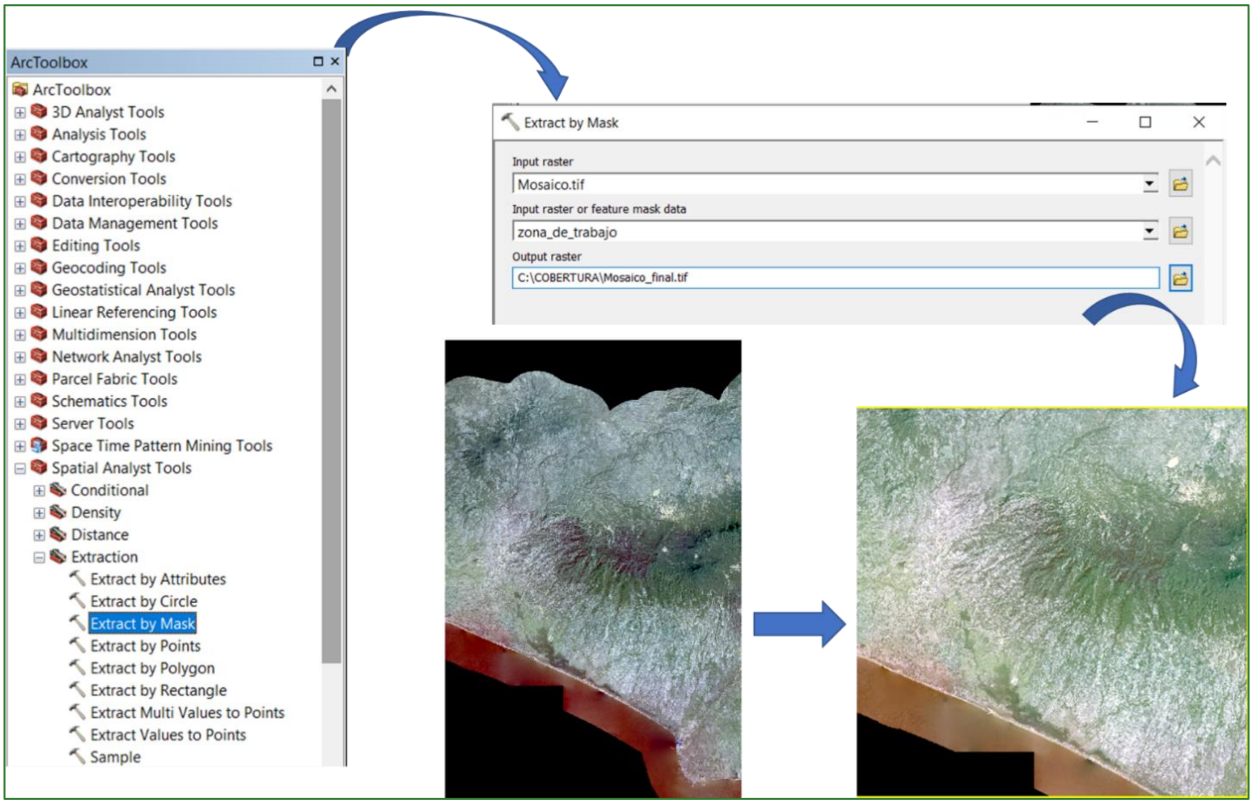
  You must import all the images in the Input Raster box. Name the mosaic **Mosaico.tif** in the **COBERTURA** folder. Select option 16_BIT_UNSIGNED in the Pixel Type box.



- You can now proceed to cut the mosaic for the project area using the "**Extract by Mask**" tool found in **ArcToolBox/Spatial Analyst Tools/Extraction/Extract by Mask.**
  Enter the mosaic entitled Mosaico.tif in the Input Raster box or feature mask data box in the study area file. This file is in the **VECTORES** folder and called **zona_de_trabajo.shp.**

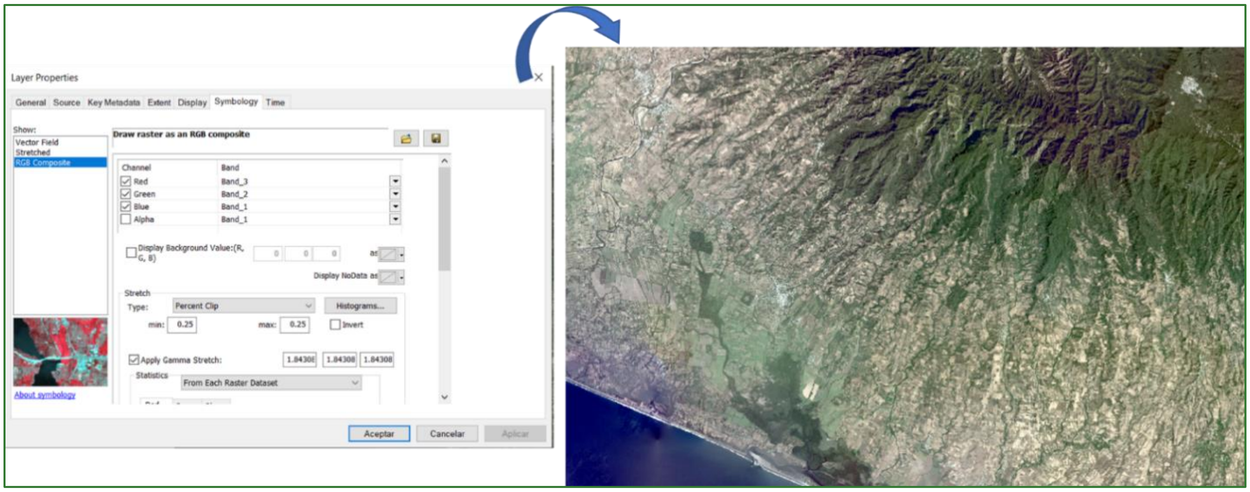
  Save the file in the COBERTURA folder, naming it **Mosaico_final.tif.**

You will get a satellite image mosaic cut to the limits of the project area.



- Now place the mouse on the Mosaico.tif image, right-click on Properties/Symbology and combine the true colour: the images of the different **bands** can be combined between them to produce an image in real or fake colour, depending on the **bands** chosen. You do this by applying each of the three primary colours (red, green, blue) to a different image **band**. Bands 3, 2, 1 (RGB): is a natural-coloured image. It depicts the entire areas as seen by the human eye in a colour aerial photograph.

  Place the colour bands as follows:



Phase 2. Segmenting satellite images

Segment-based classification of tree cover: this type of classification is based on objects grouped by neighbouring pixels in accordance with their likeness. The process is called segmentation. Segmentation takes into account characteristics such as colour and shape when deciding which pixels should be grouped. As this method averages the pixel values and considers geographical information, the objects that are created from segmentation look much more like the objects in the real world that are present in the images, thus the results of the classification are cleaner.

Image segmentation is based on the mean shift approach. This technique uses a moving window that calculates a mean pixel value to determine which pixels should be included in each segment. As the window moves over the image, it repeatedly recalculates the value to make sure that each segment is suitable. The result is a grouping of image pixels into a segment characterised by an average colour.

The segmentation mean shift tool accepts any Esri-supported raster and generates a 3-band, 8-bit colour segmented image with a key property established in Segmented. The characteristics of the image segments depend on three parameters: spectral detail, spatial detail and minimum segment size. You can vary the amount of detail that characterises a feature of interest. For example, if you are more interested in impervious features than in individual buildings, adjusting the spatial detail parameter to a small number will result in more smoothing and less detail.

"Spectral detail" is defined to specify the level of importance of the segment. Valid values from 1.0 to 20.0 are defined in spectral detail. A higher value is more suitable for objects that you want to classify separately, but which share somewhat similar spectral characteristics. Smaller values create more spectrally uniform outputs. For example, greater spectral detail in a forest scene allows you to better distinguish between different species of trees.

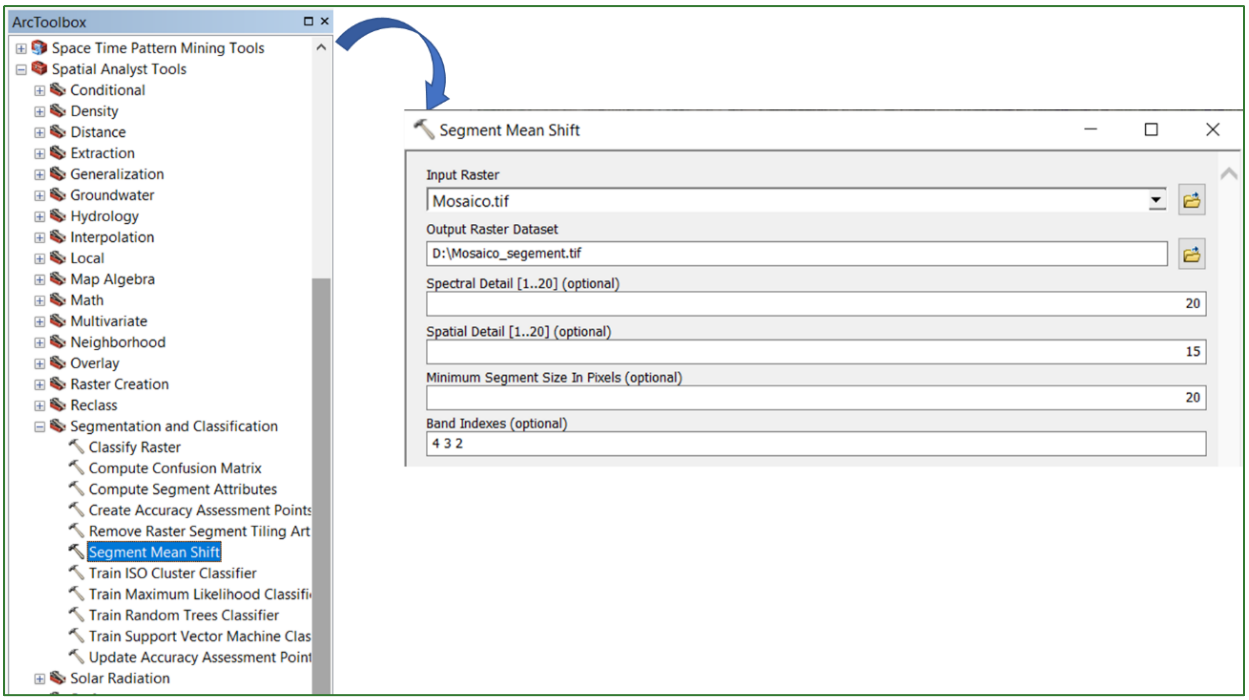
In addition, "spatial detail" is defined, which establishes the level of importance given to the proximity between objects in the images. Values range from 1 to 20. The higher value is more suited to a scene where the objects of interest are small and grouped. Smaller values create more spatially uniform outputs. For example, in an urban scene you can classify an impervious area using lower spatial detail or classify buildings and roads as separate classes using a higher spatial detail value.

The procedure is shown below:

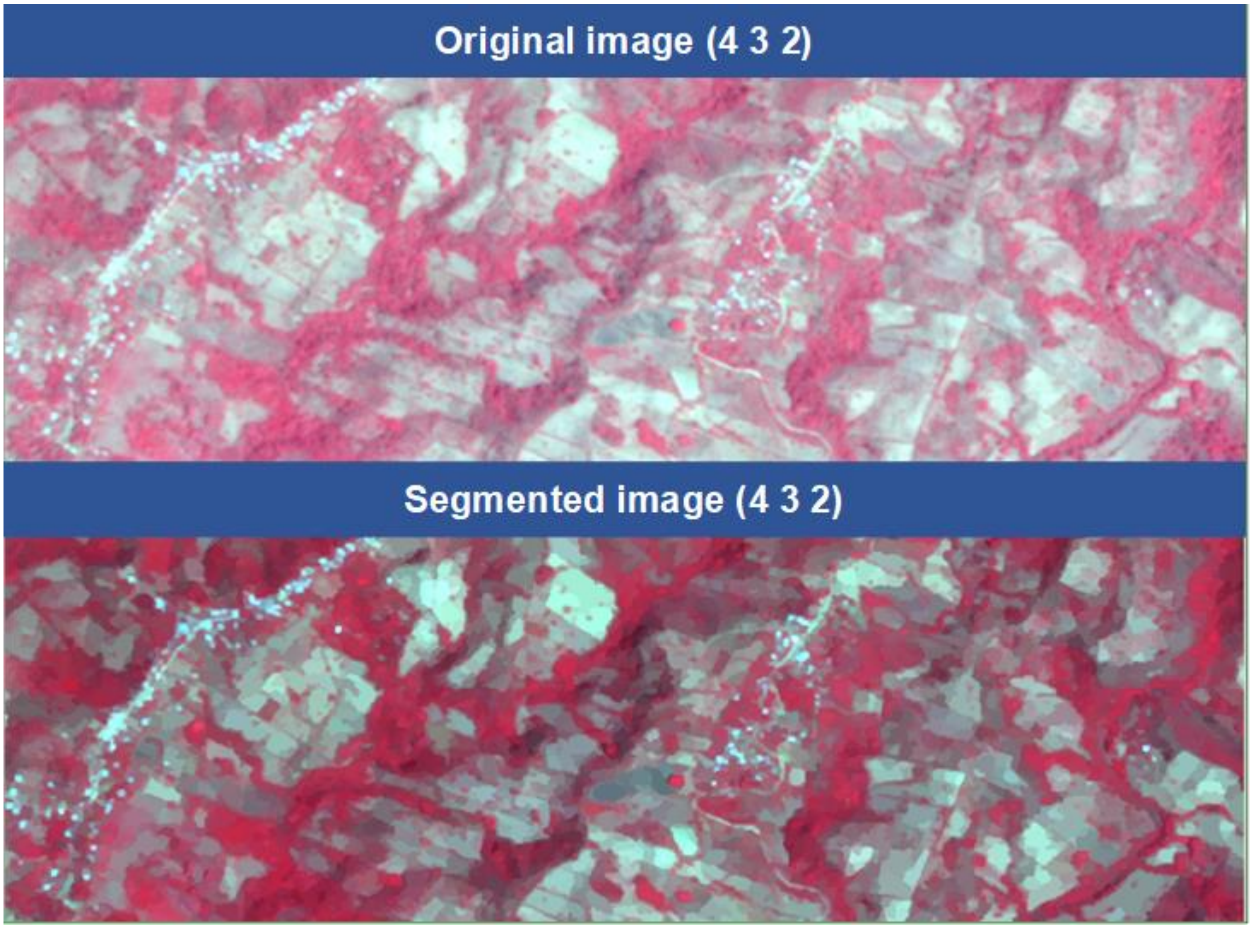
Use the tool called the "**Segment Mean Shift**", which can be found in **ArcToolBox/Spatial Analyst Tools/Segmentation and Classification/Segment Mean Shift.**

Place the project area mosaic called **Mosaico.tif** in the Input Raster box.

Name the output file **Mosaico_segment.tif** and save it in the **COBERTURA** folder. To generate the segments in this exercise, you must define maximum values for spectral detail (20) and 15 for spatial detail. The minimum pixel size per segment will be 20 in the 4, 3 and 2 band indices.



The resulting segmented image is shown below.



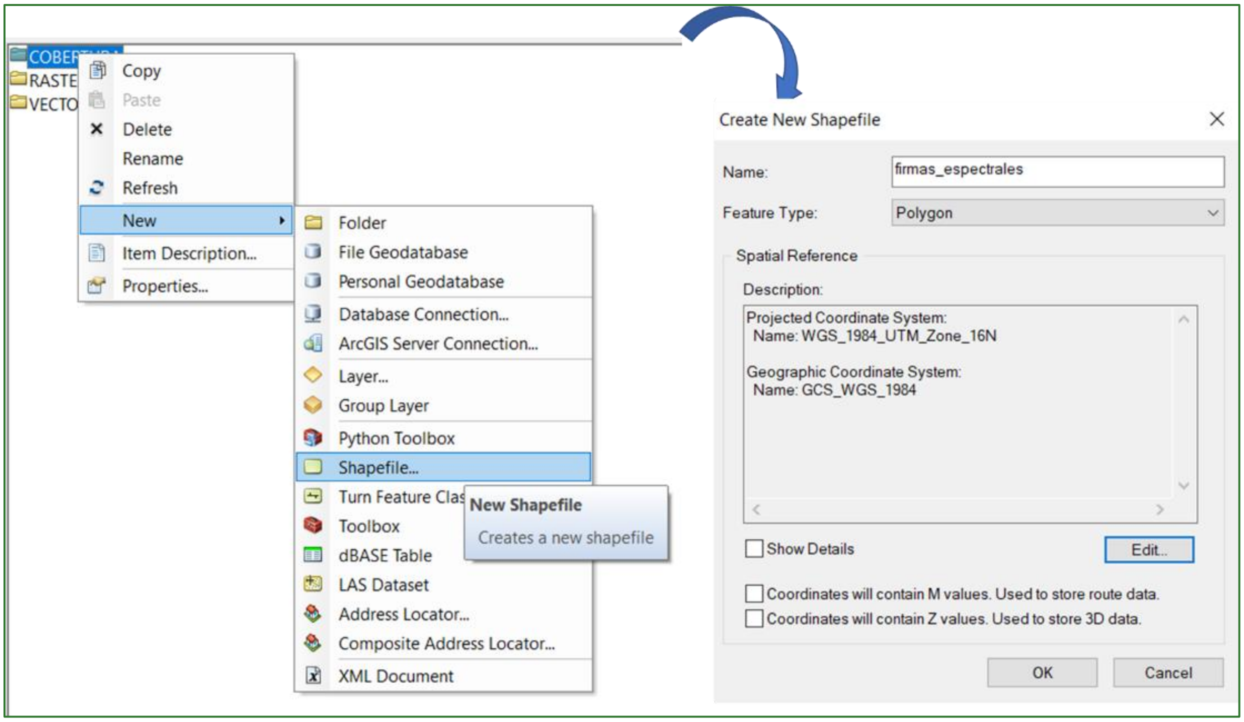
Phase 3. Collecting or creating spectral signatures

Spectral signatures comprise a series of samples that will serve to train the algorithm which will be used later on for classification purposes using the satellite image supervised method. Generate a new polygon-type vector layer and select several representative sites with and without tree cover in the work area. These sites or polygons are called training samples. A training sample has location (polygon) information and an associated soil cover class. The image classification algorithm (Maximum Likelihood Classification that will be used to generate the tree cover map) uses spectral signatures to identify soil cover classes throughout the image. Training samples must be saved as a class of object or signature.

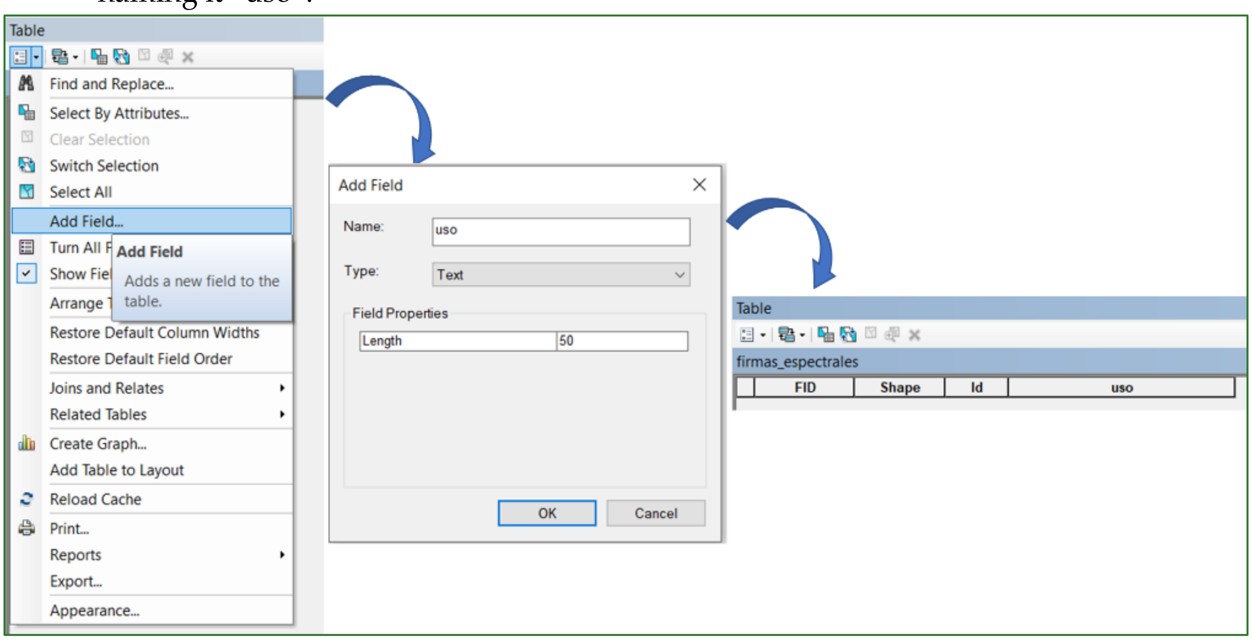
N.B.: There are other types of processes available which generate spectral signatures that allow the enabling of other classification algorithms, such as: Train Random Trees Classifier, Train Maximum Likelihood Classifier or Train Support Vector Machine Classifier. They are available in Segmentation and Classification in Spatial Analyst Tools in the ArcToolBox.

The procedure to **collect or create spectral signatures** is indicated below:

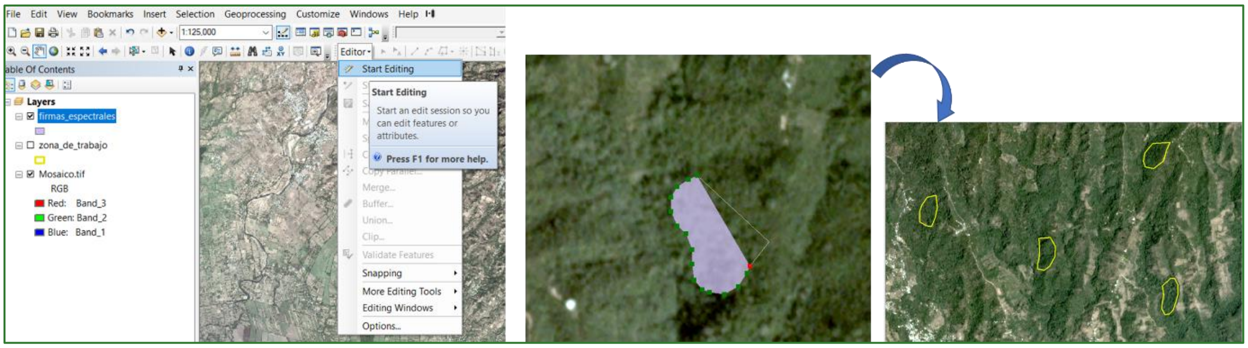
- Generate a new polygon type shapefile in the **COBERTURA** folder, naming it **firmas_espectrales.shp**, and enter the respective spatial reference for your country.



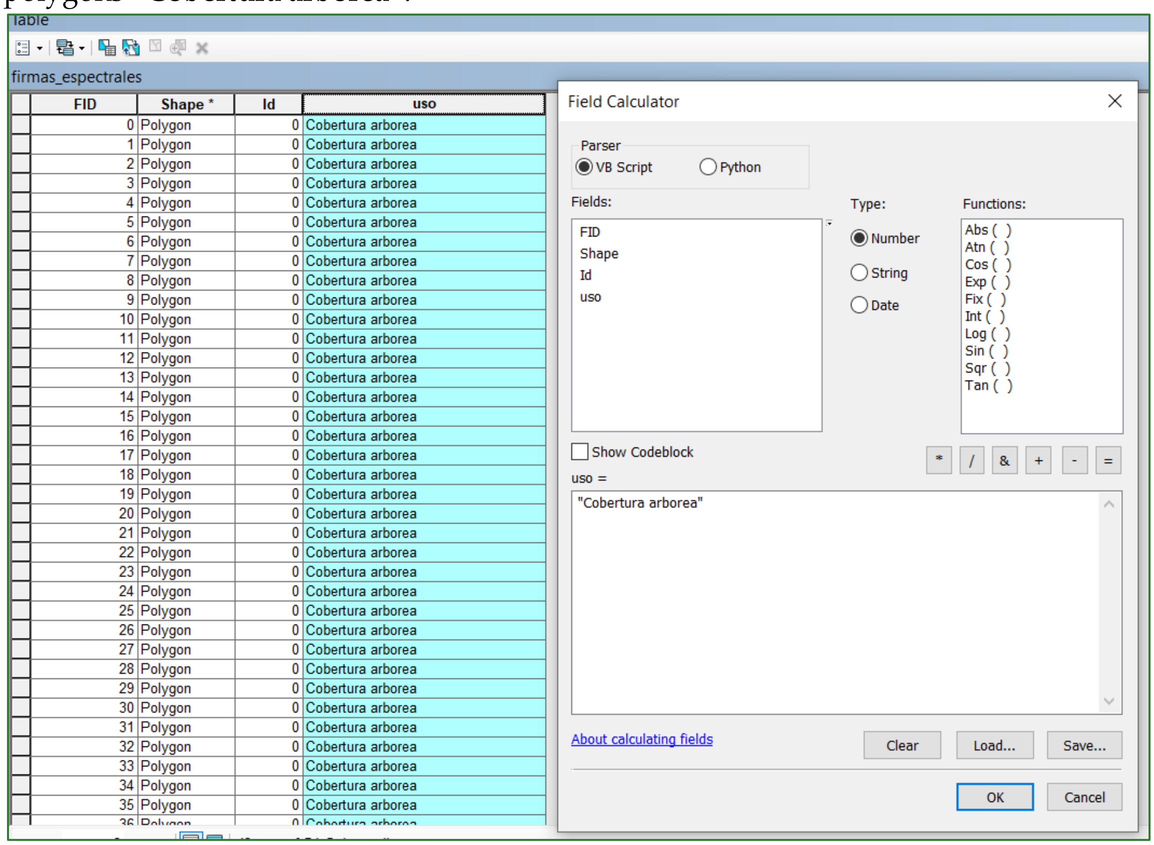
- Open the shapefile table called **firmas_espectrales.shp** and add a text type column, naming it "uso".



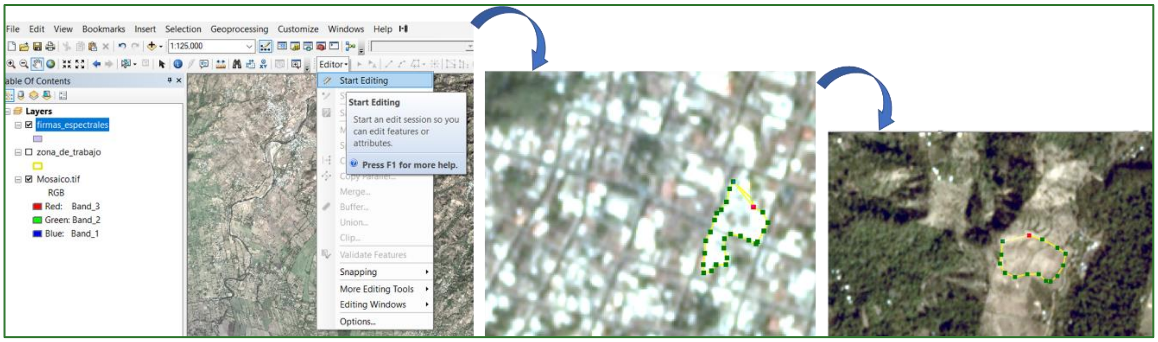
- "Start editing" the **firmas_espectrales.shp** layer and draw the polygons in the areas where you see tree cover. This is a very important step given that map quality depends on how good the signatures created at this stage are. Accordingly, it is important to digitalise or "draw" polygons where the tree cover is evident (mainly forests). It is also important that the polygons are distributed across the entire study area. Approximately 50 polygons for each class is regarded as a suitable number. In this exercise we are going to create 50 tree cover and 50 no-tree cover polygons.



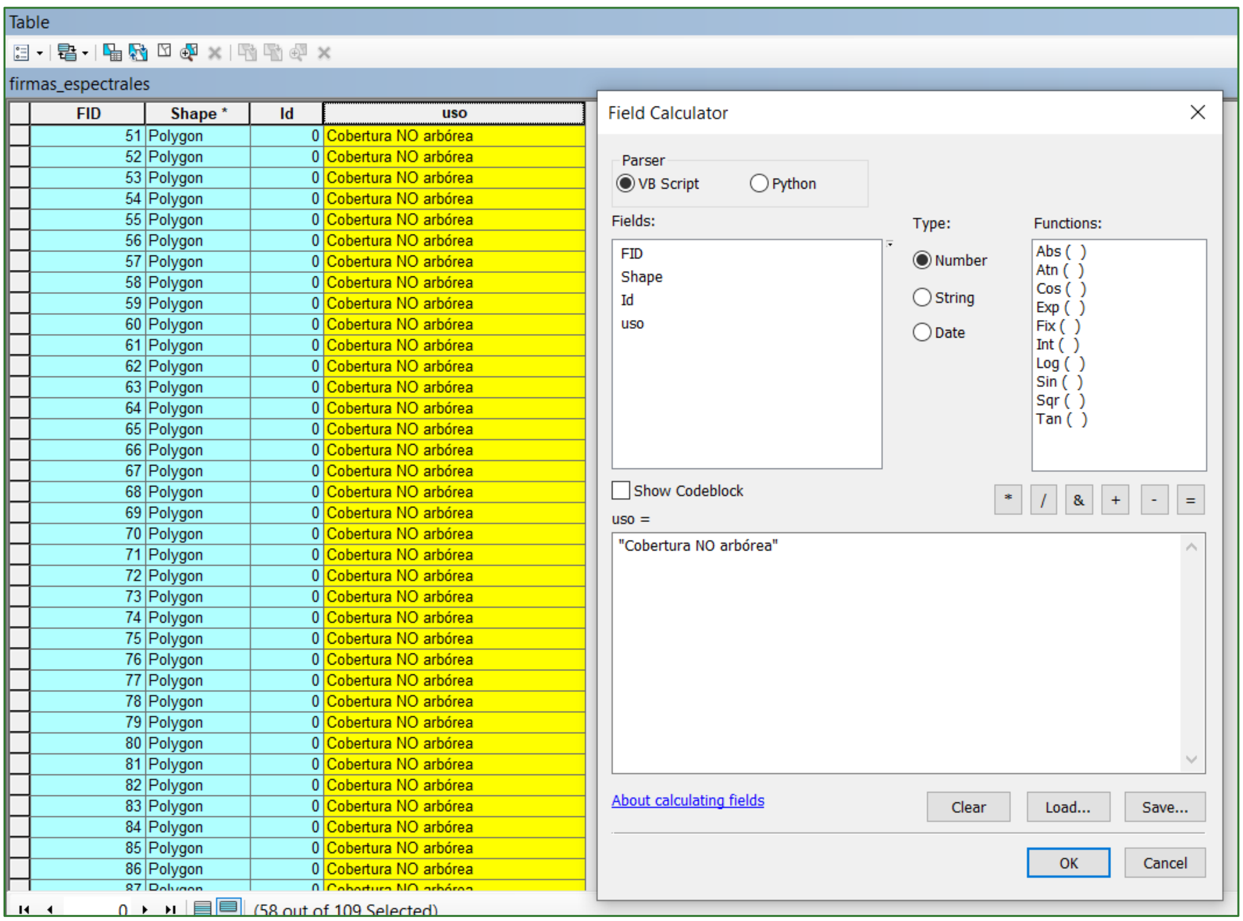
- After the polygons where tree cover has been identified are digitalised, go to the shapefile attributes table called **firmas_espectrales.shp** and in the "uso" column, call the polygons "**Cobertura arbórea**".



- You must now digitalise 50 no-tree cover polygons or signatures. You must select the sites without trees to digitalise or "draw" these polygons. For example: bodies of water, farmland, pastures, bare ground and populated areas, among others.



- After the polygons without tree cover are digitalised, go to the shapefile attributes table called **firmas_espectrales.shp** and in the **"uso"** column, call the polygons "**Cobertura NO arbórea**".



- When you have finished creating the spectral signatures, convert the **firmas_espectrales.shp** file into a file with the "signature" format. To do so, use the

"**Create Signatures**" tool which is found in **ArcToolBox/Spatial Analyst Tools/Multivariate/Create Signatures.** Enter the segmented mosaic file called "**Mosaico_segment**" in Input Raster or Feature Sample Data as the input file. Enter the spectral signature shapefile called **firmas_espectrales.shp** in the Sample File box. Select "uso" and save the file in the **COBERTURA** folder, naming it **firmas.GSG**.

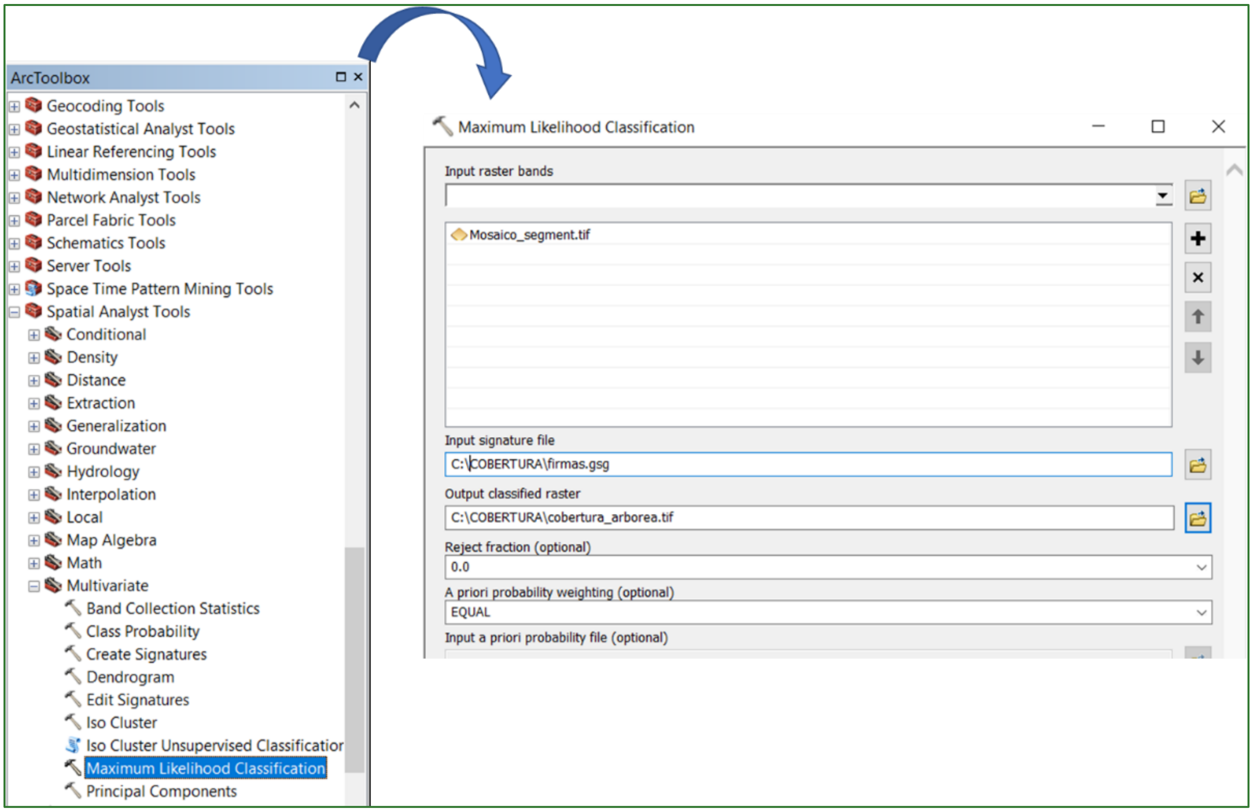
Phase 4. Classification

You can classify soil cover using satellite images in two ways: as supervised classification or as unsupervised classification.

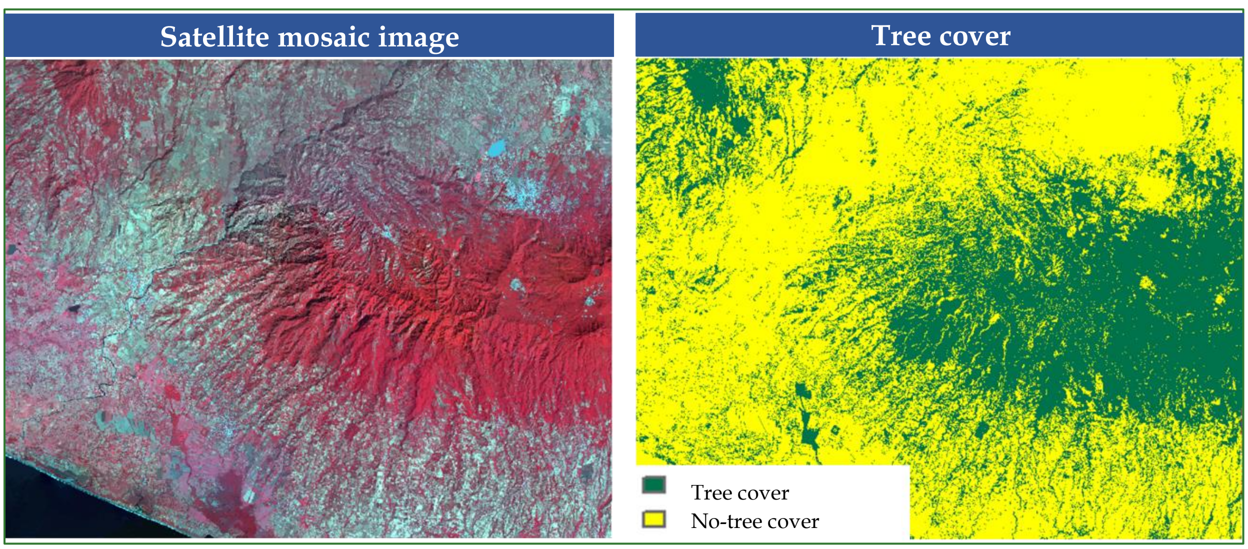
Supervised classification uses spectral signatures obtained from training samples to classify an image. Unsupervised classification looks for spectral classes (or clusters) in a multi-band image without any intervention from an analyst.[1] This exercise will conduct a supervised classification using digitalised spectral signatures in the "**firmas.GSG**" file. The procedure for this process is explained below.

- There is a set of algorithms in ArcMap located in **ArcToolBox/Spatial Analyst Tools/Segmentation and Classification** for supervised classification purposes. This exercise uses the **Maximum Likelihood Classification** tool.
    - Enter the segmented mosaic raster called **Mosaico_segment.tif** in the Input Raster window.
    - Enter the polygon file called **firmas.GSG** in the Input Signature File window.
    - Save the file in the **COBERTURA** folder naming it **cobertura_arborea.tif**.

[1] https://desktop.arcgis.com/en/arcmap/10.3/guide-books/extensions/spatial-analyst/image-classification/what-is-image-classification-.htm



This will result in a map classified into two categories (i) tree cover and (ii) no-tree cover.



A summary of the process used to obtain a tree cover map for the work area through this exercise is given below.

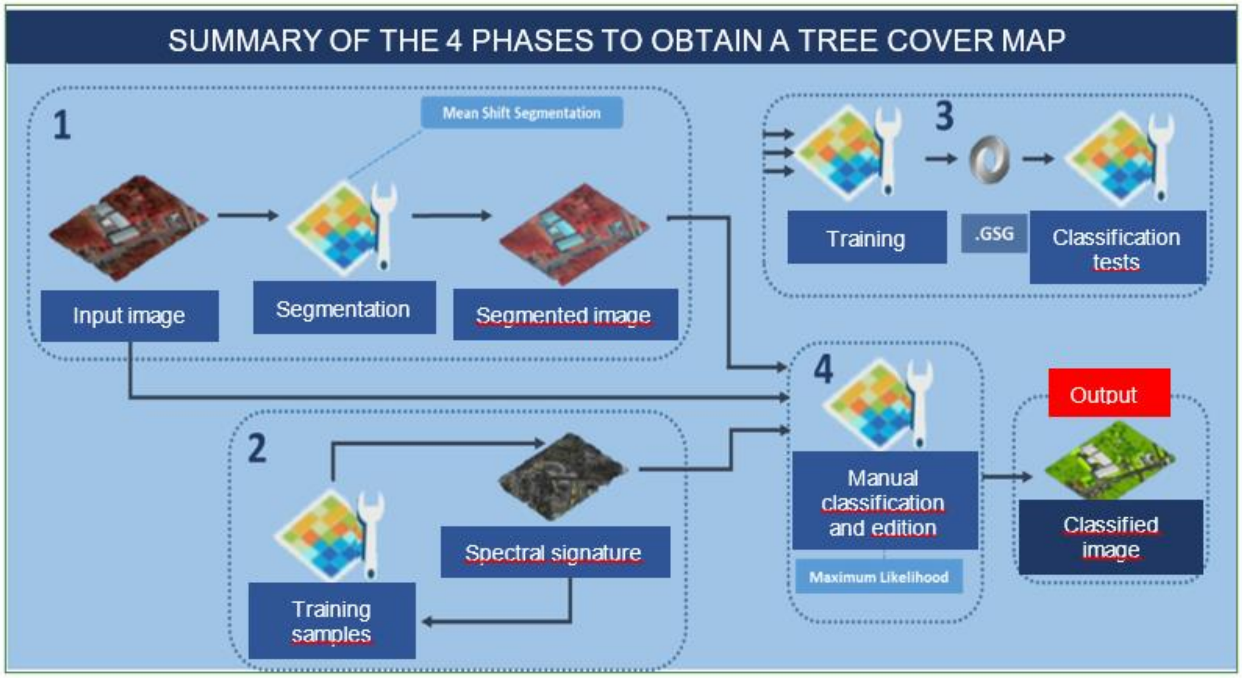


Image: summary of the method used to generate the tree cover map.

Part 10. Obtaining the aboveground biomass carbon map

Introduction

Forests are the biggest carbon sinks in the world. Over the last two decades they removed over a quarter of the carbon emissions caused by fossil fuel consumption worldwide (Le Quéré et al., 2015).

Aboveground tree biomass represents on average 70% of the accumulated carbon in the forest ecosystem. Aboveground stored biomass is found in tree trunks, branches and leaves.

Knowledge of the aboveground biomass carbon content is useful for determining the national Greenhouse Gas Effect balance, the construction of the respective national indicators and the creation of baselines for future projects that can be traded on the carbon market. What follows is an exercise to quantify the carbon stored in aboveground biomass in the project area.

Input data:

- Tree cover map (in raster format) located in the **COBERTURA** folder and called **cobertura_arborea.tif.**
- Aboveground carbon density value for each type of cover (units: megagrams per hectare (Mg/ha) = tonne/ha.

Steps of the method

1. Create a folder in your work directory naming this 01_CARBONO and create the following subfolders:
    - Mapa_Cobertura
    - Mapa_Carbono
    - Zona_Estudio

2. If the cover types raster is in geographical coordinates, reproject it to UTM or to the reference system projection shapefile **zona_de_trabajo.shp** generated in step 1, which is in the **VECTORES** folder.

    - Use the ArcGIS tool to reproject the raster: **Projections and Transformations/Raster/Project Raster** and save the output file in the **01_CARBONO/ Zona_Estudio** folder, naming it **lim_zona_estudio_project.shp.**

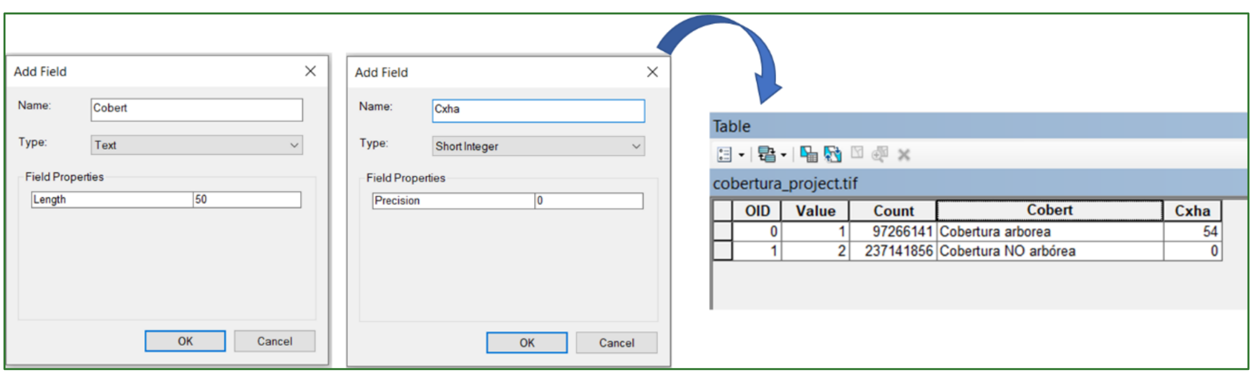
    - Use the ArcGIS tool to reproject the tree cover map raster: **Projections and Transformations/Raster/Project Raster.** Save the output file in the **01_CARBONO/ Mapa_Cobertura** folder naming it **cobertura_project.tif.**

3. Reclassify the cover types map in such a way that it matches the classes for which there are mean carbon density values (see your country's carbon tables). We will be using 54 C tonne/ha for this exercise.

Aboveground C (tonne/ha)	HN	PN	CR	NI	SV	GT	RD
Forest (general mean)		71.30	92.65	44.91	54	122.06	
Mangrove forest		81.60			39.15		
Scrub		17.20					
Crops		11.70					
Pasture		5.50		5.36			13.42
Other land		1.70					
Broadleaf forest					54.43		
Shade-grown coffee tree forest	28.37				36.72	28.16	46.59
Moist BL forest	64.92						
Deciduous BL forest	19.25						
Mixed forest	37.47						
Dense coniferous forest	28.23						
Coniferous forest (general)							49.09
Cloud forest							64.28
Dry forest							24.98
Dry scrubland							14.24

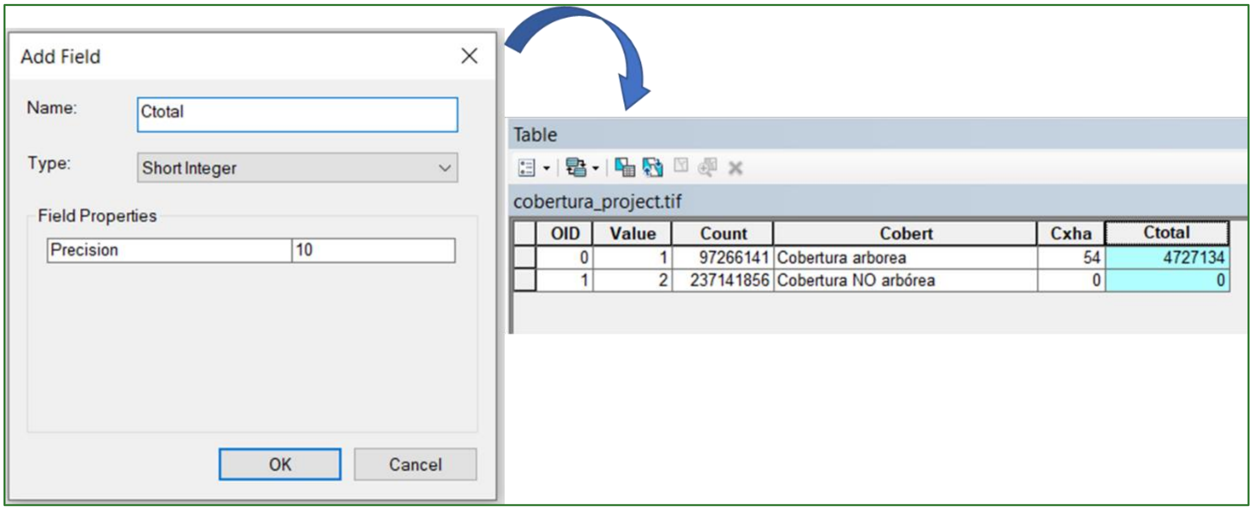
Stage 1: Generating the carbon raster.

Open the attributes table in the tree cover map called **cobertura_project.tif** and add a text-type column naming this "Cobert". Fill in this column with the soil cover categories and add another numerical-type column naming this "Cxha". Here, place the values in carbon tonnes per hectare for the type of forest in question.
There are two cover categories in our exercise: (i) tree cover and (ii) no-tree cover. if you use a map with different types of cover, enter the value associated with each one.

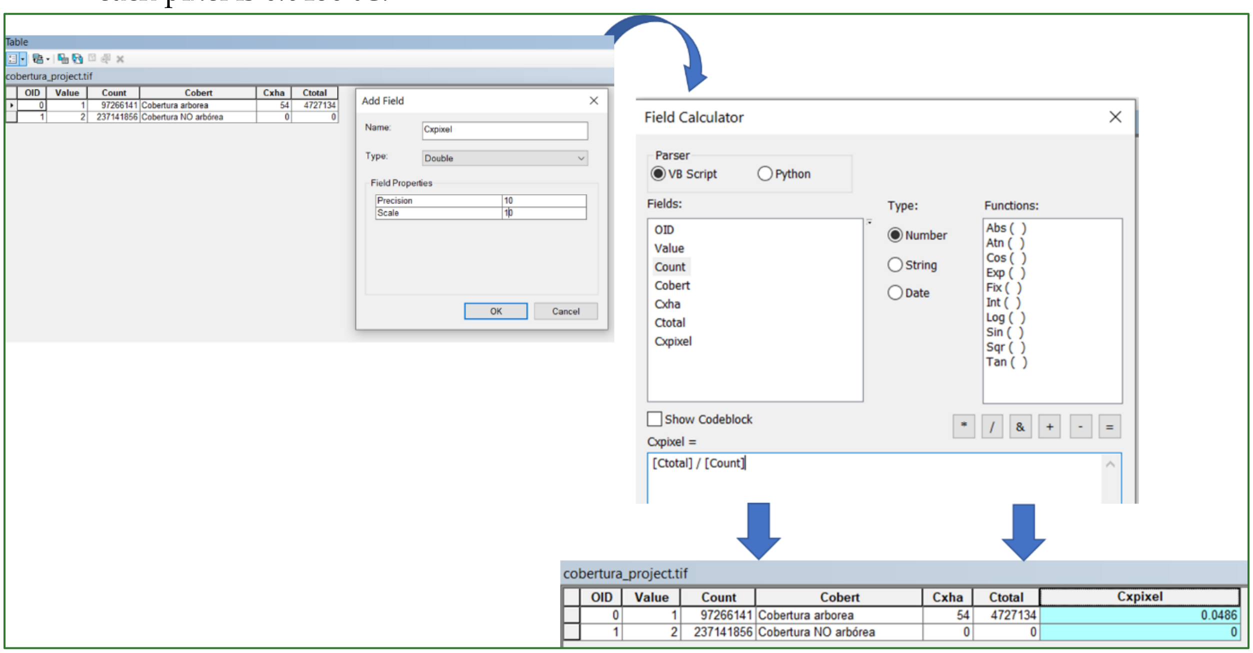


- You have to add a new numerical-type column named "Ctotal" and apply the following equation to find out the total tree cover: ("PixelSize" ^2/10000) *(pixel number)*(Cxha).

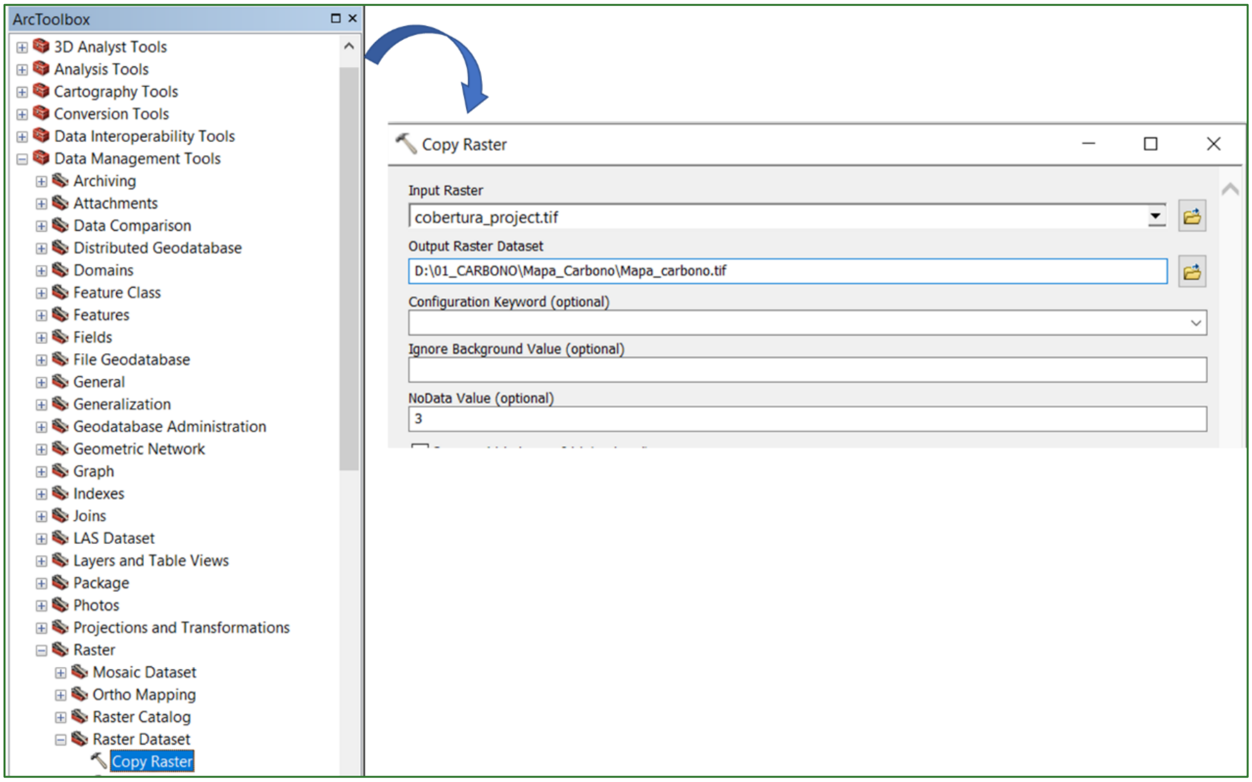
- In our example we will use **(3*3)/10000)* [Count]* [Cxha].**
- The result we get is that in our project area there are 4,727,134 tonnes of carbon stored in the aboveground biomass with 87,539 hectares of tree cover there.



- Calculating carbon by pixel: to find out the carbon per pixel you have to generate a new numerical-type column naming this "Cxpixel", while applying the following equation in the calculator: Cxha/pixel number.
- We will use **[Cxha]/[Count]** in our example. The result is that the carbon tonne value for each pixel is 0.0486 tC.



- Lastly, make a copy of **cobertura_project.tif** map raster naming it **mapa_carbono.tif** and save it in the **01/CARBONO/Mapa_Carbono** folder. Use the "**Copy Raster**" tool found in **ArcToolBox/Data Management Tools/Raster/Raster Dataset/Copy Raster.**



Estimating the carbon map using the forest edge method

Forest edge is another way to calculate carbon. This calculation uses the models developed by Chaplin-Kramer et al. (2015).

In the Chaplin-Kramer et al. publication "Degradation in carbon stocks near tropical forest edges[2]" they estimated that the biomass in the first 500 m of the forest edge is on average 25% lower than in forest interiors. They also found that reductions of 10% extend to 1.5 km from the forest edge. These findings suggest that the Tier 1 methods of the Intergovernmental Panel on Climate Change (IPCC) overestimate carbon stocks in tropical forests by nearly 10%.

Therefore, it is recommended that this method is used in areas where there are extensive forest areas or "patches" of large forest. More details are given in ANNEX 1 of this document.

[2] https://www.nature.com/articles/ncomms10158#citeas

Part 11. Preparing soil data

Soil data were obtained from SoilGRIDS. These data have a resolution of 250 m. In this section a process is carried out to transfer the 250 m data to a resolution of 3 m.

Step 1: downloading Soil Data

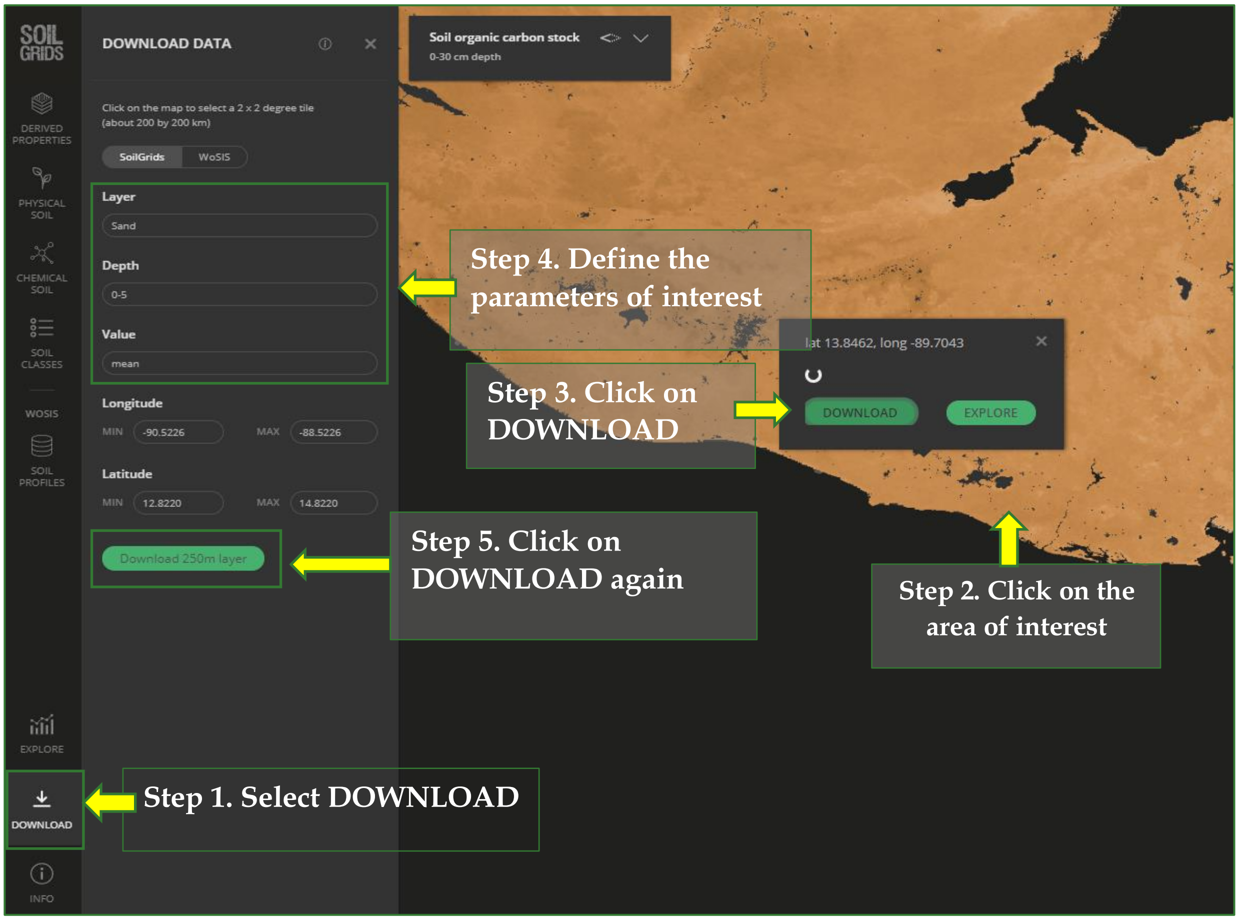
Soil data can be downloaded from the following link: https://soilgrids.org/; the following window will come up on screen.

You must download 4 files from this platform.

- Soil Organic Carbon Stock to 5 cm in dg/kg units
- Sand to 5 cm in g/kg units
- Silt to 5 cm in g/kg units
- Clay to 5 cm in g/kg units

The mean value must be downloaded for each type of data. You must take the following steps during the download process:

> Click on the **DOWNLOAD** tab and then click on the map in the area of interest or project area. Bear in mind that the downloads will be done in a grid every 2 degrees (200 km x 200 km).



After you have completed the process, go to the Data download folder, copy the downloaded files and save them in the **RASTER/SUELO folder.** The data are downloaded with the name out.tif. You will need to rename them to match the name they have on the platform.

- clay_descarga.tif
- sand_descarga.tif
- silt_descarga.tif
- orgcarb.tif

Step 2:

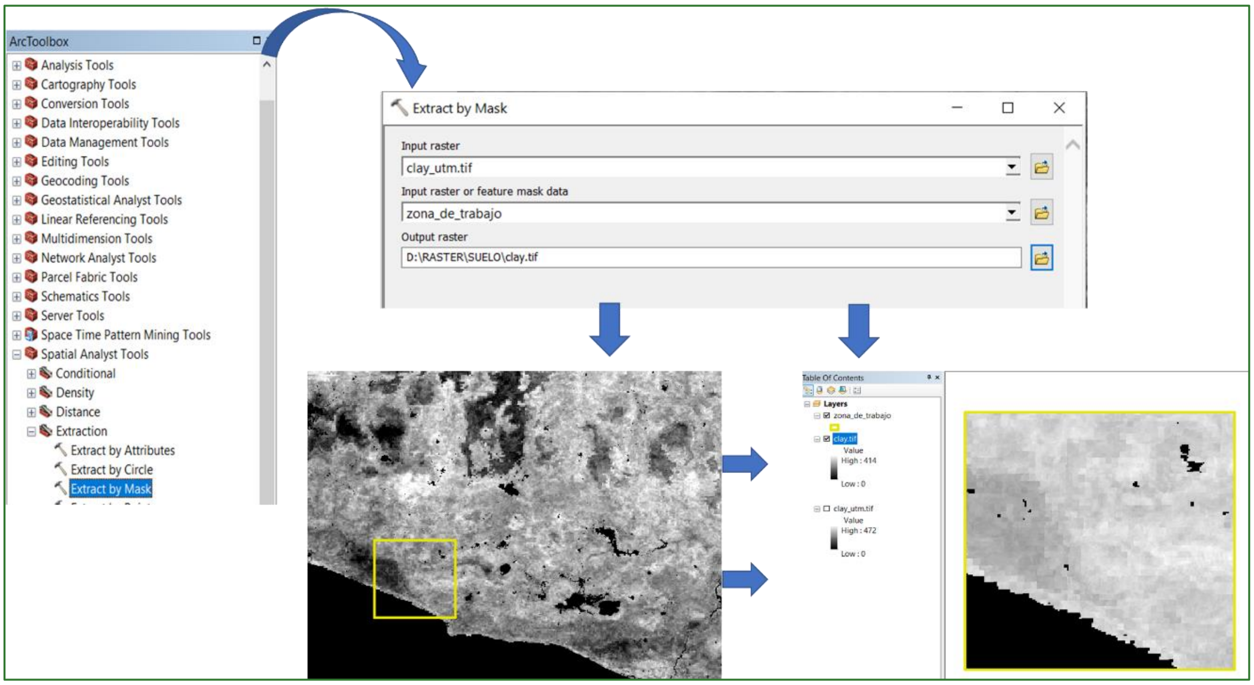
Reproject each of the raster layers onto the coordinate system of your country by following the steps indicated above in PART 1, entitled "PART 1. PROJECTING THE LAYERS ONTO THE COUNTRY'S GEODESIC SYSTEM". Save the reprojected layers in the **RASTER/SUELO** folder and name them as follows:

- clay_utm.tif
- sand_utm.tif
- silt_utm.tif

- orgcarb_utm.tif

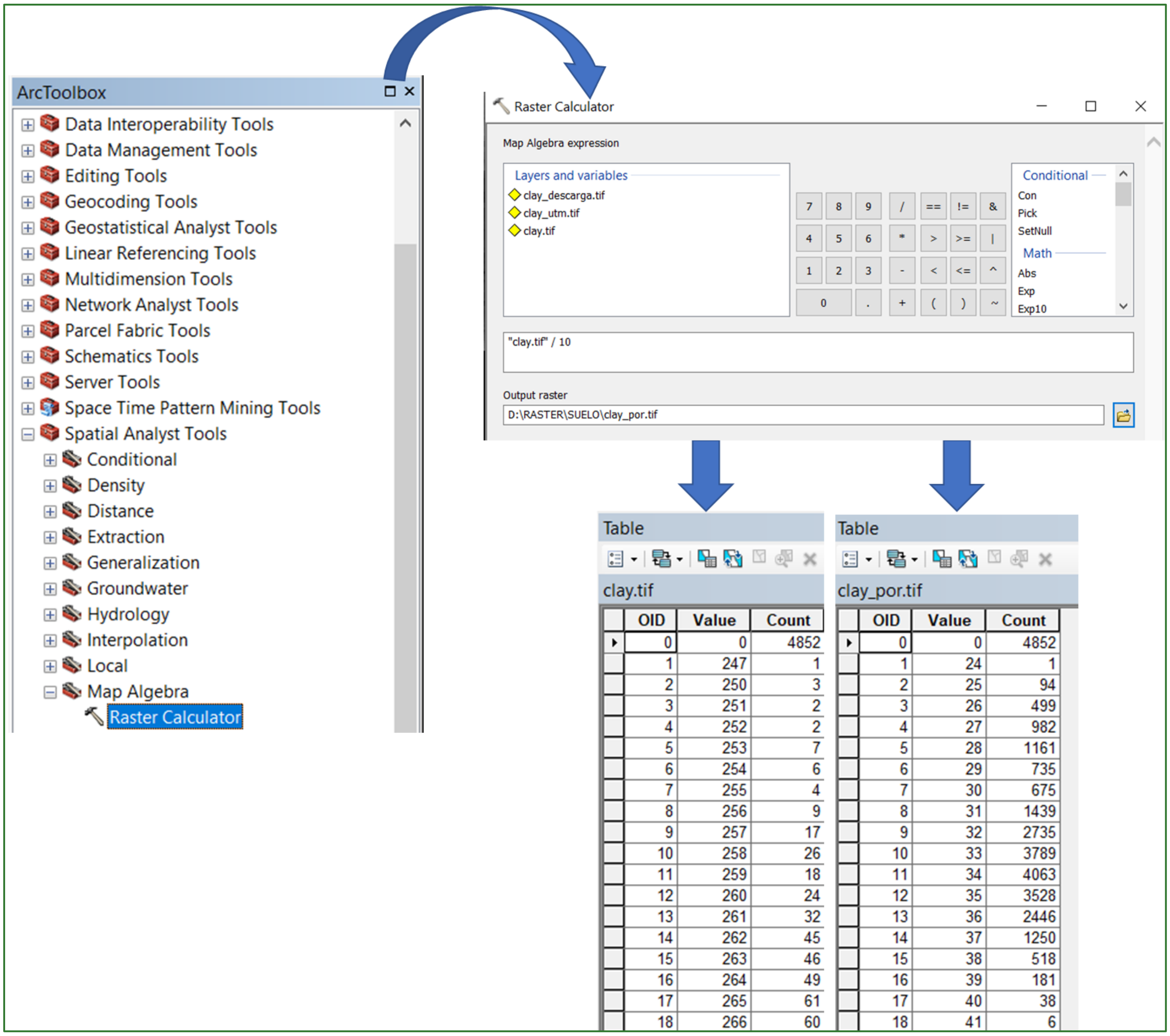
Step 3:
Cut each layer to the project area limit. Use the layer called **zona_de_trabajo.shp** that is stored in the **VECTORES** folder and use the "Extract by Mask" tool located in: **ArcToolBox/Spatial Analyst Tool/Extraction/Extract by Mask**. Enter the reprojected layer (e.g. clay_utm) in the Input Raster box. Enter the **zona_de_trabajo.shp** file in the Input Raster or Feature Mask Data box and save the file in the **RASTER/SUELO** folder with the following names:

- clay.tif
- sand.tif
- silt.tif
- orgcarb.tif

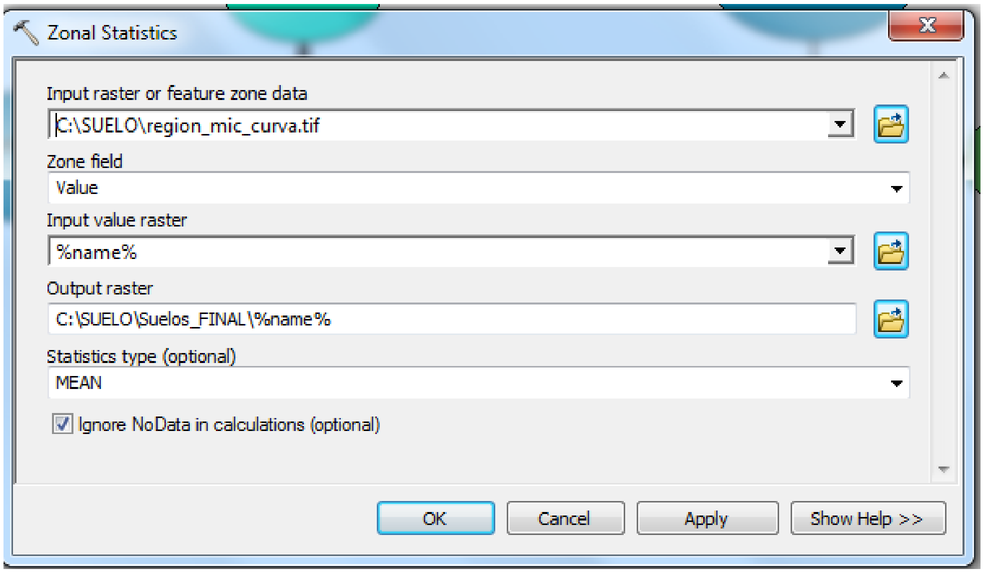


Step 4:
As the last step in this process, calculate the sand, silt, clay and organic carbon raster as percentage values. Use the map calculator to do so, dividing the sand, silt and clay layers by 10 and the soil organic carbon layer by 100. Use the "Raster Calculator" in **ArcToolBox/Spatial Analyst Tool/Map Algebra/Raster Calculator** to do this. Save the files in the **RASTER/SUELO** folder and name the layers as follows:

- clay_por.tif
- sand_por.tif
- silt_por.tif
- orgcarb_por.tif



Statistics type: MEAN


Zonal Statistics
Input raster or feature zone data
C:\SUELO\region_mic_curva.tif
Zone field
Value
Input value raster
%name%
Output raster
C:\SUELO\Suelos_FINAL\%name%
Statistics type (optional)
MEAN
Ignore NoData in calculations (optional)
OK
Cancel
Apply
Show Help >>

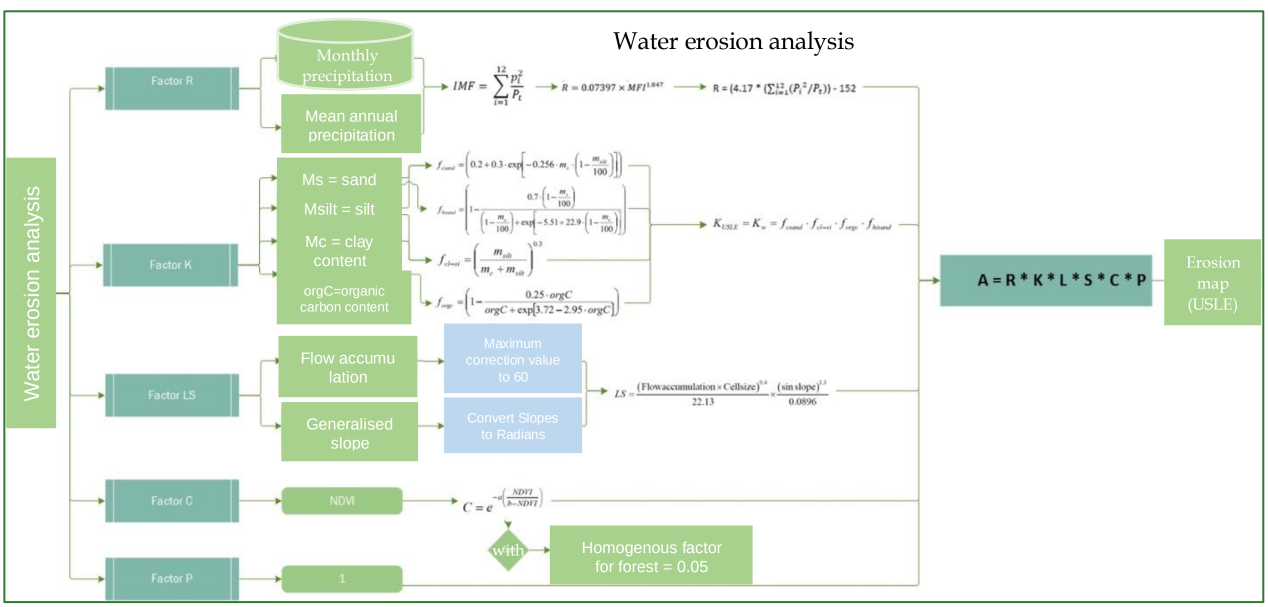
Soil and hydrological analysis

Module 2: Soil and hydrological analysis

Water and soil conservation require knowledge of the relationships between the positive and negative effects on soil loss. In addition to the direct action of precipitation and the resulting runoff, these losses can be worsened by human action through unsustainable logging, land development and non-conservational farming.

Accordingly, erosion studies must be conducted to determine the land affected and the different degrees of erosion, the potential risks associated with different land uses and the conflict situations to adopt prevention, maintenance, mitigation and/or recovery measures.

Remote sensing can be very useful to assess risk and water erosion dynamics (Wang et al., 2013). Knowledge of these factors make it possible to conduct several zoning exercises and take land planning decisions at the landscape level (Delgadillo et al., 2009). In this section, a set of climate, topography and vegetation variables will be geoprocessed to create an erosion map using the Universal Soil Loss Equation (USLE) method. USLE is a method that uses six factors: rainfall erosivity (R), soil erodibility (K), slope length (L), slope steepness (S), cover management (C) and conservation practice (P) to estimate mean soil loss (A) over a period of time represented by R, generally taken as one year (Wischmeier and Smith, 1978).



The diagrams in this methodological guide are available in an online GitHub repository by clicking on the following link (Spanish original): https://github.com/guialandscape/Diagramas

Part 12. Generating the water erosion map

The erosion raster will be obtained by using the Universal Soil Loss Equation (USLE). This equation is made up of 6 factors:

A = R * K * L * S * C * P

A = Erosion (tonne/ha.year)

R = Rainfall erosivity (MJ.mm/ha.h)

K = Soil erodibility (tonne.ha.h ·ha/ha.MJ.mm)

L = Slope length (adimensional)

S = Slope steepness (adimensional)

C = Vegetation cover (adimensional)

P = Conservation practices (adimensional)

The following layers are required to conduct a water erosion analysis:

File type	Location and name of input data file
Precipitation	RASTER/CLIMA/ malla_base_LLUVIA
Sand content	RASTER/SUELO/Sand_por.tif
Clay content	RASTER/SUELO/Clay_por.tif
Silt content	RASTER/SUELO/ Silt_por.tif
Organic carbon content	RASTER/SUELO/Orgcarb_por.tif
Flow accumulation	DATOS_HIDRO/ flowacc.tif
Slope	RASTER/MDT/pendiente_region_curva_generalizada.tif
NDVI	RASTER/NDVI/NDVI.tif

Step 1: Calculate the R factor

Formulae to estimate the R factor

The R factor is calculated using the **Modified Fournier Index (MFI)**, which is obtained by using the following equation:

$$IMF = \sum_{i=1}^{12} \frac{p_i^2}{P_t}$$

Where:

Pi = each month's rainfall (mm)

Pt = mean yearly rainfall (mm)

The MFI can be used to calculate the R factor using the Arnoldus equation, 1980:

$$R = 0.07397 \times MFI^{1.847}$$

Or this alternative one:

$$R = 95.77 - 6.081MFI + 0.4770MFI^2$$

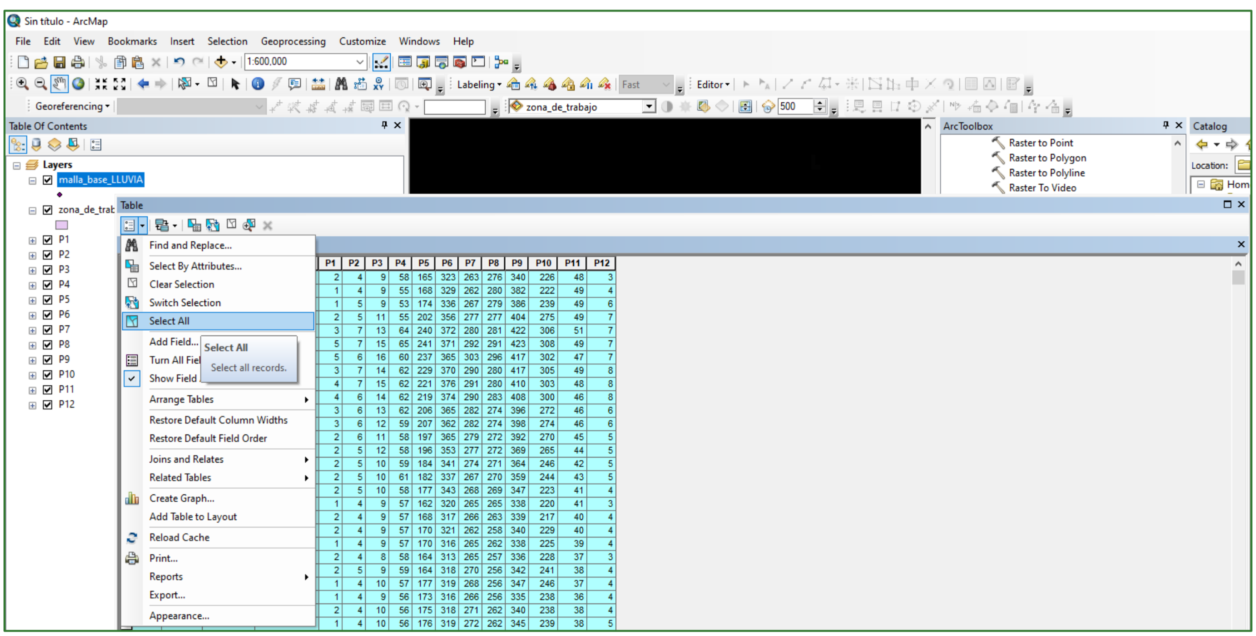
There are other adjusted equations to calculate R like Arnoldus, 1998, which has been used for some studies in Nicaragua:

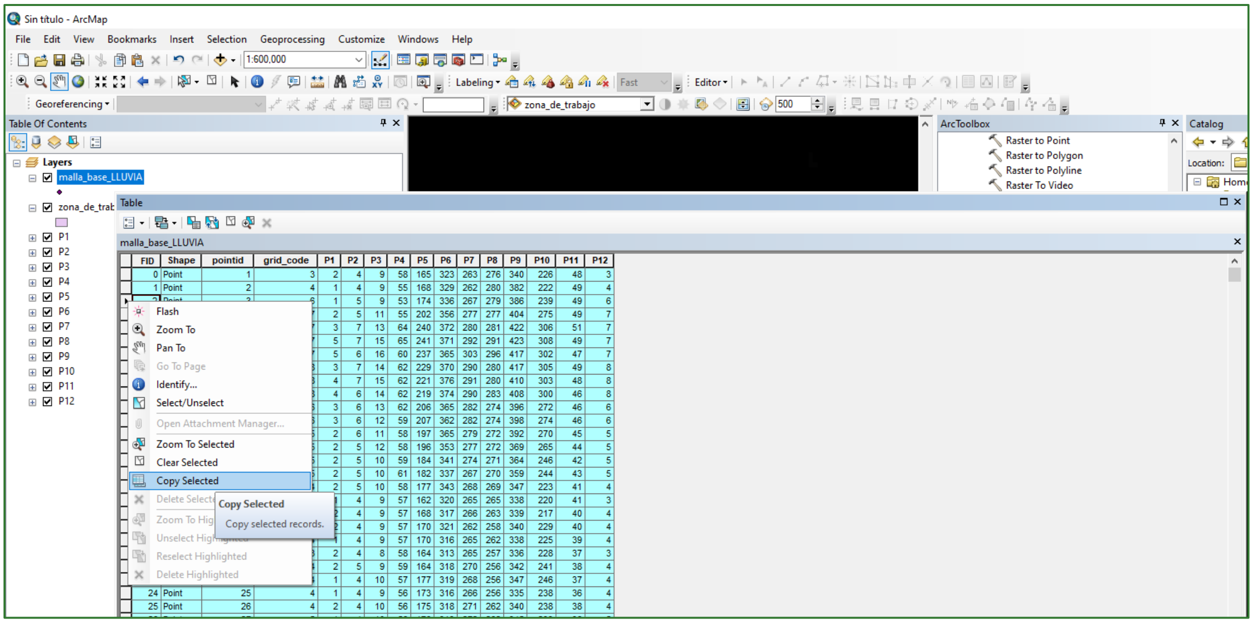
$$\mathrm{R} = (4.17 * (\textstyle\sum_{i=1}^{12}(P_i{}^2/P_t)) - 152$$

Procedure to estimate the R factor in Excel

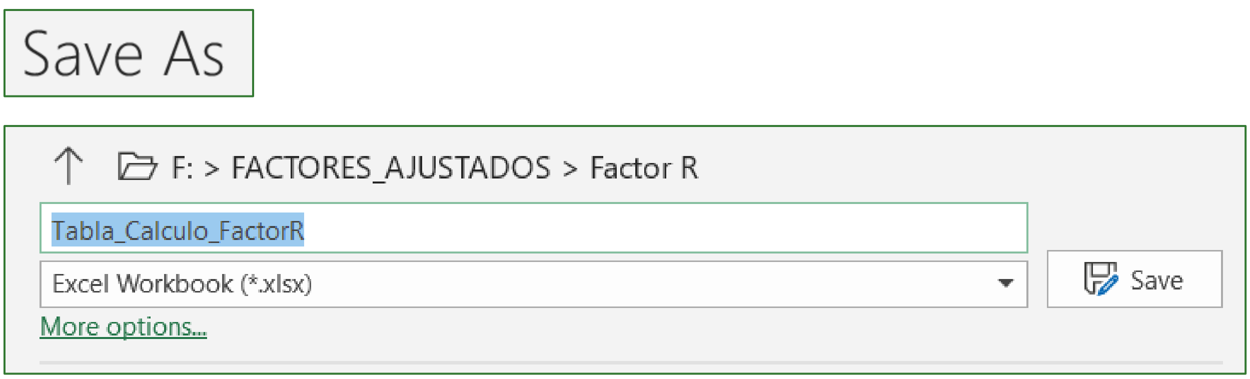
It is recommended that Excel is used to calculate the MFI and the R factor based on the point mesh monthly rainfall data file **malla_base_LLUVIA.shp** (in RASTER/CLIMA). Follow these steps:

- Open the shapefile attributes table **malla_base_LLUVIA.shp**, select all values and copy them.





- Open Excel and paste the selected values. Save this spreadsheet in the following location, naming it: … FACTORES\Factor R\Tabla_Calculo_FactorR.xlsx[3]
- Save the Excel file:



- You must now apply the **Modified Fournier Index (MFI)** calculation formula.

$$IMF = \sum_{i=1}^{12} \frac{p_i^2}{P_t}$$

Where:

Pi = each month's rainfall (mm)
Pt = mean yearly rainfall (mm)

[3] Table available in the GitHub repository: https://github.com/guialandscape/Tablas

Follow these steps:

- Add the headings to the following fields:

F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P_Anual	IMF	Factor R
2	4	9	58	165	323	263	276	340	226	48	3			
1	4	9	55	168	329	262	280	382	222	49	4			
1	5	9	53	174	336	267	279	386	239	49	6			
2	5	11	55	202	356	277	277	404	275	49	7			
3	7	13	64	240	372	280	281	422	306	51	7			
5	7	15	65	241	371	292	291	423	308	49	7			
5	6	16	60	237	365	303	296	417	302	47	7			

- Calculate the annual rainfall in the P_Anual field, adding up the rainfall for every month of the year. Example **=SUM(F2:Q2).**

F	G	H	I	J	K	L	M	N	O	P	Q	R	S
P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P_Anual	IMF
2	4	9	58	165	323	263	276	340	226	48	3	=Suma(F2:Q2	
1	4	9	55	168	329	262	280	382	222	49	4	SUMA(**número1**, [número2], ...)	

- Calculate the MFI. Example:

F	G	H	I	J	K	L	M	N	O	P	Q	R	S
P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P_Anual	IMF
2	4	9	58	165	323	263	276	340	226	48	3	1717	=((F2^2/R2)+(G2^2/R2)+(H2^2/R2)+(I2^2/R2)+(J2^2/R2)+(K2^2/R2)+(L2^2/R2)+(M2^2/R2)+(N2^2/R2)+(O2^2/R2)+(P2^2/R2))
1	4	9	55	168	329	262	280	382	222	49	4	1765	

=(F2^2/R2)+(G2^2/R2)+(H2^2/R2)+(I2^2/R2)+(J2^2/R2)+(K2^2/R2)+(L2^2/R2)+(M2^2/R2)+(N2^2/R2)+(O2^2/R2)+(P2^2/R2))

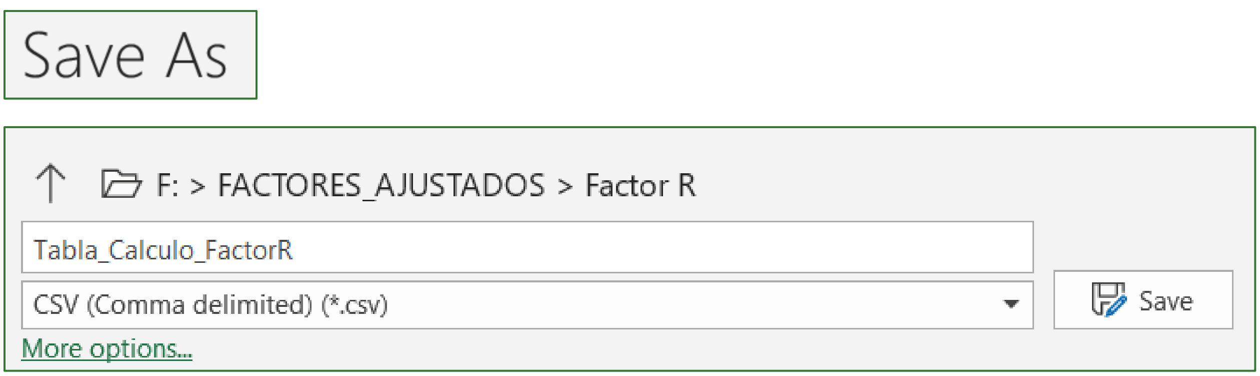
- Add the Factor_R field and calculate it using the formula taken from Pradhan B. et. al (2012):
  = (4.17 ∗ MFI) – 152

F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P_Anual	IMF	Factor R
2	4	9	58	165	323	263	276	340	226	48	3	1717	261.70297	=(4.17*S2)-152
1	4	9	55	168	329	262	280	382	222	49	4	1765		

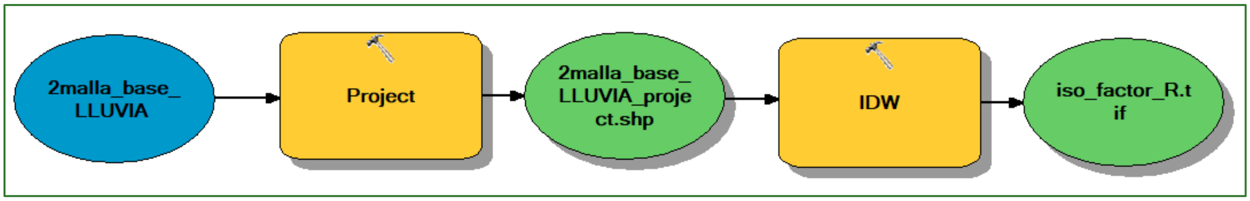
- Do the calculations for all table rows.

F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P_Anual	IMF	Factor R
2	4	9	58	165	323	263	276	340	226	48	3	1717	261.70297	939.30139
1	4	9	55	168	329	262	280	382	222	49	4	1765	274.357507	992.0708
1	5	9	53	174	336	267	279	386	239	49	6	1804	279.232816	1012.4008
2	5	11	55	202	356	277	277	404	275	49	7	1920	294.486979	1076.0107
3	7	13	64	240	372	280	281	422	306	51	7	2046	308.890029	1136.0714
5	7	15	65	241	371	292	291	423	308	49	7	2074	311.661041	1147.6265
5	6	16	60	237	365	303	296	417	302	47	7	2061	310.547307	1142.9823
3	7	14	62	229	370	290	280	417	305	49	8	2034	307.40118	1129.8629
4	7	15	62	221	376	291	280	410	303	48	8	2025	305.997531	1124.0097
4	6	14	62	219	374	290	283	408	300	46	8	2014	305.212512	1120.7362
3	6	13	62	206	365	282	274	396	272	46	6	1931	293.751942	1072.9456
3	6	12	59	207	362	282	274	398	274	46	6	1929	294.328149	1075.3484
2	6	11	58	197	365	279	272	392	270	45	5	1902	292.309674	1066.9313

- Save the changes.
- Export the table to (*.CSV) format.

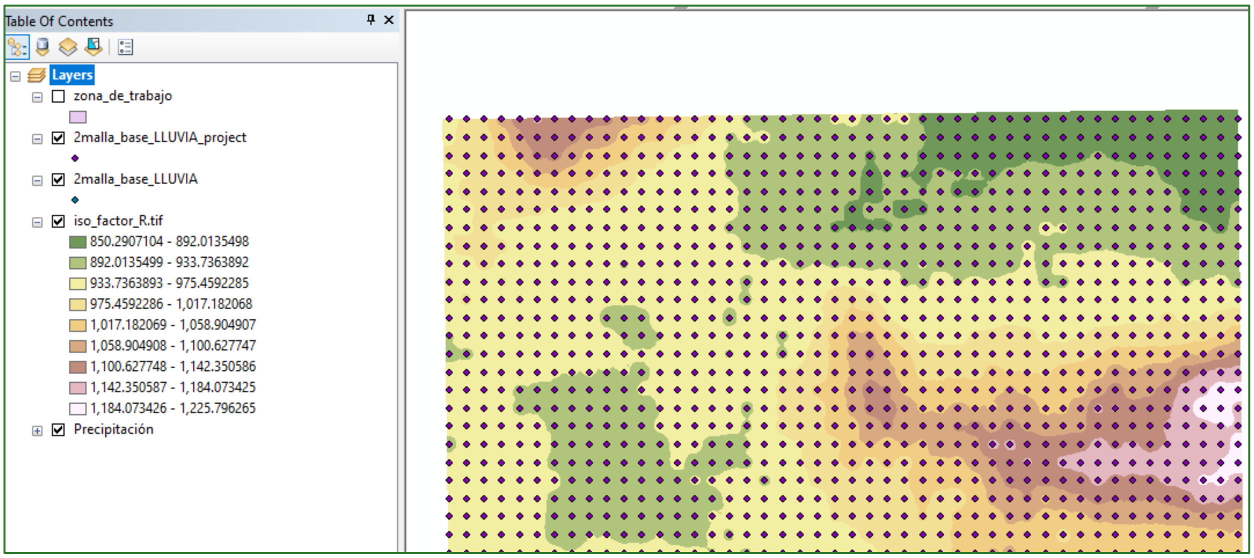


- In ArcMap, open the **malla_base_LLUVIA.shp** table and Join this to the **Tabla_Calculo_FactorR.csv.**
- In ArcMap, save as the **malla_base_LLUVIA.shp** point file naming it **2malla_base_LLUVIA.shp** and save it in the **RASTER/FACTORES/FACTOR R** folder.
- Next, interpolate the aforementioned file using the IDW function (**Spatial Analyst Tools/Interpolation/IDW**) using the Factor_R column and rename the output file **iso_factor_R.tif**. Save it in the **RASTER/FACTORES/FACTOR R folder.** Bear in mind that the resolution (Output cell size) that has to be set in the interpolation must be 3 m. Leave the rest of the default settings.
- The model will look as follows:



N.B.: it is important that the projection to be used in each process must be WGS 84 zone 16 N.

- The output will be displayed as follows:



Step 2: Calculate the K factor:
The K factor is calculated from the soil characteristics' data using the following formula:

$$K_{USLE} = K_w = f_{csand} \cdot f_{cl-si} \cdot f_{orgc} \cdot f_{hisand}$$

The following data in raster format are required to apply the formula:

Formula Prefix	Layer and unit	Location and name of input data file
Ms	Sand content (%)	RASTER/SUELO/Sand_por.tif
Msilt	Silt content (%)	RASTER/SUELO/ Silt_por.tif
Mc	Clay content (%)	RASTER/SUELO/Clay_por.tif

orgC	Organic carbon content (%)	RASTER/SUELO/orgcarb_por.tif

N.B.: for the K factor estimation process you can structure the application of the different formulae in ArcMap using the Raster Calculator or downloading the Model Builder Erosion available in the GitHub repository at the following link: https://github.com/guialandscape/Model_Builder

Try to follow the steps given below to apply each formula in the ArcGis Raster Calculator (**Spatial Analyst Tools/Map Algebra/Raster Calculator**):

$$f_{csand} = \left(0.2 + 0.3 \cdot \exp\left[-0.256 \cdot m_s \cdot \left(1 - \frac{m_{silt}}{100}\right)\right]\right)$$

Option 1: Float((0.2+(0.3*(Exp(-0.256 * ("%sand_por%" * (1-("%silt_por%"/100))))))))

Option 2: 0.2+(0.3*(Exp(-0.256*(Float("%sand_por.tif%”) *(1-(Float("%silt_por.tif%")/100))))))

N.B.: Bear in mind that on account of the formulae being expressed in the Raster Calculator, the layers appear between %%. This is automatically generated when calling up a layer that has previously been generated in a model. This does not express a percentage unit; it may or may not be present in our expression in the Raster Calculator.

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3}$$

Option 1: Float(Power(("%silt_por%" / ("%clay_por%" + "%silt_por%")),0.3))

Option 2: Power((Float("%silt_por.tif%")/(Float("%clay_por.tif%")+ Float("%silt_por.tif%"))),0.3)

$$f_{orgc} = \left(1 - \frac{0.25 \cdot orgC}{orgC + \exp[3.72 - 2.95 \cdot orgC]}\right)$$

Option 1: Float((1-((0.25 * "%orgcarb_por%") / ("%orgcarb_por%" + (Exp(3.72-(2.95 * "%orgcarb_por%")))))))

Option 2: 1-((0.25 * Float("%orgcarb_por.tif%")) / (Float("%orgcarb_por.tif%") + (Exp(3.72-(2.95 * Float("%orgcarb_por.tif%"))))))

$$f_{hisand} = \left(1 - \frac{0.7 \cdot \left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + \exp\left[-5.51 + 22.9 \cdot \left(1 - \frac{m_s}{100}\right)\right]} \right)$$

Option 1: Float((1-((0.7 * (1-("%sand_por%" / 100))) / (((1-("%sand_por%" / 100)) + Exp(-5.51 + (22.9 * (1 - ("%sand_por%"/100)))))))))

Option 2: 1-((0.7 * (1-(Float("%sand_por.tif%") / 100))) / (((1-(Float("%sand_por.tif%") / 100)) + Exp(-5.51 + (22.9 * (1 - (Float("%sand_por.tif%")/100)))))))

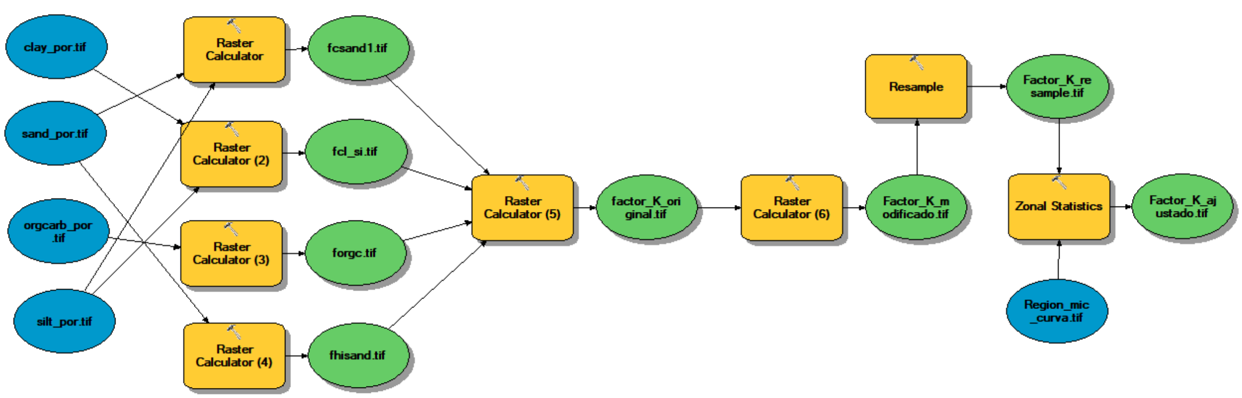
The K factor is calculated using the corresponding equation:

$$K_{USLE} = K_w = f_{csand} \cdot f_{cl-si} \cdot f_{orgc} \cdot f_{hisand}$$

Expression in Raster Calculator:

Float("%fcsand1.tif%") *Float("%fcl_si.tif%") * Float("%forgc.tif%")* Float("%fhisand.tif%")

After applying each model formula, it will look as follows:

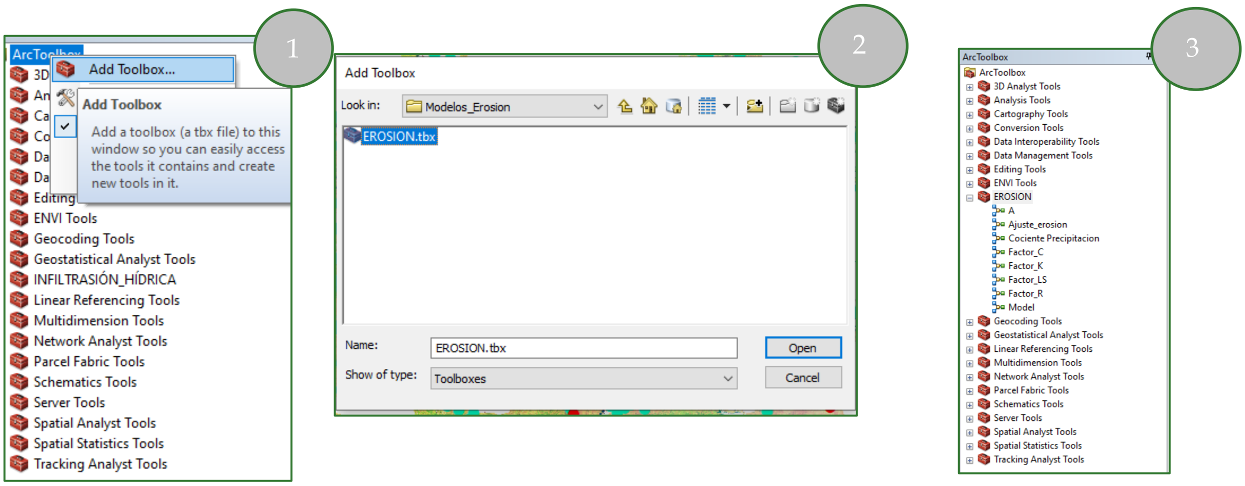


N.B.: Bear in mind that at the end of the process the data is scaled to 3 m using the Resample function (**Data Management Tools/Raster/Raster Processing/Resample**) and then a mean is calculated using the zonal statistics function (**Spatial Analyst Tools/Zonal/Zonal Statistics**) depending on the **Region_mic_curva.tif** layer found in the **RASTER/MDT** folder. This process is done to enhance the quality of the data depending on the land proportions defined (región_mic_curva.tif). **Name the output file Factor_K_ajustado.tif and save it in the RASTER/FACTORES/FACTOR K** folder.

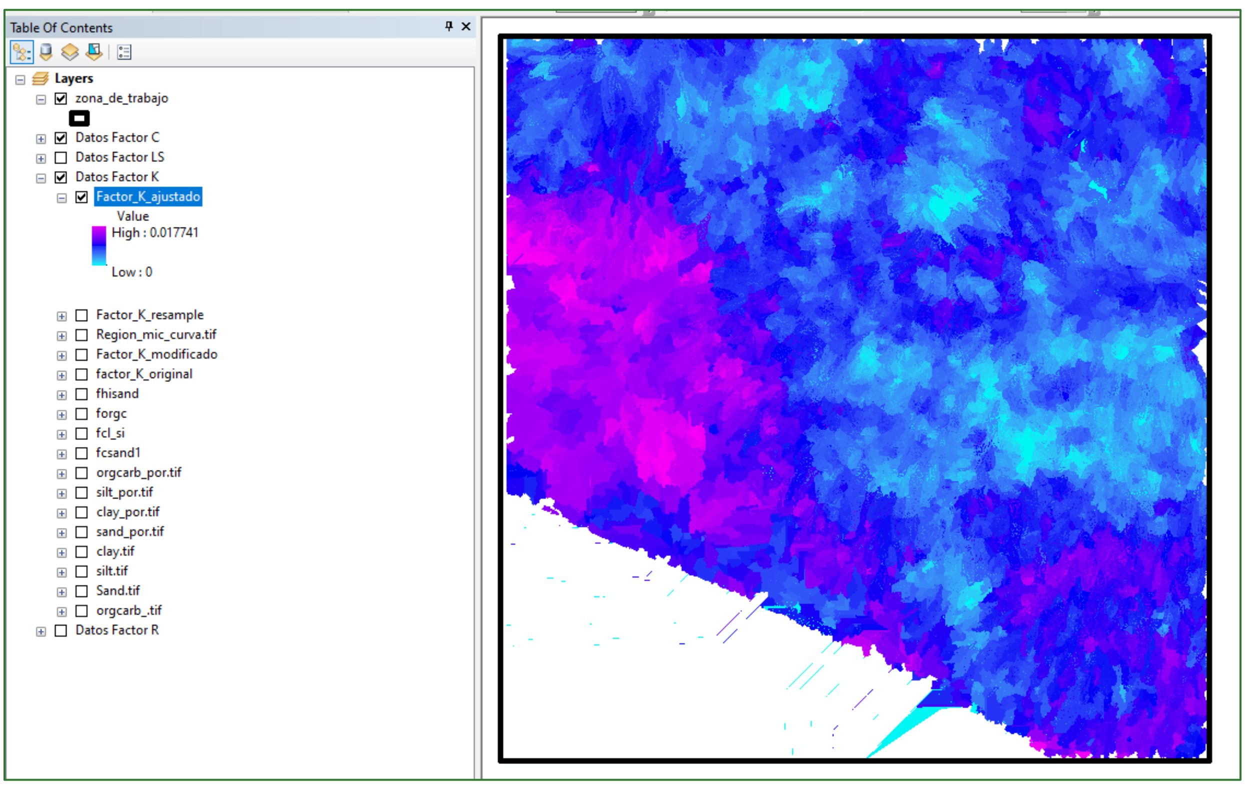
If you want to download the Model Builder to run this process automatically, follow these steps:

- Download the ToolBox: https://github.com/guialandscape/Model_Builder

- Right-click on ArcToolBox, then click on Add:



The result of the analysis can be seen below:



Comments on K factor results

Check that the parameters used in calculating the **K Factor** when using the Williams, J. R. formula (1995) do not have values higher than 1. These parameters are fcsan, fcl-si, forgc and fhisand.

fcsan: factor that assigns low erodibility to soil with a high coarse-sand content and assigns high erodibility to soil with finer sand.

fcl-si: factor that assigns low erodibility to soil with high clay and lime content.

forgc: factor that assigns low erodibility to soil with high organic carbon content.

fhisand: factor that assigns low erodibility to soil with extremely high sand content.

Step 3: Calculate LS

This is calculated using the unitary potential flow theory expressed in the following equation:

$$LS = \left(A/22.13\right)^{0.6} \left(\sin B/0.0896\right)^{1.3}$$

Where:

A: factor that contributes to the ascending slope

B: Slope angle

The following layers are needed to calculate the LS factor:

Layer	Location and name of input data
Flow accumulation	RASTER/DATOS_HIDRO/flowacc.tif
Generalised slope	RASTER/MDT/pendiente_región_mic_curva_generalizada.tif

Consider the following aspects when calculating the LS factor:

- **Calculation of the maximum length of the slope**

When calculating slope length, it is possible to restrict maximum length to 180 m, which is the equivalent of 60 pixels of 3 m. Other authors propose limiting the definition of this maximum length to 50 or 100 m to avoid overestimates. Accordingly, it is recommended that you adjust to allow for a maximum length of 75 m which is equivalent to 25 pixels of 3 m.

N.B.: To restrict the flow accumulation raster to 25 pixels, the cells in the accumulation raster with a value of less than 25 must keep their original value, but those with a higher value must all take a value of 25 (maximum fixed value).

- **Calculation of the slope in radians**

Slope in radians: slope calculation in ArcGis is given in degrees, but the formula to be applied requires conversion into radians, thus the raster in degrees must be multiplied by:

$$\frac{\pi}{180},$$

Expression in Raster Calculator: "%Pendiente_grados.tif%" * (3.1416/180)

The LS factor is calculated using the **Raster Calculator** with the following equation:

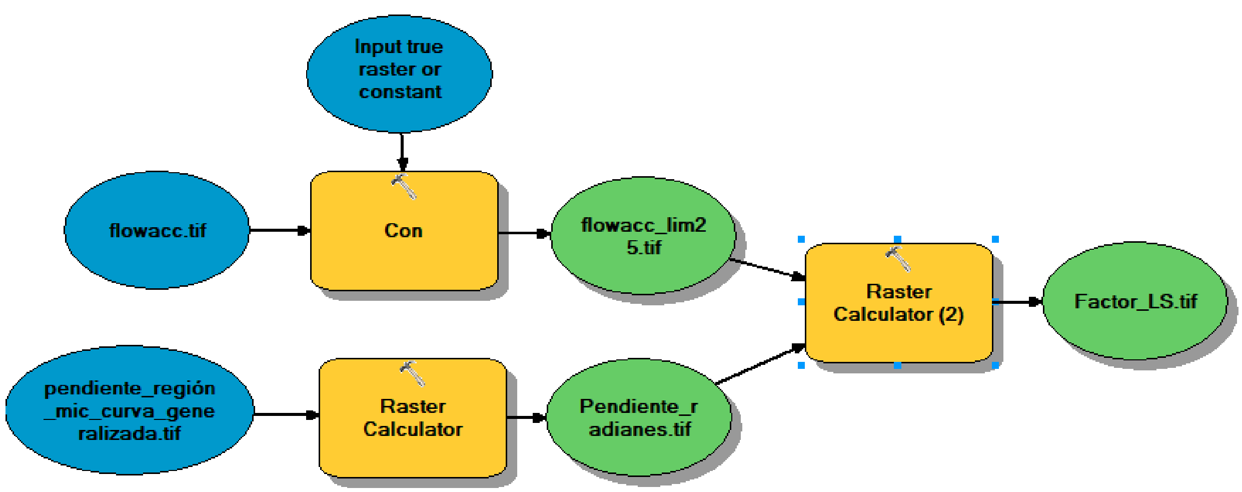
Formula (includes the conversion of degrees into radians).

$$LS = \text{Pow}\left(\left[\text{flow accumulation}\right]\ \text{resolution}/22.13, 0.6\right)$$
$$\times \text{Pow}(\text{Sin}\left(\left[\text{slope of DEM}\right] \times 0.01745/0.0896, 1.3\right)$$

Expression in Raster Calculator:

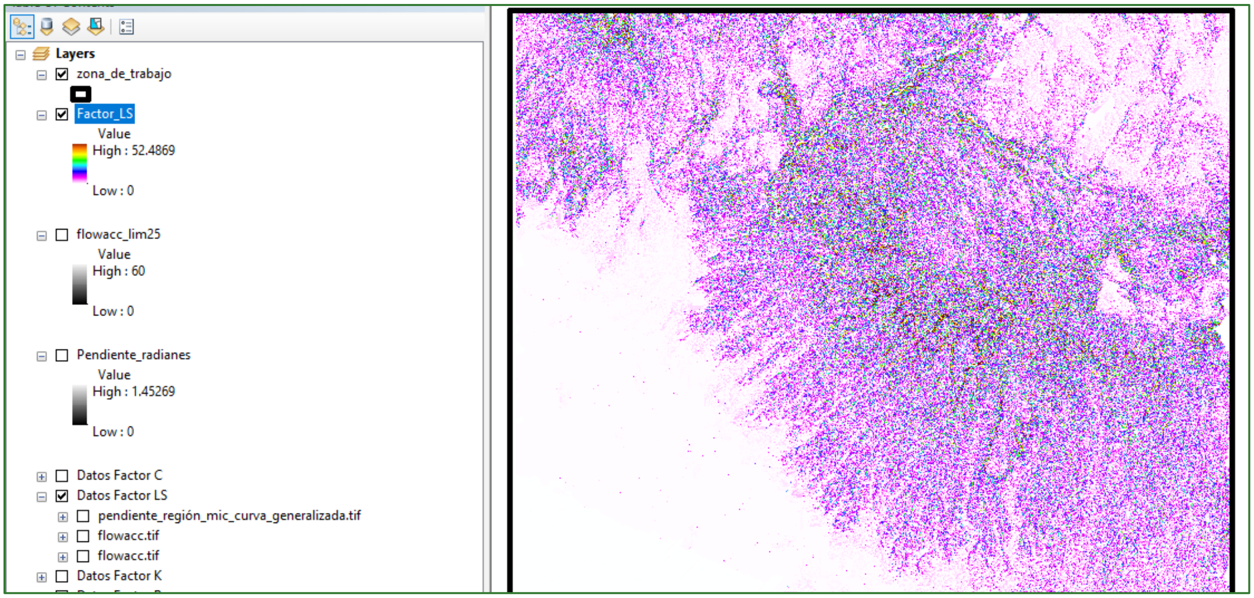
Power("%flowacc_lim60.tif%" * 3 / 22.3,0.4) * Power(Sin("%Pendiente_radianes.tif%") / 0.0896,1.3)

The model will look as follows:



N.B.: Bear in mind that for complex processes requiring mathematical expressions, you can run the model practically or adapt certain functions according to your needs or interests.

The output will look as follows:



Step 4. Calculate the C factor:

The following raster layer is required to calculate the C factor:

Layer	Location and name of input data
Normalised difference vegetation index	RASTER/NDVI/NDVI.tif

The C factor is calculated using the formula proposed by J. M. Van der Knijff, R. J. A. Jones and L. Montanarella in the official document entitled ‘Soil Erosion Risk Assessment in Europe’.

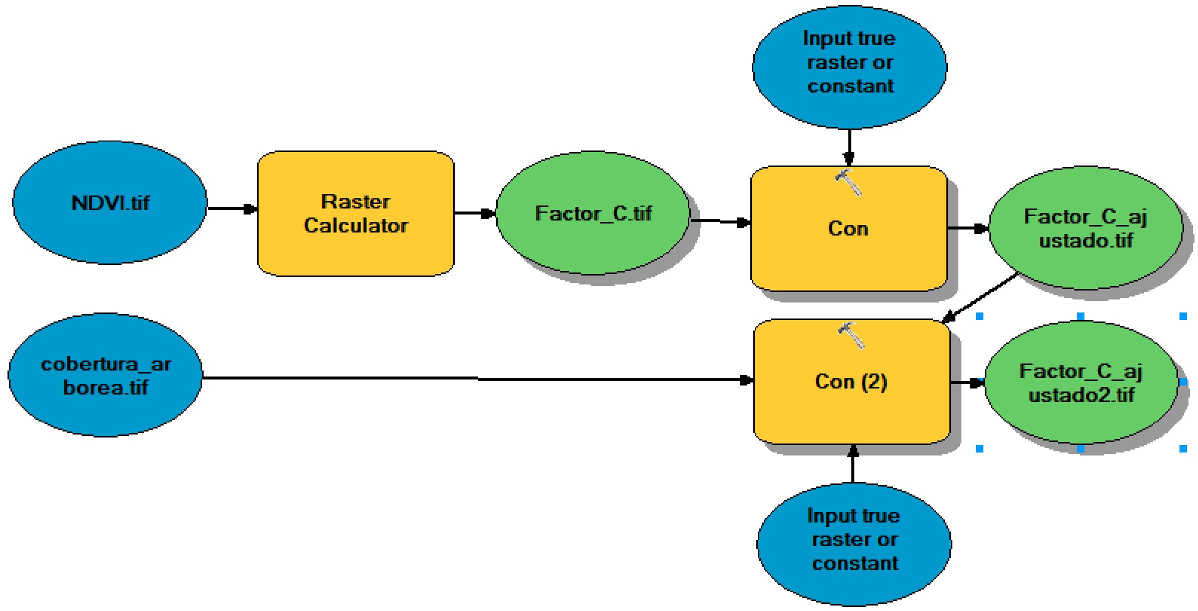
$$C = e^{-a\left(\frac{NDVI}{b-NDVI}\right)}$$

Expression in Raster Calculator: Exp(-1 * ("%NDVI.tif%" / (2 - "%NDVI.tif%")))

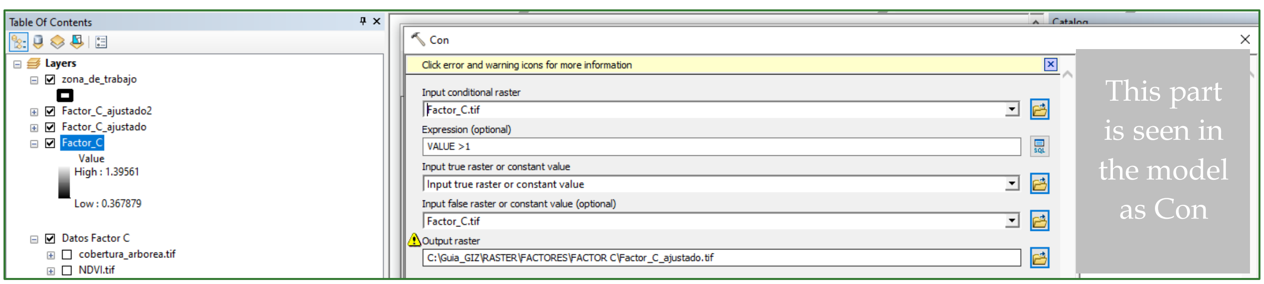
Where a and b are dimensionless coefficients that determine the correlation curve between the NDVI and the C factor. According to Van der Knijff, the values a = 1 and b = 2 seem to return reasonable results. See the following article for references:

https://www.scirp.org/pdf/JGIS_2012123123523619.pdf

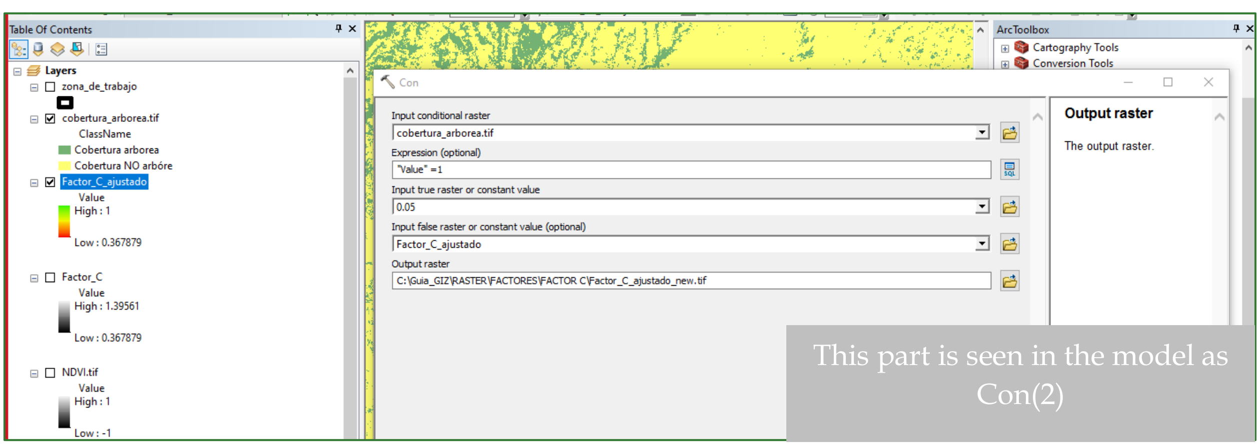
The model to estimate the C factor is structured as follows:



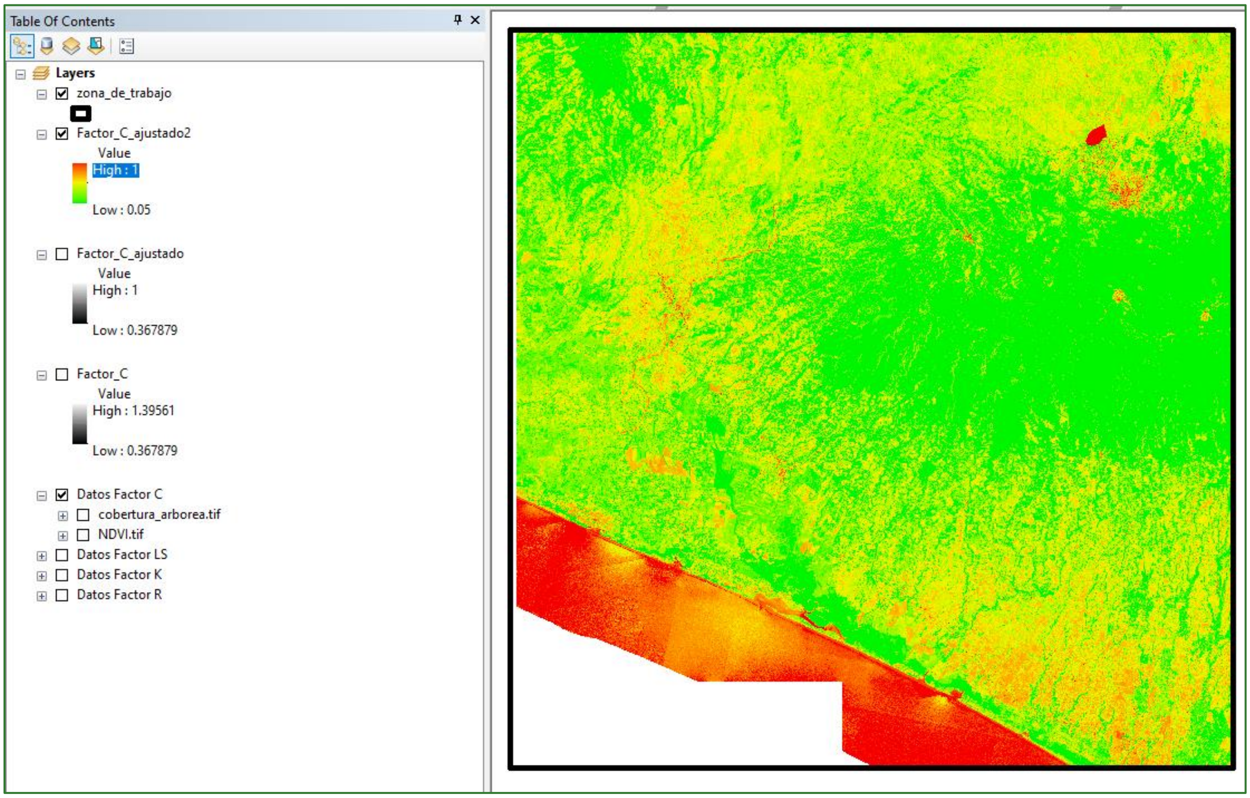
N.B.: As the C factor ranges from 0 to 1, a value of 0 must be assigned to the few pixels with negative values and a value of 1 to pixels with a value greater than 1. This process is done using the Conditional function (Spatial Analyst Tools/Conditional/Con).



A homogenous factor must be used in the process to calculate the C factor for the forest category. It is suggested that a value of 0.05 be used. Use the conditional tool (Con) to apply this adjustment.



The following is an example of the result of the model:



The C factor can also be calculated using local factors associated with the different types of cover. As an example, a table is given below with the C factor for a micro-basin in Guatemala:

Table 8: C factor value for each sampling point, micro-basin Tsalá, San Marcos, Guatemala.

Micro-basin location	**Community**	**Cover**	**Value**
High	Estancia	Broadleaf forest	0.003
High	Escupija	Scrub	0.017
Medium	Poj	Pasture	0.009
Medium	Chual	Broadleaf forest	0.003
Low	Llano Grande	Maize	0.519
Low	Pie de la Cuesta	Tomato with plastic mulch	0.090
Low	Salém	Coniferous forest	0.003

Source: (Lianes et al., 2009)

The C factor ranges from 0 to 1, with practices with less erosion potential (forest) approaching 0, whereas practices that provoke greater erosion (crops) approaching 0.5 or more.

Step 5: Calculate the P factor

To calculate the P factor, it would be ideal to have a raster reclassified by soil conservation practices and to assign the respective factors to these. However, as such information is not available, a factor of P = 1 will be assumed.

The P factor ranges from 0 to 1, where 1 represents the absence of any conservation work. A reference table is given below:

Table 9: P factor values for each sampling point according to conservation works implemented.

Micro-basin location	Community	Use	Conservation works	P
High	Estancia	Natural broadleaf forest	Unnoticeable.	1.0
High	Escupija	Peach tree farming with growing scrub and shrub.	Non-maintained terrace.	0.9
Medium	Poj	Crop land affected by soil displacement.	Unnoticeable.	1.0
Medium	Chual	Natural broadleaf forest	Unnoticeable.	1.0
Low	Llano Grande	Associated growing of maize and kidney beans, minimal manual tilling.	Unnoticeable.	1.0
Low	Pie de la Cuesta	Tomato growing with plastic cover and drip irrigation, manual tilling.	Sown in level curves.	0.5
Low	Salém	Coniferous forest recently subject to forest fire that affected the undergrowth.	Unnoticeable.	1.0

Source: (Wischmeier and Smith, 1978).

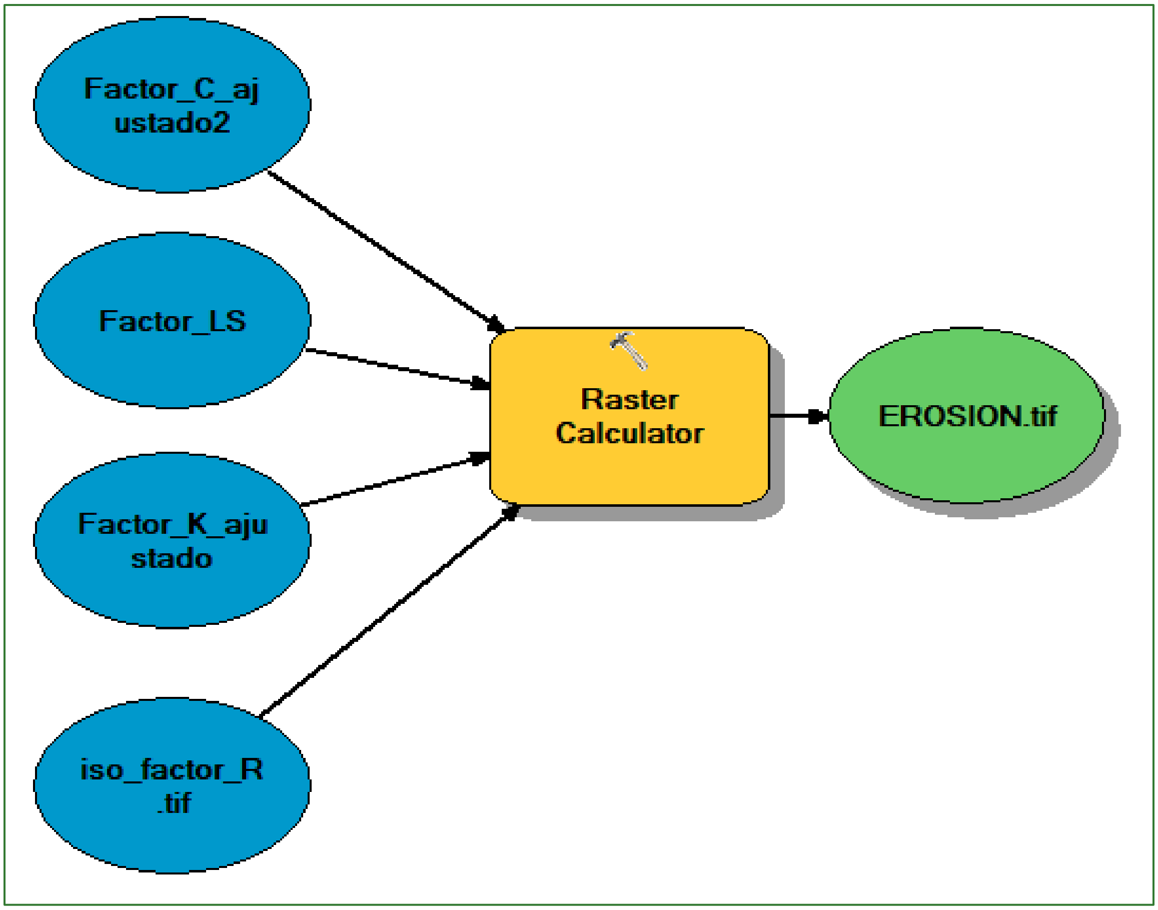
Step 6. Apply the USLE equation to generate the erosion raster

$$\mathbf{A = R * K * L * S * C * P}$$

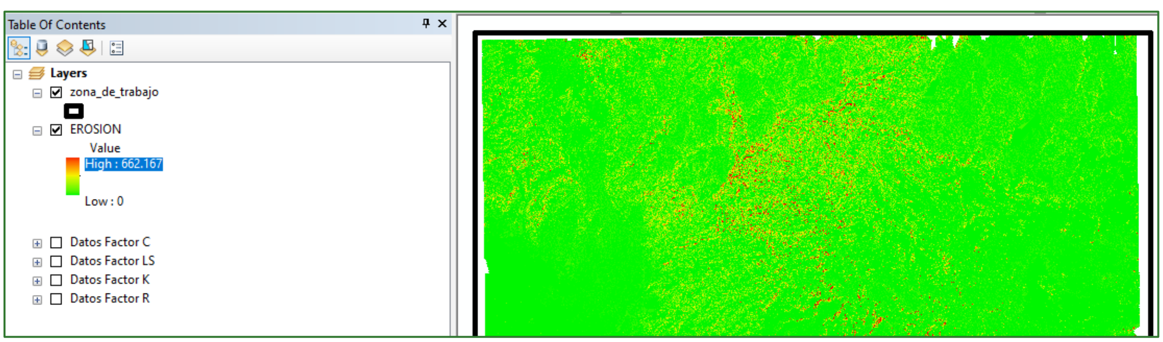
You can apply the formula using the Raster Calculator as follows:

"%Factor_C_ajustado2%"*"%Factor_LS%"*"%Factor_K_ajustado%"*"%iso_factor_R.tif%"*1

The model will look as follows:



The output will be displayed as follows.

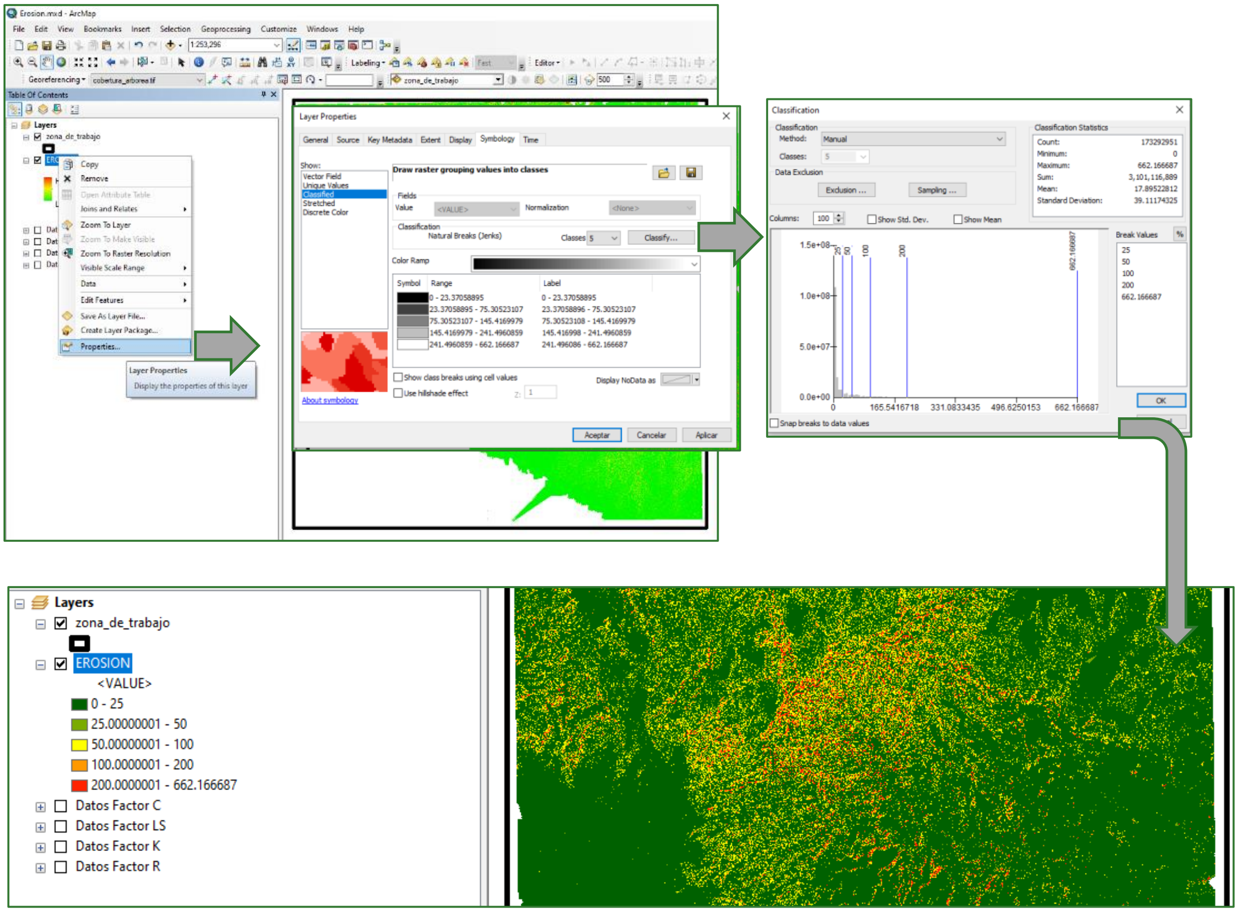


Step 7: Interpretation of erosion values (reclassifying the raster)
The following table shows an interpretation of the erosion levels by the Regional Government of the Basque Country, Spain. You can look for references for your country.

Table 10: Interpretation of erosion levels by the the Regional Government of the Basque Country, Spain

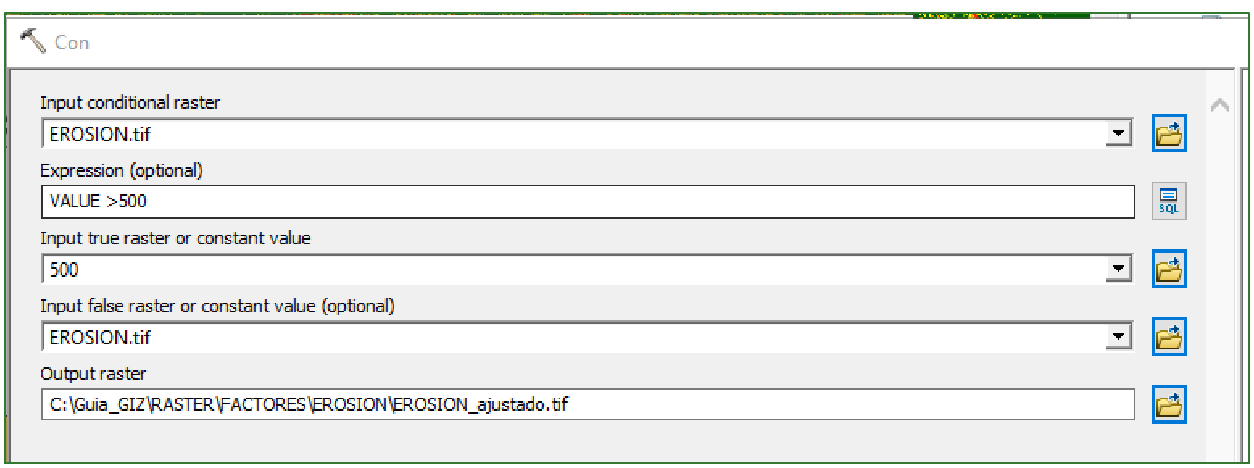
Soil loss (t/ha.year)	Interpretation
0	Areas not vulnerable to erosion, such as urban spaces, roadways, reservoirs, etc.
0 – 5	Areas with very low erosion levels and tolerable soil losses. There is no net erosion.
5 – 10	Areas with low erosion levels and potentially tolerable soil loss. There is probably no net erosion.
10 – 25	Areas with slight erosive processes. There is erosion, but it is not noticeable to the naked eye.
25 – 50	Areas with moderate erosive processes. There is erosion but it may not be noticeable to the naked eye.
50 – 100	Areas with serious erosive processes. There is erosion and it is noticeable.
100 – 200	Areas with very serious erosive processes. There is erosion and it can be clearly seen.
> 200	Areas with extreme erosive processes. There is erosion and it is evident.

N.B.: if you have the data for your country it is suggested that you reclassify this visually into ranges for better interpretation. Please see the following example:



N.B.: depending on the literature consulted, observe the maximum erosion tonne/ha/year values and try to transfer that value to our map as a maximum value.

Maximum values were raised to 500 for this example.



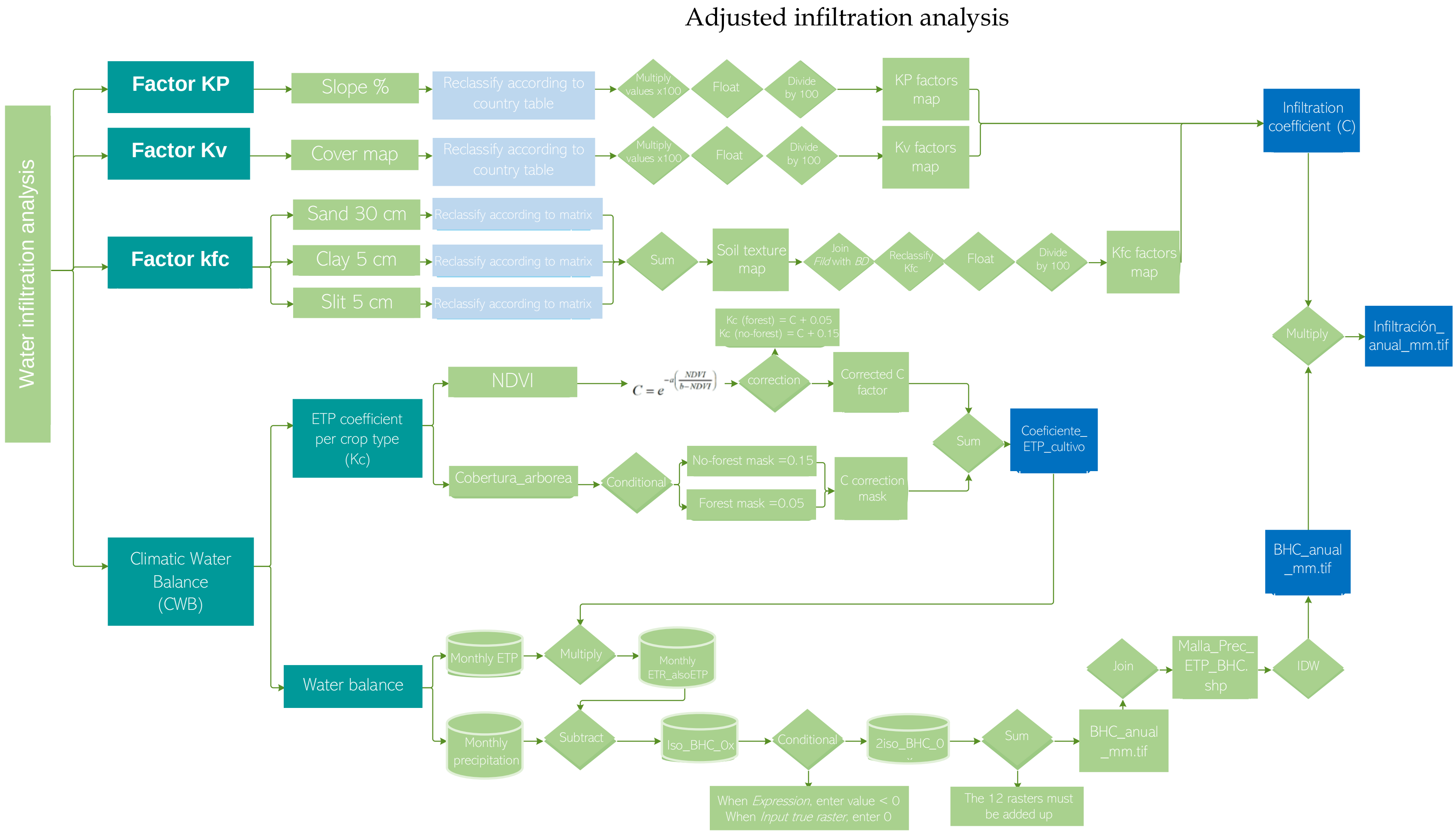
Part 13. Water infiltration

Water infiltration plays a key role in the hydrologic cycle. Depending on the geological conditions, water may stay in the soil in form of moisture; run off as a subsurface flow and surface as a short-lived water course; or recharge the aquifer (Batres & Barahona-Palomo, 2017).

The soil water balance is based on the principle of the conservation of mass, where all the water entering the soil must be equal to the amount of water stored there plus the water that leaves it. Inputs into the system are caused by rainfall that filters water through the soil and outputs are caused by evapotranspiration and discharge to aquifers (Fetter, 2001). Meteorological (rainfall, temperature, hours of sunshine, etc.), geographical (land use and slope) and geological (soil texture, infiltration speed) parameters are the factors that influence the soil water balance.

According to Parr and Bertrand (1960), the rate of infiltration is only determined by the soil mass and is largely unaffected by surface conditions. However, Horton (1940) claimed that the rate of infiltration is mainly governed by the conditions near the soil surface. Water infiltration into soil has been widely studied given the importance of water management for agriculture, the conservation of soil as a resource, recharging towards aquifers and other technical activities. Infiltration speed determines the amount of surface runoff and with it, the danger of water erosion. For practically all irrigation methods, the speed of water entry into the soil determines irrigation times and the design of systems, as far as the size of the surface units and the flows to be used are concerned.

Moreover, the infiltration process is of great practical importance, given that its speed generally determines the amount of runoff, thereby enabling the detection of the threat of erosion during flooding or very heavy rainfall. In cases where infiltration speed is restricted, the entire root zone water system can be affected. Detailed knowledge of the infiltration process is required to efficiently manage soil and water given that this is correlated with soil properties and the water contribution to the system (Gurovich, 1985).



The diagrams in this methodological guide are available in an online GitHub repository by clicking on the following link (Spanish original): https://github.com/guialandscape/Diagramas

Step 1: Calculate the Kp factor

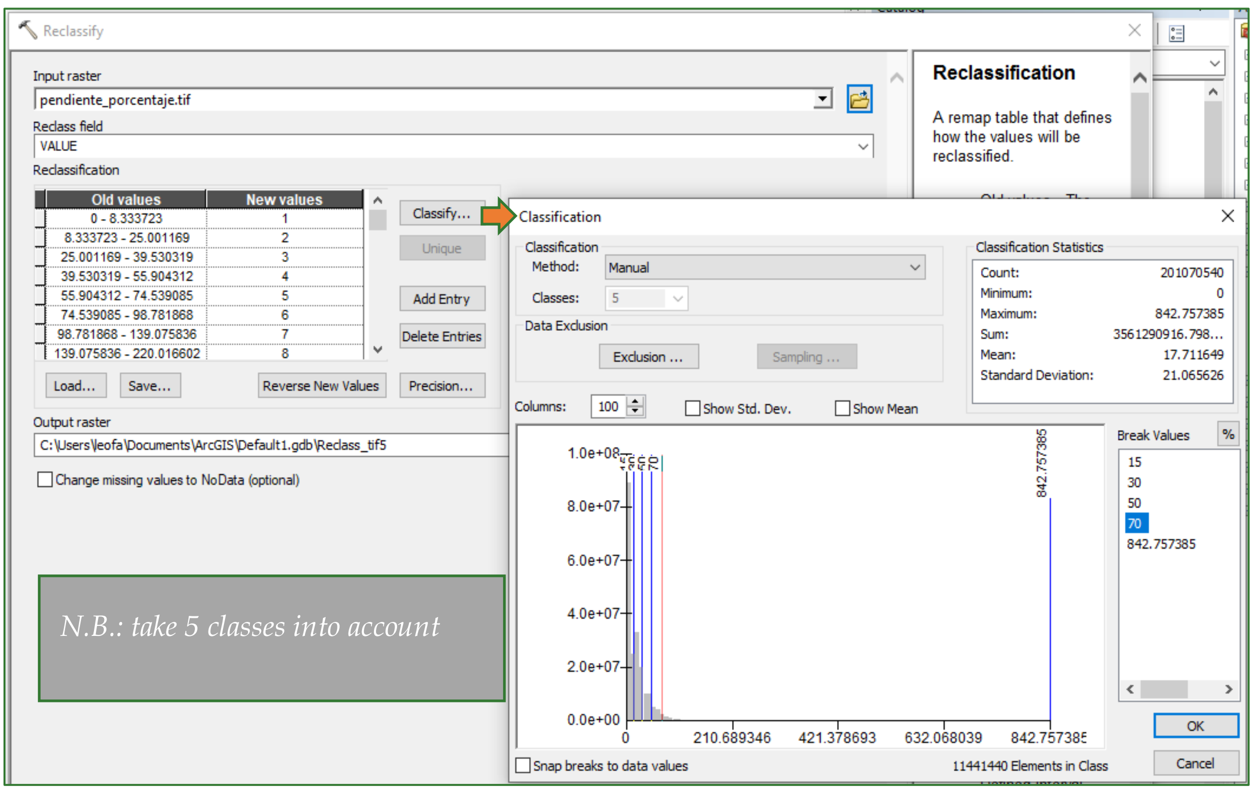
The Kp factor or infiltration coefficient is calculated from the following raster layer:

Layer	Location and name of input data
Slope (%)	RASTER/MDT/pendiente_porcentaje.tif

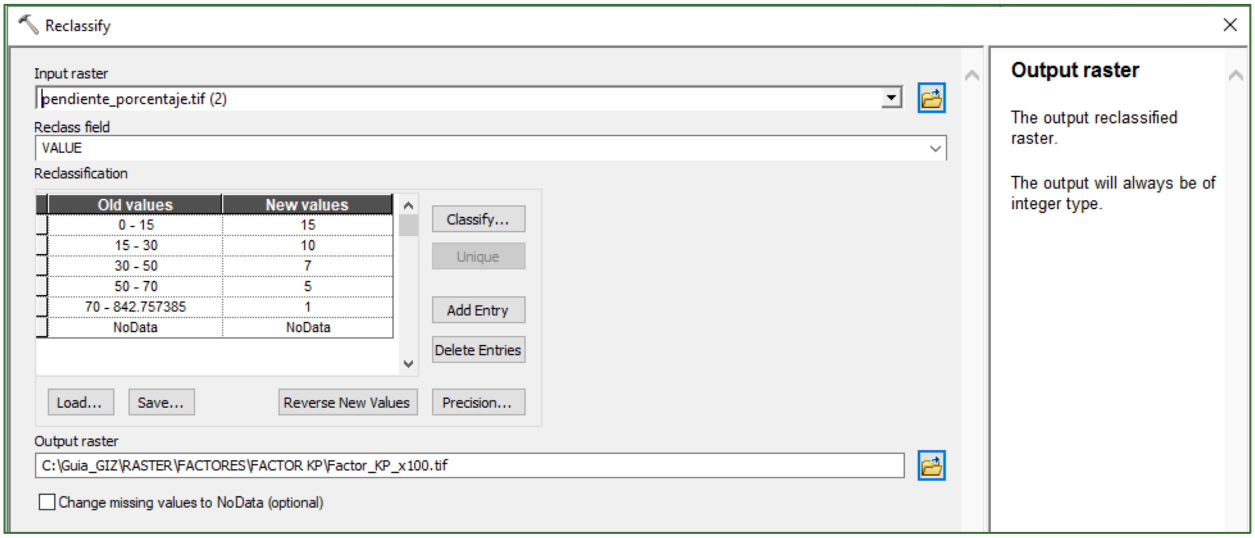
Reclassifying the slope raster into the following classes:

Slope range %	Value
<15%	0.15
15-30%	0.10
30-50%	0.07
50-70%	0.05
>70%	0.01

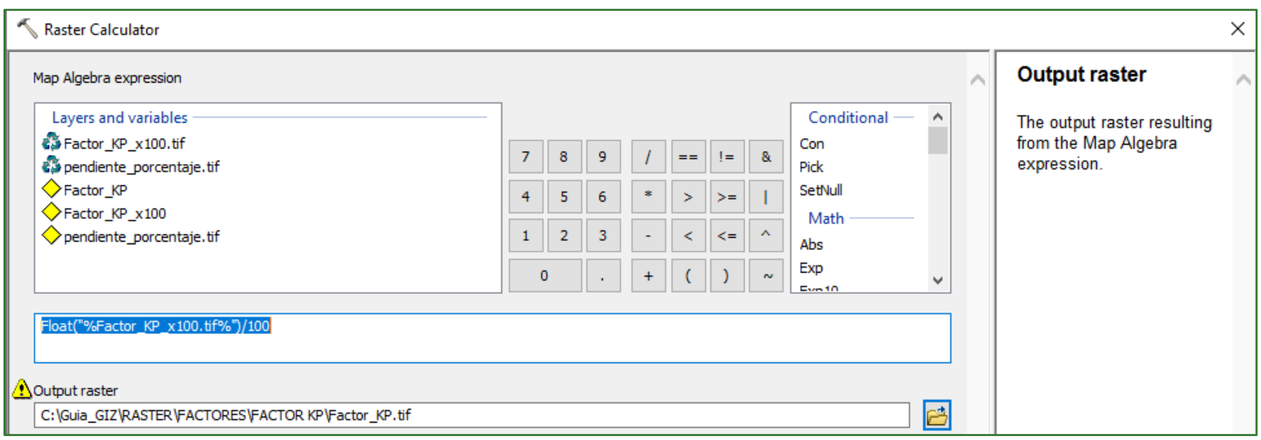
Use the Reclassify tool (**Spatial Analyst Tools/Reclass/Reclassify**) to reclassify, then name the file **pendiente_porcentaje_reclass.tif** and save it in the **RASTER/FACTORES/FACTOR KP** folder.



A new pop-up window will then show the ranges that have been established. You must assign the new value according to the table described at the start of the process. Bear in mind that the values were multiplied by 100 to get integers, e.g. 0.15 = 15 and 0.1 = 10.



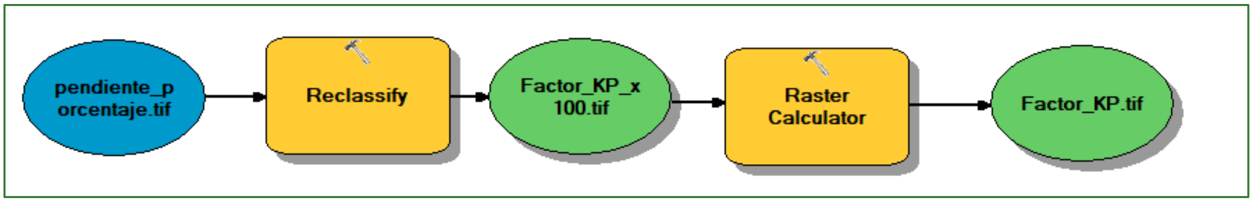
To convert the result to decimal values, divide it by 100 in FLOAT format using the Raster Calculator (**Spatial Analyst Tools/Map Algebra/Raster Calculator**) as indicated below:



Name the aforementioned file **Factor_KP.tif** and save it in the **RASTER/FACTORES/FACTOR KP** folder.

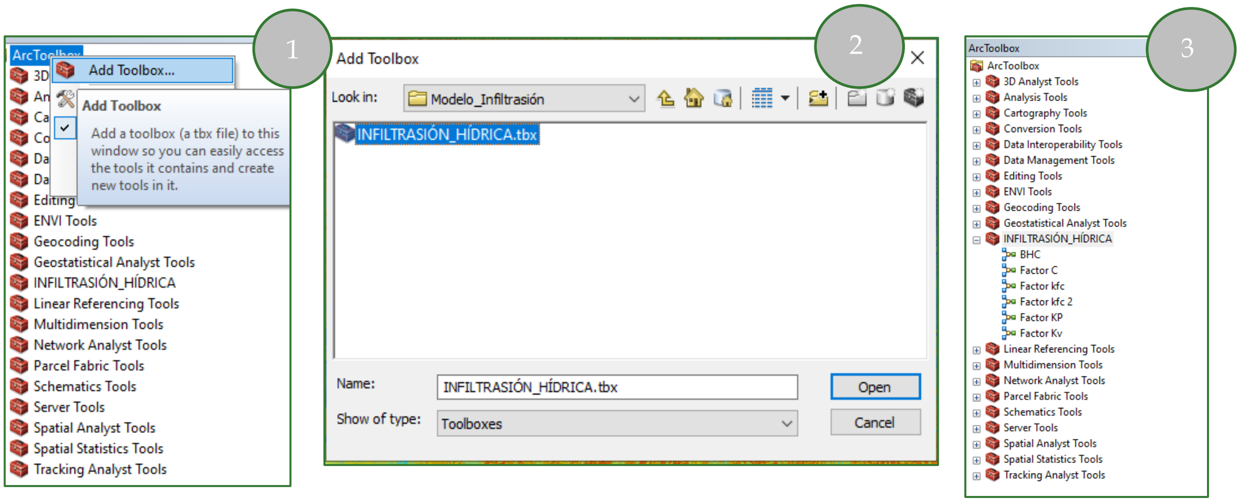
N.B.: if you do not get a satisfactory result, try applying the float function only to the Factor_KP_x100.tif layer to ensure that the raster is converted and supports decimal numbers. Bear in mind that the final Kp factor must be expressed in decimal values and must therefore always be divided by 100.

The model should end up as follows:

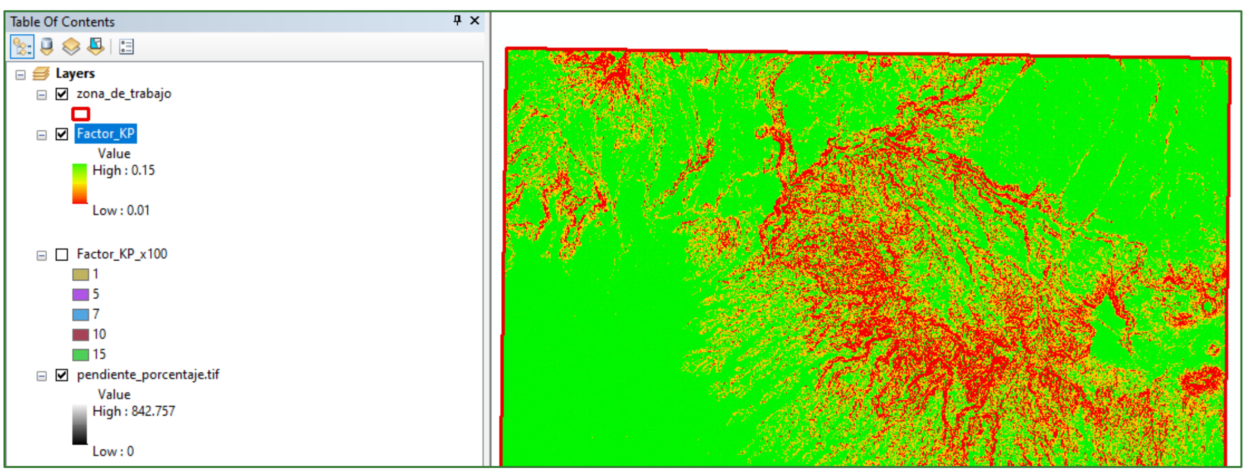


N.B.: If you want to add the entire Kp factor Model Builder, follow these steps:

- *Download the Water Infiltration model:* https://github.com/guialandscape/Model_Builder
- *Right click on ArcToolBox, then click on Add:*



The result will be as shown below:



Step 2: Calculate the Kv factor

The Kv factor or infiltration coefficient for vegetation cover effect is calculated based on the following raster layers:

Layer	*Location and name of input data*
Cover Map	*RASTER/MDT/pendiente_porcentaje.tif*

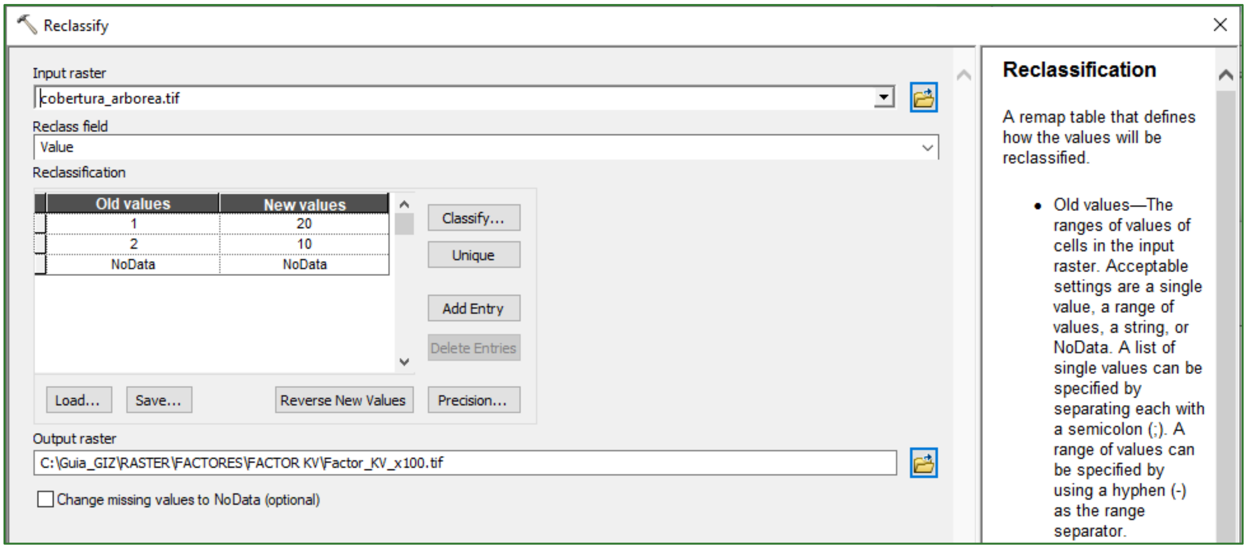
Take the factors available for Central America into account to generate the infiltration coefficient layer for the vegetation effect (Kv).

Table #18. Factor Kv for El Salvador

Use – soil cover	KV
Urban Areas	0.05
Forests	0.20
Water Bodies	0.00
Annual Crops	0.10
Mixed Crops	0.10
Permanent Crops	0.10
Wetlands	0.01
Mangrove Forests	0.01
Mining	0.15
Pasture	0.10
Shrub Vegetation	0.15
Industrial Areas	0.05
Artificial Green Zones	0.15

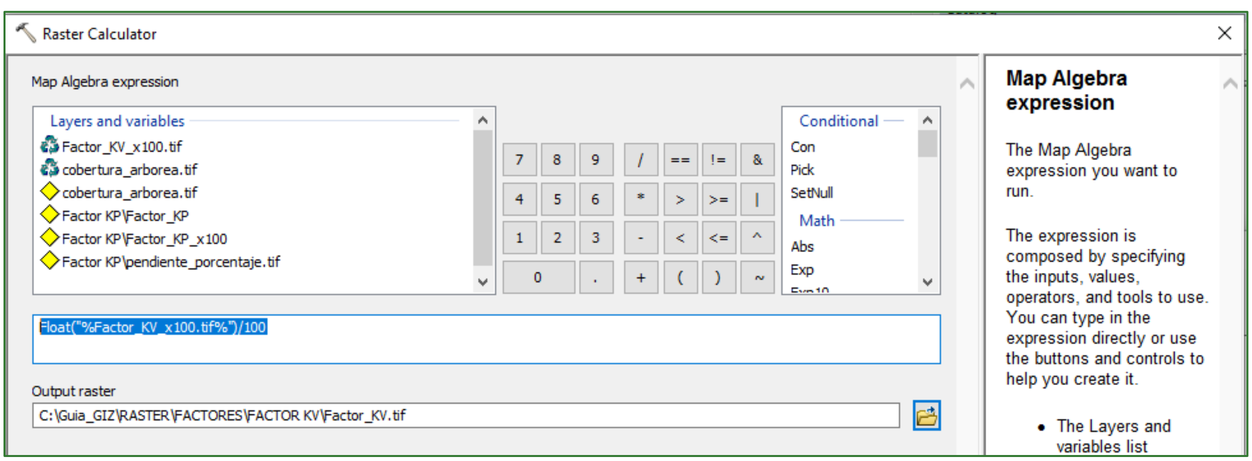
There is a variety of documentation in the GitHub at the following link that can serve to support the implementation of this guide: https://github.com/guialandscape/Documentos .

Reclassify the cover raster using the factors corresponding to your country, albeit multiplying each one by 100, i.e. 0.2 = 20.



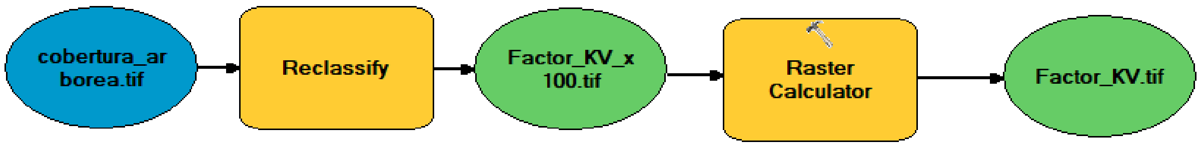
N.B.: A forest (1) and no-forest (2) layer is being used for this example, considering a value of 20 for forest and 10 for the no-forest class. The values assigned are integers multiplied by 100, which express the values defined in the El Salvador Kv factor table. It is important to consult all the documentation to see the values that apply to the country of interest.

Divide the previous result by 100 to get the Kv factor in decimals.



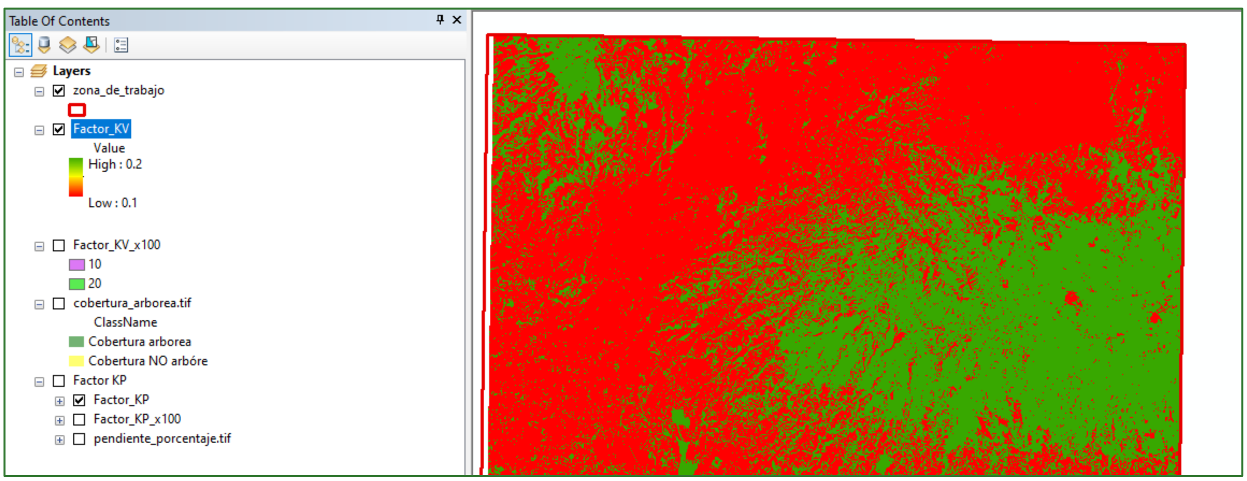
N.B.: if the operation does not give a satisfactory result, try applying the float function only to the **Factor_KV_x100.tif** layer to ensure that the raster is converted and supports decimal numbers. Bear in mind that the final Kv factor must be expressed in decimal values, and therefore must always be divided by 100.

The model should end up as follows:



N.B.: this model is located in ArcToolBox/INFILTRACIÓN_HÍDRICA if you want to open it.

The result will be as shown below:



Step 3: Calculate the Kfc factor

The Kfc factor or infiltration coefficient for the soil texture effect is calculated from the available clay, silt and sand rasters.

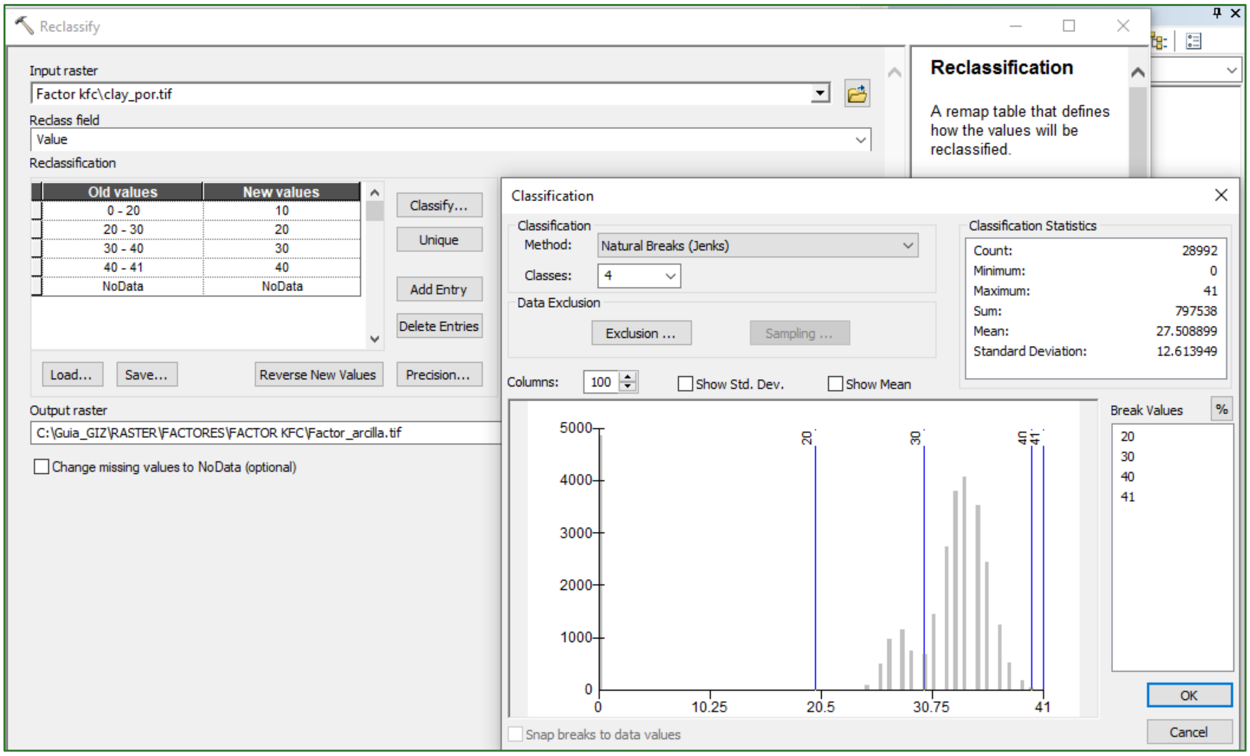
Layer	Location and name of input data
Clay	RASTER/SUELO/Clay_por.tif
Silt	RASTER/SUELO/ Silt_por.tif
Sand	RASTER/SUELO/Sand_por.tif

Reclassify the clay, sand and silt rasters using the following parameters:

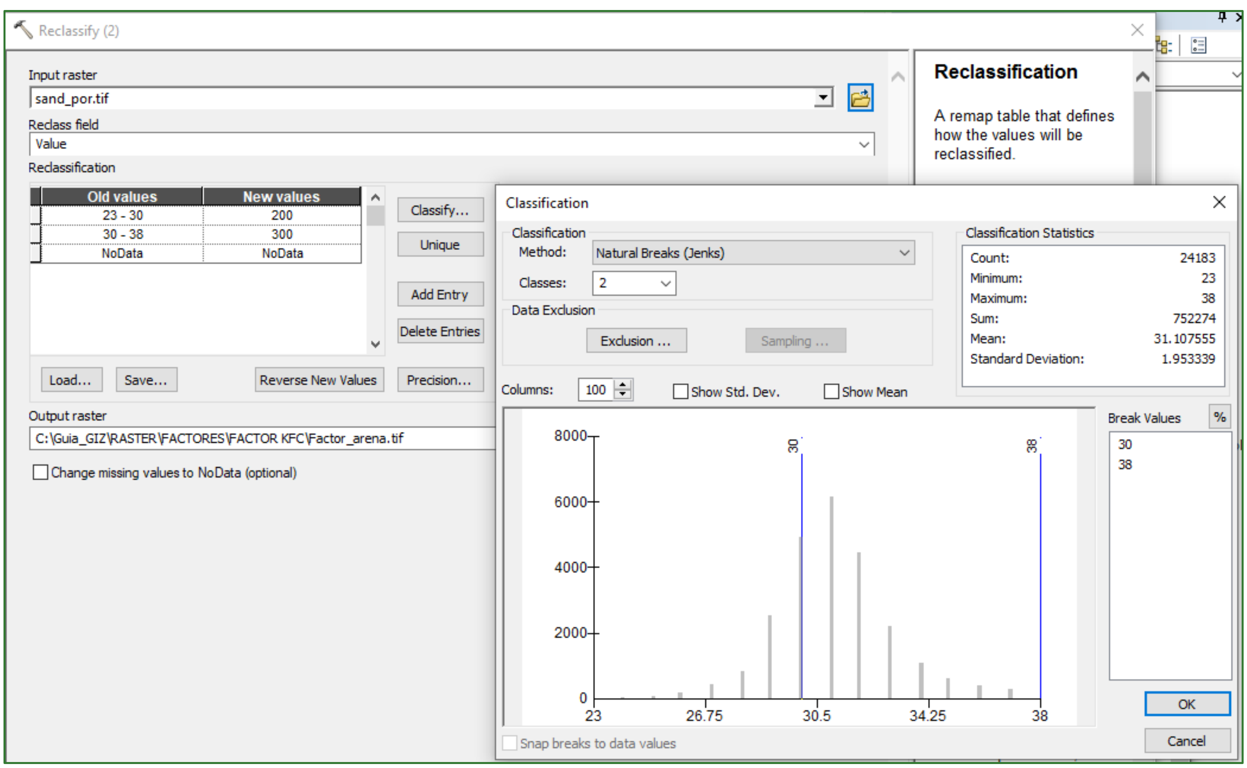
				Arena			
				100	**200**	**300**	**400**
Cod	**Arcilla**		**Limo**	<20	20-30	30-40	>40
10	<20	**1**	<10	FL	FL	F	FAre
		2	10-20	FL	FL	F	FAre
		3	20-30	FL	FL	F	FAre
		4	>30	FL	FL	F	FAre
20	20-30	**1**	<10	FL	FL	F	FArcAre
		2	10-20	FL	FL	F	FArcAre
		3	20-30	FL	FL	F	FArcAre
		4	>30	FL	FL	F	FArcAre
30	30-40	**1**	<10	FArcL	FArc	FArc	FArcAre
		2	10-20	FArcL	FArc	FArc	FArcAre
		3	20-30	FArcL	FArc	FArc	FArcAre
		4	>30	FArcL	FArc	FArc	FArcAre
40	>40	**1**	<10	Arc	Arc	Arc	ArcAre
		2	10-20	Arc	Arc	Arc	ArcAre
		3	20-30	Arc	Arc	Arc	ArcAre
		4	>30	ArcL	Arc	Arc	Arc

Example of the reclassification:

Reclassify the 5 cm deep clay raster as shown in the image, name the file **Factor_arcilla.tif** and save it in the **RASTER/FACTORES/FACTOR KFC** folder.

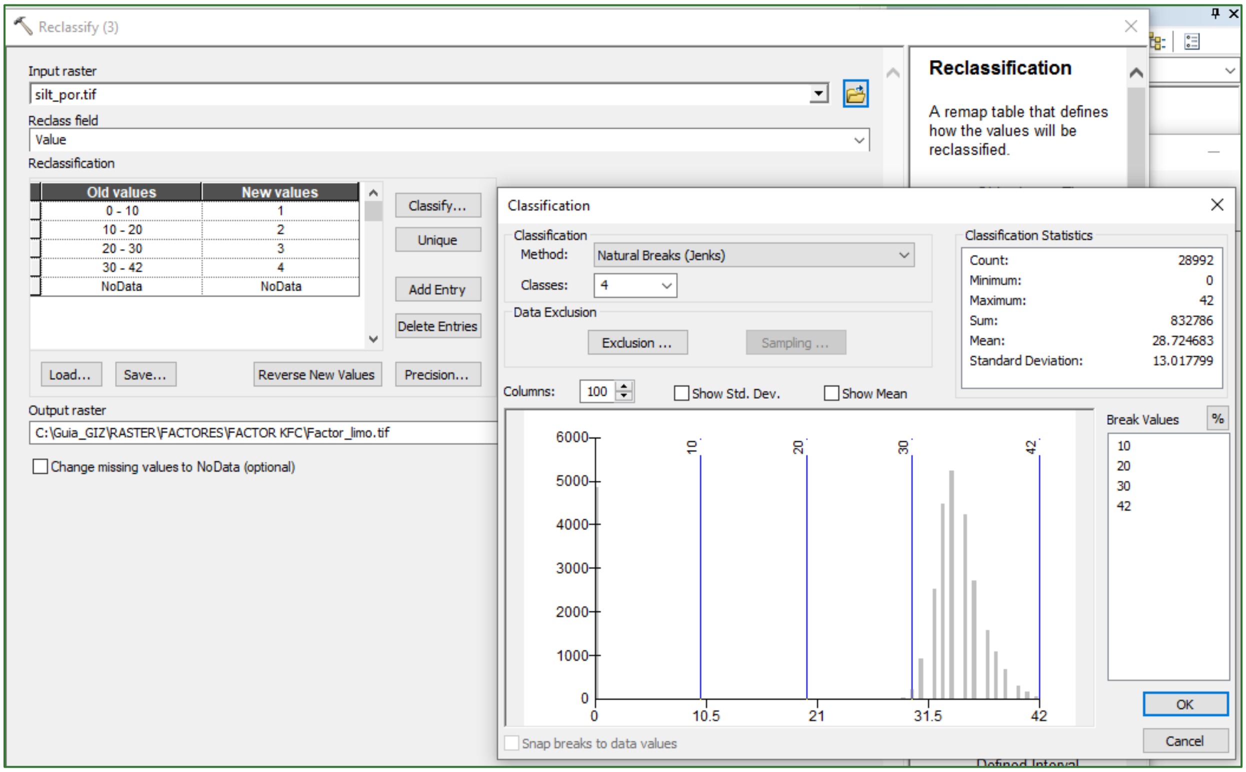


Reclassify the 5 cm deep sand raster as shown in the image, name the file **Factor_arena.tif** and save it in the **RASTER/FACTORES/FACTOR KFC** folder.

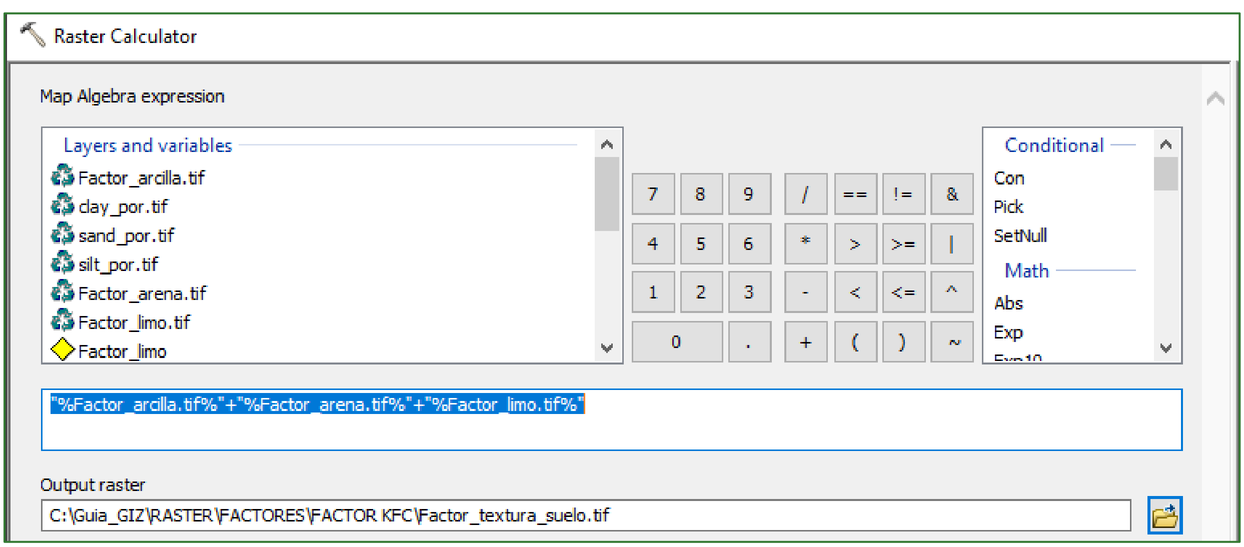


N.B.: The values of the **sand_por.tif** layer for this example are 23 minimum and 38 maximum, which means that they can only be grouped into two classes according to the table (20-30 and 30-40). If this process is carried out with a layer that encompasses values under 20 and over 40, 4 classes should be applied as described in the table.

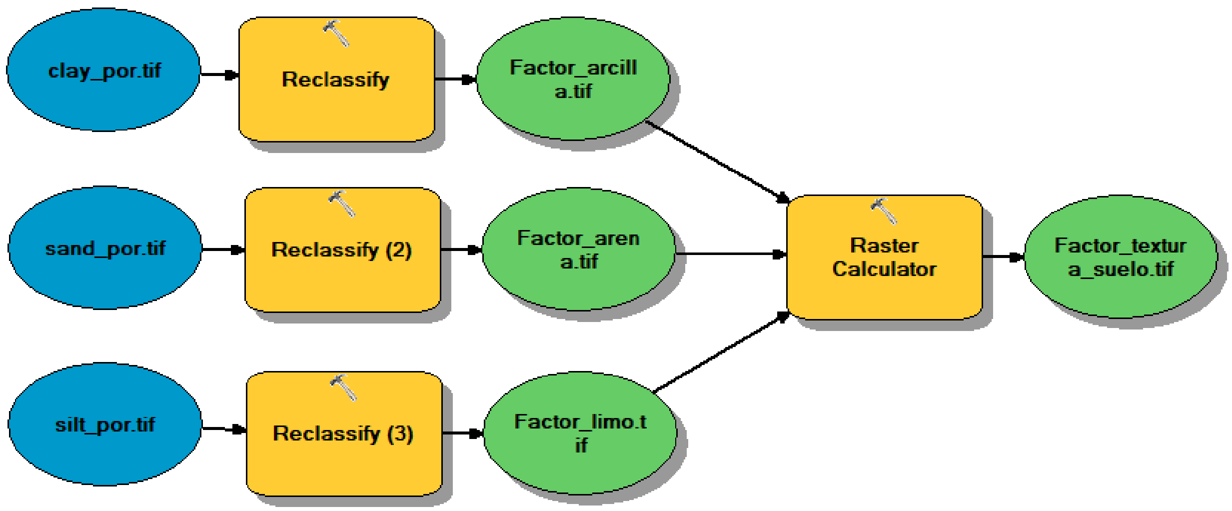
Reclassify the 5 cm deep silt raster as shown in the image, name the file **Factor_limo.tif** and save it in the **RASTER/FACTORES/FACTOR KFC** folder.

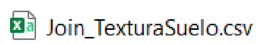


Add up the reclassified clay, sand and silt rasters.



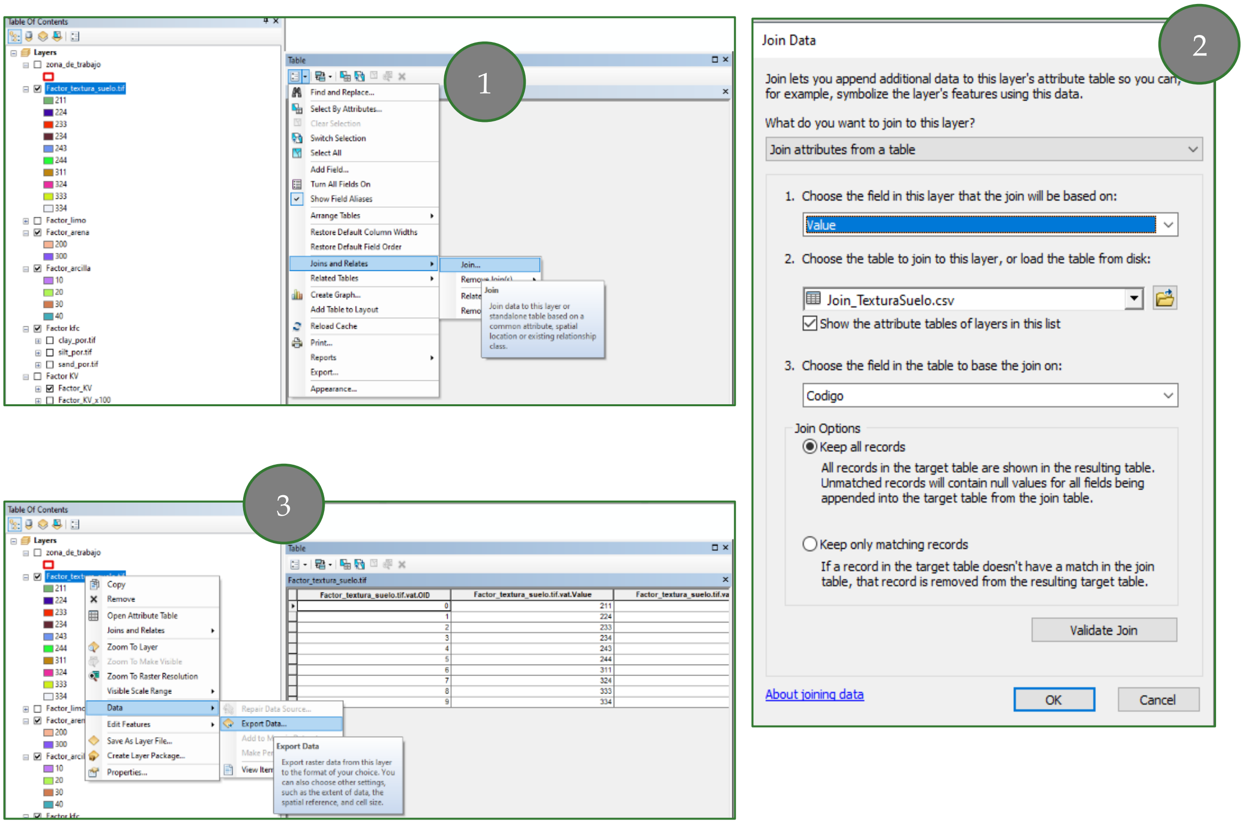
The model will look as follows:



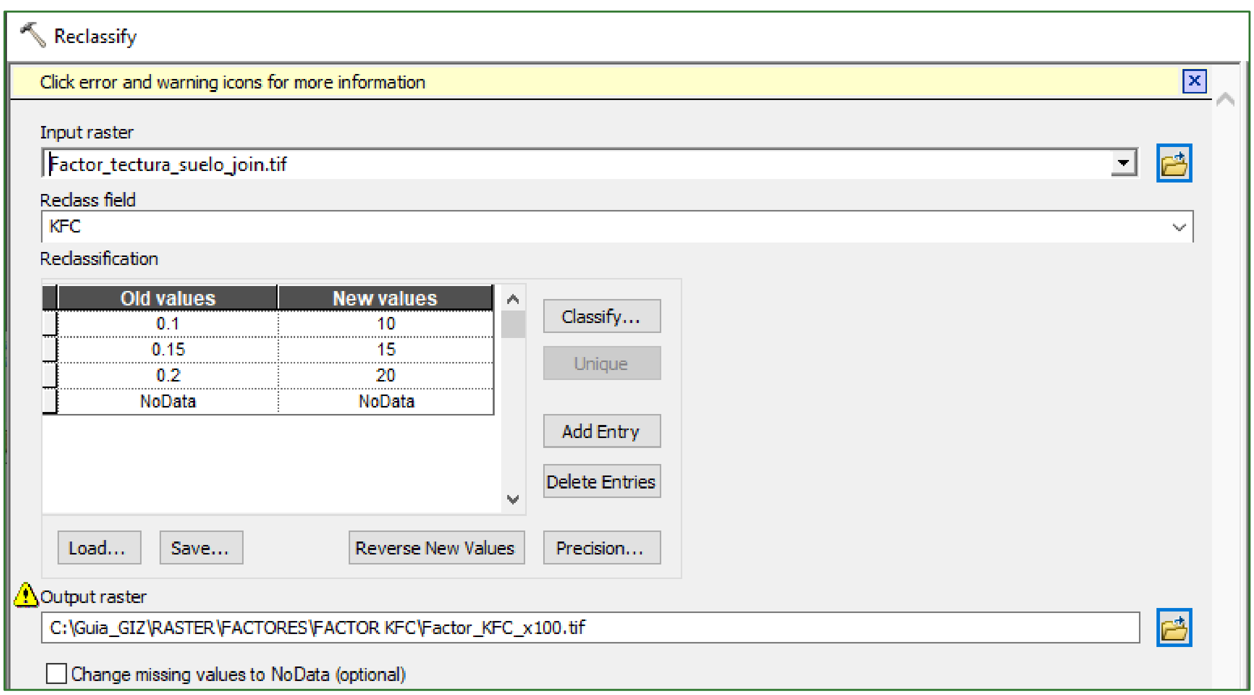
Do a JoinField between the aforementioned raster and the table  in the **INPUT** folder.

To do so, open the **Factor_textura_suelo.tif** layer attributes table, join it to the **Join_TexturaSuelo.csv** [4] table, name it **Factor_textura_suelo_join.tif** and save it in the **RASTER/FACTORES/FACTOR KFC** folder. The above step is carried out to make sure that the properties of the joined tables are established in our baseline layer.

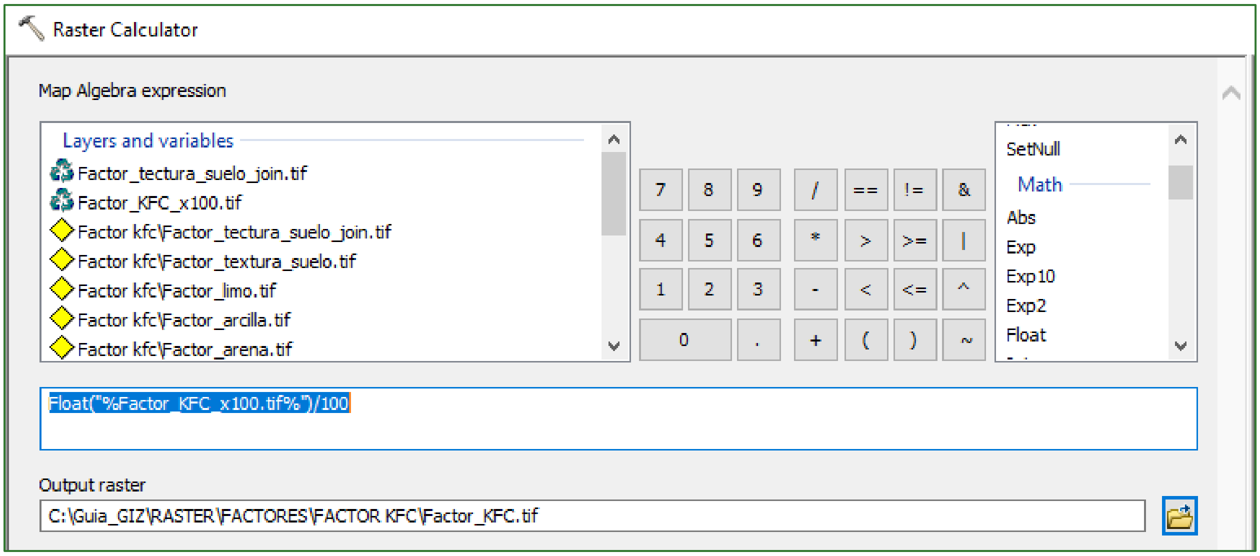
[4] The table is available in the GitHub repository at: https://github.com/guialandscape/Tablas



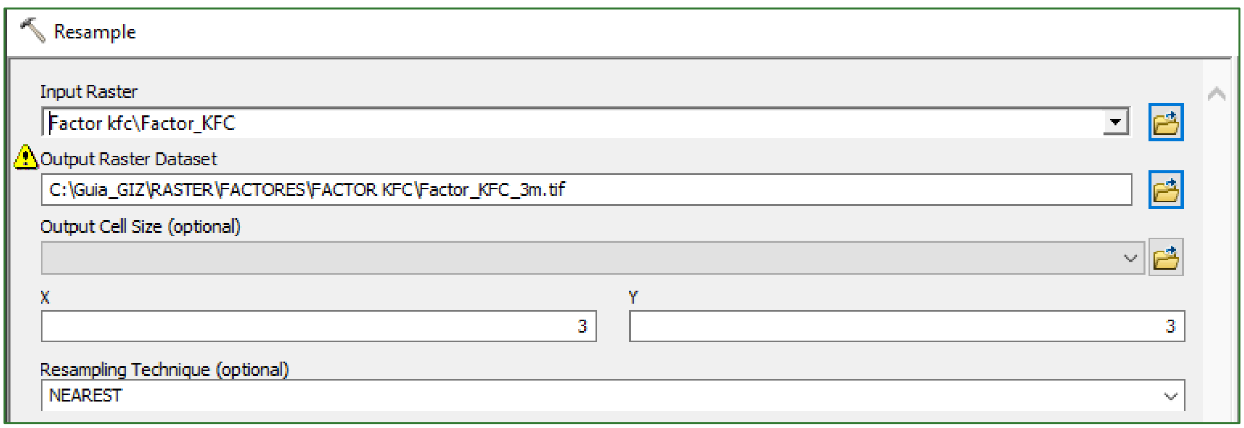
Reclassify the Kfc field by entering the new value in it multiplied by 100. Example 0.15 = 15.



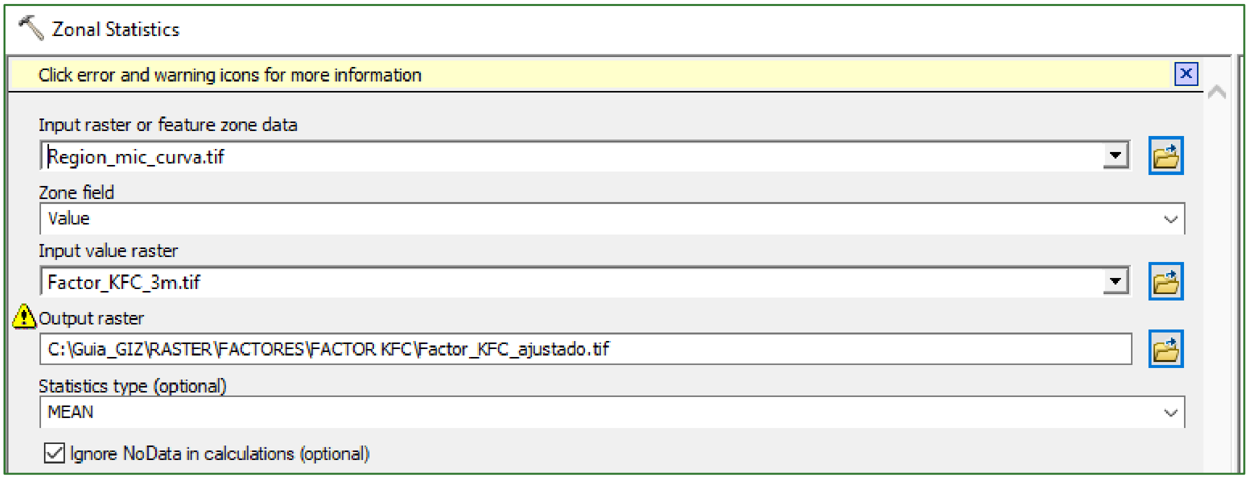
Divide the raster from the previous step by 100 to get the Kfc factor in decimals.



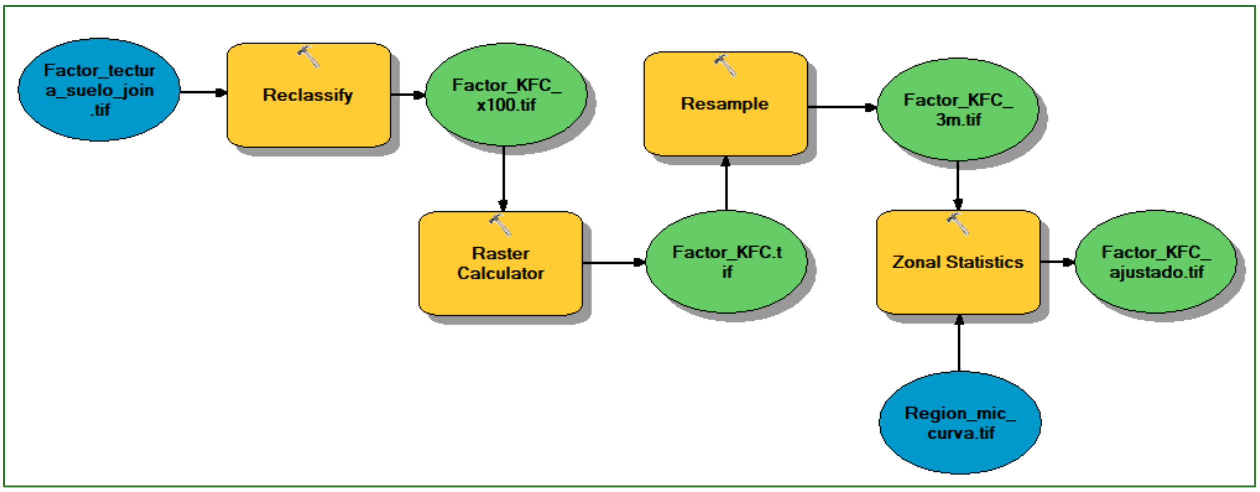
You must then rescale the values to 3 m using the Resample function (**Data Management Tools/Raster/Raster Processing/Resample**).



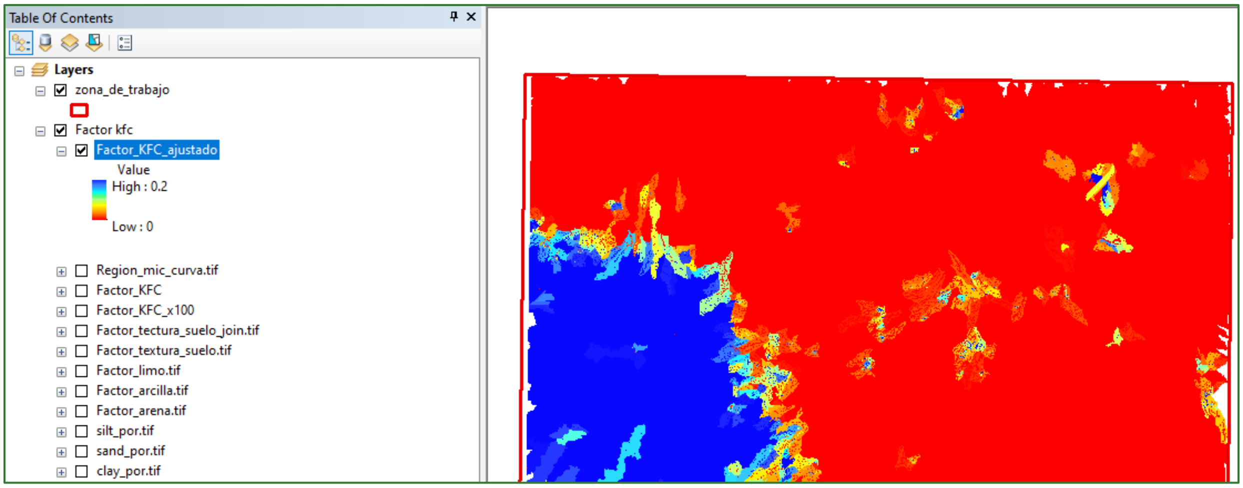
As the final part of the process, and with a view to better adjusting the data, calculate the mean for the **Factor_KFC_3m.tif** values in accordance with the **Region_mic_curva.tif** layer. Do this using the Zonal Statistics tool (**Spatial Analyst Tools/Zonal/Zonal Statistics**).



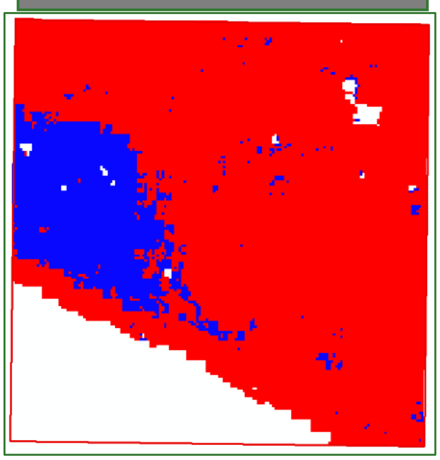
The model will look as follows:



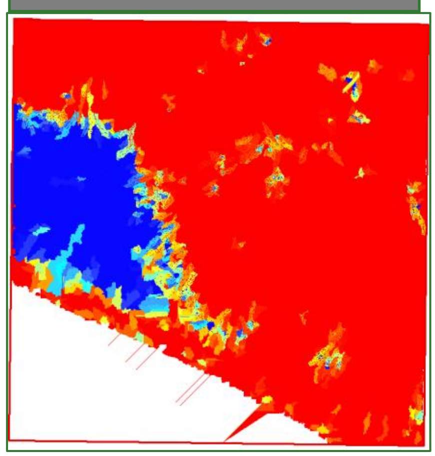
The output will be as shown below:



Unadjusted Kfc factor



Adjusted Kfc factor



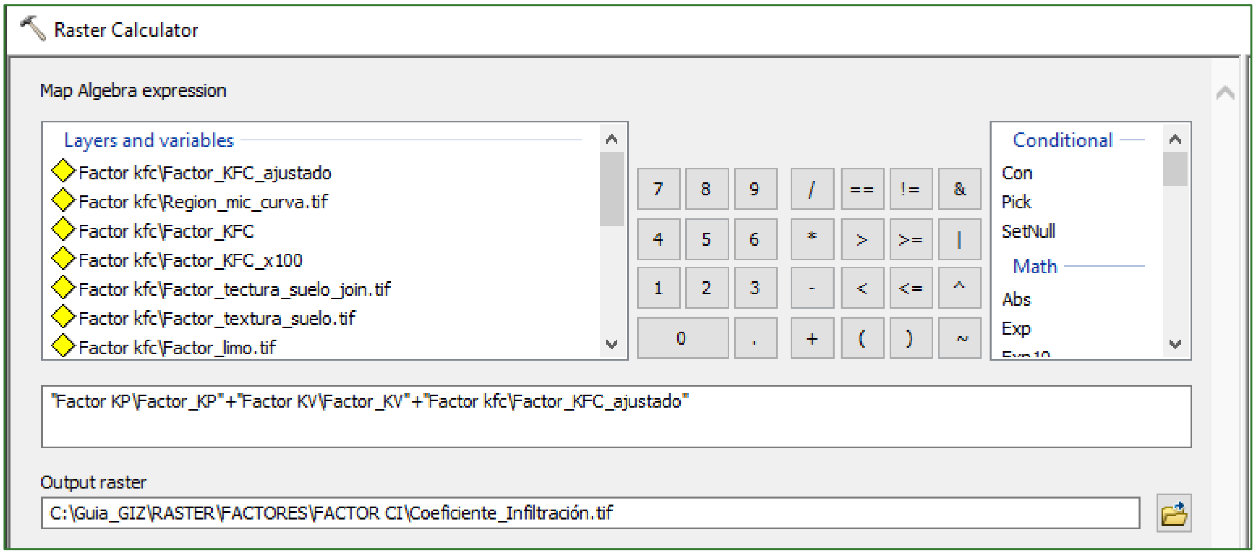
Step 4: Calculate the C factor

The infiltration coefficient is calculated based on the following raster layers.

Layer	Location and name of input data
Kp factor	RASTER/FACTORES/FACTOR KP/Factor_KP.tif
Kv factor	RASTER/FACTORES/CATOR KV/Factor_KV.tif
Kfc factor	RASTER/FACTORES/FACTOR KFC/Factor_KFC_ajustado.tif

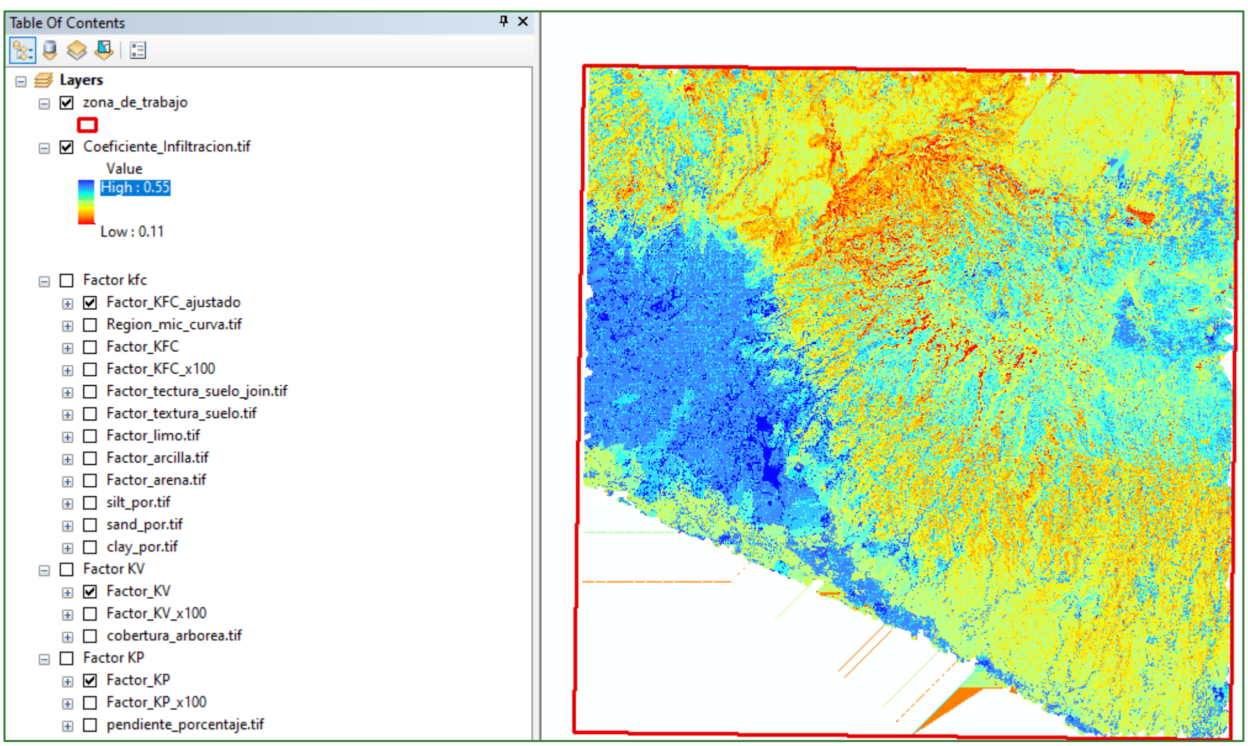
The **"Infiltration Coefficient"** (C) layer is obtained from the sum of the layers generated in the previous steps. It is a relative value that indicates the potential portion of water that would infiltrate to the aquifer.

$$C = (kp + kv + kfc)$$



N.B.: the sum of the C coefficient can reach a maximum of 0.9, which indicates a maximum theoretical recharge of 90%.

The result will be as shown below:



Step 5: Calculate the Climatic Water Balance (CWB)

The Climatic Water Balance (CWB) is calculated from the following raster layers.

Layer	Location and name of input data
Forest Mask	COBERTURA/Cobertura_arborea.tif
Normalised difference vegetation index	RASTER/NDVI/NDVI.tif
Potential evapotranspiration	RASTER/CLIMA/ETP/isoETP_0x.tif
Precipitation	VECTORES/LLUVIA/2malla_base_lluvia_project.shp

Two calculations must be made:

- **Crop Coefficient (Kc):** this process will give you the ETP coefficient for the type of crop or vegetation.
- **Water Balance:** this process will give you the annual Climatic Water Balance.

Calculating the Crop Coefficient (Kc)

To carry out this process you must first calculate the Kc factor or crop coefficient as follows:

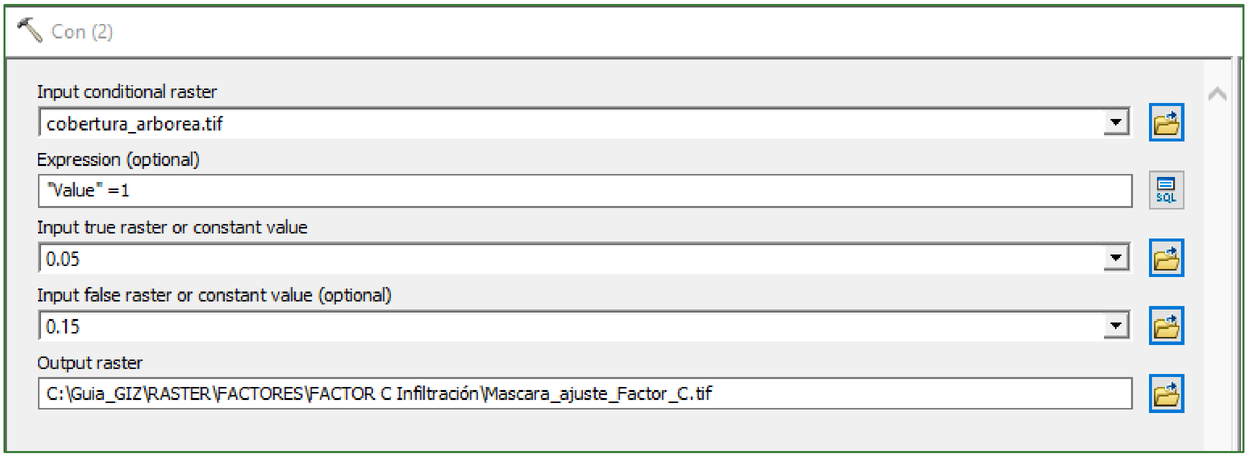
a) You are recommended to obtain the Kc from the NDVI and apply the (adjusted) C factor formula:

$$C = e^{-a\left(\frac{NDVI}{b-NDVI}\right)}$$

N.B.: see the C factor calculation process in the Water Erosion section.

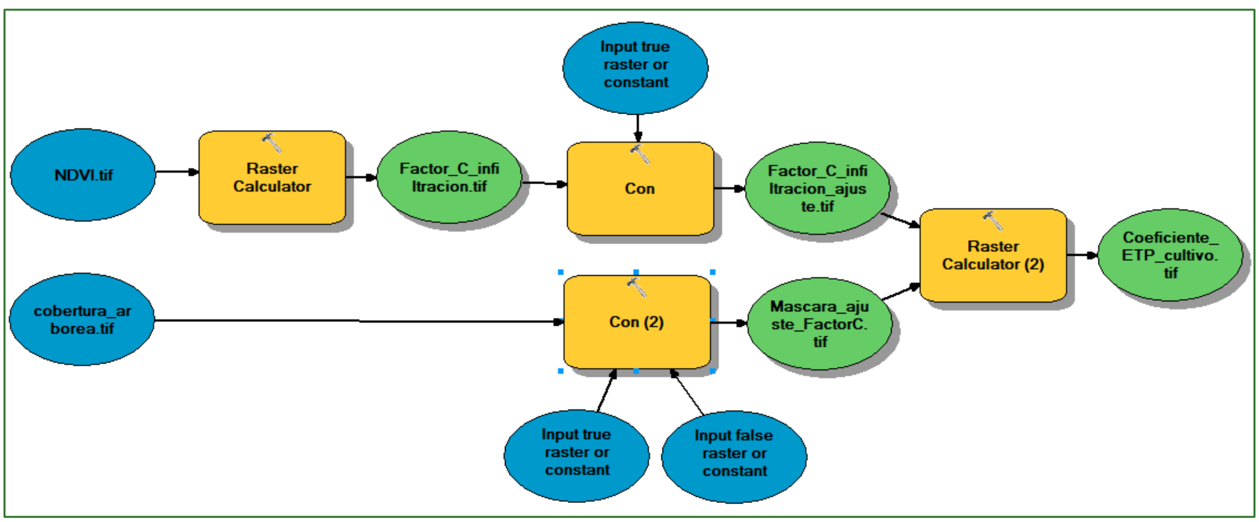
You then make a second adjustment in the forest and no-forest zones:

- Kc (Forest) = C + 0.05.
- Kc (No-forest) = C + 0.15.
- Using the conditional tool **(Con)** on the "no-forest mask" (obtained from the carbon calculation), assign a value of 0.05 to the forest zones and a value of 0.15 to the no-forest zones to generate the adjustment mask. The Con function is located in **Spatial Analyst Tools/Conditional/Con.**

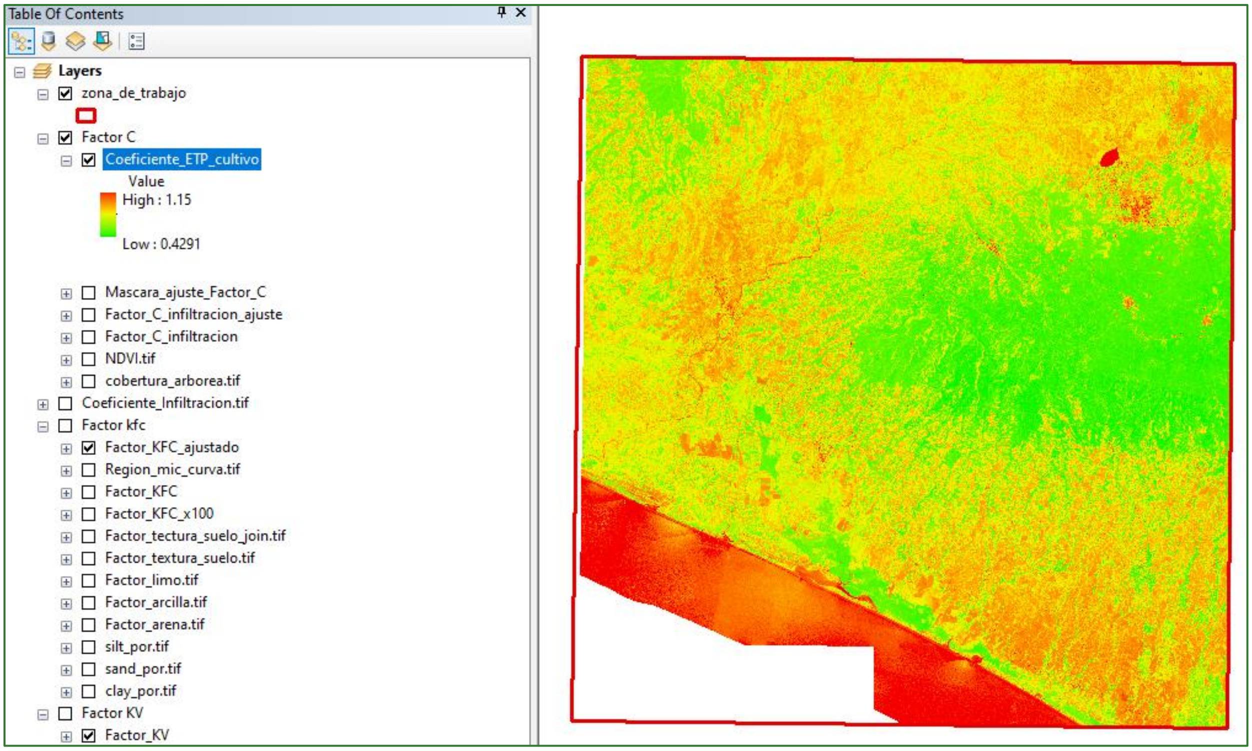


You must then add the **Mascara_ajuste_FactorC.tif + Factor_C_ajustado.tif** layer, naming the output **Coeficiente_ETP_cultivo.tif** and saving it in the **RASTER/FACTORES/FACTOR C Infiltración** folder.

The model will look as follows:



The output will be displayed as follows:



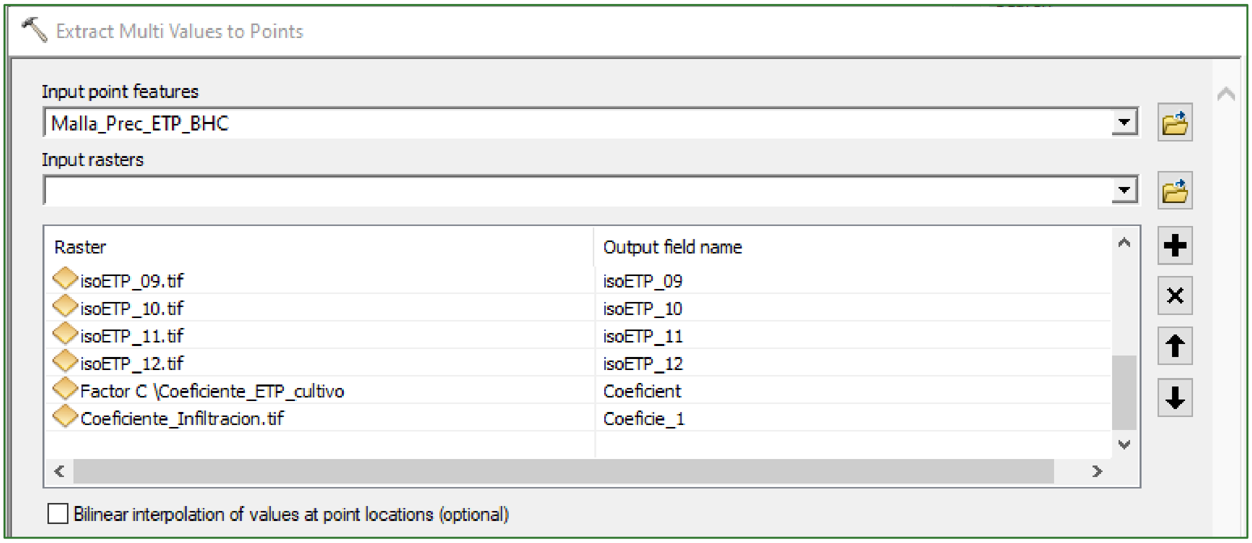
Climatic Water Balance Calculation

The annual water availability or "Climatic Water Balance" (CWB) layer is obtained from subtracting the annual evapotranspiration (ETP) from the annual precipitation (P).

- BHC = P – ETP

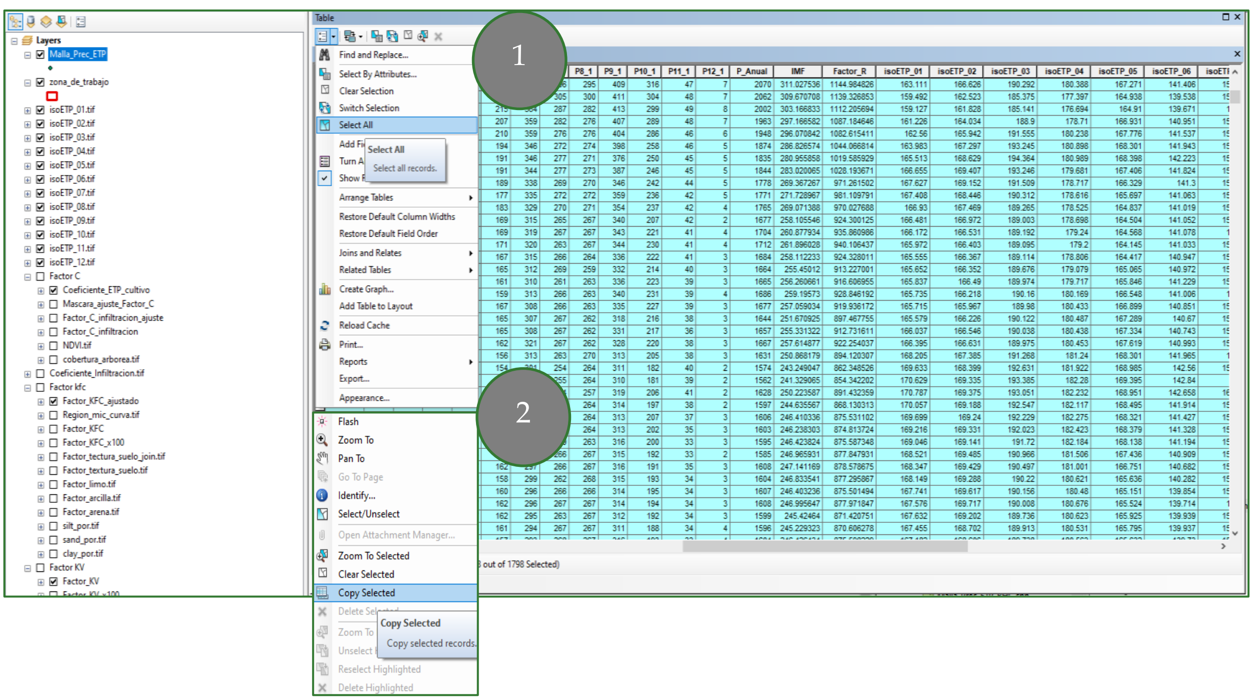
First copy **2malla_LLUVIA_project.shp**, rename it **Malla_Prec_ETP_BHC.shp** and then save it in the **VECTORES/LLUVIA/BHC** folder.

Next, use the Extract Multi Values to Point function to add all the isoETP layers (12 rasters) and the **Coeficiente_ETP_cultivo.tif and Coeficiente_Infiltración.tif** layers.

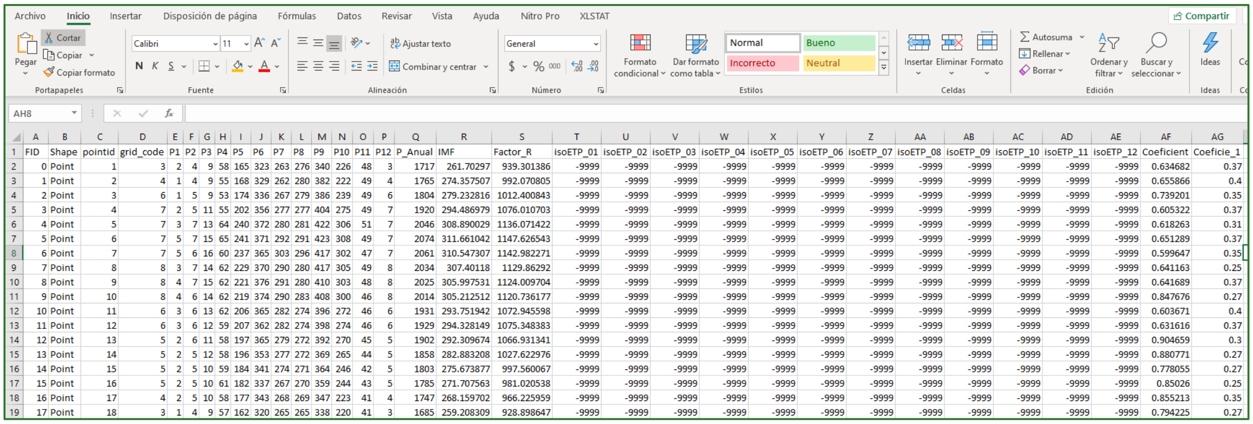


N.B.: If this process does not work, try and extract just the values of the 12 isoETP rasters and then, separately, in the same database, extract the remaining layers (Coeficiente_ETP_cultivo and Coeficiente_Infiltracion). Try to preserve the same mesh name (Malla_Prec_ETP_BHC.shp).

Next, open the layer attributes table to select and copy all the values.



Open a new Excel spreadsheet and paste the values.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	FID	Shape	pointid	grid_code	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P_Anual	IMF	Factor_R
2	0	Point	1	3	2	4	9	58	165	323	263	276	340	226	48	3	1717	261.70297	939.301386
3	1	Point	2	4	1	4	9	55	168	329	262	280	382	222	49	4	1765	274.357507	992.070805
4	2	Point	3	6	1	5	9	53	174	336	267	279	386	239	49	6	1804	279.232816	1012.400843
5	3	Point	4	7	2	5	11	55	202	356	277	277	404	275	49	7	1920	294.486979	1076.010703
6	4	Point	5	7	3	7	13	64	240	372	280	281	422	306	51	7	2046	308.890029	1136.071422
7	5	Point	6	7	5	7	15	65	241	371	292	291	423	308	49	7	2074	311.661042	1147.626543
8	6	Point	7	7	5	6	16	60	237	365	303	296	417	302	47	7	2061	310.547307	1142.982271
9	7	Point	8	8	3	7	14	62	229	370	290	280	417	305	49	8	2034	307.40118	1129.86292
10	8	Point	9	8	4	7	15	62	221	376	291	280	410	303	48	8	2025	305.997531	1124.009704
11	9	Point	10	8	4	6	14	62	219	374	290	283	408	300	46	8	2014	305.212512	1120.736177
12	10	Point	11	6	3	6	13	62	206	365	282	274	396	272	46	6	1931	293.751942	1072.945598
13	11	Point	12	6	3	6	12	59	207	362	282	274	398	274	46	6	1929	294.328149	1075.348383
14	12	Point	13	5	2	6	11	58	197	365	279	272	392	270	45	5	1902	292.309674	1066.931341
15	13	Point	14	5	2	5	12	58	196	353	277	272	369	265	44	5	1858	282.883208	1027.622976
16	14	Point	15	5	2	5	10	59	184	341	274	271	364	246	42	5	1803	275.673877	997.560067
17	15	Point	16	5	2	5	10	61	182	337	267	270	359	244	43	5	1785	271.707563	981.020538
18	16	Point	17	4	2	5	10	58	177	343	268	269	347	223	41	4	1747	268.159702	966.225959
19	17	Point	18	3	1	4	9	57	162	320	265	265	338	220	41	3	1685	259.208309	928.898647

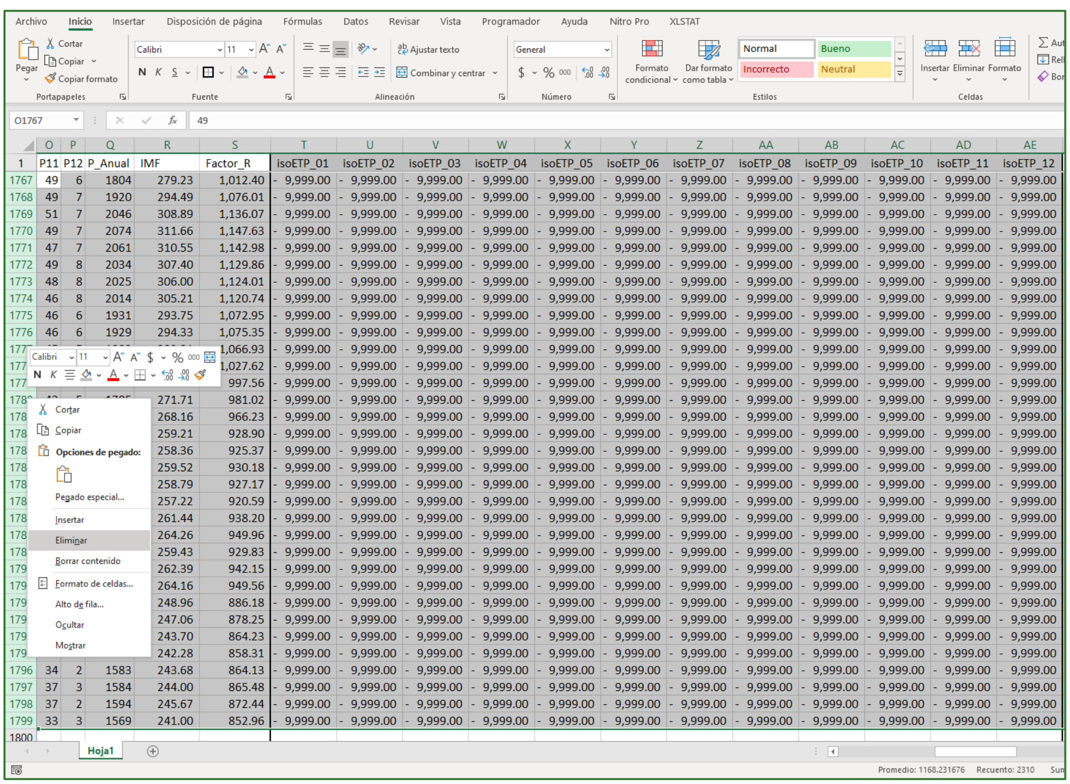
	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG
1	isoETP_01	isoETP_02	isoETP_03	isoETP_04	isoETP_05	isoETP_06	isoETP_07	isoETP_08	isoETP_09	isoETP_10	isoETP_11	isoETP_12	Coeficient	Coeficie_1
2	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.634682	0.37
3	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.655866	0.4
4	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.739201	0.35
5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.605322	0.37
6	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.618263	0.31
7	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.651289	0.37
8	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.599647	0.35
9	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.641163	0.25
10	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.641689	0.37
11	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.847676	0.27
12	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.603671	0.4
13	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.631616	0.37
14	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.904659	0.3
15	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.880771	0.27
16	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.778055	0.27
17	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.85026	0.25
18	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.855213	0.35
19	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.794225	0.27

N.B.: If you want to follow this example practically you can access the Excel "Balance Hídrico Climático" (Climatic Water Balance) template in the GitHub repository at: https://github.com/guialandscape/Tablas

The database must then be cleaned.

Delete the -9999 values, which are the result of NoData entries in some of the layers. It can happen that the layers do not coincide with each other and null data is generated at the boundaries of our study area.

Therefore, you need to select all the rows with -9999 values and delete them from the database.



	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
1	P11	P12	P_Anual	IMF	Factor_R	isoETP_01	isoETP_02	isoETP_03	isoETP_04	isoETP_05	isoETP_06	isoETP_07	isoETP_08	isoETP_09	isoETP_10	isoETP_11	isoETP_12
1767	49	6	1804	279.23	1,012.40	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
1768	49	7	1920	294.49	1,076.01	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
1769	51	7	2046	308.89	1,136.07	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
1770	49	7	2074	311.66	1,147.63	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
1771	47	7	2061	310.55	1,142.98	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
1772	49	8	2034	307.40	1,129.86	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
1773	48	8	2025	306.00	1,124.01	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
1774	46	8	2014	305.21	1,120.74	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
1775	46	6	1931	293.75	1,072.95	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
1776	46	6	1929	294.33	1,075.35	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
177	[illegible]	[illegible]	[illegible]	[illegible]	1,066.93	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
177	[illegible]	[illegible]	[illegible]	[illegible]	1,027.62	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
177	[illegible]	[illegible]	[illegible]	[illegible]	997.56	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
178	[illegible]	[illegible]	[illegible]	271.71	981.02	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
178	[illegible]	[illegible]	[illegible]	268.16	966.23	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
178	[illegible]	[illegible]	[illegible]	259.21	928.90	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
178	[illegible]	[illegible]	[illegible]	258.36	925.37	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
178	[illegible]	[illegible]	[illegible]	259.52	930.18	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
178	[illegible]	[illegible]	[illegible]	258.79	927.17	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
178	[illegible]	[illegible]	[illegible]	257.22	920.59	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
178	[illegible]	[illegible]	[illegible]	261.44	938.20	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
178	[illegible]	[illegible]	[illegible]	264.26	949.96	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
178	[illegible]	[illegible]	[illegible]	259.43	929.83	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
179	[illegible]	[illegible]	[illegible]	262.39	942.15	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
179	[illegible]	[illegible]	[illegible]	264.16	949.56	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
179	[illegible]	[illegible]	[illegible]	248.96	886.18	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
179	[illegible]	[illegible]	[illegible]	247.06	878.25	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
179	[illegible]	[illegible]	[illegible]	243.70	864.23	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
179	[illegible]	[illegible]	[illegible]	242.28	858.31	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
1796	34	2	1583	243.68	864.13	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
1797	37	3	1584	244.00	865.48	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
1798	37	2	1594	245.67	872.44	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
1799	33	3	1569	241.00	852.96	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00	- 9,999.00
1800																	

Then try to change the names of the last two columns to the following ones:

AF1 Coeficient

	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG
1	isoETP_04	isoETP_05	isoETP_06	isoETP_07	isoETP_08	isoETP_09	isoETP_10	isoETP_11	isoETP_12	Coeficient	Coeficie_1
59	180.989	168.398	142.223	157.348	151.735	130.029	129.726	135.472	147.269	0.892194	0.3
60	179.681	167.406	141.824	157.316	152.346	130.494	130.333	135.806	148.023	0.918426	0.3
61	178.717	166.329	141.3	157.075	152.871	131.181	130.818	136.232	148.255	0.855855	0.3
62	178.616	165.697	141.063	157.029	153.023	131.77	131.058	136.154	147.807	0.899703	0.35
63	178.525	164.837	141.019	156.949	153.105	132.056	131.707	136.339	147.008	0.626361	0.4
64	178.698	164.504	141.052	156.666	153.274	132.253	132.202	136.246	146.608	0.835279	0.3
65	179.24	164.568	141.078	156.74	153.437	132.523	132.952	136.422	146.627	0.844864	0.35
66	179.2	164.145	141.033	156.566	153.159	132.35	132.845	136.22	146.293	0.772022	0.45

- Coefficient = ETP Crop Coefficient
- Coeficien_1 = Infiltration Coefficient

Then try to add the following columns:

Column: ETR_aisoETP_01, ETR_aisoETP_02…….

AL3

	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS
1	ETR_aisoETP_01	ETR_aisoETP_02	ETR_aisoETP_03	ETR_aisoETP_04	ETR_aisoETP_05	ETR_aisoETP_06	ETR_aisoETP_07	ETR_aisoETP_08	ETR_aisoETP_09	ETR_aisoETP_10	ETR_aisoETP_11	ETR_aisoE
2	0	0	0	0	0	0	0	0	0	0	0	
3												
4												

Column: iso_BHC_01, iso_BHC_02……

AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF
iso_BHC_01	iso_BHC_02	iso_BHC_03	iso_BHC_04	iso_BHC_05	iso_BHC_06	iso_BHC_07	iso_BHC_08	iso_BHC_09	iso_BHC_10	iso_BHC_11	iso_BHC_12

Column: 2iso_BHC_01, 2iso_BHC_02…..

BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR
2iso_BHC_01	2iso_BHC_02	2iso_BHC_03	2iso_BHC_04	2iso_BHC_05	2iso_BHC_06	2iso_BHC_07	2iso_BHC_08	2iso_BHC_09	2iso_BHC_10	2iso_BHC_11	2iso_BHC_12

Column: BHC_anual_mm and Infiltración_anual_mm

BS	BT
BHC_anual_mm	Infiltración_anual_mm

Next, perform the calculations for each of the columns as follows.

For the ETR_aisoETP_0x columns, multiply the isoETP_01 value by the Coeficiente_ETP_Cultivo.

=T50*$AF50

AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS
ETR_aisoETP_01	ETR_aisoETP_02	ETR_aisoETP_03	ETR_aisoETP_04	ETR_aisoETP_05	ETR_aisoETP_06	ETR_aisoETP_07	ETR_aisoETP_08	ETR_aisoETP_09	ETR_aisoETP_10	ETR_aisoETP_11	ETR_aisoETP_12
108.8648671	110.2201608	125.6679099	118.0743646	110.0648058	93.8103807	102.3516566	99.73662216	86.58409724	86.74855256	89.53714265	95.36588095
96.85994789	98.74395145	112.3694691	105.5361121	98.38943153	83.57038287	91.52938406	88.84408425	76.7283225	76.75153166	79.46294178	84.95887087
101.5516193	103.9222361	118.5706165	111.5921667	103.5771076	87.51333316	95.9383854	92.89770523	79.62371967	79.46155822	82.98688695	89.34116807
99.68186232	101.8299808	116.2929597	110.2403381	102.224159	86.41730737	94.60338033	91.41267582	78.19517781	77.75822057	81.5099415	88.33014114
121.0305042	123.3305786	140.6718188	134.6177135	125.1632013	105.8884113	116.1359217	111.9645233	95.77521735	94.91923455	99.6263811	107.8659744
108.292766	110.1309126	125.9964116	120.2478648	112.2283461	95.05212135	104.4429342	100.5856165	85.93624787	85.25706595	89.66970677	96.60307885
128.3607248	130.5963252	150.3934906	142.2806813	132.9027834	112.2187025	123.7509931	119.0656269	101.8901966	101.1131503	106.2594898	114.3707067
138.517376	141.3991782	163.2240155	153.5807998	142.9619296	120.6036777	133.0494503	128.1081224	109.6414112	108.8966758	114.2171882	123.5783588
157.0288089	160.2022688	185.049866	173.2264776	161.1636912	135.9234813	149.914858	144.4881841	123.6528974	123.1760166	128.8794345	139.907064
147.6697055	150.449782	173.4103946	161.4772999	150.2436852	126.8905073	140.3849415	135.3770566	116.0110936	115.7407588	120.8673056	131.3925182
153.060285	155.5877934	177.4821508	165.0237021	153.750023	130.254849	144.4831046	139.9185274	119.8490824	119.7012159	124.7277614	135.9481718
143.4644061	144.769585	163.9039352	152.955838	142.3535063	120.9323115	134.4334241	130.8354097	112.2719148	111.9612394	116.5948384	126.884783

For the iso_BHC_0x columns, subtract the ETR_aisoETP_0x (Real Evapotranspiration) values from the Precipitation values (P1, P2, P3, etc.).

=E50-AH50

AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE
iso_BHC_01	iso_BHC_02	iso_BHC_03	iso_BHC_04	iso_BHC_05	iso_BHC_06	iso_BHC_07	iso_BHC_08	iso_BHC_09	iso_BHC_10	iso_BHC_11	iso_BHC_12
-106.8648671	-106.2201608	-116.6679099	-60.07436459	60.93519418	239.1896193	166.6483434	179.2633778	292.4159028	138.2514474	-40.53714265	-90.36588095
-94.85994789	-93.74395145	-101.3694691	-51.53611212	82.61056847	261.4296171	181.4706159	179.1559157	304.2716775	182.2484683	-32.46294178	-78.95887087
-98.55161929	-96.92223611	-106.5706165	-55.59216673	112.4228924	278.4866668	184.0616146	189.1022948	319.3762803	218.5384418	-33.98688695	-82.34116807
-94.68186232	-94.82998075	-101.2929597	-47.24033805	133.775841	287.5826926	201.3966197	203.5873242	330.8048222	238.2417794	-34.5099415	-81.33014114
-115.0305042	-116.3305786	-124.6718188	-72.61771345	101.8367987	263.1115887	188.8640783	188.0354768	315.2247827	209.0807655	-51.6263811	-100.8659744
-104.292766	-103.1309126	-112.9964116	-59.24786484	102.7716539	268.9478786	182.5570658	181.4143835	327.0637521	213.742934	-40.66970677	-88.60307885
-124.3607248	-123.5963252	-138.3934906	-77.28068134	74.09721663	246.7812975	158.2490069	156.9343731	305.1098034	187.8868497	-58.25948976	-107.3707067
-135.517376	-135.3991782	-151.2240155	-89.5807998	67.0380704	238.3963223	142.9505497	147.8918776	294.3585888	177.1033242	-68.2171882	-117.5783588
-155.0288089	-155.2022688	-173.049866	-111.2264776	32.83630881	210.0765187	122.085142	129.5118159	274.3471026	134.8239834	-82.8794345	-134.907064

Perform the same calculation as above for the 2iso_BHC_0x columns, except for the fact that in this step all negative values become 0 values. Use the MAX function in this process indicating that the ETR_aisoETP_0x (Real Evapotranspiration) is subtracted from the Precipitation (P1, P2, P3) column.

=MAX(K5-$AG5,0)

BF	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ
2iso_BHC_01	2iso_BHC_02	2iso_BHC_03	2iso_BHC_04	2iso_BHC_05	2iso_BHC_06	2iso_BHC_07	2iso_BHC_08	2iso_BHC_09	2iso_BHC_10	2iso_BHC_11	2iso_BHC_12
-	-	-	-	2.50	136.50	104.50	107.50	146.50	43.50	-	-
-	-	-	-	-	136.01	106.01	108.01	151.01	29.01	-	-
-	-	-	-	12.98	145.98	120.98	116.98	159.98	42.98	-	-
-	-	-	-	-	142.80	113.80	108.80	154.80	42.80	-	-
-	-	-	-	10.88	159.88	129.88	125.88	175.88	59.88	-	-
-	-	-	-	6.17	141.17	112.17	112.17	161.17	31.17	-	-
-	-	-	-	17.54	155.54	126.54	128.54	174.54	44.54	-	-
-	-	-	-	-	154.49	117.49	113.49	158.49	38.49	-	-

For the BHC_anual_mm column, all the 2iso_BHC_0x cells must be added up.

=SUMA(BF2:BQ2)

_04	2iso_BHC_05	2iso_BHC_06	2iso_BHC_07	2iso_BHC_08	2iso_BHC_09	2iso_BHC_10	2iso_BHC_11	2iso_BHC_12	BHC_anual_mm
-	2.50	136.50	104.50	107.50	146.50	43.50	-	-	541.00
-	-	136.01	106.01	108.01	151.01	29.01	-	-	530.05
-	12.98	145.98	120.98	116.98	159.98	42.98	-	-	599.90
-	-	142.80	113.80	108.80	154.80	42.80	-	-	562.99
-	10.88	159.88	129.88	125.88	175.88	59.88	-	-	662.28

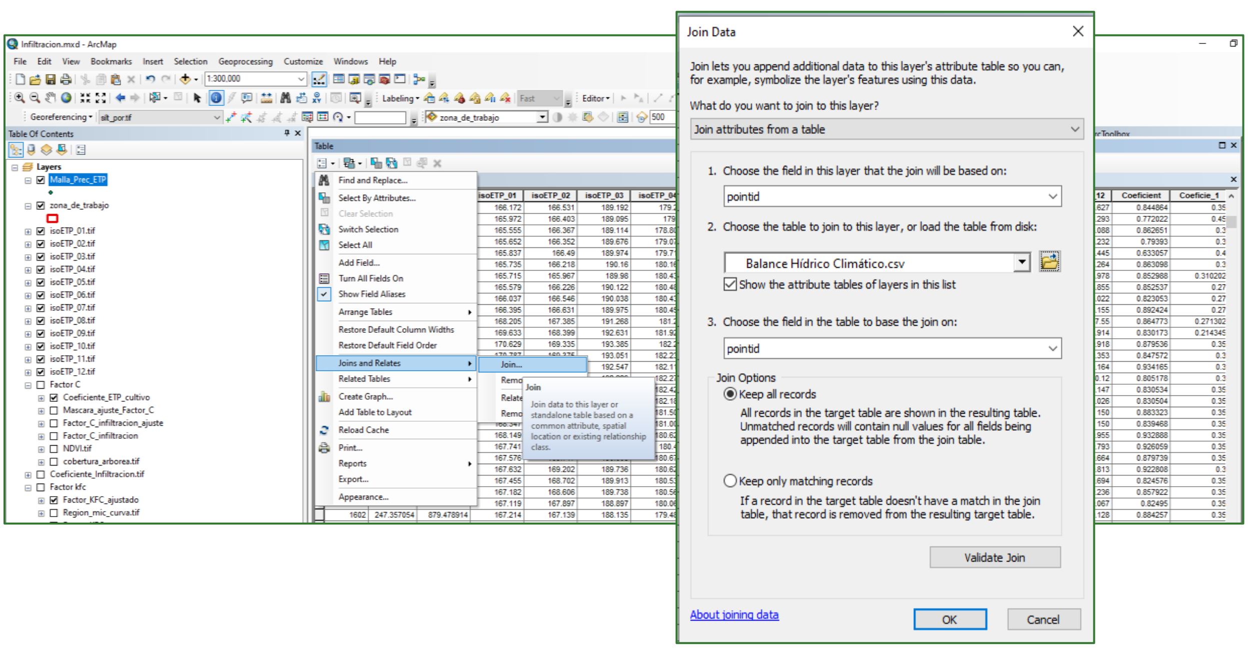
For the Infiltración_anual_mm column, multiply the BHC_anual_mm x Coeficiente_Infiltración values.

=BR2*AG2

C_06	2iso_BHC_07	2iso_BHC_08	2iso_BHC_09	2iso_BHC_10	2iso_BHC_11	2iso_BHC_12	BHC_anual_mm	Infiltración_anual_mm
323	263	276	340	226	48	3	1717	635.29
329	262	280	382	222	49	4	1765	706
336	267	279	386	239	49	6	1804	631.4
356	277	277	404	275	49	7	1920	710.4
372	280	281	422	306	51	7	2046	634.26
371	292	291	423	308	49	7	2074	767.38
365	303	296	417	302	47	7	2061	721.35
370	290	280	417	305	49	8	2034	508.5
376	291	280	410	303	48	8	2025	749.25

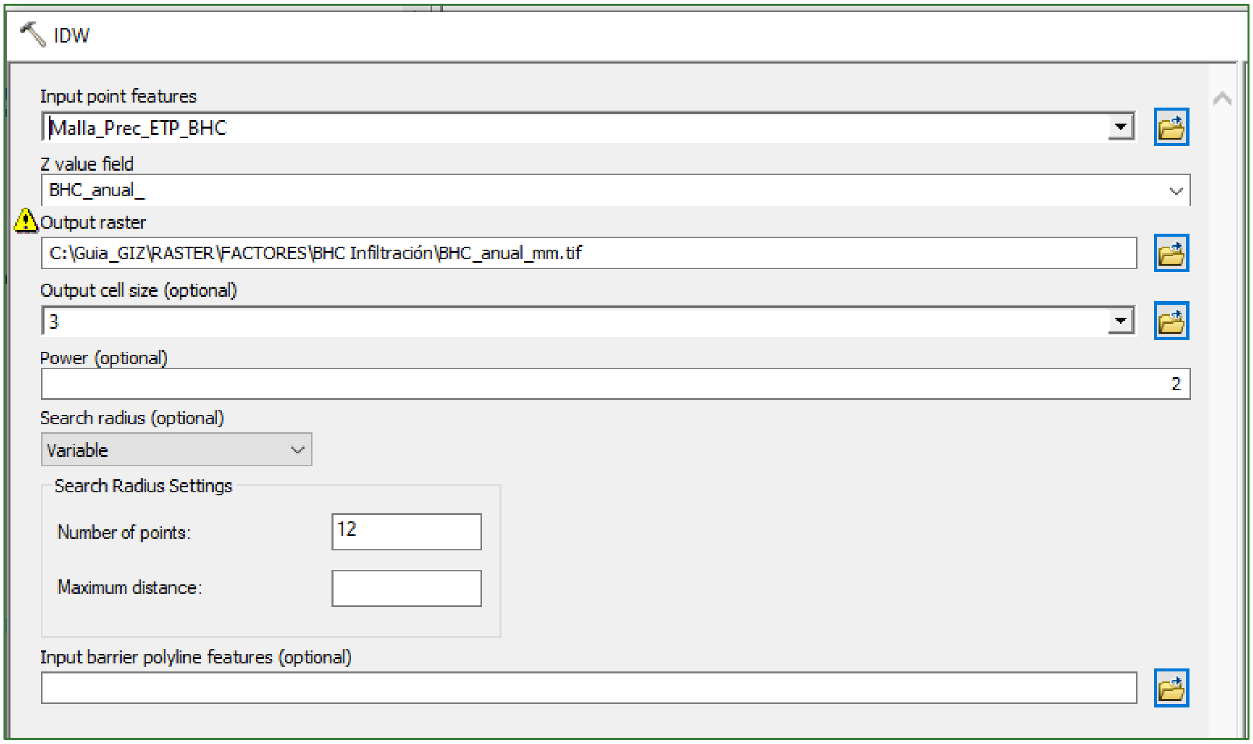
Save the table, naming it Balance_Hidrico_Climatico.csv.

Then open the attributes table of the Malla_Prec_BHC layer and join it to the database generated in the previous process (**Balance_Hidrico_Climatico.csv**). The **pointid** columns make the join possible.

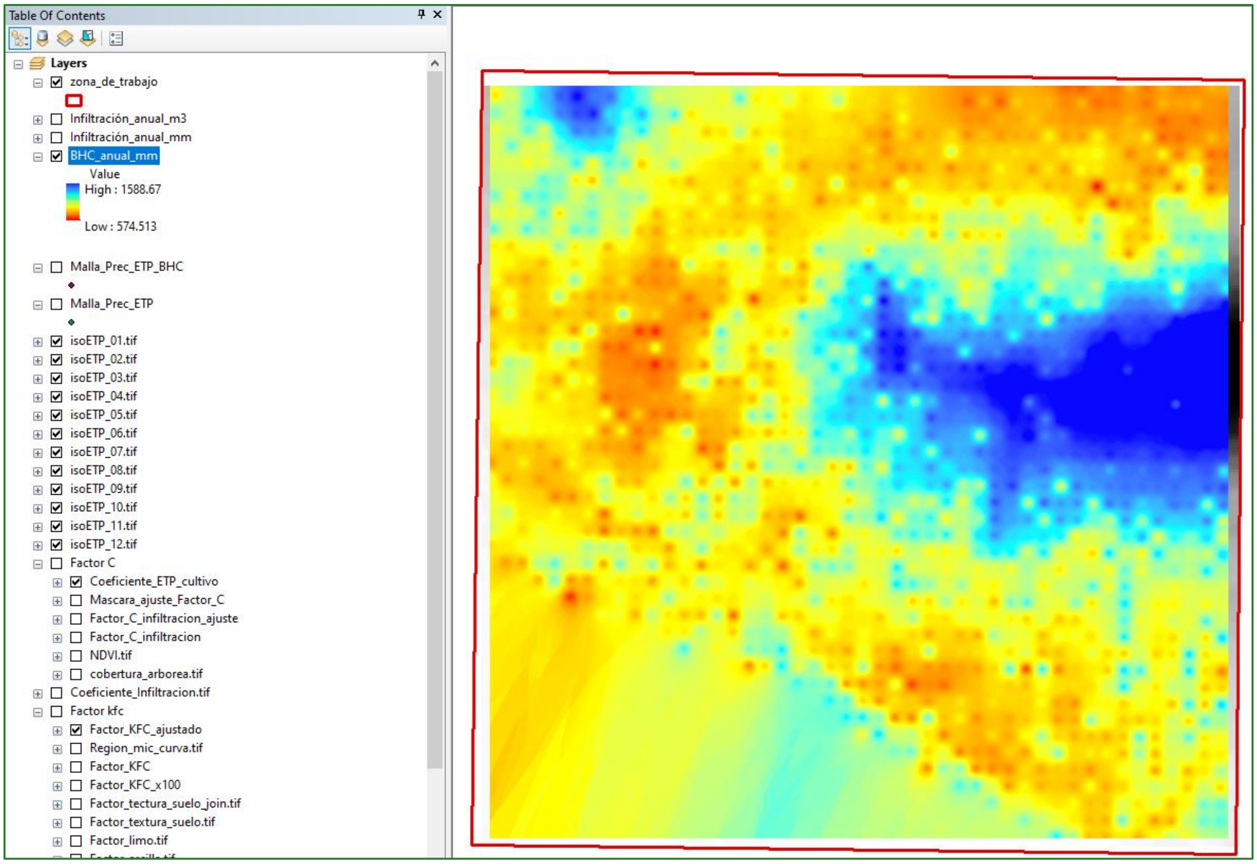


N.B.: a copy of the aforementioned file must be saved to ensure that the data are preserved. Name it **Malla_Prec_ETP_BHC.shp** and save it in the **VECTORES/LLUVIA/BHC** folder.

You must then do an IDW interpolation using the **BCH_anual_mm.tif** column to generate the annual Water Balance in mm. Save this layer in the **RASTER/FACTORES/BHC Infiltración** folder. The IDW function can be found in **Spatial Analyst Tools/Interpolation/IDW.**

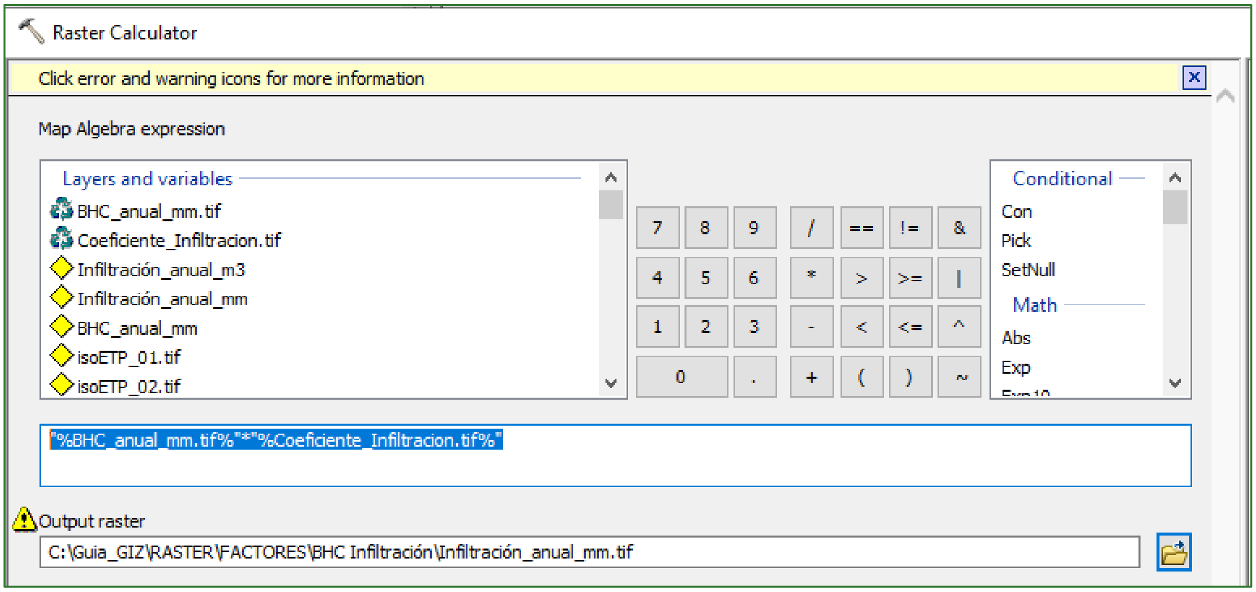


The result will be as shown below:



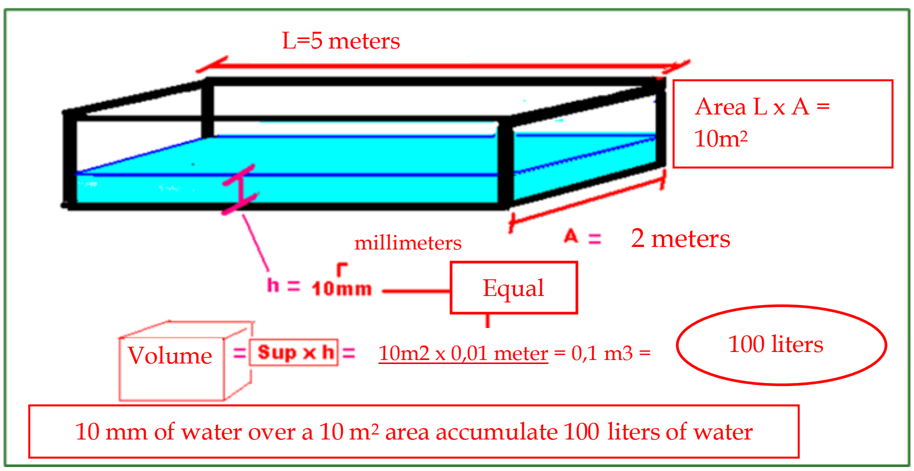
Step 6: Calculation of total infiltration

The **Coeficiente_Infiltracion.tif** (CI Factor) must be multiplied by the annual water availability obtained from the **BHC_anual_mm.tif** (BHC) raster to get the annual infiltration mm. The result of this process must be named **Infriltración_anual_mm.tif** and saved in the **RASTER/FACTORES/BHC Infiltración** folder.



Bear in mind that 1 mm of water corresponds to a 0.001 m film of water that spreads over the entire surface it covers. If you want the m3 per pixel you must multiply:

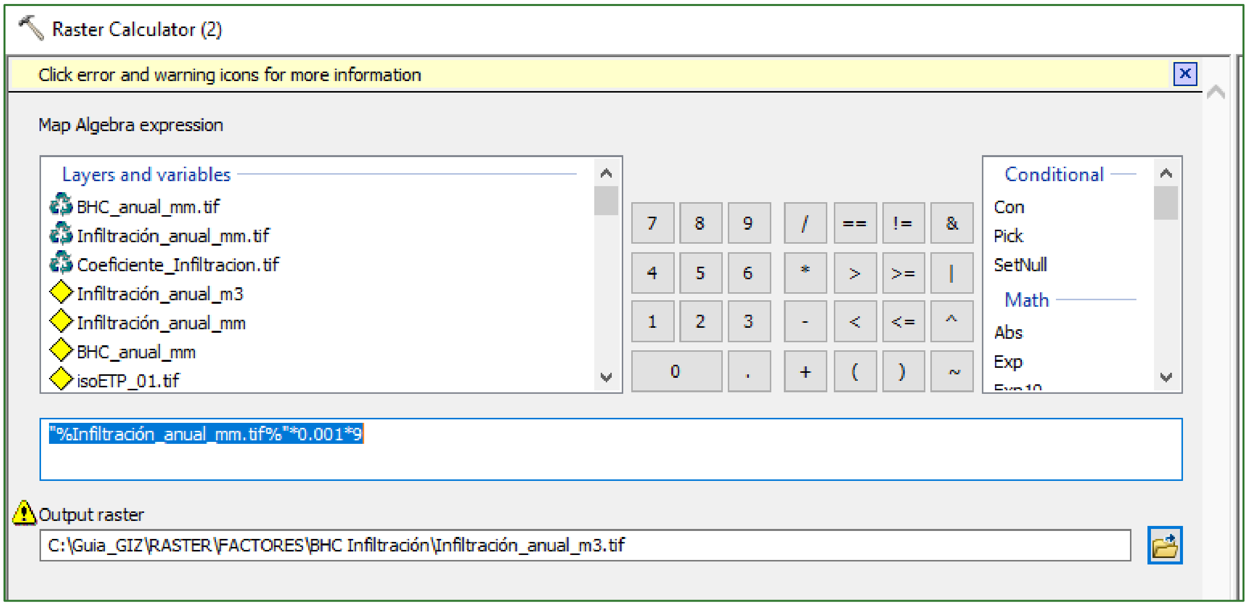
Amount of mm * 0.001m * Pixel size^2



N.B.: consider the following metrics for water balance data analysis purposes:

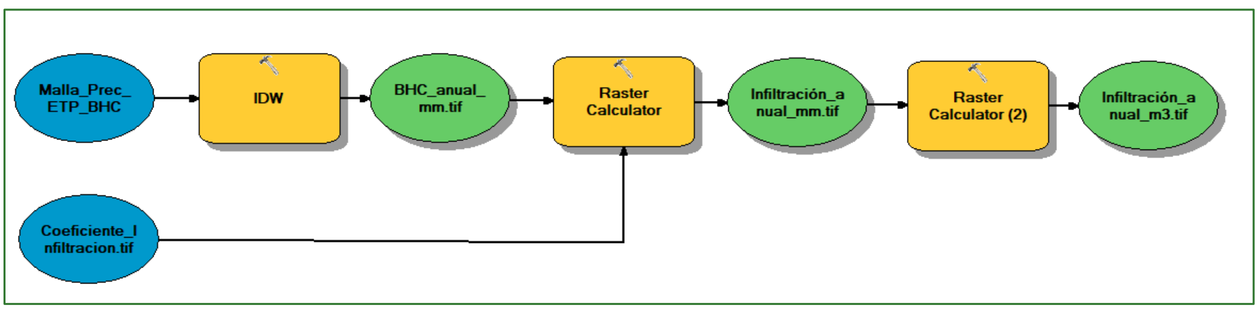
a) Mean mm per year
b) m^3 per pixel per year

Use the Raster Calculator to convert the mm into m^3 as follows:



Name the file **Infiltración_anual_m3.tif** and save it in the **RASTER/FACTORES/BHC Infiltración** folder.

The model will look as follows:



The output can be seen as shown below:

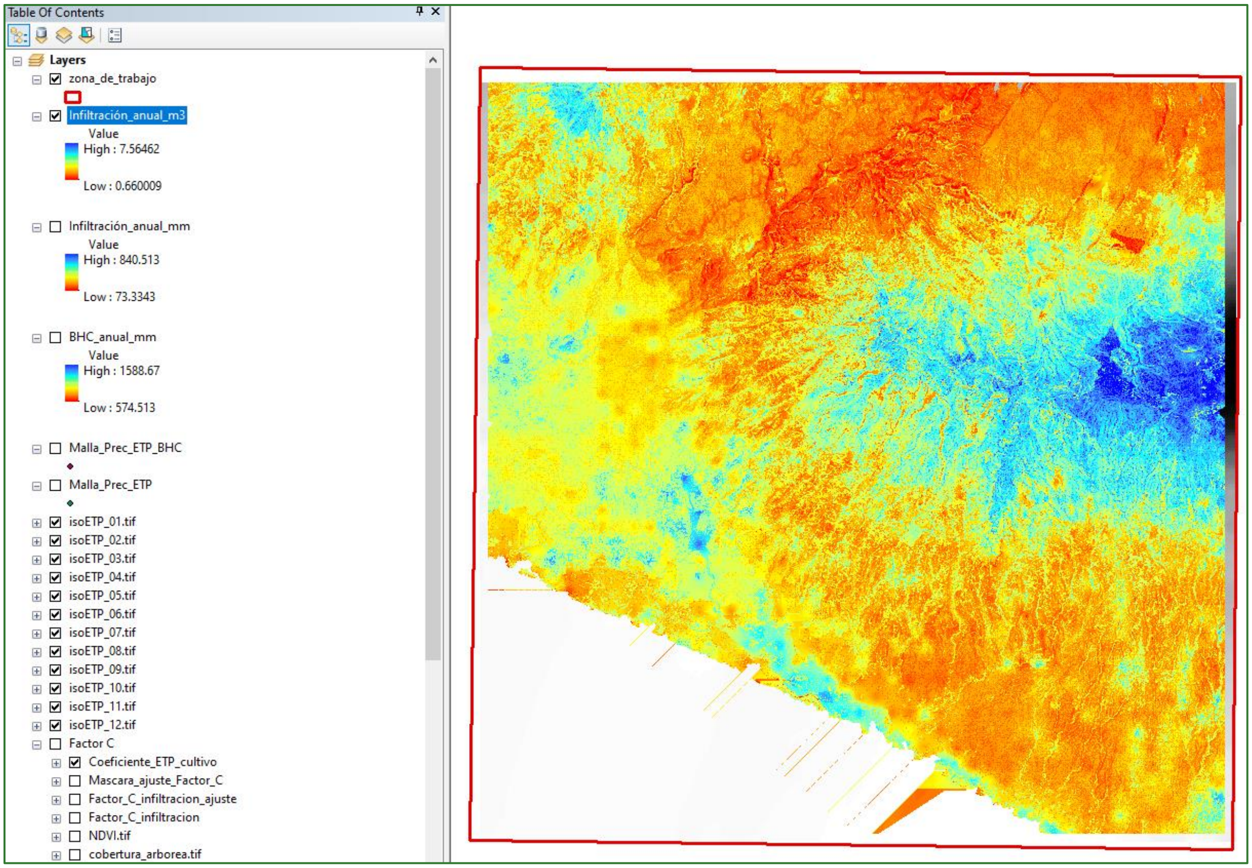


Table Of Contents
Layers
zona_de_trabajo
Infiltración_anual_m3
Value
High : 7.56462
Low : 0.660009
Infiltración_anual_mm
Value
High : 840.513
Low : 73.3343
BHC_anual_mm
Value
High : 1588.67
Low : 574.513
Malla_Prec_ETP_BHC
Malla_Prec_ETP
isoETP_01.tif
isoETP_02.tif
isoETP_03.tif
isoETP_04.tif
isoETP_05.tif
isoETP_06.tif
isoETP_07.tif
isoETP_08.tif
isoETP_09.tif
isoETP_10.tif
isoETP_11.tif
isoETP_12.tif
Factor C
Coeficiente_ETP_cultivo
Mascara_ajuste_Factor_C
Factor_C_infiltracion_ajuste
Factor_C_infiltracion
NDVI.tif
cobertura_arborea.tif

Landscape structural connectivity analysis

Module 3: Landscape structural connectivity analysis

Landscape connectivity can be defined as the degree to which the landscape facilitates or impedes the movement of species among patches of vegetation.

In the landscape structural connectivity analysis module, a set of landscape connectivity metrics are generated that are particularly associated with its fragmentation. Fragmentation is the process of dividing a continuous habitat into sections. The main reasons for the loss and fragmentation of habitat are certain land uses such as farming and stockbreeding, land development, as well as the construction and presence of artificial barriers including transport infrastructure.

Safeguarding Spatial connectivity is even more important in the current context of climate change. Creating connectivity networks is a strategy that is frequently proposed to mitigate the negative effects of climate change on biodiversity, as it allows species to adapt their spatial distribution to changing temperatures and climatic patterns.

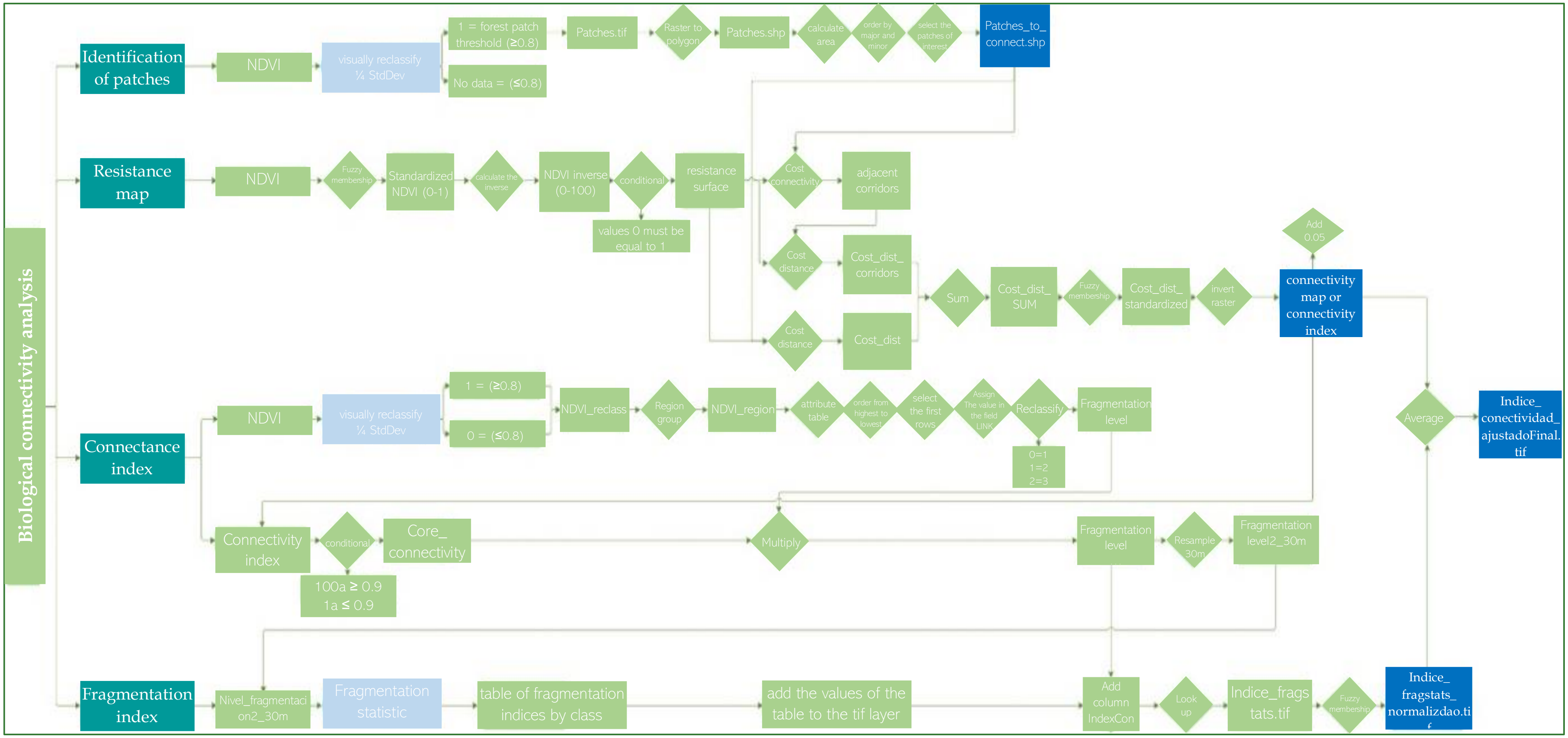
Consequently, it will be necessary to conduct a biological connectivity analysis of the project area. For this, four steps must be taken:

(i) Identification of patches
(ii) Generation of a resistance map based on a landscape connectivity index
(iii) Generation of a connectivity index
(iv) A landscape fragmentation index

These four metrics will be used to generate an adjusted landscape connectivity index.

The diagrams in this methodological guide are available in an online GitHub repository by clicking on the following link (Spanish original):

https://github.com/guialandscape/Diagramas


Biological connectivity analysis
Identification of patches
NDVI
visually reclassify ¼ StdDev
1 = forest patch threshold (≥0.8)
No data = (≤0.8)
Patches.tif
Raster to polygon
Patches.shp
calculate area
order by major and minor
select the patches of interest
Patches_to_connect.shp
Resistance map
NDVI
Fuzzy membership
Standardized NDVI (0-1)
calculate the inverse
NDVI inverse (0-100)
conditional
values 0 must be equal to 1
resistance surface
Cost connectivity
adjacent corridors
Cost distance
Cost_dist_corridors
Cost distance
Cost_dist
Sum
Cost_dist_SUM
Fuzzy membership
Cost_dist_standardized
invert raster
connectivity map or connectivity index
Add 0.05
Connectance index
NDVI
visually reclassify ¼ StdDev
1 = (≥0.8)
0 = (≤0.8)
NDVI_reclass
Region group
NDVI_region
attribute table
order from highest to lowest
select the first rows
Assign The value in the field LINK
Reclassify
0=1
1=2
2=3
Fragmentation level
Connectivity index
conditional
100a ≥ 0.9
1a ≤ 0.9
Core_connectivity
Multiply
Fragmentation level
Resample 30m
Fragmentation level2_30m
Average
Indice_conectividad_ajustadoFinal.tif
Fragmentation index
Nivel_fragmentacion2_30m
Fragmentation statistic
table of fragmentation indices by class
add the values of the table to the tif layer
Add column IndexCon
Look up
Indice_fragstats.tif
Fuzzy membership
Indice_fragstats_normalizdao.tif

Part 14. Biological connectivity

Options

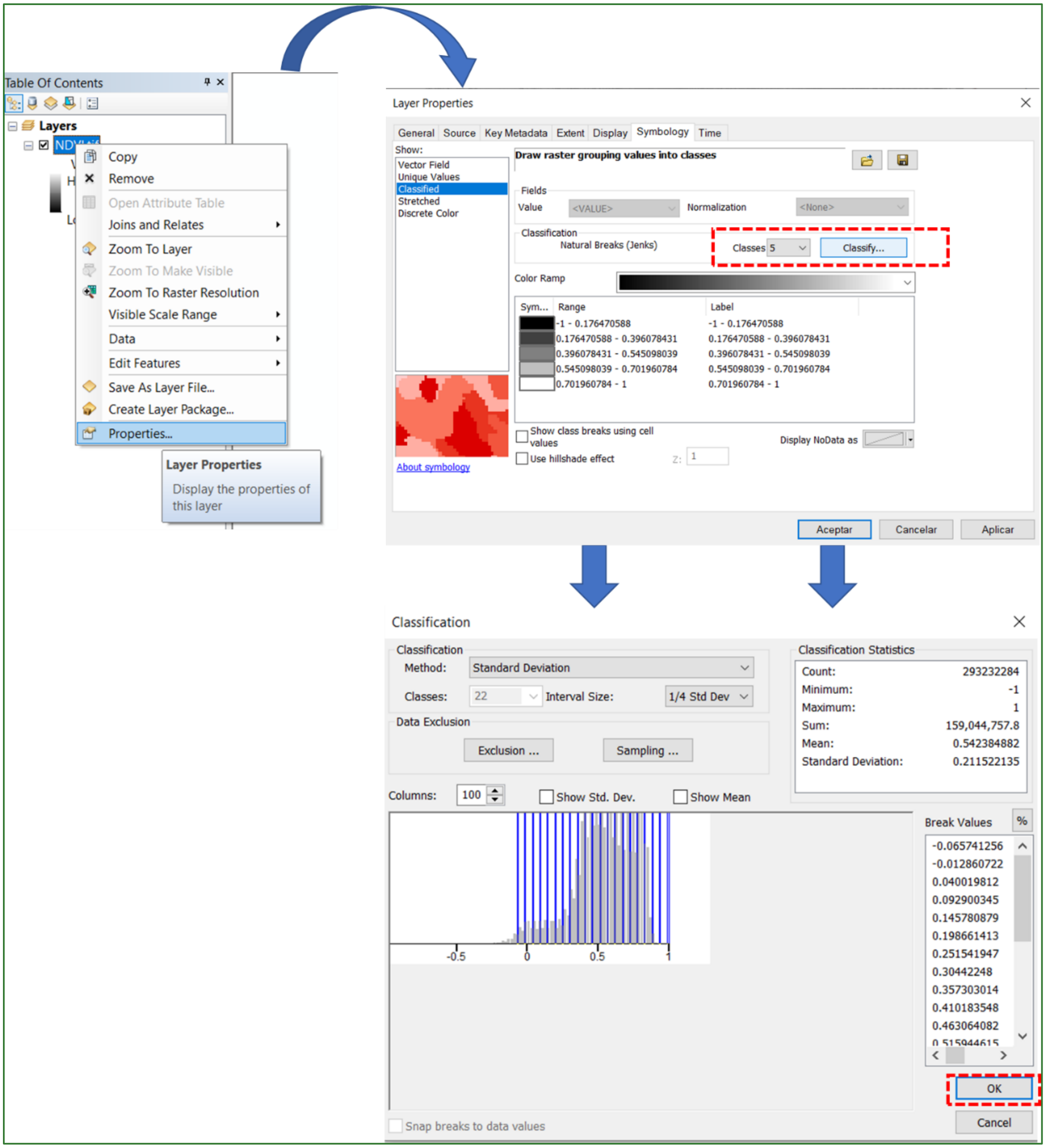
The connectivity analysis requires the selection of core patches that need to be connected. To this end, there are several options: one involves using the available protected area polygons; another would be to use the carbon density map and select the biggest patches with greater carbon density; or to use the NDVI by selecting the biggest patches with high NDVI values. This exercise explains the procedure using the NDVI option.

Use the carbon density map to define the patches to be connected and use NDVI as the friction map for connectivity. To do so, invert the NDVI values (1-NDVI) so that the highest values represent the lowest resistance.

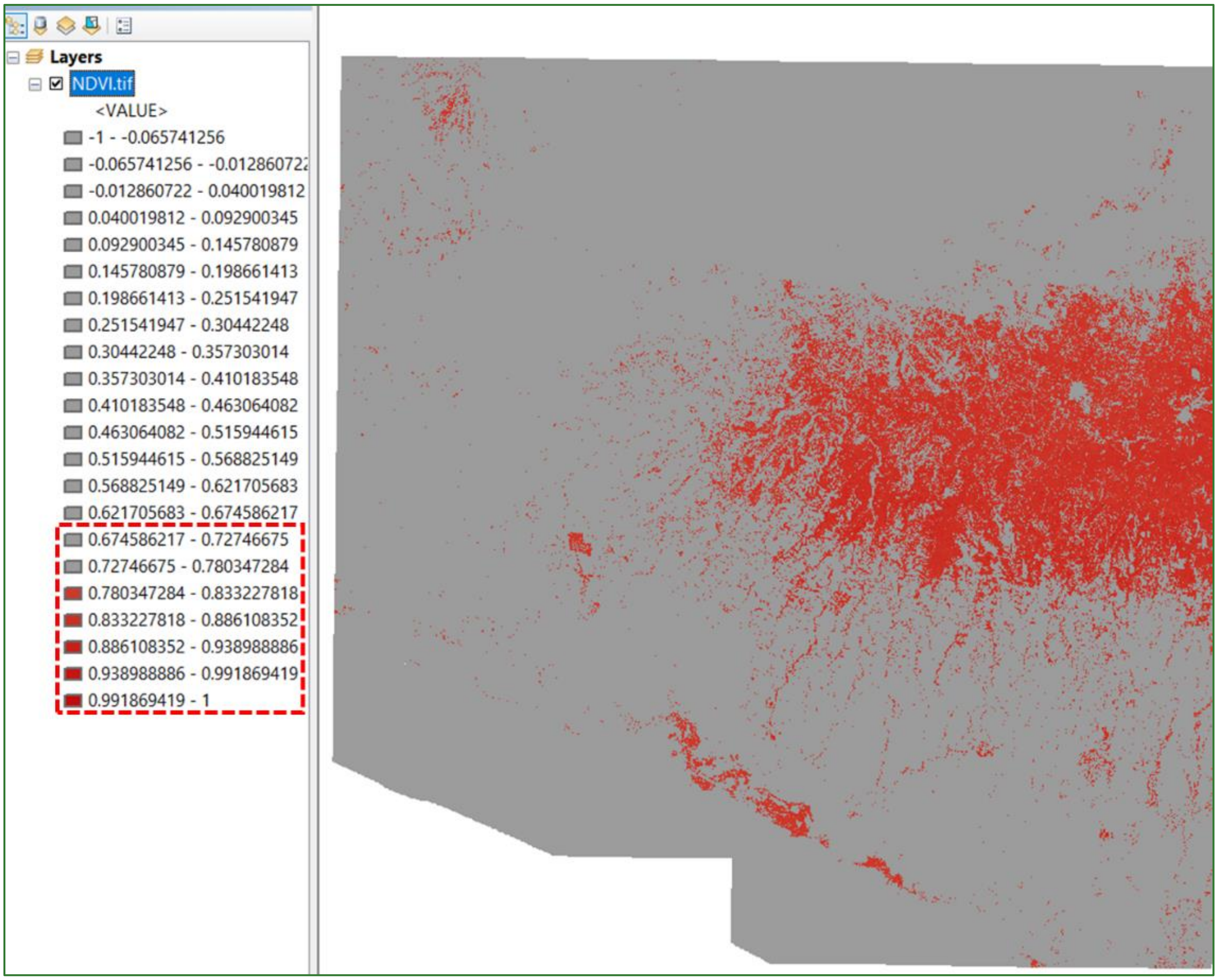
Steps

Step 1: Identification of patches

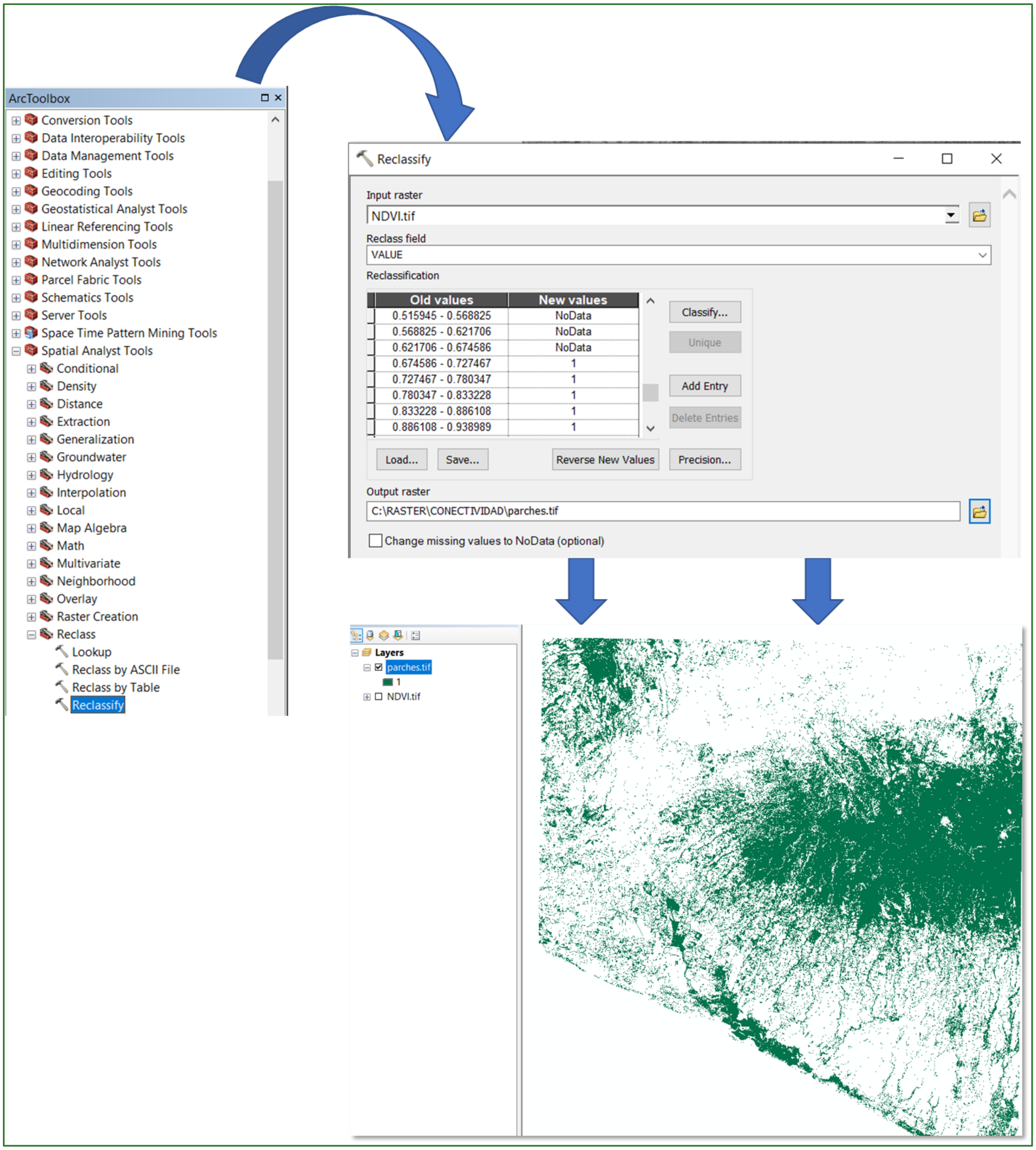
Select the core patches of interest for biological connectivity:
Visually reclassify the NDVI using the 1/4 StdDev option with the standard deviation method and observe the last 4 or 5 classes to define the threshold of the forest patches you want to connect. To carry out this process, open the raster called **NDVI.tif** in the **RASTER/NDVI** folder, right click on it and open the raster properties. Next, click on classify, select the Standard Deviation (1/4 Std Dev) method and click on OK.



a) As a second step, identify the last five NDVI classes (or those you consider suitable and capable of representing the patches to be connected) that will serve as the threshold of the patches you will be connecting; **in this case** select the NDVI indices higher than **0.67.**

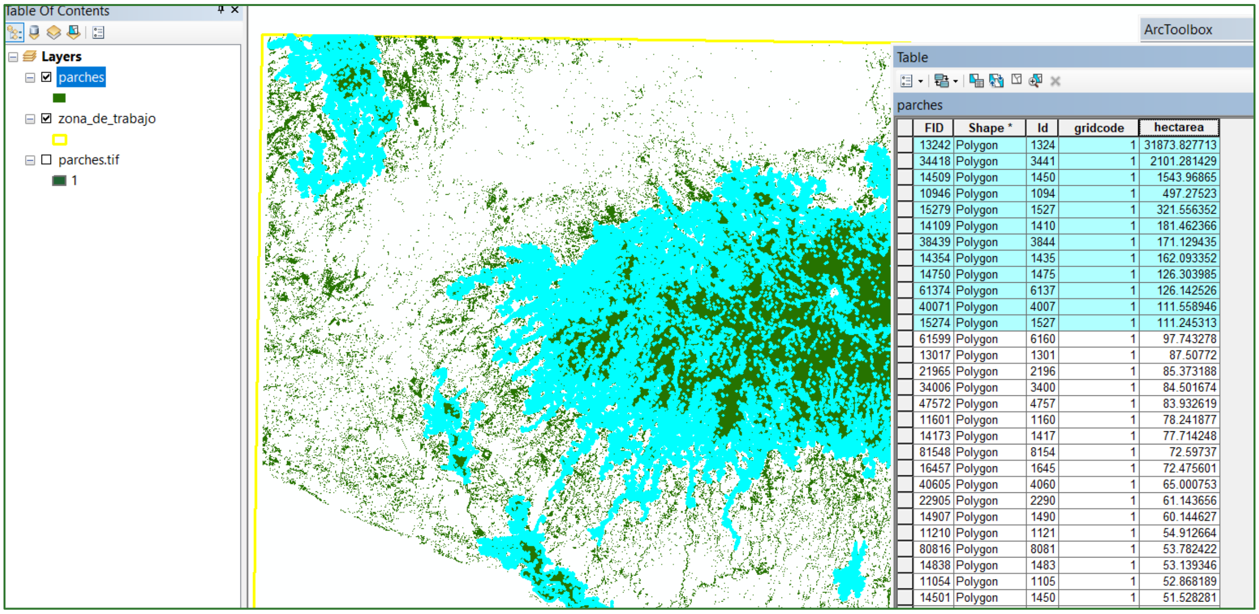


b) Subsequently, reclassify 2 classes, indicating NoData for NDVI values below the threshold selected and 1 for values that are higher than that threshold. Reclassification must be done using the "Reclassify" tool in **ArcToolBox/Spatial Analyst Tools/Reclass/Reclassify**; name the file **parches.tif** and save it in the **RASTER/CONECTIVIDAD** folder.



c) Now convert the raster generated called **parches.tif** into a vector format file (shapefile) and name it **parches.shp**. This will be the file that will connect the patches of vegetation. To carry out this process, find the "Raster to Polygon" tool in the **ArcToolBox/Conversion Tools/From Raster/Raster to Polygon**, name the file **parches.shp** and save it in the **RASTER/CONECTIVIDAD** folder.

d) In the patches shapefile that is generated, calculate the area and order the fields from the largest to the smallest area. Then select the patches with the biggest area that you want to connect and export them to a new shapefile, naming it **parches_a_conectar.shp** and save it in the **RASTER/CONECTIVIDAD** folder.



FID	Shape *	Id	gridcode	hectarea
13242	Polygon	1324	1	31873.827713
34418	Polygon	3441	1	2101.281429
14509	Polygon	1450	1	1543.96865
10946	Polygon	1094	1	497.27523
15279	Polygon	1527	1	321.556352
14109	Polygon	1410	1	181.462366
38439	Polygon	3844	1	171.129435
14354	Polygon	1435	1	162.093352
14750	Polygon	1475	1	126.303985
61374	Polygon	6137	1	126.142526
40071	Polygon	4007	1	111.558946
15274	Polygon	1527	1	111.245313
61599	Polygon	6160	1	97.743278
13017	Polygon	1301	1	87.50772
21965	Polygon	2196	1	85.373188
34006	Polygon	3400	1	84.501674
47572	Polygon	4757	1	83.932619
11601	Polygon	1160	1	78.241877
14173	Polygon	1417	1	77.714248
81548	Polygon	8154	1	72.59737
16457	Polygon	1645	1	72.475601
40605	Polygon	4060	1	65.000753
22905	Polygon	2290	1	61.143656
14907	Polygon	1490	1	60.144627
11210	Polygon	1121	1	54.912664
80816	Polygon	8081	1	53.782422
14838	Polygon	1483	1	53.139346
11054	Polygon	1105	1	52.868189
14501	Polygon	1450	1	51.528281

d) The shapefile of the patches to be connected may look as shown below:

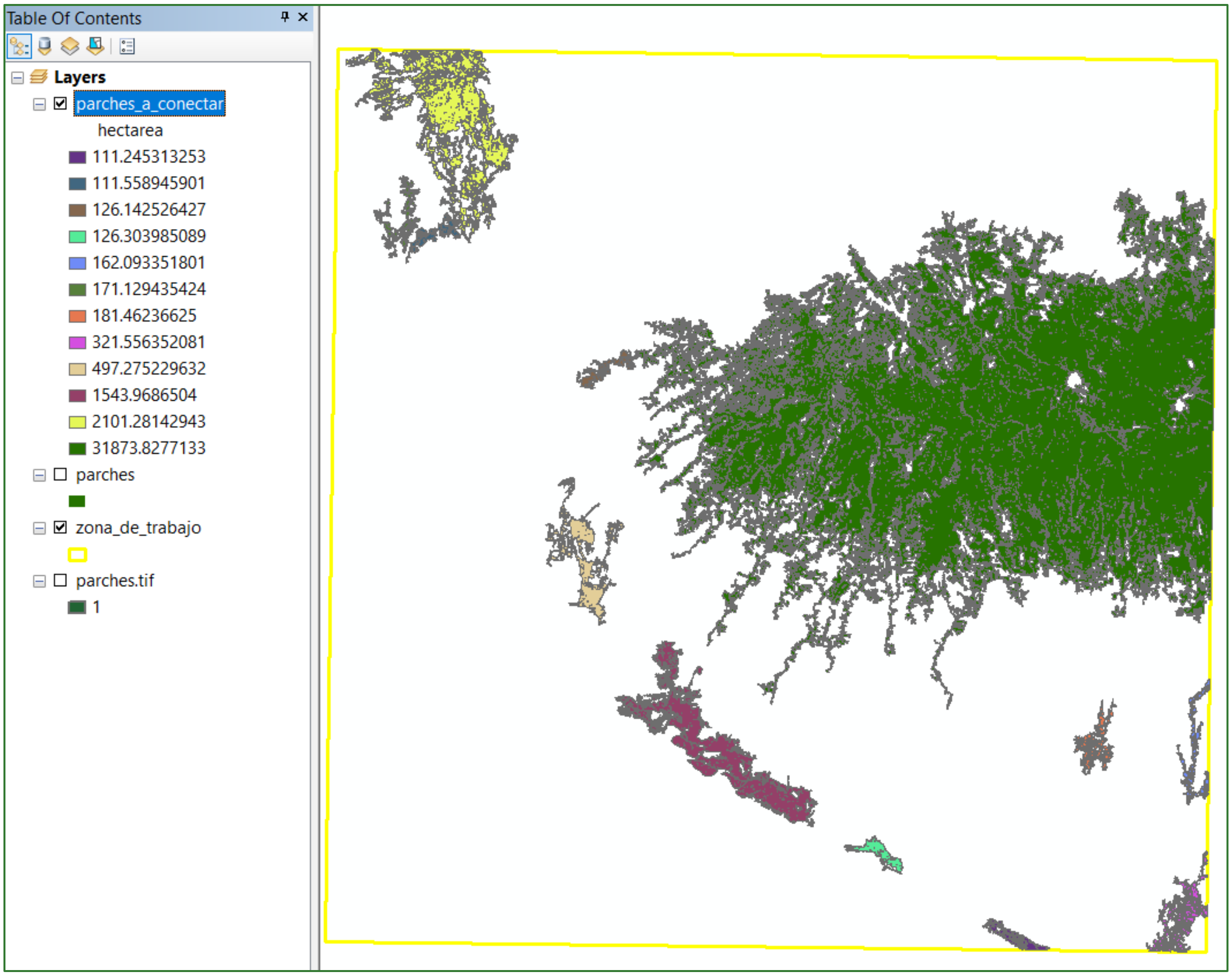
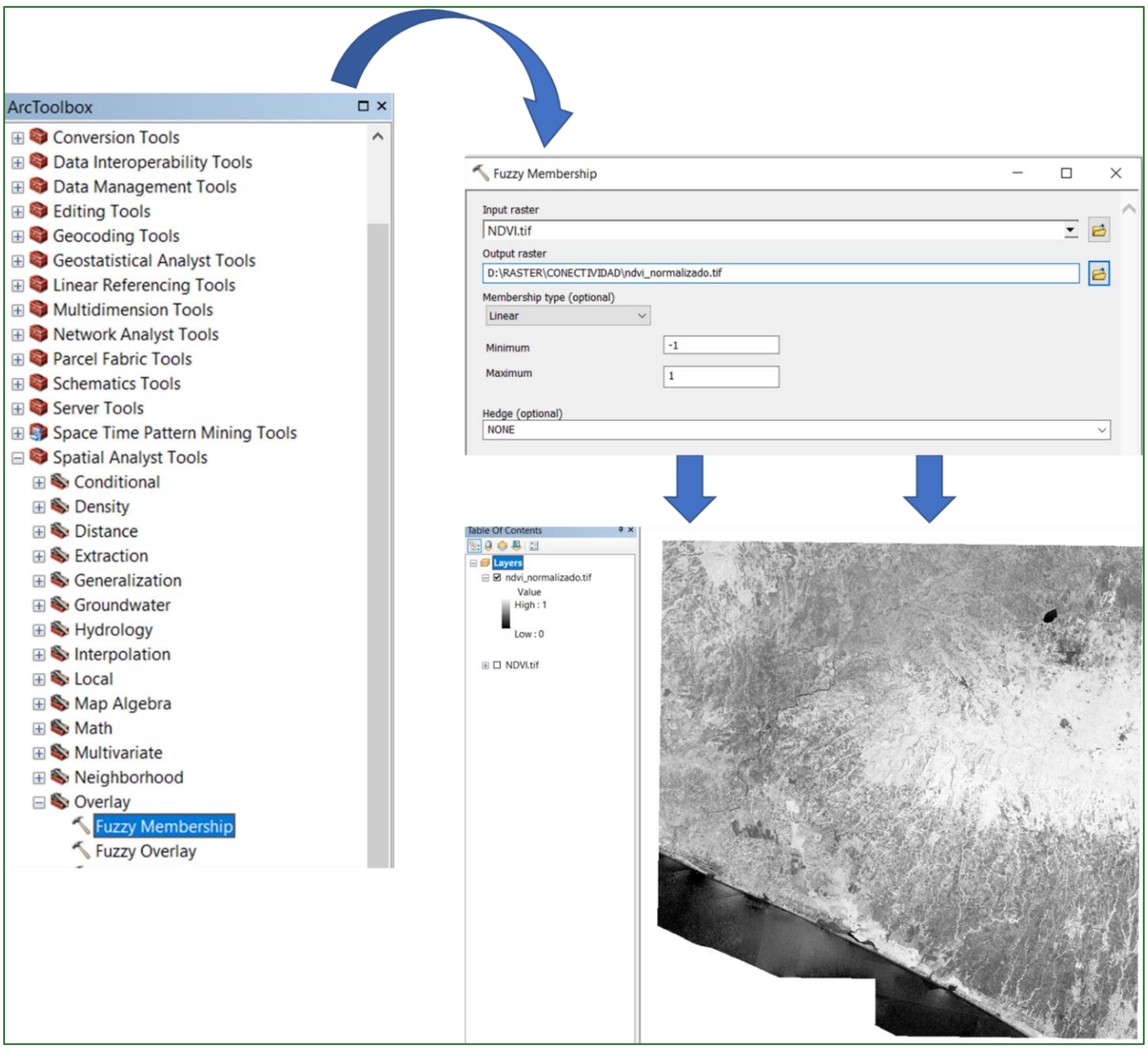


Table Of Contents
Layers
parches_a_conectar
hectarea
111.245313253
111.558945901
126.142526427
126.303985089
162.093351801
171.129435424
181.46236625
321.556352081
497.275229632
1543.9686504
2101.28142943
31873.8277133
parches
zona_de_trabajo
parches.tif
1

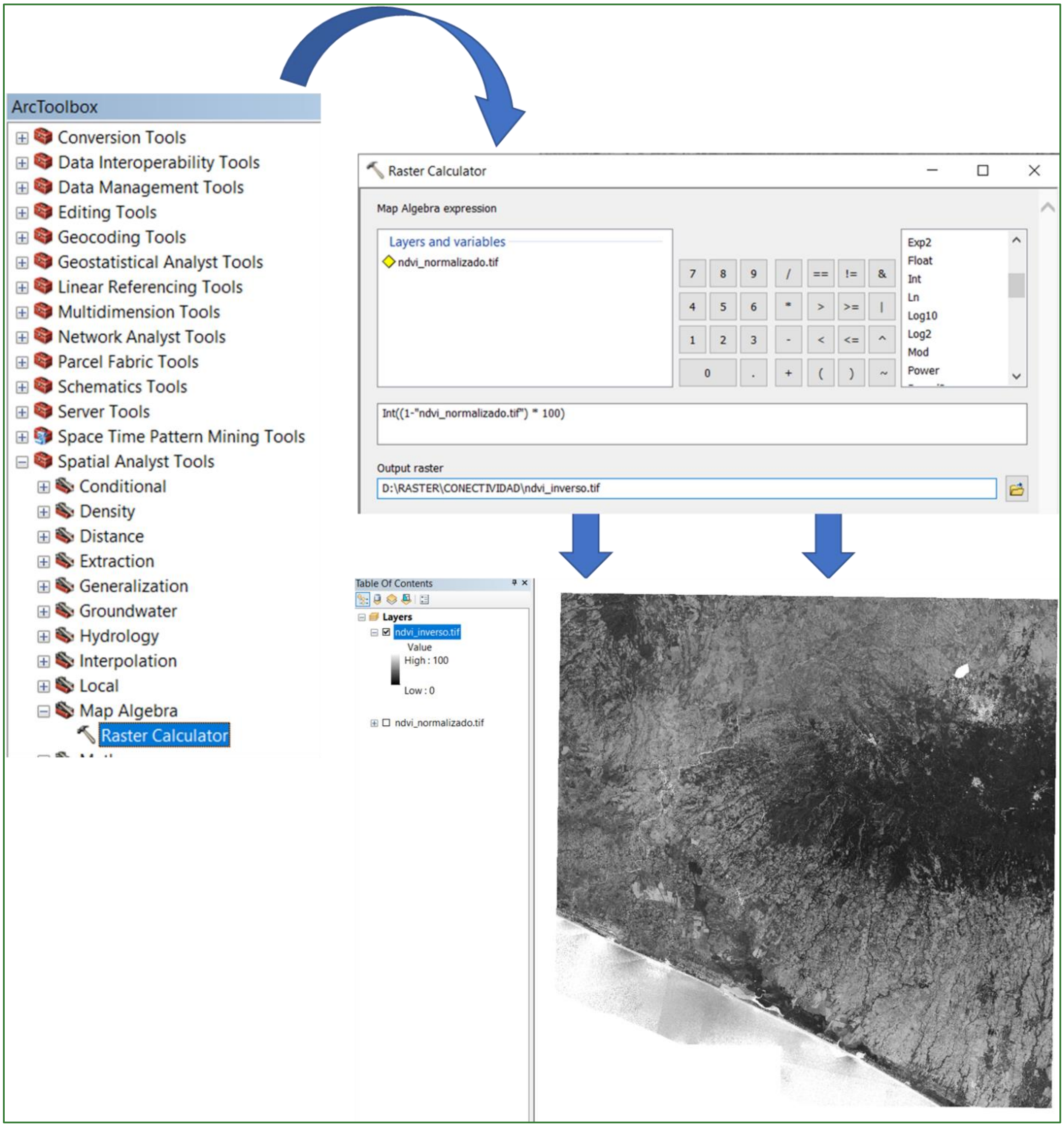
Step 2: Resistance map

Generate a landscape resistance map based on the NDVI. This map will indicate the ease of movement of a species through continuous or fragmented patches of the landscape. Less vegetation, in other words, a low NDVI, will indicate high resistance and high NDVI values will indicate low resistance. For this purpose, you will need to convert the NDVI raster to a scale of 1 to 100, where values of 1 indicate low resistance to movement (high NDVI), while those of 100 indicate high resistance (low NDVI).

a) First convert the NDVI to normalised values between 0-1 using the Fuzzy Membership tool, name the file **ndvi_normalizado.tif** and save it in the **RASTER/CONECTIVIDAD** folder. Use the **"Fuzzy Membership"** tool to carry out the process; this can be found in **ArcToolBox/Spatial Analyst Tools/Overlay/Fuzzy Membership.**

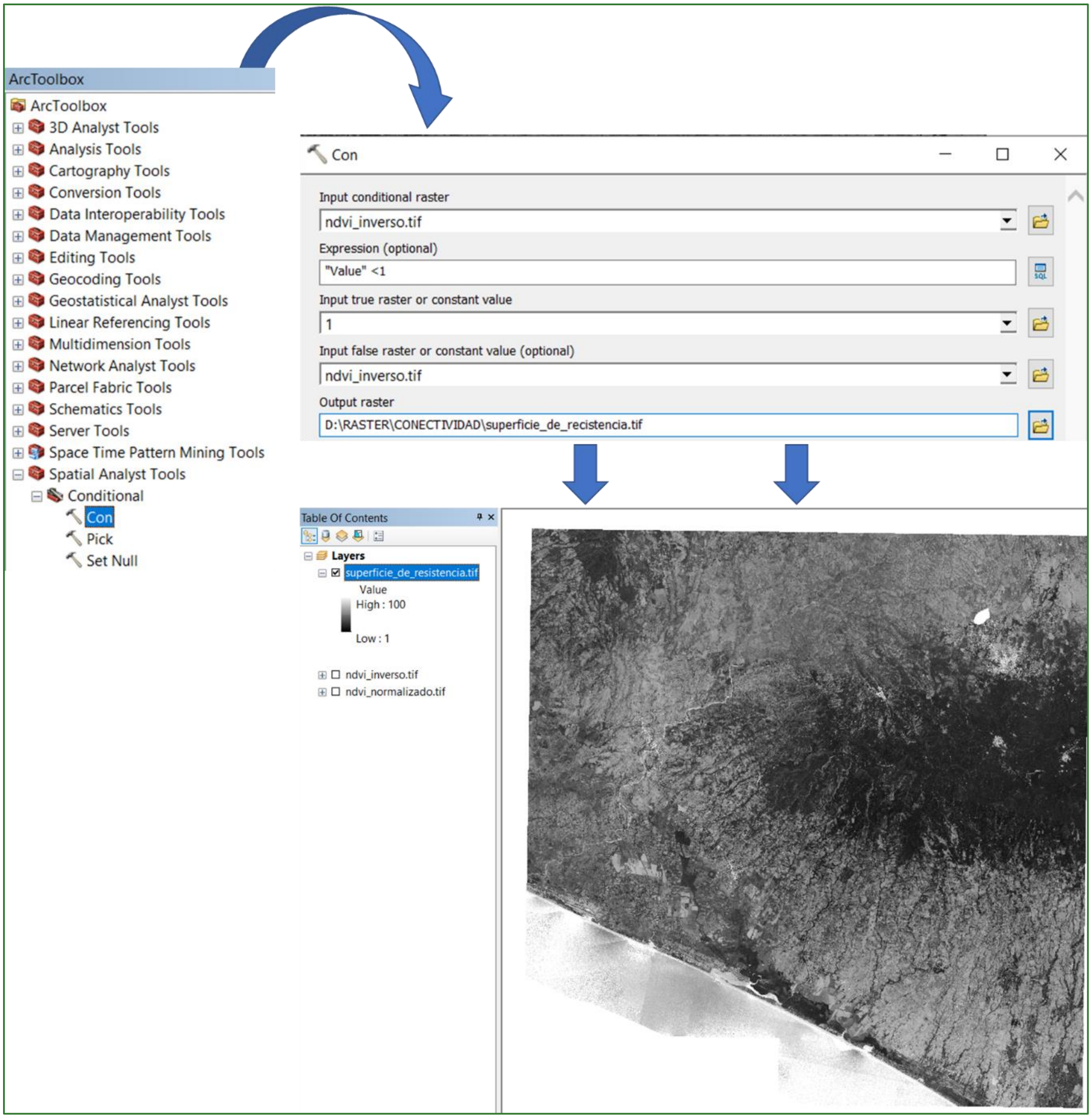


b) As the result from the above process consists of high values and what we want is the opposite, you will need to calculate the reverse NDVI using the following operation: Int((1 - "%ndvi_normalizado.tif%") * 100), name the file **ndvi_inverso.tif** and save in the **RASTER/CONECTIVIDAD** folder.

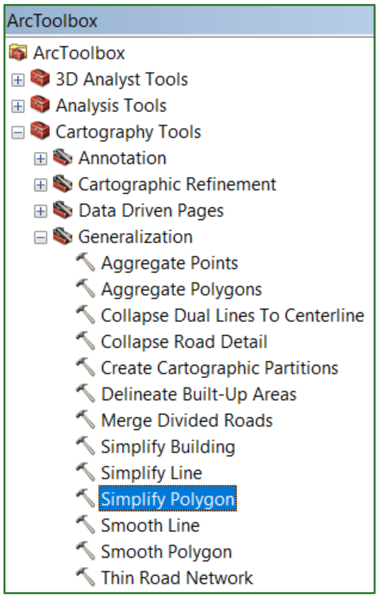


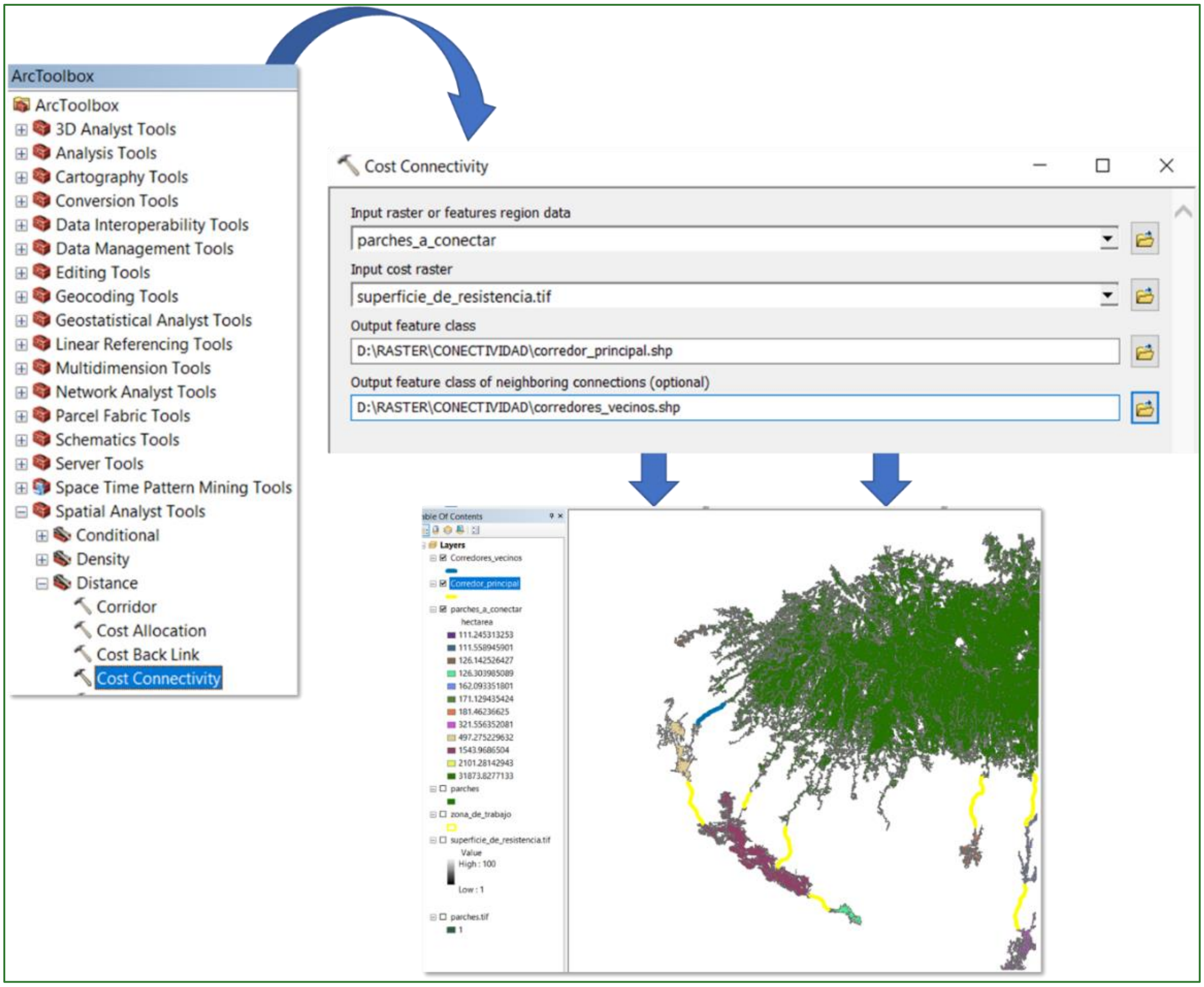
c) There can be no zero values when running the connectivity model. Accordingly, we must convert the zero values in the above raster to 1. Use the "Con" tool to do so, located in

ArcToolBox/Spatial Analyst Tools/Conditional/Con. Name the output file **superficie_de_resistencia.tif** and save it in the **RASTER/CONECTIVIDAD** folder.

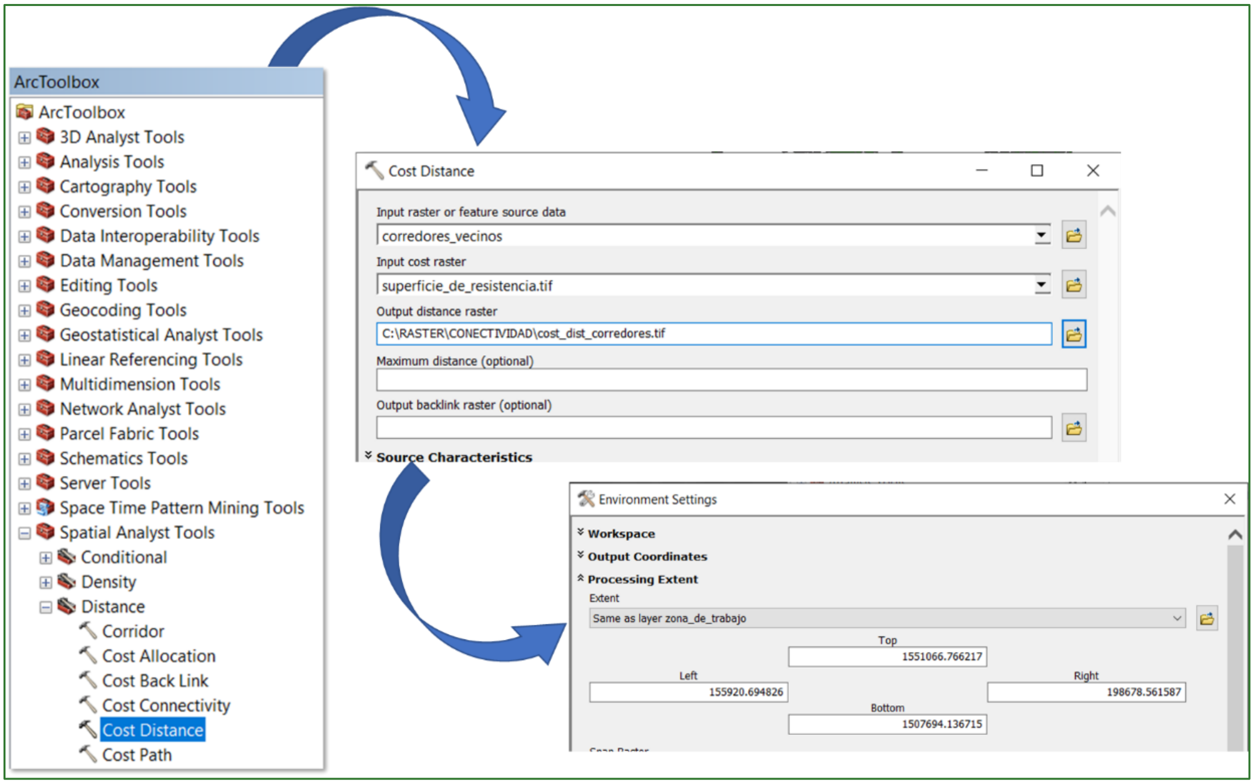


d) Now use the Cost-Connectivity algorithm to generate the optimum corridor shapefile and that of the neighbouring corridors (all optimum corridors). To this end, use the **"Cost Connectivity"** tool in **ArcToolBox/Spatial Analyst Tools/Distance/ Cost Connectivity** using the shapefile called **parches_para_conectar.shp**, generated in step 1, as the data input. Enter the **superficie_de_resistencia.tif** file in the Input cost raster box. Lastly, name both the output files as **corredor_principal.shp** and **corredores_vecinos.shp** and save both in the **RASTER/CONECTIVIDAD** folder (this process may take approximately 30 minutes to complete). If the process takes a lot longer, simplify the polygon shapefile using the **"Simplify Polygon"** tool located in **ArcToolBox/Cartography Tools/Generalization/Simplify Polygon.**

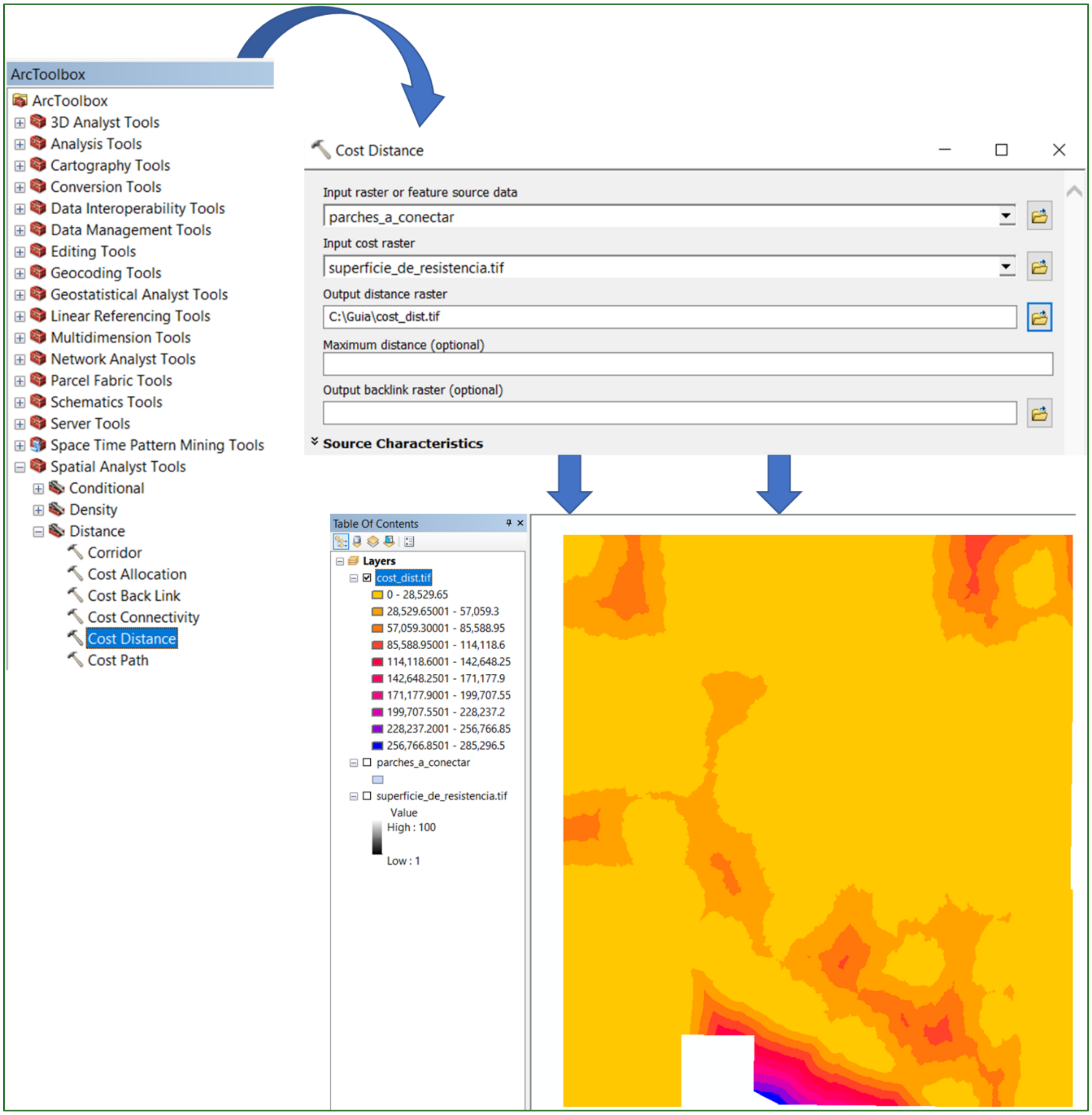




e) Now use the cost-distance algorithm to calculate the accumulated movement resistance value for movement to the neighbouring corridors. To do so, use the "Cost Distance" tool in **ArcToolBox/Spatial Analyst Tools/Distance/Cost Distance**, naming the output file **cost_dist_corredores.tif** and saving this in the **RASTER/CONECTIVIDAD** folder. Adjust the process to the project limit area in the environment box.

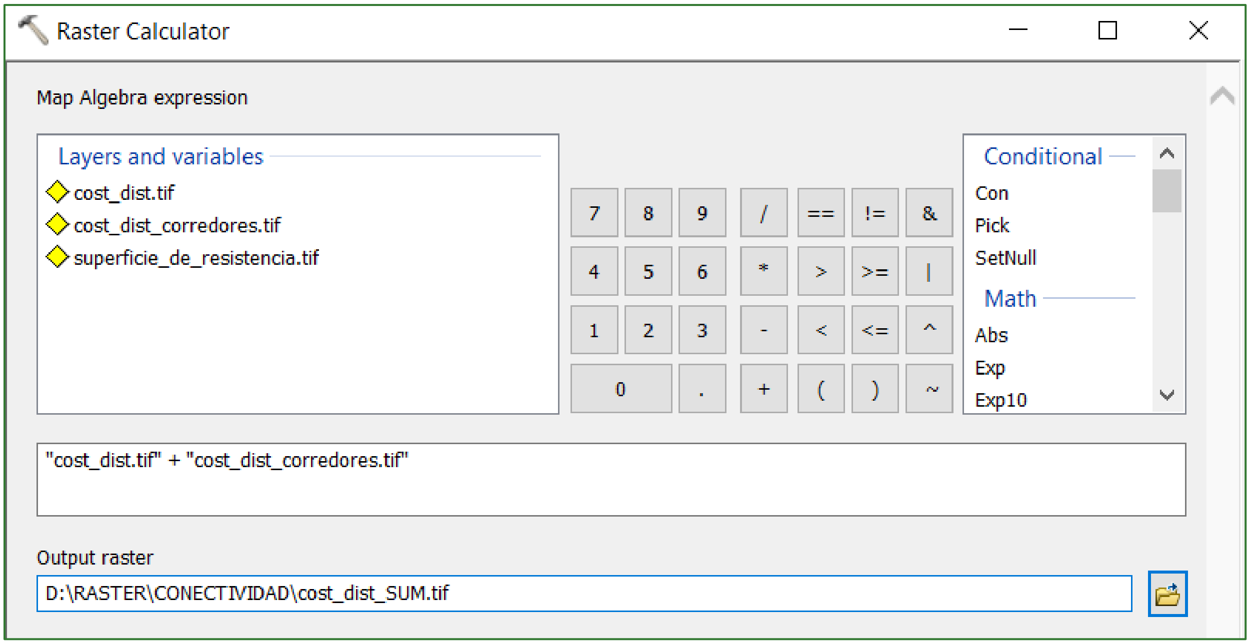


f) Use the cost-distance algorithm to calculate the accumulated movement resistance value for movement to the nearest target patches from each pixel. To do so, use the "Cost Distance" tool in **ArcToolBox/Spatial Analyst Tools/Distance/Cost Distance**, naming the output file **cost_dist.tif** and saving this in the **RASTER/CONECTIVIDAD** folder. Adjust the process to the project limit area in the environment box.

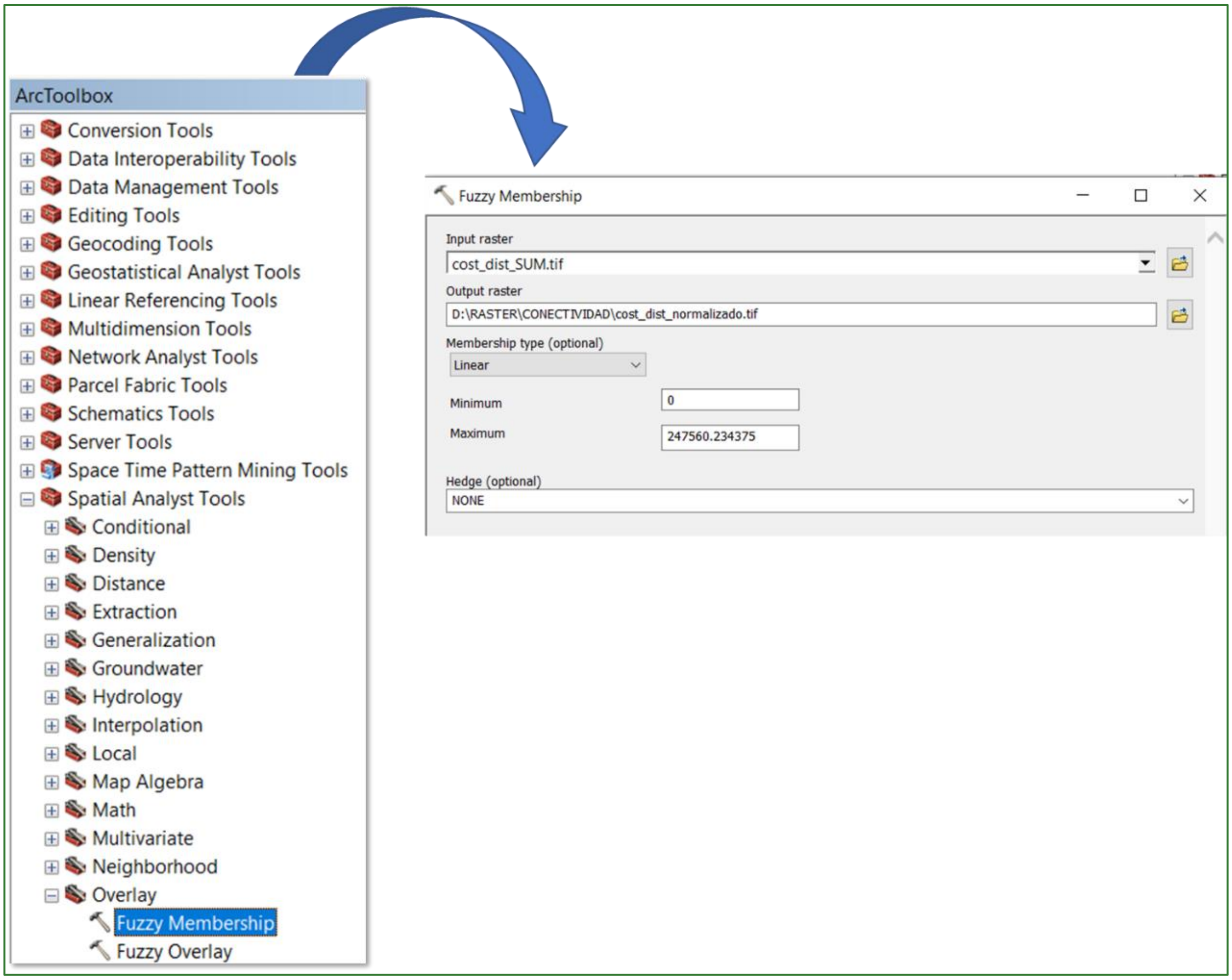


g) Calculate a standard metric for each pixel that will serve to evaluate the connectivity of fragmented landscapes, adding the movement costs to the target patches and towards the optimum corridors. In fragmented landscapes, the highest values must indicate greater connectivity potential. To this end you must:

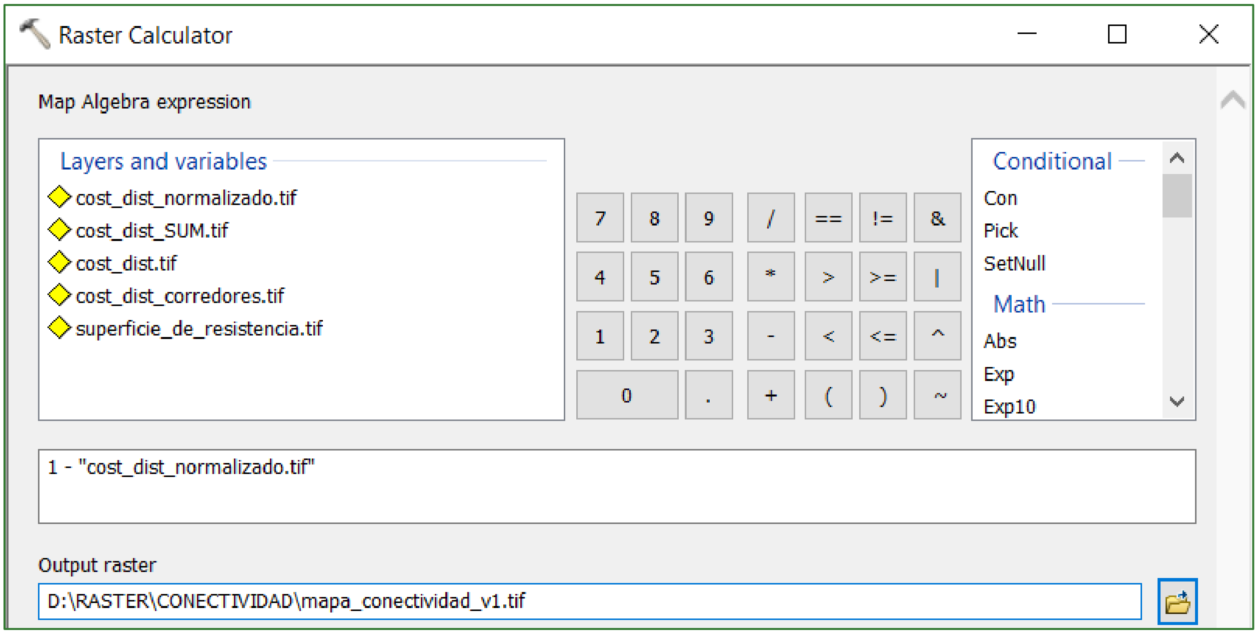
- Add the cost of movement towards the target patches and towards the optimum corridors. Use the Raster Calculator to do this, naming the file **cost_dist_SUM.tif** and saving it in the **RASTER/CONECTIVIDAD** folder.



- Standardise the values between 0 and 1. Use the **"Fuzzy Membership"** tool to run the process. This is located in **ArcToolBox/Spatial Analyst Tools/Overlay/Fuzzy Membership.** Enter the **cost_dist_SUM.tif** file in the Input raster box, name the output file **cost_dis_normalizado.tif** and save it in the **RASTER/CONECTIVIDAD** folder.



h) You now have to reverse the normalised raster values generated in the previous step so that higher values indicate greater connectivity potential in fragmented landscapes and lower values less connectivity potential. Use the Raster Calculator to do this, name the output file **mapa_conectividad_v1.tif** and save it in the **RASTER/CONECTIVIDAD** folder.



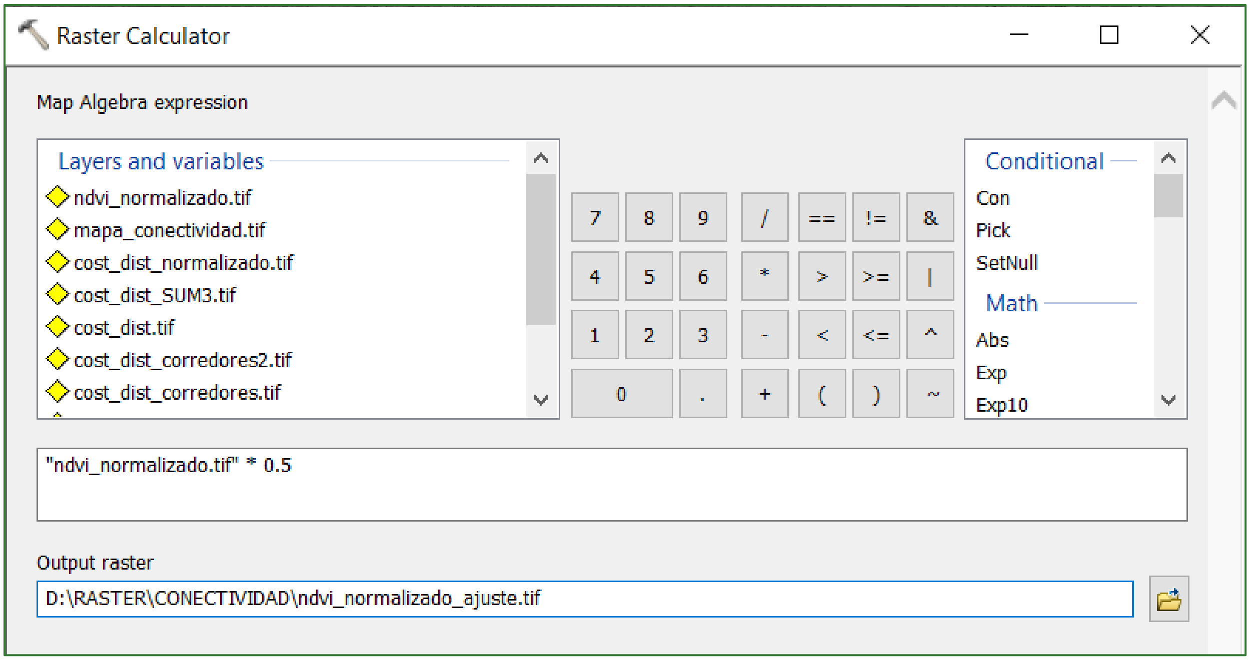
i) In the next step you will need to generate an adjusted connectivity map: the high Connectivity Index values indicate greater connectivity potential in fragmented landscapes and lower values less connectivity in fragmented landscapes. Their definition is related to "target patches" that you want to connect and the resulting corridors that are defined by the shortest route through which a species could move following the nearest forest patches.

For baseline and monitoring purposes in subsequent measurements, the same target patches must be considered. For cost-distance reasons, the forest areas that are further away from target patches are classified with lower potential connectivity values than those that are nearby. This makes it difficult to apply this metric to analyse the state of complete landscape connectivity beyond the context of the target patches.

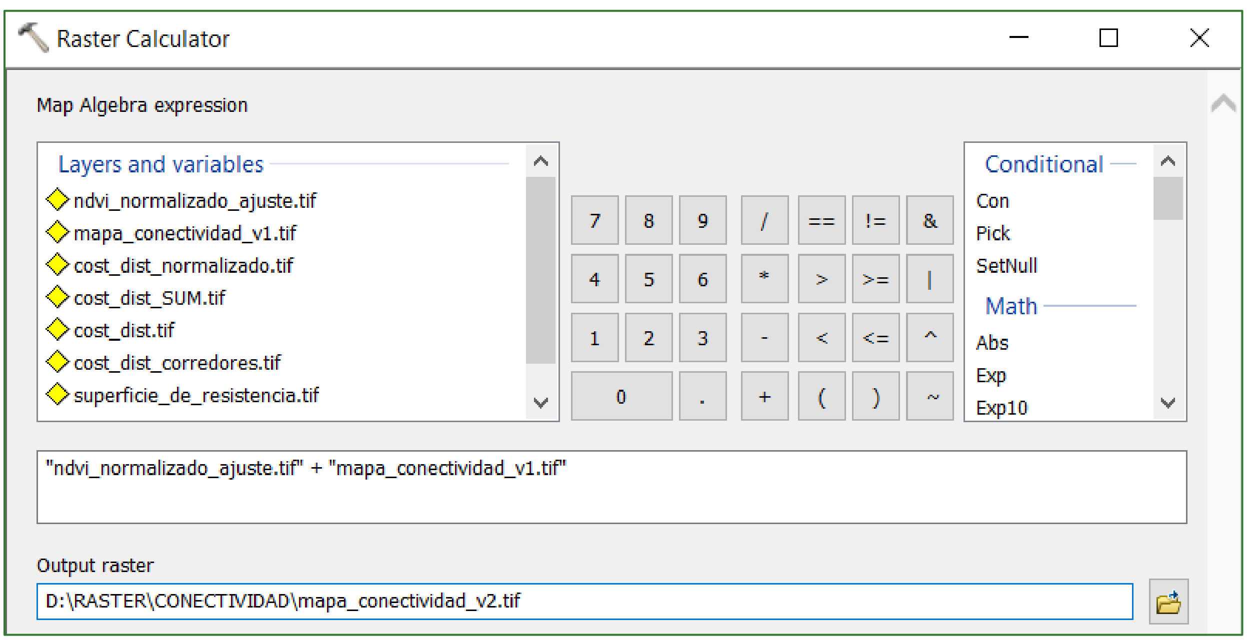
For this reason, it is recommended that for landscape level calculation purposes, you should adjust the connectivity map by multiplying it by the normalised NDVI (between 0 and 1) and giving it a weight of 0.5. I.e.:

Adjusted Connectivity Index = Connectivity map + (Normalised NDVI * 0.5)

Use the Raster Calculator for this process, multiplying the **ndvi_normalizado.tif** raster by 0.5 and naming the output file **ndvi_normalizado_ajuste.tif**. Save the file in the **RASTER/CONECTIVIDAD** folder.

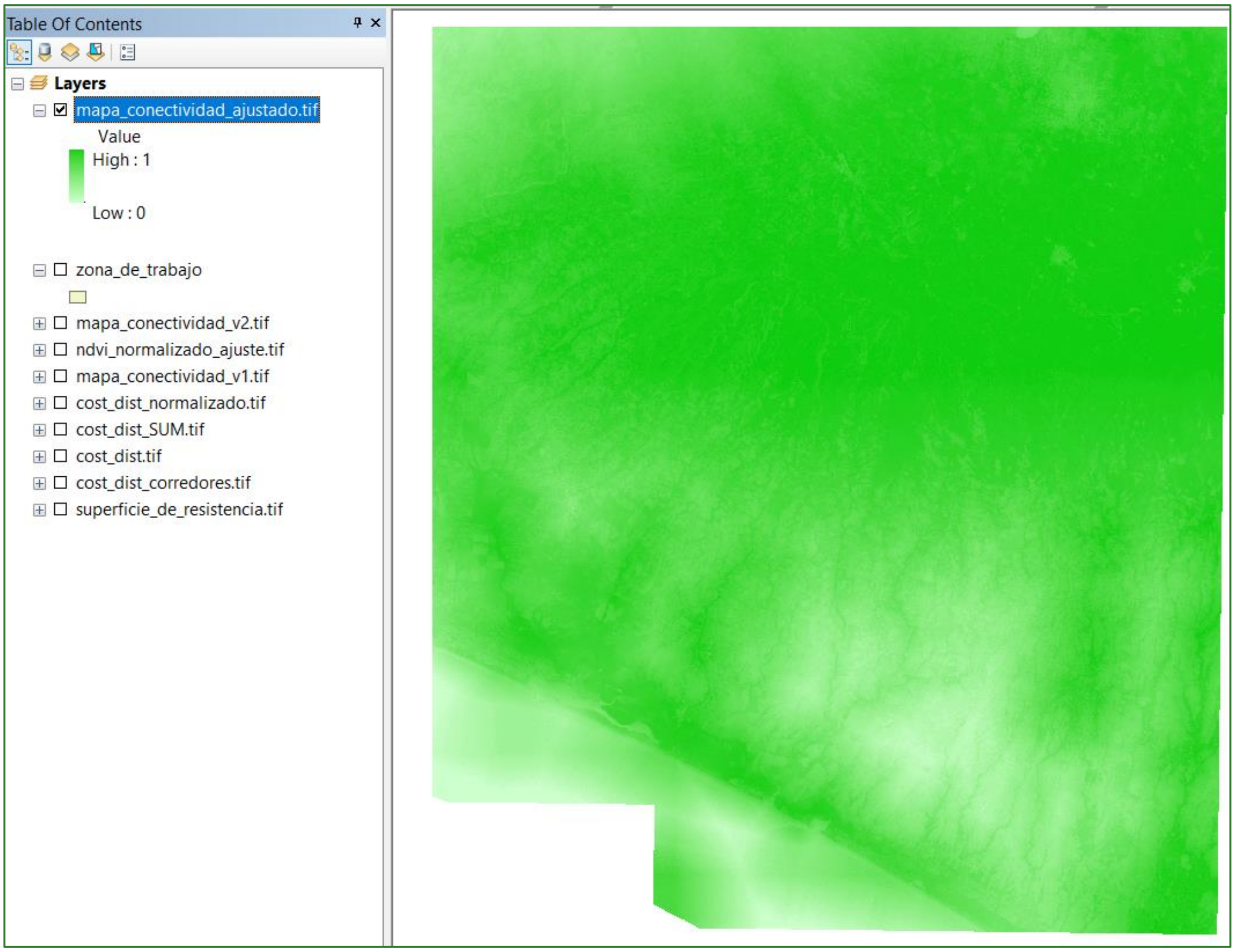


j) Now proceed to generate the Adjusted Connectivity Index using the **"Raster Calculator" tool**, adding the **mapa_conectividad_v1.tif** raster to the **ndvi_normalizado_ajuste.tif** raster, naming the output file **mapa_conectividad_v2.tif** and saving it in the **RASTER/CONECTIVIDAD** folder.



k) As a final step, you will need to standardise the **mapa_conectividad_v2.tif** file values between 0 and 1 generated in the previous process using the **"Fuzzy Membership"** tool located in **ArcToolBox/Spatial Analyst Tools/Overlay/Fuzzy Membership.** Enter the **mapa_conectividad_v2.tif** file in the Input raster box, name the output file **mapa_conectividad_ajustado.tif** and save it in the **RASTER/CONECTIVIDAD** folder.

The resulting connectivity map should look as follows:



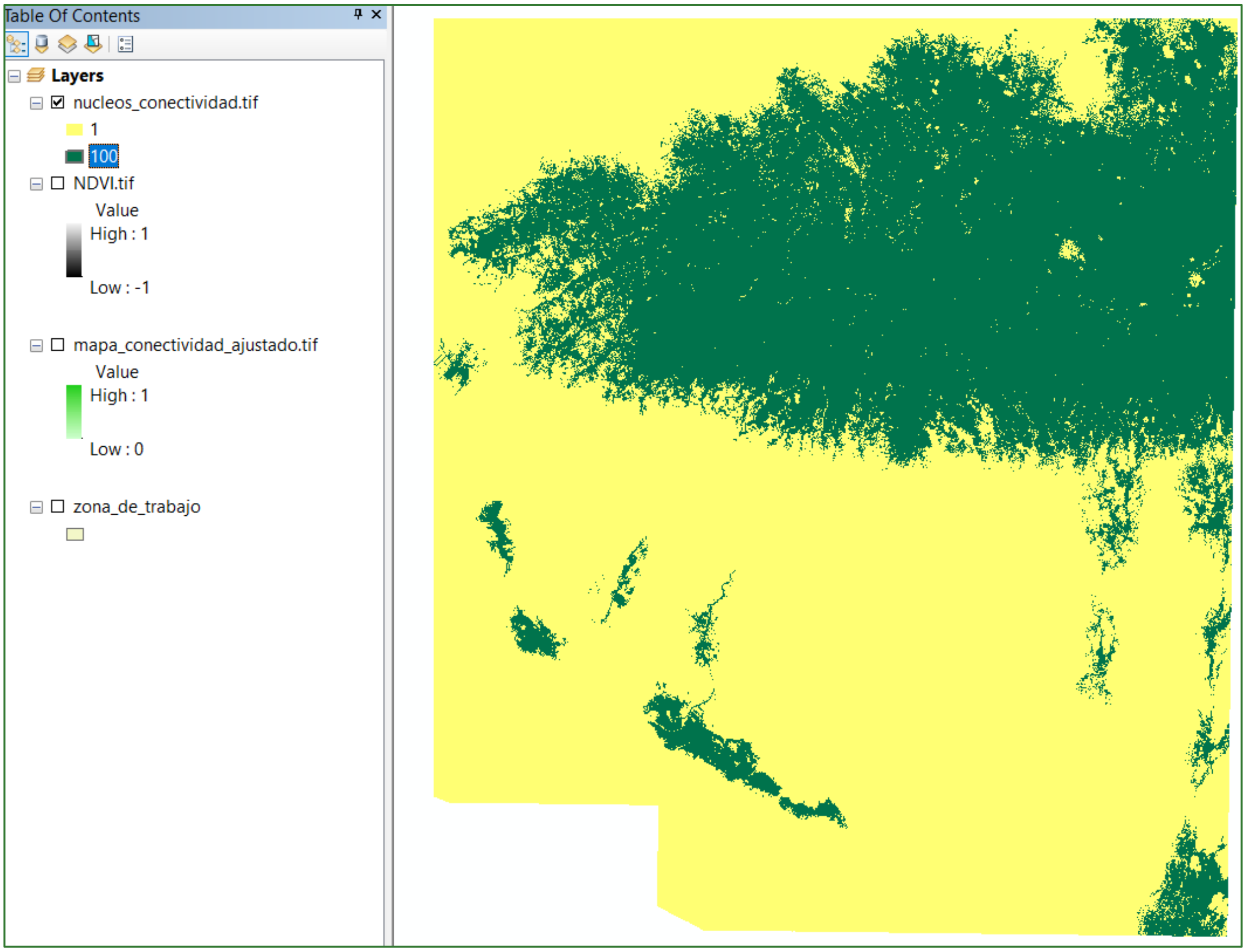
Step 3: Connectivity index

In this third step you will obtain a metric that measures the degree of physical connectivity between the fragments of each type of vegetation cover, as well as an indirect spatial connectivity indicator. To this end, the Connectivity Index incorporated into the FRAGSTATS5 software, which is defined by the number of functional links between fragments of the same type, where each fragment may or may not be connected, based on a distance criterion (MGarigal et al., 2002 Kindlmann and Burel, 2008), will be calculated. This calculation in FRAGSTATS corresponds to the CONNECT (class) metric, which returns percentage values from 0 to 100. The value equals 0 when the class consists of a single isolated fragment or none of the fragments are connected and equals 100 when all the class fragments are connected.

Follow the instructions given below to carry out this process:

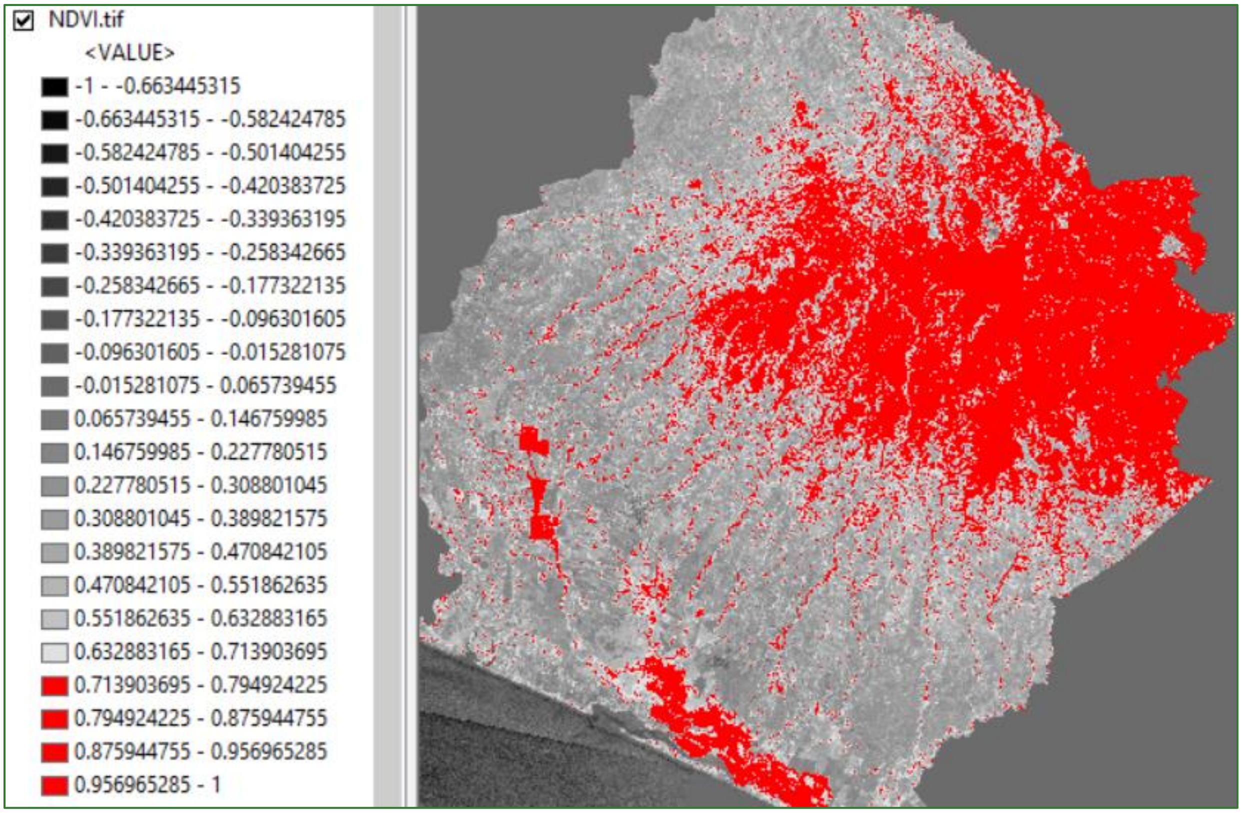
- Create a new folder in the **RASTER** folder and name it **Ajuste_Final_Conectividad.** All the files generated in this exercise must be saved in this folder.
- Add the **indice_conectividad_ajustado.tif y NDVI.tif** rasters to ArcMap.
- Use the conditional tool **"Con"** to assign a value of 100 to >0.9 pixels in the **indice_conectividad_ajustado.tif** raster and a value of 1 to <0.9 ones. Name the file **nucleos_conectividad.tif** and save it in the **RASTER/AjusteFinal_Conectividad** folder.

[5] FRAGSTATS: https://www.umass.edu/landeco/research/fragstats/fragstats.html

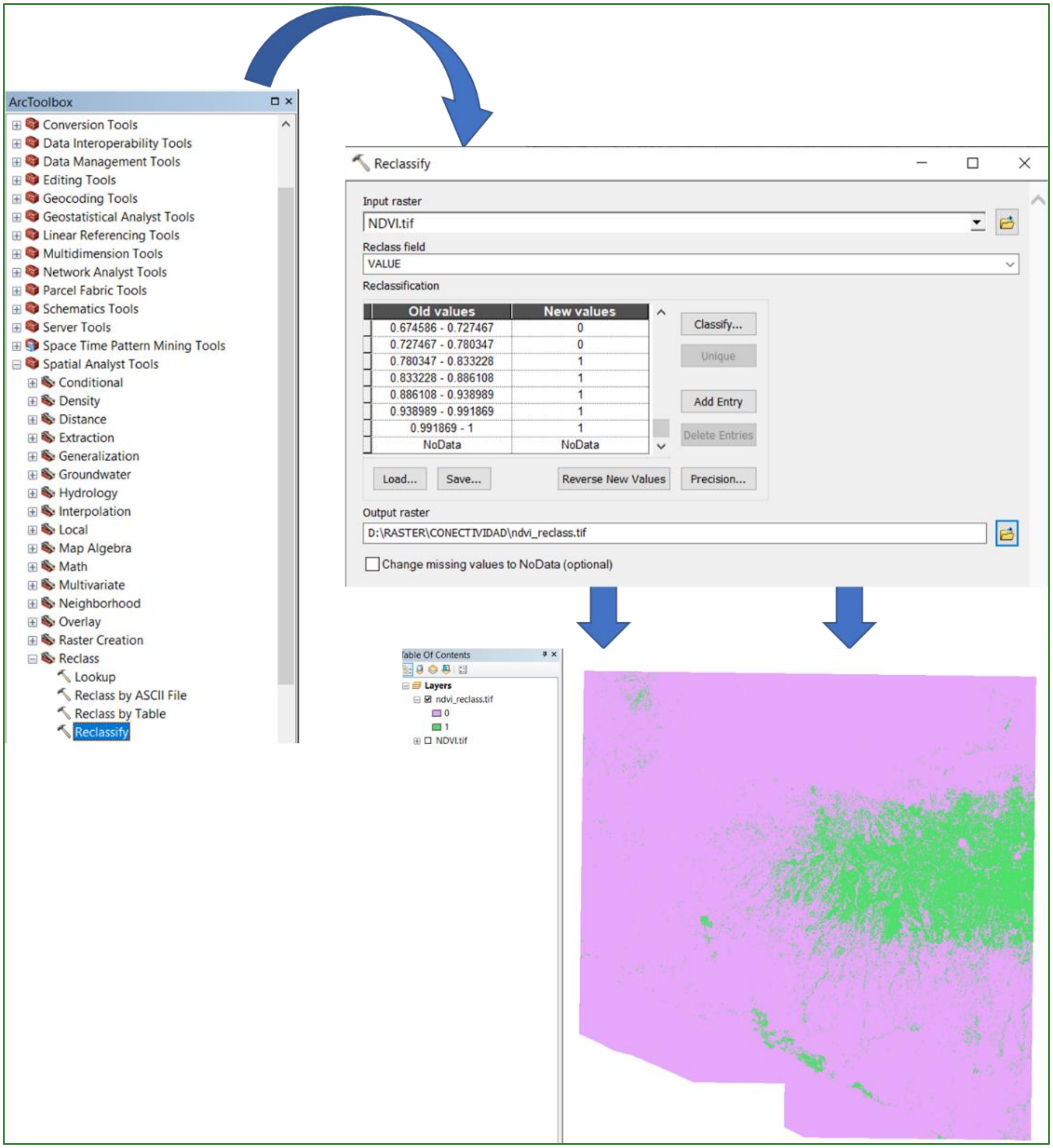


Use the NDVI to generate a raster for fragmentation levels following these steps:

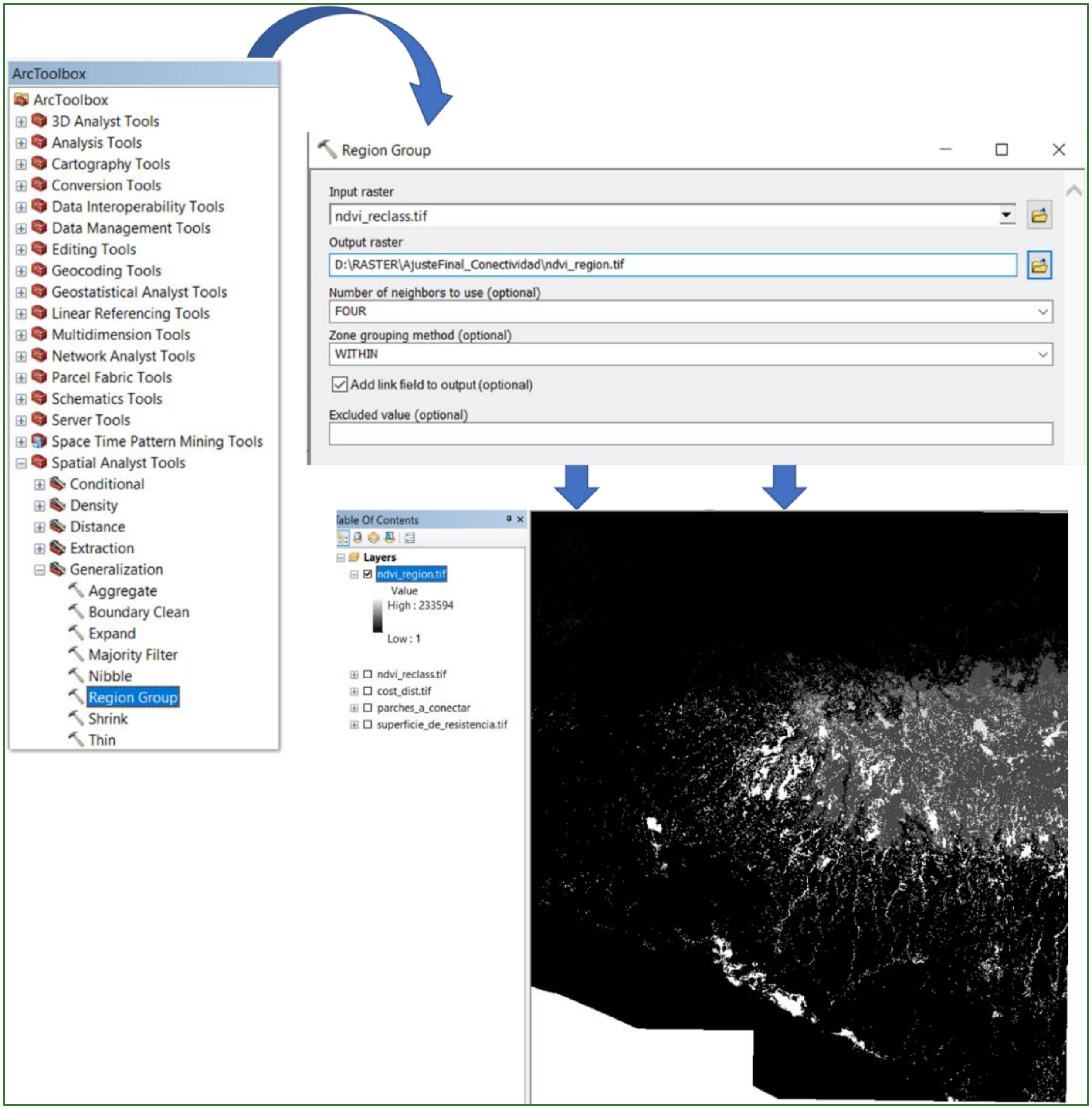
- Visually reclassify the NDVI using the 1/4 StdDev option with the standard deviation method and observe the last class ranges to define the threshold where the biggest continuous vegetation masses appear.



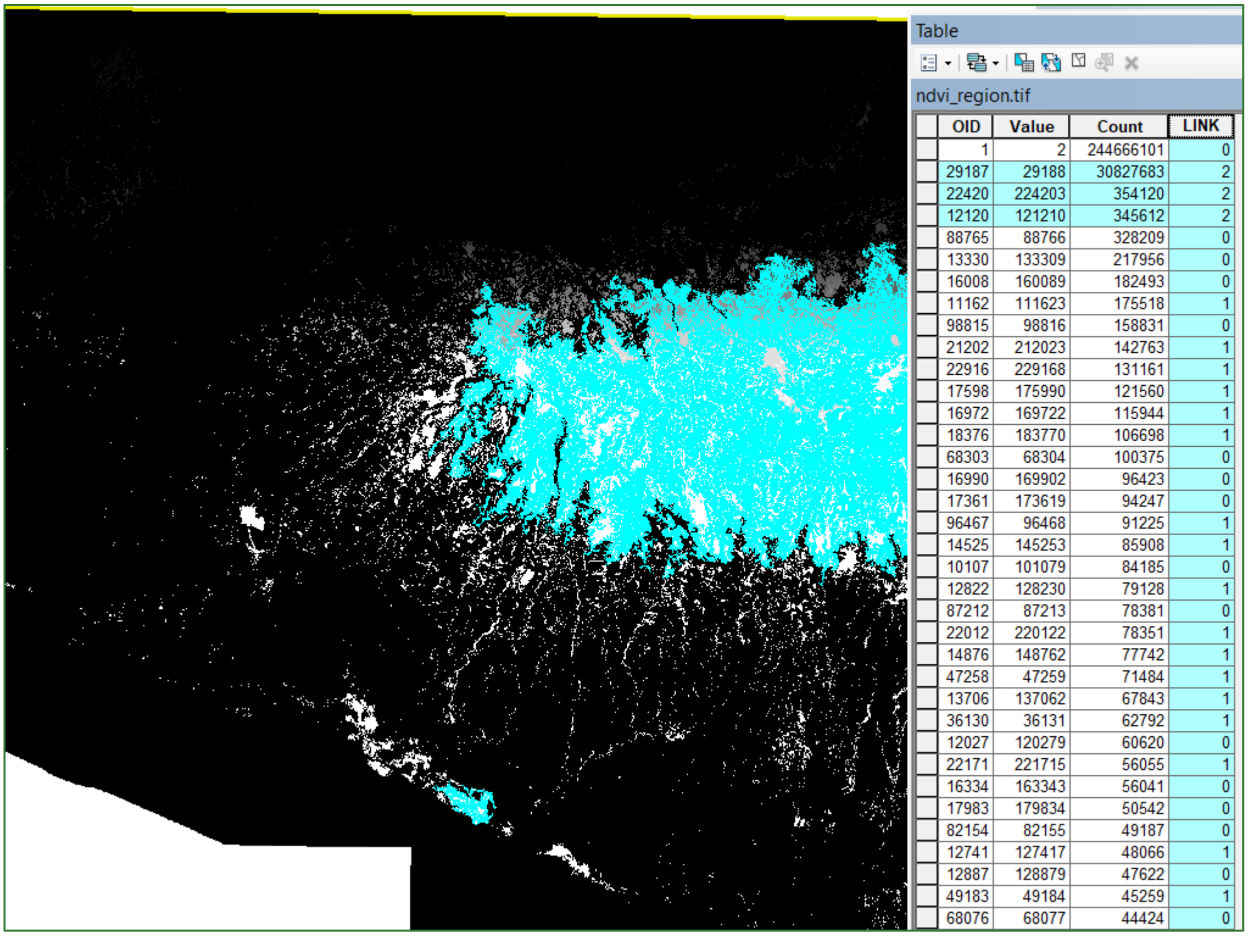
- Reclassify the NDVI by assigning "0" to the values below the defined threshold and 1 to those above the defined threshold. Assign the name **ndvi_reclass.tif** to the output file and save it in the **RASTER/AjusteFinal_Conectividad** folder.



- Apply the **"Region Group"** tool located in the **ArcToolBox/Spatial Analyst/Generalization/Region Group** folder to the resulting **ndvi_reclass.tif** raster. Assign the name **ndvi_region.tif** to the output file and save it in the **RASTER/AjusteFinal_Conectividad** folder.

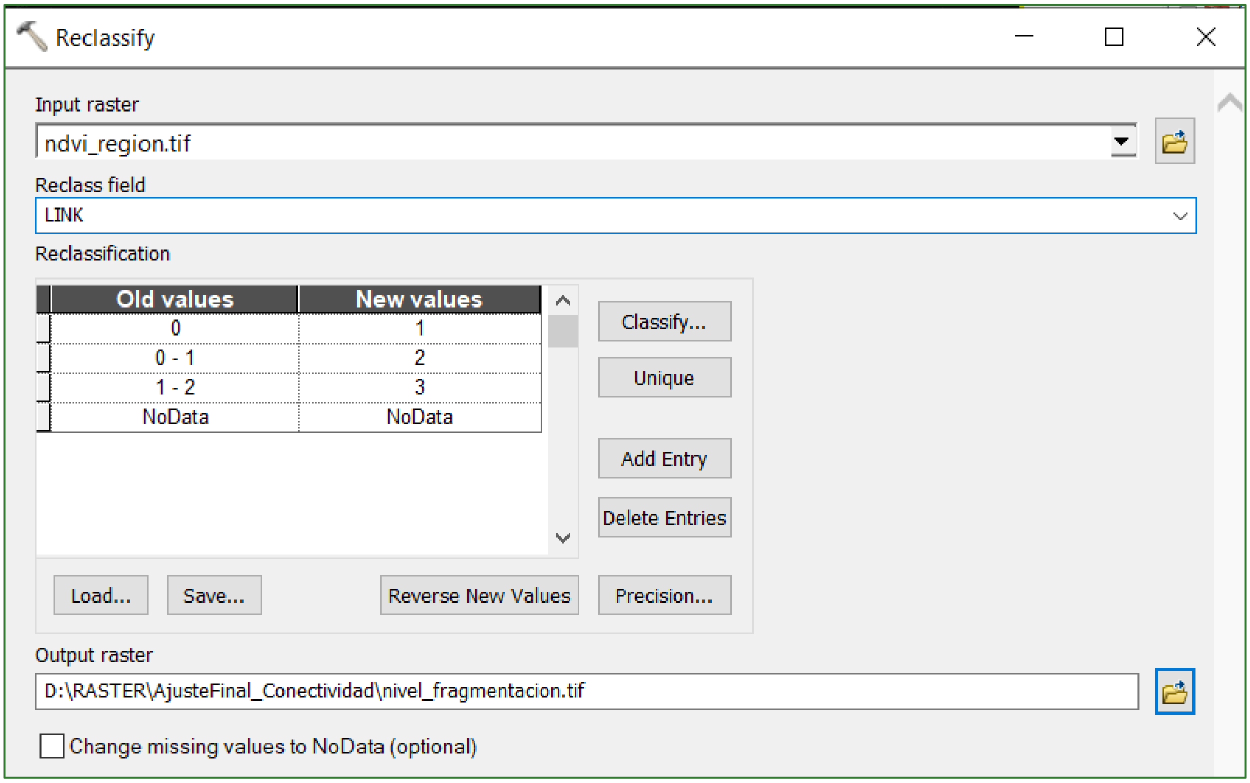


- Open the attributes table for the **ndvi_region.tif** rasters and proceed as follows:
    i. Place the Count field values in descending order.
    ii. Select the value 1 rows in the LINK field. The number of rows to be selected will be what you consider to correspond to the large continuous forest patches. Assign the value of 2 to the selected records in the Count field. Lastly, undo the selection.

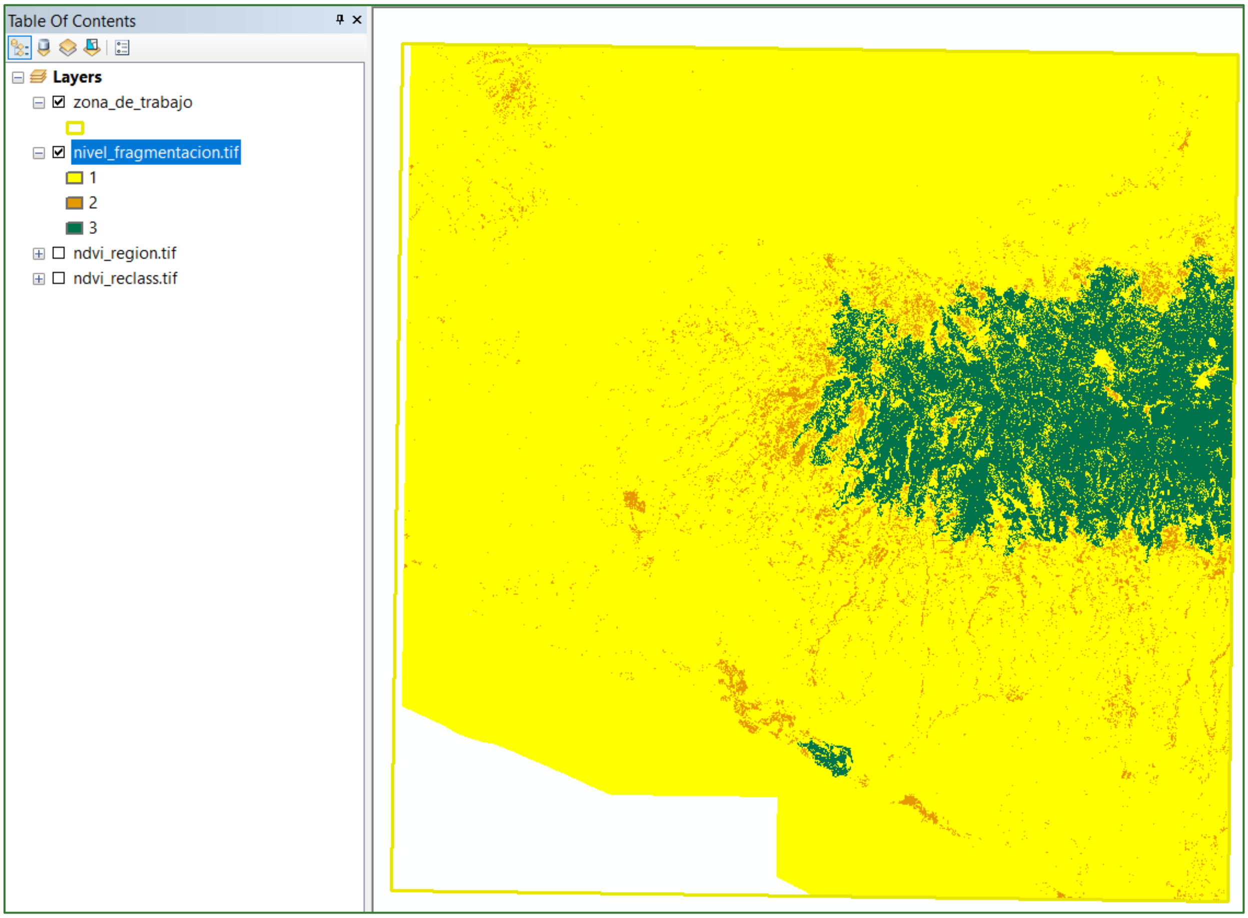


OID	Value	Count	LINK
1	2	244666101	0
29187	29188	30827683	2
22420	224203	354120	2
12120	121210	345612	2
88765	88766	328209	0
13330	133309	217956	0
16008	160089	182493	0
11162	111623	175518	1
98815	98816	158831	0
21202	212023	142763	1
22916	229168	131161	1
17598	175990	121560	1
16972	169722	115944	1
18376	183770	106698	1
68303	68304	100375	0
16990	169902	96423	0
17361	173619	94247	0
96467	96468	91225	1
14525	145253	85908	1
10107	101079	84185	0
12822	128230	79128	1
87212	87213	78381	0
22012	220122	78351	1
14876	148762	77742	1
47258	47259	71484	1
13706	137062	67843	1
36130	36131	62792	1
12027	120279	60620	0
22171	221715	56055	1
16334	163343	56041	0
17983	179834	50542	0
82154	82155	49187	0
12741	127417	48066	1
12887	128879	47622	0
49183	49184	45259	1
68076	68077	44424	0

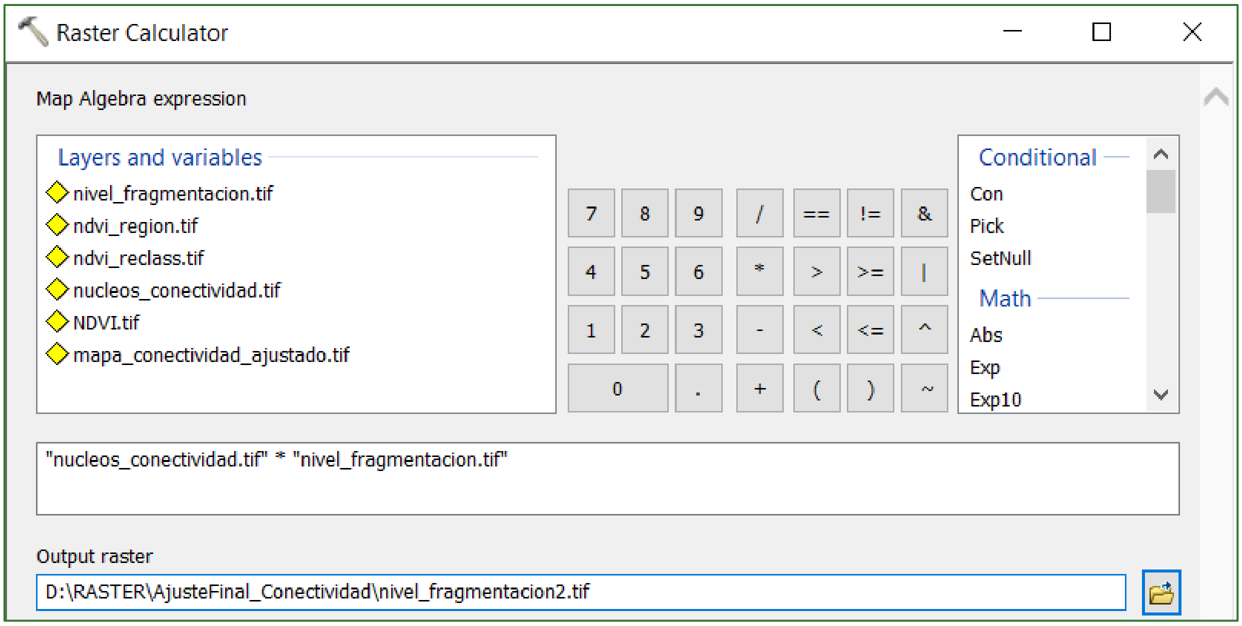
- Reclassify **ndvi_region.tif**, assigning the values indicated below. Assign the name **nivel_fragmentación.tif** to the output file and save it in the **RASTER/AjusteFinal_Conectividad** folder.


Reclassify
Input raster
ndvi_region.tif
Reclass field
LINK
Reclassification
Old values
New values
0
1
0 - 1
2
1 - 2
3
NoData
NoData
Classify...
Unique
Add Entry
Delete Entries
Load...
Save...
Reverse New Values
Precision...
Output raster
D:\RASTER\AjusteFinal_Conectividad\nivel_fragmentacion.tif
Change missing values to NoData (optional)

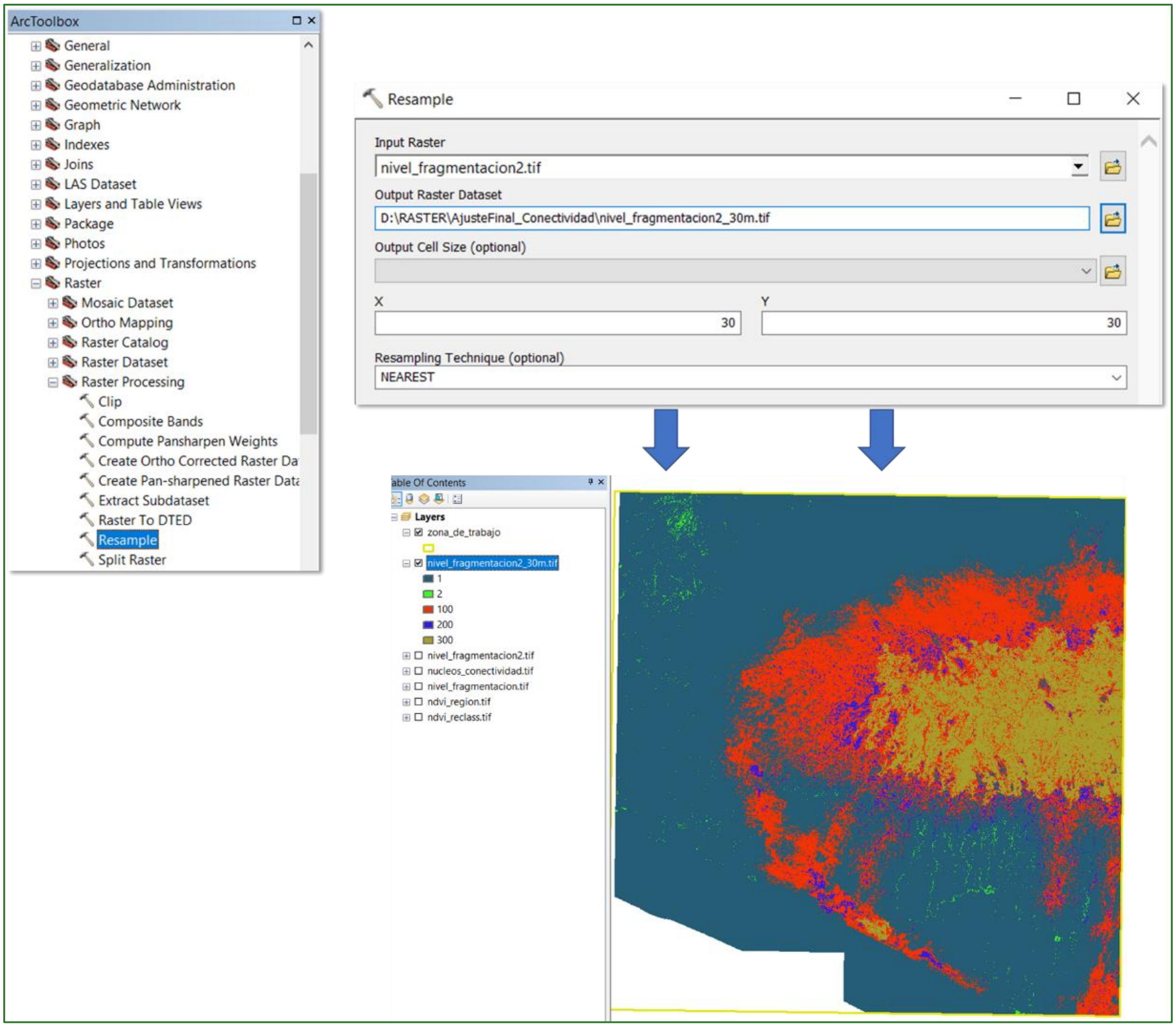
The result of this step is shown below:



Use the Raster Calculator to multiply **nucleos_conectividad.tif** by **nivel_fragmentación.tif**. Assign the name **nivel_fragmentación2.tif** to the output file and save it in the **RASTER/AjusteFinal_Conectividad** folder.



- Lastly, resample **nivel_fragmentación2.tif** by taking the raster to 30 m. Use the **"resample"** tool to do so; this is located in **ArcToolBox/Data Management Tools/Raster/Raster Processing/Resample.** Assign the name **nivel_fragmentación2_30m.tif** to the output file and save it in the **RASTER/AjusteFinal_Conectividad** folder.



Step 4: Fragmentation index

- Download and install the Fragstats software:

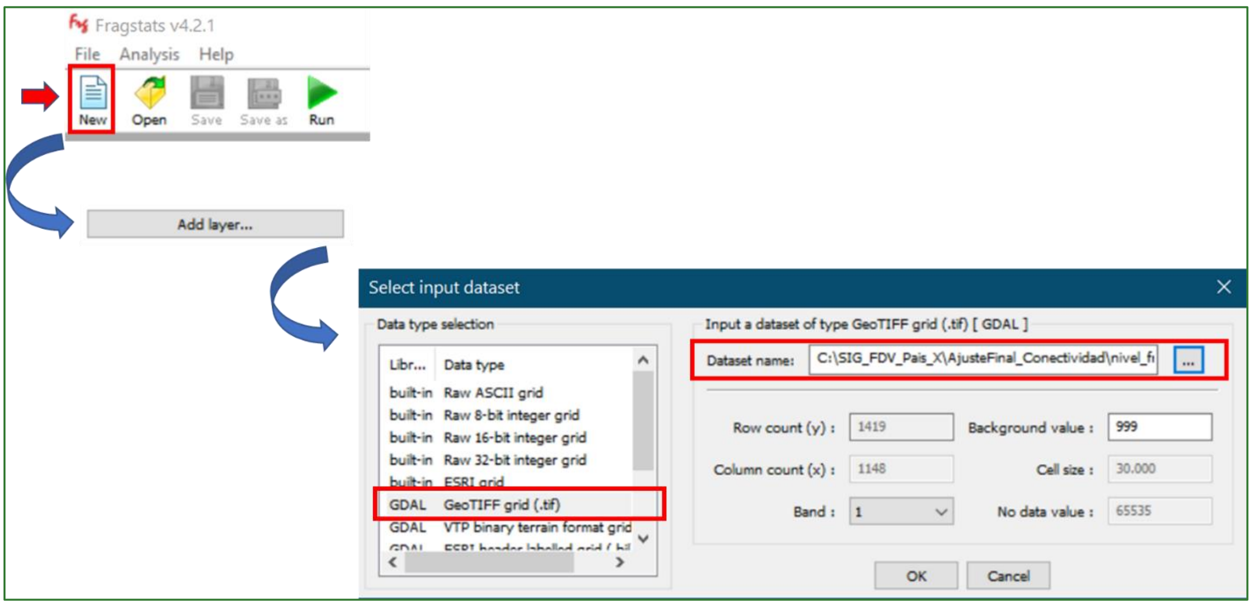
https://www.umass.edu/landeco/research/fragstats/downloads/fragstats_downloads.html#FRAGSTATS

FRAGSTATS software (version 4.2)

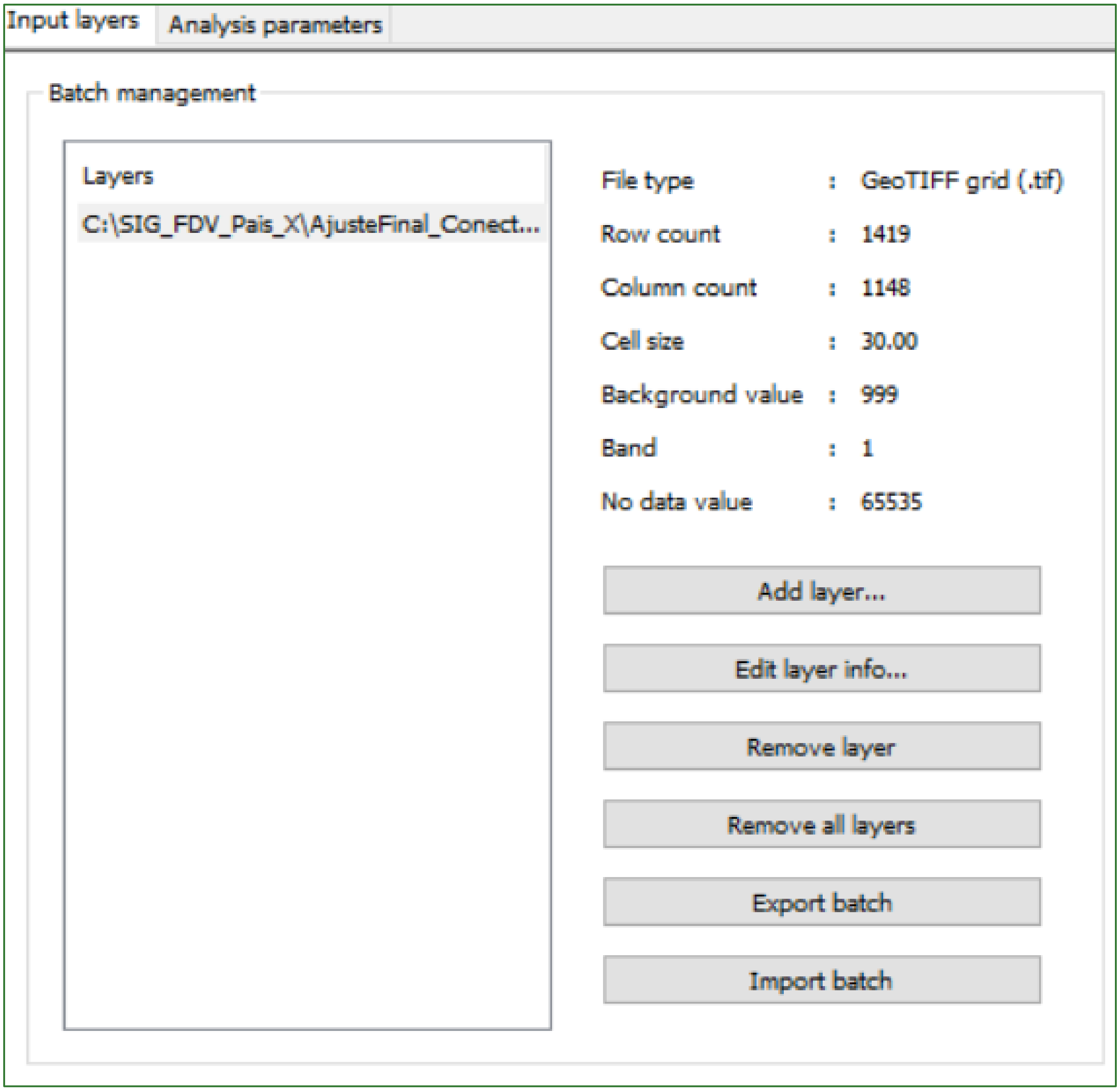
File: fragstats4.2.zip

- Open Fragstats

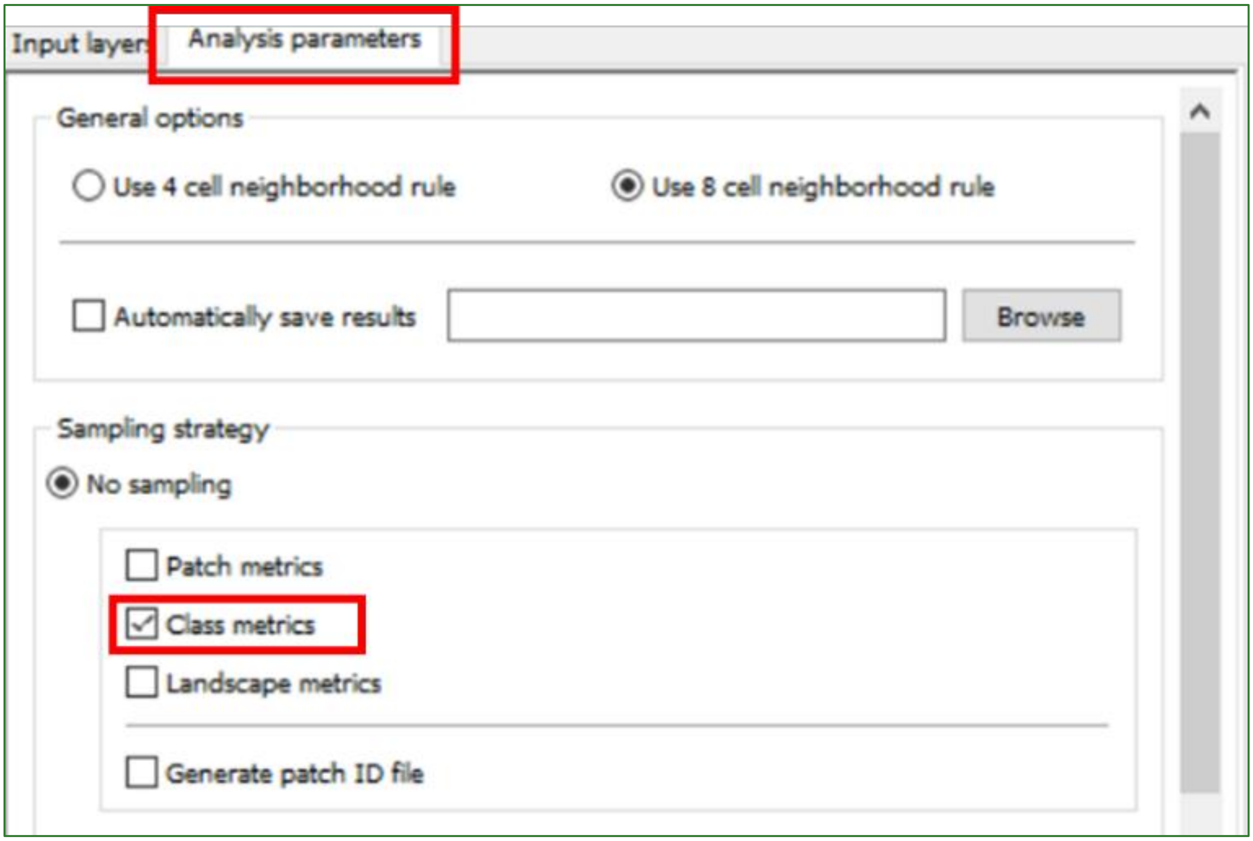
- Click on New and then on Add layer. In the window that comes up: select GDAL GeoTIFF in Data type and add the file nivel_fragmentación2_30m.tif in Input dataset.



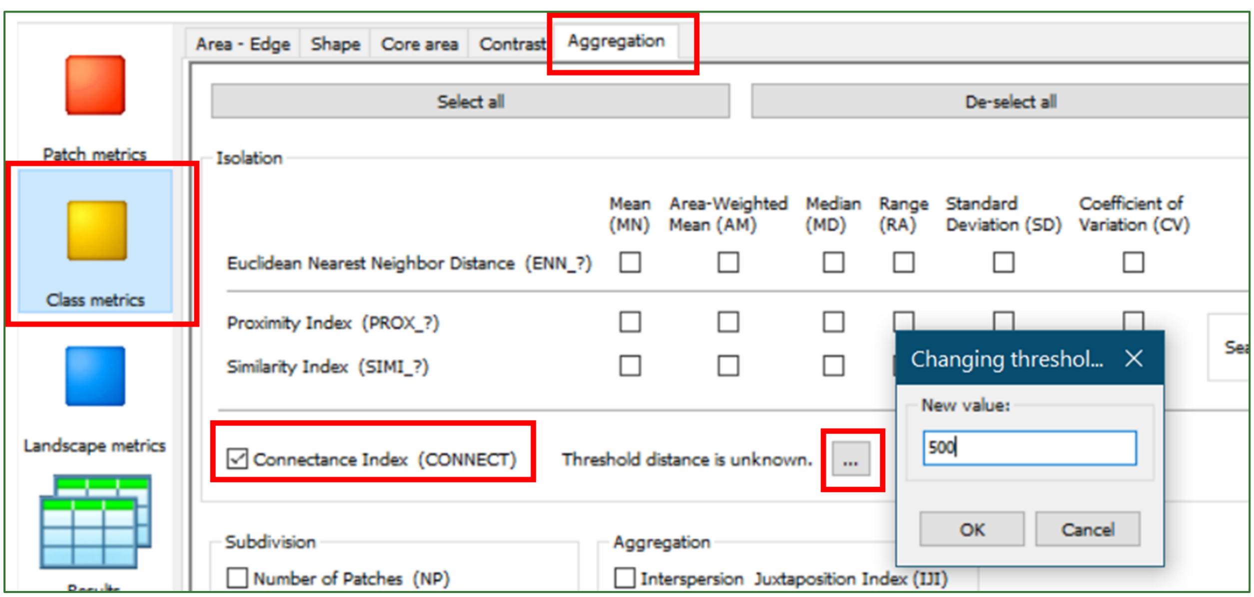
- Select the layer **nivel_fragmentación2_30m.tif** and the values that describe this will appear on screen:



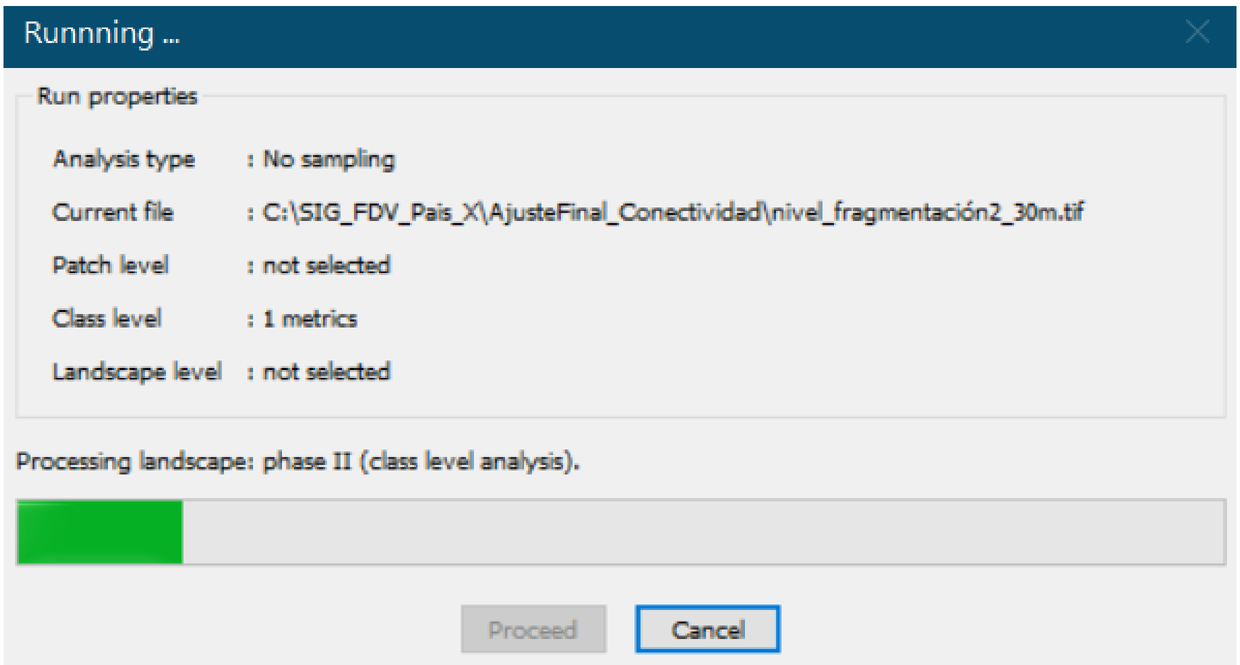
- Next, go to the **Analysis parameters** tab and select the **Class metrics** option.



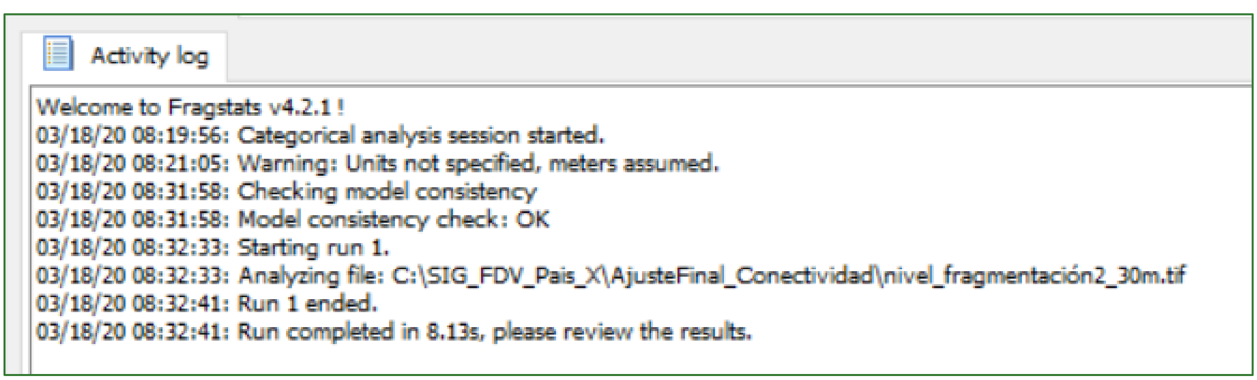
- Select the **Class metrics yellow button** in the right-hand screen and then go to the **Aggregation** tab. Select the **Connectance Index (CONNECT)** option there and in "Threshold distance" click on the 3 dots (…) and enter 500.



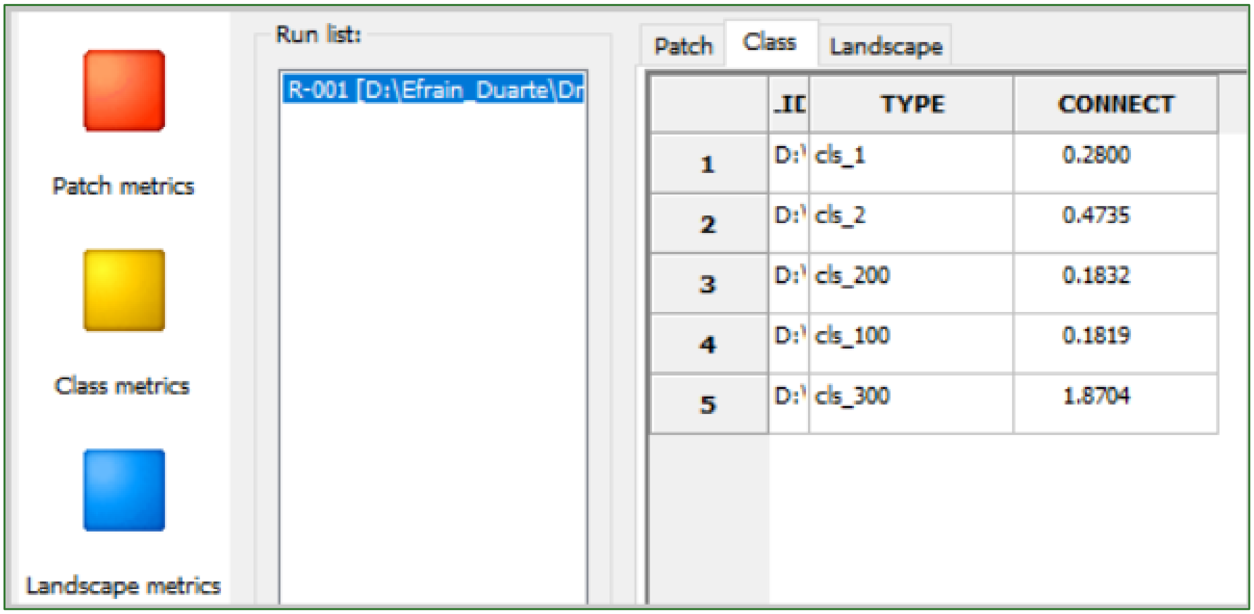
- Click on **Run** in the top menu then click on **Proceed** in the window that opens up.



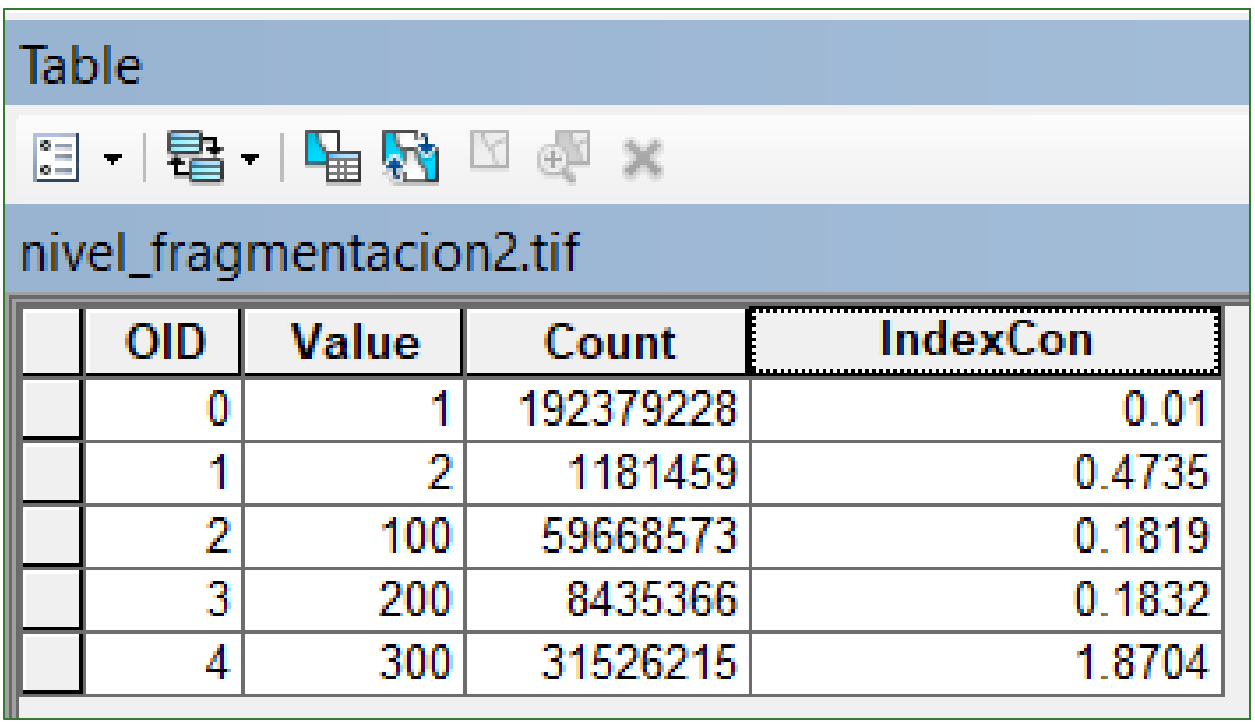
- When you have finished, the last message in the **Activity log** window should read **Run completed.**



- Go to the **Result** menu and select the **Run list** file and then the **Class** tab.



- Go to ArcMap and open the raster attributes table **nivel_fragmentación2.tif** (not the 30 m one) in the **RASTER/AjusteFinal_Conectividad** folder and add a **"IndexCon"** number type field. Next, assign a value of 0.01 to class 1 and write the corresponding values calculated in Fragstats for the rest of the classes.

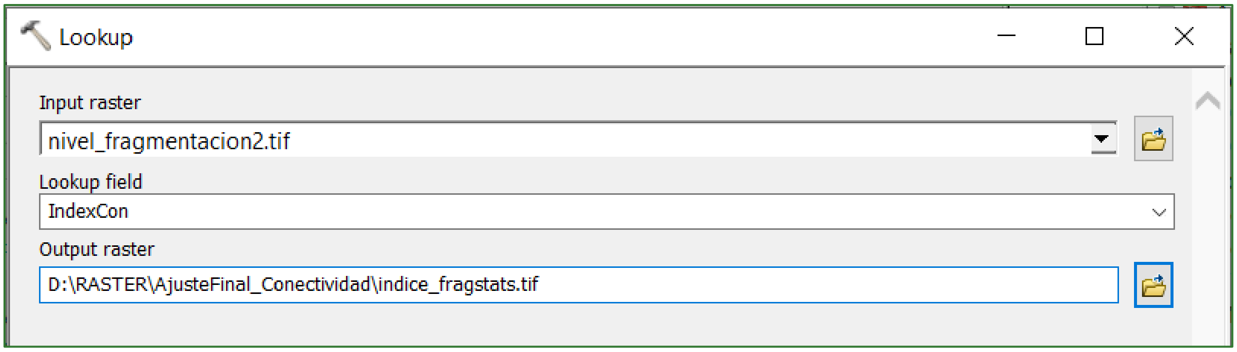


Table

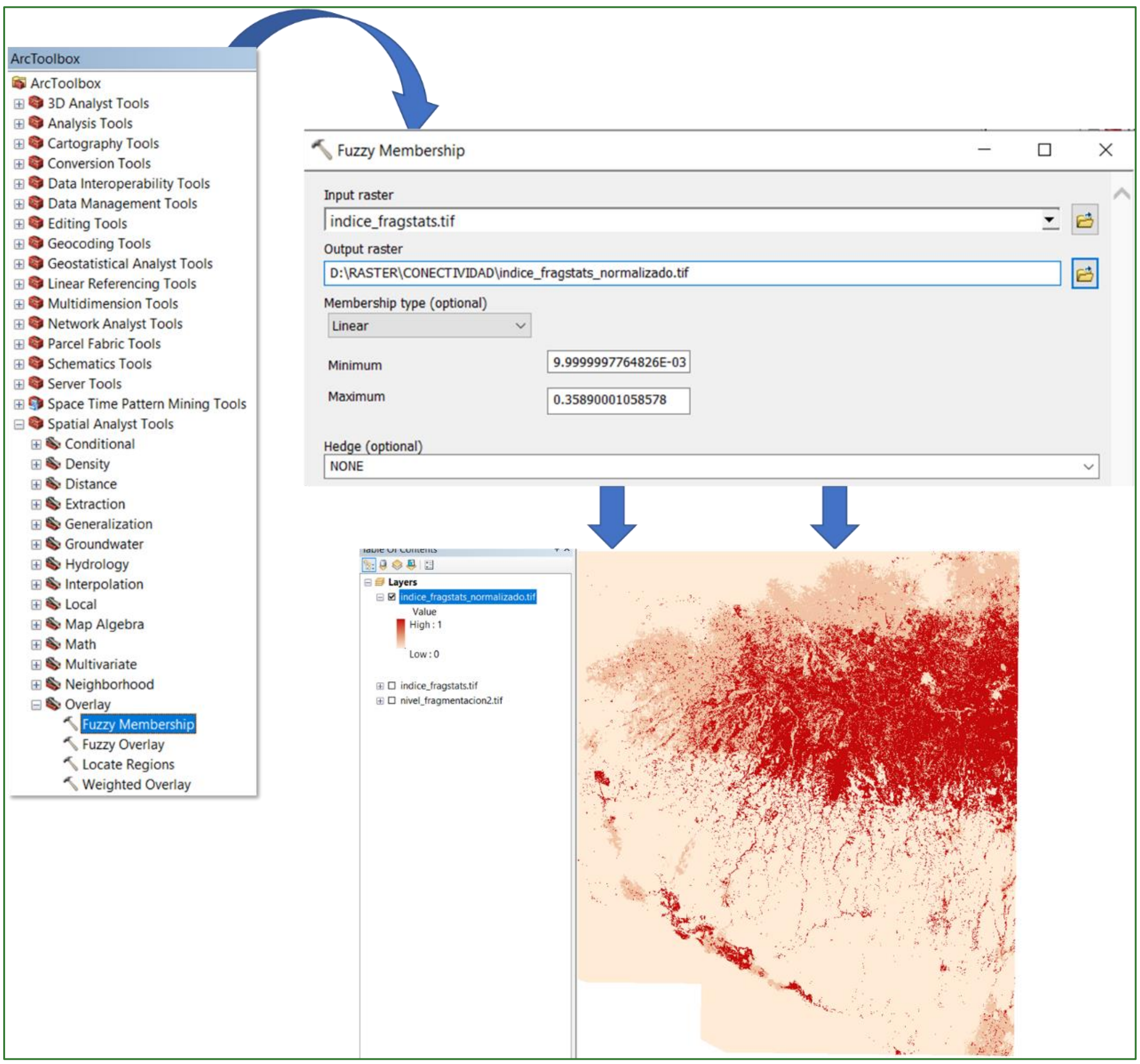
nivel_fragmentacion2.tif

OID	Value	Count	IndexCon
0	1	192379228	0.01
1	2	1181459	0.4735
2	100	59668573	0.1819
3	200	8435366	0.1832
4	300	31526215	1.8704

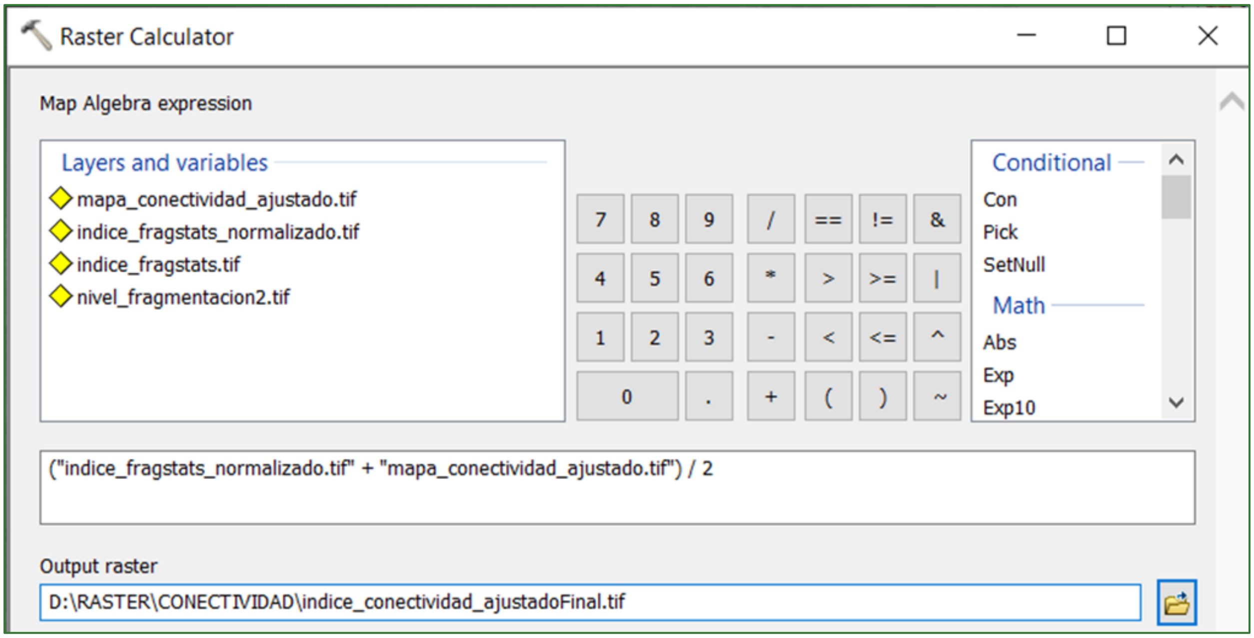
- Use the Reclass/Lookup tool to transfer the IndexCon values to a new raster named **indice_fragstats.tif** and save it in the **RASTER/AjusteFinal_Conectividad** folder.



- Apply Fuzzy Membership to standardise the connectivity index calculated in Fragstats **indice_fragstats.tif.** Assign the name **indice_fragstats_normalizado.tif** to the output file and save it in the **RASTER/CONECTIVIDAD** folder.



- Calculate a mean from between **mapa_conectividad_ajustado.tif** and **indice_fragstats_normalizado.tif.** This will be the final output. Name it **indice_conectividad_ajustadoFinal.tif** and save it in the **RASTER/CONECTIVIDAD** folder.



The output is shown below: yellow and green represent high connectivity (presence of vegetation) and blue represents low connectivity (absence of tree cover).

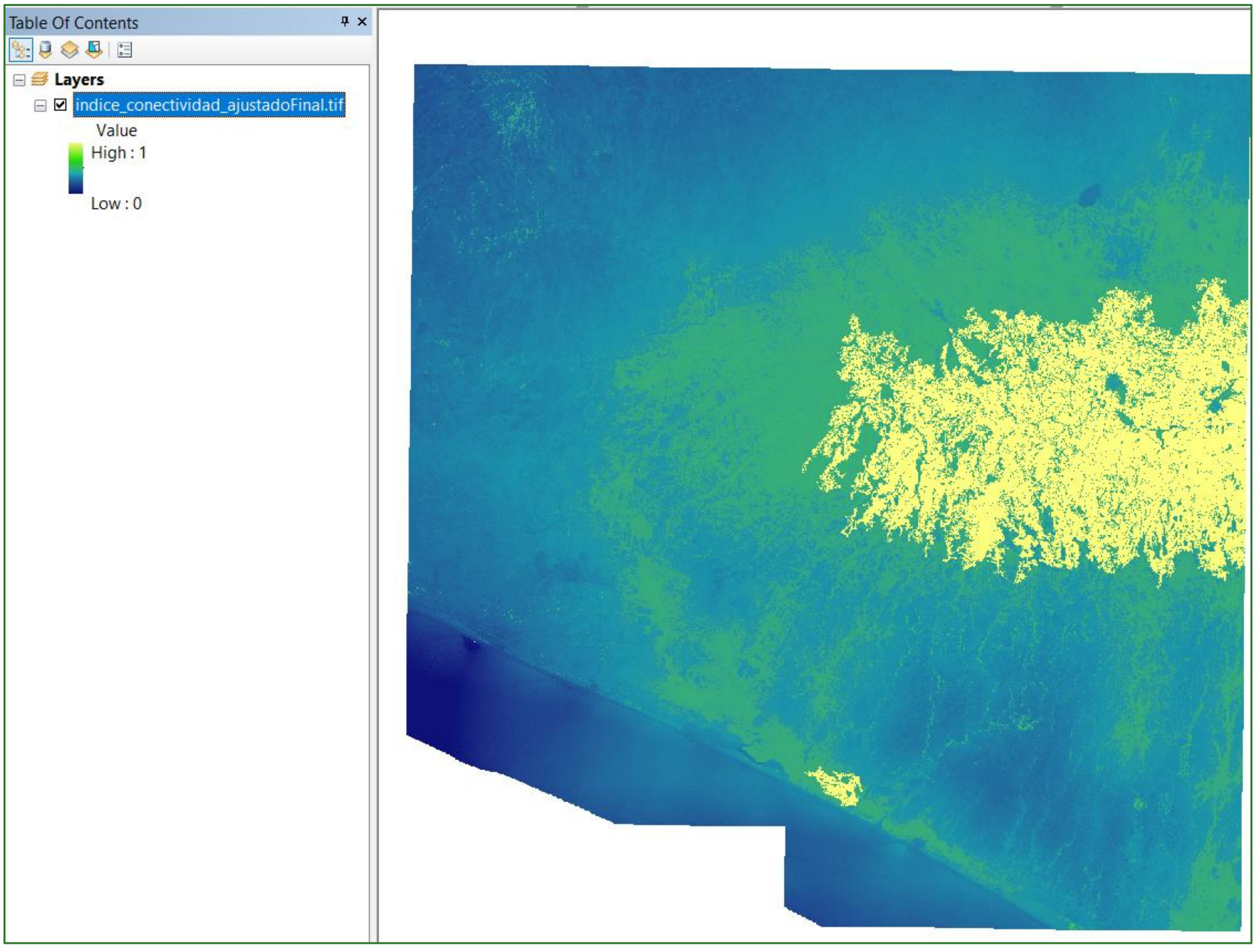


Table Of Contents
Layers
indice_conectividad_ajustadoFinal.tif
Value
High : 1
Low : 0

Integrated geospatial data analysis

Module 4: Integrated geospatial data analysis

A database is a collection of interrelated elements or data that can be processed by one or more application systems. Designing and working with a database has the following advantages:

a) Availability of structured data and avoidance of data redundancy.

b) Better data handling capacity as indexed files enable the control of queries and the existence of unique identifiers.

c) Availability of data and division processes, which means greater data dependency and enhanced processing flexibility. The option to build queries ensures quicker and more efficient data handling and avoids excessive programming.

d) Data integrity, in other words data consistency, as well as data security and protection.

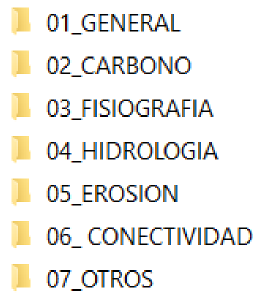
e) Long-lasting, durable data.

During the drafting of this methodological guide, a large volume of spatial data was created in relation to a range of topics which is costly to obtain and which has been appropriately processed and analysed with Geographic Information Systems (GIS). Although the goal of this data analysis is to create a baseline for Green Development Fund (FDV) projects, it has diverse applications.

Because the process involves the creation of a GIS environment model, the data are diverse, ranging from models based on the combination of maps via logical, arithmetical, statistical and probabilistic rules to more complex models based on artificial intelligence algorithms. In light of the above, and to properly handle the data obtained up to this point, it is vital to systematise and integrate the information.

Part 15. Organisation of the results folder

You must create a folder called RESULTADOS in your work directory. All the output files resulting from the steps above must be organised there, as indicated below:



01_GENERAL

Project area limits

- lim_zona_estudio_project.shp
- zona_de_trabajo.shp

Basemap data

- Limites_municipales.shp
- Limites_de_aldeas.shp
- Subcuencas_hidrograficas.shp
- Areas_protegidas.shp
- Areas_urbanas.shp
- Red_hidrica.shp
- Red_vial.shp

02_CARBONO

Tree cover by type and other land uses

- cobertura_project.tif

Forest carbon

- mapa_carbono

03_FISIOGRAFIA

Topography

- MDT_Corregido.tif
- Hillshade.tif
- pendiente_grados.tif
- pendiente_porcentaje.tif

Hydrography

- microcuencas_orden_7.tif
- microcuencas_orden_7.shp
- microcuencas_orden_9.tif
- microcuencas_orden_9.shp

Landforms

- Curvatura.tif
- Pendiente_porcentaje_reclass.tif
- MDT_Corregido_reclass.tif
- geoforma_combina.tif
- curvatura_reclass.tif
- Region_mic_curva.tif.

04_HIDROLOGIA

Climate

- malla_base_ETP.shp
- malla_base_LLUVIA.shp
- malla_base_TEMP.shp
- malla_base_RADSOLAR.shp

Infiltration factors

- Factor_KP.tif
- Factor_KV.tif
- Factor_KFC_ajustado.tif

Infiltration

- BHC_anual_mm.tif
- Infiltracion_anual_mm.tif
- Infiltracion_anual_m3.tif
- Coeficiente_ETP_cultivo.tif
- Coeficiente_Infiltracion.tif

05_EROSIÓN

Factors

- Sand_por.tif
- Silt_por.tif
- Clay_por.tif
- Orgcarb_por.tif
- Factor_K_ajustado.tif
- Factor_LS.tif
- Factor_C_ajustado2.tif

Erosion

- EROSION.tif

06_CONECTIVIDAD

- NDVI.tif
- parches_a_conectar.shp
- superficie_de_resistencia.tif
- Corredor_principal.shp
- Corredores_vecinos.shp
- Indice_conectividad_ajustadoFinal.tif

7_OTROS

Carbon factors table

- Factores carbono.xlsx
- forest_edge_carbon_lu_table.csv
- join_clasesderelieve.csv
- Balance Hídrico Climático.csv
- Join_TexturaSuelo.

Module 5: Integrated landscape analysis

Module 5: Integrated landscape analysis

Geographical space is a dynamic set made up of spatial structures mobile in time and space. The visual part of this complex is known as the geographical landscape. Accordingly, we can define landscape as a part of the space characterised by a sort of dynamic combinations of different geographical elements.

The integrated landscape analysis seeks to define the structural and functional elements of the different physical, biotic and anthropogenic components of the area. Data integration will start with climate data, followed by hydrology and relief. Biotic variables like vegetation and soils will then be integrated. Based on the baseline composed of the variables carbon, infiltration, soil erosion and landscape connectivity, we will model a series of geographical processes to obtain an integrated landscape index for the study area.

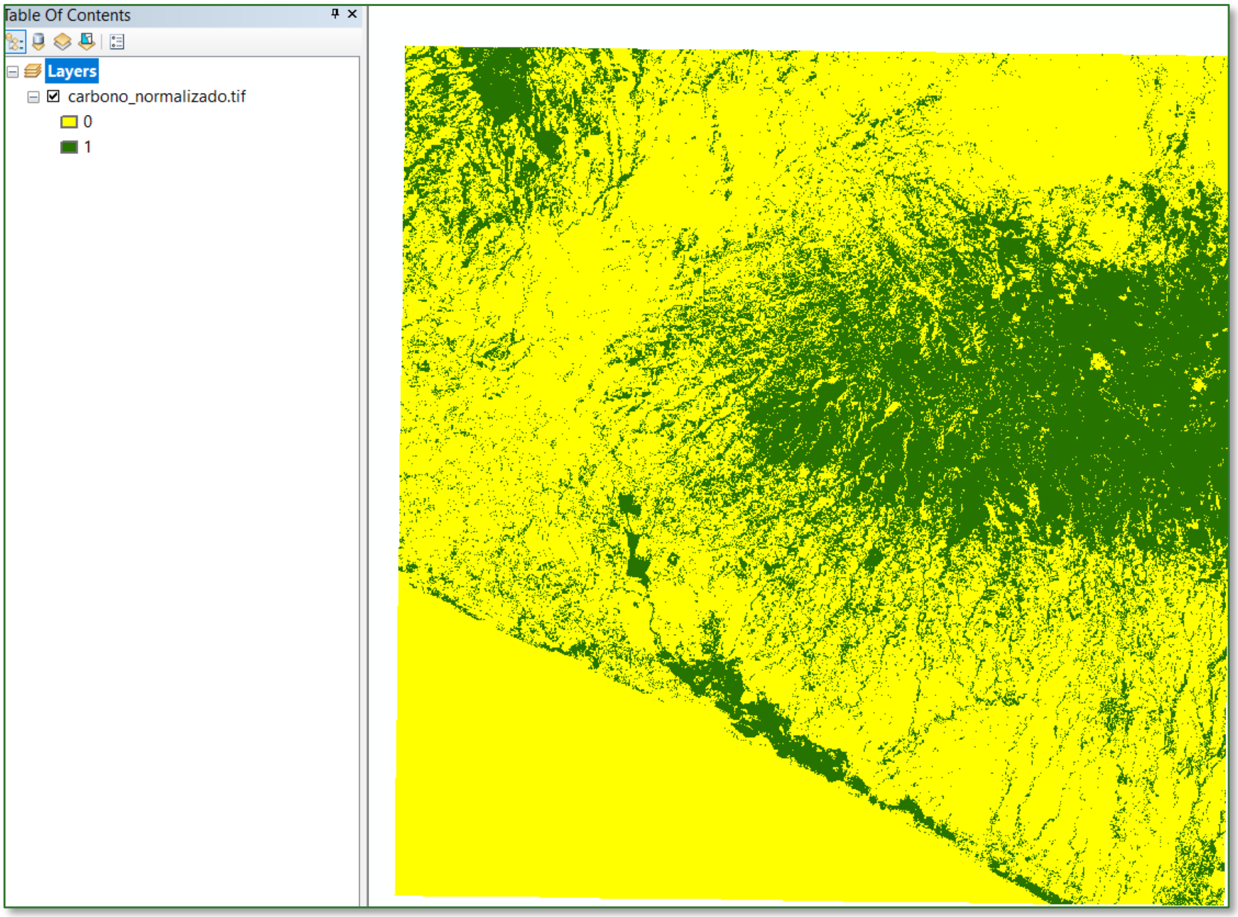
Part 16. Integrated landscape analysis: integration of Ecosystem Services Stock

- Generate an integrated index using the different ecosystem services rasters generated as input data. Follow these steps:

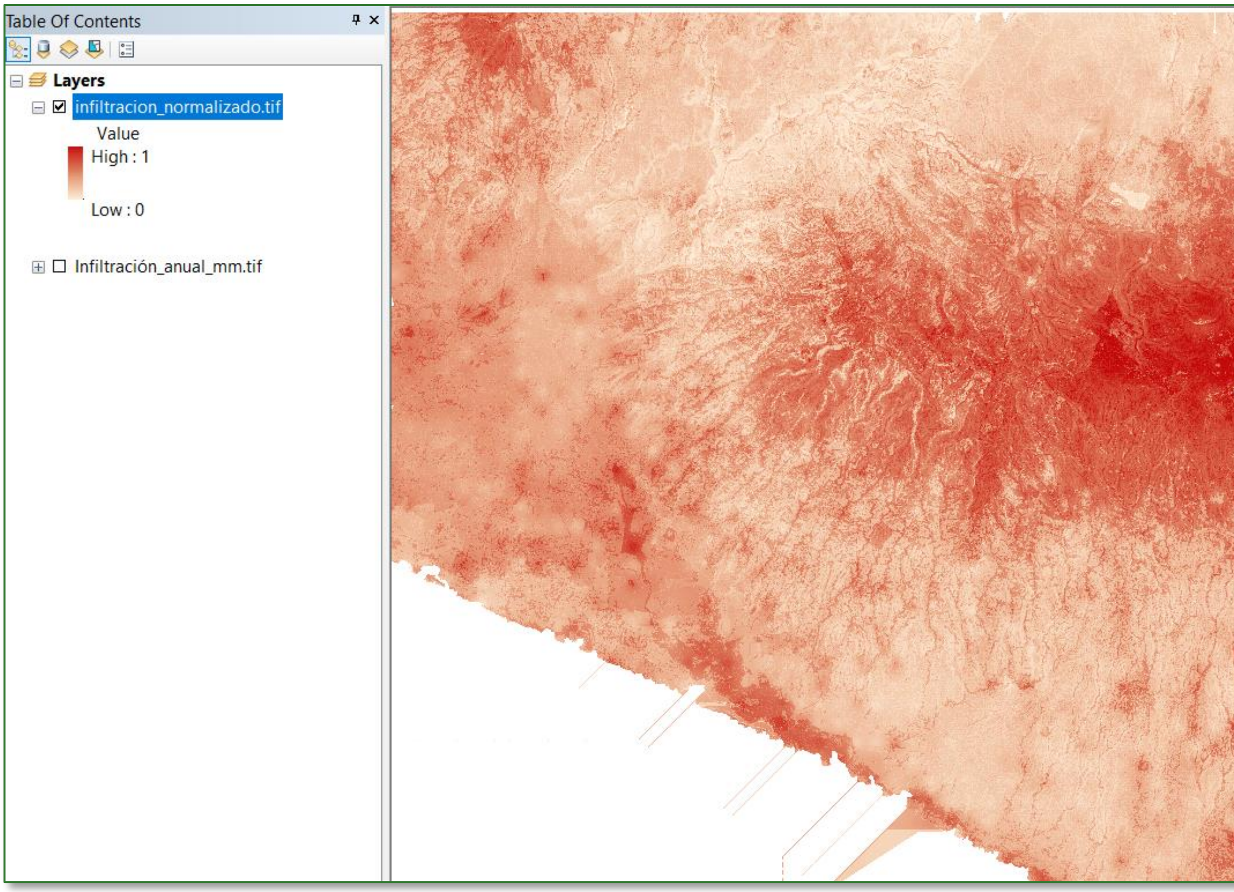
- Normalise the index values from 0 – 1. Consider the following:

Subindices	Description
Carbon	0 is less and 1 is more carbon stock
Infiltration	0 is less and 1 is more infiltration
Erosion	0 is more and 1 is less erosion
Connectivity	0 is less and 1 is more connectivity

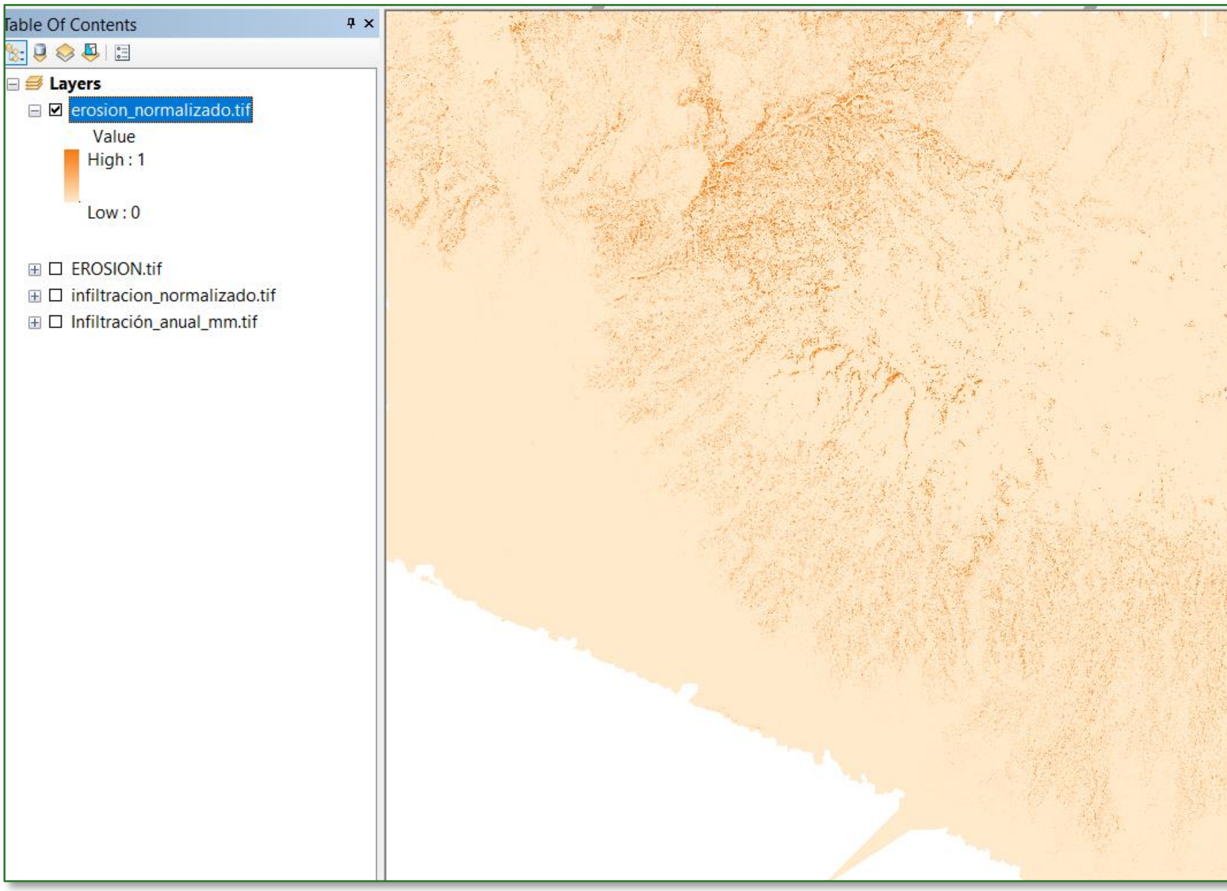
a) First, convert the **mapa_carbono.tif** to normalised values from 0-1 using the Fuzzy Membership tool, name the file **carbono_normalizado.tif** and save it in the **RESULTADO/01_GENERAL** folder. Use the **"Fuzzy Membership"** tool to run the process. This is located in **ArcToolBox/Spatial Analyst Tools/Overlay/Fuzzy Membership.**



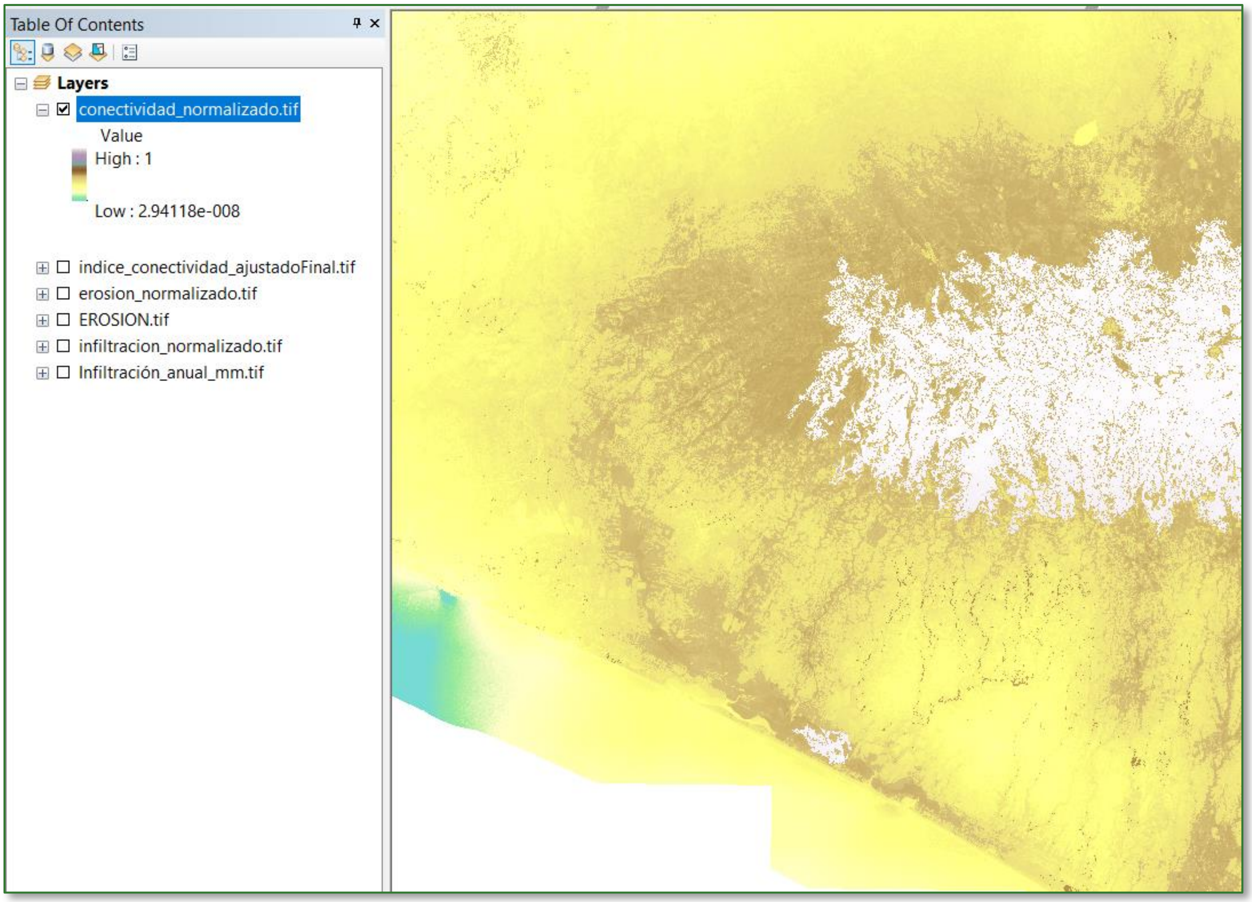
b) Second, convert the **infiltración_anual_mm.tif** raster to normalised values from 0-1 using the Fuzzy Membership tool, name the file **infiltracion_normalizado.tif** and save it in the **RESULTADO/01_GENERAL** folder. Use the **"Fuzzy Membership"** tool to carry out the process. This is located in **ArcToolBox/Spatial Analyst Tools/Overlay/Fuzzy Membership.**



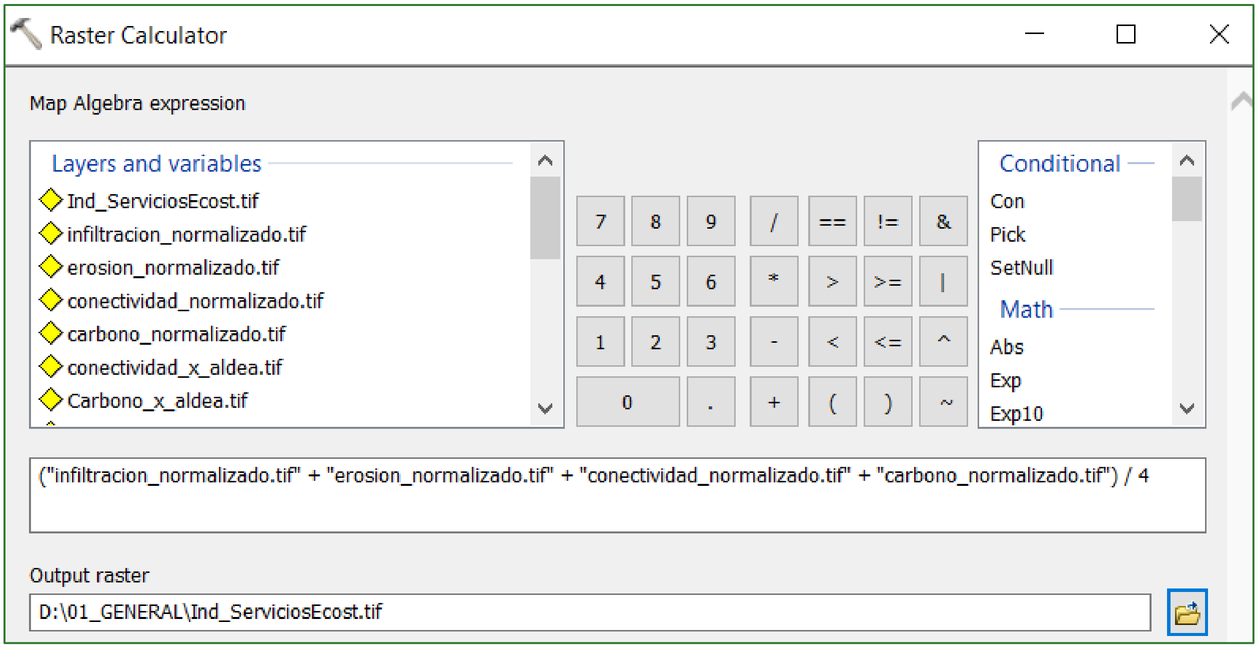
c) Third, convert the **EROSION.tif** to normalised values from 0-1 using the Fuzzy Membership tool, name the file **erosion_normalizado.tif** and save it in the **RESULTADO/01_GENERAL** folder. Use the **"Fuzzy Membership"** tool to carry out the process. This is located in **ArcToolBox/Spatial Analyst Tools/Overlay/Fuzzy Membership.**

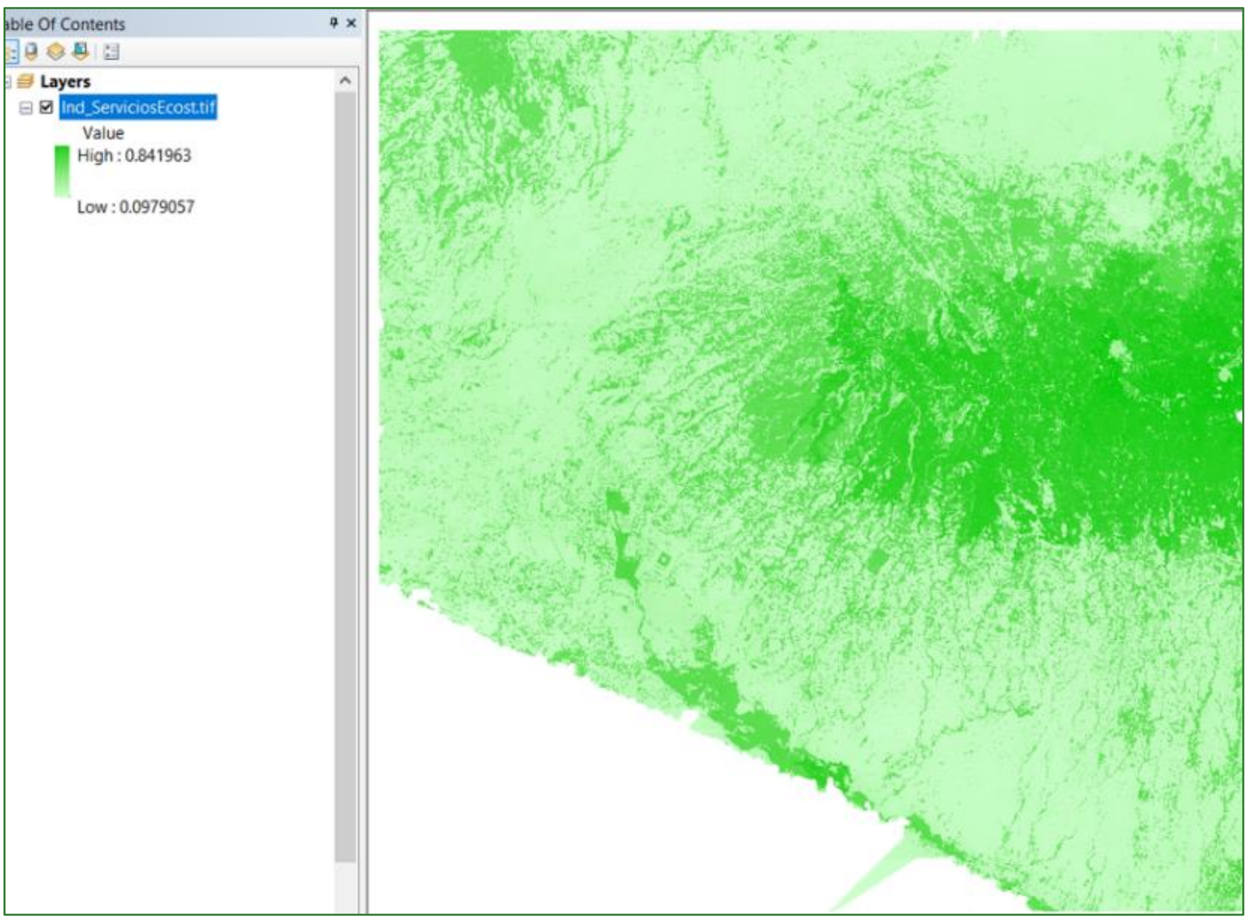


d) Fourth, convert the **indice_conectividad_ajustadofinal.tif** to normalised values from 0-1 using the Fuzzy Membership tool, name the file **conectividad_normalizado.tif** and save it in the **RESULTADO/01_GENERAL** folder. Use the **"Fuzzy Membership"** tool to run the process. This is located in **ArcToolBox/Spatial Analyst Tools/Overlay/Fuzzy Membership.**



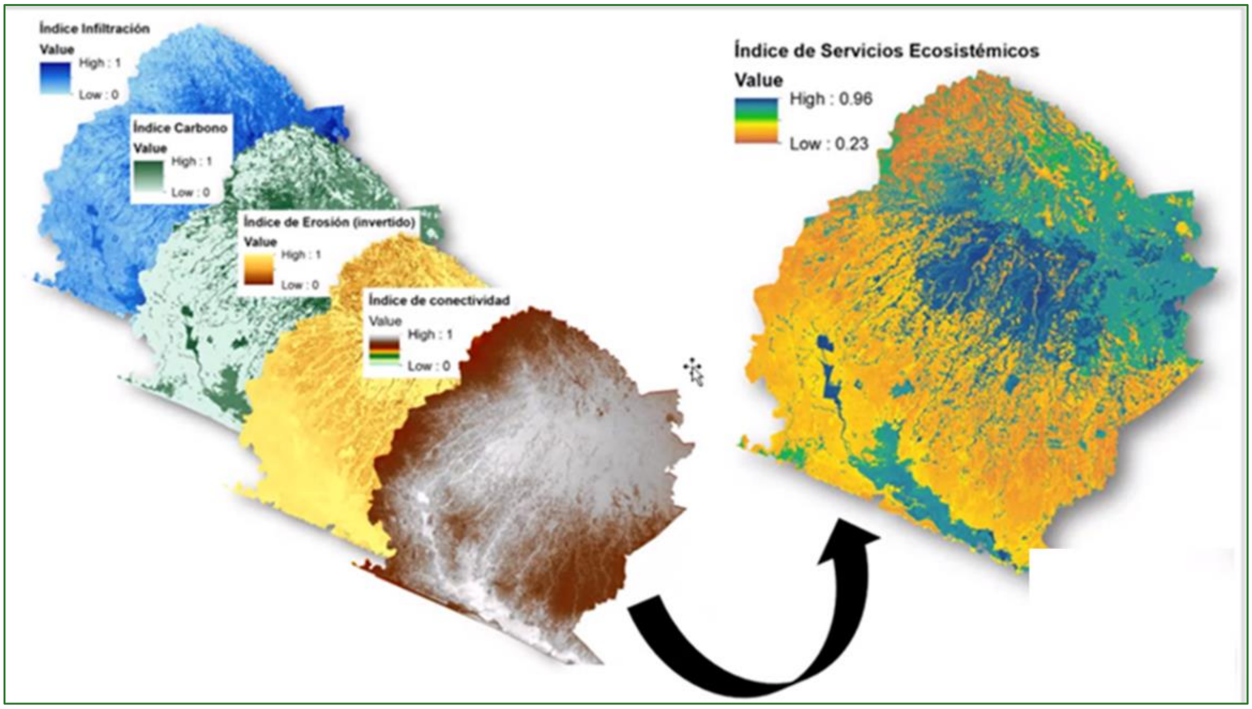
e) Now, add up the four indices mentioned above using the **"Raster Calculator"** tool to obtain an ecosystem services index. Name the new file **Ind_ServiciosEcost.tif** and save it in the **RESULTADO/01_GENERAL** folder.





The following figure shows the process to integrate the 4 indices mentioned above with a view to generating an Ecosystem Services Index for the project area (**Ind_ServiciosEcost.tif**). Each index is weighted the same (0.25) for this exercise.

Notwithstanding, if you want to weight each one differently, you can do so on multiplying each layer in the raster calculator.



Part 17. Integration of territorial management unit data

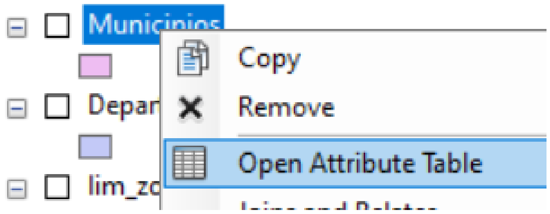
Before integrating the data into territorial management units, make sure that all the data have been projected on the same coordinate system. If not, reproject the layers following the steps in **PART 1** titled **"PROJECTING THE LAYERS ONTO THE COUNTRY'S GEODESIC SYSTEM"** which can be found at the beginning of this document.

Step 1:
Add the political-administrative and territorial management limits of the project area for which you need to obtain aggregate area figures and other baseline variables to ArcMap. Save these files into a folder called **LIMITES** and place it in **VECTORES/LIMITES**. The recently created LIMITES folder must contain at least the following shapefiles:

- **Political-Administrative Limits**
  - Municipios.shp
  - Cantones.shp
- **Territorial Management Limits**
  - Área_natural_protegida.shp
  - Subcuencas.shp

Step 2:
Generate a summary table with the unique identifiers for the aforementioned shapefiles. To this end:

a) Go to the shapefile attributes table.

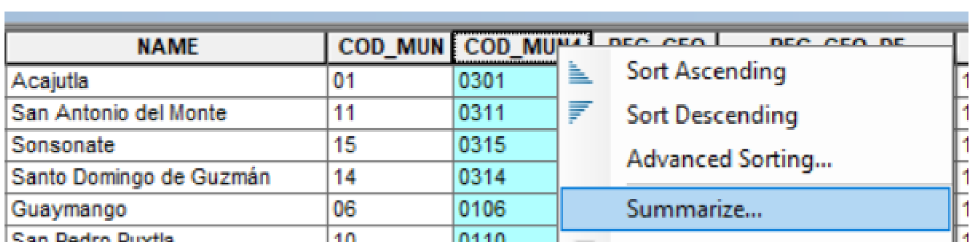


b) Locate the field that contains the ID or Unique Code that identifies each of the shapefile elements. For example, in the following image this is the COD_MUNI field. You must also identify the field that contains the element name (in this example it would be the NAME field, which contains the name of the municipality).

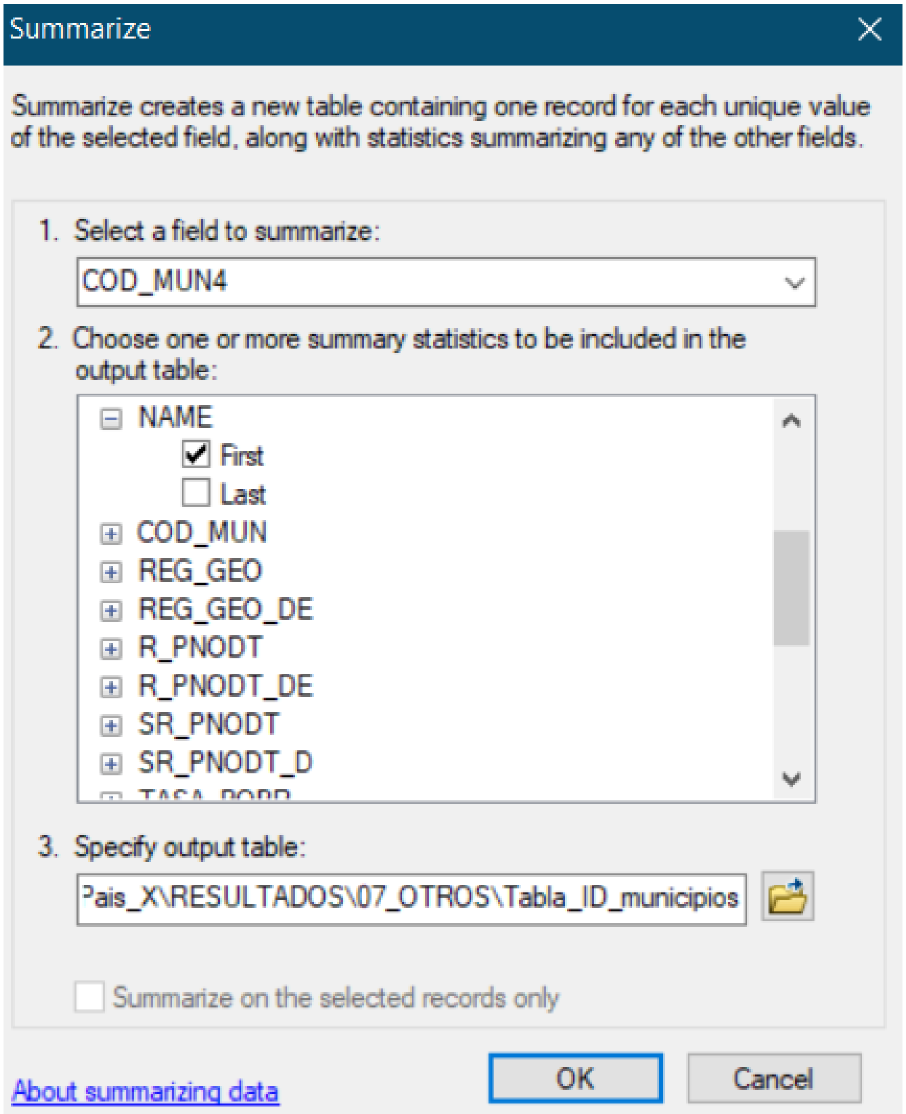
N.B.: If the records do not have a unique identifier, you must create one, adding a Code field. Example:

CODIGO	NOMBRE
1	Acaxual
2	Atehuesian
3	Cara Sucia
4	El Chino
5	El Corozo
6	El Imposible
7	El Salto

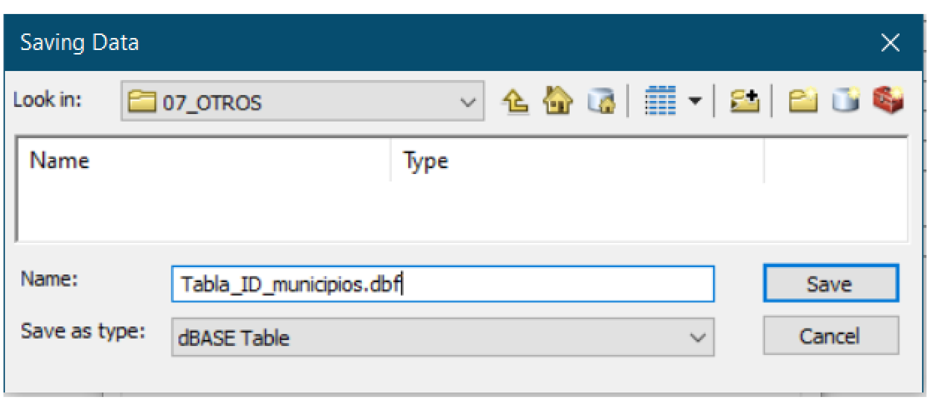
Next, right click on the code field and select the "Summarize" option.



c) In the Summarize window, select the **First** option in the field that contains the **NAME.**



d) Assign the output name for the table (Tabla_ID_xxxxxx), making sure to select the dBASE Table option in "Save as type". Save the tables in the **VECTORES/LIMITE** folder.



e) Lastly, open the resulting table and delete the **"Count_..."** field.

Tabla_ID_municipios

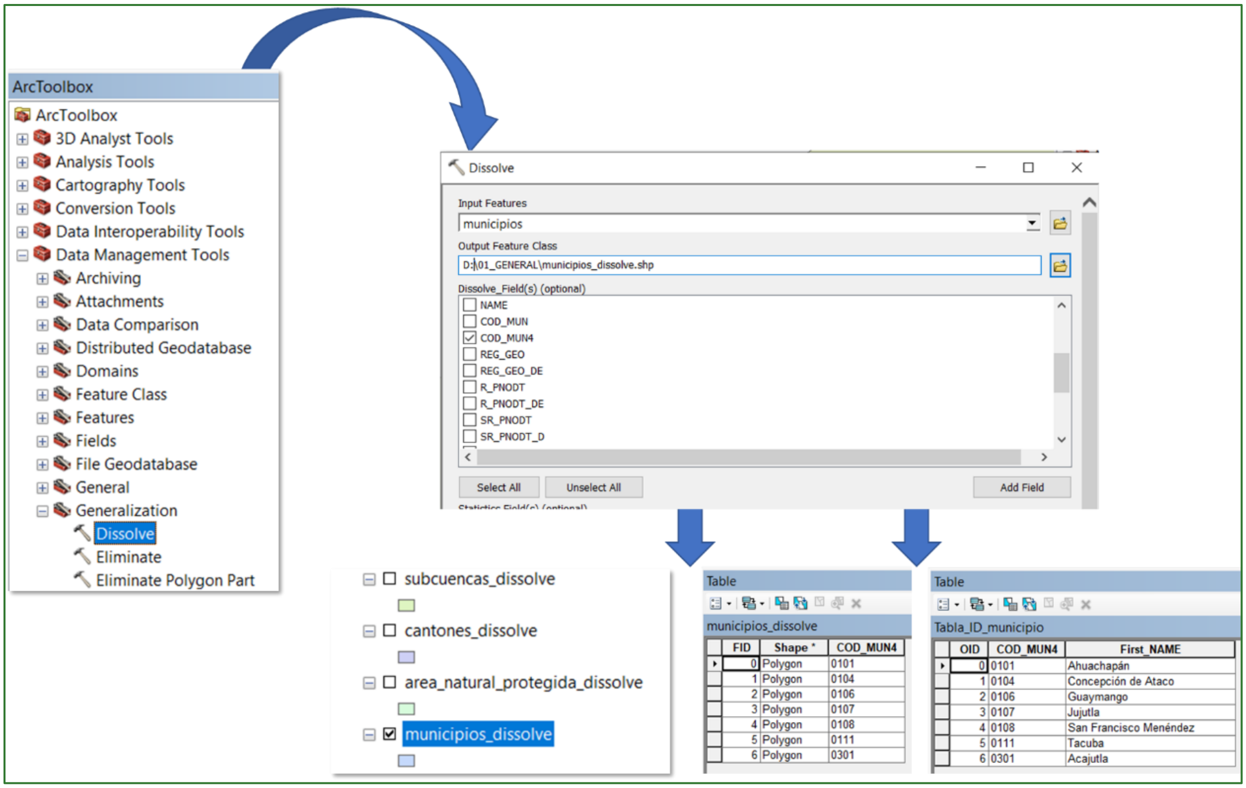
OID	COD_MUN4	Count_COD_MUN4	First_NAME
0	0101	1	Ahuachapán
1	0102	1	Apaneca
2	0103	1	Atiquizaya
3	0104	1	Concepción de Ataco
4	0106	1	Guaymango

Repeat the procedure to get the summary tables for the unique identifiers of all the shapefiles that will be used to obtain the baseline aggregate figures. Save the tables in the **VECTORES/LIMITE** folder.

Step 3:
Use the **Dissolve** tool to delete any redundancies in the shapefiles selected in Step 1. Apply dissolve as of the CODE field.

N.B.: Make sure that the code field selected is the same one you used to generate the corresponding table in the previous step.

The "Dissolve" tool is located in **ArcToolBox/Data Management Tools/Generalization/Dissolve.** Apply Dissolve to all the shapefiles selected in Step 1 and save them in the **01_GENERAL** folder adding the word **_dissolve** after the name, e.g. **municipios_dissolve.shp.**



a) Add 2 fields for each summary table with its corresponding name as indicated below. And transfer the corresponding values to these new fields.

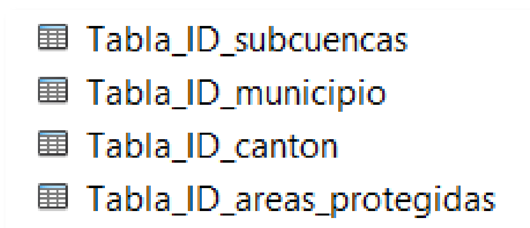
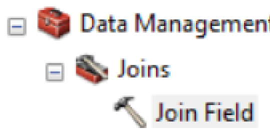
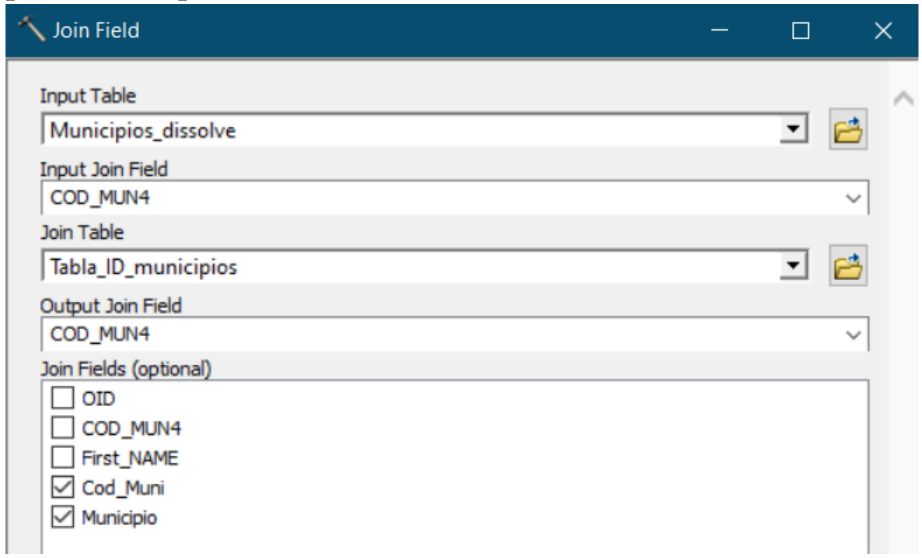


Table	Campo_ Código (Text)	Name Field (Text)
Tabla_ID_municipio	Cod_Muni	Municipality
Tabla_ID_canton	Cod_Canton	Canton
Tabla_ID_areas_protegidas	Cod_Areap	AreaProt
Tabla_ID_subcuencas	Cod_Subc	Sub-basin

b) Use the **"Join Field"** tool to link the summary tables to their corresponding dissolve shapefile. Make sure that the common code field selected is the same one in both tables.



c) In “Join Fields” (optional), select the 2 new fields that you added in the previous step.

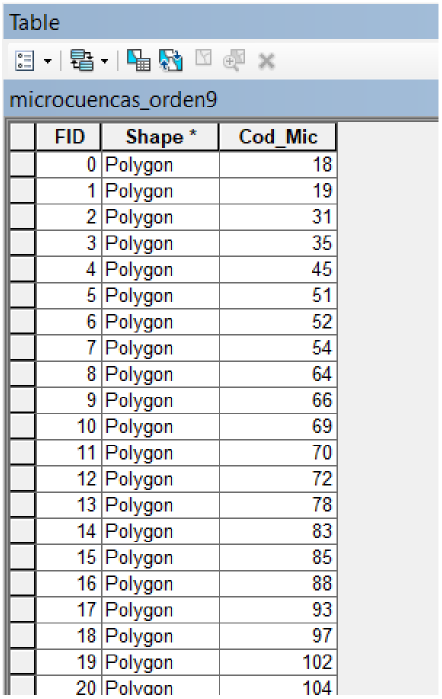


After you have completed the join, open the dissolve shapefile and delete the duplicated code field (leaving only the new one).

Repeat this step for all dissolve shapefiles.

d) Copy the microcuencas_orden9.shp shapefile and paste it in the **RESULTADO/01_GENERAL** folder.

e) Add the shapefile and in its attribute table, add the **Cod_Mic** field and transfer the Campo ID values to it. Delete the other fields, leaving just the **Cod_Mic** field.

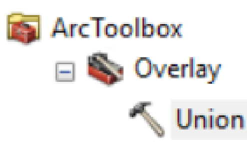


Table

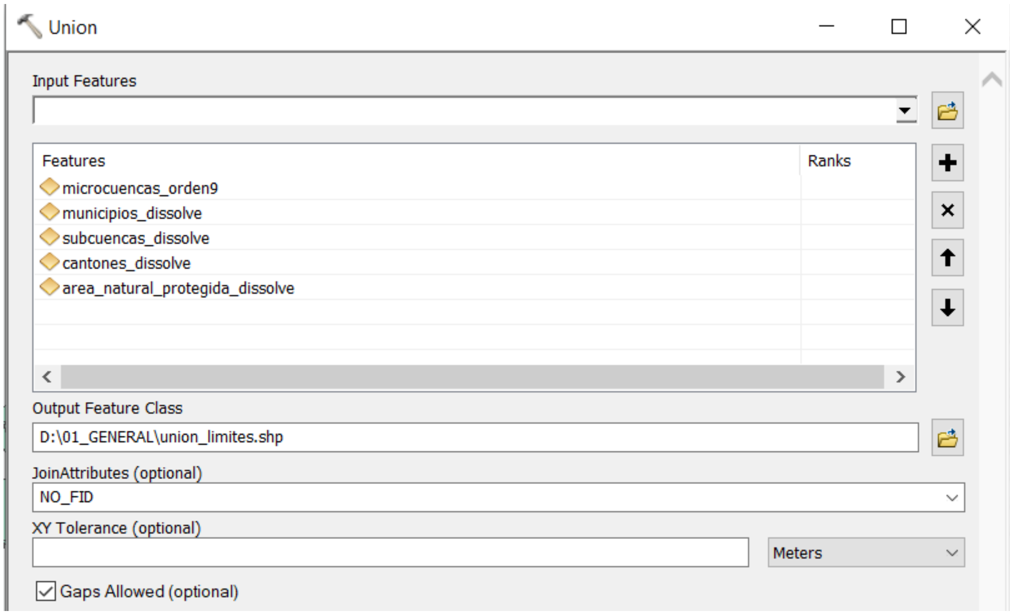
microcuencas_orden9

FID	Shape *	Cod_Mic
0	Polygon	18
1	Polygon	19
2	Polygon	31
3	Polygon	35
4	Polygon	45
5	Polygon	51
6	Polygon	52
7	Polygon	54
8	Polygon	64
9	Polygon	66
10	Polygon	69
11	Polygon	70
12	Polygon	72
13	Polygon	78
14	Polygon	83
15	Polygon	85
16	Polygon	88
17	Polygon	93
18	Polygon	97
19	Polygon	102
20	Polygon	104

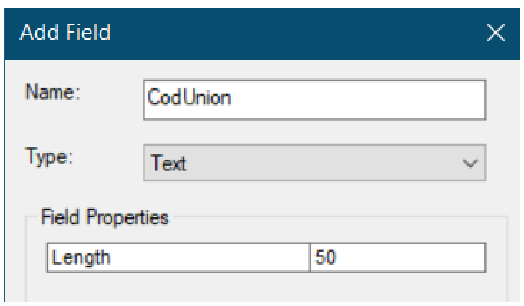
f) Apply the Join tool to integrate all the political-administrative and/or territorial management unit layers with the micro-basins in a single shapefile. Name the output file **union_limites.shp** and save it in the **RESULTADO/01_GENERAL** folder.



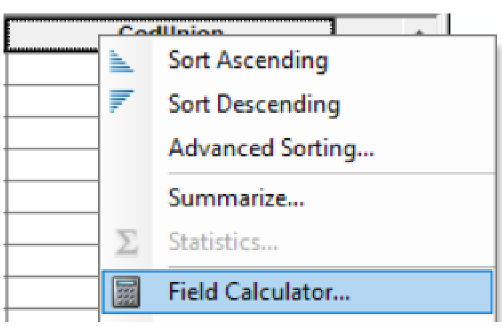
Add the shapefiles to be joined in **Input Feature**. Select **NO_FID** in Join Attributes (optional).



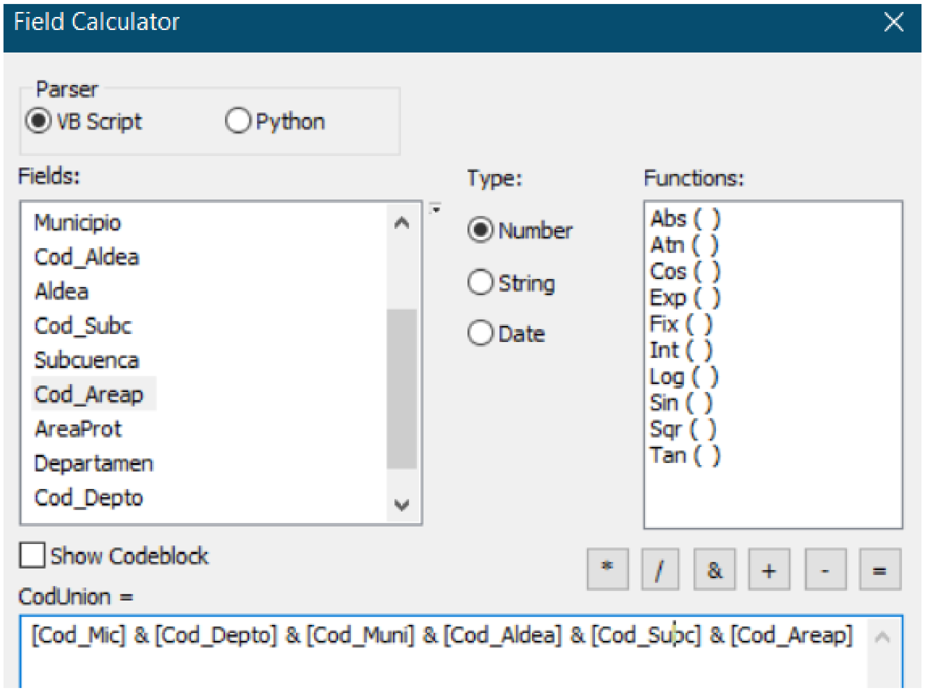
g) Add the **CodUnion** field to the **union_limites.shp** attributes table.



h) Right-click on the CodUnion field created in the previous step and select Field Calculator.



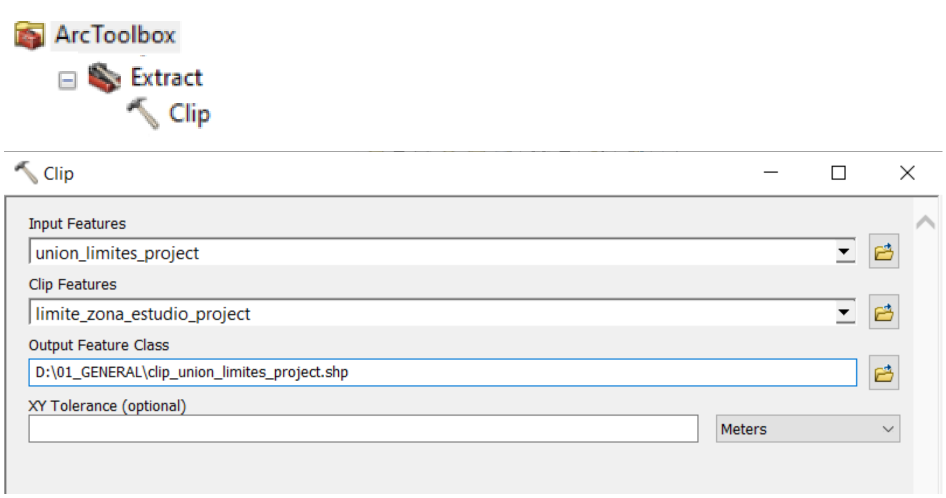
Link the different code fields in the Field Calculator as shown below: **[Cod_Mic] & [Cod_Subc] & [Cod_Canton] &[Cod_Areap] & [Cod_Muni].**



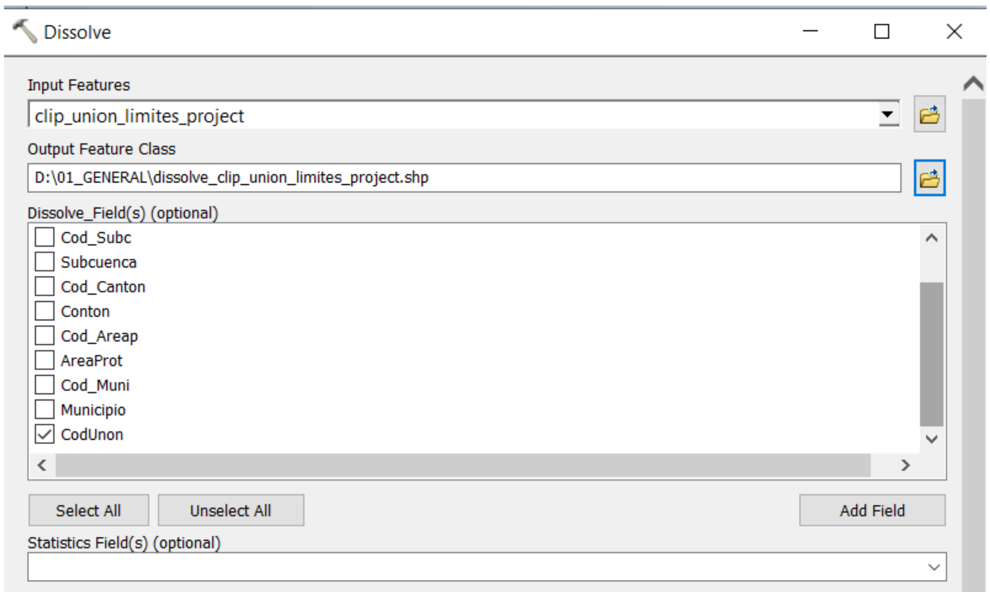
i) Add the **lim_zona_estudio_project.shp** shapefile.

j) If **union_limites.shp** is in geographical coordinates, reproject it to the **lim_zona_estudio_project.shp** projection system following the instructions given in **PART 1** of this methodological guide. Indicate the following as the output file: **union_limites_project.shp** and save it in the **RESULTADO/01_GENERAL** folder.

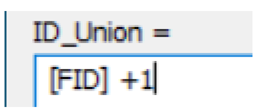
k) Use the Clip tool to cut **lim_zona_estudio_project.shp** out from **union_limites_project.shp** and save it in the **RESULTADO/01_GENERAL** folder, naming it **clip_union_limites_project.shp**.



l) Dissolve the **clip_union_limites_project.shp** using the **CodUnion** field and save it in the **RESULTADO/01_GENERAL** folder, naming it **dissolve_clip_union_limites_project.shp.**



m) Add the **ID_union** field to the **dissolve_clip_union_limites_project.shp** shapefile and assign it a correlative number as of the FID+1 field.



Table

dissolve_clip_union_limites_project

FID	Shape *	CodUnon	ID_union
0	Polygon	0 0107	1
1	Polygon	0 0108	2
2	Polygon	0 0301	3
3	Polygon	0 30108	4
4	Polygon	0 60107	5
5	Polygon	0 60108	6
6	Polygon	0 60301	7
7	Polygon	0 70108	8
8	Polygon	0 010701 0107	9
9	Polygon	0 010701 0301	10
10	Polygon	0 01070160107	11
11	Polygon	0 01070160301	12
12	Polygon	0 010804 0107	13
13	Polygon	0 010804 0108	14
14	Polygon	0 01080430108	15
15	Polygon	0 01080460108	16

n) Lastly, use the **Join Field** tool to transfer the attributes of the **union_limites_project.shp** raster to **dissolve_clip_union_limites_project.shp**, using **CodUnion** as a common field.

Table

dissolve_clip_union_limites_project

FID	Shape *	CodUnon	ID_union
0	Polygon	0 0107	1
1	Polygon	0 0108	2
2	Polygon	0 0301	3
3	Polygon	0 30108	4
4	Polygon	0 60107	5
5	Polygon	0 60108	6
6	Polygon	0 60301	7
7	Polygon	0 70108	8
8	Polygon	0 010701 0107	9
9	Polygon	0 010701 0301	10
10	Polygon	0 01070160107	11
11	Polygon	0 01070160301	12
12	Polygon	0 010804 0107	13
13	Polygon	0 010804 0108	14
14	Polygon	0 01080430108	15
15	Polygon	0 01080460108	16

Table

dissolve_clip_union_limites_project

FID	Shape *	CodUnon	ID_union	Cod_Mic	Cod_Subc	Subcuenca	Cod_Canton	Conton	Cod
0	Polygon	0 0107	1	0					
1	Polygon	0 0108	2	0					
2	Polygon	0 0301	3	0					
3	Polygon	0 30108	4	0					3
4	Polygon	0 60107	5	0					6
5	Polygon	0 60108	6	0					6
6	Polygon	0 60301	7	0					6
7	Polygon	0 70108	8	0					7
8	Polygon	0 010701 0107	9	0			010701	BARRA DE SANTIAGO	
9	Polygon	0 010701 0301	10	0			010701	BARRA DE SANTIAGO	
10	Polygon	0 01070160107	11	0			010701	BARRA DE SANTIAGO	6
11	Polygon	0 01070160301	12	0			010701	BARRA DE SANTIAGO	6
12	Polygon	0 010804 0107	13	0			010804	EL ZAPOTE	
13	Polygon	0 010804 0108	14	0			010804	EL ZAPOTE	
14	Polygon	0 01080430108	15	0			010804	EL ZAPOTE	3
15	Polygon	0 01080460108	16	0			010804	EL ZAPOTE	6
16	Polygon	0 010805	17	0			010805	GARITA PALMERA	
17	Polygon	0 010805 0108	18	0			010805	GARITA PALMERA	
18	Polygon	0 0108057	19	0			010805	GARITA PALMERA	7
19	Polygon	0 01080570108	20	0			010805	GARITA PALMERA	7
20	Polygon	0 010808	21	0			010808	LA HACHADURA	
21	Polygon	0 010808 0108	22	0			010808	LA HACHADURA	

o) As a final step, copy the **dissolve_clip_union_limites_project.shp** shapefile and save it as **limites_administrativos.shp** in the **RESULTADO/01_GENERAL** folder.

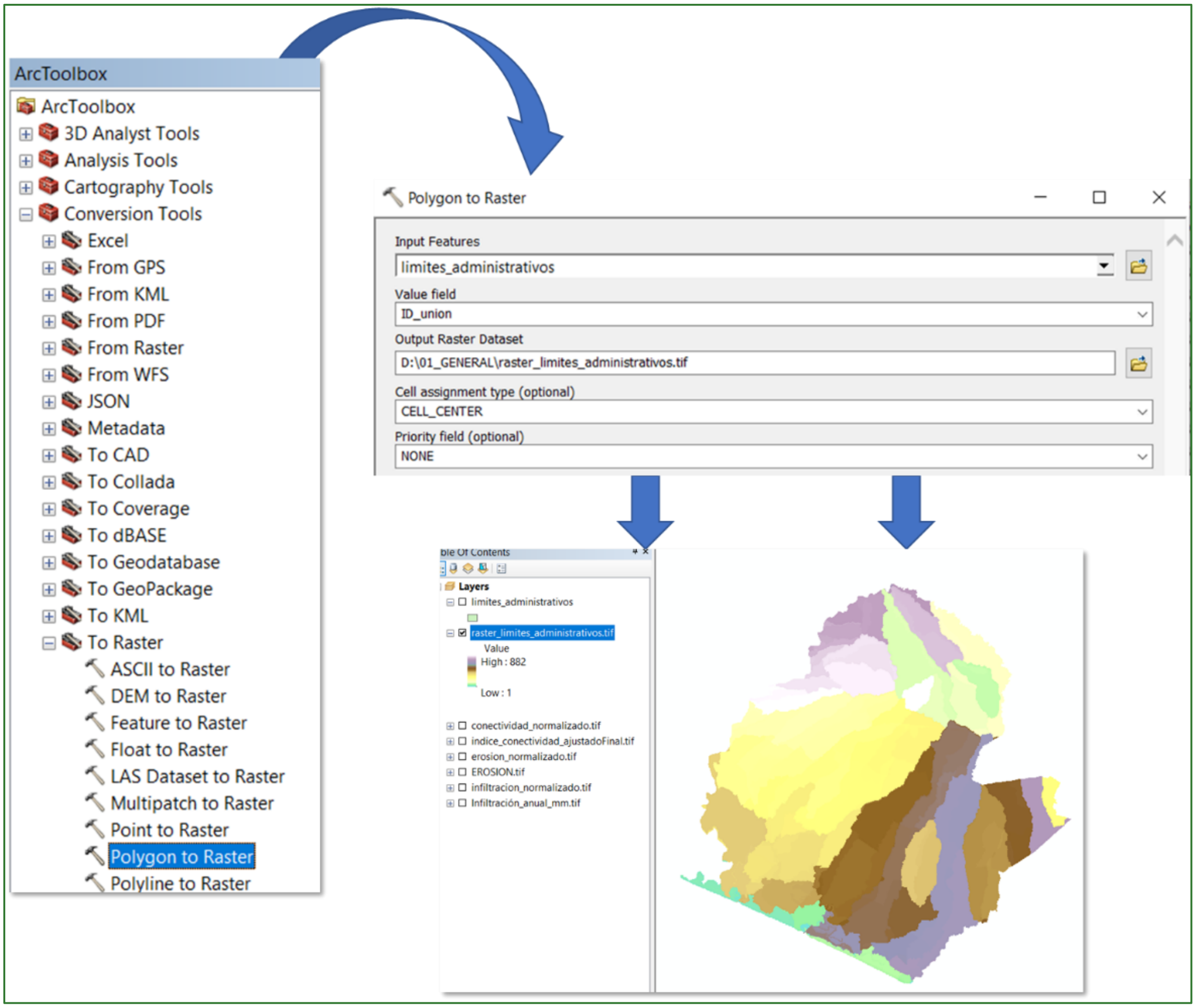
Part 18. Assigning the raster value of the variables analysed to the Territorial Management Units integrated table

You now have the integrated political-administrative limits and integrated management limits shapefiles integrated into a single file, **limites_administrativos.shp**, and also integrated with the adjusted carbon, erosion, infiltration and connectivity rasters. But before going on to obtain the sum of these rasters for each one of the **limites_administrativos.shp** polygons, they need to be combined with types of cover.

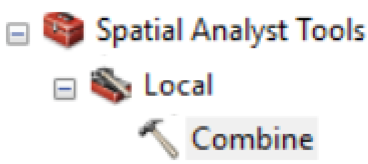
Combining union_limites with types of cover

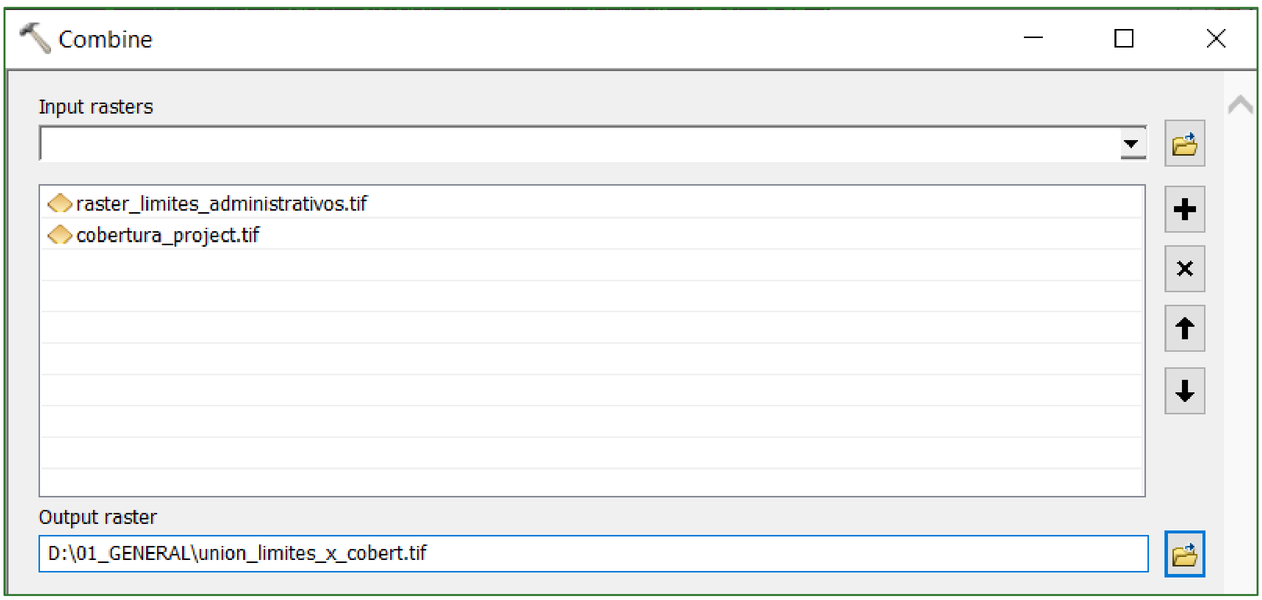
Step 1:

Convert **limites_administrativos.shp** to a raster using the **ID_union** field as the value. Use the **"Polygon to Raster"** tool found in **ArcToolBox/Conversion Tools/To Raster/Polygon to Raster** for this step. Name the file **raster_limites_administrativos.tif** and save it in the **RESULTADO/01_GENERAL** folder.

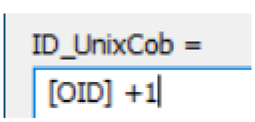

ArcToolbox
ArcToolbox
3D Analyst Tools
Analysis Tools
Cartography Tools
Conversion Tools
Excel
From GPS
From KML
From PDF
From Raster
From WFS
JSON
Metadata
To CAD
To Collada
To Coverage
To dBASE
To Geodatabase
To GeoPackage
To KML
To Raster
ASCII to Raster
DEM to Raster
Feature to Raster
Float to Raster
LAS Dataset to Raster
Multipatch to Raster
Point to Raster
Polygon to Raster
Polyline to Raster
Polygon to Raster
Input Features
limites_administrativos
Value field
ID_union
Output Raster Dataset
D:\01_GENERAL\raster_limites_administrativos.tif
Cell assignment type (optional)
CELL_CENTER
Priority field (optional)
NONE
Layers
limites_administrativos
raster_limites_administrativos.tif
Value
High : 882
Low : 1
conectividad_normalizado.tif
indice_conectividad_ajustadoFinal.tif
erosion_normalizado.tif
EROSION.tif
infiltracion_normalizado.tif
Infiltración_anual_mm.tif

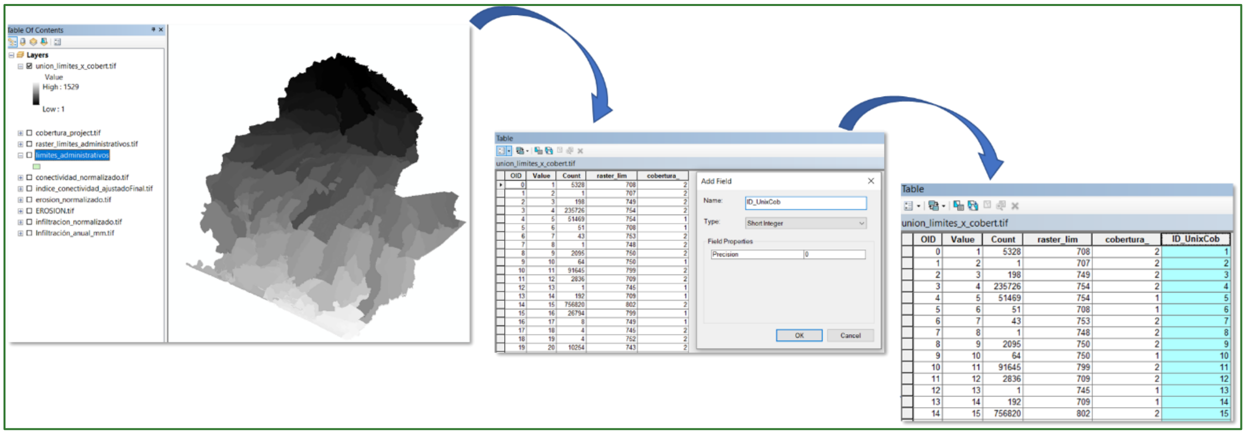
Step 2:
Use the **“Combine”** tool to assign the **cobertura_project.tif** classes to the **raster_limites_administrativos.tif** raster (generated in the previous step). Name the output file **union_limites_x_cobert.tif** and save it in the **RESULTADO/01_GENERAL** folder.





Add the **ID_UnixCob** field to the shapefile generated (**union_limites_x_cobert.tif**) and assign it a correlative number as of the **OID+1** field.





Calculating pixel level values for each of the areas identified by ID_UnixCob

Step 3: Export the union_limites_x_cobert.tif, naming it **TABLA_RESULTADOS.dbf** and save it in the **RESULTADO/01_GENERAL** folder.

Step 4: Calculate the sum or mean (as appropriate) of the variables (at pixel level) for each of the **union_limites_x_cobert.tif** raster units, using **ID_UnixCob** as the reference field. Use the **"Zonal Statistics as Table"** to do so which is found in **ArcToolBox/Spatial Analyst Tools/Zonal/Zonal Statistics as Table.** Do the calculations for each of the final rasters using this tool.

Main calculations

Variable	Operation	Output table	Field
Carbon tonne per pixel	SUM	SUM_Carbono.dbf	SUM_C
Carbon tonne per ha	MEAN	MEDIA_Carbono_xha.dbf	MED_C
C stock Index	MEAN	MEDIA_Ind_Carbono.dbf	MED_IndC
Erosion tonne per pixel	SUM	SUM_Erosion.dbf	SUM_EROS
Erosion tonne per ha	MEAN	MEDIA_Erosion_xha.dbf	MED_ EROS
Erosion Index	MEAN	MEDIA_Ind_Erosion.dbf	MED_IndEr
Infiltration m3 per pixel	SUM	SUM_Infiltración_m3.dbf	SUM_INFIL
Infiltration mm	MEAN	MEDIA_Infiltracíón_mm.dbf	MED_INFIL
Infiltration Index	MEAN	MEDIA_Ind_Infiltracion.dbf	MED_IndINF
Connectivity per pixel	MEAN	MEDIA_Infiltración.dbf	MED_CONECT
Connectivity Index	MEAN	MEDIA_Ind_Conectividad.dbf	MED_IndCON
Integrated Ecosystem Services Stock Index	MEAN	MEDIA_Ind_ServiciosEcost.dbf	MED_IndSEc

Additional carbon-related calculations

Variable	Operation	Output table	Field
CO2 tonne per pixel	SUM	SUM_CO2.dbf	SUM_CO2
CO_2 tonne per ha	MEAN	MEDIA_CO2_xha.dbf	MED_CO2
Biomass tonne per pixel	SUM	SUM_Biomasa.dbf	SUM_BIOM
Biomass tonne per ha	MEAN	MEDIA_Biomasa.dbf	MED_BIOM

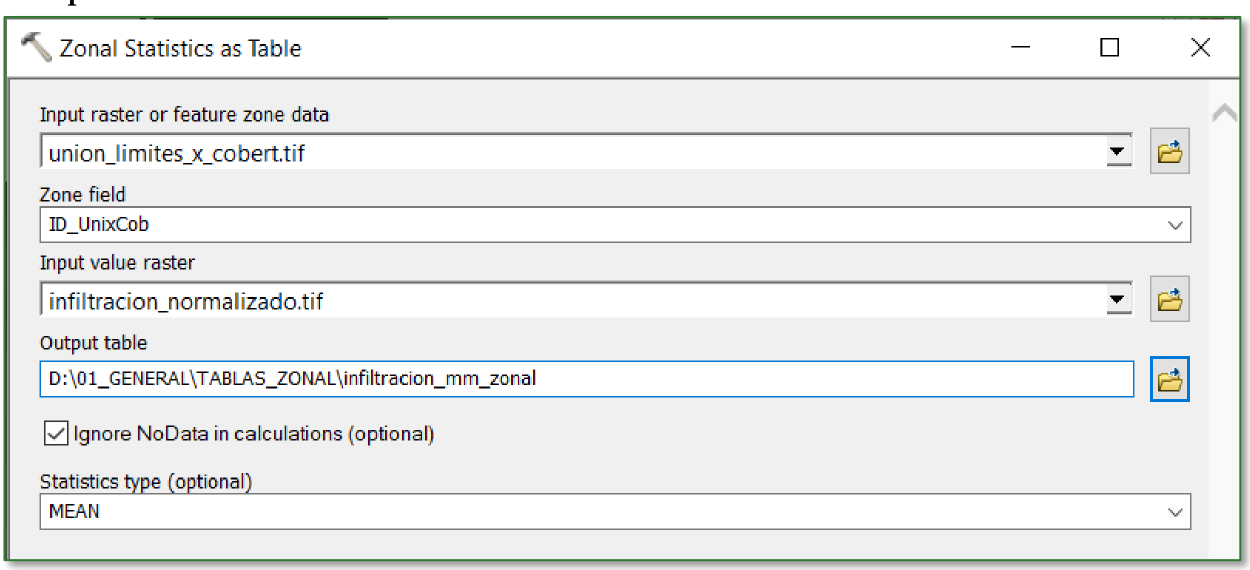
Additional reference calculations

Variable	Operation	Output table	Field
Elevation	MEAN		
Slope in degrees	MEAN		
Slope in percentage	MEAN		
Predominant landform	MAJORITY		
Annual precipitation	MEAN		
Mean temperature	MEAN		
Mean solar radiation	MEAN		
Potential ET	MEAN		
Real ET	MEAN		
Order 7 river density	SUM/COUNT		
Order 9 river density	SUM/COUNT		
% clay in soil	MEAN		
% sand in soil	MEAN		
% silt in soil	MEAN		
% organic C in soil	MEAN		
Predominant soil texture	MAJORITY		

Additional monthly variable calculations

Variable	Operation	Output table	Field

Example of Infiltration variable calculation:



A table like the one shown below will be generated as a result.

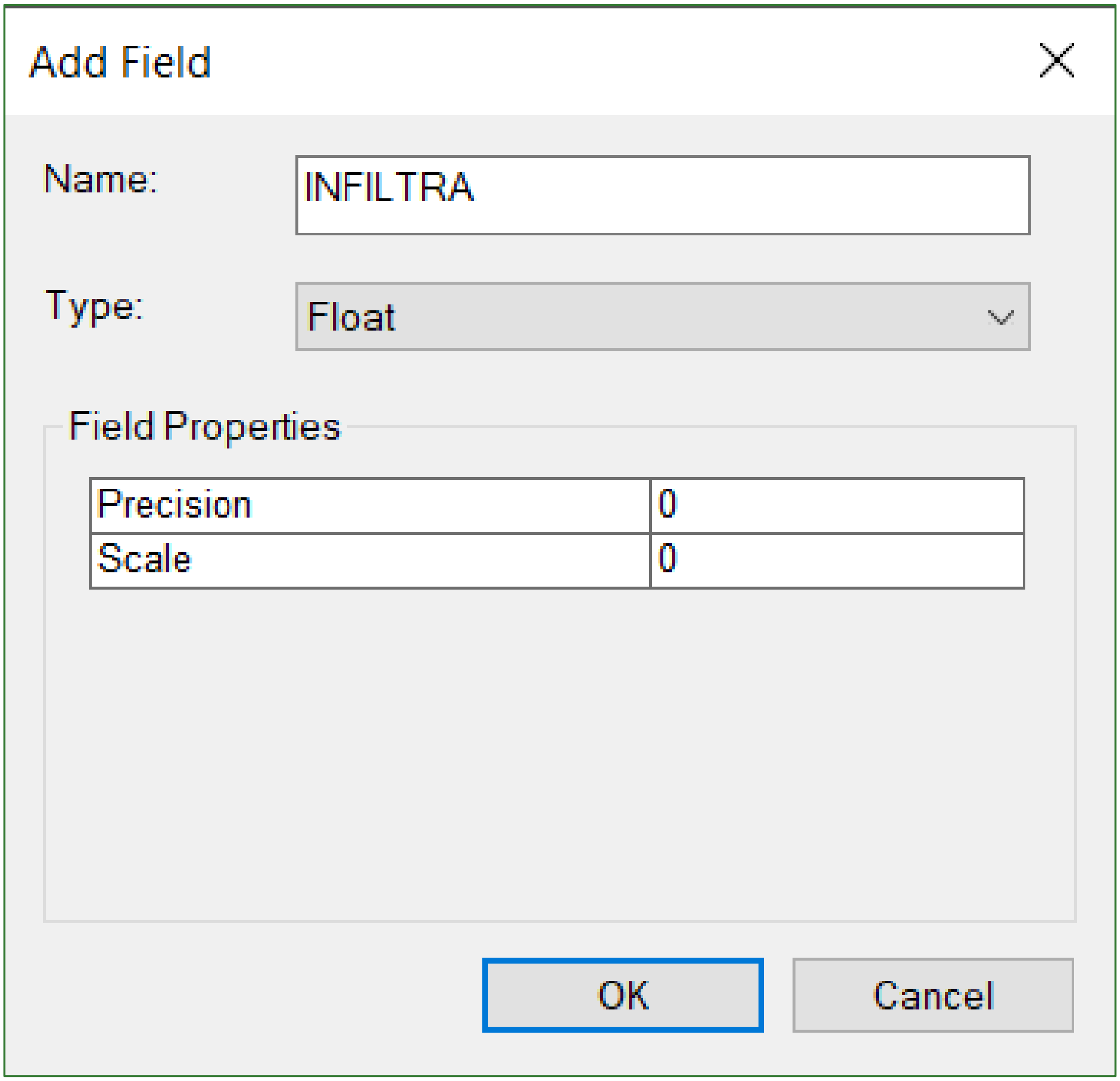
Table

infiltracion_mm_zonal

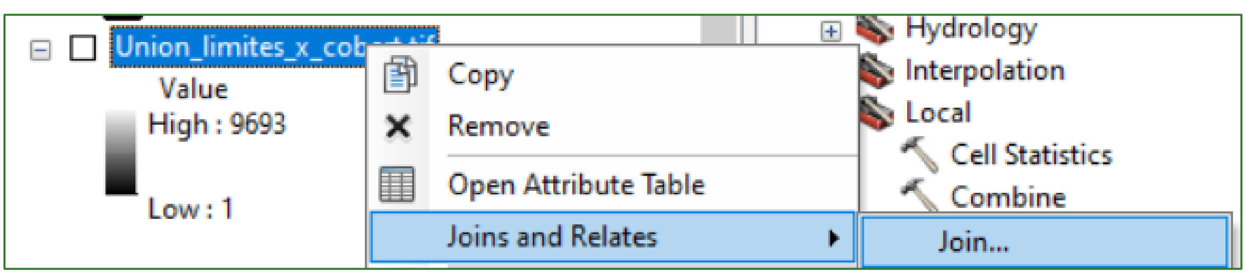
Rowid	ID_UNIXCOB	COUNT	AREA	MEAN
1	1	3380	19285.208208	0.155604
2	3	128	730.327411	0.140718
3	4	149420	852543.139187	0.200876
4	5	32665	186376.131987	0.300663
5	6	30	171.170487	0.225702
6	7	28	159.759121	0.22311
7	8	1	5.705683	0.172032
8	9	1325	7560.029845	0.234933
9	10	38	216.81595	0.239297
10	11	58113	331574.350472	0.23026
11	12	1798	10258.817857	0.148813
12	14	120	684.681948	0.212985
13	15	479785	2737501.071042	0.224594
14	16	16942	96665.679722	0.390573
15	17	5	28.528415	0.243194
16	18	3	17.117049	0.215001

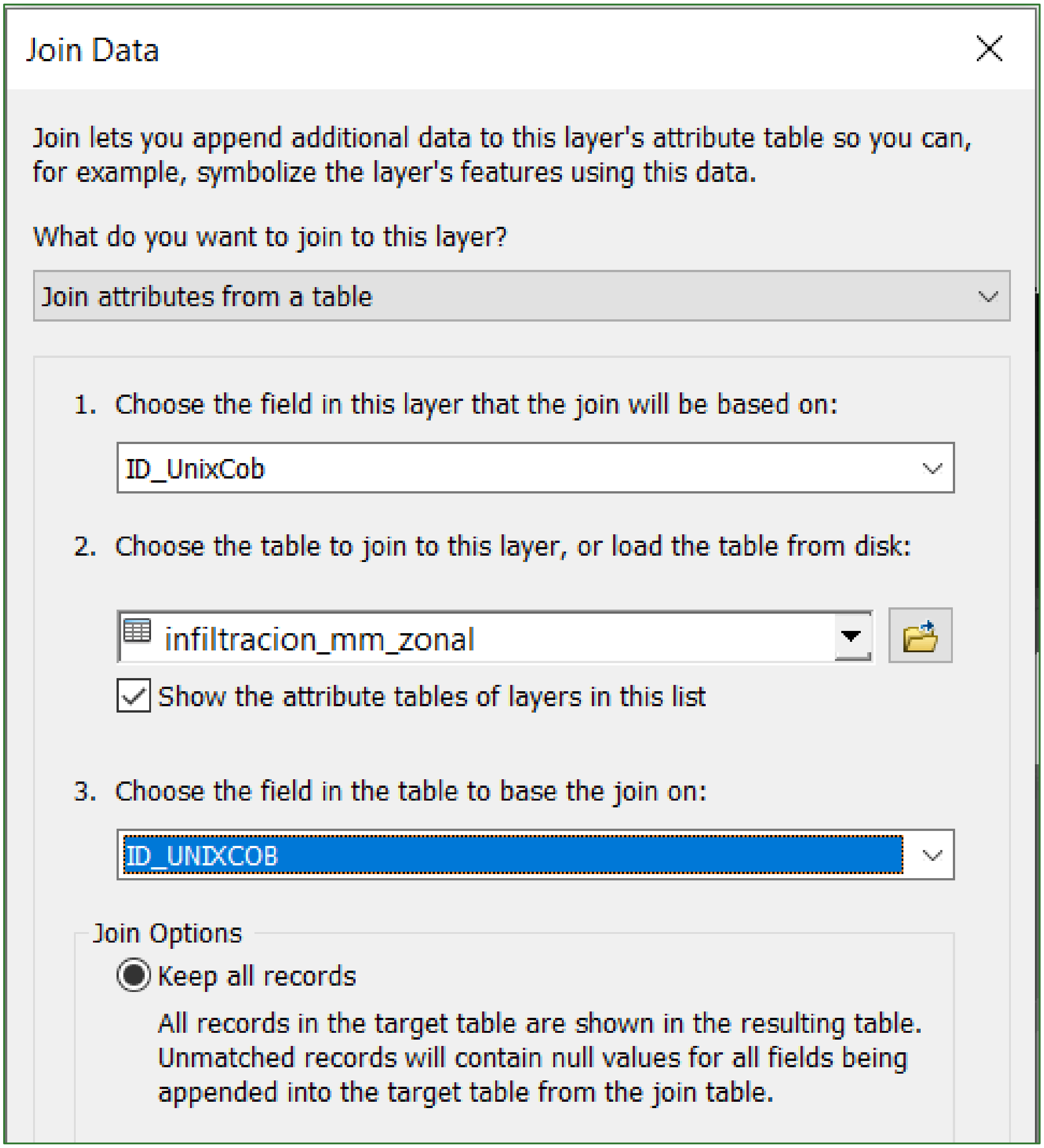
Follow the steps given below to transfer the variable data calculated to the union_limites_x_cobert.tif raster:

a) Add a field to the **Union_limites_x_cobert.tif** with the name of the float-type variable, e.g., INFILTRA.

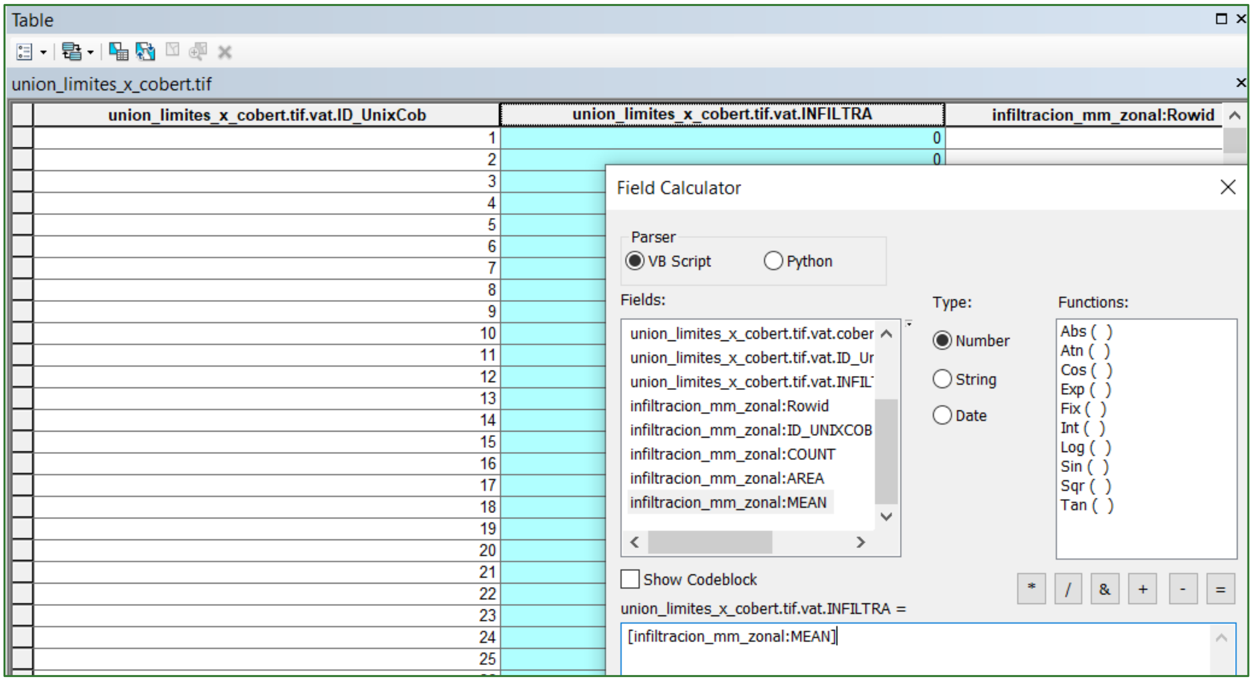


b) Right-click on the **Union_limites_x_cobert.tif** layer and select the **Join and Relates** option, then click on **Join.**

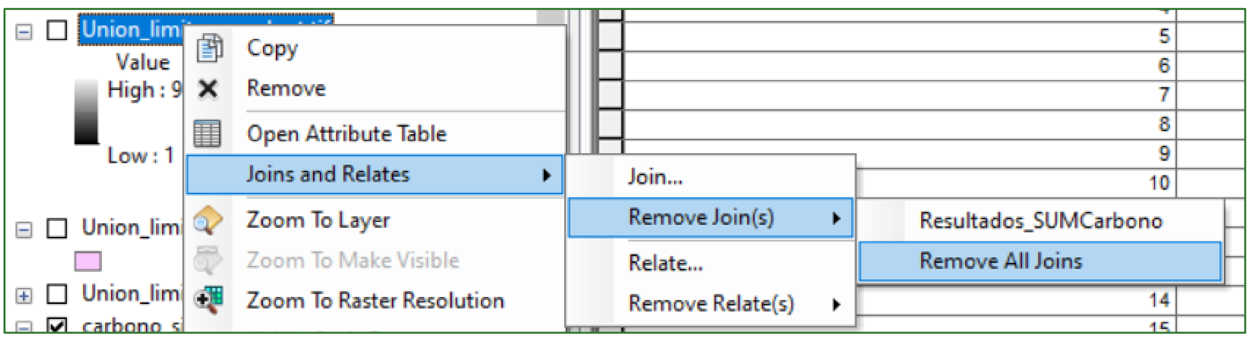




c) After completing the Join, transfer the values of the table containing the mean values to the variable field (e.g., INFILTRA).



d) Remove the Join



Repeat the above steps for the other variables.

Generating zonal statistics for political-administrative and territorial management units.

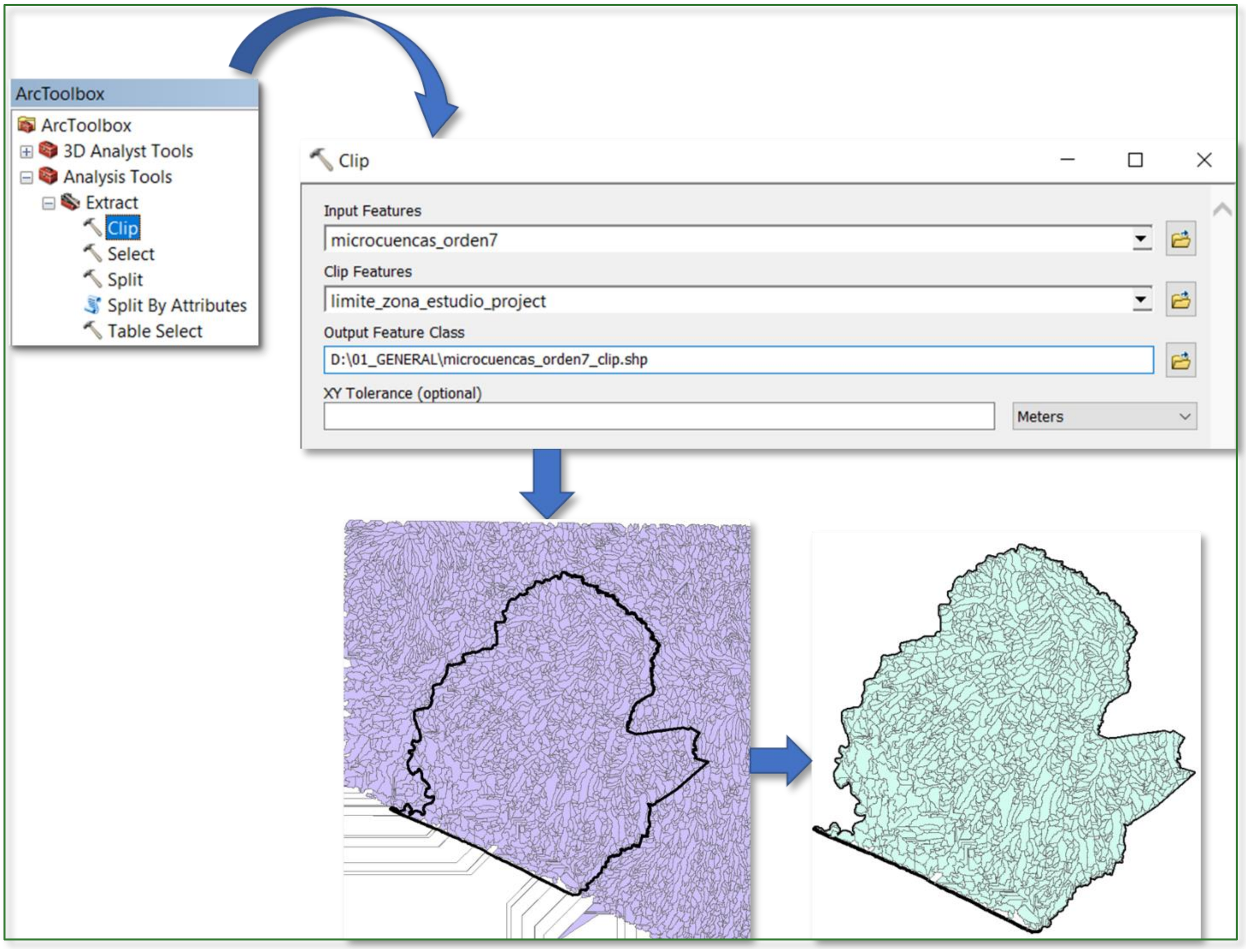
Step 5:

Use the **"Zonal Statistics"** tool located in **ArcToolBox/Spatial Analyst Tools/Zonal/Zonal Statistics.** Do the calculations for each of the final rasters using this tool. To generate summary rasters for political-administrative units (municipalities, villages) and for territorial management units (protected areas and micro-basins).

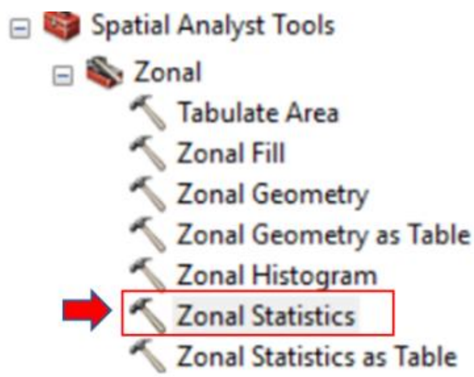
For example, follow the below steps to generate a water infiltration summary raster for an order 7 micro-basin:

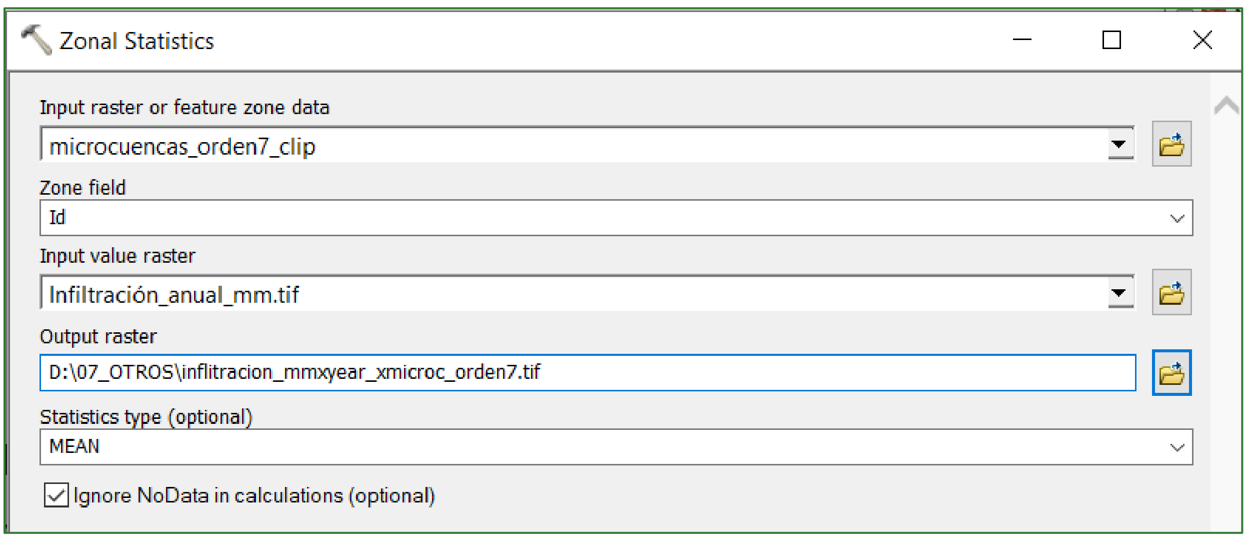
a) Add the microcuencas_orde7.shp and the **limite_zona_estudio_project.shp** shapefiles to the view.

b) Use the "Clip" tool located in **ArcToolBox/Analysis Tools/Extract/Clip** to cut the study limit area out from the order 7 micro-basins, naming it: **microcuencas_orden7_clip.shp** and save it in the **RESULTADOS/01_GENERAL** folder.



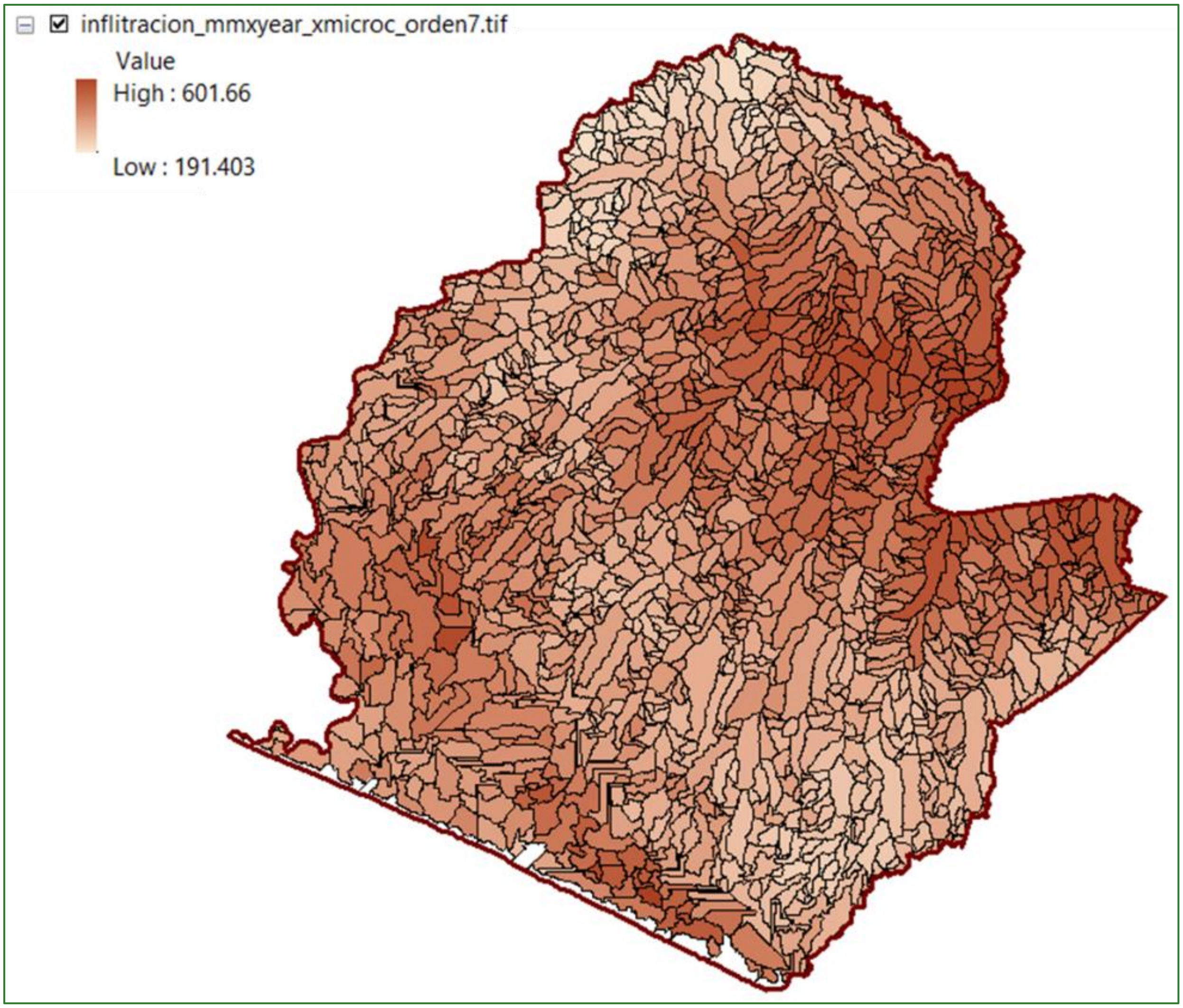
c) Run Zonal Statistics to obtain the mean of the **infiltración_anual_mm.tif** values for each **order 7 micro-basin in the microcuencas_orden7_clip.shp shapefile.** Use the micro-basin ID field to do the sum. Save the result in the **07_OTROS** folder naming it **inflitracion_mmxyear_xmicroc_orden7.tif**.





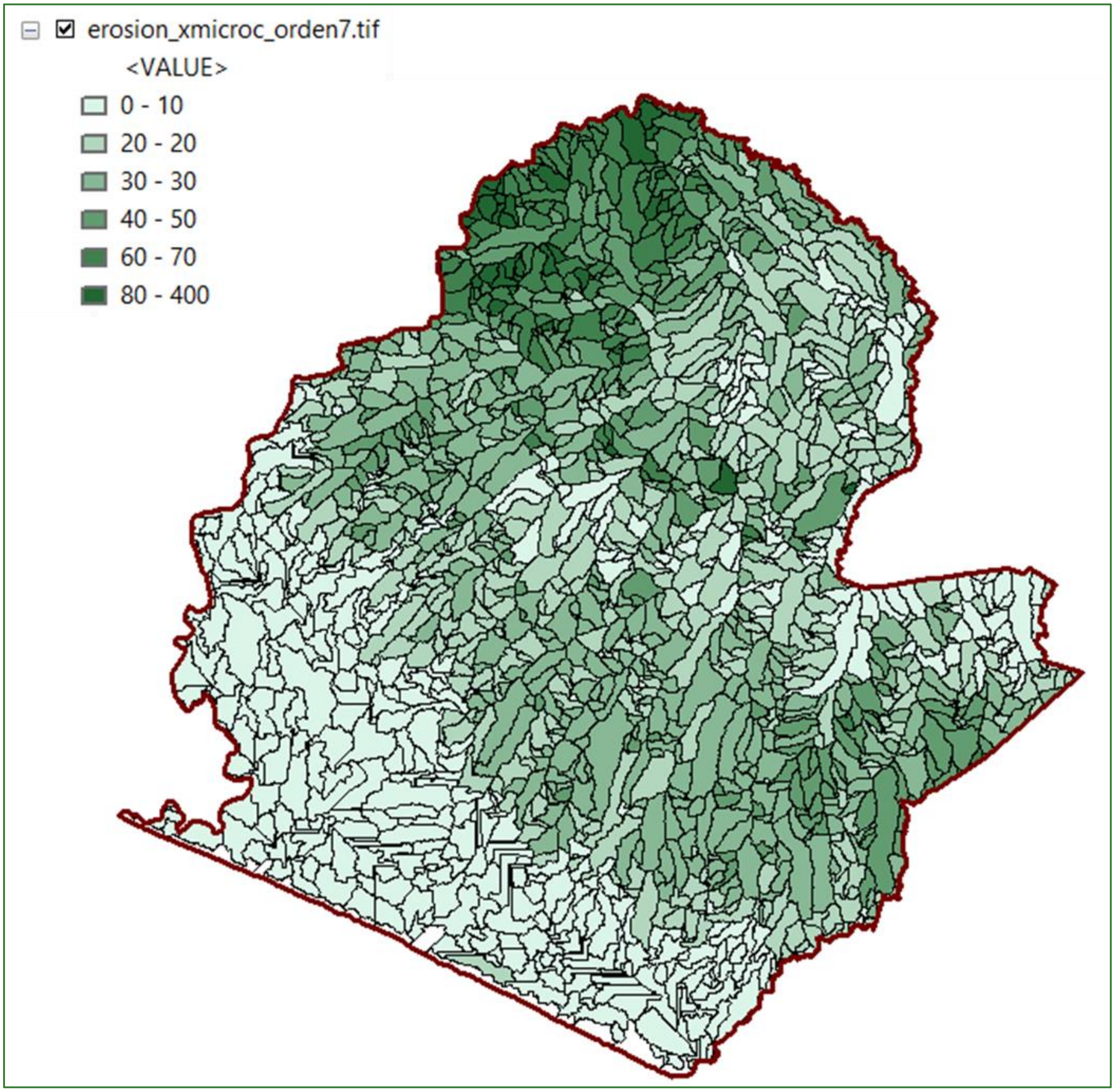
d) Lastly, if the territorial units are associated with a name (e.g. municipalities, villages, protected areas), run a **Join Field** to transfer the names to the raster created. This step does not apply to order 7 and 9 micro-basins because they are not associated with any name.

The process will result in the infiltration mean being displayed in mm/year for each order 7 micro-basin.

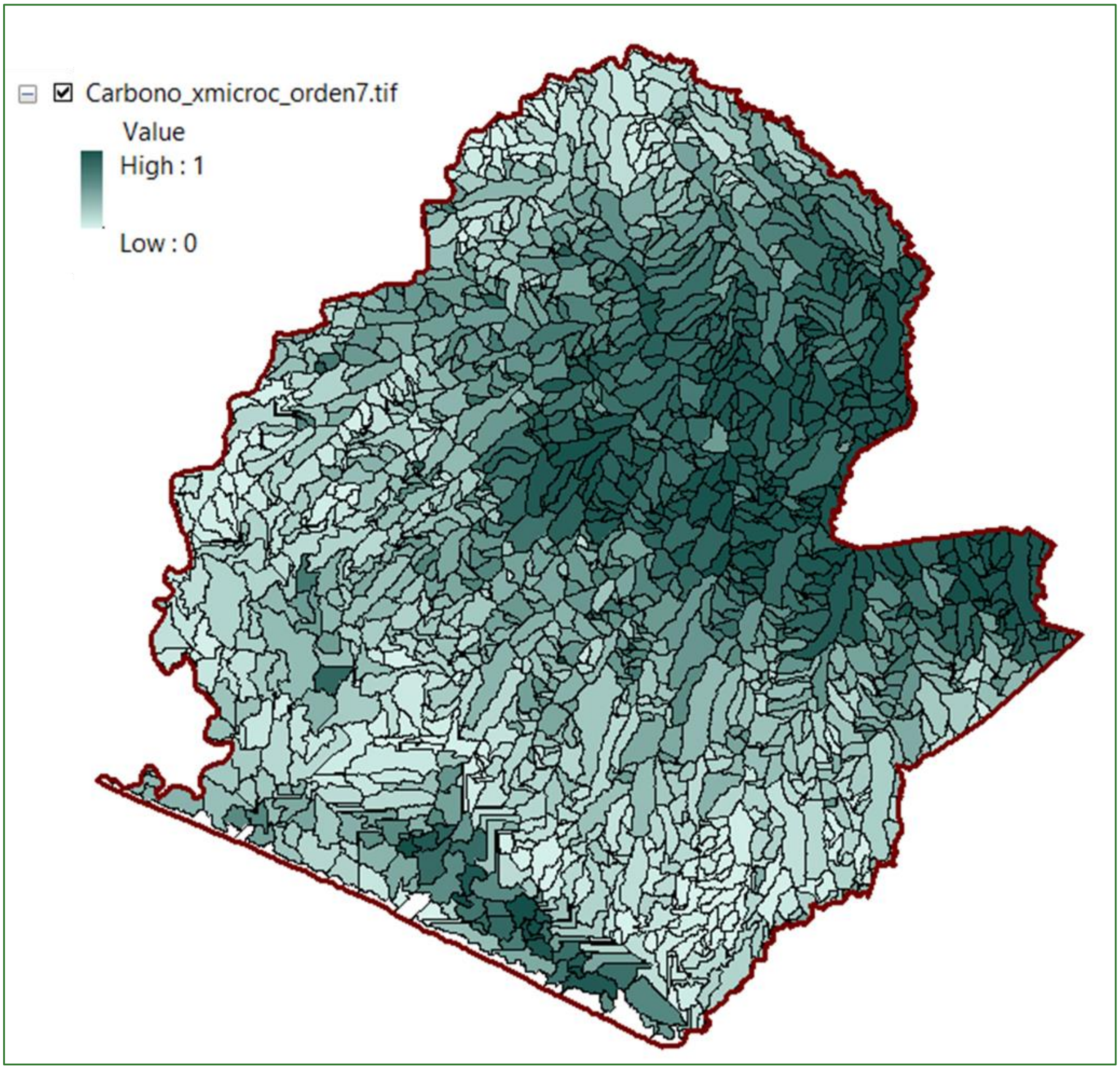

inflitracion_mmxyear_xmicroc_orden7.tif
Value
High : 601.66
Low : 191.403

Repeat the procedure for the following rasters:

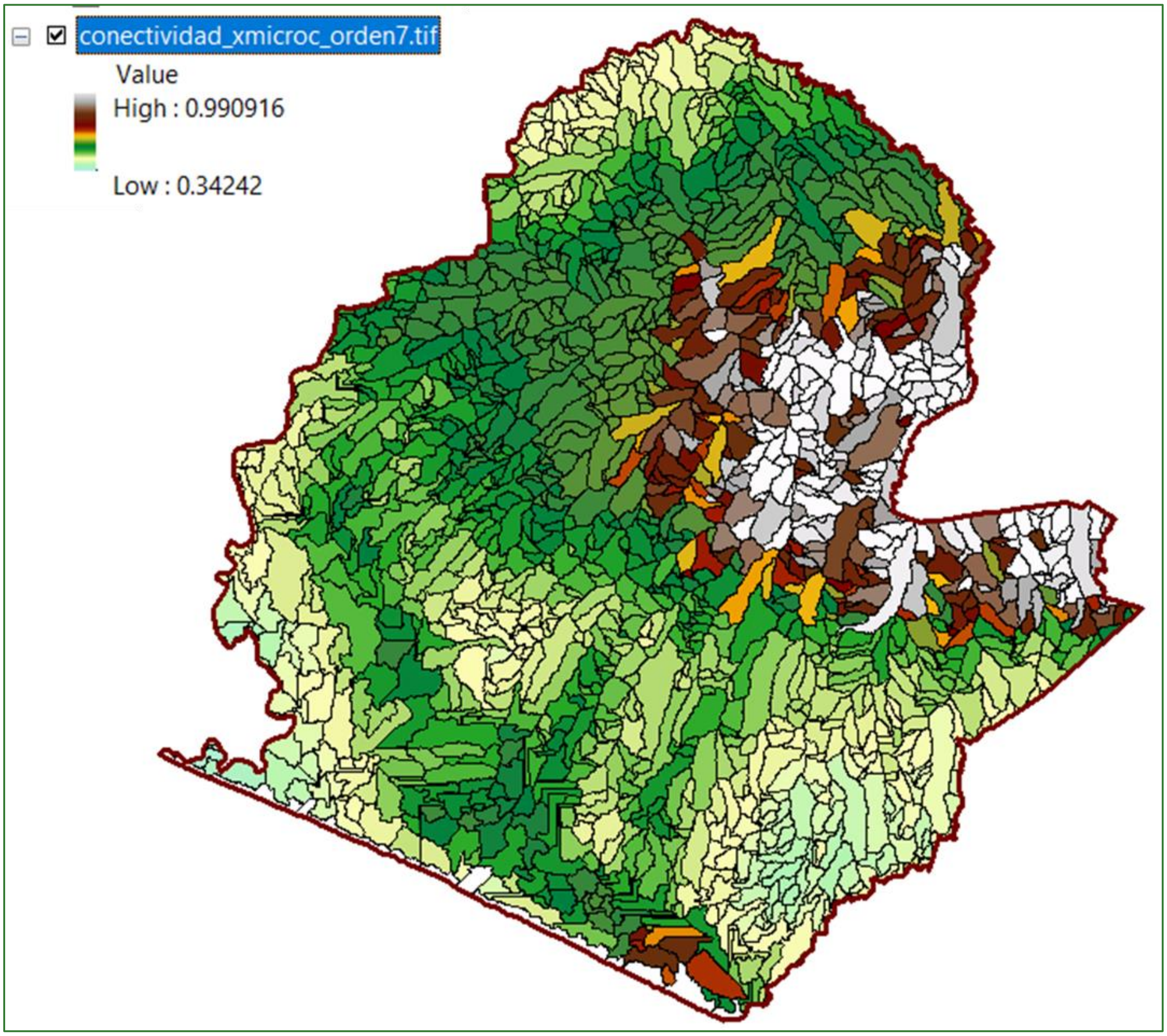
Data zone feature	Zone field	Input value raster	Output raster	Statistics
microcuencas_ orde7_clip	Id	Erosion_ton_ha_year_ajustado.tif	Erosión_ton hayear_mic7	MEAN



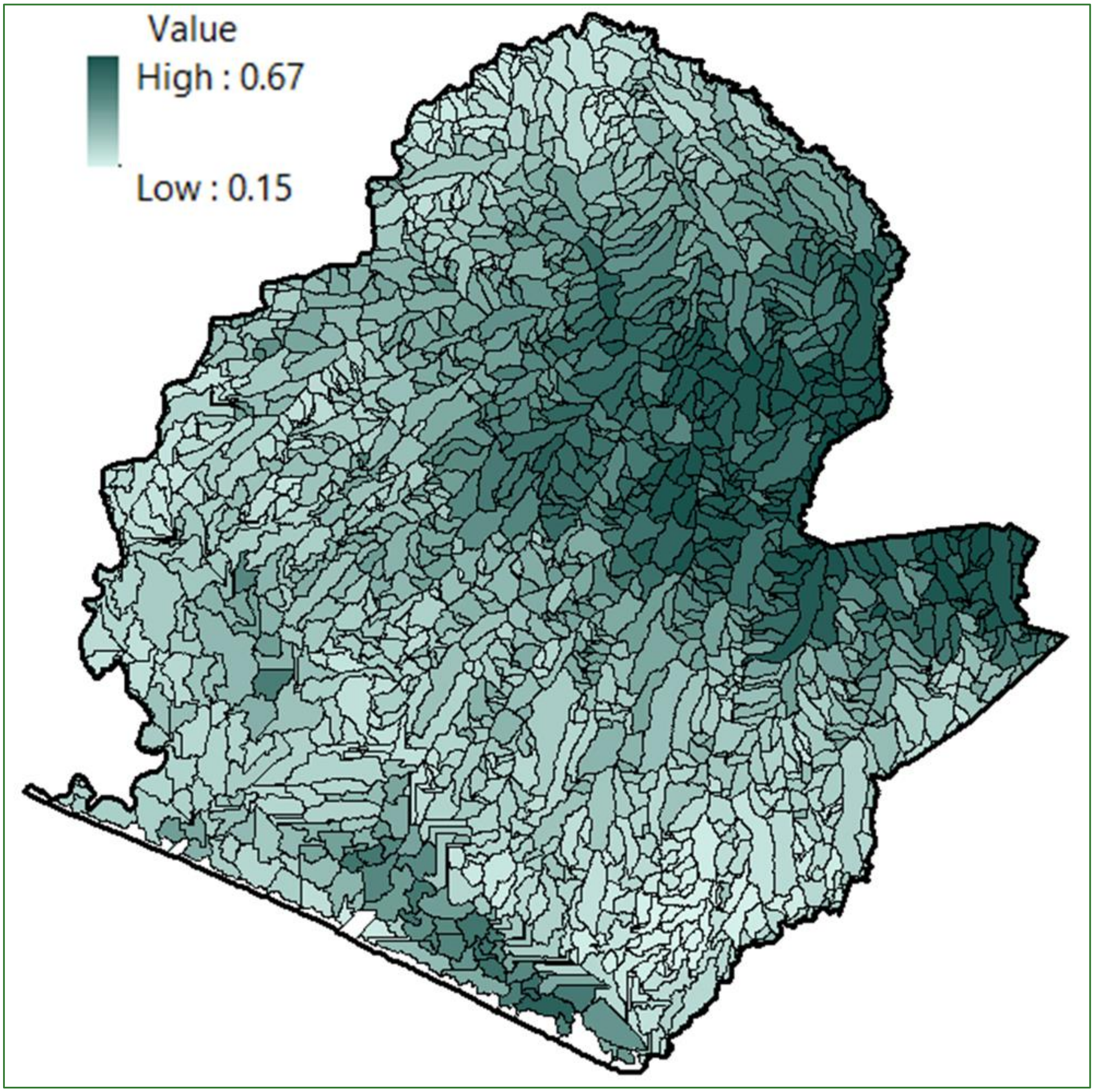
Data zone feature	Zone field	Input value raster	Output raster	Statistics
microcuencas_ orde7_clip	Id	carbonoxha.tif	Carbono_ tonha_mic7	MEAN



Data zone feature	Zone field	Input value raster	Output raster	Statistics
microcuencas_orde7_clip	Id	indice_conectividad.tif	Conect_mic7	MEAN



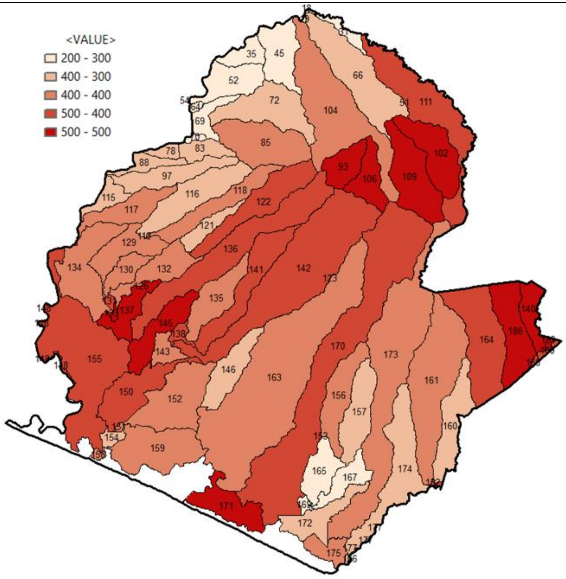
Data zone feature	Zone field	Input value raster	Output raster	Statistics
microcuencas_ orde7_clip	Id	Ind_ServiciosEcost.tif	IndServEcos_ mic7	MEAN



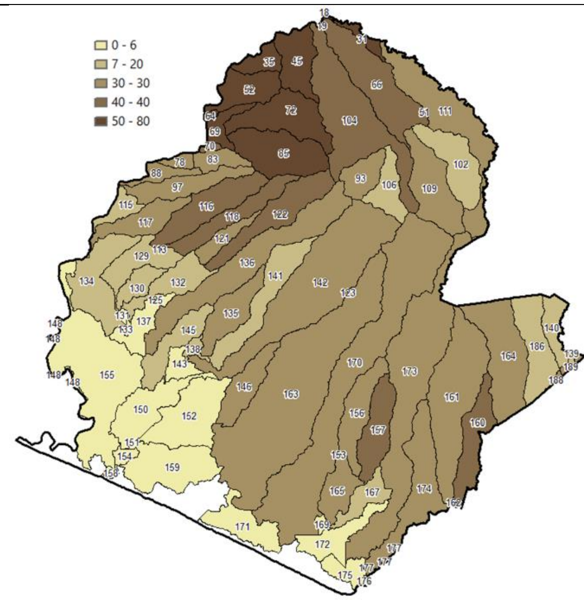
e) You can also run "Zonal Statistics" for order 9 micro-basins and to generate summary rasters for territorial units such as protected areas, micro-basins, municipalities and villages.

Example of a value summary by order-9 micro-basin

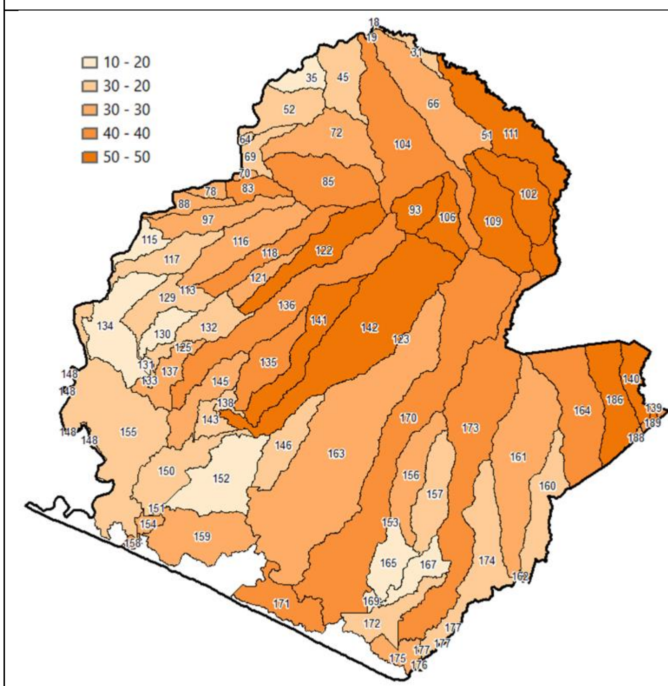
Infiltration in mm/year: Order 9 micro-basins



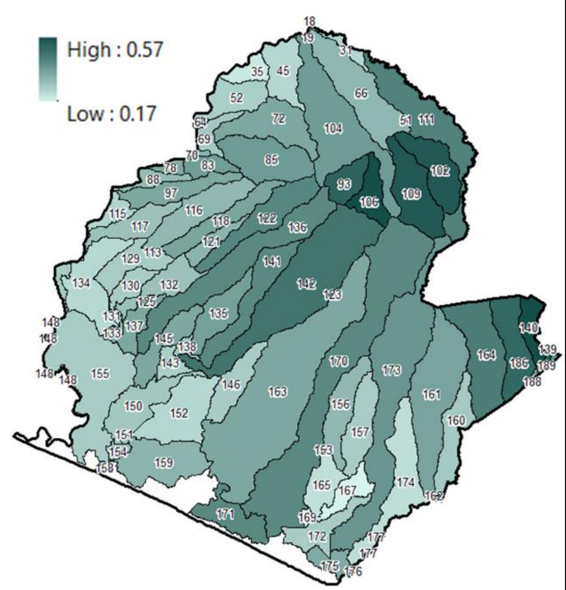
Erosion in tonne/year: Order 9 micro-basins



Carbon in ha/year: Order 9 micro-basins

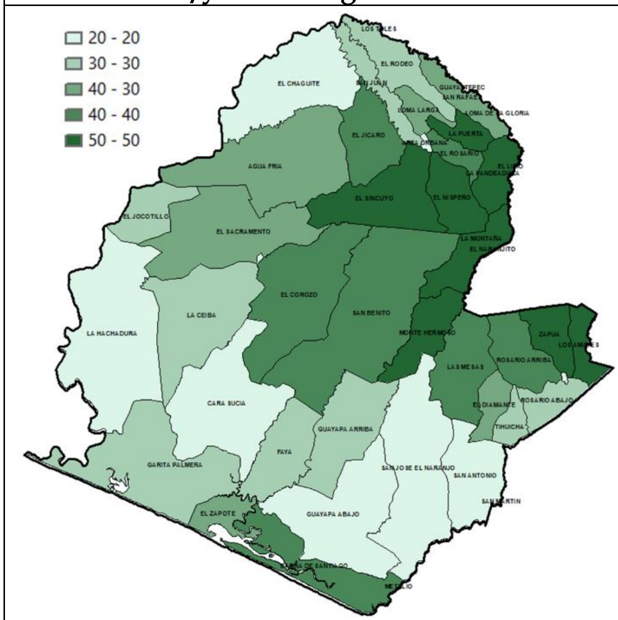


Ecosystem Services Index: Order 9 micro-basins

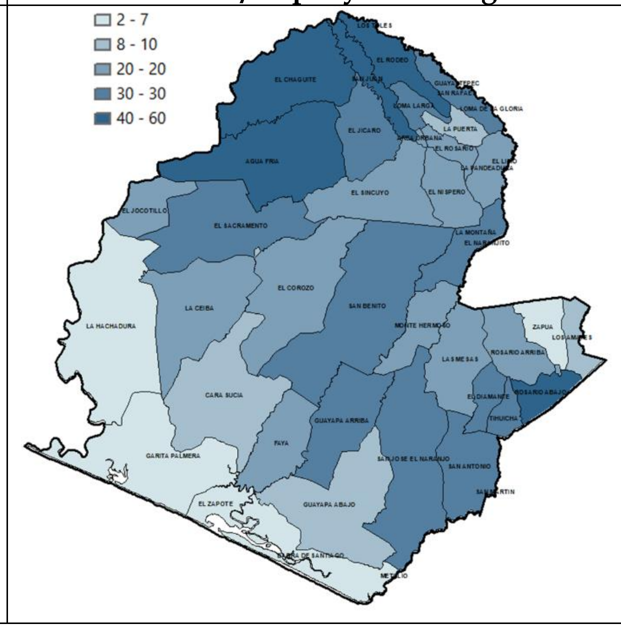


Example of value summary by village

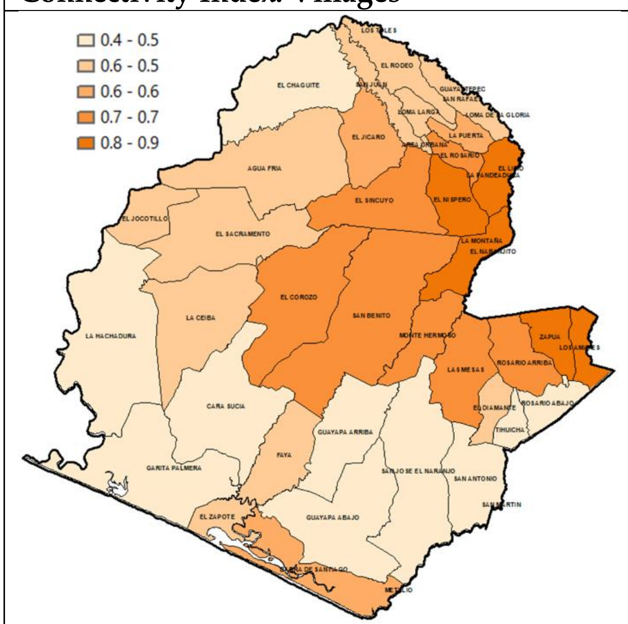
Carbon in ha/year: Villages



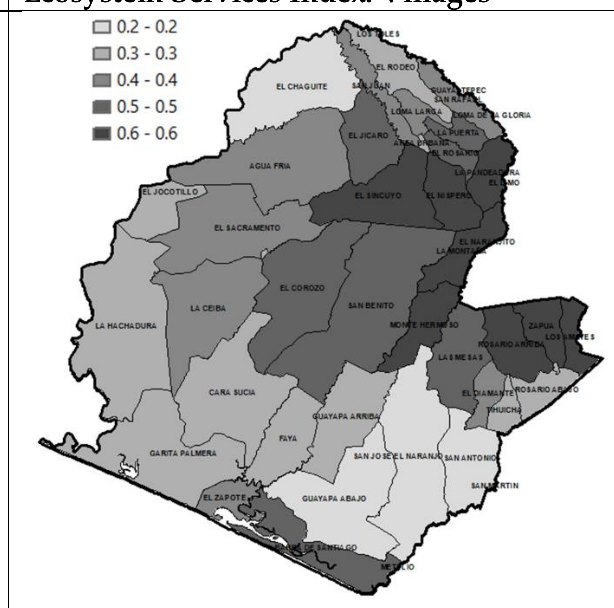
Erosion in tonne/ha per year: Villages



Connectivity Index: Villages

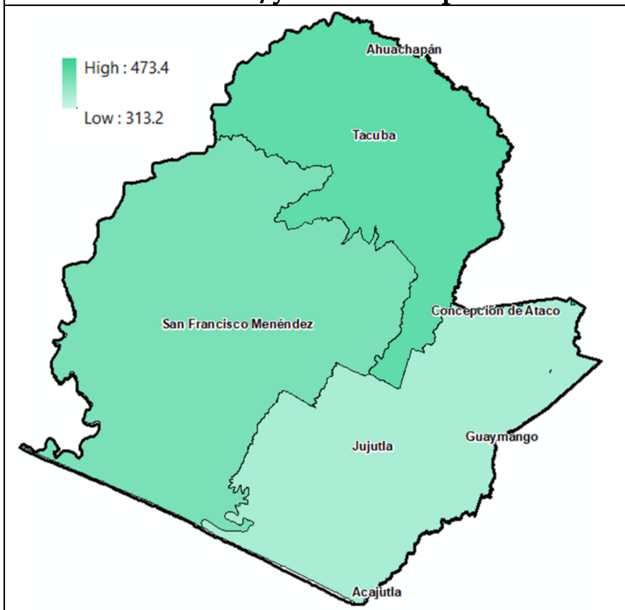


Ecosystem Services Index: Villages

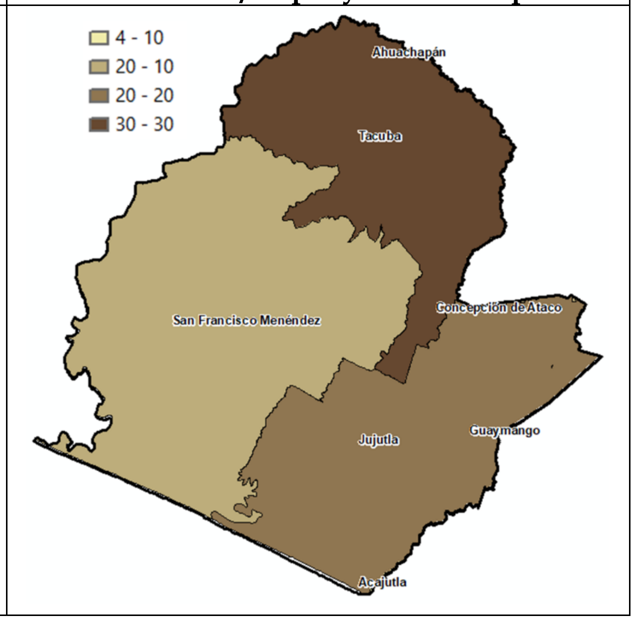


Example of value summary by municipality

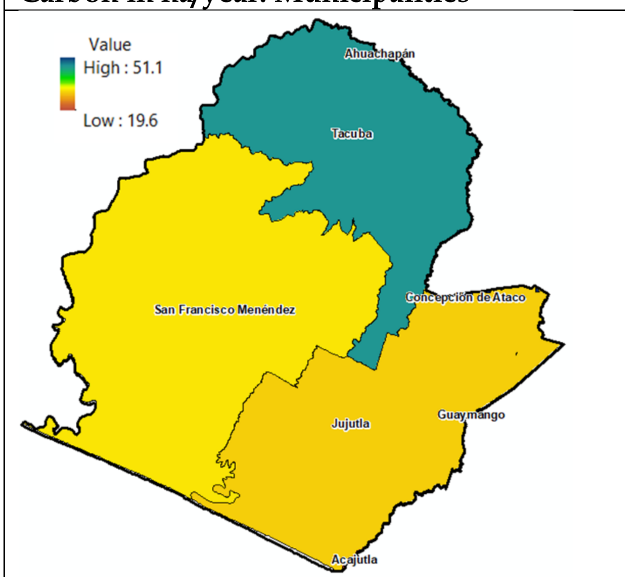
Infiltration in mm/year: Municipalities



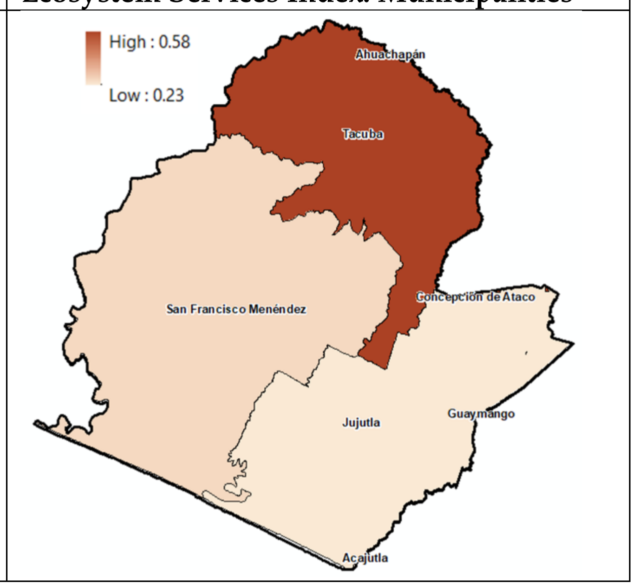
Erosion in tonne/ha per year: Municipalities



Carbon in ha/year: Municipalities



Ecosystem Services Index: Municipalities



Annexes

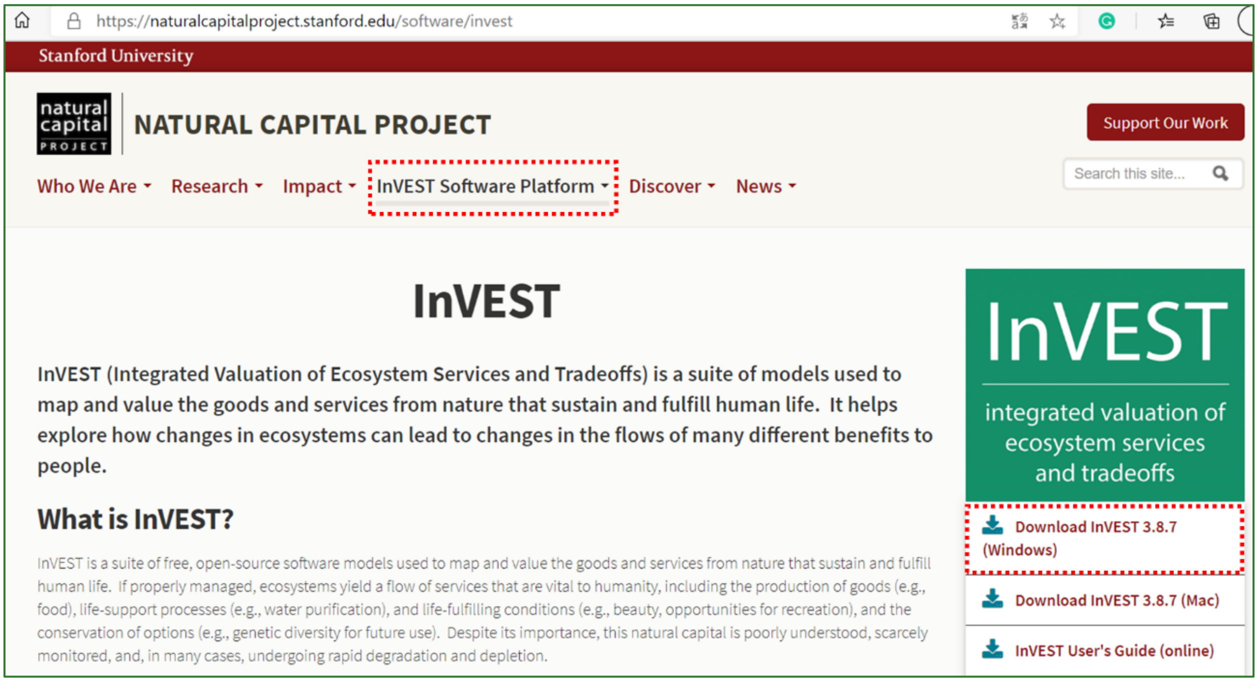
Annexes

Annex 1. Obtaining the carbon map using the forest edge method

Software to be used:

- ArcGis 10.x + Spatial Analyst Extension
- InVEST v3.7

Download and install InVEST from the following link: https://naturalcapitalproject.stanford.edu/



The steps to generate the carbon raster considering the forest edge are explained below.

1. Complete table[6] forest_edge_carbon_lu_table.csv ” located in the **INPUT** folder, filling the fields as indicated below:

[6] Tabla Forest_edge_carbon_lu_table.csv available at: https://www.dropbox.com/s/1zcj3eitb41hbrf/forest_edge_carbon_lu_table.csv?dl=0

lucode: cover type code that matches the "Value" field in the raster obtained in the section on obtaining the carbon map called **mapa_carbono.tif** located in the **01_CARBONO/Mapa_Carbono** folder.

is_tropical_forest: assign a value of "1" for the categories that correspond to forest and "0" for no-forest.

c_above: enter the aboveground carbon density values for each type of cover.

c_below: if you have belowground carbon pool values (roots), enter them here. If not, enter n/a.

c_soil: if you have soil carbon pool values, enter them here. If not, enter n/a.

c_dead: if you have dead matter carbon pool values (deadwood + dead leaves), enter them here. If not, enter n/a.

Description: enter the name of each cover map class here.

Example:

	A	B	C	D	E	F	G
1	lucode	is_tropical_forest	c_above	c_below	c_soil	c_dead	Description
2	1	1	76.69	n/a	n/a	n/a	Arboreo
3	2	0	58.48	n/a	n/a	n/a	Arbustivo
4	3	0	10	n/a	n/a	n/a	Agricola
5	4	0	0	0	0	0	Urbano
6	5	0	0	0	0	0	Humedal
7	6	0	0	0	0	0	Agua

2. Go to the InVEST 

module and specify the files and values requested as indicated below:

   Workspace: indicate the file where outputs will be saved, which is 01_CARBONO/Mapa_Carbono for this exercise.

   Result suffix: a suffix that will identify the output raster. For example, here you can enter the suffix that identifies the country or study area.

Land-Use/Land-Cover Map: enter the 01_CARBONO/Mapa_Cobertura/cobertura_project.tif cover types raster.

Biophysical table: enter the forest_edge_carbon_lu_table.csv table from the INPUT folder.

Carbon Pools to Calculate: indicate if you want to calculate all the carbon pools or just the aboveground one. If there is only aboveground carbon data, select the **"above ground only"** option.

Compute forest edge effects: if you select this option, the carbon map will be generated considering the edge effect. This calculation will use the models developed by Chaplin-Kramer et al. (2015) in which it is considered that applying a homogenous carbon factor to a forest area overestimates the carbon because it has been shown that the carbon storage degrades at the borders where the carbon stock is lower in comparison to the forest core.

Global forest carbon edge regression models: add the shapefile containing the regression models' parameters that will be used to model the forest edge. This file[7] is located in the **INPUT** folder and is called:
forest_carbon_edge_regression_model_parameters.shp.

Number of nearest model point to average: indicate the number of regression models nearest to the study area that will be used to do the calculation considering the forest edge. If you use the value 1, the nearest model will be used; if you use more than 1 model the result will smooth the variation between pixels to a greater degree.

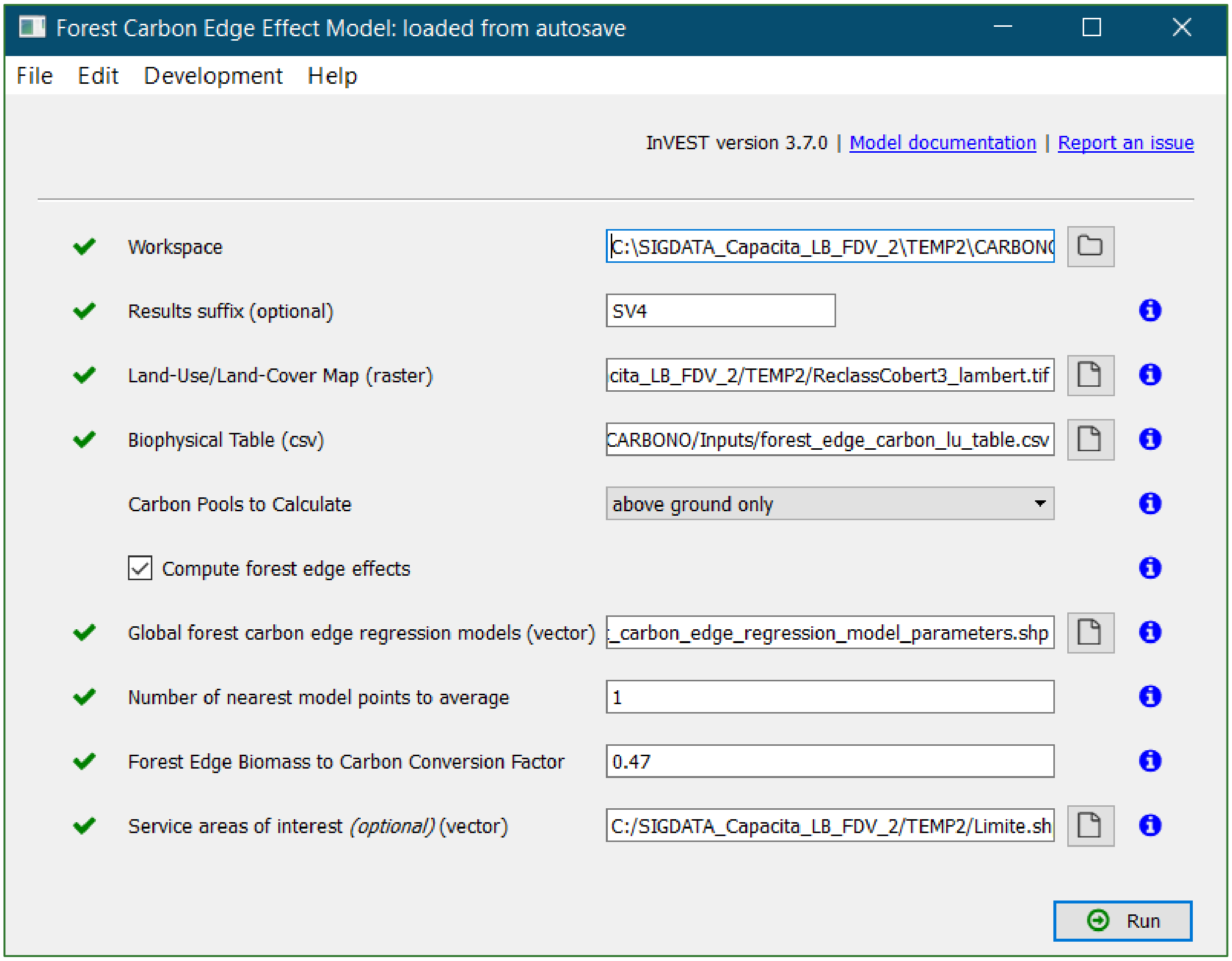
Forest Edge Biomass to Carbon Conversion Factor: even though the table data to do the calculation are valued in terms of carbon, the regression models to calculate the forest edge are biomass-based. Accordingly, a biomass conversion factor to carbon is required. The default value is 0.47 (according to IPCC 2006).

Service areas of interest: enter the study area shapefile for which the total carbon stock will be added up. In this exercise it corresponds to the following file:
01_CARBONO/Zona_Estudio/ lim_zona_estudio_project.shp.

3. Run the model by clicking on Run

---

[7] File available in:



4. Use ArcGis to explore the outputs that have been saved in the following folder:
5. 01_CARBONO/Mapa_Carbono

The output raster contains the carbon value per pixel (not per hectare).

6. Of the outputs, the one of interest in this case is the **tropical_forest_edge_carbon_stocks**, which contains the carbon estimate using the model developed by Chaplin-Kramer et al. (2015). Nevertheless, in this case, we are interested in the values being adjusted to local values, which explains why the InVEST output will be used to obtain a forest edge correction factor. Follow these steps:

a) Use the **non_forest_mask** raster and reclassify it to generate a forest mask.

Reclassification

Old values	New values
0	1
1	NoData
NoData	NoData

b) Use the Extract by Mask tool to cut out the **forest mask** from the **tropical_forest_edge_carbon_stocks** raster.

c) Next, generate a no-forest mask (as you did for the forest in point "a").

Reclassification

Old values	New values
0	NoData
1	0
NoData	NoData

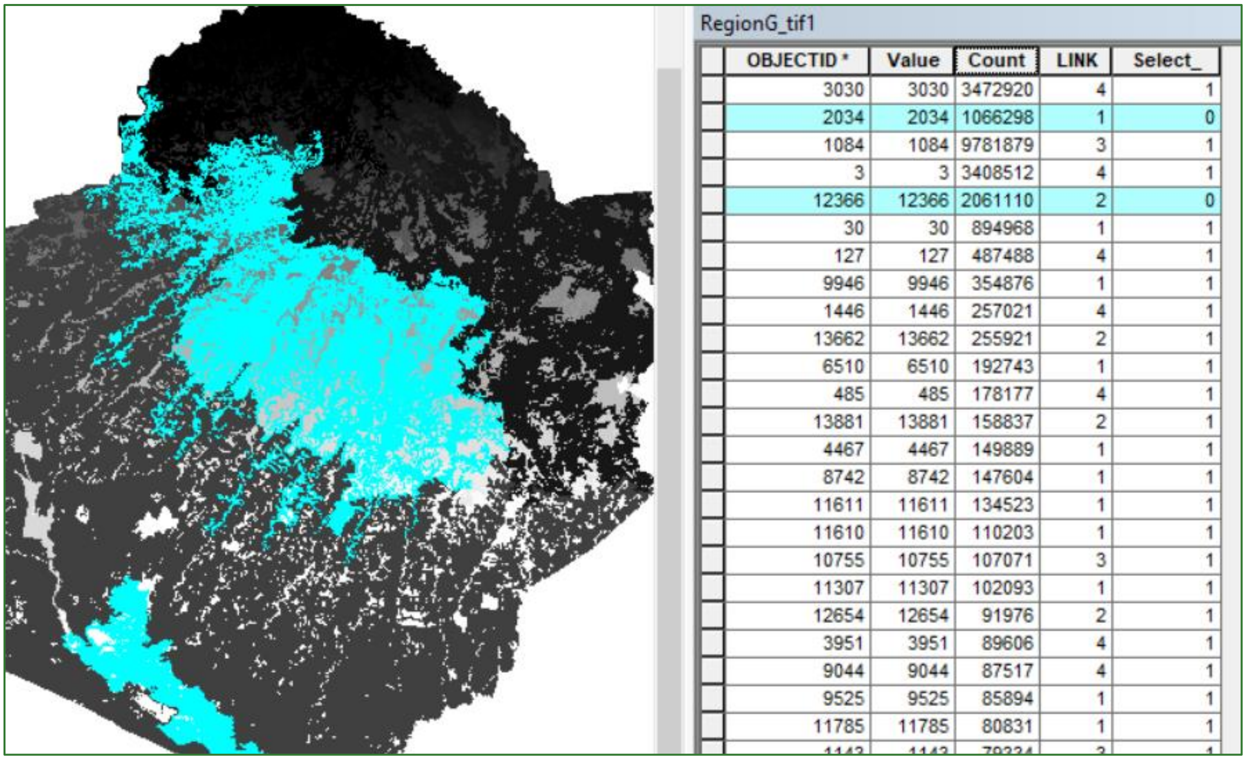
d) Use the **Mosaic to New Raster** tool to integrate the no-forest mask (point "c") with the raster output from point "b". Make sure to select 32_BIT_FLOAT as the **Pixel Type**. Name it **carbono_conborde_xpixel_original.**

e) Use the **Zonal Statistics** tool to get the maximum value of **carbono_conborde_xpixel_original** with respect to each type of cover (**raster cobertura_project.tif**).

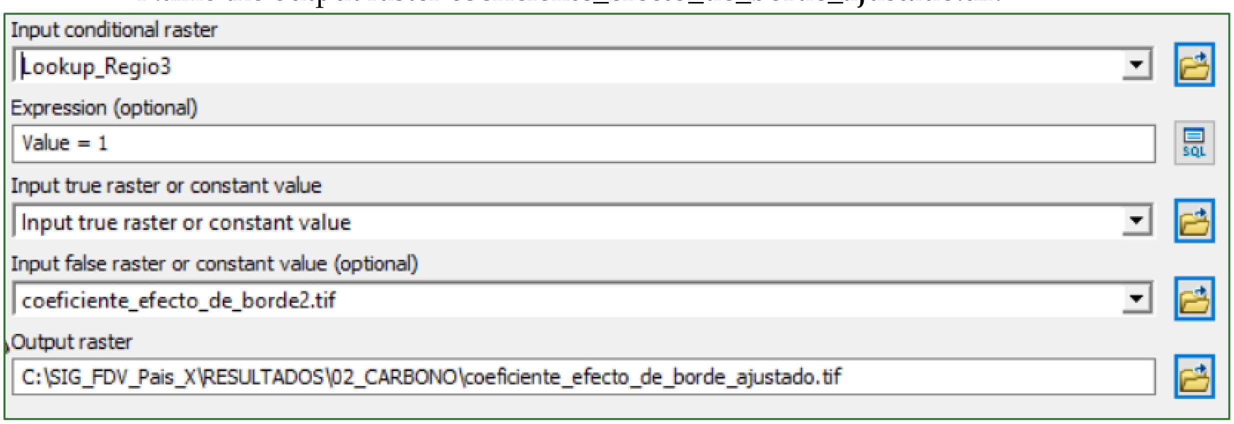
f) To obtain the correction factor using the map calculator, divide the raster obtained in "d" by the maximum value raster obtained in point "e". Name it **coeficiente_efecto_de_borde.tif.**

g) Generate a mask to indicate the types of cover to which the forest edge coefficient will not be applied. To this end:

- Use the Region Group tool (in Generalisation).
- In the output file order the records in descending order using the Count field.
- Add a new field and call it "Select".
- Select the polygons that need to be corrected.
- Then do a reverse selection and assign these entries a value of 1 in the Select field.
- Use the **Reclass/Lookup** tool to generate a new raster based on the Select field.



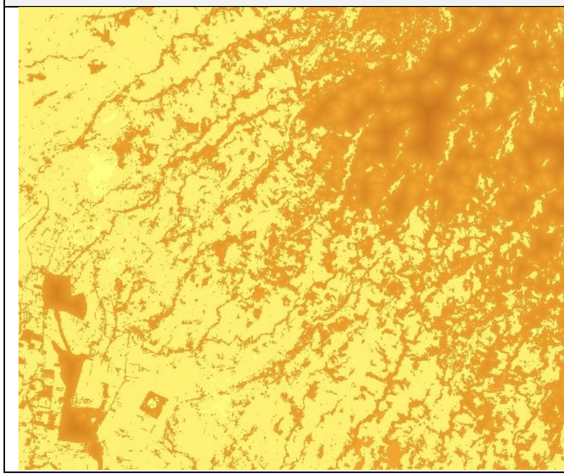
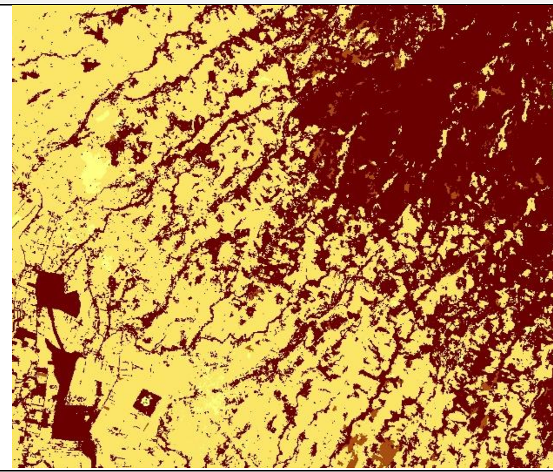
h) Use the conditional tool (Con) to generate a raster containing the correction values. Name the output raster **coeficiente_efecto_de_borde_ajustado.tif.**



i) Lastly, multiply the **coeficiente_efecto_de_borde_ajustado.tif** by the **carbono_sinborde_xpixel.tif** raster.

The output is a raster in which each pixel will contain the carbon value per pixel. To convert this to CxHa, you will need to apply the following formula = **"RásterCxPixel" * 10000 / "TamañoPixel"^2.**

An example of an output with and without the forest edge effect is shown below:

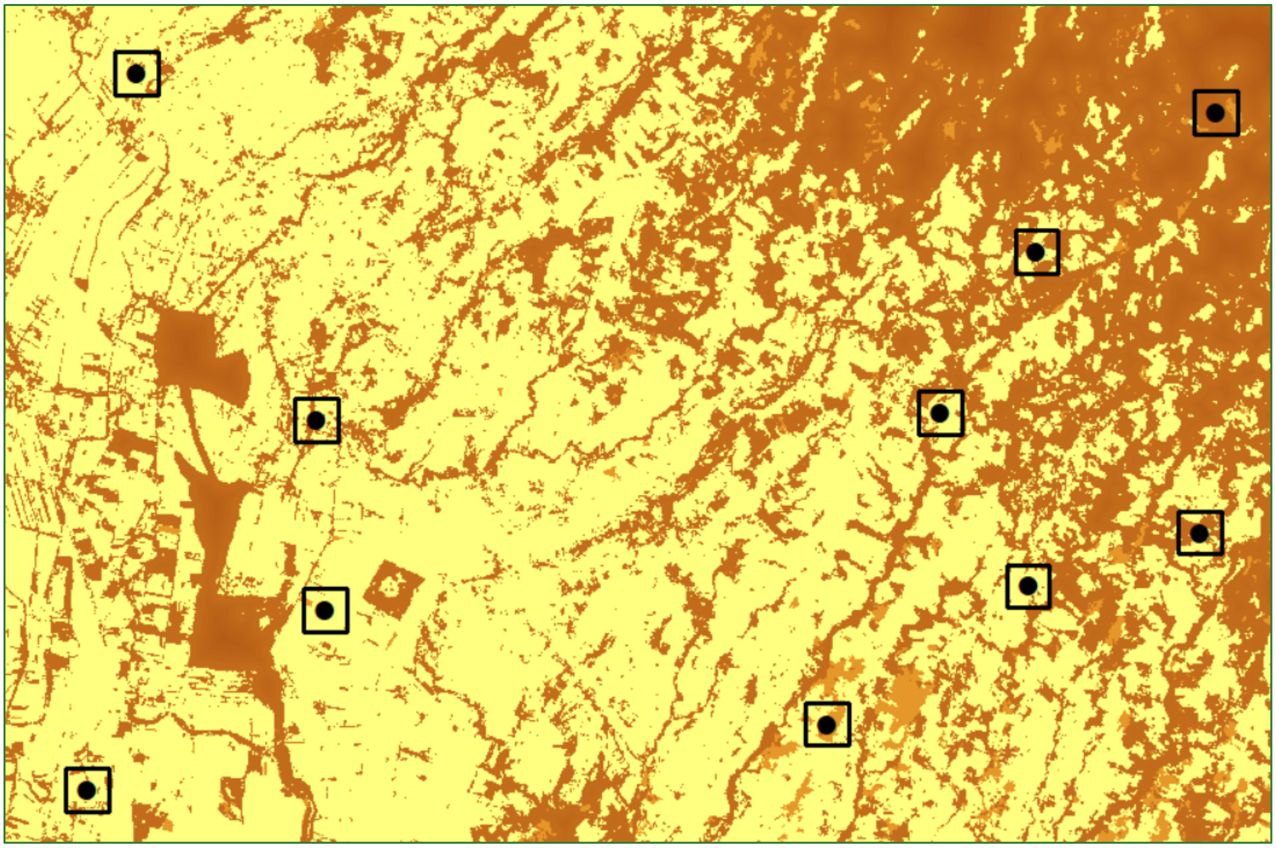
Considering the forest edge	Not considering the forest edge
	

7. If you think the forest edge effect is not as pronounced in your study area, you can do a calculation considering and not considering the edge effect and subsequently get a mean of both results using the **ArcGis Spatial Analyst Tools/Local/Cell Statistics** tool.

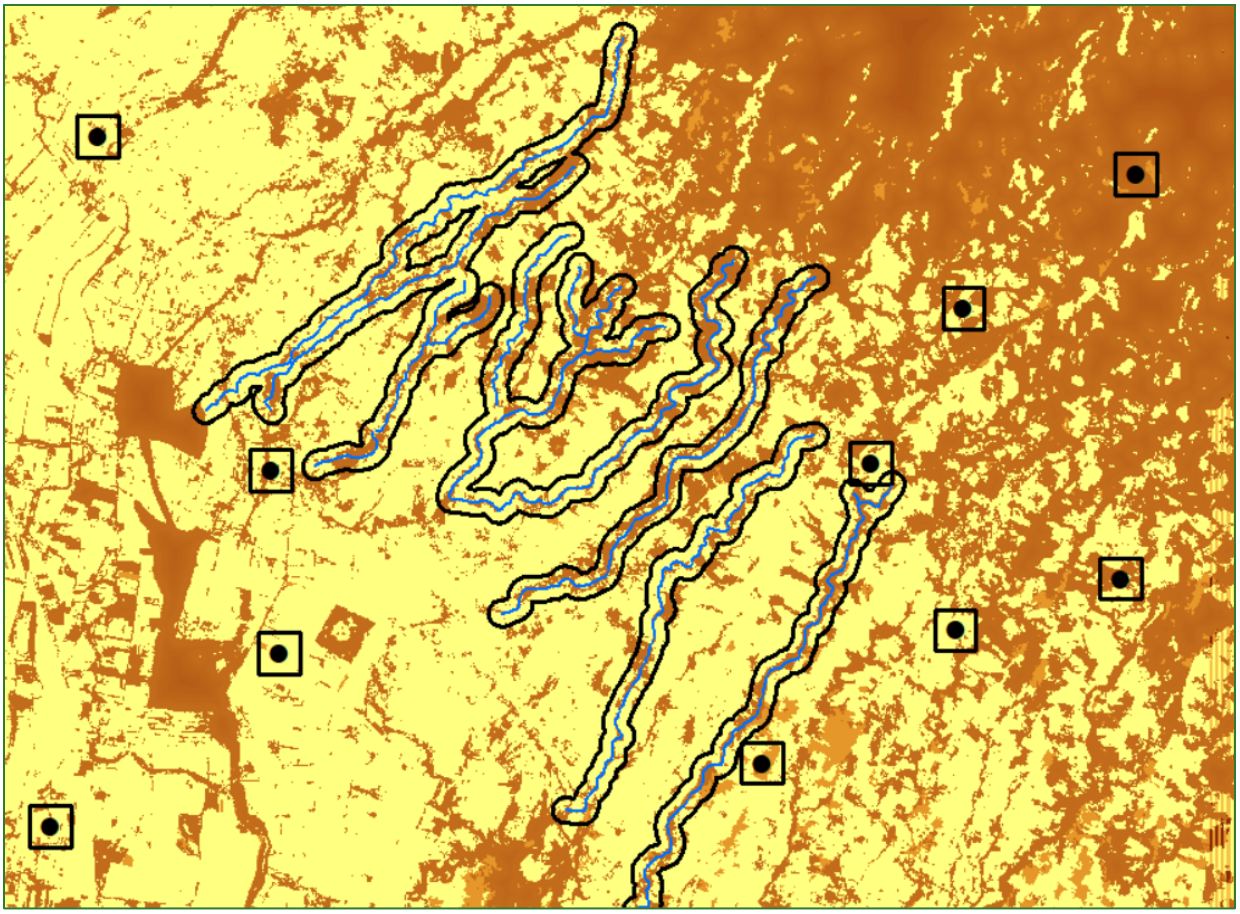
8. The resulting carbon map can be used to calculate the carbon stock in a plot, site or estate. Carry out the following procedure to simulate this calculation process:

   - Use the ArcGis **Data Management Tools/Sampling/Create Random Points** tool to generate a shapefile with random points.

   - Generate 250 x 250 m plots using the **ArcGis Analysis Tools/Proximity/Graphic Buffer** tool.



- If other types of intervention are envisaged for the project, for example, recovering riverbanks, you can generate a buffer around the elements to be conserved, protected and/or restored.



- To get a **table** of the total carbon inside each polygon to be worked on, get a **summary** of the values of all the pixels located in each polygon using the **Spatial Analyst Tools/Zonal/Zonal Statistics** as Table tool. Select the **SUM** option in the "Statistics type", ensuring that the **ZoneField** displays the ID that identifies each plot. Name the output table **CarbonoxParcela.dbf.**

- You can open the **CarbonoxParcela.dbf** table in Excel and save it as an XLS file for subsequent use in reports and to create graphs or do further calculations. For example, to convert **Carbon to CO_2 equivalent** you have to multiply the carbon value by 44/12 = 3.67.

- The Zonal Statistics as Table tool can be used at the plot or polygon intervention level to get another variable it has already calculated and which are in the RASTER folder, for example:

Variable	Raster	Operation
Mean altitude	MDT_Corregido.tif	MEAN
Mean slope in degrees	Pendiente_grados.tif	MEAN
Mean slope in percentage	Pendiente_porcentaje.tif	MEAN

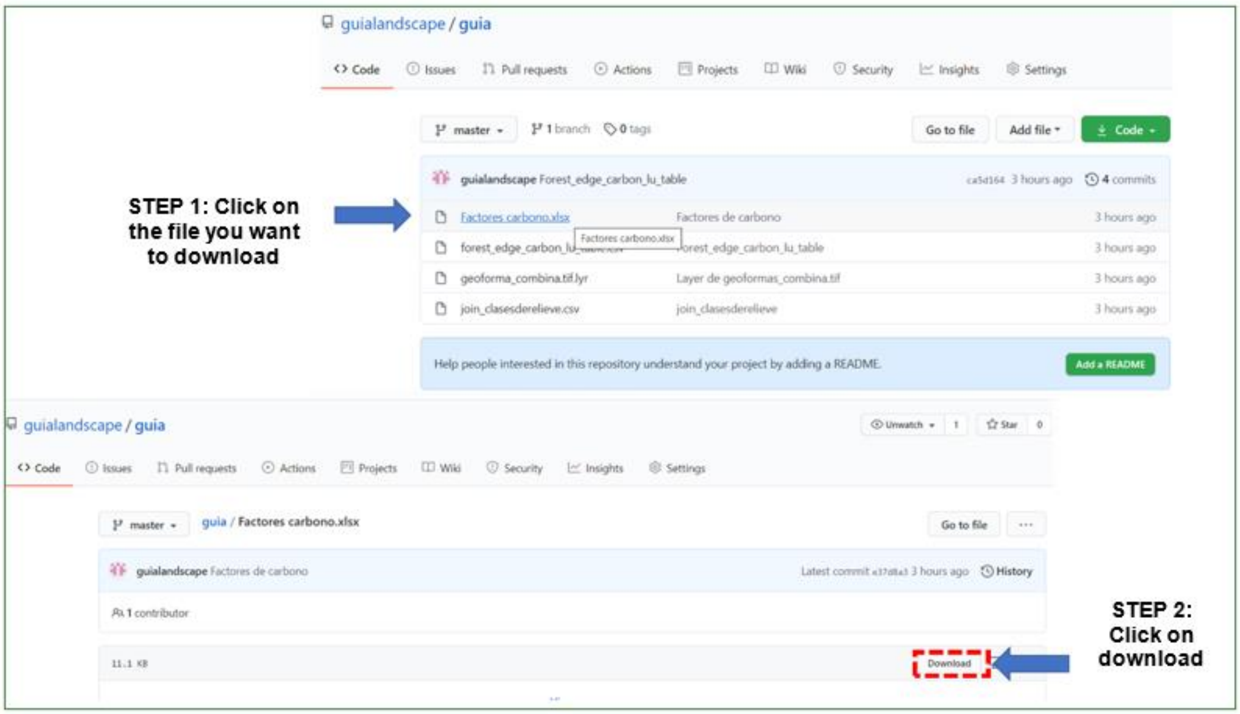
Variable	Raster	Operation
Predominant relief type	geoforma_combina.tif	MAJORITY
Predominant type of cover or use	Cover map	MAJORITY

- Finally, you can project the carbon increase in each polygon by assigning an annual carbon rise for each practice and multiplying it by the number of years. It is easiest to do this calculation in Excel. As a reference for the annual increase in carbon by type of practice you can use the values in the **FLR Carbon Storage Calculator** tool at: https://www.winrock.org/flr-calculator/

Annex 2. Baseline document structure

To maximise the use of this methodological guide, an online repository has been created on the GitHub where you can access tables, layers and models built using the ArcMap "Model Builder" for modules like hydrology and erosion. Moreover, there are different Excel spreadsheets available that are used in the water infiltration module.

The online repository address is as follows: https://github.com/guialandscape/guia



Annex 3. Baseline document structure

1. GENERAL DESCRIPTION OF THE PROJECT AREA

1.1 Location of the project area

- Map indicating political-administrative units.
- List (or mention) of small towns or their equivalent (villages, cantons, etc.)

1.2 Protected areas and Tree Cover

- Map of cover + protected areas.
- NDVI map.
- Tree cover surface area table by political-administrative unit.
- List (or mention) of protected areas in the pilot zone.

1.3 Topography

- Landform Map (geomorphology).
- Elevation map.
- Slope map.
- Soil texture map.
- Water network and order 9 micro-basin map.

1.4 Climate

- Annual mean precipitation map.
- Annual mean temperature map.
- Annual mean evapotranspiration map.
- Annual Climatic Water Balance map.

2. FOREST CARBON

2.1 Introduction

- What it consists of and how to calculate it (summary of the methodology).

2.2 Carbon Stock Maps

- Map of mean carbon per ha.
- Map of carbon index by order 9 micro-basin.
- Map of carbon index by political-administrative unit.

2.3 Carbon Stock summary tables/graphs

- Table of carbon tonnes/ha by cover type (show CO_2 and biomass as well).
- Table of total carbon tonnes by political-administrative unit (show CO_2 and biomass as well).
- Summary graph of the carbon index by political-administrative unit.

3. INFILTRATION

3.1 Introduction

- What it consists of and how to calculate it (summary of the methodology).

3.2 Water infiltration maps

- Map of mean infiltration in mm/year.
- Map of infiltration index by order 9 micro-basin.
- Map of infiltration index by political-administrative unit.

3.3 Water infiltration summary tables/graphs

- Table of mean infiltration in mm by cover type.
- Table of total infiltration in m3 by political-administrative unit.
- Summary graph of the infiltration index by political-administrative unit.

4. EROSION

4.1 Introduction

- What it consists of and how to calculate it (summary of the methodology).

4.2 Potential erosion maps

- Map of mean erosion in tonnes/ha/year.
- Map of erosion index by order 9 micro-basin.
- Map of erosion index by political-administrative unit.

4.3 Potential erosion summary tables/graphs

- Table of mean erosion by cover type (tonnes/ha/year).
- Table of total erosion by political-administrative unit (tonnes/ha/year).
- Summary graph of the erosion index by political-administrative unit.

5. CONNECTIVITY

5.1 Introduction

- What it consists of and how to calculate it (summary of the methodology).

5.2 Landscape biological connectivity maps

- Map of target patches and optimum corridors.
- Map of connectivity index by order 9 micro-basin.
- Map of connectivity index by political-administrative unit.

5.3 Landscape biological connectivity summary tables/graphs

- Summary graph of the connectivity index by political-administrative unit.

5. INTEGRATED ECOSYSTEM SERVICES INDEX

5.1 Introduction

- What it consists of and how to calculate it (summary of the methodology).

5.2 Integrated ecosystem services index maps

- Single page map showing the different indices calculated.
- Map of integrated ecosystem services index.
- Map of integrated ecosystem services index by order 9 micro-basin.
- Map of integrated ecosystem services index by political-administrative unit.

5.3 Integrated ecosystem services index summary tables/graphs

- Integrated ecosystem services index summary graph.

Methodological guide for defining suitability indices for landscape restoration practices

Methodological guide for defining suitability indices for landscape restoration practices

Landscape restoration is a way of optimising land use, generally to return a landscape to a state in which it has a minimum set of biophysical features, for example, a clean water supply, the improvement of biodiversity or simply to return a very degraded place to an acceptable functionality level. The ecosystem does not necessarily have to try and resemble its original state.

Landscape restoration can be defined as a continuous process to regain the ecological functionality of landscapes and enhance human well-being. This process involves much more than mere tree planting. It seeks to restore ecosystem connectivity and functions across entire landscape to meet present and future needs, as well as to offer numerous benefits and land uses over time.

Primarily, this guide seeks to provide users with a methodology enabling them to promote the integrated restoration approach on a landscape scale. It is geared towards recovering the functionality of ecosystems and degraded land by improving ecosystem services and territorial as well as community resilience against the impacts of climate change.

This methodology aims to identify land suited for restoration by applying project-scale geospatial tools to analyse biophysical factors and resulting ecosystem services. For example, it takes into account ecological connectivity in the light of climate change. A set of analyses will be carried out to define several suitability indices, such as:

- Restoration of gallery forest
- Restoration of wood pasture
- Restoration of non-wood pasture
- Restoration of shade grown coffee
- Restoration of agroforestry
- Reforestation
- Restoration of secondary and degraded forests

N.B.: this guide to defining suitability indices for landscape restoration practices has been drafted using a project located in El Salvador as a sample case. Accordingly, when using it for another country, the specific basemaps and land use (in which pasture and agricultural categories are defined) for that country; a map in which forest gains are identified and a land cover map defining the classes of forest will have to be incorporated.

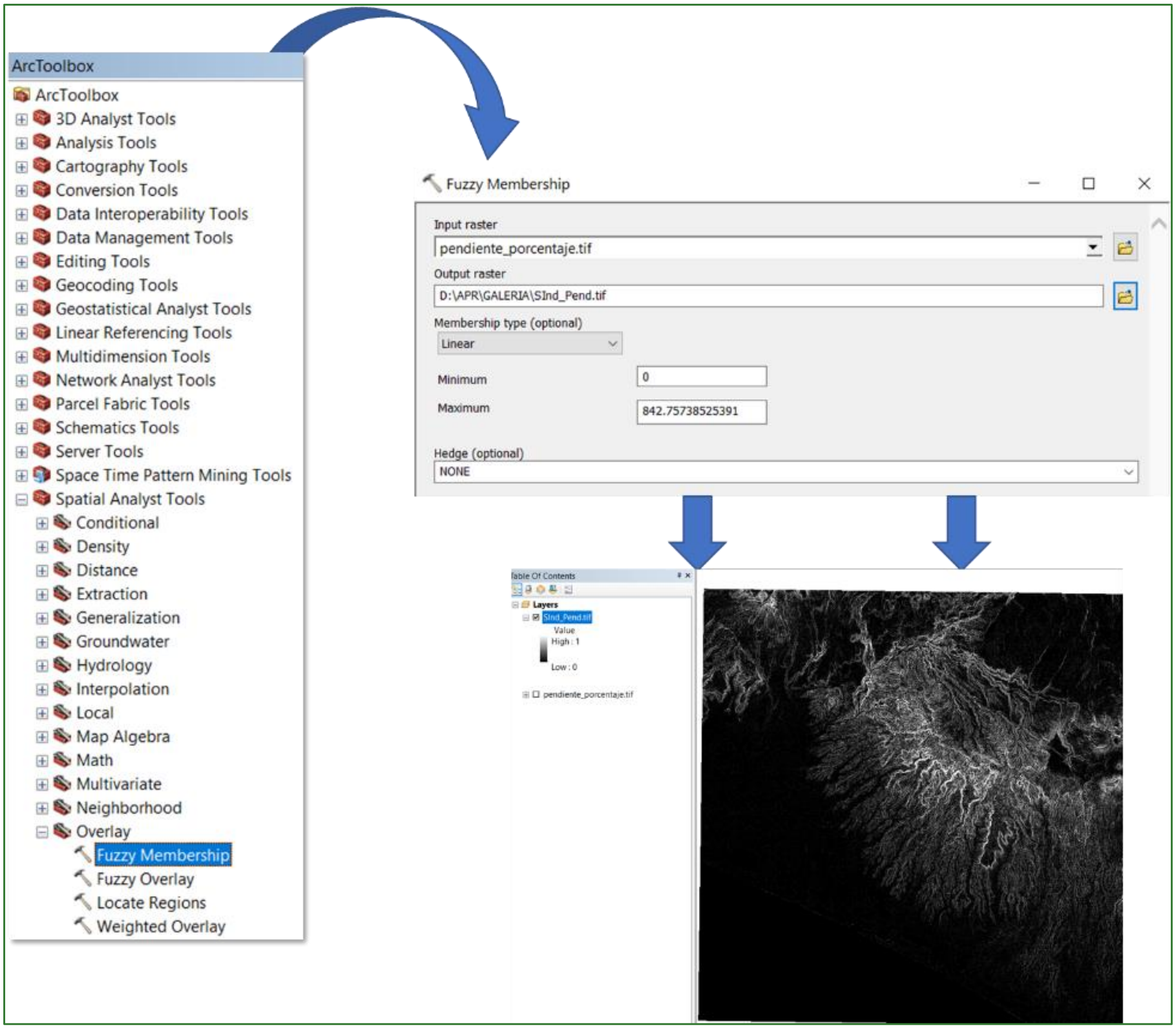
Part 1. Gallery forest restoration suitability index (IRBG)

Gallery forests are defined as a structurally and floristically heterogeneous long and narrow forest vegetation along rivers or wetlands. They depend on the water courses they lie along and maintain a more temperate microclimate above the river. Thus, they are offering ecosystem services such as climate regulation, water purification and erosion control. Consequently, for any territorial unit, the quality and importance of the riverside ecosystems must be determined.

To obtain the gallery forest restoration suitability index you must create a main or root folder called **APR** which refers to Restoration Practices Suitability (APR). Inside this folder, you need to create a subfolder called **GALERIA**. Therefore, the PART 1 output files will be saved in the **APR/GALERIA** folder. The files to be used to generate the processes will, for the most part, be obtained or called up from the **ECOYSYSTEM SERVICES** BASELINE guide directory.

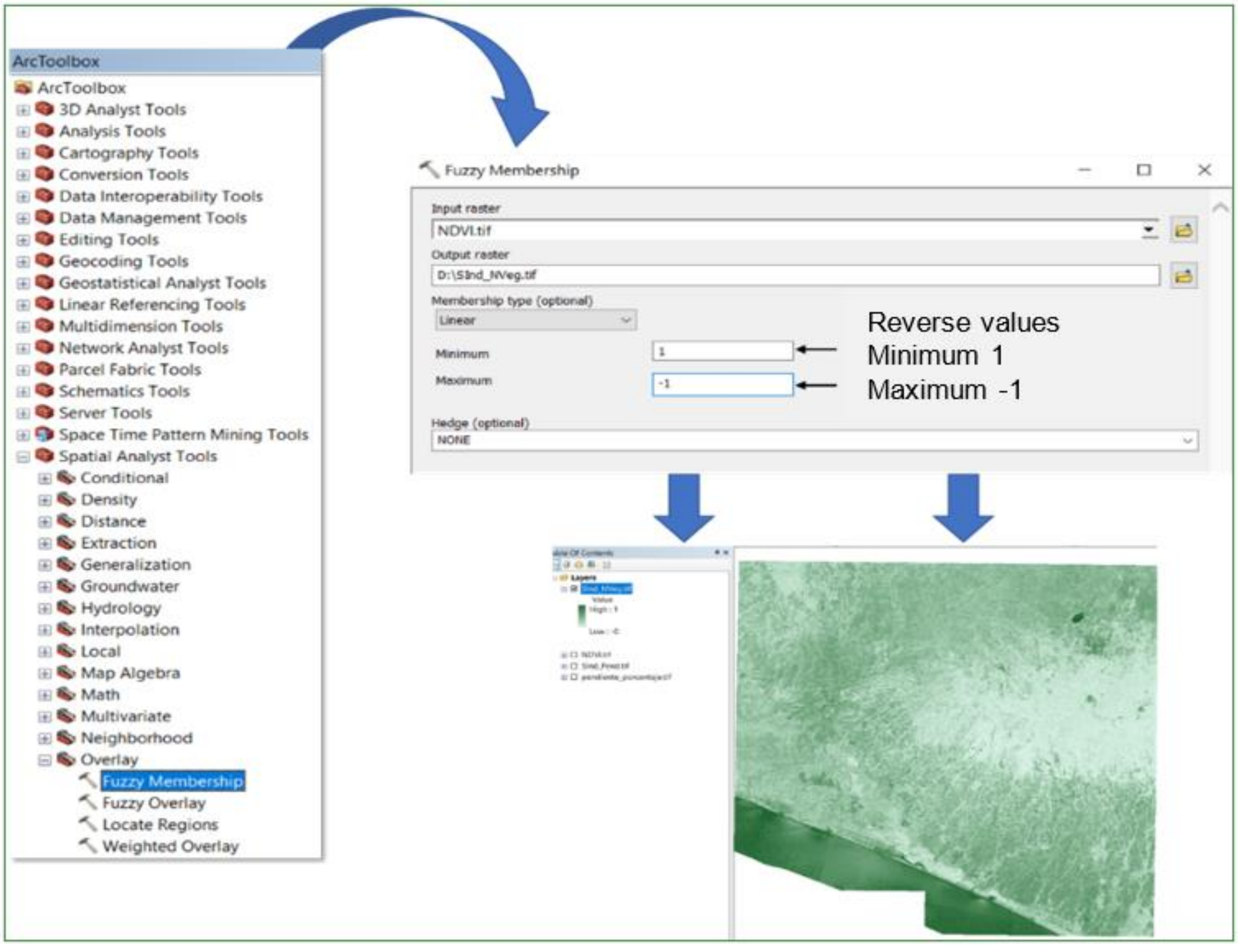
Step 1: slope subindex

Use the **"Fuzzy Membership"** tool to normalise land slope data. This process will serve to identify the maximum and minimum slope values. In this regard, the bigger the slope defined the more suited it is to restoration. The **"Fuzzy Membership"** tool is located in **ArcToolBox/Spatial Analyst Tools/Overlay/Fuzzy Membership.** Enter the **pendiente_porcentaje.tif** file in the Input Raster box and name the output file **SInd_Pend.tif** and save it in the **APR/GALERIA** folder.



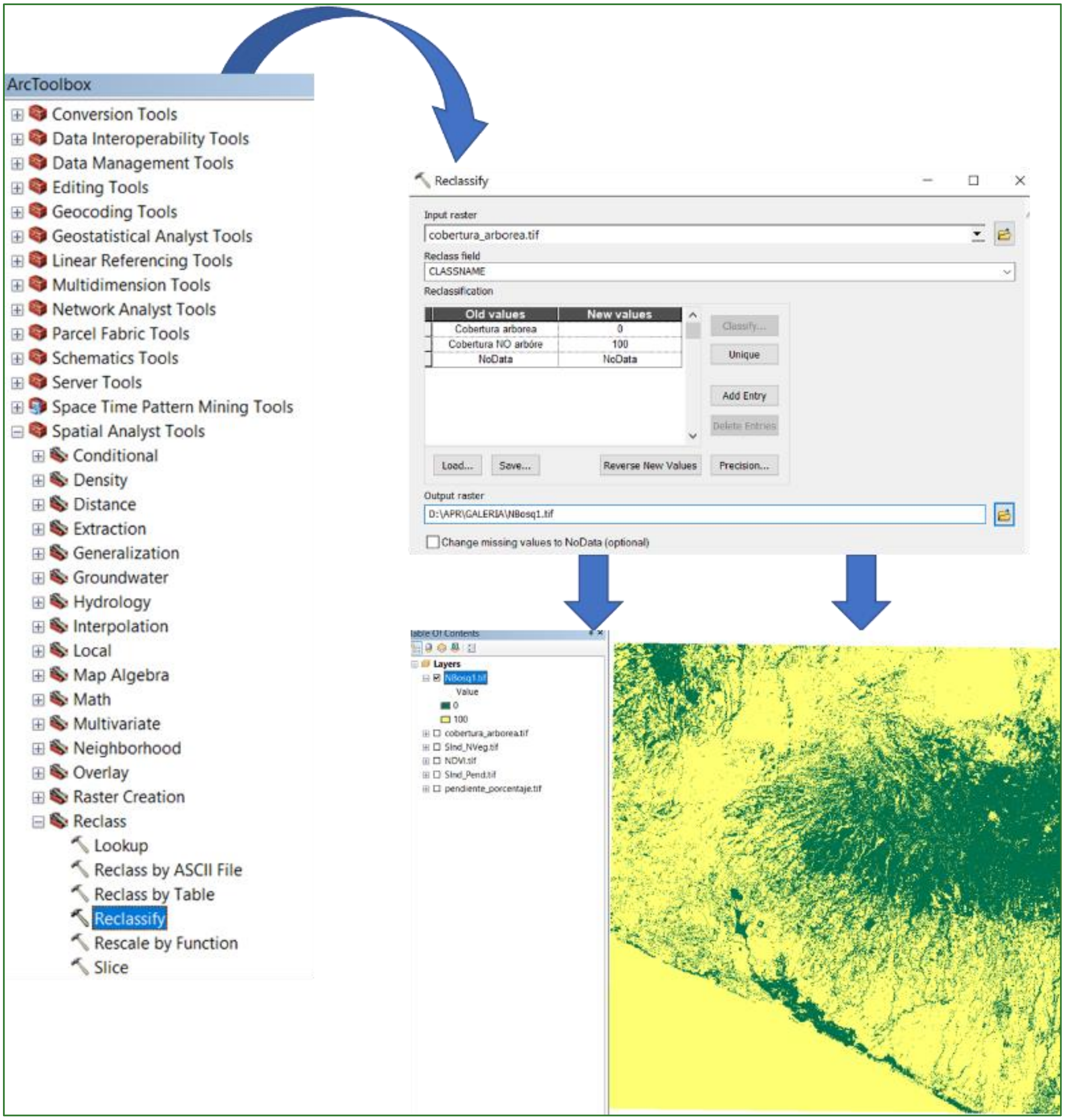
Step 2: no-vegetation subindex

Use the **"Fuzzy Membership"** tool (Reverse Linear) to normalise the NDVI data. This process will serve to identify the maximum and minimum NDVI values. In this regard, it is established that the smaller the amount of vegetation (NDVI) defined, the more suited it is to restoration. The **"Fuzzy Membership"** tool is located in **ArcToolBox/Spatial Analyst Tools/Overlay/Fuzzy Membership.** Enter the **NDVI.tif** file in the Input Raster box and name the output file **SInd_NVeg.tif** and save it in the **APR/GALERIA** folder.



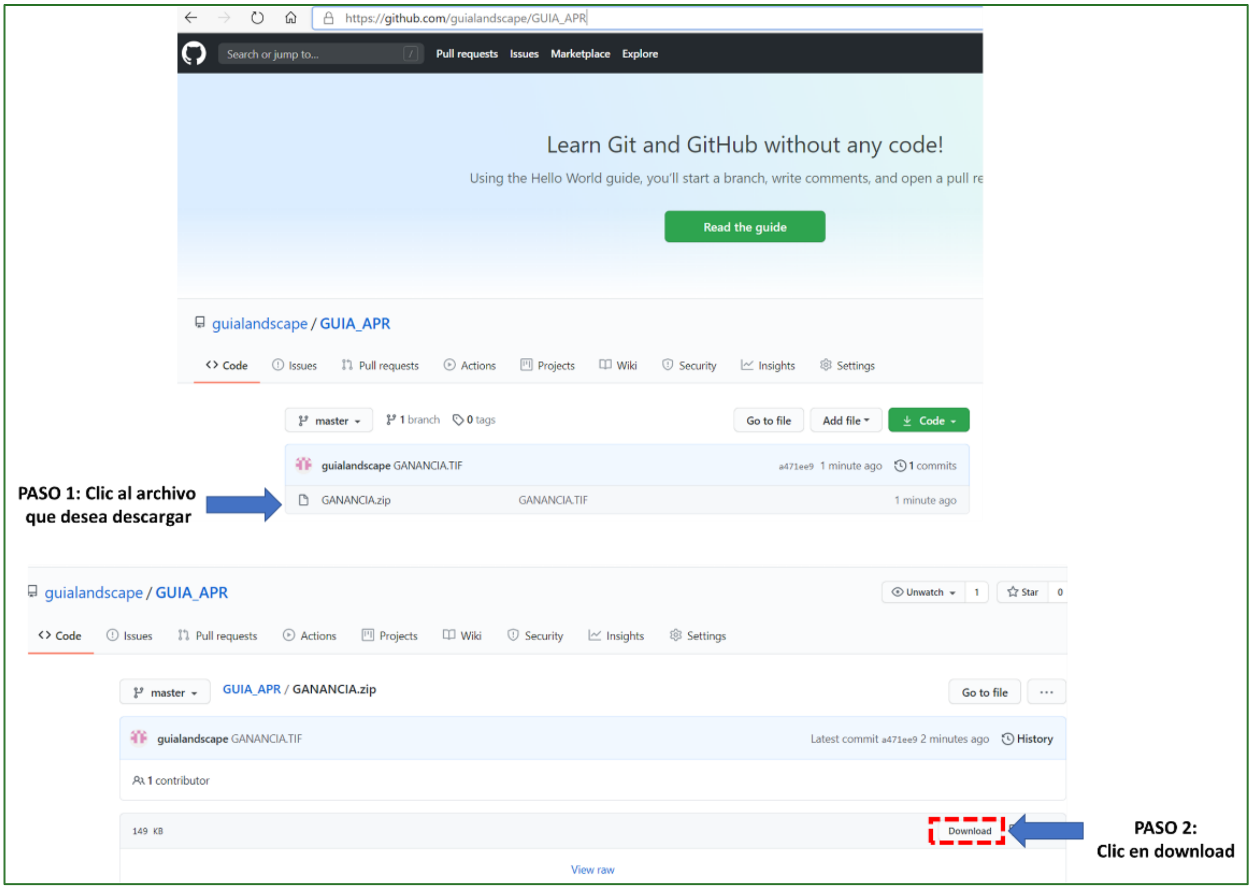
Step 3: no-forest subindex
Here you must generate two layers, one for established no-forest and another for growing no-forest, as explained in the following steps.

Step 3.1: established no-forest
This layer is generated by reclassifying the tree cover map, so use the **"Reclassify"** tool located in **ArcToolBox/Spatial Analyst Tools/Reclass/Reclassify**. Use the **cobertura_arborea.tif,** raster as the input file and assign a value of 100 to the no-tree cover category and a value of 0 to the tree cover category. Name the output file **NBosq1.tif** and save it in the **APR/GALERIA** folder.



Step 3.2: growing no-forest

This layer is generated based on the raster called **ganancias.tif**, a file that is located in a web repository in GitHub. You can download it from the following link: https://github.com/guialandscape/GUIA_APR. Save it in a subfolder in **GALERIA** called **GANANCIAS (APR/GALERIA/GANANCIA).**



Reclassify the **ganancias.tif.** layer you have downloaded. Use the **"Reclassify"** tool located in **ArcToolBox/Spatial Analyst Tools/Reclass/Reclassify.** Use the **ganancias.tif** raster as the input file and apply the following parameters:

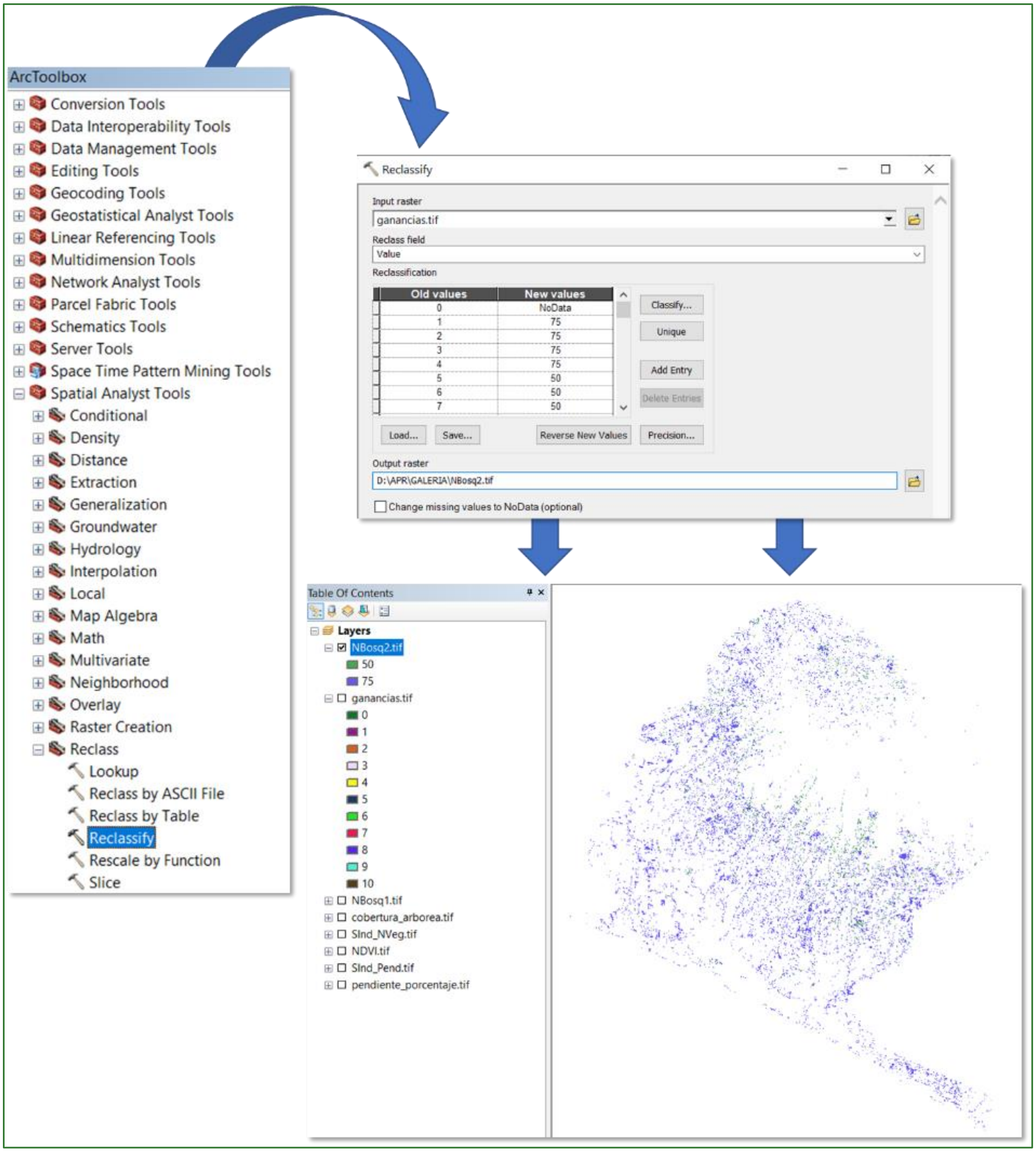
Reclassify:

0 = NoData

2-5m = 75

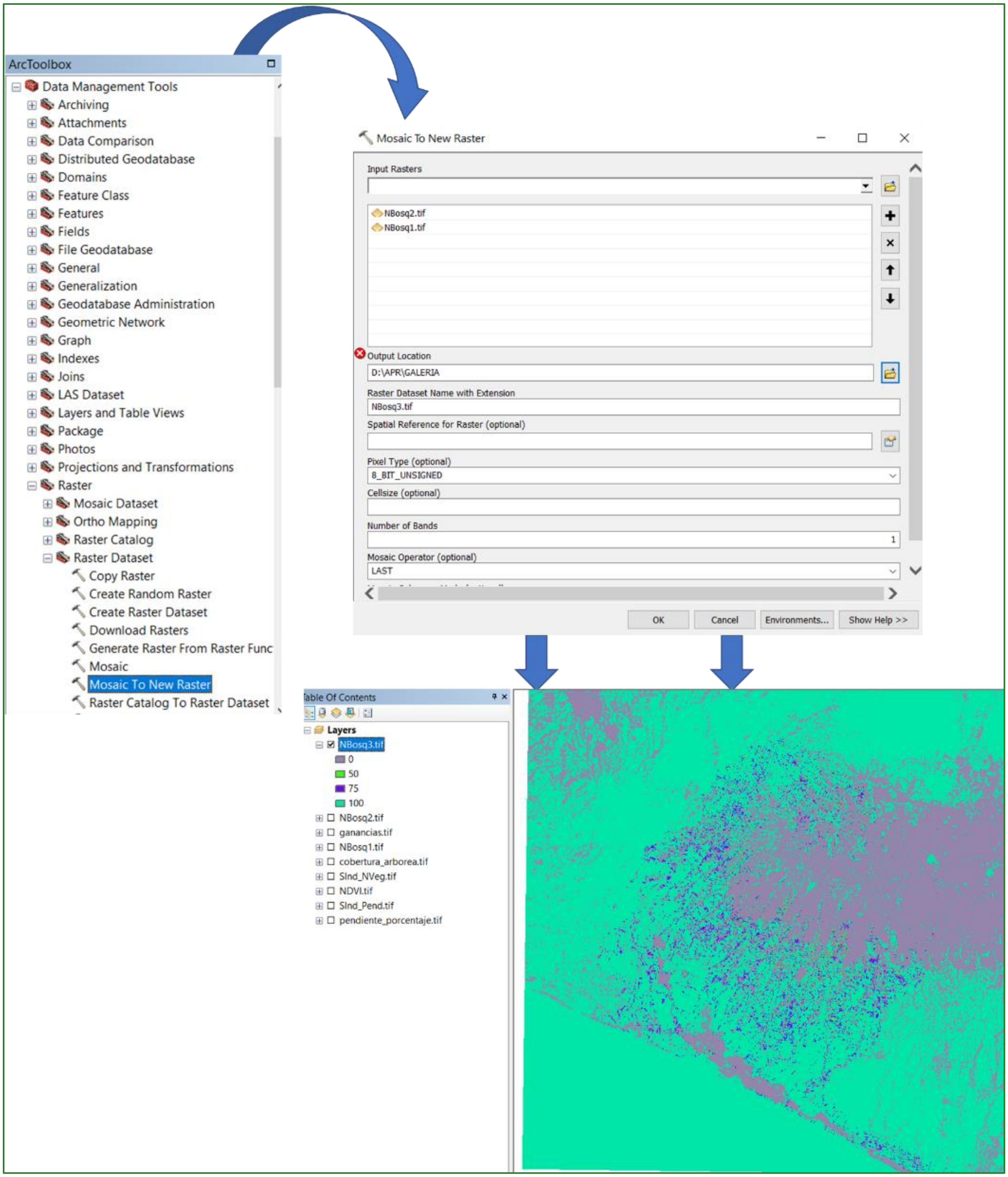
>=5m = 50

Name the output file **NBosq2.tif** and save it in the **APR/GALERIA** folder.



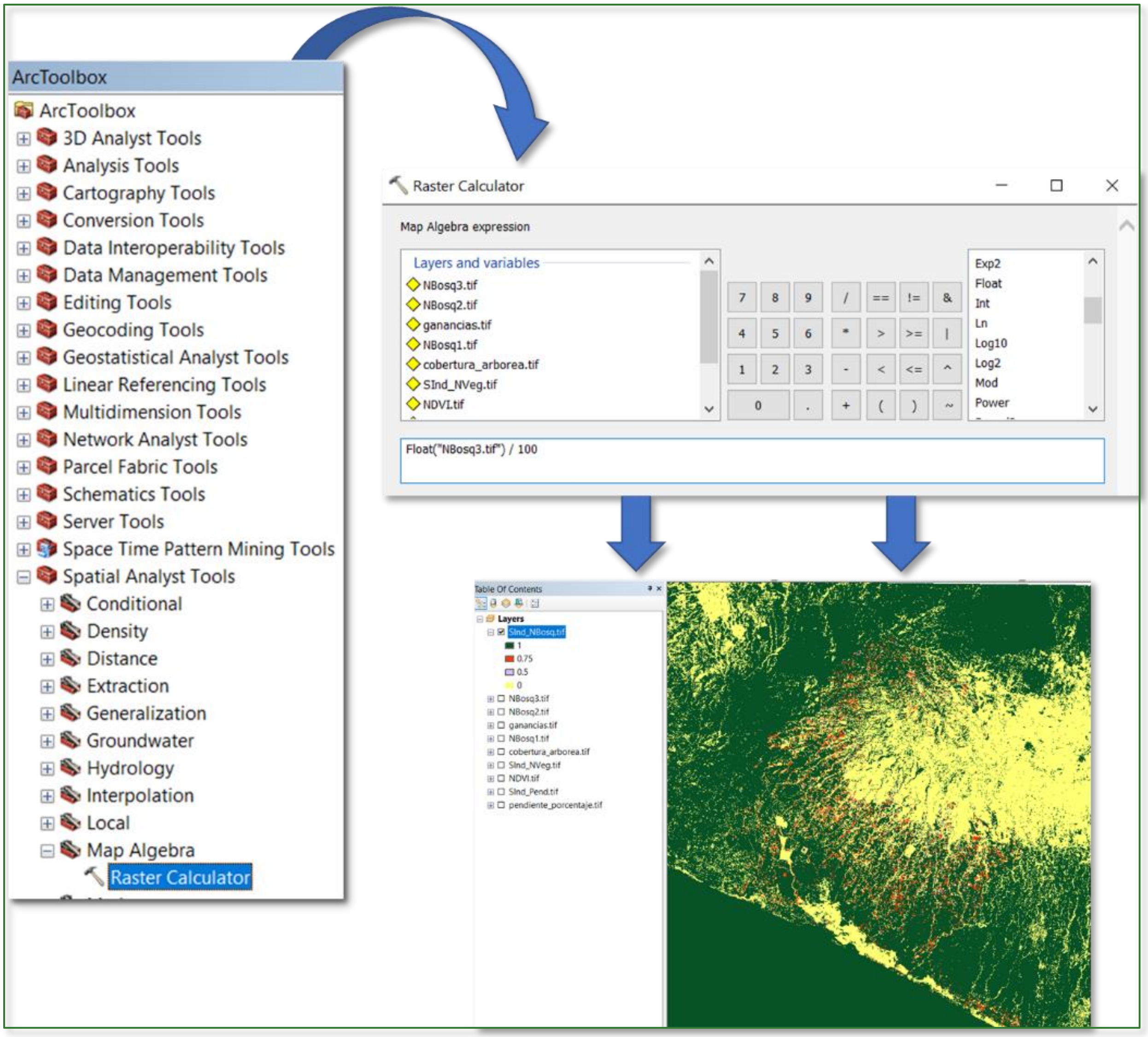
Step 3.3: mosaic

Generate a new mosaic from the two layers you have just generated using the **"Mosaic To New Raster"** tool located in **ArcToolBox/Data Management Tools/Raster/Raster Dataset/Mosaic To New Raster.** Use the files **NBosq1.tif** and **NBosq2.tif** (NBosq2.tif will be above NBosq1.tif) and name the output file **NBosq3.tif** and save it in the **APR/GALERIA** folder.



Step 3.4 no-forest subindex
Run a FLOAT-type raster calculator function and convert the values of the raster created above (**NBosq3.tif**) to decimal numbers. The **"Raster Calculator"** tool is located in **ArcToolBox/Spatial**

Analyst Tools/Map Algebra/Raster Calculator. Name the output file **SInd_NBosq.tif** and save it in the **APR/GALLERY** folder.



Step 4: distance subindex
Step 4.1: river buffer
At this juncture you will carry out a series of processes that will generate a restoration suitability layer in the gallery zones. Therefore, use a **redhIdrica.shp** shapefile located in an online repository in GitHub. You can download it from the following link https://github.com/guialandscape/GUIA_APR. Save the file in a subfolder in **GALERIA** called **RIOS (APR/GALERIA/RIOS).**

Add numerical field "Buffer" to the redhidrica.shp Attribute Table with the following values:

- Principal Rivers (P) = 150
- Secondary Rivers (S) = 100

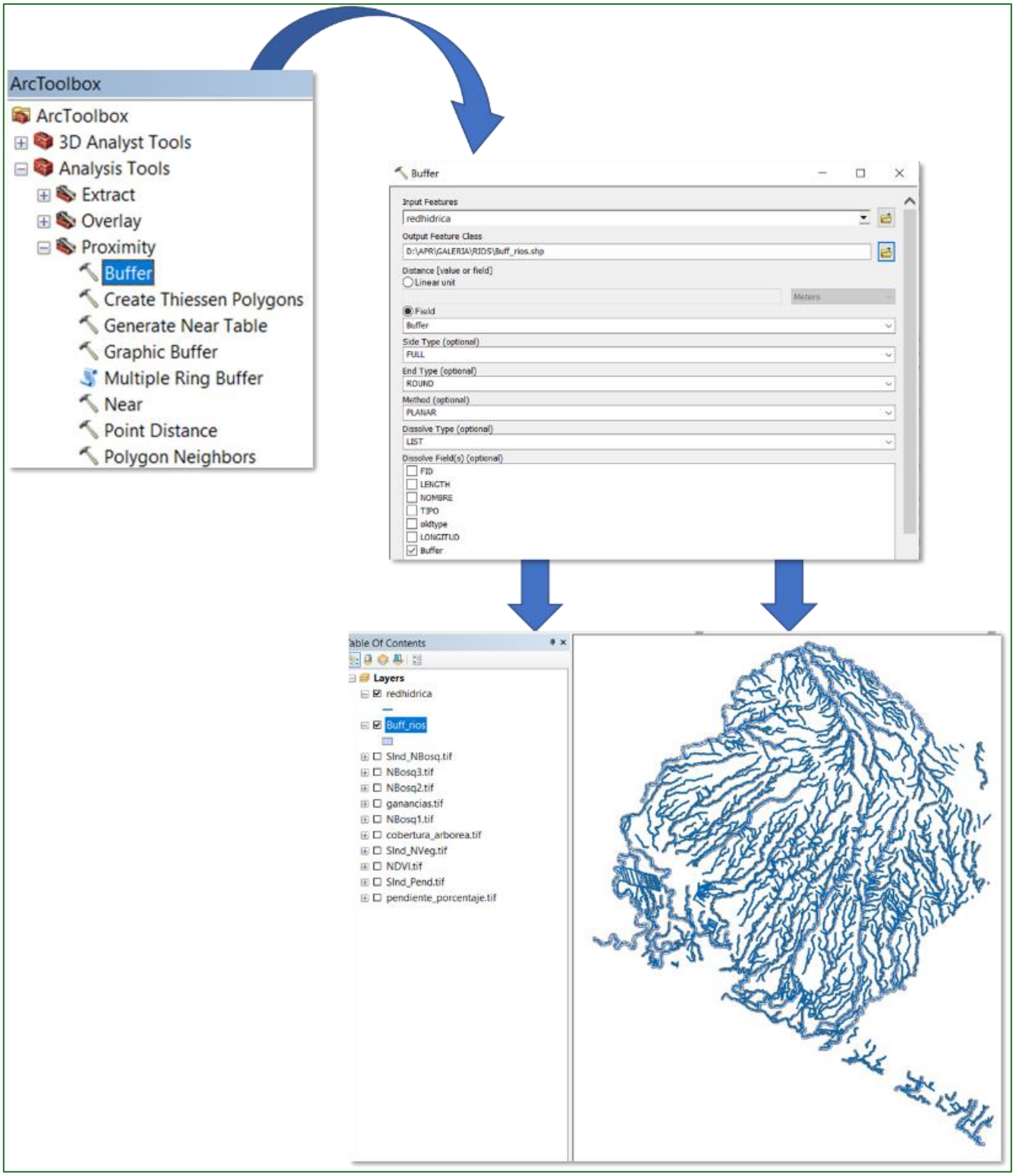
- Tertiary or Streams (Q) = 50

Run a Buffer using the “Buffer” tool located in **ArcToolBox/Analysis Tools/Proximity/Buffer** in the Buffer attributes table. Name the file **Buff_rios.shp** and save it in the **APR/GALERIA/RIOS** folder.

Table

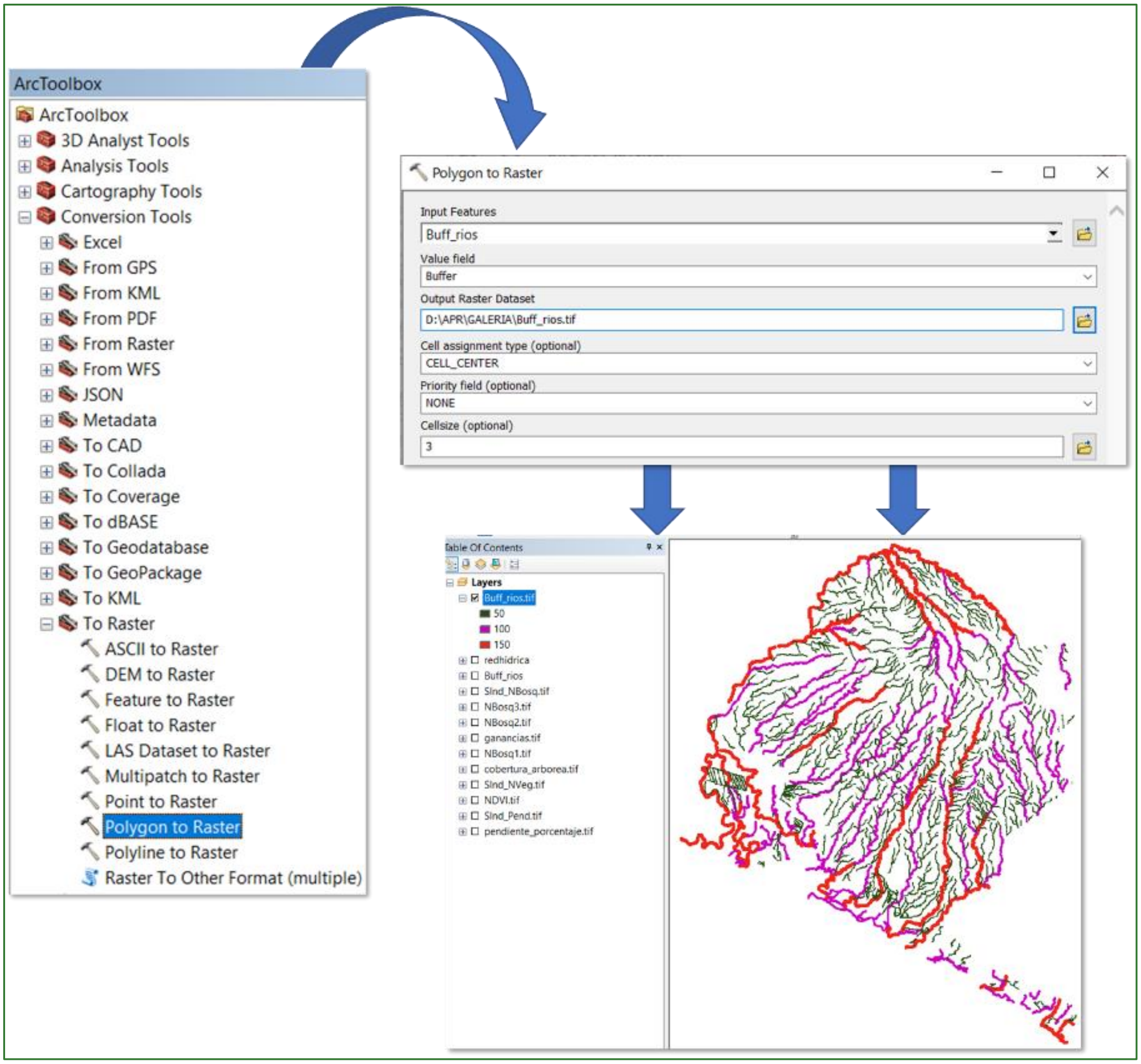
redhidrica

FID	Shape *	LENGTH	NOMBRE	TIPO	oldtype	LONGITUD	Buffer
0	Polyline M	564.26992		Q	Q	1	50
1	Polyline M	177.914539	ZANJON EL AGUA	S	P	0	150
2	Polyline M	2066.090562	RIO GUAYAPA o D	S	P	2	150
3	Polyline M	2538.192285		Q	Q	3	50
4	Polyline M	916.941506		Q	Q	1	50
5	Polyline M	415.369594		Q	Q	0	50
6	Polyline M	2603.535851	Río Asino	T	S	3	100
7	Polyline M	121.721297		Q	Q	0	50
8	Polyline M	913.426598		Q	Q	1	50
9	Polyline M	306.447236	Río Aguachapio	T	S	0	100
10	Polyline M	1347.474585		Q	Q	1	50
11	Polyline M	122.333895		T	S	0	100
12	Polyline M	858.297581	RIO EL SUNZA o E	S	P	1	150
13	Polyline M	79.380695	Río El Rosario	T	S	0	100
14	Polyline M	484.620699	RIO GUAYAPA o D	T	S	0	100
15	Polyline M	845.487811		Q	Q	1	50



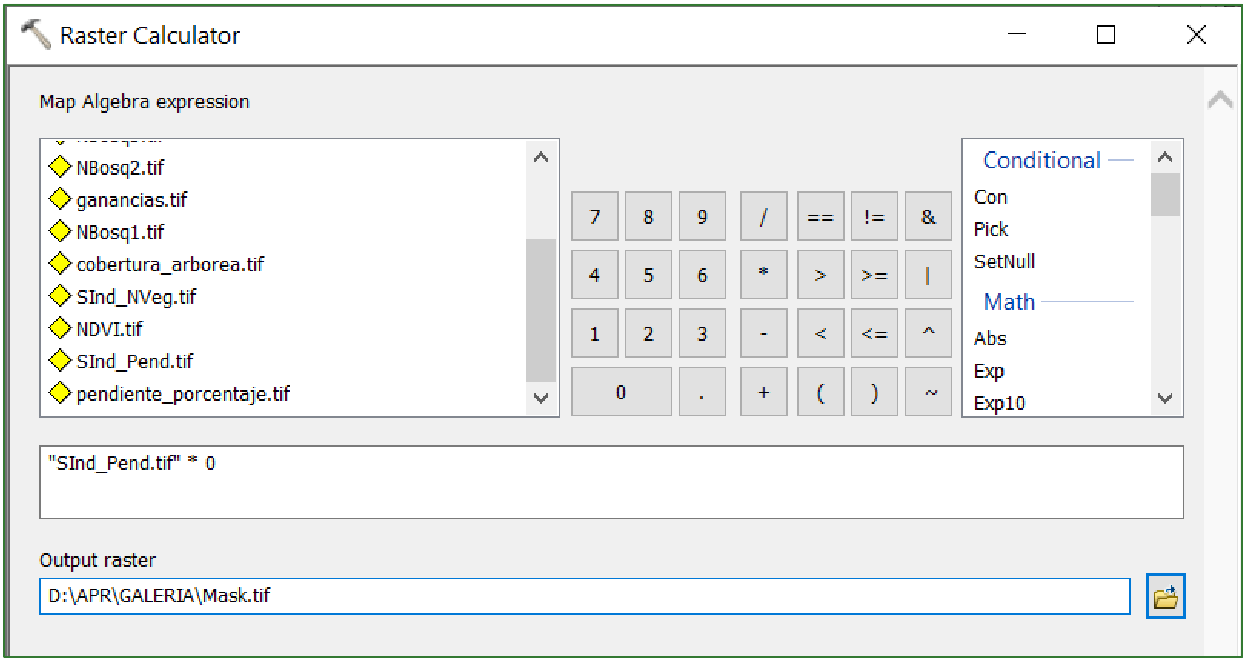
Step 4.2: polygon-to-raster

Convert the **Buff_rios.shp** file to a raster. Use the **"Polygon to Raster"** tool in **ArcToolBox/Conversion Tools/To Raster/Polygon to Raster.** Name the output file **Buff_rios.tif** with a pixel size of 3 m and save it in the **APR/GALERIA** folder.



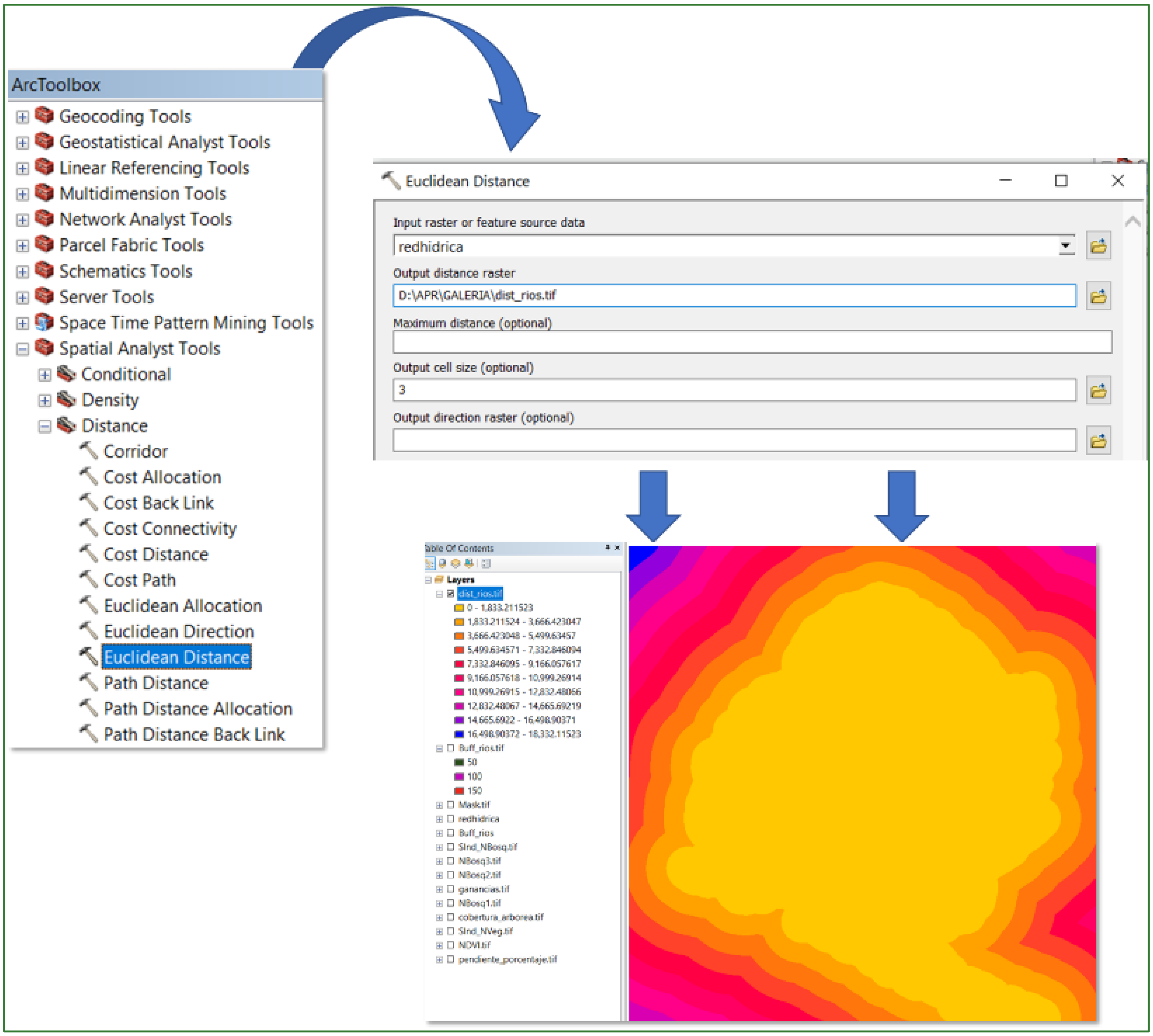
Step 4.3: generate a mask

You must generate a mask in this step that will be used in the next step. To do so, select the **Sind_Pend.tif** layer and multiply it by 0 using the raster calculator. Name the output file **Mask.tif** and save it in the **APR/GALERIA** folder.



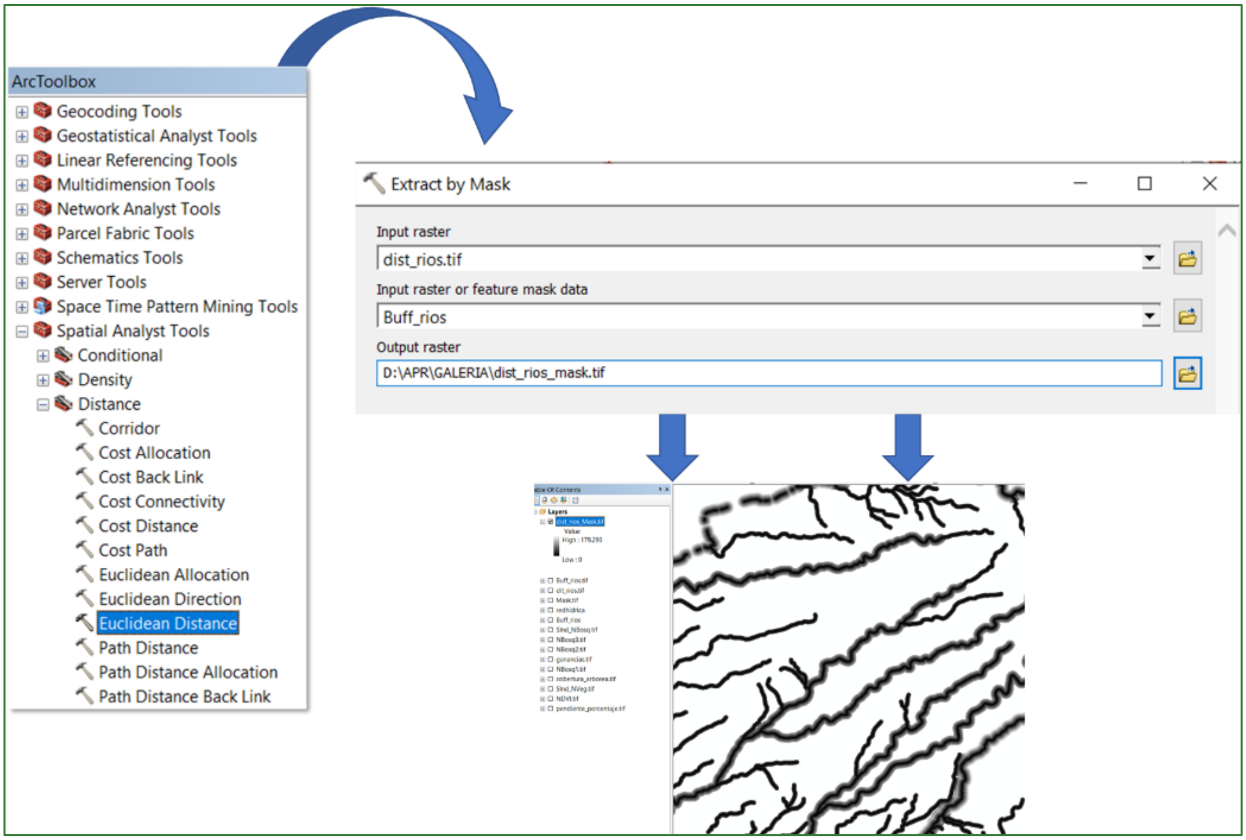
Step 4.4: obtain the distance to rivers

You must now obtain a raster layer by running the **"Euclidean Distance"** tool available in **ArcToolBox/Spatial Analyst Tools/Distance/Euclidean Distance.** Name the output file **dist_rios.tif** and save it in the **APR/GALERIA** folder (remember to enter (Environments) in the raster properties as expansion of the project area).



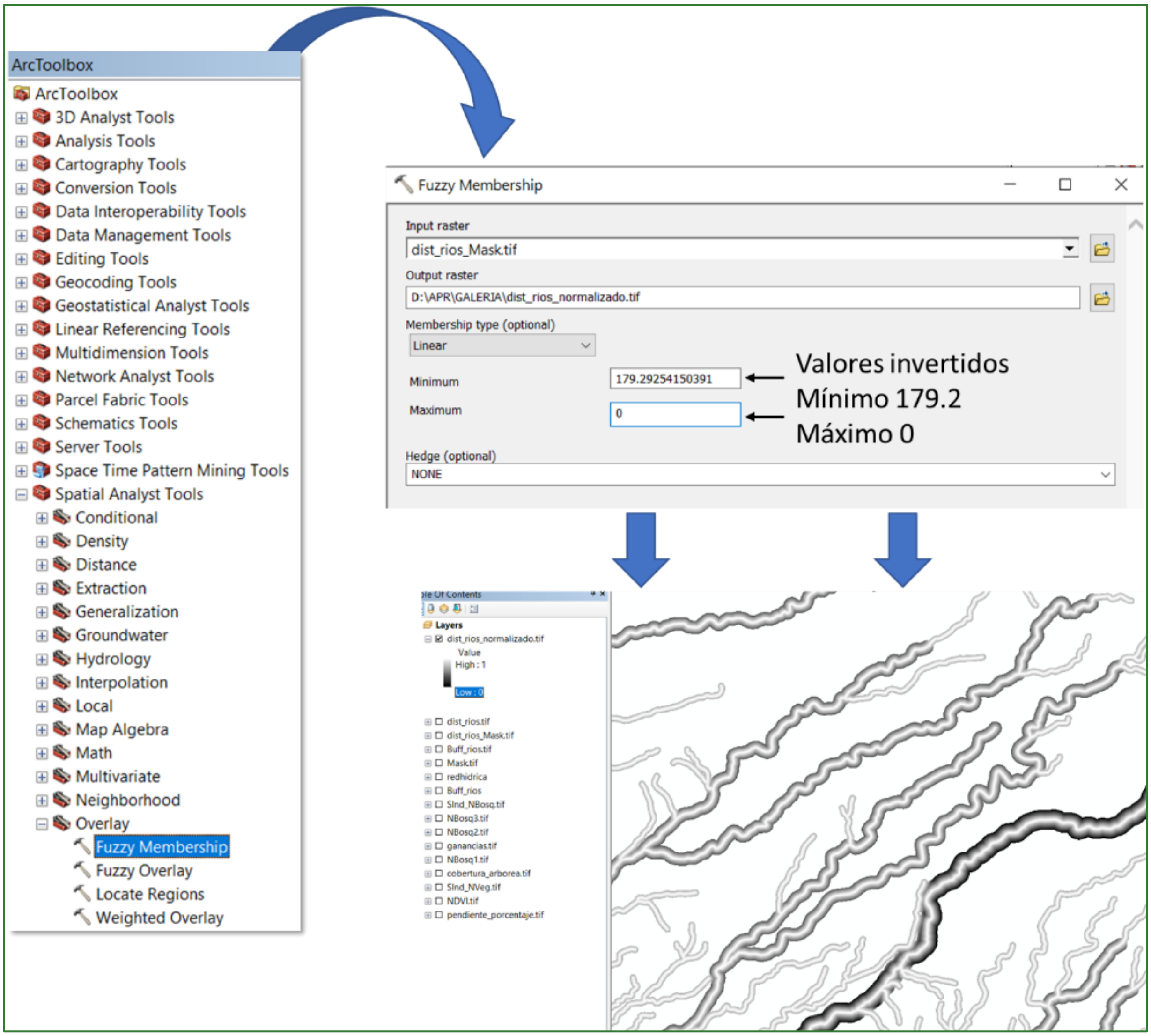
Step 4.5: extract distance to rivers values

In this step, you will extract the distance to rivers value obtained from the aforementioned file called **dist_rios.tif**. To do so, use the **"Extract by Mask"** located in **ArcToolBox/Spatial Analyst Tools/Extraction/Extract by Mask.** Use the **Buff_rios.shp** layer as the input file and name the output file **dist_rios_Mask.tif** and save it in the **APR/GALERIA** folder.



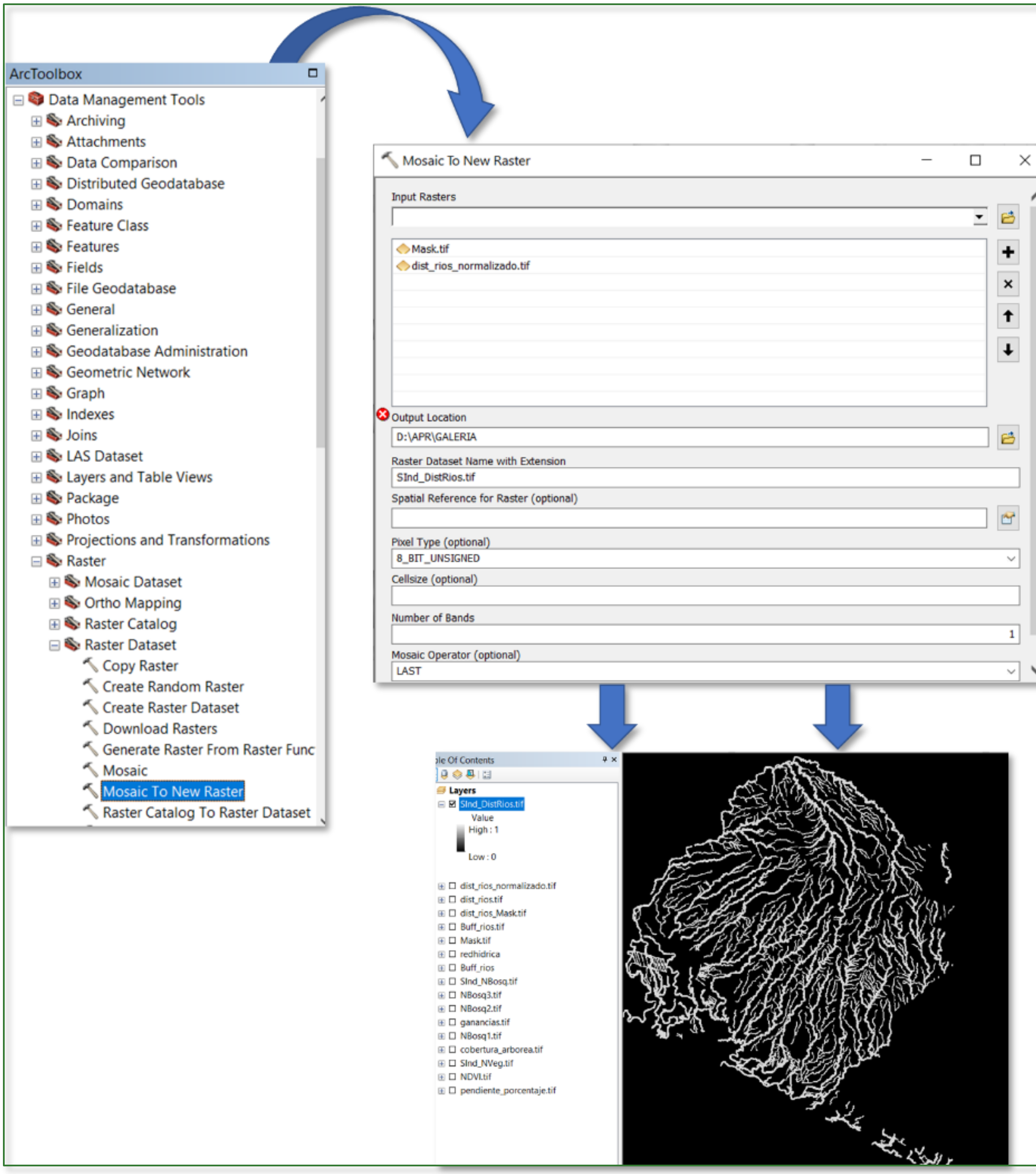
Step 4.6: normalise distance to rivers values

In this step you will normalise the values of the raster created above, **dist_rios_Mask.tif**. To do so, run the **"Fuzzy Membership"** (Reverse linear) to normalise the data. This process will serve to identify the maximum and minimum distance values. In this regard, it is established that the smaller the distance to the river, the more suited it is to restoration. The **"Fuzzy Membership"** tool is located in **ArcToolBox/Spatial Analyst Tools/Overlay/Fuzzy Membership.** Enter the **dist_rios_Mask.tif** file in the Input Raster box and name the output file **dist_rios_normalizado.tif** and save it in the **APR/GALERIA** folder.



Step 4.7: create the river distance subindex

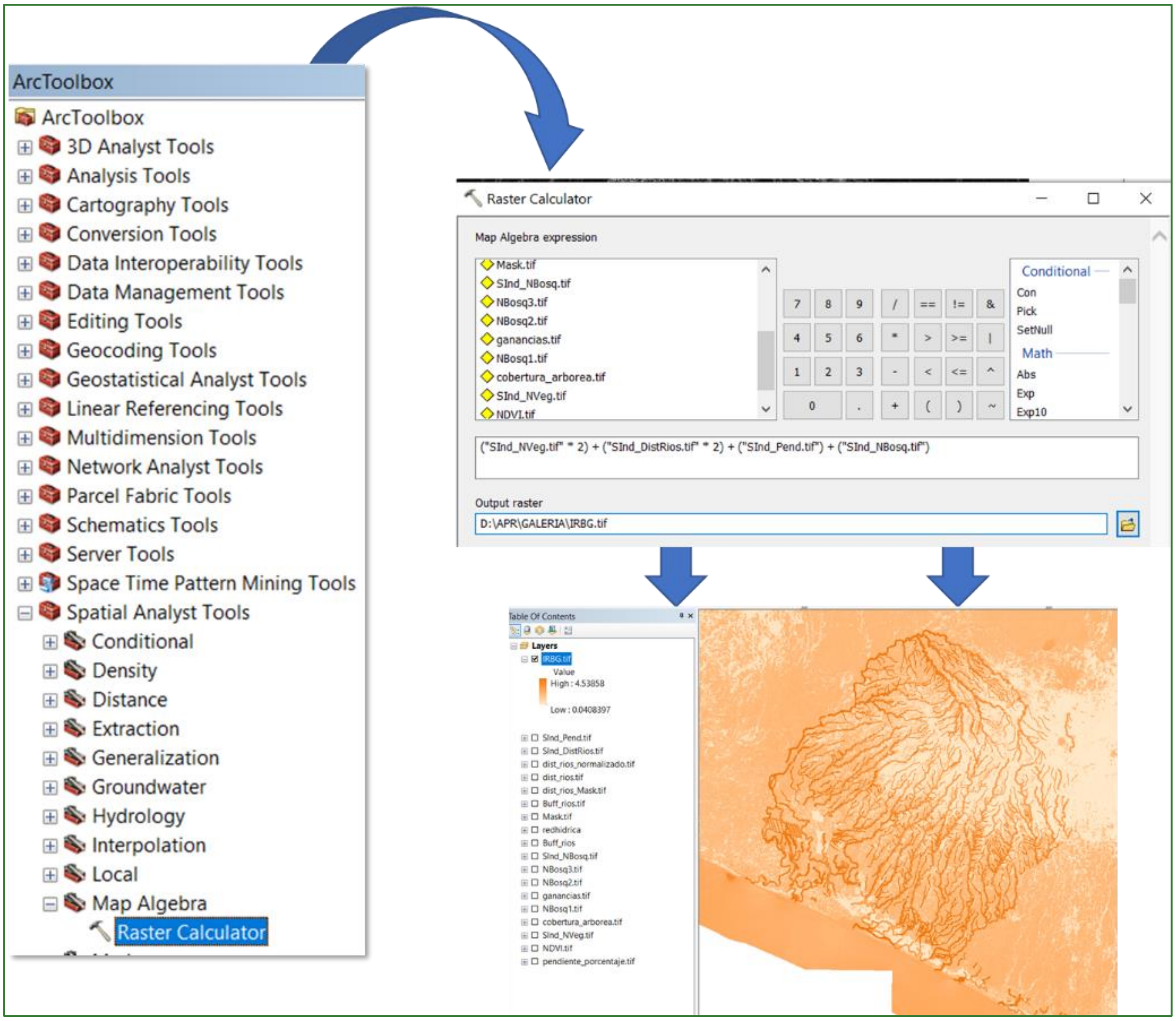
As the penultimate stage, you must generate a mosaic for the study area. This mosaic is generated using the aforementioned layer called **dist_rios_normalizado.tif** and the **Mask.tif** raster generated in the previous steps. Run the "**Mosaic to New Raster**" tool located in **ArcToolBox/Data Management Tools/Raster/Raster Dataset/Mosaic to New Raster.** Use the files **dist_rios_normalizado.tif** and **Mask.tif** as the input files and name the output file **SInd_DistRios.tif** and save it in the **APR/GALERIA** folder.



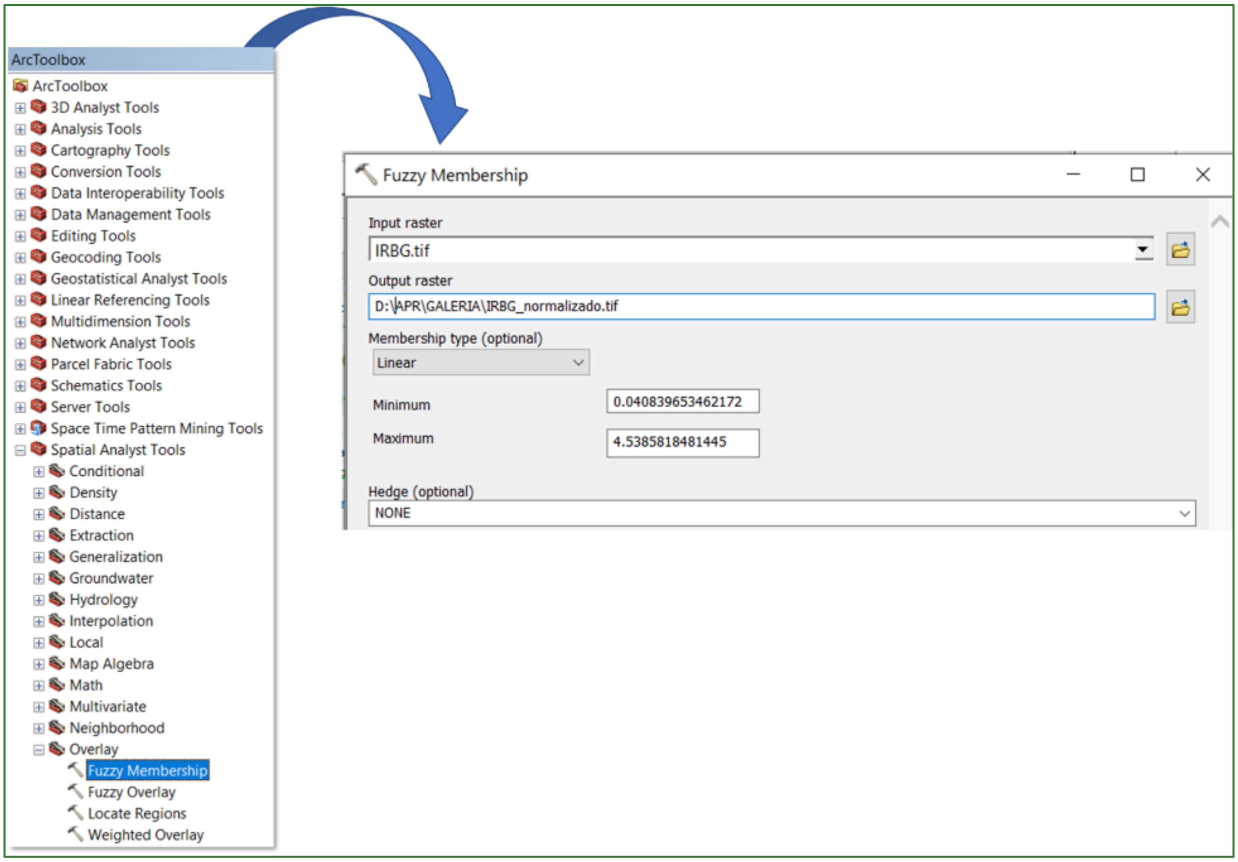
Step 5: create the Gallery Forest Restoration Suitability Index (IRBG)

This index is created from adding together the four subindices created above together with applying a certain weighting criterion. Use the **"Raster Calculator"** tool in **ArcToolBox/Spatial Analyst Tools/Map Algebra/Raster Calculator** to create the index. Name the output file **IRBG.tif** and save it in the **APR/GALLERY** folder. Apply the following weightings:

SInd_NVeg.tif * 2 + SInd_DistRios.tif * 2 + SInd_Pend.tif + SInd_NBosq.tif



Step 6:
Normalise the Gallery Forest Restoration Suitability Index (IRBG)
Lastly, normalise the **IRGB.tif** file created in the previous step using the **"Fuzzy Membership"** tool to normalise the data. This process will serve to identify the maximum and minimum forest gallery restoration suitability values. In this regard it is established that the greater the index, the more suited it is to restoration. The **"Fuzzy Membership"** tool is located in **ArcToolBox/Spatial Analyst Tools/Overlay/Fuzzy Membership.** Enter the **IRGB.tif** file in the Input Raster box and name the output file **IRGB_normalizado.tif** and save it in the **APR/GALERIA** folder.



The output should appear as follows: values approaching 1 correspond to those areas identified as being most suited to gallery forest restoration.

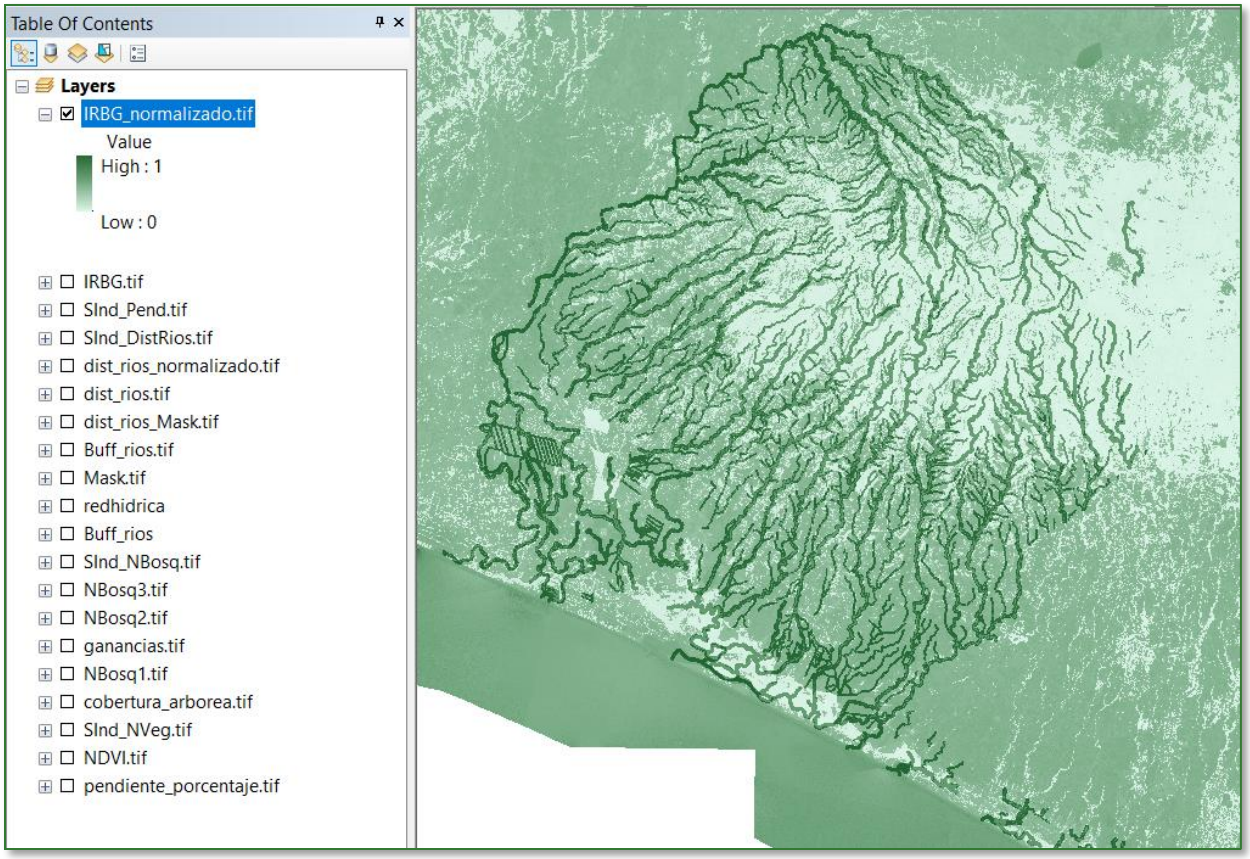


Table Of Contents
Layers
IRBG_normalizado.tif
Value
High : 1
Low : 0
IRBG.tif
SInd_Pend.tif
SInd_DistRios.tif
dist_rios_normalizado.tif
dist_rios.tif
dist_rios_Mask.tif
Buff_rios.tif
Mask.tif
redhidrica
Buff_rios
SInd_NBosq.tif
NBosq3.tif
NBosq2.tif
ganancias.tif
NBosq1.tif
cobertura_arborea.tif
SInd_NVeg.tif
NDVI.tif
pendiente_porcentaje.tif

Part 2. Wood pasture restoration suitability index (IRPArb)

Permanent wood pasture refers to areas with disperse tree cover and a well-developed herbaceous layer in which a large part of the shrub layer has been eliminated.

To get the wood pasture restoration suitability index (IRPArb) you need to create a subfolder and name it **PASTOS_ARB**. Therefore, the PART 2 output files will be saved in the **APR/PASTOS_ARB** folder. The files to be used to generate the processes will, for the most part, be obtained or called up from the APR/GALERIA folder and the GitHub repository.

Input file name	Location
SInd_Pend.tif	APR/GALERIA
SInd_NVeg.tif	APR/GALERIA
Mapa_uso_suelo.tif	https://github.com/guialandscape/GUIA_APR

Step 1: slope subindex

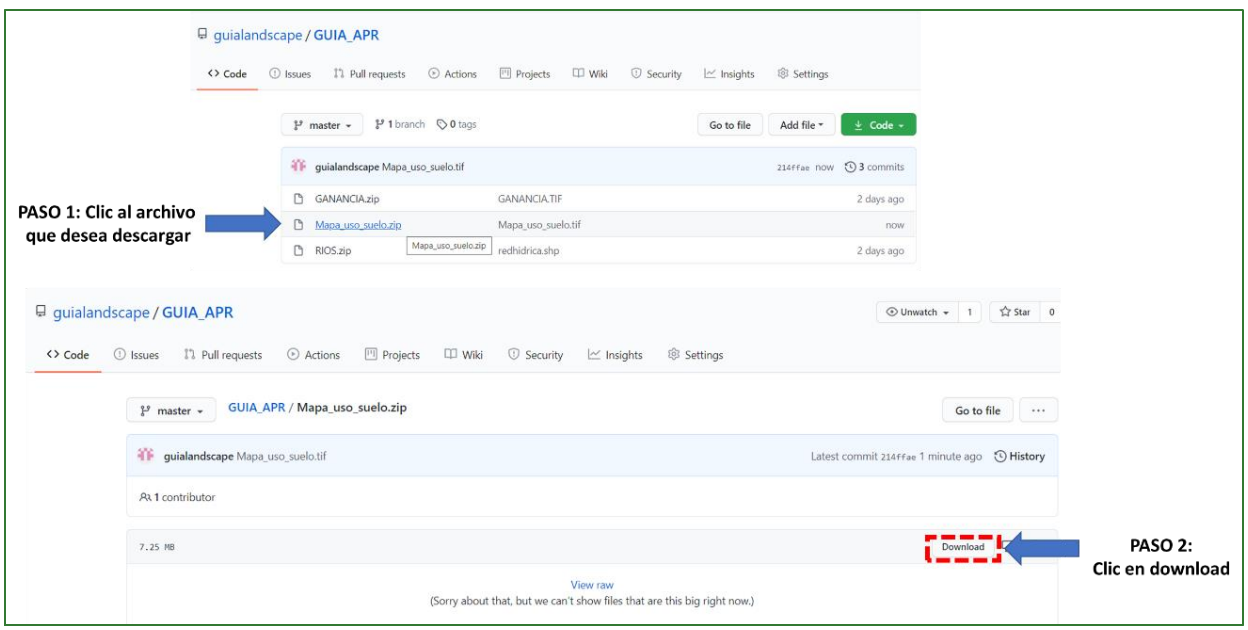
Add the layer called **SInd_Pend.tif** to ArcMap. This layer is located in the **APR/GALERIA** folder.

Step 2: no-vegetation subindex

Add the layer called **SInd_NVeg.tif** to ArcMap. This layer is located in the **APR/GALERIA** folder.

Step 3: pasture mask

Step 3.1: From the GitHub repository (https://github.com/guialandscape/GUIA_APR) download the file called **Mapa_uso_suelo.tif** and save it in the **APR/PASTOS_ARB** folder.



Step 3.2: reclassify the file Mapa_uso_suelo.tif.

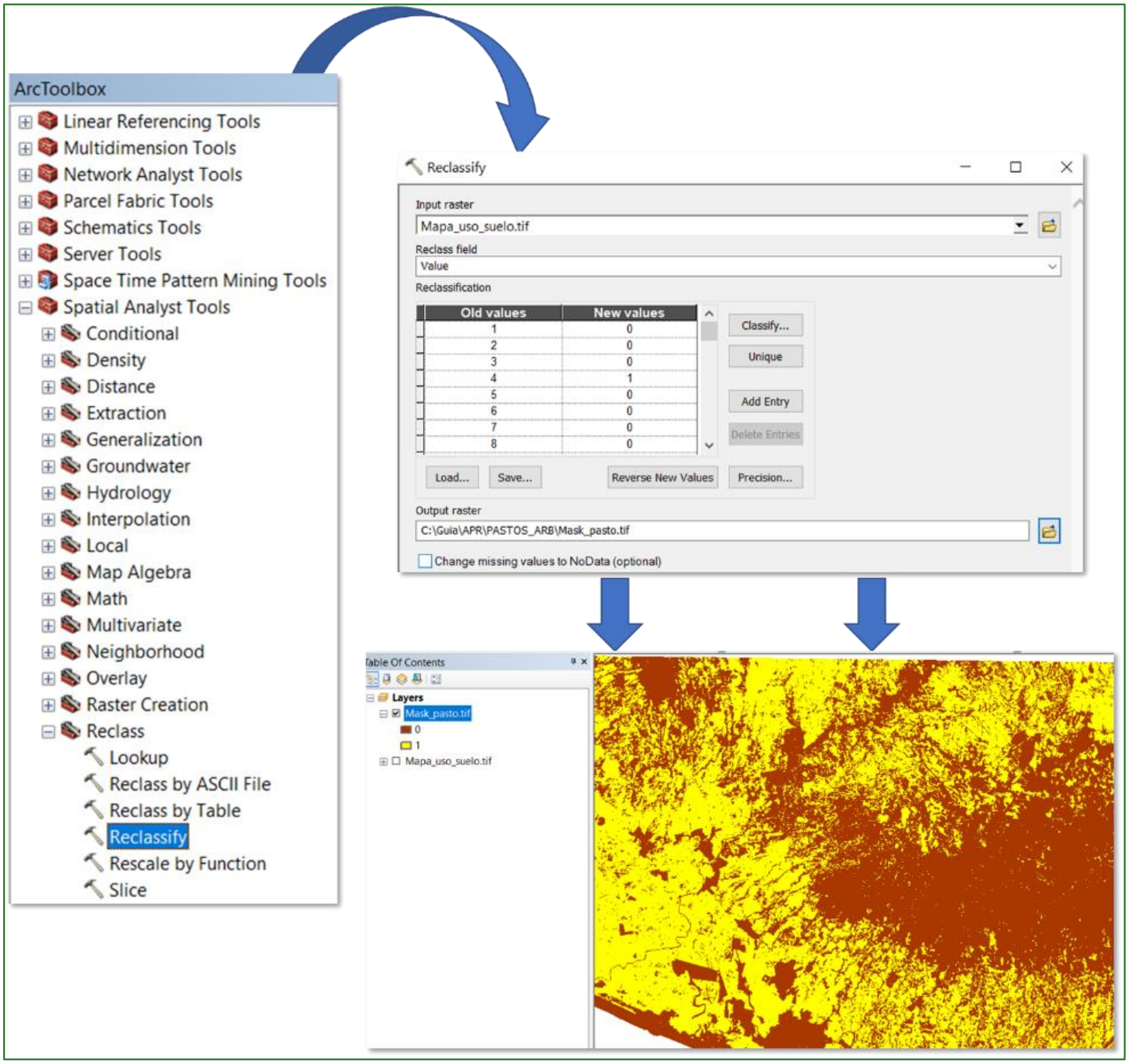
To do so use the **"Reclassify"** tool located in **ArcToolBox/Spatial Analyst Tools/Reclass/Reclassify.** Use the **Mapa_uso_suelo.tif** raster as the input file and apply the following parameters:

Reclassify:

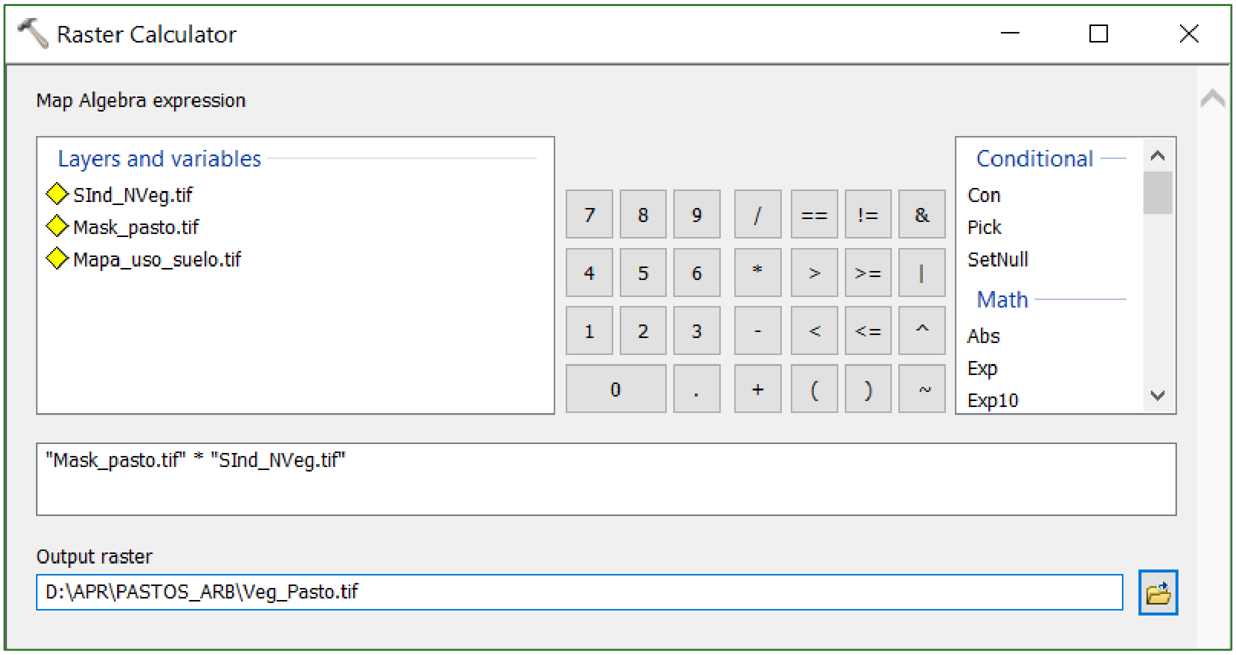
Pasture = 1

No Pasture = 0

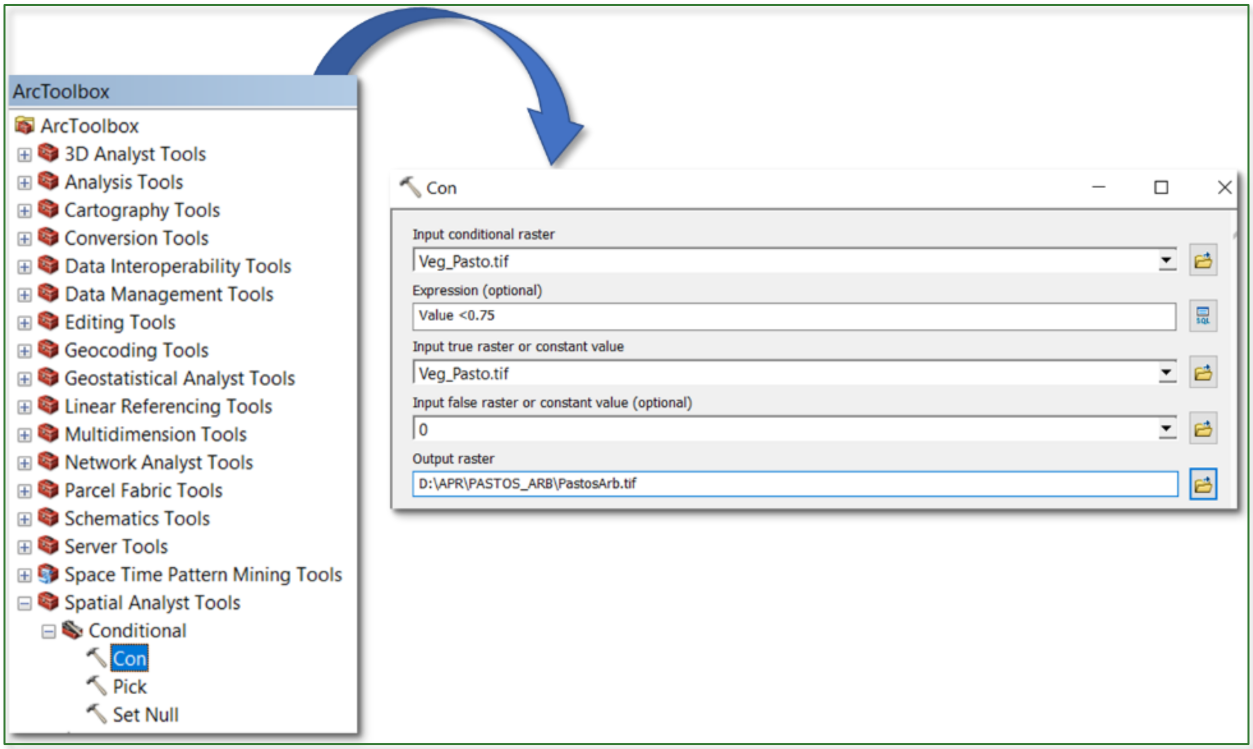
Name the output file **Mask_Pastos.tif** and save it in the **APR/PASTOS_ARB** folder.



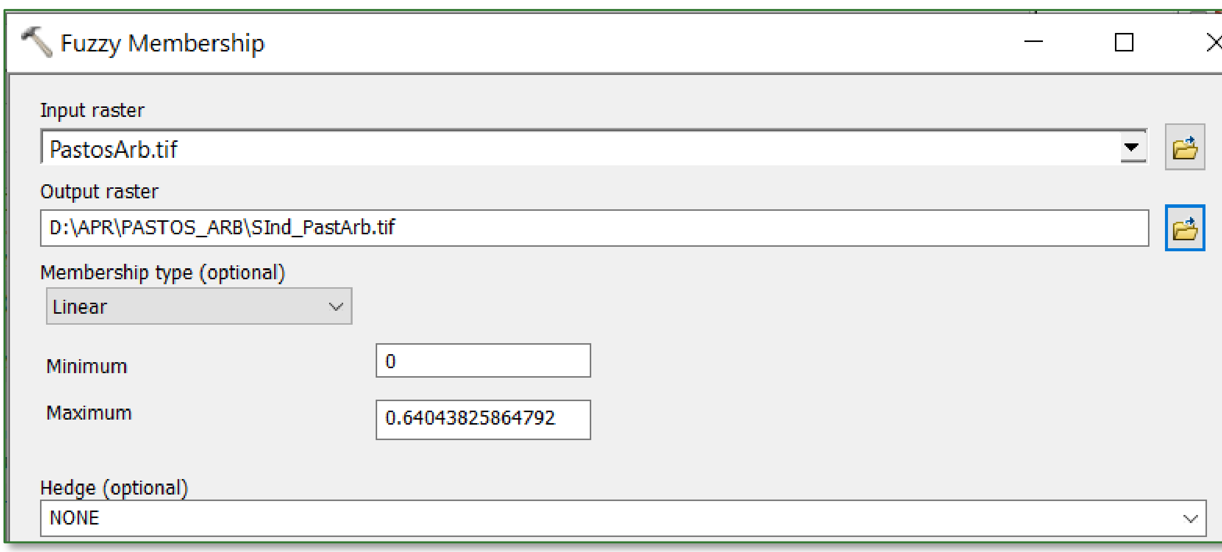
Step 4:
Use the **"Raster Calculator"** tool in **ArcToolBox/Spatial Analyst Tools/Map Algebra/Raster Calculator**, multiply the **Mask_Pastos.tif * SInd_NVeg.tif** raster, name the output file **Veg_Pasto.tif** and save it in the **APR/PASTOS_ARB** folder.



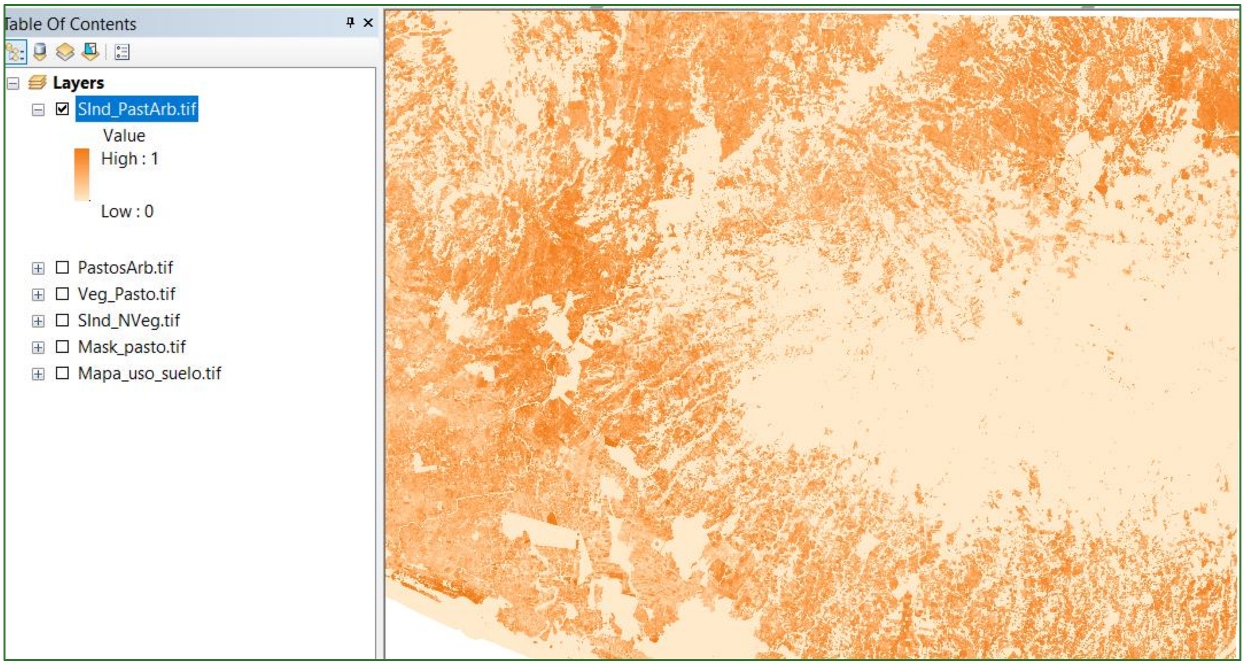
Step 5:
Apply a raster conditional created in the previous step using the "Con" tool located in **ArcToolBox/Spatial Analyst Tools/Conditional/Con**. Apply values of under 0.75 to the **Veg_Pasto.tif** raster, name the file **PastosArb.tif** and save it in the **APR/PASTOS_ARB** folder.



Normalise the **PastosArb.tif** by using the "Fuzzy Membership" (Type: Linear) tool. Name the output file **SInd_PastArb.tif** and save it in the **APR/PASTOS_ARB** folder.



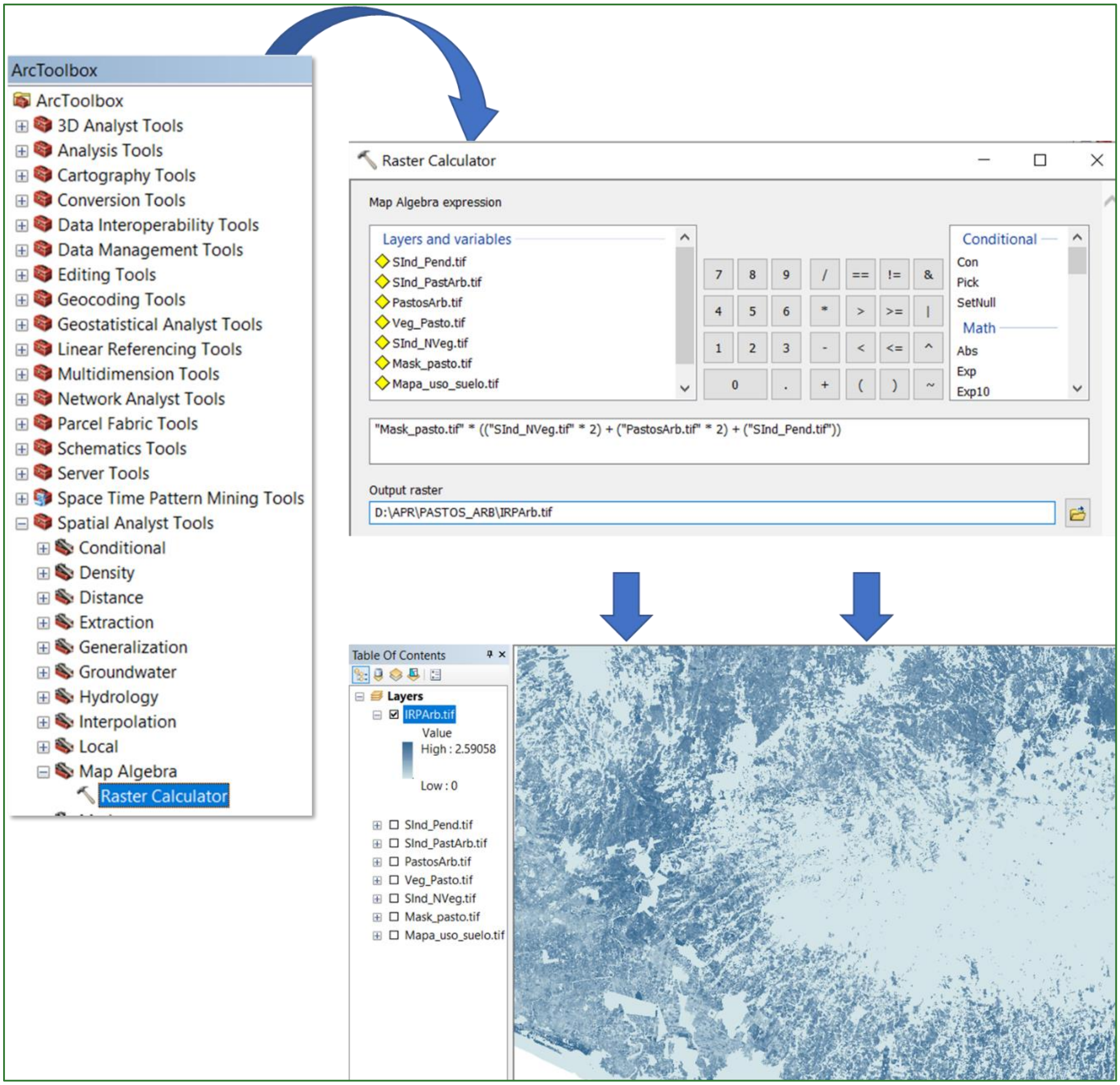
The closer the values are to 1, the more suited they are to wood pasture restoration. The output is shown below.



Step 6: Wood Pasture Restoration Suitability Index (IRPArb)

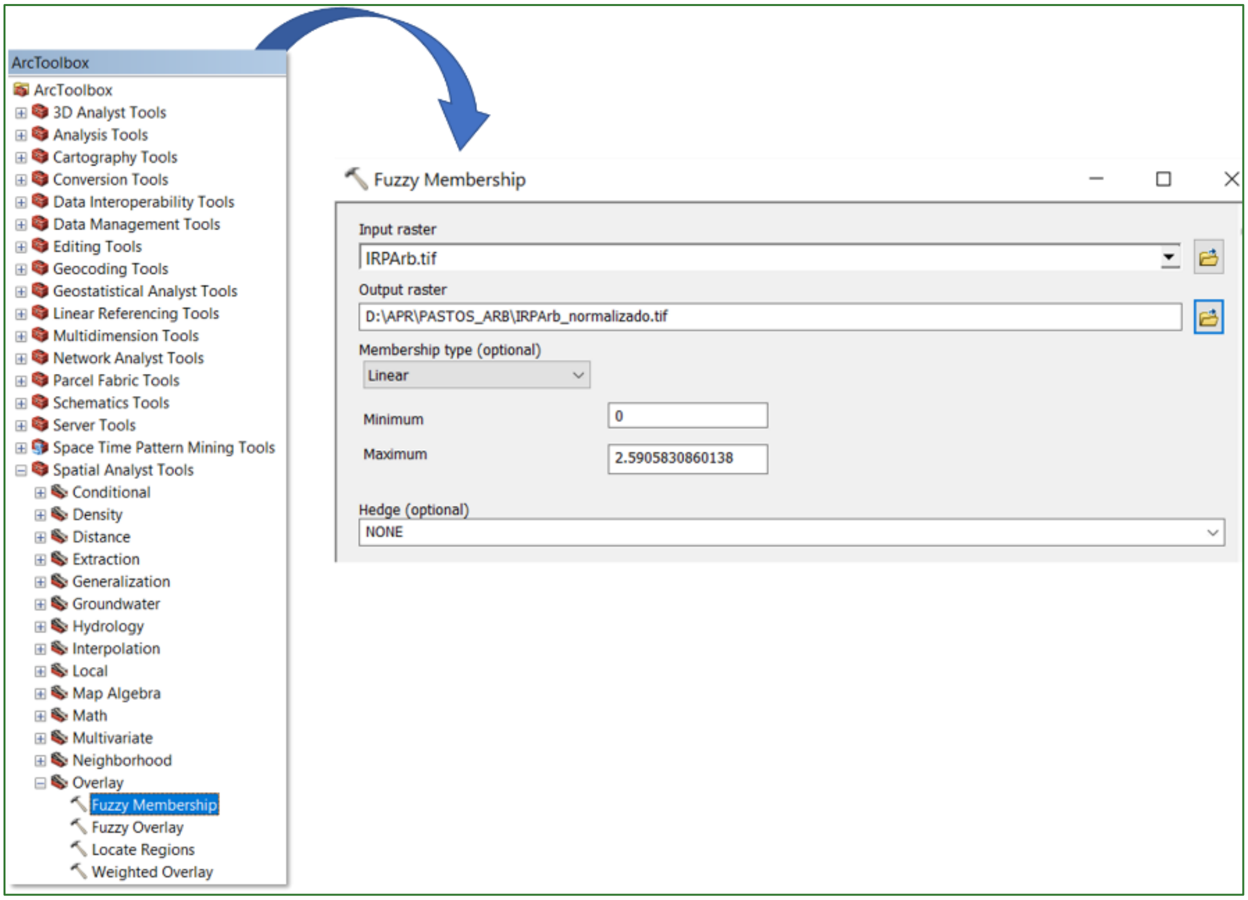
The last step consists of creating a Wood Pasture Restoration Suitability Index (IRPArb). This index is obtained by multiplying the pasture mask by the three subindices created above together with a certain weighting criterion. Use the **"Raster Calculator"** tool located in **ArcToolBox/Spatial Analyst Tools/Map Algebra/Raster Calculator** to create the index. Name the output file **IRPArb.tif** and save it in the **APR/PASTOS_ARB** folder. Apply the following weightings:

Mask_Pastos.tif * [(SInd_NVeg.tif * 2) + (SInd_PastArb.tif*2) + (SInd_Pend.tif)]

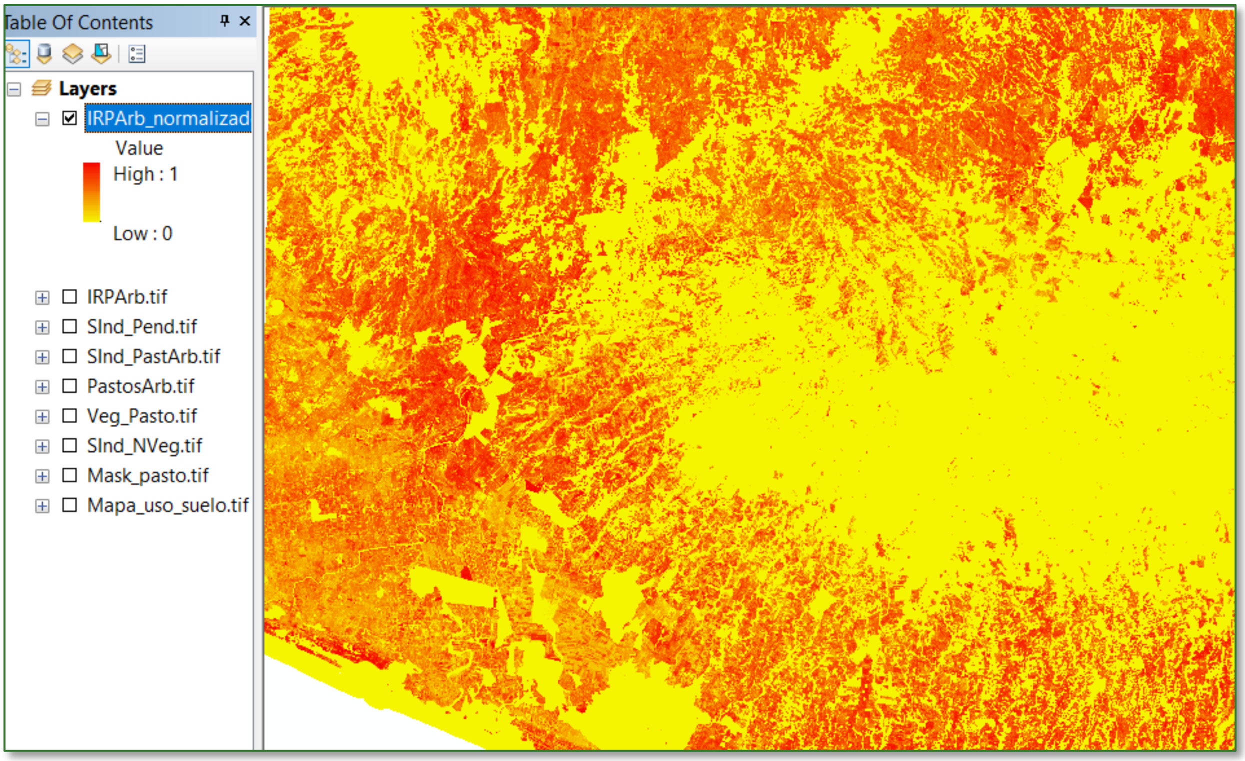


ArcToolbox
ArcToolbox
3D Analyst Tools
Analysis Tools
Cartography Tools
Conversion Tools
Data Interoperability Tools
Data Management Tools
Editing Tools
Geocoding Tools
Geostatistical Analyst Tools
Linear Referencing Tools
Multidimension Tools
Network Analyst Tools
Parcel Fabric Tools
Schematics Tools
Server Tools
Space Time Pattern Mining Tools
Spatial Analyst Tools
Conditional
Density
Distance
Extraction
Generalization
Groundwater
Hydrology
Interpolation
Local
Map Algebra
Raster Calculator
Raster Calculator
Map Algebra expression
Layers and variables
SInd_Pend.tif
SInd_PastArb.tif
PastosArb.tif
Veg_Pasto.tif
SInd_NVeg.tif
Mask_pasto.tif
Mapa_uso_suelo.tif
Conditional
Con
Pick
SetNull
Math
Abs
Exp
Exp10
"Mask_pasto.tif" * (("SInd_NVeg.tif" * 2) + ("PastosArb.tif" * 2) + ("SInd_Pend.tif"))
Output raster
D:\APR\PASTOS_ARB\IRPArb.tif
Table Of Contents
Layers
IRPArb.tif
Value
High : 2.59058
Low : 0
SInd_Pend.tif
SInd_PastArb.tif
PastosArb.tif
Veg_Pasto.tif
SInd_NVeg.tif
Mask_pasto.tif
Mapa_uso_suelo.tif

Step 7: Normalise the Wood Pasture Restoration Suitability Index (IRPArb)
Lastly, normalise the **IRPArb.tif** file created in the previous step using the **"Fuzzy Membership"** tool to normalise the data. This process will serve to identify the maximum and minimum wood pasture restoration suitability values. In this regard, it is established that the higher the index, the more suited it is to restoration. The **"Fuzzy Membership"** tool is located in **ArcToolBox/Spatial Analyst Tools/Overlay/Fuzzy Membership.** Enter the **IRPArb.tif** file in the Input Raster box, name the output file **IRPArb_normalizado.tif** and save it in the **APR/PASTOS_ARB** folder.



The output should appear as follows: values approaching 1 correspond to those areas identified as being most suited to wood pasture restoration.



Part 3. Non-wood Pasture Suitability Index (IRPArb)

Pastures comprise a combination of grasses and pulses that serve as a balanced diet for livestock, providing protein (blood formation and thereby more milk production) and carbohydrates (energy to carry out daily activities). By combining different pasture species green fodder production can be increased.

To get the non-wood pasture restoration suitability index (IRPnArb) you need to create a subfolder and name it **PASTOS_noARB**. Therefore PART 3 output files will be saved in the **APR/PASTOS_noARB** folder. The files to be used to generate the processes will, for the most part, be obtained or called up from the APR/GALERIA folder and the GitHub repository.

Input file name	Location
SInd_Pend.tif	APR/GALERIA
SInd_NVeg.tif	APR/GALERIA
Mask_Pastos.tif	APR/PASTOS_ARB
Veg_Pasto.tif	APR/PASTOS_ARB
Mapa_uso_suelo.tif	https://github.com/guialandscape/GUIA_APR

Step 1: slope subindex
Add the layer called **SInd_Pend.tif** to ArcMap. This layer is located in the **APR/GALERIA** folder.

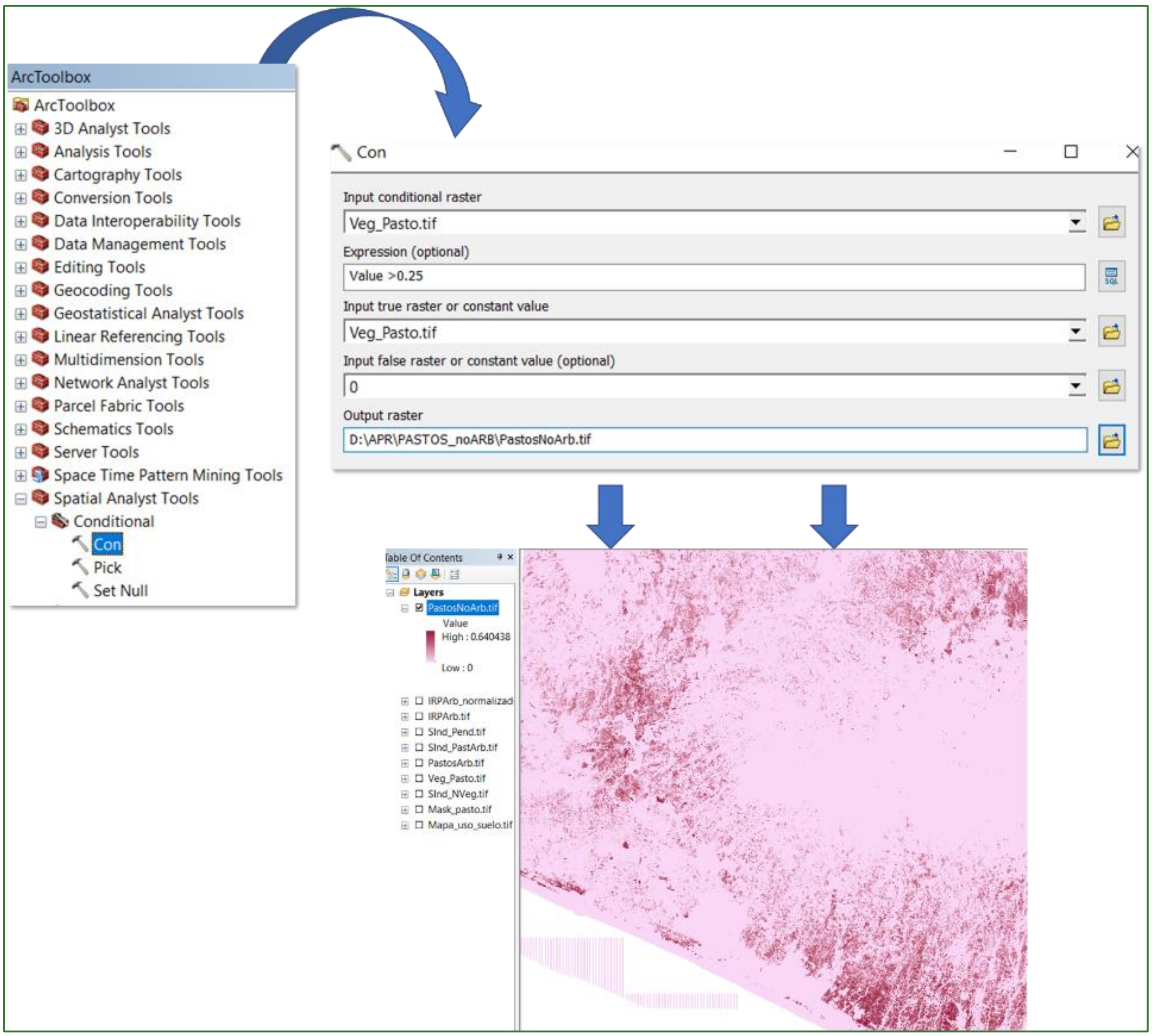
Step 2: no-vegetation subindex

Add the layer called **SInd_NVeg.tif** to ArcMap. This layer is located in the **APR/GALERIA** folder.

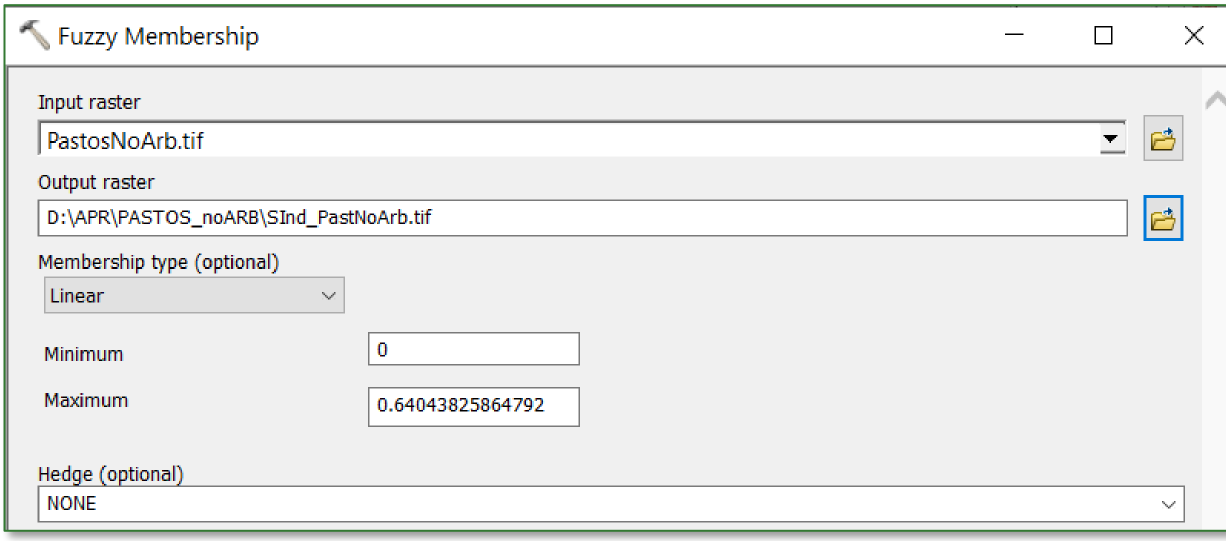
Step 3: pasture mask
Add the layer called **Mask_Pastos.tif** to ArcMap. This layer is located in the **APR/PASTOS_ARB** folder.

Step 4: pasture vegetation
Add the layer called **Veg_Pasto.tif** to ArcMap. This layer is located in the **APR/PASTOS_ARB** folder.

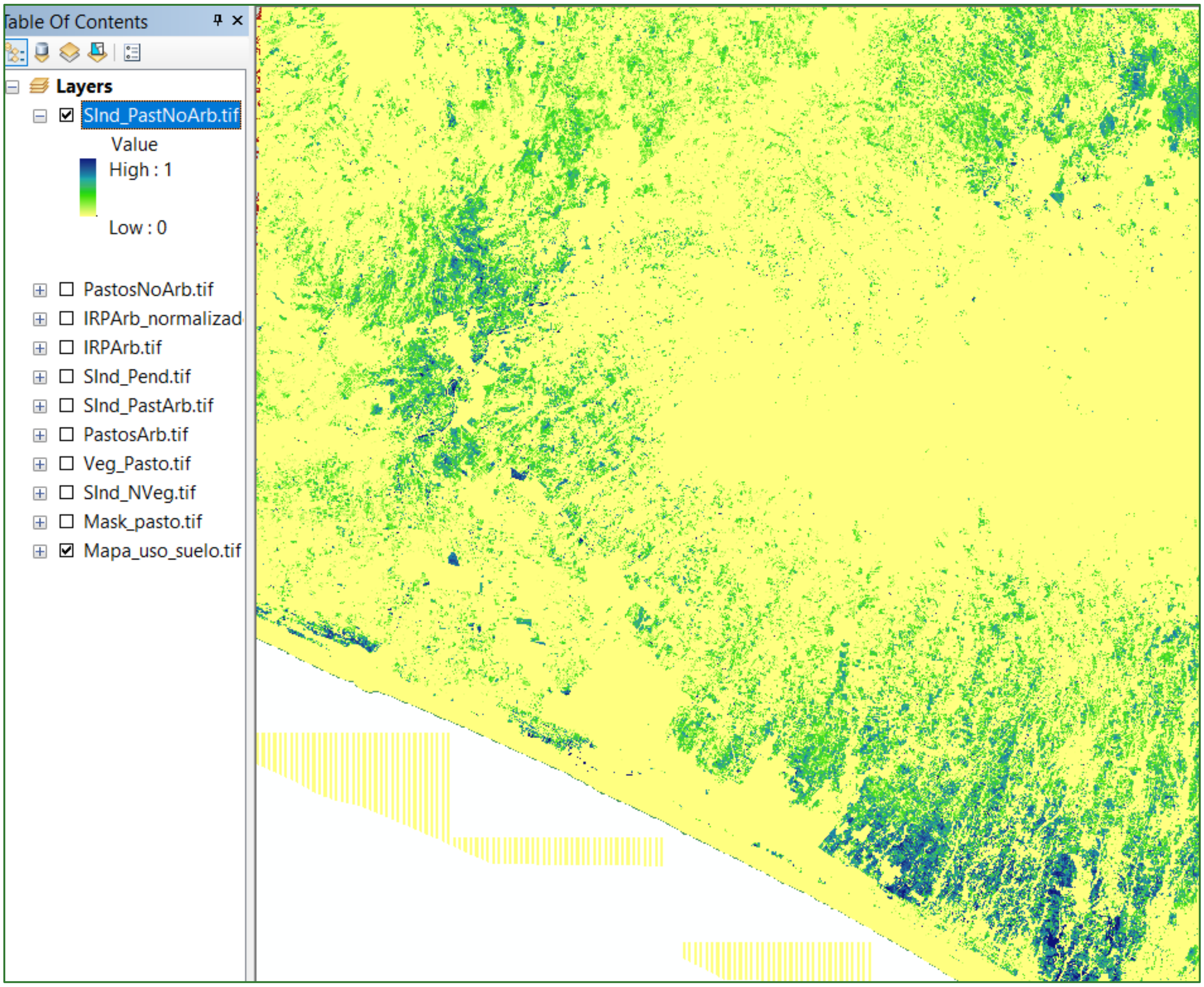
Step 5:
Apply a **Veg_Pasto.tif** raster conditional using the "Con" tool. Apply values of over 0.25, name the file **PastosNoArb.tif** and save it in the **APR/PASTOS_noARB** folder. The "Con" tool is located in **ArcToolBox/Spatial Analyst Tools/Conditional/Con.**



Step 6:
Normalise the **PastosNoArb.tif** raster by using the "Fuzzy Membership" (Type: Linear) tool. Name the output file **SInd_PastNoArb.tif** and save it in the **APR/PASTOS_noARB** folder.



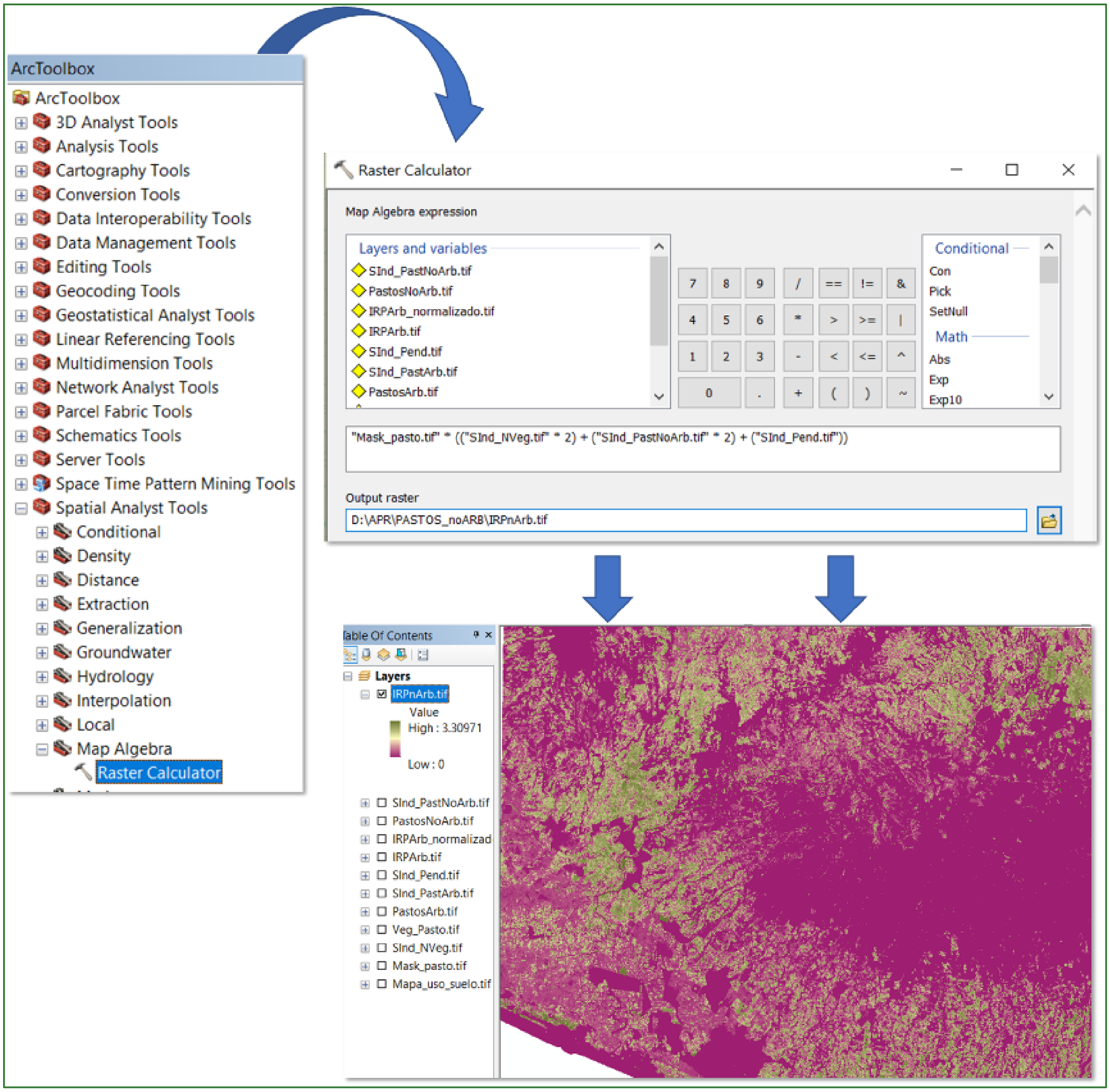
The more these approach values of 1, the more suited they are to non-wood pasture restoration. The output is shown below.



Step 7: Non-wood Pasture Restoration Suitability Index (IRPnArb)

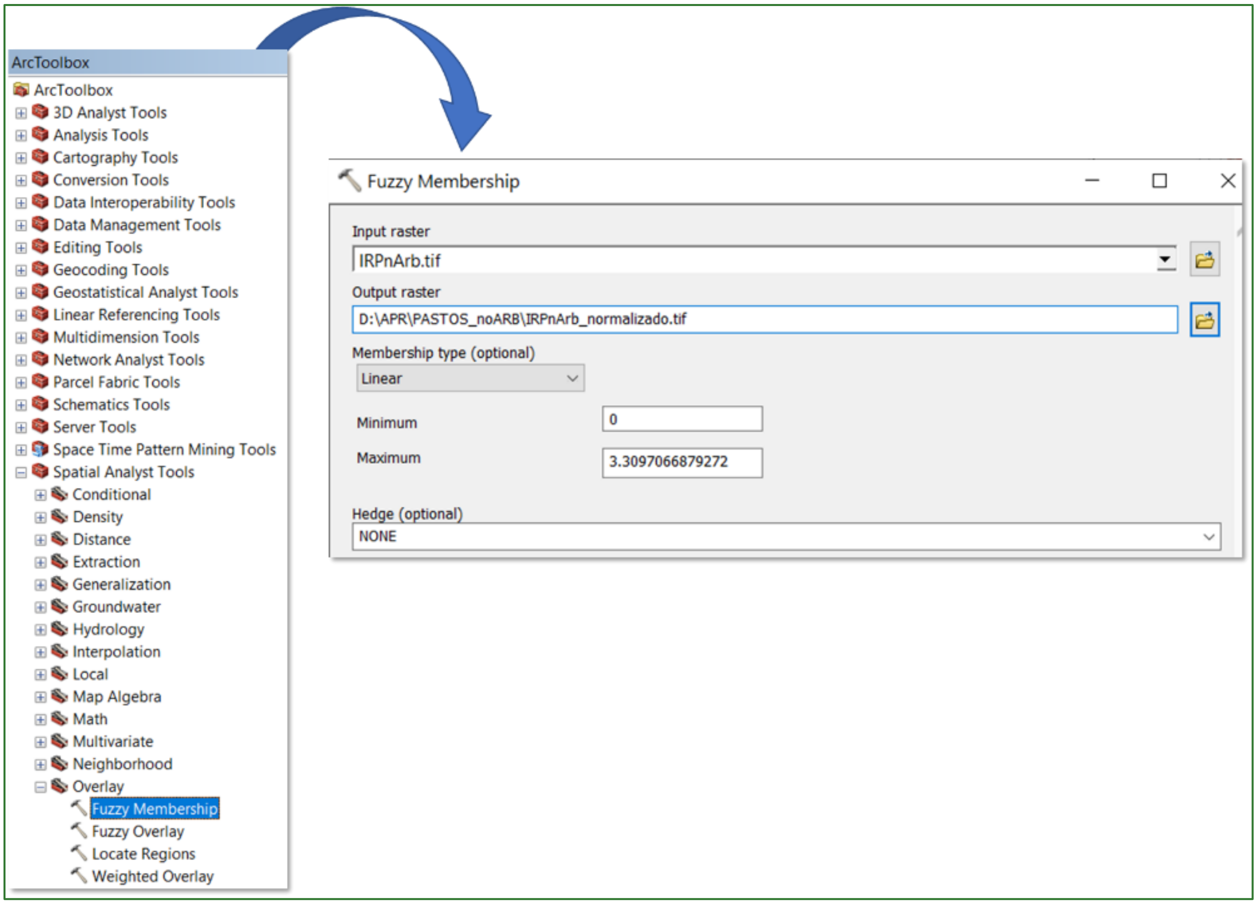
The last step consists of creating a Non-wood Pasture Restoration Suitability Index (IRPnArb). This index is obtained as a result of multiplying the pasture mask by the three subindices created above together with a certain weighting criterion. Use the **"Raster Calculator"** located in **ArcToolBox/Spatial Analyst Tools/Map Algebra/Raster Calculator** to create the index. Name the output file **IRPnArb.tif** and save it in the **APR/APR/PASTOS_noARB** folder. Apply the following weightings:

Mask_Pastos.tif * [(SInd_NVeg.tif * 2) + (SInd_PastNoArb.tif*2) + (SInd_Pend.tif)]



Step 8: normalise the Non-wood Pasture Restoration Suitability Index (IRPnArb)

Finally, normalise the **IRPnArb.tif** file created in the previous step using the **"Fuzzy Membership"** tool to normalise the data. This process will serve to identify the maximum and minimum non-wood pasture restoration suitability values. In this regard it is established that the higher the index, the more suited it is to restoration. The **"Fuzzy Membership"** tool is located in **ArcToolBox/Spatial Analyst Tools/Overlay/Fuzzy Membership.** Enter the **IRPnArb.tif** file in the Input Raster box, name the output file **IRPnArb_normalizado.tif** and save it in the **APR/PASTOS_noARB** folder.



The output should appear as follows: values approaching 1 correspond to those areas identified as being most suited to non-wood pasture restoration.

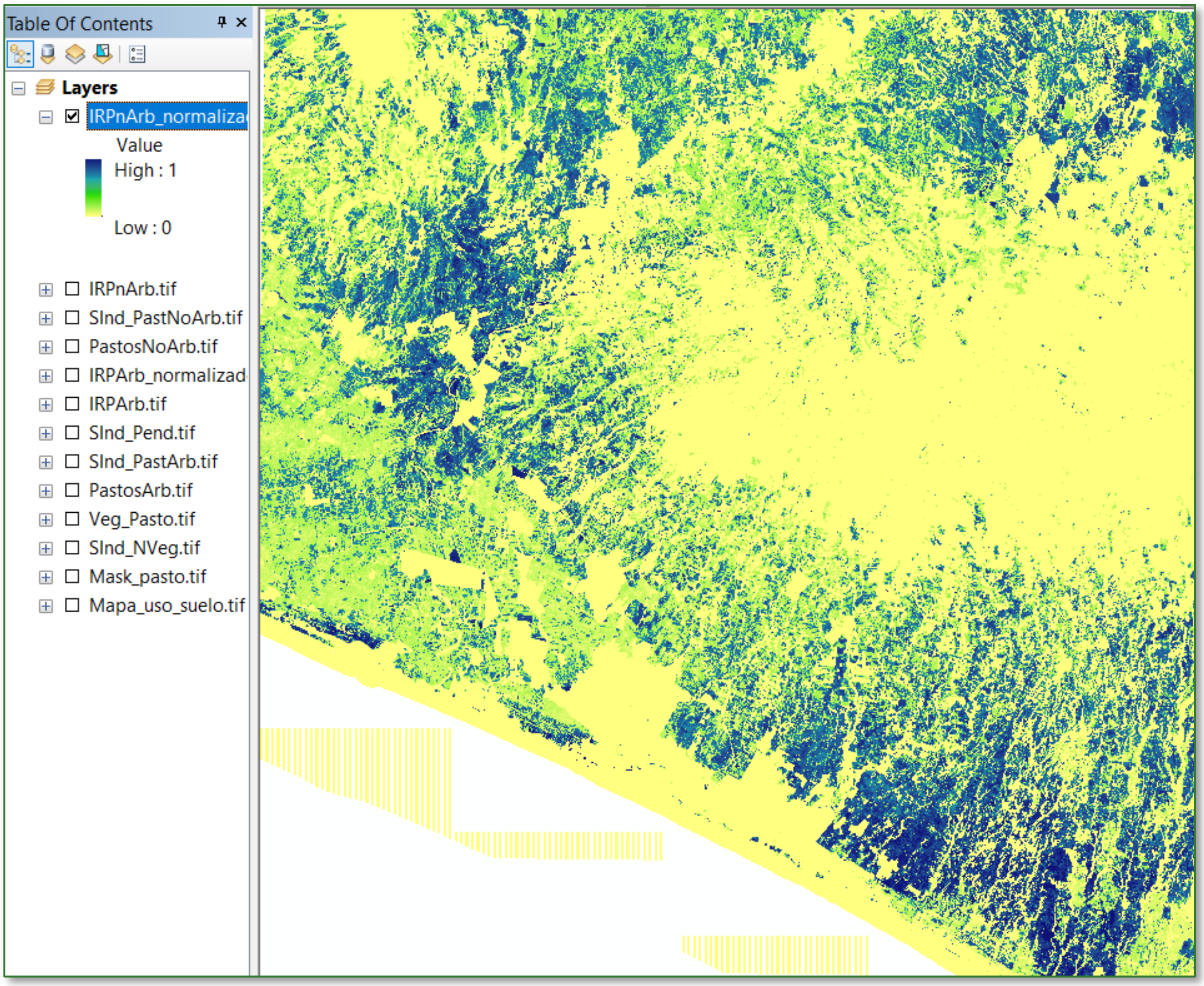


Table Of Contents
Layers
IRPnArb_normaliza
Value
High : 1
Low : 0
IRPnArb.tif
SInd_PastNoArb.tif
PastosNoArb.tif
IRPArb_normalizad
IRPArb.tif
SInd_Pend.tif
SInd_PastArb.tif
PastosArb.tif
Veg_Pasto.tif
SInd_NVeg.tif
Mask_pasto.tif
Mapa_uso_suelo.tif

Part 4. Shade-grown coffee restoration suitability index (IRCbS)

Shade-grown coffee areas provide important environmental services, such as capturing atmospheric water, regulating its infiltration and recharging aquifers, which protects against surface runoff and erosion. Another important environmental service is carbon storage, mainly by trees both in their trunks and in their roots.

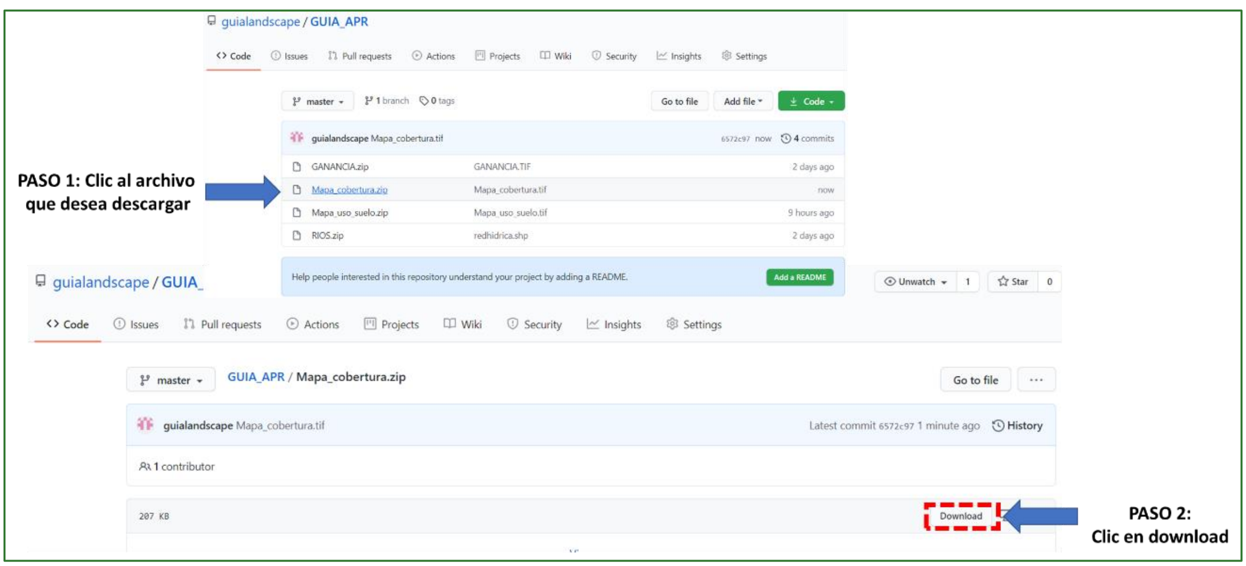
To get the Shade-grown Coffee Restoration Suitability Index (IRCbS) you will need to create a subfolder and name it **CAFETALES**. Therefore PART 3 output files will be saved in the **APR/CAFETALES** folder. The files to be used to generate the processes will, for the most part, be obtained or called up from the APR folder and the GitHub repository.

Input file name	Location
SInd_Pend.tif	APR/GALERIA
SInd_NVeg.tif	APR/GALERIA
Mapa_cobertura.tif	https://github.com/guialandscape/GUIA_APR
MDT_corregido.tif	PROCESOS/RASTER/MDT

Step 1: slope subindex
Add the layer called **SInd_Pend.tif** to ArcMap. This layer is located in the **APR/GALERIA** folder.

Step 2: no-vegetation subindex
Add the layer called **SInd_NVeg.tif** to ArcMap. This layer is located in the **APR/GALERIA** folder.

Step 3: coffee tree forest mask
Download the raster called **Mapa_cobertura.tif** from GitHub (https://github.com/guialandscape/GUIA_APR), save it in the **APR/CAFETALES** folder and then add it to the ArcMap.



Step 3.1: reclassify the file **Mapa_cobertura.tif**

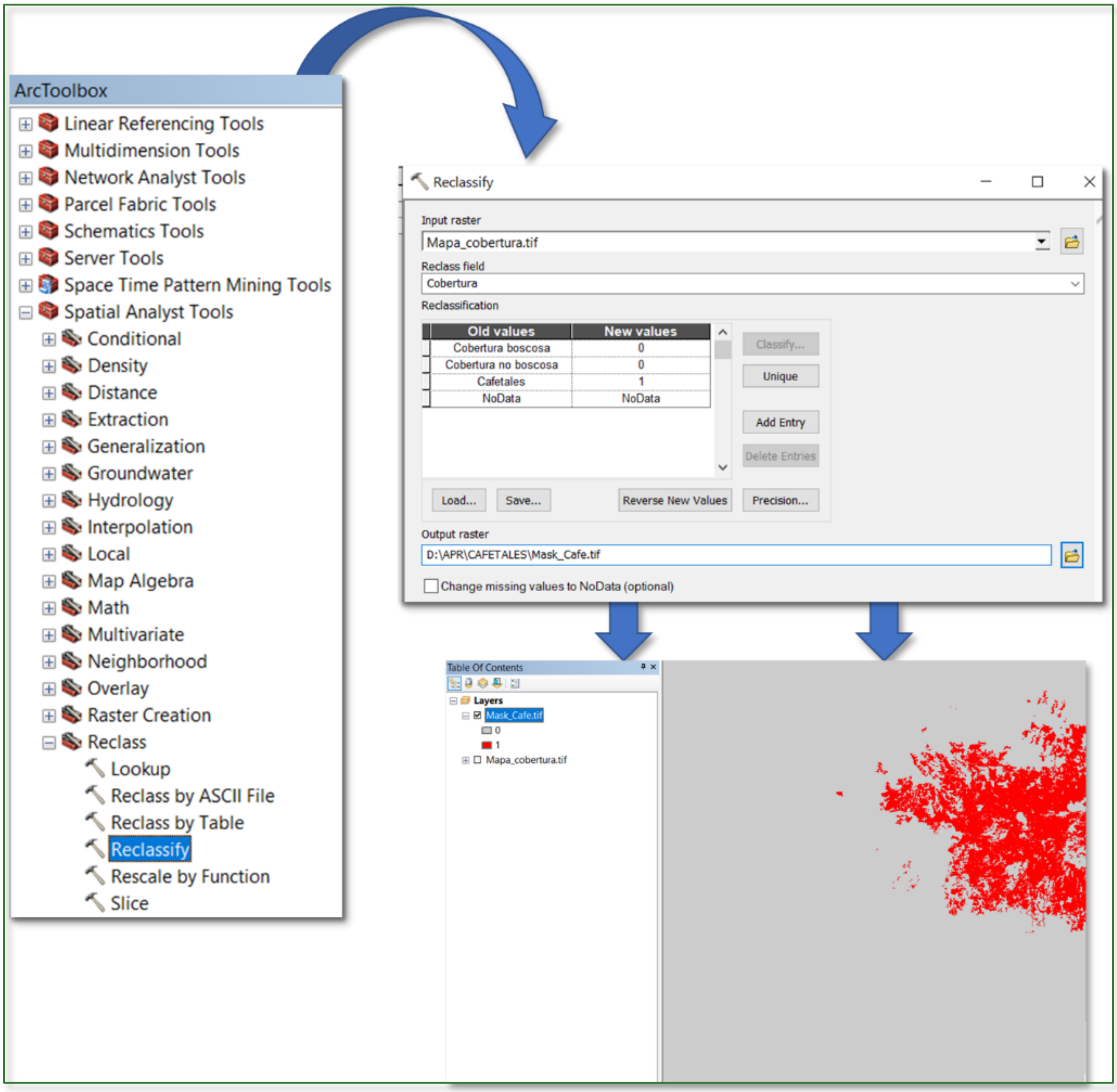
To do so use the **"Reclassify"** tool located in **ArcToolBox/Spatial Analyst Tools/Reclass/Reclassify.** Use the **Mapa_cobertura.tif** raster as the input file. Apply the following parameters:

Reclassify:

Coffee = 1

No Coffee = 0

Name the output file **Mask_Cafe.tif** and save it in the **APR/CAFETALES** folder.



Step 4: Altitude for Coffee subindex
Add the layer called **MDT_corregido.tif** to ArcMap which is located in the **PROCESOS/RASTER/MDT** folder. To do so use the **"Reclassify"** tool in **ArcToolBox/Spatial Analyst Tools/Reclass/Reclassify.** Use the **MDT_corregido.tif** raster as the input file, click on Class and define 4 classes with the following ranges:

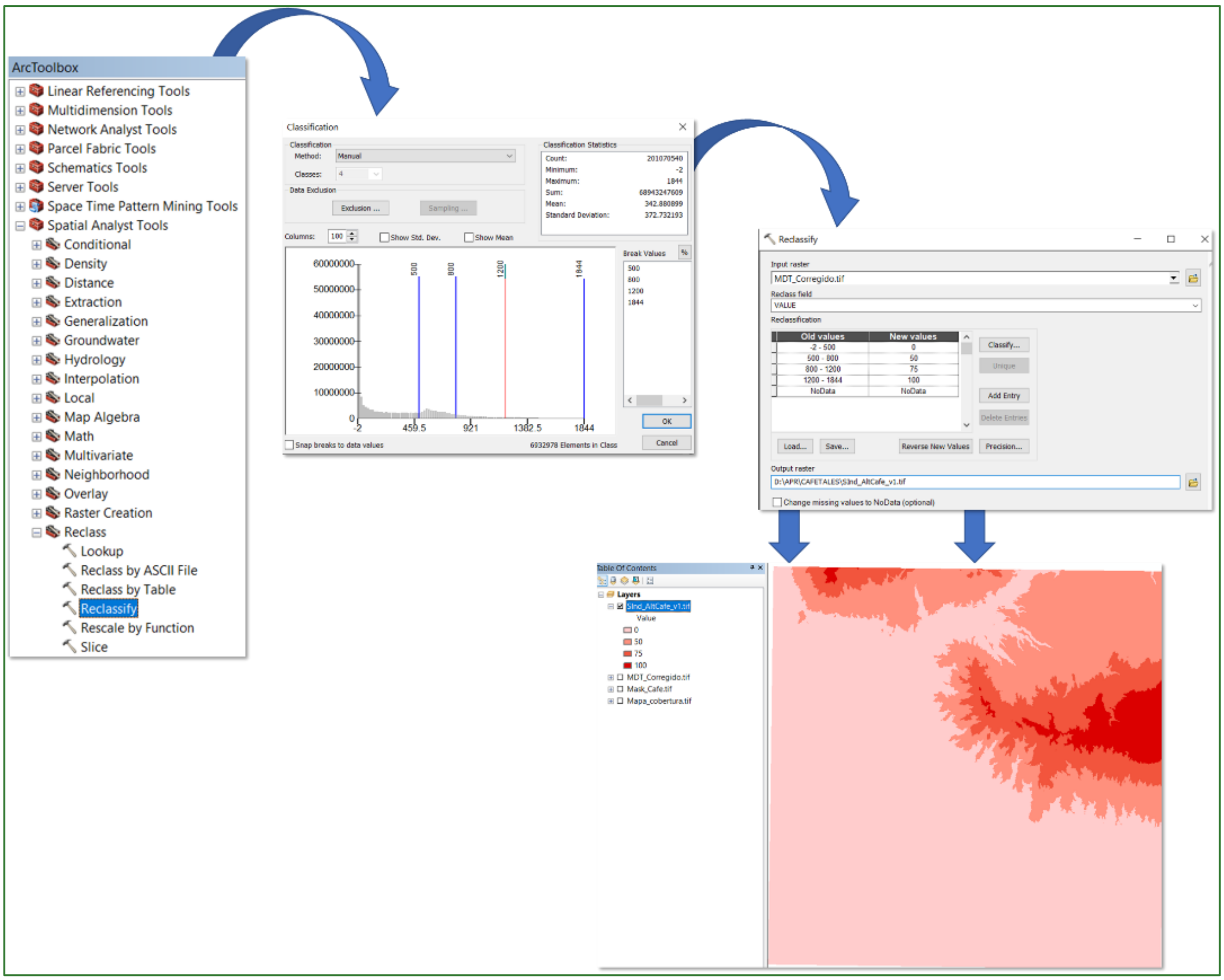
< = 500 = **0**

500 – 800 = **50**

800 - 1200 = **75**

>1200 = **100**

Name the output file **SInd_AltCafe_v1.tif** and save it in the **APR/CAFETALES** folder.



Step 4.1: convert the integer values to decimals
You now have to use the map calculator to cover the integer values to decimals. To do so use the **"Raster Calculator"** tool located in **ArcToolBox/Spatial Analyst Tools/Map Algebra/Raster**

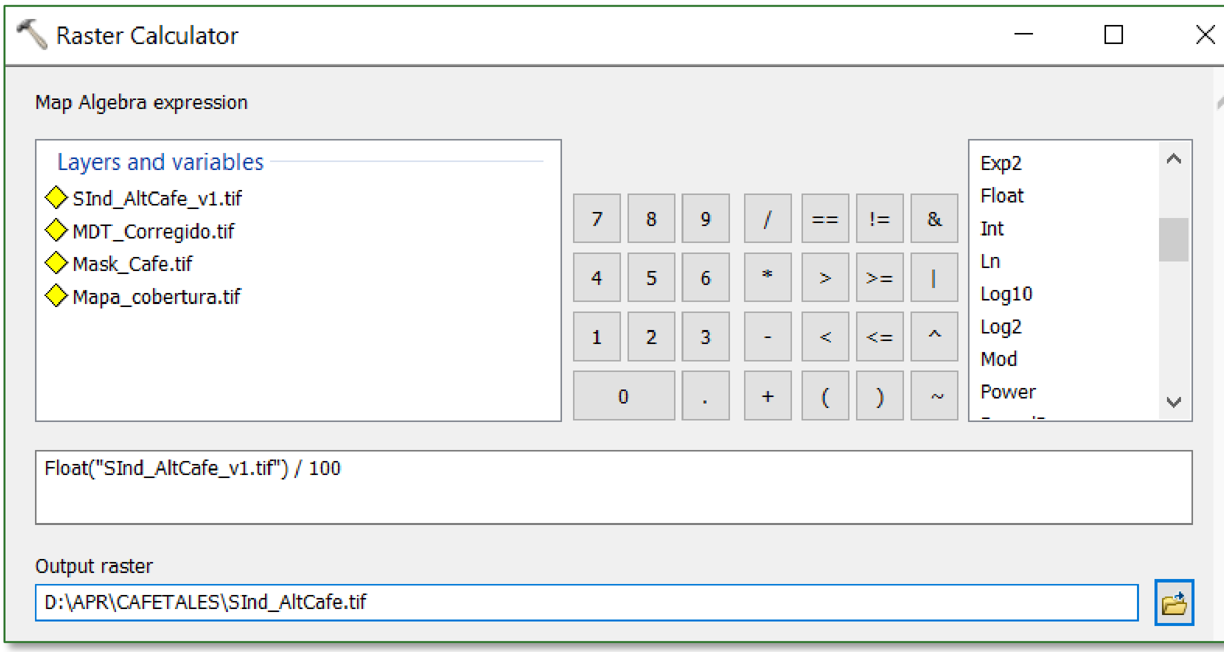
Calculator. Name the output file **SInd_AltCafe.tif**, divide it by 100 as FLOAT and save it in the **APR/CAFETALES** folder. Classes must end up with the following ranges:

< = 500 = **0**

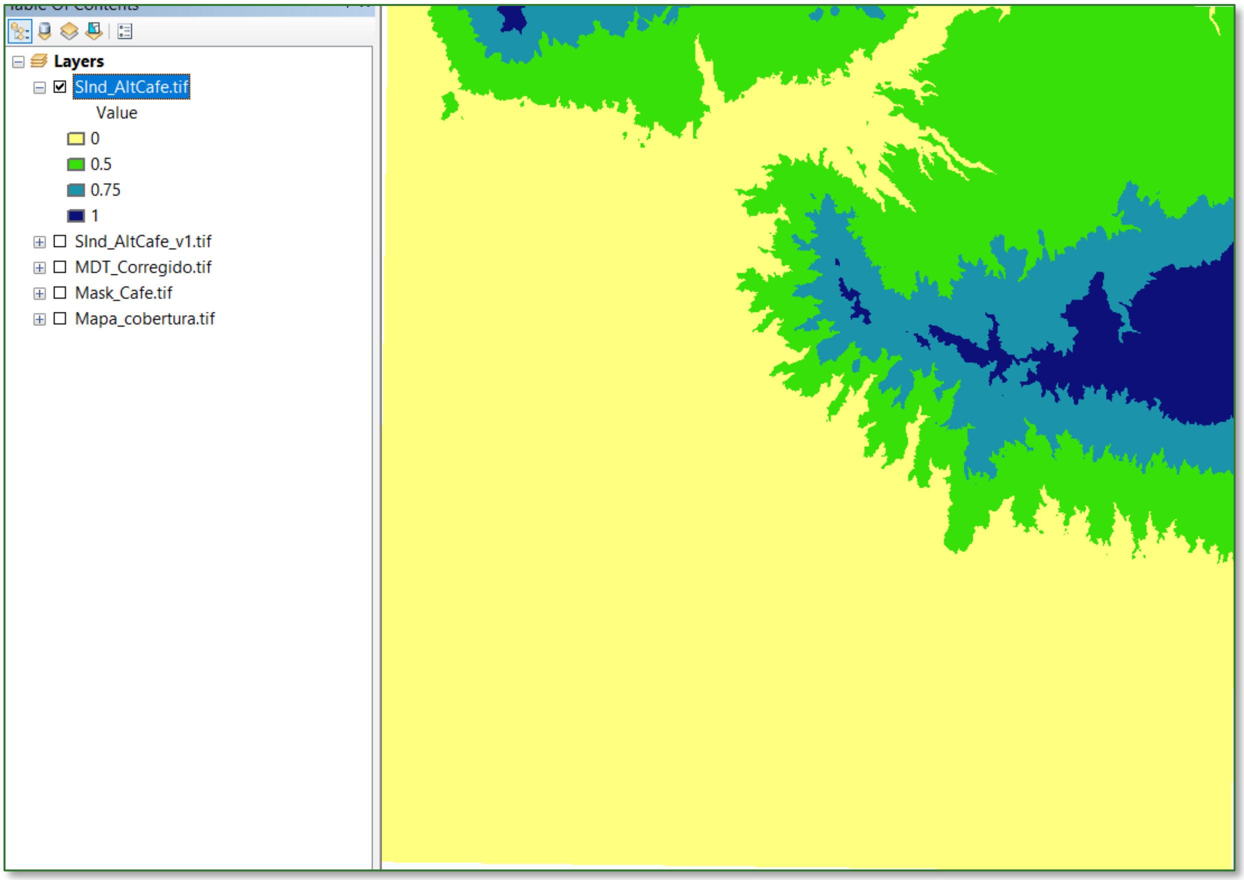
500 – 800 = **0.5**

800 - 1200 = **0.75**

>1200 = **1**

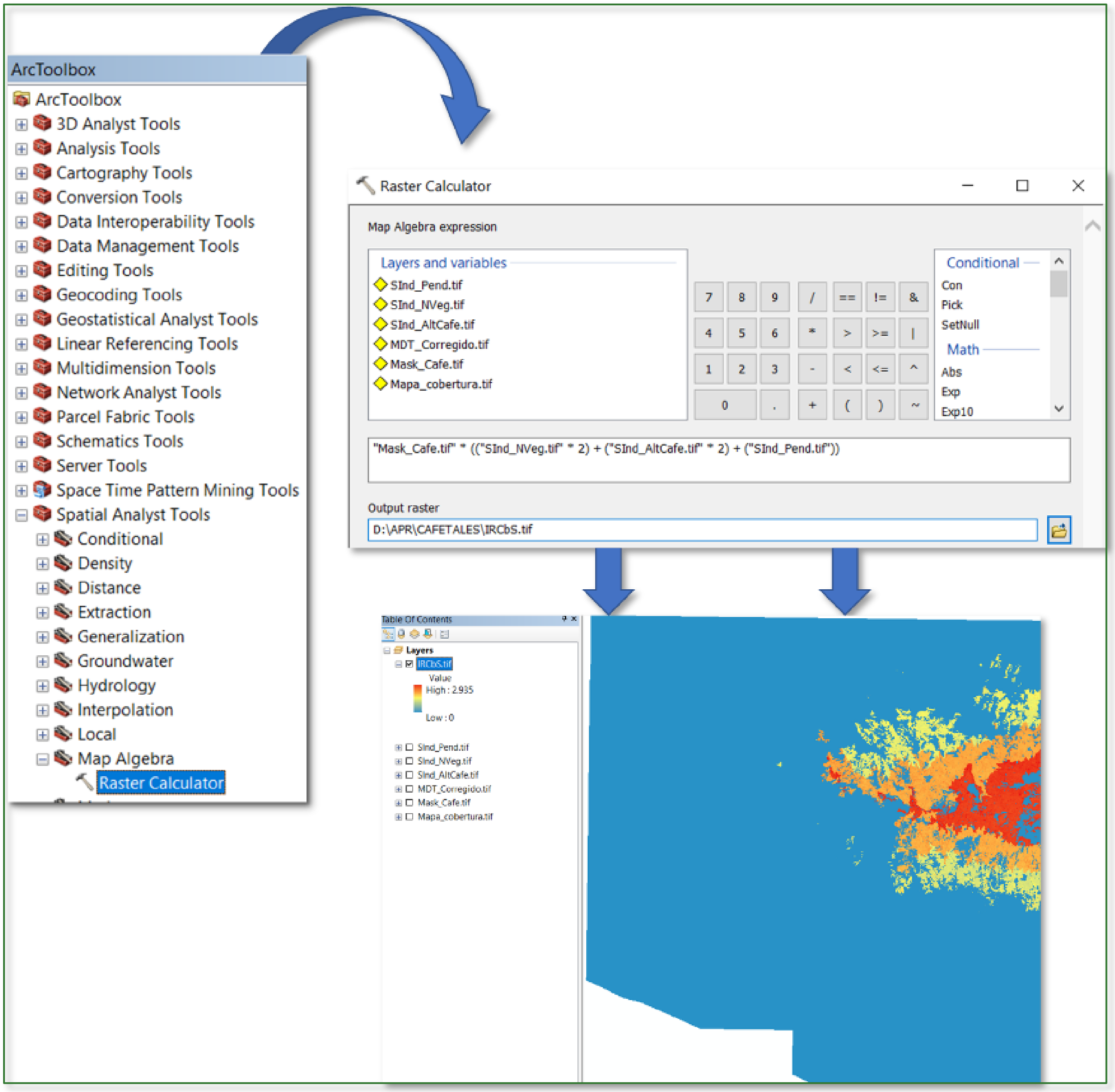


The output of this process is shown below:

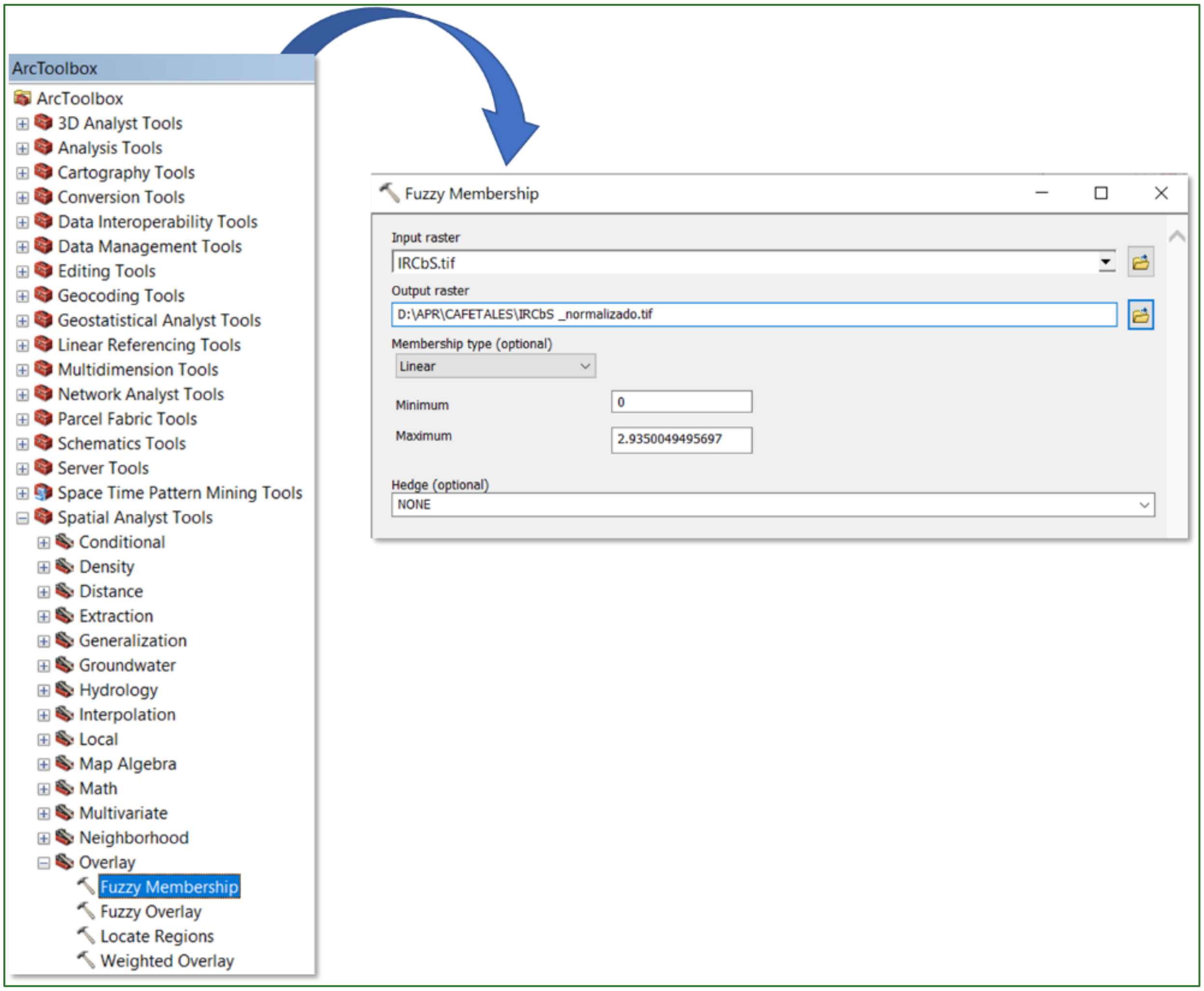


Step 5: create the Shade-grown Coffee Tree Forest Restoration Suitability Index (IRCbS)
This index is created from adding together the three subindices created above together with applying a certain weighting criterion. Use the **"Raster Calculator"** tool in **ArcToolBox/Spatial Analyst Tools/Map Algebra/Raster Calculator** to create the index. Name the output file **IRCbS.tif** and save it in the **APR/CAFETALES** folder. Apply the following weightings:

Mask_Cafe.tif * [(SInd_NVeg.tif * 2) + (SInd_AltCafe.tif*2) + (SInd_Pend.tif)]



Step 6: normalise the Shade-grown Coffee Tree Forest Restoration Suitability Index (IRCbS)
Finally, normalise the **IRCbS.tif** file created in the previous step using the **"Fuzzy Membership"** tool to normalise the data. This process will serve to identify the maximum and minimum shade-grown coffee restoration suitability values. In this regard it is established that the higher the index, the more suited it is to restoration. The **"Fuzzy Membership"** tool is located in **ArcToolBox/Spatial Analyst Tools/Overlay/Fuzzy Membership.** Enter the **IRCbS.tif** file in the Input Raster box, name the output file **IRCbS_normalizado.tif** and save it in the **APR/CAFETALES** folder.



The output should appear as follows: values approaching 1 correspond to those areas identified as being most suited to shade-grown coffee tree forest restoration.

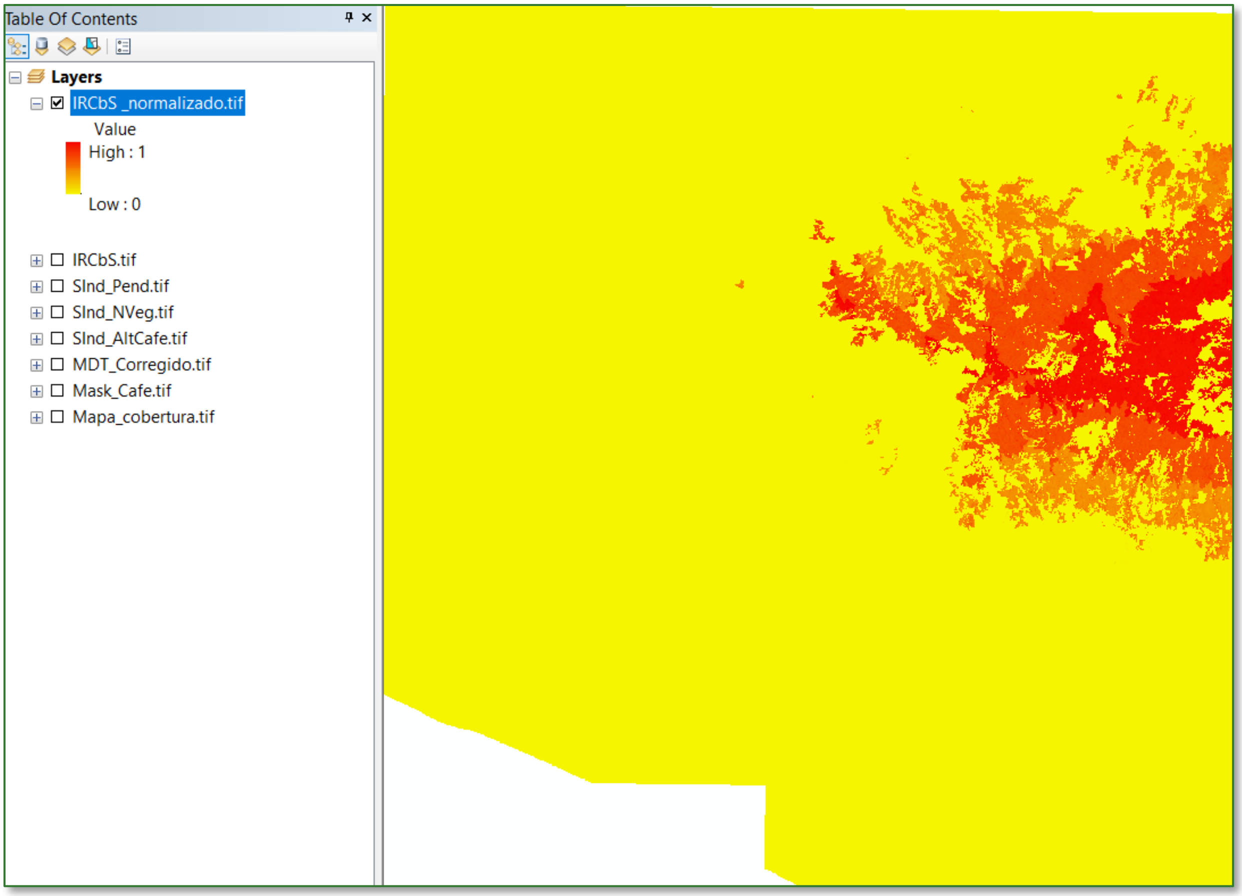


Table Of Contents
Layers
IRCbS _normalizado.tif
Value
High : 1
Low : 0
IRCbS.tif
SInd_Pend.tif
SInd_NVeg.tif
SInd_AltCafe.tif
MDT_Corregido.tif
Mask_Cafe.tif
Mapa_cobertura.tif

Part 5. Agroforestry systems restoration suitability index (IRAgro)

Agroforestry production systems are defined as a set of time and space-related land use systems and technologies that combine trees with crops and/or pasture to increase and optimise sustainable production.

In comparison to single-crop production systems, agroforestry systems offer farmers several advantages, for example:

- Increased and year-round income through the diversification of crops with different production cycles and the option to additionally sell wood and non-wood products such as rubber, nuts, colorants and honey
- Increased resilience against pests through the diversification of crops.
- Reduction in production costs.

To get the agroforestry systems restoration suitability index (IRAgro), you need to create a subfolder and name it **AGROFOR**. Therefore PART 5 output files will be saved in the **APR/AGROFOR** folder. The files to be used to generate the processes will, for the most part, be obtained or called up from the subfolders created in the previous steps and from the GitHub repository.

Input file name	Location
SInd_Pend.tif	APR/GALERIA
SInd_NVeg.tif	APR/GALERIA
Mapa_uso_suelo.tif	https://github.com/guialandscape/GUIA_APR APR/GALERIA
NBosq2.tif	APR/GALERIA
NBosq3.tif	APR/GALERIA
SInd_NBosq.tif	APR/GALERIA
MDT_corregido.tif	PROCESOS/RASTER/MDT

Step 1: slope subindex
Add the layer called **SInd_Pend.tif** to the ArcMap. This layer is located in the **APR/GALERIA** folder.

Step 2: no-vegetation subindex
Add the layer called **SInd_NVeg.tif** to the ArcMap. This layer is located in the **APR/GALERIA** folder.

Step 3: farming mask
Add the layer called **Mapa_uso_suelo.tif** to the ArcMap. This layer is located in the **APR/PASTOS_ARB** folder. Alternatively, download the raster called **Mapa_uso_suelo.tif** from the GitHub repository (https://github.com/guialandscape/GUIA_APR) and save it in the **APR/AGROFOR** folder and then add it to the ArcMap.

Step 3.1: reclassify the file Mapa_uso_suelo.tif

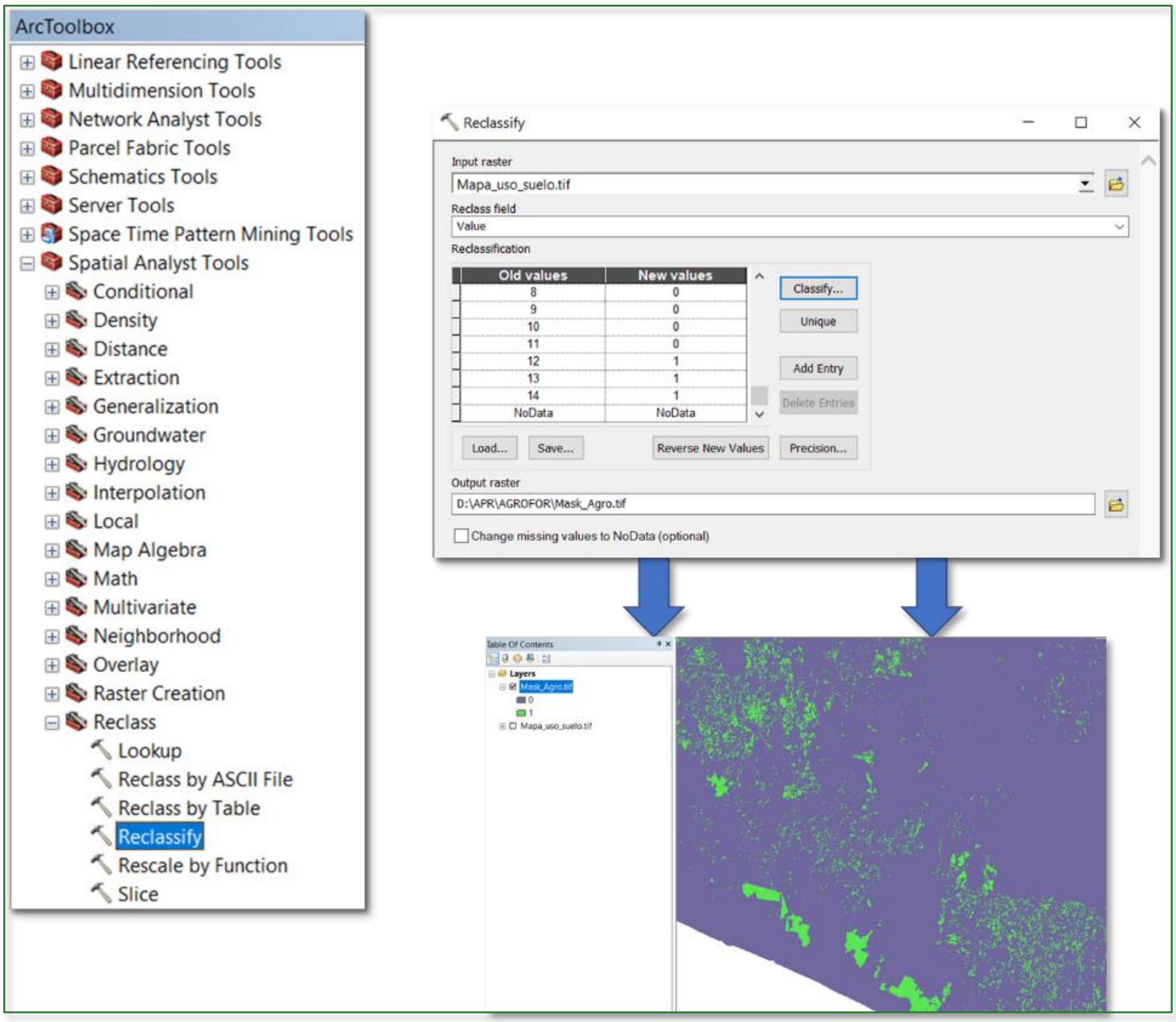
To do so use the **"Reclassify"** tool located in **ArcToolBox/Spatial Analyst Tools/Reclass/Reclassify.** Use the **Mapa_uso_suelo.tif** raster as the input file and apply the following parameters:

Reclassify:

Agricultural = 1 (on the map this corresponds to the other crops (basic grains, vegetables, rice, flower growing and the like), shrub vegetation class (scrub) and bare ground classes.

Non-agricultural = 0 (on the map this corresponds to the rest of the classes not mentioned above).

Name the output file **Mask_Agro.tif** and save it in the **APR/AGROFOR** folder.



Step 4:

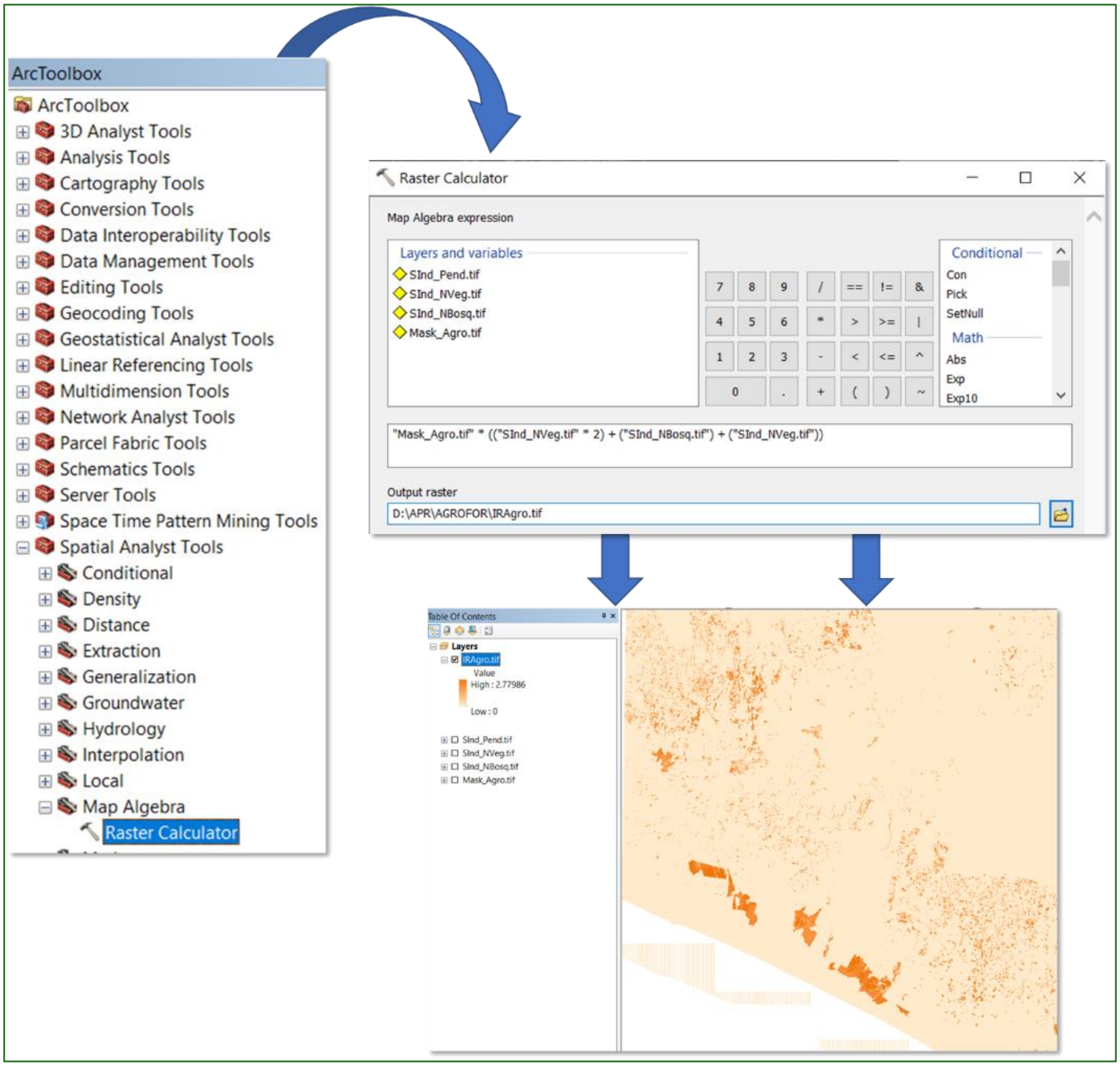
Add the layer called **NBosq2.tif** to the ArcMap. This layer is located in the **APR/GALERIA** folder.

Step 5:
Add the layer called **NBosq3.tif** to the ArcMap. This layer is located in the **APR/GALERIA** folder.

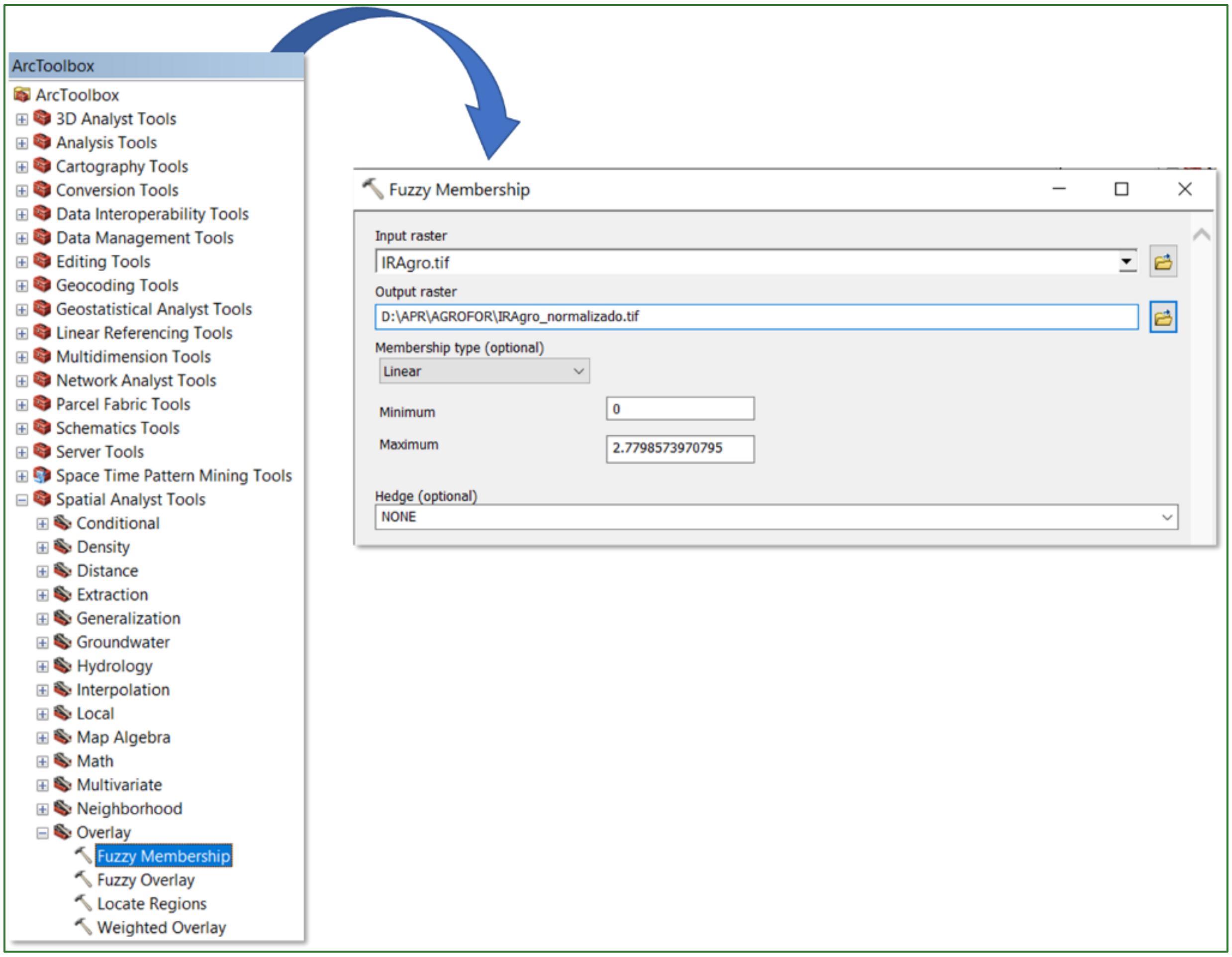
Step 6:
Add the layer called **SInd_NBosq.tif** to the ArcMap. This layer is located in the **APR/GALERIA** folder.

Step 7: create the Agroforestry System Restoration Suitability Index (IRCbS)
This index is created from adding together the three subindices created above together with applying a certain weighting criterion. Use the **"Raster Calculator"** tool in **ArcToolBox/Spatial Analyst Tools/Map Algebra/Raster Calculator** to create the index. Name the output file **IRAgro.tif** and save it in the **APR/AGROFOR** folder. Apply the following weightings:

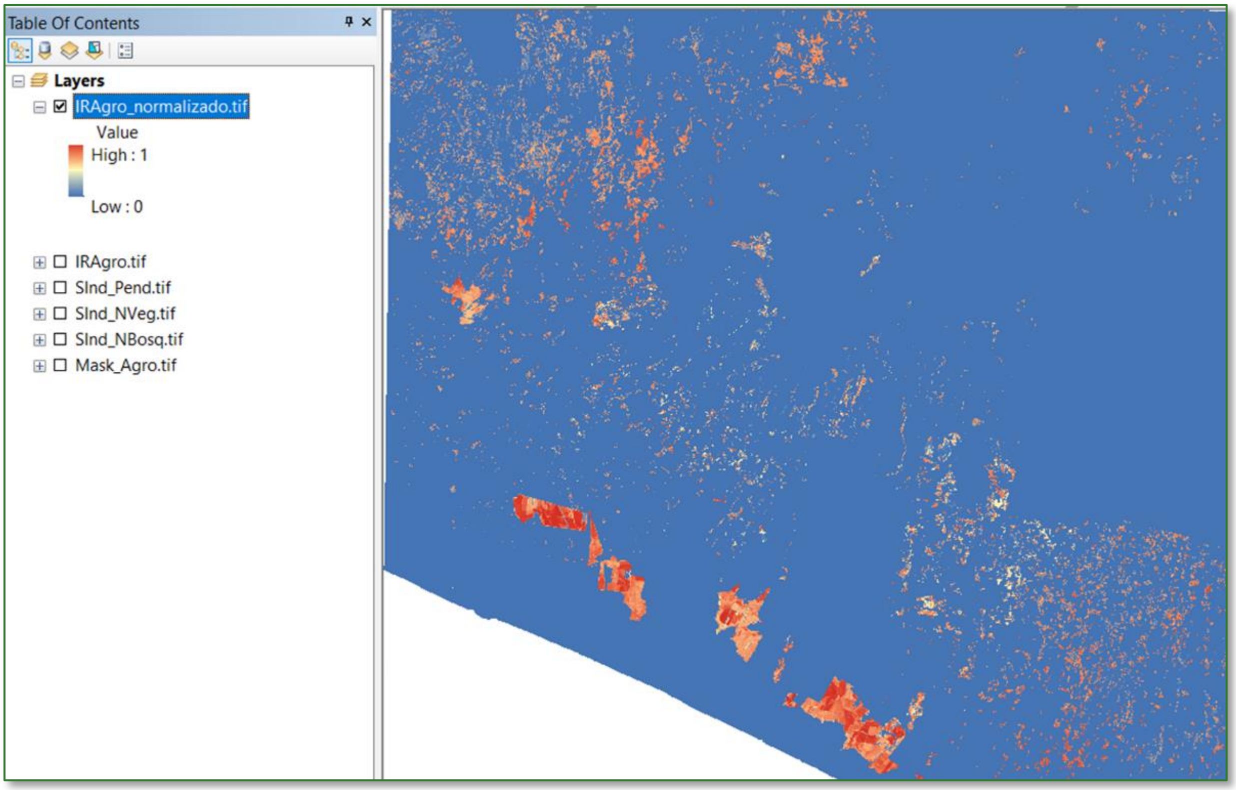
Mask_Agro.tif * [(SInd_NVeg.tif * 2) + (SInd_ NBosq.tif) + (SInd_Pend.tif)]



Step 8: normalise the Agroforestry System Restoration Suitability Index (IRAgro)
Finally, normalise the **IRAgro.tif** file created in the previous step using the **"Fuzzy Membership"** tool to normalise the data. This process will serve to identify the maximum and minimum agroforestry system restoration suitability values. In this regard, it is established that the higher the index defined or the closer it is to 1, the more suited it is to restoration. The **"Fuzzy Membership"** tool is located in **ArcToolBox/Spatial Analyst Tools/Overlay/Fuzzy Membership.** Enter the **IRAgro.tif** file in the Input Raster box, name the output file **IRAgro_normalizado.tif** and save it in the **APR/AGROFOR** folder.



The output should appear as follows: values approaching 1 correspond to those areas identified as being most suited to agroforestry system restoration.



Part 6. Reforestation suitability index (IRef)

Reforestation means to replant trees in areas that have lost their forest cover in the recent past, for example through industrial logging.

In this section, the soil surfaces suited for forest growth and that are available for reforestation and their location in the project area will be identified.

To obtain the Reforestation Suitability Index (IRef), you need to create a subfolder and name it **REFORESTA**. Therefore PART 6 output files will be saved in the **APR/REFORESTA** folder. The files to be used to generate the processes will, for the most part, be obtained or called up from the subfolders created in the previous steps and from the GitHub repository.

Input file name	Location
SInd_Pend.tif	APR/GALERIA
SInd_NVeg.tif	APR/GALERIA
SInd_NBosq.tif	APR/GALERIA

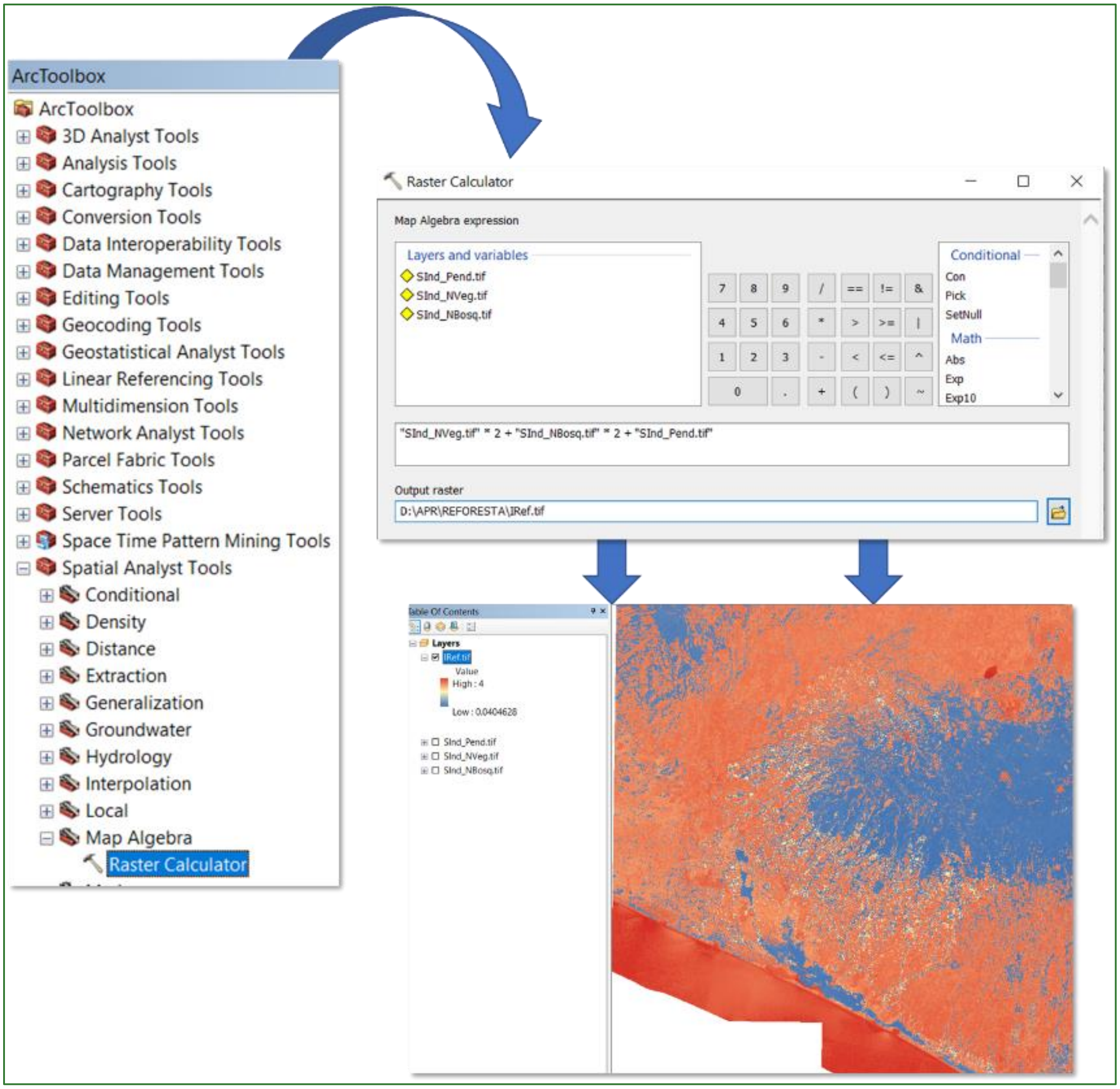
Step 1: slope subindex
add the layer called **SInd_Pend.tif** to the ArcMap. This layer is located in the **APR/GALERIA** folder.

Step 2: no-vegetation subindex
Add the layer called **SInd_NVeg.tif** to the ArcMap. This layer is located in the **APR/GALERIA** folder.

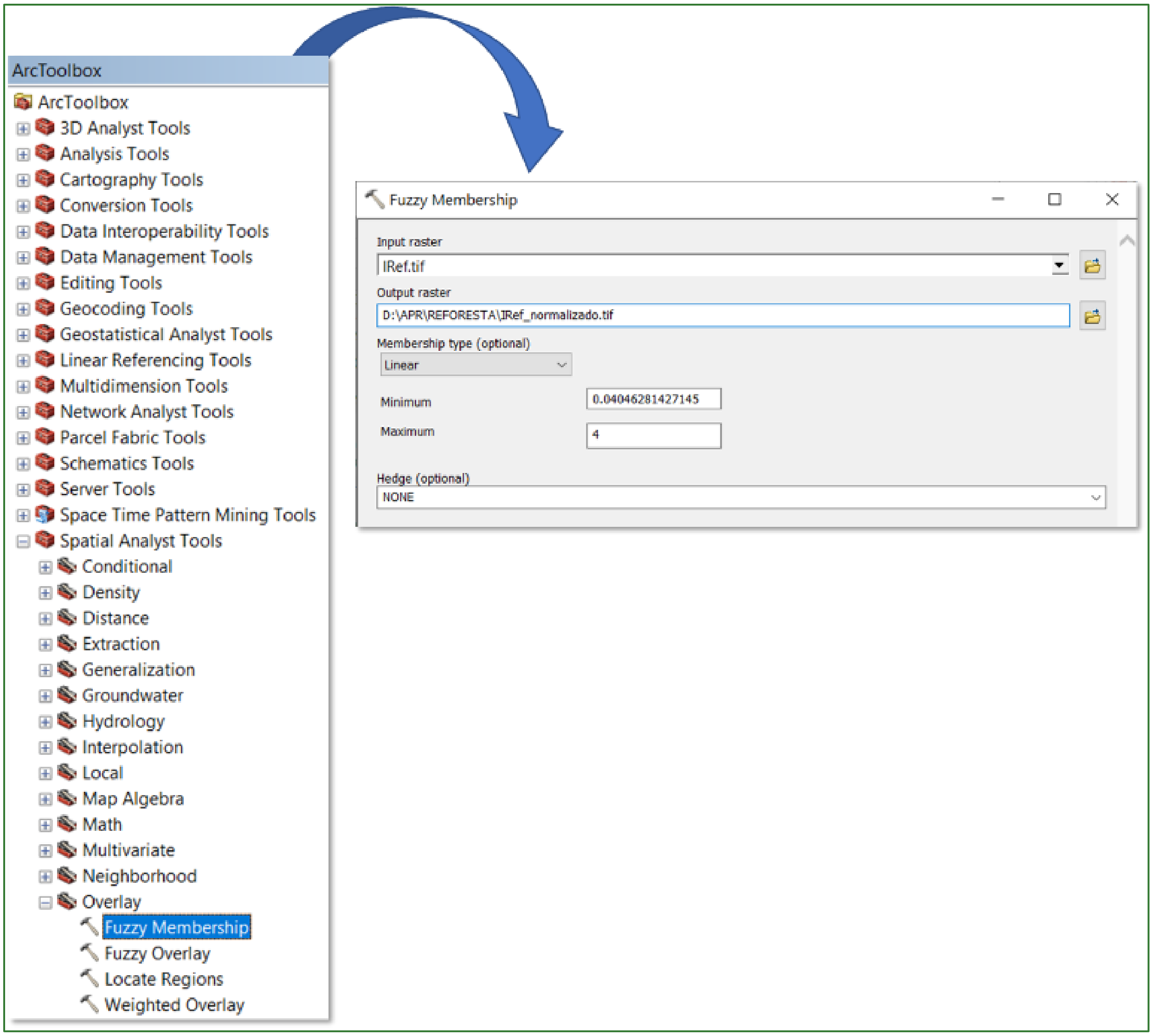
Step 3: no-forest subindex
Add the layer called **SInd_NBosq.tif** to the ArcMap. This layer is located in the **APR/GALERIA** folder.

Step 4: create the Reforestation Suitability Index (IRef)
This index is created from adding together the three subindices created above together with applying a certain weighting criterion. Use the **"Raster Calculator"** tool in **ArcToolBox/Spatial Analyst Tools/Map Algebra/Raster Calculator** to create the index. Name the output file **IRef.tif** and save it in the **APR/ REFORESTA** folder. Apply the following weightings:

SInd_NVeg.tif * 2 + SInd_NBosq.tif * 2 + SInd_Pend.tif



Step 5: normalise the Reforestation Suitability Index (IRef)
Lastly, normalise the **IRef.tif** file created in the previous step using the **"Fuzzy Membership"** tool to normalise the data. This process will serve to identify the maximum and minimum reforestation restoration suitability values. It is established that the higher the index or the closer it is to 1, the more suited it is to restoration. The **"Fuzzy Membership"** tool is located in **ArcToolBox/Spatial Analyst Tools/Overlay/Fuzzy Membership.** Enter the **IRef.tif** file in the Input Raster box, name the output file **IRef_normalizado.tif** and save it in the **APR/REFORESTA** folder.



The output should appear as follows: values approaching 1 correspond to those areas identified as being most suited to reforestation.

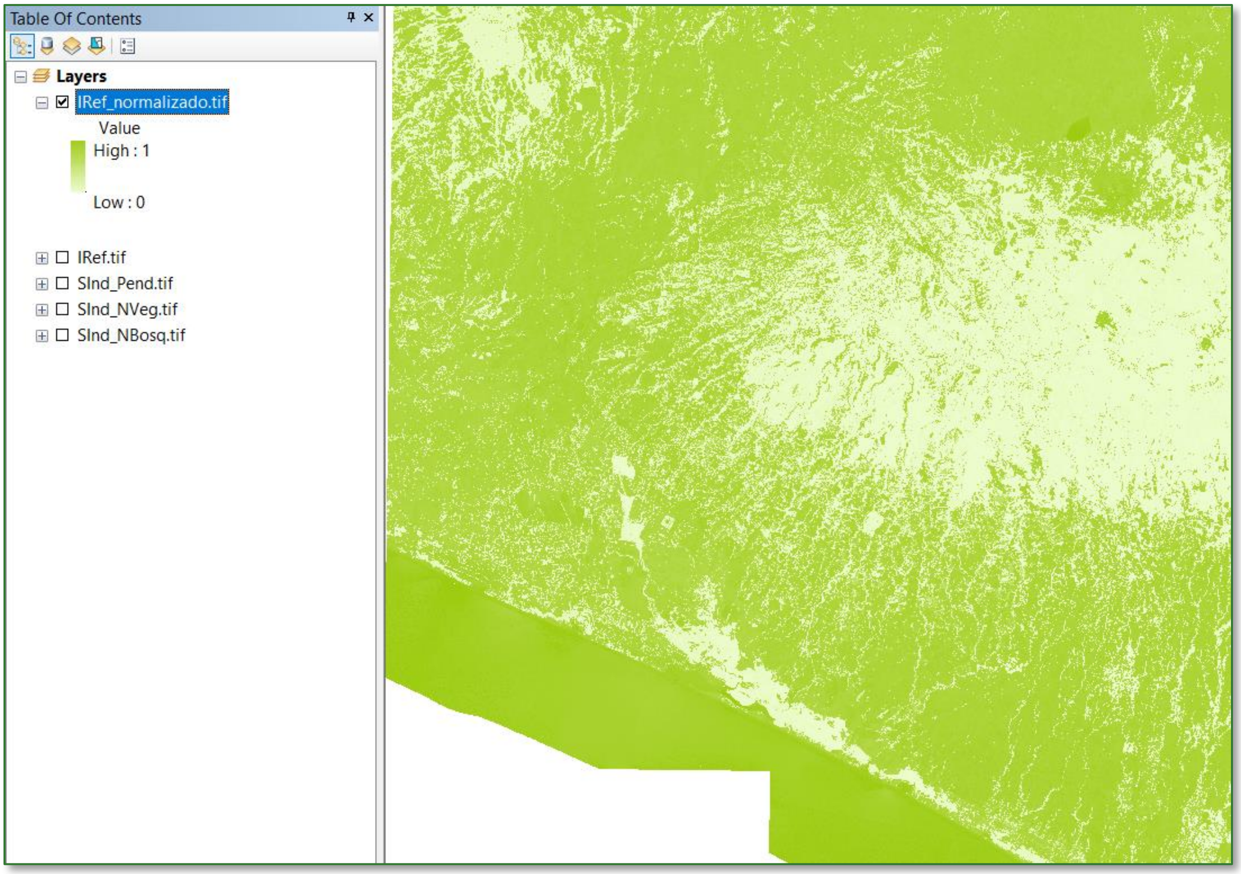


Table Of Contents
Layers
IRef_normalizado.tif
Value
High : 1
Low : 0
IRef.tif
SInd_Pend.tif
SInd_NVeg.tif
SInd_NBosq.tif

Part 7. Secondary forest restoration suitability index (IRBS)

Secondary forests are forests regenerating largely through natural processes after significant human and/or natural disturbance of the original forest vegetation at a single point in time or over an extended period. They are displaying a major difference in forest structure and/or canopy species composition with respect to primary forests on similar sites (Chokkalingam and de Jong, 2001).

With the continuing growth and maturation of secondary forests important ecological processes and ecosystems services are restored as well, including:

- soil formation.
- regulation of water flows.
- erosion control (caused by water and/or wind).
- carbon accumulation.

In this section, the soil surfaces preferably suited to forestry and that are potentially available for secondary forest restoration in the project area will be identified and determined.

To get the Secondary Forest Restoration Suitability Index (IRBS) you will need to create a subfolder and name it **B-SECUNDARIO**. Therefore PART 7 output files will be saved in the **APR/B_SECUNDARIO** folder. The files to be used to generate the processes will, for the most part, be obtained or called up from the subfolders created in the previous steps and from the GitHub repository.

Input file name	Location
SInd_Pend.tif	APR/GALERIA
SInd_NVeg.tif	APR/GALERIA
ganancias.tif	APR/GALERIA/GANANCIA
Mapa_cobertura	APR/CAFETALES

Step 1: slope subindex
Add the layer called **SInd_Pend.tif** to the ArcMap. This layer is located in the **APR/GALERIA** folder.

Step 2: no-vegetation subindex
Add the layer called **SInd_NVeg.tif** to the ArcMap. This layer is located in the **APR/GALERIA** folder.

Step 3: secondary forest subindex

Step 3.1

Add the layer called **Mapa_cobertura.tif** to the ArcMap. This layer is located in the **APR/CAFETALES** folder.

Step 3.2: reclassify the file **Mapa_cobertura.tif**

To do so use the **"Reclassify"** tool located in **ArcToolBox/Spatial Analyst Tools/Reclass/Reclassify.** Use the **Mapa_cobertura.tif** raster as the input file and apply the following parameters:

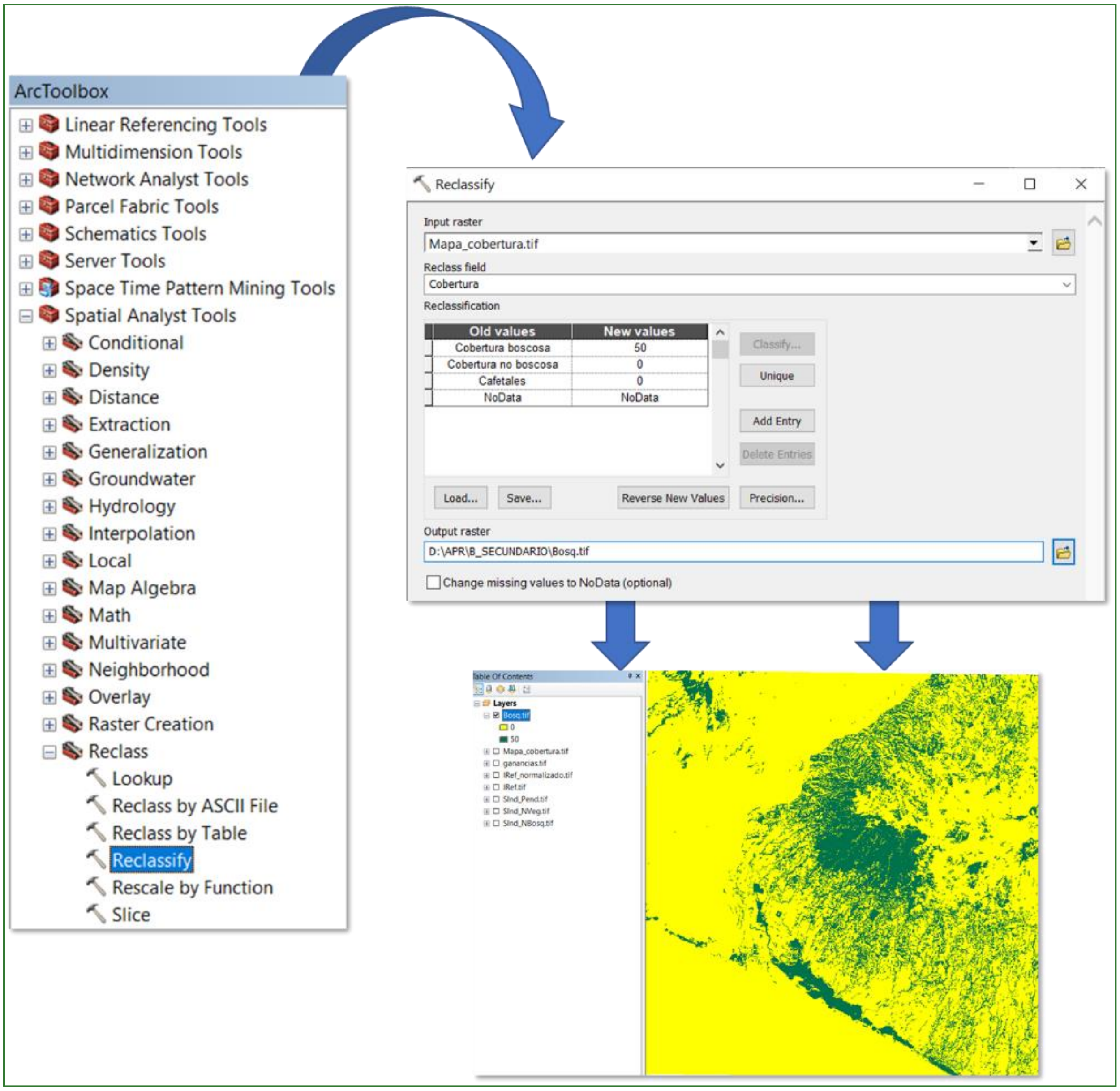
Reclassify:

Forest = 50 (this corresponds to "forest cover" on the map)

No Forest = 0 (this corresponds to "no-forest cover" and "coffee tree forests" on the map)

N.B.: If the area under analysis has no primary forest, this must be reclassified as 0 (no-forest). In the specific example of El Salvador, the map does not have the primary forest category.

Name the output file **Bosq.tif** and save it in the **APR/B_SECUNDARIO** folder.



Step 3.3:
Add the layer called **ganancias.tif** to the ArcMap. This layer is located in the **APR/GALERIA/GANANCIA** folder.

Step 3.4:
Reclassify the **ganancias.tif** file using the **"Reclassify"** tool located in **ArcToolBox/Spatial Analyst Tools/Reclass/Reclassify**. Use the **ganancias.tif** raster as the input file and apply the following parameters:

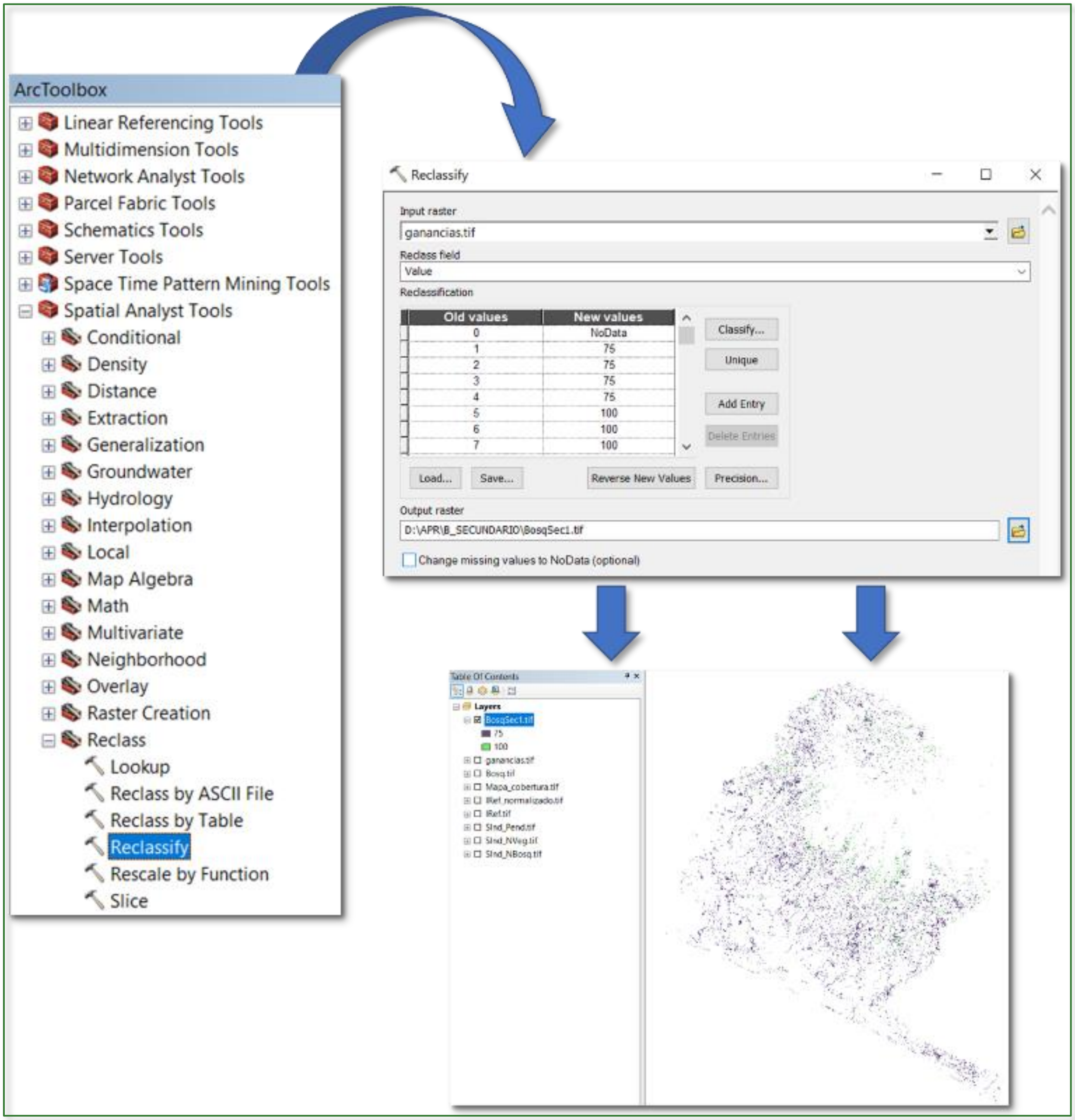
Reclassify:

0 = NoData

2-5m = 75

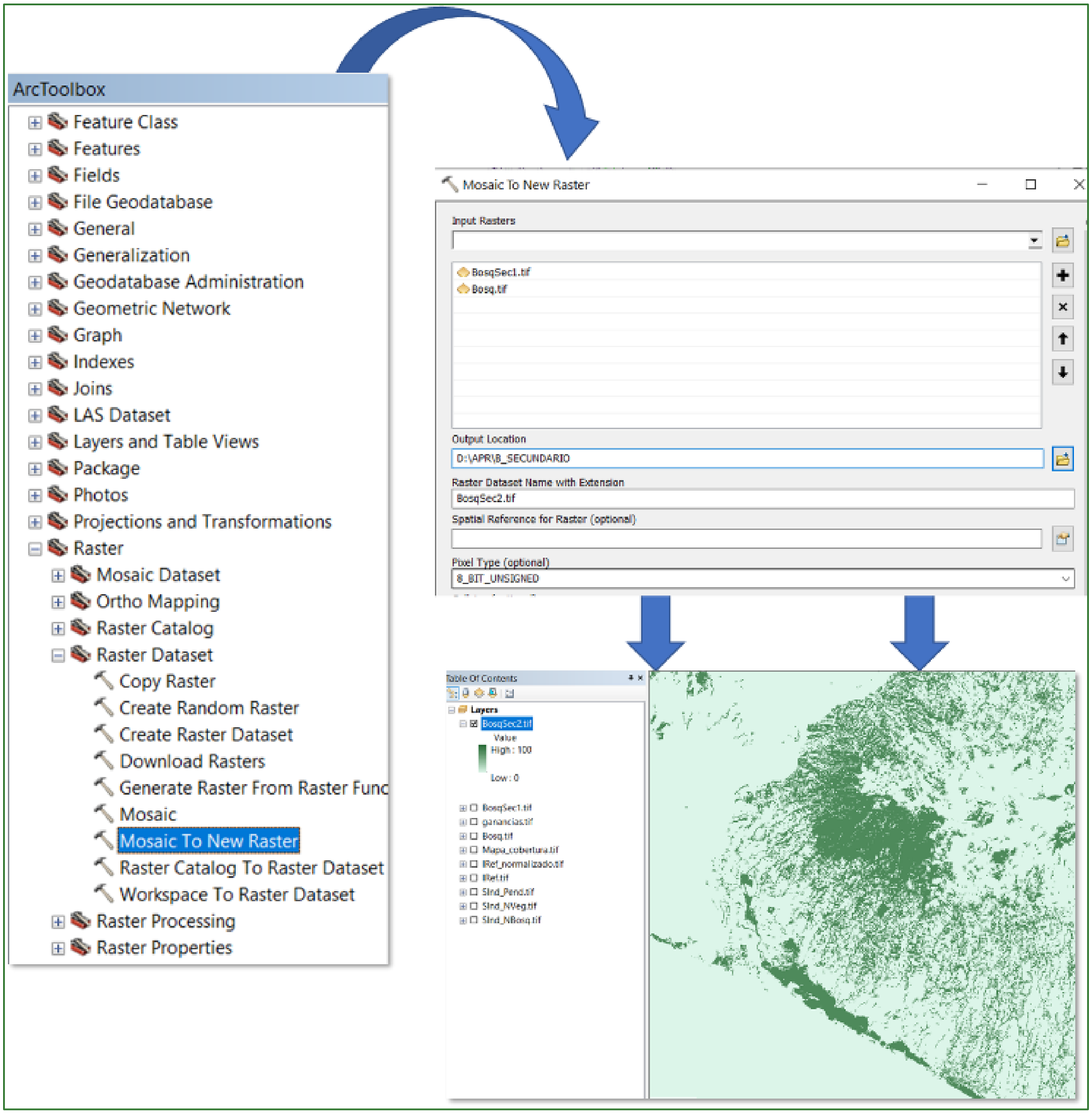
>= 5m = 100

Name the output file **BosqSec1.tif** and save it in the **APR/B_SECUNDARIO** folder.

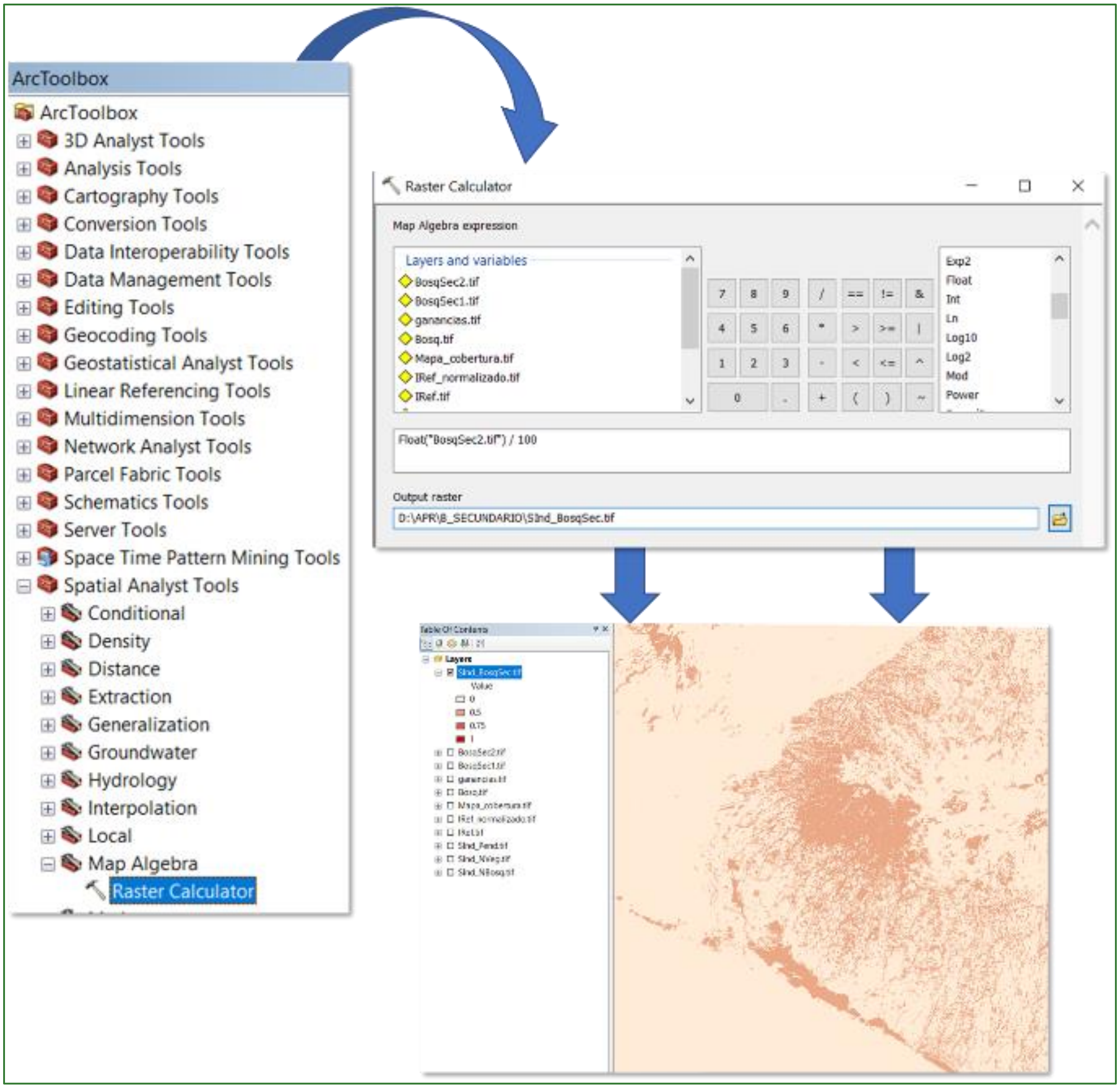


Step 3.5: generate a mosaic for the study area

Use the aforementioned **BosqSec1.tif** layer and the **Bosq.tif** raster to do so. Run the "**Mosaic to New Raster**" tool located in **ArcToolBox/Data Management Tools/Raster/Raster Dataset/Mosaic to New Raster.** Use the files **BosqSec1.tif** (which will be at the top) and **Bosq.tif** (which will be at the bottom). Name the output file **BosqSec2.tif** and save it in the **APR/B_SECUNDARIO** folder.

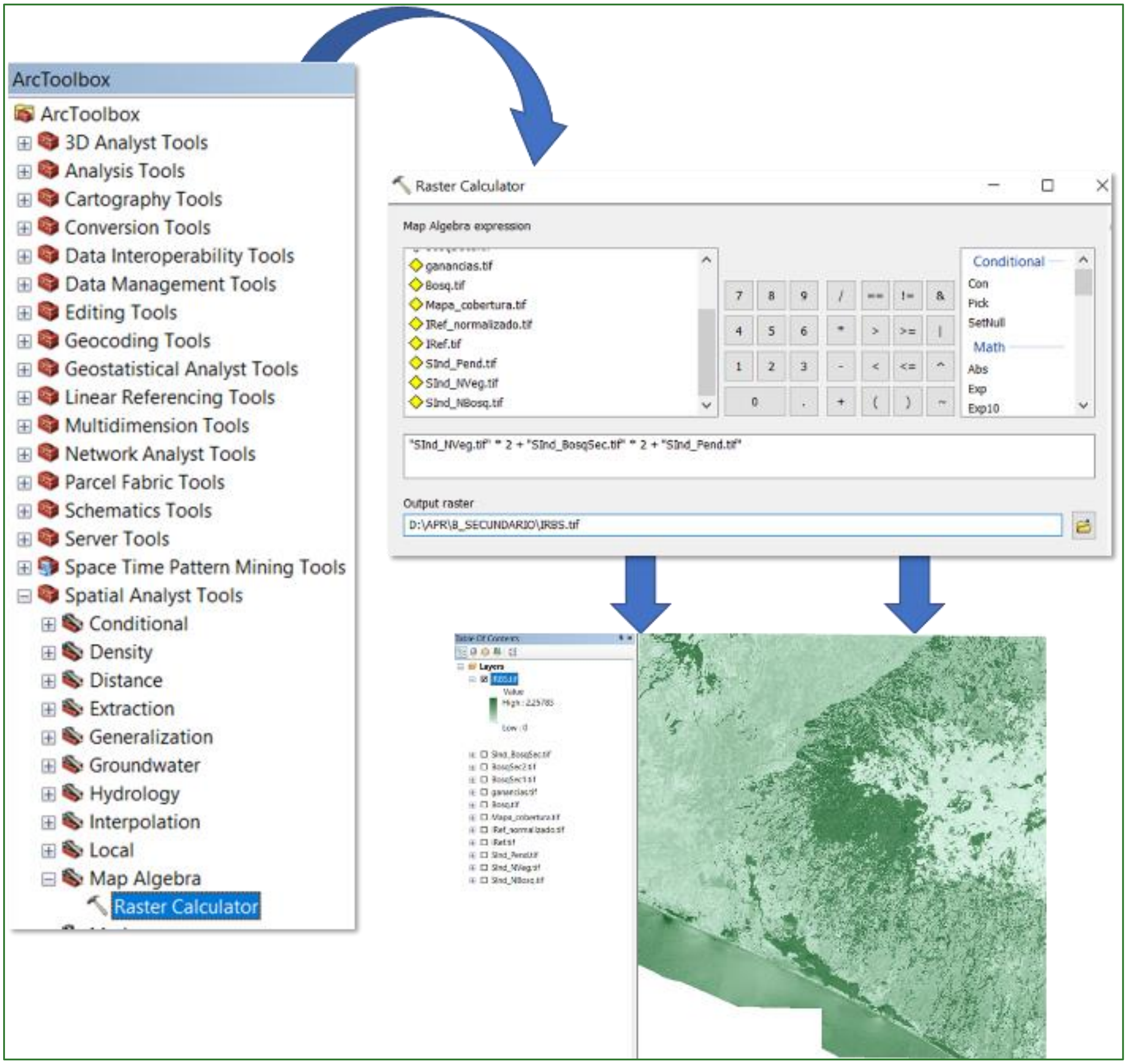


Step 3.6:
Convert the integer values to decimals using a FLOAT-type **"Raster Calculator"** tool located in **ArcToolBox/Spatial Analyst Tools/Map Algebra/Raster Calculator.** Name the output file **SInd_BosqSec.tif** and save it in the **APR/B_SECUNDARIO** folder.



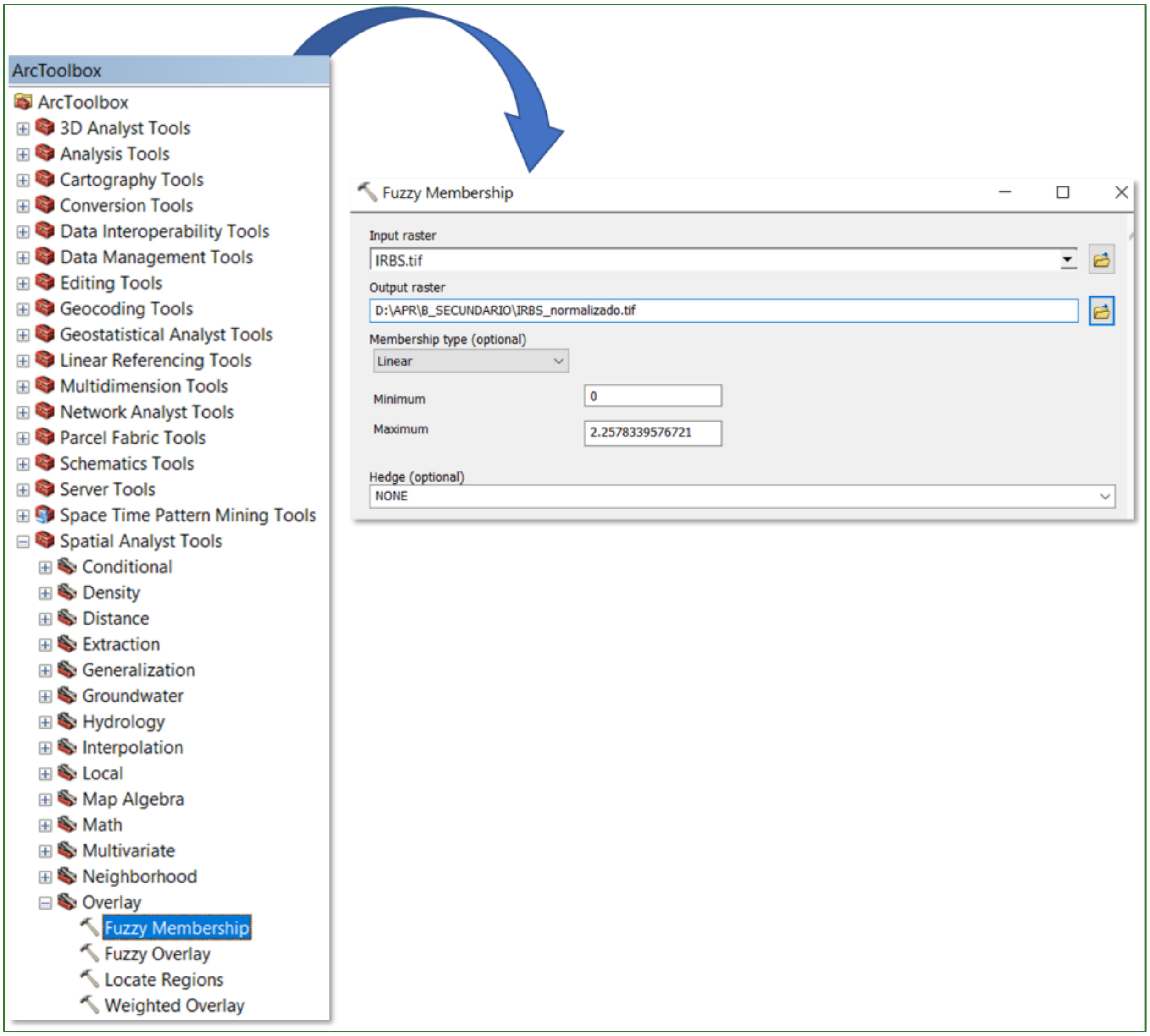
Step 4: Secondary Forest Restoration Suitability Index (IRBS)
This index is created from adding together the three subindices created above together with applying a certain weighting criterion. Use the **"Raster Calculator"** tool in **ArcToolBox/Spatial Analyst Tools/Map Algebra/Raster Calculator** to create the index. Name the output file **IRBS.tif** and save it in the **APR/B_SECUNDARIO** folder. Apply the following weightings:

SInd_NVeg.tif * 2 + SInd_BosqSec.tif * 2 + SInd_Pend.tif



Step 5: normalise the Secondary Forest Restoration Suitability Index (IRBS)

Lastly, normalise the **IRGS.tif** file created in the previous step using the **"Fuzzy Membership"** tool to normalise the data. This process will serve to identify the maximum and minimum secondary forest restoration suitability values. In this regard, it is established that the higher the index (the closer to 1), the more suited it is to restoration. The **"Fuzzy Membership"** tool is located in **ArcToolBox/Spatial Analyst Tools/Overlay/Fuzzy Membership.** Enter the **IRGS.tif** file in the Input Raster box, name the output file **IRGS_normalizado.tif** and save it in the **APR/B_SECUNDARIO** folder.



The output should appear as follows: values approaching 1 correspond to those areas identified as being most suited to secondary forest restoration.

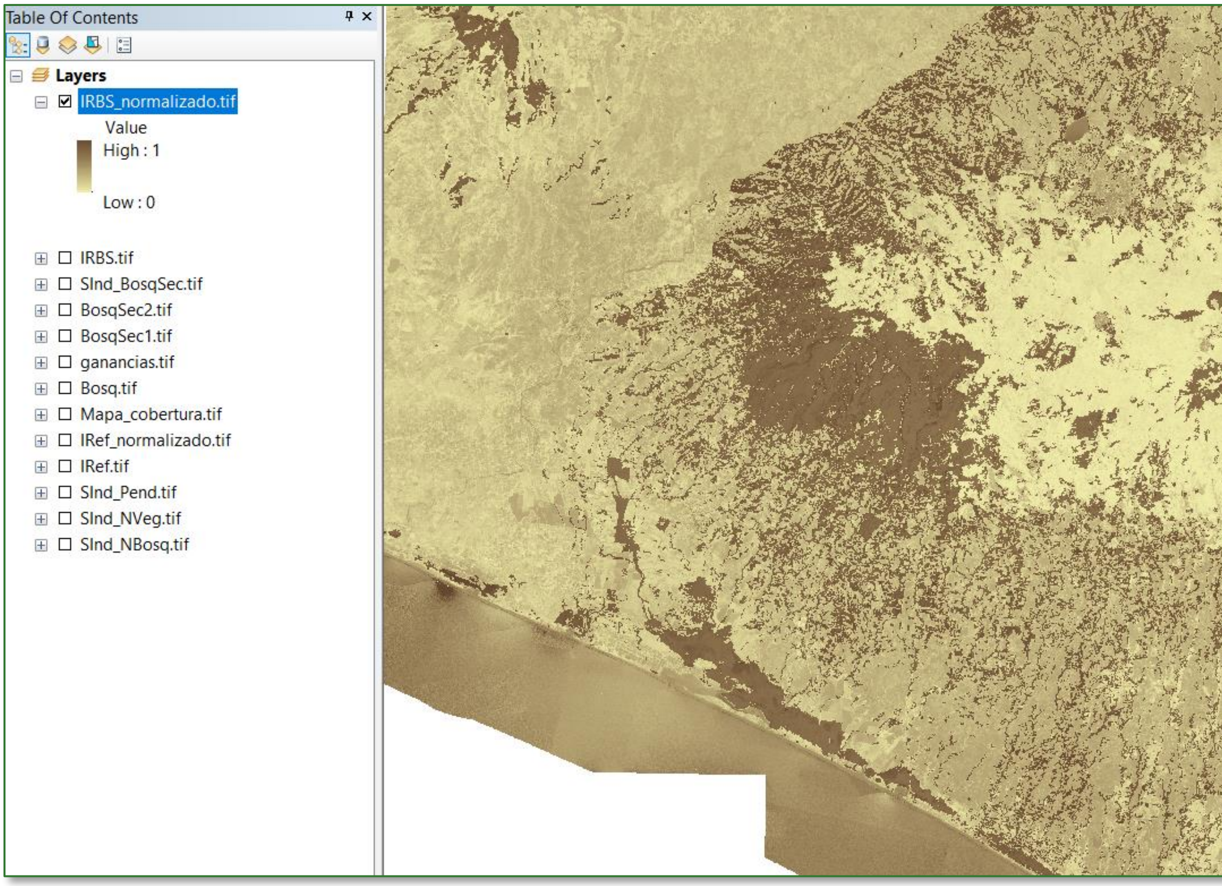


Table Of Contents
Layers
IRBS_normalizado.tif
Value
High : 1
Low : 0
IRBS.tif
SInd_BosqSec.tif
BosqSec2.tif
BosqSec1.tif
ganancias.tif
Bosq.tif
Mapa_cobertura.tif
IRef_normalizado.tif
IRef.tif
SInd_Pend.tif
SInd_NVeg.tif
SInd_NBosq.tif

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Restoring Ecosystems and Landscapes

Green Development Fund for the SICA region

Bulevar Orden de Malta, Casa de la Cooperación Alemana,
Urbanización Santa Elena, Antiguo Cuscatlán, La Libertad, El Salvador, C.A.

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