







## **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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# Content

Introduction	6
Summary of the manual	7
Earth Observing Systems	8
Methodological guide to developing an ecosystem services baseline	10
Module 1: Baseline data preparation	10
Part 1. Projecting the layers onto the country's geodesic system	11
Part 2. Prepare the project area	12
Baseline data: Topography	14
Part 3. Preparing the Digital Terrain Model (DTM)	15
Part 4. Correcting the Digital Terrain Model (DTM)	27
Part 5. Obtaining metrics from the Digital Terrain Model	30
Baseline data: Climate	54
Part 6. Climate data pre-processing	55
Baseline data: Hydrography	68
Part 7. Preparing hydrographic and micro-basin data	68
Part 8. Obtaining relief baseline units (region-group)	77
Baseline data: Tree cover, carbon and soil	80
Part 9. Obtaining the cover map	83
Phase 1. Creating a mosaic for the study area from satellite images	85
Phase 2. Segmenting satellite images	87
Phase 3. Collecting or creating spectral signatures	89
Phase 4. Classification	93
Part 10. Obtaining the aboveground biomass carbon map	96
Part 11. Preparing soil data	100
Module 2: Soil and hydrological analysis	106
Part 12. Generating the water erosion map	107
Part 13. Water infiltration	125
Landscape structural connectivity analysis	155

### Module 1: Baseline data preparation

Module 3: Landscape structural connectivity analysis	156
Part 14. Biological connectivity	158
Integrated geospatial data analysis	194
Module 4: Integrated geospatial data analysis	195
Part 15. Organisation of the results folder	195
Module 5: Integrated landscape analysis	200
Part 16. Integrated landscape analysis: integration of Ecosystem Services Stock	200
Part 17. Integration of territorial management unit data	206
Part 18. Assigning the raster value of the variables analysed to the Territorial Management Units integrated table	217
Annexes	238
Annex 1. Obtaining the carbon map using the forest edge method	238
Annex 2. Baseline document structure	248
Annex 3. Baseline document structure	249
Methodological guide for defining suitability indices for landscape restoration practices	253
Part 1. Gallery forest restoration suitability index (IRBG)	254
Part 2. Wood pasture restoration suitability index (IRPArb)	273
Part 3. Non-wood Pasture Suitability Index (IRPArb)	280
Part 4. Shade-grown coffee restoration suitability index (IRCbS)	287
Part 5. Agroforestry systems restoration suitability index (IRAgro)	295
Part 6. Reforestation suitability index (IRef)	300
Part 7. Secondary forest restoration suitability index (IRBS)	305
Bibliography	314

# 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<sub>2</sub> 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): <u>https://github.com/guialandscape/Diagramas</u>

*Green Development Fund methodological guide to implementing baseline ecosystem services and generating suitability indices for landscape restoration practices for the SICA region*/ 10

### 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**.

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🗄 🗞 Attachments								1
🕀 🌭 Data Comparison								
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🕀 🏷 Layers and Table Views		Geographic Transformatio	on (optional)					
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✓ 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.

- 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

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# **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): <u>https://github.com/guialandscape/Diagramas</u>

## 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.

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



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



Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ 15

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.

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ALPSRP262730260		Baseline Tool SBAS Tool Citation	More Like This		4.05 MB		0	₽

6. After downloading the files, extract them and select the first one called AP\_26696\_FBS\_F0260\_RT1.dem.tif.



- 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.

Windows Help	*=
Overview Magnifier Viewer	MDT_ZonaPiloto_SV
Table Of Contents	<
Search Ctrl+F	Processing
	Clip Use the data view extent or a selected polygon graphic or feature to chip out a portion of the selected layer(s), and create a temporary layer for each selection.
	<ol> <li>Select the work area polygon</li> <li>Select the DTM in the Image Analysis window</li> </ol>

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.

			- Sec	Colormap Function
Function Chain     x28312cb9_7	7a89_4303_a251_22eecbfda1c6y0.afr		le A	Colormap To RGB Function
	Insert Function	>	Jes Js:	Composite Band Function
	Insert Python Raster Function		fx:	Constant Function
	Remove		ſx.	Contrast And Brightness Function
	Properties		Jx:	Convolution Function
	· .		Js:	Curvature Function
			ſx.	Elevation Void Fill Function
			£.	Extract Band Function

General	Elevation Void Fill	Output Info Key Metadata	
Inpu	t Raster:	<clip function.outputraster=""></clip>	6
Shor (-1 -	t Range IDW Radius off):	-1	
Max	Void Width (0 - fill all	I): 0	



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

Kunction Chain     x28312cb9_7a89_4303_a251_	22eecbfda 1c6y0.afr			
E Clip Function	Insert Function	>	Js;	Resample Function
AP_26696_FBS_	Insert Python Raster Function Remove			
	Properties			

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.

Raster Function Properties		×
General Resample		
Input Raster:	<elevation fill="" function.outputraster="" void=""></elevation>	5
Resampling type:	Cubic Convolution $\sim$	
Input cell size:	12.5	
Output cell size:	3	
About the Resample function		
	OK Cance	el

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

Kernetion Chain     K	a251_22eecbfda1c6v0.afr			
Resample Function	Insert Function	>	ſs:	Reproject Function
Clip Fur	Insert Python Raster Function Remove		December	
	Properties			
Raster Function Properties				×
General Reproject				
Input Raster:	<resample function.outputraster=""></resample>		6	
Spatial Reference	WGS_1984_UTM_Zone_16N			
X Cell Size	0			
Y Cell Size	0			
X Registration Point	0			
Y Registration Point	0			
About the Reproject function	'n			
	C	Ж	Car	ncel

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

### Module 1: Baseline data preparation



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

Function Chain	03_a251_22eecbfda1c6y0.afr		000	
⊡∫ <sub>∞</sub> Resample	Insert Function	>	ſx.	Hillshade Function
⊡∫x Elevat ⊟∫x Cli	Insert Python Raster Function Remove			
	Properties			

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



Raster Function Properties	57 - T	×
General Hillshade Output Info	Key Metadata	
Input DEM:	mdt_clip	Ċ
Azimuth:	315	
Altitude:	45	
Scaling:	NONE	
Z Factor:	1	
Pixel Size Power:	0.664	
Pixel Size Factor:	0.024	
Disable default edge pixel ir	nterpolation	
	ОК	Cancel

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



Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ 24

#### Module 1: Baseline data preparation

	Spatial Reference		
) inal) ipping) Clip Inside	Spatial Reference O Data Frame (Current) Raster Dataset (Original)		
Square:	Cell Size (cx, cy):	3	3
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Hillshade	Format: [] Compression Quali	ty 75	~
	ipping) Clip Inside Square: Clip Inside Square: Clip Inside Clip I	innal)       Image: Clip Inside         Ipping)       Clip Inside         Square:       Cell Size (cx, cy): Image: Cell Size (c	inal)       Ipping)       Clip Inside       Image: Cell Size (cx, cy):

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.

General Source       Key Metadata       Extent       Display       Symbology       Time         Show:       Vector Field Unique Values Classified       Stretch values along a color ramp       Image: Color       Image: Color			
Wector Field   Unique Values   Classified   Stretch values along a color ramp     Color   Color   Color   Color Ramp:   Display Bade   Display Bade   Display Bade   Use hillshade effect   2: 1   Display NoData as   Stretch   Type:   Percent Clip   Month Symbology	General Source	Key Metadata Extent Display Symbology Time	
Unique Values Classified Siretched Discrete Color Color Color Ramp: Display Back Display Back Use hillshade effect 2: 1 Display NoData as v Stretch Type: Percent Clip v Histograms min: 0.5 max: 0.5 Invert Apply Gamma Stretch: 1	how: /ector Field	Stretch values along a color ramp	
Use hillshade effect       2: 1       Display NoData as         Stretch       Type:       Percent Clip       Histograms         min:       0.5       max:       0.5         Apply Gamma Stretch:       1       1	Inique Values Classified Stretched Discrete Color	Color Color Ramp:	
	bout symbology	Use hillshade effect       Z: 1       Display NoData as         Stretch       Type:       Percent Clip       Histograms         min:       0.5       max:       0.5       Invert         Apply Gamma Stretch:       1       V	

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.



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.

1 Raster Calculator					—		×
2 Map Algebra expression Layers and variables MDT_Procesado.tif Hillshade.tif Float("MDT_Procesado.tif")	7     8       4     5       1     2       0     1	9 / 6 * 3 - . +	== != > >= < <= ( )	&   ^ ~	Math Abs Exp Exp10 Exp2 Float Int Ln		<ul> <li></li> <li></li> </ul>
Output raster C:\SIG_FDV_Pais_X\RASTER\MDT_Proce	sado_FLOAT.tif OK	3	ancel E	Environm	ents	Show Help	· · · · · · · · · · · · · · · · · · ·

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 **Environments...** button and then assign the **zona\_de\_trabajo.shp** file in the **Raster Analysis/Mask** section.

### Module 1: Baseline data preparation

- Fill -		>	×
Input surface raster			~
MDT_Procesado_FLOAT.tif	•	2	
Output surface raster			
C:\SIG_FDV_Pais_X\RASTER\MDT_Corregido.tif		6	
Z limit (optional)			
			Ť
OK Cancel Environments	Sme	` >>	•
🛠 Environment Settings			×
	4		
			^
* Coverage			
Raster Analysis			
Cell Size			
Maximum of Inputs			
Mask	_	<b></b>	
	_		
MDT Procesado FLOAT.tif			
➤ MDT_Procesado.tif			
♥ Hillshade.tif			

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**:

🔨 Slope	—		×
Input raster			
MDT_Corregido.tif		•	2
Output raster			
C:\Users\Abner\Documents\ArcGIS\Default.gdb\Slope_tif2			2
Output measurement (optional)			
DEGREE			$\sim$
DEGREE			
PERCENT_RISE			
Z factor (optional)			
			1
Z unit (optional)			
METER			$\sim$
OK Cancel Environment	s	Show He	elp >>

- 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.

😑 🌍 Geomorphometry & Gradient Metrics
🕢 🗞 Directionality
💮 🚳 Statistics
🖃 🗞 Surface Texture
Dissection
I Landform
💐 Roughness
Slope Position
💐 Surface Area Ratio
💐 Surface Relief Ratio

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**.

💐 Landform					-	- 🗆	×
Select DEM							^
MDT_Corregid	o.tif					•	<b>6</b>
Analysis Window		_					
Rectangle	~						
Neighborhood	Settings						
Height:	25						
Width:	25						
Units:	Cell	() Мар					
ALandform Raster	Output						
C:\SIG_FDV_Pa	is_X\RASTER\Cur	vatura.tif					<b>2</b>
			OK	Cancel	Environments	Show H	Help >>

### Module 1: Baseline data preparation

Curvatura.tif Value High : 15.8784 Low : -13.6968

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

```
Iandform.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.

Classification	
Classification Method:	Natural Breaks (Jenks)
Classes:	
Data Exclusion	3 <b>^</b> 4 5 5 Sampling
	7

Slope	New Value	Altitude	New Value
0-7%	10	0-500	100
7-15%	20	500-1,000	200
15-30%	30	1,000-2,000	300
30-50%	40	>2000	400
50-70%	50		
>70%	60		

Assign the name **Pendiente\_porcentaje\_reclass.tif** to the slope output file in the **RASTER/MDT** folder.

Classification		Х
Classification	Classification Statistics	
Method: Manual	Count:	242688912
Classes: 6	Minimum:	0
Data Exclusion	Maximum:	747.890564
	Sum:	3514707329.45974
Exclusion Sampling	Mean:	14.482356
	Standard Deviauori:	19:032092
Columns: 100 - Show Std. Dev. Show Mean	ı	
	564	Break Values %
1.5e+08	õ	7
	747.	15
		30
1.0+02-		50
1.00+00		70
		7171030301
5.0e+07-		
		< >
0.0e+00		OK
0 186.972641 373.945282 5	60.917923 747.890564	
Snap breaks to data values	4661905 Elements in Class	Cancel

- v			
class neid			
ALUE			
classification			
Old values	New values	^	
0 - 7	10		Classify
7 - 15	20		Uninus
15 - 30	30		Unique
30 - 50	40		
50 - 70	50		Add Entry
70 - 747.890564	60		-
NoData	NoData		Delete Entries
		~	
Load Save	Reverse New Va	lues	Precision



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.

Input raster			
MDT_Corregido.tif		•	6
Reclass field			
VALUE			~
Reclassification			
Old values	New values		
	100	Classify	
500 - 1000	200	Lininun	
1000 - 1844	300	Unique	
NoData	NoData		
		Add Entry	
		Delete Febrier	
	~	Delete Entries	
Load Save	Reverse New Values	Precision	
Output raster			
C:\SIG_FDV_Pais_X\RASTER\	MDT_Corregido_reclass.tif		2

### Example of the reclassified DTM output:



Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ 43

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.

Map Algebra expression	7		
Layers and variables MDT_Corregido_reclass.tif Pendiente_porcentaje_reclass.tif Curvatura_reclass.tif	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	Conditional — Con Pick SetNull Math — Abs Exp Exp10	-
"Curvatura_reclass.tif" + "MDT_Corregido_reclass.tif" + "	'Pendiente_porcentaje_reclass.tif"		
Output raster C:\RASTER\geoforma_combina.tif			<b>6</b>

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.

Table Of Contents		Ψ×	
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🖃 🥌 Layers			
🖃 🗹 geoforma_com	bina	Constant of the second s	
Value	官	Сору	
High : 363	×	Remove	
Low : 111		Open 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: <u>https://github.com/guialandscape/Tablas</u>





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		Shap	e of the terrain	100	200	300	400	
		a <b>-</b> a/	11	Ridge	1	1	2	2	
10	Flat	0-7%	12	Hillside/Plain(hilly)	1	1	2	2	1
			13	Foothill	1	1	2	2	2
•••			21	Ridge	3	3	4	4	3
20	Slightly flat	7-15%	22	Hillside/Plain(hilly)	3	3	4	4	5
			23	Foothill	3	3	4	4	6
			31	Ridge	11	12	12	13	7
30	Moderately	15-30%	32	Hillside/Plain(hilly)	5	7	7	9	0
	sloped		33	Foothill	14	15	15	16	9
			41	Ridge	11	12	12	13	10
40	sloped	30-50%	42	Hillside/Plain(hilly)	5	7	7	9	12
			43	Foothill	14	15	15	16	13
			51	Ridge	11	12	12	13	14
50	Steeply	50-70%	52	Hillside/Plain(hilly)	6	8	8	10	16
	sioped		53	Foothill	14	15	15	16	
			61	Ridge	11	12	12	13	
60	Precipitous	>70%	62	Hillside/Plain(hilly)	6	8	8	10	
			63	Foothill	14	15	15	16	

Plain (flat) Tableland (flat) Plain (hilly) Tableland (hilly) Lowland sloped hillside Lowland precipitous hillside Medium altitude sloped hillside Medium altitude precipitous hillside High altitude sloped hillside High altitude precipitous hillside Lowland ridge Medium altitude ridge High altitude ridge Lowland foothill Medium altitude foothill 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.

geoforma_combina.tif.vat	1	Sort Ascending
	₹	Sort Descending
		Advanced Sorting
		Summarize
	Σ	Statistics
		Field Calculator

Double-click on **join\_clasesderelieve.csv.Cod\_Class** in the window that comes up and then on OK.

Field Calculator			×	
Parser VB Script Python Fields: geoforma_combina.tif.vat.OID geoforma_combina.tif.vat.Value geoforma_combina.tif.vat.Value geoforma_combina.tif.vat.TipRelieve geoforma_combina.tif.vat.ID_Relieve join_clasesderelieve.csv.Cod_Class join_clasesderelieve.csv.Clase Show Codeblock geoforma_combina.tif.vat.ID_Relieve = [ioin_clasesderelieve.csv.Cod_Class]	Type: Number String Date	Functions: Abs ( ) Atn ( ) Cos ( ) Exp ( ) Fix ( ) Int ( ) Log ( ) Sin ( ) Sqr ( ) Tan ( ) * / & + -	=	
[Join_clasescel elleveltsv.cou_class]			<u> </u>	

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

geoforma_combina.tif.vat.TipReliev	<b>A</b>	1 geoforma_combina_tif vat
	1	Sort Ascending
	₹.	Sort Descending
		Advanced Sorting
		Summarize
	Σ	Statistics
	<b></b>	Field Calculator

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

Field Calculator			×
Parser            • VB Script         • Python          Fields:         geoforma_combina.tif.vat.OID         geoforma_combina.tif.vat.Value         geoforma_combina.tif.vat.Value         geoforma_combina.tif.vat.Count         geoforma_combina.tif.vat.TipRelieve         geoforma_combina.tif.vat.ID_Relieve         geoforma_combina.tif.vat.ID_Relieve         join_clasesderelieve.csv.Codigo         join_clasesderelieve.csv.Cod_Class         join_clasesderelieve.csv.Clase            Show Codeblock          geoforma_combina.tif.vat.TipRelieve =	Type: Number String Date	Functions: Abs ( ) Atn ( ) Cos ( ) Exp ( ) Fix ( ) Int ( ) Log ( ) Sin ( ) Sqr ( ) Tan ( ) * / & + -	

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

➡ Eayers ➡ layers ♥ geoforma_combin Value High : 363 Low : 111	na.tif	Copy Remove Open Attribute Table	aryst Tools is Tools Taphy Tools sion Tools teroperability Tools anagement Tools			
		Joins and Relates		Join		
		Zoom To Layer		Remove Join(s)	•	join_clasesderelieve.csv
		Zoom To Make Visible		Relate		Remove All Joins
	<b>€</b>	Zoom To Raster Resolution		Remove Relate(s)	•	
		Visible Scale Range	Fab	naiyst roois ric Tools		

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: <u>https://github.com/guialandscape/Tablas</u>



### 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**.

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ا ا 😓 😓 ا	🔨 Zonal Statistics	– 🗆 X
<ul> <li>⇒ Layers</li> <li>≥ zona.de_trabajo</li> <li>⇒ pendierte_grados.tt</li> <li>Value</li> <li>High: 83.233</li> </ul>	Input raster or feature zone data Datos Factor LSiRegion_mic_curva.tif Zone field Value Pupt value raster Datos Exert O Spandiente grader tif Datos Exert O Spandiente grader tif Datos Exert O Spandiente grader tif	Output raster
Low : 0     Region_mic_curva.ht     Value     High : 784102     Low : 1	Cutput raster     C:(Guis G12PASTER:WOT)pendiente_regidn_mic_curve.thf     Statistics type (optional)     MEAN     Upnore NoData in calculations (optional)	

- 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.

	· · · · · · · · · · · · · · · · · · ·			
( 1	Layer Properties	2 Classification		
pendiente_región_mic_curva_generalizada.tif		Carrifration	Clareification Statistics	
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0 · I. X Remove	Show:	Classes: 10 V	Interval Size: 1/2 Std Dev V Minimum:	0
Stop2 Copen Attribute Table	Vector Field Draw raster grouping values into classes	E Data Exclusion	Maximum: 8	80.96603394
9.001 Joins and Relates	Unique Values Classified	Endering	Sumi 1,0	853,477,750
13.05 Zoom to Layer 17.08 E Zoom To Make Works	Stretched Value <value> Value Normalization</value>	<none> ~</none>	Standard Deviation: 7	7.993425542
21.08 Joom To Rester Resolution	Discrete Color	Columns: 100 🚔	Show Stri Day	
25.08 Visible Scale Range	Standard Deviation Classes 10	Classify 8 8 5	있는 것 전 전 Break!	Values 9
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pendier Edit Features	Color Ramp	A 001 000 000 000 000 000 000 000 000 00	90 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	705366
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Create Layer Package	0 - 1.100340889 0 - 1.100340889		17.0	8719197
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• 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**.

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🖃 🥩 Layers 🔨 🔨	6. S. S.	🔨 Con			_	
zona_de_trabajo	1					
	1.12	Input conditional raster	_	$\sim$	Output raster	~
pendiente_region_mic_curva.tir		pendiente_región_mic_curva.tif	6			
0 - 1 100340899	1.11	Expression (optional)			The output raster.	
1.10034089 - 5.09705366	1997 - S. 1 1997 - S. 1997 - S. 19	VALUE <5.09	SQL			
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9.093766432 - 13.0904792	1. 1.	pendiente_región_mic_curva.tif	1			
13.09047921 - 17.08719197	1.1.1	Input false raster or constant value (optional)	_			
17.08719198 - 21.08390474		pendiente grados.tif	<b>1</b>			
21.08390475 - 25.08061752	1.1	Output raster				
25.08061753 - 29.07733029	1. 1. 1. 1.	C:\Guia GIZ\RASTER\MDT\bendiente región mic guiva generalizada.tif	<b>4</b>			
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High : 83.233	1.1					
	1.11					
Low:0	$(x_{i},y_{i}) \in \mathbb{R}^{n}$					
Dening anis successiv						
Value	100					
High : 784102						
	1.1					
Low:1	1.0					
	1.11					
Factor_C_ajustado						
Value	1.1					
righ: 1	1.1					
Low: 0.367879						
2001.0.001015						
E Eactor C	1.1					
Value						
High : 1.39561	10 A 1					
Low : 0.367879						
NDVI.tif						
Value			_			

• 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): <u>https://github.com/guialandscape/Diagramas</u>

### 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 (<u>https://worldclim.org/data/index.html</u>)

🌤 WorldClim	Home
Global climate and weather data Future climate data	
Welcome to the WorldClim data website.	
WorldClim is a database of high spatial resolution global weather and climate data. These data can be used for mapping and spatial modeling. The data are provided for use in research and related activities; and some specialized skill and knowledge is needed to use them (here is some help). More easily available data for the general public will soon be available here.	
You can download gridded weather and climate data for historical (near current) and future conditions.	
13 March 2020: The website is being redesigned. Sorry for the inconvenience. Please let us know if you find a broken link.	
© Copyright 2020, worldclim.org.	about WorldClim

The following window will come up on screen:

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

🌤 WorldClim							
Historical clima	Historical climate data Historical monthly weath						
his is WorldClim version 2.1 cli	mate data for 1	970-2000. This	s version was rel	eased in January			
olar radiation, wind speed, wat "bioclimatic" variables. The data is available at the four	er vapor pressu spatial resolutio	re, and for tot	al precipitation.	There are also 19 (m2) to 10	7		
ninutes (~340 km2). Each down each month of the year (January	lload is a "zip" / is 1; December	file containir r is 12).	ng 12 GeoTiff (.ti	f) files, one for			
ninutes (~340 km2). Each down each month of the year (January variable	iload is a "zip" / is 1; December <b>10 minutes</b>	file containir r is 12). 5 minutes	ng 12 GeoTiff (.ti <b>2.5 minutes</b>	if) files, one for <b>30 seconds</b>	]		
ninutes (~340 km2). Each down each month of the year (January variable minimum temperature (°C)	lload is a "zip" ( is 1; December <b>10 minutes</b> tmin 10m	file containir r is 12). 5 minutes tmin 5m	ng 12 GeoTiff (.ti <b>2.5 minutes</b> tmin 2.5m	if) files, one for <b>30 seconds</b> tmin 30s			
ninutes (~340 km2). Each down ach month of the year (January variable minimum temperature (°C) maximum temperature (°C)	10ad is a "zip" v is 1; December 10 minutes tmin 10m tmax 10m	file containing r is 12). 5 minutes tmin 5m tmax 5m	ng 12 GeoTiff (.ti 2.5 minutes tmin 2.5m tmax 2.5m	if) files, one for 30 seconds tmin 30s tmax 30s			
ninutes (~340 km2). Each down each month of the year (January variable minimum temperature (°C) maximum temperature (°C) average temperature (°C)	10 noad is a "zip" 7 is 1; December 10 minutes tmin 10m tmax 10m tavg 10m	file containing r is 12). 5 minutes tmin 5m tmax 5m tavg 5m	2.5 minutes tmin 2.5m tmax 2.5m tavg 2.5m	if) files, one for <b>30 seconds</b> tmin 30s tmax 30s tavg 30s			
ninutes (~340 km2). Each down each month of the year (January variable minimum temperature (°C) maximum temperature (°C) average temperature (°C) precipitation (mm)	10 minutes 10 minutes tmin 10m tmax 10m tavg 10m prec 10m	file containing r is 12). 5 minutes tmin 5m tmax 5m tavg 5m prec 5m	2.5 minutes tmin 2.5m tmax 2.5m tavg 2.5m prec 2.5m	if) files, one for 30 seconds tmin 30s tmax 30s tavg 30s prec 30s			
variable minimum temperature (°C) maximum temperature (°C) average temperature (°C) precipitation (mm) solar radiation (kJ m <sup>-2</sup> day <sup>-1</sup> )	10 minutes 10 minutes tmin 10m tmax 10m tavg 10m prec 10m srad 10m	file containing r is 12). 5 minutes tmin 5m tmax 5m tavg 5m prec 5m srad 5m	2.5 minutes tmin 2.5m tmax 2.5m tavg 2.5m prec 2.5m srad 2.5m	if) files, one for 30 seconds tmin 30s tmax 30s tavg 30s prec 30s srad 30s			
ninutes (~340 km2). Each down each month of the year (January variable minimum temperature (°C) maximum temperature (°C) average temperature (°C) precipitation (mm) solar radiation (kJ m <sup>-2</sup> day <sup>-1</sup> ) wind speed (m s <sup>-1</sup> )	10 minutes 10 minutes tmin 10m tmax 10m tavg 10m prec 10m srad 10m wind 10m	file containing r is 12). 5 minutes tmin 5m tmax 5m tavg 5m prec 5m srad 5m wind 5m	2.5 minutes tmin 2.5m tmax 2.5m tavg 2.5m prec 2.5m srad 2.5m wind 2.5m	f) files, one for 30 seconds tmin 30s tmax 30s tavg 30s prec 30s srad 30s wind 30s			

In this step, download the precipitation (mm), temperature (T) and solar radiation (RS) data with the highest resolution ( $30s \approx 1 \text{ km}^2$ ) 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\_ETO\_Cli mate\_Database\_v2/7504448/3 and must also be saved in the GLOBAL\_DATA/WorldClim folder.

🆏 fig <b>share</b>	Browse Search on figshare	ə Q	Log in Sign up
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GlobalPET.jpg (266.44 kB)	global-et0_monthlzip (992.48 MB)	global-et0_annual.tif.zip (210.96 MB)	Global AI_PET v2pdf (846 kB)
ARCHIVE			
global-ai_et0.zip (421.71 MB)			
Cite Download all (1.59 GB	) Share Embed + Collect (you	need to log in first)	5 files 📕 🗮

- 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.

ArcToolbox		
🚳 ArcToolbox		
🗄 😂 3D Analyst Tools		
🗄 😂 Analysis Tools	🔨 Extract by Mask — 🗆 🗙	
🗄 😂 Cartography Tools		_
Conversion Tools	Input raster	
🗄 😂 Data Interoperability Tools	P_01.tf ⊻ 🖻	
🗄 📦 Data Management Tools	Input raster or feature mask data	
🕀 😂 Editing Tools	zona_de_trabajo	
🗄 😂 Geocoding Tools	Output raster	
🗄 📦 Geostatistical Analyst Tools		
🗄 😂 Linear Referencing Tools		
🗄 😂 Multidimension Tools		
🗄 😂 Network Analyst Tools		
🗄 🚳 Parcel Fabric Tools		-
🗄 😂 Schematics Tools		
🗄 😂 Server Tools		L
🗄 🌖 Space Time Pattern Mining Tools		
🖃 😂 Spatial Analyst Tools		
🗄 🗞 Conditional		
🗄 🗞 Density		
🖽 🇞 Distance	OK Cancel Environments Show Help >>	
🖃 🗞 Extraction		
Extract by Attributes		5
Extract by Circle		
🔨 Extract by Mask		
Extract by Points		
Extract by Polygon		
🔨 Extract by Rectangle		
K Extract Multi Values to Points		
Stract Values to Points		
🔨 Sample		
표 🗞 Generalization		

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.

ArcToolbox 🗆 ×	
SArcToolbox	
🗄 😂 3D Analyst Tools	
🗄 😂 Analysis Tools	
Gartography Tools	
Conversion Tools	Input raster
🗄 🗞 Excel	P_01_corte.tif
🗄 🗞 From GPS	Field (optional)
🗄 🗞 From KML	Value
🗄 🗞 From PDF	Output point features
🖃 🗞 From Raster	C:\fuia\VECTORES\CLIMA\LLUVIA\maila_base_LLUVIA.shp
Raster to ASCII	
🔨 Raster to Float	
🔨 Raster to Point	
Raster to Polygon	
🔨 Raster to Polyline	
🔨 Raster To Video	
🕀 🎭 From WFS	
🗄 🗞 JSON	
표 🗞 Metadata	
표 🗞 To CAD	
표 🗞 To Collada	OK Cancel Environments Show Help >>
표 🗞 To Coverage	
🗄 🗞 To dBASE	
🗄 🗞 To Geodatabase 🦳	
🗄 🗞 To GeoPackage	
🗄 🗞 To KML	
🕀 🗞 To Raster	
🗄 🗞 To Shapefile	
🗄 😂 Data Interoperability Tools	
🗄 😂 Data Management Tools	
🗄 😂 Editing Tools	
🗄 😂 Geocoding Tools 🗸 🗸	

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)

ArcToolbox	□ ×				
S ArcToolbox	^				
🗄 😂 3D Analyst Tools					
🗄 😂 Analysis Tools		S Extract Multi Values to Pr	sints	- n x	1 📕
🗄 😂 Cartography Tools		Condict many values to re			
Conversion Tools		Input point features		^	Table
🗄 📦 Data Interoperability Tools		malla_base_LLUVIA		- 🖻	ロ・148・149 10 中世 X malla hase 111MA
🖽 😂 Data Management Tools		Input rasters			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
🖽 😂 Editing Tools				- 🖻	Opeint         1         2         2         9         55         170         320         263         276         367         222         46         44           1         1         2         2         2         4         9         56         170         320         263         276         367         222         46         44           1         Point         2         2         2         4         9         58         165         323         263         276         340         226         48         3
🖽 😂 Geocoding Tools					2 Point 3 1 1 4 9 55 168 329 262 260 382 222 49 4 3 Drive 4 1 1 5 9 53 174 336 267 279 385 210 49 5
🗄 😂 Geostatistical Analyst Tools		Raster	Output field name	<u>^</u>	4 Point 6 2 2 6 11 56 202 356 277 277 404 275 49 7
Elinear Referencing Tools		P_01.0	P_01 P_02	×	6 Point 7 6 6 7 16 66 241 371 292 291 423 308 49 7
🗄 📦 Multidimension Tools		P_03.tif	P_03		I         I
Network Analyst Tools		P_04.tif	P_04	1	9 Point 10 4 4 7 15 62 221 376 291 280 410 303 48 1 10 Point 11 4 4 6 14 62 219 374 290 283 408 300 46 8
Parcel Fabric Tools		P_05.tif	P_05	1	11 Peint 12 3 3 6 13 62 206 365 282 274 396 272 46 6 12 Peint 13 3 5 6 12 59 207 362 282 274 396 272 46 6
Schematics Tools		P_00.0i	P_00		13 Point 14 2 2 6 11 58 197 365 279 272 392 270 45 5 5 10 2 2 2 6 12 58 197 365 279 272 392 270 45 5
Server Tools		A D NO HE	0.00	Ň	16 Point 16 2 2 6 10 59 184 341 274 271 364 246 42 5
Space Time Pattern Mining Tools				/	$\begin{array}{c c c c c c c c c c c c c c c c c c c $
Spatial Analyst Tools		Bilinear interpolation of va	lues at point locations (optional)	~	10 Point 19 1 1 4 9 57 162 320 205 265 338 220 41 3 19 Point 20 2 2 4 9 57 168 317 266 263 339 217 40 4
🗄 🗞 Conditional		(		>	20 Puint 21 2 2 4 9 57 170 321 262 258 340 229 40 4 21 Puint 22 1 1 4 9 57 170 316 265 262 338 225 39 4
🗄 🦠 Density					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
🗉 🦠 Distance			OK Cancel Environme	ents Show Help >>	24 Point 28 1 1 4 10 57 177 319 288 256 347 246 37 4
Extraction		L			→ + + = (0 out of 1827 Selected)
Extract by Attributes					malia_base_LLUVIA
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Extract by Points					
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	EID Shane 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															
L.	FID	Deint	poinud	grid_code	P_01	P_02	P_03	P_04	P_03	P_00	P_07	P_00	P_09	P_10	P_11	P_12
Ľ		Point	2	2	2	2	9	55	165	320	263	276	340	222	40	- 4
F		Point	3	1	1	4	9	55	168	329	262	280	382	2220	40	4
F	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
i.	alla ba	1 → se LLUVIA	H   🔳 🗖	(0 out of 1827	Selected	)										

- 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.**



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



Tab	ole															
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ma	lla_ba	se_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
F	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
Ц	5	Point	6	163	163	166	191	181	168	142	155	150	128	127	134	145
Ц	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
Ц	8	Point	9	160	160	162	186	177	166	141	155	149	128	126	133	142
Ц	9	Point	10	159	159	162	187	178	166	140	155	149	128	126	132	142
Ц	10	Point	11	160	160	164	189	179	167	140	154	149	127	126	132	143
Ц	11	Point	12	163	163	166	194	182	168	142	157	151	129	129	134	146
Ц	12	Point	13	164	164	168	195	181	168	142	157	151	129	129	135	147
Ц	13	Point	14	166	166	171	194	180	167	142	157	152	130	130	135	148
Ц	14	Point	15	167	167	171	192	178	166	141	157	153	131	130	136	149
Ц	15	Point	16	168	168	169	190	178	165	141	158	153	132	131	136	148
Ц	16	Point	17	168	168	168	188	177	164	141	157	153	132	131	136	147
Ц	17	Point	18	166	166	166	188	178	164	141	157	154	132	132	136	147
Ц	18	Point	19	167	167	167	189	179	163	141	157	154	133	133	137	147
Ц	19	Point	20	166	166	167	188	178	163	141	157	154	132	133	137	146
Ц	20	Point	21	166	166	166	189	178	164	140	157	154	132	132	136	146
Ц	21	Point	22	166	166	166	189	178	165	141	157	154	132	133	136	146
Ц	22	Point	23	166	166	166	190	180	166	141	158	154	132	133	137	146
Ц	23	Point	24	166	166	165	189	180	166	141	157	153	131	132	135	146
Ц	24	Point	25	165	165	166	189	180	167	140	157	153	131	132	136	145
н	4	1 ⊁	н 📃 🗖	(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:



- 1	i -   🏪 🎦	2 % ×													
alla_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_1
(	) Point	1	19195	19195	21429	22607	22530	21554	19900	20851	20604	18797	18114	18264	17
	1 Point	2	19156	19156	21474	22666	22624	21572	19904	20856	20592	18753	18025	18176	17
	2 Point	3	19219	19219	21517	22737	22712	21597	19926	20799	20509	18615	17960	18157	17
	3 Point	4	19261	19261	21569	22822	22845	21670	19988	20810	20504	18598	17903	18126	17
	4 Point	5	19292	19292	21617	22914	23240	21821	19997	20818	20459	18560	17843	18062	17
	5 Point	6	19318	19318	21629	22934	23363	21884	20020	20738	20466	18533	17786	17974	17
	5 Point	7	19283	19283	21534	22877	23216	21841	19967	20666	20427	18481	17744	17912	17
	7 Point	8	19270	19270	21476	22840	23133	21788	19937	20681	20419	18453	17752	17863	17
	B Point	9	19326	19326	21428	22929	23120	21828	20003	20844	20474	18537	17781	17954	17
	9 Point	10	19305	19305	21399	22923	22993	21799	19995	20855	20475	18547	17784	17908	1
1	0 Point	11	19308	19308	21408	22855	23000	21803	19996	20864	20480	18551	17792	17864	1
1	1 Point	12	19340	19340	21446	22873	23010	21784	20002	20903	20508	18577	17847	18019	18
1	2 Point	13	19342	19342	21450	22841	23007	21681	20001	20878	20592	18600	17854	18044	18
1	3 Point	14	19338	19338	21485	22840	23011	21628	19971	20891	20599	18651	17876	18052	18
- 1	4 Point	15	19376	19376	21629	22880	23016	21643	19991	20919	20611	18730	17923	18078	18
1	5 Point	16	19337	19337	21633	22711	22938	21545	19990	20937	20616	18736	17923	18089	18
1	5 Point	17	19335	19335	21546	22605	22720	21446	19982	20943	20620	18741	17931	18106	18
1	7 Point	18	19302	19302	21482	22564	22607	21208	19918	20947	20627	18752	17971	18140	18
1	B Point	19	19281	19281	21465	22481	22510	21003	19909	20944	20595	18759	18011	18169	18
1	9 Point	20	19269	19269	21528	22417	22404	21056	19925	20951	20617	18759	18047	18162	18
2	0 Point	21	19303	19303	21540	22573	22425	21069	19931	20958	20673	18758	18141	18159	18
2	1 Point	22	19349	19349	21483	22611	22535	21182	19947	21005	20724	18773	18153	18181	18
2	2 Point	23	19375	19375	21536	22672	22672	21378	19991	21117	20678	18775	18186	18243	1
2	3 Point	24	19405	19405	21707	22785	22731	21472	20044	21078	20679	18781	18172	18168	1
2	4 Point	25	19390	19390	21713	22802	22939	21567	20067	21135	20680	18817	18168	18214	1
2	5 Point	26	19383	19383	21703	22792	23004	21602	20045	21139	20684	18897	18186	18232	1
^	0.1	07	40004	40004	04744	00070	00040	04000	00070	04000	00000	40004	40400	40050	40

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 correspond malla_base_ETP	ding climate variable mesh, for example,
Z value field		Select the field that example: ETP_01 ETP_02	contains the values for each month, for
Output raster		Enter the raster output of each monthly raster for example, CLIMA\ETP\isoETP_0 CLIMA\ETP\isoETP_0	name. Use the prefix <b>iso</b> before the name and save it in the RASTER/CLIMA folder: 1.tif 2.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): <u>https://github.com/guialandscape/Diagramas</u>

### 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.** 

Module 1: Baseline data preparation



1. As a first step, create the Flow Direction raster using the **How 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.

Input surface raster	_
MDT_Corregido.tif	6
Output flow direction raster	
C:\pATOS_HIDRO\flowdir.tif	<b>6</b>
Force all edge cells to flow outward (optional)	
Output drop raster (optional)	
	<b>6</b>
Flow direction type (optional)	
D8	~

2. Create the Flow Length raster using the **How 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.

Input flow direction raster		
Flowdir.tif	-	eð
Output raster		
C:\DATOS_HIDRO\flowlength.tif		eð
Direction of measurement (optional)		
DOWNSTREAM		$\sim$
Input weight raster (optional)		
·	·	eð

3. Create the Flow Accumulation raster using the **How 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.

Input flow direction raster		
Flowdir.tif	•	<b>6</b>
Output accumulation raster		
C:\DATOS_HIDRO\flowacc.tif		2
Input weight raster (optional)		
	-	<b>6</b>
Output data type (optional)		
FLOAT		~
FLOAT		$\sim$

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.

🔨 Stream Order	_		×
Input stream raster			_ ^
flowacc.tif		•	<b>6</b>
Input flow direction raster			
flowdir.tif		•	<b>2</b>
Output raster			
D:\DATOS_HIDRO\redhidro.tif			<b>6</b>
Method of stream ordering (optional)			
STRAHLER			$\sim$

 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				_		×
Input raster						^
redhidro.tif					<b>–</b>	<b>6</b>
Reclass field						
Value						$\sim$
Reclassification						
Old values	Neurophiae					
	New Values A	Classify				
3	NoData					
4	NoData	Unique				
5	NoData					
6	NoData	Add Entry				
7	7	Add End y				
8	8	Delete Entries				
9	9 🗸					
Load Save	Reverse New Values	Precision				~
Ŷ						>
		ОК	Cancel	Environments	Show He	ilp >>

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

Reclassify						_		×
Input raster								~
redhidro.tif							-	2
Reclass field							L	_
Value								~
Reclassification								_
Old values	New values	^	Classify					
3	NoData		,					
	NoData	_	Unique					
6	NoData							
7	NoData							
8	NoData		Add Entry					
9	9							
10	10	~	Delete Entries					
Load Save	Reverse New Valu	ies	Precision					
<								>
			ОК	Cancel	Environme	ents	Show He	elp >>

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 **Stream to** 

the **Feature** tool. Check the Simplify Polylines box and save the file as **riosorden7.shp** in the **DATOS\_HIDRO** folder.
Stream to Feature		×
Input stream raster		_ ^
streamlink7.tif	•	<b>6</b>
Input flow direction raster		
flowdir.tif	•	<b>6</b>
Output polyline features		
D:\DATOS_HIDRO\riosorden7.shp		<b>2</b>
Simplify polylines (optional)		

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.

- Stream Link -		×
Input stream raster		_ ^
redhidro_orden9.tif	•	<b>6</b>
Input flow direction raster		
flowdir.tif	•	<b>6</b>
Output raster		
þ:\DATOS_HIDRO\streamlink9.tif		<b>6</b>

You can take advantage of this step to convert the order 9 stream into a shapefile using **Stream to** 

the **Feature** tool. Check the Simplify Polylines box and save the file as **riosorden9.shp** in the **DATOS\_HIDRO** folder.

≪ Stream to Feature	—		×
Input stream raster			_ <
streamlink9.tif		•	<b>6</b>
Input flow direction raster			
flowdir.tif		-	<b>6</b>
Output polyline features			
D:\DATOS_HIDRO\riosorden9.shp			<b>2</b>
Simplify polylines (optional)			_

8. Generate order 7 micro-basins with the **Watershed** tool and save the file as **microcuencas\_orden7.tif** in the **DATOS\_HIDRO** folder.

Natershed	_		×
Input flow direction raster			_ ^
flowdir.tif		•	<b>6</b>
Input raster or feature pour point data			
streamlink7.tif		•	<b>6</b>
Pour point field (optional)			
Value			~
Output raster			_
D:\DATOS_HIDRO\microcuencas_orden7.tif			<b>6</b>

Convert the **microcuencas\_orden7.tif** raster into a shapefile using the **Polygon** tool and save the file as **microcuencas\_orden7.shp** in the **DATOS\_HIDRO** folder.

🔨 Raster to Polygon	-		$\times$
Input raster			~
microcuencas_orden7.tif		-	<b>2</b>
Field (optional)			
Value			~
Output polygon features			
D:\DATOS_HIDRO\microcuencas_ord	en7.shp		<b>6</b>
Simplify polygons (optional)			
ArcToolbox	Raster to Polygon	_	п х
SD Analyst Tools			
Analysis Tools     Cartography Tools	Input raster		<b>-</b> 🗖 ^
Conversion Tools	Field (optional)		_ 😐
🗄 🗞 Excel	Value		~
E Strom GPS	Output polygon features		
E S From PDF	D:\DATOS_HIDRO\microcuencas_orden7.shp		8
🖃 🇞 From Raster	Simplify polygons (optional)		
<ul> <li>Raster to ASCII</li> <li>Raster to Point</li> <li>Raster to Polygon</li> <li>Raster to Polyline</li> <li>Raster To Video</li> <li>Son</li> </ul>			

9. Generate the order 9 micro-basins with the **Watershed** tool and save the file as **microcuencas\_orden9.tif** in the **DATOS\_HIDRO** folder.

Natershed	_		×
Input flow direction raster			_ ^
flowdir.tif		•	<b>6</b>
Input raster or feature pour point data			
streamlink9.tif		<b>•</b>	<b>6</b>
Pour point field (optional)			
Value			~
Output raster			
D:\DATOS_HIDRO\microcuencas_orden9.tif			<b>ĕ</b>

Convert the **microcuencas\_orden9.tif** raster into a shapefile using the **Polygon** tool and save the file as **microcuencas\_orden9.shp** in the **DATOS\_HIDRO** folder.

Naster to Polygon	_		×
Input raster			_ ^
microcuencas_orden9.tif		•	<b>6</b>
Field (optional)			
Value			$\sim$
Output polygon features			_
D:\DATOS_HIDRO\microcuencas_orden9.shp			<b>6</b>
Simplify polygons (optional)			

Raster to

ArcToolbox	□ ×	Paster to Polyago		~
S ArcToolbox	^	Raster to Polygon		^
🗄 😂 3D Analyst Tools		Input raster		1
Analysis Tools		microcuencas_orden9.tif	-	0
Cartography Tools		Field (optional)		
E Story Conversion Tools		Value		~
🗄 🗞 Excel		Output polygon features		
E S From GPS		D:\DATOS_HIDRO\microcuencas_orden9.shp		6
E S From KML		Simplify polygons (optional)		-
H S From PDF		Simplify polygons (optional)		
E S From Raster				
Raster to ASCII				
Raster to Point				
Rester to Polygon			N	
S Raster to Polyline				
Raster To Video				
🗄 🗞 From WFS				
🗄 🗞 JSON				

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.





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

# 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

	PLANETSCOPE
Bands	4 (RGB, NIR)
Products	Color enhanced Visual Analytic
Pixel Resampled	3 m
Radiometric Resolution	Visual: 8 bit Analytic: 16 bit
Positional Accuracy	<10 m RMSE

#### **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.

ArcToolbox				
🗄 🌍 Space Time Pattern Mining Tools	^			
🖃 😂 Spatial Analyst Tools				
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Segmentation and Classification				_
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Segment Mean Shift				
Train ISO Cluster Classifier				
Train Maximum Likelihood Clas	SITI			
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Opdate Accuracy Assessment Po	Sini			
H Solar Radiation				

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.

COBER RASTE	In the second s	Copy Paste Delete Rename Refresh		Create New Shapefile	firmas_espectrales
		New > Item Description Properties	Folder File Geodatabase Personal Geodatabase Database Connection ArcGIS Server Connection Layer Group Layer Python Toolbox	Feature Type: Spatial Reference Description: Projected Coordinat Name: WGS_1984_ Geographic Coordin Name: GCS_WGS_	Polygon ~
			Shapefile Turn Feature Clas Toolbox dBASE Table LAS Dataset Address Locator Composite Address Locator XML Document	<ul> <li>Show Details</li> <li>Coordinates will of Coordinates will of Coordin</li></ul>	Edit Contain M values. Used to store route data. Contain Z values. Used to store 3D data.

• Open the shapefile table called **firmas\_espectrales.shp** and add a text type column, naming it "uso".

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	Reports +
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	Appearance

• "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**".

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• 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**".

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	77	Polygon	0	Cobertura NO arbórea			
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	79	Polygon	0	Cobertura NO arbórea			
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• 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.<sup>1</sup> 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**.

 $<sup>^{1}\</sup> https://desktop.arcgis.com/en/arcmap/10.3/guide-books/extensions/spatial-analyst/image-classification/what-is-image-classification-.htm$ 

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🗄 🗞 Map Algebra	Reject fraction (optional)	
🗄 📚 Math	0.0	$\sim$
🖃 🗞 Multivariate	A priori probability weighting (optional)	
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Class Probability	Input a priori probability file (optional)	
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Edit Signatures		
Siso Cluster		
Iso Cluster Unsupervised Classificati Maximum Likelihood Classificati	τ ( )	
Principal Components		

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.

Add Field		×	Add Field			×		1						
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Length	50		Precision		0			OID 0 1	Value 1 2	Count 97266141 237141856	Cobert Cobertura arborea Cobertura NO arbórea		Cxha 54 0	
Length	50		Precision		0			OID 0 1	Value 1 2	Count 97266141 237141856	Cobertura arborea Cobertura NO arbórea		Cxha 54 0	

• 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.

Add Field		×			)				
Name:	Ctotal								
			Tat	ble					
Type:	Short Integer ~		• •	•	- 🖣 🔂	Z 🗄 X			
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Field Flop	erues			OID	Value	Count	Cobert	Cxha	Ctotal
Precision	10			0	1	97266141	Cobertura arborea	54	4727134
				1	2	237141856	Cobertura NO arbórea	0	0
		- 1							
	OK Cancel								

- 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.

Table	7				
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cobertura_project.tif					
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• 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<sup>2</sup>" 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.

<sup>&</sup>lt;sup>2</sup> <u>https://www.nature.com/articles/ncomms10158#citeas</u>

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ **99** 

# 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: <u>https://soilgrids.org/</u>; 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

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#### 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**

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Ignore NoData in calculations (optional)	~
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# 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): <u>https://github.com/guialandscape/Diagramas</u>

*Green Development Fund methodological guide to implementing baseline ecosystem services and generating suitability indices for landscape restoration practices for the SICA region*/ 106

# 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	RASTER/SUELO/Orgcarb_por.tif
content	
Flow	DATOS_HIDRO/ flowacc.tif
accumulation	
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)

*Green Development Fund methodological guide to implementing baseline ecosystem services and generating suitability indices for landscape restoration practices for the SICA region*/ 107 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:

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

#### 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.


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- Open Excel and paste the selected values. Save this spreadsheet in the following location, naming it: ... FACTORES\Factor R\Tabla\_Calculo\_FactorR.xlsx3
- 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)

<sup>&</sup>lt;sup>3</sup> Table available in the GitHub repository: <u>https://github.com/guialandscape/Tablas</u>

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ 109

Follow these steps:

• Add the headings to the following fields:

F	G	Н	I	J	K	L	М	Ν	0	Р	Q	R	S	Т
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	Н	I	J	K	L	М	Ν	0	Р	Q	R	S
P1	P2	<b>P3</b>	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, [r	1úmero2],)

• Calculate the MFI. Example:

F	G	Н	1	J	K	L	М	N	0	Р	Q	R	S	Т	U	V	W	Х	Y	Z	AA
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)+(0	52 <b>^2/R2)+(H2</b>	^2/ <mark>R2)+(</mark> I2^2/	/R2)+(J2^2/R2	)+(K2^2/R2)+(	L2^2/R2)+(M2	2^2/R2)+(N2^	2/R2)+(O2^2/	R2)+(P2^2/R2))
1	4	9	55	168	329	262	280	382	222	49	4	1765									

# $=(F2^{2}/R2)+(G2^{2}/R2)+(H2^{2}/R2)+(I2^{2}/R2)+(J2^{2}/R2)+(K2^{2}/R2)+(L2^{2}/R2)+(M2$

• Add the Factor\_R field and calculate it using the formula taken from Pradhan B. et. al (2012):

= (4.17 \* MFI) - 152

F	G	Н	Т	J	Κ	L	М	Ν	0	Ρ	Q	R	S	Т
P1	P2	<b>P3</b>	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* <mark>S2</mark> )-152
1	4	9	55	168	329	262	280	382	222	49	4	1765		

• Do the calculations for all table rows.

F	G	Н	Т	J	Κ	L	М	Ν	0	Р	Q	R	S	Т
P1	P2	<b>P3</b>	P4	P5	P6	P7	P8	P9	P10	P11	P12	P_Anual	IMF	Factor R
2	4	9	<mark>58</mark>	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	<mark>59</mark>	207	362	282	274	398	274	46	6	1929	294.328149	1075.3484
2	6	11	<mark>58</mark>	197	365	279	272	392	270	45	5	1902	292.309674	1066.9313

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

Save As

↑	
Tabla_Calculo_FactorR	
CSV (Comma delimited) (*.csv)	🦻 Save
More options	

- 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:

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#### **Step 2: Calculate the K factor:**

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

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

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
Мс	Clay content (%)	RASTER/SUELO/Clay_por.tif

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

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:* 

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

#### **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: <u>https://github.com/guialandscape/Model\_Builder</u>

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

Arc Torlbow 30 Add Toolbox An Ca Ca Da Da Da Editing Eliting Eliting Cocoding Tools Geocoling Tools Geocoling Tools Geocoling Tools Geocoling Tools Geocoling Tools Multidingersion Tools Multidingersion Tools	Add Toolbox Look in: Consistent and the second seco	AcCoolbox AcCoolbox
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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:

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

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).

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

#### **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	RASTER/NDVI/NDVI.tif
difference	
vegetation	
index	

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).

Table Of Contents # ×		atalog
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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.

able Of Contents		Arc loolbox * 2
		🗑 📦 Conversion Tools
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	Output raster	
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Value		
High : 1.39561		
Low : 0.367879		
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NDVI.tif		
Value		on(2)
High : 1		OH(Z)
Low : -1		

#### Module 2: Soil and hydrological analysis

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:

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

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

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	Community	Use	Conservation	Р
location			works	
High	Estancia	Natural broadleaf forest	Unnoticeable.	1.0
High	Escupija	Peach tree farming with growing scrub and shrub.	Non-maintained terrace.	0.9
Medium	Рој	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

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

#### 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.



#### Module 2: Soil and hydrological analysis

#### 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	Interpretation						
(t/ha.year)							
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:

#### Module 2: Soil and hydrological analysis



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.

•	<b>6</b>
	SQL
•	2
-	<b>6</b>
	2

### 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).



Adjusted infiltration analysis

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

*Green Development Fund methodological guide to implementing baseline ecosystem services and generating suitability indices for landscape restoration practices for the SICA region*/ *126* 

#### 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.

🔨 Reclassify		×
Input raster pendiente_porcentaje.tif Reclass field VALUE Reclassification	Reclassification     A remap table that defin     how the values will be     reclassified.	nes
Old values         New values           0         8.333723         1           8.333723         1         1           25.001169         2         1           39.530319         55.904312         4           55.904312         74.539085         5           74.539085         98.781868         6           98.781686         139.075836         7           139.075836         220.016602         8           Load         Save         Reverse New Values           Precision         Output raster           C: Wsers Veofa Vocuments / ArcGIS / Default 1.gdb / Reclass_tff5           Change missing values to NoData (optional)	Classification Classification Classification Classification Classification Classification Count: Minimum: Maximum: Maxim	CS 201070540 0 842.757385 3561290916.798 17.711649 21.065626 Break Values % 15 30 50 70 842.757385
N.B.: take 5 classes into account	4.0e+07- 2.0e+07- 0.0e+00 0 210.689346 421.378693 632.068039 842.75738E Snap breaks to data values 11441440 Elements in Ck	< > OK Cancel

*Green Development Fund methodological guide to implementing baseline ecosystem services and generating suitability indices for landscape restoration practices for the SICA region*/ *127* 

#### Module 2: Soil and hydrological analysis

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.

🔨 Reclassify				×
Input raster				Output raster
pendiente_porcentaje.tif (2)	)		🖃 🖻	
Reclass field				The output reclassified
VALUE			~	raster.
Old values           0 - 15           15 - 30           30 - 50           50 - 70           70 - 842.757385           NoData	New values 15 10 7 5 1 NoData	Classify Unique Add Entry Delete Entries		The output will always be of integer type.
Load Save Output raster	Reverse New	Values Precision		
C:\Guia_GIZ\RASTER\FACTOR	RES\FACTOR KP\Factor	_KP_x100.tif	<b>🖻</b>	

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:

🔨 Raster Calculator										×
Map Algebra expression									~	Output raster
Layers and variables ♣ Factor_KP_x100.tif ♣ pendiente_porcentaje.tif ♦ Factor_KP ♦ Factor_KP_x100 ♦ pendiente_porcentaje.tif	7 4 1	8 5 2	9 6 3	/ *	== > <	<= >= <=	&   ^	Conditional — ^ Con Pick SetNull Math — Abs		The output raster resulting from the Map Algebra expression.
	C	)	•	+	(	)	~	Exp ¥		
[Float("%Factor_KP_x100.trf%")/100										
Output raster C:\Guia_GIZ\RASTER\FACTORES\FACTOR KP\Factor_KP.tif										

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: <u>https://github.com/guialandscape/Model\_Builder</u>
- 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).

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

#### Table #18. Factor Kv for El Salvador

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

#### Module 2: Soil and hydrological analysis

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

🔨 Reclassify	×
Input raster	Reclassification
kobertura_arborea.tif     Image: Comparison of the second se	A remap table that defines how the values will be reclassified.
Old values     New values       1     20       2     10       NoData     NoData         Add Entry       Delete Entries	<ul> <li>Old values—The ranges of values of cells in the input raster. Acceptable settings are a single value, a range of values, a string, or NoData. A list of single values, can be</li> </ul>
Load Save Reverse New Values Precision	specified by separating each with
Output raster	a semicolon (;). A
C:\Guia_GIZ\RASTER\FACTORES\FACTOR KV\Factor_KV_x100.tif	be specified by using a hyphen (-) as the range separator.

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.

Raster Calculator											
Map Algebra expression										^	Map Algebra
Layers and variables	^	]							Conditional — 🔺		expression
🖏 Factor_KV_x100.tif			_	_		1		-	Con		The Map Algebra
🖏 cobertura_arborea. tif		7	8	9	1	==	!=	&	Pick		expression you want to
🔷 cobertura_arborea.tif		4	5	6	*	>	>=	1	SetNull		run.
Factor KP\Factor_KP			_	_				_	Math		
Factor KP\Factor_KP_x100		1	2	3	-	<	<=	^	Abs		The expression is
Factor KP\pendiente_porcentaje.tif									Exp		composed by specifying
	~		)	•	+	(	)	~	Eve 10		the inputs, values,
											You can type in the
loat("%Factor_KV_x100.tit%")/100											expression directly or use
											the buttons and controls to
utout raster											help you create it.
C:\Guia GIZ\RASTER\FACTORES\FACTOR KV\Factor K	V.tif										
											<ul> <li>The Layers and variables list</li> </ul>

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

					A	Irena	
				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

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

#### 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.

🔨 Reclassify (2)		× <sup>+ :</sup>
Input raster	Reclassification	^
sand_por.ttf Reclass field  Value Reclassification	A remap table that define how the values will be reclassified.	:5
Old values New values A 23-30 200 Classify	Classification	×
30 - 38 300 NoData NoData Unique	Classification Classification Statistics Classification Statistics Count:	24183
Add Entry Delete Entries	Classes: 2 ~ Minimum: Data Exclusion Sampling Standard Deviation:	21133 23 38 752274 31.107555 1.953339
Load Save Reverse New Values Precision	Columns: 100 🔹 Show Std. Dev. Show Mean	1,55555
Output raster C:\Sula_GIZ'RASTER\FACTORES\FACTOR KFC\Factor_arena.tif Change missing values to NoData (optional)	8000	Break Values % 30 38
	2000- 0 23 26.75 30.5 34.25 38 Snap breaks to data values	OK

#### Module 2: Soil and hydrological analysis

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.

Layers and variables	^								Conditional —	^
🐉 Factor_arcilla.tif		7	8	9	1	==	!=	&	Con	
sand_por.tif		4	5	6	*	>	>=		SetNull	
🖏 silt_por.tif									Math	
Factor_arena.tif		1	2	3	-	<	<=	^	Abs	
Factor_limo.tif						1	1		Exp	
Factor_limo	×		,		+	C	)	~	Even10	$\sim$

#### The model will look as follows:



Do a JoinField between the aforementioned raster and the table <sup>ID</sup> Join\_TexturaSuelo.csv</sup> in the **INPUT** folder.

To do so, open the **Factor\_textura\_suelo.tif** layer attributes table, join it to the **Join\_TexturaSuelo.csv**<sup>4</sup> 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.

<sup>&</sup>lt;sup>4</sup> The table is available in the GitHub repository at: <u>https://github.com/guialandscape/Tablas</u>



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

5	Reclassify				
Cl	ick error and warning icons fo	r more information			×
In	put raster				
	actor_tectura_suelo_join.tif	f			💌 🔁
Re	eclass field				
k	ιFC				~
Re	eclassification				
	Old values 0.1 0.15 0.2 NoData	New values 10 15 20 NoData	^	Classify Unique	
	Load Save	Reverse New Val	v	Delete Entries Precision	
Ao	utput raster				
	:\Guia_GIZ\RASTER\FACTOR	RES\FACTOR KFC\Factor_K	FC_	_x100.tif	
	_ change missing values to IV	ovata (optional)			

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

Circle tura_suelo_join.tif       7       8       9       /       ==       !=       & Math         Abs       Factor_KFC_x100.tif       4       5       6       *       >=       I       Exp         Factor kfc\Factor_tectura_suelo.tif       Factor kfc\Factor_textura_suelo.tif       Factor_textura_suelo.tif       Factor_text	-
$\begin{array}{c c} 7 & 8 & 9 & / & == & \\ \hline & & & \\ \hline \hline & & & \\ \hline \hline \\ \hline \hline & & & \\ \hline \hline \hline \\ \hline \hline \\ \hline \hline \\ \hline \hline \hline \\ $	-
♦ Factor kfc\Factor_tectura_suelo_join.tif ♦ Factor kfc\Factor_tectura_suelo_join.tif ♦ Factor kfc\Factor_textura_suelo.tif	
✓ Factor kfc/Factor_textura_suelo.tif 4 5 6 * > >= 1 Exp	
Eactor kfr/Factor limo tif	
Exp2	
✓ Factor kfc/Factor arena.tif ✓ 0 . + ( ) ~ Float	~

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

🔨 Resample	
Input Raster	
Factor kfc\Factor_KFC	🖃 🖻
🔥 Output Raster Dataset	
C:\Guia_GIZ\RASTER\FACTORES\FACTOR KFC\Factor_KFC_3m.tif	<u>6</u>
Output Cell Size (optional)	
	~ 🖆
X Y	
3	3
Resampling Technique (optional)	
NEAREST	~

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**).

Zonal Statistics	
Click error and warning icons for more information	×
Input raster or feature zone data	
Region_mic_curva.tif	- 🖻
Zone field	
Value	~
Input value raster	
Factor_KFC_3m.tif	- 🖻
1 Output raster	
C:\Guia_GIZ\RASTER\FACTORES\FACTOR KFC\Factor_KFC_ajustado.tif	
Statistics type (optional)	
MEAN	~
Ignore NoData in calculations (optional)	

The model will look as follows:



The output will be as shown below:





#### 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)

Layers and variables	^							Conditional —	^
Factor kfc\Factor_KFC_ajustado							•	Con	
Factor kfc\Region_mic_curva.tif		/ 8	9	1	==	!=	8	Pick	
Factor kfc\Factor_KFC		4 5	6	*	>	>=		SetNull	
Factor kfc\Factor_KFC_x100							-	Math	
Factor kfc\Factor_tectura_suelo_join.tif		1 2	3	-	<	<=	^	Abs	
Factor kfc\Factor_textura_suelo.tif								Exp	
Factor kfc\Factor_limo.tif	~	0	1.1	+	(	)	~	Eve 10	¥
Factor KP\Factor_KP"+"Factor KV\Factor_KV"+"Factor k	fc\Factor_KFC_aj	justado"							

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.

nput conditional raster		
cobertura_arborea.tif	•	<b>B</b>
xpression (optional)		
"Value" =1		SQL
nput true raster or constant value		
0.05	•	<b>B</b>
nput false raster or constant value (optional)		
0.15	•	<b>B</b>
utout raster		

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:

Module 2: Soil and hydrological analysis



### **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).

#### $\circ$ 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.
		-
		- <b>-</b>
nput rasters		
		I 🖻
Paster	Output field name	^ <b>_</b>
isoETP_09.tif	ISOETP_09	×
visoETP_10.tif	isoETP_10	
visoETP_11.tif	isoETP_11	▲
isoETP_12.tif	isoETP_12	
Factor C \Coeficiente_ETP_cultivo	Coeficient	1
Coeficiente_Infiltracion.tif	Coeficie_1	
		<u>u</u>

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.

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ 145

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2	0 Point	1	3 3	249	58 16	5 323	263	276 3	40 226	48	3	1717	261.70297	939.301386	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.634682	0.37
3	1 Point	2	4	149	55 16	8 329	262	280 3	82 222	49	4	1765	274.357507	992.070805	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.655866	0.4
4	2 Point	3	6	159	53 17	4 336	267 3	279 3	86 239	49	6	1804	279.232816	1012.400843	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.739201	0.35
5	3 Point	4	7	2 5 11	55 20	2 356	277 3	277 4	04 275	49	7	1920	294.486979	1076.010703	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.605322	0.37
6	4 Point	5	7	3 7 13	64 24	0 372	280	281 4	22 306	51	7	2046	308.890029	1136.071422	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.618263	0.31
7	5 Point	6	7	5 7 15	65 24	1 371	292	291 4	23 308	49	7	2074	311.661042	1147.626543	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.651289	0.37
8	6 Point	7	7	5 6 16	60 23	7 365	303	296 4	17 302	47	7	2061	310.547307	1142.982271	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.599647	0.35
9	7 Point	8	8	3 7 14	62 22	9 370	290	280 4	17 305	49	8	2034	307.40118	1129.86292	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.641163	0.25
10	8 Point	9	8 4	4 7 15	62 22	1 376	291	280 4	10 303	48	8	2025	305.997531	1124.009704	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.641689	0.37
11	9 Point	10	8 4	4 6 14	62 21	9 374	290	283 4	08 300	46	8	2014	305.212512	1120.736177	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.847676	0.27
12	10 Point	11	6	3 6 13	62 20	6 365	282	274 3	96 272	46	6	1931	293.751942	1072.945598	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.603671	0.4
13	11 Point	12	6	3 6 12	59 20	7 362	282	274 3	98 274	46	6	1929	294.328149	1075.348383	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.631616	0.37
14	12 Point	13	5	2 6 11	58 19	7 365	279	272 3	92 270	45	5	1902	292.309674	1066.931341	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.904659	0.3
15	13 Point	14	5	2 5 12	58 19	6 353	277 3	272 3	69 265	44	5	1858	282.883208	1027.622976	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.880771	0.27
16	14 Point	15	5	2 5 10	59 18	4 341	274	271 3	64 246	42	5	1803	275.673877	997.560067	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.778055	0.27
17	15 Point	16	5	2 5 10	61 18	2 337	267	270 3	59 244	43	5	1785	271.707563	981.020538	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.85026	0.25
18	16 Point	17	4	2 5 10	58 17	7 343	268	269 3	47 223	41	4	1747	268.159702	966.225959	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.855213	0.35
19	17 Point	18	3	149	57 16	2 320	265	265 3	38 220	41	3	1685	259.208309	928.898647	-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: <a href="https://github.com/guialandscape/Tablas">https://github.com/guialandscape/Tablas</a>

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.

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1767 49 0 1804	279.25 1,012.40	- 9,999.00 - 9,999.	0 - 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
1760 51 7 2046	294.49 1,070.01	- 9,999.00 - 9,999.	0 - 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	211.65 1.147.62	- 9,999.00 - 9,999.	0 - 9,999.00	- 0,000,00	- 9,999.00	- 0,000,00	- 9,999.00	- 0.000.00	- 0,000,00	- 0,000,00	- 9,999.00	- 9,999.00
1771 47 7 2051	210 55 1 142 08	- 9,999.00 - 9,999.	0 - 9,999.00	- 0,000,00	- 9,999.00	- 0,000,00	- 9,999.00	- 0.000.00	- 0,000,00	- 0,000,00	- 9,999.00	- 9,999.00
1772 49 8 2034	307.40 1.129.86	- 9,999.00 - 9,999.	- 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
1777		- 9,999.00 - 9,999.0	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 Calibri • 11 • A A	\$ ~ % 🚥 🖬 1.027.62	- 9,999.00 - 9,999.0	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
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1780 40 5 4705	271.71 981.02	- 9,999.00 - 9,999.0	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 Cortar	268.16 966.23	- 9,999.00 - 9,999.0	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 Dopiar	259.21 928.90	- 9,999.00 - 9,999.0	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 🛗 Opciones de pegado:	258.36 925.37	- 9,999.00 - 9,999.0	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 🕰	259.52 930.18	- 9,999.00 - 9,999.0	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	258.79 927.17	- 9,999.00 - 9,999.0	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 Pegado especial	257.22 920.59	- 9,999.00 - 9,999.0	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 Insertar	261.44 938.20	- 9,999.00 - 9,999.0	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 Eliminar	264.26 949.96	- 9,999.00 - 9,999.0	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 Borrar contenido	259.43 929.83	- 9,999.00 - 9,999.0	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	262.39 942.15	- 9,999.00 - 9,999.0	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 E Formato de celdas	264.16 949.56	- 9,999.00 - 9,999.0	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 Alto de fila	248.96 886.18	- 9,999.00 - 9,999.0	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 Ocultar	247.06 878.25	- 9,999.00 - 9,999.0	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 Mostrar	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
1/9	242.28 858.31	- 9,999.00 - 9,999.0	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
1/96 34 2 1583	243.68 864.13	- 9,999.00 - 9,999.0	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
1/9/ 3/ 3 1584	244.00 865.48	- 9,999.00 - 9,999.0	0 - 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	245.07 872.44	- 9,999.00 - 9,999.0	0 - 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
199 33 3 1569	241.00 852.96	- 9,999.00 - 9,999.0	- 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
Hoja1 (	( <del>+</del> )											
10	~									Promedio: 1	168.231676 Recu	iento: 2310 Sur

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

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region 146

AF1	• : × .	/ fx Coeficient									
	W	Х	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......



Column: iso\_BHC\_01, iso\_BHC\_02.....



Column: 2iso\_BHC\_01, 2iso\_BHC\_02.....

	BG	BH	BI	BJ	ВК	BL	BM	BN	BO	BP	BQ	BR
2is	o_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.

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ 147

√ <i>f</i> <sub>x</sub> =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
4 108.8648671	110.2201608	125.6679099	118.0743646	110.0648058	93.8103807	102.3516566	99.73662216	86.58409724	86.74855256	89.53714265	95.36588095
7 96.85994789	98.74395145	112.3694691	105.5361121	98.38943153	83.57038287	91.52938406	88.84408425	76.7283225	76.75153166	79.46294178	84.95887087
7 101.5516193	103.9222361	118.5706165	111.5921667	103.5771076	87.51333316	95.9383854	92.89770523	79.62371967	79.46155822	82.98688695	89.34116807
5 99.68186232	101.8299808	116.2929597	110.2403381	102.224159	86.41730737	94.60338033	91.41267582	78.19517781	77.75822057	81.5099415	88.33014114
1 121.0305042	123.3305786	140.6718188	134.6177135	125.1632013	105.8884113	116.1359217	111.9645233	95.77521735	94.91923455	99.6263811	107.8659744
5 108.292766	110.1309126	125.9964116	120.2478648	112.2283461	95.05212135	104.4429342	100.5856165	85.93624787	85.25706595	89.66970677	96.60307885
8 128.3607248	130.5963252	150.3934906	142.2806813	132.9027834	112.2187025	123.7509931	119.0656269	101.8901966	101.1131503	106.2594898	114.3707067
8 138.517376	141.3991782	163.2240155	153.5807998	142.9619296	120.6036777	133.0494503	128.1081224	109.6414112	108.8966758	114.2171882	123.5783588
8 157.0288089	160.2022688	185.049866	173.2264776	161.1636912	135.9234813	149.914858	144.4881841	123.6528974	123.1760166	128.8794345	139.907064
8 147.6697055	150.449782	173.4103946	161.4772999	150.2436852	126.8905073	140.3849415	135.3770566	116.0110936	115.7407588	120.8673056	131.3925182
8 153.060285	155.5877934	177.4821508	165.0237021	153.750023	130.254849	144.4831046	139.9185274	119.8490824	119.7012159	124.7277614	135.9481718
8 143 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.).

)	$\times  \checkmark  f_x$	=E50-AH50										
	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE
2	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
995	-106.8648671	-106.2201608	-116.6679099	-60.07436459	60.93519418	239.1896193	166.6483434	179.2633778	292.4159028	138.2514474	-40.53714265	-90.36588095
87	-94.85994789	-93.74395145	-101.3694691	-51.53611212	82.61056847	261.4296171	181.4706159	179.1559157	304.2716775	182.2484683	-32.46294178	-78.95887087
807	-98.55161929	-96.92223611	-106.5706165	-55.59216673	112.4228924	278.4866668	184.0616146	189.1022948	319.3762803	218.5384418	-33.98688695	-82.34116807
114	-94.68186232	-94.82998075	-101.2929597	-47.24033805	133.775841	287.5826926	201.3966197	203.5873242	330.8048222	238.2417794	-34.5099415	-81.33014114
744	-115.0305042	-116.3305786	-124.6718188	-72.61771345	101.8367987	263.1115887	188.8640783	188.0354768	315.2247827	209.0807655	-51.6263811	-100.8659744
885	-104.292766	-103.1309126	-112.9964116	-59.24786484	102.7716539	268.9478786	182.5570658	181.4143835	327.0637521	213.742934	-40.66970677	-88.60307885
067	-124.3607248	-123.5963252	-138.3934906	-77.28068134	74.09721663	246.7812975	158.2490069	156.9343731	305.1098034	187.8868497	-58.25948976	-107.3707067
688	-135.517376	-135.3991782	-151.2240155	-89.5807998	67.0380704	238.3963223	142.9505497	147.8918776	294.3585888	177.1033242	-68.2171882	-117.5783588
064	-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.

-													
×	~	fx =MA	((K5-\$AG5,0)										
		BF	BG	BH	BI	BJ	ВК	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
þ		-	-	-	-	2.50	136.50	104.50	107.50	146.50	43.50	-	-
Ð		-	-	-	-	-	136.01	106.01	108.01	151.01	29.01	-	-
2		-	-	-	-	12.98	145.98	120.98	116.98	159.98	42.98	-	-
þ		-	-	-	-	-	142.80	113.80	108.80	154.80	42.80	-	-
2		-	-	-	-	10.88	159.88	129.88	125.88	175.88	59.88	-	-
В		-	-	-	-	6.17	141.17	112.17	112.17	161.17	31.17	-	-
5		-	-	-	-	17.54	155.54	126.54	128.54	174.54	44.54	-	-
1			_				154.49	117.49	113/10	158.40	38 / 0		-

=SUI	MA(BF2:BQ2)								
	BJ	ВК	BL	BM	BN	BO	BP	BQ	BR
_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 BHC\_anual\_mm column, all the 2iso\_BHC\_0x cells must be added up.

For the Infiltración\_anual\_mm column, multiply the BHC\_anual\_mm x Coeficiente\_Infiltración values.

$\times \checkmark$	$f_X$ :	=BR2*AG2																				
		BL		BM			BN			BO			BP			BQ			BR		E	IS
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.

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ 149

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.** 

Input point features	
Malla_Prec_ETP_BHC	I 🖻
Z value field	
BHC_anual_	~
C:\Guia_GIZ\RASTER\FACTORES\BHC Infiltración\BHC_anual_mm.tif	🖻
Output cell size (optional)	
	⊥ <u>⊏</u>
Power (optional)	2
Search radius (optional)	<b></b>
Variable	
Search Radius Settings	
Number of points: 12	
Maximum distance:	
Input harrier polyline features (optional)	

The result will be as shown below:

Module 2: Soil and hydrological analysis



#### 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.

Click error and warning icons for more information										×
Map Algebra expression										
Layers and variables	~								Conditional —	^
BHC_anual_mm.tif		7	8	9	1	==	!=	&	Con Pick	
✓ Infiltración_anual_m3		4	5	6	*	>	>=		SetNull	
		1	2	2				•	Math	
isoETP_01.tif		1	2	5			~-		Abs	
♦ isoETP_02.tif	¥	0		•	+	(	)	~	Exp Event0	×
"%BHC anual mm tif%"*"%Coeficiente Infiltrac	ion tif%"									
C:\Guia GIZ\RASTER\FACTORES\BHC Infiltración	\Infiltración anual mm.tif									<u></u>

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<sup>2</sup>



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

- a) Mean mm per year
- b) m<sup>3</sup> per pixel per year

Use the Raster Calculator to convert the mm into m<sup>3</sup> as follows:

Click error and warning icons for more information Map Algebra expression									X
Layers and variables BHC_anual_mm.tif Infiltración_anual_mm.tif Coeficiente_Infiltracion.tif Infiltración_anual_m3 Infiltración_anual_mm BHC_anual_mm isoETP_01.tif	~	7 8 4 5 1 2 0	9 6 3	/ * -	== > < (	!= >= <=	&   ^ ~	Conditional — Con Pick SetNull Math — Abs Exp Exp	<b>^</b>
"%Infiltración_anual_mm.tif%"*0.001*9 Output raster								, r	

### 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:





# 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



*Green Development Fund methodological guide to implementing baseline ecosystem services and generating suitability indices for landscape restoration practices for the SICA region*/ 157

#### 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

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ **161** 

connect and export them to a new shapefile, naming it **parches\_a\_conectar.shp** and save it in the **RASTER/CONECTIVIDAD** folder.



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



#### 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.** 

ArcToolbox				
Conversion Tools	^			
🗄 😂 Data Interoperability Tools		6	-	~
🗄 😂 Data Management Tools		- Fuzzy Membership -		
Editing Tools		Input raster		_ ^
Geocoding Tools		NDVI.tif	•	6
Geostatistical Analyst Tools		Output raster	_	
General State Provide Address Telephone T		D:\RASTER\CONECTIVIDAD\ndvi_normalizado.tif		8
Multidimension Tools		Membership type (optional)		
Network Analyst Tools		Lineur		
Parcel Fabric Tools		Minimum -1		
Schematics Tools		Maximum 1		
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Space Time Pattern Mining Tools		NONE		~
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🗄 🚳 Density				
🗄 🚳 Distance		Table Of Contents + ×		
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🗄 🚳 Generalization		□ ☑ ndvi_normalizado.tif		1 4
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🗄 🗞 Hydrology		Low:0		Contraction of the
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Fuzzy Overlay				
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			56	

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ **164** 

**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

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ **165** 

**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 generated in step 1, as the data input. Enter parches\_para\_conectar.shp, the superficie\_de\_resistencia.tif file in the Input cost raster box. Lastly, name both the output files corredor\_principal.shp corredores\_vecinos.shp and in as and save both 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.

🔨 Raster Calculator								_			X
Map Algebra expression											^
Layers and variables	]							Condition	nal —	^	
<ul> <li>cost_dist.tif</li> <li>cost_dist_corredores.tif</li> </ul>	7	8	9	1	==	!=	&	Con Pick			
superficie_de_resistencia.tif	4	5	6	*	>	>=	I.	SetNull Math			
	1	2	3	-	<	<=	^	Abs			
	1	0	•	+	(	)	~	Exp Exp10		~	
"cost_dist.tif" + "cost_dist_corredores.tif"											
Output raster											
D:\RASTER\CONECTIVIDAD\cost_dist_SUM.tif										2	

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.

Module 3: Landscape structural connectivity analysis

Raster Calculator								—			×
Map Algebra expression											^
Layers and variables	]							Conditio	nal —	^	
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<ul> <li>cost_dist.tif</li> <li>cost_dist_corredores.tif</li> </ul>	4	5	6	*	>	>=	I.	SetNull Math —			
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		0	•	+	(	)	~	Exp Exp10		~	
1 - "cost_dist_normalizado.tif"											
Output raster											
D:\RASTER\CONECTIVIDAD\mapa_conectividad_v1.tif										eð	

**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.

Module 3: Landscape structural connectivity analysis

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Layers and variables	^	]							Conditio	nal —	^	
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♦ cost_dist.tif ♦ cost_dist_corredores2.tif		1	2	3	-	<	<=	^	Abs			
<pre>cost_dist_corredores.tif</pre>	~	(	)	•	+	(	)	~	Exp Exp10		~	
"ndvi_normalizado.tif" * 0.5												

**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.

Kaster Calculator Map Algebra expression								_		3	×
Layers and variables ndvi_normalizado_ajuste.tif mapa_conectividad_v1.tif cost_dist_normalizado.tif cost_dist_SUM.tif cost_dist_SUM.tif cost_dist_corredores.tif superficie_de_resistencia.tif	~	7 8 4 5 1 2 0	9 6 3	/ * -	=== > < (	!= >= <= )	&   ^	Condition Con Pick SetNull Math — Abs Exp Exp Exp10	onal —	<b>^</b>	
"ndvi_normalizado_ajuste.tif" + "mapa_conectividad Output raster D:\RASTER\CONECTIVIDAD\mapa_conectividad_v2.t	_v1.til	aı									

**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.

<sup>&</sup>lt;sup>5</sup> FRAGSTATS: <u>https://www.umass.edu/landeco/research/fragstats/fragstats.html</u>



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.


• 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					•	<b>6</b>
Reclass field						
LINK						$\sim$
Reclassification						
Old values 0 0 - 1 1 - 2 NoData	New values 1 2 3 NoData		Classify Unique Add Entry Delete Entries			
Load Save	Reverse New Va	lues	Precision			
Output raster						
D:\RASTER\AjusteFinal_Cone	ctividad\nivel_fragmentac	ion.ti	F			<b>2</b>
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.

Module 3: Landscape structural connectivity analysis

🔨 Raster Calculator								—			×
Map Algebra expression											^
Layers and variables nivel_fragmentacion.tif ndvi_region.tif ndvi_reclass.tif nucleos_conectividad.tif NDVI.tif mapa_conectividad_ajustado.tif	7 4 1	8 5 2	9 6 3	/ * -	=== > <	!= >= <=	&   ^	Condition Con Pick SetNull Math Abs Exp Exp	onal —	*	
"nucleos_conectividad.tif" * "nivel_fragmentacion.tif" Output raster D:\RASTER\AjusteFinal_Conectividad\nivel_fragmentac	cion2.tif										

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.

#### Module 3: Landscape structural connectivity analysis



#### **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:

Module 3: Landscape structural connectivity analysis



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

Module 3: Landscape structural connectivity analysis

Use 4 cell neighborhood rule         Ouse 8 cell neighborhood rule         Automatically save results	Browse
Automatically save results	Browse
Sampling strategy No sampling	
Patch metrics Class metrics Landscape metrics	

• 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.

	Area - Edge	Shape	Core area	Contrast	Agg	regation	r						
			Sele	ect all							De-select all		
Patch metrics	- Isolation												
						Mean (MN)	Area-We Mean (A	eighted M)	Median (MD)	Range (RA)	Standard Deviation (SD)	Coefficient of Variation (CV	0
	Euclidean	Nearest I	Neighbor Di	stance (EN	IN_?)			]					
Class metrics	Proximity	Index (F	ROX_?)					]					
	Similarity	Index (S	IMI_?)					]		C	nanging thres	nol ×	Se
										N	lew value:		_
Landscape metrics	Conne	ctance Ir	ndex (CON	NECT)	Thre	shold d	stance is (	unknow	/n		500		
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Paraulta	Numbe	er of Pato	hes (NP)			🗌 In	terspersio	n Juxta	position I	ndex (II	11)		

#### Module 3: Landscape structural connectivity analysis

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



Runnning		$\times$
Run properties		
Analysis type Current file Patch level Class level Landscape level	<ul> <li>No sampling</li> <li>C:\SIG_FDV_Pais_X\AjusteFinal_Conectividad\nivel_fragmentación2_30m.tif</li> <li>not selected</li> <li>1 metrics</li> <li>not selected</li> </ul>	
Processing landscap	e: phase II (class level analysis). Proceed Cancel	

• 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.

	Run list:	Patch	Class	Landscape	
	R-001 [D:\Efrain_Duarte\Dr		11.	ТҮРЕ	CONNECT
Patch metrics		1	D:	cls_1	0.2800
		2	D:	cls_2	0.4735
		3	D:	cls_200	0.1832
		4	D:	cls_100	0.1819
Class metrics		5	D:	cls_300	1.8704
Landscape metrics					

• 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.

Tat	ole						
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niv	el_frag	mentacio	n2.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.

#### Module 3: Landscape structural connectivity analysis

🔨 Lookup	_		×
Input raster			_ ^
nivel_fragmentacion2.tif		<b>-</b>	<b>2</b>
Lookup field			
IndexCon			$\sim$
Output raster			
D:\RASTER\AjusteFinal_Conectividad\indice_fragstats.tif			<b>2</b>

• 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.

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ArcToolbox					
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H Analysis Tools					
E Cartography Tools	Fuzzy Membership	-		)	$\times$
E Conversion Tools					-
Data Interoperability Tools	Input raster				$\sim$
Gata Management Tools	indice fragstats tif		•	F3	
Geocoding Tools	Output sector			-	
Geostatistical Analyst Tools	Output raster				
Section 2	D:\RASTER\CONECTIVIDAD\indice_fragstats_ne	ormalizado.tif		B	
H S Multidimension Tools	Membership type (optional)				
Network Analyst Tools	Linear				
Parcel Fabric Tools	Lines.				
Schematics Tools	Minimum 9.999999	7764826E-03			
🗄 😂 Server Tools					
🗄 🌍 Space Time Pattern Mining Tools	Maximum 0.358900	01058578			
🖃 😂 Spatial Analyst Tools					
🗄 🇞 Conditional	Hedge (optional)				
🕀 🇞 Density	NONE			~	
🗄 🇞 Distance					
🗄 🍣 Extraction					
🗄 🏷 Generalization	-				
🕀 🌭 Groundwater	Table Of Contents				
🗄 🏷 Hydrology	📷 🖗 😣 🗉				
🗄 🗞 Interpolation	E 🗃 Layers	States and the second			
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• 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.

🔨 Raster Calculator								—		×	
Map Algebra expression										,	
Layers and variables mapa_conectividad_ajustado.tif indice_fragstats_normalizado.tif indice_fragstats.tif nivel_fragmentacion2.tif	7 4 1	8 5 2	9 6 3	/ *	=== > <	!= >= <=	&   ^	Condition Con Pick SetNull Math Abs Exp Exp10	onal —	~	
("indice_fragstats_normalizado.tif" + "mapa_conectividad_ Output raster D:\RASTER\CONECTIVIDAD\indice_conectividad_ajustadoF	ajusta Final.tif	do.tif"	) / 2								

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

#### Module 3: Landscape structural connectivity analysis





# 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
- 02\_CARBONO
- 03\_FISIOGRAFIA
- 04\_HIDROLOGIA
- 05\_EROSION
- 06\_ CONECTIVIDAD
- 07\_OTROS

#### 01\_GENERAL

#### **Project area limits**

- lim\_zona\_estudio\_project.shp
- zona\_de\_trabajo.shp

#### Basemap data

- Limites\_municipales.shp
- Limites\_de\_aldeas.shp
- $\circ \quad Subcuencas\_hidrograficas.shp$
- Areas\_protegidas.shp
- Areas\_urbanas.shp
- Red\_hidrica.shp
- o Red\_vial.shp

#### 02\_CARBONO

#### Tree cover by type and other land uses

cobertura\_project.tif

#### Forest carbon

o mapa\_carbono

#### 03\_FISIOGRAFIA

#### Topography

- MDT\_Corregido.tif
- o 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
- o 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

- o 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
- $\circ$  Factor\_C\_ajustado2.tif

#### Erosion

o EROSION.tif

#### 06\_CONECTIVIDAD

- o NDVI.tif
- parches\_a\_conectar.shp
- superficie\_de\_resistencia.tif
- Corredor\_principal.shp
- $\circ$  Corredores\_vecinos.shp
- Indice\_conectividad\_ajustadoFinal.tif

#### 7\_OTROS

#### **Carbon factors table**

- Factores carbono.xlsx
- forest\_edge\_carbon\_lu\_table.csv
- o join\_clasesderelieve.csv
- o Balance Hídrico Climático.csv
- Join\_TexturaSuelo.



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:

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

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

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.

Municipios	
	Сору
🖃 🗌 Depar 🗙	Remove
	Open Attribute Table
	Internet Deleter

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	Ē
1	Acaxual	
2	Atehuesian	1
3	Cara Sucia	1
4	El Chino	1
5	El Corozo	1
6	El Imposible	1
7	FLSalto	ľ

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

					-
NAME	COD_MUN	COD_MU			T
Acajutla	01	0301	Α.	Sort Ascending	ſ
San Antonio del Monte	11	0311	₹.	Sort Descending	1
Sonsonate	15	0315		Advanced Sorting	ľ
Santo Domingo de Guzmán	14	0314		Advanced Sorting	ſ
Guaymango	06	0106		Summarize	ſ
San Dadro Duvtla	10	0110			1

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

Summarize X
Summarize creates a new table containing one record for each unique value of the selected field, along with statistics summarizing any of the other fields.
1. Select a field to summarize:
COD_MUN4 ~
<ol> <li>Choose one or more summary statistics to be included in the output table:</li> </ol>
<ul> <li>NAME</li> <li>Inst</li> <li>Last</li> <li>COD_MUN</li> <li>REG_GEO</li> <li>REG_GEO_DE</li> <li>R_PNODT_DE</li> <li>SR_PNODT_DE</li> <li>SR_PNODT_D</li> <li>✓</li> </ul>
3. Specify output table:
Pais_X\RESULTADOS\07_OTROS\Tabla_ID_municipios
About summarizing data OK Cancel

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

Saving Data								×
Look in: 🛅	07_OTROS		~ 1	- 🏠	•	<u>-</u>	🛍 🗊	6
Name		Туре						
Name: Tabla_ID_municipios.db Save as type: dBASE Table					 ~	[	Save Cancel	

e) Lastly, open the resulting table and delete the **"Count\_..."** field.

Tal	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.** 

ArcToolbox			
T S 3D Analyst Tools			
Gartography Tools	Dissolve		= U X
Conversion Tools	Input Features		_ ^
Data Interoperability Tools	municipios		· 🖻
	Output Feature Class		
H S Archiving	D:\01_GENERAL\municipios_dissolve.shp		ē
H S Attachments	Dissolve_Field(s) (optional)		0
🗄 🗞 Data Comparison			
🗄 🗞 Distributed Geodatabase			
🗄 🗞 Domains			
🗄 🗞 Feature Class			
🕀 🗞 Features			
🕀 🇞 Fields	SR_PNODT_D		~
표 🦠 File Geodatabase	<		>
🗄 🎭 General	Select All Unselect All		Add Field
🖃 🇞 Generalization	Ctatistics Eiold(s) (ontional)		
Dissolve			-
Keininate Polygon Part	Subcuencas dissolve	Table	Tabla
		[] • ] 碧 • ] 晶 [] [] [] # ×	
		municipios_dissolve	Tabla ID municipio
		FID Shape * COD_MUN4	OID COD_MUN4 First_NAME
	area patural protogida dissolva	O Polygon 0101     Dolygon 0104	00101 Ahuachapán     10104 Concepción de Ateace
		2 Polygon 0106	2 0106 Guaymango
		3 Polygon 0107 4 Polygon 0108	3 0107 Jujutla
	municípios_dissolve	5 Polygon 0111	5 0111 Tacuba
		6 Polygon 0301	6 0301 Acajutla

- a) Add 2 fields for each summary table with its corresponding name as indicated below. And transfer the corresponding values to these new fields.
  - Tabla\_ID\_subcuencas
     Tabla\_ID\_municipio
  - Tabla\_ID\_canton
  - Tabla\_ID\_areas\_protegidas

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.

Data Management Tools
 Soins
 Join Field

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

🔨 Join Field	—		×
Input Table			_ ^
Municipios_dissolve		-	<b>2</b>
Input Join Field			
COD_MUN4			~
Join Table			
Tabla_ID_municipios		•	<b>2</b>
Output Join Field			
COD_MUN4			~
Join Fields (optional)			
Municipio			

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.

Tal	Table							
0 0	🗄 •   🖶 •   🖫 🌄 🖾 🐠 🗙							
mi	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	Polvaon	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.

ArcToolbox ⊟ Source Overlay Source Union

Add the shapefiles to be joined in **Input Feature**. Select **NO\_FID** in Join Attributes (optional).

nput Features		-	<b>C</b> 2
		·	
Features	Ranks		+
microcuencas_orden9			
🔷 municipios_dissolve			×
🔷 subcuencas_dissolve			
			T
🔷 area_natural_protegida_dissolve			
			+
<		>	
)utput Feature Class			
D:\01_GENERAL\union_limites.shp			<b>6</b>
oinAttributes (optional)			
NO_FID			~~
0(T-l(			

g) Add the **CodUnion** field to the **union\_limites.shp** attributes table.

Add Field		×
Name:	CodUnion	
Туре:	Text	$\sim$
Field Prop	erties	
Length	50	

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].

Field Calculator			×
Parser VB Script	)Python		
Fields:		Type:	Functions:
Municipio Cod_Aldea Aldea Cod_Subc Subcuenca Cod_Areap AreaProt Departamen Cod_Depto		<ul><li>Number</li><li>String</li><li>Date</li></ul>	Abs ( ) Atn ( ) Cos ( ) Exp ( ) Fix ( ) Int ( ) Log ( ) Sin ( ) Sqr ( ) Tan ( )
Show Codeblock			* / & + - =
[Cod_Mic] & [Cod_Dep	oto] & [Cod_Muni] & [	[Cod_Aldea] &	[Cod_Subc] & [Cod_Areap] \land

- 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.



 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.

S Dissolve	- 🗆	×
Input Features		
clip_union_limites_project	<b>•</b>	<b>6</b>
Output Feature Class		
D:\01_GENERAL\dissolve_clip_union_limites_project.shp		<b>6</b>
Dissolve_Field(s) (optional)		_
Cod_Subc		^
Subcuenca		
Cod_Canton		
Cod_Areap		
CodUnon		~
<	>	
Select All Unselect All	Add Field	
Statistics Field(s) (optional)		
		$\sim$

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	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.

Tab	le			Table									□ ×
13													
		~ **		dissol	e_clip_union	limites_project							×
diss	solve_clip_union_li	imites_project		F	D Shape	CodUnon	ID_union	Cod_Mic	Cod_Subc	Subcuenca	Cod_Canton	Conton	Cod ^
П	FID Shape *	CodUnon	ID_union		0 Polygon	0 0107	1	0					
F	0 Polygon	0 0107	1	H-	1 Polygon	0 0108	2	0	2				
Πî	1 Polygon	0 0108	2	H-	2 Polygon 3 Polygon	0 30108	3	0					3
H	2 Polygon	0 0301	3	H	4 Polygon	0 60107	5	0					6
H	3 Polygon	0 30108	4		5 Polygon	0 60108	6	0					6
H	4 Polygon	0 60107	5		6 Polygon	0 60301	7	0	)				6
H	6 Polygon	0 60109	6	H-	7 Polygon	0 70108	8	0					7
H	C Delveen	0 00100	7	H-	8 Polygon	0 010701 0107	9	0			010701	BARRA DE SANTIAGO	
H	6 Polygon	0 60301	1	H-	9 Polygon	0 010701 0301	10	0			010701	BARKA DE SANTIAGO	-
Ц	7 Polygon	0 70108	8	H-	11 Polygon	0.01070160301	12	0			010701	BARRA DE SANTIAGO	6
	8 Polygon	0 010701 0107	9	H-	12 Polygon	0 010804 0107	13	0			010804	EL ZAPOTE	
	9 Polygon	0 010701 0301	10		13 Polygon	0 010804 0108	14	0			010804	EL ZAPOTE	
	10 Polygon	0 01070160107	11	H	14 Polygon	0 01080430108	15	0			010804	EL ZAPOTE	3
H	11 Polygon	0.01070160301	12		15 Polygon	0 01080460108	16	0			010804	EL ZAPOTE	6
	12 Polygon	0.010804.0107	13		16 Polygon	0 010805	17	0			010805	GARITA PALMERA	
H	12 Polygon	0.010004.0107	1.5	<u> </u>	17 Polygon	0 010805 0108	18	0	)		010805	GARITA PALMERA	
H	13 Polygon	0 0 10604 0 108	14		18 Polygon	0 0108057	19	0			010805	GARITA PALMERA	1
	14 Polygon	0 01080430108	15	H-	19 Polygon	0 010805/0108	20	0			010805	GARITA PALMERA	/
	15 Polygon	0 01080460108	16		20 Polygon	0 010000	21	0			010000		+

 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.





#### 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.



The combine	_		×
Input rasters			_ ^
		•	<b>6</b>
raster_limites_administrativos.tif			+
♦ cobertura_project.tif			
			×
			1
			Ŧ
D:\U1_GENERAL\UNION_IIMITes_X_CODERT.TIF			

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.

ID\_UnixCob = [OID] +1



# 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.

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	SUM	SUM_Infiltración_m3.dbf	SUM_INFIL
pixel			
Infiltration mm	MEAN	MEDIA_Infiltración_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	MEAN	MEDIA_Ind_ServiciosEcost.dbf	MED_IndSEc
Services Stock Index			

#### Main calculations

#### Additional carbon-related calculations

Variable	Operation	Output table	Field
CO2 tonne per pixel	SUM	SUM_CO2.dbf	SUM_CO2
CO <sub>2</sub> 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:**

🔨 Zonal Statistics as Table	—		×
Input raster or feature zone data			_ ^
union_limites_x_cobert.tif		•	<b>6</b>
Zone field			
ID_UnixCob			$\sim$
Input value raster			
infiltracion_normalizado.tif		•	<b>6</b>
Output table			
D:\01_GENERAL\TABLAS_ZONAL\infiltracion_mm_zonal			<b>6</b>
Ignore NoData in calculations (optional)			_
Statistics type (optional)			
MEAN			~

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

Tal	ole				
°==	•   ª •	📲 🌄 🖸 🐳 🗙			
inf	iltracion_r	nm_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.

Add Field				×	
Name:	INFILTRA	L.			
Туре:	Float			~	
Field Prop	erties		-		
Precision			0		
Scale			0		
		ОК		Cancel	

b) Right-click on the Union\_limites\_x\_cobert.tif layer and select the Join and Relates option, then click on Join.



Join Data	×
Join lets you append additional data to this layer's attribute table so you can for example, symbolize the layer's features using this data.	n,
What do you want to join to this layer?	
Join attributes from a table	$\sim$
1. Choose the field in this layer that the join will be based on:	1
ID_UnixCob ~	
2. Choose the table to join to this layer, or load the table from disk:	
🕮 infiltracion_mm_zonal 💽 🖻	
Show the attribute tables of layers in this list	
3. Choose the field in the table to base the join on:	
ID_UNIXCOB ~	
Join Options • Keep all records	
All records in the target table are shown in the resulting table. Unmatched records will contain null values for all fields being appended into the target table from the join table.	

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

#### Module 5: Integrated landscape analysis

Table	
🖽 •   🖶 •   🖳 🏡 🖾 🐗 🗙	
union_limites_x_cobert.tif	×
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11	1 union_limites_x_cobert.tif.vat.ID_Ur Atn ( )
12	union_limites_x_cobert.tif.vat.INFIL: String Exp()
13	infiltracion_mm_zonal:Rowid
14	infiltracion_mm_zonal:ID_UNIXCOB
15	infiltracion_mm_zonal:COUNT
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#### d) Remove the Join

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	7	Zoom To Make Visible	Relate	Remove All Joins	
🗄 🗌 Union_lim		Zoom To Raster Resolution	Remove Relate(s)	14	
🖃 🗹 carbono si			 	15	

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).

#### Module 5: Integrated landscape analysis

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**.



🔨 Zonal Statistics	—		$\times$
Input raster or feature zone data			_ ^
microcuencas_orden7_clip		-	<b>6</b>
Zone field			
Id			$\sim$
Input value raster			
Infiltración_anual_mm.tif		-	<b>2</b>
Output raster			
D:\07_OTROS\inflitracion_mmxyear_xmicroc_orden7.tif			<b>2</b>
Statistics type (optional)			
MEAN			$\sim$
✓ Ignore NoData in calculations (optional)			

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.





#### Module 5: Integrated landscape analysis

#### 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



#### Module 5: Integrated landscape analysis

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



#### Module 5: Integrated landscape analysis

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







## Example of value summary by village





## Example of value summary by municipality





## 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 table6 in forest\_edge\_carbon\_lu\_table.csv " located in the **INPUT** folder, filling the fields as indicated below:

<sup>6</sup> Tabla Forest\_edge\_carbon\_lu\_table.csv available at: <u>https://www.dropbox.com/s/1zcj3eitb41hbrf/forest\_edge\_carbon\_lu\_table.csv?dl=0</u>

*Green Development Fund methodological guide to implementing baseline ecosystem services and generating suitability indices for landscape restoration practices for the SICA region*/ 238 **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:

	А	В	С	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 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.

module and specify the files and

#### Land-Use/Land-Cover Map: enter the

01\_CARBONO/Mapa\_Cobertura/cobertura\_project.tif cover types raster.

Biophysical table: enter the so 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 file7 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

<sup>&</sup>lt;sup>7</sup> File available in:

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ **240** 

E F	orest	Carbon Edge Effect Model: loaded from autosa	ive —		×
File	Edit	Development Help			
			InVEST version 3.7.0   <u>Model documentation</u>	<u>Report</u>	<u>an issue</u>
	~	Workspace	C:\SIGDATA_Capacita_LB_FDV_2\TEMP2\CARBON		
	~	Results suffix (optional)	SV4		0
	~	Land-Use/Land-Cover Map (raster)	cita_LB_FDV_2/TEMP2/ReclassCobert3_lambert.tif		0
	~	Biophysical Table (csv)	CARBONO/Inputs/forest_edge_carbon_lu_table.csv		0
		Carbon Pools to Calculate	above ground only		0
		Compute forest edge effects			0
	~	Global forest carbon edge regression models (vector)	_carbon_edge_regression_model_parameters.shp		0
	~	Number of nearest model points to average	1		0
	*	Forest Edge Biomass to Carbon Conversion Factor	0.47		0
	~	Service areas of interest <i>(optional)</i> (vector)	C:/SIGDATA_Capacita_LB_FDV_2/TEMP2/Limite.sh		0
				Θ	Run

- 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.

Reclassificat	ion		
0	ld values	New values	1
	0	1	
	1	NoData	
T	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").

Reda	ssification		
	Old values	New values	^
T	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.

	RegionG_tif1				
	OBJECTID *	Value	Count	LINK	Select_
	3030	3030	3472920	4	1
	2034	2034	1066298	1	0
and the set	1084	1084	9781879	3	1
	3	3	3408512	4	1
	12366	12366	2061110	2	0
	30	30	894968	1	1
	127	127	487488	4	1
	9946	9946	354876	1	1
	1446	1446	257021	4	1
A P Of Care of the	13662	13662	255921	2	1
State of the second	6510	6510	192743	1	1
	485	485	178177	4	1
	13881	13881	158837	2	1
	4467	4467	149889	1	1
A Contract of the State of the	8742	8742	147604	1	1
	11611	11611	134523	1	1
	11610	11610	110203	1	1
	10755	10755	107071	3	1
	11307	11307	102093	1	1
	12654	12654	91976	2	1
in the second	3951	3951	89606	4	1
	9044	9044	87517	4	1
	9525	9525	85894	1	1
	11785	11785	80831	1	1

h) Use the conditional tool (Con) to generate a raster containing the correction values. Name the output raster **coeficiente\_efecto\_de\_borde\_ajustado.tif.** 

Input conditional raster	_
Lookup_Regio3	<b>e</b>
Expression (optional)	
Value = 1	SQL
Input true raster or constant value	
Input true raster or constant value	6
Input false raster or constant value (optional)	
coeficiente_efecto_de_borde2.tif	e3
Output raster	
C:\SIG_FDV_Pais_X\RESULTADOS\02_CARBONO\coeficiente_efecto_de_borde_ajustado.tif	2

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:

- 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<sub>2</sub> 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: <a href="https://www.winrock.org/flr-calculator/">https://www.winrock.org/flr-calculator/</a>

### 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: <u>https://github.com/guialandscape/guia</u>

🖵 guialand	scape / guia		
↔ Code	🗇 Issues 🏥 Pull requests 💿 Actions 🔄 Projects 🖽 Wilds 🗇 Security	/ 🗠 Insights 🐵 Settings	
	14 master - 14 1 branch 15 0 tags	Go to file Add file *	± Code +
	guialandscape Forest_edge_carbon_lu_table	ca5d164 3 hours ago	3 4 commits
STEP 1: Click on	Factores carbono.xlsz Factores de carbono		3 hours ago
to download	forest_edge_carbon_lu_memocorest_edge_carbon_lu_table		3 hours ago
	geoforma_combina.tif.lyr Layer de geoformas_combina.tif		3 hours ago
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### 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<sub>2</sub> and biomass as well).
- Table of total carbon tonnes by political-administrative unit (show CO<sub>2</sub> 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

#### Annexes

• 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

*Green Development Fund methodological guide to implementing baseline ecosystem services and generating suitability indices for landscape restoration practices for the SICA region*/ *253*  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 noforest, 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: <u>https://github.com/guialandscape/GUIA\_APR</u>. Save it in a subfolder in **GALERIA** called **GANANCIAS** (APR/GALERIA/GANANCIA).

	$\leftarrow$ $\rightarrow$ O $\widehat{\Box}$ $\triangle$ https://github.com/guialandscape/GUIA_APR
	Search or jump to
	Learn Git and GitHub without any codel
	Using the Hello World guide, you'll start a branch, write comments, and open a pull re
	Read the guide
	guialandscape / GUIA_APR
	<> Code ① Issues 弐 Pull requests ② Actions 凹 Projects □□ Wila ③ Security ビ Insights ⑧ Settings
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-	guialandscape GANANCIA.TIF Latest commit #471ee9 2 minutes ago 🕥 History
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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 <a href="https://github.com/guialandscape/GUIA\_APR">https://github.com/guialandscape/GUIA\_APR</a>. 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.

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	FID	Shape *	LENGTH	NOMBRE	TIPO	oldtype	LONGITUD	Buffer		
F	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	Ρ	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	Т	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	Т	S	0	100		
	10	Polyline M	1347.474585		Q	Q	1	50		
	11	Polyline M	122.333895		Т	S	0	100		
	12	Polyline M	858.297581	RIO EL SUNZA o E	S	Р	1	150		
	13	Polyline M	79.380695	Río El Rosario	Т	S	0	100		
	14	Polyline M	484.620699	RIO GUAYAPA o D	Т	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.

♦ NBosq2.tif	^								Condition	al —	^	
		7	8	9	1	==	!=	&	Con Pick			
♦ cobertura_arborea.tif ♦ SInd_NVeg.tif		4	5	6	*	>	>=	1	SetNull Math			
♦ NDVI.tif ♦ SInd Pend tif		1	2	3	-	<	<=	^	Abs			
pendiente_porcentaje.tif	~	(	)	•	+	(	)	~	Exp Exp10		~	
"SInd_Pend.tif" * 0												
"SInd_Pend.tif" * 0												

# **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

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ **269** 



## 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.

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Conversion Tools	Selection		×
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🗄 🚳 Geocoding Tools	IRBG.tif	•	6
🗄 💐 Geostatistical Analyst Tools	Output raster		
🗉 🚳 Linear Referencing Tools	D:\\APR\GALERIA\IRRG_normalizado.tif		<b></b>
🗄 😂 Multidimension Tools			
🗄 👒 Network Analyst Tools	Membership type (optional)		
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E 😂 Schematics Tools			
🗄 😂 Server Tools	Minimum 0.040839653462172		
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Spatial Analyst Tools	4.5365010401445		
🗄 🗞 Conditional			
🕀 🇞 Density	Hedge (optional)		
🗄 🗞 Distance	NONE		$\sim$
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Generalization			
Groundwater			
H W Hydrology			
Interpolation			
🗄 👒 Local			
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The output should appear as follows: values approaching 1 correspond to those areas identified as being most suited to gallery forest restoration.



# 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 (<u>https://github.com/guialandscape/GUIA\_APR</u>) download the file called **Mapa\_uso\_suelo.tif** and save it in the **APR/PASTOS\_ARB** folder.

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# Step 3.2: reclassify the file Mapa\_uso\_suelo.tif.

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ 273

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:



Name the output file Mask\_Pastos.tif and save it in the APR/PASTOS\_ARB folder.



Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ 274

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.

&	Conditional - Con Pick	- ^	
&	Con		
	SetNull Math		
^	Abs		
~	Exp Exp10	~	
			]

# 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.

ArcToolbox			
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3D Analyst Tools			
🕀 😂 Analysis Tools	🔨 Con —		>
E Startography Tools			
🕀 😂 Conversion Tools	Input conditional raster		
🗄 😂 Data Interoperability Tools	Veg_Pasto.tif	•	6
🗄 😂 Data Management Tools	Expression (optional)		
🗄 😂 Editing Tools	Value <0.75		SQL
🗄 😂 Geocoding Tools	Input true raster or constant value		
🗄 😂 Geostatistical Analyst Tools	Veg_Pasto.tif	•	6
🗄 😂 Linear Referencing Tools	Input false raster or constant value (optional)		_
🗄 😂 Multidimension Tools	0	•	6
🗄 😂 Network Analyst Tools	Output raster		_
🕀 😂 Parcel Fabric Tools	D:\APR\PASTOS_ARB\PastosArb.tif		6
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🗄 😂 Server Tools			
🗄 🌍 Space Time Pattern Mining Tools			
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Pick			
Set Null			

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.

🔨 Fuzzy Membership			_		×
Input raster					
PastosArb.tif				-	<b>6</b>
Output raster					
D:\APR\PASTOS_ARB\S	nd_PastArb.tif				<b>6</b>
Membership type (option	)				_
Linear	$\sim$				
Minimum	0				
Maximum	0.6404382586479	92			
Hedge (optional)					
NONE					~

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)]



# 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.

ArcToolbox			
S ArcToolbox			
🗄 😂 3D Analyst Tools			
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Multidimension Tools	Membership type (optional)		
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🗄 🗞 Groundwater			
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Solution			
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🗄 👒 Map Algebra			
🖽 👒 Math			
Some Multivariate			
Fuzzy Membership			
Fuzzy Overlav			
✓ Locate Regions			
Weighted Overlay			
,			

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**

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ **280** 

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.** 

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S ArcToolbox			
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Conversion Tools	Input conditional raster		
Data Interoperability Tools	Veg_Pasto.tif	<u>•</u>	8
Data Management Tools	Expression (optional)		
Editing Tools	Value >0.25		5.04
Geocoding Tools	Input true raster or constant value		
Geostatistical Analyst Tools	Veg Pasto.tif	-	R
Multidimension Tools	Input false raster or constant value (ontional)	_	-
Network Analyst Tools		-	-
Parcel Fabric Tools	10		
Schematics Tools	Output raster		
E Server Tools	D:\APR\PASTOS_noARB\PastosNoArb.tif		
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L			

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ **281** 

#### 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.

🔨 Fuzzy Membership		_		$\times$
Input raster				
PastosNoArb.tif			•	<b>6</b>
Output raster				
D:\APR\PASTOS_noARB\SInd_	PastNoArb.tif			<b>6</b>
Membership type (optional)				_
Linear	~			
Minimum	0			
Maximum	0.64043825864792			
Hedge (optional)				
NONE				$\sim$

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.

ArcToolbox					
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Space Time Pattern Mining Tools	Maximum 3.3097066879272				
🖃 😂 Spatial Analyst Tools	3.307/000/52/2				
🗄 🗞 Conditional					
🗄 🕸 Density	Hedge (optional)				
🗄 🗞 Distance	NONE	~			
🗄 🗞 Extraction					
🗄 🗞 Generalization					
🕀 🗞 Groundwater					
🕀 🗞 Hydrology					
🕀 🗞 Interpolation					
🗄 🗞 Local					
🗄 🗞 Map Algebra					
🕀 🗞 Math					
🗄 🗞 Multivariate					
🗄 🗞 Neighborhood					
🗆 🗞 Overlay					
Fuzzy Membership					
<ul> <li>Fuzzy Overlay</li> </ul>					
Locate Regions					
∽ Weighted Overlay					

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



# 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 (<u>https://github.com/guialandscape/GUIA\_APR</u>), save it in the **APR/CAFETALES** folder and then add it to the ArcMap.

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Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ **287** 

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.



Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ **288**
#### **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 = 500 - 800 = 800 - 1200 = >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

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ **289** 

**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** 

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Float("SInd_AltCafe_v1.tif") / 100			
Output raster D:\APR\CAFETALES\SInd_AltCafe.tif			<b>6</b>

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 shadegrown 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.



# 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 (<u>https://github.com/guialandscape/GUIA\_APR</u>) 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:

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ **296** 

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

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ **300** 

#### 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.

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Multidimension Tools	Minimum 0.04046281427145	
Network Analyst Tools		
Parcel Fabric Tools	Maximum 4	
Schematics Tools	Hedge (optional)	
Server Tools	NONE	~
Space Time Pattern Mining Tools		
Spatial Analyst Tools		
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H S Neighborhood		
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Fuzzy Membership		
Fuzzy Overlay		
Locate Regions		
weighted Overlay		

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



## 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

Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region/ **307** 

#### >= 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.

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Geocoding Tools	D:\APR\B_SECUNDARIO\IRBS_normalizado.tif		6
Geostatistical Analyst Tools	Membership type (optional)		
Linear Referencing Tools	Linear V		
Multidimension Tools	Minimum 0		
Network Analyst Tools	Maximum 2.5576230576731		
Parcel Fabric Tools	2.2376339570721		
Schematics Tools	Hedge (optional)		
Server Tools	NONE		$\sim$
Space Time Pattern Mining Tools			
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The output should appear as follows: values approaching 1 correspond to those areas identified as being most suited to secondary forest restoration.



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*Green Development Fund methodological guide to implementing baseline ecosystem services and generating suitability indices for landscape restoration practices for the SICA region*/ *314* 

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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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Implemented by



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Methodological guide for developing a baseline for ecosystem services and generating suitability indices for landscape restoration in the SICA region 316