Fundamentals of GIS

Book · March 2018

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Fundamentals of GIS

Applications with ArcGIS

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Credits

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1. Introduction

The use of geographic information in decision-making tends to go unnoticed, but it is actually present in many of our daily activities. By unconsciously selecting the route to work, the vacation route, going to meet a friend, going to a store using a smartphone and more, decisions are made that involve analyzing geographic information without being aware of it. When this type of analysis or decision making is carried out using computers, it is usually done through what is known as Geographic Information Systems (GIS).

According to López Trigal (2015), a GIS is a set of tools made up of hardware, software, data and users, which allows us to capture, store, manage and analyze digital information, as well as make graphs and maps, and represent alphanumeric data. According to Burrough (1994) a GIS can also be seen as a computer model of geographic reality to meet specific information needs, i.e., create, share and apply useful information based on data and maps.

For decades, GIS have been applied to land and natural resource management problems, environmental issues, military logistics or in contexts directly linked to Earth sciences, such as geography, geology, etc. In addition, GIS is of potential use for other relatively unpublished fields and disciplines, particularly in research related with Human and Social Sciences (Del Bosque González, Fernández Freire, Martín-Forero Morente, & Pérez Asensio, 2012).

ArcGIS Desktop (hereafter ArcGIS) is the main component of ESRI's ArcGIS application suite, and the software that contains the classic desktop GIS functionalities. ArcGIS is a set of tools that allows the visualization and management of geographic information, and also has an extensible architecture through which new functionalities can be added (Olaya, 2011). These are the well-known extensions, among which are Spatial Analyst (raster analysis), 3D Analyst (3D and relief analysis) or Geostatistical Analyst (geostatistics).

The purpose of this technical paper is to introduce basic GIS concepts through the development of case studies that involve the entire mapping process. There are literally hundreds of tools in ArcGIS, but it is not possible to work with all of them, although you can familiarize yourself with them. This document is designed so that, as you progress, you can acquire skills or improve those you already have in order to create maps, search for geographic information, and finally publish a well edited map.

In addition, an attempt is made to share this document by all possible means by authorizing the copying, remixing, transformation, or partial or total redistribution of the material in any **non-commercial** medium or format, but always quoting the corresponding source of this work.

With no further introduction, we start by expressing our wish that it will be of great use to you.

2. Geographical terms

Geographical information in digital formats requires the standardization of criteria and the incorporation of minimum parameters that guarantee its quality and also allow interoperability between users to optimize its use and exchange, leading to the reuse and democratization of information (SENPLADES, 2013).

The following is a glossary of the most relevant geographical terms that will be used in this document. Some terms come from the technical series "Geographic Information Standards" published by SENPLADES (2013) in its section "Terminology for Geographic Information", which are based on ISO / TS 19104: 2008 Geographic information - Terminology and ISO / TC 211 Multi-Lingual Glossary of Terms. Note that the terms followed by the letters numbered "A" refer to the Annexes of the technical series SENPLADES (2013).

- **Band:** Each of the parts into which the electromagnetic spectrum is divided to enable the sensors to capture the electromagnetic radiation. The radiation data (numerical values) captured for each defined band are usually organized as raster files (Moreno Jiménez, 2008).
- **Layer:** Basic unit of geographic information that can be requested as a map from a server [ISO 19128:2005]. Conceptually, a layer is a portion or stratum of geographic space in a particular area, and could be considered the equivalent of an element of the legend of the map (SENPLADES, 2013).
- **Coordinate:** Measured value on the earth's surface that serves to determine the position of any point on it and, consequently, with respect to the position of any other place. To determine these values imaginary lines, perpendicular to each other, are used. These are termed parallels and meridians, whose intersection defines the position of the point in the coordinate system (López Trigal, 2015).
- **Datum:** Parameter or set of parameters that define the position (A.282) of the origin, scale and orientation of a coordinate system [ISO 19111:2007].

- **Vertical datum:** Datum describing the relationship of height related to gravity or depth with the Earth. NOTE: In most cases, the vertical datum is related to the mean sea level. The geodesic heights are treated in relation to a three-dimensional ellipsoidal coordinate system that refers to a geodetic datum [ISO 19111:2007].

- **Ellipsoid:** Surface formed by the rotation of an ellipse around a main axis. NOTE: In this international standard, the ellipsoids are always oblong, which means that the axis of rotation is always the minor axis [ISO 19111:2007].

- **Scale:** Relationship between the magnitudes of the elements represented on the map and those that they have in reality. It defines the reduction to which the earth's surface must be submitted to be able to represent it in a document or on a map, whose size is much smaller. The representation of the scale on a map can be graphical or numerical (López Trigal, 2015).

- **Geopositioning:** Retrieving the geographic position of an object [ISO/TS 19130:2010].

- **Georeferencing:** Operation of obtaining and assigning geographical coordinates to information (usually a layer) that lacks it. Usually applied to place Earth images or events associated with postal addresses (Moreno Jiménez, 2008).

- **Image:** Raster type coverage whose attribute values are a numeric representation of a physical parameter [ISO 19115-2:2009].

- **Latitude:** Usually represented by the greek letter φ (capital letter fi), latitude is the angle formed from the center of the Earth on the meridian plane by the normal to the ellipsoid at the point considered and the plane of the equator. All points on the Earth's surface with equal latitude define the parallel lines. The measure is expressed in sexagesimal notation starting from the equator, positive towards the north (0° to 90°) and negative towards the south (0° to -90°) (Del Bosque González et al. 2012).

- **Legend:** Application of a classification (A.52) in a specific area using a defined map scale and a specific set of data [ISO 19144-1:2009].

- **Longitude:** Usually represented by the greek letter λ (lambda), longitude is the dihedral angle, formed from the center of the Earth on the plane of the equator, between the meridian containing the point and the meridian taken as the origin. The plane of the equator is that which passes through the center of the Earth and is perpendicular to the axis of rotation. The meridians are lines formed by all points of equal length, and represent the intersection of the Earth's surface with planes perpendicular to the plane of the equator and containing the axis of rotation (Del Bosque González et al. 2012).

  - **Digital terrain model and digital elevation model:** A digital terrain model is a spatial representation of a quantitative and continuous variable, such as temperature,

elevation, or atmospheric pressure. In particular, when the variable to be represented is the elevation of the terrain, it is called the Digital Elevation Model or DEM. Therefore, a digital elevation model is a numerical data structure that represents the spatial distribution of the altitude of the terrain surface (Mancebo, Ortega, Martín, & Valentín, 2008).

- **Slope:** Relation of elevation change with respect to the length of the curve [ISO 19133:2005].

- **Cartographic projection:** Geometric operation that allows the curved surface of the earth (three-dimensional) to be represented on a flat (two-dimensional) surface. This procedure is used to transform the angular coordinates with which the location of the geographic objects is determined on the terrestrial globe into plane coordinates that allow the cartographic representation on a surface of two dimensions (López Trigal, 2015).

- **Remote sensing:** In a broad sense it can be defined as the acquisition of information about an object at a distance, that is, without there being material contact between the observed object or system and the observer (Sobrino, 2000).

3. Data models

It might seem obvious, but before working with GIS data, it must be in digital format. Almost all the elements on the Earth's surface can be encoded so that a computer can understand them, and, depending on the type of information, one data model or another can be used. What is not so obvious is how to represent the real world in a digital medium (ESRI, 2010).

Despite the heterogeneity of geographic information, there are two basic approaches to simplify and model space, so that it can be stored and manipulated in a computer system, giving rise to two data models: the vector model, usually used to treat discrete geographic phenomena (communications routes, urban fabric, plant cover, etc.), and the raster model, which is generally used to represent continuous phenomena. Both systems are complementary and coexist within GIS, although each of them is more or less appropriate for studying a specific type of information (Del Bosque González at al. 2012).

3.1. Vector model

The vector data model is based on the assumption that the Earth's surface is composed of discrete objects such as trees, rivers, lagoons, etc. (ESRI, 2010). In this model, there are no fundamental units that divide the collected area, but, rather, the variability and characteristics

of this area are collected by means of geometric entities. For each geometric entity the characteristics are constant. The form of these entities is explicitly codified, because it models the geographic space through a series of primitive geometrics containing the most outstanding elements of that space. These primitives are of three types: points, lines and polygons (Olaya, 2014).

3.2.   Raster model

The raster structure is based on a matrix of cells represented in rows and columns. Each cell can store information about a given variable (precipitation, temperature, relative humidity, solar radiation, radiance, reflectivity, etc.).

The raster model does not explicitly collect the coordinates of each cell, but, rather, the values of each cell. It is not necessary to accompany these values with a specific spatial location, since they refer to a particular element of the mesh, which represents a fixed and regular structure. But it is necessary to place this grid in space so that the coordinates of each cell can be calculated (Olaya, 2014).

4.   ArcMap main window

ArcGIS contains a set of applications to solve real-world geographic problems through a sequence of spatial operations. ArcMap is the central application that allows you to perform the usual tasks and advanced analysis, as well as show the results by means of attractive printed or digital maps.

The structure of the main ArcMap window (Figure 1) provides a Menu Bar, below which are the toolbars that can be customized from the "*Customize*" menu. On the left-hand side is the *Table of Contents*, where all the participating layers are located. Panels: Results, ArcToolbox, Catalog, Search, etc. can be found vertically on the right and can be activated independently. To explore the geographic information, it is possible to use *Data View*, and *Layout View* can be used to design the map before its publication.
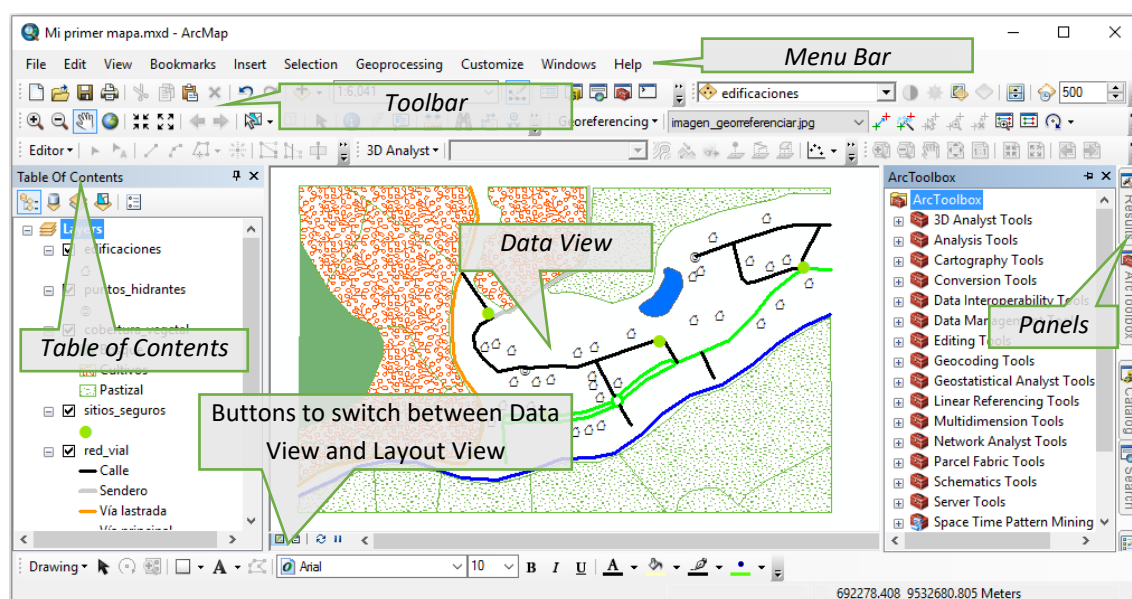
Figure 1. Overview of the ArcMap application

The **Tools** toolbar contains the most commonly used functions in ArcMap. The main functions of each tool are described in Figure 2.
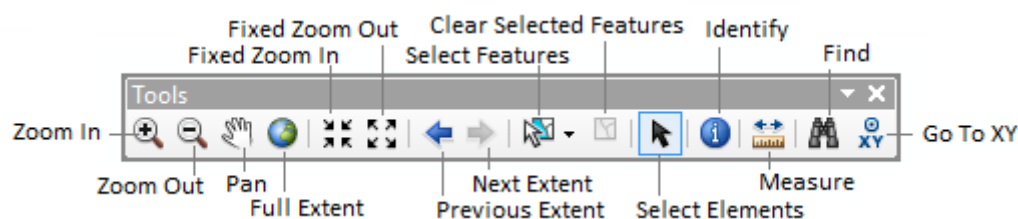

Figure 2. Tools toolbar

- The **Zoom In/Zoom Out** tools allow you to zoom in or out within the *Data View*. You can draw a box on the map to see a specific area in greater or less detail.

- The **Pan** tool is used to move the map freely up, down, left or right without changing the extension and without suffering a change in the working scale. This action is called panning.

- **Full Extent** allows you to see the total extent of all the participating layers of the active map.

- **Fixed Zoom In/Fixed Zoom Out** tools have the ability to prevent zooming in or out too much and so lose sight of the map, because with each click, you can zoom in or out only by a fixed amount.

- **Previous Extent/Next Extent** are used to return to a previous zoom-in or zoom-out view. It permits you to "undo" the navigation screen, which is very useful when the map view has been lost by mistake.

- **Select Features/Clear Selected Features.** The first tool allows entities to be selected within a rectangle, polygon, loop, circle or line. Once selected, the entities are highlighted in blue. The second tool (Clear Selected Features) removes the selection.

- **Select Elements** lets you select, move, or re-size graphics or text on the map. This facility is also available on the *Draw* toolbar.

- The **Identify** tool identifies the geographic characteristics of an element by means of a click.

- **Measure** measures the distance and/or area of a sector within the workspace. This tool may appear inactive if, at the beginning of the work with ArcMap, we load a layer with no spatial reference system. The reason for this is that the program does not know the units of the layer. In this case it is necessary to indicate the coordinate system. Assuming that the spatial reference system of the layer is WGS84 17S (we will see later what this means), then the map units are meters. Double click in the *Data Frame* (in Layers), go to the *General* tab, and click on *Map* and on *Display* in the *Units* section, and indicate *Meters*.

- **Find** allows you to search for an entity, place or address.

- **Go To XY** allows you to locate a point by means of a coordinate in XY format.

5. Coordinate systems

Human beings have always felt a need to represent the Earth's surface and the elements on it, as a result of which maps emerged (IGN & UPM-LatinGEO, 2013). Coordinate systems are fundamental when working with GIS, although they are often overlooked. But, while all locations are identified using a coordinate system, the same location may have different coordinates depending on the coordinate system used by the dataset (ESRI, 2011b).

To better understand coordinate systems it is necessary to comprehend the following terms: projection, ellipsoid, geoid and datum.

The **projection** is intended to geometrically represent the Earth's surface, which is curved, on a flat surface. But when this process is carried out, deformations inevitably occur and each projection generates a different type of distortion. Before drawing up a map, one of the most important decisions is to know which projection will be used, because each projection works best in a specific place. Projections can distort the shape, area, distance and direction on a map, attributes by which they can be categorized into conforms: these projections conserve the angles between meridians and parallels, but maintain the shapes. If equivalent, they maintain

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constant surface relationships, and if equidistant, they maintain the relations of distance (Del Bosque González et al. 2012).

An **ellipsoid** is the geometric figure that best adapts to the real shape of the Earth, and so it is the one that best allows a good fitting. Once a theoretical expression for the shape of the Earth is available, the next step is to determine the parameters that define it. If a sphere is used, its radius must be calculated. If an ellipsoid is taken as a reference form, the minor and major semi-axes must be measured (Olaya, 2014). In addition, an ellipsoid (also called a spheroid) may be defined as a three-dimensional shape created from a two-dimensional ellipse. The ellipse is an oval, with a major axis (the longest axis) and a minor axis (the shortest axis). If the ellipse is spun, the shape of the spun figure is the spheroid (ESRI, 2015).

The **geoid** is defined as the surface of the Earth's gravity field, which is approximately equal to the mean sea level. It is perpendicular to the direction of gravitational attraction since the Earth's mass is not uniform at all points and the direction of gravity changes. The shape of the geoid is irregular (ESRI, 2015).
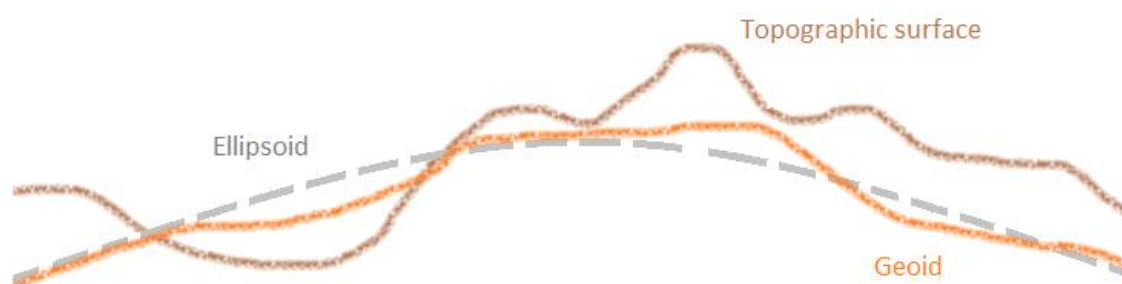

Figure 3. Relationship between geoid, topographic surface and ellipsoid fitting. Image Credit: Peter H. Dana, 1994.

The datum specifies the spheroid that will be used to give the shape to the coordinate system. It also directs the spheroid to a series of land control points, ensuring the accuracy of a reference point for its intended region or spatial extent (ESRI, 2011b). The datum is generated above the selected spheroid and can incorporate local variations in elevation. With the spheroid, the rotation of the ellipse creates a totally smooth surface of the whole world. Since reality is not properly represented in this way, a local datum may incorporate local variations in elevation (ESRI, 2015).

Put simply, projection is the method used to represent the circular shape of the Earth in a plane, and the datum is the set of parameters that is used to do it.

Geographic information can be displayed according to a geographic coordinate system or a projected coordinate system. The geographic coordinate system indicates a location using the longitude and latitude based on a sphere (spheroid). The XY projected coordinate system is based on a plane (Hillier, 2011). The most commonly used geodetic reference systems are: WGS84, NAD 27, NAD 83, ED50, ETRS89, PSAD56, and SIRGAS. In addition, some coordinate systems have certain advantages, such as the ability to quickly measure distances and surfaces.

6. Georeferencing

Georeferencing is a technique of spatial positioning by means of which a digital image is assigned a reference system based on known coordinates.

Figure 4. Aerial image without georeferencing

Some raster information is not associated with a reference system, such as maps, scanned topographic maps, aerial images, etc. To link an image to a known coordinate system, you must perform the georeferencing process, which is explained below.

In the georeferencing of an aerial image, once the ArcMap application is executed, click on the **Add Data** icon in the **Standard** bar load the image (Figure 5).
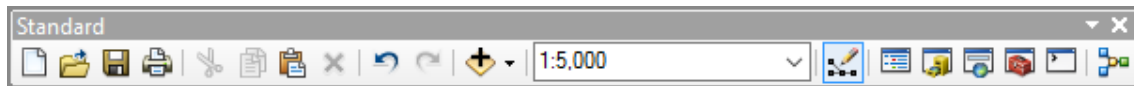
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Figure 5. Standard Toolbar

The directory is scanned and the raster file that is to be georeferenced is selected (for the present example it is possible to capture and / or save the image of Figure 4 in tif, jpg, png format), ignoring the unknown spatial reference message. In topographic maps, several control points can generally be identified through the coordinates shown on the X and Y axes. In this example, two known points **P1** (UTMX: 691194; UTMY: 9532767) and **P2** (UTMX: 691895; UTMY: 9532347) are used.

Activate the **Georeferencing** toolbar (Figure 6): If not found use the *Customize > Toolbars* menu.
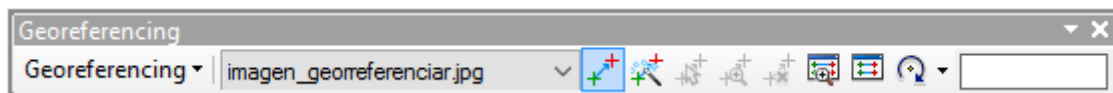

Figure 6. Georeferencing toolbar

Make sure that the added image (georeference_image.jpg) is inside the bar. If you cannot see the image in the current screen view, click *Georeferencing > Fit To Display*.

Now click on **the Add Control Points** icon; this tool allows you to adjust the image spatially by means of known points. The first step is to mark a known point on the image (P1). Once the cursor is positioned, it turns green, then right-click and select **Input X and Y** to enter the XY coordinates (Figure 7). The process is repeated for the second point (P2) and for the other points that need to be added.

To finish with georeferencing after acceptable adjustment of the control points, go to ***Georeferencing > Update Georeferencing***. This will create auxiliary files to the current image containing the transformations made. If *Rectify* is selected, the changes are saved and a new georreferenced image is created.
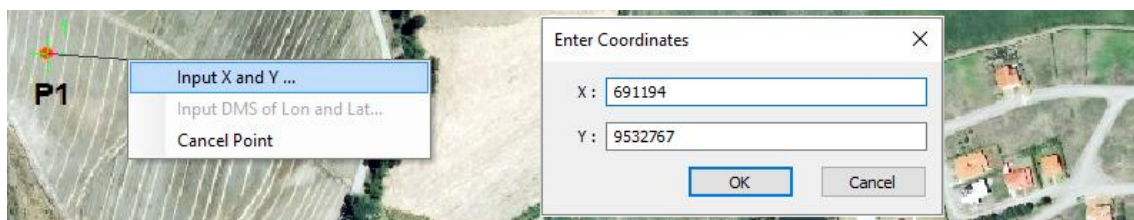

Figure 7. Enter XY coordinates

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If you do not have the coordinates of the control points on the ground, but you do have reference elements such as roads, buildings, trees, etc., it is still possible that these elements can be used for georeferencing. For example, the georeferencing of an image based on a track shapefile is done by identifying a common point (intersection) in both layers (call up *Zoom To Layer* with right click on the track layer, then call up the *Fit To Display* image from the *Georreferencing* bar). To create a link, first click on the image to mark the starting point (green cross in Figure 8a), a second click is marked at the actual point on the terrain (grey cross in Figure 8a). For the following points, the process is repeated in a similar way. The blue line joining the checkpoints means that an associated link has been created between a point in the image and the real world (Figure 8b). The adjustment of the two layers is done automatically after each point association.

Figure 8. Georeferencing process, (a) initial linking point, (b) linked points

The number of control points is not strictly reflected in the quality of the result, and the important thing is to make an adequate distribution. Try not to concentrate the control points in a single sector (Figure 9b) but distribute them homogeneously within the image (Figure 9a). The more points you can apply, the more complicated the transformations (polynomial, spline, adjustment or projective) you can use to determine the proper location of the coordinates for each cell of the raster image.

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Figure 9. Distribution of control points: (a) homogeneous distribution, and (b) heterogeneous distribution

7. Generation of vector entities

7.1. Creating shapefiles

The **ArcCatalog** application (open from the Windows Start menu) is used to create new vector entities such as points, lines or polygons. On the left-hand side of the window there is a panel called **Catalog Tree**. Right-click on **Folder Connections** (Figure 10) to select the directories that will serve as the location of working files within ArcGIS (it is possible to select an entire hard disk drive, to avoid creating excessive connections).
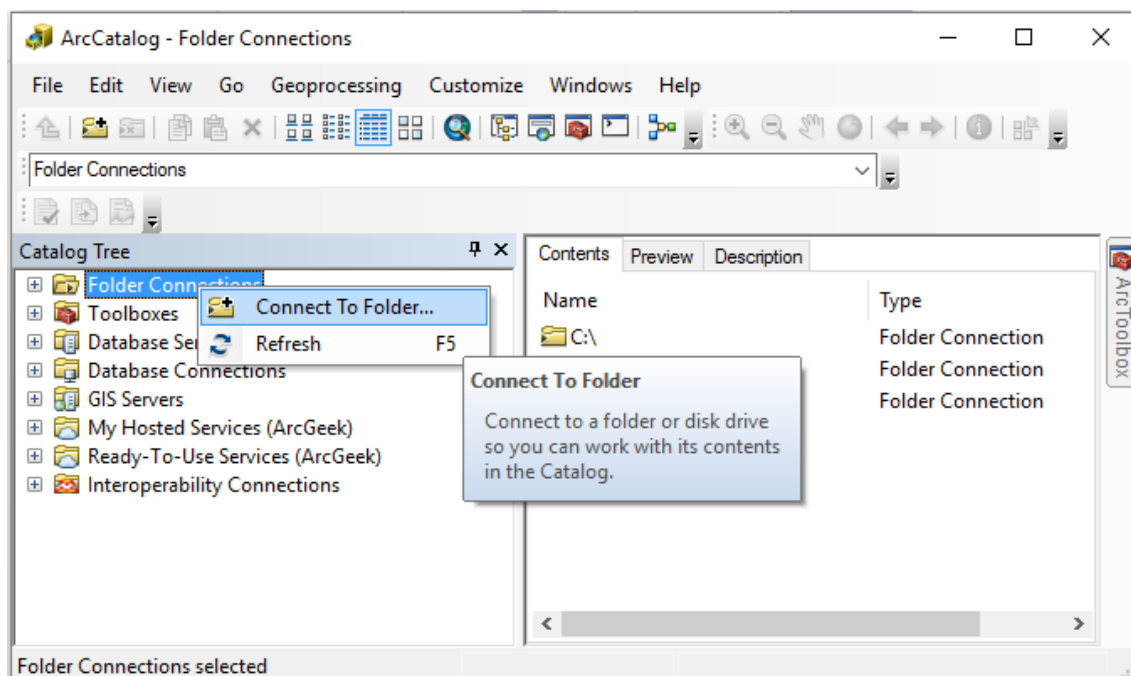

Figure 10. Connecting to a Directory in ArcCatalog

Once the directories have been connected, a new entity can be created by right-clicking on the **Contents > New > Shapefile...** section or by going to the **File > New > Shapefile...** menu.
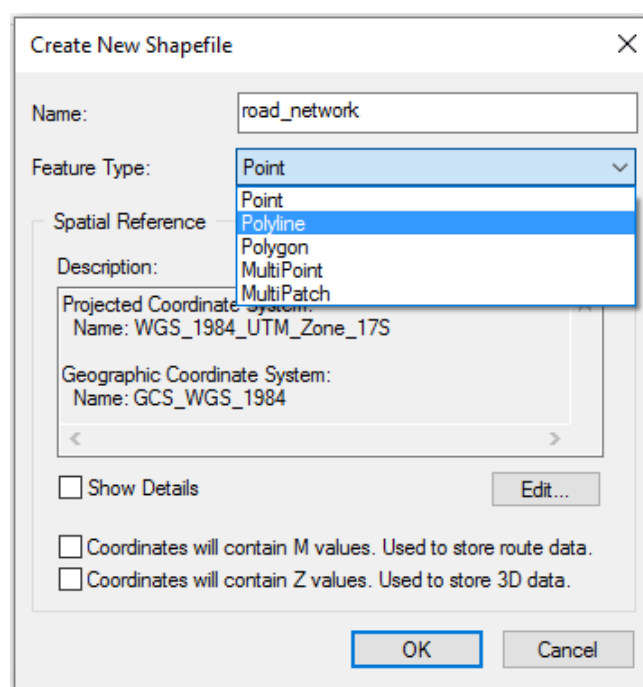
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Figure 11. Creation of new shapefile entities

Set up the fields shown in Figure 11 as follows:

- **Name:** Assign a name to the new shapefile; it is recommended not to use special characters or spaces.

- **Feature Type:** Select the type of layer: point, line or polygon.

- **Spatial Reference:** In this section you define the reference system using the **Edit** button. For the present case, the following applies: *Projected Coordinate Systems > UTM > WGS 1984 > Southern Hemisphere > WGS 1984 UTM Zone 17S*. The boxes "*Coordinates will contain M values. Used to store route data*" and "Coordinates *will contain Z values. Used to store 3D data*" are left, as they are by default.

Practice**:** Create point, line and polygon shapefiles from *Table 1*; use reference system WGS 1984 UTM Zone 17S.

Table 1. List of shapefiles

Shapefile	Type
buildings	Point
hydrant_points	Point
secure_sites	Point
road_network	Line
water_network	Line
plant_cover	Polygon
lake	Polygon

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7.2. Shapefiles edition

To create new elements or edit existing ones within a shapefile, return to the ArcMap application and add the shapefiles generated as layers using the *Add Data* icon in the *Standard* toolbar (Figure 2).

To start editing, activate the **Editor** toolbar (Figure 12). Go to ***Editor > Start* editing** to enable editing in the workspace (in shapefile). In the next dialog box that appears, select the layer or workspace to edit. In case of warnings, omit them and click continue. The **Create Features** panel (left) then appears with a list of the current layers sorted by their geometry (points, lines and polygons), and in **Construction Tools** select the feature you want to edit. The central idea of editing a shapefiles is to map the elements present in an image (to maintain an order, start first to work with the points, then with the lines and finally with the polygons). All required changes can then be made to the selected shapefile. To finish editing, go to ***Editor > Stop editing*** and save the modifications. Changes only affect the selected vector entity.

Figure 12. Toolbar Editor

7.3. Working with points

To start digitizing the points, select a point layer (e. g. *buildings*) in the **Create Features** panel. It is advisable to make sure that the **Point** tool is marked in **Construction Tools** (lower part). Then place the cursor on the center of a house and click to mark a point. The process is repeated until all the buildings are digitized (Figure 13). To make it easier to work with small objects, zoom tools are used and for large images the panning tool can be used, increasing versatility during the process. Besides using the mouse, it is possible to use the arrow keys of the keyboard, which allow greater precision in movement. It is recommended that you periodically go to the ***Editor > Save Edits*** toolbar to save your changes.
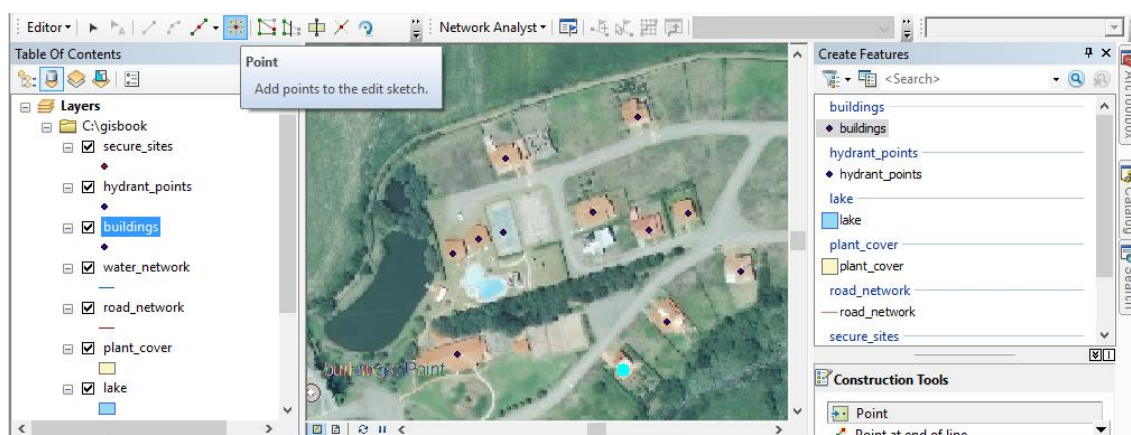
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Figure 13. ArcMap application editing mode

You can also create new points by entering the XY coordinates. In this case, select a point layer (e. g. *hydrant_points*) in the **Create Features** panel; do not forget to mark "**Point**" in **Construction Tools**. Then position yourself anywhere on the map, right click and select Absolute X, Y... (Figure 14). A window opens where you can enter the XY values (e. g. X = 691491; Y = 9532534 for the first point, X = 691735; Y = 9532696 for the second point). The entry is accepted by pressing the "Enter" key.
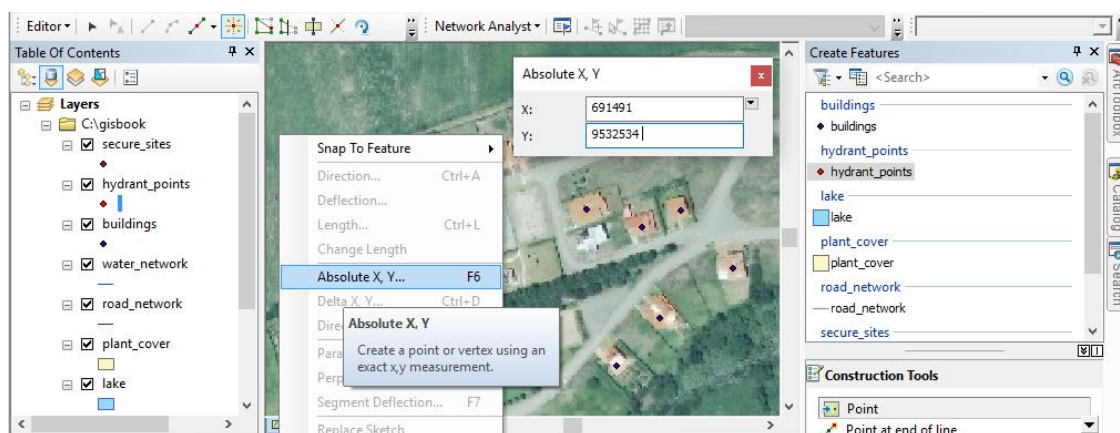

Figure 14. Manually insert points using coordinates

Coordinates can be entered in different formats such as meters, decimal degrees, MGRS (Military Grid Reference System), UTM, etc. To change the format, the **Absolute X, Y** window opens as explained above and click on a pop-up icon in the upper right corner. A list of options opens where you can select the format. The UTM format is entered as shown in Figure 15 (e. g. *secure_sites*: 17M 691523 9532468,17M 691684 9532576,17M 691889 9532681,17M 691437 9532615). Press the "Enter" key to enter each of the required points. Finally, you must save the edition using the Editor bar (***Editor > Save Edits***).
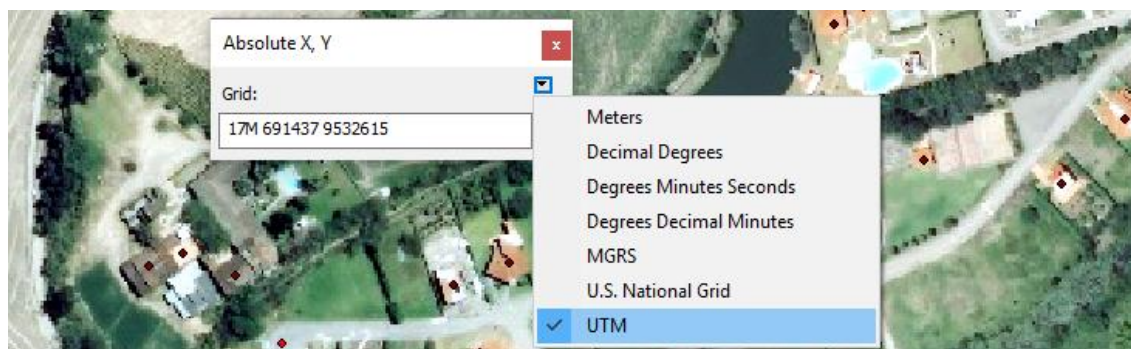
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Figure 15. Coordinate format available in Absolute X, Y.

To correct the spatial location of a point, first select the layer to be modified (shapefile) in the **Create Features** panel. Then click on the **Editor** bar in the symbol ▶ (= **Edit Tool**). To change the location of a point or delete it, select the required point with a click (this becomes light blue). It is now possible to drag it to a new location (see Figure 16) or delete it by pressing "Delete" on the keyboard.
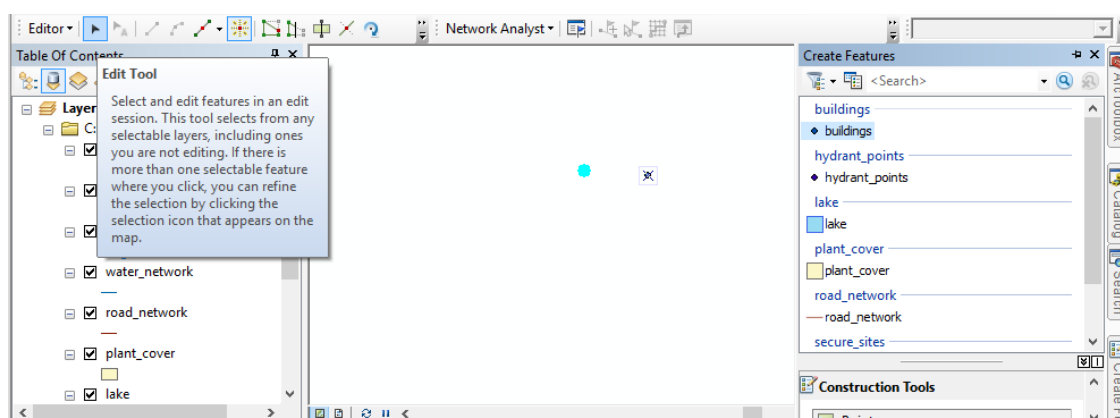

Figure 16. Edit Tool

7.4.   Working with lines

To digitize lines, select the required layer in the **Create Features** panel (e. g. *road_network*). In the **Construction Tools** section, click **Line** as shown in Figure 17. To draw the line, click on the starting point and then follow point to point until a section is completed (e. g. a railway). To end the line, double-click on the last vertex or press the F2 key. The green nodes indicate the number of points that have been marked to construct the polyline; the red node is the last marked point. The procedure is repeated for all sections of the shapefile (e. g. the entire road network).

When digitizing lines, it is important to maintain connectivity between elements. For example, in the case of the road network, you cannot have sections that do not connect to each other,

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nor sectors where the connections go beyond the borders of an existing entity. In order to be more accurate in editing and avoid errors, **Snapping** tools (*Customize > Toolbars*) allow the pointer to automatically adjust to the edges, vertices or other nearby geometric elements within a given degree of tolerance.

Practice: For the *water_network* layer, identify the riverbed in Figure 4, then proceed with digitizing in the same way as with the road network.

Figure 17. Line digitizing in ArcMap

To modify a polyline, select the **Edit Tool ( )** icon in the **Editor** toolbar. Then click on a segment, which give it a light blue color. You can now delete the line or move the entire line. If you double-click on the required segment, all the vertices of the polyline will be shown. Each of the vertices can then be moved freely until the desired path is obtained (Figure 18).

Figure 18. Modification of polylines

It is recommended to avoid placing too many vertices in a straight line; it is feasible to place only vertices at the end points. In the case of a curvature, more vertexes are needed to fit the shape. To delete a vertex, right click on it and then select **Delete Vertex**. To add one or more vertices right click on the polyline segment and select **Insert Vertex**. In some cases, a polyline needs to be divided into two or more parts.

To do this, select the polyline and with **Split Tool ( ),** located in the **Editor** toolbar. The line is divided with a click on the required point (which is highlighted in red).

To delete a line completely, select the line with the **Edit Tool** and press the "Delete" key. To select two or more lines, press the "Shift" key.

7.5. Working with polygons

The process of digitizing polygons is similar to that of polylines. In the **Create Features** panel, select the layer (e. g. *plant_cover*) and choose **Polygon** in the **Construction Tools**. To start, mark the first vertex with a click and then continue drawing the entire perimeter of the area. To finish, double-click or press the "F2" key. You can define several categories (e. g. Figure 4: Grassland, crops and forest).
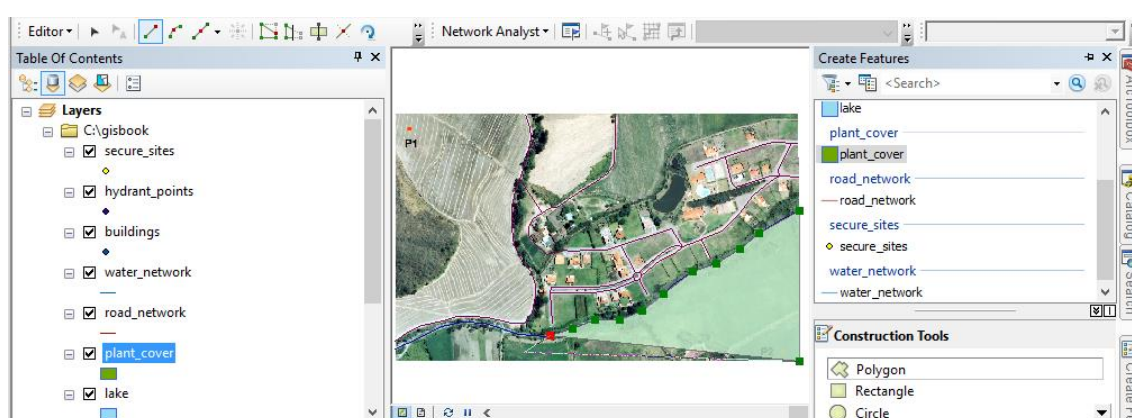

Figure 19. Editing polygons in ArcMap

In the case of polygons sharing one side, it is necessary to ensure that there are no overlapping surfaces or empty spaces in the boundaries of the polygons.

Figure 20. Gaps and overlap in polygons

Gaps or empty spaces are not usually visible to the naked eye, but only when there is a close approximation to the boundaries of the plots. Similarly, areas shared by two or more polygons may occur, which is called overlap (see Figure 20). These topological errors usually occur when no methods for maintaining the topological rules were used in the edition. The same may occur when compiling information from different sources or scales.

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There are several tools in ArcMap that allow you to maintain integrity and quality when editing spatial information. Two fundamental tools are located in the **Editor** bar (Cut Polygons Tool and Reshape Feature Tool) and another one in the section **Construction Tools** (Auto Complete Polygons) that allow a polygonal layer to be successfully digitized, significantly reducing the amount of errors that are usually generated in this activity.

When attempting to draw a surface with subdivisions, it is preferable to first create the external perimeter and then make the internal division. For example, when building a land use map, it is recommended to draw the entire study area and then divide into categories. To carry out this process, activate the **Edit Tool ( )** in the **Editor** bar and select the required polygon (the edges of the polygon turn light blue). Then click on **Cut Polygons Tool ( )** to proceed. To cut the polygon, mark the first point outside the polygon and continue drawing a cutting line inside the area. The last point must be outside the polygon (see Figure 21). The cut is completed with a double click or by pressing the "F2" key. The process can be repeated as many times as necessary until all required divisions of the area are made. It should be emphasized that this tool is only activated when one or more polygons are selected.

Figure 21. Cutting polygons in ArcMap

Editing polygons also requires knowing how to change their shape, especially when certain geometric readjustments are required. To do this, select the polygon (with the **Edit Tool**) and then click on the **Reshape Features Tool** icon ( ) located on the **Editor** toolbar. An example of how to change the shape of the polygon is given in Figure 22. In the first two polygons on the left, it is shown how to increase the area of a polygon (in this example: a square). The important thing is always to start and finish the readjustment inside the polygon. On the right-hand side, the last two polygons show how to reduce the area of a polygon (in this example, to obtain a square shape). For the readjustment, you must start and finish outside the polygon.

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Figure 22. Change shape to a polygon

If polygons need to be created next to each other, do not draw a border twice, but maintain a continuous structure (no overlapping or gaps). To create continuous polygons, go to the **Create Features** panel, in the **Construction Tools** section check the **Auto Complete Polygons** ( ) option. To start drawing the new continuous polygons, it is not necessary to select the entities. The new polygon is drawn with at least two vertices connecting it to its neighbors (Figure 23).
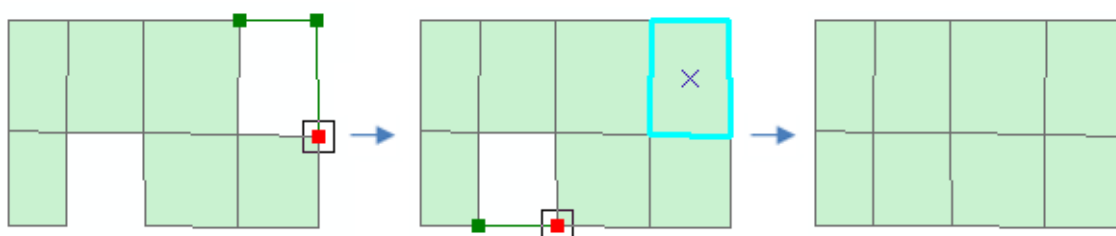

Figure 23. Autocomplete polygons

Additionally, it is often necessary to merge two or more polygons into a shapefile. To do this, select the participating polygons by pressing the "Shift" key during selection. The **Merge** tool is then applied from the Editor toolbar (***Editor > Merge***).

Practice: In the *plant_cover* and *lake* layers, digitize the polygons, making use of the editing tools. When you have finished all the activities involved in digitizing points, lines or polygons, finish editing with **Stop Editing** located in the Editor toolbar (***Editor > Stop Editing***).

7.6.   Define projection of a layer

At certain times when loading new layers into ArcMap, a warning message ("*The following data sources you added are missing spatial reference information. This data can be drawn in ArcMap, but cannot be projected*"). This is because the added layers do not have a coordinate system, probably because, while creating the layers, the spatial reference system was omitted.

It is recommended not to define a coordinate system if you are not sure it is the correct one. To define the coordinate system in a layer (vector or raster) go to the following address:

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ArcToolbox > Data Management Tools > Projections and Transformations > Define Projection

In the pop-up window you must configure the parameters described below:

- **Input Dataset or Feature Class:** Select the vector or raster layer.
- **Coordinate System:** Select the coordinate system (*Projected Coordinate Systems > UTM > WGS 1984 > Southern Hemisphere > WGS 1984 UTM Zone 17S*).

7.7. Project a layer to another reference system

The **Project** tool allows you to project spatial data from one coordinate system to a different coordinate system.

Practice: A layer projected with the coordinate system "WGS 1984 UTM Zone 17S" is required to be projected with "Provisional South American Datum UTM Zone 17S". Note that both systems have a different datum (WGS84 and PSAD56). Therefore, it is necessary to apply the corresponding transformations for each locality. The list of transformations can be found in the **geographic_transformations.pdf** file located in the ArcGIS "*C:\Program Files\ArcGIS\Desktop10.x\Documentation* " installation folder (Figure 24).

Name	WKID	Accuracy	Area of Use	Minimum Latitude	Minimum Longitude	Maximum Latitude	Maximum Longitude
PSAD_1956_To_WGS_1984_1	1201	42.000	South America - Bolivia; Chile; Ecuador; Guyana; Peru; Venezuela	-45.0000	-81.4000	12.5100	-56.4700
PSAD_1956_To_WGS_1984_10	1582	3.000	Bolivia - Madidi	-14.4300	-68.9500	-13.5700	-67.7900
PSAD_1956_To_WGS_1984_11	1583	0.500	Bolivia - Block 20	-21.7000	-63.4300	-21.0900	-62.9500
PSAD_1956_To_WGS_1984_12	1811	10.000	Brazil - Amazon cone shelf	-1.0500	-51.6400	5.5900	-48.0000
PSAD_1956_To_WGS_1984_13	1095	15.000	Venezuela	0.6500	-73.3800	16.7500	-58.9500
PSAD_1956_To_WGS_1984_14	3990	5.000	Ecuador - mainland onshore	-5.0000	-81.0300	1.4500	-75.2200
PSAD_1956_To_WGS_1984_2	1202	19.000	Bolivia	-22.9000	-69.6600	-9.6800	-57.5200
PSAD_1956_To_WGS_1984_3	1203	44.000	Chile - onshore north of 21~30'S	-21.5000	-70.4800	-17.5100	-68.1900
PSAD_1956_To_WGS_1984_4	1204	35.000	Chile - onshore 39~S to 45~S	-45.0000	-75.2200	-39.0000	-71.1100
PSAD_1956_To_WGS_1984_5	1205	26.000	Colombia - mainland	-4.2400	-79.1000	12.5100	-66.8700
PSAD_1956_To_WGS_1984_6	1206	7.000	Ecuador - mainland onshore	-5.0000	-81.0300	1.4500	-75.2200
PSAD_1956_To_WGS_1984_7	1207	17.000	Guyana	1.1900	-61.3900	10.6900	-55.7800
PSAD_1956_To_WGS_1984_8	1208	16.000	Peru	-21.0500	-84.6700	-0.0400	-68.6700
PSAD_1956_To_WGS_1984_9	1209	23.000	Venezuela	0.6500	-73.3800	16.7500	-58.9500

Figure 24. Fragment of the "Geographic and Vertical Transformation Tables" document

To reproject, open the **Project** tool (Figure 25) and configure it as below in:

ArcToolbox > Data Management Tools > Projections and Transformations > Project
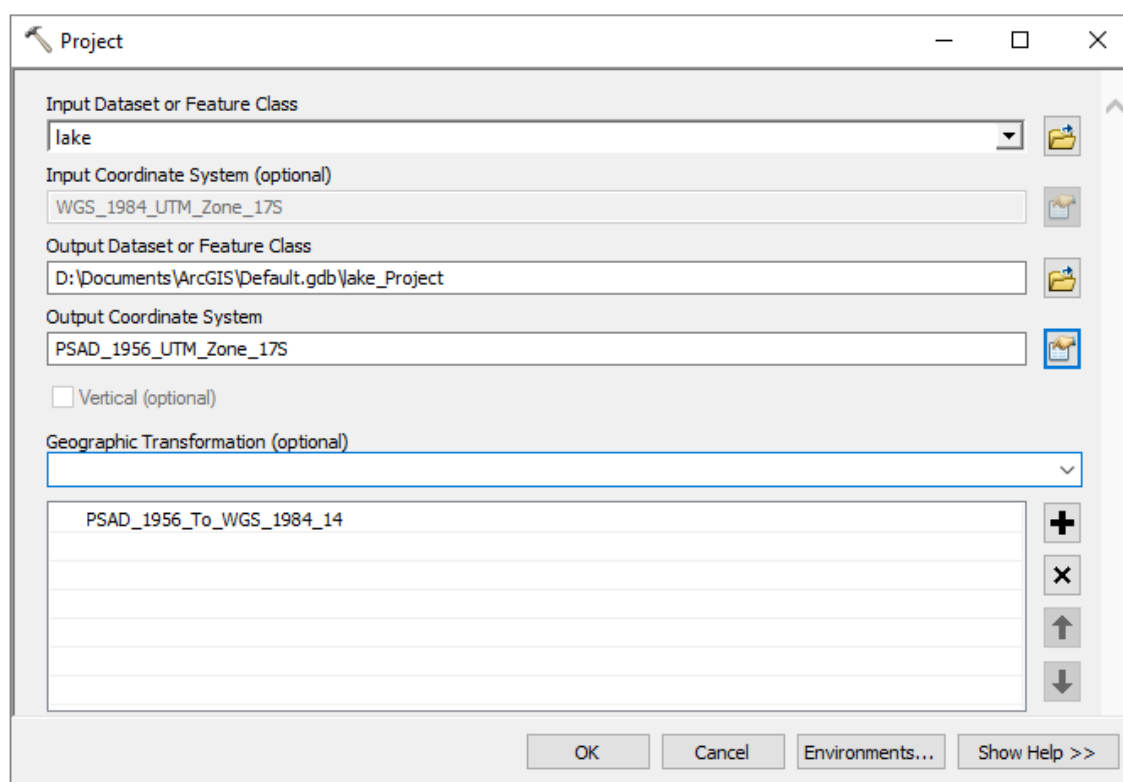

Figure 25. Projecting a layer to another coordinate system

- **Input Dataset or Feature Class:** Select the layer to be projected.
- **Input Coordinate System:** By default, the current layer coordinate system is displayed.
- **Output Dataset or Feature Class:** Select the directory or geodatabase where the resulting file will be stored.
- **Output Coordinate System:** Select the new coordinate system. In this case go to: *Projected Coordinate Systems > UTM > South America > Provisional South American Datum UTM Zone 17S.*
- **Geographic Transformation:** Select the transformation from the list of the "Geographic and Vertical Transformation Tables" document. In this case "PSAD_1956_To_WGS_1984_14" because the layer to be projected is located in continental Ecuador. You could also select "PSAD_1956_To_WGS_1984_6", but note that the accuracy will be lower, see Figure 24.

In versions prior to ArcGIS 10.3, the **Project** tool is usually located in *Projections and Transformations > Features*. To **change** the coordinate system in a **raster** file, use the **Project Raster** tool located in *Projections and Transformations > Raster*.

8. Tables administration

Tables are used to store descriptive information. In ArcGIS they are usually linked to a vector layer or appear individually. The alphanumeric information forming a table can be stored as an integer, decimal number, text or date. The supported table formats are diverse: Geodatabases, databases, INFO, dBASE, text files, Microsoft Excel, Access, SQL, etc.

8.1. Working with tables

Each shapefile contains an associated table in **DBF format**. To view the table of a vector file in ArcMap right click on a layer and select **Open Attribute Table**.

A table is structured in rows and columns. Each row can be considered as an object containing values in different fields. A column is restricted to a single data type and is considered as a field. You can add as many fields as required to a table.

Once the table has been opened, a new field can be created by going to **Table Options** ( ) and selecting **Add Field** (note that no edition is active, if it is active, click on "*Stop Editing*"). Then a dialog box appears where you must specify the new field (see Figure 26). First you must name the new field, taking into account that you cannot include spaces or special characters and are limited to a length of eight characters in shapefiles and dfb tables. Then, specify the field type for which there are several options clarifying which data are allowed within this field (**numerical**: short integer, long integer, float or double; **text**: text; **date:** date). Finally, you specify the properties of this field ("*Field Properties*"), where the accuracy (numbers) and/or space (text) is limited.
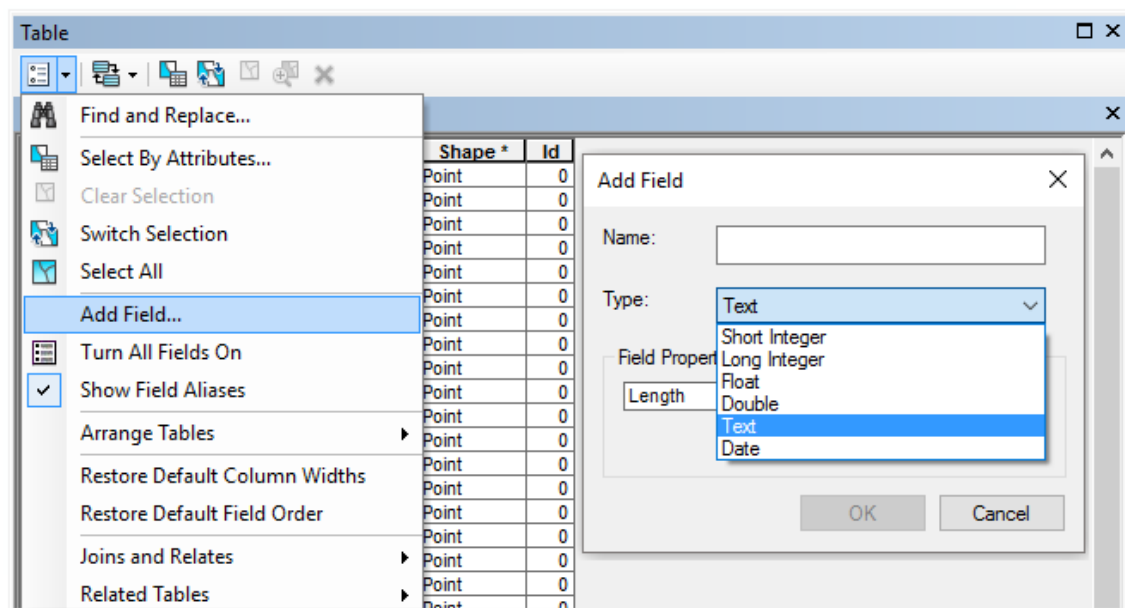
Figure 26. Adding fields to a table

To choose the type of new field, consider the information provided by (Neer, 2005):

- Short Integer, are numbers integers between -32768 y 32767.

- Long Integer, are integer numbers between -2147483648 and 2147483647.

- Float, are fractional numbers between -3.4E38 and 1.2E38.

- Double, are fractional numbers between -2.2E308 and 1.8E308.

- Text, is a text string limited to 255 characters in length.

- Date, are data stored in Universal Time Coordinates (UTC).

To enter information within each field, you need to be in Edit Mode (***Editor > Start Editing***). The attribute table ("*Open Attribute Table*") opens and values can be entered directly in cell.

To add the same information/calculation to one or more rows, right-click on the required field (e. g. Type) and select the "**Field Calculator"** tool. A new dialog box opens where by default VB Script from the "**Parser"** section is enabled (if necessary, switch to Python). In the "**Fields**" section you can find all the fields of the current table, and in the "**Type**" section you can see the type of data (Figure 27).

To enter the information, you must type the numbers directly, enclosing the text in quotation marks (" "; for example, randomly select one or more buildings and call them "School"; you can repeat the process for "Church", "Hospital" or "Housing") in the window at the bottom.
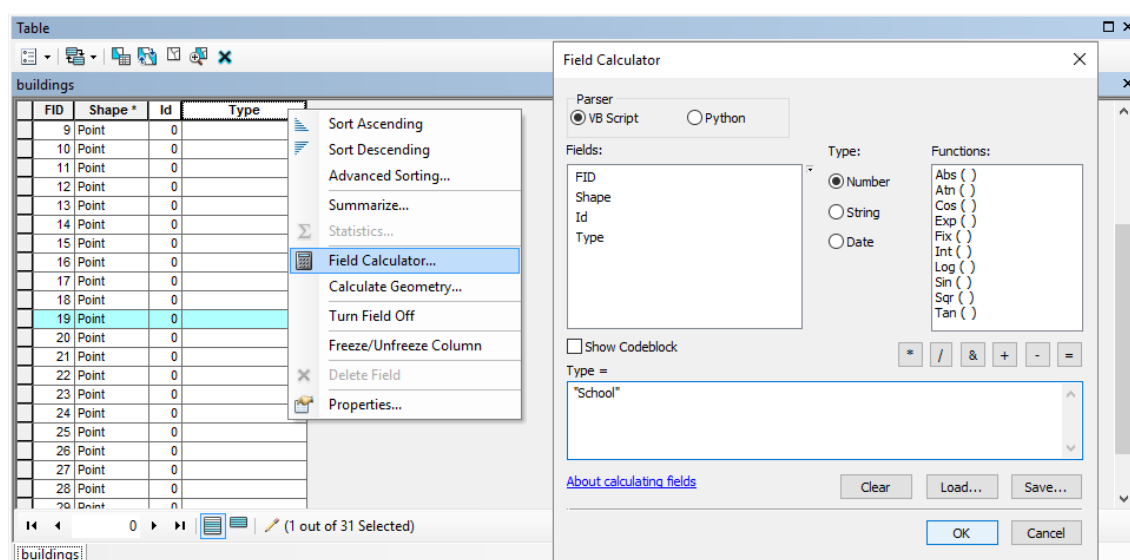
Figure 27. Data entry with Field Calculator

Practice: Add new fields to shapefiles and configure their name, type and properties as shown in *Table 2*.

Table 2. Structure for creating fields in tables

Shapefile	Name	Type	Properties
buildings	Type	Text	Length: 25
hydrant_points	Name	Text	Length: 25
secure_sites	Name	Text	Length: 25
road_network	Type	Text	Length: 25
	Length	Double	Precision: 0, Scale: 0
water_network	Name	Text	Length: 25
	Length	Double	Precision: 0, Scale: 0
plant_cover	Type	Text	Length: 25
	Area	Double	Precision: 0, Scale: 0
	Percentage	Double	Precision: 0, Scale: 0
lake	Name	Text	Length: 25
	Area	Double	Precision: 0, Scale: 0
	Perimeter	Double	Precision: 0, Scale: 0

Fill in the table values based on the following information:

- hydrant_points, in the **Name** field, call the first point "Main" and the second "Secondary".
- secure_sites, in the **Name** field, call the first and fourth points "Secure sites" and the second and third point "Meeting zone".
- road_network, in the **Type** field, name the entities that extend along the coordinate X: 691723 Y: 9532552 as "*Main way*", name the segment that extends along coordinate X: 691394 Y: 9532401 as "*Unpaved way*", name as "*Path*" the segment that extends along

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the coordinate X: 691570 Y: 9532693, and name as "*Street*" all remaining segments in the urban area.

- water_network, in the **Name** field call it "*Malacatos River*".
- plant_cover, based on Figure 4 name the polygons in the *Type* field as "*Grassland*", "*Crops*" or "*Forest*", as appropriate.
- lake, in the **Name** field, name it "*Santa Anilla Lake*".

8.2. Calculation of area, perimeter and length

To calculate the area, perimeter or length of the different entities, it is necessary to take into account the geometry of each layer. First, ensure that the participant layer has a defined reference system. It is important to remember that when you work with shapefiles and make changes in the geometry, the area, perimeter and length fields are not automatically updated. It is necessary to recalculate the current values after each change.

To start, right-click on the layer and open the attribute table (e. g. lake). Then right-click on the header of the required field (e. g. Area) and select the "**Calculate Geometry**" tool. Finally, select the geometric property, coordinate system and units you want to use (see Figure 28; area in Acres US).

Practice: Repeat the process and calculate the area in acre for the *plant_cover* layer.
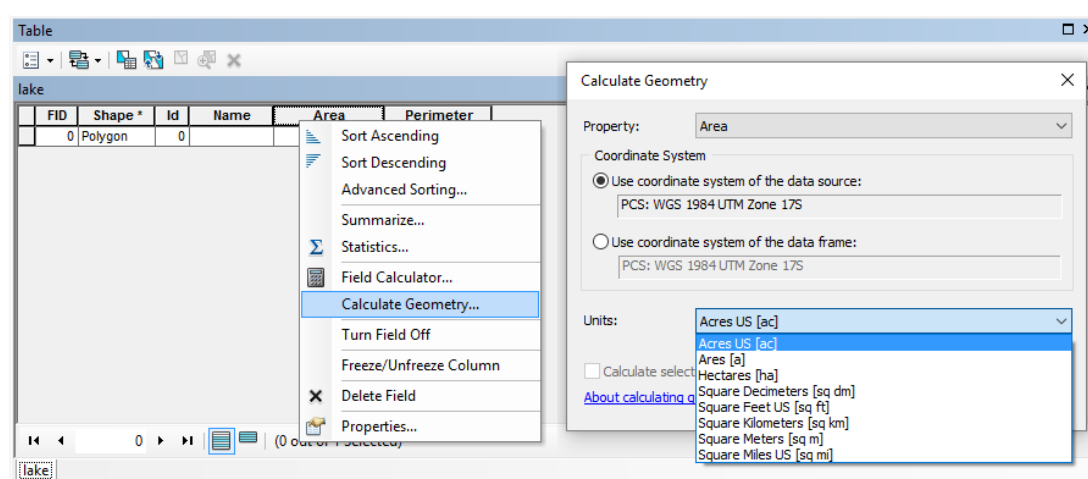

Figure 28. Geometry calculations

The same process as described in the previous paragraph can also be used to calculate the perimeter (e. g. in meters) of the layer: you simply have to change from **Area** to **Perimeter** in the "Property" section. For polyline layers (e. g. road_network and water_network) only the

length can be calculated (e. g. in meters) and for point layers only the XY coordinates can be calculated. In summary, the "Calculate Geometry" tool allows the geometry to be calculated, depending on the nature of each layer.

8.3.   Calculation of XY coordinates

The **Add XY Coordinates** tool allows the values of the XY coordinates to be calculated (if the layers have the Z coordinate (height), it can also be calculated). To execute, go to the following address:

ArcToolbox > Data Management Tools > Features
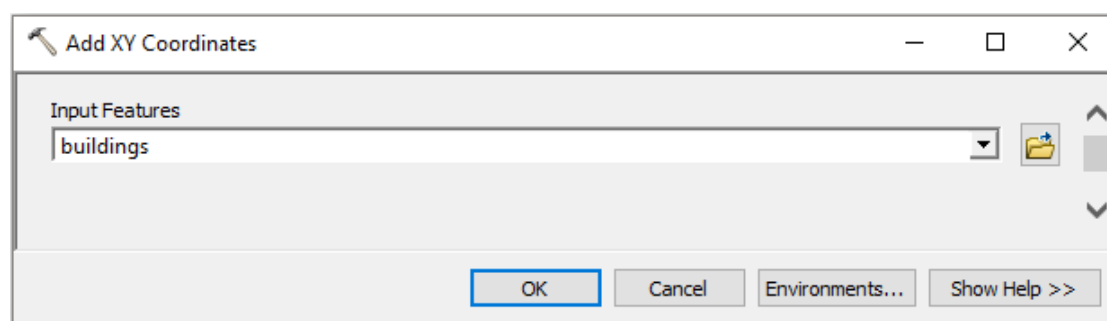
Figure 29. Add XY coordinates

In the "*Input Features*" section, first select the layer (e. g. buildings) and confirm the selection by pressing "OK" (Figure 29). Then the attribute table opens, where it can be seen that two new fields have been created. These new fields store the XY coordinates of the point layer. The same process can be repeated for all point layers (e. g. *secure_sites* and *hydrant_points*).

8.4.   Operations

The **Field Calculator** performs simple and complex calculations for both text strings and mathematical operations. Note that the modifications affect all records (if none is selected) or only the selected records.

To calculate the percentage of each polygon with respect to the total surface area (e. g. *plant_cover* layer), the value of the total surface area must first be determined. To do this, open the attribute table, right click on the field header (Area), select **Statistics** and in the **Sum** line you will find the total area of all polygons in this layer. Then right click on the header of the created field (**Percentage**), select the "Field Calculator" tool and use the following expression: [Area] *

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100 / total area value. The expression [Area] in the equation corresponds to the name of the field, which can be selected directly by double-clicking on the "Fields" section (Figure 30).
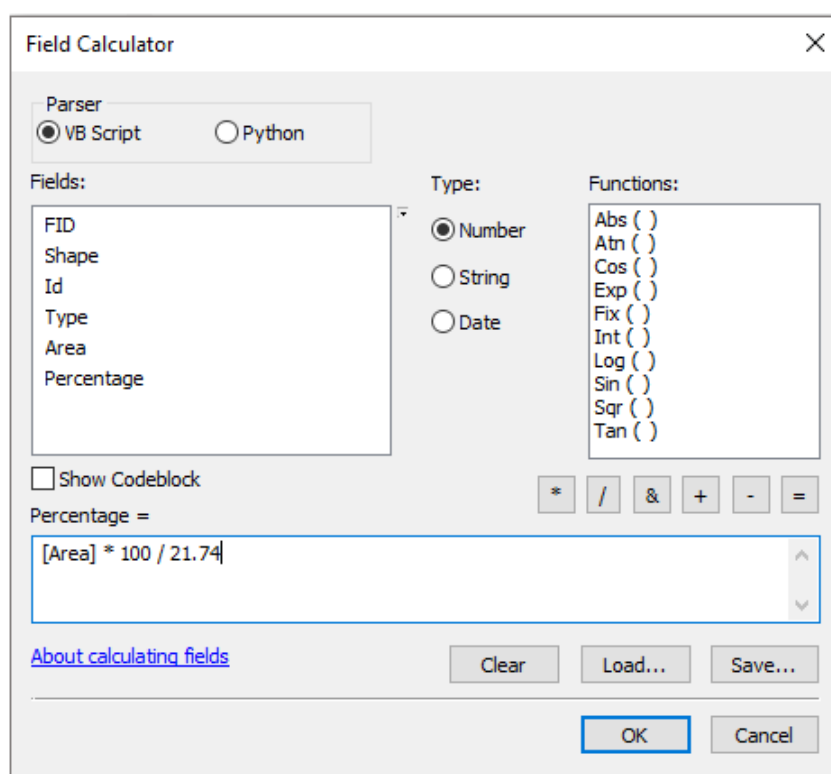

Figure 30. Field Calculator operations

Equations can contain different mathematical operations (sum, subtraction, division and multiplication), including parentheses. Calculations can be developed using VB Script or Python. When accessing geoprocessing functions is required (including entity geometry calculation), Python is recommended. In addition, this language provides greater opportunities for scripting calculations. Further information about the field calculator can be found in "**About calculating fields**", where a comprehensive list of examples is available (Figure 30).

9. Geoprocessing tools

GIS tools undoubtedly automate processes that used to take a long time to carry out. In general, manual tasks often require a great deal of effort to complete. Geoprocessing is the methodical execution of a sequence of operations over geographic data to create new information. The two fundamental purposes of these tools are to help with modeling and analysis, and to automate GIS tasks (ESRI, 2016b).

From this point onwards, the most frequently used tools will be those of **ArcToolbox ( )**, although some of the most common geoprocessing tools can still be accessed from the Geoprocessing menu. The use of each tool presents a similar structure: a pop-up window requests input and output files, apart from configurable fields depending on the nature of the tool.

9.1.   Buffer

Imagine for a moment that a drop of water falls on a mass of water and generates a shock wave. The wave is shifted and the propagation phenomenon can cause positive or negative changes from its point of origin. Influence zones are polygons created from an entity at a set distance. This spatial analysis allows the affected surface to be identified (e. g. a new factory), influence zones (e. g. "opening of a road within a protected area"), those affected by a contaminant (e. g. "fertilizers"), and the range of antennas (e. g. telecommunications or weather radar).

Using the **Buffer** tool, you can create influence zones for points, lines and polygons. The tool is available in the **Geoprocessing** menu bar or at the following address:

ArcToolbox > Analysis Tools > Proximity > Buffer
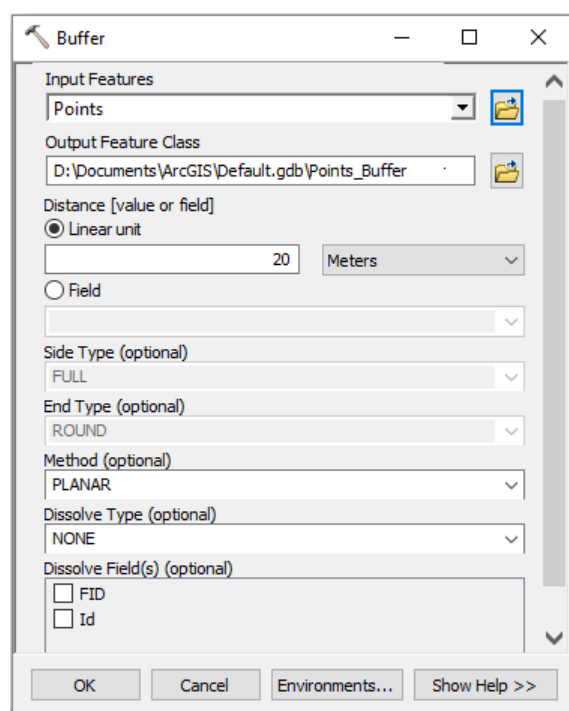

Figure 31. Buffer tool configuration

The "Buffer" pop-up window (Figure 31) can be configured in the following way:

-        **Input Features:** Select the layer of points, lines or polygons.

-        **Output Features Class:** Select the directory or geodatabase where the resulting entity will be stored.

-        **Distance [value or field]:** There are two options: "Linear unit", which allows you to set a fixed value with the respective unit (e. g. meters), and "Field", which creates an influence zone based on the values of a field selected from the attribute table.

-        **Method:** Specifies the method used to create the zone of influence. The "Planar" method uses Euclidean distance (as if

measured with a ruler in a projected plane), and "Geodesic" takes into account the curvature of the earth regardless of the layer coordinate system. Influence zones are not influenced by the distortion of a projected coordinate system.

Figure 32 shows influence zones for three points, one line and two polygons using a linear unit of 20 meters and the planar method as a distance.
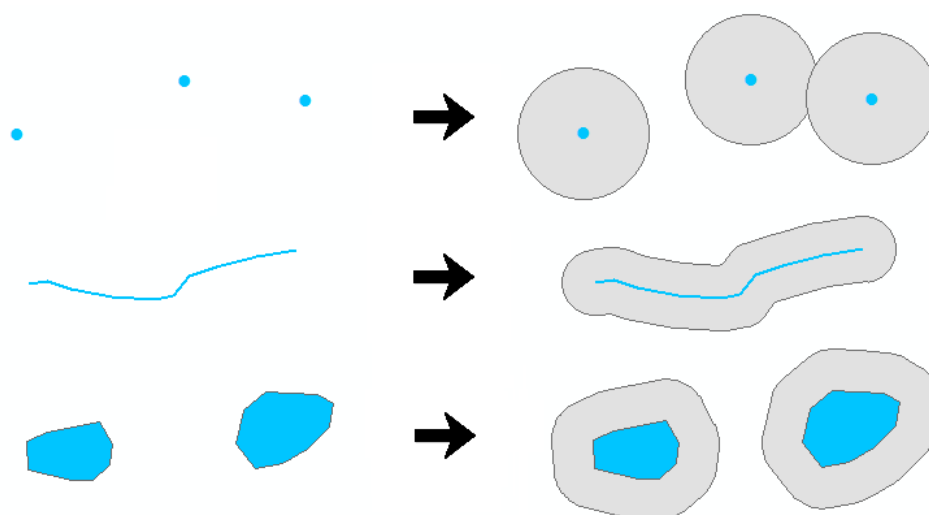
Figure 32. Influence zones

9.2. Intersect

The intersection allows you to search for the area of two or more overlapping layers. The **Intersect** tool calculates the intersection area in a new layer. To use the tool, go to:

ArcToolbox > Analysis Tools > Overlay > Intersect

The **Intersect** tool pop-up window opens. In the **Input Features** section, you can add all the layers that are going to be searched for intersection areas. An example of the result can be seen in Figure 33.
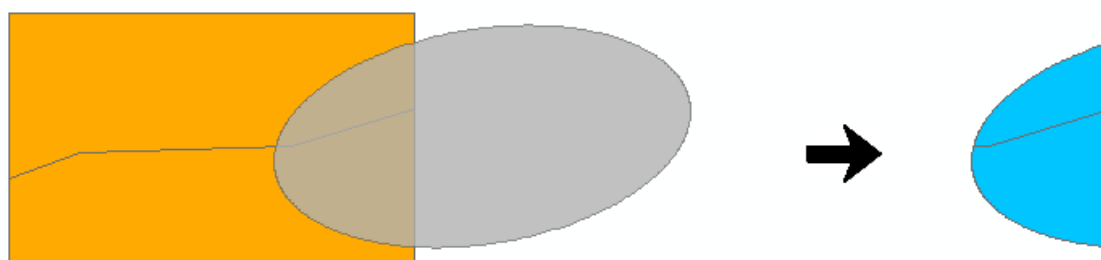
Figure 33. Intersection area

9.3. Clip

The **Clip** tool allows you to trim part of an entity based on the perimeter of a polygonal layer (Figure 35). The polygonal layer is used to limit the extent of the layers to a specific area. For example, if you have a layer of contour lines at country level, you can make a clipping to work at province level. The tool is located at the following address:
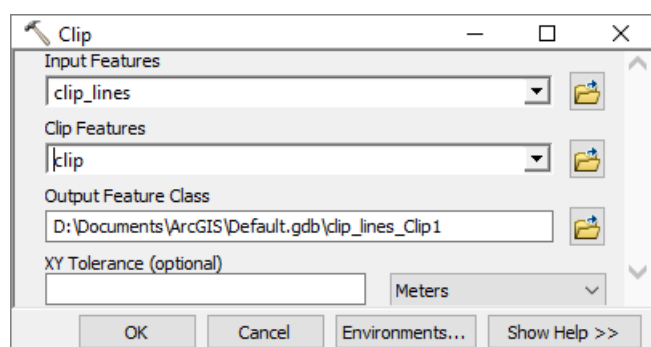
A*rcToolbox > Analysis Tools > Extract > Clip*

Figure 34. Clip tool configuration

To configure the tool, proceed as follows (Figure 34):

- **Input Features:** Select the layer of points, lines or polygons to be trimmed.

- **Clip Features:** Select the polygonal layer containing the trimming perimeter.

- **Output Features Class:** Select the directory or geodatabase where the new cropped layer will be saved.

- **XY Tolerance:** This is an optional tolerance parameter that establishes the distance that a coordinate can be moved in both X and Y.
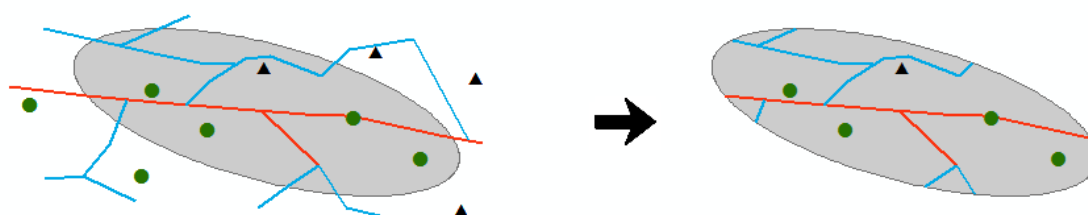

Figure 35. Trimming of vector entities

9.4. Merge

Merge tool can be used to merge two or more entities into a single layer. All merging entities must be of the same type (points, lines or polygons). Caution should be exercised because this tool does not modify the geometry of the entities, even if there is overlap. The tool is located at the following address:

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ArcToolbox > Data Management Tools > General > Merge

In the **Merge** tool pop-up window, you will find the **Input Dataset** section where all the layers to be merged are selected (remember that they must be of the same geometry). In the **Output Dataset** section, a name and directory are assigned to the resulting layer. In the **Field Map** section, fields of the participating layers are added, renamed or deleted. An example is shown in Figure 36, where two layers of separate polygons are located on the left and the merging of the two layers into one is shown on the right.
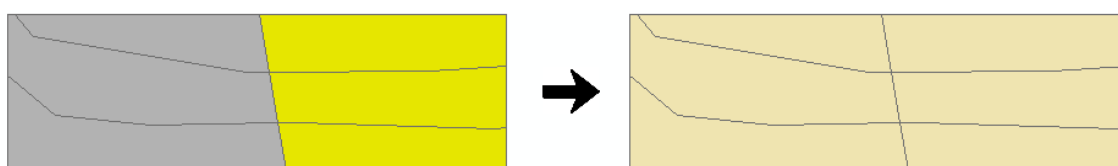
Figure 36. Merging entities

9.5.   Dissolve

This tool unifies geographic information on the basis of an attribute; in other words, it merges information that shares an identical value within the attribute table. Figure 37 shows that all polygons containing a common attribute are merged. For example, this tool is used when a layer of districts is required to obtain a layer of regions. However, in this case the table associated with the districts must have a field indicating the region to which each district belongs. To open the **Dissolve** tool, go to:

ArcToolbox > Data Management Tools > Generalization > Dissolve

In the pop-up window of the Dissolve tool you must configure the parameters as follows:

- **Input Features:** Select the layer of points, lines or polygons on which to work.
- **Output Features Class:** Select the directory or geodatabase where the resulting file will be stored.
- **Dissolve Field:** Select the field containing the attributes according to which the entities will merge.
- **Statistics Field:** This allows statistical calculations of the fields to be dissolved.
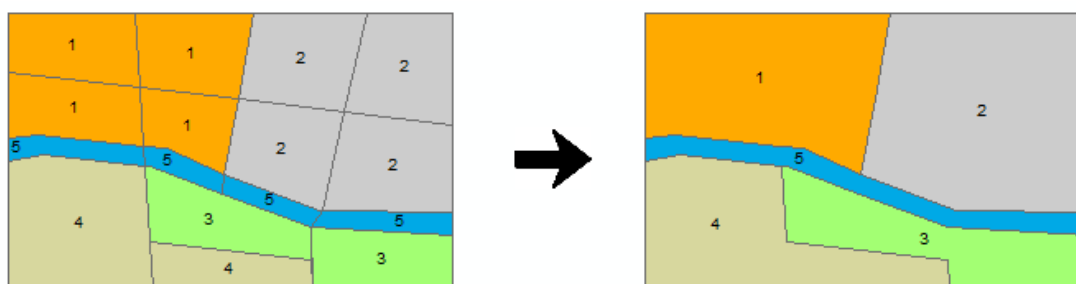
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Figure 37. Dissolving entities

10. Spatial analyst

Spatial analysis is the process of modeling and obtaining results through computer processing and then examining and interpreting the results of the model. Spatial analysis is useful for assessing suitability and capacity, for calculating and predicting, and for interpreting and understanding spatial phenomena (ESRI, 2016b).

A license from the **Spatial Analyst** extension is required to run the tools used in this section.

10.1. Interpolations

Tobler's first geography law (1970) states: "Everything is related to everything else, but near things are more related than distant things. For example, if it rains on one side of a street, it is highly likely to rain on the other side of the street as well".

According to Gruver & Dutton (2014) interpolation is a process that uses measurements made on some phenomenon (precipitation, temperature, elevation) in certain places (samples or stations) to make a prediction for the same phenomenon in places where no measurements have been made.

There are many methods of interpolation, some of which have a greater presence in GIS because they are more adapted to the type of data handled. The usual application within a GIS is two-dimensional, since a raster layer is such an entity. We are therefore talking about spatial interpolation. However, these methods are not only restricted to a plane, but can be extended to a larger number of dimensions to reflect other variables such as depth (e. g., to construct a three-dimensional model of soil characteristics between two established depths and at a given interval), or time (Olaya, 2014).

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The interpolation techniques mentioned by Childs (2004) are deterministic and geostatistical. The deterministic interpolation technique creates surfaces based on measured points or mathematical functions. Methods such as Inverse Distance Weighting (IDW) are based on the degree of similarity of cells, while methods such as Trend are adapted to a smooth surface determined by a mathematical function. The geostatistical interpolation technique, Kriging, is statistics based and is used for the most advanced prediction of surface modeling, which also includes some degree of prediction certainty or accuracy. There are different classifications of interpolation methods, some of which can be consulted in Olaya (2014).

Without going into more detail on the various methods of interpolation, all of these are available at the following address:

ArcToolbox > Spatial Analyst Tools > Interpolation

Table 3 contains precipitation data from weather stations located at different points. The central idea is to construct a raster surface with estimated precipitation values for places where there are no weather stations.

Table 3. Monthly precipitation and temperature data from a network of meteorological stations

Station	UTM_X	UTM_Y	UTM_Z	Precipitation (mm)	Temperature (°C)
A	694294	9558872	2377	89.4	13.13
B	697901	9563240	2033	40.2	15.51
C	700975	9560679	2218	53.1	14.23
D	694716	9555060	2816	75.9	11.17
E	692138	9559012	2952	72.8	11.07
F	706230	9560170	2850	102.4	10.34
G	699711	9553629	2160	72.5	14.59

However, to interpolate the data it is necessary to have a shapefile or vector layer of points. If the point layer does not exist, XY coordinates can be imported and transformed into a shapefile. ArcGIS supports different table formats such as Excel 97-2003 files, tab delimited text, DBF, and CSV.

Practice: Add XY coordinates and export them as shapefile.

In a new ArcMap window, from the menu bar go to ***File > Add Data > Add XY Data***. In the pop-up window that appears, you should set up the fields as follows:

- **Choose a table from the map or browse for another table:** Select the table containing precipitation data. Information from *Table 3* is stored as an XLS file (Excel Book 97-2003).
- **X Field:** Select the field containing the longitude values (UTM_X).
- **Y Field:** Select the field containing the latitude values (UTM_Y).
- **Z Field:** This is optional, but you can select the field containing the altitude values (UTM_Z).
- **Coordinate System of Input Coordinates:** With the **Edit** button, select the coordinate system, in this case *Projected Coordinate Systems > UTM > WGS 1984 > Southern Hemisphere > WGS 1984 UTM Zone 17S*.

This process generates an event layer; however, to store this layer on the hard disk in shapefile format, it is necessary to follow the following steps: Right click on the layer in the table of contents and go to **Data > Export Data**. A pop-up window opens where the address and name of the file to be saved must be selected. If you do not save the file in shapefile format, you must verify that the format type has been selected correctly (in **Save as type**). This step is necessary for the information to be stored in a shapefile.

Of the various interpolation options allowed by ArcGIS, the method used here to interpolate precipitation is Kriging, which is located at the following address:

ArcToolbox > Spatial Analyst Tools > Interpolation > Kriging

The speed of execution of the process depends on the number of points to be processed and the available system resources. The configuration pop-up window in all interpolation tools looks similar. An example of the parameters required by the tool, in this case Kriging (Figure 38), is described below:

- **Input point features:** Select the point layer containing the precipitation values (e. g. shapefile created from *Table 3*).
- **Z value field:** Select the field that stores the precipitation values.
- **Output surface raster:** Select a directory or geodatabase to store the output raster file.

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- **Semivariogram properties:** Allows you to select the Kriging interpolation method with its respective semivariogram model.

- **Output cell size:** Sets the cell size (resolution of the resulting map).

- **Search radius:** Sets the radius of the entry points to interpolate each cell.

- **Output variance of prediction raster:** This is an optional raster containing the semivariance values.
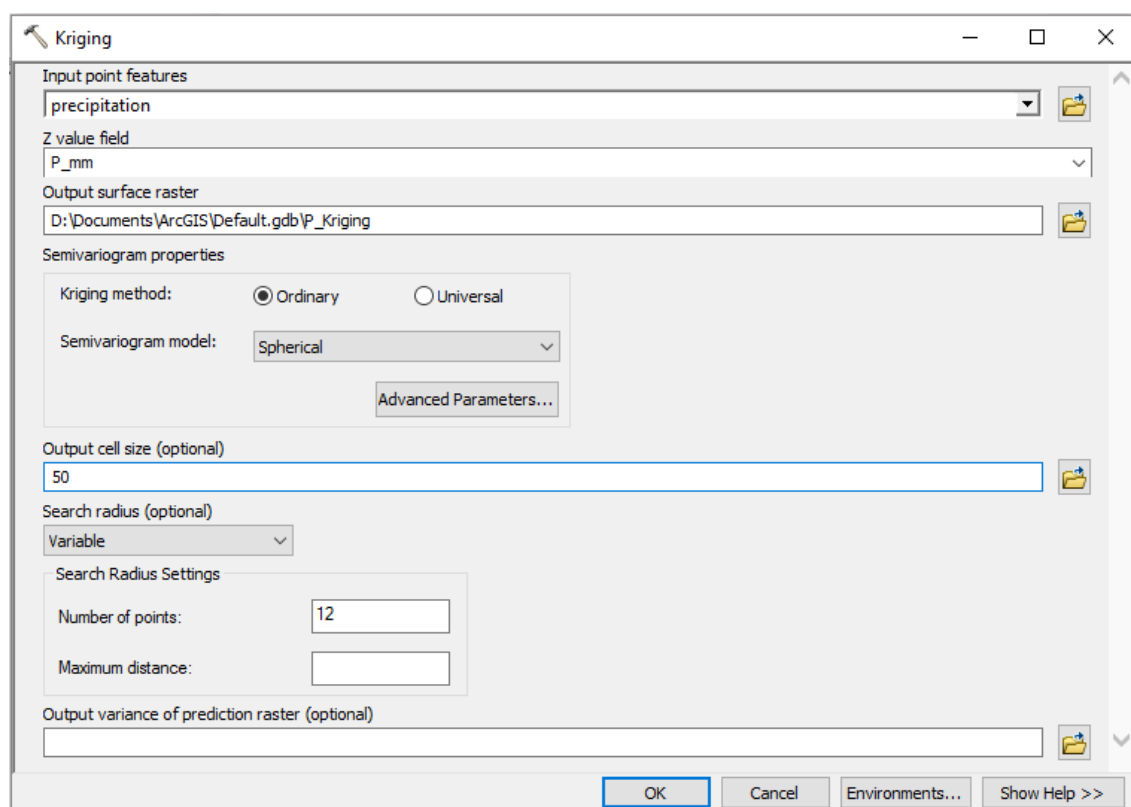

Figure 38. Configuration of Kriging tool parameters

Figure 39 shows the results of interpolation on a raster surface with estimated values. On the left, you can see the points where the weather stations are located (converted to shapefile format). On the right, you can see the map resulting from the interpolation as a raster image, including the estimated precipitation values for each cell. The same process can be repeated to obtain a temperature raster image using the values in *Table 3*.
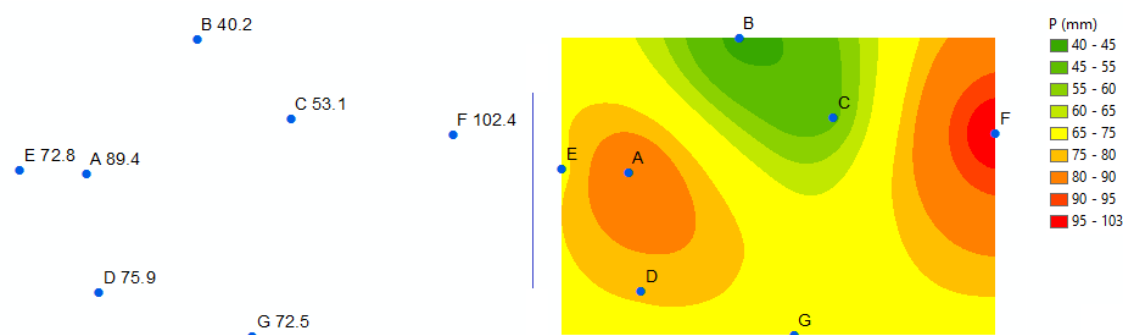
Figure 39. Rainfall interpolation. Weather station points (left) and interpolated prediction surface (right).

10.2. Digital elevation models

A Digital Elevation Model (DEM) is a raster representation of a continuous surface. It usually refers to the earth's surface, using a set of points whose X, Y and Z values are known and defined in an arbitrary coordinate system (Fallas, 2007).

The information that can be derived from digital elevation models can be applied in different fields, such as hydrology, risk analysis, urban planning, among others. The main products that can be obtained from a DEM are slope maps, contours, relief maps, visibility maps, aspect maps, watersheds, viewshed, etc.
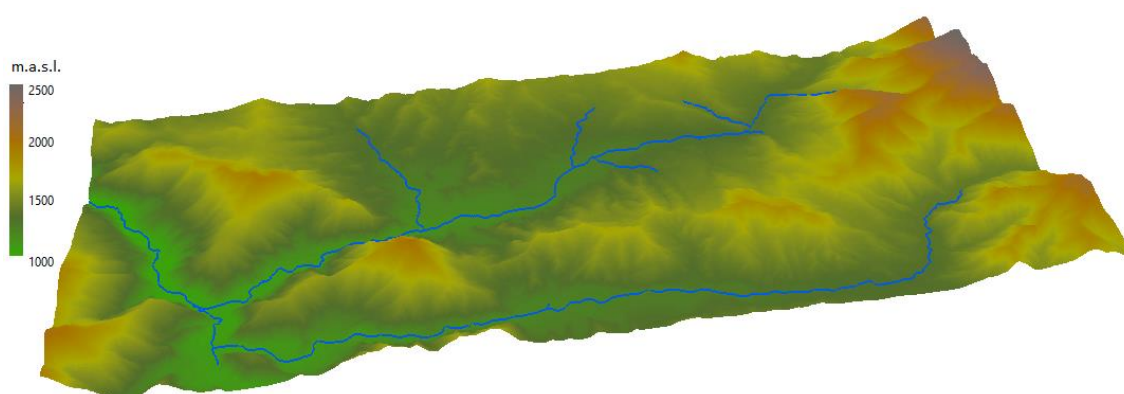
Figure 40. Digital Elevation Model

10.3. Creation of slope maps

Slope is the main factor that determines and differentiates the shapes of the relief. Given two points of different altitudes, the slope of the terrain is understood to be the mathematical ratio determined by the proportional relationship between the difference in altitudes and the horizontal distance between the two points (Hernández, 1998).

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The slope can be expressed in percent or sexagesimal degrees. To create a slope raster, a DEM is required as input information, and the *Slope* tool is used to generate the slope raster, which is located at:

ArcToolbox > Spatial Analyst Tools > Surface > Slope
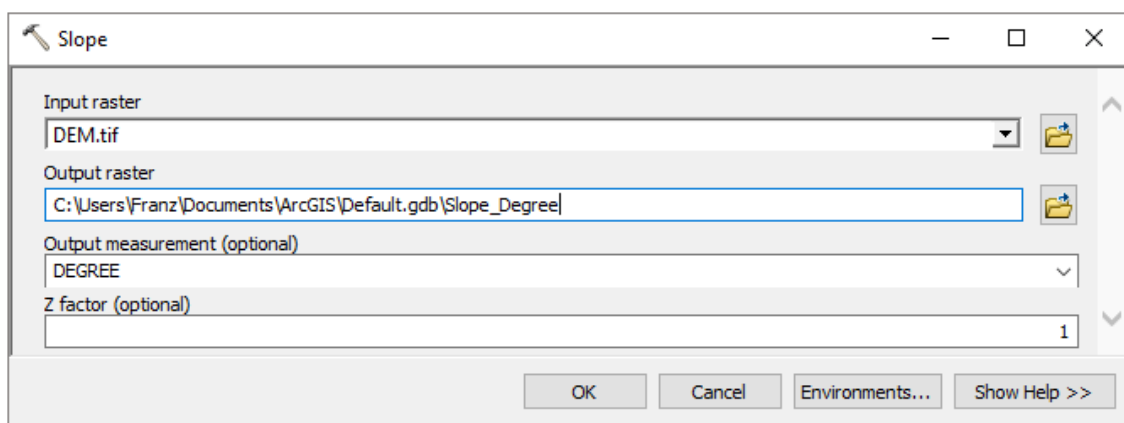

Figure 41. Configuration of Slope tool parameters

The **Slope** tool configuration (Figure 41) is described as follows:

- **Input raster:** Select the layer containing a DEM.
- **Output raster:** Select a directory or geodatabase to store the slope raster file.
- **Output measurement:** Select "DEGREE" for decimal degrees, and "PERCENT_RISE" for percentage.
- **Z factor:** This is an optional factor, used to match Z linear units to XY linear units.
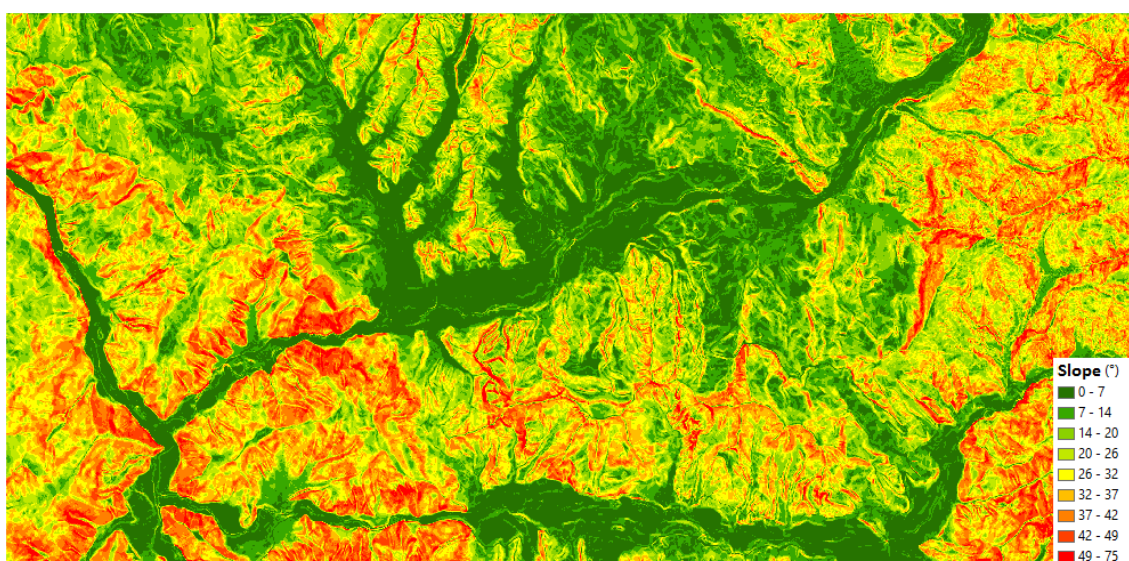
Figure 42. Raster of slopes in degrees

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10.4. Reclassifications

The **Reclassify** tool allows the values of a raster to be reclassified; that is, it replaces the current values of each cell with new information. Data can be reclassified from any variable stored in raster format (slope, elevation, precipitation, temperature, etc.).

Practice: Build a slope map based on the classification proposed by FAO (2009) and group the values of the slope raster into classes (e. g. Figure 42). Table 4 presents eight classes, each of which contains the slope values in percent and decimal degrees.

Table 4. *Slope gradient classes*

Class*	Description	Percentage	Degrees
01	Flat	0 - 1	0 - 0.57
02	Very slightly sloping	1 - 2	0.57 - 1.15
03	Slightly sloping	2 - 5	1.15 - 2.86
04	Inclined	5 -10	2.86 - 5.71
05	Strongly sloping	10 - 15	5.71 - 8.53
06	Moderately steep	15 - 30	8.53 - 16.70
07	Steep	30 - 60	16.70 - 30.96
08	Very steep	> 60	> 30.96

* Class 01 is a consolidation of the first three gradient classes of (FAO, 2009).

To run the reclassification, open the **Reclassify** tool at the following address:

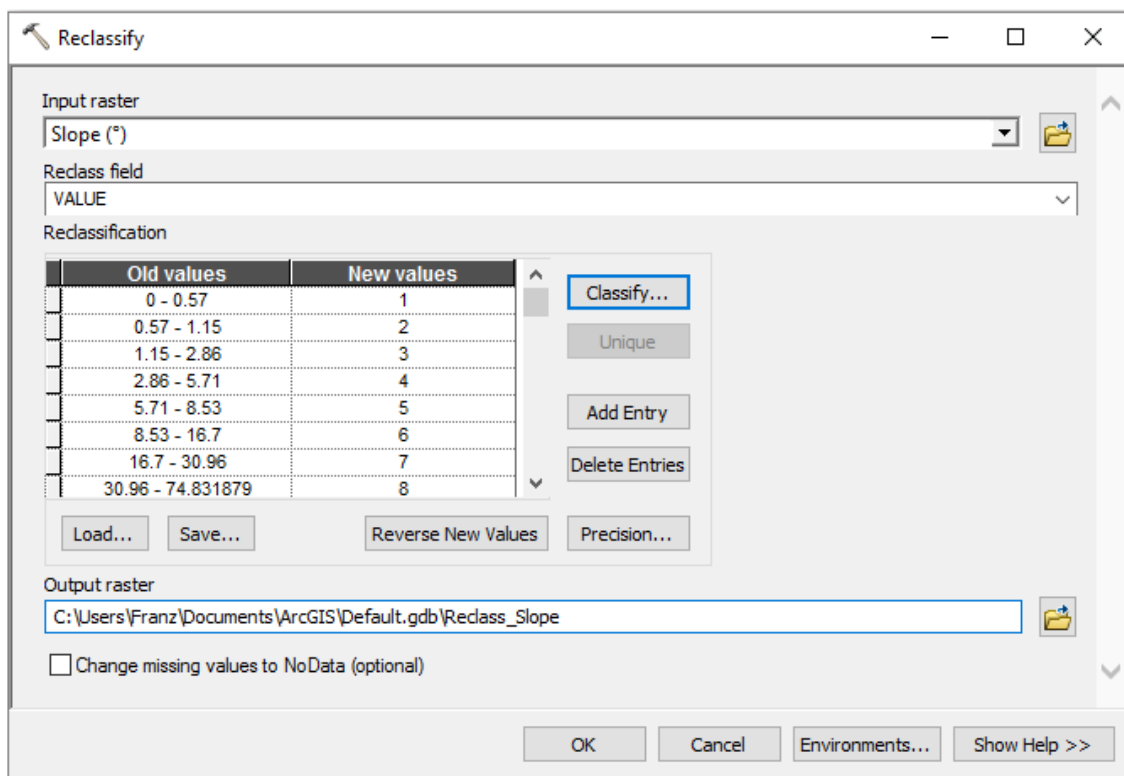*ArcToolbox > Spatial Analyst Tools > Reclass > Reclassify*

Figure 43. Configuration of parameters of the Reclassify tool

In the pop-up window, the parameters described below (Figure 43) must be configured:

- **Input raster:** Select the layer containing the slope raster.
- **Reclass Field:** Select the field containing the slope values. By default, this is usually VALUE.
- **Reclassification:** Within this section clicking on the **Classify** button opens a sorting window where class values can be adjusted. In the **Classification** section of the classification window you can select the classification method and define the number of classes (8). In the lower right-hand corner of the **Break Values** section, you can manually enter the limits of each class (e. g. gradient values as a percentage of Table 4).
- **Output raster:** Select a directory or geodatabase to store the reclassified slope raster file.
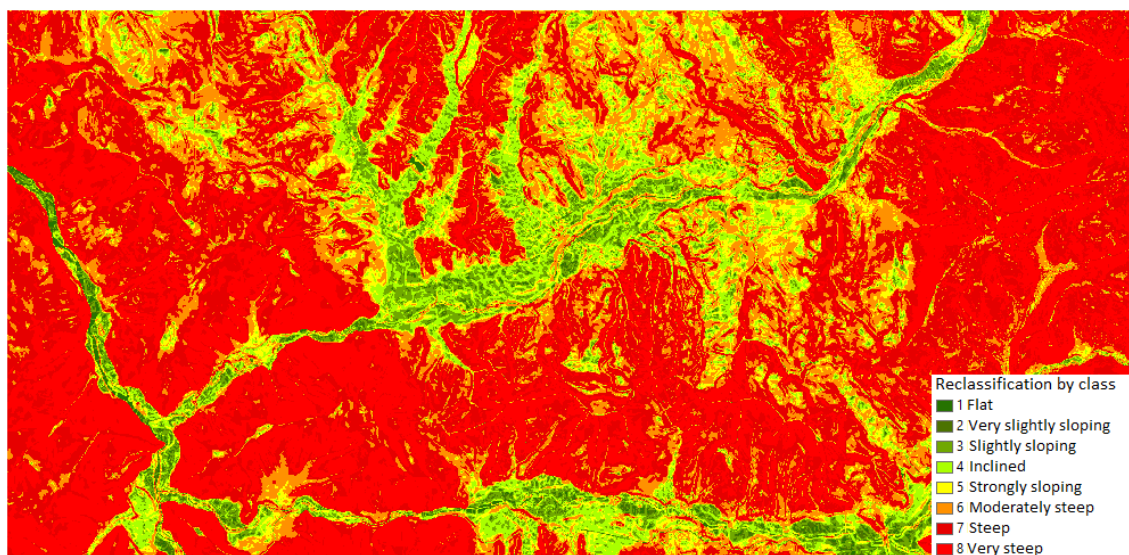
Figure 44. Raster of reclassified slopes

10.5. Contour creation

Contours are lines connecting points of equal value that represent continuous phenomena (Huisman & A. de By, 2009). Contours are called isolines, but may also have specific terms depending on the phenomenon. These are called contour lines (Figure 45) when used to represent elevation, isobars for atmospheric pressure, isohyet for precipitation, isotherms for temperature and isochrons for time (Olaya, 2014).

Figure 45. Contour lines (m.a.s.l.)

The process for generating isolines of all kinds is similar. If you need to create contours, you need a DEM as input information. The isolines are generated with the **Contour** tool, located at:

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ArcToolbox > Spatial Analyst Tools > Surface
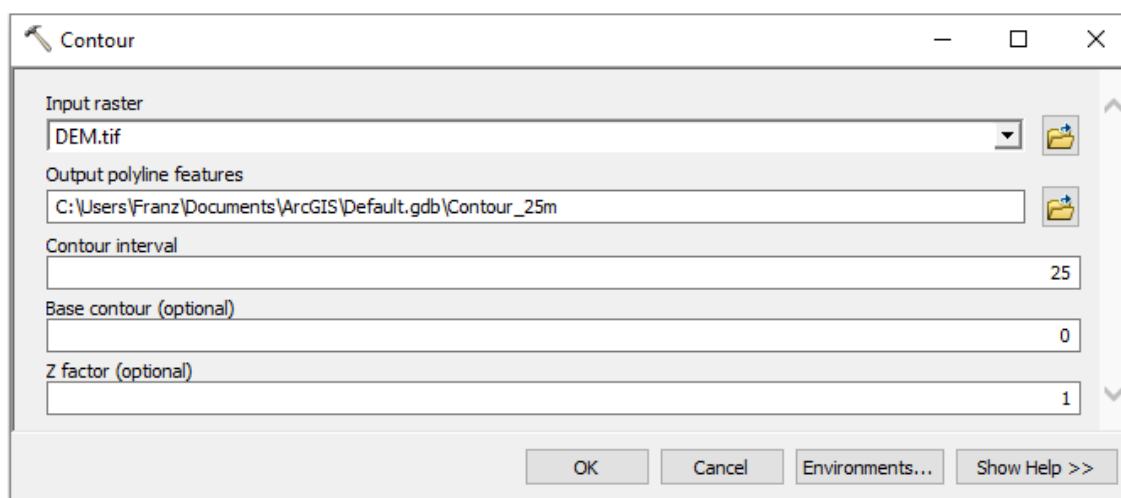
Figure 46. Configuration of the Contour tool parameters

The settings of the **Contour** tool parameters (Figure 46) are detailed below:

- **Input raster:** Select the raster containing the values (to generate contour lines a DEM raster is required, isohyets a precipitation raster, for isotherms a temperature raster).

- **Output polyline features:** Select the directory or geodatabase to store the line layer (level curves).

- **Contour interval:** Define the interval between isolines. It is important to take into account the resolution of the raster; for example, if the DEM has a resolution of 30 meters, it is not recommended to create contours of less than 30 meters.

- **Base contour:** Optionally, a base level value can be assigned.

- **Z factor:** Optionally, a conversion factor can be assigned to generate the isolines. This is used to perform unit conversions (e.g. meters to feet).

10.6. Map algebra

The raster layer calculator (or simply raster calculator) is created to run algebraic expressions using various tools and operators through the interface of a simple calculator tool (**Raster Calculator** tool). The performance of equations depends on the tools or operators involved in an expression. In general, data processing is faster if each operator or tool is executed individually (ESRI, 2016c). The versatility of the map algebra lies in its simplicity and power to perform geographical analysis.

A raster layer can be created from an algorithm by assigning numerical values to the pixels that compose it or it can be derived from one or more previously existing raster layers. A simple example is shown in Figure 47. On the left-hand side you can see the initial raster map, in which you want to execute a simple operation consisting of multiplying all the pixels of the layer with by factor 5. The result is stored in a new raster layer (Figure 47 right).

2	2	3	4
3	5	2	5
5	3	3	2
2	4	5	3

x 5 =

10	10	15	20
15	25	10	25
25	15	15	10
10	20	25	15

Figure 47. Basic map algebra operation

Practice: From the data in *Table 3*, you can create a raster image by interpolating the temperature values (see Figure 49, left), following the steps in section 10.1. The idea of this exercise is to familiarize yourself with the use of algebraic expressions using the **Raster Calculator** tool. The temperature raster layer is generated in Celsius Degrees, but if we want to convert the values to Fahrenheit (see Figure 49 right), the following equation must be applied within the raster image calculator:

$$F = \left(C * \frac{9}{5} \right) + 32$$

where:

F = Temperature in degrees Fahrenheit
C = Temperature in degrees Celsius

The **Raster Calculator** tool for running algebra map expressions is located at:

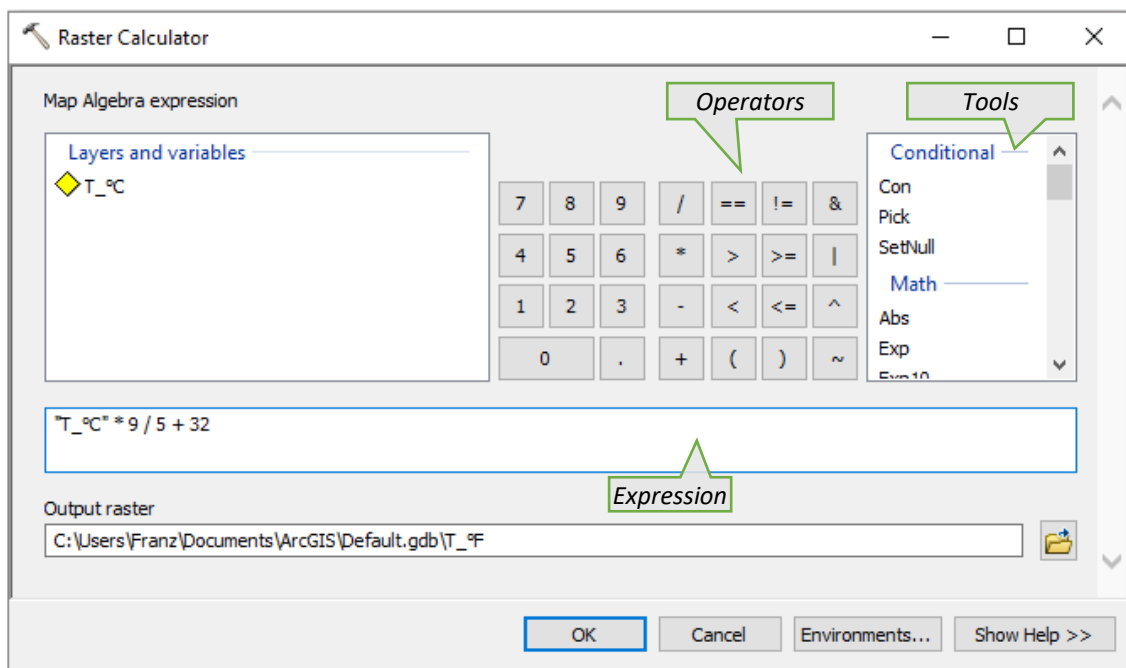*ArcToolbox > Spatial Analyst Tools > Map Algebra > Raster Calculator*

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Figure 48. Configuration of expressions in Raster Calculator

The configuration of the **Raster Calculator** tool (Figure 48) is as follows:

- **Layers and variables:** Displays a list of layers available for use in the map algebra expression.

- **Operators:** Allows you to enter mathematical and logical operations in the expression. Click on the calculator button to enter the number or operator into the expression.

- **Tools:** Displays a list of tools (sine, cosine, tangent) to use anywhere in the expression.

- **Expression:** This allows you to create a set of rules to execute a valid statement. It is not necessary to place the sign "*equal*" (=) at the beginning of the expression. In the equation for converting degrees Celsius to Fahrenheit, replace **"C"** with the raster image name: **"T_°C" * 9 / 5 + 32**. Use parentheses to group algebraic expressions, if needed.

- **Output raster:** Select a directory or geodatabase to store the raster file generated by the resulting expression.

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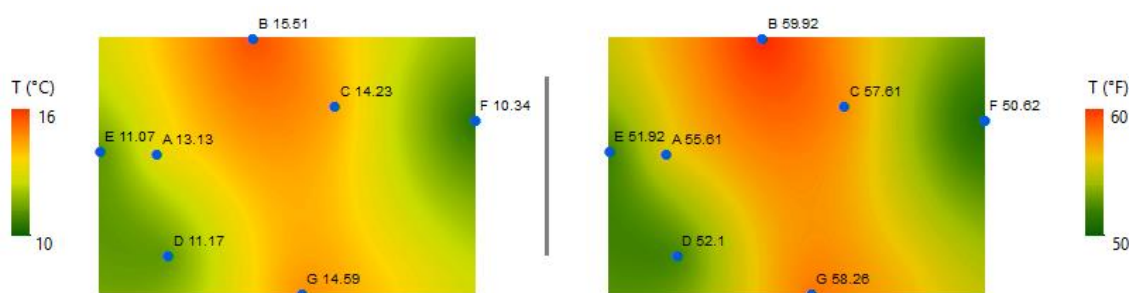
Figure 49. Temperature raster in °C (left). Temperature raster in °F obtained through a map algebra expression (right).

10.7. Topographic profiles

A topographic or elevation profile is a two-dimensional cross-section of the terrain. It is a side view of the terrain represented by a line drawn between two or more points on a map. The **Y** axis corresponds to the altitude or elevation values, while the **X** axis corresponds to the values of the distance between these points.

Creating a topographic profile can be easy, but creating an attractive and elegant graphic is a laborious task. In ArcMap you can generate simple graphics, but with the help of Microsoft Excel you can considerably improve the final design of the graphic.

Practice: Create a topographic profile of several points corresponding to populated sites. The main activities to be developed in this practice are:

- Create a Profile Graph and Point Profile in ArcMap.
- Export the created profile table to Excel.
- Create a scatter plot (XY) with the two sets of data (Profile Graph and Point Profile) in Excel.
- Add labels, and fine-tune details and graphic design with formatting options in Excel.

The first step is to add a DEM and a layer of points inside ArcMap (Figure 50). The points layer corresponds to villages that exist in the area.
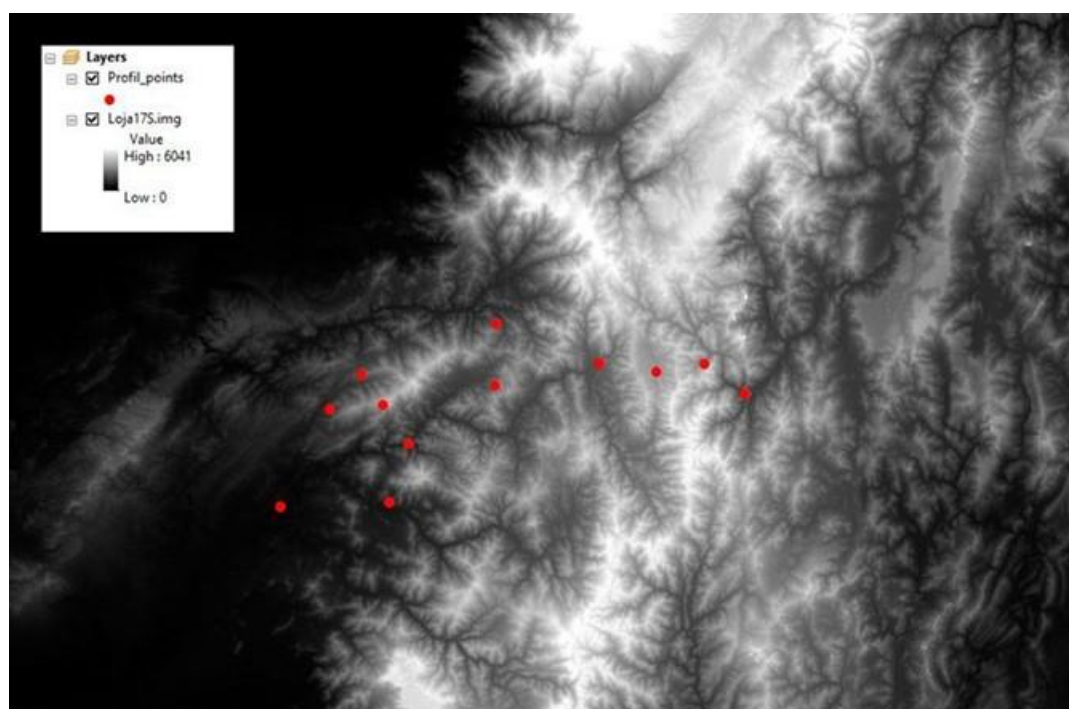
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Figure 50. Digital Elevation Model (DEM) with one layer of points

If the points are only in 2D (XY coordinates), it is necessary to convert these vector points into 3D to obtain the **Z** (height) values of the points. For this, a DEM is required, from which altitudinal information can be extracted for each point. You should address it to:

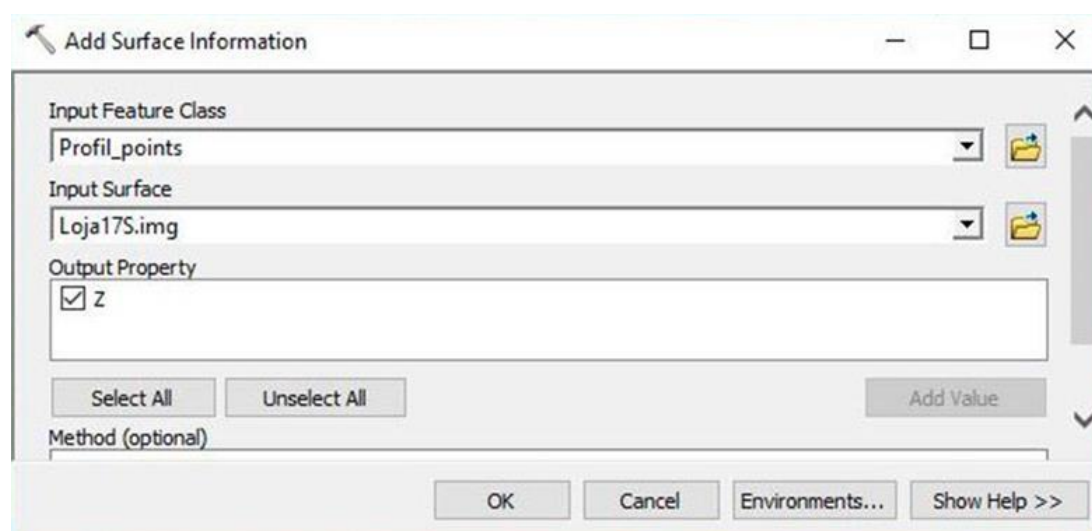*ArcToolbox > 3D Analyst Tools > Functional Surface > Add Surface Information*

Figure 51. Configuration of the Add Surface Information tool

The "Add Surface Information" window, shown in Figure 51, must be configured as follows:

- **Input Feature Class:** Enter the point layer (*Profile_points*).

- **Input Surface:** Enter the digital elevation model (*Loja17S.img*).
- **Output Property:** Check the Z box.

Click on "OK" and then by opening the attribute table of the point layer you can see the **Z** values in a new field. To convert points from 2D to 3D you should go to the following address:

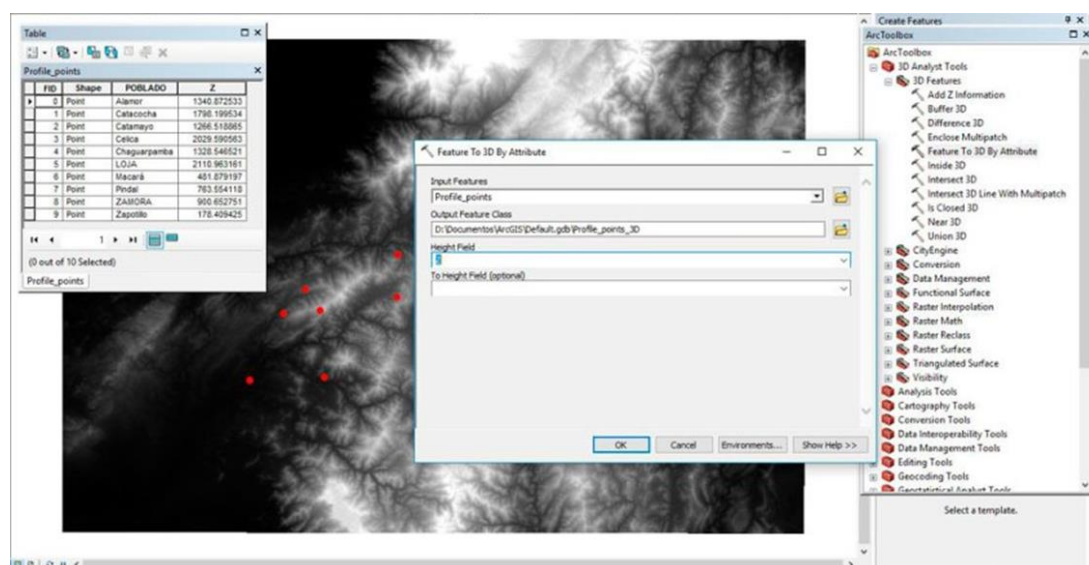*ArcToolbox > 3D Analyst Tools > 3D Features > Feature To 3D By Attribute*

Figure 52. Feature To 3D By Attribute tool configuration

The Feature To 3D By Attribute tool window (Figure 52) must be set up as follows:

- **Input Features:** Enter the point layer (*Profile_points*).
- **Output Feature Class:** Assign a name to the output layer (*Profile_points_3D*).
- **Height Field:** Select the field containing the **Z** values.

Once the plot layer is set up, you can create a profile graph based on the points. In order to generate the **Profile Graph**, you must perform the following steps:

- First make sure to activate the **3D Analyst** toolbar (*Customize menu > Toolbars*). Then, click the **Interpolate line** ( ) icon.
- With this tool you can freely draw the line of the topographic profile. To create this line it is very important to take into consideration the direction (from left to right or vice versa) because the *Profile Graph* tool will be plotted according to the direction of the starting point. In this example it was used in a left-to-right direction.

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- Once the profile line has been created, click the **Profile Graph** (🏔) button on the 3D Analyst toolbar. Here, a profile graphic should appear as shown in Figure 53.
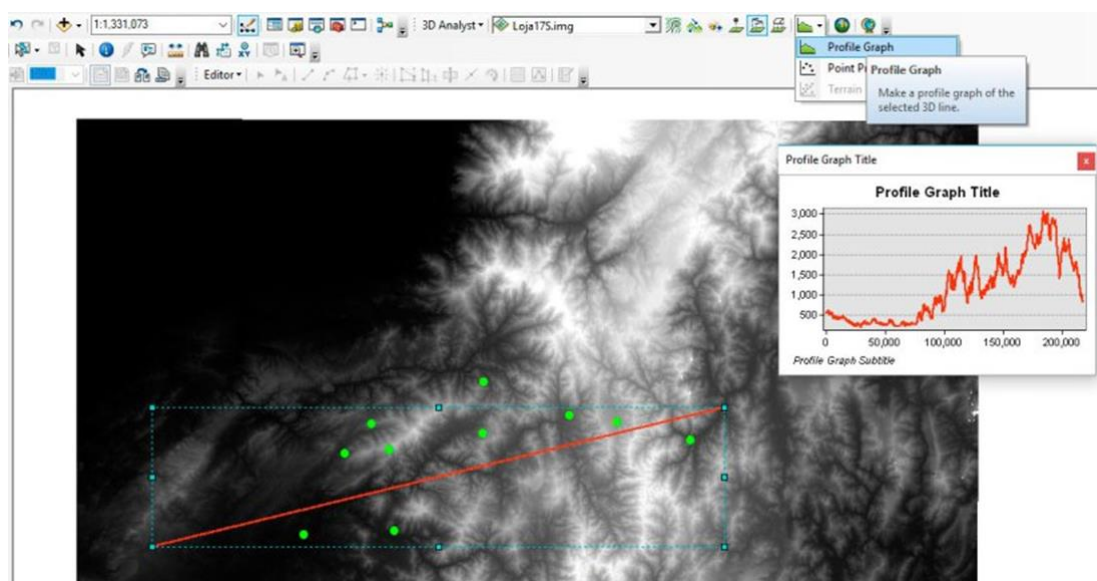

Figure 53. Creation of an elevation profile with the Profile Graph tool

Now you need to create a new graph using the plot layer. To do this, you must carry out the following steps:

- On the *3D Analyst* toolbar click on the **Point Profile** (⊡) icon.
- Draw a new line with the same length and direction as the first red line (best to be accurate, but no problem if you can't get a line exactly the same as the first). It is recommended to click first at the beginning of the first line (red), with the second click at the end of the line. Then, move the mouse pointer up or down by drawing an area that includes all the desired points (black box). Finally, a third click is made to create the *Point Profile*. We recommend looking at Figure 54.
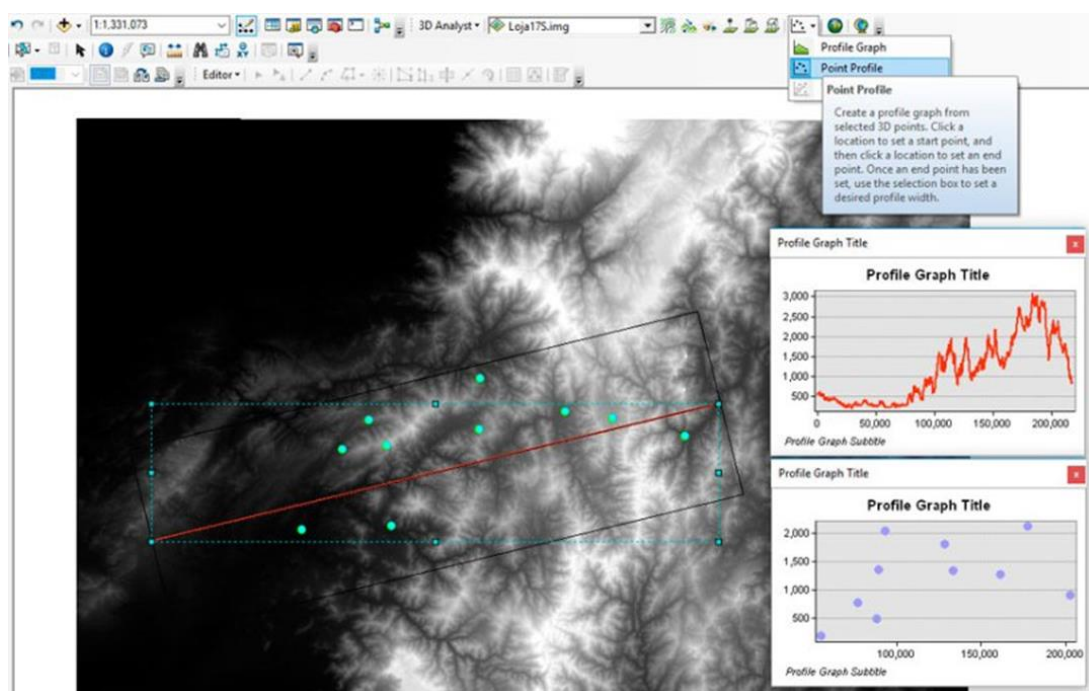
52

Figure 54. Creating an elevation profile with the Point Profile tool

We have already created elevation profiles in ArcMap. However, in order to improve the presentation with a more attractive and elegant design, the data should be exported to Microsoft Excel. This is done in the following way:

- From ArcMap, right click on the first *Profile Graph > Advanced properties.*
- In the new window, click **Data**, then click on the **Copy** (⧉) button (see Figure 55).
- Once in Excel, you must paste the data into a new book.
- Then, repeat the process with the second point profile graph.
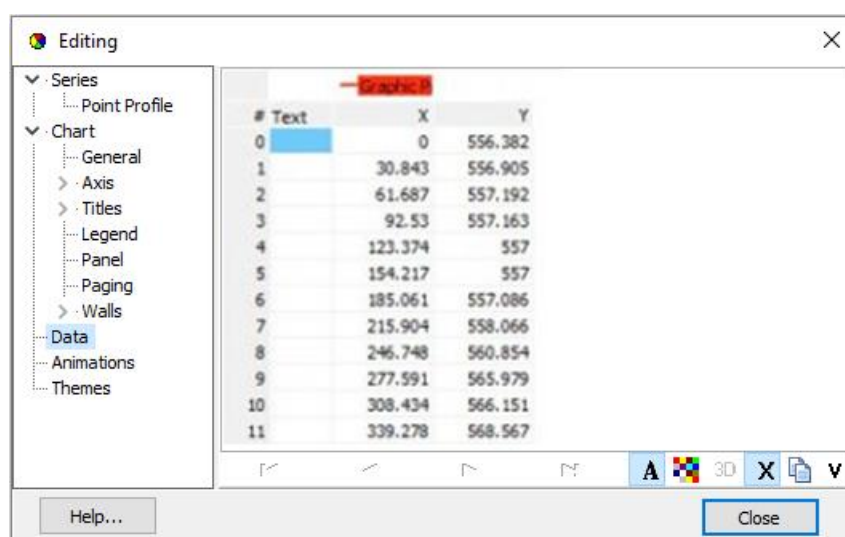

Figure 55. Advanced profile graph options

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Once the data for both profiles are found within Excel, the point labels must be added (Figure 56). In our example, these are city names. Several options exist to obtain the labels on our chart; for example:

- The names can be typed manually in a new Excel column.
- Labels can be obtained by directly opening the *. dbf file in Excel, and copying these names into a new column.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Index	X	Graphic Profile 1				Index	X	Point Profile			
2	0	0	556.3821				0	89448.7788	1340.8725	Alamor		
3	1	30.8434484	556.9049				1	128463.18	1798.1995	Catacocha		
4	2	61.6868969	557.1923				2	161306.977	1266.5189	Catamayo		
5	3	92.5303453	557.1629				3	93734.2916	2029.5906	Celica		
6	4	123.373794	557				4	133434.441	1328.5465	Chaguarpamba		
7	5	154.217242	557				5	177741.984	2110.9632	LOJA		
8	6	185.060691	557.0855				6	88428.1654	481.8792	Macará		
9	7	215.904139	558.0659				7	77436.4476	763.5541	Pindal		
10	8	246.747588	560.8538				8	202822.308	900.6528	ZAMORA		
11	9	277.591036	565.9785				9	55612.9004	178.4094	Zapotillo		
12	10	308.434484	566.151									

Figure 56. Data of elevation profiles within Excel

To improve the appearance of the profile graphic, it is necessary to prepare the data. Two steps are sufficient: transform the **X** values, which are the length scale, from meters to kilometers, and smooth the **Y** data of the elevation line as follows:

- First, the length values must be transformed from meters to kilometers. This is very easy, and you can do it in a new column by dividing the values of **X** by one thousand. For example. In cell D2 type: =B2/1000. The same is true for Point Profile length values, in a new column you can type: =H2/1000 (See in Figure 57 the columns D and I).
- Second, the profile line must be smoothed, based on the data. This is basically to show the most important patterns or trend of the profile line by removing the finer details. In other words, we obtain a smoothed line of the elevation profile. There are many methods to accomplish this task, but in our example we use a simple method by calculating simple moving averages in Excel. However, remember that you can use any other technique. Subsequently, consecutive averages are calculated in sets of 100 rows (or another number of rows according to the degree of smoothing desired). The rows can be changed depending on the length of the elevation profile, or according to the required smoothing force. For example. In an empty column, in the first row (E2), you can use this formula: =AVERAGE(C2:C101), then drag to all cells of the column (see Figure 57).

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Figure 57. Data smoothing in Microsoft Excel

For plotting Excel graphics, insert a new scatter diagram (X, Y):

- Select two columns: Length (as X axis) and Elevation (as Y axis). In our example, columns D and E are used.

- Go to the *Insert menu > Charts > Scatter with Smooth Lines*. The line of the smoothed profile is shown in Figure 58.
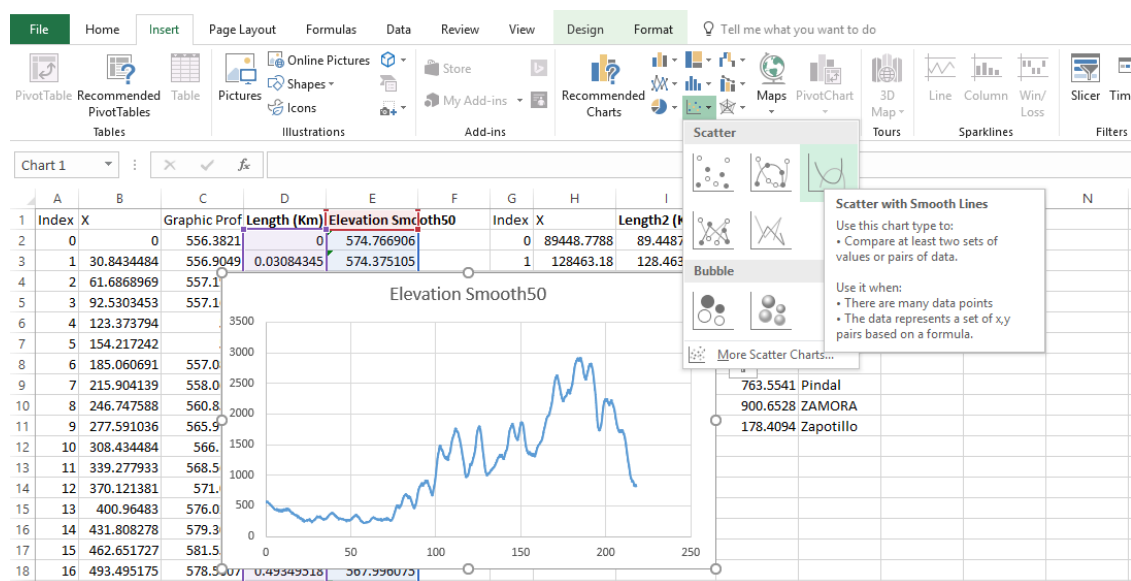

Figure 58. Plotting scatter plots in Microsoft Excel

To add a new series containing the points with their locations within the same graphic, you must do the following:

- Right click on the graphic > Select Data...

- Click on Add.

- Put a new name under Series Names: (In this case "Sites").

- Under "Series X Values:" select the **X** values of the second graph (In this case the column "Length2 (Km)" =Sheet1!$I$2:$I$11).

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- Under "Series Y Values:" select the **Y** values from the second graphic (In this case the column "Point Profile" =Sheet1!$J$2:$J$11).

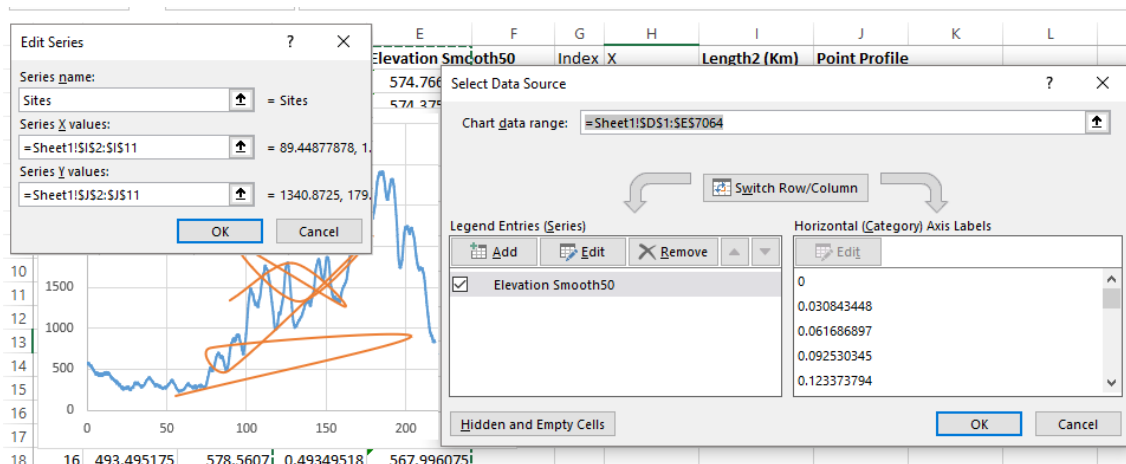- A second line is added to the chart (Figure 59), but not yet ready.

Figure 59. Dispersion graph that includes two series

The graph of the second line (Sites) must be changed to points by means of the indications shown in Figure 60:

- Select the newly added line (orange).

- Right-click select Change Series Graph Type...

- Click on the name of the second series (Sites).

- Click on the drop-down menu.

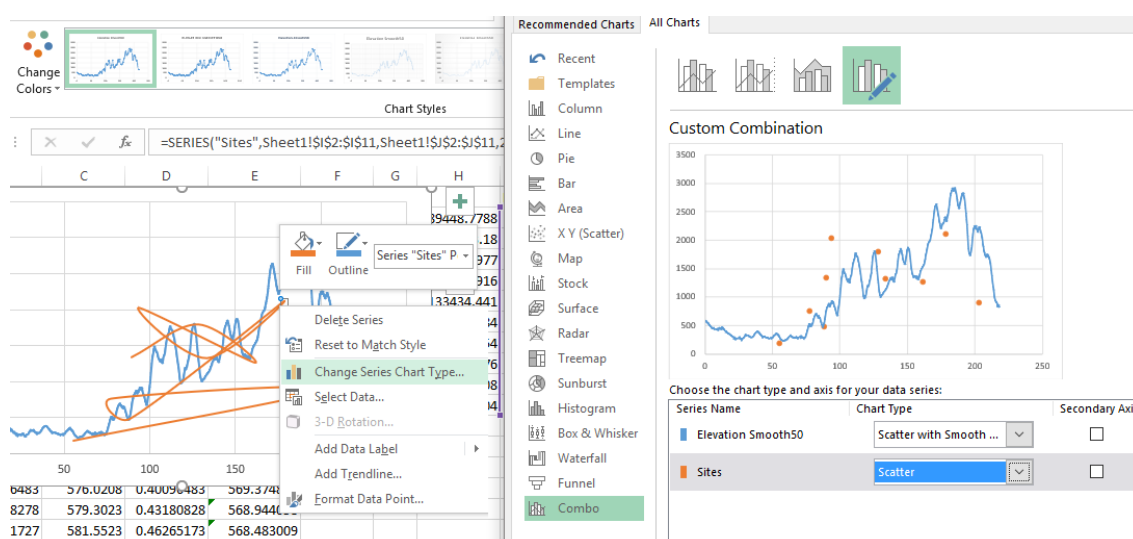- Click on the type of graphic called "**Scatter**"

Figure 60. Change of chart type, from lines to points

The elevation profile is almost ready, but the point names are not yet displayed. To add the labels, the following actions must be carried out (Figure 61):

- Select the point series ("Sites").

- Go to the "*Design*" menu > Add Chart Element> Data Labels > More Data Label Options...

- Select "*Value From Cells*" from the right panel in the label options.

- Select the column containing the labels (=Sheet1!$K$2:$K$11).
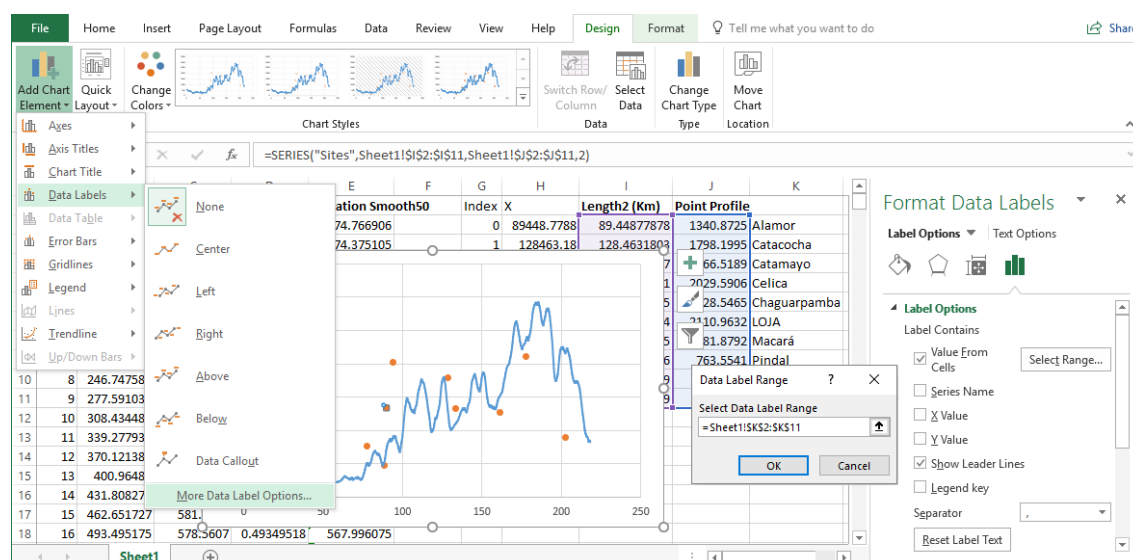
- Deactivate the "*Y Value*" checkbox.

Figure 61. Add labels to point information

Finally, after a laborious process the topographic profile or elevation profile is ready, including all the points and their locations (Figure 62. Topographic or elevation profile.

). Additionally, you can further improve the graph by customizing the following features:

- Title and legend.

- Text color and size.

- Axis titles.

- You can also customize the profile line with a color gradient (as in our example, the profile line goes from orange to green).

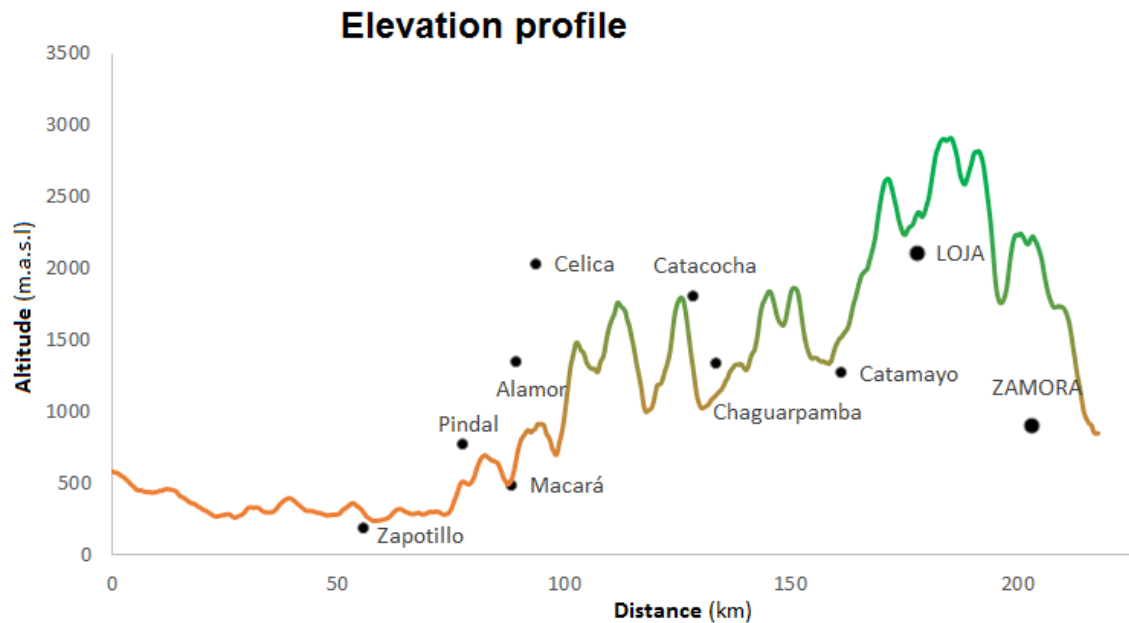- Remove internal dividing lines, scale adjustment, etc.

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Figure 62. Topographic or elevation profile.

11. Design and publication

Mapping can be a laborious process until you get the right result. Viewing data to analyze and interpret spatial information on a computer is one thing, but printing a map for others to analyze and interpret is quite different. ArcMap makes available a number of tools for map design prior to publication (Hillier, 2011). In general, the simpler a map is, the easier it is to understand. This means avoiding unnecessary content, selecting appropriate colors, selecting the correct text size and prioritizing information according to its relevance. In other words, it is not just a matter of creating a map that is pleasing to the eye, but one that can convey the purpose for which it was designed.

A map is an incomplete representation or perception of the territory. The map offers the public only what the cartographer wants to show. The designer selects in a reasoned way the elements he wishes to map, but his choice depends on his own knowledge, sensitivity and intentions (Rekacewicz, 2006).

11.1. Symbology of points, lines and polygons.

Symbology allows you to define how each element will be displayed on the map (symbols, colors, frames, text). It must be decided whether or not it is required to display the information according to the attribute table of each layer.

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To configure the symbology of the layers created in section 7.1, right click on the layer to be customized (*buildings*), select **Properties**, and click on the **Symbology** tab.
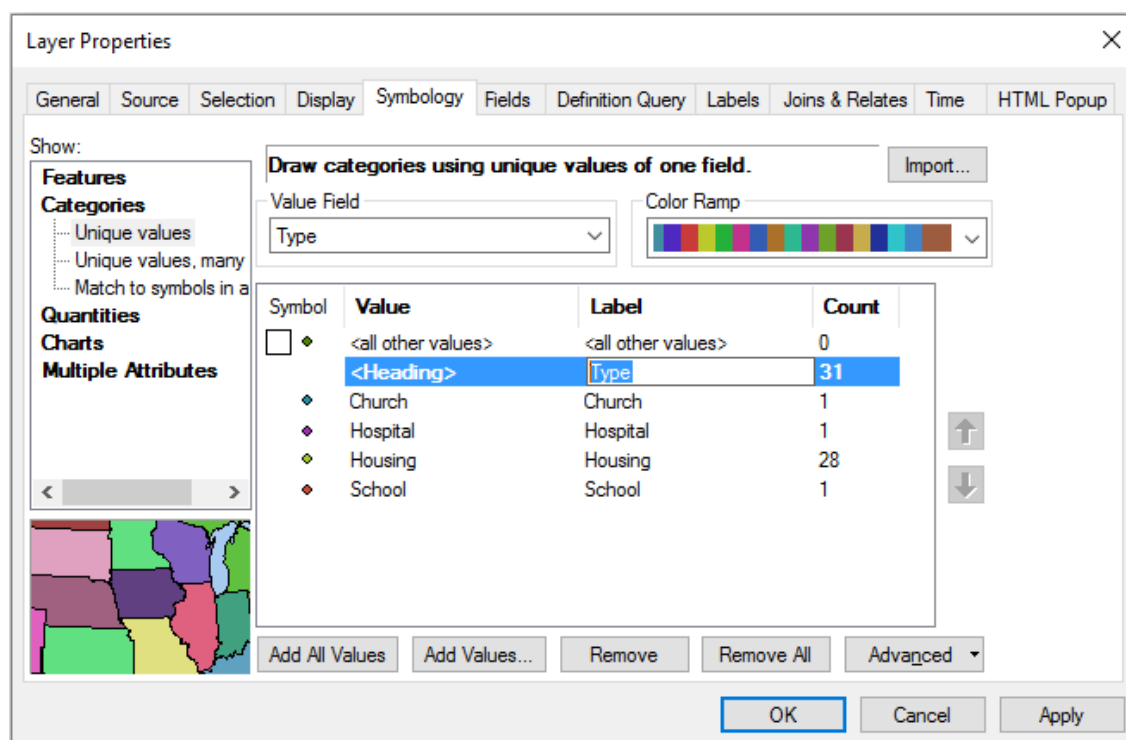

Figure 63. Symbology tab of a layer properties

On the Symbology tab, to represent geographic information, the following aspects must be considered for its configuration:

- **Show:** This is on the left-hand side of the window. It allows information to be organized individually, by categories, numbers, graphs and multiple attributes. For the *building* layer, select **Categories > Unique values**.

- **Valued Field:** Select the **Type** field to represent in categories the information stored within the same field. Clicking **Add All Values** adds all categories, clicking **Add Values** adds categories individually, **Remove** deletes the selected category and **Remove All** deletes all added categories.

- **Color Ramp:** A default color palette can be selected.

When you add all the categories of a layer, by default, ***<all other values>*** are added, it is recommended to uncheck the box. You can also remove the tag (Type) from the ***<Heading>*** header (see Figure 63). To see the changes in the table of contents click **Apply** and to accept them click **OK**. It is recommended to arrange the layers according to their geometry within the table of contents.

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The same procedure can be applied to the *road_network* and *plant_cover* layers to add all their categories based on the information contained in the attribute table.
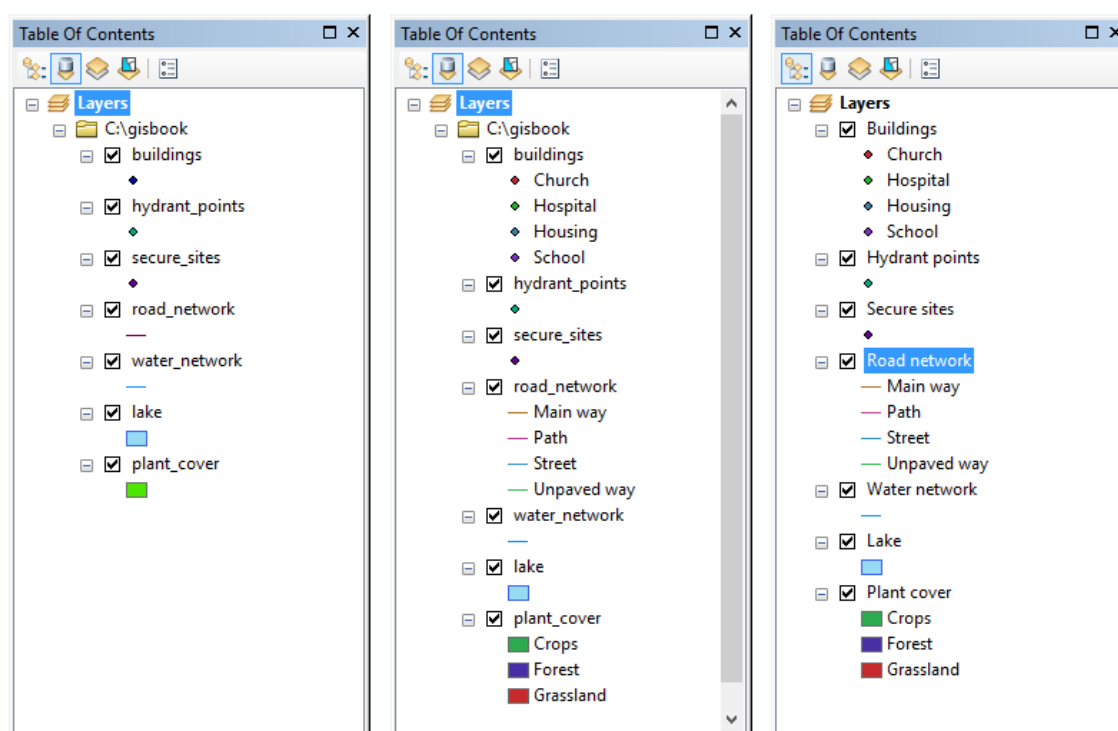

Figure 64. Configuration of the Table of Contents

In the table of contents, the **List By Drawing Order** ( ) button must be enabled to drag and drop layers in the required order (e. g. polygon at the bottom, lines in the middle and finally points on top).

By default each layer has exactly the same file name (Figure 64 **left**) and each category has the name according to the attribute table (Figure 64 **center**). To edit the name of a layer or category, click on it and you can change it individually. It is important to check that everything is written correctly (Figure 64 **right**), because the map legend will show those names.

When a layer is first loaded into ArcMap it is assigned symbols of the same size, shape and color (Single Symbol). In order to represent the real world through a map, it is necessary to use appropriate symbols that can properly represent the nature of the information.

ArcMap contains an extensive library of symbols used in various disciplines. The symbol that conveys what really needs to be represented must be carefully chosen. The symbol for each point in the list can be sorted individually. For example, to customize the **School** symbol (from the **Buildings** points layer) you must perform the following steps (Figure 65):

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- Double click on the layer (or directly in the symbol).

- Double click on the symbol in the list.

- In the **Symbol Selector** window, click the **Style Reference** button.

- Check the **Civic** checkbox (or the required symbol libraries).

- In **Symbol Selector** select the **School 1** symbol.

- In the **Color** button select the black color from the drop-down list (to customize click **More Colors**, in the **Color Selector** window you can customize RGB values).

- Select the size of the points layer symbol in the Size button. For lines, select **Width** for the line width, for polygons select **Outline Width** for the contour line width, and select **Outline Color** for the color of the contour line.
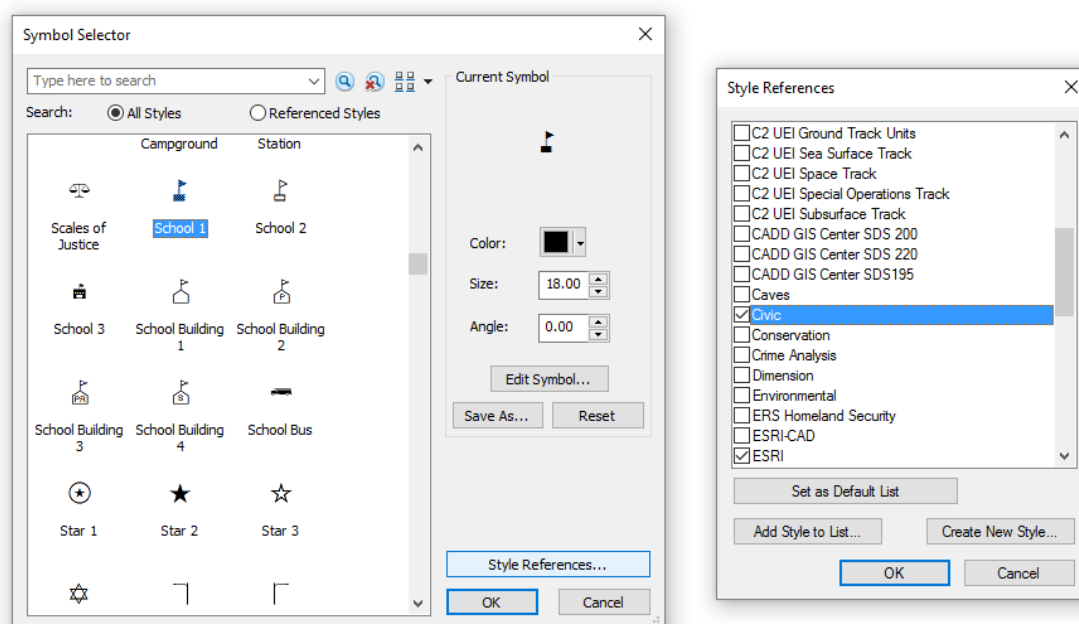

Figure 65. ArcMap symbol library

For the remaining layers, assign the symbology according to *Table 5* based on the process described in the previous paragraph.

Table 5. Definition of symbol properties

Shapefile	Categories	Symbol	RGB color	Symbol size or line width
buildings	School	School 1	0,0,0	18
	Hospital	Hospital 1	255,255,255	14
	Church	Place of Worship 1	0,0,0	18
	House	Building 1	255,255,255	8
hydrant_points	Hydrant points	Faucet	0,0,0	18
secure_sites	Secure sites	Rnd Square 1	0,0,0	14
road_network	Street	Road, Proposed	255,55,55	1
	Path	Dashed 4:4	0,0,0	0.40
	Unpaved way	Road, Unpaved	115,76,0	2
	Main way	Highway	250,52,17	1.70
water_network	Water network	River	10,147,252	1
plant_cover	Forests	Scattered Trees 1	109,187,67	0.40
	Crops	Cropland	227,158,0	0.40
	Grassland	Grassland	109,187,67	0.40
lake	Lagoon	Lake	151,219,242	0.40

11.2. Map design

It is impossible to transpose the real world onto a map, so that anyone who picks up a map has no option but to believe in it. The cartographer is completely free to transcribe the world as he sees fit (Rekacewicz, 2006), but in depicting reality one should not bias or manipulate information, but maintain as impartial as possible.

The distribution of the elements of a map is subject to the author's requirements. The important thing is that a map can be understood by the target audience. Figure 66 suggests the layout of the map elements - although not all elements are obligatory, at least it should contain the title, grid, geographic north, scale, and legend.
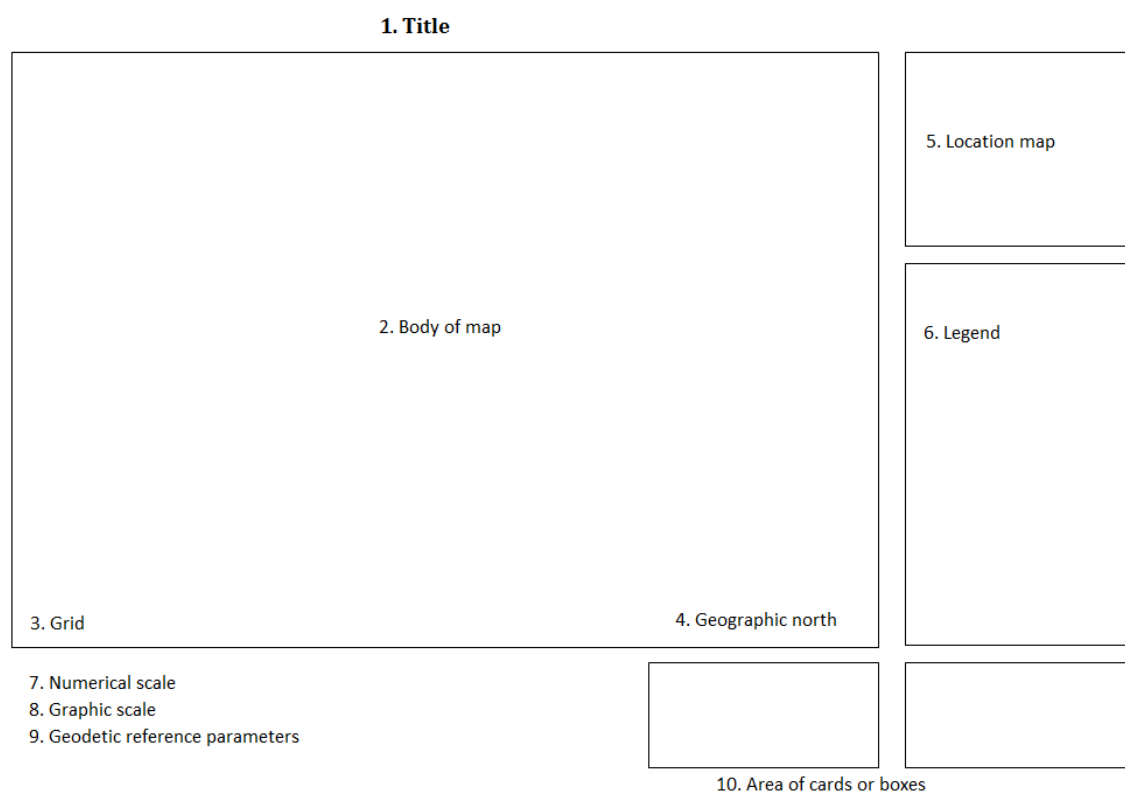
1. Title

Figure 66. Elements to design a map

Before you start with the map layout, it is recommended that you set the orientation and size of the paper. From the **File** menu, go to **Page and Print Setup** to select the printer. In the **Paper > Size** section, select the size (e. g. A4 paper) and orientation (**Orientation > Landscape** to orientate the sheet horizontally; select **Portrait** for vertical presentation.

From the **Customize > Toolbars** menu, activate the **Draw** toolbar (Figure 67), because it contains tools for adding and editing graphic elements in the **Layout**.

Figure 67. Draw toolbar

To start designing the map, change the **Data View** screen to **Layout View** from the View menu, or using the buttons shown in Figure 1. It is important to note that what you see in the **Layout View** is how it will look when printing or exporting the map.

The configuration of the elements in Figure 66 is as follows:

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Title (1)

From the **Insert** menu select **Title**, and in the dialog box set the title as: **My first map in ArcGIS**.

Body of the map (2)

The data frame is automatically displayed by default when you switch to the **Layout View** screen. The body of the map is the fundamental part of a map, which contains all the layers to be represented within a map. To reduce or enlarge the map body, click on the map rectangle and adjust the borders as required.

Grid (3)

To insert a grid in UTM coordinates, use the Grids and Graticules Wizard (see Figure 68), performing the following steps:

- Go to the **View** menu**.**
- Click on **Data Frame Properties.**
- Go to the **Grids** tab**.**
- Click on **New Grid** to open the wizard (click the *Next* button to complete the configuration in each window).
- In the **Grids and Graticules Wizard** window, select **Measured Grid** to display the coordinate grids projected on the map. **Graticule:** for crosshairs divided by longitude meridians and parallel meridians of latitude. **Reference Grid** generates a reference grid divided into rows and columns.
- If **Measured Grid** is selected, the **Create a measured grid** window appears. In the **Appearance** section, select the shape and style of the grid. By default the **Coordinate System** section shows the coordinate system used in the current map, but it is possible to change it. In the Intervals section, the XY axis spacing is defined, in this case 100 meters.
- If **Appearance** is selected in the **Grid and Labels** option, the **Axes and Labels** window will appear where you can configure the Axes of the grid and line style. To customize the text style, click on **Text style**. When all parameters have been set, click **Next**.
- Finally, the **Create a measured grid** window appears, in which you can configure the place of the borders in the grid. The **Grid Properties** section allows you to store the grid as a static or upgradeable graph in the event of changes in location and scale of the map.
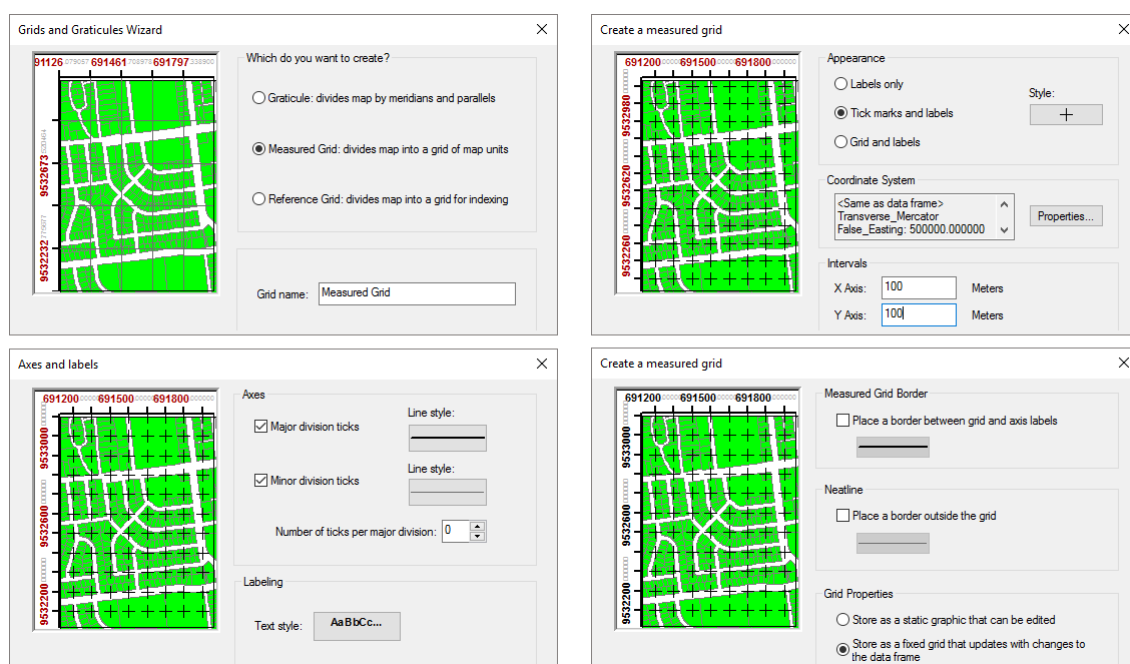
Figure 68. Grids and Graticules Wizard steps in the order: Grids and Graticules Wizard, Create a measured grid, Axes and labels, and Create a measured grid.

Usually when a projected coordinate grid is added, the axis labels show six decimal places (e. g., 691900^{000000} 9532700^{000000}). In the properties of each grid, existing grids and reticles can be managed. To remove the remaining decimal places from the grid axes, follow these steps:

- Go to the **View** menu.
- Click on **Data Frame Properties**.
- Go to the **Grids** tab.
- Select the grid and click on **Properties**.
- Go to the **Labels** tab.
- Click on **Additional Properties**.
- Click on **Number Format**.
- In the **Rounding** section, leave the number of decimal places at zero.

Geographic North (4)

To indicate the orientation of the map, use the North arrow. From the **Insert** menu, select **Insert North Arrow**. Then place it on the required North 2 arrow symbol (ESRI North 2) and click **OK** to add. With the **Selects Elements** ( ) button on the **Draw** toolbar you can select the North arrow and resize it and move it freely over the map.

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Location map (5)

Knowing where the study area is located allows the map reader to be spatially orientated in a wider context. In ArcMap you can add location indicators to connect data frames (Data Frame). The location map can be added by considering the following steps:

- Go to the **Insert > Data Frame** menu to add a new blank data frame.

- Use the **Select Elements** button (⬉ ; on the Draw toolbar) to adjust the size and position of the new data frame.

- Add one or more layers to indicate the spatial extension greater than the study area using the **Add Data** button (⬥ ; on the Standard toolbar). For example, if the study area is Ecuador, it would be convenient to add the South American layer.

- Configures the symbology and design of the layers of the new data frame.

- In the Table of Contents, right click on the **New Data Frame** and select **Properties**.

- Go to the **Extent Indicators** tab (Figure 69).

- From the **Other data frames** box add the Data Frame (**Layers**) to the **Show extent indicator for these data frames** box.

- Optionally, you can configure the style of the Data Frame in the **Options** section (name of the Data Frame).

- Insert a text box from the **Insert > Text** menu to add the title (for example: Location map).
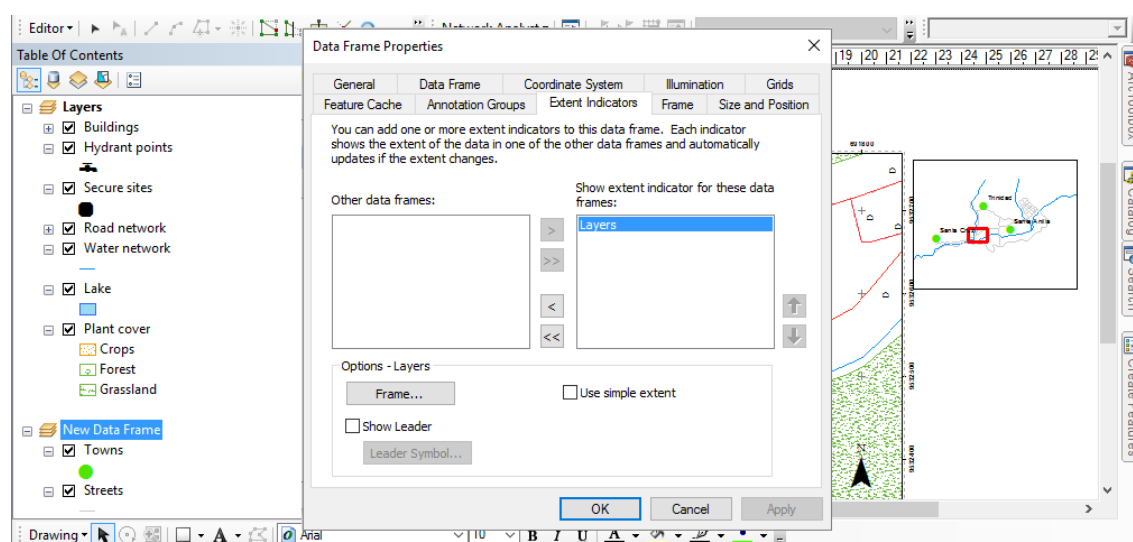

Figure 69. Configuration of location indicators

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As many data frames as required can be inserted. Try not to use a study area that is too small in comparison with the area showing its location.

To switch between each data frame ( ) in the table of contents, right click on **Layers** and select **Activate**. You can only manipulate the layers of a Data Frame when it is active.

Legend (6)

A legend allows the map reader to know the meaning of the symbols used to represent each element built into the map. To open the legend wizard, proceed as follows:

- Go to the **Insert** menu and select **Legend** (to advance between windows, click **Next**).
- In this window, in the **Choose which layers you want to include in your legend** section, from **Map Layers** you must pass the layers you want to show to **Legend Items** using the existing arrows. When there are several elements in the legend, you can choose to organize in columns in **Set the number of columns in your legend**.
- In the next window, in **Legend Title** you must assign a title to the legend. The text can be customized at the bottom.
- The following window in **Legend Frame** allows you to customize the border, background and shading of the legend. Styles should be combined carefully for an attractive design.
- The following window allows you to change the size and shape of the symbols used to represent lines and polygons. Usually the default settings are left.
- In the last window you can configure the spacing between each part of the legend. If everything has been configured successfully, click **Finish**.
- Use the **Select Elements** button (; on the Draw toolbar) to adjust the size and position of the legend.
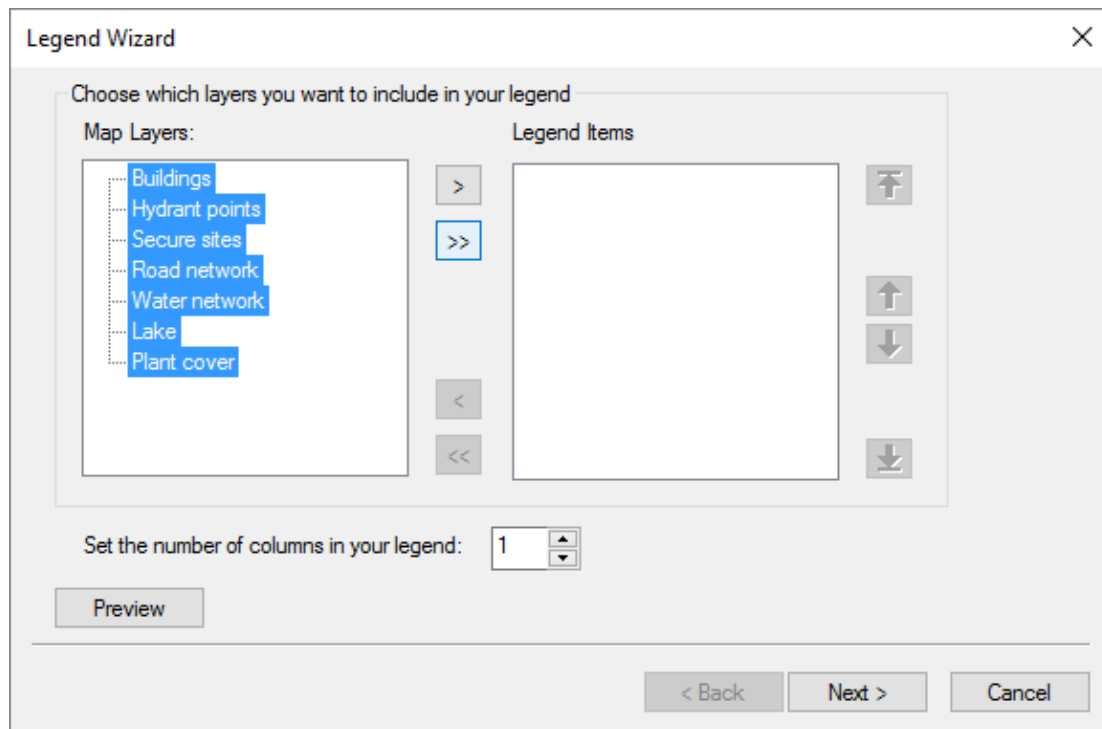
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Figure 70. Start window of the legend wizard

Numerical scale (7)

The numeric scale shows the relationship between the length values shown on the map and the actual length values of the terrain. Before inserting the numeric scale into the map, specify the scale value (3000) on the **Map Scale** in the **Standard** toolbar (Figure 5).

To do this, go to the **Insert** menu and click on **Scale Text**. From the list of various numerical scale formats select **Absolute Scale** and click **OK**. It can be verified that the denominator of the generated numeric scale is dynamic: when modifying the scale of the map the denominator of the scale is automatically modified.

The **Select Elements** button ( ) can be used to adjust the position of the map. In addition, you must also go to the **Insert > Text** menu to add a text box. Write the word "*Scale*:". Use the **Select Elements** button to set the text box in front of the numeric scale. So that you can read: "Scale 1:3.000"

Graphic scale (8)

The graphic scale is a bar divided into parts that visually indicates the length on the ground. To add a graphic scale, go to the **Insert** menu and select **Scale Bar**. From the list of scale bars you

can select the preferred scale (e. g. **Alternating Scale Bar 1**). Use the **Select Elements** button (

) to adjust the position.

To configure the graphical scale, the following aspects must be taken into account:

- Click the **Select Elements** button ( ) to right click on the graphic scale and select **Properties**.

- Go to the **Scale and Units** tab.

- In the **Units** section select meters as the division unit. In **Label** write: *Meters*.

- In the **Scale** section, in **When resizing** select **Adjust width**. Insert the value 2 in **Number of divisions and Number of subdivisions**; in **Division value** insert 50 (the length of the graphic scale is obtained by multiplying the values of **Division value** and **Number of divisions**).
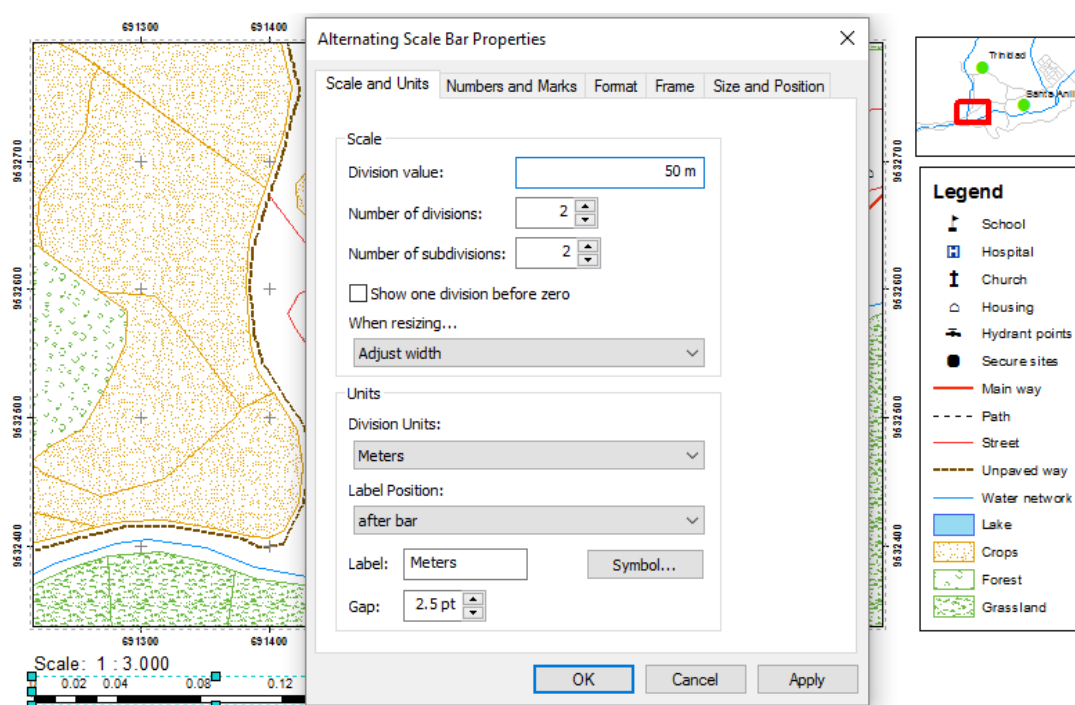

Figure 71. Graphic scale configuration

Geodetic reference parameters (9)

It is always necessary to specify the geodetic reference system used in mapping. To do this, go to the **Insert > Text** menu and type the following text:

Universal Transverse of Mercator Projection.
Elipsoid and Horizontal Datum WGS 84 Zone 17 South.

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Area of cards or boxes (10)

The cards or boxes allow you to add information to the map. You can include the names of those responsible for its elaboration, the name of the project or program, logos, the source of the cartographic inputs, date of elaboration, working scale, etc.

To add a logo, go to the **Insert > Picture** menu. Browse and select the image to use. Adjust the size and position with the **Select Elements** button ( ).

In addition, you can build an information box with ArcMap drawing tools. But it is recommended to insert it as an object. To do this, go to the menu **Insert > Object > Microsoft Word Document**. In the Word document that opens, as an example, you can copy *Table 6*, then close Word. Finally, the size and position is adjusted with the **Select Elements** button ( ).

Table 6. Information card

Information box	
Communal base map	
Topic: My first map in ArcGIS	
Source: Ortofoto Programa SIG Tierras	**Date:** February 2018

When you have entered all the elements to be published on the map, it is recommended to organize each one of the elements to improve the visual presentation. For example, selecting multiple items and right-clicking on them displays options for grouping, aligning, distributing, and so on.

11.3. Export and print a map

Once the mapping process is complete, a map can be printed or exported in various formats.

To print the map, go to **File > Print** menu, and configure the printer according to the features you have.

If you need the map to be in another digital format, it is exported from the **File > Export Map** menu. Select between EMF, EPS, AI, PDF, SVG, BMP, JPEG, PNG, TIFF, and GIF formats. The resolution and additional parameters can be configured in each format.

In some cases, especially when special characters are available, a PDF file is not usually readable. We recommend using a PDF printer that is installed in the system.

Finally, you can see the result of the map prepared following the instructions in this document (Figure 72).
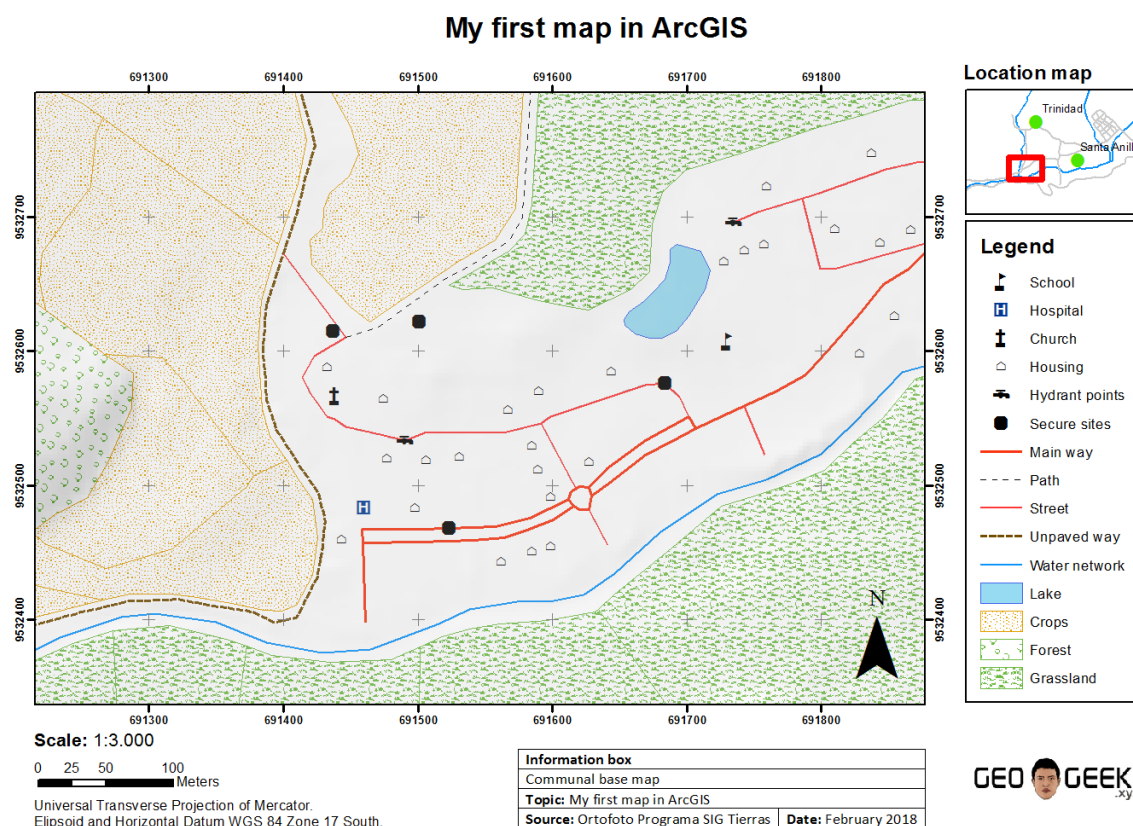
Figure 72. Example of a map elaborated with ArcGIS 10

12. Frequently asked questions

Which zone do I select if my study area shares two UTM zones?

What you usually do in this case is work with the UTM zone that contains most of the study area.

If I copy an MXD project, will all the map layers (shapefiles and images) be copied?

No, an MXD file simply manages file paths and displays settings for legends, display scales, case selection, etc., among other things, but not the layers themselves. Before starting a project, it is recommended to store all layers within a single directory. In the **File > Map Document Properties** menu, select the **Store relative pathnames to data sources** check box to make it easier to connect files linked to the MXD.

You can also package a map project and all associated layers. To do this, go to the **File > Share As** menu to create a **Map Package**. The reader is allowed to investigate the uses (and drawbacks) of this tool.

How do I put labels on a layer?

Labels allow you to display the information of the elements that make up a layer: for example, if you want to display values for a layer of contour lines, hospital names in a point layer, the name of national parks in a polygon layer.

To add labels right click on a layer and select **Properties**. Go to the **Labels** tab and select the **Label features in this layer** check box. In the **Text String** section in **Label Field** select the field containing the information to be displayed on the map.

Although in the **Label** tab you can configure the style, positioning and other options for labels, for greater personalization you can change the tagging engine from the **View > Data Frame Properties > General Tab > Label Engine > Maplex Label Engine** menu.

What are the main elements that a map should have?

This depends on many factors, among others: the map's audience, size of the paper to be printed, distance from which it will be visualized, etc. Assuming that we are preparing a map for an academic work or consultancy, from our point of view the elements that will always be necessary are the graphic/text scale, the legend (s), the grid of coordinates and the north. If the map is presented on a separate page, it is highly recommended to use boxes, where the title of the map, the authors, the institution where it was made and the date will be indicated; for example, if the map is part of a text document and is to be inserted in the same, the title of the map must be in the figure footer.

What is the difference between projection and datum?

In simple terms, projection is the method used to represent the curvature of the earth on a flat surface, and datum is the set of parameters that are used to do it.

Is it possible to create several layouts in ArcMap?

No, you can only create one per map project (one for each MXD).

Can I insert a grid of flat coordinates and a grid of geographical coordinates?

Yes, it can be done. In the Data Frame properties, go to the **Grids** tab **> New Grid**. You can add multiple grid coordinates.

Why don't my data have a reference system?

This problem is very common in GIS. It is possible that the person who created the data did not define the spatial reference system used. Nor can one guess the reference system used if there is no record. In shapefiles the reference file has a PRJ extension.

Can I import CAD files into ArcGIS?

Yes. Let's assume we have an AutoCAD (DWG) file that is storing a topographic map. Click on **Add Data** and locate the AutoCAD file. Double-click on it and a list of files, which are actually the types of geometries contained in the AutoCAD file, appears. Now let's assume that we want to export the contours from the AutoCAD file. The contours are always polylines, so choose **Polyline** and click on **Add**. With this we have uploaded all the polylines of the AutoCAD file into ArcMap. Since we only want to export the contours (we will assume that these are in layer 27), we have to tell ArcMap that we only want to visualize this layer. To do this, go to **Layer Properties** and click on the **Drawing Layers** tab; this deactivates all layers and activates only the layer of the contours. When only the contour lines are visible, we can export the layer to any vector format (**Data > Export Data**).

Can I add new symbols to ArcGIS?

Yes. New symbols can be inserted in the style manager. Go to the **Customize > Style Manager** menu. Go to the Windows local user style file. Choose a category and right click on **New**.

Is it possible to convert a slope map from degrees to percent?

Yes. It can be done with Raster Calculator. The formula is:

s[%]=tang(s[°])*100
where s[%] is the slope in percent and s[°] is the slope in degrees.

Can I import a shapefile table into Microsoft Excel?

Yes, at least in the old versions of Excel, and also in Excel 2016. You have to open the program and tell it that you want to open a file. In the file type, indicate dBase (*.dbf). With LibreOffice you can do it, too. But be careful - the fact that it can be done does not mean that it is advisable. In fact, it is not advisable, because if you do something unexpected, like delete a column or even delete a row, the shapefile may be damaged and become unusable. We recommend you to copy only the DBF file to another directory and then open it and modify it as you want. Any modification of the database associated with a shapefile is recommended to be done in a GIS.

Can I convert a point shapefile to polygons?

It's possible, but the outcome may not be what you expect. To put it simply: from, say, 100 points, and without violating the topologic rules, you can form a number of different polygons. On the other hand, there is a tool that generates a single polygon from a layer of points. It's called **Minimum Bounding Geometry** and can be found in **ArcToolbox**, under **Data Managemet Tools > Features**. Its use is very intuitive.

Why does ArcGIS usually close unexpectedly?

ArcGIS applications sometimes close unexpectedly for no reason. When you agree to submit the bug report, it is sent directly to the Esri developer team. Some bugs are usually corrected by installing the Service Pack for each version.

When I export a map to PDF, why not all the symbols are properly displayed?

Usually, when special characters are used when exporting a map in PDF format, not all characters are displayed. It is recommended to export in PDF format from **File > Print** using a local PDF printer.

How can I view the Table of Contents if I have closed it?

Sometimes we accidentally close the Table of Contents. We go crazy for a while because we think it's a toolbar and try to activate it where toolbars are activated. However, to reactivate the table of contents, go to the **Windows** menu **> Table of Contents**.

Is it possible to calculate the centroid of a polygon?

Of course. This is very easily done with the **Feature To Point** tool in **ArcToolbox > Data Management Tools > Features**. The operation of this tool is very simple. Just remember one thing: if you activate the "Inside (optional)" checkbox, all the points will fall within their respective polygons, but these points will not always be the centroids of the polygons in the strict sense of the word centroid.

Why are the layers of my project displaced?

It is quite possible that the layers have different spatial reference systems. It is also likely that the scale of work and inputs were different at the time of generating the layers.

How can I know the resolution of a raster?

Click twice on the layer, go to the **Source tab** and in the **Property table** you search for the **Cell Size (X, Y)** row (in my version it is the third one). Be careful! Don't get confused: in this field there are two data, the resolution in **X** and the resolution in **Y**. So if you see 3,3, it doesn't mean that the spatial resolution of the layer is three point three meters, but rather that the resolution in X is three meters and the resolution in Y is three meters. GIS can theoretically handle raster layers of different resolutions in X and Y, although this layer type is very rare. To the best of the authors' knowledge, only some GIS like GRASS or R can handle these situations properly.

Is the pixel size equal to the cell size?

Yes, the pixel size is the cell size or spatial resolution of a raster. According to (ESRI, 2016d) a cell must be small enough to capture the necessary detail and large enough to run analysis tasks and efficiently store the information. The smaller the pixel size, the higher the raster resolution and the file size.

How can I copy a shapefile to another computer?

You can easily use ArcCatalog. This program has similar features to Windows Explorer, but with GIS layers, so it is very easy to copy, cut and paste GIS layers, including shapefiles. If you want to do it with Windows Explorer and, for example, you want to copy the layer "*road_network.shp*", make sure to copy all the files that are in that directory and whose names start with

"*road_network*" because, as you know, a shapefile layer is composed of several files, at least three and in most cases six.

Can I open an MXD in a previous version of ArcMap?

Not in principle. What you can do is save the MXD as a project file from an earlier version of ArcMap. This can be done from **File > Save A Copy** and in **Type** you choose the version of ArcMap for which you want the project file to work. Remember that the higher versions open the project files of the lower ones, but not vice versa.

Do I have problems running an ArcToolbox tool?

If opening an ArcToolbox tool gives a message similar to this *"Unable to execute the selected tool. You do not have the necessary license to execute the selected tool ",* you must be sure that you have a license for the extension you want to use. To activate an extension, go to **Customize > Extensions** menu. Extensions are only activated if you have a license.

In some cases when you try to open an ArcToolbox tool, it sends the message *"Do you want to open or save this file?"* with reference to the **MdDlgContent.htm** file. To fix this error, Microsoft Windows Programs must be selected as the default in Windows settings.

Why can't I select A1 in the print size?

The default paper size available in ArcMap depends on the printer options installed. If a printer only supports A4, it is not possible to select a larger size. To select any paper size in the print window (File > Print) uncheck the **Use Print Paper Settings** check box.

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