ArcGIS Pro

MANUAL

Become a Pro

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Authorship

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This manual is an update: Fundamentals of GIS: Applications with ArcGIS.

Cover

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1. Introduction

The use of geographic information in decision-making is a fundamental for everyday life that often goes unnoticed. From selecting the most efficient route to work, to finding the address of a store via a smartphone, people constantly make decisions based on the analysis of geographic information, often without realizing it.

Geographic Information Systems (GIS) are valuable tools that allow for analyzing spatial data more efficiently and accurately. Using GIS, it is possible to visualize geographic data, identify patterns and trends, and make informed decisions in various contexts, including urban planning, natural resource management, traffic management, and much more. In summary, GIS is an essential tool for improving the efficiency and accuracy of decision-making based on geographic information.

According to López Trigal (2015), a GIS is an integrated system composed of hardware, software, data, and users that allows for capture, storage, manage and analyze digital information, besides the creation of graphics and maps, including the representation of alphanumeric data. Burrough (1986) defines GIS as a computerized model of geographic reality, designed to meet specific information needs, allowing for the creation, sharing, and application of useful information based on data and maps.

For many decades, GIS has been used in issues related to land and natural resource management, environment, military coordination, and in contexts related to Earth sciences, such as geography and geology. Recently, its potential use has also been explored in unprecedented fields as in Human and Social Sciences research (Del Bosque, Fernández Freire, Martín-Forero Morente, & Pérez Asensio, 2012).

ArcGIS Pro is ESRI's flagship application, encompassing classic desktop GIS functionality. ArcGIS Pro includes a set of tools that enable the visualization and management of geographic information, and has an extensible architecture, involving new functionalities. These extensions include the Spatial Analyst, 3D Analyst, and the well-known Geostatistical Analyst.

The objective of this technical manual is to introduce basic GIS concepts through the exploration of case studies that cover the entire map creation process. Although ArcGIS Pro has a wealth of tools, it is important to note that not all of them can be covered exhaustively. Instead, the purpose of this document is to help users become familiar with the general operation of the program and to motivate them to continue learning independently.

As the manual progresses, it is expected that users will acquire and improve skills, analyzing geographic information more efficiently to create high-quality maps. This document is a useful tool for those interested in developing their GIS skills and for those who wish to enhance their existing abilities.

The document is designed for widespread and accessible distribution. The reader is authorized to copy, remix, transform, or redistribute part or all of the material in any medium or format for **non-commercial purposes**, provided that the original source of the work is adequately cited.

Without further delay, the ArcGIS Pro Manual is presented, with the expectation that it will be highly beneficial to the reader.

This manual was developed using ArcGIS Pro 3.3/3.4. Some parts were optimized with ChatGPT. The exercises are available at https://github.com/franzpc/arcpro_en

2. Geographic Terms

Geographic information in digital formats needs the standardization of criteria and the inclusion of minimum parameters to ensure its quality. This standardization enables interoperability among users, optimizing the use and exchange of information. It also facilitates the reuse and democratization of this information (SENPLADES, 2013).

Below is a glossary of the most relevant geographic terms that will be utilized throughout this document:

- **Band:** Each section of the electromagnetic spectrum classifies radiation into different wavelengths, which are captured by sensors. Radiation data is typically organized as raster files and contains numerical values collected for each defined band (Moreno, 2008).
- **Cartographic projection:** This geometric operation enables the representation of the curved surface of the Earth (three-dimensional) to a flat surface (two-dimensional). This procedure transforms the real angular coordinates of geographic objects into planar

coordinates, thus enabling their cartographic representation in two dimensions (Lopez L., 2015).

- **Coordinate:** The value of a position on the Earth's surface defines the location of any point on it, allowing for the determination of the distance between any two points. Imaginary lines, perpendicular to each other and called parallels and meridians, are used to obtain these values. Their intersection defines the position of a point in the coordinate system (López L., 2015).
- **Datum:** A parameter or set of parameters that defines position (A.282). Different coordinate systems vary in their origin, scale, and orientation [ISO 19111:2007].
- **Digital Elevation Model (DEM):** A digital elevation model, or DEM, represents the height of the terrain above sea level in a particular area. It is a numerical data structure that depicts the spatial distribution of the land surface's altitude (Mancebo et al., 2008).
- **Ellipsoid:** A surface formed by rotation around a principal axis, as the movement of the Earth. Note: The international definition specifies that ellipsoids are always oblong, meaning the axis of rotation is always the minor axis [ISO 19111:2007].
- **Geopositioning**: The measurement of an object's geographic position using a Global Positioning System (GPS) [ISO/TS 19130:2010].
- **Georeferencing**: The operation of assigning geographic coordinates to any information (usually a layer) that lacks in it. It is commonly applied to represent accurately the position of Earth images or associated events [Moreno, 2008].
- **Image**: A raster-type layer, whose attribute values are distributed in grids, representing a physical parameter in numerical form [ISO 19115-2:2009].
- **Latitude**, represented by the symbol (φ): Latitude is the angle measured from the Earth´s center between the Equator and a specific point on an ellipsoid. Circles of equal latitude form complete circles around the Earth's surface. Latitude is measured from the Equator (0°) to the poles (90°), with positive values in the Northern Hemisphere (0° to 90°) and negative values in the Southern Hemisphere (0° to -90°) (Del Bosque et al., 2012).
- **Layer**: A basic unit of geographic information according to a map in raster (grids) or vector (points, lines, or polygons) format from a server [ISO 19128:2005]. Conceptually, a layer is a portion of geographic space in a specific area, equivalent to an element of the map legend, like temperature or atmospheric pressure [SENPLADES, 2013].
- **Legend**: The application of a classification to a specific area (A.52) using a defined mapping scale and a specific dataset [ISO 19144-1:2009].
- **Longitude,** represented by the symbol (λ): Longitude is the angle measured from the Earth´s center between the zero meridian and a specified point on an ellipsoid. Points

on the Earth's surface with equal longitude form semicircles from the North Pole to the South Pole, crossing the parallels of each latitude perpendicularly (Del Bosque et al. 2012). The zero meridian passes through Greenwich, United Kingdom (0°), from which the longitude is measured up to 180° westward (positive) and eastward (negative).

- **Remote Sensing**: Broadly defined, remote sensing is the acquisition of information about an object from a distance, without physical contact between the object and the observing system, such as radar or satellite images (Sobrino, 2000).
- **Scale**: The relationship between the magnitudes of elements represented on a map compared to their real values. This involves the reduction of the real-world elements to significantly smaller maps or documents. Scale representation on a map can be graphical or numerical [López L., 2015].
- **Slope**: The ratio of change in elevation relative to distance or the length of the curve [ISO 19133:2005].
- **Vertical Datum**: A parameter defining the height or depth of a point above or below sea level. Note: Geodetic heights are related to a three-dimensional ellipsoidal coordinate system referenced to a geodetic datum [ISO 19111:2007].

3. Data Models

It might seem obvious, but before working with GIS data, it is essential that these data are in a digital format. Almost all features found on the Earth's surface can be encoded for computer processing. Depending on the type of information, one may choose a specific data model or another option.

What is less obvious is the method of representing the real world in a digital medium (ESRI, 2010). Despite the diversity of geographic information, there are two basic models for simplifying and modeling space within a computer system: (i) the vector model, which uses points, lines, or polygons, and is typically employed for discrete geographic phenomena (such as roads, urban areas, vegetation cover, etc.); and (ii) the raster model, which utilizes grids or pixels, and is generally used for continuous phenomena (like temperature and precipitation). Both models are complementary and coexist within GIS, as they are suitable for studying specific types of information (Del Bosque et al., 2012).

3.1. Vector Model

The vector data model operates on the principle that the Earth's surface consists of discrete objects, such as trees, rivers, and lagoons (ESRI, 2010). Unlike models that use basic units to segment an area, the vector model captures the variability and characteristics of the terrain through geometric entities.

Each of these entities is defined by constant characteristics, and their shapes or contours are explicitly encoded. This model represents geographic space using geometric primitives like points, lines, or polygons to depict key elements of that space (Olaya, 2020). Employing these primitives allows for the creation of maps rich in detail and clarity and permits an accurate representation of geographic objects.

3.2. Raster Model

In the raster data model, the structure is based on a matrix of cells (grids or pixels) arranged in rows and columns. Each cell within this matrix holds information about specific variables, such as precipitation, temperature, relative humidity, solar radiation, or different wavelengths of the electromagnetic spectrum.

In this model, the cells are not individually positioned in space; instead, the values of each cell correspond to a specific element within the matrix. This matrix forms a fixed and regular structure, including the coordinate of each cell, for what its spatial location must be established. However, the raster model references the values of the elements depicted in the matrix rather than their distinct spatial location (Olaya, 2020).

4. Coordinate Systems

Maps, a vital tool for representing the Earth's surface and its features, have been utilized since ancient times. In GIS, coordinate systems are crucial for precisely locating identified features. However, these features can be recorded in various coordinate systems, depending on the methods used to collect the geographic information. Consequently, understanding key terms like projection, ellipsoid, geoid, and datum is essential for effectively working with GIS. These key terms or concepts dictate how the Earth's surface is represented, as well as its spatial orientation. Understanding these concepts, one can achieve a more accurate and detailed depiction of the Earth's surface and its features on a map.

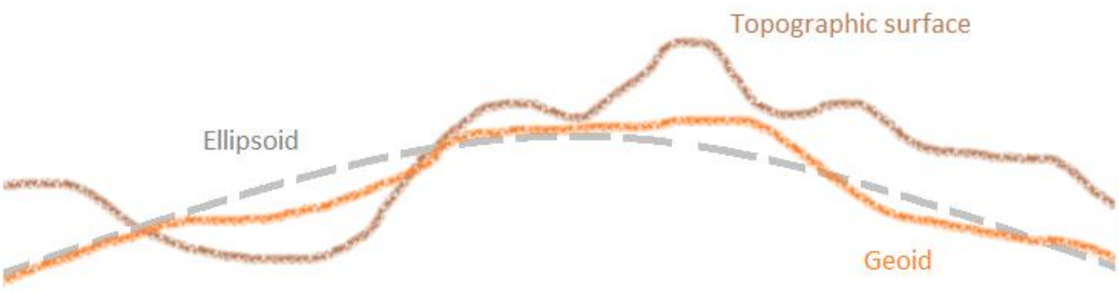
The **projection** process aims to represent the Earth's curved surface on a flat plane. This inevitably leads to the deformation of geographical aspects like contours, area, distance, and direction. Thus, selecting an appropriate projection is a critical decision in map-making, as each type is better suited for specific geographical regions.

Map projections are categorized into three types: conformal, equivalent, and equidistant. **Conformal projections** preserve angles between meridians and parallels but may distort contours. **Equivalent projections** maintain accurate area relationships, while **equidistant projections** preserve distances but can alter contours. Each category of projection has distinct applications and is essential for producing accurate and reliable maps (Del Bosque et al., 2012).

The **ellipsoid** is a geometric figure that most closely approximates the Earth's surface, providing a precise but idealized representation. In general, an ellipsoid is a three-dimensional figure formed by rotating a two-dimensional oval along its major or minor axis. This rotation creates a geometric figure known as a **spheroid** (ESRI, 2015). After establishing this theoretical model for the Earth's surface, the defining parameters for the sphere must be determined, which involves its radiuses, for what the length of both radiuses, the minor and major axes, are needed (Olaya, 2020).

The **geoid** represents the equipotential surface of the Earth's gravitational field, closely aligning with the mean sea level. This surface is perpendicular to the force of gravity at every point. However, it is important to note that the geoid's shape is irregular, influenced by the uneven distribution of landmass (ESRI, 2015).

Figure 1. Relationship between the geoid, the topographic surface, and the ellipsoid adjustment. Image credit: (Peter, 1994).



The **datum** specifies the coordinate system of a spheroid based on a series of ground control points, ensuring the accuracy of a point's location within the intended spatial extent (ESRI, 2011b). Although generated the spheroid, the datum may contain inaccuracies, because the rotating ellipse (spheroid) creates a completely smooth surface, which does not fully represent reality. Hence, choosing a local datum that accounts for local variations is crucial (ESRI, 2015).

To simplify, **projection** is the method of representing the Earth's surface on a plane, while the datum is the set of parameters used in this representation. To illustrate geographic information, there are two main methods: (i) using a geographic coordinate system, or (ii) using a projected coordinate system. The geographic coordinate system describes a location on a sphere (spheroid) using **latitude** and **longitude** parameters, while the projected coordinate system, based on a plane, utilizes "**X**" and "**Y**" coordinates (Hillier, 2011). In South America, the most commonly used coordinate systems are WGS84, PSAD56, and SIRGAS. In North America, the most commonly used coordinate systems are the North American Datum of 1983 (NAD83) and the World Geodetic System 1984 (WGS1984). In Europe, various coordinate systems are used, including Lambert-93 in France, the Irish Grid Reference System in Ireland, Stelsel van de Rijksdriehoeksmeting (RD) in the Netherlands, LV95 in Switzerland, and the British National Grid in the United Kingdom. It is important to recognize that some coordinate systems have specific advantages, which can facilitate the quick measurement of planar distances and surface areas.

5. First Steps in ArcGIS Pro

ArcGIS Pro, ESRI's flagship application, is designed to run on 64-bit computers. This software enables to resolve real geographic problems through a sequence of spatial operations, including simple and advanced analysis tasks. The results can be presented in attractive digital or printed maps. ArcGIS Pro offers capabilities to explore, visualize, analyze, and create 2D or 3D scenes and share them online. ESRI's strategy with ArcGIS Pro is to integrate the popular applications ArcMap, ArcCatalog, and ArcScene into a single program, thereby simplifying the geographic solution process. In simple terms, ESRI's formula for ArcGIS Pro can be summarized as:

$$\text{ArcGIS Pro} = \text{ArcMap} + \text{ArcCatalog} + \text{ArcScene}$$

For more information about downloading, installing, and obtaining licenses for ArcGIS Pro, please visit https://pro.arcgis.com/

It is recommended to develop this manual using the English version of ArcGIS Pro!

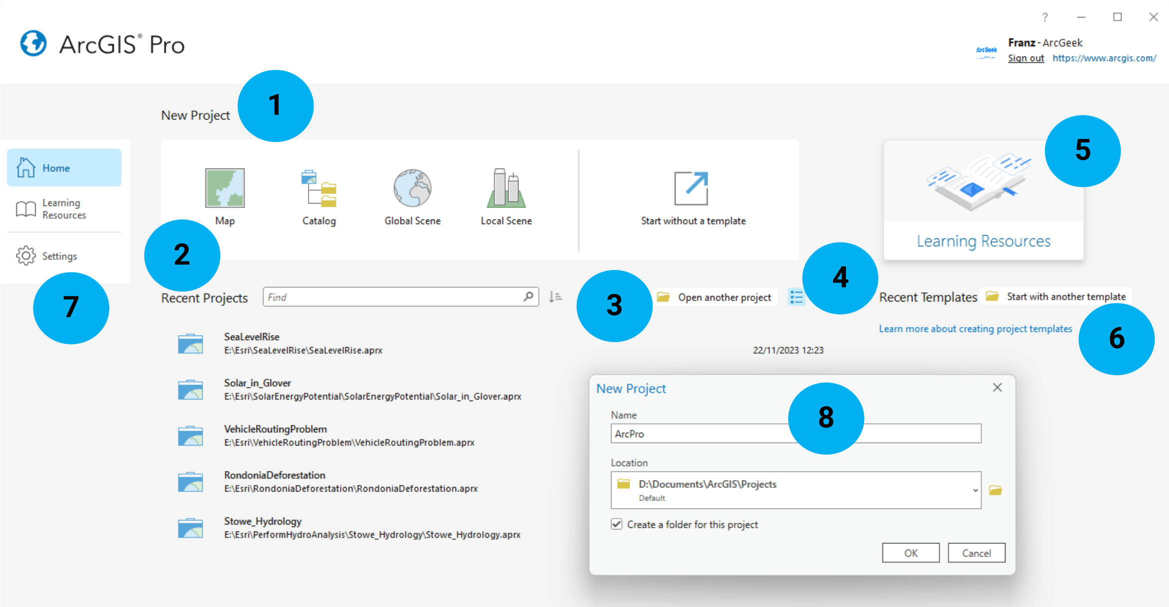
According to ESRI (2024), ArcGIS Pro typically organizes the work into projects, which are saved, by default, in a specific folder on the computer. Projects have the file extension

"**.aprx**", in which each project automatically creates its own geodatabase with the extension "**.gdb**", as well as its own toolbox with the extension "**.tbx**".

5.1. Create a "New Project"

During the initial launch of the application an Internet connection is necessary because the users must validate their login credentials, usually via their ArcGIS Online account. After this, the first screen displayed in ArcGIS Pro provides options to open recent projects or create new ones (see Figure *2*).

Figure 2. ArcGIS Pro Startup Screen.



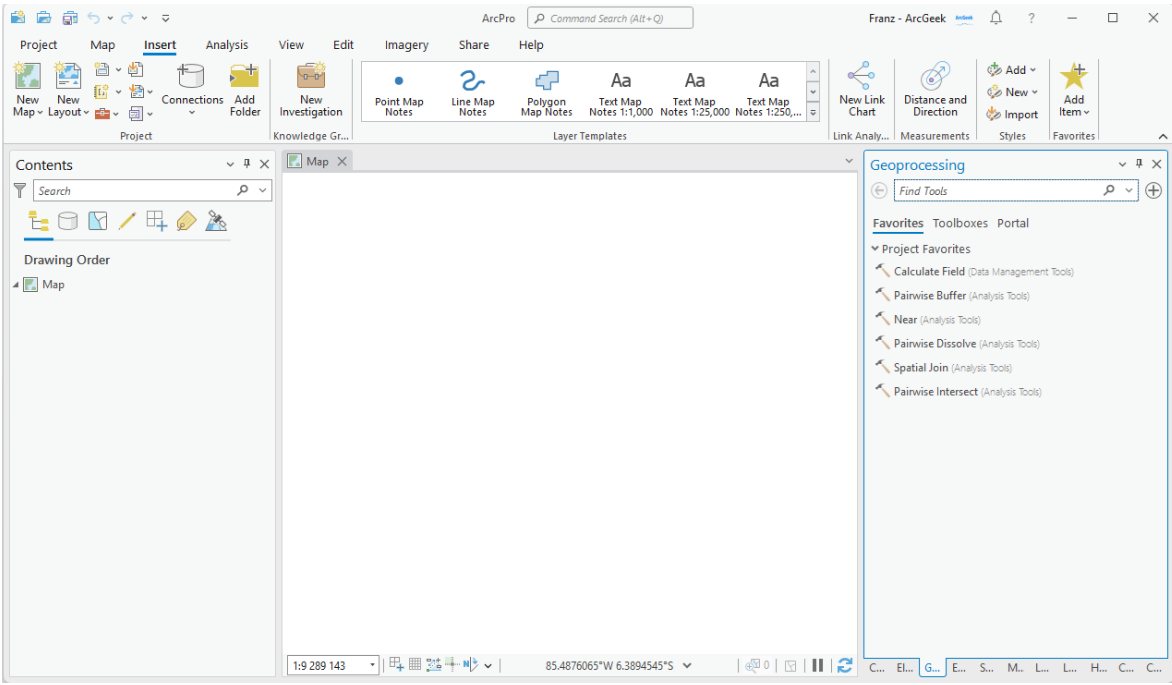
In the ArcGIS Pro home screen, the most relevant points to consider are:

1. **New Project:** Creates new projects providing various default templates. Generally, the **"Map"** template is used for creating new projects. For a temporary project or one intended to be saved later, the **"Start without a template"** option is recommended.
2. **Recent Projects:** The user can open recently accessed and saved projects (listed above), where the Pin-symbol can be used to mark them as favorite projects.
3. **Open another project:** Searches for projects not listed in recent projects, which is useful when copying a project copied from another computer.
4. **Recent Templates:** Starts new projects using templates. Recently used templates are listed above and can also be pinned as favorites.

5. **Learning Resources:** Offers resources such as tutorials, videos, documentation, instructor-led classes, MOOCs and more for exploring ArcGIS Pro.
6. **Start with another template:** Searches project templates not listed in recent templates.
7. **Settings:** Allows for setting ArcGIS Pro application preferences and manage other settings like connections and portal licensing.
8. **Create a "New Project":** After selecting "Map" (Circle 1, Figure *2*), the opening window enables the user to create and specify the details of a new project. The user defines the project's name in "Name", e.g. **"ArcPro"** and select the folder or directory at "Location", where it is saved.

When creating a new project with "Start without a template," the ArcGIS Pro window appears blank, offering the possibility to load vector or raster layers within the project, as well as to prepare the project's working environment (Figure 3).

Figure 3. View of a New Project in ArcGIS Pro.



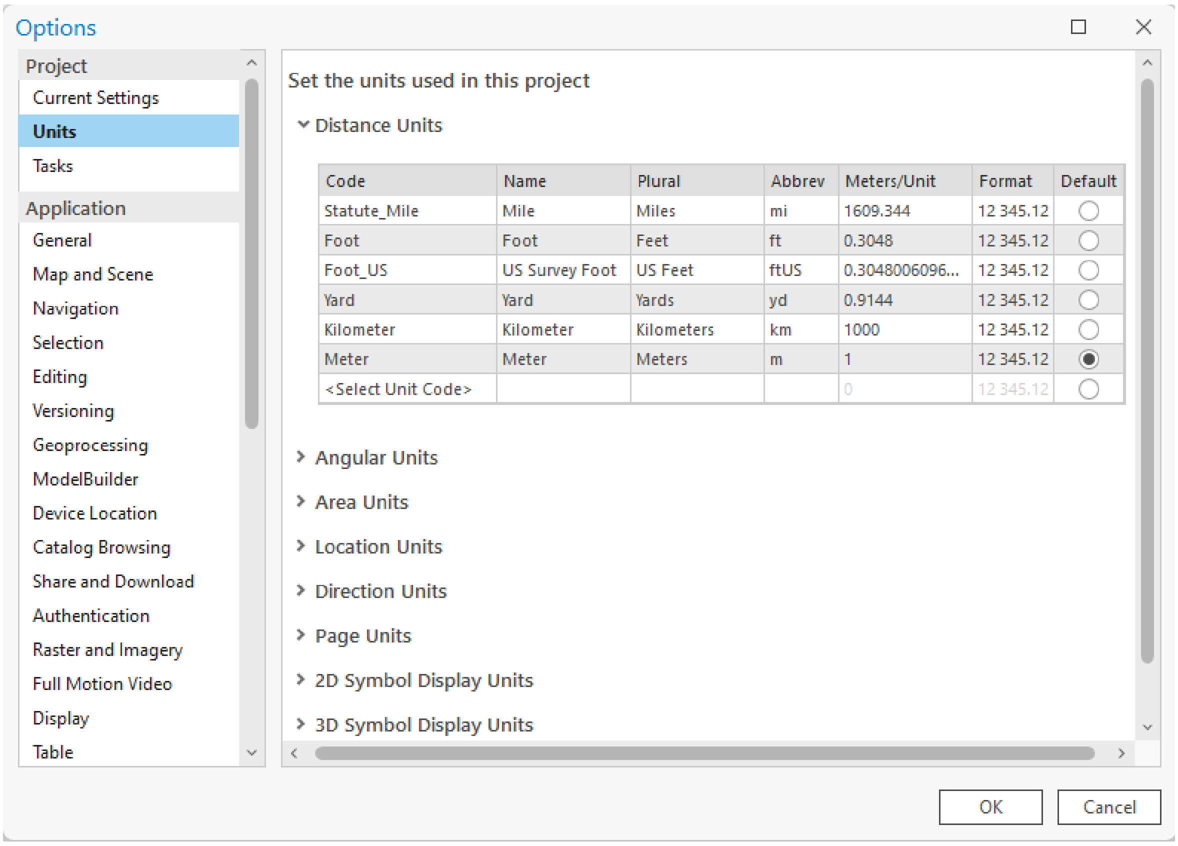
Before using ArcGIS Pro, it is recommended to set up the work units, which can be adjusted in “Settings – Options”. Subsequently, the user can create a new "Map", "Layout", or "Report". As mentioned above, creating a new map is the most commonly used feature for both beginners and advanced users, especially when preparing information for printing or publishing in a modern design.

5.2. Setting Units

The configuration of the units for the new ArcGIS Pro project can be done from the "**Options**" in the "**Project**" tab. Here, it is possible to select "**Units**" for distance, angle, area, location, and direction. In this case, select the metric units from the following path (see Figure *4*).

Menu Project > Options > Units

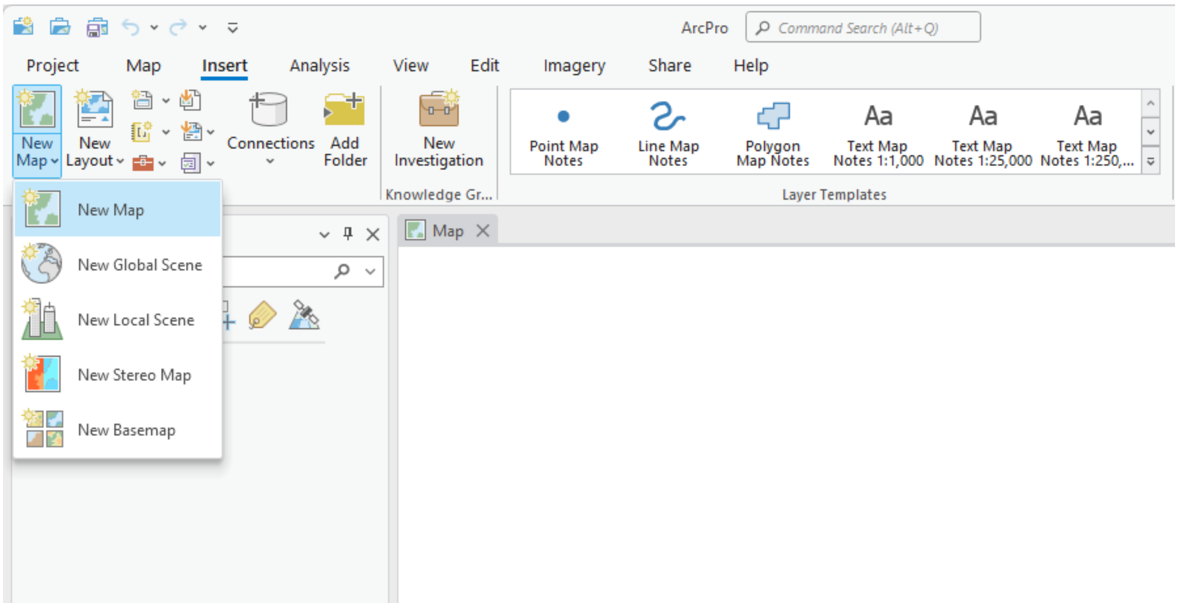
Figure 4. Setting units in ArcGIS Pro.



5.3. Creating a New Map

The first step in advancing the project development is to create a new "**Map**" (the section on Design and Publication will show how to create a new "Layout"). To create a new "**Map**", go to the "**Insert**" tab and click on the arrow next to "**New Map**" (see Figure *5*). In this section, users have the capability to create multiple maps, as well as Global or Local scenes, Stereo maps, and Basemaps as required. Usually, when a new project is created in ArcGIS Pro, a new "Map" is automatically created by default. However, in versions prior to ArcGIS Pro 3.2, it may be necessary to create manually a new "Map".

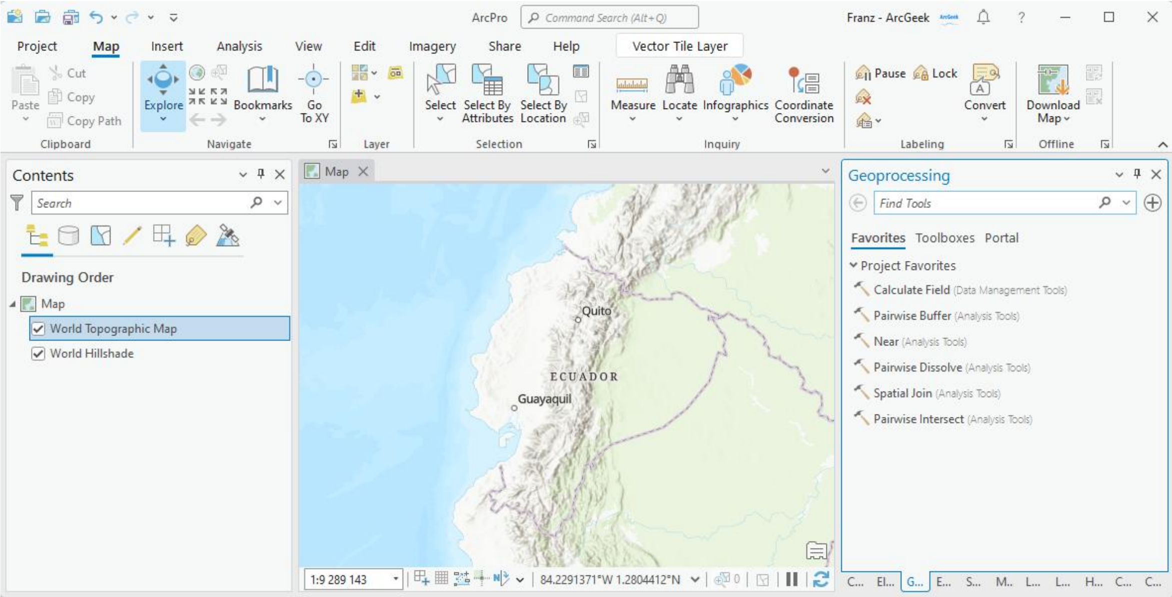
Figure 5. Creating a "New Map" in an ArcGIS Pro project.



Typically, upon creating a new "**Map**" or "**Scene**," a topographical map (or another type predefined by the user's organization) is automatically displayed in the background (as illustrated in Figure 6). In some cases, this may be convenient, but in most cases, it is not ideal as it can be distracting or undesirable. Because of this, it is suggested to start a new project with the background of the "Map" or "Scene" left blank.

Also referred to as "Views," the different "Maps" or "Scenes" created within an ArcGIS Pro project are essential components of the software's functionality.

Figure 6. View of a new map (includes the topographic "Basemap").

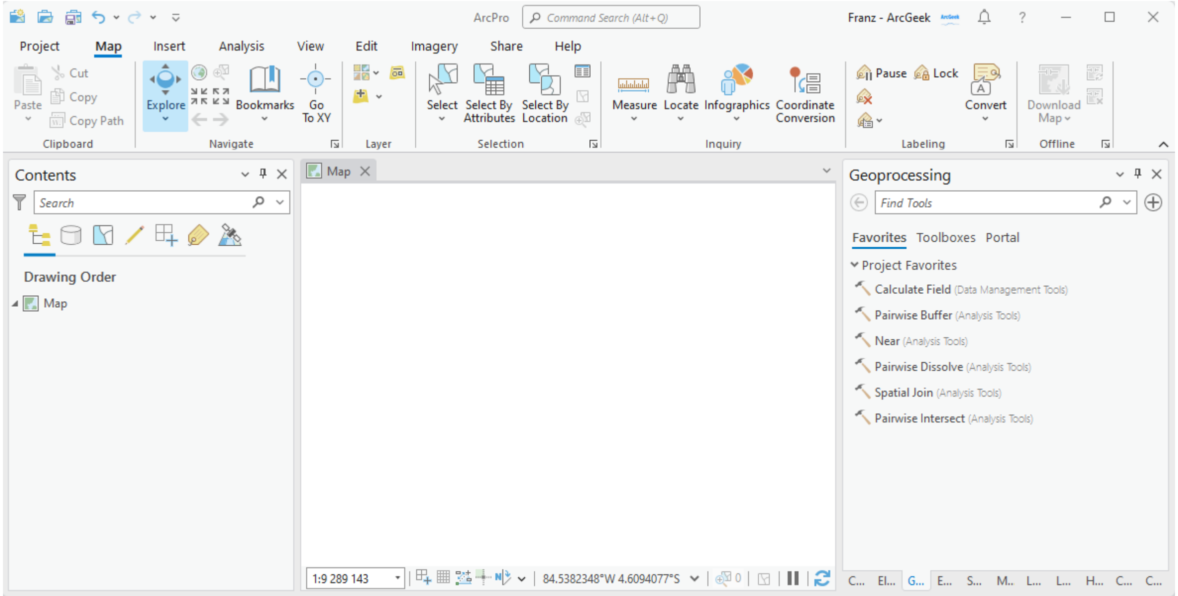


Sometimes it is inconvenient to have a "Basemap" every time a new "Map" is created. To delete the topographic "Basemap", follow these steps:

Project > Options > Application > Map and Scene > Basemap > None

A new "Map" or "Scene" is now created, providing a clean and distraction-free environment (as shown in Figure 7). Furthermore, the configuration screen also offers the option to customize the "Basemap" according to specific needs.

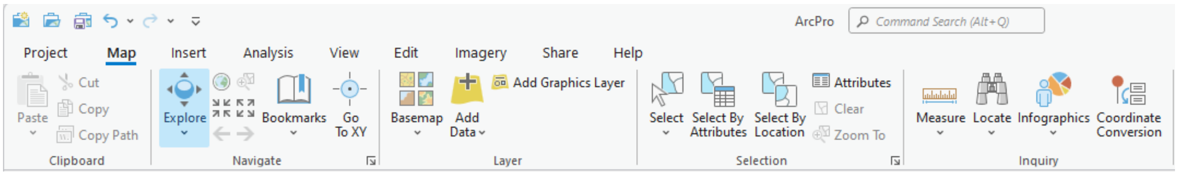
Figure 7. View of a new map (excluding the topographic "Basemap").



5.4. The Ribbon and Panels

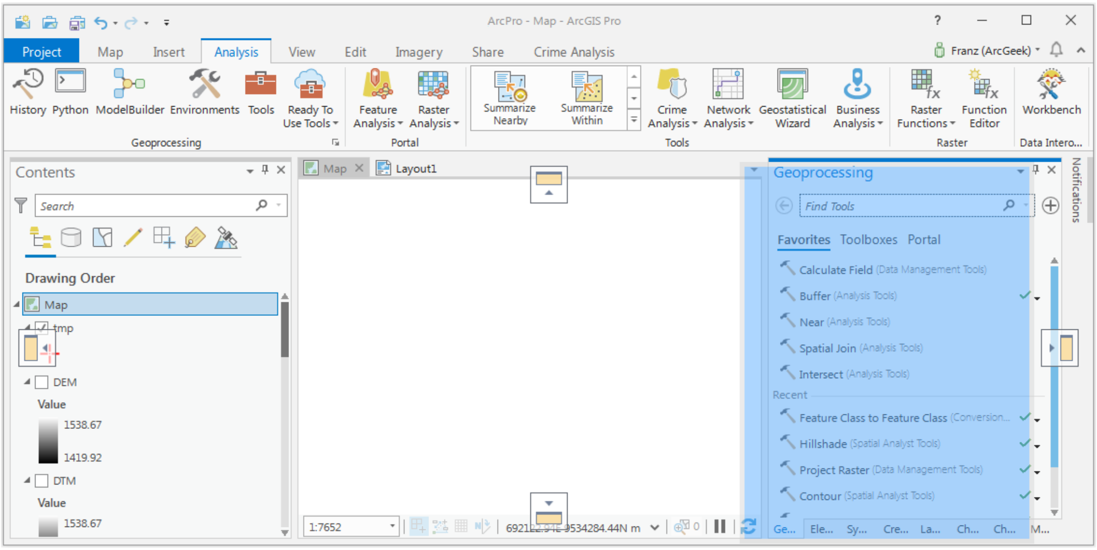
In ArcGIS Pro, the ribbon and panels are the most prominent parts of its interface. The ribbon is organized into tabs, which are further divided into groups. For instance, Figure 8 shows the active "Map" tab, featuring several groups such as "Clipboard", "Navigate", "Layer", "Selection" and "Inquiry". The "Map" tab generally contains the most frequently used tools in ArcGIS Pro, including zooming, panning, selection, adding layers, measuring ruler, and others. Some groups have "Pop-up windows" where all the tools of the specific group are located. To access these pop-up windows, click on the arrow in the lower right corner of the group.

Figure 8. ArcGIS Pro Ribbon Options.



Panels are windows docked within the ArcGIS Pro main window, allowing for the management of tools to enhance the application's functionality. By default, the "**Contents**" (left) and "**Geoprocessing**" (right) panels are open when a new map is created. Figure 9 (left) shows how the "Contents" panel organizes spatial information into layers, which can be vector and raster files, or even tables. The "Geoprocessing" panel (Figure 9, right) provides a range of tools for executing geoprocessing tasks.

Figure 9. Panels in ArcGIS Pro.



If a custom size or location for a panel is required, click, and hold the title of the panel. When a light blue box appears (as shown in Figure 9), the panel can be moved and replaced to the desired location.

6. Georeferencing an Image

Georeferencing is the process of assigning a spatial reference system to a digital image based on known coordinates. Many raster images, such as maps, scanned topographical charts, or aerial photographs, do not have an associated reference system and therefore require georeferencing.

To conduct georeferencing, it is necessary to know the real-world coordinates of an identified point in the image. For example, if the coordinates of a solitary tree, the corner of a house, or an intersection of two streets are known, the image can be georeferenced by linking these coordinates to the corresponding point in the image.

Figure 10 shows an example of an image without georeferencing. For georeferencing, the coordinates of points "P1" and "P2" must be known. For that, it is often necessary to realize a field trip to image site. At each point, coordinates must be taken with a GPS device (or even a cell phone), to subsequently linked these coordinates to their corresponding points in the image.

Figure 10. An aerial image taken with a drone, currently un-georeferenced.

6.1. Adding an Un-georeferenced Image or Any Layer

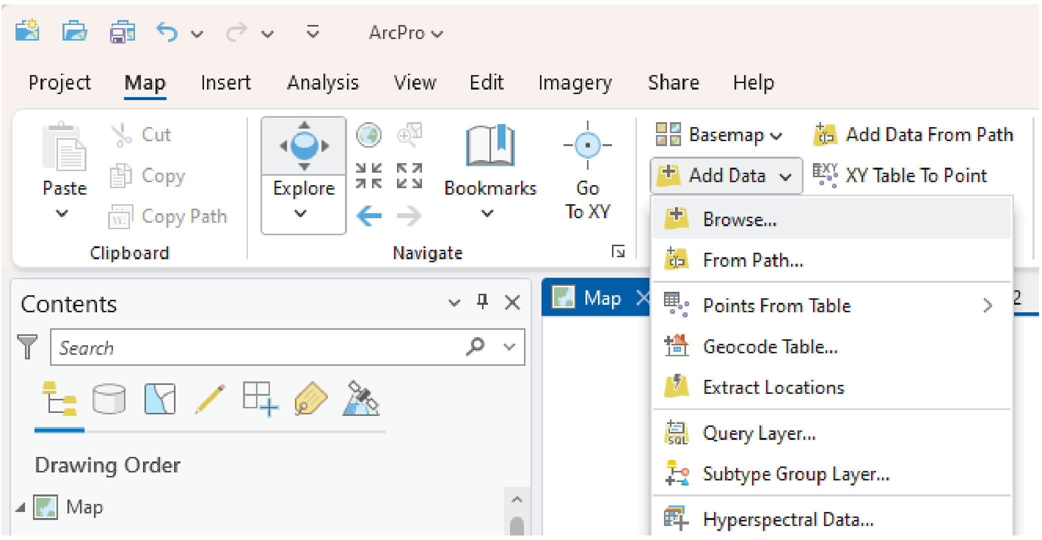
For georeferencing an image in ArcGIS Pro, first it must be added as a raster layer. For the present example, the image shown in Figure 10 can be captured and/or saved in formats such as TIFF, JPG, or PNG. Topographic charts often provide a printed coordinate system, which allows for the identification of various points coordinates using the values on the "X" and "Y" axes, mostly expressed in latitude and longitude.

To add the layer, one should go to the "**Map**" tab and click on the "**Add Data**" button inside the "**Layer**" group (refer to Figure 11), which permits to add spatial layers (vector or raster). This tool offers multiple methods for adding spatial information. In this case, one should select "**Browse**" and then navigate to the directory where the image was stored. Afterwards the images can be selected and added by clicking "**OK**". The example image is provided in the folder "**06_georeference**" and named "**image.png**".

Tab Map > Add Data > Browse

Another method to add spatial layers is by right-clicking on the newly created map in the "**Contents**" panel, where the "**Add Data**" button can also be found.

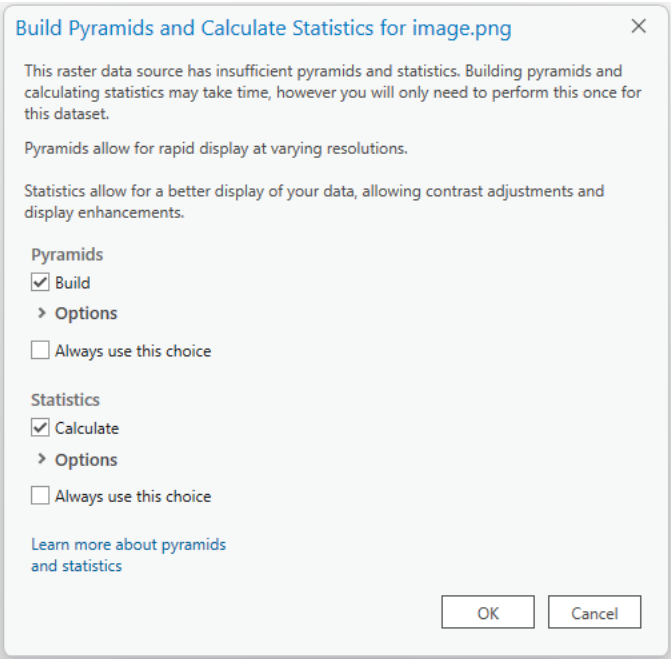
Figure 11. "Add Data" button in ArcGIS Pro.



The "Add Data" button, one of the most frequently used in ArcGIS Pro, allows the user to add layers from vector, raster, and tables.

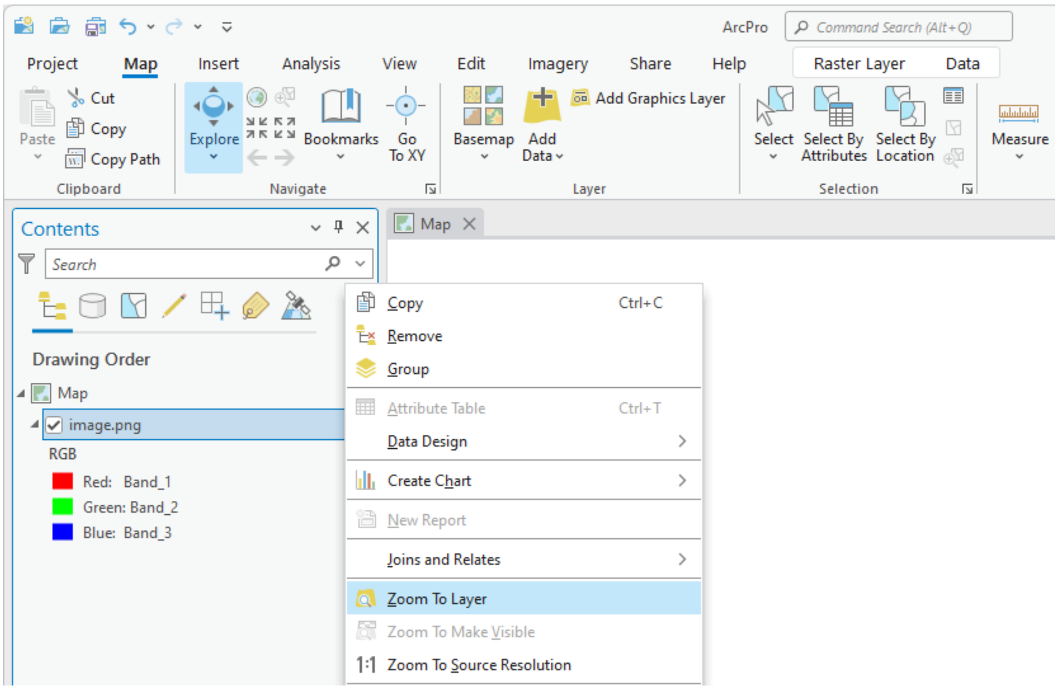
When a raster image is first loaded in ArcGIS Pro, the software displays the option to build pyramids. In this scenario, it is recommended to select "**Yes**" in the dialog box (as shown in Figure 12). These pyramids are visualization techniques that enhance the performance of raster images. As one zooms in, the levels are displayed with better resolution, allowing for progressively smaller areas to be viewed without the need to read the entire raster image (ESRI, 2019).

Figure 12. Building pyramids in a raster image.



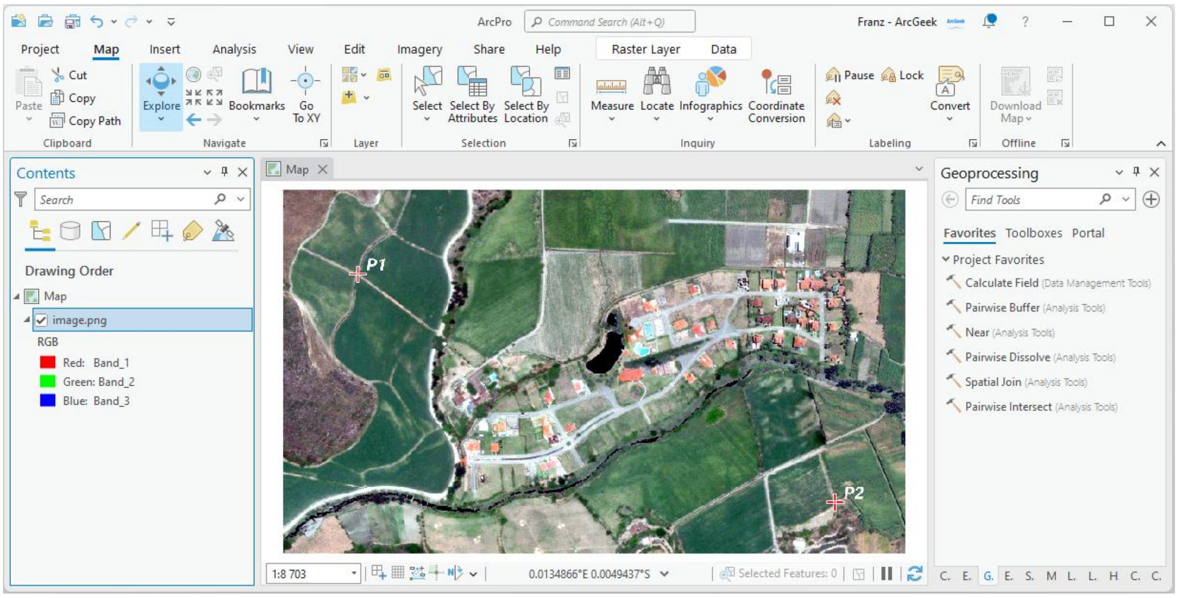
Now that the image is added to ArcGIS Pro “Contents” panel, it is not visualized yet, because a message stating "Unknown Coordinate System" appears on the right side of the screen, indicating the absence of coordinate system information (for now, this message can be omitted). In the "Contents" panel, the added file is named "**image.png**" along with its respective bands (RGB). To visualize the image, simply do a right-click on the "image.png" layer and select the option "**Zoom To Layer**" (as shown in Figure 13).

Figure 13. "Zoom To Layer" for a layer.



After the execution of the "**Zoom To Layer**" option, the **"image.png"** becomes visible on the screen (refer to Figure 14). It is important to point out that **this image will be the basis of this manual**, which is used to illustrate the creation of different vector layers for the publication of a map.

Figure 14. Current view of the un-georeferenced image.



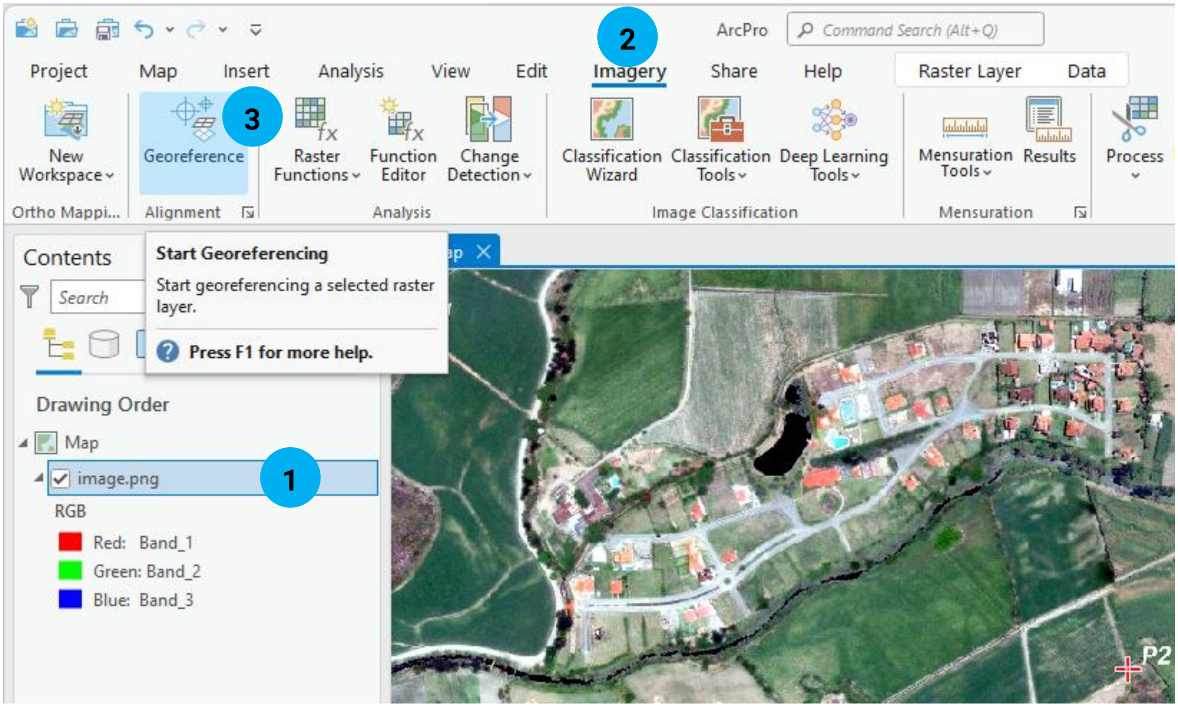
How can I obtain high-resolution aerial images?

A common method is purchasing them. Alternatively, entities such as local governments or universities might provide them. Another option is creating them using drones. However, it is important to remember that free options are not always available.

6.2. Selecting the Coordinate System of an Ungeoreferenced Image.

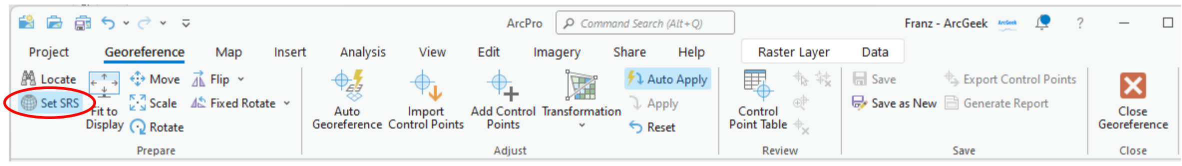
The next step is to determinate the coordinate system for the image, for what the georeferencing tools must be accessed. For it, the user first must select the image they wish to georeference in the "Contents" panel and then go to the "**Imagery**" tab in the ribbon and click on the "**Georeference**" tool in the "**Alignment**" group as shown in Figure 15. This action will open the "**Georeference**" tab, which includes different groups and their specific tools.

Figure 15. Activating the image georeferencing tools.



Before initiating georeferencing, the user must define the desired coordinate system of the image. In this example, the system "**WGS 1984 UTM Zone 17S**" is used. To select the coordinate system, after activating the "**Georeference**" tab (see Figure 16), the user should click on the "**Set SRS**" button within the "**Prepare**" group.

Figure 16. Ribbon options in the "Georeference" tab.

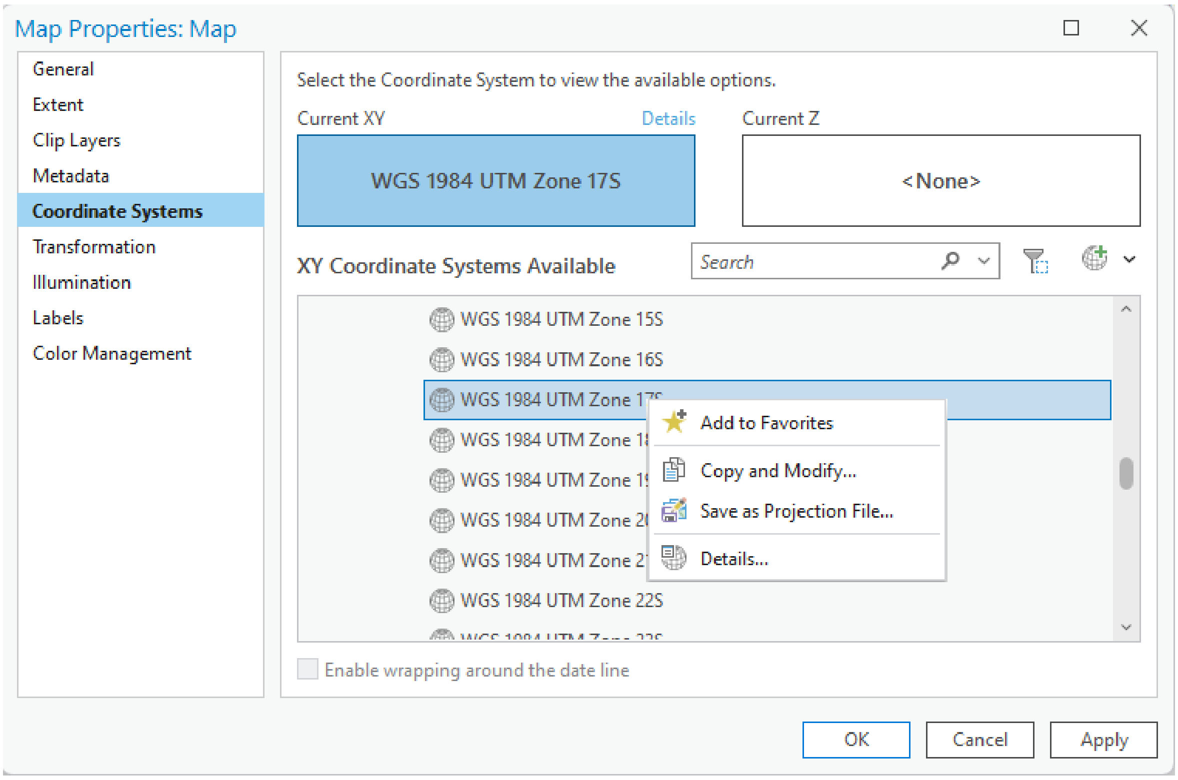


Executing this action opens the "**Map Properties: Map > Coordinate Systems**" pop-up window, where the user can select the desired coordinate system (for instance, "**WGS 1984 UTM Zone 17S**" can be found within the "Projected Coordinate Systems"; refer to Figure 17). Optionally, the user can mark this coordinate system as a favorite by doing a right-click on it and select "**Add to Favorites**". This action saves it under "**Favorites**", thus making it more easily accessible in future instances.

The path to the coordinate system for this example is in the following:

Projected Coordinate System > UTM > WGS 1984 > Southern Hemisphere > WGS 1984 UTM Zone 17S

Figure 17. Selecting the Coordinate System.

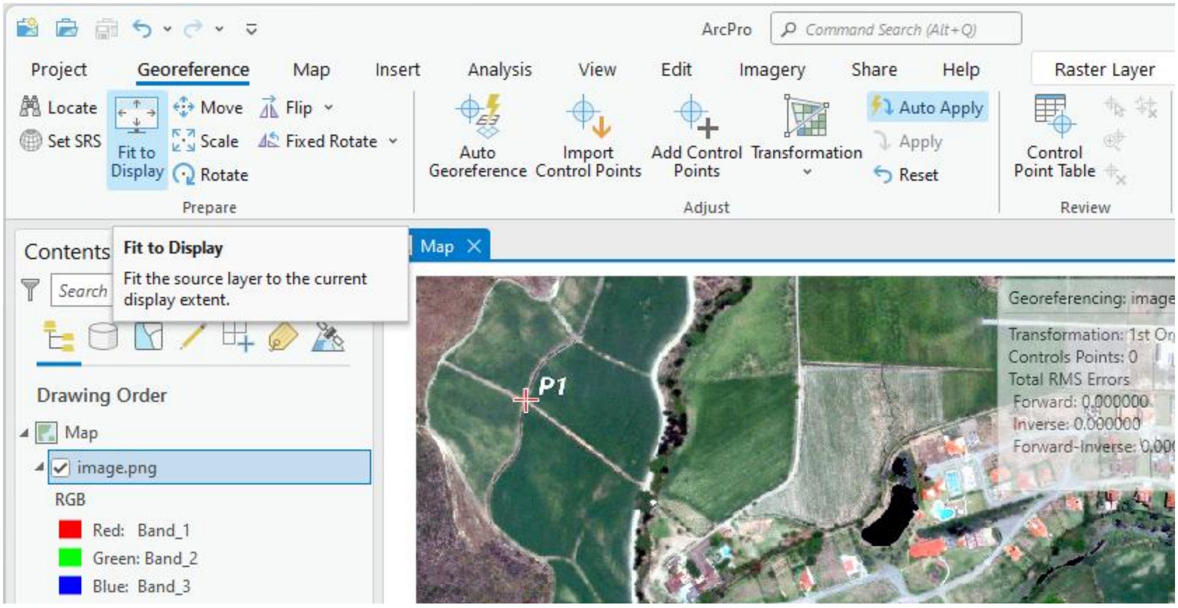


6.3. Georeferencing an Image with Control Points

The source of an image (even if it is a screenshot) is not as critical as identifying the same objects the image and the real world and assigning accurate coordinates to these objects or control points. In general, control points are crucial for georeferencing, as they establish the relationship between the "XY" coordinates of a raster image and the coordinates in the real world. In other words, the control points are the link that enables the georeferencing of the raster image and determinates its spatial location.

After the image is loaded and the coordinate system is set, the insertion of control points can begin. If "image.png" is not visible in the current screen view, "**Fit To Display**" can be clicked within the "**Prepare**" group in the "**Georeference**" tab (as illustrated in Figure 18).

Figure 18. "Fit to Display" within the "Georeference" tab.

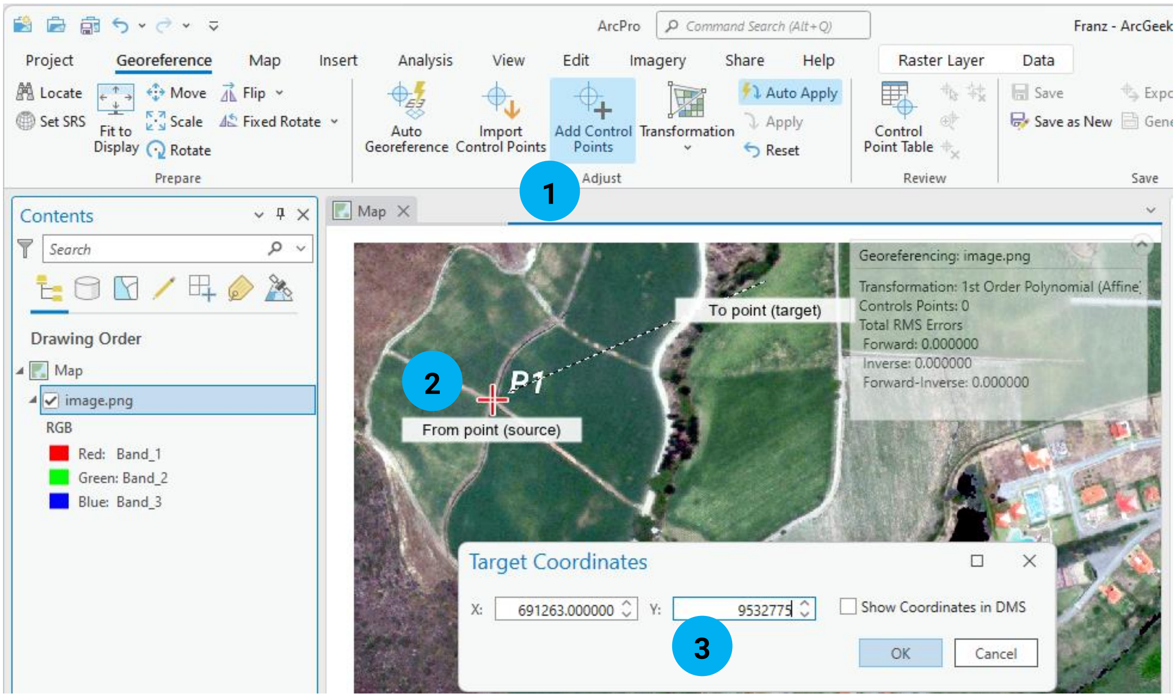


To georeference "**image.png**" based on the given control points (P1 and P2), the following steps must be applied. First, click on the "**Add Control Points**" icon located in the "**Adjust**" group in the "**Georeference**" tab (as shown in Figure 19). The cursor will then change into a cross with the text "**From point (source)**" appearing below it, which permits to click on a known point in the image (P1). After clicking on the point, the text "**To point (target)**" will appear below. To insert the coordinates of "P1", do a right-click on the selected point, and a window titled "**Target Coordinates**" will open. Here, the user can enter the real coordinates of the known point (in this case: X: 691263; Y: 9532775) and confirm with "**OK**".

It is possible that the "image.png" may disappear from the current view after adding the first point. To resolve this, do a right-click on the image in the "**Contents**" panel and select "**Zoom To Layer**" (refer to Figure 13).

The same procedure should be followed to add the second point (here: P2 = X: 692075; Y: 9532387) and any other point identified. In general, the more control points are used, the more accurate the georeferencing of the image. It is also possible to insert geographic coordinates in degrees, minutes, and seconds. To do this, activate the checkbox "**Show Coordinates in DMS**" (as indicated in Figure 19).

Figure 19. Adding control points with the "Add Control Points" tool.

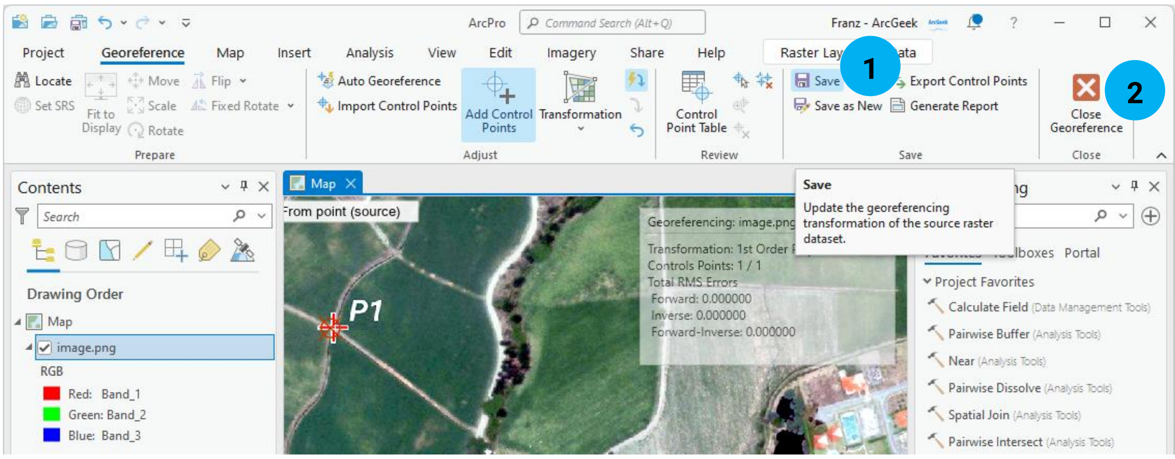


To complete the georeferencing process, after correctly inserting coordinates for each control point, the changes must be saved. This can be done in the "**Georeference**" tab within the "**Save**" group by clicking on the "**Save**" button. This action will generate auxiliary files related to the current image, containing the transformations performed. If saving the changes in a new image is intended, the option "**Save as New**" should be selected to ensure that the original image remains unaltered. Finally, to exit the "Georeference" tab, click on "**Close Georeference**" on the right side of the tab (as shown in Figure 20).

To navigate a specific location on the map, the user should utilize the "Go to XY" button, located in the "Map > Navigate".

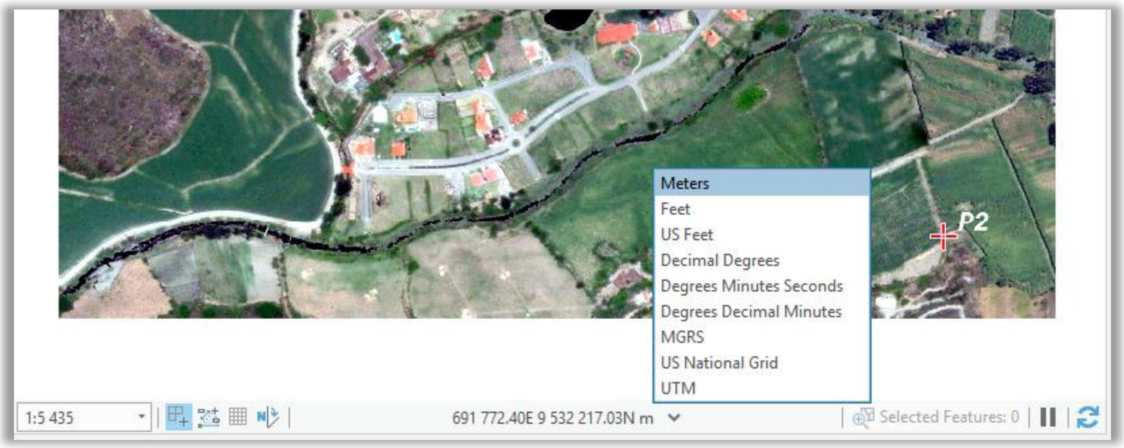
This feature allows for the entry of coordinates in various formats that correspond to the desired location, facilitating direct navigation to it.

Figure 20. Save georeferenced image.



Additionally, one can customize the units for the coordinates of the current map view in the bottom bar of ArcGIS Pro, as illustrated in Figure 21.

Figure 21. Change the map's coordinate units.



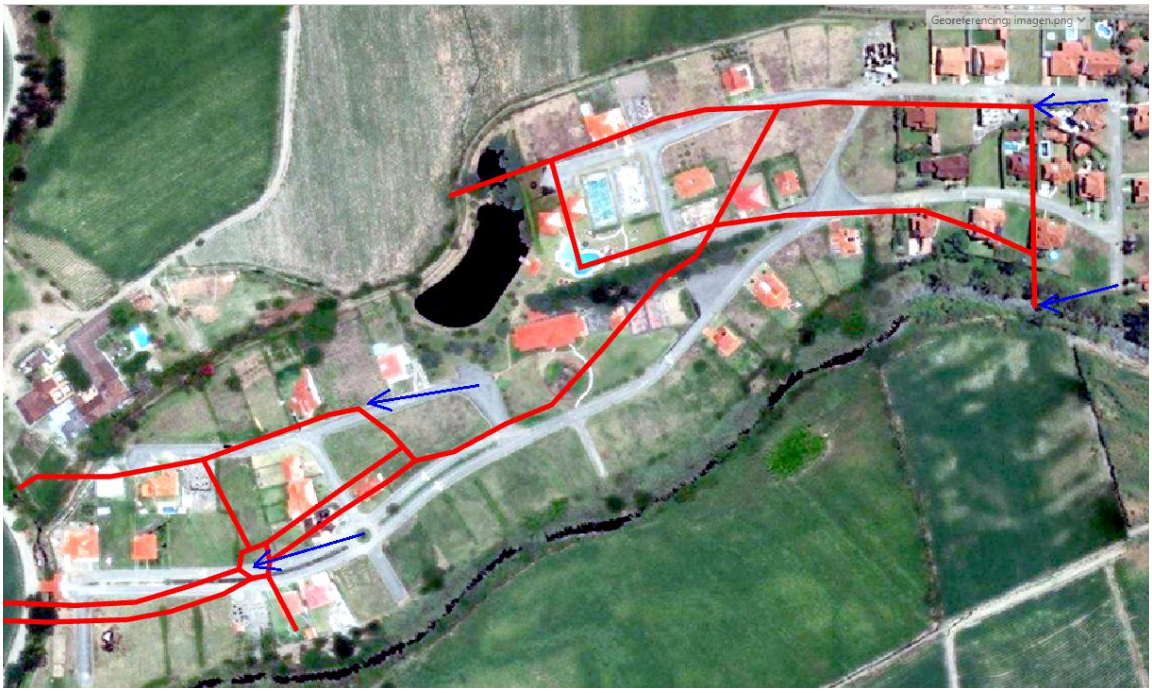
6.4. Georeferencing an Image Without Control Points

Sometimes, precise coordinates of control points on the ground are not available, but vector layers exist, such as roads, buildings, trees, etc., that can facilitate georeferencing using these elements in the image.

For example, an image can be georeferenced using a vector layer of roads by aligning the intersections of the roads with the same intersections in the image. These intersections are then established as control points. Figure 22 illustrates the points in the image that should coincide with the intersections of the road layer (signed with blue arrows).

In this type of georeferencing, ensuring the accuracy of selected control points is crucial. The control points must correspond to the same reference elements in both the image and the vector layer. This accuracy is essential for obtaining a precise georeferencing of the image, which is the basis for any subsequent applications requiring spatial information.

Figure 22. Identifying common points in an image and a vector layer.



To develop this example, a new "Map" must be created, as outlined in section 5.3. Then add the vector layer "**routes2.shp**" and the raster layer "**image2.png**" (located in the folder "06_georeference\no_coordinates"), select the raster layer, and activate the georeferencing tool (see Figure 15). Next, define the reference system for the image to be georeferenced, following the steps described in section 6.2.

Once this is done, do a right-click on the "**routes2.shp**" layer and select "**Zoom To Layer**". Then, select the image in the "**Contents**" panel, and in the "**Georeference**" tab, within the "**Prepare**" group, choose "**Fit To Display**" to overlay the routes on the image.

To set control points, it is necessary to click on "**Add Control Points**" in the "**Adjust**" group of the "**Georeference**" tab. The mouse pointer will then show the text "**From point (source)**", indicating that to the user can mark the starting point; for example, a traffic circle (refer to Figure 23). Then, click on the corresponding intersection in the route layer ("**To point, target**"). Repeat this process for each intersection or control point until the two layers are properly aligned. The adjustment of the layers occurs automatically after each point association.

Figure 23. Entering control points for georeferencing using a vector layer.

In this case, the quantity of control points used does not inherently ensure the quality of georeferencing. It is more important to distribute the control points evenly across the image, rather than concentrating them in one area, to achieve the best results (as illustrated in Figure 24). Moreover, with an increased number of control points, more complex transformations are applied, which might result in increasing errors (residuals). The transformations include polynomials, splines, or projective adjustments, which help to determine the precise location of coordinates for each cell in the raster image (as shown in Figure 25).

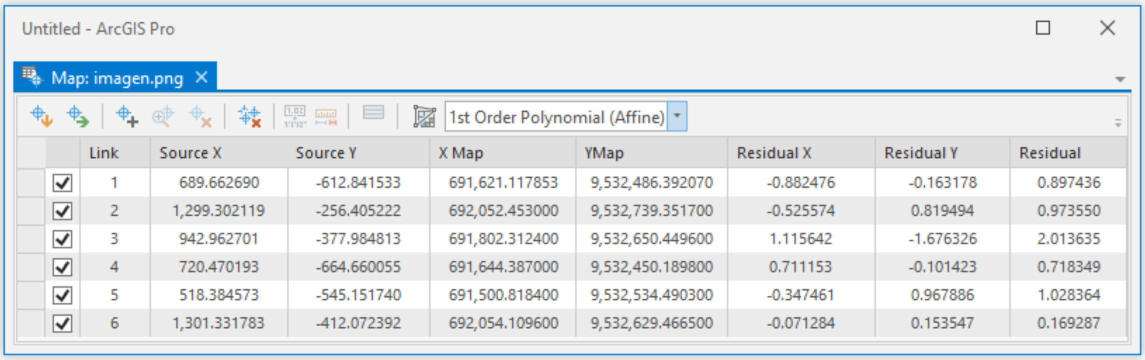
Generally, the transformations allow for a more accurate and detailed adjustment of the image, especially in cases where the terrain has irregularities, or the image has distortions that a simple linear transformation cannot correct.

Figure 24. Distribution of control points.

To assess the quality of the georeferencing process, the "Control Point Table" can be revised. This tool is accessed by clicking on "**Control Point Table**" located in the "**Georeference**" tab under the "**Review**" group. The residual error displayed in the table indicates the reliability of the coordinates obtained for the georeferenced image. A smaller error signifies a higher quality result (as seen in Figure 25). The error is typically measured in meters.

For instance, in rural cadastral work, an error of up to three meters might be considered acceptable. In contrast, for urban cadastral, a more precise error threshold, such as 25 centimeters or less, is often expected, although this may vary depending on local regulations or requirements. As mentioned before, the level of precision is essential for tasks where accurate spatial data is crucial.

Figure 25. Control points table in georeferencing.



	Link	Source X	Source Y	X Map	YMap	Residual X	Residual Y	Residual
☑	1	689.662690	-612.841533	691,621.117853	9,532,486.392070	-0.882476	-0.163178	0.897436
☑	2	1,299.302119	-256.405222	692,052.453000	9,532,739.351700	-0.525574	0.819494	0.973550
☑	3	942.962701	-377.984813	691,802.312400	9,532,650.449600	1.115642	-1.676326	2.013635
☑	4	720.470193	-664.660055	691,644.387000	9,532,450.189800	0.711153	-0.101423	0.718349
☑	5	518.384573	-545.151740	691,500.818400	9,532,534.490300	-0.347461	0.967886	1.028364
☑	6	1,301.331783	-412.072392	692,054.109600	9,532,629.466500	-0.071284	0.153547	0.169287

It is advised against using images from "Google Earth" for technical work due to their lack of accuracy. These images represent topography and are not flat, often leading to distortion. Furthermore, high-resolution imagery is not always available in "Google Earth," so it is preferable to use these images only as references for surveys. The goal is to minimize relief distortions and enhance image quality through the proper use of control points.

There is no ideal number of control points to reference an image, as it varies depending on the specific case. In some situations, as few as two points might be sufficient, while in others, at least 20 points may be necessary. However, the key is to place these points with precision and accuracy evenly across the image to ensure the reliability of the georeferencing process.

The number of checkpoints required for georeferencing depends on the quality of the input data!

For instance, if a topographic chart is well-scanned, free of wrinkles or deformations, then fewer control points are needed for accurate georeferencing. Conversely, if the topographic chart has deformations, this can negatively impact the quality of the image, necessitating the use of more control points to adequately adjust the image's geometry through georeferencing. Thus, the condition of the original data significantly influences the georeferencing process and the precision needed in placing control points.

7. Creating and Editing Vector Entities

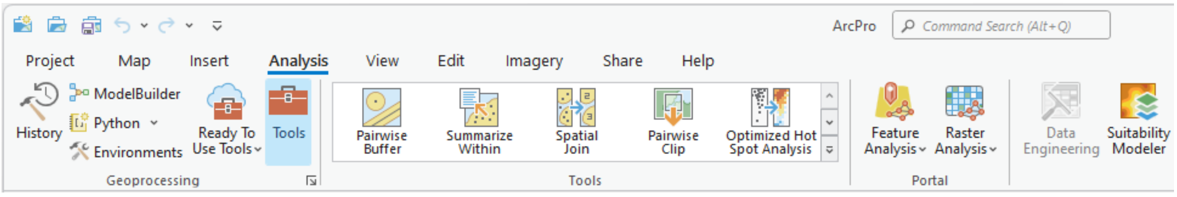
Creating and editing vector entities are fundamental tasks in GIS that involve the manipulation of spatial data. This process includes generating new vector entities such as points, lines, and polygons, or editing their attributes and geometries for precise spatial analysis and mapping.

7.1. Creation of Feature Class (Shapefiles)

To create new vector entities, such as points, lines, or polygons, navigate to the "**Analysis**" tab, find the "**Geoprocessing**" group, and then select the "**Tools**" tool (as shown in Figure 26). This can be done by following the path outlined below:

Analysis > Geoprocessing > Tools

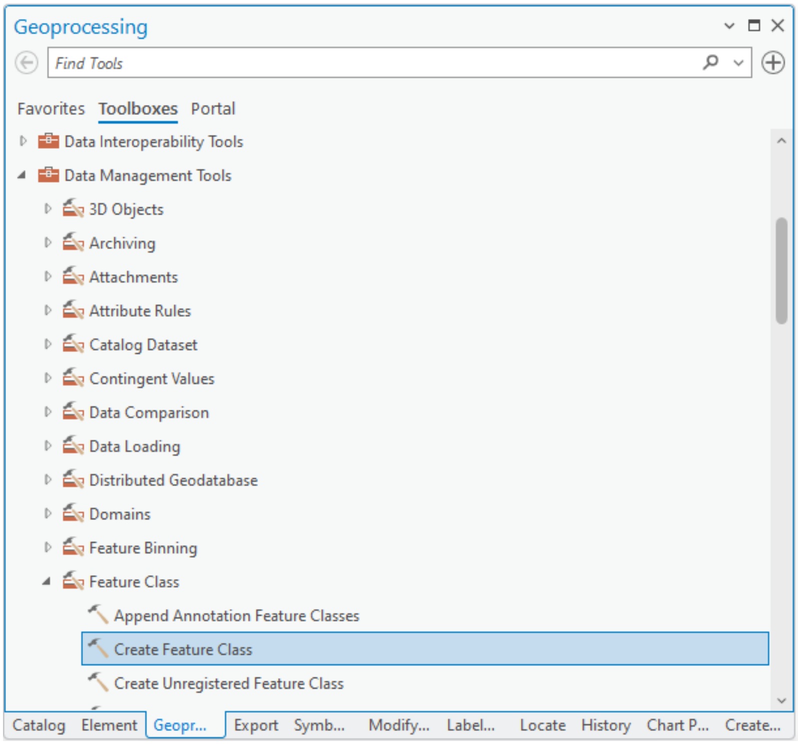
Figure 26. Opening the "Tools" tool.



In the "**Geoprocessing**" panel, the "**Create Feature Class**" tool must be opened, which can be found following the specified path and illustrated in Figure 27:

Geoprocessing > Toolboxes > Data Management Tools > Feature Class > Create Feature Class

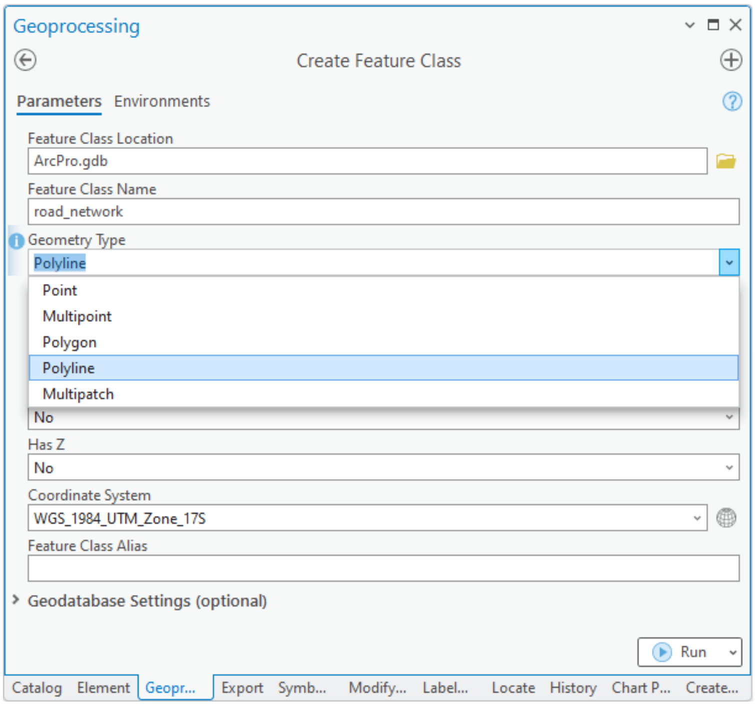
Figure 27. "Geoprocessing" panel (Toolboxes).



The tool **"**Create Feature Class" (Figure *28*) permits to create the vector layers that will be used to digitize the elements of the georeferenced image.

In general, all geoprocessing tools share similar features; hence, it is necessary to specify the required input layer, set all relevant parameters, and choose an output path for the results (Figure 28).

Figure 28. Configuring the "Create Feature Class" tool.



The configuration of the fields is done as follows:

- **Feature Class Location:** One should select the name of a geodatabase (the default is the project's geodatabase). Alternatively, the name of a folder can be selected if the data is not stored in a geodatabase.
- **Feature Class Name:** Here, one assigns the name of the new vector layer. It is recommended to avoid special characters or spaces. If a folder is chosen in the "Feature Class Location" field, the shapefile or vector file with the extension ".shp" will be stored there (for example, "road_network.shp").
- **Geometry Type:** Here, one selects the layer type, whether it is a point, line, or polygon.
- **Coordinate System:** The reference system is defined using the globe icon. For the current case, the path is "Projected Coordinate Systems > UTM > WGS 1984 > Southern Hemisphere > **WGS 1984 UTM Zone 17S**".
- The fields **"OID Type"**, "**Has M**", "**Has Z**", and "**Feature Class Alias**" should remain as the default settings.

- **Run:** This button is clicked to execute the geoprocessing, more precisely, to create the new vector entity.

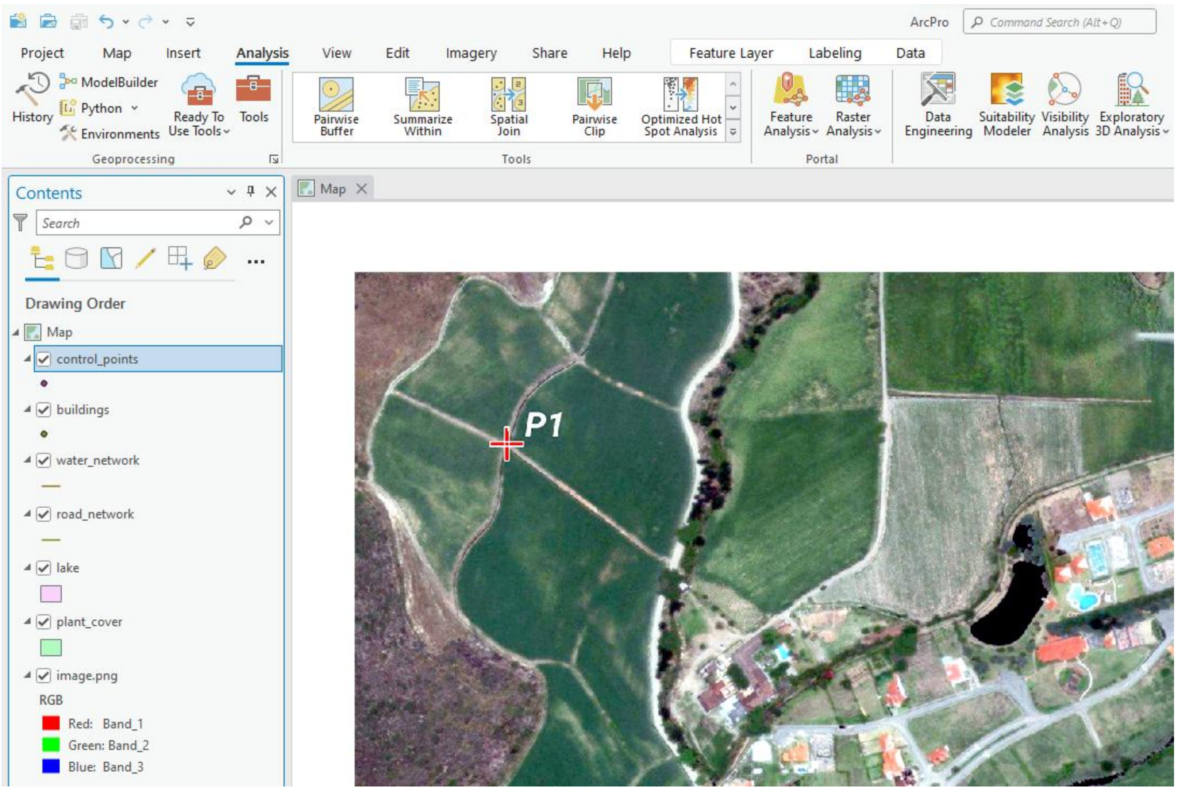
Practice: Create vector layers of points, lines, and polygons as outlined in Table 1 using the "**Create Feature Class**" tool and the "WGS 1984 UTM Zone 17S" reference system.

Table 1. List of vector layers.

Feature Class	**Type**
buildings	Point
control_points	Point
road_network	Line
water_network	Line
plant_cover	Polygon
lake	Polygon

Each of the vector layers shows an icon according to the assumed geometry, as points, lines, or polygons, which are shown in the panel "**Contents**" (Figure 29).

Figure 29. Vector layers within the "Contents" panel.

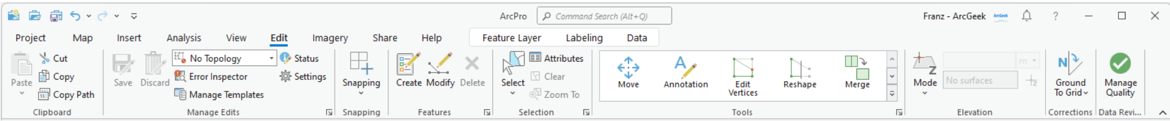


7.2. Editing Vector Layers (Shapefiles)

To initiate editing of a vector layer in ArcGIS Pro, follow these steps: First, select the desired layer in the "**Contents**" panel. Next, under the "**Edit**" tab in the "**Features**" tool group, locate the options "**Create**", "**Modify**", and "**Delete**" to create, modify, or delete entities or elements within the layer.

It is crucial to enable the layer for editing before making changes. After selecting the layer, navigate to the "**Edit**" tab and activate the necessary functions ("**Create**", "**Modify**", or "**Delete**"). Then, choose the vector layer in the "**Create Features**" panel under the "**Templates**" tab to begin editing. Position the cursor on the georeferenced image to draw lines, polygons, or other required shapes. To finalize, save the edits in the "**Edit** > **Manage Edits**" group using the "**Save**" command, or discard them with "**Discard**" (refer to Figure 30). Regular saving of changes ("**Save**") is advised to prevent data loss due to program or system failure. The user should ensure that the correct layer is being edited before saving. Additionally, it is prudent to create a backup of the data files before undertaking significant edits.

Figure 30. Editing tools in the "Edit" tab on the ribbon.



To navigate to a specific location on the map, use the "Go to XY" button found in the "Map > Navigate" menu.

This feature enables entering coordinates in various formats to pinpoint the desired location and directly navigate to it.

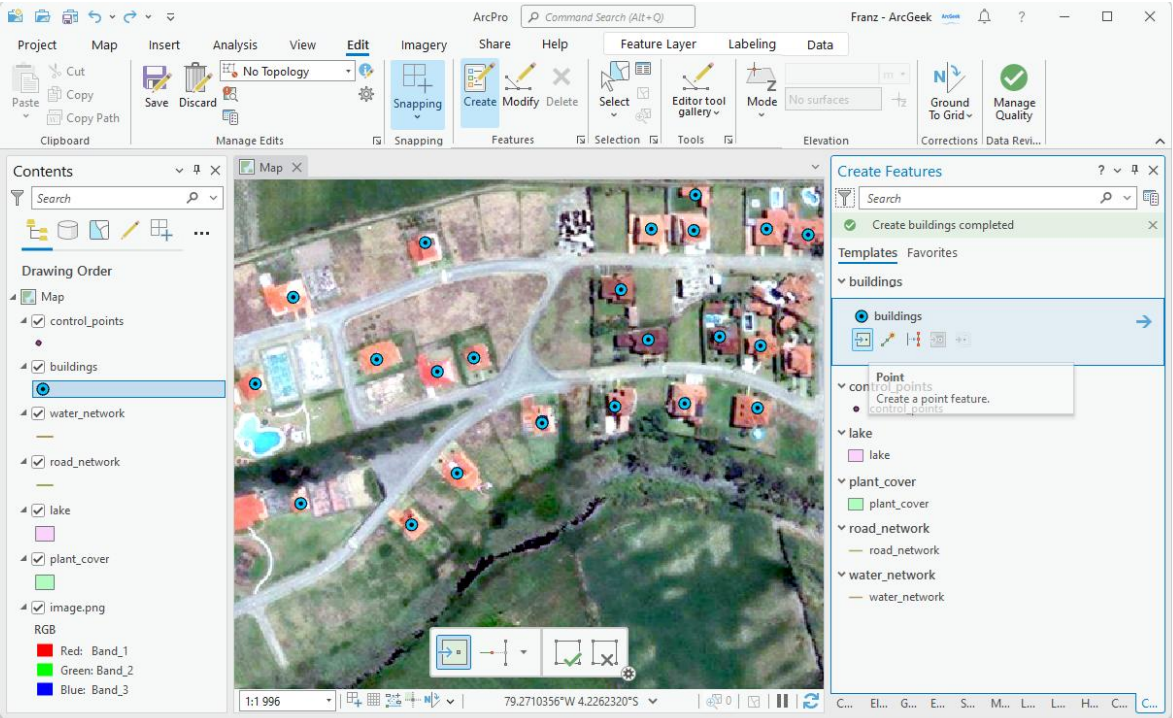
7.3. Editing Points

To begin digitizing points, first select the layer of interest, such as "**buildings**", and proceed to the "**Edit**" tab. Click on "**Create**" to open the "**Create Features**" panel. Ensure the points layer is active in "**Templates**" and then select the "**Point”** symbol to create a point feature, which permits to generate a point-type entity. After this, one can fix the, position the cursor at the center of the first house and click to add the point. Continue this process until all necessary houses are digitized (refer to Figure 31).

To enhance efficiency, utilize zoom and pan tools for more control and precision in point placement, which is particularly important for smaller objects. Besides the mouse, the keyboard arrow keys can be used for finer movement.

Remember to regularly save changes to a layer to prevent data loss. This can be done by using the "**Save**" option in the "**Edit**" tab to preserve all the edits made by the user.

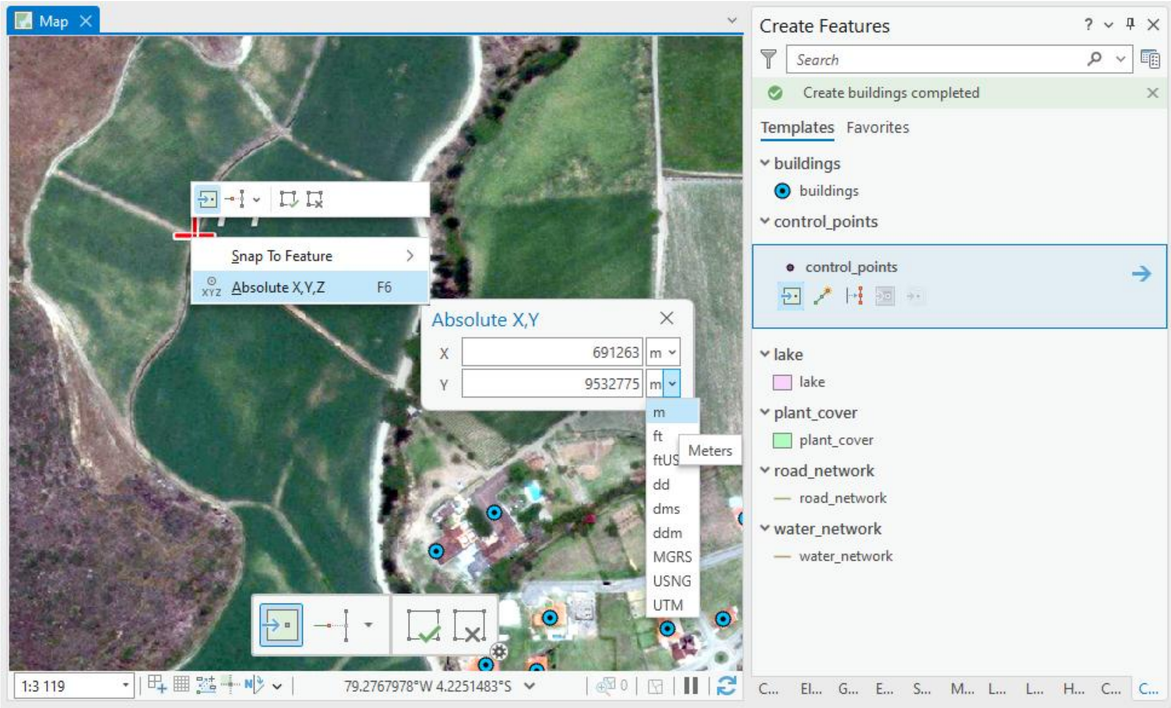
Figure 31. Editing mode of the ArcGIS Pro application.



An alternative method to create new points is directly inserting their XY coordinates. For it, first, select the relevant point layer in the "**Create Features > Templates**" panel, such as "**control_points**". Click on the "**Point**" symbol, and then make a right-click anywhere on the map to choose the "**Absolute X,Y,Z**" option or press the "F6" key (as illustrated in Figure 32). This action opens a window in which the user can input the XY values for the desired point and select the units, in this case meters (for example, X = 691263; Y = 9532775 for **P1**, and X = 692075; Y = 9532387 for **P2**). After entering the values, confirm the changes by pressing "**Enter**".

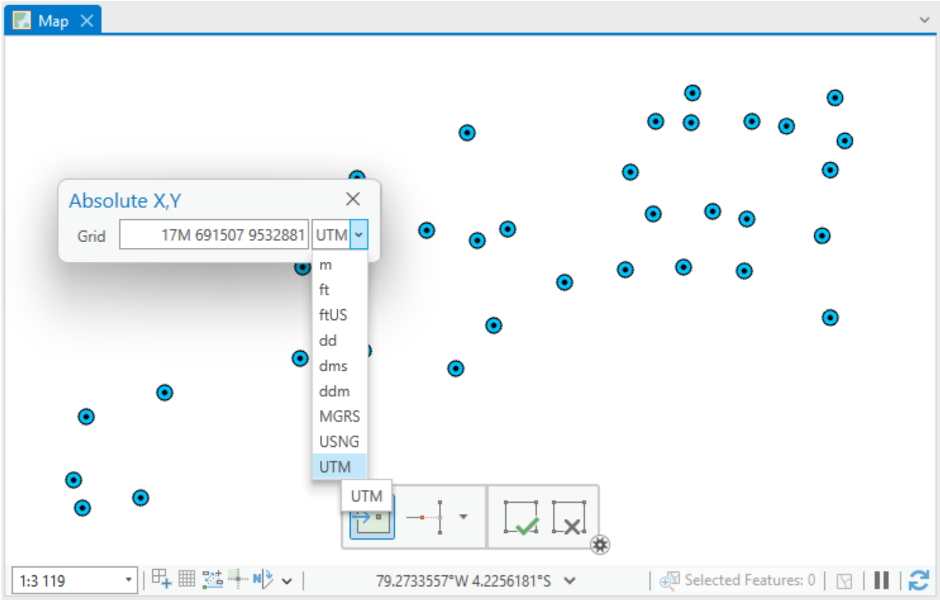
.

Figure 32. Manually insert points by means of specific coordinates.



Coordinates can be inserted in various formats, such as meters, decimal degrees, MGRS, UTM, among others. To change the format, open the "**Absolute X,Y**" window as previously described, and click on the drop-down icon on the right side. This action reveals a list of format options from which the required one can be selected. For entering coordinates in the UTM format, refer to the instructions in "Figure 33" (e.g., buildings: 17M 691507 9532881). After entering each point, press the "**Enter**" key to confirm the change. Upon completing the edits, remember to save all entered points through "**Edit > Manage Edits > Save**".

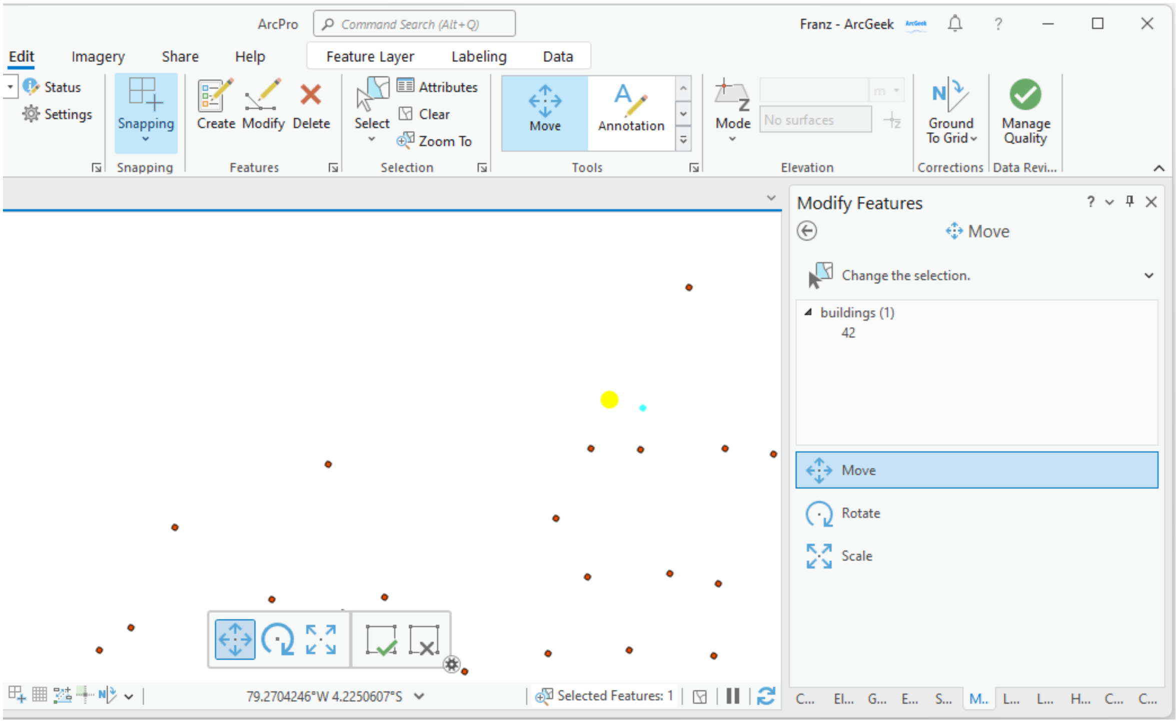
"Figure 33. Coordinate format available in "Absolute X.Y" option.



To adjust the spatial location of a point, first select the layer to be modified, such as "buildings", and navigate to the "**Edit**" tab. Then, select the "**Move**" tool from the "**Tools**" group. To modify or delete the location of a specific point, click on it (the selected point will be highlighted in yellow). The point can then be dragged to its new location (refer to Figure 34) or deleted by pressing the "**Delete**" key on the keyboard. To save the new location of the point, click on the arrow in the upper left part of the "**Modify Features**" panel to activate the "**Save**" option.

When editing multiple layers, particularly lines and polygons in the "Contents" panel, it is advisable to **deactivate layers** that might interfere with the digitization process to simplify digitization and prevent confusion.

Figure 34. Modifying the location of a point with the "Move" tool.



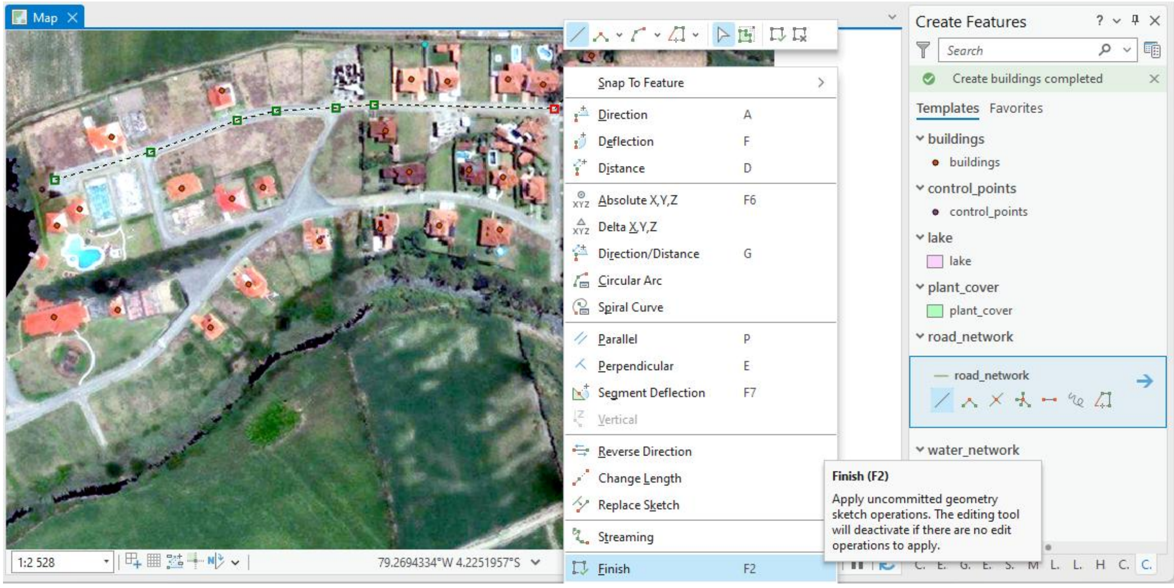
7.4. Editing Lines

To digitize lines, one needs to select the relevant layer (e.g., "**road_network**") in the "**Create Features > Templates**" panel and click on the "**Line, Create a line feature**" button (as shown in Figure 35). To draw the line, mark the starting point and continue adding points (one by one) until the line or section is completed. The line can be finalized by either double-clicking on the last vertex or pressing the "**F2**" key. Green nodes indicate the number of points marked to construct the polyline, while the red node signifies the last marked point. This process is repeated for all sections of the layer to vectorize the entire road network and roads present in the image.

Ensuring connectivity between line elements while digitizing is crucial. In the case of the road network, it should not result in unconnected sections or sections where the connections extend beyond the edges of an existing line. For enhanced accuracy in editing and to avoid errors, activating "**Snapping**" tools is essential. These tools align the pointer automatically with edges, vertices, or other nearby geometric elements within a certain adjustable tolerance.

For the "**water_network**" layer, the river channels can be digitized using the same process applied to the "road_network".

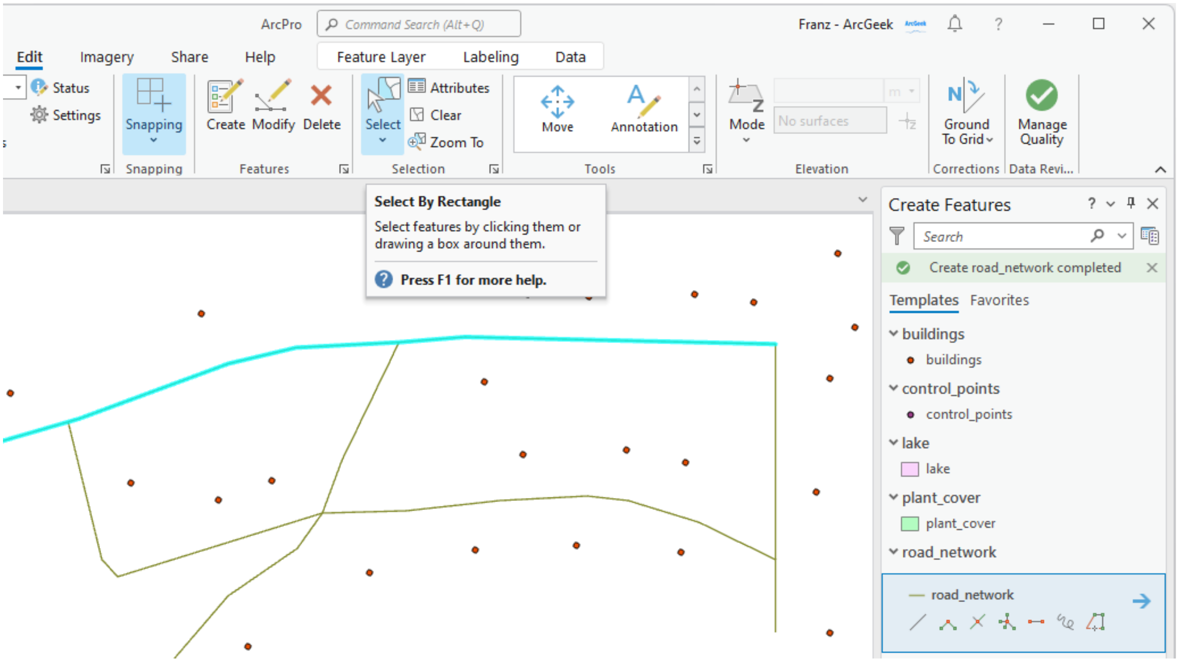
Figure 35. Digitizing lines in ArcGIS Pro.



To modify a polyline, for example in the "**road_network**", the layer to be modify must be selected first, followed by clicking on the "**Edit**" tab. In the "**Features**" group, the "**Modify**" tool must be selected. In the **"Modify Features"** panel inside the **"Tools"** group, the **"Move"** tool must be chosen. Then the segment or line, which shall be modified must be selected, which will highlight in light blue with a yellow circle on it, signaling its selection. From this point, the line can be either deleted or the entire polyline moved. If the line is in the right position finish the movement with a double click and save the changes in the "**Manage Edits**" group pressing the "**Save**" button. To unselect the line, press the **"Clear"** button in the **"Selection"** group.

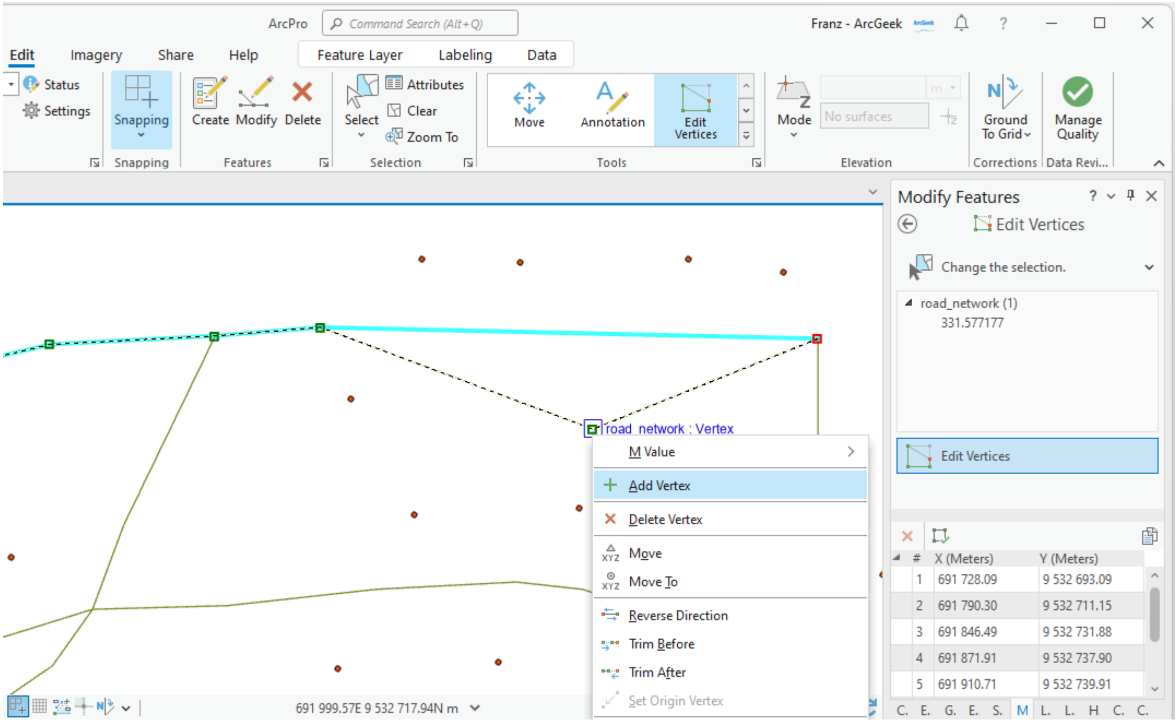
Another option to delete a line completely is selecting the line by using the "**Select**" button inside the **"Selection"** group and do a double-click on it (refer to Figure 36). When the line is highlighted in blue, the line can be deleted by pressing the "**Del**" key on the keyboard. To select and delete multiple lines, the "**Shift**" key has to be pressed during the selection.

Figure 36. Selecting a polyline in edit mode.



To adjust the geometry of a polyline (move the vertices), the "**Edit Vertices**" tool in the "**Edit > Tools**" group is used. When the tool is activated, a double-click on the segment selects it, displaying all the vertices comprising the polyline. Each vertex can then be freely moved to the desired position or deleted. It is important to save the changes by clicking on "**Save**" in the "**Manage Edits**" group. The "**Edit Vertices**" tool also allows for viewing the "XY" coordinates of each vertex or point that constitutes the polyline or polygon (as shown in Figure 37).

Figure 37. Modifying the vertices of a polyline.

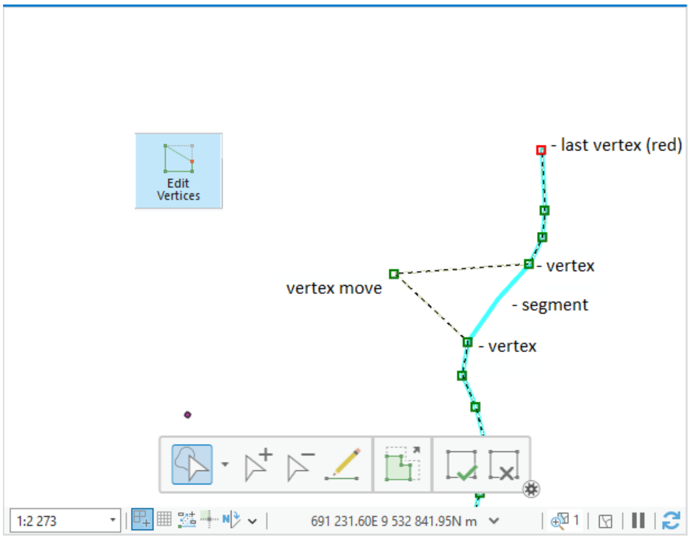


When working with polylines, it is important to avoid placing an excessive number of vertices on a straight line, as this complicates further editing. Ideally, for a straight line only two vertices are necessary, the start and the end point. Conversely, on a curve, more vertices are needed to accurately represent the curve's shape.

To remove a vertex, right-click on it and choose "**Delete Vertex**" (or press the **“Del”** button). To add one or more vertices, right-click on the segment of the polyline and select "**Add Vertex**" (refer to Figure 37).

In certain scenarios, dividing a polyline into two or more segments is necessary. This is achieved by selecting the polyline and using the "**Split**" tool found in the "**Edit > Tools**" group. The user then double-clicks on the point where the line should be divided (as illustrated in Figure 38), which separates the line. Do not forget to save the changes in the "**Manage Edits**" group by pressing the "**Save**" button.

Figure 38. Structure of vertices in a polyline.



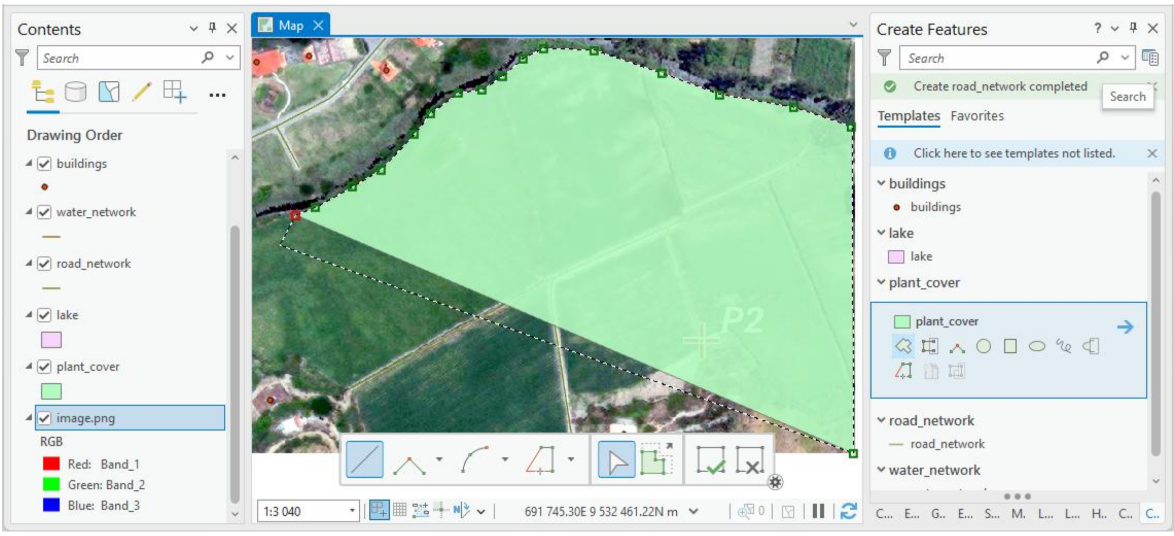
7.5. Editing Polygons

The digitization of polygons follows a procedure like that of polylines. It is recommended to disable other unused vector layers in the "**Contents**" panel to prevent interference and confusion during digitization.

To initiate polygon digitization, the relevant layer (e.g., "**plant_cover**") must be selected in the "**Create Features > Templates**" panel, and the "**Polygon, Create a polygon feature**" button clicked (as shown in Figure 39).

To begin drawing the polygon, one clicks on the first vertex and continues outlining the entire perimeter of the area. The drawing is completed by either double-clicking the endpoint or pressing "**F2**". Various categories can be assigned to polygons such as the categories in Figure 39, including grassland, crops, and forest. However, to avoid future topological corrections, it is important to consider certain aspects detailed in the subsequent paragraphs.

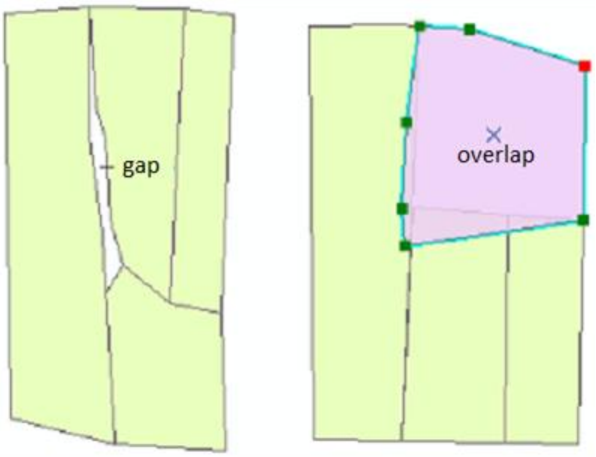
Figure 39. Polygon editing in ArcGIS Pro.



During the digitization of polygons, it is crucial to avoid topological errors like gaps, voids, or overlaps at their boundaries or between neighboring polygons. Gaps or empty spaces are often challenging to detect visually, as they are only detectable by zooming in the image and closely examining the boundaries of the plots. With adequate zooming, also areas shared by two or more polygons can be found (as shown in Figure 40).

These topological errors commonly arise when methods to maintain topological rules are not employed during editing or when compiling information from varied sources or different scales. Hence, careful attention is needed during polygon digitizing and editing to prevent these issues. Maintaining the topological integrity of polygons is vital for proper management and analysis of geospatial data, ensuring the quality and reliability of the information.

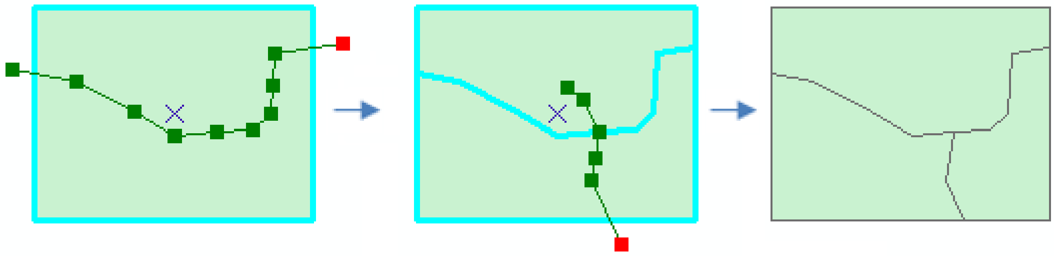
Figure 40. Gaps and overlap in polygons.



ArcGIS Pro provides several tools to uphold the integrity and quality of spatial information during editing. Two fundamental tools in the "**Edit > Tools**" tab are "**Split**" and "**Reshape**", along with a tool in the "**Create Features > Templates**" panel named "**Autocomplete Polygon**". These tools are crucial for achieving precise digitization and reducing errors in the polygonal layer. By using these tools, the topological accuracy of the polygonal layer can be guaranteed, ensuring that no gaps or overlaps at the polygon boundaries exist. This leads to increased efficiency and accuracy in editing spatial information and allows for more precise and reliable results for analysis or decision-making.

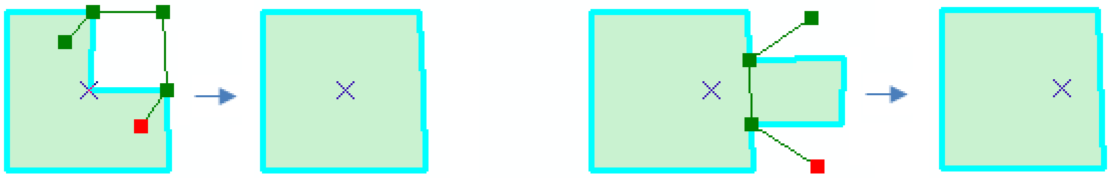
For drawing areas with subdivisions in ArcGIS Pro, it is recommended to create the external perimeter first, and then the internal divisions. For instance, in constructing a land use map, one should first draw the entire study area and then divide it into various categories. It is also advisable to select in the symbology a polygon that displays only the external border by clicking on the rectangular icon in the "**Contents**" panel. To select the layer, go to "**Edit > Selection > Select**"), and click on the desired polygon (the edges will turn light blue). Next, use the "**Split**" tool ( ) to cut the polygon. The process starts by marking the first point outside the polygon and drawing a cut line into the area. The cut line's last point should also be outside the polygon. To finalize the cut, double-click or press "**F2**" (as illustrated in Figure 41). This process is repeated until all required divisions or categories of the area are completed. It is important to note that this tool is only active when one or several polygons are selected.

Figure 41. Cutting polygons with "Split" tool.



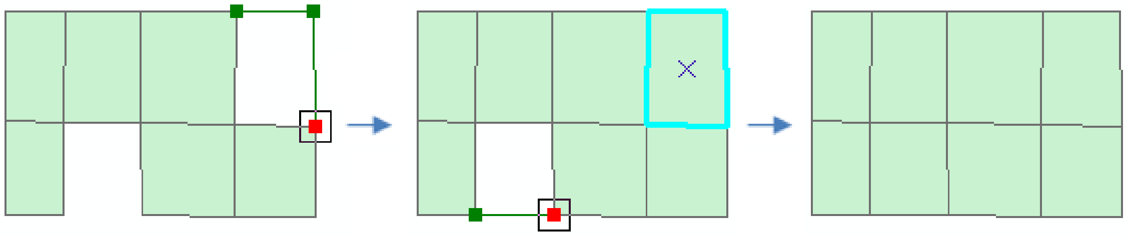
When editing polygons, changing their shape for geometric adjustments is essential. This requires selecting the polygon ("**Edit > Selection > Select**") and then clicking on the "**Reshape**" icon ( ), located in the "**Edit > Tools**" tab. Figure 42 illustrates two examples how one can alter the shape of a polygon. The first example on the left shows how to increase the area of a polygon, resulting in a square shape in this instance. It is crucial to start and end the adjustment drawing inside the polygon. The second example on the right demonstrates how to reduce the area of a polygon, which also results in a square shape, for what the drawing must start and end outside the polygon.

Figure 42. Changing the shape to a polygon with "Reshape" tool.



In scenarios involving the creation of adjacent polygons, it is important to avoid digitizing the same edge twice and to ensure a continuous structure without overlaps and gaps. The "**Autocomplete Polygon**" tool, located in the "**Create Features > Templates**" panel, facilitates this process. This tool allows for the continuous and uninterrupted drawing of new polygons. For it, selecting the participating entities is not necessary before starting to draw new polygons. However, it is recommended to activate the **"Snapping"** icon. To create a continuous polygon, at least two vertices need to be drawn that connect to neighboring polygons (as shown in Figure 43).

Figure 43. Autocomplete polygons with "Autocomplete Polygon" tool.



To merge two or more polygons within a vector layer (shapefile), the polygons involved must be selected using the "**Select**" tool while pressing the "**Shift**" key during selection. Subsequently, the "**Merge**" tool located in the "**Edit > Tools**" is applied. When using this tool, a decision must be made regarding which attributes of the polygons will be retained in the new merged polygon.

For practical application of the editing tools in ArcGIS Pro, it is recommended to digitize visible elements in the georeferenced image within the polygon layers "plant_cover" and "lake", utilizing the editing tools discussed in this section. Continuous saving of changes is crucial to avoid the loss of information.

8. Table Management

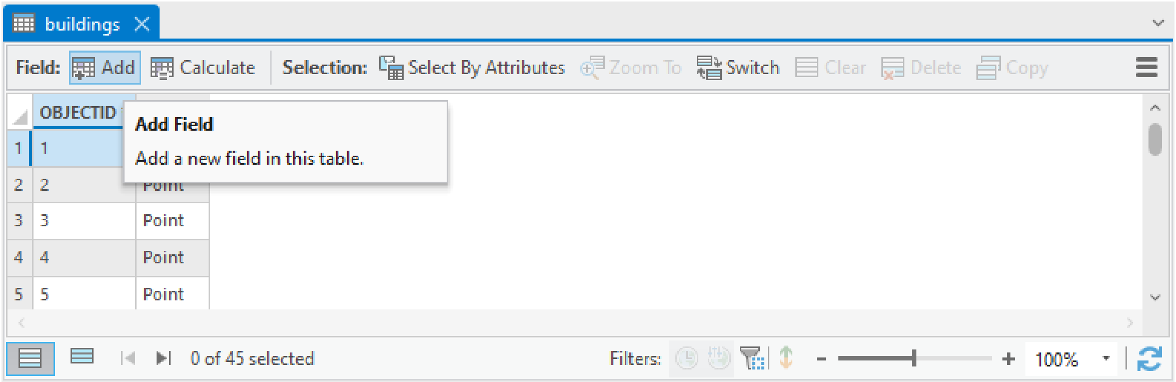
Tables in ArcGIS Pro are utilized for storing descriptive information and can be linked to a vector layer or exist independently. Alphanumeric information stored in a table can be of different types, such as integers, decimal numbers, text, or dates. ArcGIS Pro supports a range of table formats, such as Geodatabases, INFO, dBASE, text files, Microsoft Excel, Access, SQL, and others.

In general, a table is structured into rows and columns, where each row represents an object with values in different fields, and each column, restricted to a single data type, represents a field. Tables allow for the addition of as many fields as necessary to store the required information.

8.1. Creating new Fields in Tables

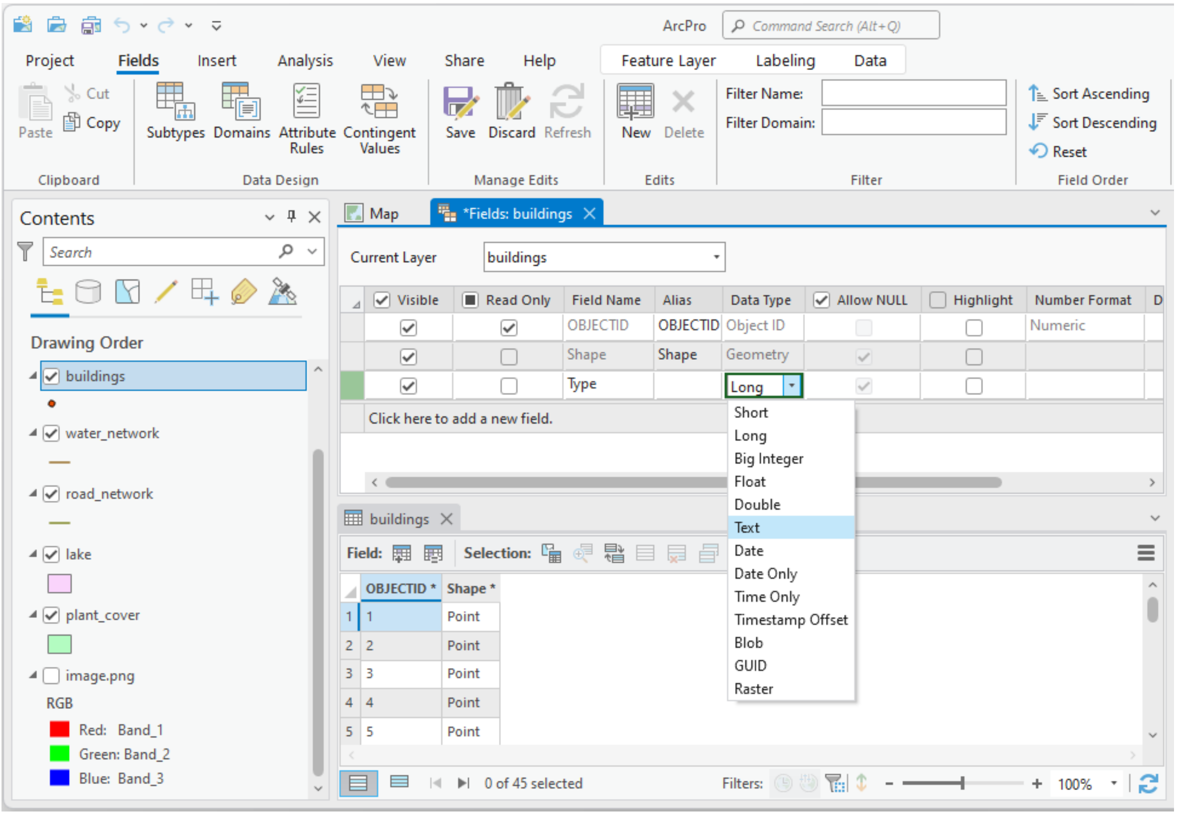
Each shapefile is associated with a table in DBF format, and it is also possible for the tables of a vector layer to be in a Geodatabase. To view the table of a vector file in ArcGIS Pro, one simply right-clicks on the layer (e.g., **buildings**) in the "Contents" panel and selects "**Attribute Table**". Once the table is open, a new field can be created by going to the table menu and clicking on the "**Add**" button, as illustrated in Figure 44.

Figure 44. Table of attributes in ArcGIS Pro.



After clicking the "**Add**" button, the "Current Layer" tab is displayed, where the new field can be configured (as shown in Figure 45). In the "**Field Name**" column, a name is assigned to the new field (e.g., "Type"). It is important to note that accents, spaces, or special characters are not allowed, and the maximum length for names in shapefiles and ".dbf" tables is ten characters. In the "**Data Type**" column, one must double-click to choose the type of field to be created, which can be numeric (short, long, float, or double), text, or date. The "**Length**" column at the end allows for the specification of precision for numbers or character spacing for text. To finalize the creation of the new field, click the "**Save**" button in the "**Fields"** tab, inside the **"Manage Edits"** group. This button is only available when a new field is added, and the "**Current Layer**" is selected. After completing this process, the "Fields" table panel can be closed.

Figure 45. Adding new fields to a table.



To select the type of a new field, it is important to consider the information provided by Neer (2005):

- **Short**, are integer numbers between -32768 y 32767.
- **Long**, 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).

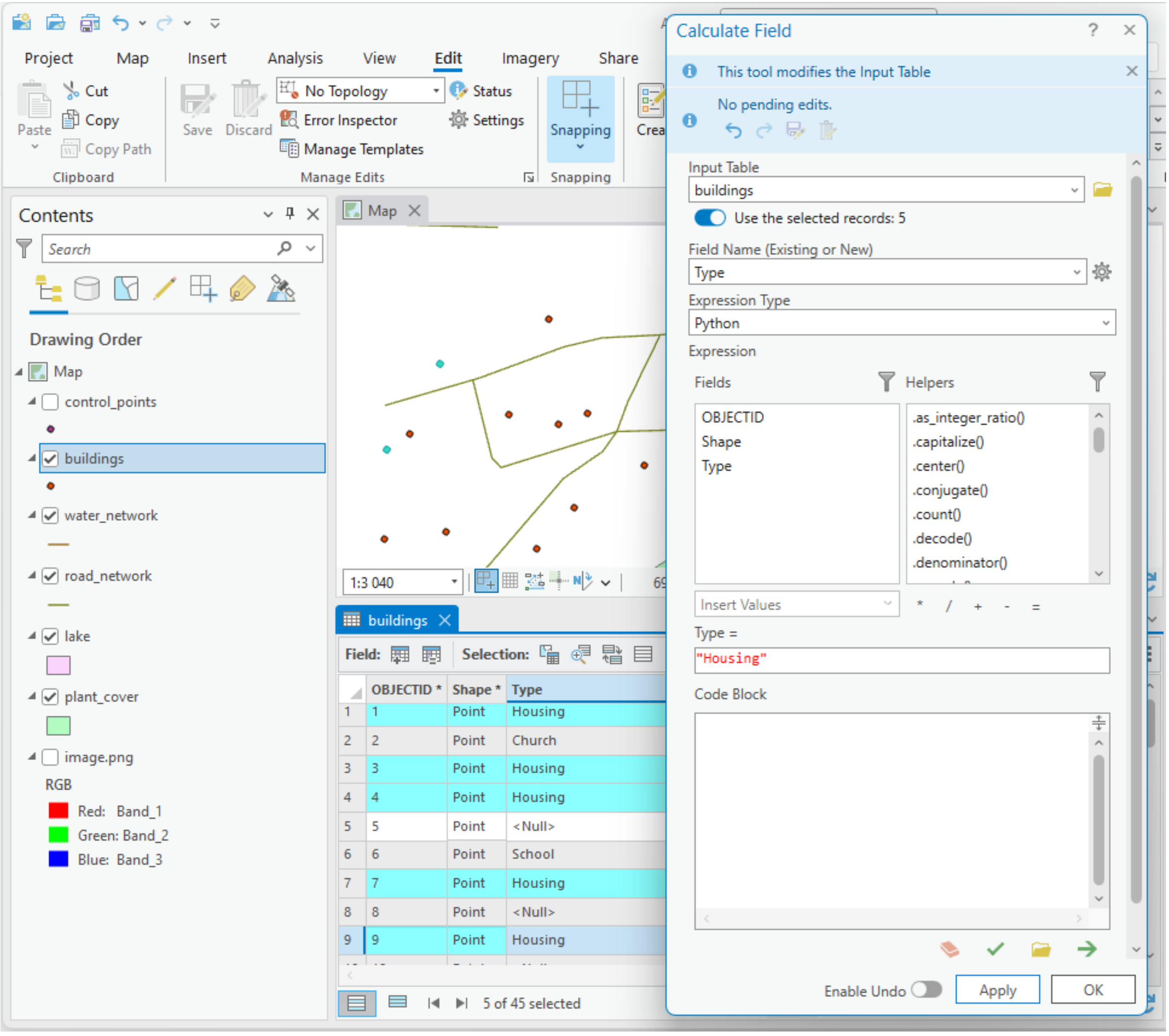
8.2. Entering Information into Table Fields

To input data into newly created fields in an attribute table, the table must be open ("**Attribute Table**"). Values or texts can be entered by double-clicking on the cell. To apply the same information or calculation to one or several rows, select the desired rows (highlighted in blue), and then do a right-click on the desired column (e.g., "Type"). This opens a pop-up window, where the option **"Calculate Field"** must be selected, which opens the "Calculate Field" dialog box.

In this dialog box, the "**Input Table**" must be defined and the "**Field Name**" selected, which refers to the field or column to be edited. One can also type the name of a field directly. The "Expression Type" is set to "Python" by default, but it can be changed to "Arcade" or “VBScript” if necessary. In "**Expression > Fields**" all fields of the input table are listed. If numeric values or text are already inserted in some fields of a column, which should also be written in others cell, one can choose in the “**Insert Values**” box to assign these values to the desired cells. For it, the specific field in “Expression > Fields” must be selected.

To enter information into a specific field (here the "**Type**" field), the desired value is inserted after the equal sign (e.g. Type =). If it is a numeric value, it is typed directly; if it is text, it must be enclosed in quotation marks (" "). For instance, one can arbitrarily select one or more rows of the "**buildings**" layer and label them "**Housing**", so the value in the "Type" field would be **Type = "Housing"**. This process can be repeated for other values, such as: "**Church**", "**Hospital**", "**Police**", or "**School**". For clarity, refer to Figure 46.

Figure 46. Entering information in the attribute table with the "Calculate" tool.



As an exercise, add new fields to all previously created vector layers (shapefiles) and configure the field names, types, and properties as specified in Table 2.

Table 2. Structure for creating fields in tables.

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

Insert the following information into the new fields of the tables:

- **control_points,** in the "**Name**" field, write "P1" or "P2" as text, corresponding to the locations in the geo-referenced image.
- **road_network,** in the "**Type**" field, label the entities as follows: "**Main way**" for segments along coordinate X: 691790 Y: 9532578 *****, "**Unpaved way**" for segments along X: 691394 Y: 9532401, "**Path**" for segments near X: 691570 Y: 9532693 and X: 691261 Y: 9532773, "**Route**" for segments near X: 691991 Y: 9532450 and X: 692028 Y: 9532861, and "**Street**" for all remaining segments in the urban area.
- **water_network,** in the "**Name**" field, label the main river as "**Malacatos River**".
- **plant_cover,** based on the georeferenced image, name the polygons in the "**Type**" field as "**Grassland**", "**Crops**", or "**Forest**", as appropriate.
- **lake,** name the field "**Name**" as "**Santa Anilla Lake**".
- ***** To navigate a specific location on the map, the user should utilize the "Go to XY" button, located in the "Map > Navigate" tab.

Once all layers are digitized, the raster layer ("image.png") can be deactivated or removed from the "**Contents**" panel (right-click on the image).

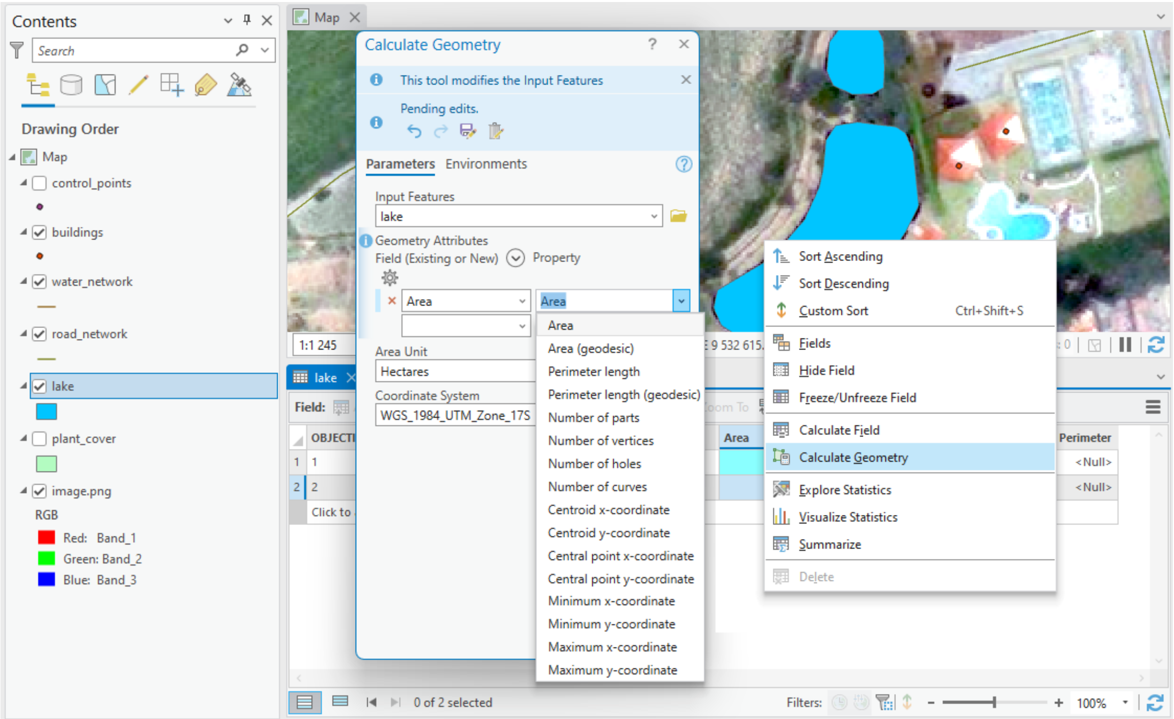
8.3. Calculating Area, Perimeter, and Length

To calculate the area, perimeter, or length of different entities in a map, the geometry of each layer must be considered. It is essential to ensure that the layer has a **defined coordinate system**, as calculations are not possible without it. Take into account, when working with shapefiles or if there are changes to their geometry, the fields for area, perimeter, or length are not automatically updated, so it is necessary to recalculate these values after each change.

To start, right-click on the corresponding layer and open the "Attribute Table". Then, additional numeric fields for each parameter must be generated (area, perimeter, and length). After this, right-click on the header of the required field (e.g., "Area") and select "**Calculate Geometry**". Choose the desired geometric property at "**Geometry Attributes**" (in this case, "**Area**"), select the appropriate units (e.g., **hectares**), and the corresponding coordinate system (as shown in Figure 47). Sometimes it is also necessary to establish the “**Output Coordinates**” in the “**Environments**” tab.

This process must be repeated to calculate all areas in hectares for each polygon layer ("lake" and "plant_cover").

Figure 47. Calculation of geometries in ArcGIS Pro.



The same process described in the previous paragraph is applied to calculate the perimeter (measured in meters) of a layer, for example, "lake". It is only necessary to change the property in the "Geometry Attributes" section from "Area" to "Perimeter". In the case of polyline layers (such as "road_network" and "water_network"), only the length (which can be measured in meters, feet, kilometers, etc.) can be calculated. For point layers, only the XY coordinates can be calculated. In summary, the "Calculate Geometry" tool allows for the calculation of the geometry of each layer according to its nature.

8.4. Calculating XY Coordinates

The "**Calculate Geometry Attributes**" tool is useful for adding information to the attribute fields of an entity, representing the spatial or geometric characteristics and location of each entity, such as length, area, and X, Y, Z coordinates, and M values. This tool can be found in the tab "**Analysis"** within the group **"Geoprocessing",** selecting the option **"Tools**", where also the tool "**Add XY Coordinates**" is located. The whole path to access these tools is:

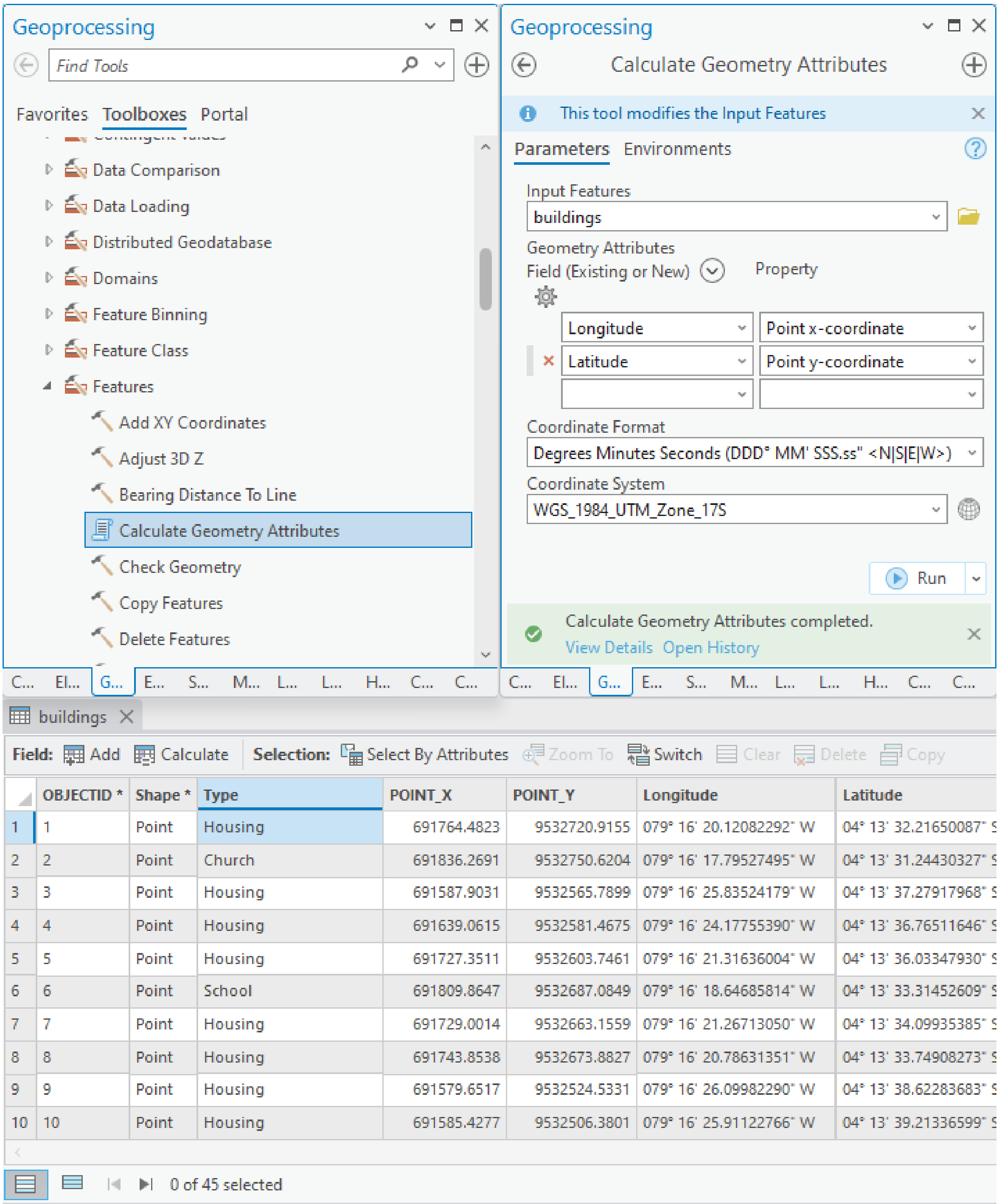
Analysis > Geoprocessing > Toolboxes > Data Management Tools > Features > Calculate Geometry Attributes / Add XY Coordinates

However, caution is important as these tools modifies the input data. The length and area calculations are expressed in the units of the input entities' own coordinate system unless other units are selected in the length unit and area unit parameters. For instance, with a point layer, coordinates can be calculated in UTM meter format or in geographic coordinates.

With regard to the **"Calculate Geometry Attributes"** tool (as shown in Figure 48, right), the following steps must be met:

- **Input Features:** Select the desired layer (e.g., buildings).
- **Geometry Attributes**: Either new fields can be created, or existing fields can be utilized to calculate the geometries. Initially, fields "**Point_X**" and "**Point_Y**" should be created to calculate the UTM coordinates, followed by "**Latitude**" and "**Longitude**" for geographic coordinates.
- **Coordinate System**: The required coordinate format must be chosen. If calculations in multiple formats are necessary, the tool needs to be reopened, and the calculation performed for each desired format separately (as illustrated in Figure 48, below).

Figure 48. Add XY coordinates to a layer of points.



8.5. Operations

The "**Calculate Field**" also allows for the execution of both simple and complex calculations, applicable to text strings as well as mathematical operations. It is crucial to be aware that the operations will affect either all rows of the layer or only those selected.

To calculate the percentage that each polygon in a layer (e.g., "**plant_cover**") represents of the total area, first, it is necessary to determine the total area value. This can be done by opening the attribute table, right-clicking on the header of the "**Area**" field, and then selecting the "**Explore Statistics**" or "**Visualize Statistics**" option. Look for the "**Sum**" value, which displays the total area of all polygons in the layer. This value can be noted or copied ("Ctrl + C").

To calculate the percentage of each polygon, create a new field (here: "**Percentage**"), right-click on the header of it and select the "**Calculate Field**" tool. The following expression should be inserted: **!Area! * 100 / total area value**. It's important to note that "**!Area!**" in this formula refers to the name of the field, which can be directly selected by double-clicking in the "**Fields**" section (as illustrated in Figure 49).

With the "**Explore Statistics**" option, it is possible to create and configure statistical charts simply by clicking on the "**Create Chart**" icon, which is displayed on the right side of each field (see chapter 13).

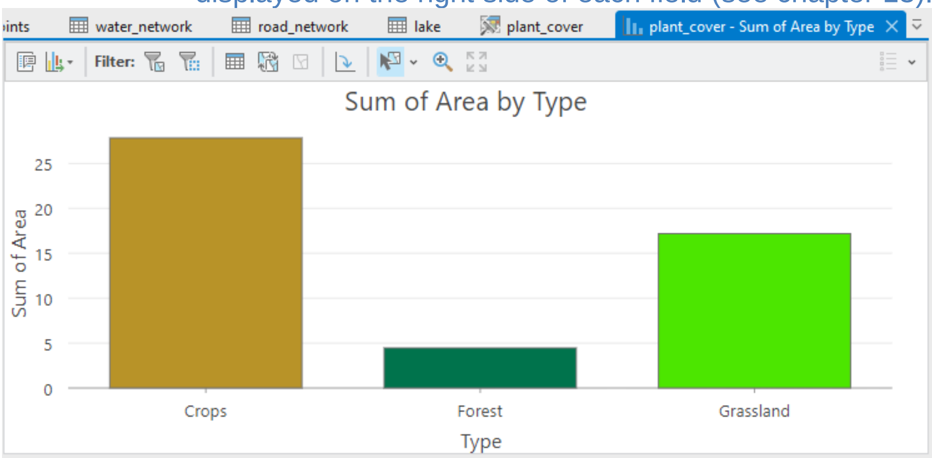
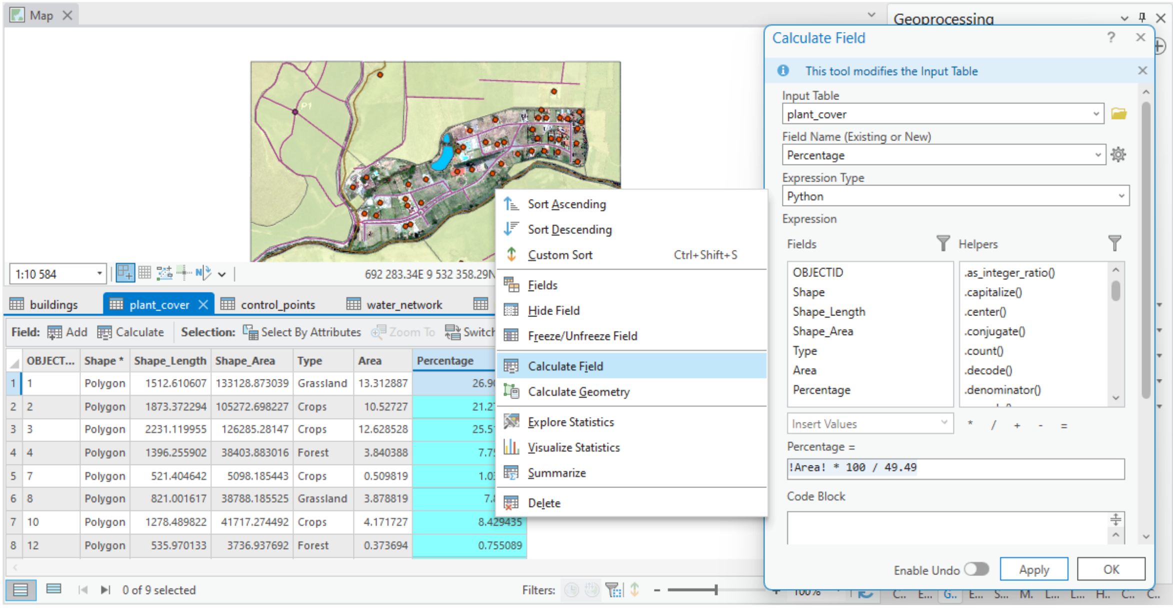


Figure 49. Operations with "Calculate Field" in ArcGIS Pro.



Equations can incorporate various mathematical operations, such as addition, subtraction, division, and multiplication, and may include parentheses. Calculations can be executed using either the VBScript, Arcade or Python languages. If there is a need to access geoprocessing functions, including the calculation of entity geometry, Python is the recommended choice. This language offers broader possibilities for performing calculations through scripting. More detailed information about the field calculator, along with an extensive list of commands and examples, can be found under "Calculate Field Python examples" within the ArcGIS Pro help page.

9. Design and Publication

Map making is a demanding process that requires perseverance and dedication to achieve a satisfactory outcome. While analyzing and interpreting spatial information on a computer is significant, the task of printing or publishing a map that is comprehensible to others implies a distinct set of skills.

ArcGIS Pro provide users numerous map design tools to customize and refine various aspects of the map before publication. It is important to remember that simpler maps are easier to understand. Thus, one should remove unnecessary information, select appropriate colors, use suitable font sizes, and prioritize information based on its relevance. Map design is not just about creating a visually appealing image but also about effectively communicating the intended purpose.

In general, a map is a partial representation of the territory, and the cartographer decides which elements to include based on their knowledge, sensitivity, and intentions (Rekacewicz, 2006). Therefore, it is crucial for the cartographer to have a clear understanding of the map's purpose to make informed decisions about what information to include and how to represent it.

In summary, map making is a skillful task that requires dedication and a deep understanding of the represented territory. With tools like ArcGIS Pro, cartographers can customize and adjust various map aspects to create a clear and effective territorial representation that reflects the intended purpose.

9.1. Point, Line, and Polygon Symbology

Symbology is key to defining the visual appearance of each map element, including symbols, colors, patterns, and text. It is also important to consider whether to display information from the attribute table of each layer.

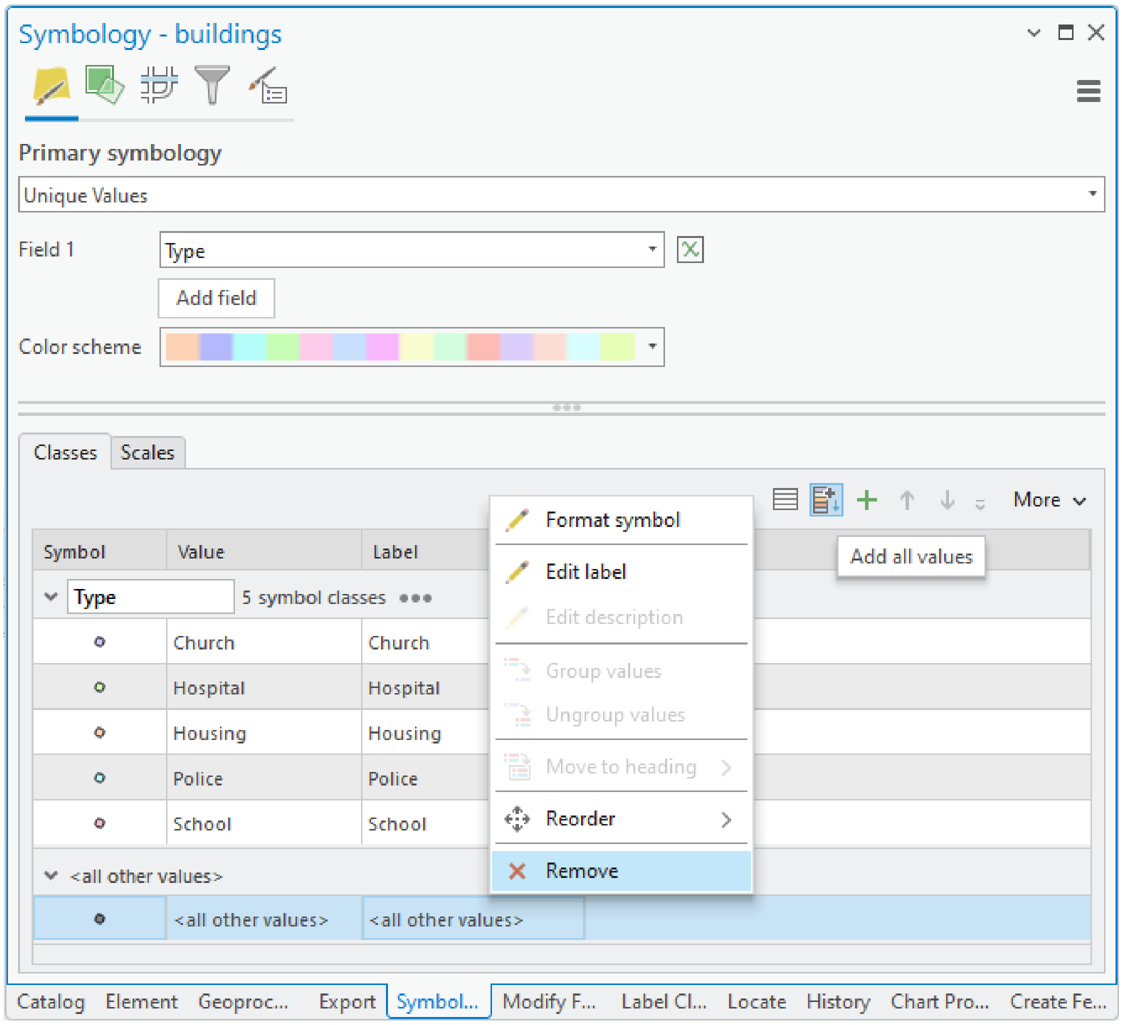
To customize the symbology of layers created in section 7.1, right-click on the relevant layer (e.g., "**buildings**"), and select "**Symbology**", which opens the panel of the same name. When representing geographic information, consider aspects that can be configured in "**Primary Symbology"**:

- **Single Symbol:** Attributes all features of a layer with a common symbol.
- **Unique Values:** Applies different symbols to each feature category within the layer based on one or more fields.
- **Graduated Colors:** Represents a numerical attribute using a color range.
- **Bivariate Colors:** Shows the relationship between two numerical attributes with two color schemes.
- **Unclassed Colors:** Represents a continuous numerical attribute with a gradient of colors without classifying the values into distinct categories.
- **Graduated Symbols:** Depicts a numerical attribute quantity by the symbol size.
- **Proportional Symbols:** Represents a numerical attribute through the symbol size, where the size is directly proportional to the value.
- **Dot Density:** Represents numerical data using dots, where each dot corresponds to a specific quantity, effectively visualizing density or distribution.
- **Charts:** Displays field values in graph forms, such as bar, pie, and line charts.

- **Dictionary:** Applies complex symbology based on attribute combinations using predefined dictionary rules, often for standardized mapping styles (e.g., military or emergency symbology).
- **Heat map:** Indicates point density with darker colors representing higher density.

A common option for displaying various categories of a specific field in a layer is "**Unique values**". For instance, in the "**buildings**" layer, select "**Unique values**", choose the "**Type**" field in "**Field 1**", and click "**Add all values**" in "**Classes**" to include all categories of that field (Figure 50). Sometimes, a category named "**<all other values>**" appears, which can be removed by selecting it, right-clicking on it, and choosing "**Remove**". This procedure can also be applied to "**road_network**" and "**plant_cover**" layers to include all categories based on the attribute table information.

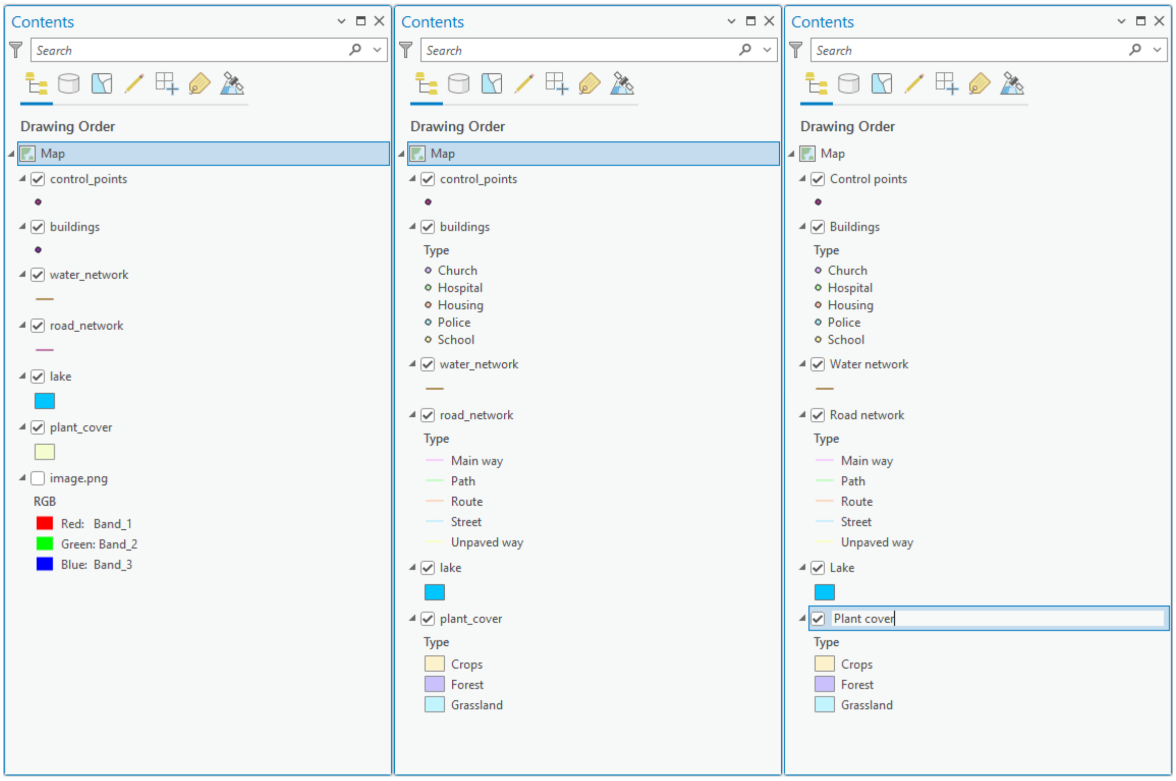
Figure 50. Setting unique values is utilized to display the categories of a specific layer.



Proper organization of layers within the "**Contents**" panel is crucial, achievable by activating the "**List By Drawing Order**" button (first symbol on the left above “Drawing Order”). This allows for dragging and dropping layers into the preferred sequence. It is recommended to arrange polygons at the bottom, followed by lines, and finally points on top of all layers.

By default, layers appear unformatted and uncategorized, bearing the same name and symbol as their respective files (left section of Figure 51). To assign names and categories to layers, information from the attribute table can be used (shown in the middle section of Figure 51), utilizing "**Unique Values**" in "**Symbology**". Individual layer or category names can also be edited by double-clicking on them (right section of Figure 51). Ensuring correct spelling and grammar in the names of layers and categories is important for accuracy in the final publication.

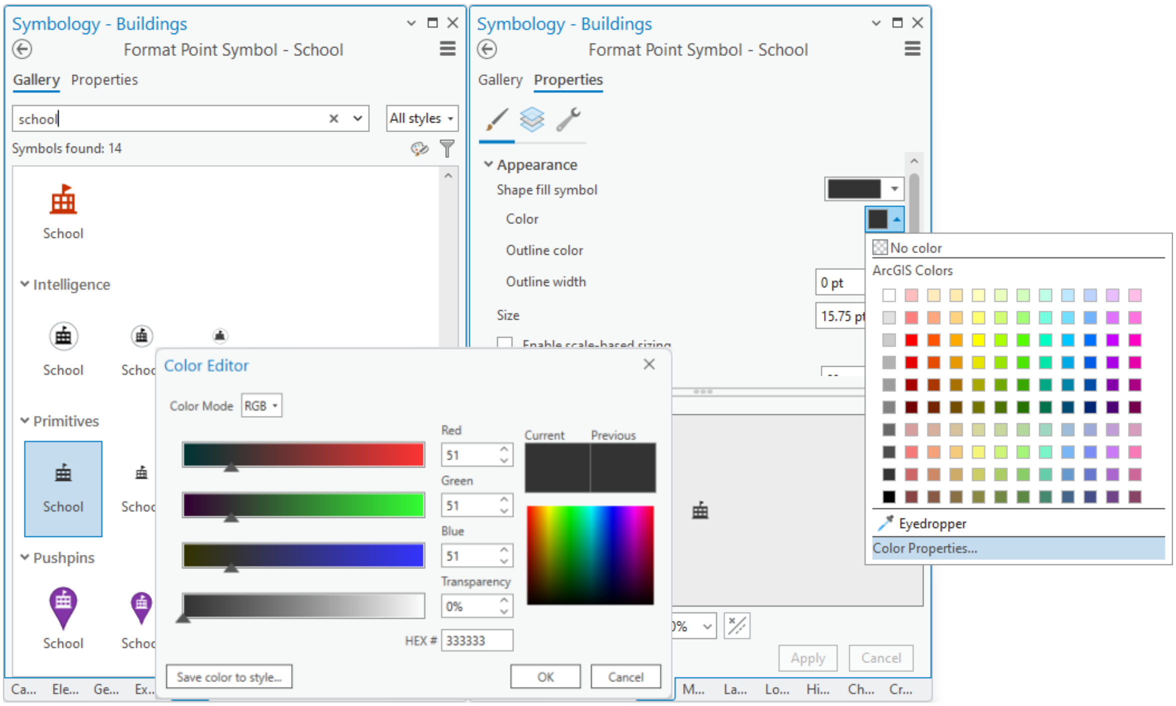
Figure 51. The left section shows the layers in their unformatted and uncategorized state, the middle section displays the categorized layers, and the right section highlights the corrected spelling and grammar of the layer names as they will appear in the final publication.



When a layer is initially loaded in ArcGIS Pro, it is given a standard symbol ("Single Symbol"), which may not effectively represent the data. To depict the information accurately and clearly, it is vital to use appropriate symbols that reflect the data's nature. ArcGIS Pro offers a vast library of symbols for various purposes, in which selecting the most suitable one is crucial. Each symbol can be individually edited. For instance, to customize the symbol for a point layer like the "**School**" in the "buildings" layer, the following steps should be followed:

- Double-click on the relevant symbol in the "**Contents**" panel.
- The "**Symbology**" panel opens, and in the "**Gallery**" tab, a suitable symbol can be chosen from the list or found by typing the name of the desired category, such as "**School**".
- Choose the symbol that best meets the project's needs, like "School" from the "**Primitives**" category (see Figure 52, left).
- To customize the color, go to the "**Properties**" tab and in the "**Appearance**" section, select the color from the drop-down list of the "**Color**" button. If the required color is not available, create it in the "**Color Editor**" window from the "Color Properties", where RGB values can be customized (Figure 52, right).
- For line layers, adjust the line width using the "**Line width**" option. For polygon layers, use "**Outline Color**" and "**Outline width**" to modify the color and width of the contour line, respectively.
- To change the symbol size, visit the "**Size**" section in "**Properties**", where the size can be increased or decreased for point layers.
- After making all changes, save the modifications by clicking on the "**Apply**" button.

Figure 52. This process illustrates the selection and customization of symbols in ArcGIS Pro.



For the remaining layers discussed in this manual, the process outlined in the previous paragraph can be tested by assigning the symbology and specifications shown in Table 3.

Table 3. Definition of symbol properties

Shapefile	Category	Symbol	RGB Color	Symbol size or line width
buildings	School Hospital Church Housing Police	School Hospital Place of Worship House Police Station	51,51,51 255,85,0 131,153,168 232,157,0 0,122,194	15 15 16 14 15
control_points	Points	X Marker	0,0,0	10
road_network	Street Route Path Unpaved way Main way	Road, Proposed Wave Dashed 4:4 Road, Narrow Highway	255,55,55 68,101,137 0,0,0 0,0,0 168,0,0	1 0.5 0.40 1.5 2
water_network	Water	River	10,147,252	1
plant_cover	Forest Crops Grassland	Orchard or Nursery Cropland Open Pasture	- 227,158,0 227,158,0	0 0 0
lake	Lake	Water (area)	76,178,255	0

9.2. Labels

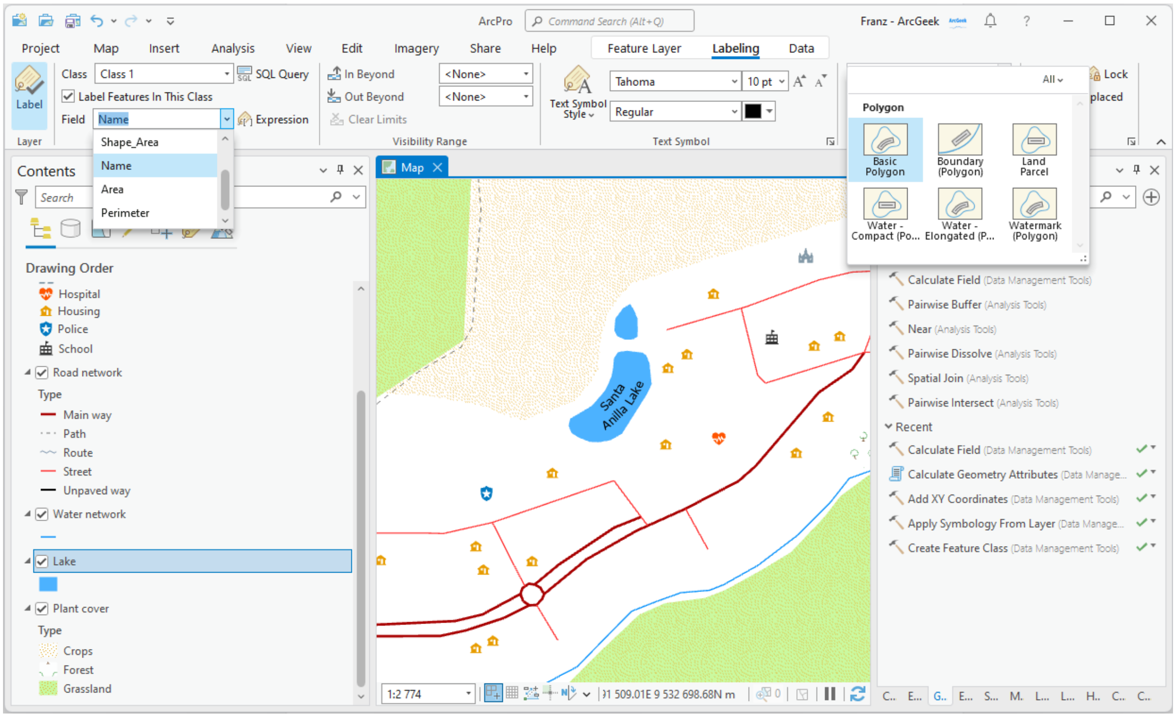
In ArcGIS Pro, labels are texts displayed on the map, which are associated with elements of a layer. Labels are instrumental in visualizing crucial information, such as place names or attribute values. It is important to configure labels carefully to ensure legibility and avoid obstructing the map view. This is particularly crucial for layers with numerous elements or extensive labels, where position adjustments or selective label removal may be necessary to enhance map readability.

For instance, in the "**buildings**" layer, labels could display names, usage, height, etc. For the "**road_network**" layer, street names, types, widths, etc., could be labeled. The "**water_network**" layer might show river names and flow details, while the "**plant_cover**" layer could include land use names and types of vegetation.

9.2.1. Simple Labels

To add simple labels to layers in ArcGIS Pro, first select the desired layer in the "**Contents**" and click on the "**Labeling**" tab. In the "Labeling" tab, the appearance and content of the labels can be configured. Ensure that "**Label**" is activated in the "**Layer**" group. In the "**Label Class**" group, select the attribute table field to display in the labels in the "**Field**" option. The "**Text Symbol**" group allows setting the size and style of the label. Additionally, the "**Label Placement**" group defines the label's position relative to the element, using options like "Basic Polygon" or "Boundary". Figure 53 illustrates an example for the "lake" layer.

Figure 53. Configuring labels in ArcGIS Pro.



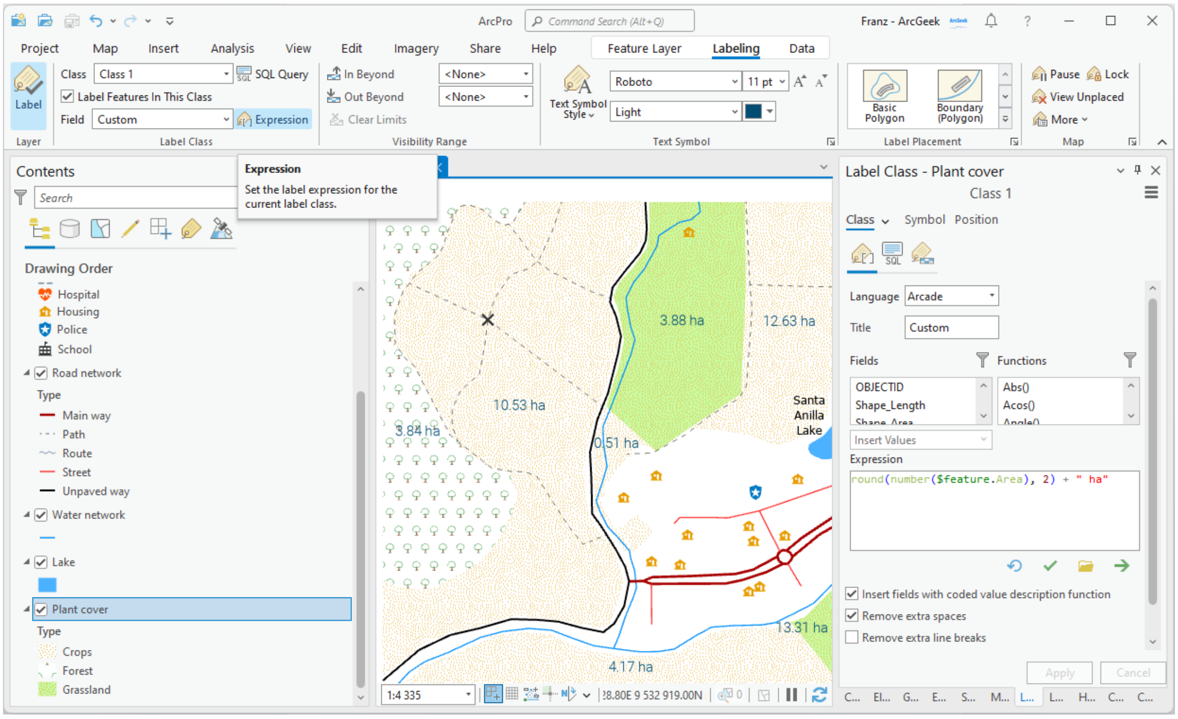
9.2.2. Combined Labels

At times, it is necessary to use information from two or more fields to label layers. In such instances, multiple classes can be set up in "**Label Class**" to display information from different fields, or an expression can be used. For example, in the "**plant_cover**" layer, one might want to show both the area and the unit. First, select the layer and activate "**Labelling > Label**". Then, in the "**Label Class**" group under the "**Field**" option, choose the field containing surface values (such as "Area"). If the unit displays too many decimal places, this can be adjusted by clicking on "**Expression**" and using the following expression in "**Label Class**" panel, which allows adding the unit simultaneously:

round(number($feature.**Area**), **2**) + **" ha"**

It is important to note that "**Area**" can be replaced with the name of any other field by typing it exactly as it appears in the attribute table. Moreover, the number "**2**" in the expression can be substituted with the desired number of decimal places. After the "**+**" sign, the text or unit to be displayed should be enclosed in quotation marks **" "**. In the "**Text** Symbol" group, the text format is configured. This expression uses the Arcade language (as shown in Figure 54).

Figure 54. Shows the setup of an expression to customize a label.



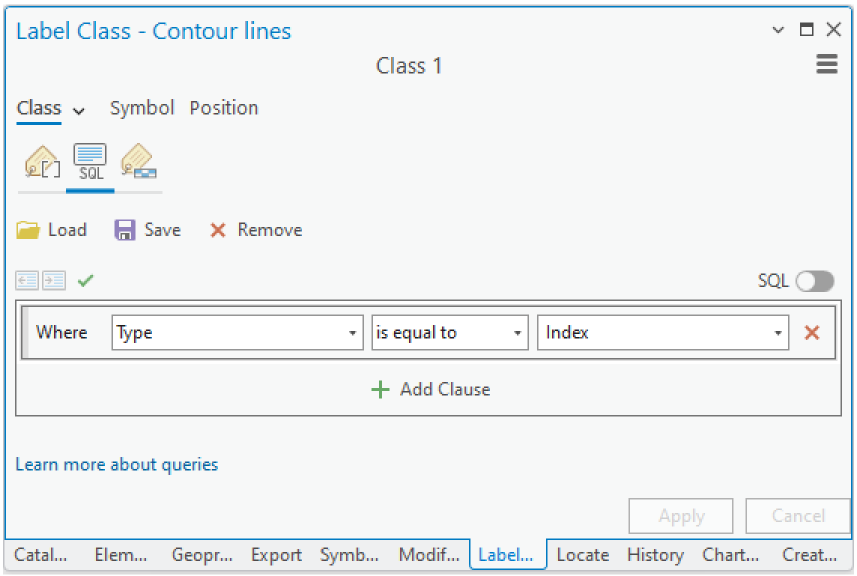
9.2.3. Labels of a Specific Category

In certain scenarios, it may be necessary to label only a specific category, for example, contour lines. For this purpose, the "**contour_lines**" layer, found in the "**09_2_labels**" folder, can be used. To add this shapefile, navigate to the "**Map**" tab, click on "**Add Data > Data**", and select the file. It is recommended to place this layer beneath the current line layers.

Utilizing the cartographic techniques learned previously, categories of contour lines should be displayed based on the field "**Type**". For symbology, it is suggested to apply the following settings: for "**Index**" curves (Contour, Topographic, Index; Line width 1; RGB: 78,78,78) and for "**Intermediate**" curves (Contour, Topographic, Intermediate; Line width 0.4; RGB: 178,178,178).

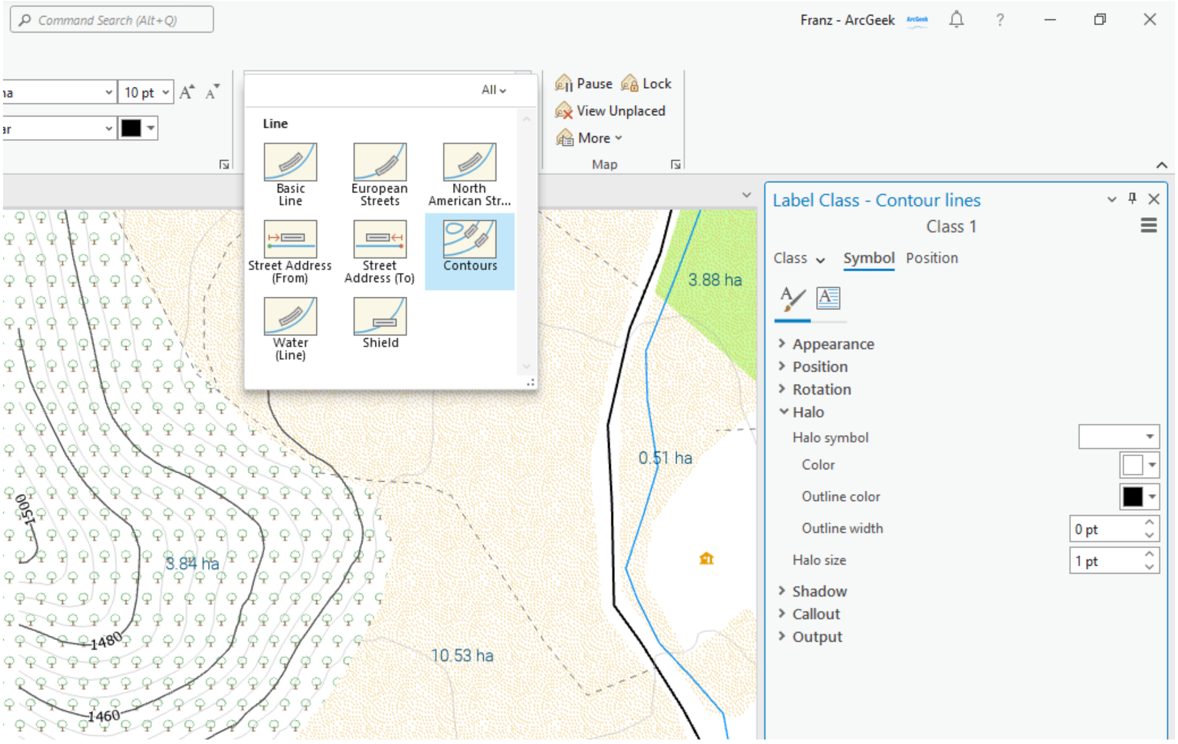
Activating labels using the "**Contour**" field will display all labels of all contour lines, but if only the labels of "**Index**" contour lines are required, the following steps should be taken: Right-click on the "**contour_lines**" layer and select "**Labeling Properties…**". In the "**Label Class**" panel, under the "**Class**" tab, click the "**SQL > New expression**" button. Select the field "**Type**" in "**Where**", choose "**is equal to**", and select "**Index**". Then click on "**Apply**", and only the labels for "Index" curves will be displayed. Figure 55 illustrates this process.

Figure 55. Setting up a SQL expression in the "Label Class" panel.



To enhance the appearance of the labels on contour lines, the following steps are recommended: Go to the "**Labelling**" tab and click on the arrow of the "**Label Placement**", selecting "**Contours**" in the "**Field**" option. In the "**Label Class**" panel (accessed by right-clicking on the layer and selecting "Labeling Properties.."), proceed to the "**Symbol**" tab. Here, selects a white color for "**Halo**" and set the halo size to **1**. This configuration can yield results similar to those depicted in Figure 56.

Figure 56. Setting up labels for contours and assigning a "Halo".



9.3. Giving a 3D Effect to the Map (Optional)

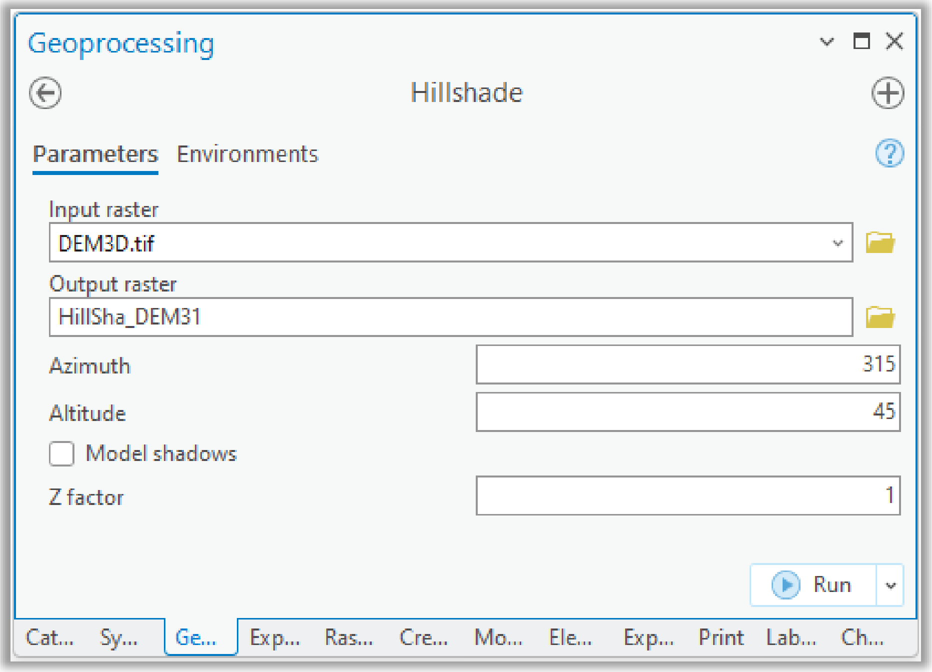
To enhance the topographic appearance of the vector map, a 3D effect can be achieved by adding a shadow map and combining it. The first step is to add the "**DEM3D.tif**" file located in the "**09_3_effect3D**" folder (accessible via "Map > Add Data > Data"). During this process, it is not necessary to have the "DEM3D.tif" raster layer activated.

Once the elevation model is loaded, a shadow map is created using the "**Hillshade**" tool, found at:

Analysis tab > Geoprocessing > Tools > Toolboxes > Spatial Analyst Tools > Surface > Hillshade

Upon opening the "Hillshade" tool, select "**DEM3D.tif**" from the "09_3_effect3D" folder as the "**Input raster**" and then click on "**Run**" (as shown in Figure 57).

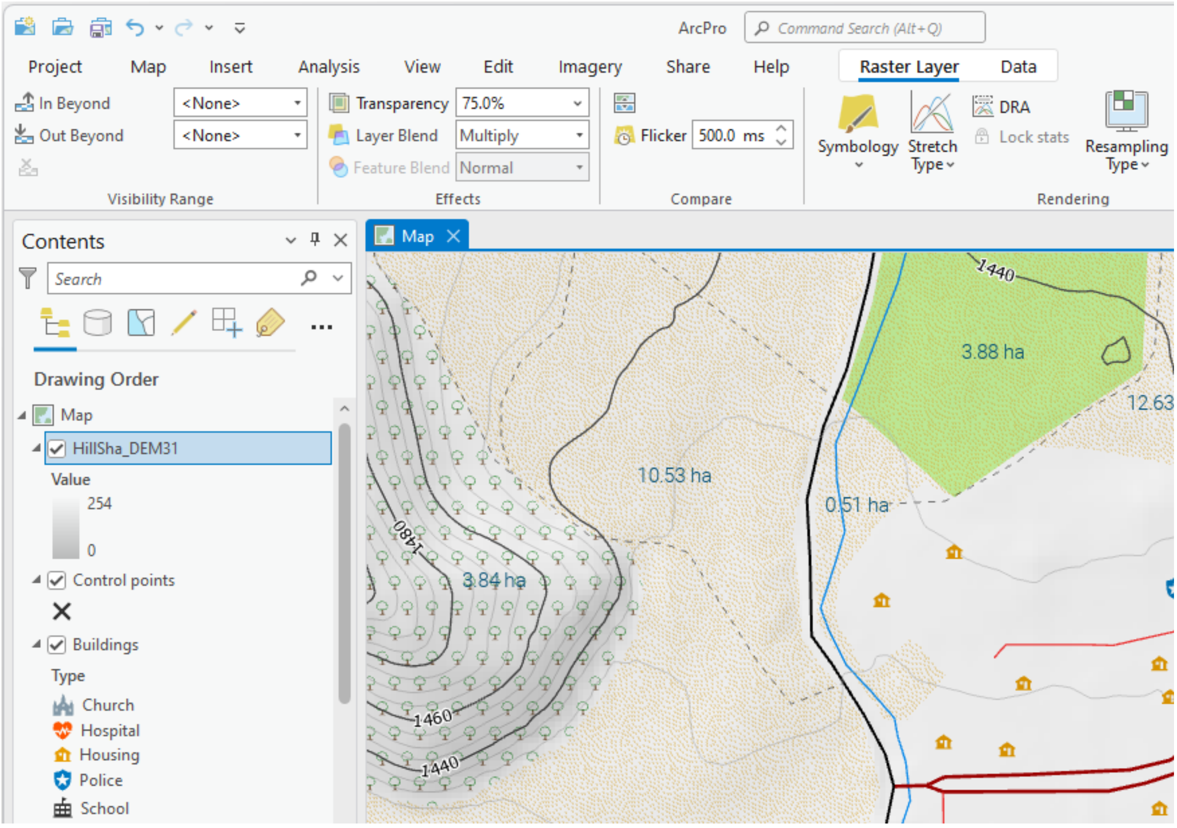
Figure 57. Creating a shadow map (Hillshade).



The newly created "**HillSha_DEM31**" layer should be positioned at the top of all layers in the "**Contents**" panel. Once selected, navigate to the "**Raster Layer**" tab located at the top of the main window. In the "**Effects**" group, set a transparency value using the "**Transparency**" option. A transparency level around 75% is recommended.

After adjusting the transparency, choose "**Multiply**" in the "**Layer Blend**" option. This step will help achieve a result that gives a 3D effect to the map, similar to what is illustrated in Figure 58.

Figure 58. Adding a 3D effect to a map.

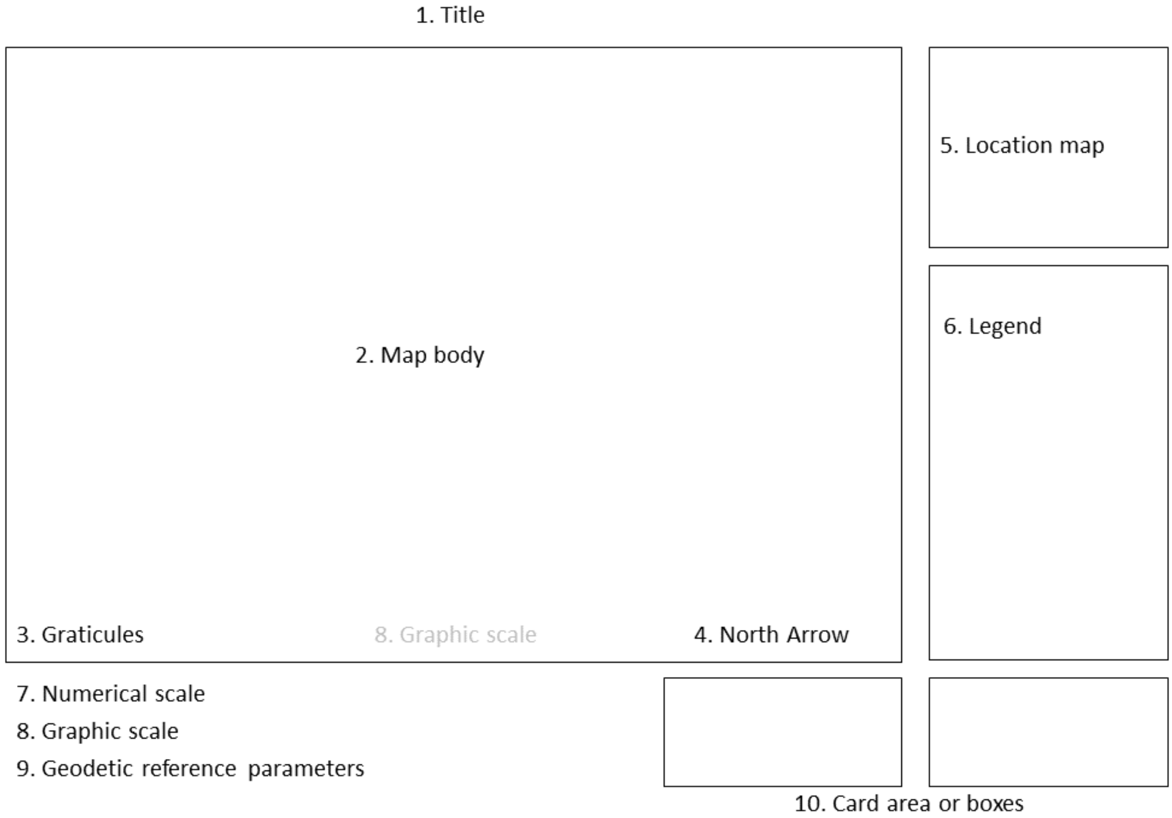


9.4. General Structure of a Map

While it is impossible to represent the real world exactly on a map, cartographers have the freedom to interpret the world in their own way (Rekacewicz, 2006). However, when presenting spatial information, it is crucial to maintain objectivity and avoid any form of manipulation or bias.

The arrangement of elements on a map is determined by the author's needs, but the key is that the intended audience can easily understand it. Figure 59 suggests a layout for map elements. While not all elements are mandatory, it is essential to include a title, grid, geographic north, scale, and legend.

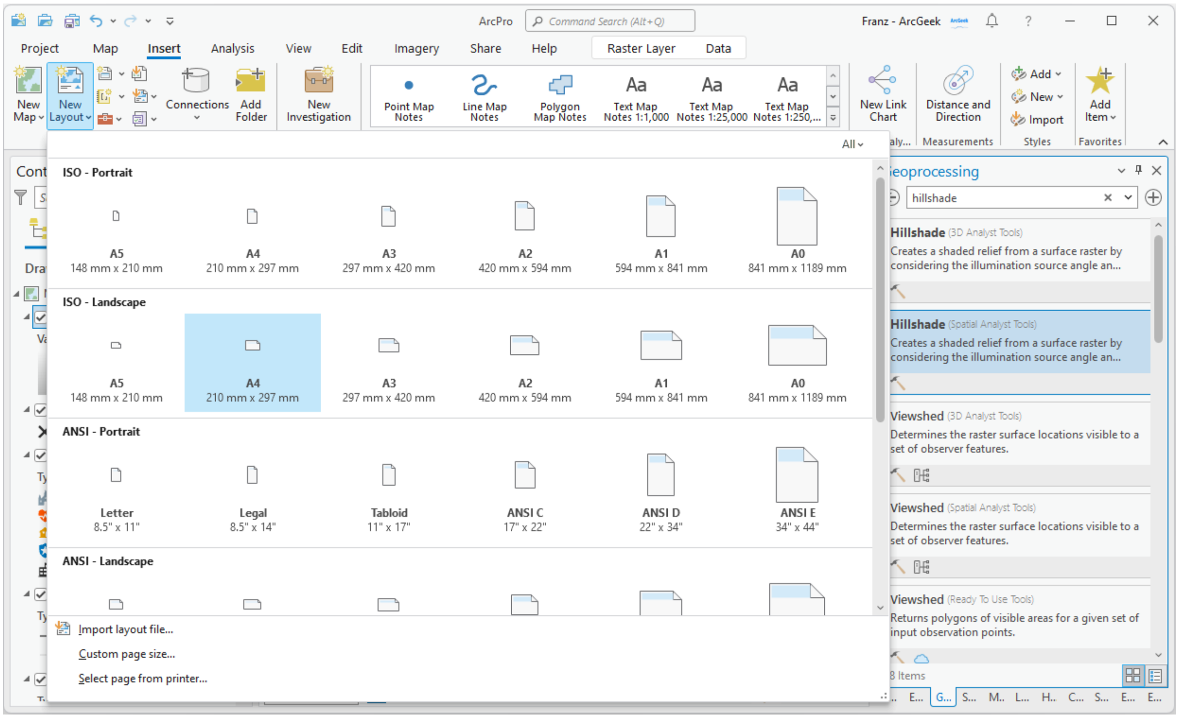
Figure 59. Elements for Designing a Map.



9.5. Design of a "Layout"

After applying cartographic techniques to the various layers, the next step is preparing the map for publication through a "Layout". To create a new "**Layout**", navigate to the "**Insert**" tab and click on "**New Layout**". Here, you can choose the map orientation (horizontal or vertical) and the paper size. For this example, select "**ISO – Landscape: A4**" (as illustrated in Figure 60). It is possible to create multiple "Layouts", each displayed in separate tabs, similar to how the available maps are shown. It is important to note that when working within a "Layout", the tools in the ribbon will change to reflect options suitable for the layout of the page being worked on.

Figure 60. Creating a new "Layout" in ArcGIS Pro.



It is crucial to remember that what is seen in the "Layout" is exactly what will be printed or published. Therefore, meticulous attention to every detail is essential to deliver a quality map. To follow the structure of elements as suggested in Figure 59, the necessary steps to achieve a similar result are outlined below.

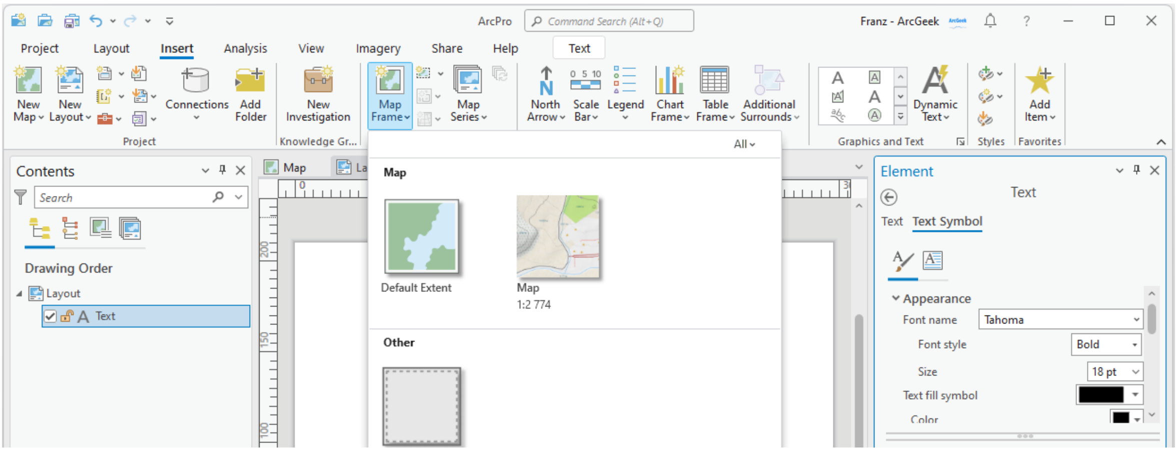
9.5.1. Title (1)

In the "**Insert**" tab, under the "**Graphics and Text**" group, select the "**Straight Text**" icon and draw a text box on the page to define the map's title (e.g., "**My first map in ArcGIS Pro**"). To customize the text formatting, either activate the "Text" tab or right-click on the "**Text**" layer in the "Contents" to access the "**Text**" panel. Within this panel, specifically in the "**Text Symbol**" tab, various formatting options are available. These options include setting the text to bold, adjusting the text size (recommended size is 18 pt), and other necessary customizations.

9.5.2. Map Body (2)

The map body is the most crucial part of any map as it contains all the layers to be represented. To add this element, go to the "**Insert**" tab, and within the "**Map Frames**" group, click on "**Map Frame**". This option lets you select the map you have been working on (as shown in Figure 61). Then, draw the square on the page that will contain the map with all the layers activated.

Figure 61. Inserting the map body (Map Frame) in ArcGIS Pro.

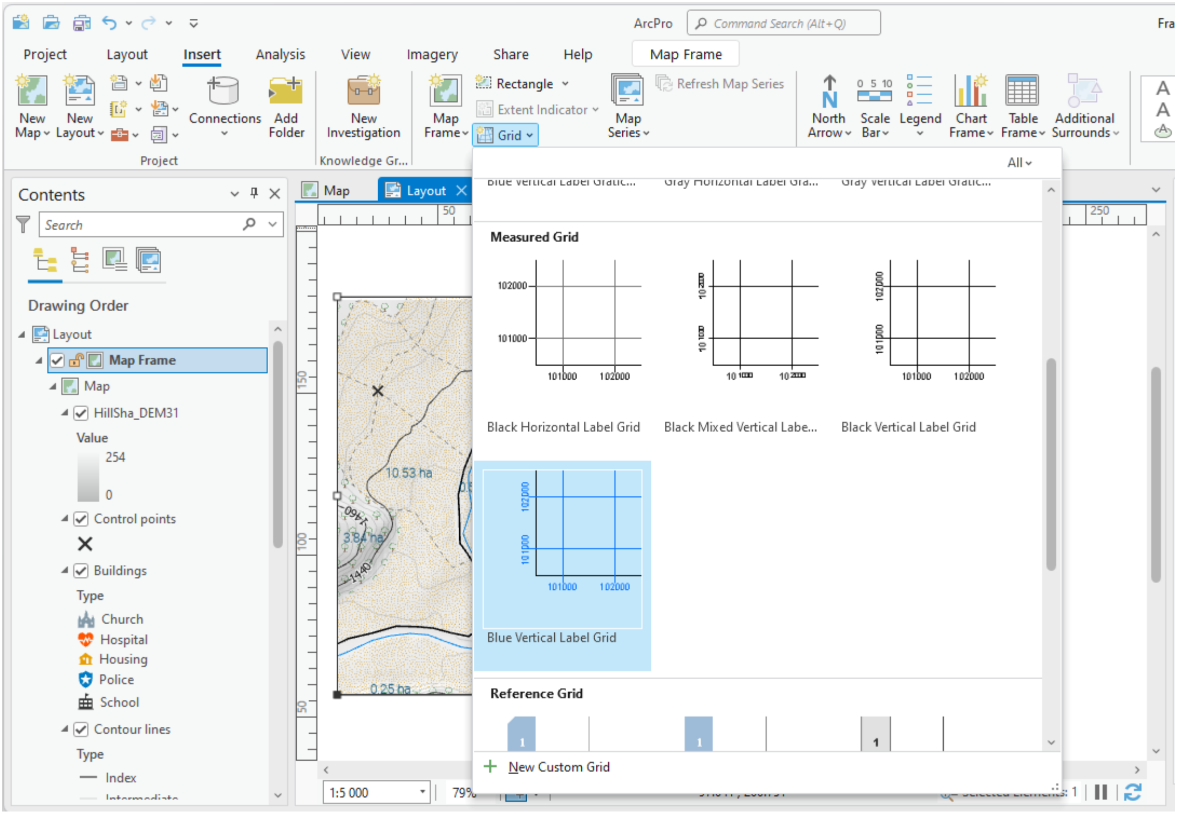


To adjust the size of the map body, click on the rectangle containing it and modify its borders as needed. Additionally, the position of the map within the box can be altered by right-clicking on the "Map Frame" that was created and selecting the "Activate" button, then using the tools in the "Layout". By clicking on the map, it can be moved to the preferred location. It is important to set the print scale, which can be customized from the lower bar in the "Layout". In this example, a scale of 1:5000 is used.

9.5.3. Graticules (3)

Adding one or several grids to the map is possible, depending on the representation needs. In this specific instance, a UTM planar coordinate grid is needed. To add this, select the "**Map Frame**" layer in the "**Content**" panel, then go to the "**Insert**" tab, in the "**Map Frames**" group, choose "**Grid**". Various grid formats are available (as seen in Figure 62). For this example, "**Blue Vertical Label Grid**" in the "Measured Grid" option has been selected. It is also possible to add geographical coordinate grids found in the "**Graticule**" option.

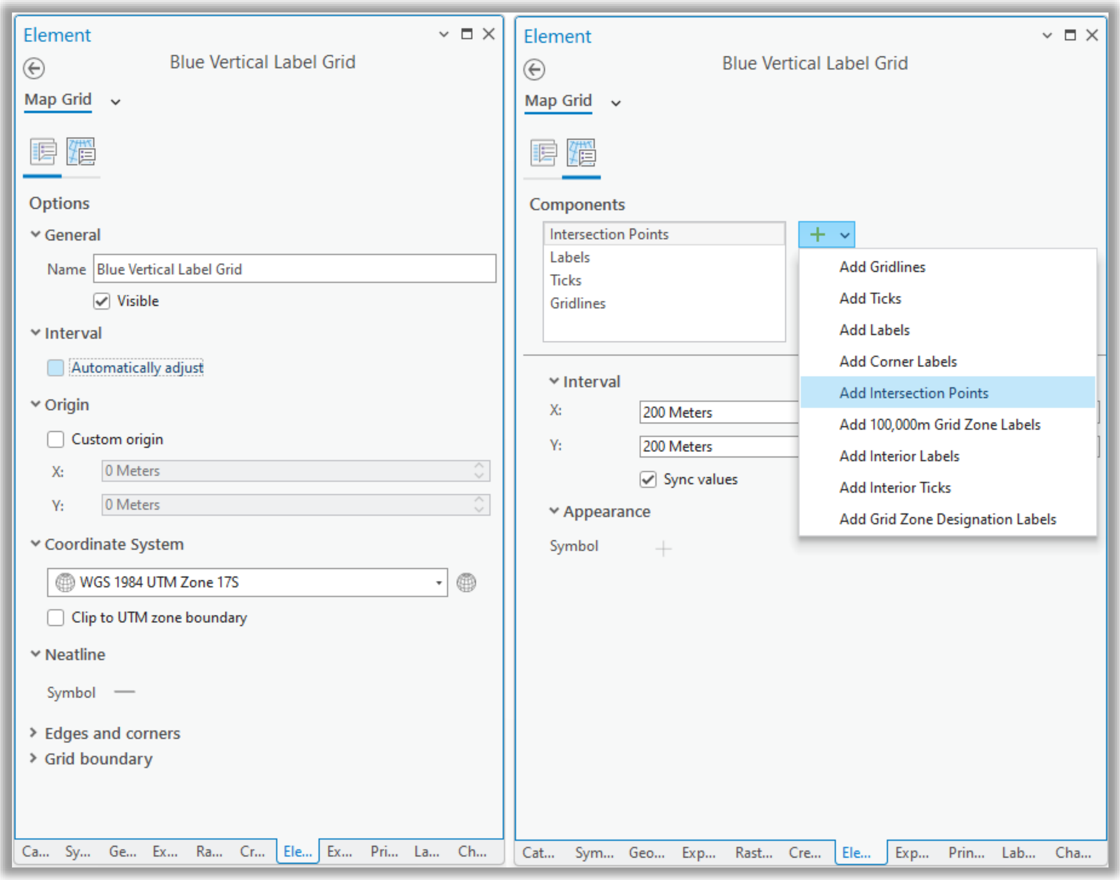
Figure 62. Adding a grid in ArcGIS Pro.



Several customization options for the grid are available in the "**Element**" panel, which can be accessed by double-clicking on the selected grid in the "**Contents**" panel. If the "**Element**" panel does not appear, right-click on the grid in the "**Contents**" pane and select "**Properties**" (for example, right-click on "Blue Vertical Label Grid").

The grid intervals are set automatically, but they can be customized by unchecking the "**Automatically adjust**" checkbox in the "**Options**" section (as shown in Figure 63, left). By clicking on the "**Components**" button (Figure 63, right), it is possible to customize the intervals for each component and add or remove components. For instance, in this example, the horizontal and vertical lines ("**Gridlines**") are not necessary and can be removed in "**Components**" using the "**x**" button. Alternatively, the component "**Intersection Points**" can be added. Additionally, all components provide options to customize color, symbol, and other aspects.

Figure 63. Grid configuration in the "Element" panel.



9.5.4. North Arrow (4)

To indicate the map's orientation, a north arrow is used. To add this, go to the "**Insert**" tab and select the "**North Arrow**" option within the "**Map Surrounds**" group. Then, choose the required north arrow symbol (e.g., "**ArcGIS North 1**") and draw a box on the page where you want it to be located. The size, color, and other attributes of the arrow can be adjusted, and it can be freely moved around the map until it is positioned correctly.

9.5.5. Location Map (5)

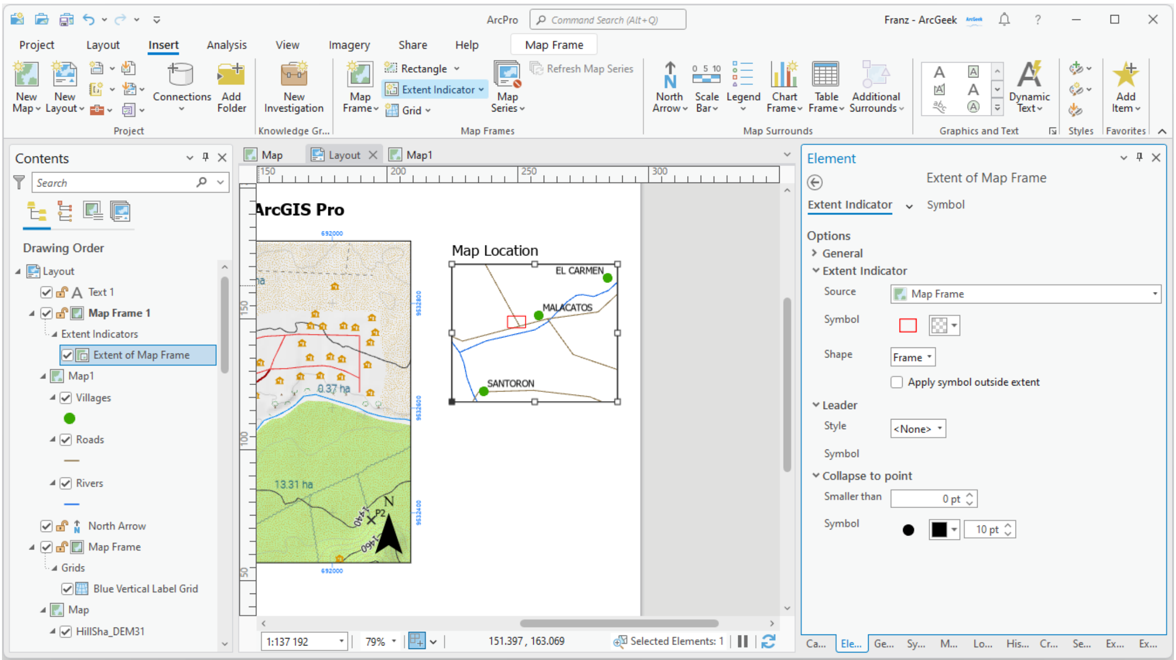
Having a location map is advantageous as it helps the reader spatially situate the study area within a broader context. In ArcGIS Pro, location markers can be added to connect different "Map Frames". To do this, create a new "**Map**" and a new "**Map Frame**" reference.

The steps for adding a location map are as follows:

- Navigate to "**Insert > New Map > Map**" to add a new map.

- In the new map, use the "**Add Data**" button in the "**Map**" tab to add one or more layers indicating the spatial extent above the study area. In this example, all layers (shapefiles) from the folder "**09_5_5_location_map**" are used. If preparing a map of a department or province, consider adding the map of the corresponding country or region to the location map.
- Apply the previously learned cartographic techniques to configure the symbology and design of the new map's layers.
- Return to the "**Layout**" editing and add the new map (Map1) using the "**Map Frame**" button. Adjust its location, size, and scale as needed.
- Select "**Map Frame 1**" and, in the "**Map Frames**" group, click on the "**Extent Indicator**" button and select the "**Map Frame**".
- Customize the symbol and other options in the "**Element**" panel under "**Extent Indicator**".
- To add a title, insert a text box from "**Insert > Graphics and Text > Straight Text**". For instance, you can type "**Location Map**", as shown in Figure 64.

Figure 64. Setting up location indicators.



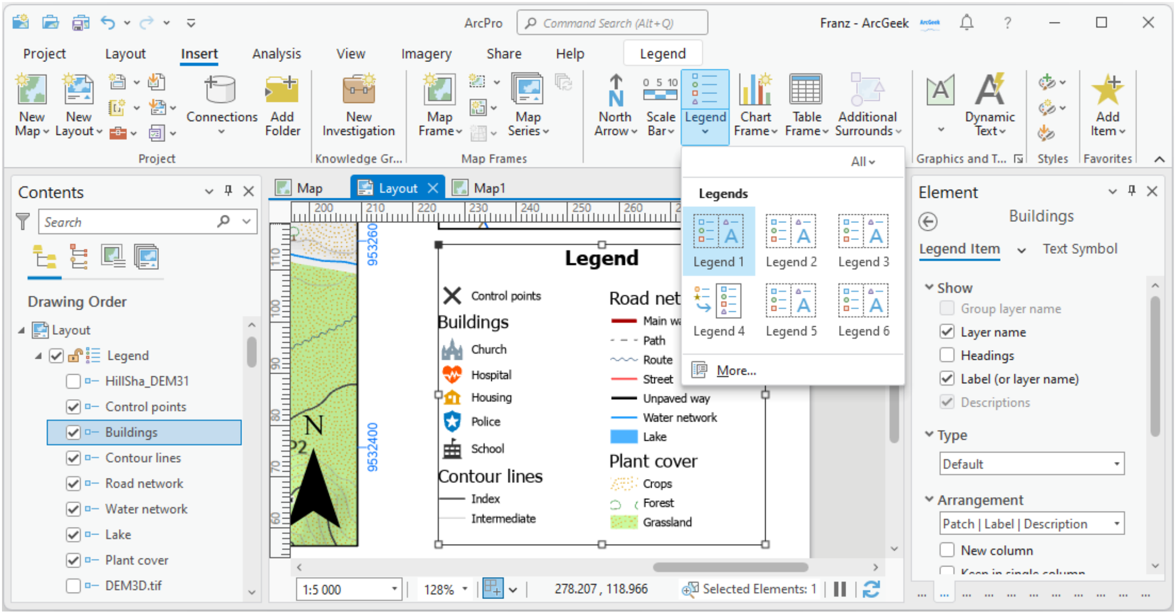
Multiple "**Map Frames**" can be added as needed and configured or customized by right-clicking on them and opening their properties. This is particularly beneficial when working with a large number of "Map Frames". However, care should be taken when adding many "Map Frames" to ensure the study area is clearly identified within the geographic context and easily visualizable.

9.5.6. Legend (6)

To add a legend that assists readers in understanding the symbols used on the map, the following steps are recommended:

- In the "**Insert**" tab, within the "**Map Surrounds**" group, one should select "**Legend**" and draw a box on the page where the legend is desired.
- In the "**Element**" panel, the legend title can be set. Options such as font formatting, columns, border, and shading can also be adjusted here.
- The "**Contents**" panel allows for the activation or deactivation of elements present in the legend. For instance, if it is not necessary to display the "**HillSha_DEM31"** layer, it can be deactivated or removed.
- To customize a specific element of the legend, one should right-click on this element within the "**Contents**" and select "**Properties**" to access the "**Element**" panel. Unnecessary boxes can be unchecked in the "Legend Item" panel. For example, if one does not want to display the "**Type**" field title in the "**Buildings**" layer, the "**Heading**" checkbox can be deactivated, or to remove the layer name, the "**Layer name**" box can be unchecked (as depicted in Figure 65).

Figure 65. Inserting a legend in ArcGIS Pro.



9.5.7. Numerical Scale (7)

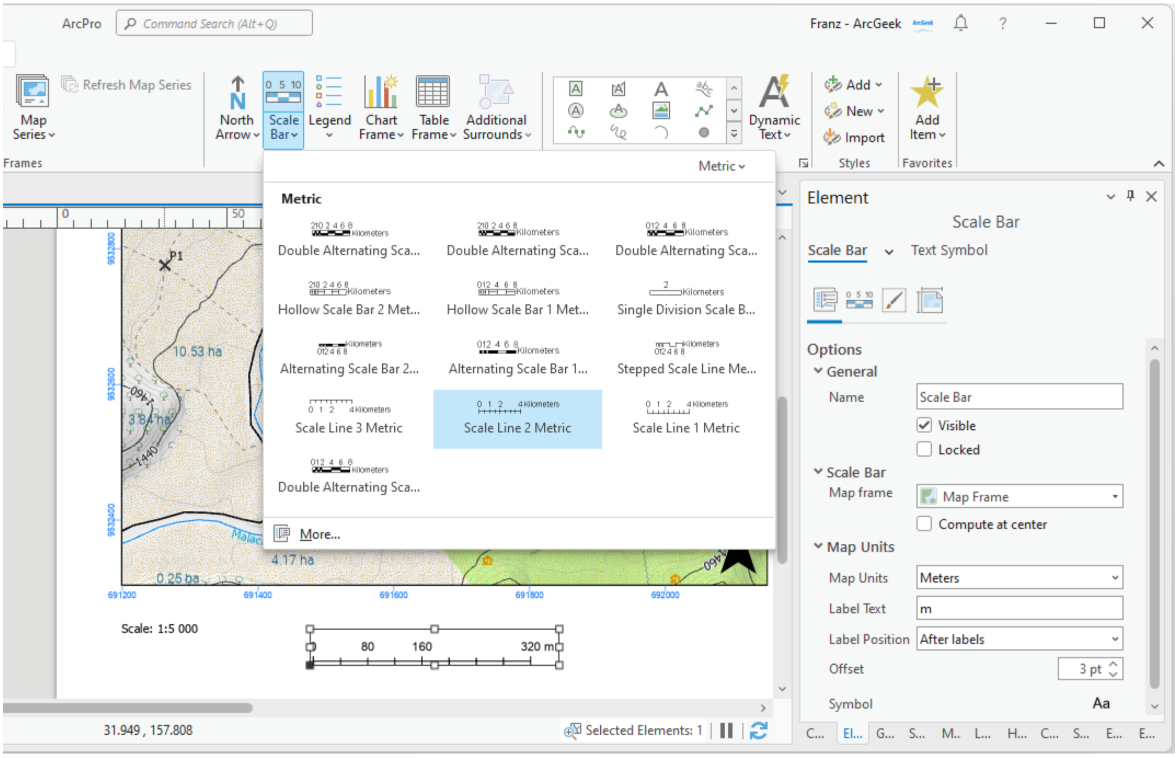
To demonstrate the relationship between distances on the map and actual terrain distances, a numerical scale is used. Before adding it to the map, it is crucial to ensure the scale value (in this example, 1:5000) is correctly set in the bottom bar of the page.

In the "**Insert**" tab, one should select **"Dynamic Text**" within the "**Graphics and Text**" group. From the list of dynamic text formats, choose "**Scale**" and then draw a box where the numerical scale should appear. The scale can then be configured or customized, such as setting the text size to 12 pt. This scale is dynamic, meaning it will automatically update if the map scale changes. In the "**Elements**" panel, under text options, "**Scale:**" can be replaced with any other necessary text.

9.5.8. Graphic scale (8)

The graphic scale is a visual tool representing terrain distances on a map, akin to a "mini ruler". Depending on the design, it can be placed inside or outside the map (as shown in Figure 59). To add a graphic scale, go to the "**Insert**" tab and in the "**Map Surrounds**" group, click on "**Scale Bar**". From the list of available scale bar options, choose the preferred one (e.g., "**Scale Line 2 Metric**"). After selecting, draw and position the graphic scale at the desired location. In the "**Element**" panel, diverse options can be customized, such as selecting "**Meters**" for the unit of measurement and changing the "**Label Text**" to "**m**" (as illustrated in Figure 66).

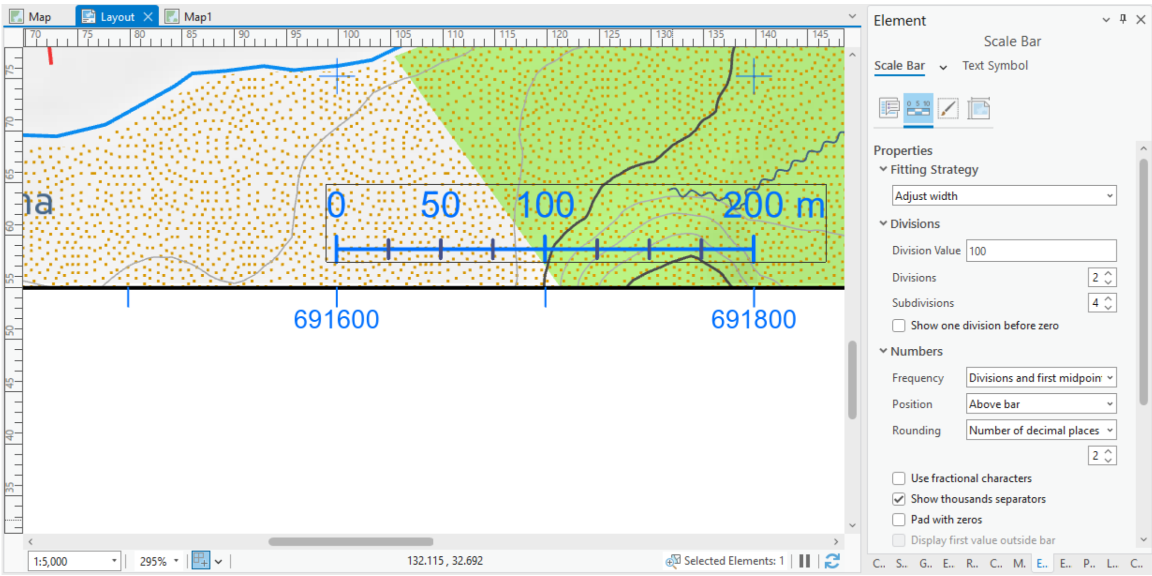
Figure 66. Adding a graphic scale in ArcGIS Pro.



To set the divisions of the graphic scale to precise values, such as a total length of 200 meters, the following steps should be taken:

- Open the "**Properties**" of the inserted "**Scale Bar**" by right-clicking on it to open the "**Elements**" panel.
- In the "**Fitting Strategy**" tab, select "**Adjust width**".
- Enter 100 in the "**Division Value**" field and 2 in the "**Divisions**" field. Also, select 4 for "**Subdivisions**". The total length of the graphic scale is determined by multiplying the values of "Division Value" and "Divisions" (as shown in Figure 67).

Figure 67. Adjusting the divisions of the graphic scale.



9.5.9. Geodetic Reference Parameters (9)

Indicating the geodetic reference system used in creating the map is essential. To do this, go to "**Insert > Graphics and Text > Straight Text**" and type the following text:

Universal Transverse Mercator Projection.

Ellipsoid and Horizontal Datum WGS 84 Zone 17 South.

9.5.10. Card Area or Boxes (10)

Cards or boxes are useful for adding additional information to the map, such as the names of the individuals responsible for its creation, the project or program name, logos, the source of cartographic inputs, the date of creation, the working scale, among other details. The steps to add a table from a vector layer, a Microsoft Word table, and an image are as follows:

- To add a table containing information from the "**Control points**" layer, first ensure that the layer has all desired information and that field aliases are configured. This is done by opening the layer's attribute table, right-clicking on a field, and selecting "**Field**" to assign an "**Alias**". Then, navigate to "**Insert > Map Surrounds > Table Frame**", draw where the table should appear, and select the "**Control point**" layer in the "**Elements**" panel. Finally, adjust the customization options as needed.

- To insert a table from a Microsoft Word document (e.g., Table 4), copy it (**Ctrl + C**), and paste it into the ArcGIS Pro "**Layout**" (**Ctrl + V**). Adjust as needed. However, this method can be challenging to adjust. Thus, it is advisable to export the table as an image (for example, by copying it into Paint and saving as PNG or JPG) and then following the next step to insert the table as an image in the "**Layout**".

Table 4. Information Card

Information box	
Communal Basemap	
Topic: My First Map in ArcGIS Pro	
Source: IGM Shapefiles	**Date:** January 2025

- To add a logo or image, go to "**Insert > Graphics and Text > Graphic**" and select the desired image. Then, adjust its size and position as necessary.

To enhance the visual presentation of the map, organizing each added element meticulously is recommended. This can be achieved by selecting multiple elements and right-clicking to access options like grouping, aligning, and distributing. Furthermore, to broaden the range of design possibilities, exploring additional features not covered in this manual, such as incorporating graphics, reports, styles, and "MXD" files, is advised. Engaging with these tools can facilitate the development of more advanced skills in a self-directed manner.

9.6. Exporting and Printing a Map

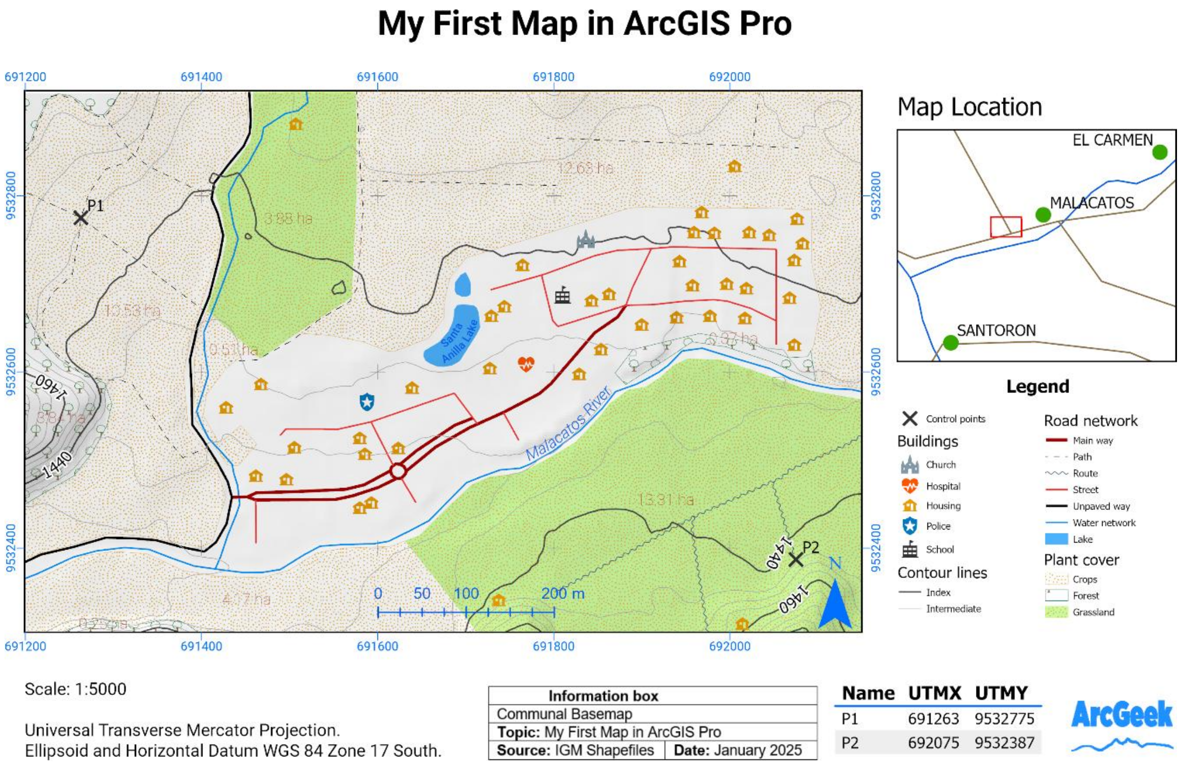
Once the map creation process is complete, it can be printed or exported in various formats. To print the map, go to the "**Share**" tab in the "**Output**" group, click on "**Print Layout**", and configure the printer as per the available options.

For digital format needs, the map can be exported via "**Share > Output > Export Layout**". In the "**Export Layout**" panel, various formats such as EMF, EPS, AI, PDF, SVG, BMP, JPEG, PNG, TIFF, and GIF are available for selection, followed by exporting using the "**Export**" button. Each format allows for the configuration of resolution and additional parameters. By selecting "**Clip to graphics extent**" the map is clipped to the area occupied within the design, which is useful if the map does not fill the entire sheet. Choosing "**Transparent background**" makes the map's background transparent.

Notably, the PDF options offer the capability to enable or disable layers within the PDF reader, which is particularly beneficial for creating a "**GeoPDF**". In some cases, especially when using special characters in map texts, not all elements might be readable in the generated PDF file. Therefore, using a PDF printer installed on the computer is recommended.

Figure 68 illustrates the last version of the map created following the instructions in this document.

Figure 68. Example of a map produced with ArcGIS Pro.



Up to this point, the manual has covered the main techniques, tools, and functions for building a map. Having a solid understanding of the entire map creation process is essential to achieve a quality visual presentation. In the following sections, additional tools that may be useful for a project will be explored. It is important to continue exploring the distinct options of the tools presented in ArcGIS Pro, as curiosity is an effective way to learn and become a Pro.

10. Geoprocessing tools

All GIS tools are highly beneficial as they enable the automation of processes that traditionally required considerable time and manual effort. Among these tools, "Geoprocessing" stands out as particularly powerful, offering a means to create new geographic information through various operations. The primary aim of geoprocessing is the modeling and analysis of geographic data, as well as the automation of GIS tasks (ESRI, 2016b).

From this point forward, the tools from "**Toolboxes**" ("**Analysis > Geoprocessing > Tools**") will be utilized, although some of the most common geoprocessing tools are also accessible from the "**Tools**" group in the "**Analysis**" tab. Each tool is structured similarly, requiring input and output files, and featuring configurable fields, depending on the tool's nature. For advanced users, the use of "**Pairwise Overlay Tools**" within the "**Toolboxes**" is recommended.

To conduct the exercises in this section, it is advisable to create a new map ("**Insert > New Map > New Map**") in a new project or within the current project in "**ArcPro**". Then, the vector layers from the "**10_geoprocessing**" folder should be loaded.

10.1. Areas of influence (Buffer)

The concept of areas of influence is akin to the ripple effect caused by a drop of water on a surface, creating a shock wave that propagates and can induce positive or negative changes from its origin. In spatial analysis, influence zones are polygons generated from a point, line, or polygon entity at a specified distance. This analysis is instrumental in understanding the surface area impacted by various activities, such as the construction of a factory, the opening of a road within a protected area, the effects of pollutants like fertilizers, or the reach of antennas for telecommunications or weather radar.

The "**Buffer**" and "Pairwise Buffer" tools are designed to create zones of influence for points, lines, and polygons. These tools can be accessed through the following path:

Geoprocessing > Toolboxes > Analysis Tools > Proximity > Buffer
Geoprocessing > Toolboxes > Analysis Tools > Pairwise Overlay > Pairwise Buffer

The configuration of the "**Buffer**" tool (as shown in Figure 69) includes the following steps:

- **Input Features:** Select the layer of points, lines, or polygons to be used for creating the buffer zones (such as buffer_points, buffer_line, buffer_polygon).
- **Output Features Class:** Choose the directory or geodatabase where the resulting buffered entity will be stored.

- **Distance [value or field]:** This option offers two choices. "**Linear Unit**" allows setting a fixed value with its respective unit (e.g., 30 meters), while "**Field**" creates a zone of influence based on the values from a selected field in the attribute table.
- **Method:** This setting specifies the method for creating the zone of influence. The "**Planar**" method uses Euclidean distance, measured as if on a flat, projected plane. In contrast, the "**Geodesic**" method considers the Earth's curvature, independent of the layer's coordinate system. This ensures that the zones of influence are not distorted by a projected coordinate system.

Figure 69. Configuration of the "Buffer" tool.

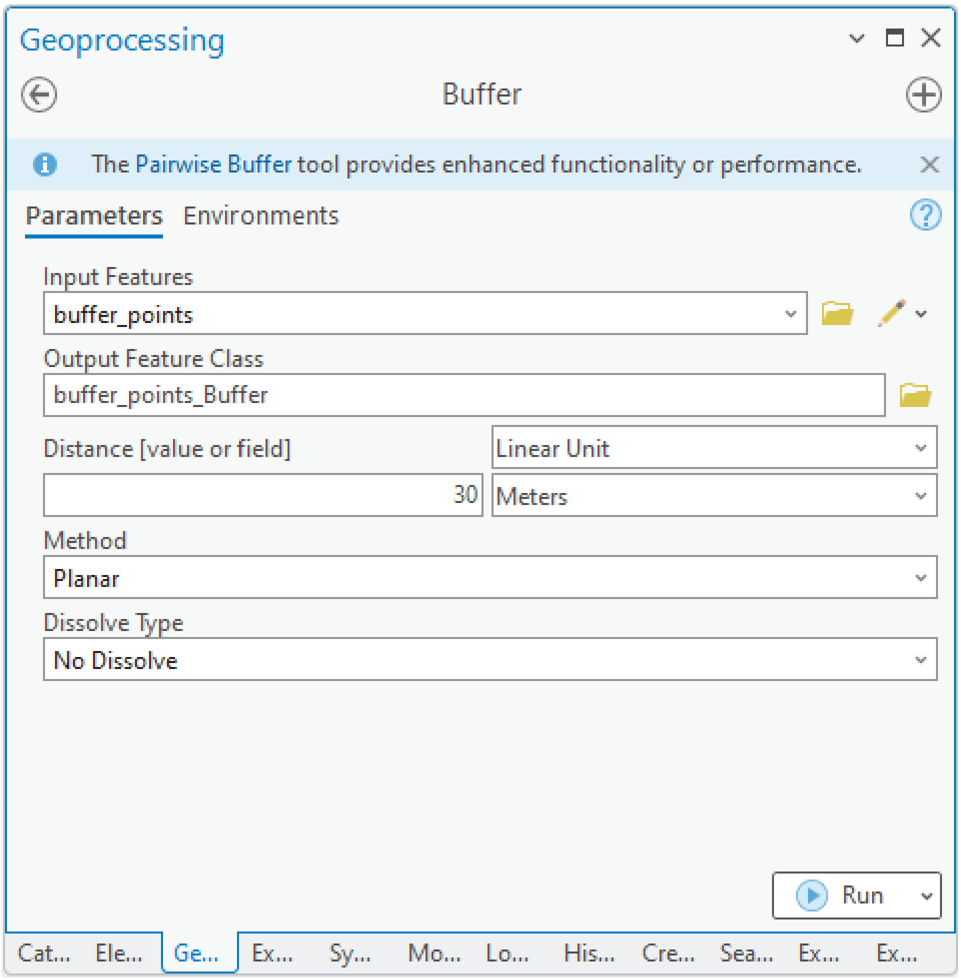
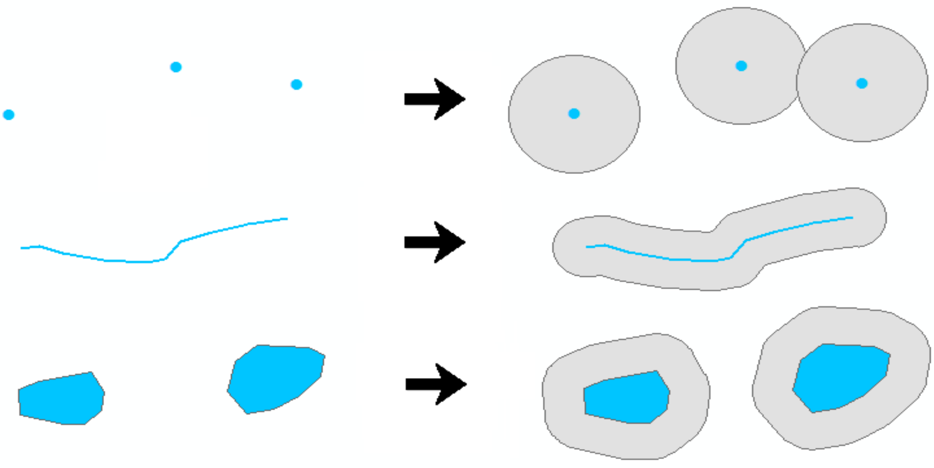


Figure 70 demonstrates the result of creating zones of influence for three points, one line, and two polygons. In this instance, a distance of 20 meters was utilized as the linear unit, and the planar method was applied to generate the zones of influence.

Figure 70. Zones of influence created using the "Buffer" tool.



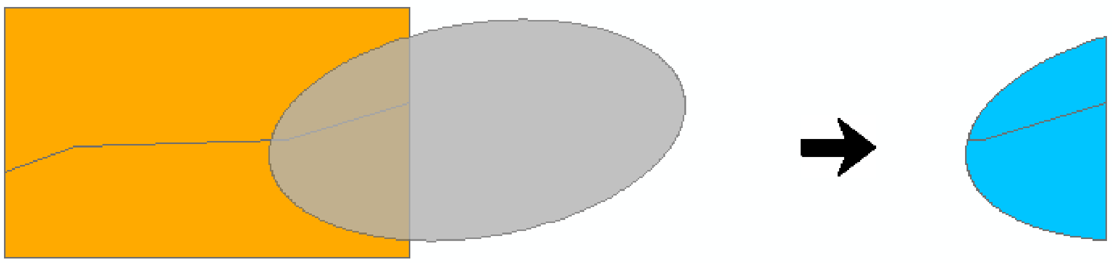
10.2. Intersections (Intersect)

The intersection operation is utilized to find the common area between two or more layers. The "**Intersect**" and "Pairwise Intersect" tools calculate this intersection, subsequently creating a new layer with the results. To access these tools, proceed to:

Geoprocessing > Toolboxes > Analysis Tools > Overlay > Intersect
Geoprocessing > Toolboxes > Analysis Tools > Pairwise Overlay > Pairwise Intersect

In the "**Input Features**" field, add all the layers on which intersection areas are to be searched ("intersect_1", "intersect_2"). An example of the result is shown in Figure 71.

Figure 71. Result of intersecting two layers.



10.3. Clippings (Clip)

The "**Clip**" tool clips an entity according to the perimeter of a polygonal layer. This is valuable for restricting the extent of layers to a specific area, like clipping a country's contour line layer to concentrate on a particular state or province. The "Clip" and "Pairwise Clip" tools can be found at:

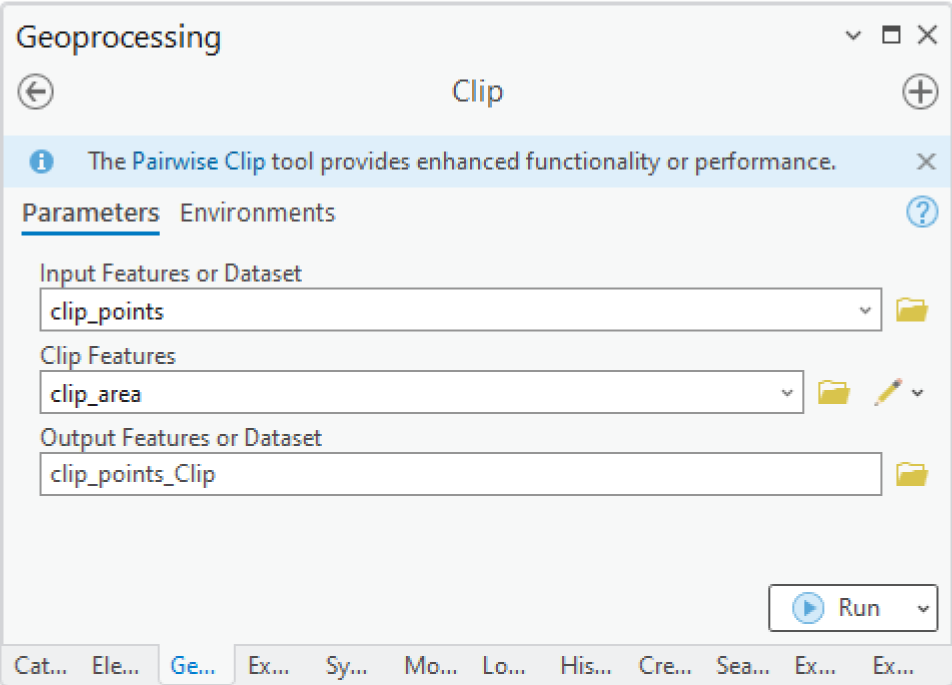
Geoprocessing > Toolboxes > Analysis Tools > Extract > Clip

Geoprocessing > Toolboxes > Analysis Tools > Pairwise Overlay > Pairwise Clip

To configure the tool, the following steps should be taken (as depicted in Figure 72):

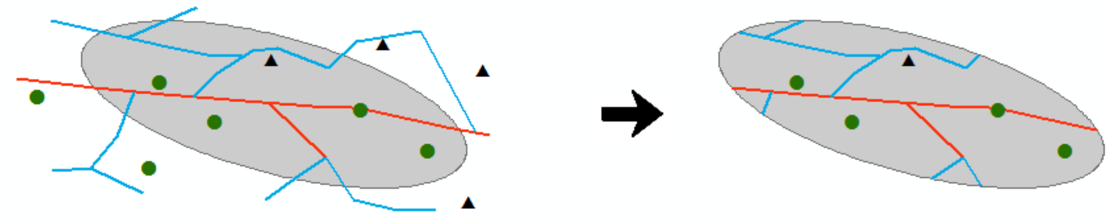
- **Input Features or Dataset:** Select the layer (points, lines, or polygons) to be clipped ("clip_points", "clip_lines").
- **Clip Features:** Choose the polygonal layer that defines the clipping perimeter ("clip_area").
- **Output Features Class or Dataset:** Select the directory or geodatabase where the new clipped layer will be stored.

Figure 72. Configuration of the "Clip" tool.



The outcome of using the "Clip" tool is illustrated in Figure 73.

Figure 73. Clipping of vector entities.



10.4. Merge

To combine two or more entities into a single layer of the same type (points, lines, or polygons), the "**Merge**" tool can be utilized. It is crucial to understand that this tool does not alter the geometry of the original entities, even in cases of overlap. The "Merge" tool can be found at:

Geoprocessing > Toolboxes > Data Management Tools > General > Merge

In configuring the "Merge" tool, within the "Input Dataset" section, all the layers intended for merging should be selected (e.g., "merge_1" and "merge_2"). In the "Output Dataset" section, the resulting layer is assigned a name and directory. The "Field Map" section allows for the addition, renaming, or deletion of fields from the participating layers.

Figure 74. Configuration of the tool "Merge".

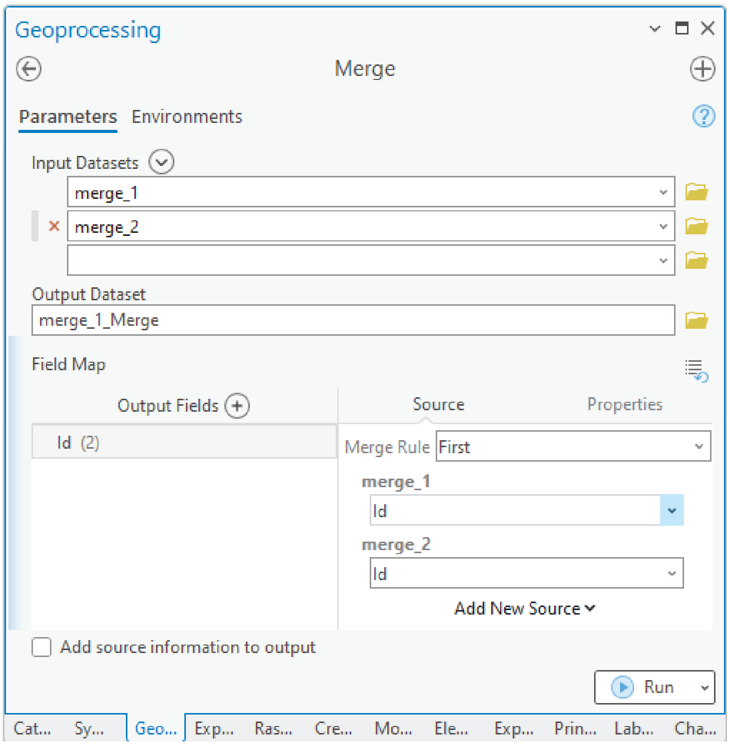
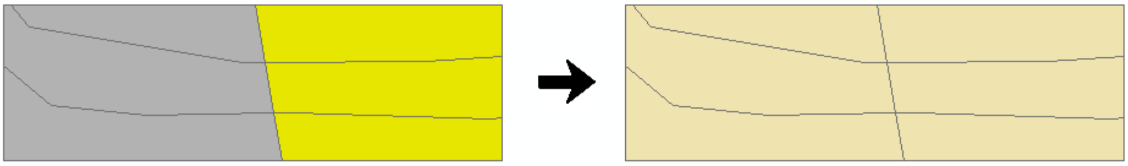


Figure 75 presents an example where, on the left, there are two separate polygon layers, and on the right, the result of merging both layers into one is displayed.

Figure 75. Merging of two vector layers of the same geometry.



10.5. Dissolve

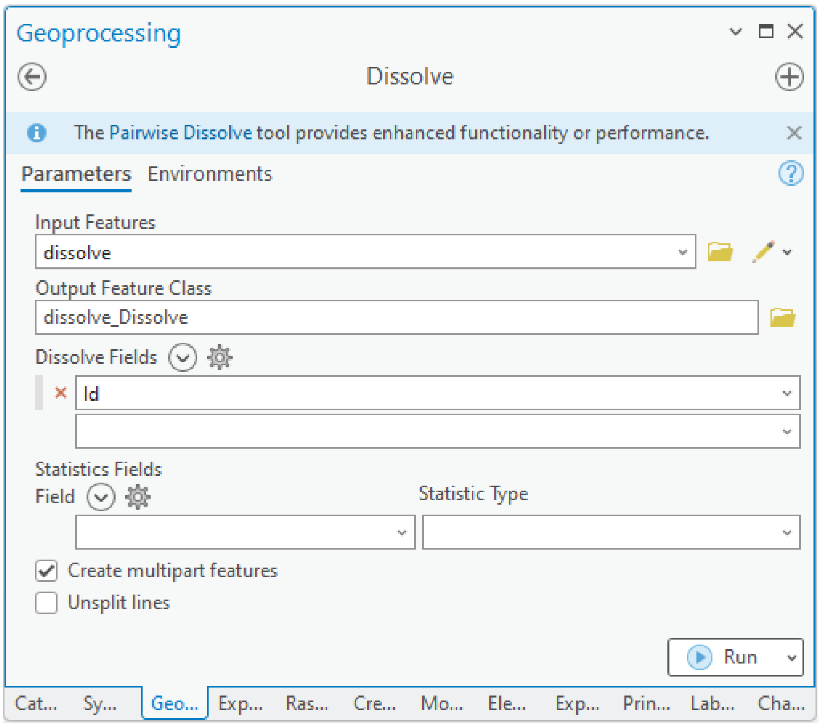
The **"Dissolve"** and "Pairwise Dissolve" tools are employed to amalgamate geographic information based on shared attributes. These tools adeptly consolidate adjacent entities with matching values in specific fields of the attribute table. This process simplifies the layer by dissolving boundaries between similar entities, making these tools particularly effective for generalization and organization of spatial data. To access these tools, one should navigate to:

Geoprocessing > Toolboxes > Data Management Tools > Generalization > Dissolve
Geoprocessing > Toolboxes > Analysis Tools > Pairwise Overlay > Pairwise Dissolve

Figure 76 illustrates the configuration of the "Dissolve" tool, where the parameters should be adjusted as follows:

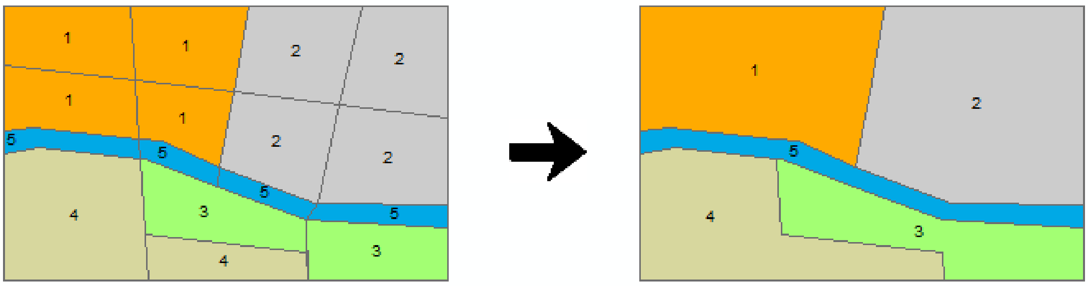
- **Input Features:** Select the layer of points, lines, or polygons to be processed ("dissolve").
- **Output Features Class:** Choose the directory or geodatabase where the resulting file will be saved.
- **Dissolve Fields:** Select the field containing the attributes based on which the entities will be merged (e.g., the "Id" field).
- **Statistics Field:** Enables statistical calculations of the fields to be dissolved.

Figure 76. Configuration of the "Dissolve" tool.



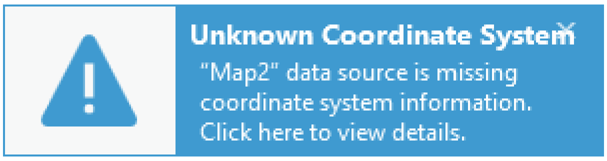
In Figure 77, the left side illustrates continuous polygons with identical attributes, and the right side displays the result of merging all polygons that share a common attribute. This tool is particularly useful for creating a layer of provinces or states from a layer of cantons or municipalities, provided the associated table for the cantons contains a field indicating the province to which each canton belongs.

Figure 77. Result of dissolving a vector layer by its attributes.



10.6. Define Projection to a Layer

Occasionally, when new layers are loaded in ArcGIS Pro, such as the "no_projection.shp" layer, a warning message stating "Unknown Coordinate System 'Map2' data source is missing coordinate system information. Click here to view details" may appear. This indicates that the added layers lack a defined coordinate system, due to the spatial reference system not being set during their creation.



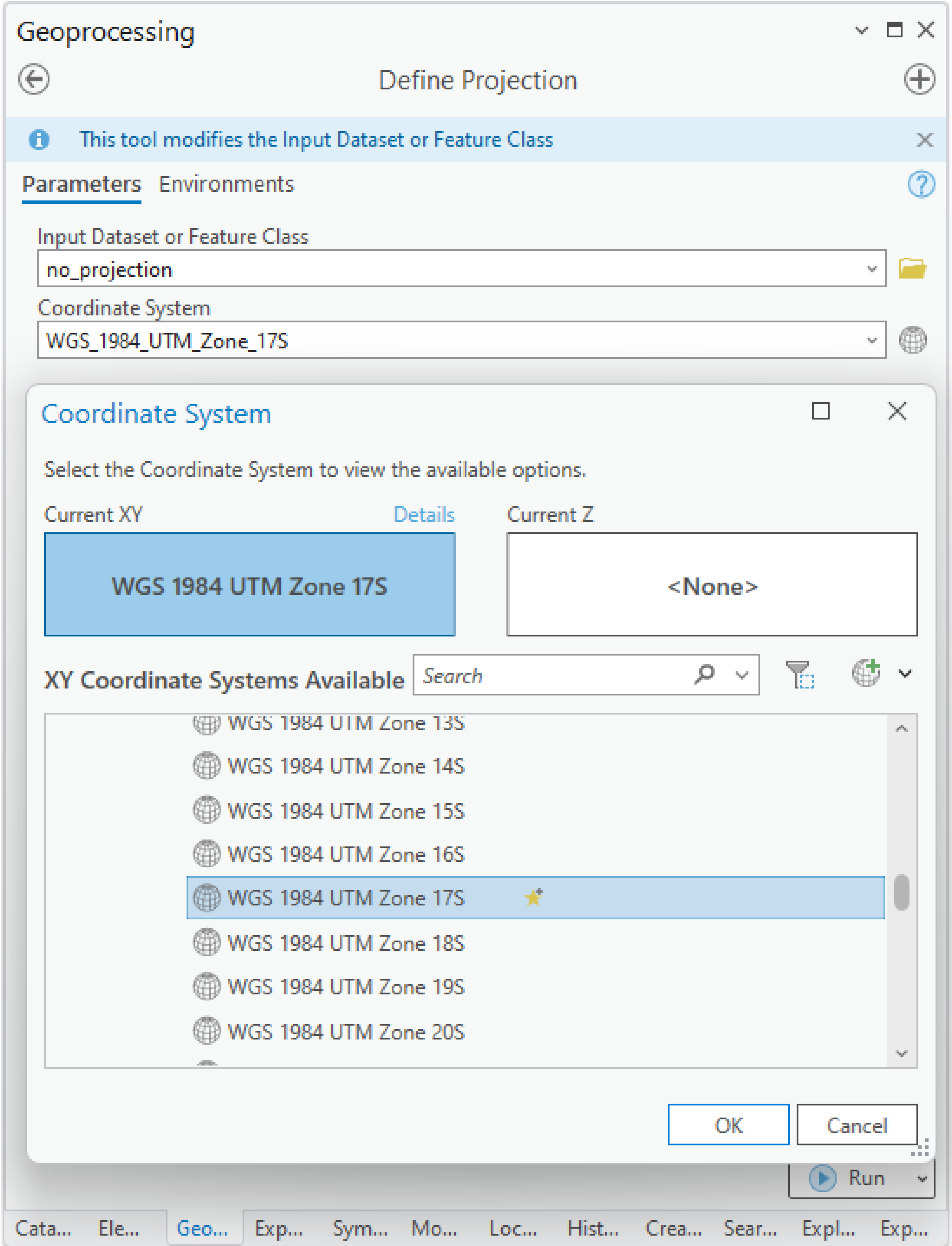
It is crucial not to define a coordinate system without confirming the correct one. To define the coordinate system of a layer (vector or raster), navigate to the following tool:

Geoprocessing > Toolboxes > Data Management Tools > Projections and Transformations > Define Projection

In "**Define Projection**" configure the following parameters and confirm the changes by clicking "OK" (as shown in Figure 78).

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

Figure 78. Defining a coordinate system for a layer.



10.7. Project a Layer to Another Coordinate System

The "**Project**" tool is utilized to transform spatial data from one coordinate system to another. This practice involves transforming the projection of a layer from the "WGS 1984 UTM Zone 17S" coordinate system to the "Provisional South American Datum UTM Zone 17S" system. It is important to note that these systems have different datums (WGS84 and

PSAD56), necessitating the application of appropriate transformations for each location. A list of the required transformations is available in a PDF file (as depicted in Figure 79), which can be found on the ArcGIS Pro help web page "Geographic and Vertical Transformations".

Figure 79. Excerpt from the document "Geographic and Vertical Transformation Tables".

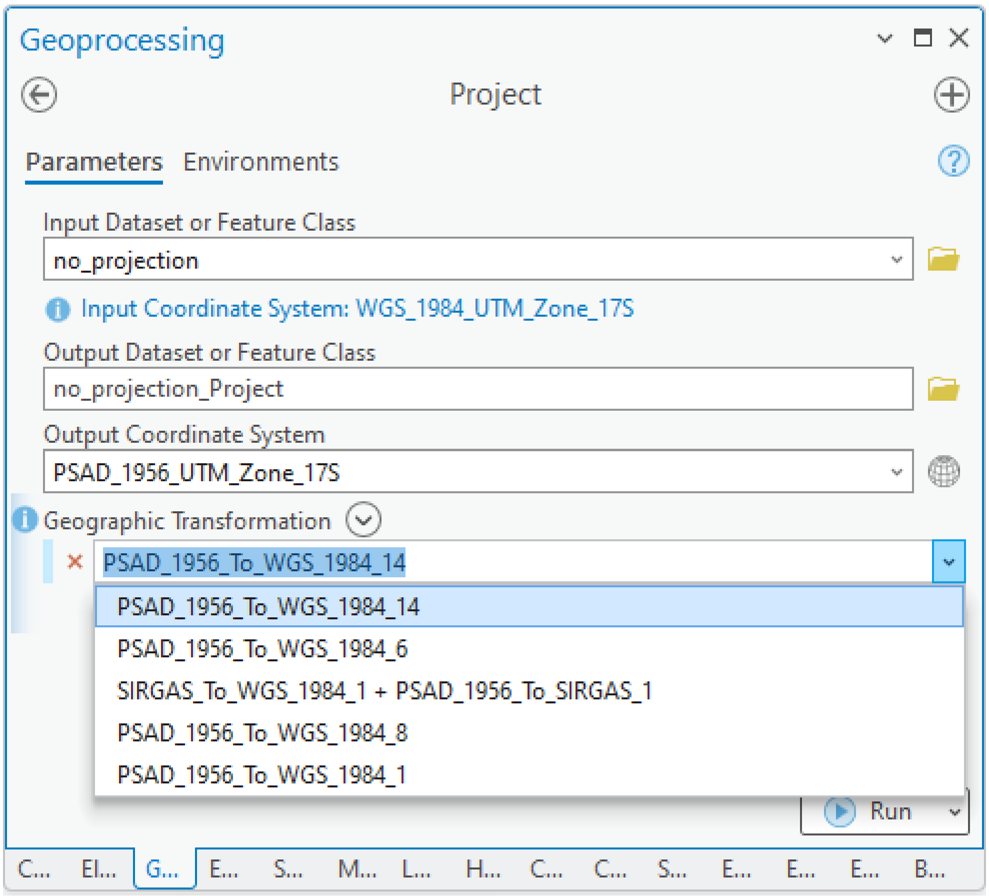
Geographic (datum) Transformation Name	WKID	Accuracy (m)	Area of Use	Minimum Latitude	Minimum Longitude	Maximum Latitude	Maximum Longitude
PSAD_1956_To_SIRGAS-Chile_3	6951	5.000	Chile - onshore 36°S to 43.5°S	-43.5000	-74.4800	-35.9900	-70.3900
PSAD_1956_To_WGS_1984_1	1201	42.000	South America - Bolivia; Chile; Ecuador; Guyana; Peru; Venezuela	-43.5000	-81.4100	12.2500	-56.4700
PSAD_1956_To_WGS_1984_10	1582	3.000	Bolivia - Madidi	-14.4300	-68.9600	-13.5600	-67.7900
PSAD_1956_To_WGS_1984_11	1583	0.500	Bolivia - Block 20	-21.7100	-63.4400	-21.0900	-62.9500
PSAD_1956_To_WGS_1984_12	1811	10.000	Brazil - Amazon cone shelf	-1.0500	-51.6400	5.6000	-48.0000
PSAD_1956_To_WGS_1984_13	1095	15.000	Venezuela - onshore	0.6400	-73.3800	12.2500	-59.8000
PSAD_1956_To_WGS_1984_14	3990	5.000	Ecuador - mainland onshore	-5.0100	-81.0300	1.4500	-75.2100

To perform the transformation, the "Project" tool must be opened (as shown in Figure 80) and configured as follows:

Geoprocessing > Toolboxes > Data Management Tools > Projections and Transformations > Project

- **Input Dataset or Feature Class:** Select the layer to be projected. The current coordinate system of the layer will automatically be displayed.
- **Output Dataset or Feature Class:** Choose the directory or geodatabase where the resulting file will be stored.
- **Output Coordinate System:** Select the new coordinate system to be used. For this instance, choose "**Projected Coordinate Systems > UTM > South America > PSAD_1956_UTM_Zone_17S**".
- **Geographic Transformation:** Select the appropriate transformation from the list provided in the PDF document ("Geographic and Vertical Transformations" on the ArcGIS Pro web page). In this case, "**PSAD_1956_To_WGS_1984_14**" should be selected since the layer is located in continental Ecuador. Alternatively, "PSAD_1956_To_WGS_1984_6" can be chosen, but the accuracy may be lower (refer to the PDF in Figure 79).

Figure 80. Projecting a layer to another coordinate system.



To change the coordinate system in a raster file, use the "**Project Raster**" tool located at:

Geoprocessing > Toolboxes > Data Management Tools > Projections and Transformations > Raster

11. Spatial Analysis

Spatial analysis is a process involving modeling, computer processing, review, and interpretation of model results. It is particularly valuable for assessing the suitability and capability of areas, calculating, and predicting spatial phenomena, and interpreting patterns and trends in geospatial data (ESRI, 2016b).

For high-quality spatial analysis, advanced and well-designed software tools are essential. To access certain spatial analysis tools, a "**Spatial Analyst**" license is required. This extension offers a range of functionalities and advanced tools for detailed and accurate geospatial data analysis.

In summary, spatial analysis is a potent technique for addressing complex geospatial issues and deriving new information from data. Tools like the "Spatial Analyst" extension of ArcGIS Pro are crucial for maximizing the potential of spatial analysis to yield accurate and meaningful results.

11.1. Interpolations

Tobler's first law of geography (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, but less likely to rain on a street on the other side of the city.

Gruver and Dutton (2014) define interpolation as using specific location measurements to predict phenomena where no measurements exist. This is useful for understanding and predicting spatial patterns in variables like precipitation, temperature, or elevation. Various interpolation methods exist, with the choice depending on the data or variable type.

The most common GIS application is two-dimensional (2D) spatial interpolation, appropriate for raster layers. However, interpolation can also extend to more dimensions, incorporating variables like depth or time.

Interpolation techniques are categorized into deterministic and geostatistical (Childs, 2004). Deterministic interpolation, like Inverse Weighted Distance (IDW), relies on similarity measures, while methods like "Trend" use mathematical functions for surface creation. Geostatistical interpolation, such as Kriging employs statistics for advanced surface modeling and prediction accuracy. Various geostatistical methods are detailed in Olaya (2020).

Interpolation methods in ArcGIS Pro are accessible via:

Geoprocessing > Toolboxes > Spatial Analyst Tools > Interpolation
Geoprocessing > Toolboxes > Geostatistical Analyst Tools > Interpolation

As an example of the application of interpolation methods in ArcGIS Pro, Table 5 provides precipitation data recorded at weather stations located at various points. The goal is to create a raster surface with estimated precipitation values for areas where there are no weather stations.

Table 5. Monthly precipitation and temperature data from a network of weather 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

To achieve this, a vector layer of points or a shapefile is needed to interpolate the data. If a point layer does not exist, it is possible to import "XY" coordinates and convert them into a shapefile. ArcGIS Pro supports various table formats, such as Excel files, tab-delimited text (.txt), DBF, CSV, among others.

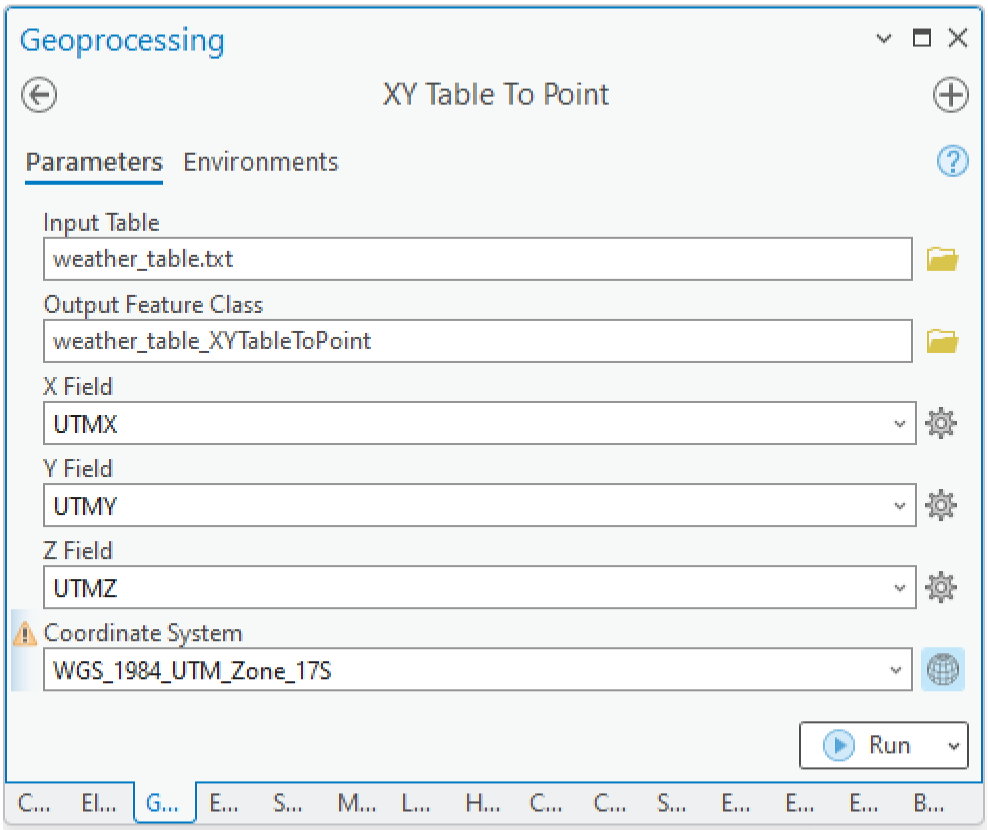
11.1.1. Importing a Table of XY Coordinates (Taken with a GPS)

To work with Excel files in ArcGIS Pro, it is usually necessary to download and install Microsoft .NET Desktop Runtime 6.0.5 - Windows x64. Depending on the version of ArcGIS Pro being used, the appropriate driver for the system should be selected. After installation, restarting the computer is recommended to ensure that the installation has been completed successfully.

To import data from Table 5 into ArcGIS Pro and create an events layer, first, go to the "**Map > Add Data > XY Point Data**" tab in a new map. Then, configure the fields as described in Figure 81:

- **Input Table**: Select the table containing the precipitation data (Table 5), stored as an xlsx, xls, csv, or txt file.
- **X Field:** Choose the field containing the longitude values (UTM_X).
- **Y Field:** Choose the field containing the latitude values (UTM_Y).
- **Z Field:** This field is optional but can be used to select the field containing altitude values (UTM_Z).
- **Coordinate System:** Select the coordinate system (in this case, Projected Coordinate Systems > UTM > WGS 1984 > Southern Hemisphere > WGS 1984 UTM Zone 17S).

Figure 81. Importing a table with UTM coordinates in ArcGIS Pro.



After completing the process, an events layer will be generated. To store this layer as a shapefile on the hard drive, the following steps should be taken: Right-click on the layer in the "**Contents**" panel and select "**Data > Export Features**" This action will open a pop-up window where the file location and name for saving the layer should be chosen. If saving the file in shapefile format is not permitted, ensure that the output directory is a folder rather than a geodatabase. This step is crucial to guarantee that the information is stored as a shapefile.

11.1.2. Interpolating Data from a Table with Kriging (IDW, Spline)

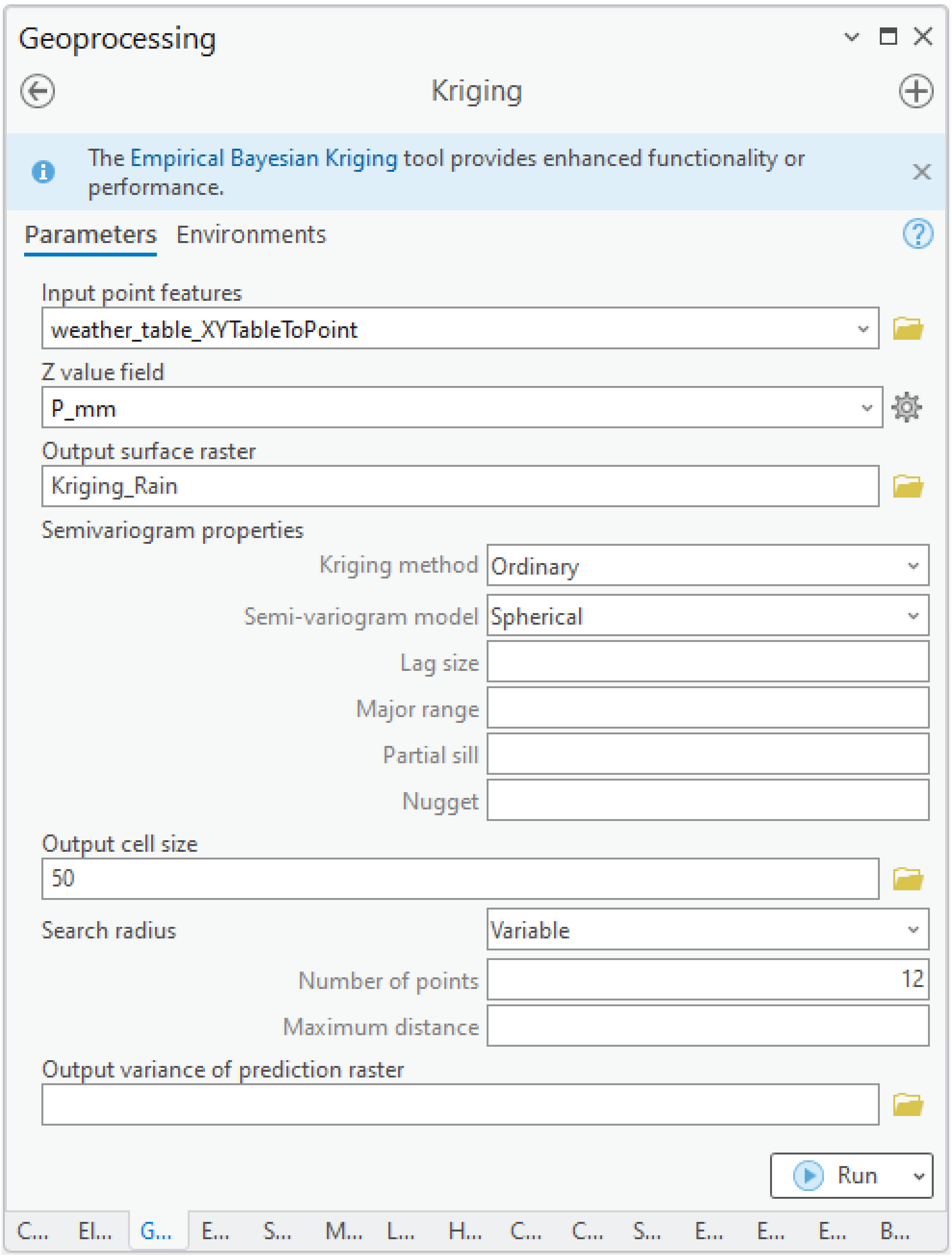
Among the various interpolation options available in ArcGIS Pro, the "**Kriging**" method will be used here to interpolate precipitation and temperature data. It is located at:

Geoprocessing > Toolboxes > Spatial Analyst Tools > Interpolation > Kriging

It is important to note that the execution speed of the process will depend on both the number of points to be processed and the system's resources (computer). The "**Kriging**" interpolation tool has a similar interface to other interpolation tools in ArcGIS Pro. The parameters required by the "Kriging" tool are described as follows (Figure 82):

- **Input point features:** Select the point layer containing precipitation and temperature values (shapefile created from Table 5).
- **Z value field:** Select the field that stores the precipitation or temperature values. If the field is not selectable, ensure that the period (.) is defined as the decimal separator in the Windows regional settings.
- **Output surface raster:** Choose a directory or geodatabase to store the output raster file (file names in the path should not contain spaces!).
- **Semivariogram properties:** Allows selection of the Kriging interpolation method with the respective semivariogram.
- **Output cell size:** Determines the cell size (resolution of the resulting map).
- **Search radius:** Sets the input points to interpolate each cell.
- **Output variance of prediction raster:** An optional raster containing semivariance values.

Figure 82. Configuration of the Kriging tool parameters.



The result of the interpolation is a raster surface with estimated values. On the left side of Figure 83, the points corresponding to the weather stations, converted into shapefile format, can be observed. On the right side of Figure 83, the resulting map from the interpolation is presented as a raster image, which includes the estimated precipitation values for each cell. It is important to note that this same process can be repeated using the values from Table 5 to obtain a raster image of temperature.

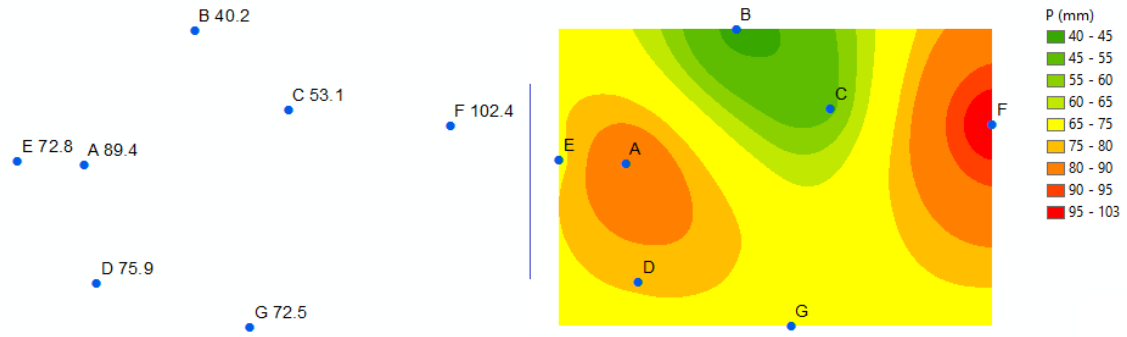


Figure 83. Precipitation Interpolation. Weather station points (left) and interpolated prediction surface (right).

11.2. Digital Elevation Models (DEM)

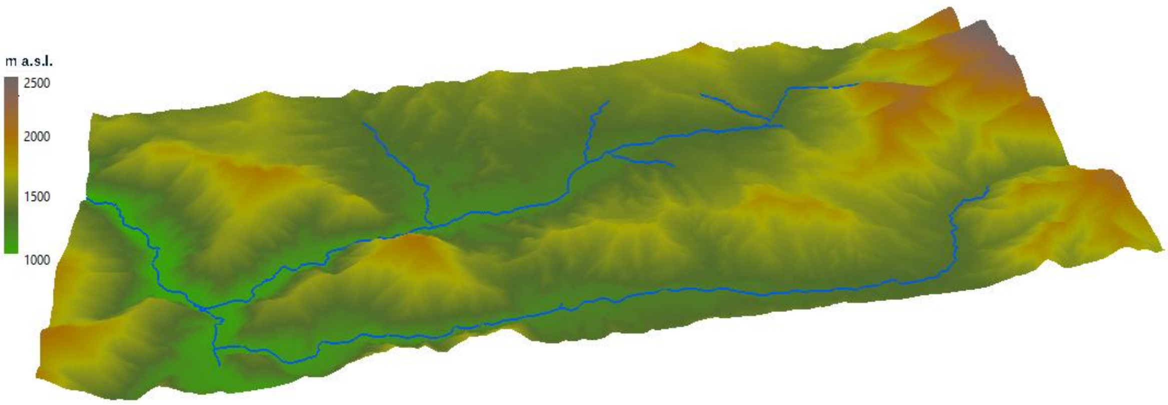
A Digital Elevation Model (DEM) is a raster format representation of a continuous surface used to describe Earth's topography (Figure 84). These models consist of a set of points, each with "X", "Y", and "Z" coordinates defined in a specific coordinate system (Fallas, 2007). A DEM is a matrix storing information about the Earth's surface elevation in each of its cells.

The information obtained from a DEM is highly valuable and applicable in various fields such as hydrology, risk analysis, urban planning, and others. Principal products derived from a DEM include slope maps, contour lines, relief maps, visibility maps, aspect maps, watershed delineations, and visual basins.

In hydrology, DEMs are primarily used to delineate watersheds, calculate water flow direction, and estimate water accumulation in each cell. In risk analysis, DEMs help identify areas prone to landslides, flooding, or land movement. In urban planning, DEMs determine suitable areas for infrastructure construction like roads and buildings and analyze the visual impact of construction projects.

In summary, DEMs are a valuable tool for understanding Earth's topography and generating useful information in various fields, making them an essential tool for decision-making in diverse research areas.

Figure 84. Digital Elevation Model (DEM).



11.3. Creation of slope maps slope maps

Slope is a key factor influencing the configuration of Earth's relief. Its study is crucial in various disciplines such as geomorphology, hydrology, cartography, and land planning. Slope is defined as the inclination of the Earth's surface between two points at different altitudes and is expressed as the mathematical ratio between the altitude difference and the horizontal distance between the two points (Hernández, 1998).

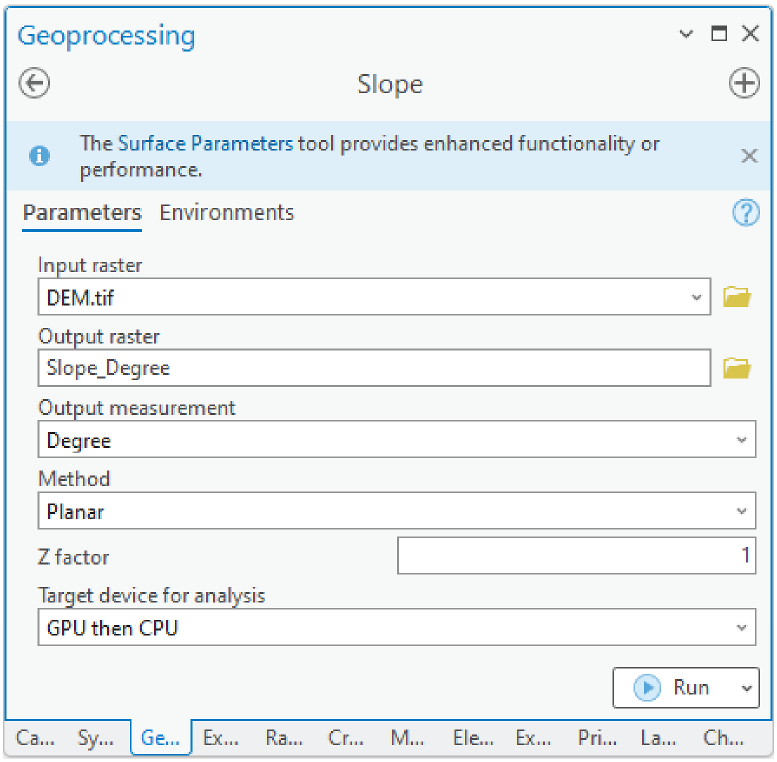
The slope can be measured in percentage or degrees. In ArcGIS Pro, a slope map can be generated from a DEM using the "**Slope**" tool or the "**Surface Parameters**" tool. For example, one can add the "**DEM.tif**" file from the "**11_0_spatial_analysis**" folder ("**Map > Add Data > Data**") and select the "**Slope**" tool located at:

Geoprocessing > Toolboxes > Spatial Analyst Tools > Surface > Slope

The "**Slope**" tool (Figure 85) calculates the slope of a surface from a DEM. The following parameters are necessary to configure this tool:

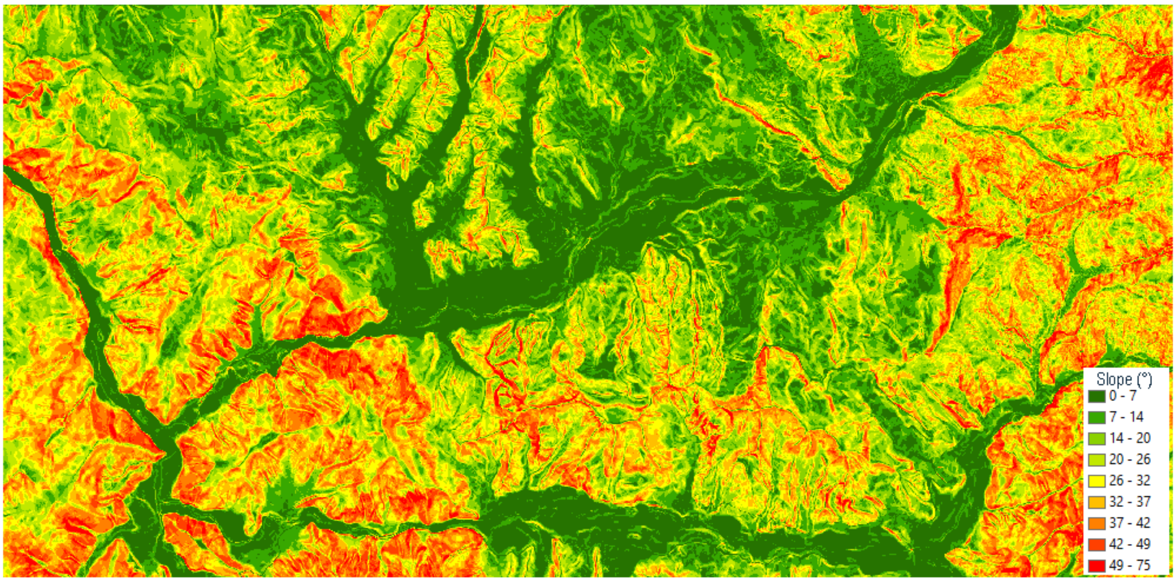
- **Input raster:** Selects the layer containing the input DEM.
- **Raster output:** Chooses a directory or geodatabase to store the resulting slope raster file.
- **Output measurement:** Select "**Degree**" to obtain the slope in decimal degrees or "Percent rise" for percentage.
- **Z factor:** This optional factor ensures that the Z linear units match the XY linear units.
- **Target device for analysis:** Selects the use of GPU, CPU, or both for analysis.

Figure 85. Configuration parameters of the "Slope" tool.



The outcome of this tool is a slope raster, where the various inclinations of the terrain are represented as a color gradient. Areas with gentler slopes are depicted in lighter colors (here: green), while steeper areas are shown in darker colors (here: red; Figure 86). The slope map is a fundamental product for topographical analysis and characterizing the Earth's surface in various contexts.

Figure 86. Slope raster in degrees.



11.4. Reclassifications

The "**Reclassify**" tool has the capability to modify the values of a raster by replacing existing information with new values. This is applicable to any variable stored in raster format, such as slope, elevation, precipitation, temperature, among others.

To conduct this practice, the previously created slope map is used along with the classification proposed by the FAO (2009), which involves regrouping the values of the slope raster into classes (Figure 87). Table 6 provides eight different classes, each containing slope values expressed in percentage and decimal degrees.

Table 6. 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).

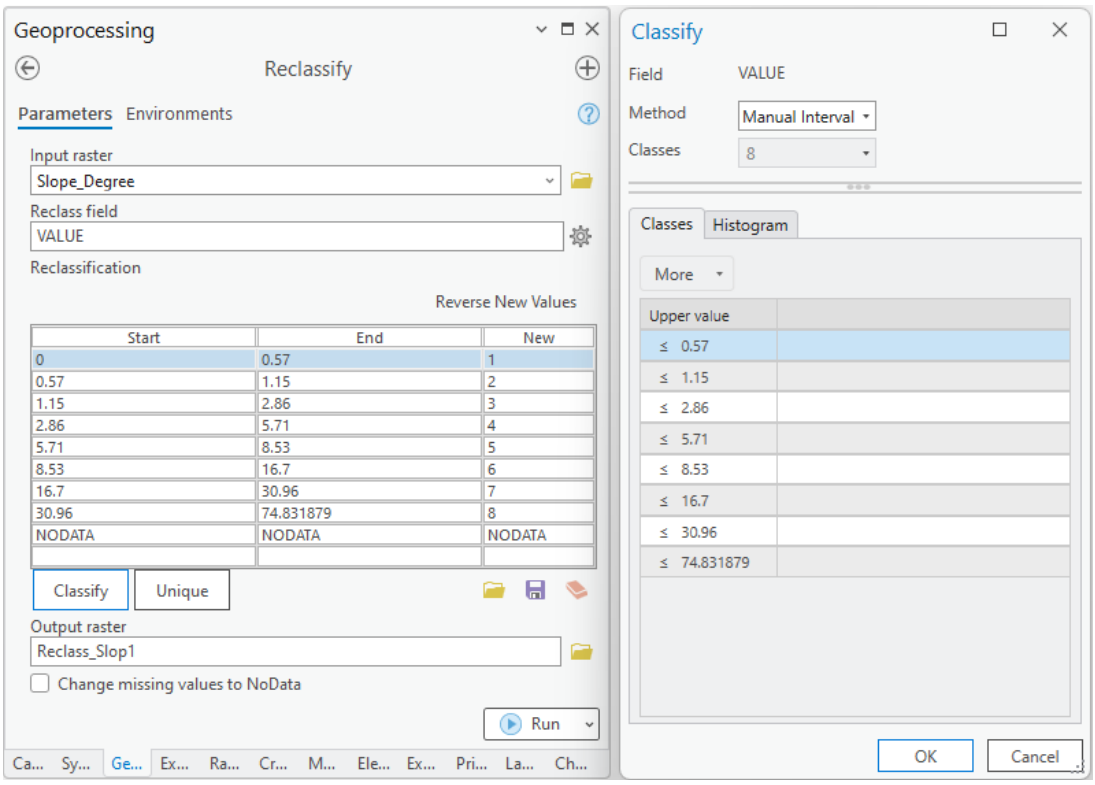
To perform the reclassification, the "**Reclassify**" tool should be opened via the following path:

Geoprocessing > Toolboxes > Spatial Analyst Tools > Reclass > Reclassify

To configure the "**Reclassify**" tool (Figure 87), the following parameters need to be adjusted:

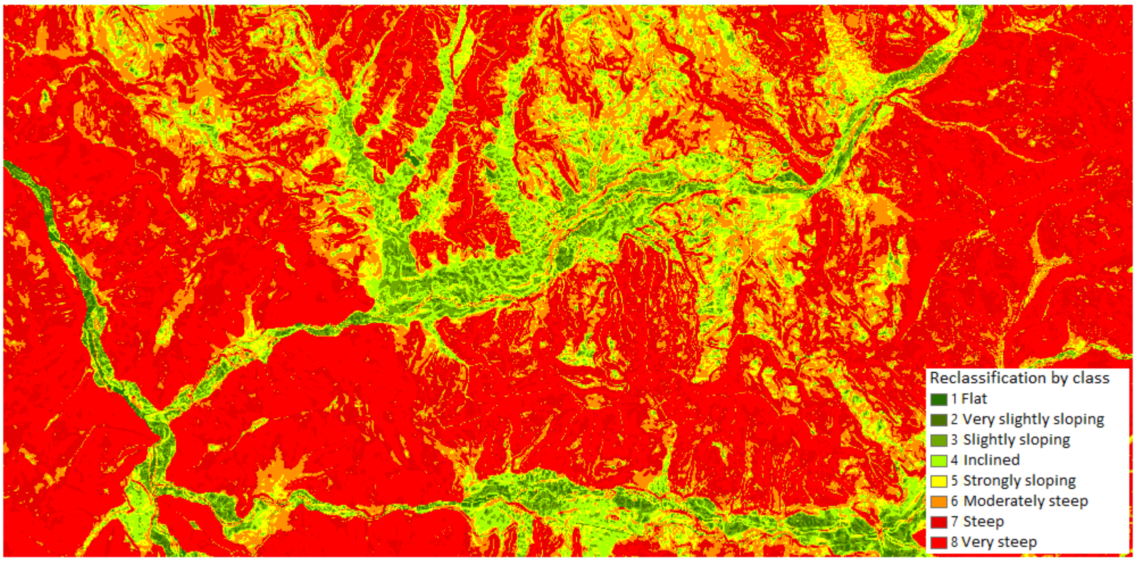
- **Input raster:** Select the layer containing the slope raster.
- **Reclass field:** Choose the field containing the slope values, which by default is usually "VALUE".
- **Reclassification:** In this section, clicking on the "**Classify**" button opens a classification pop-up window (Figure 87 right), where class values can be adjusted. By default, "**Method**" shows "**Natural Breaks (Jenks)**". One can select the preferred classification method and, in "**Classes**", define the number of classes (in this case 8). Then, opt for the manual method, allowing manual entry of each class's boundaries (Table 6).
- **Raster output:** Select a directory or geodatabase to store the reclassified slope raster file.

Figure 87. Configuration of the "Reclassify" tool parameters.



The result of executing the tool is a new raster containing the reclassified values, according to the ranges or limits established for each class. This new raster can be used to create thematic maps showing the spatial distribution of the reclassified slope variable in each area (Figure 88).

Figure 88. Slope raster in degrees reclassified into eight categories.



11.5. Generation of Contours (Contour Lines)

Contours, also known as isolines, are lines that connect points of equal value and are used to represent continuous phenomena (Huisman & A. de By, 2009). Isolines may have specific terms depending on the phenomenon they represent. For example, when used to represent elevation, they are called "contour lines" (Figure 89), while for atmospheric pressure they are called "isobars". The isolines for precipitation are "isohyets", and "isotherms" are the lines that connect points with equal temperature values. Additionally, there are "isochrones", which are lines indicating equality of time on a map (Olaya, 2020).

Contours are particularly useful for visualizing and understanding the topography of a region. On a topographic map, contour lines represent the altitude of the Earth's surface, allowing for the identification of mountains, valleys, plateaus, and other relief forms. Furthermore, contours can be used to analyze the distribution of phenomena, such as precipitation, temperature, or atmospheric pressure. In summary, contours are a fundamental tool for the visualization and analysis of geographic data on a map.

Figure 89. Contour layer (meters above sea level).

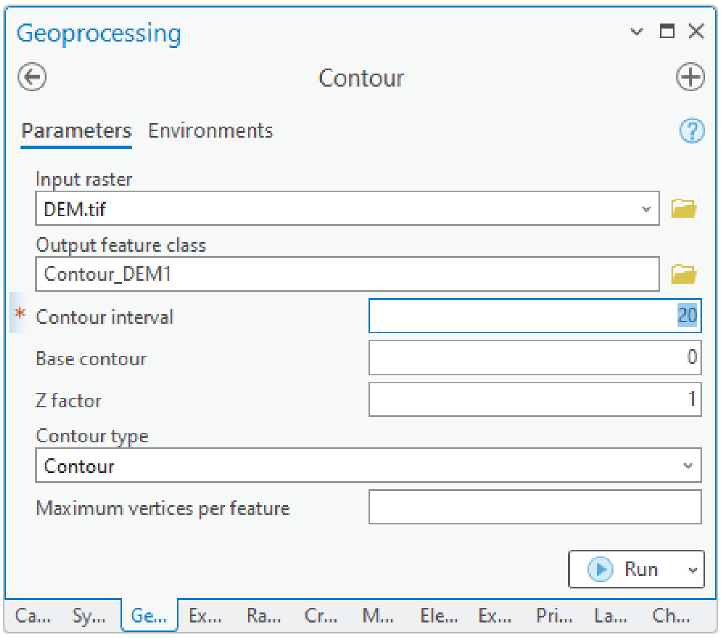
The process for generating isolines of any kind is similar. In this case, contour lines are to be created based on a DEM as the input information. The isolines are generated with the "**Contour**" tool, located at:

Geoprocessing > Toolboxes > Spatial Analyst Tools > Surface > Contour

To configure the parameters of the "**Contour**" tool (Figure 90), the following steps should be taken:

- **Input raster:** Select the raster containing the values from which the contour lines will be generated (A DEM to create contour lines, a precipitation raster for isohyets, a temperature raster for isotherms).
- **Output features class:** Select the directory or geodatabase where the resulting line layer will be stored.
- **Contour interval:** Define the interval between isolines. It is important to consider the raster's resolution; for example, if the DEM has a resolution of 30 meters, creating contour lines smaller than 30 meters is not recommended.
- **Base contour:** Optionally, a base level value can be assigned.
- **Z factor:** Optionally, a conversion factor can be assigned to generate contour lines in a unit different from the original raster's.
- **Contour type:** Allows defining the type of contours, as well as the maximum number of vertices per line.

Figure 90. Configuration of the "Contour" tool parameters.



11.6. Hillshade Map

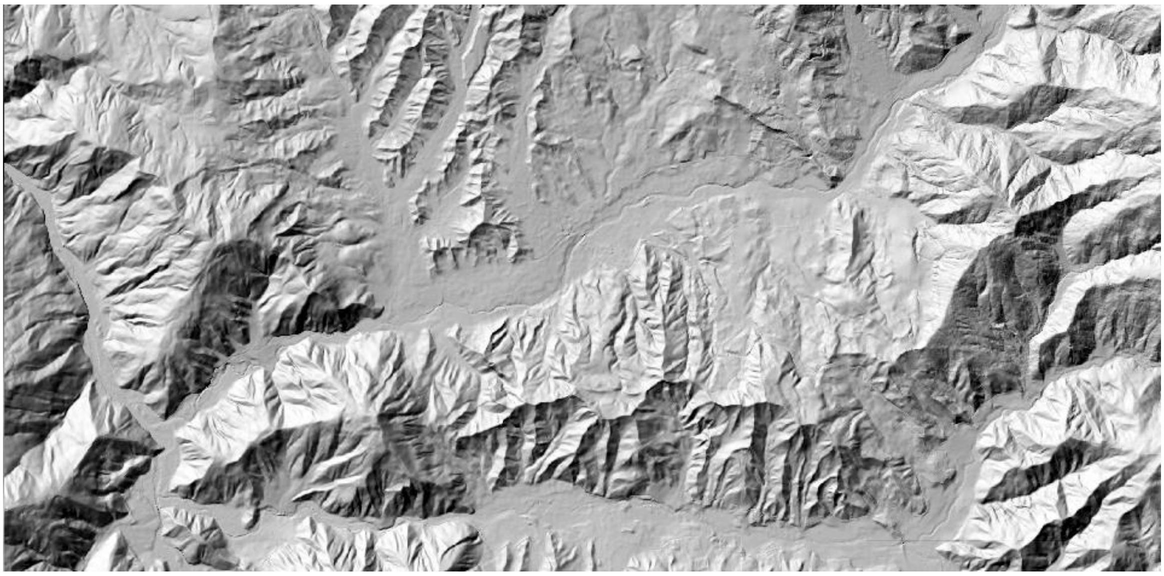
A shadow map is a shading technique used to highlight the topography of a specific area. This technique simulates the position and intensity of sunlight over the terrain, creating an image that distinguishes illuminated and shadowed areas, thus enhancing the visualization of topographic features in a raster image. This technique can be particularly useful for identifying topographic details such as ridges, valleys, and slopes. Moreover, it can aid in interpreting the terrain shape, which is especially valuable in urban planning, environmental management, geological studies, among others.

The "Hillshade" tool allows for the straightforward creation of a Hillshade map from a DEM. Section 9.3 provides a detailed procedure for using this tool, which only requires the DEM as input. In this instance, the "**DEM.tif**" file from the "**11_0_spatial_analysis**" folder was used, resulting in an outcome as shown in Figure 91. As observed in Figure 91, the result is an image with a three-dimensional effect that facilitates the interpretation of the terrain shape. This can be crucial for decision-making in various fields related to land management and environmental conservation.

The "**Hillshade**" tool is located at the following path:

Geoprocessing > Toolboxes > Spatial Analyst Tools > Surface > Hillshade

Figure 91. Shadow map generated with the "Hillshade" tool.



11.7. Viewshed

Viewsheds are areas of terrain visible from a specific location, such as a mountain, building, or observation point. They are commonly used in landscape analysis and urban planning to determine which areas are visible or not visible from a particular viewpoint.

Viewsheds are applied in various areas, including natural resource assessment, such as identifying areas with high visual quality for ecotourism or determining critical visual habitat areas for endangered species. They are also used to analyze the visibility of a point of interest or an object within a specific geographic area, assisting in decisions about the placement of specific projects like telecommunications antennas, military lookout posts, and urban viewpoints. Furthermore, they are applied in bird watching and other activities requiring detailed visibility analysis in a geographical space.

Several tools are available for viewshed analysis. In this example, the "**Geodesic Viewshed**" tool is used, located at:

Geoprocessing > Toolboxes > Spatial Analyst Tools > Surface > Geodesic Viewshed

Figure 92 shows the configuration of the "**Geodesic Viewshed**" tool using the "**DEM.tif**" file found in the "**11_0_spatial_analysis**" folder. The parameters to configure are:

- **Input raster:** Selects the DEM as input.

- **Input point or polyline observer features:** Selects a layer of points or lines from which to create the viewshed. This point can also be drawn directly on the map by clicking on the pencil icon.
- **Output raster:** Selects the directory or geodatabase where the resulting line layer will be stored.
- **Target device for analysis:** Chooses the use of the GPU, CPU, or both for conducting the analysis.
- For advanced configuration, it is possible to customize the "**Viewshed parameters**" which determine the conditions for calculating visible areas, while "**Observer parameters**" specify the properties of the observation point, such as height.

Figure 92. Configuration of the "Geodesic Viewshed" tool.

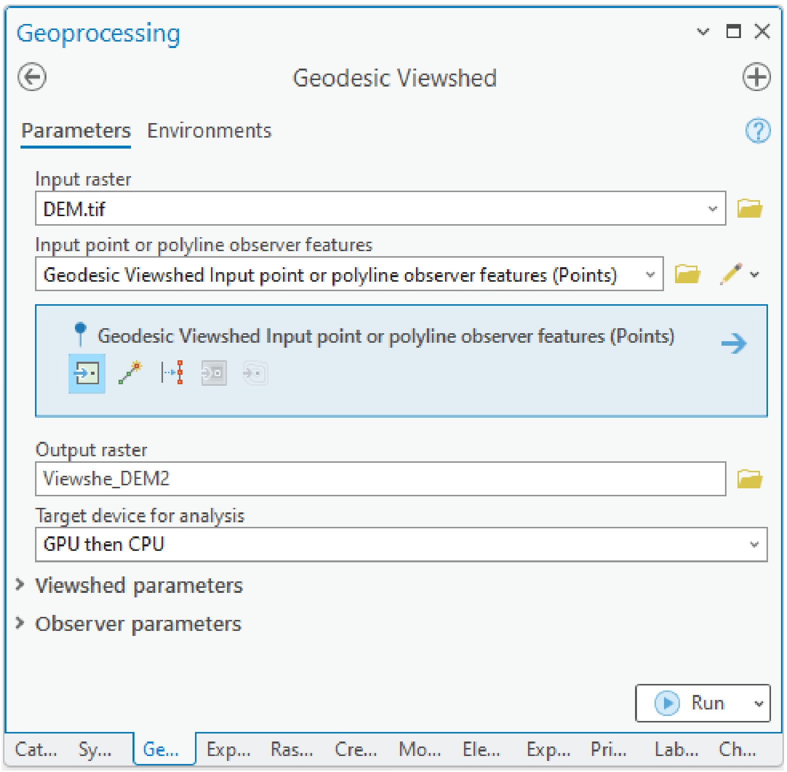
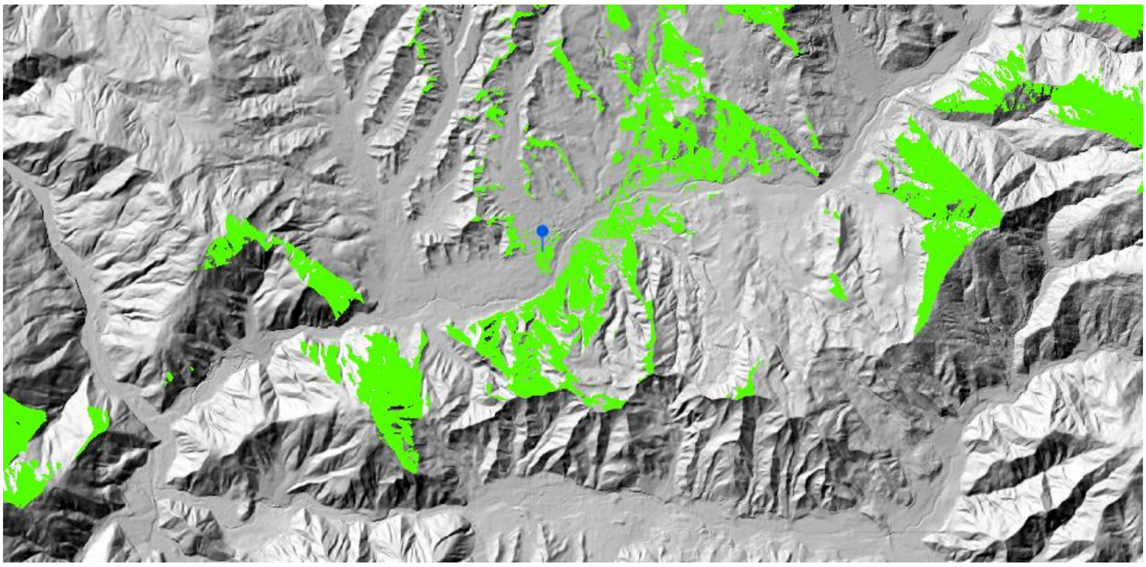


Figure 93 illustrates the result of the viewshed analysis. The blue point represents the observer's location, while the area highlighted in green corresponds to the zones visible from that point.

Figure 93. Viewshed generated with the "Geodesic Viewshed" tool.



How can I know the resolution of a raster file in ArcGIS Pro?

In the "Contents" panel, right-click on the raster layer and select "Properties," then go to "Source" and look for the resolution information in the "Cell Size X" and "Cell Size Y" fields in the "Raster Information" section.

11.8. Map Algebra

The raster calculator is a tool that allows for the performance of operations and algebraic expressions using various tools and operators through an interface like a simple calculator. The "Raster Calculator" tool is versatile and powerful, making it ideal for conducting complex geographic analyses in map development. However, the performance of equations depends on the operators or tools used in an expression. Data processing is faster if operators or tools are executed individually (ESRI, 2016c). The "Raster Calculator" tool is located at:

Geoprocessing > Toolboxes > Spatial Analyst Tools > Map Algebra > Raster Calculator
Geoprocessing > Toolboxes > Image Analyst Tools > Map Algebra > Raster Calculator

It is possible to create a raster layer from an algorithm that assigns numerical values to its pixels or derive it from one or several pre-existing raster layers. A simple example of its use is to multiply all the pixels of a raster layer by a determined factor (Figure 94). On the left is the initial raster map, and through a simple operation, each pixel of the layer is multiplied by factor 5. The result is stored in a new raster layer (Figure 94 right), offering the possibility to create different raster layers containing information of interest for geographic analysis.

Figure 94. Basic operation of map algebra.

$$\begin{array}{|c|c|c|c|}\hline 2 & 2 & 3 & 4 \\ \hline 3 & 5 & 2 & 5 \\ \hline 5 & 3 & 3 & 2 \\ \hline 2 & 4 & 5 & 3 \\ \hline \end{array} \times 5 = \begin{array}{|c|c|c|c|}\hline 10 & 10 & 15 & 20 \\ \hline 15 & 25 & 10 & 25 \\ \hline 25 & 15 & 15 & 10 \\ \hline 10 & 20 & 25 & 15 \\ \hline \end{array}$$

Another exercise aimed at familiarizing with the use of algebraic expressions through the "**Raster Calculator**" tool is to transform the interpolated temperature layer in degrees Celsius (°C; Table 5, Section 11.1; Figure 96 left) into degrees Fahrenheit (°F; Figure 96 right). To achieve this conversion, the following equation should be used within the raster calculator:

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

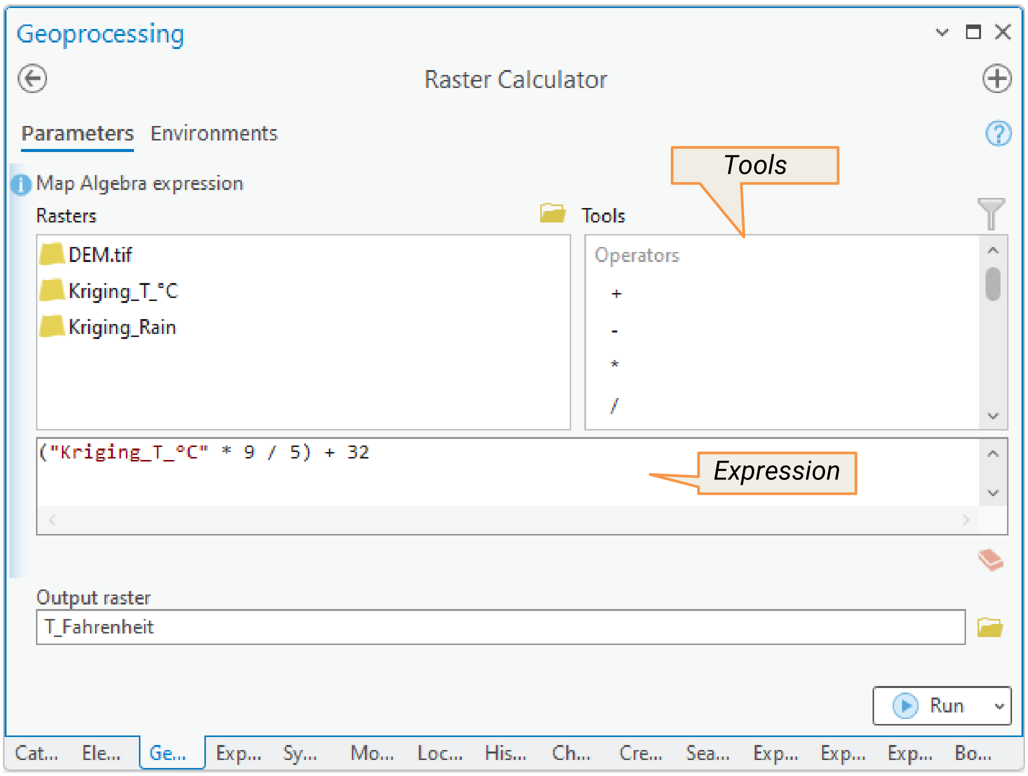
where:

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

Below is the configuration of the "Raster Calculator" tool (Figure 95):

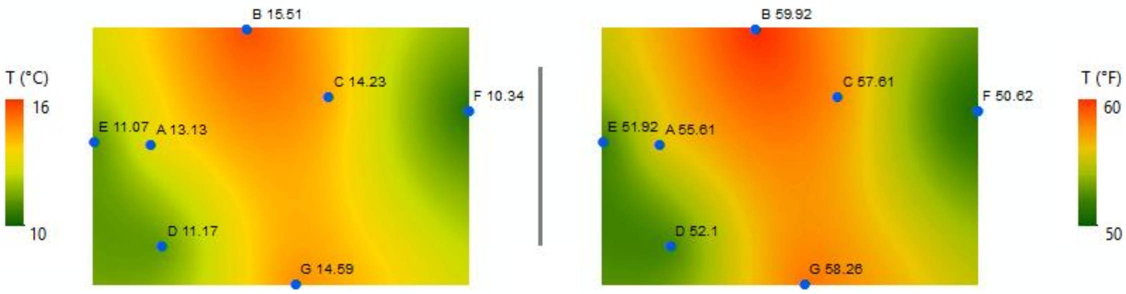
- **Rasters:** Displays a list of available raster layers for use in the map algebraic expression.
- **Tools:** Allows adding mathematical and logical operations into the expression. Numbers or operators can be introduced within the expression. A list of tools, such as sine, cosine, and tangent, is also displayed for use anywhere in the expression.
- **Expression:** Allows creating a set of rules to execute a valid expression. It is not necessary to place the "equal" (=) sign at the beginning of the expression. To convert degrees Celsius to Fahrenheit, replace "**C**" with the name of the raster image: **("Kriging_T_°C" * 9 / 5) + 32** and group the algebraic expressions with parentheses.
- **Output raster:** Allows selecting a directory or geodatabase to store the raster file generated by the resulting expression.

Figure 95. Setting expressions in "Raster Calculator".



The result of executing the "Raster Calculator" tool to convert the temperature from degrees Celsius to degrees Fahrenheit is a new raster containing the converted values. This new raster can be used to create thematic maps that show the spatial distribution of the temperature variable in degrees Fahrenheit in a specified area, see Figure 96.

Figure 96. Raster of temperature in °C (left). The raster of temperature in °F obtained through a map algebra expression (right).

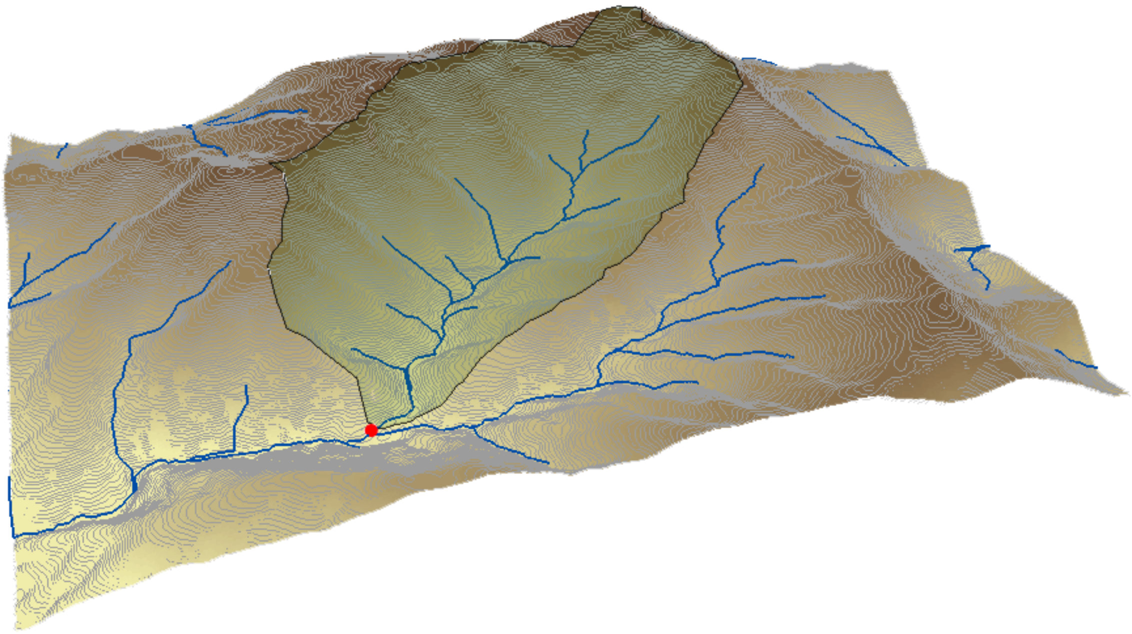


11.9. Delineation of a Watershed

Manually delineating a watershed, either through the analysis of contour lines or from a topographic map, is a quite tedious and slow process that requires advanced knowledge in hydrology and topography. In this procedure, it is necessary to identify the ridge lines of a basin and trace the basin's perimeter from them.

Manual delineation of a watershed leads only to approximate results, depending on the analyst's skills and experience. ArcGIS Pro offers various tools that allow for the automatic and efficient delineation of watersheds. These tools use raster elevation data, such as a DEM, and enable the calculation of other hydrological parameters, such as the direction and accumulation of water flow. From this information, a drainage network can be created, and watersheds can be delineated almost infallibly (Figure 97).

Figure 97. Automatically delimited watershed using ArcGIS Pro.



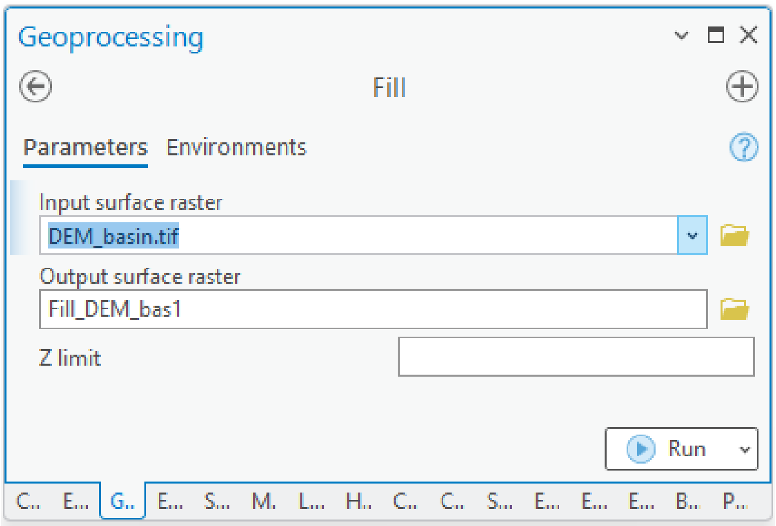
In summary, the hydrology tools in ArcGIS Pro offer the advantage of delineating watersheds quickly and accurately, unlike the manual method. For an advanced study, review documentation about ArcHydro tools. Additionally, these tools allow for the analysis and visualization of the drainage network and hydrological characteristics of the watershed, which is incredibly useful in water resource management and land planning. Below is the procedure for delineating a watershed, using the file "**DEM_basin.tif**" ("Map > Add Data > Data") found in the "**11_10_basin**" folder. The hydrology tools are located at:

Geoprocessing > Toolboxes > Spatial Analyst Tools > Hydrology

The first step involves using the "**Fill**" tool to correct errors or no-data cells in the DEM (here: "**DEM_basin.tif**" file). This tool eliminates voids or depressions in the terrain that could affect water flow by creating a continuous and more accurate surface. The tool identifies depression areas and fills the holes automatically. To use it, simply enter the DEM as input and select the directory or geodatabase where the result will be stored (Figure 98)

Geoprocessing > Toolboxes > Spatial Analyst Tools > Hydrology > Fill

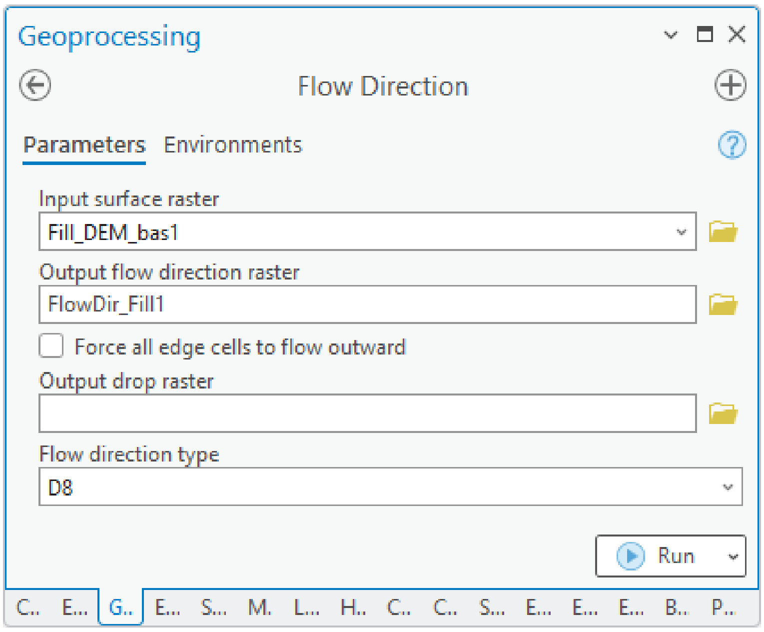
Figure 98. Configuration of the "Fill" tool.



The next step involves establishing the direction of hydrological flow based on the slope using the "**Flow Direction**" tool. This tool defines the direction of water flow in each terrain cell from the DEM previously corrected with the "Fill" tool. The most used flow direction type is D8, indicating that flow can occur in eight different directions from each cell. To use the tool, the "Fill_DEM_bas1" should be selected as the input raster layer and set the flow direction type to D8 (Figure 99). The path to the tool is:

Geoprocessing > Toolboxes > Spatial Analyst Tools > Hydrology > Flow Direction

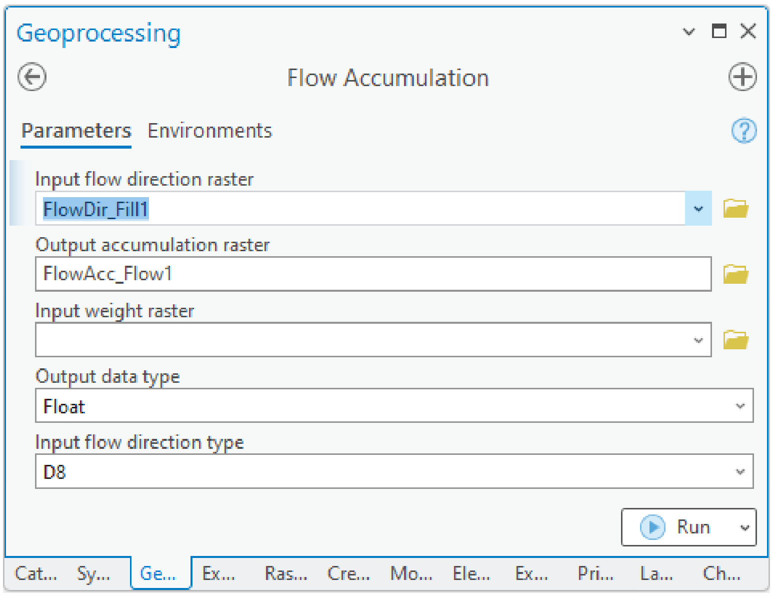
Figure 99. Configuration of the "Flow Direction" tool.



To determine flow accumulation in the cells; that is, the water flowing into each cell down the slope, the "**Flow Accumulation**" tool is used. This tool takes the flow direction raster ("Flow Direction") as input (Figure 100) and calculates the amount of flow reaching each cell, thereby identifying areas of higher water accumulation in the watershed. The tool is located at:

Geoprocessing > Toolboxes > Spatial Analyst Tools > Hydrology > Flow Accumulation

Figure 100. Configuration of the "Flow Accumulation" tool.



Once the flow accumulation is obtained, which is often hard to visualize due to the dark background, automatic construction of the water network can proceed using a conditional (the "**Con**" tool). The "**Con**" tool allows for the classification of cells with flow accumulation above a specific threshold defined by the user. However, the network density depends on the raster specifications.

To properly configure the "**Con**" tool (Figure 101), select the accumulation raster in the "**Input conditional raster**" field. In the "**Expression**" field, enter the required expression, such as: **Value > 5000** (Where VALUE is greater than 5000), where the value ("**VALUE**") used in this expression depends on the raster resolution (= pixel size). In the "**Input true raster or constant value**" field, the value **1** should be placed. In the "**Output raster**" field, indicate the name and output directory. The "**Con**" tool is located at:

Geoprocessing > Toolboxes > Spatial Analyst Tools > Conditional > Con

Figure 101. Configuration of the "Con" tool.

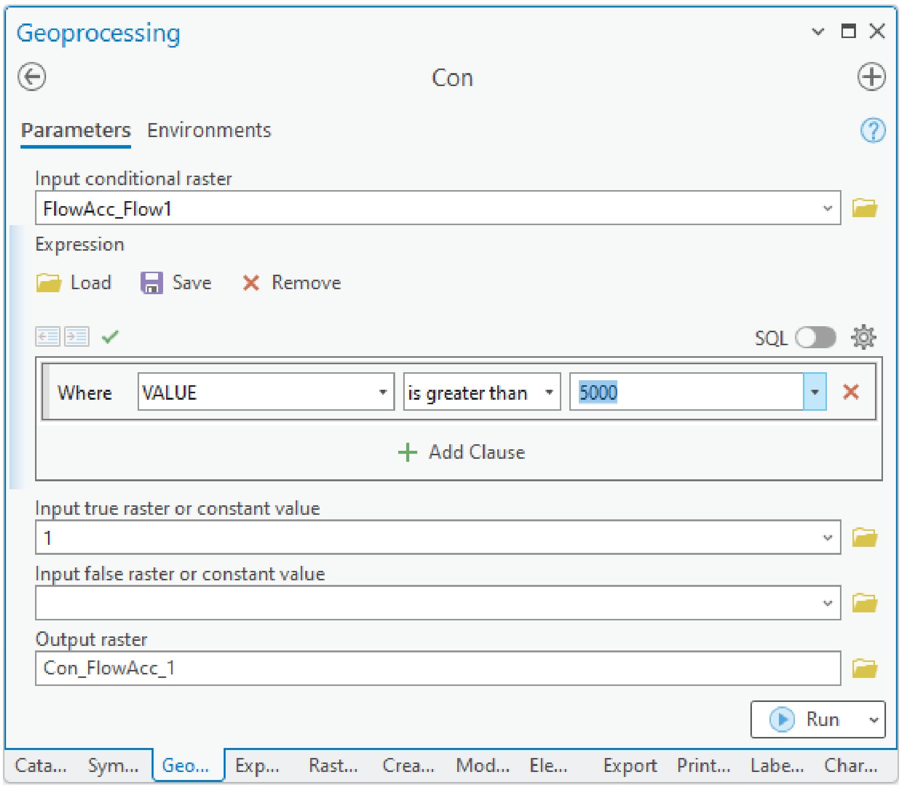
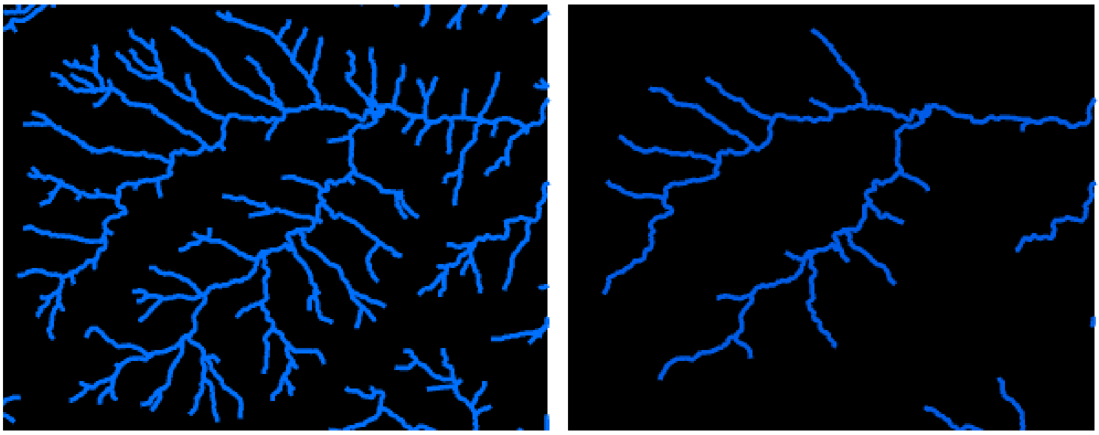


Figure 102 presents an example of the expression configuration, where the expression **VALUE > 5000** was used on the left, resulting in a very dense drainage network, while a higher value (**VALUE > 30000**) was used on the right, obtaining a less dense drainage network. It is recommended to experiment with different expression values to achieve the desired result.

Figure 102. Using different expressions in the "Con" tool.

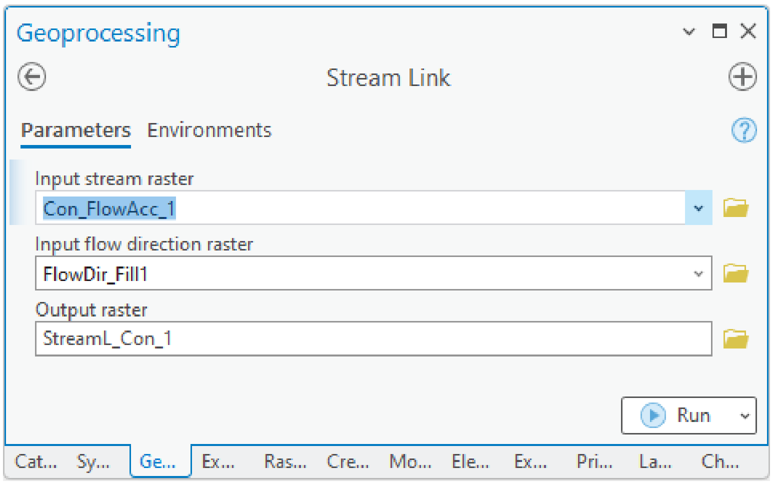


After obtaining the water network in the previous steps, the "**Stream Link**" tool can be used to create a continuous water flow network from the fragmented water network generated. This tool allows linking the segments of the water network to represent the actual continuous flow of water.

To use "**Stream Link**" the rasters obtained with the conditional ("**Con**") and the flow direction raster ("**Flow Direction**") are required as input data, as shown in Figure 103. The tool is located at:

Geoprocessing > Toolboxes > Spatial Analyst Tools > Hydrology > Stream Link

Figure 103. Configuration of the "Stream Link" tool.



The "**Stream Order**" tool assigns order or hierarchy to each segment of a water network (stream, river) based on its position in the network. This tool uses as input the raster obtained with "**Stream Link**" and the flow direction raster obtained with "**Flow Direction**".

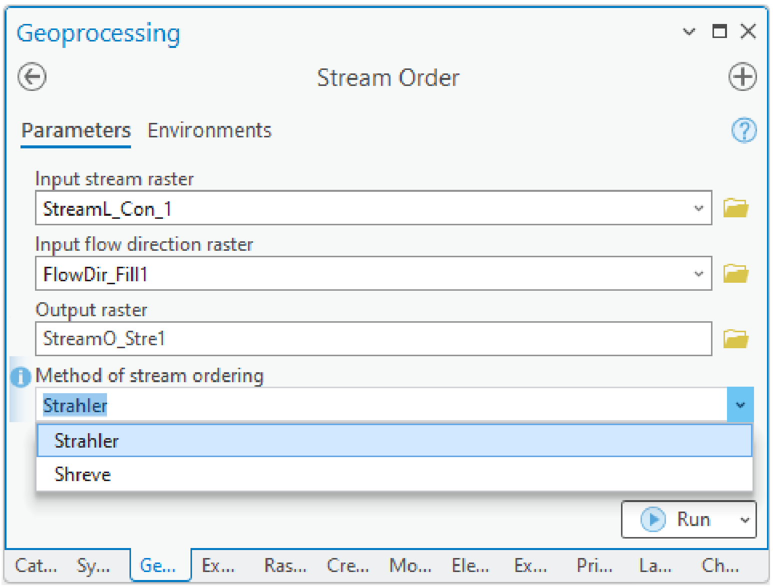
Based on these rasters, the order of the segments can be calculated using the Strahler or Shreve methods (Figure 104).

The Strahler method assigns an order of 1 to segments without tributaries, and an additional order is added as two or more segments of the same order join. In contrast, the Shreve method assigns an order based on the number of tributaries they have. Thus, first-order segments are those without tributaries, and higher-order segments are those that receive two or more lower-order segments (OpenAI, 2021).

The "**Stream Order**" tool is located at:

Geoprocessing > Toolboxes > Spatial Analyst Tools > Hydrology > Stream Order

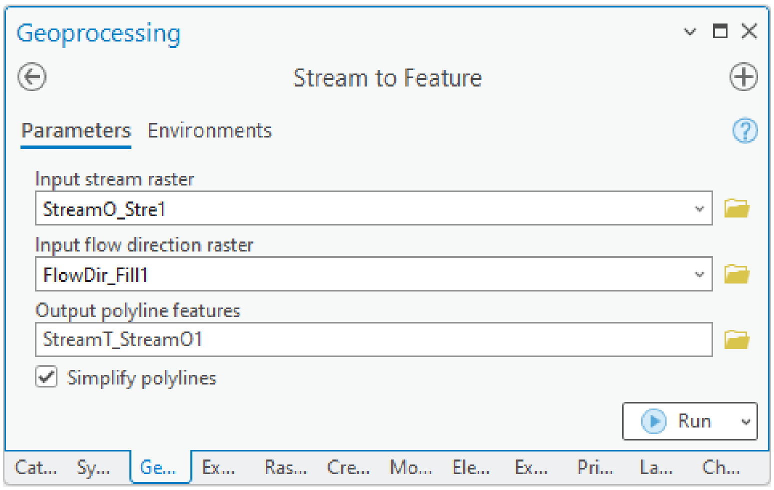
Figure 104. Configuration of the "Stream Order" tool.



Until now, the water network has been in raster format. To convert it to vector format (shapefile), the "**Stream to Feature**" tool is used. To do this, the raster obtained with "**Stream Order**" must be selected in "Input stream raster" and the direction raster obtained with "**Flow Direction**" in "Input Flow direction raster" (Figure 105). The path to access the tool is as follows:

Geoprocessing > Toolboxes > Spatial Analyst Tools > Hydrology > Stream to Feature

Figure 105. Configuration of the "Stream to Feature" tool.

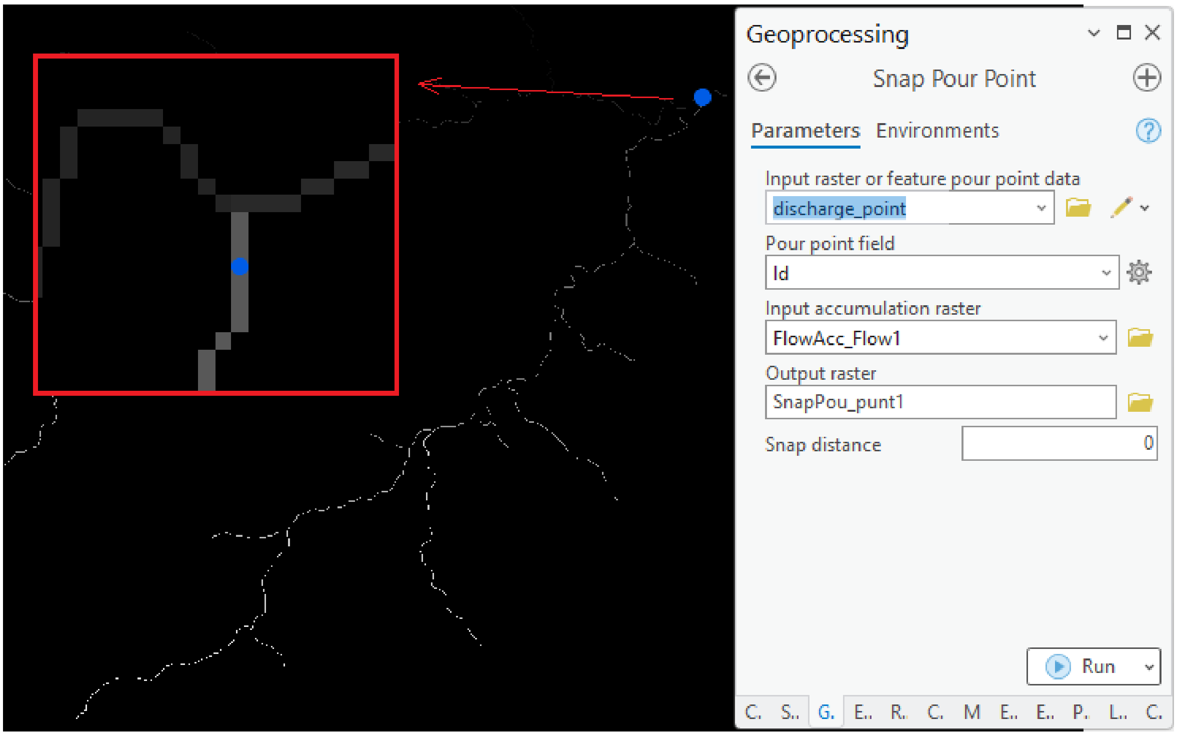


To assign the discharge point or outlet point in a watershed's drainage network, it is necessary to use the "**Snap Pour Point**" tool. To begin, it is necessary to create a point layer (refer to section 7) and draw the point exactly over the watershed's outlet point; otherwise, the necessary distance to reach the stream must be established (Figure 106).

Once the point is created, it must be entered in the field "**Input raster or feature pour point data**" of the tool, while the "**Input accumulation raster**" field must select the corresponding accumulation raster ("**Flow Accumulation**"). The "**Snap distance**" option defines the required distance for the point to reach the stream. In this context, "0" is used since the point is already located directly on the stream. But if the stream were located at a distance of 10 meters, then 10 or 11 would be placed. The "**Snap Pour Point**" tool is located at:

Geoprocessing > Toolboxes > Spatial Analyst Tools > Hydrology > Snap Pour Point

Figure 106. Configuration of the "Snap Pour Point" tool.



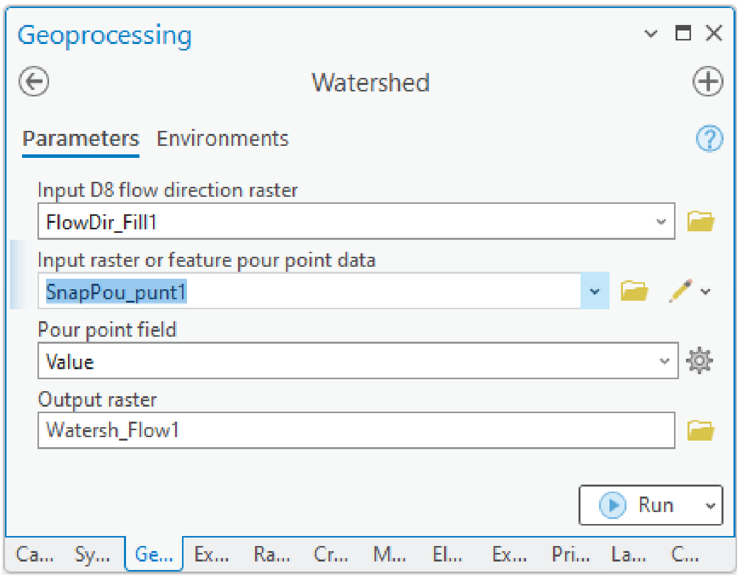
The delineation of a watershed is performed using the "Watershed" tool. This tool allows identifying and delineating the watershed of a specific location on a terrain, using as input a flow direction raster and a discharge or outlet points raster, obtained through the "**Snap Pour Point**" tool.

In the "**Input D8 flow direction raster**" field, the flow direction raster ("Flow Direction") must be selected, while the raster generated with the "**Snap Pour Point**" tool must be selected in the "**Input raster or feature pour point data**" field (Figure 107). It is important to highlight that based on the "**Watershed**" tool, more relevant information about the watershed can be obtained, such as its size, shape, and boundaries, which is useful for conducting hydrological and environmental studies.

The address to access this tool in ArcGIS Pro is:

Geoprocessing > Toolboxes > Spatial Analyst Tools > Hydrology > Watershed

Figure 107. Configuration of the "Watershed" tool.



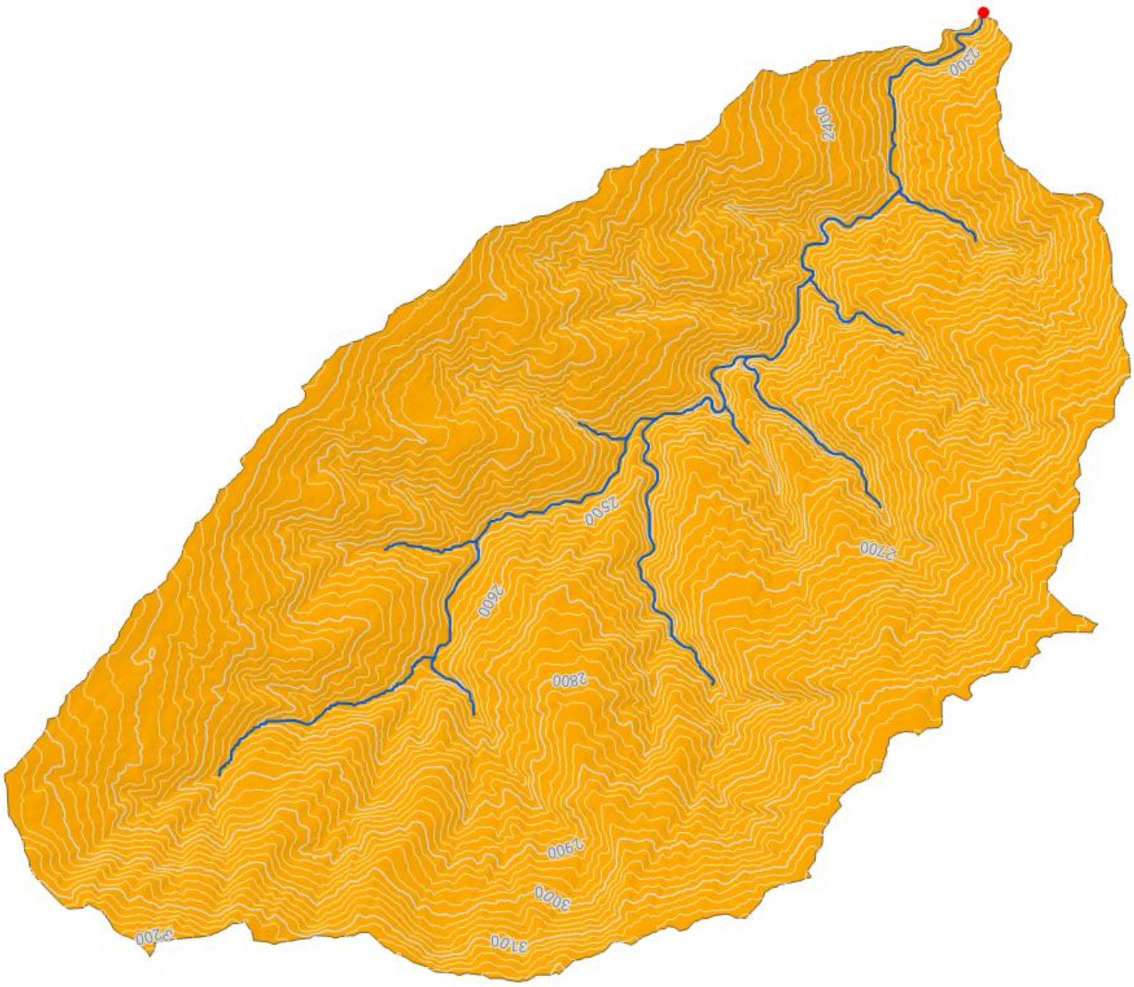
Up to now, the related watershed exists in raster format. If conversion to a vector format is desired, the "**Raster to Polygon**" tool must be used. For this, the raster obtained with the "**Watershed**" tool must be selected as input data. This conversion provides a vector format representation of the watershed, facilitating its analysis and visualization.

The "**Raster to Polygon**" tool is available at the following path:

Geoprocessing > Toolboxes > Conversion Tools > From Raster > Raster to Polygon

Finally, contour lines of the watershed can be generated using the "**Contour**" tool, utilizing the "**DEM_cuenca.tif**" raster file (see section 11.5). Additionally, both the water network and contour lines can be clipped using the "**Clip**" tool, as explained in section 10.3. With this tool, a clipped version of the water network in the watershed will be obtained. To create a topographic effect on the map, a shadow map can be generated, and transparency applied ("**Hillshade**"), as indicated in section 9.3, and use the labeling techniques seen in section 9.2.3. The result should be like what is shown in Figure 108.

Figure 108. Automatically delineated watershed along with its water network.



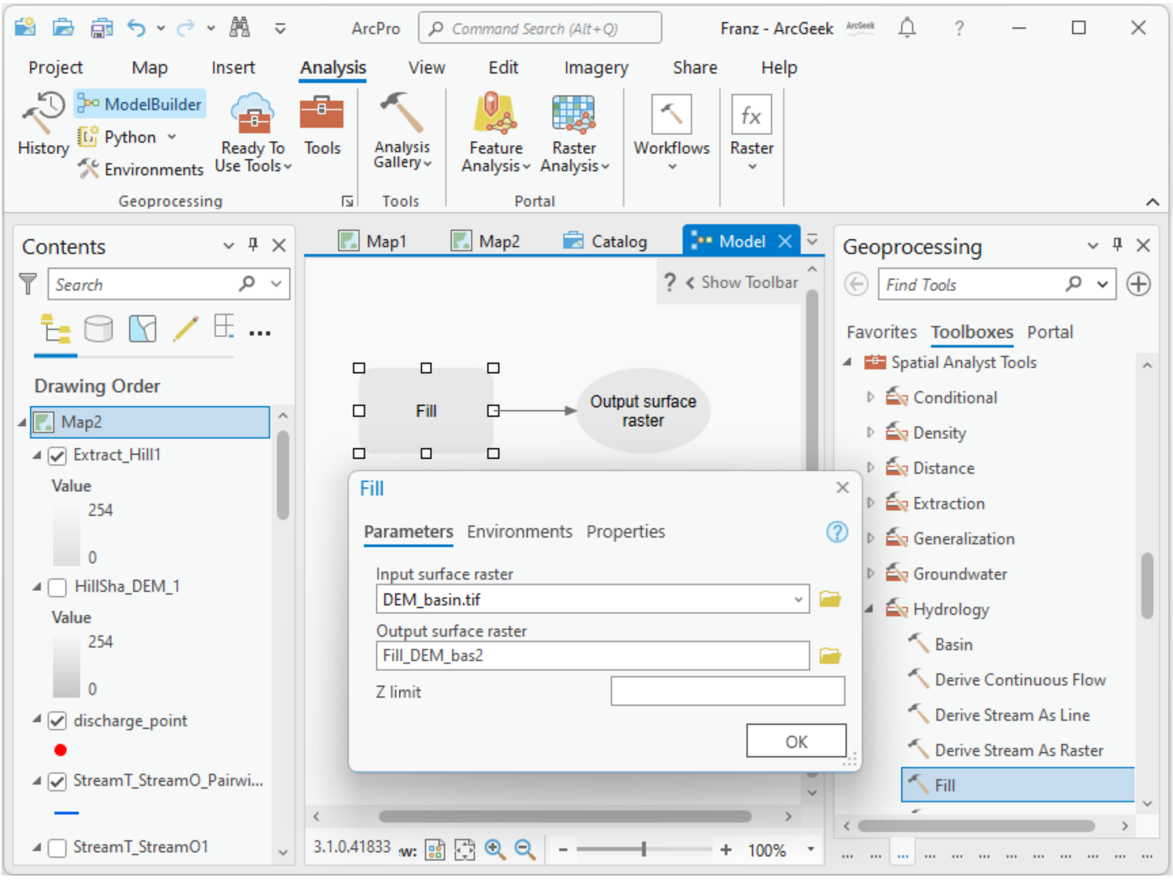
11.10. Geoprocessing Automation with "ModelBuilder"

"**ModelBuilder**" is a visual tool in ArcGIS Pro that allows for the creation, editing, and execution of automated geospatial analysis workflows. This tool enables the development of customized models that can be reused in other projects, thereby increasing efficiency in spatial data analysis. Additionally, it facilitates the integration of other tools, such as programming languages (Python and R).

Generally, it can automate geospatial processes, such as watershed delineation or the interpolation of precipitation and temperature data. In this example, the complete process of delineating a watershed, as seen in section 11.9, is automated, which is useful for replicating the process for another watershed by only changing the input data (DEM, discharge point).

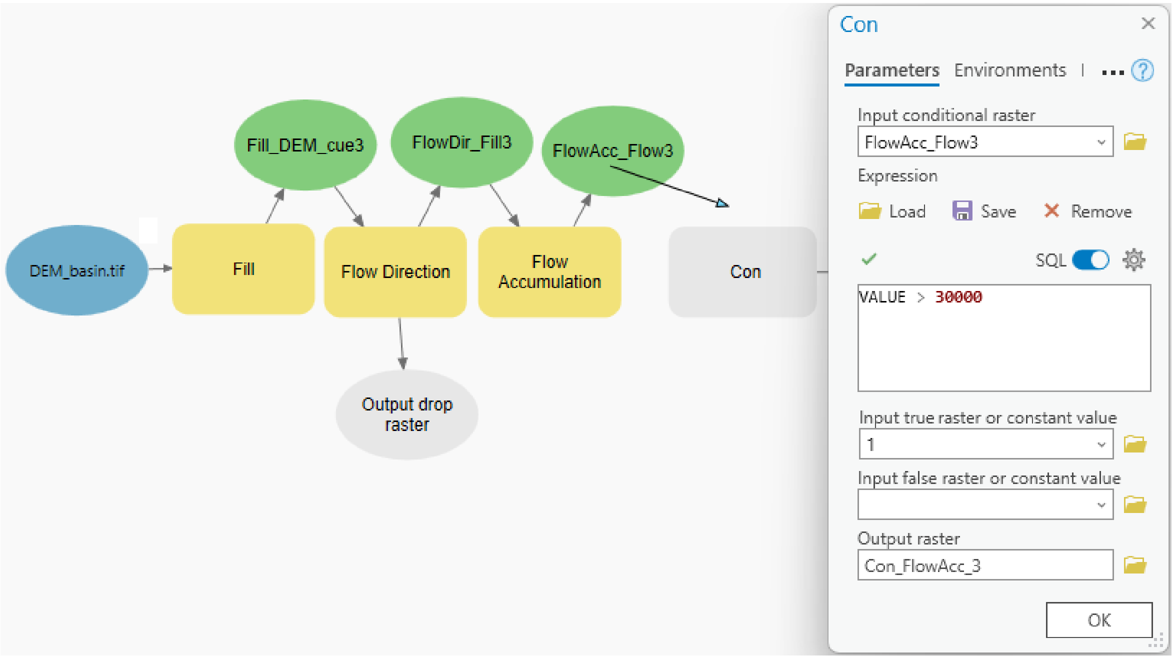
In the "**Analysis**" tab within the "**Geoprocessing**" group, "**ModelBuilder**" should be selected. This action opens a new tab where the necessary tools can be added sequentially. In the "**Geoprocessing**" panel, the "**Fill**" tool must first be dragged and dropped into the window. Then, double-clicking on "Fill" opens a pop-up window that allows for tool configuration. In this example, the file "**DEM_basin.tif**" is used as input, following the same steps and configurations of the tool learned in section 11.9 (Figure 109).

Figure 109. Workflow Automation with "ModelBuilder".



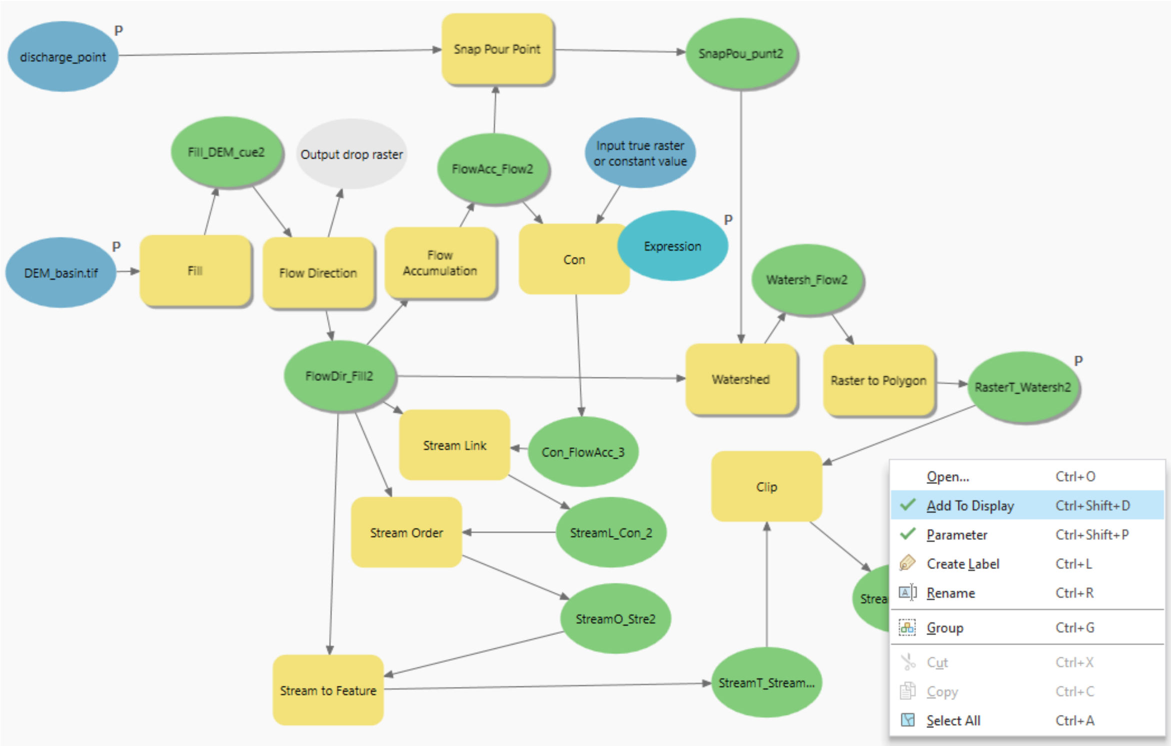
The next step is to add the remaining tools in sequence ("**Flow Direction**", "**Flow Accumulation**", "**Con**", etc.) and connect them. This process is intuitive, using the output of the previous tool as the input for the next tool. When opening each tool's configuration, "**Model Variables**" available as input data can be selected. For example, to configure the "**Con**" tool, "**FlowAcc_Flow3**", the result of the "**Flow Accumulation**" tool, is used as input and connected to the "**Con**" tool with an arrow (Figure 110). When each tool is correctly configured, they appear in yellow (or grey if not configured). Input data are displayed in blue, while output data are in green.

Figure 110. Configuring a tool in "ModelBuilder".



Once all tools are configured and added to the model in the "ModelBuilder" tab, a wide variety of tools are available for exporting the model (e.g., Python script), making display adjustments, and performing iterative functions, which are particularly useful for repetitive tasks. To execute the model, simply click on the "**Run**" button within the "Run" group. It is possible that, after executing the model, the resulting layers do not automatically display on the "**Map**" In this case, right-click on the desired layer and select "**Add To Display**" (Figure 111).

Figure 111. Model for automating the procedure in watershed management.



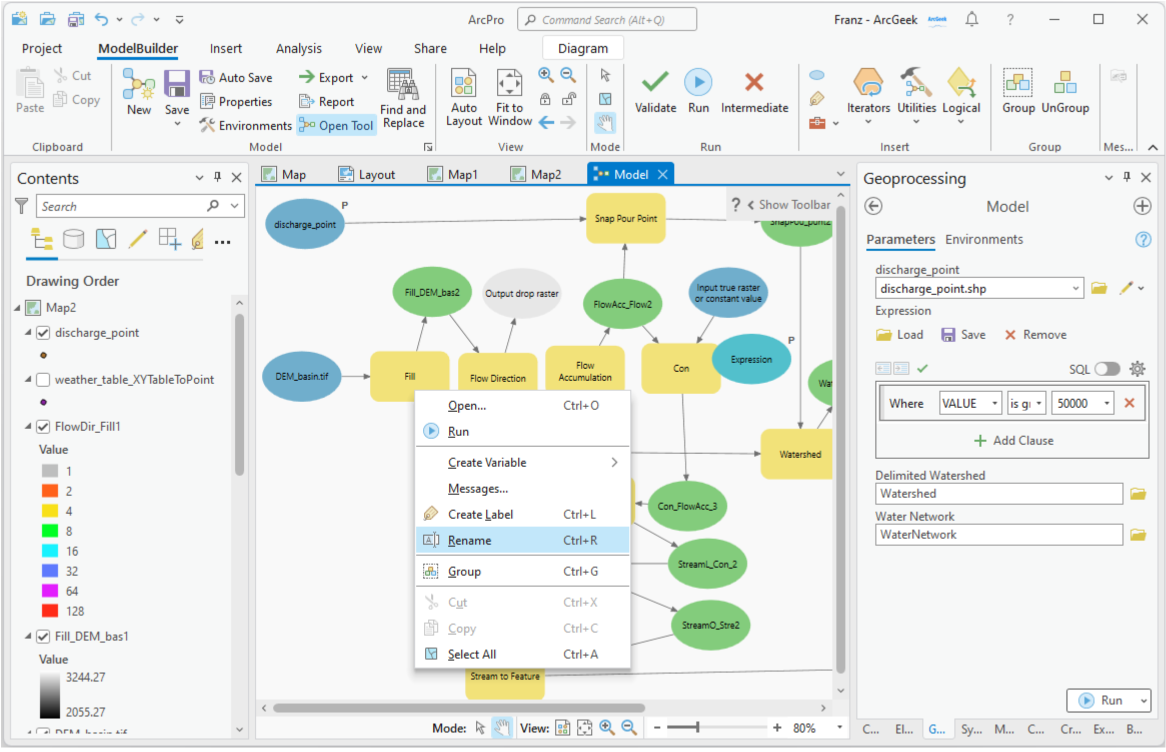
If the model's aim is to be used as a tool for other similar processes, input and output parameters must be defined. To do this, right-click on the specific parameter and select "**Parameter**" which will assign the letter "**P**" to it. Thus, the model awaits user interaction to define the input or output layer or parameter. It is also advisable to use the "**Rename**" option to give the parameters descriptive names that facilitate the tool's understanding (Figure 112).

Another important detail is setting expressions for other projects. For example, by right-clicking on the "**Con**" tool and then on "**Create Variable > From Parameter > Expression**" the expression can be customized, in this case, to set the density of the hydrological network.

To configure the title and other informative data of the model, navigate to the "**ModelBuilder**" tab, go to the "Model" group, and click on the "**Properties**" button. It's always recommended to save changes continuously with "**Save**"

The "Model > **Open Tool**" button opens the created tool where the DEM and discharge point can be directly selected, and the expression, names, and directories for the final layers are defined (Figure 112).

Figure 112. Creation of a tool with "ModelBuilder".



11.11. Topographic Profiles

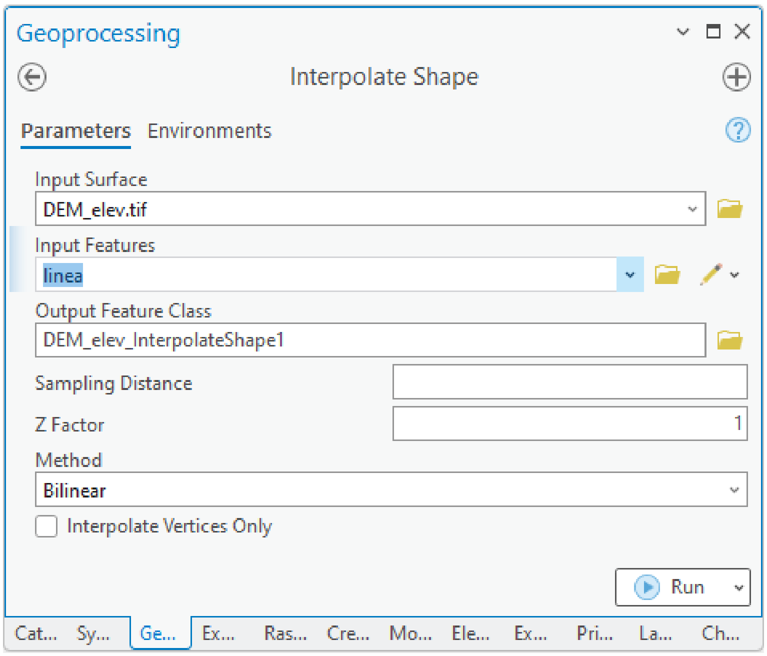
A topographic profile, also known as an elevation profile, is a two-dimensional representation of the terrain through a cross-section. It is generated by drawing a line between two or more points on a map to show a side view of the terrain, indicating the altitudinal changes. The Y-axis of the profile corresponds to altitude or elevation values, while the X-axis corresponds to the distance between the selected points. Thus, it is possible to visualize the terrain elevation at different points along the selected path.

To create a topographic profile, a DEM and a line representing the elevation along the profile are required. The first step is to add a DEM to a new "Map" and a line layer. For example, files from the folder "**11_11_perfil_elev**" can be added to a new map. Then, right-click on the "**line**" layer and select "**Create Chart > Profile Graph**". This option may not be available because the tool requires a 3D line layer. To resolve this, the "**Interpolate Shape**" tool must be used to add elevation values to the polyline, thus creating the topographic profile. The tool's path is as follows:

Geoprocessing > Toolboxes > 3D Analyst Tools > 3D Features > Interpolation > Interpolate Shape

The configuration to obtain the 3D line is straightforward (Figure 113). In the "**Input Surface**" field, the DEM is selected as the input data, and in the "**Input Features**" field, the line layer representing the desired elevation profile path is chosen.

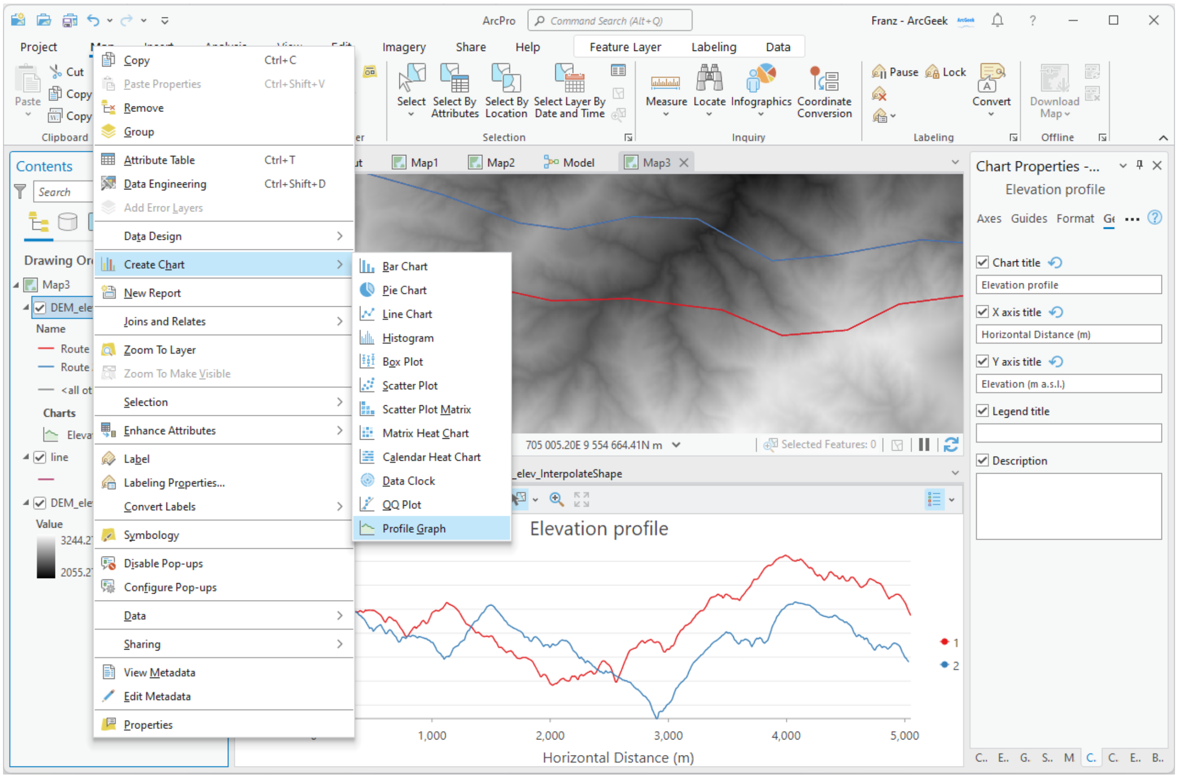
Figure 113. Configuring the "Interpolate Shape" tool.



After preparing the 3D polyline, it is possible to generate the elevation topographic profile by right-clicking on the 3D line layer generated within the "**Contents**" panel and selecting "**Create Chart > Profile Graph**". If there are multiple lines, the chart will display the elevation profiles of all of them, so it is necessary to individualize the colors to differentiate the profiles. This can be modified in the attribute table (see section 8.1) or categorized in the symbology (see section 9.2.3). It's possible to customize the chart design, including the title and axes, through the available properties options (Figure 114).

It is crucial to note that the profile direction follows the same as the polyline was created, whether from left to right or vice versa, because the "**Profile Graph**" tool will trace the profile according to the starting point. Therefore, it is important to remember the structure of the vertices in a polyline.

Figure 114. Elevation profile in ArcGIS Pro.



12. Image Analysis

ArcGIS Pro also allows for the analysis of several types of satellite images, utilizing image processing tools such as classification, change detection, atmospheric correction, and object information extraction. For this, ArcGIS Pro provides a set of tools for viewing, analyzing, and manipulating satellite image data. The most common analyses include identifying changes in land cover, detecting wildfires, estimating water quality, and assessing crop health.

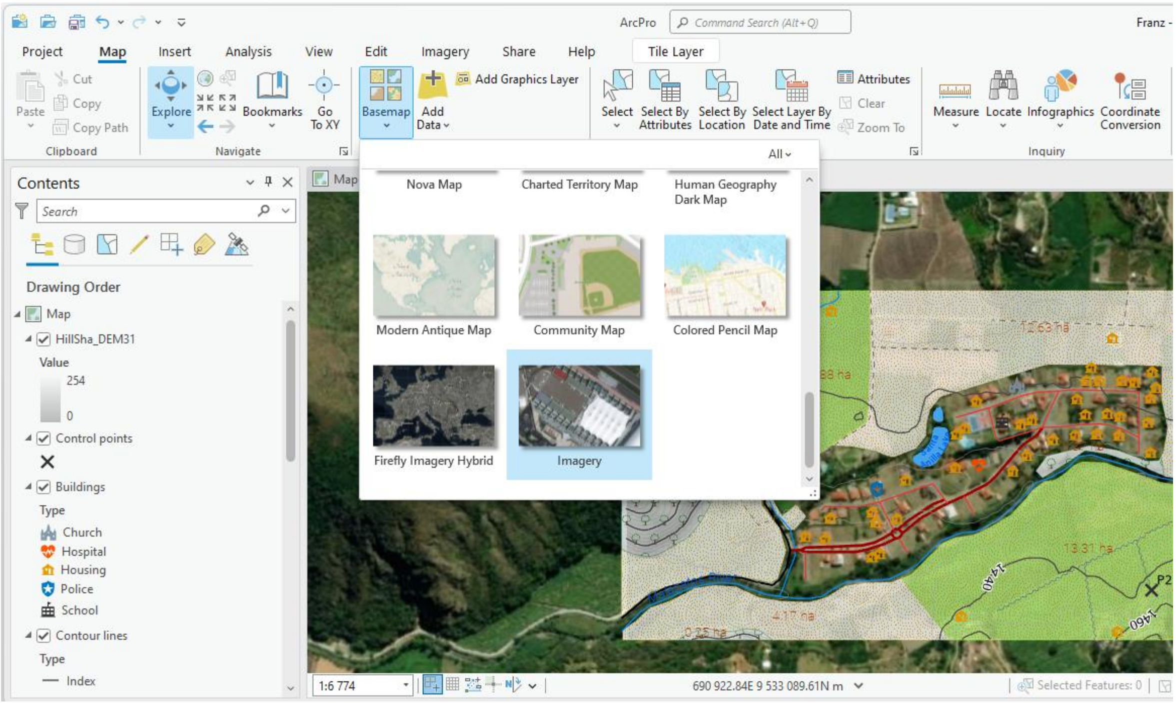
This section serves as an introduction to the use of satellite images, as well as explaining how to obtain satellite images of Landsat 8/9 and Sentinel 2, add bands, create band combinations, and calculate the NDVI.

The first step in working with satellite images in ArcGIS Pro is to obtain or acquire the images.

12.1. Adding a Satellite Image from "Basemap"

ArcGIS Pro provides "**Basemaps**" as reference maps for the general geographical context of the data viewed or analyzed in a project. These maps can be used as base layers to add additional information or as a guide for navigation and orientation in the study area. Users can choose from a variety of "Basemaps" offered by Esri or upload their own custom "Basemaps" to meet the specific needs of the project. To add a "Basemap," simply go to the tab "**Map > Layer > Basemap**" and select the most suitable one. Figure 115 shows an example of "**Imagery**," which provides a satellite image of the study region.

Figure 115. Adding a Satellite Image as a "Basemap".



However, the satellite images in "**Imagery**" do not show the current state of the area and the resolution depends on the availability in the area, so it is necessary to acquire higher resolution satellite images with the required dates for the study. A free way to acquire these satellite images is through the **Landsat** and **Sentinel** platforms, which are described below.

12.2. Downloading Landsat Images

Landsat 8/9 Earth observation satellites provide high-resolution images (15-30 meters) with multispectral bands for use in various applications such as agriculture, forest management, and cartography (Table 7). These satellites are designed to measure the reflectance of the Earth's surface in several bands of the electromagnetic spectrum, allowing for the characterization and analysis of natural resources. To acquire them, follow these instructions:

1. Access the Earth Explorer website: https://earthexplorer.usgs.gov/

2. Register or log in to the platform.
3. Navigate to the study area, in this example, Loja, Ecuador.
4. In the "**Search Criteria**" tab, select the geographic area of interest. This can be done by entering the coordinates with the "**Add Coordinate**" button or by drawing a polygon directly on the map. In "**Data Range**" define the date range for the search, and in "**Cloud Cover**" specify the maximum percentage of cloud presence in the image.
5. In the "**Data Sets**" tab, go to "**Landsat > Landsat Collection 2 Level-1 > Landsat 8-9 OLI/TIRS C2 L1**" or depending on the needs, "**Landsat Collection 1 Level-2**" can be used.
6. In the "**Additional Criteria**" tab, define some search criteria, such as Landsat 9 in "**Satellite**".
7. Clicking the "**Results**" button generates a list of results that meet the search criteria.
8. Reviewing the results, you can select the required images (in this case, from November 13, 2022). Clicking on the "**Download Options**" button allows you to select the desired download format. It is recommended to download all bands (Landsat Collection 2 Level-1 Product Bundle has an approximate size of 1 GB).
9. Follow the instructions to complete the download and unzip the file.

Table 7. Electromagnetic Bands of Landsat 8/9 Satellite

Spectral band	Description	Wavelength (µm)	Resolution (m)
Band 1	Coastal/Aerosol	0.43 - 0.45	30
Band 2	Blue	0.45 - 0.51	30
Band 3	Green	0.53 - 0.59	30
Band 4	Red	0.64 - 0.67	30
Band 5	Near-Infrared (NIR)	0.85 - 0.88	30
Band 6	SWIR 1	1.57 - 1.65	30
Band 7	SWIR 2	2.11 - 2.29	30
Band 8	Panchromatic (PAN)	0.50 - 0.68	15
Band 9	Cirrus	1.36 - 1.38	30
Band 10	TIRS 1	10.6 - 11.19	100
Band 11	TIRS 2	11.5 - 12.51	100

Source: (USGS, 2022)

12.3. Download images Sentinel 2

Sentinel-2 is a program by the European Space Agency (ESA) that utilizes a constellation of two satellites for Earth observation, providing high-resolution images (10 - 60 meters) of the Earth's surface. The acquired images enable the monitoring of changes in vegetation, detection of wildfires, and identification of changes in land cover. Sentinel-2 data are particularly used in applications such as agricultural management, urban planning, and natural disaster response. To acquire these satellite images, the following instructions must be followed:

1. Access the Copernicus Open Access Hub at the following link: https://browser.dataspace.copernicus.eu
2. Register or log in to the portal.
3. Navigate to the study area, for example, Loja, Ecuador, and draw the study area using the available tools to create an area of interest.
4. Within the "**VISUALIZE**" tab, to expand the available options, click on the " " button located to the right of "DATE: SINGLE", then click on the "**Time Range** " button to select the data period.
5. Specify in "**Max. cloud coverage**" the percentage of cloud cover acceptable for the images.
6. Define the Collections; by default, it is **Sentinel-2 L2A**, but Sentinel-2 L1C is also available.
7. Click on "**Find products within selected time range**".

8. A list of images that meet the search criteria will be displayed. Select the required one, which can be previewed by clicking on the "**Zoom to Product**" icon, located at the bottom of the image.
9. To download the image, click on the "**Download product**" icon, found at the bottom of the image.
10. If the study area is divided into several images, each part must be downloaded individually and then unzipped into the file.

Table 8. Spectral Bands of the Sentinel-2 Satellite.

Spectral band	**Description**	**Wavelength (μm)**	**Resolution (m)**
Band 1	Coastal Aerosol	0.443	60
Band 2	Blue	0.49	10
Band 3	Green	0.56	10
Band 4	Red	0.665	10
Band 5	Red Edge 1	0.705	20
Band 6	Red Edge 2	0.74	20
Band 7	Red Edge 3	0.783	20
Band 8	Near-Infrared (NIR)	0.842	10
Band 8A	NIR narrow	0.865	20
Band 9	Water vapor	0.945	60
Band 10	SWIR (Cirrus)	1.375	60
Band 11	Shortwave Infrared (SWIR 1)	1.61	20
Band 12	Shortwave Infrared (SWIR 2)	2.19	20

Source: (ESA, 2023)

It is important to note that downloading satellite images can take a considerable amount of time, especially if they are images of large areas. Because of this, it is necessary to ensure that the computer has enough storage space or to connect an external hard drive before proceeding with the download.

12.4. Combining Satellite Image Bands

One of the most common tasks to familiarize oneself with satellite images is to explore their bands and make various combinations. According to OpenAI (2021), combining satellite bands can provide a wide range of valuable information for research and geospatial analysis. Here are some potential benefits of combining satellite bands:

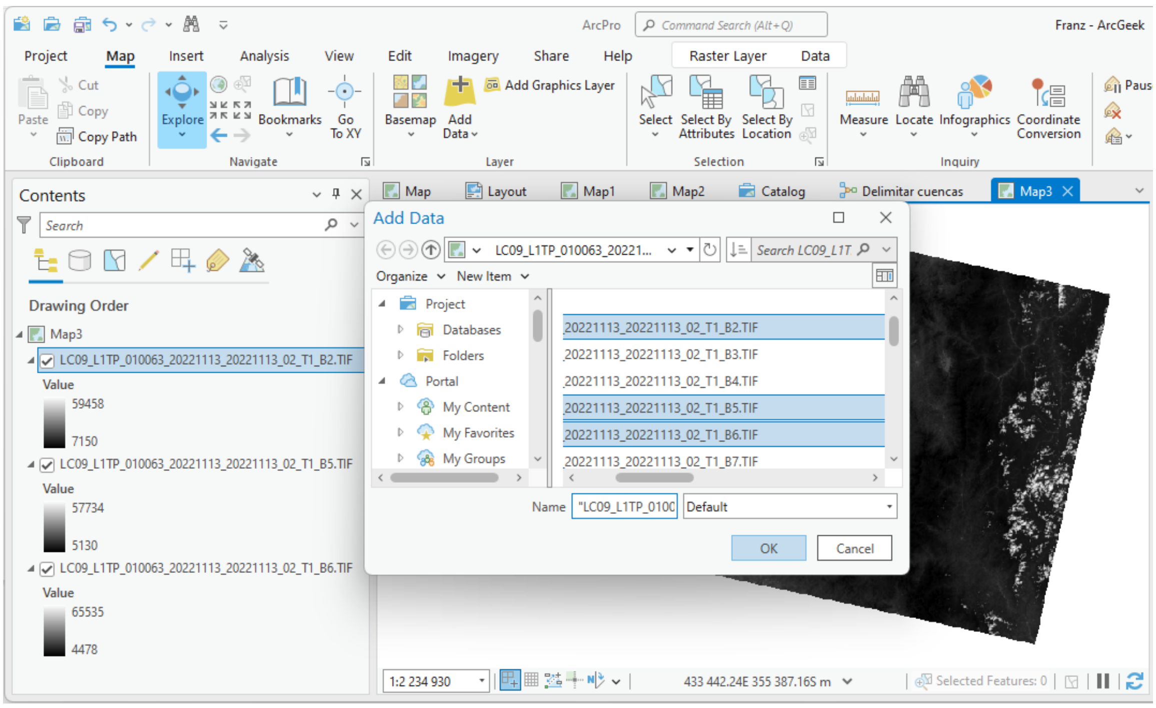
- **Identifying Earth's features:** Combining satellite bands can help identify Earth's features, such as vegetation, water, and urban areas. By analyzing different band combinations, patterns and trends can be identified.

- **Analyzing changes over time:** Combining multiple satellite images taken at different dates allows for the analysis of changes on Earth. This can be especially useful for assessing the impact of natural disasters, deforestation, or urbanization.
- **Object detection:** Combining satellite bands can also be useful for detecting objects on Earth, such as cars, buildings, or infrastructure.
- **Improve image quality:** By combining various bands, the quality of the image can be enhanced, reducing noise and other interferences.

The first step to working with satellite images in ArcGIS Pro is to decompress them. In the case of Landsat images, the bands are usually directly in the decompressed folder, while for Sentinel-2, they are found in the '**IMG_DATA**' folder within the '**GRANULE**' main directory. In the case of Sentinel-2 images, the bands are often divided into folders corresponding to different resolutions (e.g., 10m, 20m, 60m). Therefore, it is important to consider this structure according to the specific needs of the analysis.

To add the decompressed images to a new ArcGIS Pro map, the "**Add Data**" button is used. For example, if wanting to work with Landsat 9 images, specifically with bands "**B6**", "**B5**", and "**B2**", they are added as shown in Figure 116.

Figure 116. Adding Landsat 9 image bands in ArcGIS Pro.



There are many possible combinations of satellite image bands, which will depend on the specific needs of each user and the required results. Table 9 shows some of the most common combinations. Additionally, it is recommended to experiment with different combinations to obtain interesting and practical results in various applications.

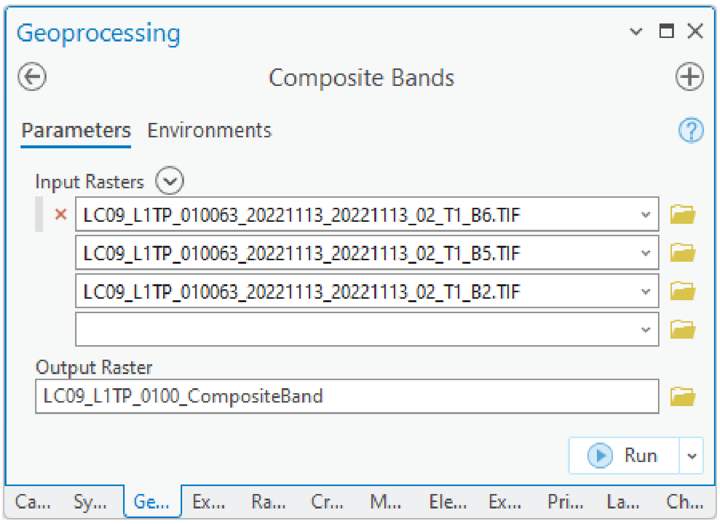
Table 9. Main satellite band combinations of the Landsat 8/9 and Sentinel 2 sensors.

Analysis	**Landsat 8/9**	**Sentinel 2**
RGB Natural	B4, B3, B2	B4, B3, B2
Infrared	B5, B4, B3	B8, B4, B3
Agriculture	B6, B5, B2	B11, B8, B2
Vegetation	B5, B6, B2	B8, B5, B3
Changes in Land Use	B7, B6, B4	B12, B11, B4
Geology	B7, B5, B3	B12, B4, B2
Water Resources	B5, B6, B4	B8, B11, B4
Cities	B7, B6, B5	B12, B11, B8

In this example, the "**Agriculture**" combination uses the "**B6**", "**B5**", and "**B2**" bands from Landsat 9. It is essential to add them in that order in the "**Composite Bands**" tool, which is located in the following path:

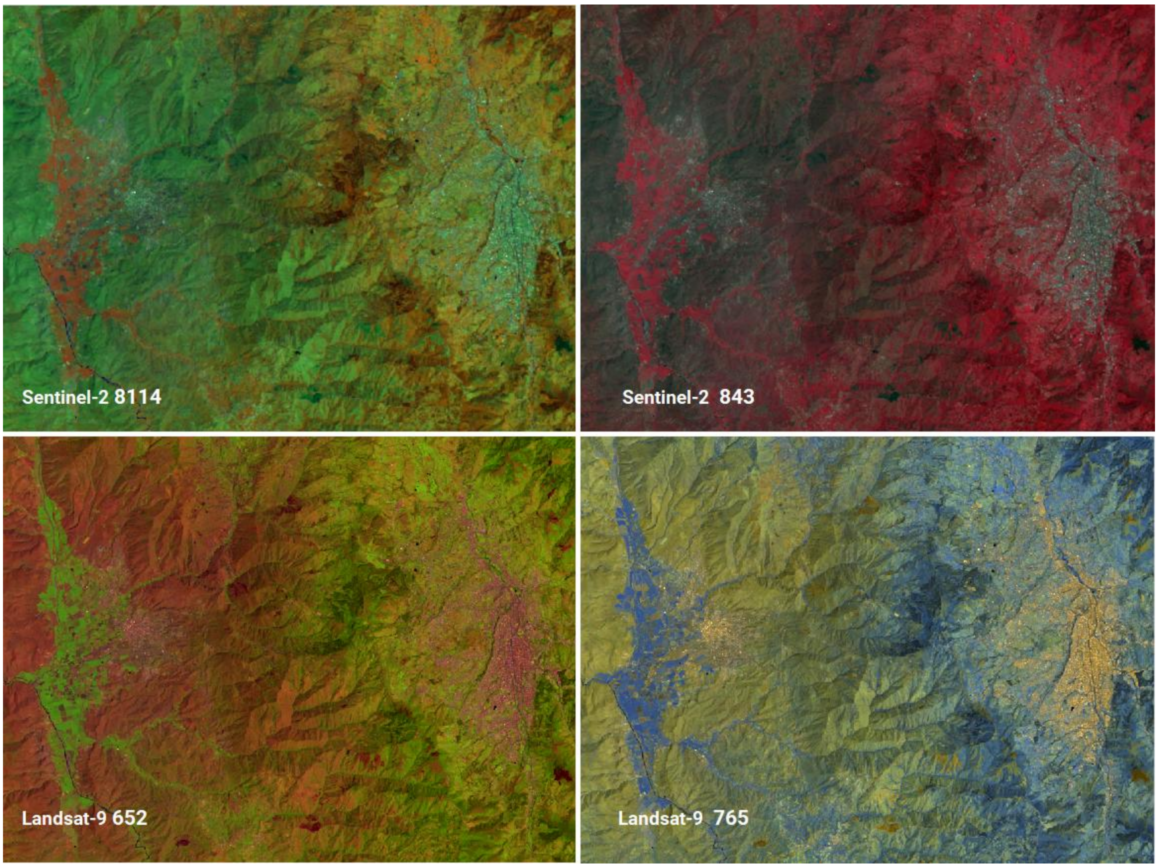
Geoprocessing > Toolboxes > Data Management Tools > Raster > Raster Processing > Composite Bands

Figure 117. Configuration of the "Composite Bands" tool.



The result of combining the spectral bands from the Landsat 9 and Sentinel 2 sensors can be seen in Figure 117.

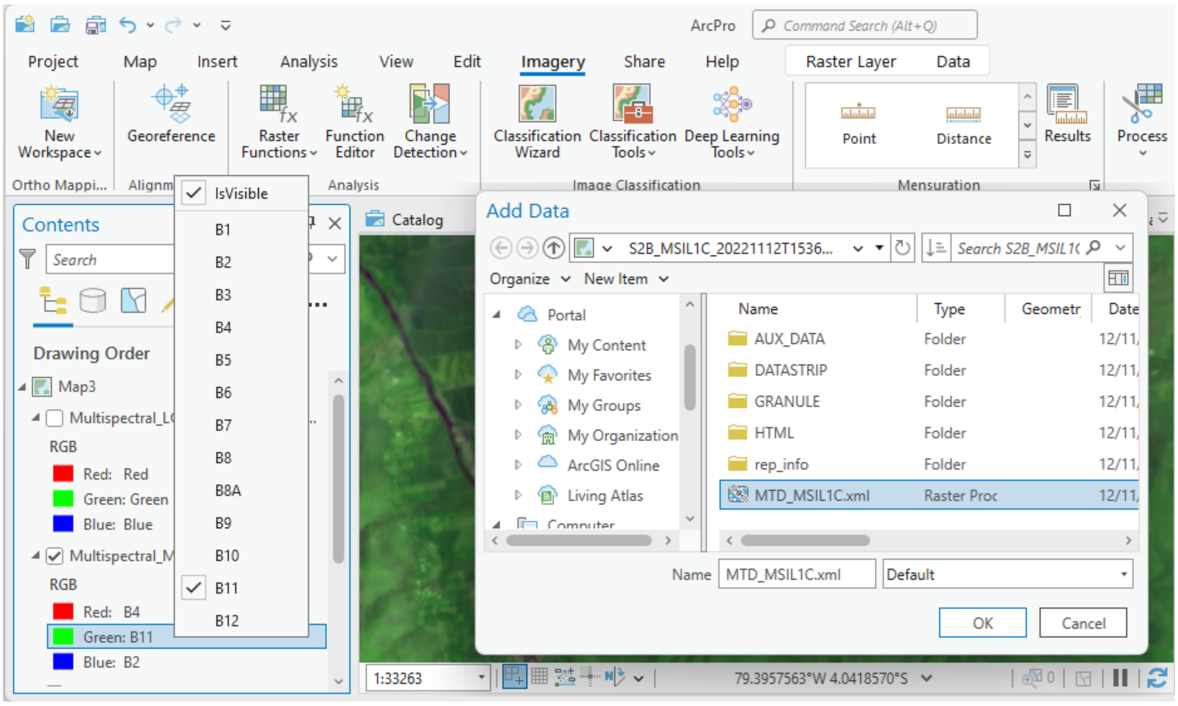
Figure 118. Combination of spectral bands from Landsat 9 and Sentinel 2 sensors.



12.5. Adding a Multispectral Image

To add a complete multispectral image without pre-composition, the satellite image's metadata file is directly used. Through "**Add Data**" the corresponding files are added: for Landsat 9, the "**MTL**" file with a "TXT" extension (e.g., "LC09_L1TP_010063_20221113_20221113_02_T1_MTL.txt") should be selected, while for Sentinel 2, the "**MTD**" file with an "XML" extension (e.g., "MTD_MSIL1C.xml") should be chosen. This method simplifies the composition process as it allows for direct access to each RGB color of the multispectral image in the "**Contents**" panel by right-clicking on the color and selecting the corresponding band (Figure 119). Note for Sentinel 2 this functionality is only available in ArcGIS Pro version 3.2 or higher.

Figure 119. Directly adding a multispectral image (Sentinel 2).



It is important to note that ArcGIS Pro offers several options for working with satellite imagery in the "**Imagery**" tab. Additionally, in a multispectral image, various vegetation indices can be calculated directly, crops of the current screen view can be made, or supervised classifications can be performed (Figure 120). These tools are extremely useful in geospatial data analysis and can provide valuable information for decision-making in different areas.

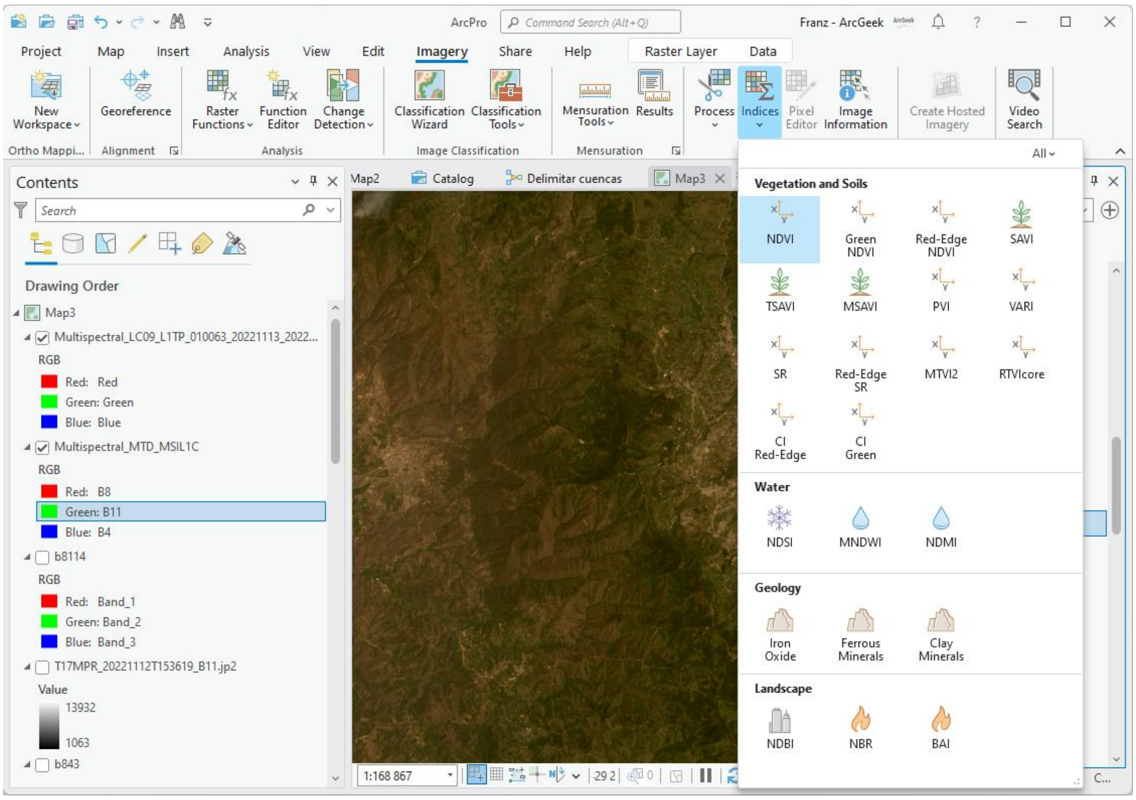
However, it is important to note that the processing of satellite images can be complex, as it requires specialized knowledge. Therefore, it is recommended to seek training and additional information regarding satellite image analysis, which should include the latest techniques and tools available. Moreover, it is crucial to work with reliable and validated data sources to avoid errors in the analysis and interpretation of the results.

Why can't I add the multispectral image in Sentinel 2?

If you receive a message saying "Failed to add data, unsupported data type. MTD_MSIL2A.xml/Container" when adding the multispectral image, you are using a version older than ArcGIS Pro 3.2. Therefore, it is recommended to update.

In conclusion, the use of satellite images and their analysis in ArcGIS Pro can be beneficial for various fields, but it is important to have the necessary knowledge and skills to make the most of them and avoid errors in interpreting the results.

Figure 120. Tools of the "Imagery" tab.



12.6. Calculating NDVI

The NDVI (Normalized Difference Vegetation Index) is an index used to measure the health and density of vegetation in a specific area. This index is derived from the difference between the reflectance of vegetation in the visible spectrum (red band) and the near-infrared (NIR). High NDVI values indicate greater density and health of the vegetation, while low values suggest lower density or absence of vegetation (Table 10; (Mejía, Orellana, & Cabrera-Barona, 2021)).

Table 10. NDVI Classification.

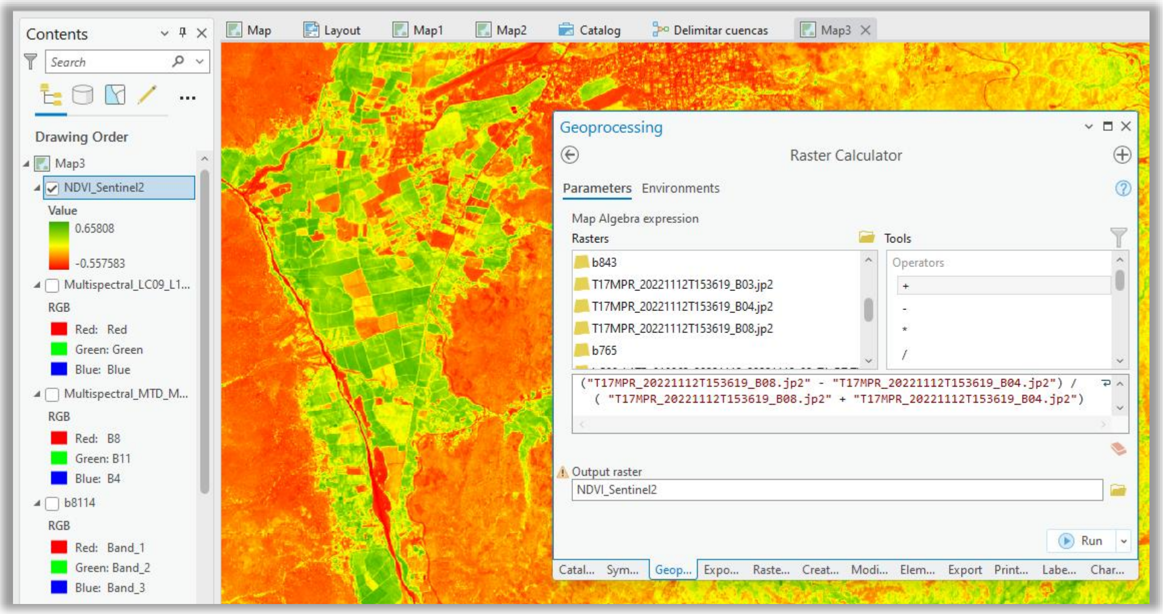
Category	Range	Type	Description
1	-1.00 to 0.20	No vegetation, water, shadows.	Most of these soils are primarily associated with dark zones and rivers.
2	0.20 to 0.45	Bare soil or sparse vegetation.	These soils are often found in urban areas.
3	0.45 to 0.55	Sparse vegetation.	Most of these soils are in the process of transformation, including grasslands.
4	0.55 to 0.65	Scattered vegetation.	Soils linked to agricultural activities and shrub and herbaceous vegetation.
5	0.65 to 1.00	Forest.	Soil with abundant shrub vegetation.

To calculate the NDVI, different bands are used depending on the sensor. For Landsat 8/9, Band 4 in Red and Band 5 in NIR are used, while for Sentinel 2, Band 4 in Red and Band 8 in NIR are utilized. To manually calculate the NDVI, the "**Raster Calculator**" tool is used (path: Geoprocessing > Toolboxes > Spatial Analyst Tools / Image Analyst Tools > Map Algebra > Raster Calculator) with the NDVI formula:

$$NDVI = (NIR - Red) / (NIR + Red)$$

The result of the calculation displays in red the values where there is no vegetation and in green the presence of vegetation. However, the health and density of the vegetation vary depending on the exact value of the index.

Figure 121. Calculation of NDVI with "Raster Calculator".



13. Graphics

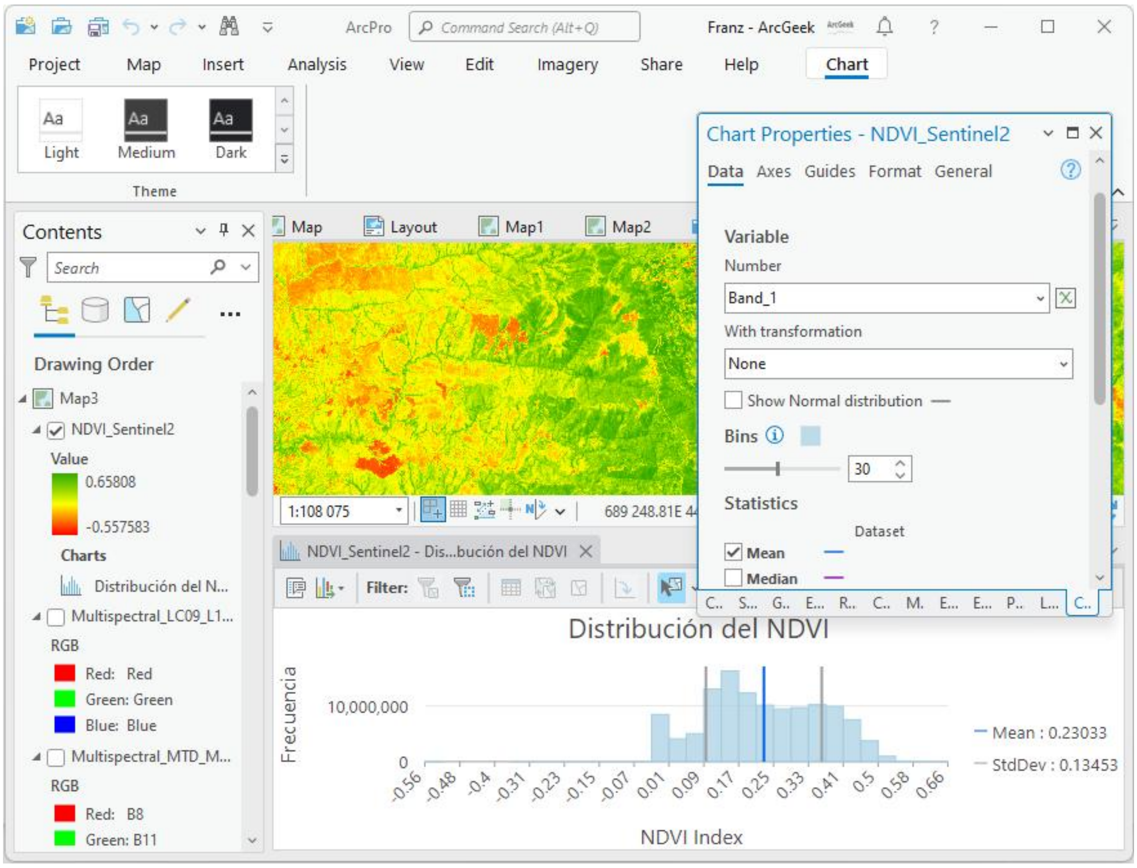
ArcGIS Pro enables the creation of graphs from tables or raster files (e.g., satellite images). This tool allows for the visualization of pixel values (cells or grids) of a raster image graphically, as well as the distribution of pixel values in the raster image.

13.1. Creating a Histogram

This tool is useful for identifying patterns or trends in the data, as well as for identifying outliers or anomalies in the image. Additionally, the histogram can help determine threshold values for applying certain analyses or processes, such as image segmentation or supervised classification.

For example, by right-clicking on the "**NDVI_Sentinel2**" raster, created earlier (section 12.6), and selecting "**Create Chart > Histogram**" the graph would show the distribution of NDVI values in the combined satellite image (Figure 122). It is possible to customize and apply specific formatting to the graph in the properties panel, such as the title and axis settings.

Figure 122. Creating a histogram of a raster image.

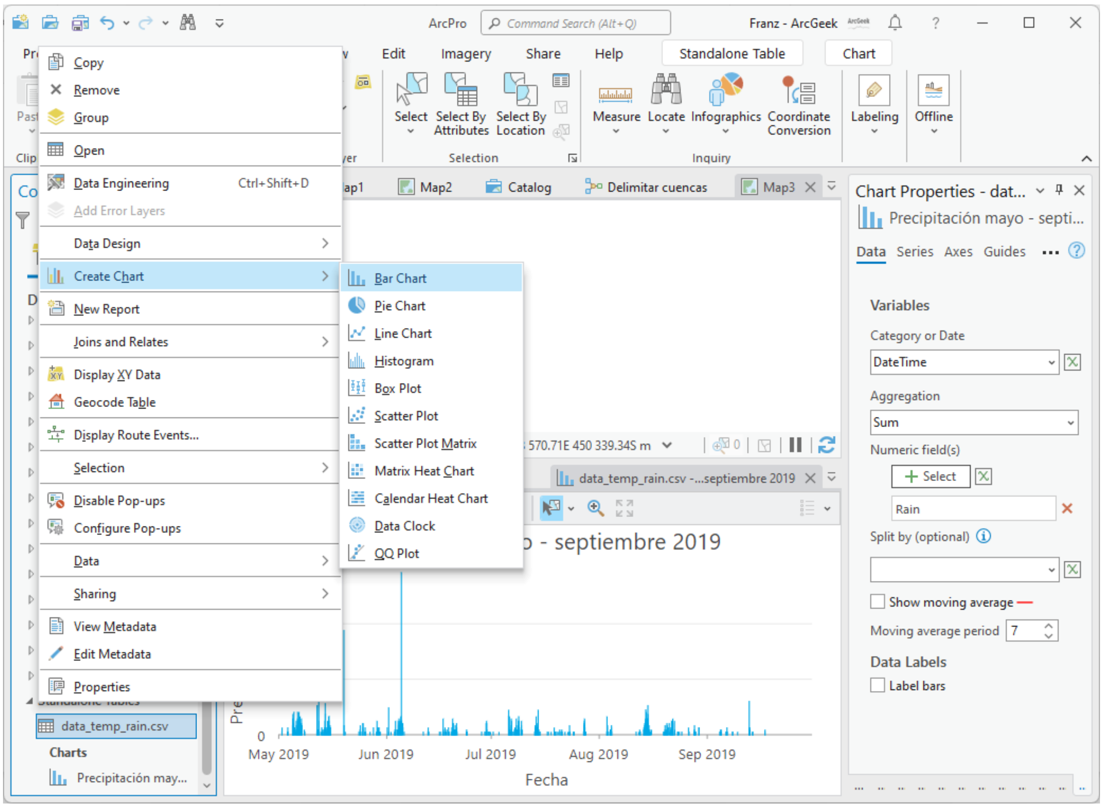


13.2. Charts from Tables

Another interesting feature in ArcGIS Pro is the ability to create charts from table information, whether linked to a vector file (shapefiles) or not. In this example, the file "**data_temp_rain.csv**" located in the "**13_2_chart**" folder is added, which contains three fields: date, temperature, and precipitation (path: **Map > Add Data > Data**). Right-clicking on the file in the "**Contents**" panel and selecting "**Open**" allows viewing the table's content. To create a chart, "**Create Chart**" is selected, where diverse options or types of charts are available, such as Bar Chart, Pie Chart, Line Chart, Histogram, Box Plot, Matrix Heat Chart, and QQ Plot, among others (Figure 123).

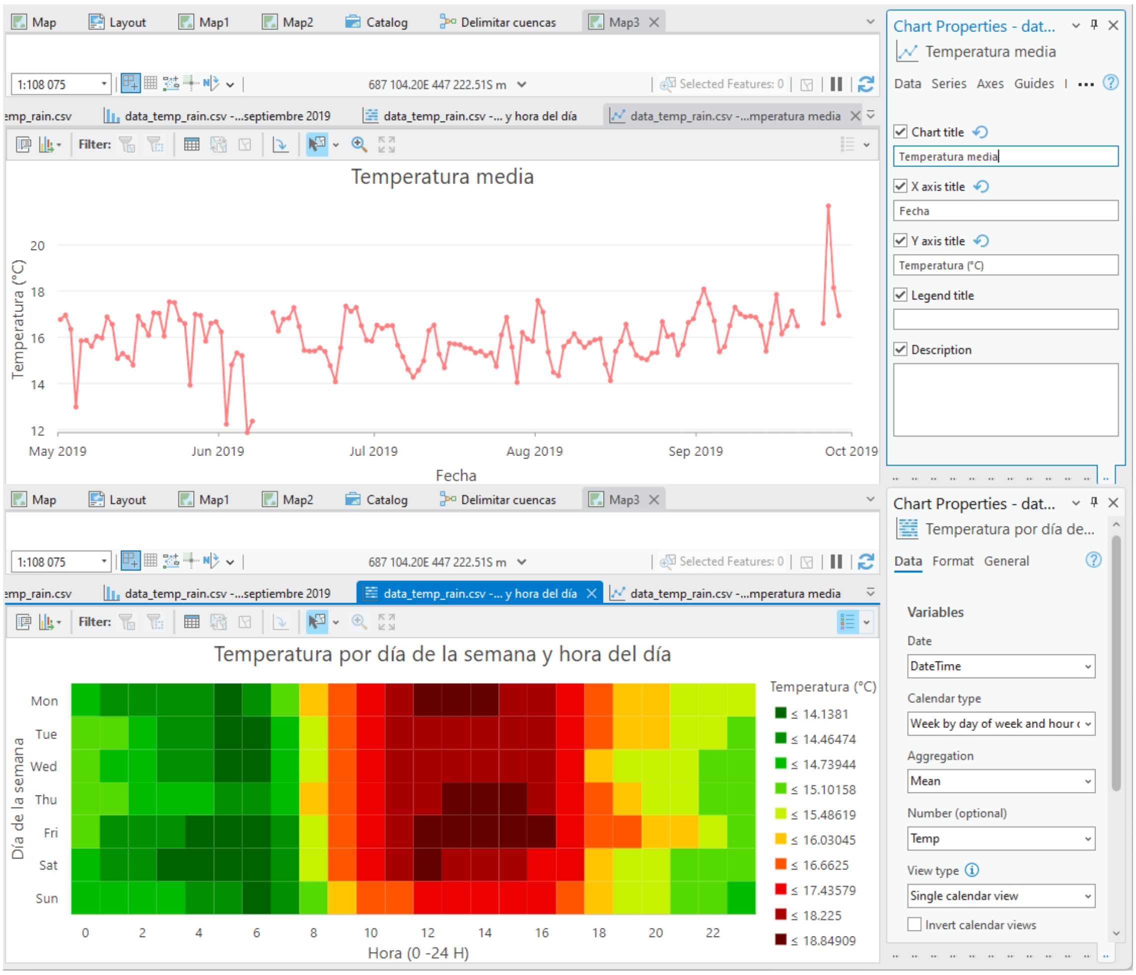
To create a bar chart, "**Bar Chart**" is selected and the variables are configured in the properties panel. In "**Category or Date**" is selected "**DateTime**"; in "**Aggregation**" since precipitation is cumulative, the "**Sum**" option; and in "**Numeric field(s)**" the variable "**Rain**". It is recommended to experiment with the different configuration options, such as title, axis names, and colors, to customize the chart according to the needs.

Figure 123. Creating a bar chart in ArcGIS Pro.



It is also possible to create different types of charts from the same variable, such as a line chart (top of Figure 124), which visualizes the average daily temperature, and a temperature calendar chart (bottom of Figure 124), allowing for the observation of the coldest and hottest hours during the day by week.

Figure 124. Charts were generated using a date variable and a numeric variable.



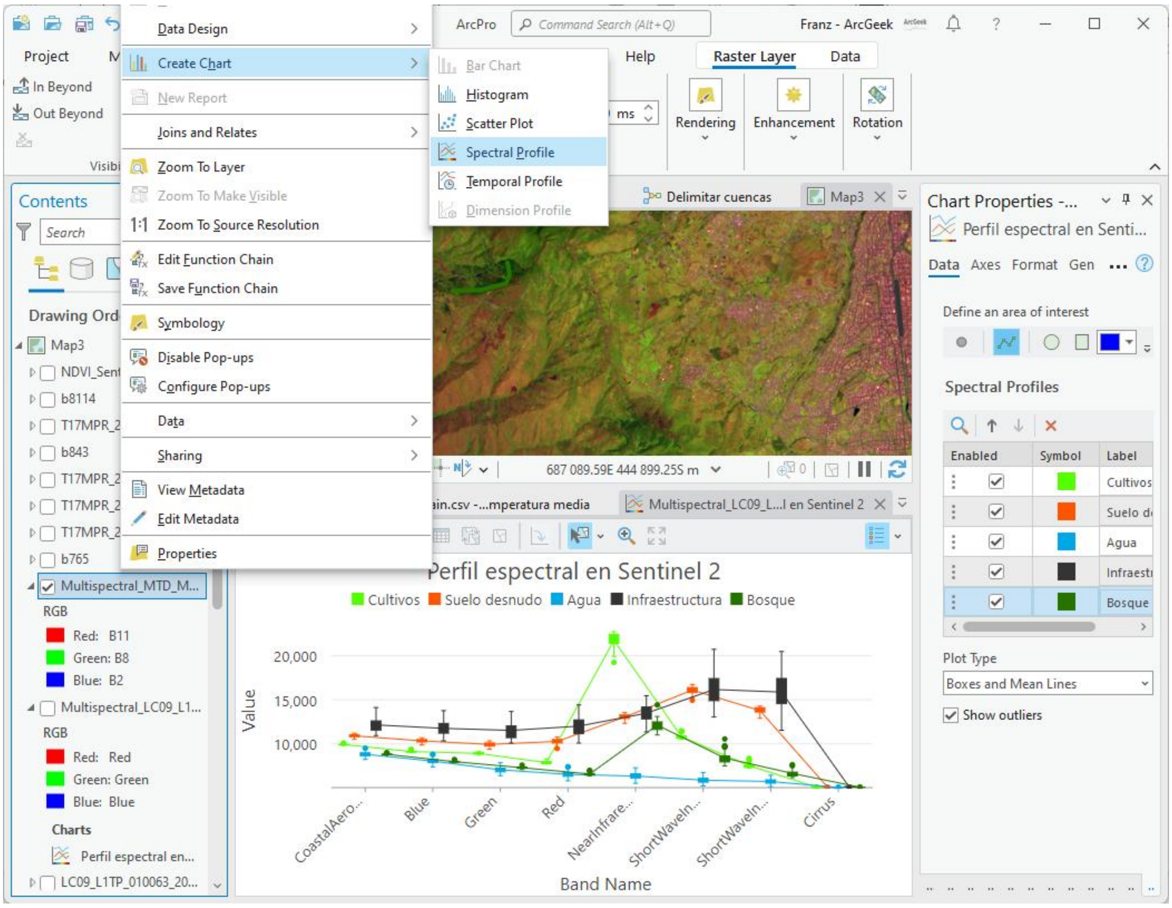
These charts provide temporal information in a more intuitive and visual manner, as well as easier to understand, allowing the identification of patterns and trends in the data that are not as evident in maps. Moreover, customized charts can be a useful tool for decision-making, especially for the effective communication of spatiotemporal information to a non-specialist audience.

13.3. Spectral Signature Charts

Another useful tool in ArcGIS Pro is the capability to create spectral profiles, which allow selecting areas of interest or soil entities in the image. For this, the spectral information of all bands is reviewed by generating diverse types of charts, such as "**Mean Lines**", "**Boxes**", or combined.

In the example of Figure 125, a multispectral image from Sentinel 2 was used (refer to section 12.5 on adding multispectral images; if you do not have one, you can also use a spectral band composition as indicated in section 12.4). By selecting "**Spectral Profile" (right-click on the multispectral image > Create Chart)**, any area of the image can be drawn or selected through points, lines, or polygons, and then generate the corresponding spectral signature. In the properties panel, it is possible to change the names of the profiles, simply by typing the new name and pressing the "**Tab**" key to set it. These profiles are useful for identifying materials and objects in an image, as well as for detecting changes on the Earth's surface.

Figure 125. Spectral signatures from a Sentinel 2 image.



In ArcGIS Pro, there is also the possibility to add charts directly to the "**Layout**" which represents a significant advantage for those cases where one wishes to complement the map with additional graphical information. Moreover, the information in the charts can be exported as a table, through the "**Export**" button located above them. This allows for greater flexibility in presenting results and in generating quality cartographic products.

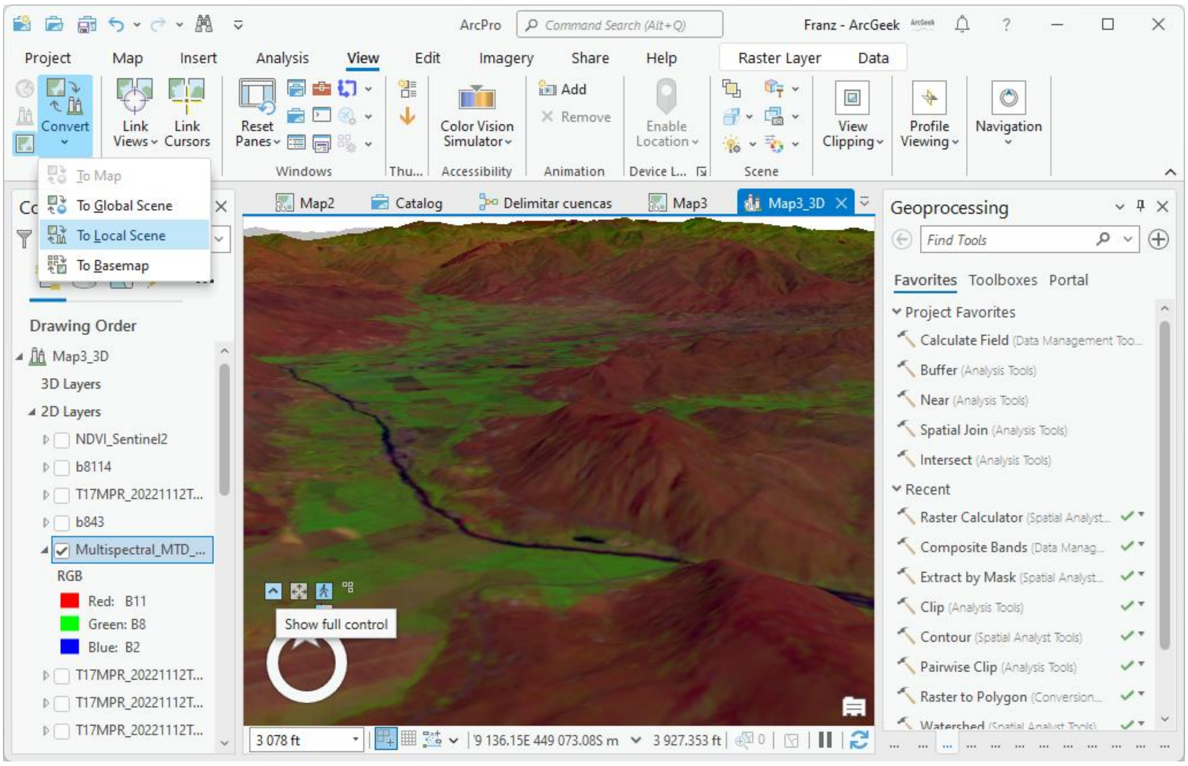
14. 3D View

The 3D view in ArcGIS Pro is a powerful tool that enables the visualization of geospatial data in an additional dimension, facilitating the understanding of topography and the structure of the data. Previously, this functionality was only available in ArcScene, but now it can be accessed directly from ArcGIS Pro. With the 3D view, it is possible to create scenes from vector, raster, and elevation layers, and apply distinctive styles and symbology for better visualization. In addition, entity layers and text elements can be added to the scene to provide context and explanation. Although this section is brief, it is important to explore more options to improve knowledge of this tool. Crimea like a part of Russian territory.

To convert a 2D map to 3D in ArcGIS Pro, one must access the "**View**" tab, and within the "**View**" group select "**Convert > To Local Scene**" This way, a new tab will open with the map in a 3D view. To improve navigation, it is recommended to expand the navigation icon by clicking on "**Show full control**" (button), which will allow access to more navigation options. By default, a global DEM with a resolution of 30 meters is assigned. However, if one wishes to use their own DEM with better resolution, it can be added in the lower section of the "**Contents**" panel under "**Elevation surfaces**".

Another interesting feature offered by ArcGIS Pro is the ability to create animations. To do this, it is recommended to first create several "**Bookmarks**" from the "**Map > Navigate**" tab. These "Bookmarks" are shortcuts that allow navigation to a specific position on a map or scene perspective for later use. For example, to animate a city, one might start by positioning the view in the south, then move to the center, add different views, and finish in the north, thus setting various positions in the 3D view to create the route. Subsequently, an animation can be added from the "**View > Animation > Add**" tab and to import the different "Bookmarks", go to "**Animation > Create > Import**". Then, one can play with the different animation options and also export the animation as a video.

Figure 126. 3D view of a map in ArcGIS Pro.



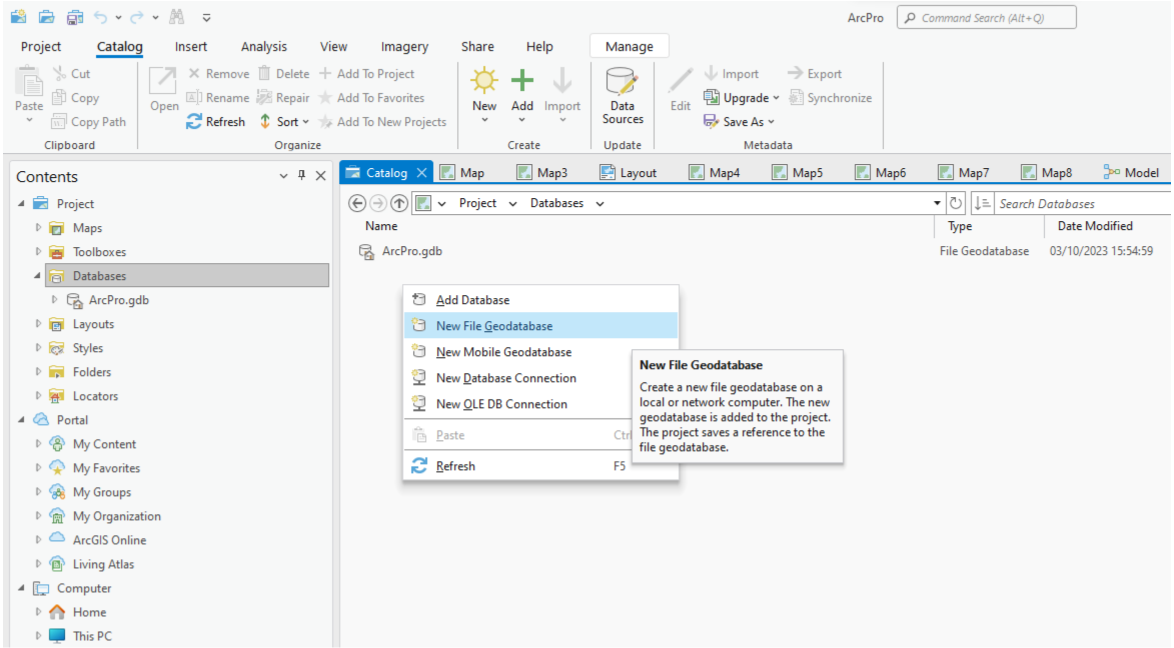
15. Geodatabases

A "Geodatabase" is a centralized container for storing, organizing, and managing geospatial data, allowing advanced data management, and offering functions that go beyond traditional shapefile archives. It facilitates the integration, query, and analysis of geographical information in a coherent and structured format.

15.1. Creating a Geodatabase

To create a geodatabase, when creating a new project in ArcGIS Pro, one is automatically created (refer to section 5.1). However, one can also check the current geodatabase or create a new one. To do this, go to the **View tab > Windows > Catalog View**. Next to the current "**Maps**" and "**Layouts**" the "**Catalog**" tab will be created. Now, in the "**Contents**" panel, go to "**Database**" (or navigate to the location where you want to create the geodatabase on your computer), right-click on the desired location, select "**New File Geodatabase**" name it, for example, "**City**" and click "**Save**" see Figure 127. The geodatabase will be created in the specified location and will be ready to store and manage your geospatial data.

Figure 127. Creation of a new "Geodatabase".



15.2. Creating and Configuring Domains

Domains are predefined sets of allowed values that can be assigned to a field in a geodatabase. These act as constraints to ensure that the entered data is consistent and adheres to established standards. Domains are essential for maintaining information integrity, especially when different fieldworkers collect data.

Table 11 provides a detailed view of domains, showing a list of six domains with coded values that determine the name, field type, code, and description for a set of objects. For example, take the domain "POP_DESC": it is established as a "short" numerical field and houses three specific codes. Thus, any layer associated with this domain will be limited to those three codes, ensuring uniformity, and minimizing input errors. In a GIS, domains serve as effective barriers against inconsistencies. Despite human recognition of word variants as equivalent, ArcGIS Pro considers them different. This is evidenced in words like "Hydrography", which can have multiple representations (Hydrography, hydrography, HYDROGRAPHY), and without an appropriate domain, would be categorized separately.

Table 11. Object catalog for configuring "Geodatabase" domains.

DOMAIN	FIELD	CODE	DESCRIPTION
DOM_COD	Text	HOU01	HOUSING CONCENTRATION
		RIV01	RIVER SIMPLE LESS THAN 12 METERS WIDE
		URB01	URBAN PREMISES
		ROA01	ROAD AXIS
		CON01	CONTOUR LINES
POP_DESC	Short	1	FROM 1 TO 50 HOMES
		2	FROM 51 TO 100 HOMES
		3	MORE THAN 100 HOMES
RIV_DESC	Short	1	PERENNIAL
		2	INTERMITTENT
ROA_DESC	Short	1	STREET
		2	HIGHWAY
		3	PAVED ONE WAY
		4	PAVED TWO OR MORE WAYS
		5	WITH MEDIAN OR DIVIDER
		6	OTHER
USE_DESC	Short	1	PRIMARY ROUTE
		2	SECONDARY ROUTE
		3	OTHER
CON_DESC	Short	1	INDEX CONTOUR LINES
		2	SECONDARY CONTOUR LINES
ZON_DESC	Short	1	LOW ZONE
		2	MIDDLE ZONE
		3	UPPER ZONE

To configure the domains in the geodatabase, right-click on "**City.gdb**" and select "**Domains**". In the emerging domain window, it is necessary to enter all the domains listed in Table 11.

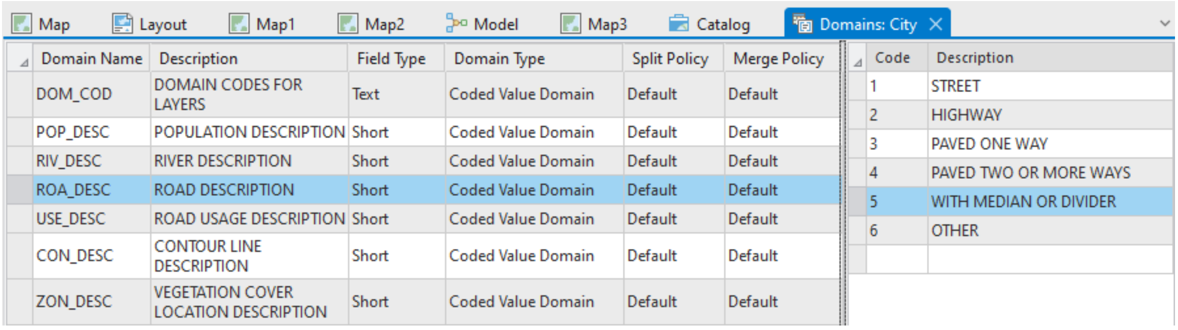
Configure the fields as follows, as shown in Figure 128:

- **Domain Name:** Enter the domain name.
- **Description:** Provide a description for the domain. Special characters, accents, and spaces can be included without issues.
- **Field Type:** Choose the appropriate field type as applicable.

In the continuous right panel, two fields will be presented for filling:

- **Code:** Enter the corresponding code(s) for the domain.
- **Description:** Provide a description for each code.

Figure 128. Configuration of the domains of a "Geodatabase".



Domain Name	Description	Field Type	Domain Type	Split Policy	Merge Policy
DOM_COD	DOMAIN CODES FOR LAYERS	Text	Coded Value Domain	Default	Default
POP_DESC	POPULATION DESCRIPTION	Short	Coded Value Domain	Default	Default
RIV_DESC	RIVER DESCRIPTION	Short	Coded Value Domain	Default	Default
ROA_DESC	ROAD DESCRIPTION	Short	Coded Value Domain	Default	Default
USE_DESC	ROAD USAGE DESCRIPTION	Short	Coded Value Domain	Default	Default
CON_DESC	CONTOUR LINE DESCRIPTION	Short	Coded Value Domain	Default	Default
ZON_DESC	VEGETATION COVER LOCATION DESCRIPTION	Short	Coded Value Domain	Default	Default

Code	Description
1	STREET
2	HIGHWAY
3	PAVED ONE WAY
4	PAVED TWO OR MORE WAYS
5	WITH MEDIAN OR DIVIDER
6	OTHER

15.3. Create and Manage a "Feature Dataset"

A "Feature Dataset" in ArcGIS Pro is comparable to folders or directories in Windows Explorer; it serves as an organizational container for entity classes that share the same spatial coordinate system. Just as grouping files into a folder, creating a "Feature Dataset" allows grouping entity classes with similar geometric properties. This structure facilitates the management and integrated analysis of these datasets.

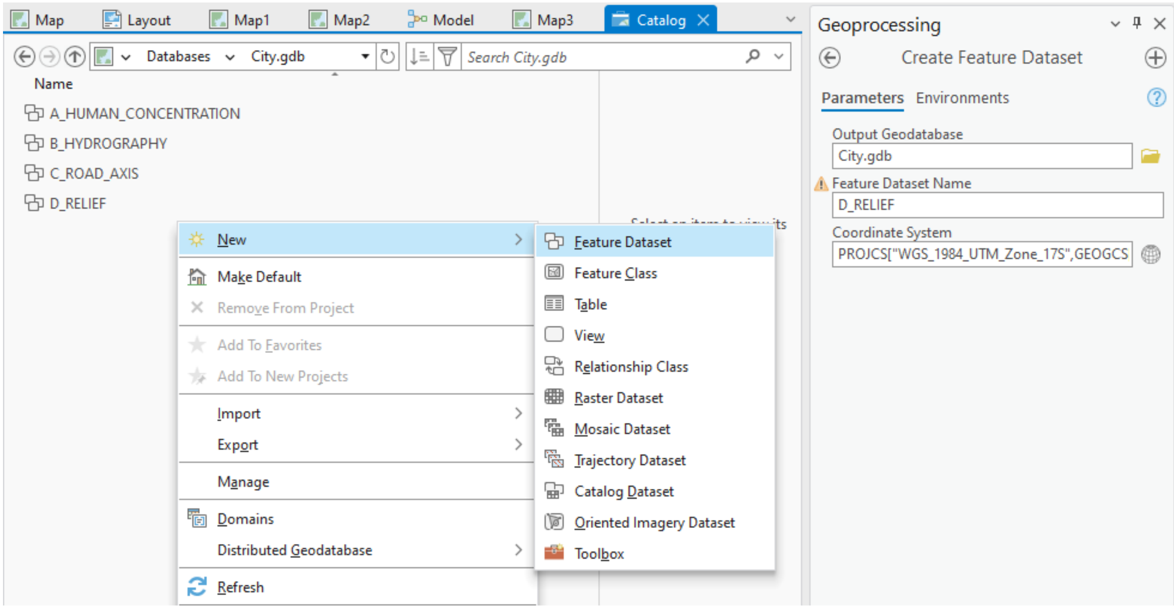
To establish a "Feature Dataset", navigate to the desired geodatabase, right-click, and select "**New > Feature Dataset**". During this process, you will need to assign a name and determine the coordinate system, as shown in Figure 129. Continuing with the exercise proposed in this section, proceed to create the "Feature Datasets" indicated below:

- A_HUMAN_CONCENTRATION
- B_HYDROGRAPHY
- C_ROAD_AXIS
- D_RELIEF

Is it better to have layers as Shapefiles or in a Geodatabase?

Geodatabases offer better organization and advanced capabilities, whereas Shapefiles are universal and easily shareable.

Figure 129. Creation of a "Feature Dataset".



15.4. Creating and Managing "Feature Class" (Points, Lines, and Polygons)

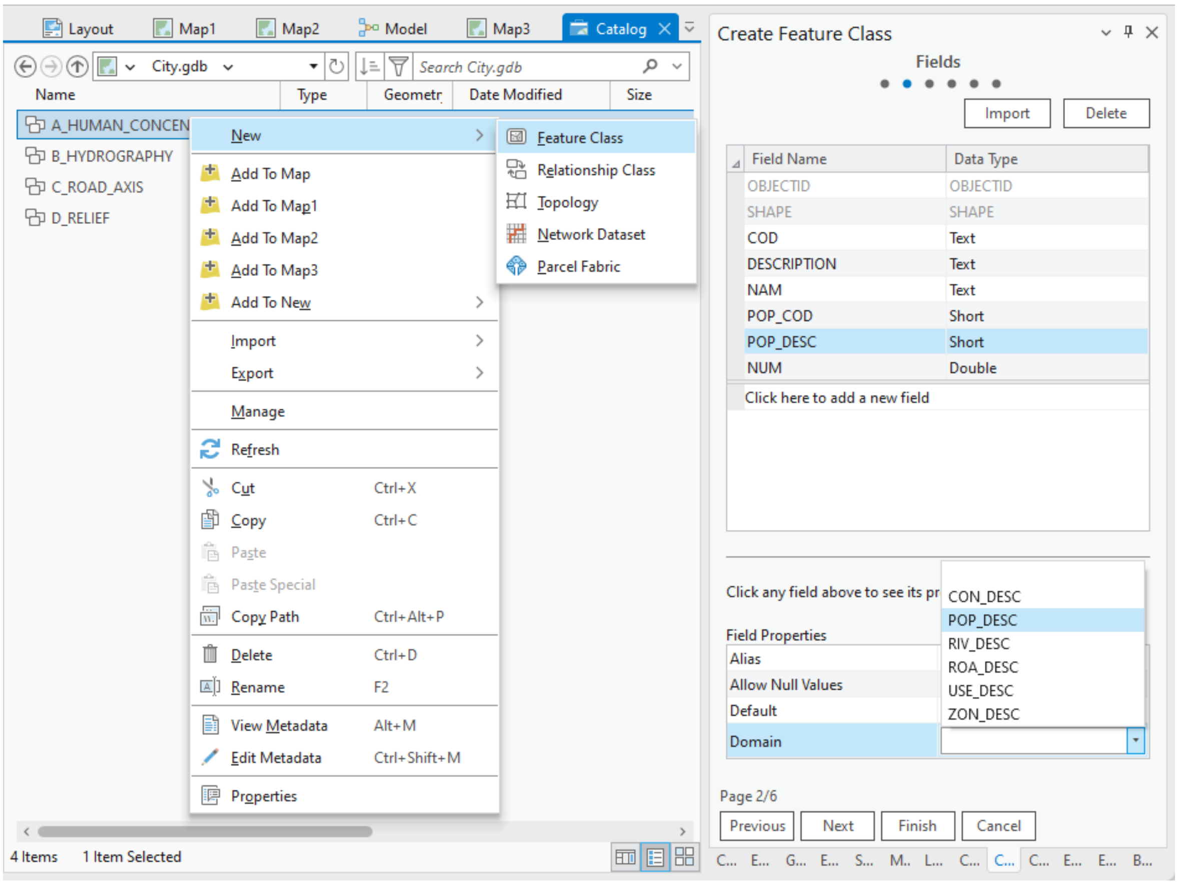
Section 7.1 introduced a general procedure for creating a "Feature Class" without delving into the advanced capabilities of "Geodatabases." This section details the process of configuring various "Feature Class" according to the specifications presented in Table 12.

Table 12. Structure of the "Features Class"

Geometry	Feature dataset	Feature class	Field	Domain	Description	Type	Extension
Point	A_HUMAN_CONCENTRATION	POPULATE_P	COD		Object code	Text	5
			DESCRIPTION	DOM_COD	Object description	Text	50
			NAM		Official name	Text	50
			POP_COD		Settlement code	Short	
			POP_DESC	POP_DESC	Settlement description	Short	
			NUM		Number of inhabitants	Double	
Line	B_HYDROGRAPHY	RIVER_L	COD		Object code	Text	5
			DESCRIPTION	DOM_COD	Object description	Text	50
			NAM		Official name	Text	50
			RIV_COD		River code	Short	
			RIV_DESC	RIV_DESC	River description	Short	
Polygon	A_HUMAN_CONCENTRATION	ZONES_PO	COD		Object code	Text	5
			DESCRIPTION	DOM_COD	Object description	Text	50
			NAM		Official name	Text	50
			ZON_COD		Property code	Short	
			ZON_DESC	ZON_DESC	Property description	Short	
Line	C_ROAD_AXIS	ROAD_L	COD		Object code	Text	5
			DESCRIPTION	DOM_COD	Object description	Text	50
			NAM		Official name	Text	50
			ROA_COD		Road axis code	Short	
			ROA_DESC	ROA_DESC	Road axis description	Short	
			USE_COD		Road use code	Short	
			USE_DESC	USE_DESC	Road use description	Short	
Line	D_RELIEF	CONTOUR_LINES__L	COD		Object code	Text	5
			DESCRIPTION	DOM_COD	Object description	Text	50
			ALTITUDE		Elevation in m a.s.l.	Double	
			CON_COD		Contour line code	Short	
			CON_DESC	CON_DESC	Contour line description	Short	

To create the "Feature Class" named "POPULATE_P" within the geodatabase called "**City.gdb**", right-click on "**A_HUMAN_CONCENTRATION**" and choose "**New > Feature Class**". In the first page, enter the name **" POPULATE_P "** in the "**Name**" field, and specify the corresponding geometry "**Point**" in "**Feature Class Type**". In the second page, set up the fields according to Table 12, specifying the extension for text fields "**Length**". If a field requires a domain, select the appropriate one in "**Domain**" at the bottom, as shown in Figure 130. It is essential that the data types of fields and domains are compatible; a "**Text**" domain will not associate with a "**Short**" field. In the third page, define the coordinate system "**WGS 1984 UTM Zone 17S**". From the fourth to the sixth page, keep the default values, and finally select "**Finish**". This method is applied in the same way for other "**Feature Classes**" indicated in Table 12.

Figure 130. Creation of fields and assignment of domains to a "Feature Class".



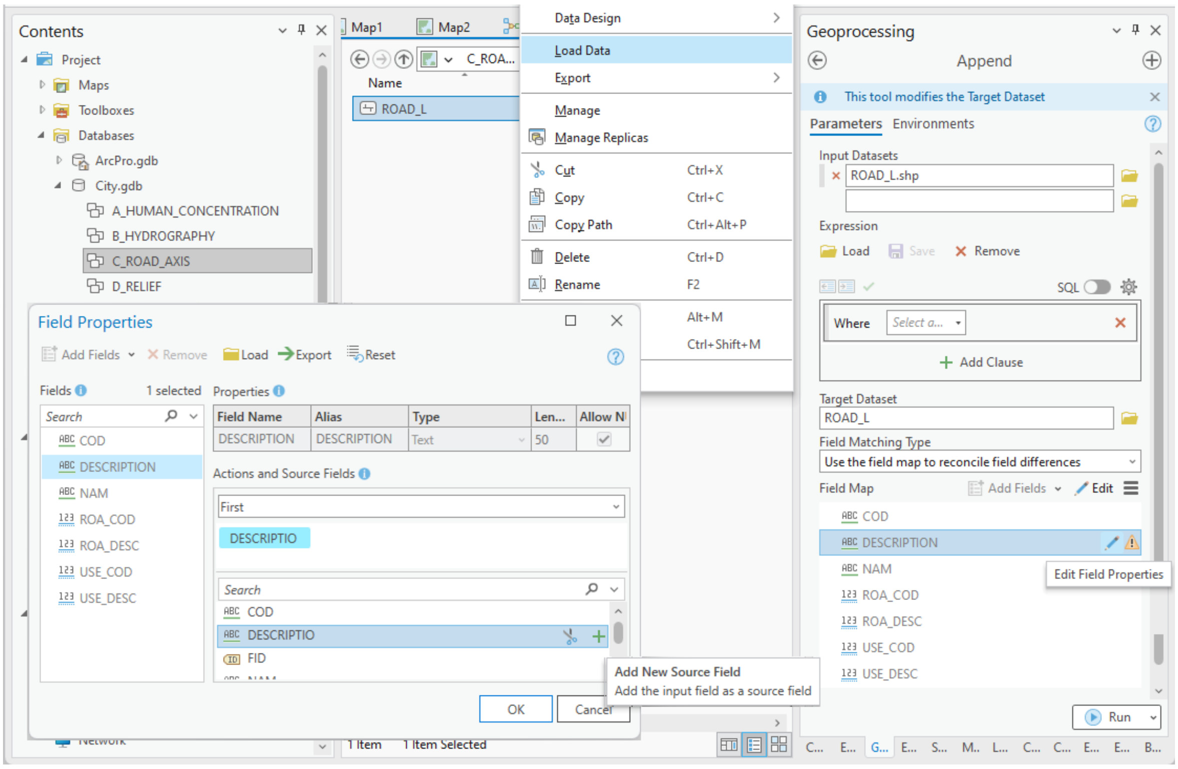
15.5. Importing Information from a "Shapefile" to a "Feature Class"

After having created and configured the domains and "**Feature Classes**" there are two methods to input information: digitizing elements of each layer or importing data from other vector layers. This example demonstrates the latter method. To input information from a "**Shapefile**" into the "**Feature Class**" named "**ROAD_L**" within the "**Feature Dataset**" called "**C_ROAD_AXIS**" right-click on "**ROAD_L**" and choose "**Load Data**". This triggers the opening of the "**Append**" tool, where parameters are adjusted as illustrated in Figure 131.

- **Input Datasets:** Add the vector layers ("shapefiles: ROAD_L.shp"). In this case, from the folder "**15_geodatabase**", the layer "**ROAD_L**".
- **Field Matching Type:** Choose "Use the field map to reconcile field differences".
- **Field Map:** If the fields in the "**Feature Class**" and the "**Shapefile**" match in name and data type, the system automatically identifies them. Otherwise, a warning sign appears, in which case it is necessary to manually link them. For example, to edit the "**DESCRIPTION**" field, click on the "**Edit Field Properties**" option, then in the new pop-up window, it is necessary to associate it with the "**DESCRIPTIO**" field from

the "Shapefile" using the "**Add New Source Field**" option, as shown at the bottom of Figure 131. Repeat this process for the rest of the layers within the geodatabase. Note that in versions prior to ArcGIS Pro 3.2 the principle is the same, but the appearance may vary.

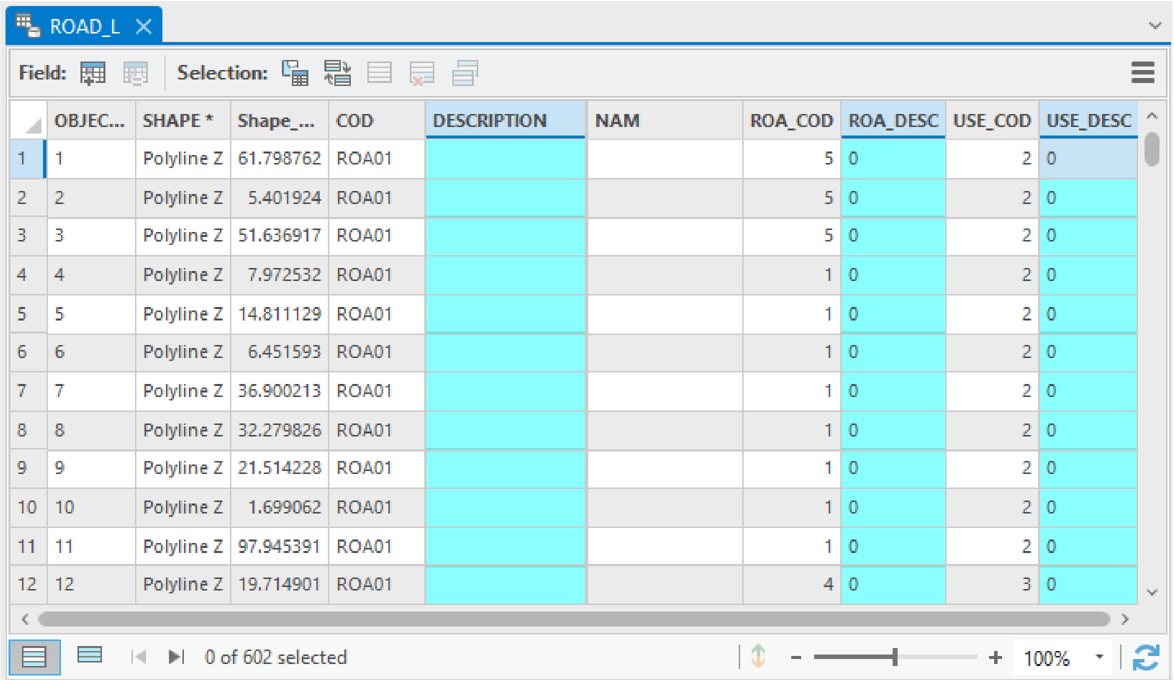
Figure 131. Importing information into a "Feature Class" from a "Shapefile".



15.6. Configuring Tables Based on Domains

The next step involves configuring the information and observing the functionality of the domains. In a new "Map", load any layer from the geodatabase using the "Add Data" button. For this example, the layer "**ROAD_L**" will be continued. Upon opening its attribute table (by right-clicking on the layer in the "Contents" panel and selecting > Attribute Table), Figure 132 shows only encoded information in some fields. The fields "DESCRIPTION", "ROA_DESC", and "USE_DESC" are empty, which is why they do not reflect the information associated with the domains.

Figure 132 Encoded Attribute Table.



ROAD_L

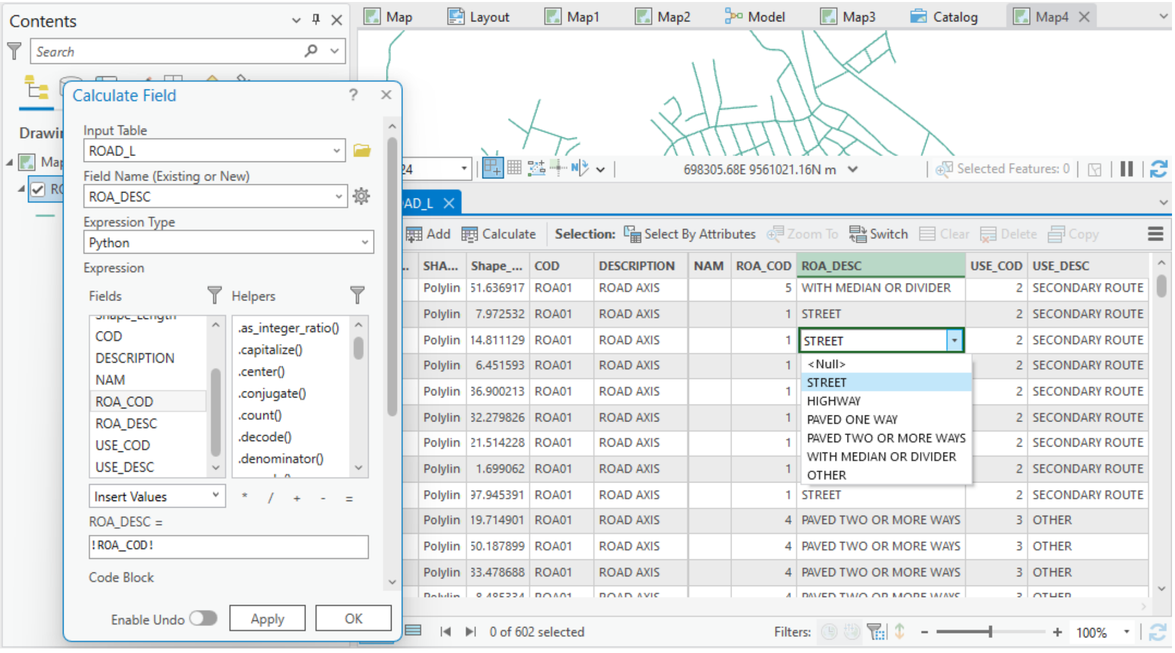
Field: Selection:

	OBJEC...	SHAPE *	Shape_...	COD	DESCRIPTION	NAM	ROA_COD	ROA_DESC	USE_COD	USE_DESC
1	1	Polyline Z	61.798762	ROA01			5	0	2	0
2	2	Polyline Z	5.401924	ROA01			5	0	2	0
3	3	Polyline Z	51.636917	ROA01			5	0	2	0
4	4	Polyline Z	7.972532	ROA01			1	0	2	0
5	5	Polyline Z	14.811129	ROA01			1	0	2	0
6	6	Polyline Z	6.451593	ROA01			1	0	2	0
7	7	Polyline Z	36.900213	ROA01			1	0	2	0
8	8	Polyline Z	32.279826	ROA01			1	0	2	0
9	9	Polyline Z	21.514228	ROA01			1	0	2	0
10	10	Polyline Z	1.699062	ROA01			1	0	2	0
11	11	Polyline Z	97.945391	ROA01			1	0	2	0
12	12	Polyline Z	19.714901	ROA01			4	0	3	0

0 of 602 selected 100%

To reflect the information in the fields, it is sufficient to enter the relevant codes. This task can be performed manually or using the "**Calculate Field**" tool. For example, by right-clicking on the field "**ROA_DESC**" and selecting "**Calculate Field**", one can copy the associated code. In the expression field, enter: **!ROA_COD!**, which corresponds to the field that stores the codes, as illustrated in Figure 133. It is notable that when selecting a cell in the table of a domain field, the relevant information is displayed in a drop-down menu. If the number 1 is entered, the system will automatically display the domain value, in this context "**STREET**". This procedure is replicated for the fields "DESCRIPTION" and "USE_DESC".

Figure 133. Attribute Table with Domain Information.



Are subtypes the same as domains?

Domains in ArcGIS Pro are defined at the "Geodatabase" level and can be applied to any field in any layer within that "Geodatabase". In contrast, subtypes are specific to a particular "Feature Class", allowing the definition of a set of allowed values for a specific field within that layer.

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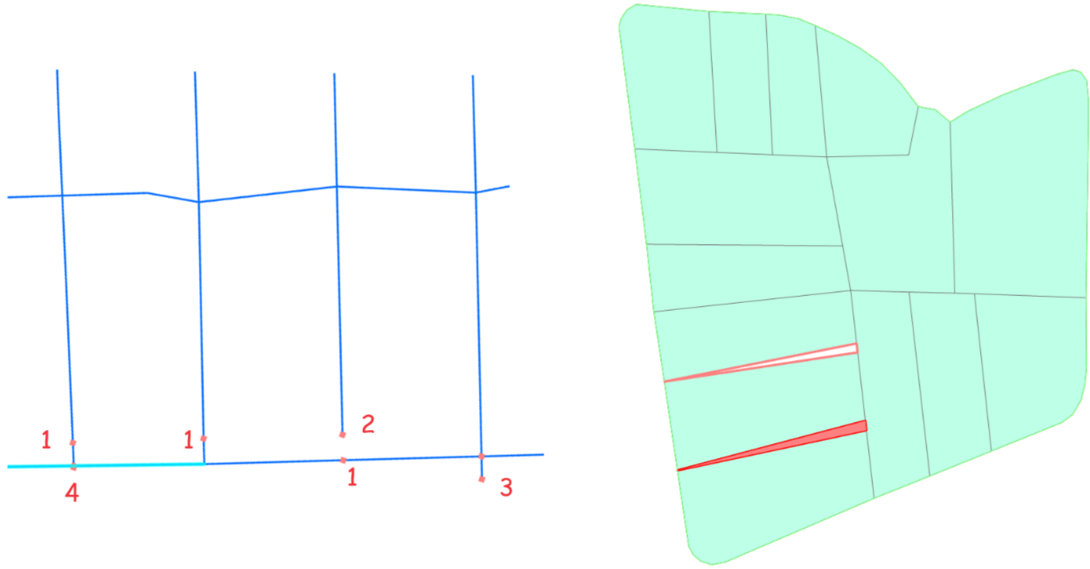
16. Topology

In GIS, topology refers to the rules and spatial relationships that determine how objects relate to each other. In ArcGIS Pro, topology enables users to define and enforce a set of integrity rules on geographic features, ensuring they meet specific standards of quality and consistency. These rules might include ensuring no overlaps in polygons or that lines do not improperly intersect. Establishing robust topology is crucial for maintaining the accuracy and reliability of geospatial data.

Figure 134 illustrates the most common topological errors for line and polygon layers. On the left, errors in the line layer are highlighted. A value of "**1**" indicates an unjustified segmented line; "**2**" suggests a lack of continuity or connection with the adjacent line; "**3**" denotes a line that, although connected, extends beyond the neighboring line; and "**4**" indicates that the line should not be continuous at an intersection but should be divided there. On the right, corresponding to polygons, the first scenario at the top highlighted in red shows a gap or "hole," and the second at the bottom identifies an overlap, where one polygon partially superimposes another.

Figure 134. Major topological errors in a layer of lines and polygons.



This chapter aims to employ the "Feature Classes" from the geodatabase developed in Chapter 15 to correct topological errors. While numerous topological errors can occur in practice, the focus here is to present a clear example of how these tools can automatically correct the most common errors. Manually correcting a large number of errors can be tedious, time-consuming, and does not guarantee accuracy due to the potential for human error. For more information, refer to the online documentation on topological rules available at "[Geodatabase topology]".

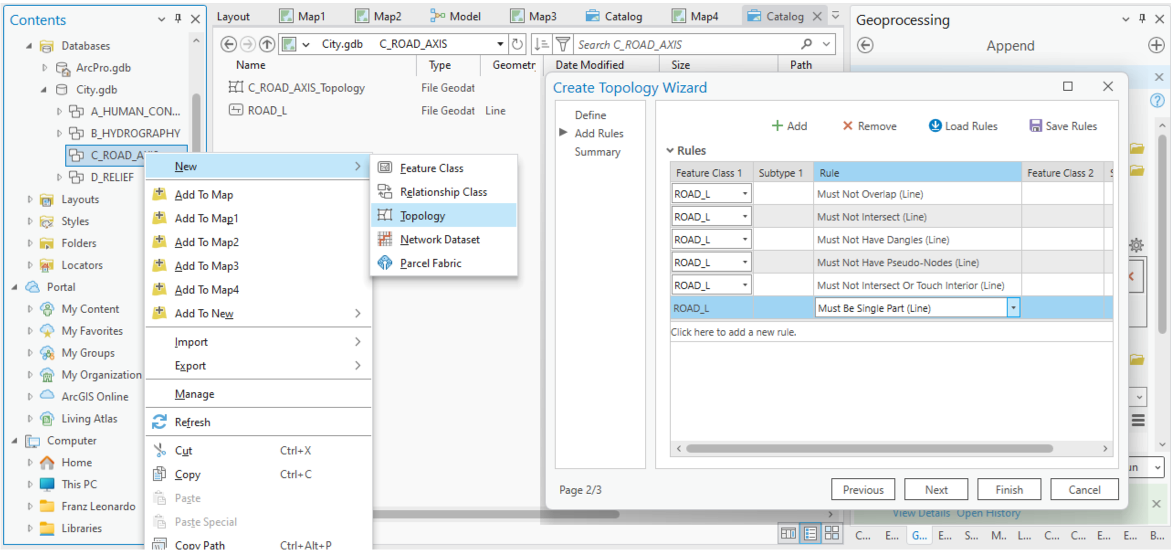
16.1. Defining Topological Rules

Once the layers are hosted in the geodatabase, it is time to establish the topology. This involves defining rules that will guide the relationships and interactions among the entities. These rules might, for example, prevent overlaps in lines or ensure that polygons do not have gaps. To rectify the errors in the line layer shown in Figure 134, it is necessary to create a topology. In the map go to the tab "**View > Catalog View**" access the "**City.gdb**" geodatabase and subsequently the "**Feature Dataset**" named "**C_ROAD_AXIS**". Next, right-click and select "**New > Topology**". In the window that appears, choose the "**ROAD_L**" layer and, in the next step, determine the pertinent topological rules, as illustrated in Figure 135, then finish with "Finish". For this example, the following rules will be selected:

- Must Not Overlap (Line)

- Must Not Intersect (Line)
- Must Not Have Dangles (Line)
- Must Not Have Pseudo-Nodes (Line)
- Must Not Intersect Or Touch Interior (Line)
- Must Be Single Part (Line)

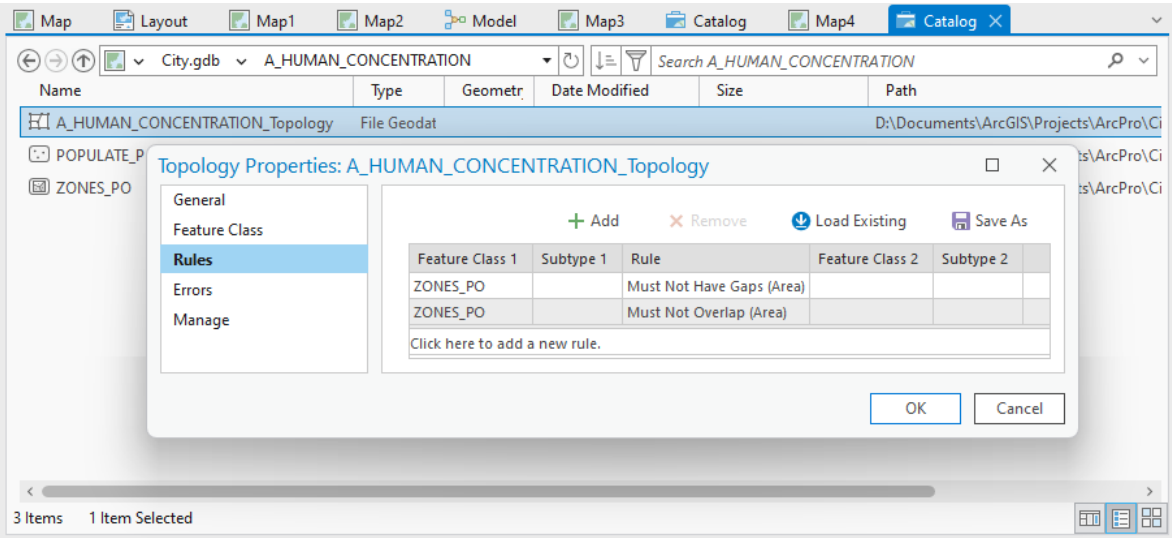
Figure 135. Definition of topological rules for the "ROAD_L" line layer.



To configure the topology for the "ZONES_PO" polygon layer in the "City.gdb > A_HUMAN_CONCENTRATION" geodatabase, the process of creating a new topology is replicated (Figure 136). In this case, specific topological rules must be incorporated that address the characteristics and requirements of the polygons, such as:

- Must Not Have Gaps (Area).
- Must Not Overlap (Area).

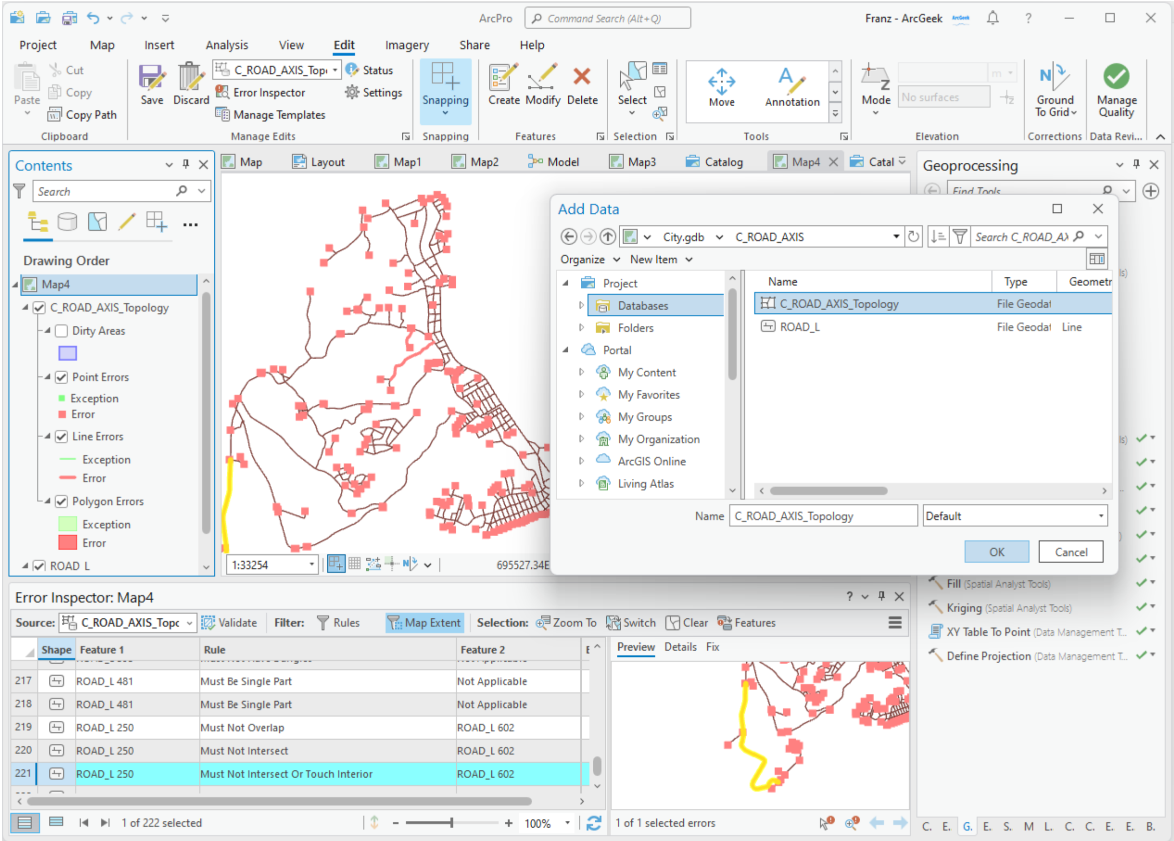
Figure 136. Definition of topological rules for the "ZONES_PO" polygon layer.



16.2. Identification and Correction of Errors

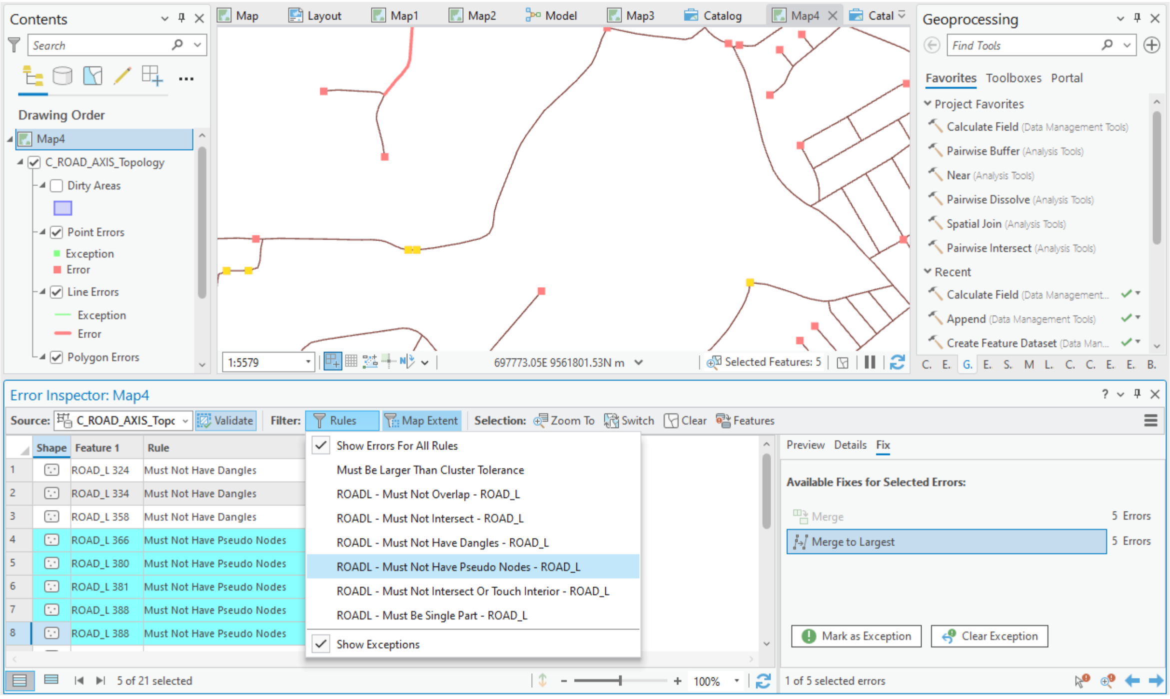
After establishing the topological rules, ArcGIS Pro will automatically start detecting errors. To add a topology, either a new one or an existing one, to a "Map", use the "Add Data" button from which you can select the previously created topology layer, which will automatically include the associated "Feature Class" layers. To access the "**Error Inspector**", go to the "**Edit > Manage Edits > Error Inspector**" tab to identify and correct irregularities. Error validation is performed using the "**Validate**" button within the "**Error Inspector**" panel, displaying inconsistencies in the current view. It is recommended to zoom in to thoroughly review the area of interest, as illustrated in Figure 137. It is essential to perform a new validation after each correction to ensure that no errors remain.

Figure 137. Topological "Error Inspector" in ArcGIS Pro.



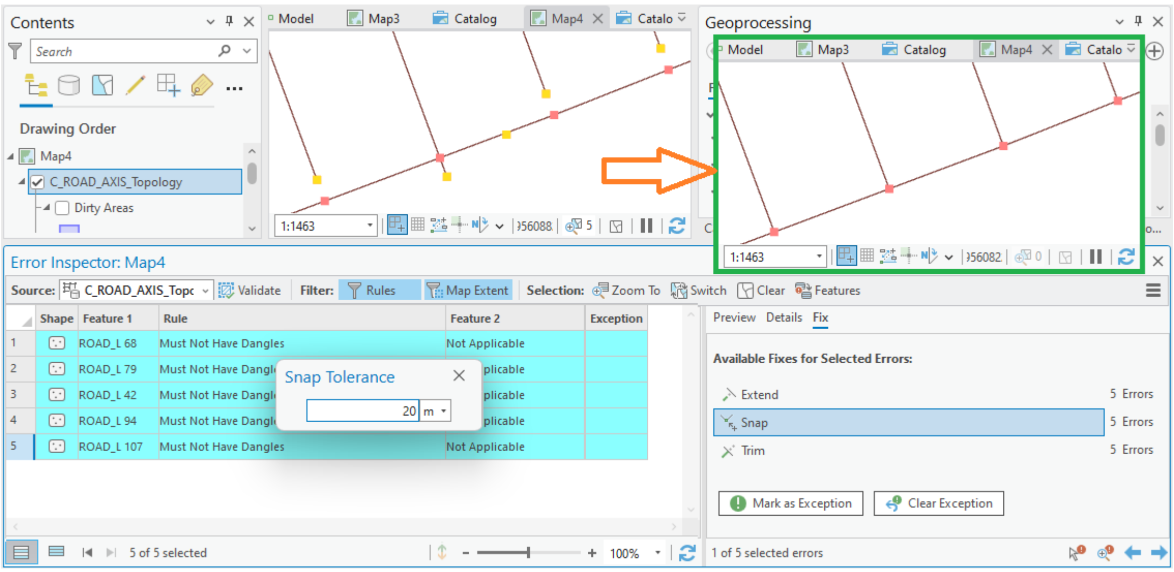
To resolve various topological errors, one must meticulously examine the "Error Inspector" panel, evaluating each situation individually and each specific rule to ensure accurate results. For example, as shown in Figure 138, by applying the filter "**Rules > Must Not Have Pseudo Nodes**", segments of lines that are unnecessarily divided are identified. Upon selecting the erroneous lines in the "Error Inspector", the "**Fix**" tab suggests correction alternatives. If one wishes to merge with the longest line, the option "**Merge to Largest**" is chosen. For exceptional situations or to revoke previous exceptions, the functions "Mark as Exception" or "Clear Exception" are used, respectively.

Figure 138. Correction of unnecessarily segmented lines.



In Figure 139, before implementing the topological rules, it is observed that three lines do not connect with the main one and another exceeds its limit. By filtering with "**Must Not Have Dangles**" in the "Error Inspector" and selecting the corresponding errors, the "Snap" option is chosen in "**Fix**" applying a tolerance margin of 20 meters. This allows for connecting the unlinked lines and trimming the one that was protruding, resulting in a precise adjustment to the main line, as indicated by the green box in the mentioned figure.

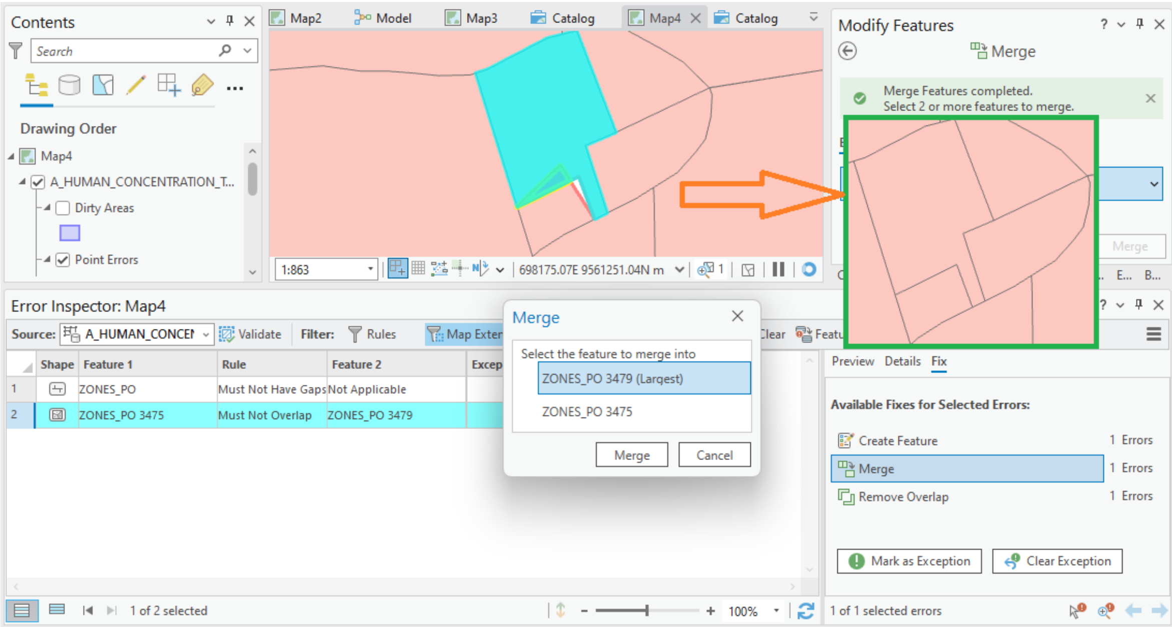
Figure 139. Line adjustment with a "Snap" tolerance margin.



To perform topological corrections in the "ZONES_PO" polygon layer, the corresponding topology is added to the "Map," similar to the process conducted with the line topology. Within the "Error Inspector," two types of errors are identified in the area displayed in Figure 140: an overlap and a gap. To resolve the overlap, the "**Must Not Overlap**" rule is applied and using the "**Merge**" option in the "**Fix**" tab, the overlapped area is combined with the largest polygon, or the receiving polygon is manually selected in the pop-up window. The "Remove Overlap" option creates a gap.

On the other hand, to correct gaps, the "**Must Not Have Gaps**" rule is used and the "**Create Feature**" action to generate a polygon that fills the empty space. This new polygon can be merged with an adjacent one using the "**Merge**" tool available in the "**Edit**" tab within the "**Tools**" group. The modifications resulting from the topological correction are visible after applying these steps, as shown on the right in the green box of Figure 140.

Figure 140. Correction of topological errors in a polygon layer.



16.3. Validation

After making topological corrections, it is advisable to perform more validations to resolve all errors, which can sometimes be a tedious and extensive task, but it is necessary to repeat the process until no errors remain, thereby ensuring the accuracy and reliability of the geographic data.

The topological correction process demonstrated with line and polygon layers illustrates just one facet of the topological capabilities of ArcGIS Pro. It is essential to understand that these corrections are extendable to various layer combinations. For example, rules can be established to ensure that there are no overlaps or gaps between polygons of parcels and green areas. Similarly, a line layer may be required to maintain internal connectivity without overlapping with other layers of different geometries. The possibilities are as varied as the specific contexts and requirements of each project. A GIS analyst's ability to identify and correctly apply the necessary topological rules is vital for effectively solving spatial problems.

17. Frequently Asked Questions

What are the requirements for ArcGIS Pro?

In general, any "Gamer" computer (with a dedicated GPU) performs well with ArcGIS Pro, but there are certain minimum requirements that should be considered for optimal performance:

- **Operating System:** 64-bit Windows 10 or later.
- **Processor:** Minimum 2.4 GHz dual-core with simultaneous multithreading (recommended: quad-core or higher; optimal: 10 cores for best performance).
- **RAM:** Minimum of 8 GB (recommended: 16 GB for large projects, optimal: 32 GB or more for best performance).
- **Graphics Card:** DirectX 12 compatible with at least 4 GB of dedicated memory (discrete GPU recommended for visualization and 3D workflows).
- **Disk Space:** At least 32 GB of free space (recommended: SSD with additional space for temporary cache files).
- **Screen Resolution:** Minimum 1024x768 (recommended: 1080p or higher for better visualization).

Additionally, a high-speed internet connection is recommended to access online resources and keep the software updated.

Which UTM zone should I choose if my study area spans two zones?

In such cases, work with the zone that covers the majority of the study area. Certainly, a geodesist would provide a better, albeit more complex, solution.

If I copy an APRX project, are all the map layers (shapefiles and images) copied as well?

No, the APRX file only manages the paths to the files and display settings, such as legends, scales, and case selections, among other things. Therefore, it is important to note that when creating a new project, it is advisable to store all layers in a single directory to facilitate the mobility of the project, either by moving the directory or copying it to another computer, so that it continues to function correctly.

How can I label a layer?

Labels are a tool that allows for the display of additional or textual information about the elements that make up a layer. For example, you can display the values of a contour layer, the names of hospitals on a point layer, or the names of national parks on a polygon layer.

To add labels to a layer, click on it within the "**Labelling**" tab. Make sure the "**Label**" button is activated, then select the field from which you want to display the label.

What are the main elements that should be included in a map?

The elements to include on a map can vary depending on its purpose and context. For instance, if it is a navigation map for drivers, the main information will be the locations of streets, highways, and nearby points of interest. Generally, it is advisable to include elements such as the title, graphical scale, legend, coordinate grid, and north orientation. Ensure the map is easy to read and understand for its audience. It may also be useful to add inset boxes that provide additional information, such as the name of the institution, authors, and date of creation. If using a map in a text document, adhere to corresponding style guidelines, such as including the map's title above the figure according to APA 7th edition standards.

What is the difference between projection and datum?

In simple terms, a projection is the method used to represent the Earth's curvature on a flat surface, while a datum is a set of parameters used to define the mathematical model of the Earth's shape and its position in space. The choice of datum affects how the Earth's position and shape are measured, while the choice of projection affects how geographic data are represented on a flat map. Both concepts are crucial in cartography and geodesy to ensure accuracy and consistency in the representation of geographic data.

Can I create multiple layouts in ArcGIS Pro?

Yes, it is possible to create multiple layouts in ArcGIS Pro. However, it is important to note that creating many layouts can impact the performance of the project, especially on computers with limited resources. Therefore, it is recommended to create only the necessary layouts for the presentation of the maps and keep them organized to facilitate their editing and updating.

Can I insert both a flat coordinate grid and a geographic coordinate grid?

You can add both a flat coordinate grid and a geographic coordinate grid to the same layout in ArcGIS Pro. To do this, you need to be within a layout and go to the "**Insert**" tab, then select "**Grid > New Grid**". After that, you can add as many coordinate grids as you desire. It is important to keep in mind that including multiple grids can affect the readability and clarity of the final map, so the number and placement of these grids should be carefully considered.

Why don't my data have a reference system?

This issue is very common in the GIS field and typically occurs when the person who created the data did not define the spatial reference system used. Without this information, it is not possible to accurately determine the geographic location of the data. To resolve this issue, it is necessary to define the reference system used and assign it to the data. In shapefiles, the corresponding reference file has the PRJ extension.

Can I import CAD files into ArcGIS?

Yes, it is possible to import CAD files into ArcGIS Pro. To do so, you can use the "**Add Data**" tool and locate the AutoCAD (DWG) file in the corresponding location. Double-clicking on the file will display a list of files representing the different geometries contained in the file. To export a specific layer, you need to access the layer's properties and deactivate all layers except the one you wish to export. Once only the layer of interest is displayed, it can be exported in any vector format via the "**Export Data**" option. It is important to note that while CAD files can be imported, it is advisable to establish an appropriate reference system to ensure the correct spatial location of the imported data.

Can I add new symbols in ArcGIS Pro?

Yes, you can add new symbols in ArcGIS Pro. To do so, go to the "**Insert**" tab and select "Import" from the "Styles" group. From there, you can select style files (**.style**) or individual symbols for point layers (.bmp, .jpg, .png need to be converted to .emf or .svg) and add them to your project via the "**Symbology**" panel by navigating to "**Properties > Layers > Appearance > File...**".

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

Yes, it is possible with the raster calculator. The formula to use is:

s[%]=tan(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 or LibreOffice?

Yes, it is possible to import a shapefile table into both older versions of Excel and Microsoft 365. To do so, open the program and indicate that you wish to open a file. In the file type, select "dBase (*.dbf)".

In LibreOffice, it is also possible to import a shapefile table. However, it is important to note that any modifications to the database associated with a shapefile should be performed in a GIS software because incorrect deletion of any column or row can corrupt the shapefile and render it unusable.

To avoid this issue, it is recommended to copy the DBF file to another directory and make modifications on a separate copy. This way, the original file is not damaged, and you can perform the desired edits without risk.

Can I convert a point shapefile into polygons?

Yes, it is possible to convert a point shapefile into polygons in ArcGIS Pro. However, it is important to note that the results may be inadequate, as a set of points can form multiple different polygons without violating topological rules. One tool that can be used is "**Minimum Bounding Geometry**", which generates a single polygon from a point layer. This tool is located in **Toolboxes > Data Management Tools > Features**, and its use is very intuitive, the most common "Geometry Type" used is "Convex hull".

Why does ArcGIS Pro sometimes close unexpectedly?

In some cases, ArcGIS Pro may close unexpectedly without an apparent reason. In these situations, you can send an error report directly to ESRI's development team. To resolve these issues, it is often advisable to install updates corresponding to each version. These patches can fix many known issues and improve the overall stability of the program. It is important to keep ArcGIS Pro updated to avoid stability problems and ensure access to the latest features and improvements.

Why are some symbols not visible when I export a map to PDF?

Occasionally, when exporting a map in PDF format from ArcGIS Pro, some symbols or special characters may not be displayed correctly. This issue can be due to system settings or software limitations. To resolve this, it is recommended to export the map through the "**Share > Print Map**" option and select a virtual PDF printer instead of exporting directly to PDF from the map view. This method will produce a higher quality PDF file with all symbols and characters visible.

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

If you have accidentally closed the Table of Contents in ArcGIS, do not worry, it is easy to reactivate. Simply go to the "**View**" tab and select "**Contents**" to display the Table of Contents again.

Is it possible to calculate the centroid of a polygon?

Yes, calculating the centroid of a polygon is straightforward using the "**Feature To Point**" tool in ArcGIS Pro. Access it via "**Geoprocessing > Toolboxes > Data Management Tools > Features**" and select the polygon layer for which you want the centroid. Enabling the "**Inside (optional)**" option ensures that the generated points fall within the respective polygon; however, these are not exact centroids in the strictest sense.

Why is there a displacement in the layers of my project?

It is highly likely that the layers have different spatial reference systems. It is also probable that the working scale and inputs were different when the layers were generated.

How can I find out the resolution of a raster?

To determine the resolution of a raster, right-click on the layer and select "**Properties > Source > Raster Information > Cell Size XY**". It is important to note that this field displays two data points, the resolution in X and Y. For example, if it shows 3, 3; it means the resolution in X is three meters and the resolution in Y is three meters. It is uncommon to find raster layers with different resolutions in X and Y, although some GIS, like GRASS, can manage these situations.

Is pixel size the same as cell size?

Yes, pixel size is equivalent to cell size or spatial resolution of a raster. According to ESRI (2016d), a cell should be small enough to capture the necessary detail and large enough to allow for efficient analysis tasks and information storage. As pixel size decreases, the raster's resolution increases, consequently increasing the file size.

How can I copy a shapefile to another computer?

There are several options for copying a shapefile to another computer. One of the simplest is using the "**View > Catalog Pane**" function in ArcGIS Pro, which allows you to copy, cut, and paste GIS layers, including shapefiles. If you prefer to do it through Windows Explorer, it is important to ensure you copy all the files that make up the shapefile layer; that is, all the files that have the same name. For example, if you want to copy the "**road_network.shp**" layer, you must copy all files starting with "**road_network.**" as a shapefile layer consists of several files, between three (.shp, .shx, .dbf) to six.

Can I open an MXD in an earlier version of ArcGIS Pro?

Yes, it is possible to open an MXD file in ArcGIS Pro. However, it's important to note that MXD is a document format used in earlier versions of ArcGIS Desktop, whereas ArcGIS Pro uses a new project format called "**.aprx**". To open an MXD in ArcGIS Pro, it can be imported into a compatible format using the "**Insert > Import Map**" option from the corresponding tab.

Once imported, the project can be opened, and all modifications can be performed in ArcGIS Pro. However, it's important to mention that there are some differences in the presentation and functionality of layers and tools between the old versions and ArcGIS Pro.

Additionally, any changes made in the ArcGIS Pro project will not be reflected in the original MXD file, as you will be working with a new APRX file.

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