DC-36 - Historical Maps in GIS

The use of historical maps in coordination with GIS aids scholars who are approaching a geographical study in which an historical approach is required or is interested in the geographical relationships between different historical representations of the landscape in cartographic document. Historical maps allow the comparison of spatial relationships of past phenomena and their evolution over time and permit both qualitative and quantitative diachronic analysis. In this chapter, an explanation of the use of historical maps in GIS for the study of landscape and environment is offered. After a short theoretical introduction on the meaning of the term "historical map," the reader will find the key steps in using historic maps in a GIS, a brief overview on the challenges in interpretation of historical maps, and some example applications.

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Topic Description:

1. Introduction

1.1 Value of Historical Maps

Scholars interested in historical approaches to geographical studies, or interested in the geographical relationships between different historical representations of the landscape in cartographic documents, will often use historical maps within a GIS-based approach. Such use of historical maps allows the comparison of spatial relationships of past phenomena and their evolution over time and permits both qualitative and quantitative diachronic analysis. This is possible because in a GIS, the spatial information (coordinates) are incorporated in the data and are paired with the attributes of the (historical) features. Phenomena such as erosion, changes in land use and in the road network, changes in borders and in coastlines, evolution of wartime fronts and battles, variations of toponyms, or deforestation-reforestation, can all be analyzed through the use of historic general or thematic maps in GIS. The use of historic maps in GIS allows for multi-scalar, multilayer and analytical analysis (e.g. overlapping of more maps of the same area for their quantitative comparison). The GIS approach to historical analysis permits a greater depth of analysis than the scholar can extract from the flat maps themselves. Moreover, the use of a GIS allows data from historic maps to be visualized using advanced techniques such as virtual landscapes, digital rendering and animations (Gregory and Healey, 2007). As Rumsey and Williams (2002) remark, scholars doing historical GIS by the incorporation of information from historical maps in stimulate new interest in these data sources "that have much to offer historical scholarship and teaching."

1.2 When is a map a "historical map"?

occurred in the represented area since the map was created. Theoretically, a map is already "dated" (and thus, "historic") when it emerges from the editing process because some changes may have occurred in the environment since the survey phase, even if minor. For example, urban areas usually change at different rates than non-urbanized areas, such as forests.

Sandy coastlines often change faster than mountain ridges. It is important to take into consideration that both natural and anthropogenic processes result in change (even very quickly!). Geomorphological processes such as meander cut offs, landslides, and volcano eruptions can change the shape of the land faster than traditional data collection processes occur, even with the most modern cartographic techniques.

Key moments in the history of cartography resulted in major advances in the quality of spatial representation. These steps can be useful to identify a map as historic and to determine in which major category the map falls. These important steps are:

1. The beginning of a more systematic use of map projections (16th century). The origin of map projections can be dated back to the ancient Greeks (Snyder 1993) and the peak of the cartographic knowledge in antiquity is associated with Ptolemy (2nd century AD). However, the period of great geographic explorations was a strong push factor for the development of cartography in the Renaissance. Accurate and reliable maps based on map projections, such as Mercator's, were produced and used for maritime and trade purposes, state government, and military scopes.
2. A more systematic use of standardized symbols (16th century). Ancient examples of pseudo standardized symbols in maps can be found in the Tabula Peutingeriana or even in the Medieval *mappamundi.* In the 16th century, with the European cartographical control on newly discovered lands, it is possible to find the beginning of a systematic use of symbols (e.g. for towns, church towers, etc.).
3. The use of remote sensing in map production (1920s-1930s). To augment or replace field surveys (around 1850 - in 1858), the Italian geodesist and optical engineer Paolo Ignazio Pietro Porro was the first to apply a panoramic camera to the process of land surveying (Birdseye, 1940). However, aerial photos were not widely incorporated in map production until after the First World War.

1.3 Types of Historical Maps

Historical maps can be categorized according to different classifications (material, scale, purpose, etc.). In this section four major types of historical maps are briefly described according to their main purpose.

Sketches and plans. The scales most often used in sketches and plans are 1:500, 1:1000, 1:2000, 1:2500 and 1:5000. Detailed engineering drawings such as building plans use scales even larger (e.g. 1:100 or 1:10). The most common features on this type of map are buildings and engineering structures (such as harbors, bridges, pumping stations, etc.), canals and railways. These sketches or plans may have been produced as part of a survey for determining the most suitable route of a railway or a canal, to aid construction and maintenance of the structure, to accompany purchase orders or, in the case of military plans, to provide useful information to enable troop or ship movements, or to illustrate strategical points in particular campaigns.

Cadastral maps. Cadastral maps show the legal definition of a land parcel and its ownership. Cadastral maps may also include geographical features as buildings, railroads, churches, cemeteries, schools, and natural features such as rivers, ridges, ponds, and quality of the soil. Their scale usually varies between 1:1,000 and 1:7,000. Cadastral maps often include written registers that describe the use of the soil (Figure 1) and the owner.

Figure 1. Historical cadastral maps often included written registers that describe the use of the soil and the owner. Source: author.

Exploration surveys maps. These maps are the product of survey activities during exploration campaigns, some of which are very well known. All of these journeys resulted in priceless cartographic publications.

- Between 1804 and 1806, Meriwether Lewis and William Clark led the first American expedition to cross the western portion of the United States (from Saint Louis to the Pacific Coast and the current state of Oregon) Allen (1972). Their exploratory mission was to document and map geology, geography, flora and fauna and native people in the western part of the United States after the Louisiana Purchase (1802) and to discover a possible water route to the Pacific Ocean.
- The John Wesley Powell geographic expedition of 1869 was the first cartographic and scientific investigation down the Green and Colorado Rivers through the Grand Canyon, in the southwestern United States. It filled the last "great blank space" on the map of the continental United States with information such as productivity, population, and natural resources (e.g. water, minerals and pastures) (Kirsch,2002).
- In the early 1800s, Matthew Flinders and Nicholas Baudin led expeditions (British and French, respectively) for the survey of the south Australian coast, resulting in accurate maps of the coast morphology and information about the associated environment.

Region or state-wide mapping projects. National, regional, or state-wide mapping projects typically use a systematic scale, definition, and symbology for the maps. The resulting maps were often organized in atlases (e.g. the Robert Mill's Atlas for the State of South Carolina) or map series. The scale typically varies between 1:10,000 and 1:250,000. Some example are the Italian IGM series at 1:25,000, 1:50,000 and 1:100,000, the American USGS quads and the French IGN series at 1:25,000, 1:75,000 and 1:100,000.

2. Acquisition of Historical Maps

Sources of historic maps are diverse and dynamic, and the maps themselves are often influenced by copyright. Maps can be stored in private or public archives or can be available in a digital version in an online repository (e.g. the Europeana, or the more local Phaidra), maps aggregators (e.g. Old Map Online), digital libraries (e.g. The Internet Archive, The Library of Congress, BNF – Gallica, the New York Public Library Digital Gallery and the University of Wisconsin Digital Collections), or be the collection of an institute (such as the topographical collection of the US Geological Survey).

In archives that still collect only hard-copies of maps, the search for a particular area can be difficult and time consuming unless the precise location (state, province or county, coordinates) or the position in the tile index of a particular map series is known. Sometimes, hard-copies of maps are organized by other attributes than the location. For example it is particularly useful to know the author, its production year, and/or the publisher of the map document. Searches in digital archives are made easier by having metadata related to the maps be organized and able to be queried through a database.

Universities, historical societies, local museums, and other nonprofits typically have only a portion of their map collection digitized or indexed online. If the user is interested in studying a particular area, visiting repositories of maps in the specific study area can be very helpful to locate documents that would otherwise never be found online. In most cases, these digital maps are not georeferenced (i.e., complete with embedded geographic coordinates that will allow the digital map to be placed within a GIS as a layer that aligns correctly with others where they fall on the surface of the earth). Some historic maps are particularly challenging to georeference when little is known about its projection or datum

The most common techniques for converting a hard-copy map to a digital form are to use a scanner (flat for small dimensions, drum scanner typically for larger formats) or photograph the document (specific techniques can minimize the distortions introduced when using cameras).

3. Symbols and Interpretation

It is not the purpose of this chapter to focus on the interpretation of historic maps, but it seems fundamental to introduce the challenges related to the use of the symbology. The discussion on the use of symbols in historical maps is a large topic, especially because, for a long time, there were no standards and the use of different pictorial signs to indicate geographical features was subjective by the cartographer (particularly so for maps produced prior to the twentieth century). Elementary *de facto* standards have been used since the antiquity. We need only to consider the use of blue color for rivers and the sea and hill profiles as a form of relief depiction.

Generally, the interpretation of symbols and signs in an historic map can vary depending on these four situations:

1. The map provides a readable legend. In this case the interpretation is facilitated even if there are still difficulties from different languages or some symbols are missing a description.
2. The map provides a legend but, for different reasons it is not readable (it has been damaged or is not complete). Sometimes it is possible to easily find another copy (even digital!) of the same map or map from the same series that provides a readable legend.
3. The map does not provide a legend. In this case there may be the possibility that symbols and signs used in the map are described in a separate written document: in this case, a further archival search is required to find the explanatory document.
4. The map does not provide a legend and no external document exists. The only solution is rely on being able to interpret the symbols and signs directly, possibly taking advantage by comparing other maps of the same area or era.

Most importantly, being able to interpret the symbology makes the map as useful as it can be for a given project. In the example of Figure 2, the presence of a specific symbol for the mills (a little circle with short rays around) could be useful, for example, in a project aimed to census all the mills in a specific district of a state. The knowledge and the interpretation of symbols are also important as the symbols could provide control points for the georeferencing process (for example, the location of a mill, a street intersection, or a bastion).

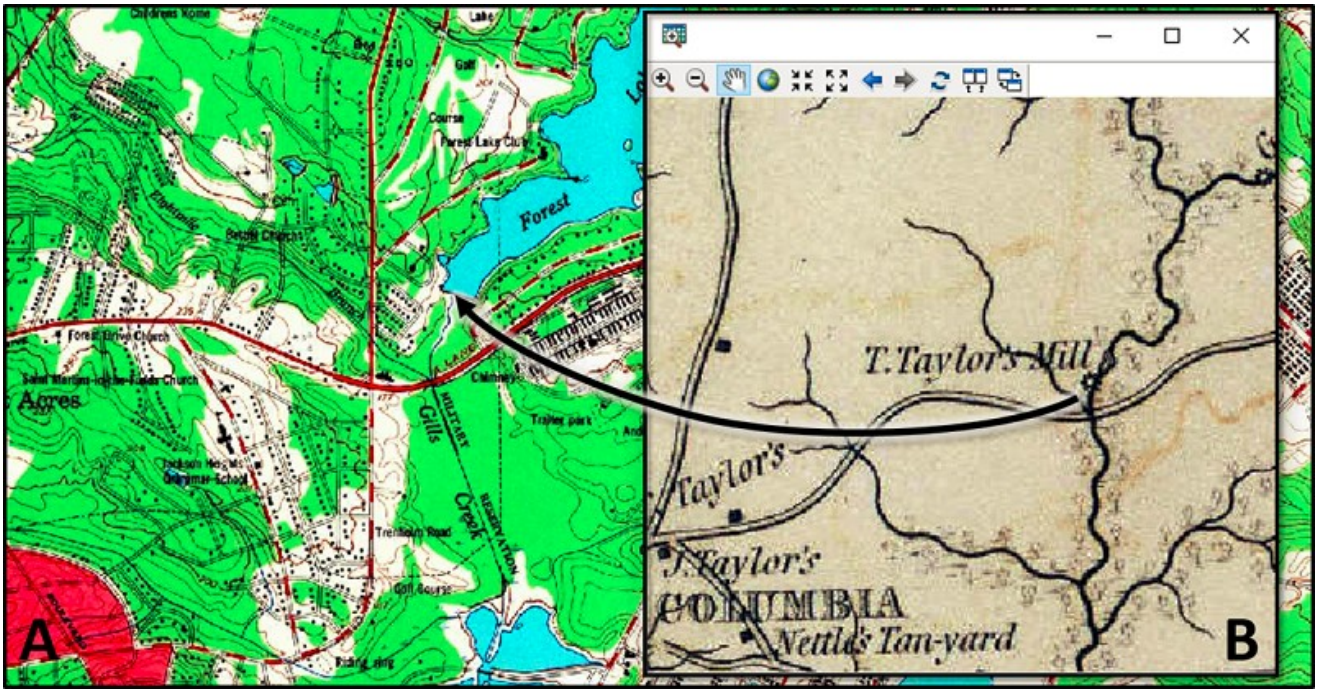

Figure 2. The presence of a specific symbol for the mills (little circle with short rays around) could be useful to census all the mills in a specific district of a state. Source: author.

Whenever possible, increase confidence in the historical data by validating it with additional sources. For example, other sources of historical information such as historical photos, newspapers, diaries, and interviews should support the geohistorical study.

4. Georeferencing an Historical Map

Digital historical maps are often raster data formats or digital pictures of an original map that are not yet georeferenced (cannot yet be placed correctly where they would fall on the surface of the earth). To be of use within a GIS, the georeferencing process must be completed and executed as accurately and precisely as possible, a process that may take several iterative steps and decisions to ensure (Brovelli et al. 2012). Georeferencing consists of specifying the coordinates of "control" points of the raster dataset in the scanned document space and relating these locations to the same ones in known geographic space. To georeference a raster means to associate points from the raster to a digital base that is already georeferenced (Figure 3). The process may involve shifting, rotating, scaling, skewing, and in some cases warping, rubber sheeting, or orthorectifying the data.

The main steps in the georeferencing process are:

1. Ensure that a GIS reference dataset is available. If at all possible, the reference dataset should be at the same or similar of the historical map. It may be possible to use a basemap provided within some GISs if no other already-georeferenced data set is available. Temporal attributes of the reference dataset are important as one must be able to discern locations of objects in the reference data layer that are also visible in the historic map (described further below).
2. Conduct research on the historical map. Make every effort to identify its projection and coordinate / datum system. Identify other reference maps that may be useful to find other landmarks.
3. Identify and select reference points to use as links to connect the two layers (the historic map with the already-georeferenced dataset or image). Types of reference points are described below:

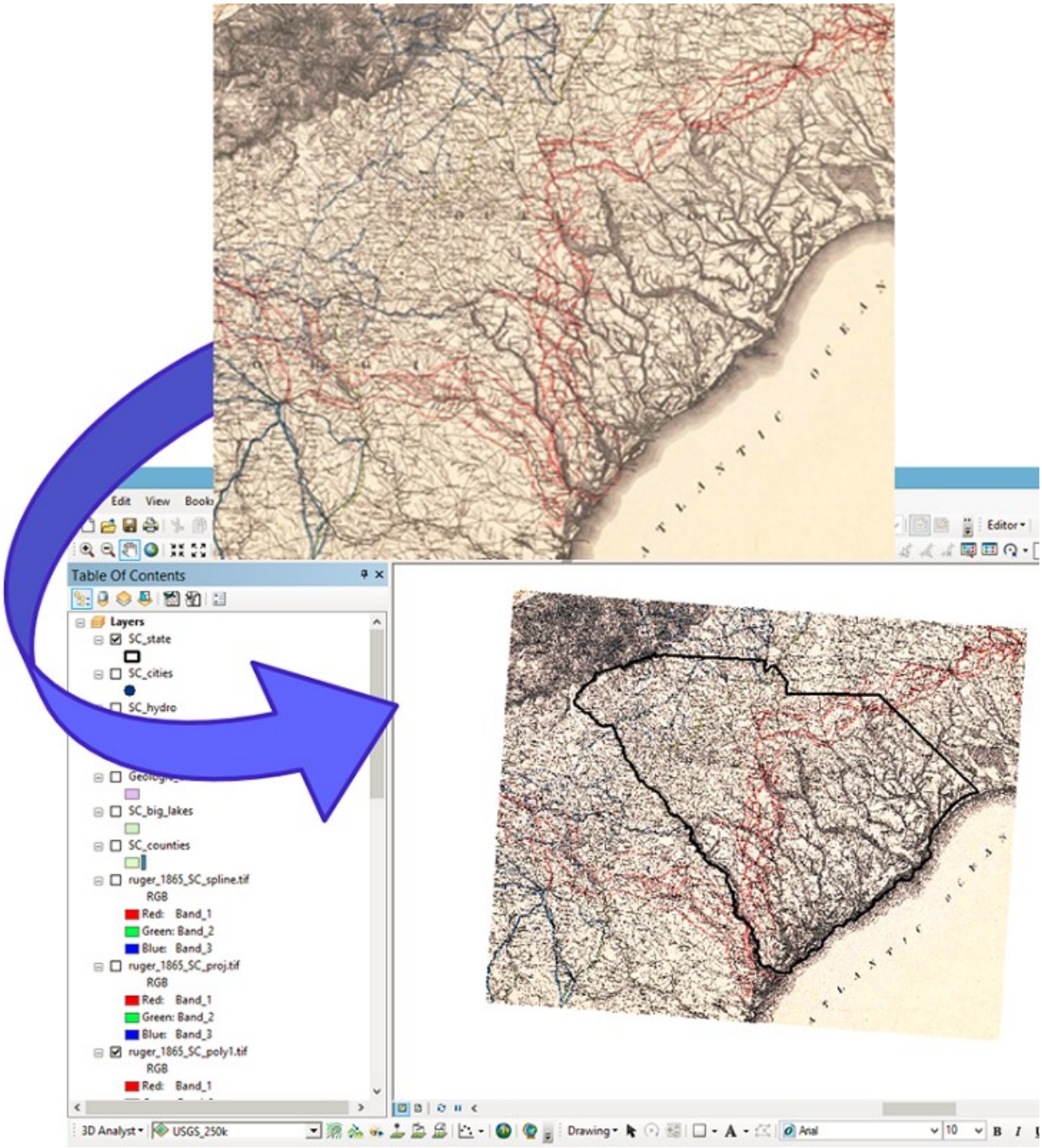

Figure 3. The georeferencing process to place a digital image into a GIS. Source: author.

- **Coordinates on the borders of a map:** Points of reference can be the coordinates listed at the corners of the map (or those reported on the edges, see an example in Figure 4). It is important to pay attention to the horizontal datum used in the historic map (for example, the prime meridian may have changed).

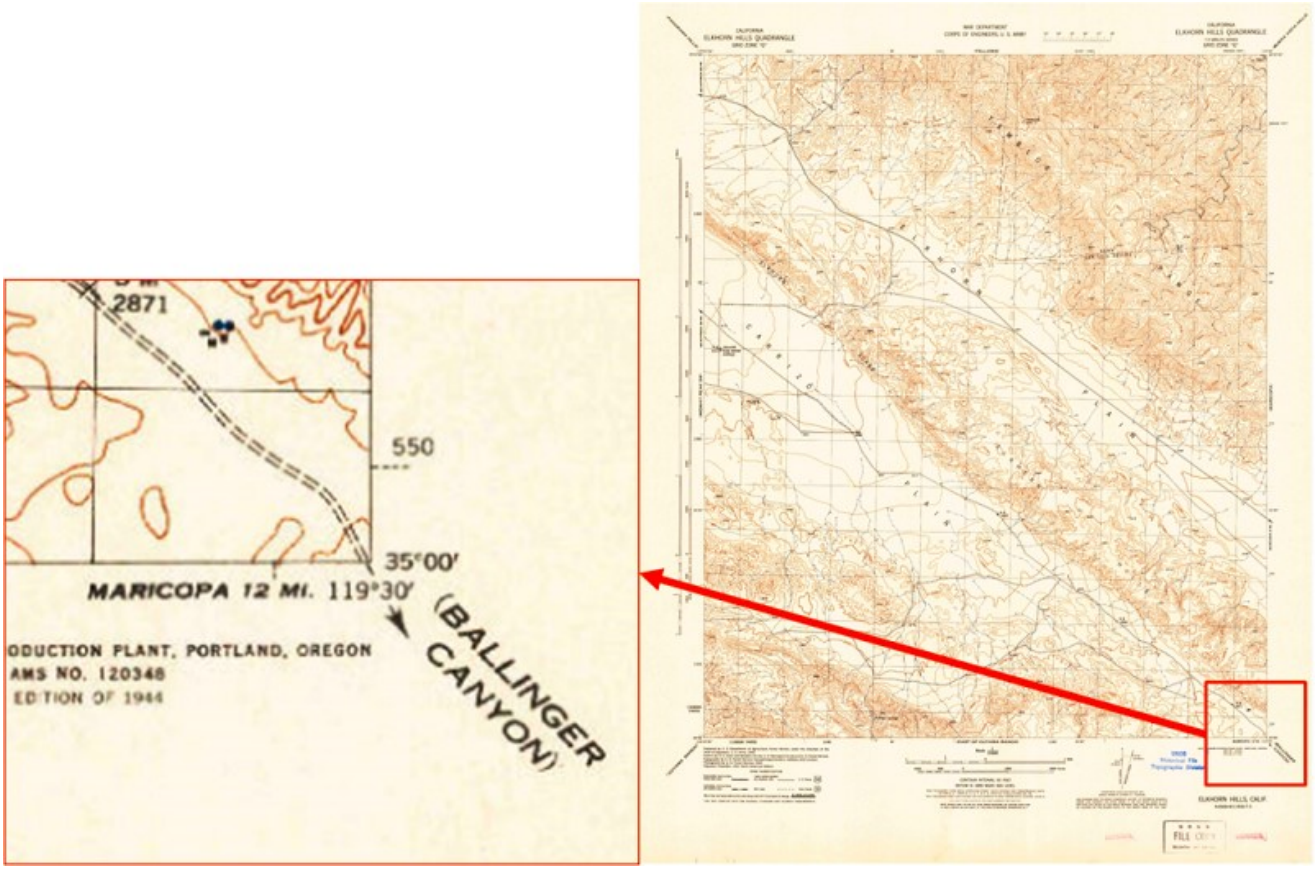

Figure 4. Coordinates used in the georeferencing process. Source: author.

Typically, the GIS software uses a plane coordinate system (e.g. map projection) for georeferencing so, coordinate systems that use latitude and longitude are not advisable. Another interesting tip is to use multiple maps during the georeferencing process to find multiple control points. In this approach, the most recent map should be georeferenced first and then, working backward over time, use each georeferenced map as a control for the next earlier (older) map of the same area. The number of control points needed depends on the transformation algorithms the user would like to apply (e.g. 4 for the first order polynomial).

- **Stable features:** Useful links may be cultural features or other reference points of the area that are unlikely to have varied over time such as intersections of roads and railways, bridges, buildings, or monuments. Items such as these are better than natural elements (coastlines, rivers, lakes, etc.) because these natural features can vary considerably over time. It is useful to check the dates of objects used as a link to be sure they are the same ones in the reference map.
- **Traditional Survey or Global Navigation Satellite System (GNSS):** this technique is used for the collection of control points in field work on features that are believed to be stable and unchanged since the map was created. Such examples are the corners of buildings, road crossings, monuments, or remains of archeological sites. This technique is useful when there are no reference data or there are no coordinates on the map, and it is used primarily for city maps or other large scale maps. It is not suitable for large regional maps as such an approach would be very laborious and expensive.

After defining the mathematical relationships between the historical map and the reference basemap it is necessary to create a new raster dataset (now georeferenced) through a "rectification" operation that creates a georeferenced copy of the original raster. Once completed, the new raster is ready to be used in subsequent GIS geospatial data collection or cartographic mapping.

5. Digitization of Historical Features

Once a historical map has been georeferenced and is a raster data layer within a GIS, it becomes a source on its own for new vector data, such as historical features of interest, to be derived. Features such as historical buildings, rivers, or land cover areas can be digitized in vector form (as points, lines or polygons) and stored within vector formats (such as a shapefile or a feature class within a geodatabase). The coordinates of the features will be implicitly incorporated once the feature is drawn since using a GIS requires working within a specified coordinate system. The creation of an attribute table associated with the feature class permits the integration of the spatial component with its description in terms of attributes (columns/fields). Once features from an historical map are digitized, they can be analyzed and compared with data from other historical maps or modern data (see the example in Figure 5).

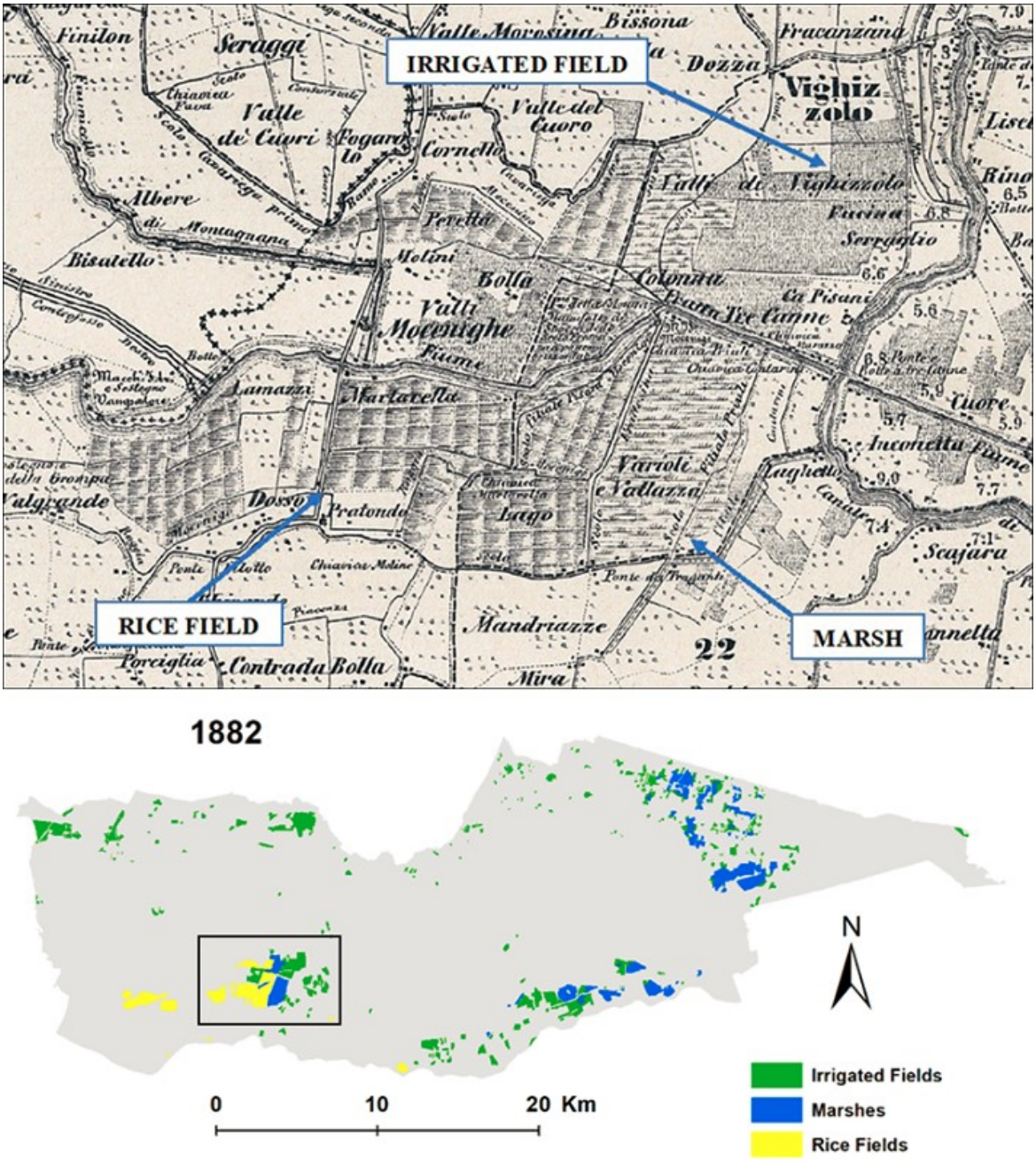

Figure 5. Example of how vector data can be digitized from georeferenced maps. Source: author.

6. Examples of Applications

These published case studies illustrate of the use of historic maps in a GIS.

6.1 Environmental Changes

Geomorphic Changes from Hydraulic Mining. James et al. (2009) examined geomorphological changes in the Feather and Yuba Rivers in the Sierra Nevada foothills (California) resulting from the use of hydraulic gold mining in the mountains in the late nineteenth century (1853-1884). For this study, historic maps were analyzed with other sources of data (such as field surveys, aerial photos, LiDAR, etc.) in a geohistorical approach. In particular, after a visual inspection of many maps, the authors georeferenced key maps using a second-order polynomial transformation. The digitization of channel boundaries and contour lines from the historic maps permitted the quantitative comparison to modern channel positions and topographic change caused by enormous fluxes in sediment. The authors suggested this approach was a "new era of historical cartometrics."

6.2 Military Geography

Sherman March Through South Carolina. Historical maps are particularly useful within studies of military history. The research by Piovan et al. (2017) considered paths across the wetlands of South Carolina made by the five union armies under General Sherman's command during the American Civil War (1861-65). The goal of this research was to provide

analytical data on the relationship between the armies' paths and the different types of wetland across the state. In particular, for the reconstruction of the paths, the historic map of Edward Ruger (1865) was used. In Ruger's map, the paths of the armies are depicted as different lines. After georeferencing the map (using a spline transformation) and digitizing the lines, the intersection between the armies' paths and the wetlands was conducted. The results show how the armies experienced, on average, about 20% of their journey on wetlands, with a preponderance for swamps with forests and shrubs. The cavalry crossed the least amount of wetlands as the cavalry trekked the farthest inland from the coastal plain, characterized by numerous wetlands. In this study, the USGS historic maps were also used for the construction of a database of the historic wetlands during the era of the Civil War.

The Telling of the Gettysburg Story. Historic maps have been used within online "story maps" in which geospatial data and maps are combined with text and multimedia files (such as photos, video and audio) that together illustrate a particular theme or a sequence of events. An example is the story map titled *"*Decisive Moments in the Battle of Gettysburg" created by Anne Kelly Knowles in collaboration with Esri and International Mapping (Knowles, 2013). Knowles used a georeferenced historic map in combination with a present-day topographic map to show the movements of the troops in the Battle of Gettysburg over the three-day-long conflict.

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Learning Objectives:

- Explain the advantages in using historical maps in a GIS.
- Plan the acquisition of historical maps both online and in archives, libraries and other repositories.
- Obtain historical maps in digital form and prepare them for georeferencing.
- Describe the georeferencing process including the techniques and transformations necessary for the use of historical maps
- Demonstrate the georeferencing process with a digital historical map.
- Explain, with examples of case studies, how diachronic and multilayer analysis in GIS using historical maps can be useful in a geo-historical study of the landscape.

Instructional Assessment Questions:

1. Discuss the definition of an "historical" map.
2. What are the main four georeferencing techniques?
3. What are the best control points to use in georeferencing an historical map?
4. Why use historical maps in GIS?
5. Cite at least one of the three exploration survey missions that brought maps of lands explored in the 19th century.

6. Describe possible issues in the interpretation of symbols from a historical map.
7. List at least 3 examples of the use of historical maps in GIS for the study of the landscape changes.

Related Topics:

- Vector data extraction

Keywords:

- georeferencing
- history
- humanities

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