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An HGIS Approach to Land-Use/Land-Cover Change in the Blanice Watershed, Czech Republic

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Chapter 1: Introduction

During the High Middle Ages, European settlers in the bohemian countryside of modern-day Czech Republic established a vast network of long narrow fields extending out from individual villages. These uniquely clustered fields still protrude from the rolling hills of the landscape, largely thanks to the structure provided by the rows of trees and scrubs that border each strip of field. These hedgerows have stabilized the land surface throughout centuries of human activity, including development and agriculture. The original construction of hedgerow-defined fields was practical in purpose, used to distinguish field ownership, as a source for wood, and to accommodate the heavy cultivation equipment of the time. However, they have also provided unintentional ecological, geomorphological, and cultural value. Researchers across disciplines and locations are interested in understanding these hedgerow features as a record of natural and human influences on the land since they were first established circa 1300 CE (Bičík et al. 2015, Houfková et al. 2015, Sklenicka et al. 2009). Understanding past land management and conditions necessitates a reconstruction of the landscape throughout history, and there are a number of well-known strategies for interpolating historical changes in land-use and land-cover (LULC). Remote sensing has been a popular tool for LULC research, using satellite imagery and other sensor types to collect land surface data over larger spatial extents quickly. However, remotely sensed data and technology only date back to 1972 when the first land satellite was launched, and are therefore of little use for historical LULC analysis prior to the 1970s (Yang et al. 2014, Kuemmerle et al. 2013). LULC researchers tend to use other methods, including reconstruction based on natural archives such as tree rings and sediment records, reconstruction based on historical geographic data, and model-based reconstruction methods (Yang et al. 2014).

This thesis examines the use of historical geographic information science and systems (HGIS) as a method of historical LULC reconstruction. HGIS is a geography subfield that provides methods and tools to manipulate, analyze, and display data of past geographies (Knowles 2005, Gregory and Ell 2007). The Blanice Watershed in South Bohemia, Czech Republic is an ideal study area for historical LULC analysis of hedgerow-defined field patterns because this region has not been subjected to the same development and growth as other, urbanized areas of the Czech Republic (Figure 1-1). Many villages and surrounding pastures within the Blanice Watershed are well-preserved, providing stable and enduring historic structures and landscape patterns since the mid-1600s and earlier (Houfková et al. 2015, Molnárová, 2008a). Linking the existence of specific LULC features throughout historical geographic data from different dates can provide a comparison of the landscape surrounding these features. This study evaluates the information provided by historical maps for studying past LULC as a reconstruction and change analysis of the hedgerow-defined landscape within the Blanice Watershed. The main purpose of this thesis is an investigation of epistemological considerations of HGIS in terms of contributions to LULC change analysis research in the study area. This purpose is addressed through two goals: to develop methods for characterizing the spatiotemporal variation of hedgerow features in the Blanice Watershed, and to consider the sources of error and nature of uncertainty that is introduced in these methods of HGIS analysis.

Figure 1-1 Location of the Blanice Watershed study area within the South Bohemian Region, Czech Republic.

The continuance of hedgerow-lined fields in the study area over roughly the last 700 years allows for observable LULC change by comparing variation within the land containing these fields at different times. Changes in LULC reflect temporal variation of hedgerow management, expansion, and disappearance within individual villages. Driven by a number of socioeconomic, political, and environmental factors, this variation is often manifested in periodic trends of agricultural village abandonment and subsequent afforestation followed by agricultural intensification and consequent hedgerow expansion (Sklenicka et al. 2009, Molnárová, 2008a).

Many of the sociopolitical factors that led to LULC changes in the study area, such as war and authoritarian regimes, are also associated with large government-ordered mapping projects. These large projects were conducted under different monarchies overtime to map out the bohemian territory under their rule, and often to identify key resources for the military such as water, terrain, travel routes, and stable structures (Molnárová, 2008c, Zimova, Pestak, and Veverka 2006). This project utilizes map sheets from the following historical mappings for LULC change analysis: the Original Stable Cadastre (1837), the Maps of Cultivation of the Stable Cadastre (1837), toposections of the Third Military Mapping (1924), the State Map Series (1952-1953), and the Topographic Maps of the General Staff of the Czechoslovak Army (1953). The research in this project conducts an analysis for one cadastral territory within the Blanice Watershed, called Křišťanovice, because it is an ideal study area for the development of HGIS methods for historical LULC changes. This is because Křišťanovice contains a well-maintained cluster of hedgerow-defined fields but also exhibits an area of afforestation, it is ideally situated for in-situ data collection since is located upslope of a floodplain sediment sink along the Blanice river, and also because the village is covered by the extent of each historical map project used. Collecting information on historical hedgerow LULC for one village in the study area allows me to develop an appropriate methodology for the collection and analysis of LULC data from historical maps in the Czech countryside. Framing research within a HGIS context improves the accuracy of such methods by acknowledging and minimizing the limitations of using historical maps as a data source.

In the next chapter, I have summarized the literature relevant to the technical, conceptual, and geographical understanding of this research project. This includes literature on hedgerows and on the specific land-use history in the study area for better understanding of the importance of this study in terms of agricultural and sedimentological significance, and ecological and cultural function of these features in the current and past South Bohemian landscape. HGIS is viewed as a relatively new and growing subfield of geography scholarship, so I have also included a review of literature regarding the use of HGIS in practice and as a conceptual basis of analysis to give context to my use of HGIS in the Blanice Watershed, Czech Republic. Following the literature review is a chapter on the purpose of this research. In this chapter I introduce the general objective of my project in terms of both historical geographic data collection and analysis, and HGIS methodological development. I also describe the specific questions my research addresses which were factored into my analysis and results. In the methods chapter, I first outline the epistemological considerations I consider an important prelude to the rest of my methods. I then detail the steps of my collection, transformation, classification, and visualization of historic and recent data, as well as my methods of qualitative and quantitative assessment of my collected spatial and nonspatial geographic data. The results of these assessments are included in chapter five, along with a description of the products I have created through my research. Products include a workflow document for continued research, a geodatabase for storage of historical geographic information specific to this project, and the historical LULC data and maps for the village of Křišťanovice, Czech Republic. In the last section of this report, I comment on the value of each specific historical map as a data source, identifying the best use and limitations of each in terms of historical LULC analysis in the study area. I conclude that while the methods used in this research are tedious, historical maps such as the Original Stable Cadastre provide valuable information for historical LULC classification. This kind of information includes locational and temporal characterization of landscape features that is not possible through methods of reconstruction or for temporal scales predating the availability of accurate remotely sensed information. Thus, this study provides a methodological and epistemological investigation of applying an HGIS framework to analyze historical maps for information about landscape change, which can fill temporal information gaps from existing remote sensing methods and validate or improve upon methods of historical landscape reconstruction from natural records.

Chapter 2: Literature Review

This chapter presents a synthesis of literature relevant to this study which allows me to give context and understanding to my research questions. Each subsection of the literature review addresses an important component of my research, for which I discuss intellectual development, identify existing research, summarize conflicting scholarly opinions, and then distinguish my own views and techniques as they differentiate this project. Situating my methodology and theoretical perspective for this project within the field of HGIS helps validate my methods and results, and gives context to its contribution to HGIS scholarship. In the first two sections, I define hedgerow features and provide an overview of the land-use history of the Blanice Watershed and the Czech Republic, where appropriate. These discussions are important in understanding the contributions of my project to current LULC research in the study area. They also serve to explain the relationship between land-use patterns and specific cultural and administrative influences, which is important when interpreting historical geographic information and historical relationships between people and their environments. The third section covers important aspects of HGIS as a developing subfield of geography, including debates about the merit and identity of HGIS scholarship. By the end of this section, the theoretical and methodological research paradigm I have defined gives context to the rest of the research presented in this thesis. In the final section of the literature review, I have summarized the successes and development of similar research using historical maps. The accuracy and spatial analysis techniques used in these studies have led me to develop methods to minimize errors during my data collection, recognize limitations of my sources, and best analyze my results.

2.1 Hedgerow Landscape Patterns

Connecting HGIS analyses to the drivers of land-use change in the Czech Republic since the Late Middle Ages demands an understanding of the nuances in the geography of this region. The Czech Republic consists of two principle areas, Bohemia and Moravia, located in the western and eastern half of the country, respectively. Bohemia is drained by the Labe and Vltava rivers, and the landscape is a vast hilly region surrounded by mountains. For this project, research has been conducted for a village within the Blanice watershed. This watershed lies at the headwaters of the Vltava River in southern Bohemia, in the foothills of the Šumava Mountains (Molnárová, 2008a). Structured patterns of landscape features stand out in aerial imagery of the modern-day countryside of this region (Figure 2-1). These features consist of networks of long narrow fields bordered by rows of trees or shrubs. Occasionally, fields within the study area are bordered by a structure made of stones or brick, but these serve the same purpose of trees in segmenting individual fields and can even have a mitigating influence on surface runoff and erosion (Kovář, Vaššová, and Hrabaliková 2011, Forman and Baudry 1984). Collectively these features located in the margins between fields are called hedgerows, a term familiar to landscape ecologists for their role in landscape connectivity and heterogeneity (Forman and Baudry 1984, Molnárová 2008c, Molnárová et al. 2008, Kadlecová et al. 2012). Hydrologically, the orientation of hedgerows can greatly affect surface runoff; a hedgerow feature oriented perpendicular to the slope on a hill, for example, can reduce runoff downslope of the hedgerow and improve infiltration (Molnárová 2008c, Kovář, Vaššová, and Hrabaliková 2011). Ecologically, hedgerows

Figure 2-1 Aerial view of the hedgerow clusters in the landscape within the study area.

can also function as a biological corridor for the passage or spread of animals and plants across the landscape. Other landscape influences common to hedgerows include evapotranspiration, sediment transport, and even microclimate fluxes such as windspeed (Molnárová et al. 2008, Kadlecová et al. 2012, Forman and Baudry 1984). While these ecological and geophysical roles are important they are difficult to measure. Spatiotemporal characterization of hedgerow features can help to better assess the impact hedgerows have on their environment when used in conjunction with analysis of in-situ ecological and geomorphological data.

Another value of hedgerows on the landscape involves regional cultural importance. In the study region, this unique landscape pattern is a relic of historical Czech plužinas. The word plužina once meant the agricultural land supporting one medieval village, but as the land itself endured repeated instances of collectivization, redistribution and division, and abandonment, the definition has also changed (Molnárová, 2008a, Molnárová 2008c, Skokanová et al. 2012). Because the word plužina has not universally assimilated into the present terminology of landscape ecology, in this paper these groupings of fields are referred to as hedgerows, landscape structures, field patterns, or landscape forms. A relatively small number of researchers have publications about the aesthetic, cultural, and ecological value of Czech hedgerows, though many studies exist on the value and function of hedgerows in other parts of the world. These studies in landscape ecology collectively recognize hedgerows to be common agents of increasing crop yields, wood harvesting, bounding grazing livestock, reducing erosion, and adding aesthetic value to a landscape (Molnárová 2008a, Baudry, Bunce, and Burel 2000). In a study published in 2015, a combination of radiocarbon dating, historical documents, and paleorecord techniques were used to finally confirm what others had inferred; this landscape structure has existed since the early 14th century (Houfková et al. 2015). Preliminary field and stratigraphic studies indicate that these features have reduced soil erosion and downstream sediment transport and as such, potentially represent a method of sustainable land management over a time period of nearly seven centuries (Daniels et al. 2018). The role of these field patterns in erosion mitigation over the last 700 years is interesting, considering it is not a reflection of their original purpose. The narrow strip fields were established for practical considerations of crop rotation and land ownership. As medieval agricultural relicts, Czech hedgerows offer the unique opportunity to study a series of features with influence on erosion rates over the course of decades to centuries.

While evidence of hedgerow use since the end of the Middle Ages and sediment transport research in the region give a decent understanding of the importance of these landscape features, the changes in agricultural practices of the region throughout history provide an opportunity to characterize how individual hedgerow networks have influenced the transportation and properties of the soil (Houfková et al. 2015, Matys Grygar et al. 2011, Daniels et al. 2018). It is important to remember that studies retrospectively gathering information about the centennial existence of this field patterns are hypothetical, and historical records and archeological methods are the only way to say with certainty how each network of hedgerows was used since the time of origin (Molnárová, 2008a). Considering the complex relationships between political, technological, and social trends and South Bohemian land management allows for a comprehensive characterization of hedgerow networks. This characterization can inform interpretations of data gathered from field methods. In the following section, I provide a summary of these relationships throughout European history since the Middle Ages. Integrating the historical land-use and the HGIS data within the study area will help me better develop and explain methods utilizing historical maps to address the gaps in spatiotemporal hedgerow network characterization.

2.2 South Bohemian Land-use History

The long narrow hedgerow-defined medieval field patterns under investigation reflect a long history of social and political changes. These changes began with a phase of colonization referred to as the Outer colonization during the 13th and 14th centuries, during which the foothills lowland area was systematically and rapidly colonized into a network of relatively dense settlements designed by German colonists. During this time the long narrow field patterns were established to increase crop yield and designed to minimize the number of times heavy machinery had to be turned. The hedgerows were born out of a need to mark clear boundaries between fields (Matys Grygar et al. 2011, Molnárová, 2008a, 2008b, Houfková et al., 2015).

Table 2-1 summarizes other historical events and movements that had a direct impact on the agricultural management practices in the Bohemian countryside. In general, periods of village abandonment and agricultural extensification led to regrowth of trees in the boundaries between and within field areas, termed afforestation. In periods of population increase or agricultural intensification, hedgerows were either well maintained and expanded, or the trees were removed for field rearrangement and wood harvesting. In rare cases, original medieval landscape structures were maintained, which is village specific. The greatest influence on afforestation occurred during the post-WWII collectivization period, when the German colonists were expelled from the country, and many Bohemian villages were abandoned. In some areas, these abandoned fields were expanded into larger farmed areas without hedgerows. Within the Blanice Watershed however, many of the villages were abandoned, leaving the hedgerows to grow into the fields. Since 1989 and the re-establishment of democracy in the Czech Republic, different trends threaten this fraction of hedgerow networks that have endured the tumultuous

Event	Approximate Date	Effect on Population	Effect on Agriculture
Plague outbreak and Hussite War	15th Century	Population decrease (30%)	Afforestation of abandoned fields, agricultural extensification
The Renaissance Period	1500 – 1620	Stable	Pluzina expansion, forest clearing
Thirty Years' War	1620 – 1648	Population decrease (43%)	Large-scale agricultural abandonment, afforestation
Baroque Period	1650 – 1780	Stable	Ordered crop system, pluzina redevelopment, grassy development along pre-existing field margins
Industrial Revolution	1814 - 1914	Loss of connection with the landscape	No change in small scale farming
"First Republic" Land Reform	1918 – 1934	Redistribution of nobility land to small farmers	Revitalization of small-scale farming
Collectivization	Post WWII	Expulsion of German inhabitants, small fields confiscated, farmers forced to join village co-ops	Ploughing of small fields created large state farms
Collectivization part II	1970s		Large-scale disappearance of field margins, increased soil erosion

Table 2-1 Notable historical events in the Czech Republic and their effect on agriculture. Information gathered from Molnárová 2008c.

pattern of Czech history. These trends include urban sprawl, land privatization, and lack of conservation efforts (Molnárová, 2008a, Houfková et al., 2015). In any case, current hedgerows in individual villages are a result of the local history of management, or lack thereof, since the Middle Ages. Therefore, understanding this history for each distinguishable field network is necessary for an accurate characterization of hedgerow use over time.

2.3 LULC Research and Historical GIS

LULC research aims to gain qualitative and quantitative understanding of types of land-use and land-cover, and the mechanisms of land-use and land-cover change. Land-cover (LC) refers to the type of physical type of land at or near the surface, such as soil, vegetation, forest, impervious materials, or water. Land-use (LU) describes the ways in which humans use or manipulate these types of land-cover, including agriculture, development, conservation, or any combination of uses (Bürgi et al. 2007, Parveen et al. 2018, Sajane and Wadkar 2016, Comber 2008). LULC data reflects the condition of the landscape within these two aspects (LU and LC) at the time and location of data collection. This kind of data allows for comparison of LULC both spatially and temporally, which provides information of how LU varies culturally and geographically, as well as how changes in LU are reflected in the LC (Yang et al. 2014). Using LULC data, researchers often connect changes in LULC to environmental conditions, or to socioeconomic changes such as population growth (Yang et al. 2014, Marcucci 2000, Skaloš 2007). Much of the changes in landscape dynamics and physical processes are delayed, meaning land management and LC changes from decades to centuries ago are reflected in the current environment. Past LULC has a major influence on current soil aggradation or degradation, sediment transfer, water quality, habitat loss or gain or fragmentation, changes in biodiversity, and the global carbon balance (Sajane and Wadkar 2016, Yang et al. 2014, Turner, Lambin, and Reenberg 2007). With information on current and past LULC, land managers can evaluate the impact of past management, better understand the surrounding landscape, and use this to estimate the results of current and future management techniques.

Approaches to digital reconstruction of previous LULC use various data sources and research methods based on their disciplinary background and their spatial and temporal research scales. The most common approaches can be categorized based on the data sources for reconstruction, including historical documents, natural archives, and digital models. Each type of LULC reconstruction approach has its strengths and limitations. although remote sensing is arguably the most important technological innovation in land use research, remotely sensed data has only been in existence since the launching of the first land satellite in 1972 (Yang et al. 2014, Kuemmerle et al. 2013). Moreover, remote sensing-derived time series face limitations due to improved sensors and changes in classification schemes when using them in Geographic Information Systems (Verburg, Neumann, and Nol 2011). While LULC models using remotes sensing data are commonly used for reliable predictions of future LULC change, there is not a widely accepted model for using remotely-sensed data to retroactively estimate past LULC before the advent of satellites. This is largely due to the fact that models estimating past LULC from current remotely-sensed LULC data often generalize the impact of socio-economic drivers of change, which can vary over relatively short periods of time (Chang-Martinez et al. 2015). The term natural archives describes the records kept by earth processes such as sedimentation (e.g., pollen, charcoal, fossils, and layers of soils), annual plant growth (e.g., tree-rings), and ice cores trapping elements from past climates. Scientists can use these records as a proxy for past landscape dynamics. Proxy record accuracy depends on the measurements taken from the natural archive. These measurements may vary based on the tool used, calibration accuracy, and recorder bias. Researchers work within these limitations, relying on agreement between many instances of data collected for higher accuracy of results. Still, the nature of the historical record does not deliver accurate temporal or spatial information and consequently the interpolation of this information is not exact, even with progress in dating methods (Yang et al. 2014, Molnárová 2008a). Historical archival documents include aerial and ground-level photographs, historical maps, and written historical records. Written records are often produced in administrative units ranging in size. Though records are thought to be accurate for the time, there is inherent bias depending on the original purpose of the records, and they are only applicable for the date and location they describe. Records are can also be lost or damaged, resulting in a lack of coherent and continuous datasets. Considering this discontinuity, as well as the time-consuming and inconsistent nature of preparing and interpreting written records respectively, LULC reconstruction from written historical documents is not the best standalone method, especially for larger extents (Yang et al. 2014). The most useful archival materials for LULC reconstruction are historical imagery and maps that allow for direct extraction of qualitative and quantitative LULC characteristics. The most appropriate images and maps are sufficient in detail for the study area and contain reliable spatial reference and time information. Historical Maps must be interpreted within their limitations, including considerations of the original purpose of the map, any bias introduced from the cartographer, the spatial and temporal extent of the map, the symbology and cartographic parameters used, and any damages to the original map during storage (Skaloš and Engstová 2010, Molnárová 2008a, Molnárová et al. 2008). Closely investigating not only the features on the map, but the contents, origin, purpose, circumstances, and production details of every historical map used is the responsibility of the researcher, in order to reduce inaccuracies or inclusion of incorrect data.

In recent years, there has been an increasing number of LULC change studies using a combination of these sources and multidisciplinary analysis techniques from archaeology, history, geography, paleoecology, and more in order to reconstruct historical LULC from multiple perspectives, filling in gaps left by one method and improving results (Yang et al. 2014, Parveen, Basheer, and Praveen 2018). While there are difficulties in assembling data from historical sources, historical cartographic resources with the inclusion of information from written sources (writings, drawings, pictures) is the most reliable way to reconstruct past landscapes (Molnárová 2008). In terms of LULC reconstruction, combining data from historical documents with data from proxy records can produce the most complete and detailed interpretation.

For this thesis, historical information on LULC from historical maps can be interpreted in its locational context within a HGIS framework, connecting landscape structure to its influences on the geomorphology, ecology, and culture within the study area of the Blanice Watershed, South Bohemian Region, Czech Republic. HGIS is most commonly defined as the use of geospatial techniques to visualize and analyze historical information in its geographic context (Knowles et al. 2008). HGIS is still in its infancy compared to the development and progress of other geography subfields, having seen its rise in only the last twenty years or so (Gregory and Healey 2007, Coppock and Rhind 1993). As such, methodology and theoretical framework for HGIS is still developing. There is also still debate among scholars about the role of HGIS within the field of geography, as either a social science research tool, or a separate body of scholarship. As a distinct field of study, HGIS incorporates methodology and theoretical paradigms into historical data analyses, though these have yet to be defined universally among HGIS proponents. I identify with one view of HGIS which emphasizes epistemological considerations for research and prioritizes HGIS methodology in this way (Griffiths 2013, Travis 2013, Knowles 2005, Bodenhamer 2007). However, it is important to acknowledge different opinions, as critical discussions among researchers and scholars are crucial for developing a more unifying HGIS identity (Goodchild and Janelle 2010, Travis 2013).

Contributions of historical geography to the traditional disciplines of geography include spatial history studies within the "locational tradition" of geography and reconstruction of past environments within the "environmental tradition" of geography (Baker 2003). This thinking relates history and geography most significantly in historical atlases and considers HGIS as an exciting development in technological historical geography research tools (Knowles 2005, Baker 2003). Other scholars have led the development of HGIS as a separate sub-field of geography, one which bridges GIS and historical geography scholarship. In this capacity, HGIS as Historical Geographic Information Systems offers a bottom-up approach using software and databases to manipulate, integrate, analyze, and visualize historical geographic data. This also describes HGIS as Historical Geographic Information Science, a top-down approach making use of the spatial and attribute data (Knowles 2005, Gregory and Healey 2007, Gregory and Ell 2007, Bodenhamer 2007, Bailey and Schick 2009).

HGIS research is well-suited for qualitative GIS analysis of historic geographical information and representing theoretical relationships. This approach necessitates a critical assessment of the limitations of HGIS in terms of uncertainty of the data, methods, and the interpretation of each (Travis 2013). In order to be effective in analysis of historical information, GIS tools must be critically considered for qualitative analysis, not just quantitative analysis. Considerations of these ideas should be reflected in development of HGIS research methods, where steps are taken to minimize errors introduced from historical sources, and the researcher can produce results within the limitations of their data (Bailey and Schick 2009, Gregory and Ell 2007, Knowles 2005).

Differentiating HGIS from purely historical research is also important, considering the growing use of GIS technology across social science disciplines. There is a distinction between space and place, space being more abstract and place being a space that has been given meaning and value (Tuan 1977). Human geographers and historians utilize the more qualitative approach to place as space with a derived value in their research, but GIS also relies on the physical spatial extent of places in order to visualize the former meaning. Thus, HGIS necessitates a user with both understandings of space and place, quantitatively and qualitatively, in order to produce sufficient results (Griffiths 2013). This is not to say historians cannot use HGIS methods in their research, rather that in order to do so, they must understand both approaches and responsibly integrate them into their research. In this way, HGIS can help historical researchers develop new and unique perspectives on their historical data sources (Griffiths 2013).

As HGIS scholarship progresses, studies using novel HGIS approaches are important for the development of the field's breadth and depth. Progress in HGIS will proliferate an ongoing deepening of the applications perspective as well as a continued broadening technical perspective (Gregory and Geddes 2014). The deepening of HGIS relates to researchers applying HGIS to gain new information on the past, while the broadening of HGIS refers to its technical scope widening to include qualitative sources as well as traditional quantitative sources. Through this perspective, there is value in researchers sharing their case studies of HGIS scholarship, as they modify and uniquely apply GIS tools in pursuit of methods that fit their specific research paradigm. It is through consideration of these ideas that I will develop methods to collect, analyze, and display historical LULC information from the village of Křišťanovice, as a case study using an HGIS approach. This approach prioritizes epistemological concerns of HGIS, considering unique ways in which new information is generated through my HGIS research for the improvement of future research in the area and also for the development of the field of HGIS. The methodological aspect of this research paradigm relates to adapting methods as they best produce results, rather than limiting research methods to one design. This adaptation is embodied in HGIS, which utilizes spatial and non-spatial historical geographic information, and thus methods must address qualitative and quantitative concerns, adapting analysis to best answer the specific questions posed by individual studies. Evaluating existing studies and literature on the use of historical maps, the reconstruction of historical LULC, or the historical geographic data available in the Czech Republic was the first step in my methodological considerations. I have summarized my key findings from this evaluation in the next section.

2.4 Analysis of Historical Maps and HGIS Data Sources in the Czech Republic

A number of existing studies in the Czech Republic utilize cadastral, military, and other maps to connect the land-use of different time periods with specific developments of society. In creating detailed reconstruction of past landscapes, these studies aim to inform management for the stabilization of present or future landscapes (Sklenicka et al. 2009, Lipský, Kopecký, Kvapil 1999, Skaloš et al. 2011, Brabec and Molnárová 2010). The Historical Geography Research Center in the Czech Republic even emphasizes the importance of GIS studies of relict boundaries, landscape evolution, and land utilization to advancing historical geographic research in the Czech Republic (Semotanová and Chromý 2012).

There are clear trends in the literature on methods of georeferencing historical maps. Paper maps are first scanned to become digital images. This step is often the second introduction of error, after the considerations of initial cartographic inaccuracies during map creation, and any distortion or damage to paper maps during storage over time. During this digitization of paper maps to raster map images, maps can be stretched, distorted, incomplete, or mis colored, altering the quality of the digital representation (Affek 2013, Brabec and Molnárová 2010, Cajthaml 2011, Molnárová 2008, Pacina and Cajthaml 2015, Skaloš et al. 2011). The next process involves using GIS software, such as ArcMap, to give the raster images spatial rectification. The raster images are imported as a .tif or .jpg layer in ArcMap along with a spatially projected reference image or map. The image is georeferenced using various techniques which utilize the original map reference system and ArcMap tools to add control points where features in the scanned raster align with features in the reference image. A popular technique for selecting ground control points is to use features from both datasets that are unlikely to have changed, such as road crossings, or geometric structures. The scanned map is then georeferenced and rectified to transform the dataset into the reference coordinate system. In georeferencing, it is common to use either a global or a local transformation method. Global transformations use an equation for each coordinate (X,Y) and people often use the least squares method for adjusting transformation parameters. Alternatively, local transformations fit the georeferencing ground control points to the image exactly, but this often results in noticeable image distortion (Cajthaml 2011, Pacina and Cajthaml 2015, Skaloš et al. 2011, Yang et al. 2014). Considering the consistency of the Gusterberg coordinate system among the original stable cadaster maps and the topo military maps, as well as the importance of maintaining image integrity of scanned map sheet images, a global transformation is more appropriate for this project (Cajthaml 2011, Skaloš et al. 2011).

Because the Military Mapping projects from the beginning of the 19th century were based on a geodetic network, the coordinates at each map sheet corner can be used to quickly georeferenced each map sheet (Cajthaml 2011, ŭova, Pestak, and Veverka 2006, Čada and Vichrová 2009). However, this is not the most appropriate first step for georeferencing in this project, which prioritizes referencing landscape features over the entire map sheet. Traditionally, when georeferencing scanned map sheets, the user assumes that the original maps met their cartographic requirements, even though the raster images are distorted by contraction of paper and by errors introduced during scanning (Affek 2013). Because I aim to minimize the influence of errors such as this raster distortion, I avoided this method of first georeferencing based on the corner map sheet coordinates. Instead, I georeferenced the features on each map sheet as they align to reference data, and then transform the entire map sheet in a way that maintains the shape of the map image, so as to minimize distortion.

All of these studies focus on the georeferencing of historical maps, for the purpose of creating a digital dataset of historical spatial features. And while these are very important for the proliferation of historical GIS databases and improvement of HGIS spatial data collection methods, these studies fall short in terms of theoretical context, addressing limitations, and incorporating non-spatial data into their methods. While a few of these existing studies had intentions regarding the methodological advancement of historical map georeferencing (Cajthaml 2011, Pacina and Cajthaml 2015, Skaloš et al. 2011), the rest had the primary objective of improving methods of georeferencing map sheets for the purpose of creating a large, cohesive digital dataset of historical maps within their proper spatial context. The latter is part of the more concrete goals of HGIS in storing and visualizing global historical geographic datasets, but it does not provide the most accurate georeferencing methods for the purposes of landscape analysis at the scale of my project. There is a gap in HGIS landscape change studies that prioritize accuracy and analysis for the area within historical map sheets. By concentrating my analysis to land-use changes within individual cadastral territories containing a cluster of hedgerow fields, I am filling in this gap. Even so, each study provided a good example of methods on which to base my research, and valuable information on the kinds of HGIS data made available in the Czech Republic.

The study that was most applicable to my research goals was conducted in the Central Bohemian lowland area of Nové Dvory and Žehušice by a group of Czech historians and researchers specializing in the historic military map projects located in present day Czech Republic (Skaloš et al. 2011). The researchers collected maps from the First (1785), Second (1851), and Third Military Surveys (1877), and compared them to present-day orthophotographs for the study area. Basing their analysis on units of cadastral territories, they compared 21 sites, quantifying elements of landscape change. The most valuable information I took from this study came from their delineation of usefulness of each Mapping. The First Military Survey maps reflect some geodetic inaccuracy and they are too small-scale (1:28,800) to be used in land-use change analysis of smaller areas. Their most appropriate use is in approximations of landscape changes across larger study areas. The Second Military Survey (1836-1852) is based on the Stable Cadastre Maps I use in my study, which is a much larger scale at 1:2880. Because they are based on the cadastral maps, the Second Military Survey Maps (in 1:28,800 scale) are considered to be much higher accuracy than the First Survey. The Third Military Mappings (1876-1880 in 1:75000 scale) include topographic maps with 20-meter contour intervals, which are a more precise representation of features such as roads and the relief.

The information on the purposes behind and the strengths and weaknesses of each mapping project allowed me to better select and evaluate each historical map I used in my methods. I also learned the value of churches and other holy places for selecting permanent features for georeferencing, as these are assumed to be relatively unchanged over time. This study used affine georeferencing, which minimizes angle and length distortion between the scanned map images and the digital georeferenced versions and is a common technique for preserving the shape of historical map sheets. The land-use classification scheme developed in this study was useful in developing my own classifications, as the authors are all distinguished Czech historians and geographers. Through an investigation of published literature, this study has proven to be the most directly applicable, emphasizing the importance of refining methods for historic and temporal landscape changes as reflected in historical maps. They also acknowledge the weaknesses of each map, refining their analyses within the limitations of such weaknesses. The primary difference between this study and the one presented in this paper is in scale. The narrowing of the study area to one cadastral territory allows me to evaluate landscape changes with much more detail, examining characteristics of certain landscape features at different times. In this way, this study is better suited for producing spatial data and land-use information that will be valuable to other geomorphological studies.

Understanding the historical geographic information available for use in this study was crucial for developing the proper scope of analysis, and therefore I have included my findings on data availability and Historical Mappings in the Czech Republic. These findings summarize information gathered from government websites, research literature, and correspondence with scholars at the Czech University of Life Sciences.

In the Czech Republic, The State Administration of Land Surveying and Cadastre maintains a comprehensive online collection of historic and modern maps of various detail and scale, available for public use. This is the source for historical maps within the Blanice Watershed study area, and more specifically for the cadastral village of Křišťanovice. I understand that the most complete map projects provided by the online archives are the original stable cadaster maps and the topographic maps from the Third Military Mapping (Kristina Janečková-Molnárová and Ivana Trpáková, personal communication). The Original Stable Cadastre maps are a 1:2880 scale evaluation study of the Hapsburg monarchy land from 1825 to 1843, describing each village's climate, land, water, roads, and more. Any updates made to these maps were marked in red ink and included in what is now called the Imperial Imprints of the Stable Cadastre (Molnárová, 2008a). There is an ongoing research project relating information found in handwritten journals to village and field locales illustrated in map sheets from the stable cadaster. The project involves translating these journals from an old Germanic script and extracting from them detailed information on agriculture and land management methods and ownership (Ivana Trpáková, personal communications). These journals could prove to be very informative for this type of study, and I hope that future work can make use of data collected from them. The maps from the toposections of the Third Military Mapping are 1:25,000 scale maps published between 1872 and 1953 covering an extent larger than the current Czech Republic boundary, as it originates from the Austro-Hungarian Empire (ČÚZK).

Historical GIS databases, such as the ones used in this project, provide resources for digital reconstruction of previous land-use and land-cover, and a platform for analyzing historical information within its temporal and spatial context. In this research, historical geographic information in the Czech Republic supplies spatial and cultural data on the agricultural systems and specifics of land-use in the Medieval Bohemian countryside. Non-spatial geographic data influences the visualization and interpretation of this historical spatial and cultural information. Using HGIS methods to synthesize the two allows production of maps, visuals, and data tables that generates and displays valuable information within the study area. This kind of information has many applications to ongoing and future research, which links the HGIS methods of this study to the epistemological role of HGIS in gaining knowledge in novel ways. The contributions of results in this capacity include gaining a better understanding of the ecological and cultural significance of these unique hedgerow field patterns, their influence on sediment transport since medieval times, and aiding in the preservation of these features for their cultural, aesthetic, and historical importance.

Chapter 3: Research Goals

3.1 General Project Objectives

The primary objective of this project is to apply HGIS methods to evaluate data from historical maps for LULC change in the Blanice Watershed, Czech Republic. This objective is twofold, incorporating both a LULC change analysis and a conceptual investigation of HGIS methodology within the study area. To satisfy this objective, I developed specific questions to guide the research methods and results. The following section presents and explains these three guiding questions.

3.2 Research Questions

Research Question 1: How can historical maps be used to characterize temporal variation of landscape patterns in the Blanice Watershed in South Bohemia, Czech Republic?

This first research question addresses two main methodological facets of HGIS research. First, what are the appropriate methods for collecting and analyzing LULC data from historical maps to best characterize hedgerow use over time? Second, how is this information best stored and visualized, using GIS tools and programs. In the context of this project, landscape characterization includes LULC change analysis within individual cadastral territories, emphasizing modifications to the hedgerow-defined agricultural landscape. Conducting a thorough evaluation of this research question for one cadastral territory allowed me to develop characterization methods for LULC change within the entire study area.

Research Question 2: What are the sources and nature of uncertainty introduced from HGIS data analysis?

In other words, what are the limitations associated with using data derived from historical maps in LULC studies in the Czech Republic? These limitations include uncertainties familiar to GIS studies such as spatial inaccuracies and cartographic misrepresentation of features. Within an HGIS framework, historical data also introduces uncertainties such as bias from historical data sources, missing or incomplete data, and inoperability of historical data and present-day technologies.

Research Question 3: Considering questions 1 and 2, how do results contribute to or inform studies of LULC change analysis in the study area?

This question contributes to the larger objective investigating the potential of an HGIS approach for LULC research by considering the information gaps affecting current analysis from reconstruction methods. I believe that the inclusion of information from historical maps can inform characterization of landscape features and improve LULC change studies within the study area.

Chapter 4: Methods

4.1 Theoretical HGIS Considerations

In order to adequately address the uncertainty and inaccuracies involved in using historical geographic information in conjunction with current GIS tools and data, I have familiarized myself with the methodological successes and weaknesses of other studies, as summarized in the literature review. Acquiring a comprehensive understanding of epistemological ideas and discussions within the field of HGIS and related fields was crucial for developing methods of and a conceptual framework for analysis suitable for my project. This includes identifying and minimizing, where possible, the sources of potential error and inconsistencies in data collection, organization, visualization, and interpretation. By acknowledging all potential introductions of error and assessing the limitations of each source of historical geographic information, I can confidently report results, as well as provide methods as a case study for HGIS. This is essential to the project objectives as I hope to advance the theoretical understanding of HGIS within a conceptual framework as well as an analysis toolset for researchers across the humanities utilizing historical geographic sources and subjects. By contributing a sound case study of HGIS methods within a spatiotemporal thinking framework, I hope to contribute to discussions on the potential of geographic information derived from historical sources in qualitative and quantitative studies. As I completed the methods outlined in the following sections, I took note of any potential introductions of error, and confined my analyses within the limits of each data source. These are explained in greater detail in chapter six, but I feel it is important to introduce them in the beginning of this chapter as they are an important aspect of every method used.

4.2 Data Collection

From the State Administration of Land Surveying and Cadastre's online database, called the Geoportal, I purchased map images for the cadastral territory of Křišťanovice from the Original Stable Cadastre, the Maps of Cultivation of the Stable Cadastre, the Third Military Mapping, the State Map Series from the 1950s, and the Topographic Maps of the General Staff of the Czechoslovak Army. Table 4-1 provides details on the names,

Czech dataset name	English translation	year	scale	format	unit price
Originální mapy stabilního katastru 1:2 880 – Čechy	Original maps of the Stable Cadastre 1: 2 880 - Bohemia	1837	1 : 2,800	JPG	25 koruna/map sheet
Topografické sekce 1:25 000 třetího vojenského mapování	Topographic Section 1:25,000 of the third military mapping	1924	1 : 25,000	JPG	25 koruna/map sheet
Soubor správních hranic a hranic katastrálních území ČR	Set of administrative boundaries and borders of cadastral territories of the Czech Republic	present		SHP (JTSK)	free
Státní mapa 1:5 000-odvozená	State Map derived	1952-53	1 : 5,000	JPG	25 koruna/map sheet
Topografické mapy 1 : 25 000 v systému S-1952	Topographic Maps of the General Staff of the Czechoslovak Army 1 : 25 000	1952	1:25000	JPG	25 koruna/map sheet
Mapa kultur stabilního katastru 1837-1844	Maps of Cultivation of the Stable Cadastre 1837-1844	1837-1844	1 : 36,000	JPG	25 koruna/map sheet

Table 4-1 Historical Map and GIS data collected from the Geoportal

years, scales, and cost of each of these geographic datasets. I also downloaded images of the map legend for the Original Stable Cadastre. This was originally written in an old

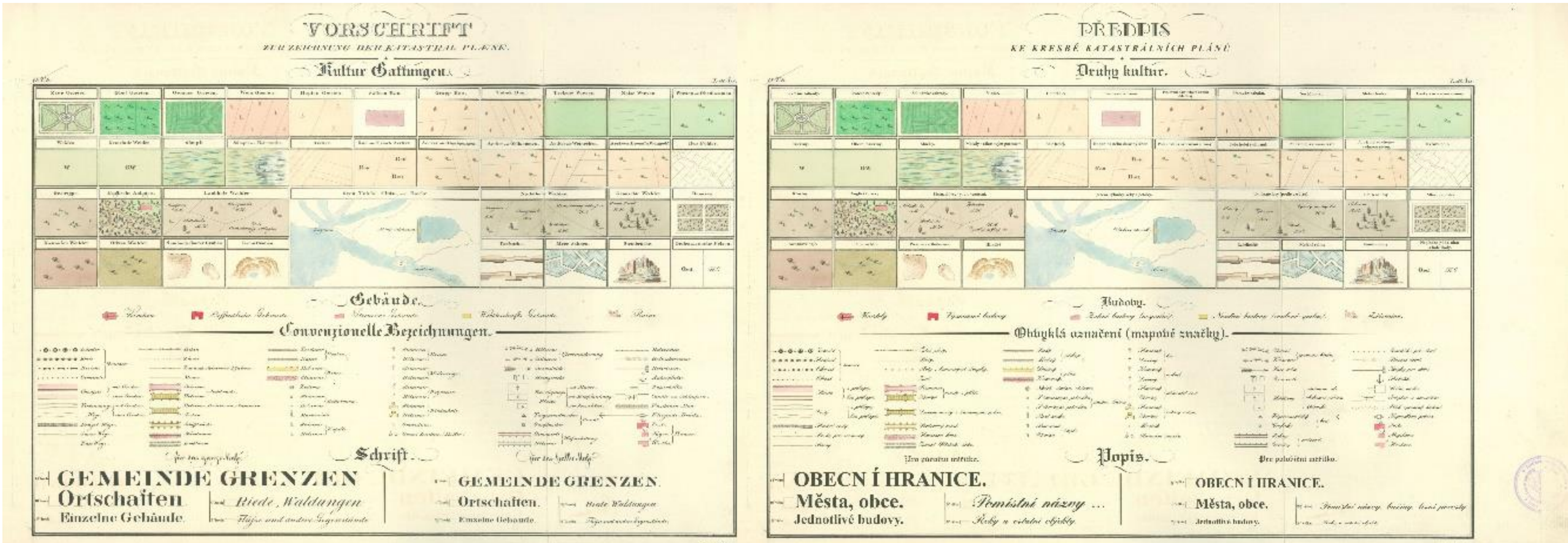

Figure 4-1 The legend for the Original Stable Cadastre maps in the original Germanic language (left) and the version translated into Czech (right).

Germanic language, then translated into Czech (Figure 4-1). Both versions were provided on the Geoportal, and I found it easier to have the Czech version translated to English, considering the original Germanic language is no longer widely spoken or understood (Molnárová 2008). The English translation of the Czech legend can be found in Appendix B. It is important to note that the Imperial Imprints are considered to reflect the original maps provided to the emperor, and then changes were made in red ink as reflected in the maps labeled as the Original Stable Cadastre Maps. The Imperial Imprints were not available from the Geoportal within the study area, so I used the Original Stable Cadastre collection. From the Geoportal I also downloaded a vector shapefile of the current administrative boundaries of the Jihocesky region, Prachatice District, and the current Křišťanovice Cadastral territory which includes vectorized roads and land parcels.

I was able to download these administrative boundary shapefiles for free in the S-JTSK Krovak EN coordinate system for interoperability with the other layers. A shapefile of the Blanice watershed was given to me by geomorphology researchers studying the area (Daniels et al. 2017), which I reprojected from WGS 1984 into the S-JTSK coordinate system using the Project tool in ArcMap. For comparison against historical LULC, I created a current land-use dataset within the present-day Křišťanovice boundary. For this current dataset, I first downloaded OpenStreetMap (OSM) data from the geofabric server for the entire Czech Republic. I had to crop this to the current Křišťanovice boundary, merge the different layers and identify areas missing data coverage. The layers of the Czech OSM data includes polygon layers of natural areas, land-use, buildings, places of worship, places of interest, traffic areas, transport, and water, as well as line layers of railways, roads, and waterways. After clipping to the study area, I merged the resulting polygons into one dataset, and kept the roads and waterways lines as separate shapefiles. There were no features from the transport, places of worship, or places layer within the study area. Using the erase tool in ArcMap, I removed the areas covered by OSM data, and identified areas within Křišťanovice that did not have current land-use information. By examining these small dispersed areas in Google Earth, I was able to classify these 13 areas into one of the existing land-use categories, and every area belonged to its neighboring OSM shape which made for a seamless dataset and consistent LULC classification. OSM is a free, open source data source with datasets produced by citizen participation and has been proven to be a very accurate LULC data source (Arsanjani et al. 2015, Estima and Painho 2013, Arsanjani et al. 2013).

Although images from the Third Military Mapping, the Maps of Cultivation of the Stable Cadastre, and the Topographic Maps of the General Staff of the Czechoslovak Army were not detailed enough to georeference landscape features from, they were still utilized. The Maps of Cultivation of the Stable Cadastre were used in previous methods to inform LULC classification in areas of Křišťanovice where the OSC was mislabeled. Besides this usage, I considered the original purpose and production year of each non-referenced map to asses information provided in each within its spatial limitations. This is an adaptable HGIS method for the integration of historical geographic information to fill in gaps or inform other aspects of analyses. It is important to only assess information from these sources within their limitations, especially considering the relatively small study area of Křišťanovice. Even though these maps cannot be used to digitize landscape features, they can provide interpretation of the general land use practices at the time, considering the purpose initiating the mapping project. For example, the military mappings were often for the purpose of identifying land ownership, relief of the landscape, and important military resources such as water and covered areas. Even with a larger geographic extent and less detail, a military map can provide reliable broader information about the distribution of land, as well as reliable data on the identification of resources; though it is still important to consider the bias of the governing authority behind the map.

4.3 Georeferencing Historical Maps

The raster images of the Maps from the Cultivation of the Stable Cadastre, the Third Military Mapping, and the Topographic Maps of the General Staff of the Czechoslovak Army datasets were of a much smaller map scale than the State Map Series from the 1950s and the Original Stable Cadastre Maps (OSC), ranging from 1:25,000 to 1:36,000. At this scale, there are simply not enough permanent features to compare to the OSC and State Maps or be used for selecting ground control points. Considering this and the purpose of these three mappings for either military use, or a general examination of the cultivation for all of Bohemia, these three datasets were not completely georeferenced. Instead, I used the rotate, shift, and scale tools on the ArcMap georeferencing toolbar to get each map sheet roughly aligned with the cadastral territory, for the primary purpose of comparison among different historical map datasets. For the OSC and State Map Series I used georeferencing methods that are very closely based on methods common within literature on similar studies using historical maps (Esri, Zimova, Pestak, and Veverka 2006, Cajthaml 2011, Skaloš et al. 2011).

In a blank ArcMap document, I first imported all of the raster map sheet images for the study area, along with the reference dataset, which in this case is the J-STK administrative shapefile of the current Křišťanovice village. In order to properly display Geoportal data, I had to change the maps display units to meters and the data frame coordinate system to S-JTSK East North Krovak ESPG 4415. For each separate map sheet (6 OSC and 4 State Map sheets), I used the rotate, shift, and scale tools to get the scale and the Křišťanovice boundary as best aligned to the reference data as possible.

This initial georeferencing step ignores the corner coordinates of the map sheets to prioritize alignment of landscape features and minimize the effects of distortion from storing and digitizing historical maps. I then used the georeferencing toolbar to add ground control points (GCPs) from the unreferenced map sheet to the reference data. GCPs are most reliable at common permanent structures or features between the two datasets, including roads, common feature intersections, religious grounds, and more. A best practice for adding control points is to have at least one link near each map sheet corner, and many more spread out across the image. Quality of GCPs should take

	Map sheet	Number of GCPs	total RMSE (m)
Original Stable Cadastre	3654-1-001	11	2.49524
	3654-1-002	10	2.08627
	3654-1-003	18	3.66643
	3654-1-004	21	1.78368
	3654-1-005	40	2.18491
	3654-1-006	29	2.01127
State Map Series	VOLA70_1953	103	3.60314
	VOLA71_1952	118	2.60377
	VOLA80_1952	35	2.7465
	VOLA81_1952	107	2.25895

Table 4-2 The calculated RMSE for each georeferenced map sheet.

precedence over quantity, as each link has some influence on the transformation and more GCPs does not necessarily lead to a more accurate transformation (Esri). As control points are added, a Root Mean Square Error (RMSE) is calculated, which reflects the transformation of each point between the raster image and the reference data in meters. It is best to attempt to minimize the RMSE, but with the potential distortion of historical

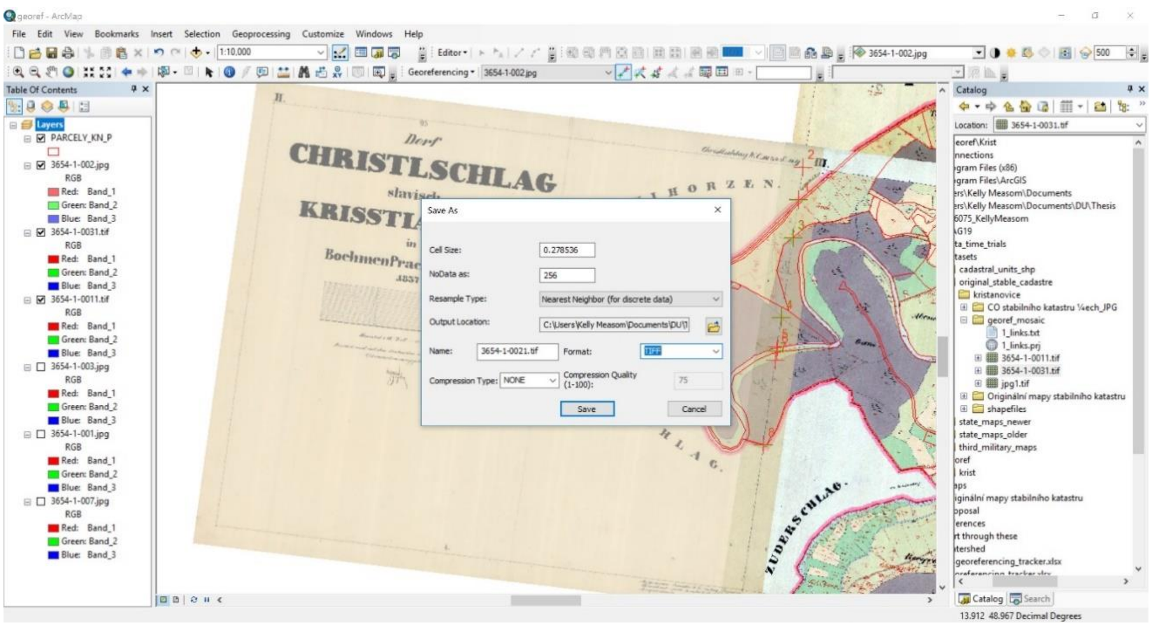

Figure 4-2 Screengrab from saving the transformation to the dataset in ArcMap. Transformations are calculated using the GCP linkages (red and green numbers on the map and reference data).

map images, there is no universal ideal RMSE value. I repeated and adjusted my addition of GCPs until the RMSE was the lowest value I could attain. Table 4-2 records the RMSE for each map sheet of both georeferenced HGIS dataset. Once a sufficient number of GCPs is added resulting in the lowest possible RMSE, the raster map image must be transformed to the updated georeferencing. In georeferencing, it is common to use either a global or a local transformation method. Global transformations use an equation for each coordinate (X,Y) and people often use the Least Squares Method for adjusting transformation parameters. Alternatively, local transformations fit the georeferencing ground control points to the image exactly, but this often results in noticeable image distortion (Cajthaml 2011). Considering the consistency and interoperability of the coordinate systems among the HGIS datasets, as well as the importance of maintaining image integrity of scanned map sheet images, a global transformation is more appropriate for this project. Using a 1^{st} Order Polynomial Affine Transformation, this global transformation updates the georeferencing of the dataset while maintaining the shape of the map sheet. In other words, this transformation attempts to satisfy the links from each GCP without distorting the image on the map sheet. Once transformed, I saved the map images as a new .tif file (Figure 4-2). I used these georeferencing methods for both the OSC and State Map images, as shown in Figure 4-3. Before I could use these georeferenced map images to generate vector files, I had to create a geodatabase to store and organize the new HGIS datasets.

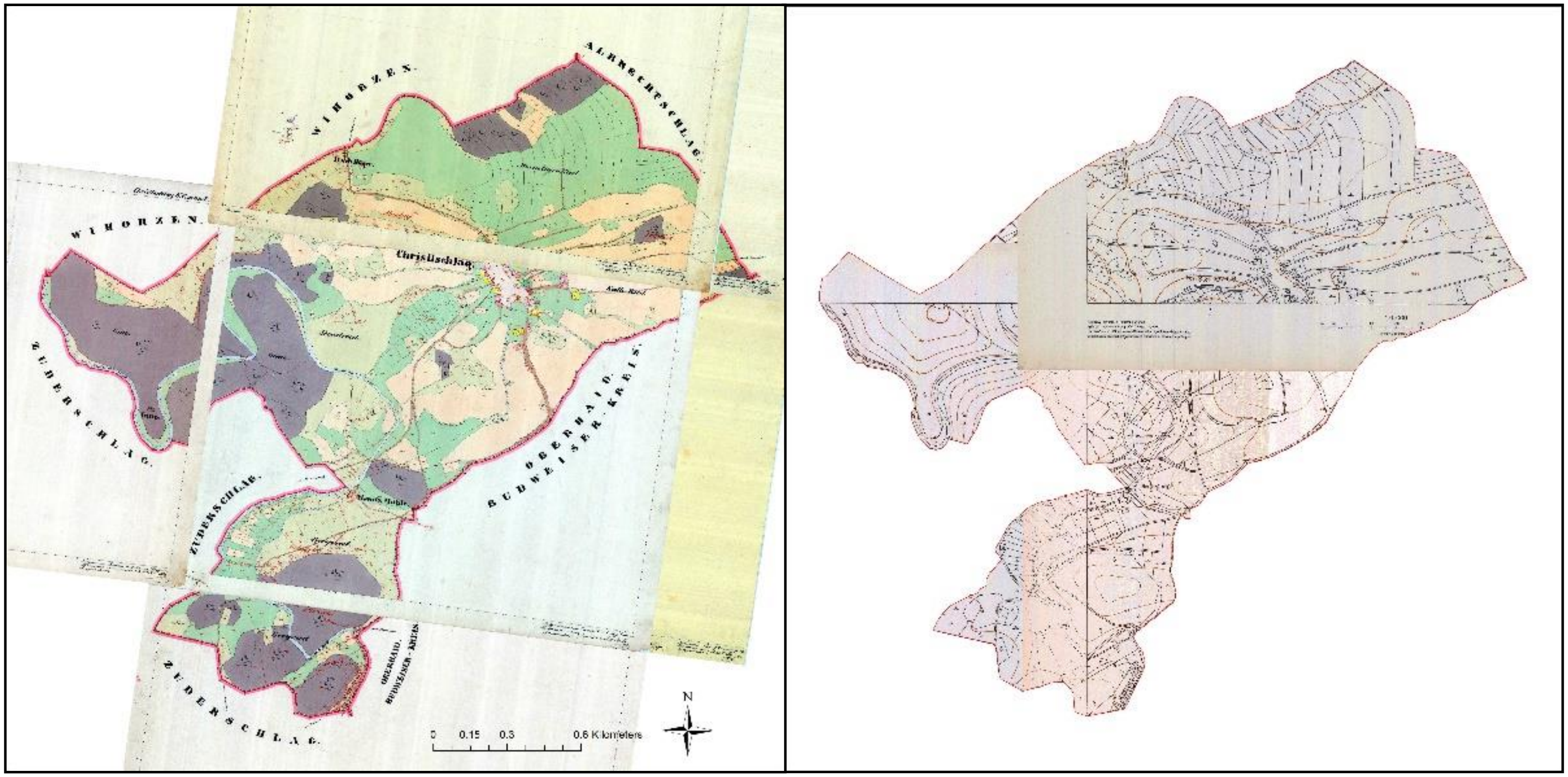

Figure 4-3 OSC (left) and State Maps (right) are shown georeferenced within the Křišťanovice boundary.

4.4 Database Schema and LULC Categorization

In ArcCatalog, I created a new file geodatabase to store each of the land-use feature classes created from the OSC maps, State maps, and the OSM data. Under the file geodatabase properties, I created four coded value domains, one for each dataset and one additional domain to store the coded values for the reclassified land-use categories to compare the datasets. Coded value domains are used to restrict attribute values to the set of values defined in the domain, which can preserve data integrity. See Appendix C to view the design and values of the geodatabase I created to store this information. I used the map legend to create the categories for the OSC dataset, ensuring the symbology was consistent among the two. For the OSM data, I used all of the LULC categories from the original dataset that were relevant to the study, excluding overlapping polygons of nature preserves and combining repetitive categories into one encompassing class. The State Maps do not have a legend available, and even though there are many symbols that are common among the State Maps and the OSC, I excluded the State Maps from analysis. Without a legend, I cannot determine the meaning of symbols and features on the State Maps without introducing interpreter bias and error of the resulting dataset. Additionally, the State Maps were originally intended only for internal use of state bodies and socialist organizations to map the planimetry of the 1950s, including settlement boundaries, water bodies, large forests, and towers; as well as the altimetry, shown by contour lines. The purpose of these maps did not include land-use related to agriculture and management of hedgerow-bounded fields, which further affirmed my decision to exclude them from LULC related analysis. I georeferenced State Map Series from the 1950's but did not create an LULC map (Figure 4-3). When creating the attribute domain for the reclassification scheme, I considered the land-uses that were most important to erosional processes and took note of the LULC types that were common between the datasets. This produced a set of LULC categories that were validated by many of the categories used by Skaloš et al. but tailored to my specific research goals and study area. The reclass LULC categories are: developed (includes built-up areas and areas developed by humans), forested areas, farmland (includes meadows, and arable land), scrub, saturated (includes wetland areas), road/path, and water (includes bodies of water and waterways).

Inside the file geodatabase, I created an empty feature class for the OSC data, defining fields to store information for each feature I would create, including the area, land-use, and the reclassified land-use. In the field properties dialogue box, I defined the proper domain for the land-use and reclassified land-use fields. For the OSM data, I simply exported the data into the file geodatabase as a feature class and added fields to the data that used the land-use and reclassified domains.

4.5 LULC Dataset Creation

To create the datasets of the georeferenced historical maps I had to create vectorized features tracing the map features. While there are some studies investigating the automation of this, methods are not developed and proven enough to justify using (Godfrey and Eveleth 2015). Thus, tracing features from the image by hand is the most effective method, although extremely time-consuming. In a blank ArcMap document, I imported the georeferenced historical OSC TIFF map sheets and the blank feature class with the domain constraints. I opened the attribute table for the OSC feature class and used the Editor Toolbar, Advanced Editing Toolbar, and the Create Features Construction Tools to create shapefile features. Knowing that after the OSC maps were first created, they were stored for some time and updated periodically in red markings, I had to ignore the red ink and create features from the original map underneath. For each feature I traced

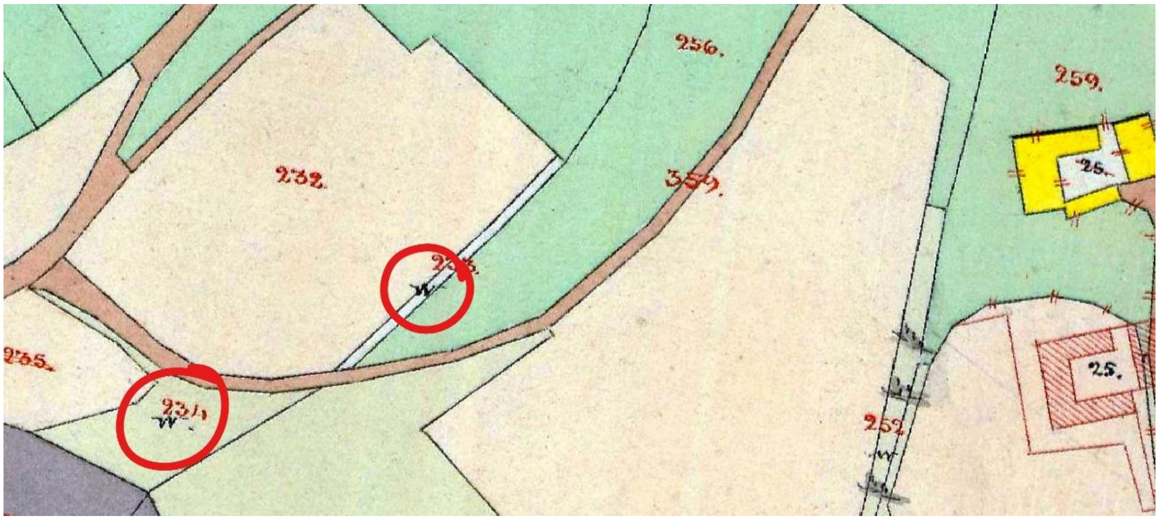

Figure 4-4 Circled mislabeled feature (in white) from the OSC map, 1837.

from the map images, I filled out the appropriate attributes from the land-use domain in the attribute table. Using caution to create the features as accurately as possible was laborious, but being the only user to create the traced features also allowed me to reduce human error introduced by multiple interpreters. This precaution combined with my preliminary study on relevant literature, GIS knowledge and experience, and my careful georeferencing of map sheets, were all important measures taken to improve accuracy of my results and reduce error. Even with all of the precautions, it is important to note the potential errors introduced during this process, resulting from my own mis-drawn or inexact tracing of features, misinterpretation of land-use, and enduring errors introduced from previous steps. There were a few instances during the vectorization process where I made judgements on the identity of features on the map images, and whether they should be included in the dataset or not. In Figure 4-4, I have circled two areas with different coloring, marked by the same OSC symbology. The best technique to use in this situation is to first identify the mislabeled feature and assign in the appropriate LULC. I used the

Figure 4-5 An area from the OSC map where the red markings obscure the underlying map features.

land-use classifications of the adjacent features, as well as examining the similar area in the Map of Cultivation to derive the best land-use. In some instances, it was difficult to observe the symbols of the OSC map because they were partially obstructed by the red markings indicating the updates and changes made to the Stable Cadastre over time (Figure 4-5). In these cases, I found it helpful to increase my screen's brightness, as well as adjust the brightness and contrast of the image using the Effects toolbar in ArcMap until the underlying symbology is more visible. Occasionally, the original map sheet images were easier to interpret under the red edits, but only when I could easily identify the area in question among both the georeferenced and unreferenced images. Within map sheets, particularly nearest the margins, there were instances where overlapping map sheets were not perfectly aligned. I noticed this often occurred in areas towards the outside of the Křišťanovice boundary, far from features being vectorized or in the small rectangular map sheets with fewer GCPs and features. As long as the features on these map sheets aligned well with the rest of the features, this slight misalignment did not have much, if any, effect on feature vectorization. If there was a noticeable misalignment between the features of one map sheet and the features of the other map sheets and the reference data, I would improve the GCP's and reapply the rectification of the original map sheet raster. There was one recurring marking on the map images that was not labeled in the map legend (Figure 4-6). When I came across this blue sinuous line feature

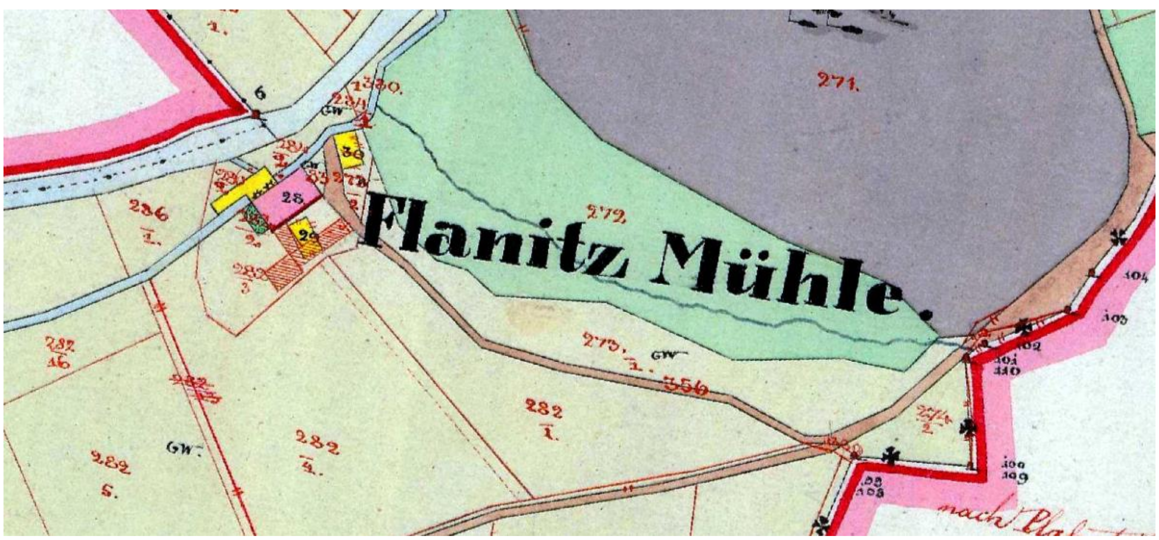

Figure 4-6 This portion of the OSC map shows the dark blue line (crossing the green feature), a potentially unlabeled feature or imperfection.

at first, I was unsure if it was a feature or just an imperfection on the paper map source. Upon identifying multiple instances of this marking, and considering the saturated land-use delineated for the fields directly surrounding them, I determined this feature is mostly likely a stream. Since it was not given a symbol on the legend and was represented by a thin line rather than a polygon with a bounding area, I included it in the final LULC vectorized map by segmenting surrounding shapes with the line feature. This maintains the characteristics of the saturated land within the larger shapefiles, while acknowledging the spatial location of this potential stream without altering the LULC. Ignoring instances of misalignment, confusing symbology, and erroneous features has an impact on the quality of the data produced during vectorization of historical map images, and therefore is an important methodological consideration. For the purposes of improving consistency and reducing data inaccuracy, I have included steps for guidance on these instances as part of the georeferencing workflow (Appendix A). Remediation of these sources of error are tailored to the maintenance or improvement of the quality of the vectorized LULC data, rather than prioritizing the rectification of the map sheets themselves.

Once I had vectorized and categorized every feature from the OSC map image within the administrative boundary of Křišťanovice, I used the reclassification attribute domain to reclassify the OSC land-use. The reclassification scheme is categorized to allow for comparison between the historical LULC terms and the current data. Reclass categories represent the LULC types from both datasets that are also highly influential on the underlying soil characteristics. Any land labeled as pastureland, grazing area, meadow, field, or cultivated from the OSC Map is reclassified into the farmland category. For the OSM LULC categories, land classified as meadow or pasture gets reclassified to the farmland category. Table 4-3 Shows the full reclassification scheme for the OSC and OSM maps. I used the Reclassified LULC maps to calculate LULC change over time, by calculating the total area for each reclassified category, as well as the percent area each category encompasses out of the total area of the administrative boundary at that time. For each original and reclassified LULC category, I chose a symbology that best reflected the important distinguishing characteristic of that category. I saved each particular symbology as a layer file within the geodatabase, which allows the symbology to be reused in other cadastral territories for the associated data source.

OSC-derived LULC categories	Reclassified LULC Categories	Current OSM-derived LULC Categories
Waterway	Water: Lakes, Rivers, Streams, Reservoirs, Ponds, etc.	Reservoir Water
Path/Road	Road/Path: Any road, path, or trail that is used to get from one place to another; includes bridges	Path Road
Barren Land Built-Up Area Fruit Garden	Developed: Built up areas or residential barren land: Parking lots, Industrial areas, Recreational areas, Buildings, etc.	Built-up Recreational
Forested areas Private Pastureland with Trees	Forested: Wooded areas with tree cover; can overlap or be located within other features.	Forested
Private Pastureland with Scrubs	Scrub: brushy area of scrubs and bushes; not cleared but not forested.	Scrub
Meadow Fields Private Pastureland Community Pastureland	Farmland: Fields, pastures, and any other grassy lands cleared of trees and scrubs.	Meadow/Pasture
Saturated Meadow	Saturated: Any LULC feature that is noted as being wet, saturated, or a wetland.	Wetland

Table 4-3 The LULC classification scheme for the OSC, OSM, and reclassification maps.

I also created maps to visualize the distribution of LULC change within Křišťanovice. I used the union tool in ArcMap's overlay analysis toolset to compare the classification from all of the OSC features which overlap with classified features from the OSM LULC data. Some features are excluded because they do not overlap with OSM features. Also excluded are all water, road, and path features because these are represented inconsistently between the two datasets. From this dataset of LULC change features, I also created a map to show just the change between features classified as forested, farmland, and scrub between the OSC and OSM maps. The classification scheme for both of these LULC change maps were added to the geodatabase.

Results of these methods produced LULC maps from historical map images and current OSM data, and a geodatabase schema for organizing, storing, and visualizing the LULC data.

Chapter 5: Results

From the vectorization of the Original Stable Cadastre Map from 1837, I created the map shown in Figure 5-1. The land-use classifications shown in the legend for this

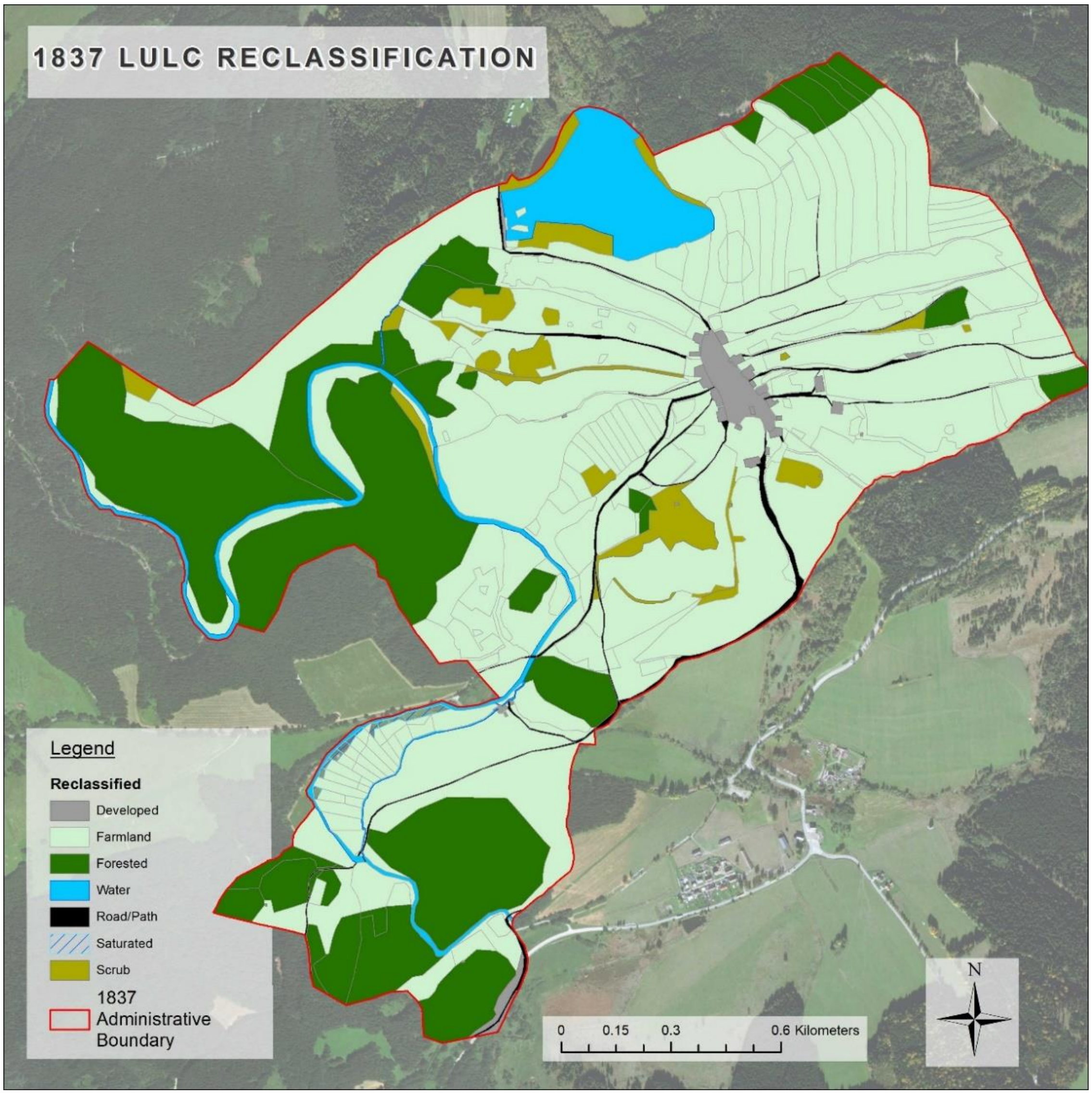

Figure 5-1 LULC map representing vectorized features from the OSC in Křišťanovice, 1837. Esri basemap.

map are the translated LULC features from the legends of the original OSC maps. From the current LULC derived from Open Street Map (OSM) and current aerial imagery, I produced the map shown in Figure 5-2. These two maps use similar symbology tailored

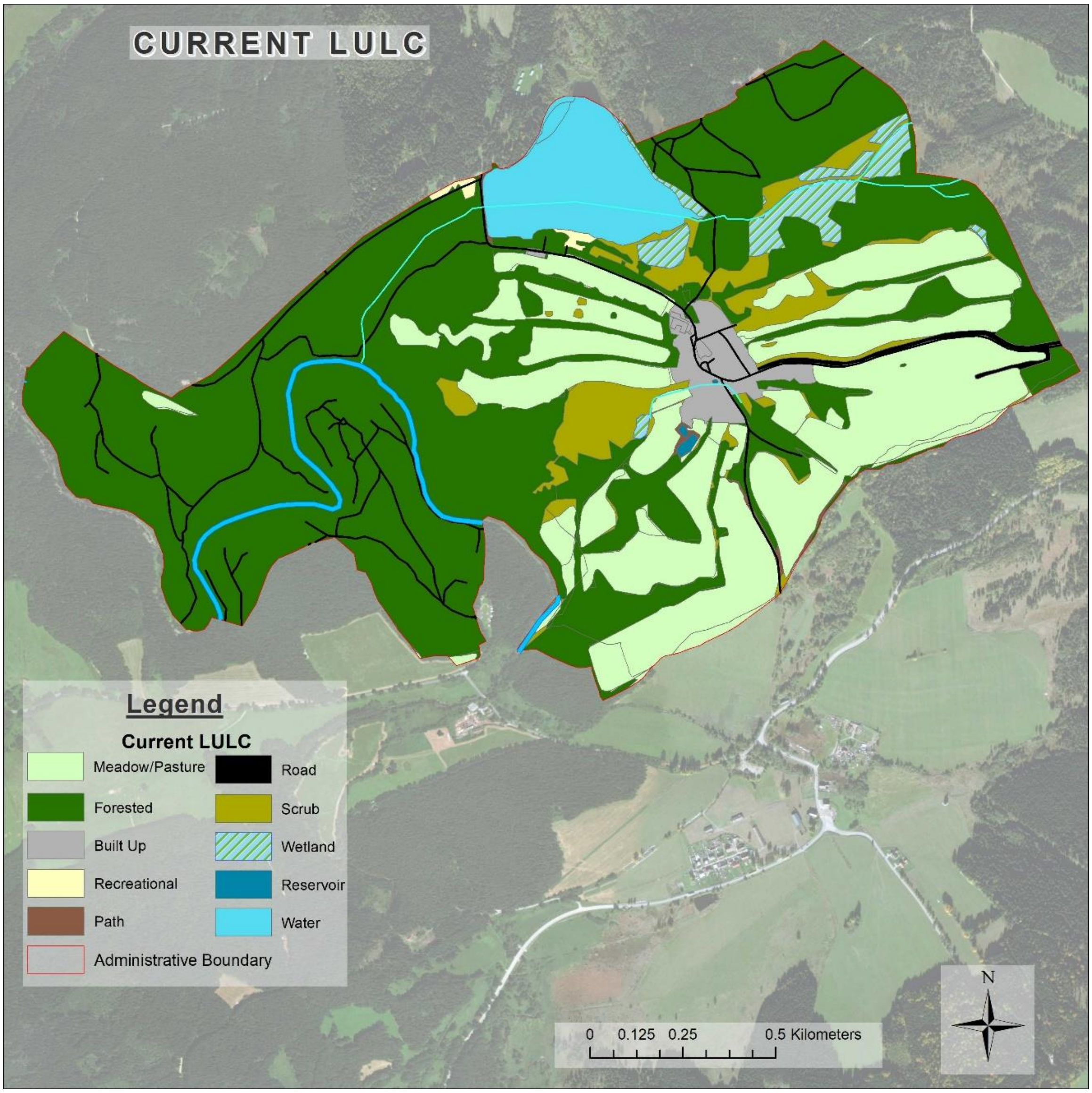

Figure 5-2 Map representing the current LULC in Křišťanovice, derived from OSM data. Esri basemap.

to the individual datasets, from the layer files stored within the geodatabase. The reclassification of the OSC and current LULC were necessary for comparison, so

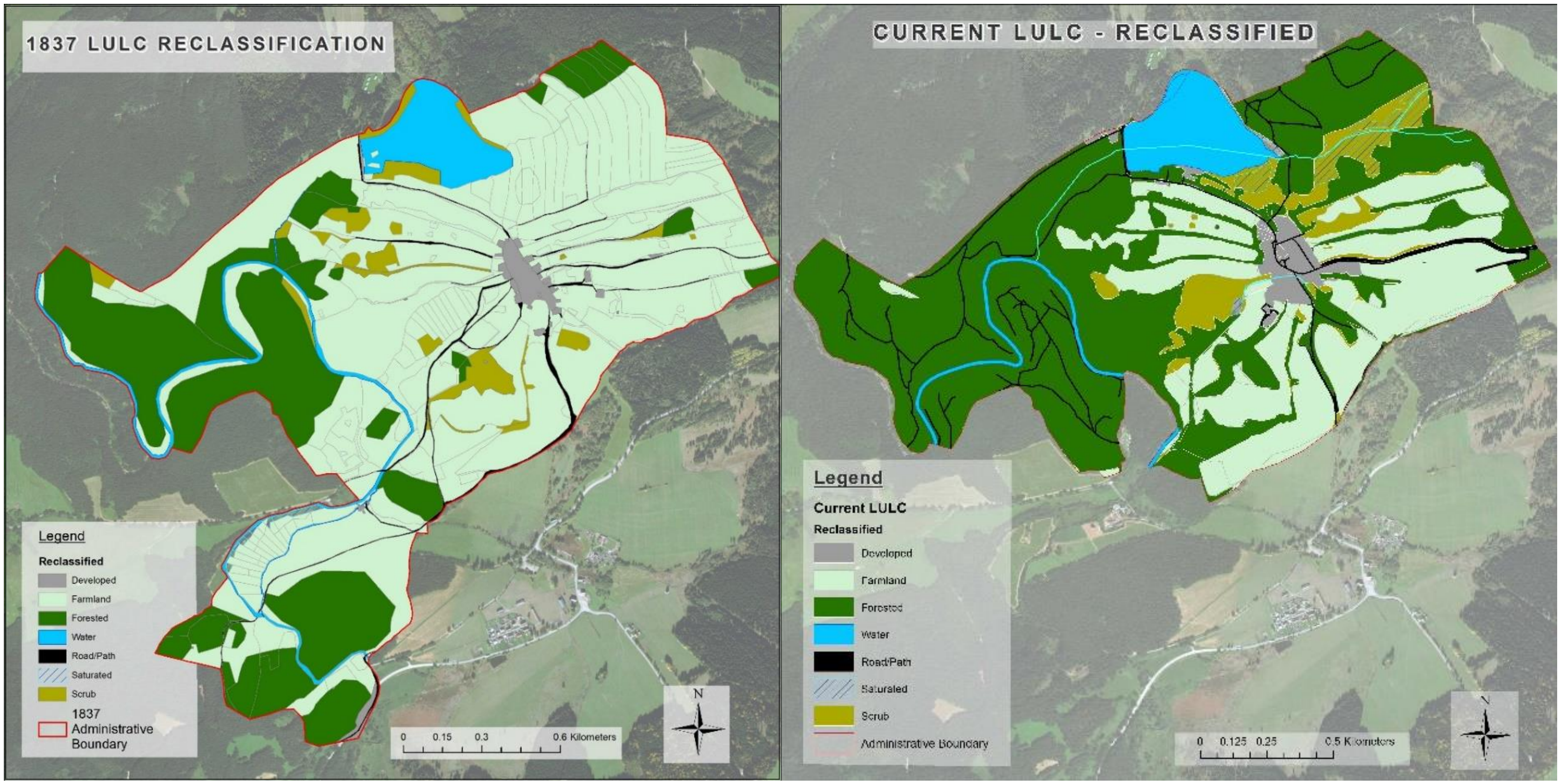

Figure 5-3 The reclassified LULC maps from the OSC (left) and the OSM (right) maps. Esri basemap.

Figure 5-3 shows the reclassification of each as a side-by-side comparison. Table 5-1 shows the calculated areas and percent of total area contained within each reclassified LULC category for the OSC and OSM maps. The percentages are helpful for comparison considering the changes to the Křišťanovice administrative boundary since the Original Stable Cadastre Maps were created. Most notable are the changes in farmland and forested areas, which also are the two land-cover types of the reclassification categories

	A - Farmland		B - Forested		C - Scrubs		D - Saturated		E - Developed		F - Road/Path		G - Water		
	Area (m^2)	Percent of Total Area	Area (m^2)	Percent of Total Area	Area (m^2)	Percent of Total Area	Area (m^2)	Percent of Total Area	Area (m^2)	Percent of Total Area	Area (m^2)	Percent of Total Area	Area (m^2)	Percent of Total Area	Total Area (m^2)
Original Stable Cadastre LULC (1837)	1988072	59.9%	870429.79	26.2%	125479.22	3.8%	175694.42	5.3%	44765.89	1.3%	53880.28	1.6%	60470.05	1.8%	3320131.1
LULC (1837) - equalized area	1710032.2	65.0%	560499.1	21.3%	124828.77	4.7%	0	0.0%	38387.23	1.5%	43333.04	1.6%	147543.76	5.6%	2630567.5
Current LULC	677639.45	25.8%	1629254.8	61.9%	256100.58	9.7%	198196.69	7.5%	82031.74	3.1%	20019.52	0.8%	137625	5.2%	2630567.5

Table 5-1 Total area calculations of each LULC type, and the percentage of total area for the OSC and OSM maps.

with the largest influence on the underlying mechanisms of sediment transport. Water is also a large contributor of sedimentation, however this has less to do with the features on land and more to do with the movement of water within waterways and from surface runoff. The water and the road/path reclassification categories are also complicated by the fact that OSM data represents waterways and roads as line files, while the OSC represents river, road, and path features as shapes with area. This makes it particularly difficult to compare the change in land covered by these classifications between the two maps, thus I have excluded these categories from further analysis. The locations of these features are still represented on the maps to allow for a visual assessment of the changes of road, path, and water features between the two maps. Between the 1837 LULC in

Křišťanovice derived from the OSC maps, and the current LULC in Křišťanovice derived

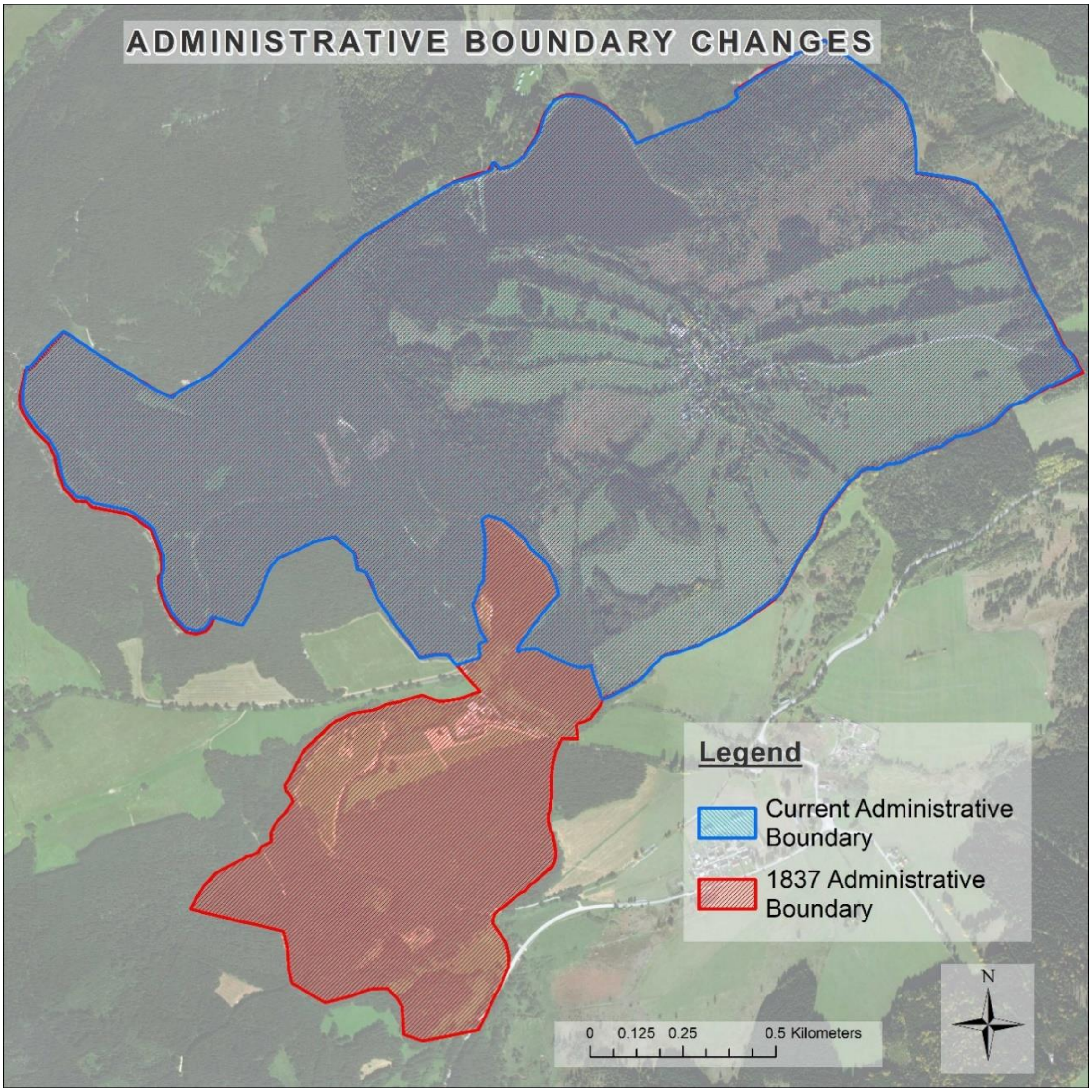

Figure 5-4 Map showing the change in Křišťanovice administrative boundary between 1837 and present-day. Esri basemap.

from OSM data, the percent of farmland to the total administrative area decreased from 65% to 25.8%. The percentage of forested area increase from 21.3% in 1837 to 61.9% in the current Křišťanovice landscape. The percentage of area covered in scrubs increased from 4.7% to 9.7%. The percentages of saturated and developed land areas also increased since 1837, though the percentage of developed land did not increase greatly from 1837 to present-day compared to other categories. Beyond changes in LULC in this time period, the current administrative boundary for Křišťanovice has noticeably changed shape and size, decreasing from 332.01 hectares in 1837 to 263.06 hectares currently (Figure 5-4). Considering this drastic change in area, I clipped the extent of the OSC

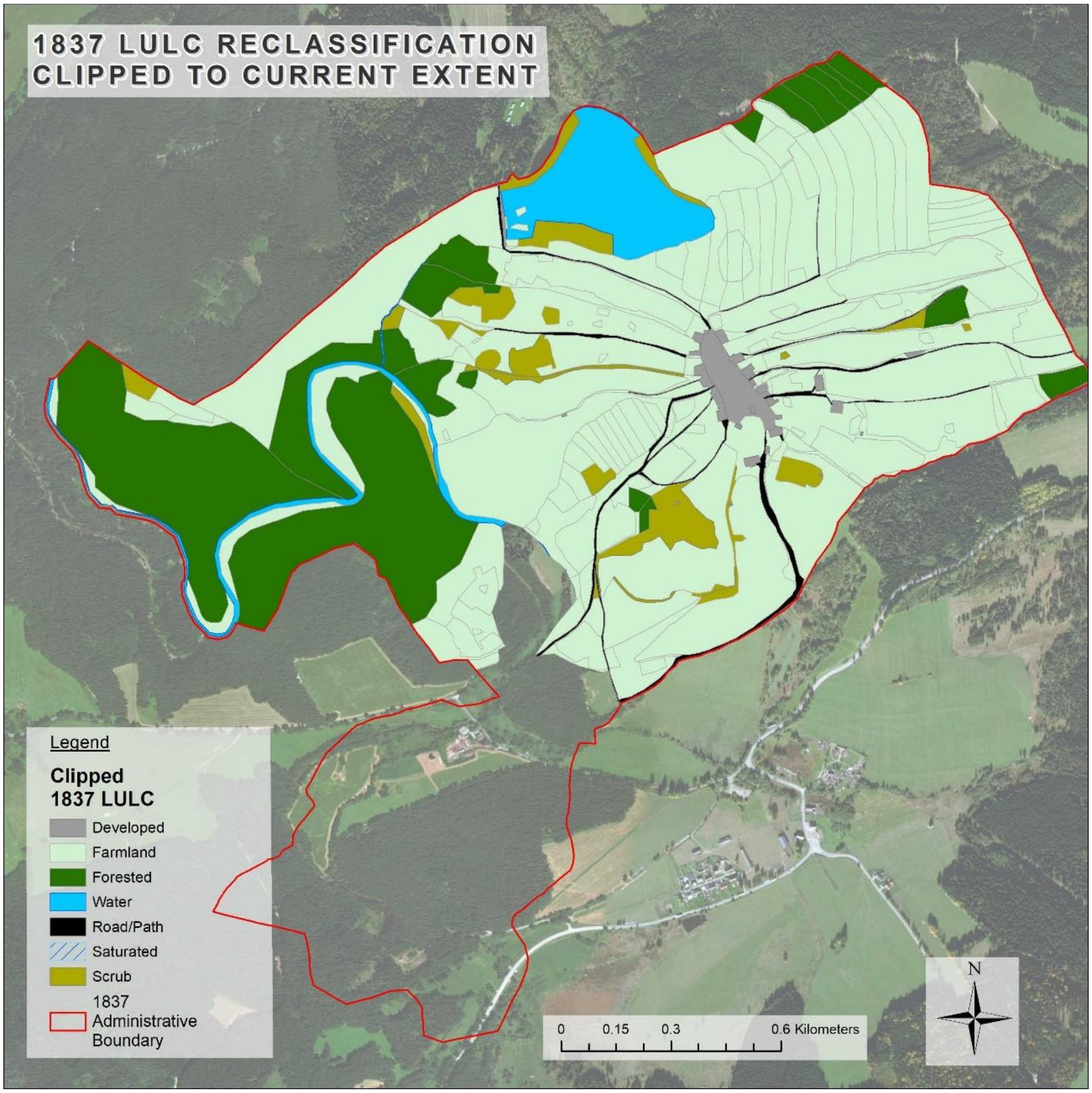

Figure 5-5 The 1837 OSC LULC map with the area reduced to the size of the current administrative boundary. Esri basemap.

LULC map to the area of the current boundary which allows for better comparison between the two. Figure 5-5 shows this map, which makes the area between the OSC LULC and the OSM LUL consistent. From this, I derived the percentages of LULC categories and change between the 1837 and current as shown in table 5-1.

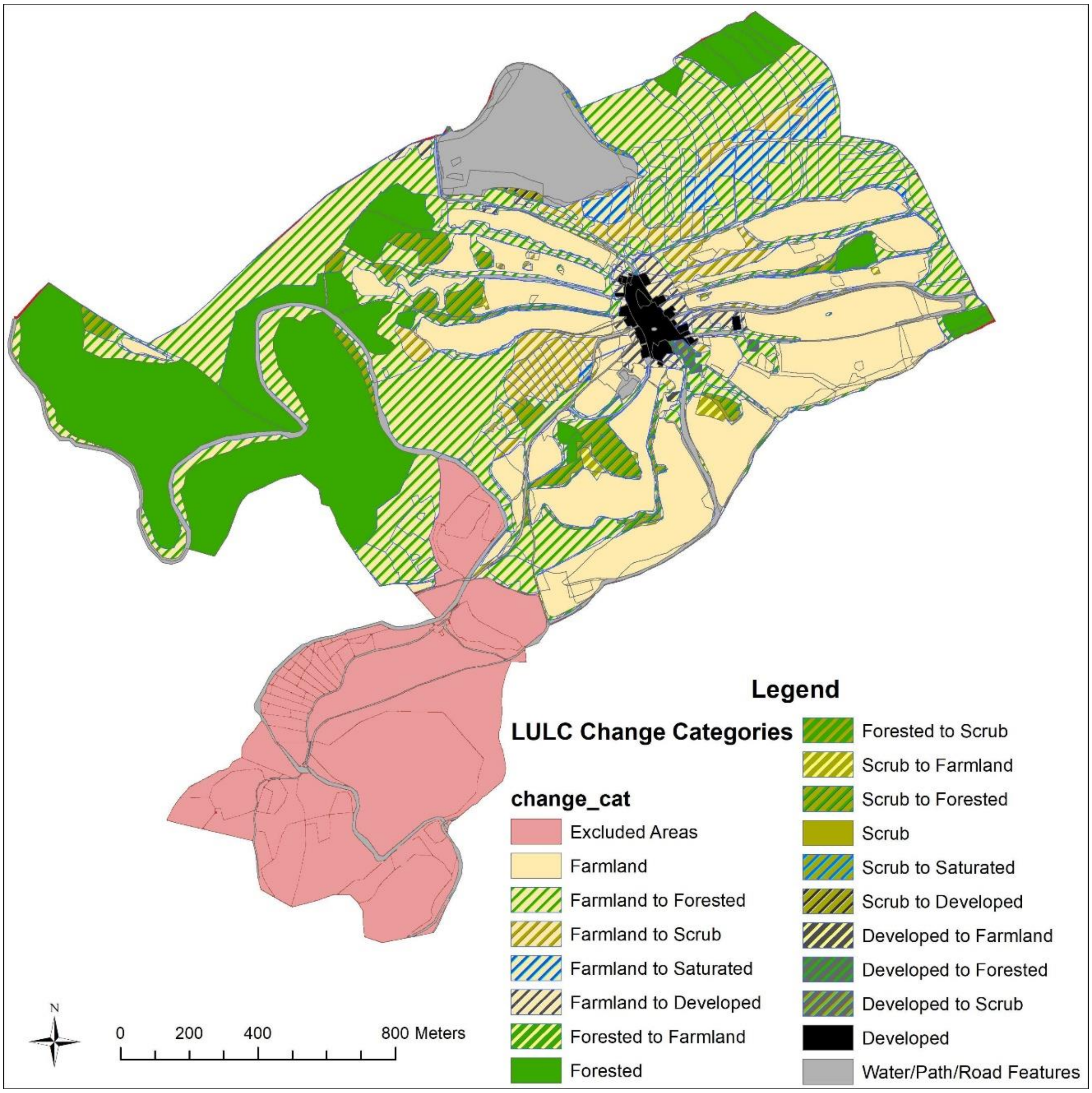

Figure 5-6 Map showing areas of LULC change between the 1837 OSC map and the current OSM LULC.

The first LULC change map visualizes seventeen different categories of land-use change between the OSC and the OSM maps, as well as excluded features (Figure 5-6). The features symbolized in red are excluded from the characterization because these are features that are excluded from the current administrative boundary of Křišťanovice. Since the OSC map was created, this land was removed from Křišťanovice and redrawn

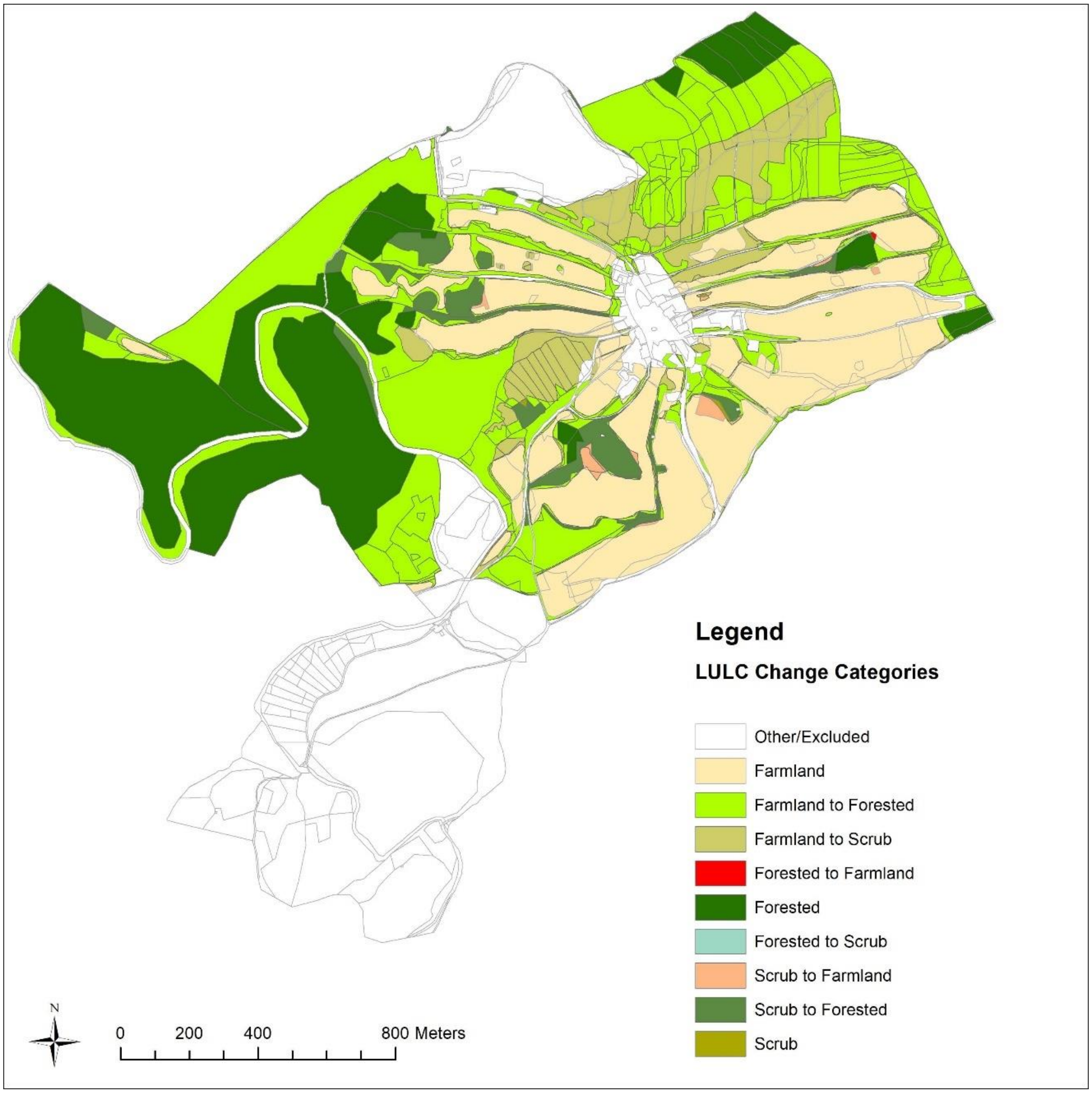

Figure 5-7 LULC map of major LULC change categories.

within the boundaries of another cadastral territory. Water, path, and road features are symbolized in gray and excluded from change analysis because these features are inconsistently represented between the OSC and the OSM maps. The OSM data represents water bodies as shapes, but waterways, roads, and paths as line features. The OSC map allowed me to vectorize all water, road, and path as shapes, which gives them a quantifiable area, unlike line features which do not have area. The discrepancies between shape and line features of these LULC makes it impossible to accurately quantify the difference in land coverage of these specific categories between the OSC and OSM maps. Considering the developed areas did not change much in area and distribution since 1837, and that saturated land can also be one of the other LULC types (i.e. saturated fields and saturated wooded areas), I created another LULC change map to visualize the changes between forested, farmed, and scrub features (Figure 5-7). These three LULC types incorporate the majority of visual change, and also have the most influence on ecological and geophysical processes within the village of Křišťanovice. The features represented in Maps of Cultivation of the Stable Cadastre (1837-1844) images for Křišťanovice roughly align with those on the Stable Cadastre Maps (Figure 5-8). This makes sense considering both maps were created around the same time, and allowed me to use the cultivation maps to validate and support the data I collected from the OSC maps. The original purpose of the cultivation maps was to map out the generalized cultivation culture of cadastral municipalities in Bohemia between 1837-1844. They coincide with the OSC maps in area and in symbolizing fields, pastures, and forested areas. The small-scale map from the Topographic Section 1:25,000 of the third military mapping (1924) shown in

Figure 5-9 provides very simplified classification of the landscape, included pastureland, meadows, villages, and water. These toposection maps were created to survey the

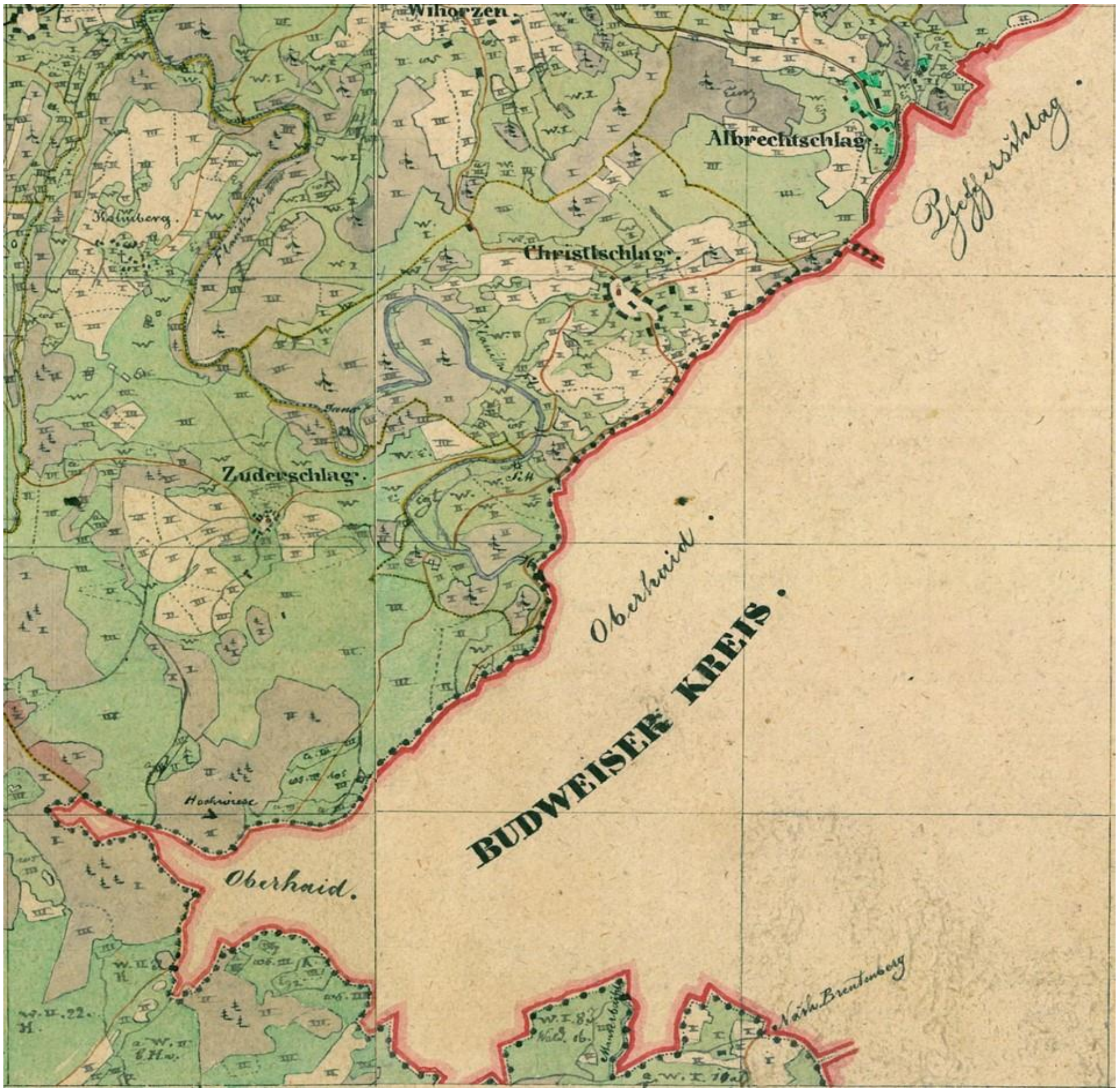

Figure 5-8 A section from the Maps of Cultivation of the Stable Cadastre 1837-1844. Křišťanovice is shown labeled as Christlschlag.

elevation of the region, and are therefore not very useful for landscape feature identification within cadastral territories. However, the area just north of the Křišťanovice settlement or village center which contained a water body in the 1837 OSC map does not show any water feature or saturated land in this 1924 representation of the area. Water bodies are an important feature in military maps and so I assume that this feature did not exist in the same capacity in 1924 as it did in 1837 and again in the current landscape. More investigation and research on this are needed before I can draw a conclusion on the

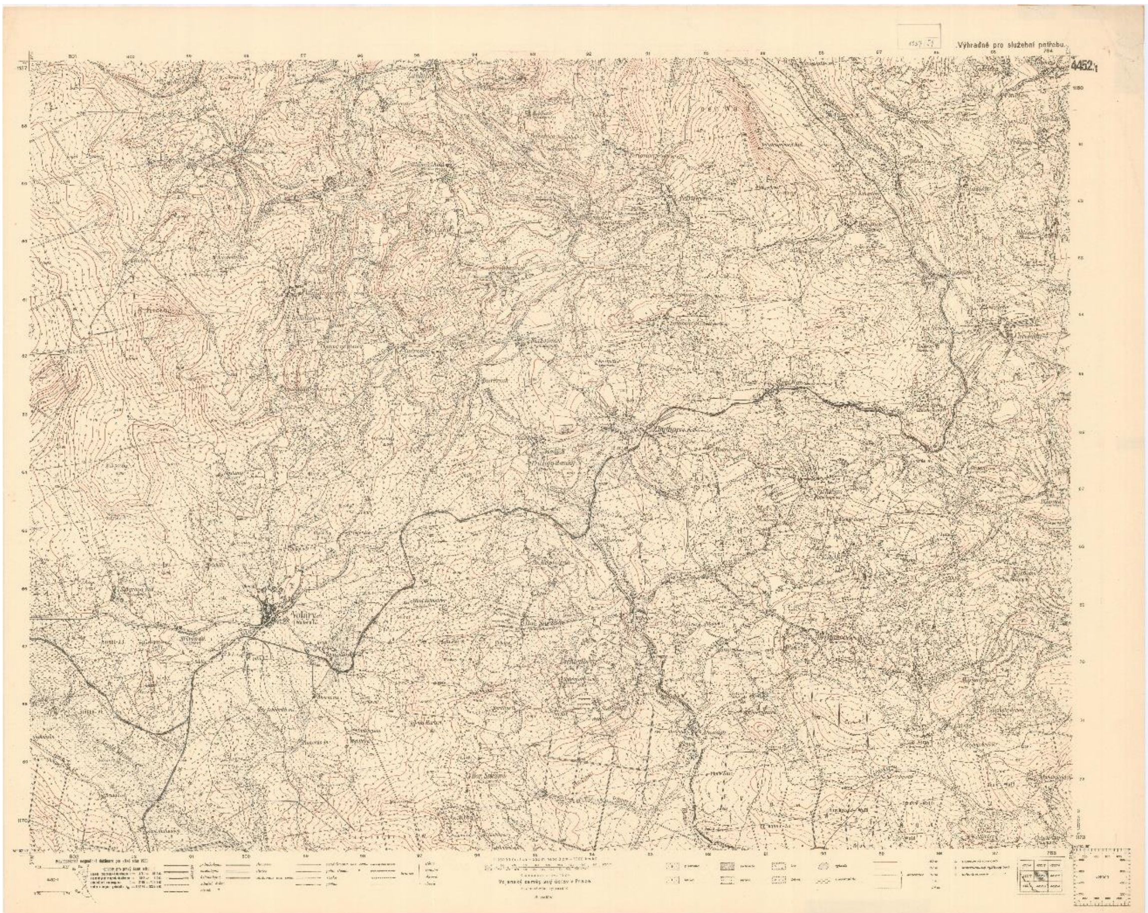

Figure 5-9 Sheet from the Topographic Section 1:25,000 from the third military mapping project of 1924.

absolute disappearance of this feature. The 1952 Topographic Maps of the General Staff of the Czechoslovak Army provide a colorful representation of the topography and land-cover in the study area, though still with less detail and a larger extent than the OSC (Figure 5-10). From this map, I can derive the existence of the water body that was seemingly nonexistent in the 1924 topo map. The saturated land, labeled as wetland, is clearly portrayed in this rendering of the landscape. Though not quantifiable, a visual assessment shows that the extent of this wetland covers a much larger area than is represented in the OSC map, but is similar to the saturated area in the OSM map.

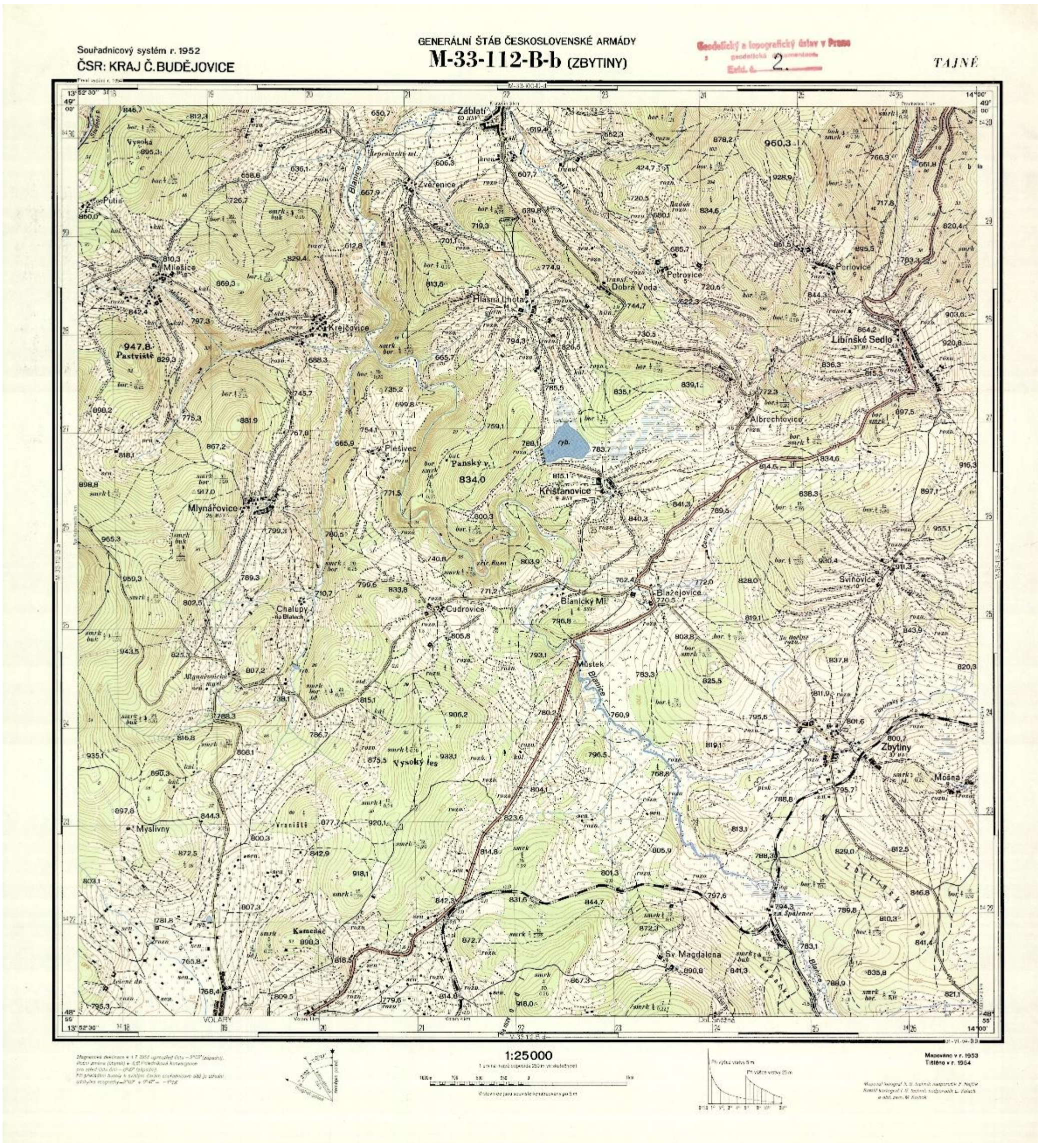

Figure 5-10 Topographic Maps of the General Staff of the Czechoslovak Army map image from 1953.

As previously stated, the lack of a key or legend defining the symbology for the State Maps (1950) led me to exclude them from analysis. These maps were derived from the Stable Cadastre Maps and produced around the same time as the 1952 Topographic map. As previously stated, the lack of a key or legend defining the symbology for the State Maps (1950) led me to exclude them from analysis. These maps were derived from the Stable Cadastre Maps and produced around the same time as the 1952 Topographic Maps of the General Staff of the Czechoslovak Army, making them redundant for the purposes of this project.

Through careful consideration of methods that both incorporated and minimized limitations and inaccuracies of historical maps, I developed a workflow. This workflow provides steps from each part of my methods section, useful for continued research in the study area. By following the methods, future researchers can apply the same techniques and improve interoperability and cross-comparison of datasets generated by multiple users and multiple cadastral territories. I have also created a geodatabase, with attribute value domains for LULC classification and symbology. This HGIS database is specific to this project within the Blanice Watershed, Czech Republic, and allows for easier and more uniform, storage, classification, and visualization of the LULC datasets.

Chapter 6: Discussion

6.1 Limitations

The principal objective of this project was the development of appropriate methods for analyzing historical and current geographic information, while including information gathered from non-spatial data. Applying an HGIS analysis framework necessitates the acknowledgement and discussion of potential errors within methods and analysis of results. For this study, errors were potentially introduced during the collection and referencing of historical map images, the vectorization of map features, the translation and interpretation of OSC map legends, and comparison with current LULC derived from crowdsourced OSM data. For each of these instances, I have outlined the techniques I used to eliminate or reduce the impact they had on analysis and results.

Historical maps can contain cartographic bias and error from its origin, and the maps can be stained, discolored, lost, or warped during storage and subsequent digitization. To minimize errors of this kind, it is important to understand the original purpose of each historical map and the accuracy of cartographic elements such as the reference system. This study only used historical maps with a consistent coordinate system, which is first seen in the 1837 OSC maps. Prior to this, maps either used inconsistent regional coordinate systems or an outdated trigonometric network based on a known control point, which are much harder to translate into a modern coordinate system for georeferencing (Zimova, Pestak, and Veverka 2006, Cajthaml 2011, Skaloš et al. 2011). Coverage of the cadastral territory of Křišťanovice was identified in historical maps prior to 1837, but none of these maps provided any information on LULC or human activity within Křišťanovice and they were excluded from this study. From the historical maps that were included, only the State Map Series from the 1950's and the 1837 OSC maps were georeferenced. Georeferencing and vectorization methods for these two maps were created with the intention of reducing errors, including tailoring GCPs to the features rather than the map sheet gridlines, repeating steps until the lowest RMSE value was calculated, and excluding questionable features from vectorization. Because the features from the State Map could not be identified from a legend, the map was excluded from LULC classification totally. I had the OSC legend translated from Czech to English by a native speaker, rather than using an online translator such as google translate. This reduced the number of confusing terms which did not directly translate to English and allowed for an interpretation of terms from the perspective of a native Czech speaker living in a rural area of South Bohemian with familiarity to agriculture. The data for the current LULC of the study area were collected from OSM data. As an open data source, OSM crowdsources information from users about LULC at any location across the world. Crowdsourced data poses potential errors, as the quality of data may depend on the number of users contributing, and hypothetically each user may introduce bias from their personal interpretations. However, many studies comparing the quality of European LULC data from OSM to remotely sensed data such as Global Land Cover, Moderate-resolution Imaging Spectroradiometer (MODIS), GlobCover, CORINE, and Global

Monitoring for Environment and Security Urban Atlas (GMESUA) have found OSM data to be comparable (Arsanjani et al. 2013, Arsanjani et al. 2015, Estima and Painho 2013). OSM data is accurate for classification of landscape surface types and features, especially at local and regional scales (Geletič and Lehnert 2016, Dorn, Törnros, and Zipf 2015, Schultz et al. 2017). Comparison of OSM LULC globally results in inconsistencies in classification types, which makes sense considering users most often contribute in areas they are familiar with. This behavior creates higher density and quality of data in areas that are more densely populated. That being said, the South Bohemian region has adequate coverage and quality of OSM LULC data. I also believe there is an advantage of utilizing OSM data over other sources. Besides being cost-effective, OSM data relies on the knowledge of locals, who can contribute an interpretation of the landscape that incorporates physical characteristics as well as cultural and geographical value that may be excluded from data collected from sensors. This kind of LULC analysis integrates elements of space as place, which is appropriate for this study. The other limitation of OSM data is that there are often gaps between features of LULC data. In the study area, there were thirteen gaps less than one hundred square meters in area. For these gaps, I created shapes to fill them, assigning LULC classification based on the surrounding features and current satellite imagery of the land surface in Google Earth Pro. Within the limitations of each of these datasets and methods, the significance of the results can be properly discussed.

6.2 Significance

Research outcomes include the LULC map derived from the 1837 OSC, the LULC map derived from OSM data, the reclassified maps of each, the methodological workflow for using historical maps to derive LULC change studies, and a structured geodatabase schema. Each product relates to elements of the research objectives and the bodies of literature behind them and contributes to understanding of the LULC in Křišťanovice.

The LULC maps from the OSC and OSM data reflect a quantifiable change in LULC. Most notably, the percentage of total area covered by farmland decreased from 59.9% to 25.8% and the percentage of total forested area increased from 26.2% to 61.9% between 1837 and present-day in Křišťanovice. This may reflect changes in land management due to sociopolitical regimes which resulted in afforestation, such as the Industrial Revolution and collectivization policies. Visual assessment of the features for roads and paths from the current LULC map compared to the OSC LULC map illustrates a disappearance of dirt footpaths, and the establishment of a network of paved roads and trails throughout the developed and forested areas of Křišťanovice. The developed village center has expanded from the OSC to include more buildings, parking lots, and recreational areas in the current LULC map. Even with this expansion, the percentage of developed area has only increased 1.8% since the OSC map. The LULC change maps identify the locations of temporal variation of LULC between 1837 and today. Most notable is the significant number of features which represent a change from farmland (pastures, fields, and meadows) to densely forested land. These maps provide spatially explicit examples of different LULC change types, which can inform or improve interpretations of ecological and geomorphological data, or indicate locations for further in-situ data collection. The map sheets from the 1953 Topographic Maps of the Czechoslovak Army and the 1924 Topographic Section from the Third Military Mapping were used to identify the existence of water and landscape features in the study area in the time between the OSC and the OSM maps. Even without spatial referencing, this information is important for qualifying a temporal influence of landscape features on the cultural, ecological, and geophysical fluxes of the surrounding landscape, such as hedgerow influence on soil erosion. Collectively, the data collected presents a detailed and thorough investigation of LULC change within the village of Křišťanovice. Researchers can use these data to make links between historical LULC change and social and political trends. Results can also be incorporated into characterizations of hedgerow features to explain the influence of individual hedgerow clusters on environmental processes.

Methodologically, the procedures outlined in this project and presented in the workflow present an application of HGIS research. This approach emphasizes methods that produce the best results for the research questions, rather than restrain methods within larger procedural expectations or standards of one discipline. Individual methods of data collection, data interpretation, data processing, data analysis, and data visualization were all derived for their intended purpose within this specific project in this study area. This includes only georeferencing historical maps that had enough detail to examine LULC within the village, understanding the purpose and cartographic details of each map, and using maps within their limitations like the State Maps which were useful for boundary delineation but not LULC classification. The workflow I have developed can be used in future research within the Blanice Watershed. Users can follow the steps and methods I outlined to collect data, justify methods, and eventually produce a comprehensive and cohesive detailed LULC change analysis for all villages within the watershed. This would result in a larger size HGIS dataset when used in conjunction with the organization and schemas from the HGIS geodatabase used in this study. While the methods from this study are not directly applicable to every other study on historical LULC change, they do provide an example of the theoretical approach to method development that is necessary to similar HGIS studies, as well as an example of integrating the spatial tool component of GIS with the conceptual and cultural considerations that are a key identifier of historical geography research. This integration of qualitative and quantitative techniques for historical geographic data collection and analysis distinguishes HGIS as a distinct field of geography as one which engages epistemological considerations of GIS methodology for historical geographic information. My hope is that through development of methodological workflows and databases, future research can utilize these and collect, visualize, and analyze historical geographic data as appropriately and accurately as possible.

6.3 Conclusions

By providing new insight on the historical patterns of land-use in the Blanice Watershed, Czech Republic using data collected from historical maps, I have presented an epistemological-based case study of HGIS research methods. From this study I conclude the following. First, that historical maps within the Blanice Watershed are valuable data sources for temporal characterization of LULC patterns. Second, that the application of HGIS methods for LULC research allows each historical map to be used most effectively within its own quantitative and qualitative limitations. And third, that the methods of this research can be applied to other cadastral territories within the Blanice Watershed to provide a highly detailed HGIS dataset and a spatially explicit improvement to LULC change analyses within each cadastral territory. Future work on the LULC in the region can apply the methodological workflow and geodatabase schema I have developed.

In terms of broader impacts, I hope my research will support efforts to create and make widely available comprehensive database collections of historical geographic information, facilitate international research relations while contributing to future projects across disciplines. Regarding the protection of Czech hedgerow networks, there currently exist two administrative Czech Acts that do not recognize these specific landscape structures but are suitable for protecting them in the future: within the "Landscape Zone" category of the Cultural Heritage Act, and the "Natural Park" category of the Nature and Landscape Preservation Act (Sklenicka et al. 2009, Vorel et al. 2006). I hope my results can be used as a tool for those advocating the importance in maintaining hedgerows, by providing methods for quantifying the age and change in extent of hedgerows over time.

Purchasing maps and data from HGIS databases such as the geoportal maintained by the State Administration of Land Surveying and Cadastre provides support to the efforts made to collect, maintain, and make available HGIS in databases, particularly those available internationally through a web interface. A secondary contribution of this study involves ongoing and future geomorphology research. Specifically, continuation of my research in other hedgerow networks in the Blanice Watershed can inform site selection for in situ stratigraphy collection in the Blanice floodplain and associated analysis of results. The LULC change maps can identify areas of greatest deforestation or afforestation of hedgerows, which may have vastly different impacts on sediment transport and can also be used to interpret soil stratigraphy. By informing studies in this way, I would be contributing to the advancement of theoretical sedimentation processes and patterns. It is also important to note that with regard to recent studies on the mitigation of soil erosion by hedgerow land-use specifically, this contribution could also support progress towards understanding longer-term agricultural sustainability practices. The present-day environment is largely a product of past land use, meaning land managers within the study area can potentially use my results to interpret the effects of past management and inform current and future management plans. Results can also help to explain current biodiversity within the study area and the effects of forestation or habitat fragmentation on distribution of current plant and animal population.

Considering this research project as an in-depth investigation of one cadastral territory within the larger Blanice Watershed study area, there is opportunity to apply the methods used in my project to the rest of the sites in the study area. The resulting maps may bring to light more questions about the changes to LULC within the study area over time, and how they relate to or drive change in land management, sociopolitical events, geophysical processes, and the surrounding ecology and microclimate. Through the continuation of this research, a detailed LULC change analysis can be produced for the entire watershed. This would be valuable as large and comprehensive HGIS database, facilitating future historical, ecological, cultural, and geomorphological research to answer questions about the relationship between these factors and LULC changes.

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Appendices

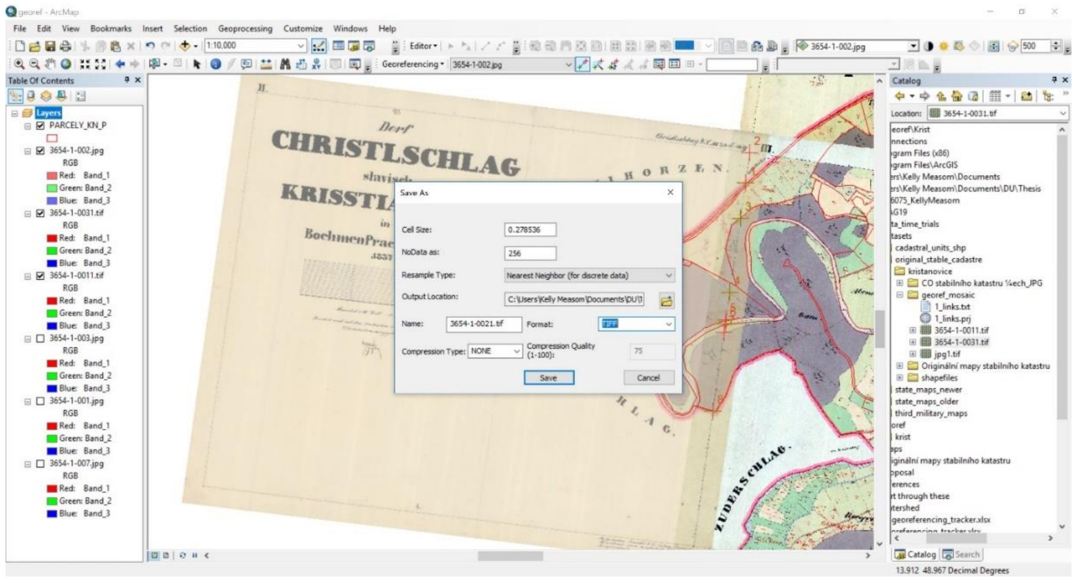
Appendix A: Cadastre Data Collection, Processing, Visualization, and Analysis

Workflow

1. Identify Cadastral territory
2. On the Geoportal E-shop data viewer application navigate to “Výběr produktu” → “DATOVÉ SADY” → “Data archiválií” to view archival datasets
    a. Select archival dataset
    b. In the “Zadání rozsahu” tab, select “katastrální území” to search by cadastral territory and then type your cadastral territory name in the bottom search box.
    c. Add products to your cart, download them as .jpgs
3. ArcMap Blank document
    a. Change coordinate system and map display units in arcmap
        i. Meters
        ii. Coordinate system: S-JTSK EastNorth Krovak ESPG 4415
    b. Import reference file (modern cadastral territory shapefile)
    c. Import jpg map sheets
4. Georeferencing – Georeferencing toolbar

    For each map sheet:

    a. Use rotate, shift, and scale tools to get it roughly aligned with reference shapes/data
    b. Add control points at common features between map sheet image and referencing data
        i. Roads, permanent structures, etc
    c. Ensure RMSE (root mean square error) improves with added control points.
    d. Transformation
        i. 1^{st} Order Polynomial (Affine)
        ii. Update georeferencing
        iii. Save as .tif

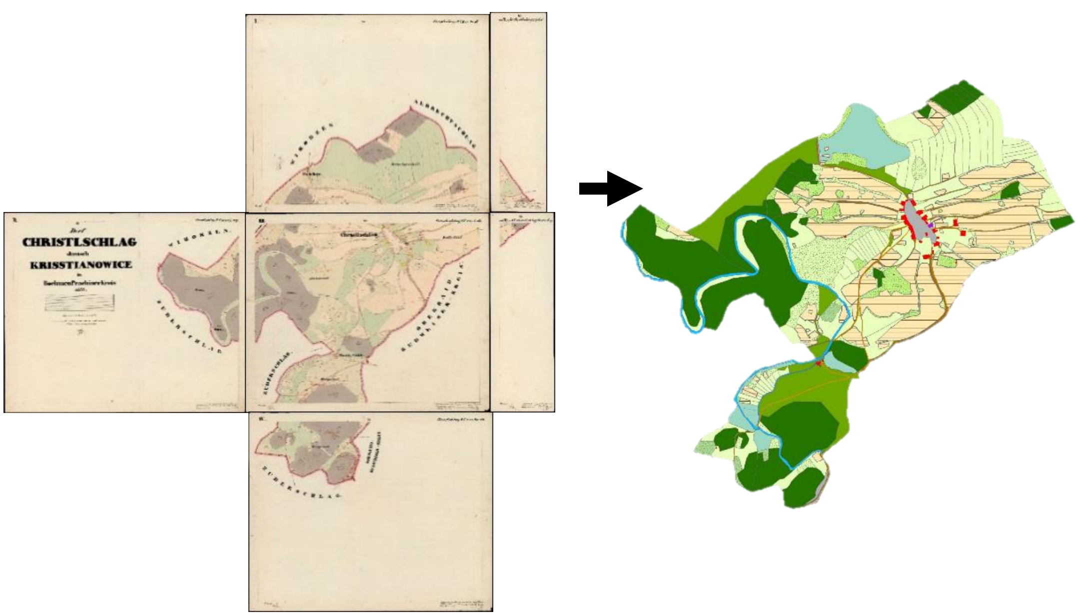


5. Creating vector dataset
    a. ArcCatalog
        i. Create new file geodatabase
        ii. Properties → domains
            1. Add domains with drop-down lists for land-use, etc
        iii. Create new feature dataset
        iv. Create new feature class
            1. Add field → Field properties → domain value
    b. ArcMap
        i. In a blank mxd, import georeferenced TIFF map sheets, and blank feature class with domain constraints
        ii. Use Create Features Construction Tools, Editor Toolbar, and Advanced Editing Toolbar to draw polygons
            1. Trace existing features
            2. For each polygon drawn, fill out attributes in the attribute table for the new feature

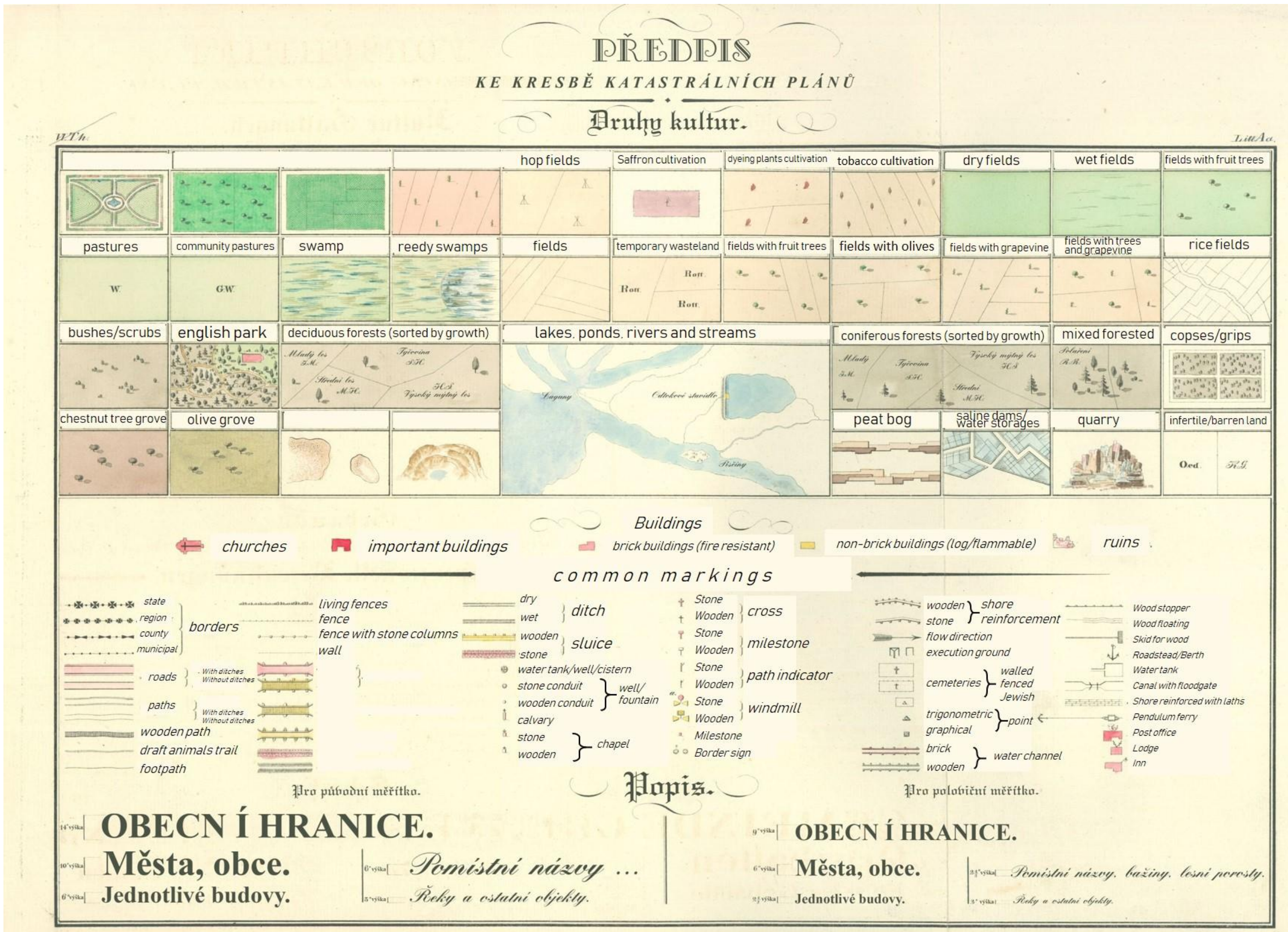
6. Comparing LULC datasets within each cadastral territory
   a. Appropriately reclass each dataset's LULC features into the scheme used below

Code	Label	Description
A	**Farmland**	Fields, pastures, and any other grassy lands cleared of trees and scrubs.
B	**Forested**	Wooded areas with tree cover; can overlap or be located within other features.
C	**Scrub**	Brushy area of scrubs, shrubs, and bushes; not cleared but not forested.
D	**Saturated**	Any LULC feature that is noted as being wet, saturated, or a wetland.
E	**Developed**	Built up areas or residential barren land: Parking lots, Industrial areas, Recreational areas, Buildings, etc.
F	**Road/Path**	Any road, path, or trail that is used to get from one place to another; includes bridges
G	**Water**	Lakes, Rivers, Streams, Reservoirs, Ponds, etc.

   b. Use the reclass_symbology.lyr layer file to symbolize reclassified LULC, and calculate the total area of features from each class



Appendix B: Imperial Imprints of the Stable Cadastre Map Legend – English Translations



Appendix C: Geodatabase Schema