FOSS FORWARD

USING OPEN DATA AND FREE OPEN SOURCE SOFTWARE TO DOCUMENT TERRACES IN THE LOWER ENGADINE, SWITZERLAND

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Using Open Data and Free and Open Source Software to Document the Terraces in the Lower Engadine, Switzerland

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Chapter 1: Introduction

1.1 Introduction and summary

The Lower Engadine is a region located along the north side of the Inn River in the easternmost part of Switzerland, within the westernmost Central Alps. This area is located within the Canton of Grisons[1] (fig. 1) and the landscape has been influenced by human occupation for at least 4000 years (Dietre *et al.* 2017, 191; Zoller *et al.* 1996, 51). The landscape and biodiversity of the Alps have been changed and shaped not only by climatic factors but also in response to human processes (Head 2011, 958). In this region, humans have relied on alpine pastoralism, which refers to the seasonal pattern of stock-raising and summer grazing in high altitudes (Head 2011, 958). This has left the lower regions free for farming activities on the geological terraces, which are still in use. The purpose of this thesis is to document the archaeological and historical terraces located near Ramosch and to investigate the spatial relationship between the terraces and the water system.
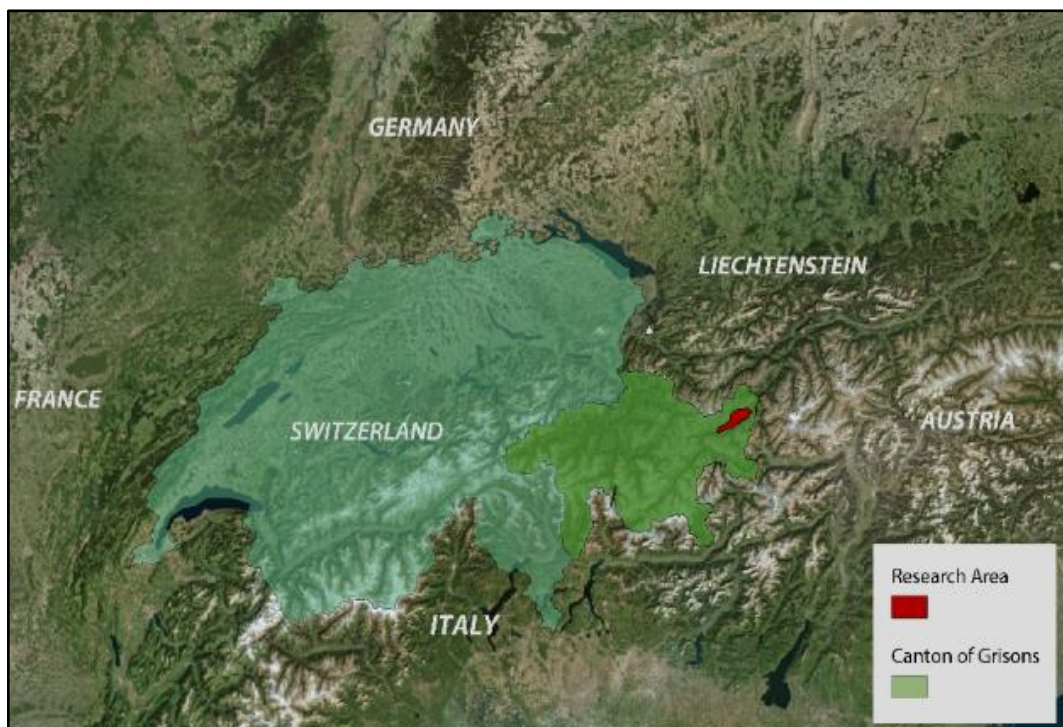
Figure 1. Context map showing the location of the research area (red) in relation to the Canton of Grisons (green), Switzerland, and neighbouring countries.

[1] Grisons is the English translation of the name of the canton. In literature, it may also be referred to as *Kanton Graubünden* (German, most common), *Chantun Grishun* (Romansh), or *Cantone dei Grigioni* (Italian). Grisons will be used throughout this thesis, unless using a direct quote or referencing a figure where a different language is used.

This will be done by collecting, studying, and analyzing a large variety of pre-existing data. The Lower Engadine has been selected as an ideal region of study based on the availability of data, the preservation of the terraces, the documented history of the terraces since medieval times, and previous archaeological and paleoecological on the landscape history and human land-use conducted in the area.

Following current research conducted by the "Terraced Landscapes of the Lower Engadine, Switzerland" project (the Terraced Landscapes project) during the 2015-2017 field seasons, the region near Ramosch will be the most intensively studied area (fig. 2), with less intensive study areas near Tschlin and in the municipality of Scoul. The purpose of this thesis is not only to examine these archaeological terraces but also to critically evaluate the effectiveness and efficiency of the digital methods used in order to answer archaeologically relevant questions.

Archaeologists collect and record a plethora of data in the field, to the minutest details, although often in a patchwork fashion (Backhouse 2006, 43-44). Computer technologies, both in the field and in post-excavation are endemic (Backhouse 2006, 43) within contemporary society and within the field of archaeology, and while the use of these programs and resources is invaluable, they must be subject to scrutiny by archaeologists to ensure the quality of the resulting conclusions.
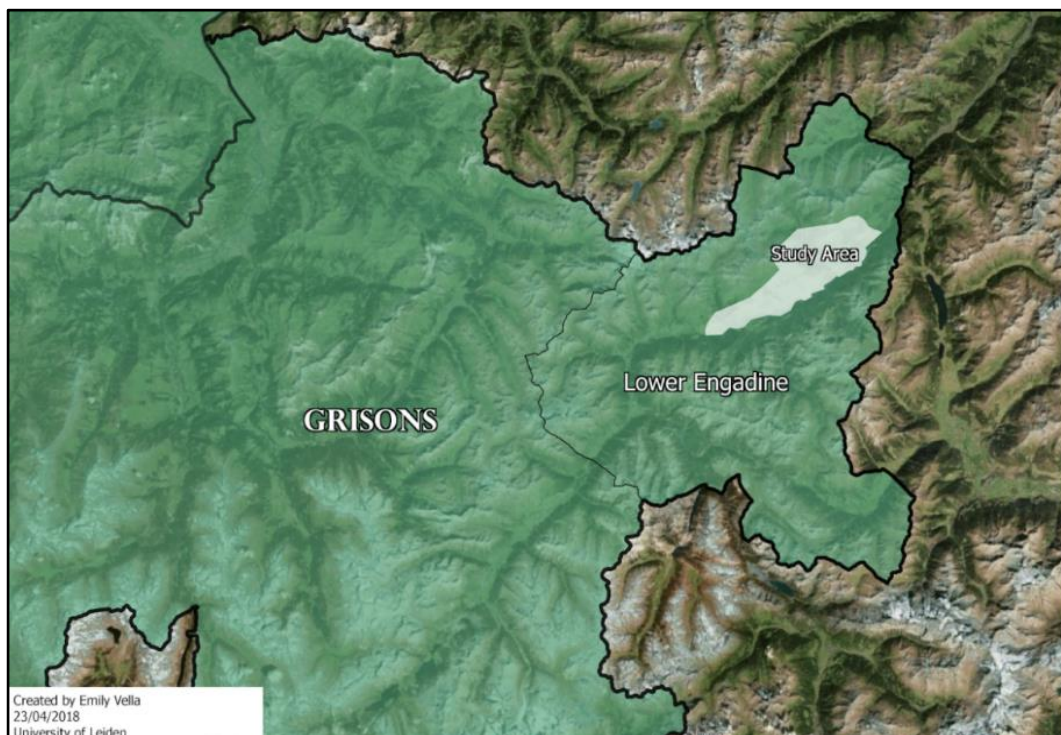
Figure 2. The study area is located within the Lower Engadine, in the Canton of Grisons. The Terraced Landscapes project focuses on the area directly surrounding Ramosch, where this project extends more to the west until Ardez.

1.2 Study Area

The study area is located in the eastern Swiss Alps, in the Rhaetian Alps range. The focus of this project is to look at the area surrounding Ramosch, including Tschlin, and Vnà, which have merged to create the municipality of Valsot and westwards into the municipality of Scuol, which includes Sent and Ardez (fig. 3). The area was divided into the following two zones: the central area and the area of interest/buffer.
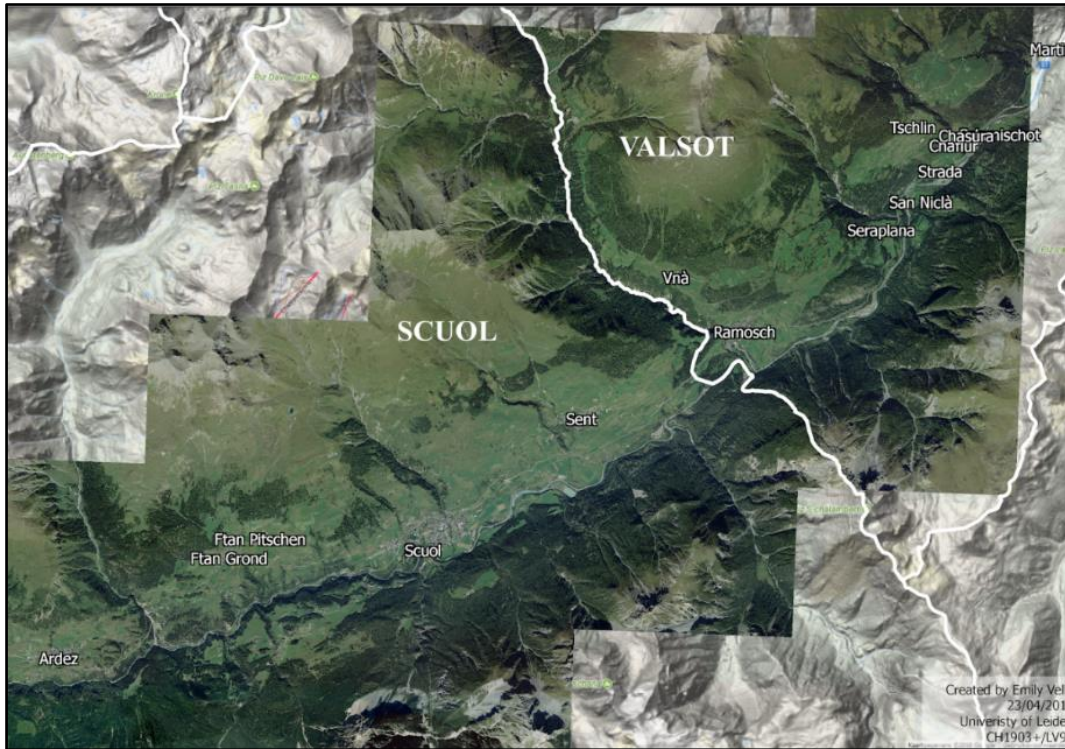
Figure 3. The study area is located within the Lower Engadine, in the Canton of Grisons.

1.2.1 Zone 1: central area

The first zone (fig. 4) is the focus of the project with an emphasis on Ramosch. The Inn River represents the southern border of the region. The slope on the opposite side of the river is used for pasturing and is currently covered in dense forests, making it impossible to detect any features using satellite imagery. The top of the tree line is roughly the northern boundary, as no crops would be able to grow past this point. In general, the slope/altitude increases towards the north of the study area, which has permitted the tree line to act as the northern boundary. However, this is not the case for the entire study region, specifically near Vnà, where the highest altitude and the tree line are towards the east. In this case, the peak of the Piz Arina Mountain (fig. 5) acts as the northern boundary. Seraplana acts as the eastern border and Sent acts as the western border. While the Lower Engadine extends further than this zone, this area has been selected due to the availability

of data and has been limited in order to define a study area that is feasible to investigate with rigour in the context of this thesis.

1.2.2 Zone 2: area of interest/buffer

Figure 4. The study area is located within the Lower Engadine, in the Canton of Grisons. The Terraced Landscapes project focuses on the area directly surrounding Ramosch, where this project extends more to the west until Ardez.

The second zone (fig. 4) forms a crescent shape around the central zone. It extends from Ardez in the east to create an arc above the tree line until Chasura in the west. These areas lie outside of the direct area of study but since the landscape is continuous, this acts as a buffer area for documenting the terraces. A large portion of this zone extends to the southwest, encompassing Scuol, Ftan, and Ardez. These areas have many known sites of archaeological importance and are thus included. Terraces exist throughout Scuol, outside of Zone 1 that will be documented but not investigated with the same rigour as Zone 1 due to the practical limitations of this project.

Figure 5. Image taken from Google Earth web application. This 3D map shows the slope to the east of Vnà (Piz Arina), which acts as the border for Zone 1. Accessed May 22nd, 2018, https://earth.google.com/web/.

1.3 Data Sources

The data for this thesis has been collected from a variety of sources. All of the data was obtained without cost, as it had either previously been purchased or is available online, free of charge. The data has been downloaded as both image files and shapefiles, amounting to approximately 130 GB of data. The data has been obtained from three sources: The Terraced Landscapes of the Lower Engadine Project/The Silvretta Project, Swisstopo, and GeoGR AG.

The Terraced Landscapes project is an extension of the earlier Silvretta Project. The Silvretta Project collected data in the field as well as purchased GeoEye (https://www.satimagingcorp.com) and orthomosaic photo, and provided a digital height model (DHM) [2], a georeferenced map, and various shapefiles. The GeoEye data and orthomosaic were purchased as tiles for the Silvretta Alps, which extended to my study area. The orthomosaic photo and DHM were purchased from Swisstopo.

Swisstopo is the federal office of topography in Switzerland. In compliance with Swiss laws on geodata (including aerial photography, historic maps, and digital height models) they act as the governmental body, which provides the official, accurate, and up-to-date geodata for a variety of consumers, ranging from corporations to private researchers. While the majority of the data is quite costly, free geodata is also available. The historical maps and aerial imagery were downloaded directly from their repository, titled "A journey through time," where these images can be downloaded for a select area as a PDF.

The last data source used is GeoGR AG (GeoGR), which hosts and provides spatial data for the of Grisons. After creating a free account, the majority of the data can be downloaded, including DEMs, land-use, road maps, and forestry data (many of which are free), in addition to linking with Swisstopo data. There is some overlap between swisstopo and GeoGR. Both are public agencies which appear to be working together to disseminate data.

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[2] Traditionally, DHM is a height model that includes cover (canopy, buildings, etc.). However, a digital height model is also the term used for a DEM in German. Swisstopo is available in English but it is uncertain whether this is a true DHM or simply a mistranslation.

1.4 Research Goals, Problems, and Framework

1.4.1 Goals and Problems

The goal of this thesis is to use data collected by second and third parties to document historical and archaeological terraces in the Lower Engadine region of the Swiss Alps, as well as the water sources used to irrigate these terraces.

One of the problems this thesis seeks to resolve the question of combining data from a variety of sources that have been collected and generated for various other purposes, with different resolutions and covering different extents, forming a patchwork of data covering the research area. Combining data becomes difficult because the formats in which the data is available are not always compatible with the software. To use an accessible example, images are available in a variety of file formats, such as JPEG, TIFF, or PNG, each with their own strengths and weaknesses as a file type. You can also see these images in a PDF or DOC file; all of these file formats are perfectly sufficient if you simply want to look at an image, however, there are many different types of file formats that can only be used by specific programs. If you wanted to edit the image in photo editing software, you will not be able to use the image in the PDF or DOC files. In order to use the data, it must either be converted or recreated in a manner that makes the data usable without losing information. One of the research goals is to create a workflow process that can combine the various sources of data into QGIS (https://qgis.org) in order to create multi-layered maps for analysis.

In order to document and analyze the historical terraces, the terraces will be looked at individually as well as collectively. They will be categorized based on morphology and location as well as their spatial relationship to each other. This presents the issue of time depth; without absolute dating methods (such as radiocarbon dating), it will be nearly impossible to accurately date the terraces using only remote sensing data. Dating of terraces is currently being completed by the Terraces Landscapes of the Lower Engadine project.

1.4.2 Sustainable Archaeology and data recycling

One of the aims of this thesis is to remain as sustainable and accessible as possible by analyzing pre-existing data, which has not been studied, and using easily accessible software, preferably open sourced when available. Sustainable Archaeology is a term that has been accredited to a joint Canadian research initiative between University of Western

Ontario and McMaster University (Ahmed *et al.* 2014, 138). In an attempt to address the collections management crisis in archaeology, the project set out to compile the Ontario archaeological record and to make it more accessible (Ahmed *et al.* 2014, 138).

While not dealing with physical material, this thesis deals with large amounts of data. Larger amounts of digital data are constantly either being generated from collection methods in the field (such as images, remote sensing, and geophysical prospection) or digitized during the post-processing endeavours. In addition, numerous organizations (government-related or otherwise) and heritage specialists are digitizing many older analogue datasets, including historical maps and aerial images.

Data recycling is a key component of sustainable archaeology, but has additional roots in digital archaeology; it is not exclusive to sustainable archaeology. This practice has also been referred to as data reuse and is a concept where archaeologists (in this context, although the principle can extend to other disciplines) recycle or reuse data, particularly remote sensing data, to investigate new research questions. This has the potential to save resources, and prevent unnecessary labour. In some cases, archaeological data collected from previous related field projects is reused, and in others, general-purpose data is purchased or obtained from non-related projects or organizations, as is often the case with satellite imagery. All the data used in this thesis has been previously collected by a variety of agents, for a variety of purposes, but has been collected with the same scientific and intellectual rigour that archaeologists require.

1.5 Research Questions

The primary research question is: In what ways can second and third- party data be incorporated into archaeological investigations and what are the minimum requirements of this data? The terms second-party and third-party are borrowed and adapted from comparative literature and marketing. In literature, a primary source has not been filtered through interpretation, a secondary source may include interpretations and an evaluation of the source, and a tertiary source is a compilation of primary and secondary sources that have been distilled down to their core components (guides.library.yale.edu). In marketing, first-party data is data collected through a direct relationship between the collector/user and the source (consumer), where third-party data is data collected by an entity that has no relationship with the source (Kaye 2014, 27). Second-party data is first-party data that has been purchased from the original source (Schneider *et al.* 2017, 593).

For the purpose of this thesis, these terms have been adapted to the data which has been used, but it is important to note that there is no known precedent for the use of these terms within archaeology. First-party data is defined as raw data that has been collected in the field by archaeologists for the purpose of investigating the terraces, where there is a direct relationship between the archaeologists and the data. Second-party data is data that has been purchased, interpreted, or filtered to be more suitable for archaeological purposes (i.e. data from the Terraced Landscapes/Silvretta projects). Third-party data is data obtained from outside organizations where the data has been collected for other purposes (i.e. Swisstopo, GeoGR).

The second research question concerns the combination of the data. The data used for this project is available from numerous sources in a variety of formats. What methodologies and workflow processes are the most effective for combining spatial data of the Lower Engadine from various sources in QGIS 1.8 Lisboa? This question specifically targets the strengths and weaknesses of QGIS as well as the quality of the data collected. On a broader scale, the use of FOSS within the context of scientific archaeological research will be evaluated.

The final research question is: What is the relationship between terrace morphology, location, altitude and proximity to water sources in the Lower Engadine? Variations in terrace morphology may be linked to a variety of factors, including altitude, slope, proximity to a settlement/water source, or associated settlement. Computational methods will be used to answer the first question.

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1.6 Outline

The second chapter provides a background on the basic history and archaeology of the region. The chapter begins with a brief archaeological and historical review of the region, focusing on the sites in the Lower Engadine and the Swiss Central Alps. The following section describes the relationship between the landscape the climate, and human presence in the region based on paleoecological studies and past human land-use patterns. This chapter is concluded with a section on the more recent studies on landscape and land-use changes in alpine environments, particularly the trend towards land abandonment in alpine regions.

The third chapter in this thesis is called "Theoretical Framework" and provides the foundation on which the methodology chapter is built. This chapter begins with sections on the theoretical framework, mainly Digital Archaeology and Sustainable Archaeology. This is followed by the technical framework, which includes a section on software, particularly FOSS programs, followed by the use of GIS in archaeology. The final sections under technical framework deal with the use of remote sensing data and mapping, primarily within an archaeological context. This is done in order to provide the necessary theoretical and technical framework with which this thesis is entangled. The theories, which this thesis is rooted in, shape the research questions, interpretation of results and are the theories/schools of thought, which have allowed this thesis to exist. The technical framework exists to describe the past and current progress of the relevant technological advances and practices within archaeology. The methodology and results of this thesis cannot be understood without first understanding the theory behind the processes that the data has undergone.

Chapter four is titled "Methodology". This chapter has been divided into two sections: Software and Specifications, and Workflow and Data. The first section will present a detailed explanation of the software used, the sources of data, and why they have been selected. The section titled "Workflow and data" will provide a detailed guide of the procedure, which lead to the subsequent results, such as the thematic maps and statistical results.

The fifth chapter, titled "Results and Analysis" presents the results of the research, which is based on the workflow procedures. The results and subsequent analysis discusses the terrace morphology and their relationship to each other and to water sources. This chapter has been divided into the results of the organization of the terraces and the changes in the landscape over time.

The following chapter, chapter six, will evaluate and interpret the results of the previous chapter and provide any additional interpretations, which may be relevant to the research questions. This discussion chapter will provide any additional research questions that may have arisen during the research and the potential for further research. It will discuss the relevance of the project within the broader field of Digital Archaeology. This chapter evaluates the methodology and answers the proposed research questions.

The final chapter, "Conclusions" will provide a summary of the results, analysis, and discussion and the implications of this project.

Chapter 2: History, ecology and archaeology of the Lower Engadine

2.1 Background

The history of the human occupation in the Central Alps is long and complex. In many cases, human presence is first inferred based on changes in the environment, as evidenced by paleoecological studies. It is important to understand the impact past humans have had on the landscape in order to differentiate modern changes in the landscape topography from prehistoric alterations. In order to understand the placement and uses of the prehistoric terraces in the study area, it is necessary to understand how past humans used their environment, not just in relation to a particular site or at a local scale, but on a regional scale.

The study area is a mountainous region, which is characterized by high altitudes, low temperatures and very specific ecosystems. Recent changes in mountain ecosystems are quite significant (Carcaillet *et al.* 2009, 7) and it is therefore necessary to explore what is known about past environments in the region. The Central Alpine landscape is characterized by low precipitation, high insolation, and high continuity, described as an inner alpine dry valley, which ultimately leads to a large biodiversity (Ammann 1997, 372).

The alps have seen a low level of urbanization (Head 2011, 958) which makes them an ideal landscape for which to study the impact humans have had on the environment without extensive modern influences (i.e., large cities, infrastructure, roadways, etc.). As of 1914, the Engadine region was described as "natural woodland free from all modifying influences" (British Ecology Society 1914, 266). Furthermore, the landscape is considered part of Swiss cultural heritage and there is an attempt to preserve the landscape (Fischer *et al.* 2008, 154). On November 7th, 1991, the Alpine Convention was signed by Switzerland, France, Italy, Liechtenstein, Germany, Yugoslavia (and later Slovenia), and Monaco for the environmental protection and development of the European Alps (Mathieu 2009, 5). Unfortunately, natural disasters, such as avalanches and rockslides are not entirely uncommon and have been known to damage infrastructure or make roads temporarily impassable (Kuehnelt-Leddihn 1945, 248), however, the damage to these sites is rarely documented.

2.2 Archaeological and historical context

Until recently, the only evidence for prehistoric alpine pastoralism was restricted to single finds at high altitudes (Reitmaier *et al.* 2017, 1). There are many reasons why past people took to the mountains; including the sourcing of raw materials, transalpine trade and transport, religion, regional conflicts, and most notably hunting and gathering, and pastoralism (Reitmaier *et al.* 2017, 1).

2.2.1 Lower Engadine

Human occupation in the Lower Engadine has been continuous since the Bronze Age as part of a supra-regional trading and communication network (Dietre *et al.* 2015, 75; Kothieringer et al 2015, 178). The earliest settlements in the Lower Engadine date to the Middle Bronze Age (1550-1350 BCE) and include the sites of Mottata, Scuol-Munt Baselgia, Ardez-Suotchaste, Lavien-Las Muottas, and Susch-Motta Palu (Dietre *et al.* 2015, 75; Kothieringer *et al.* 2015, 178). Sites in this area date from the Bronze Age to the Roman Age and include evidence of cultivated fields and the grazing of cattle (Dietre *et al.* 2015, 75). The agricultural terraces near Ramosch date to the 3rd or 4th millennium BCE (Dietre *et al.* 2015, 75; Kothieringer *et al.* 2015, 178). Scuol-Tarasp has many prehistoric settlements, many of which are found near carbogaseous waters (Bissig *et al.* 2006, 143-4). These water sources were used during the Roman period while some continue to be used as a mineral water source (Bissig *et al.* 2006, 144).

The oldest known site in the Lower Engadine, Ramosch-Mottata dates to the Middle Bronze Age (2200-1350 BCE) and continues into the Iron Age (800-50 BCE) (Reitmaier *et al.* 2017, 2). This area was optimal for settlement due to the favourable climate, which allowed for the construction of terraced fields, and its position on important inner and transalpine trade routes (Reitmaier *et al.* 2017, 3). While the keeping of livestock appears to have been important for Bronze Age and Iron Age economics, there is no evidence of stabling at Ramosch-Mottata (Reitmaier *et al.* 2017, 3, 8). Reitmaier *et al.* hypothesized that they kept animals in distant pastures which may indicate the exchange of animals between different sites enabled by social (2017, 8). This earlier pasturing was more mobile and did not allow for a focus on dairying due to the high level of labour and low level of mobility (Reitmaier *et al.* 2017, 11). A shift in land-use is evident around the time that the Laugen-Melaun group migrated to the region (1350 BCE) from exploiting primary products to secondary products (Reitmaier *et al.* 2017, 10). This shift towards dairying can be considered a more stable form of animal utilization (Reitmaier *et*

al. 2017, 10). The Bronze Age expansion in the Engadine continued into the Iron Age, as seen by numerous settlements and dwellings (Della Casa *et al.* 2013, 44-45)

The modern history of the Lower Engadine has been extensively reported on in previous publications. Between the 5th century CE and 1985, the landscape probably did not change significantly in this region (Raba 1996, 58). At the beginning of the Middle Ages, the settlement of Mottata relocated to its current position in Ramosch (Raba 1996, 58) based partially on the first written record of Ramosch which appeared in 930 CE (Raba 1996, 59). The population fluctuated throughout the Middle Ages in accordance with climatic trends and events, with an increase in agriculture between the 14th and 19th centuries CE (Raba 1996, 60-69).

2.2.2 Swiss Central Alps

The Silvretta Massif lies to the north of Ardez and contains larch meadows that have been used for grazing for more than 4000 years (Dietre *et al.* 2015, 75), although the earliest pastoral infrastructure dates to c. 600 BCE (Dietre *et al.* 2015, 76). The Urschai valley hosts some of the oldest sites, including Plan da Mattun, a Mesolithic rockshelter dating to the mid-7th millennium BCE (Cornelissen and Reitmaier 2016, 13; Dietre *et al.* 2015, 76). The fireplaces at Abri Urschai date to the 5th and 3rd millennia and have been interpreted as a Neolithic hunting site (Della Casa *et al.* 2013, 44; Dietre *et al.* 2015, 76; Kothieringer *et al.* 2015, 182). The Fimba Valley, located in the Silvretta mountain range, is host to 230 currently known archaeological sites, some of which date to the Mesolithic (Cornelissen and Reitmaier 2016, 17; Dietre *et al.* 2014, 4, 13; Reitmaier 2012). The first permanent building in the Silvretta Alps dates to the 1st millennia in the form of an alpine hut located in the Fimba Valley (Reitmaier *et al.* 2017, 2). The sites in this region have been well documented in recent years and more information can be found in Reitmaier 2012 and Reitmaier *et al.* 2013.

While sites date to the Mesolithic, there was a clear intensification of settlement in the Bronze Age (Kothieringer *et al.* 2015, 187; Lambers and Reitmaier 2010, 544). These sites can often be seen with aerial/satellite imagery and include stone structures that have been interpreted as huts and enclosures and are considered to be permanent settlements as opposed to earlier seasonal base camps for hunting (Lambers and Reitmaier 2010, 544; Reitmaier 2012).

Evidence for human occupation in the Upper Engadine dates to the Mesolithic (4850 BCE) (Gobet *et al.* 2003, 145). Throughout the Neolithic and Bronze Age, evidence for human presence is known only by single finds (Gobet *et al.* 2003, 145). The settlement

of Oberhalbstein has been settled since 2000 BCE for copper processing as well as farming and stock raising (Gobet *et al.* 2003, 145). Roman roads exist in this region and it is believed that these roads were built on existing prehistoric pathways due to the geographic position of the area (Gobet *et al.* 2003, 146). For a more complete history of the Alps, see Mathieu 2009.

2.3 Landscape changes in the Alps

2.3.1 A review of paleoecological studies

The vegetation in the Alps is highly dependent on climatic factors (Schwörer *et al.* 2015, 281; Tinner and Kaltenrieder 2005, 937). The study of the vegetation can be completed on both a local and regional scale but a regional approach is more beneficial for exploring the environmental factors that affect the vegetation, although a local variation needs to be considered. While alpine landscapes stretch across large areas, they exhibit large amounts of spatial and temporal heterogeneity (Fischer *et al.* 2008, 148). Mountain ecosystems are very sensitive to changes in both climatic factors and human land-use (Schwörer *et al.* 2014, 480; Colombaroli *et al.* 2010, 1347; Dietre *et al.* 2014, 3; Schwörer *et al.* 2015, 281; Tinner and Kaltenrieder 2005, 936). The tree line (fig. 6) is the most sensitive to changes and was primarily controlled by temperature and moisture in the first half of the Holocene, prior to human impact (Schwörer *et al.* 2014, 493). Due to the fragmented and restrictive nature of alpine ecosystems, many species have evolved locally and are extremely endangered by the current climate change conditions (Schumacher and Bugmann 2006, 1435; Tinner and Kaltenrieder 2005, 398). Dietre *et al.*
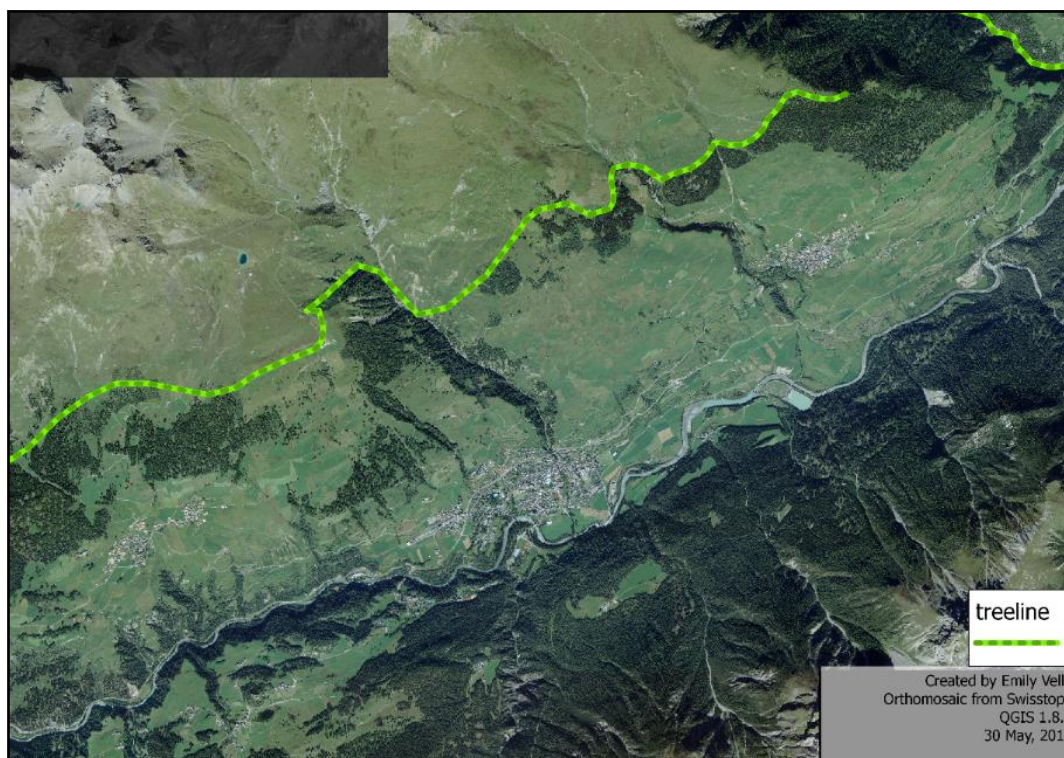
Figure 6. Basic outline of the modern treeline in Scuol. The treeline clearly marks the difference between the land-use types. The primary land-use of area south of the treeline is agriculture.

proposed that climatic fluctuations might have influenced human activities, such as anthropogenic burning or changes in subsistence strategies (2014, 3). Due to the complex nature of mountain ecosystems, it is hard to predict changes (Schwörer *et al.* 2015, 282) although there are certain variables that can be expected based on past events. For example, warmer temperatures at the beginning of the Holocene led to an upward shift in the tree line ecotone (Colombaroli *et al.* 2010, 1347; Schwörer *et al.* 2015, 282

A high temporal resolution study at the site of Gouille Rion, located at the current tree line, compared Late Glacial and Holocene oxygen-isotopes at a frequency of 50 years (Tinner and Kaltenrieder 2005, 937-947). The results of this study are interpreted to indicate that the tree line vegetation was in dynamic equilibrium with the climate, where the tree line position was largely determined by temperature and vegetation composition was the result of air and soil-moisture conditions (Tinner and Kaltenrieder 2005, 945). These results are supported by Heiri *et al.*, using the FORCLIM model, a simulator for temperate forests in Central Europe (Heiri *et al.* 2006, 208).

The past temperatures and moisture, particularly in relation to precipitation and evapotranspiration (Haas *et al.* 1998, 307) are extrapolated based on the presence or absence of particular species in the palynological and macrofossil record, often recovered from bogs or lakes. The oscillating low concentration of *Pinus cembra* at Gouille Rion, Lago Basso, Lake Seedorf, and Wallisellen-Langachermoos indicated cold phases (Haas *et al.* 1998, 302). Different species require different temperatures and moisture levels. As these levels increase, species that require more water thrive at these higher altitudes (Colombaroli *et al.* 2010, 1347). Projections suggest an increase of air temperature of 2-6 degrees Celsius and a 10-30% decrease in summer precipitation, which may increase wildfire occurrences and produce low yielding fields (Schumacher and Bugmann 2006, 1435).

2.3.2 Past human impact and land-use

Humans have impacted the environment in the Lower Engadine since the Neolithic, according to palynological evidence (Dietre *et al.* 2015, 75). The impact that humans have on their environment is particularly pronounced in the Alps (Fischer *et al.* 2006, 438). Head has described the Alps as a "historical space," meaning that change was never determined solely by the altitude or by environmental constraints but that the environment responded to the human presence (2011, 958). The tree line, which is particularly sensitive, has been affected by human land-use strategies for millennia (Schwörer *et al.* 2014, 480). The change from Mesolithic hunter-gatherers to Neolithic

agriculture and herding does not only demonstrate a change in human societies but a change in land-use which has shaped the landscape and biodiversity (Colombaroli *et al.* 2013, 158; Della Casa *et al.* 2013, 40). The human impact on the environment shows the most evidence during the Neolithic and the Bronze Age, where human impact begins in the Neolithic in most regions and intensifies during the Bronze Age, which is interpreted as a phase of intensive settlement (Della Casa 2013, 40; Zoller *et al.* 1996, 49).

The land has often been divided into two main uses: valley floors for agricultural terraces and higher meadows as pasture lands (Dietre *et al.* 2015, 75). Human land-use strategies are influential in determining grassland biodiversity (Fischer *et al.* 2008, 148), particularly in the Swiss Alps, which have been influenced by human activity for 5000 years (Maurer *et al.* 2006, 438). Below the timberline, the majority of grasslands are man-made and the low-intensity farming supports the biodiversity (Fischer *et al.* 2006, 438). In the Silvretta mountain range, the tree line ecotone is the result of not only climatic factors but also by human factors (Dietre *et al.* 2014, 8). A study of sediment cores from Lej da Champfer and Lej da San Murezzan in the Upper Engadine provides evidence for a vegetation change around 5350 BCE (Gobet *et al.* 2003, 143). The analysis of the pollen, plant macrofossils, charcoal, and kerogen indicate that local human settlements resulted in vegetation changes. (Gobet *et al.* 2003, 143).

Based on high values of cereal in pollen and macrofossil assemblages, the earliest agriculture in the Lower Engadine dates to 2200 cal BCE (Ammann 1997, 372). Paleoecological studies indicate that the earliest agriculture began in the tail-end of the Neolithic and during the Bronze Age (Zoller *et al.* 1996, 49). In addition, many anthropogenic species increase in frequency during the Middle Bronze Age in the region (Ammann 1997, 372; Zoller *et al.* 1996, 49). Historian Mathieu concluded that some prehistoric fields had been replaced by hay meadows (Zoller *et al.* 1996, 51).

There is little direct evidence to suggest that the terraces near the towns are prehistoric (Zoller *et al.* 1996, 50). However, the palynological evidence suggests five distinct cultural epochs (Zoller *et al.* 1996, 51). The first epoch ranges from 3600-2200 BCE, and the largest indicator of human impact is in land clearing proxies (Zoller *et al.* 1996, 52). The second epoch lasted from 2200 BCE-300CE and is described as the epoch of prehistoric agriculture and the third epoch (300CE-1000AD) is characterized as the decline during the Early Middle Ages (Zoller *et al.* 1996., 52-53). The last two epochs, from 1000CE-1950 CE and 1950 CE to 1995 CE are characterized by traditional agriculture followed by industrialization (Zoller *et al.* 1996, 53-54).

Grazing activities can be identified in the archaeological and palynological record by the presence of apophytes, or spores of coprophilous fungi (Reitmaier *et al.* 2017, 2; Dietre *et al.* 2014, 14). The use of herd animals for primary resources (meat consumption) is assumed due to the presence of bones in the archaeological record, but evidence of dairying in the archaeological record is rare (Carrer *et al.* 2016, 2). The production of dairy products requires an understanding of the mountain environment, the management of livestock and a large amount of manual labour (Carrer *et al.* 2016, 1).

In the Upper Engadine, there is strong evidence for human-induced changes to the vegetation starting around 3550 BCE. This is evidenced by the openings in the forest, and the expansion of *Alnus viridis* shrubs and grasses which correlate with increases in macroscopic charcoal (evidence for fire management) (Gobet *et al.* 2003, 154). A marked change in the vegetation around 1950 BCE corresponds with the beginning of the Bronze Age, due to an economic upturn, population growth, and intensified land-use as seen by enhanced forest grazing and the presence of Cerealia pollen grains (Gobet *et al.* 2003, 154, 160) which mirrors the results from the Lower Engadine (Zoller *et al.* 1996, Gobet *et al.* 2003).

Since the Neolithic slash-and-burn techniques have been used to improve the production of cereals (Dietre *et al.* 2017, 181) and small fires were used to control and maintain the expansion of shrubs and small vegetation (Dietre *et al.* 2015. 182). Due to the sensitivity of mountain ecosystems, it is relatively easy to determine the frequency of fire events in the past, although it is difficult to determine their source (Dietre *et al.* 2017, 181). Fire events are a major catalyst for deforestation within the European Alps (Dietre *et al.* 2017, 181). Fire regimes may change due to a variety of factors, including climatic variability (temperature, moisture, and fuel availability), changes in species and composition, and most notably, human-related activities (Colombaroli *et al.* 2010, 1351).

In the Lower Engadine, evidence of fire-induced forest clearance from a prehistoric terrace site dates between 2840-2470 BCE (Dietre *et al.* 2015, 75). The Lower Engadine is located in one of the driest regions in the Alps, with only 900mm of precipitation each year (Stähli *et al.* 2006, 805). Evidence from the Saglias Bog and the Cutüra Bog corroborated the use of fire in the Lower Engadine during the Neolithic (Dietre *et al.* 2015, 75). In the Upper Engadine fire was used to establish pastoral areas from 1950 BCE (Dietre *et al.* 2017, 182). In the Silvretta Massif, fire incidents are known to have occurred during the Neolithic but evidence suggests that anthropogenic burning may have occurred during the Mesolithic as well (Dietre *et al.* 2014. 13).

In 1996, Raba completed a Ph.D. thesis with a focus on the terraces in the region. The terraces were divided into six types based on elevation, location, and preservation; three of which are relevant. They were first mapped using aerial photographs (1: 2000) and then verified in the field (Raba 1996, 87). The first type is terraces that are located near modern settlements, are clearly marked in the landscape, and have a slope of ~20% (Raba 1996, 88). Type 2 terraces have a slope of 0-15% and are located away from settlements, at a higher elevation. These terraces are less obvious in the landscape (Raba 1996, 89). Type 3 terraces are similar to type 1 terraces but are located away from villages (Raba 1996, 89). In the 20th century cattle farming and agriculture was an essential part of a family's self-sufficiency in the region (Mathieu 1985, 2).

2.3.3 Recent landscape and land-use changes

Another area of study on the human impact on landscapes appears as land cover and land-use assessments, based on maps and images from the last 150 years (Rutherford *et al.* 2008, 460). The current receding Alpine glaciers are indicative of climate change (or 'global warming') (Grosjean *et al.* 2007, 203) and demonstrate how humans can impact the environment at a regional scale. Land abandonment is followed by the regeneration of the forest (Rutherford *et al.* 2008, 460), which can be mapped and tracked using aerial and satellite images over time. Land abandonment can be seen in the Alps, for numerous reasons including lack of profitability, inefficient farming techniques, and new sources of income. (Rutherford *et al.* 2008, 461). Typically, land with steep slopes, poor soils, and poor infrastructure are the areas abandoned (Gellrich *et al.* 2007, 93), which describes many regions within the Central Alps. A study of the changes between agricultural land-use and forest cover looked at Switzerland between the years 1985 and 1997 (Gehrig-Fasel *et al.* 2007, 571; Rutherford *et al.* 2008, 468). It was determined that while both intensification and extensification occurred, extensification occurred three times as frequently (Rutherford *et al.* 2008, 468), likely due to land-use changes in addition to climate change, where typically climate change is attributed to new growth, shifting the tree line to a higher altitude and land-use or land abandonment is the likely cause of new growth below the tree line (Geehrig-Fasel *et al.* 2007, 571, 576). Other findings suggest that forest regrowth in the Alps tends to occur between 1400 and 2100m a.s.l. (above sea level) and when the slope is between 20 and 40 degrees (Gellrich *et al.* 2007, 100). It is likely that this trend has continued since the abandonment of land and traditional agricultural practices can be observed worldwide (Gellrich *et al.* 2007, 93).

2.4 Relevance

In order to understand land-use changes, it is important to understand how humans have impacted the landscape over time. The rich archaeological evidence for this area and a large number of documented sites and finds supports the decision to investigate this region for archaeologically relevant research. The factors which influenced the tree line, which acts as the northern boundary of the study area, continue to cause the tree line to fluctuate. Modern data suggests that the modern tree line approximates the highest tree line in prehistoric times (Della Casa 2013, 3), indicating that the use of the tree line as a northern boundary should be sufficient to document the terraces in this region. The transition from natural landscape to agriculture and now to the current trend of land abandonment all play a role in the preservation of the terraces. Land abandonment often results in the "natural" landscape returning (i.e. Forest regrowth). While the regrowth of forests preserves the terraces from land development and natural elements (i.e. landslides, avalanches, and taphonomic processes), they are no longer visible in the imagery and could affect the number of terraces identified. Understanding these processes is key to understanding the terrace structures and placement.

Chapter 3: Theoretical and technical framework

3.1 Theoretical framework

3.1.1 Digital Archaeology

An important transformation in archaeology has been the shift from analogue to digital (Huggett 2017, 1) especially in relation to documentation and dissemination. It is without question that the digital revolution has impacted archaeology (Zubrow 2006, 9), predominantly by changing recording practices (Daly and Evans 2006, 3; Morgan and Wright 2018, 136). This field has evolved with computational methods such as remote sensing and GIS and the omnipresence of computers in today's society (Daly and Evans 2006, 2) making archaeology more accessible.

Fundamentally, Digital Archaeology explores the relationship between archaeology, Information and Communication Technology (ICT), and digital technology and reflects critically upon these innovations, specifically how they have impacted how archaeology is performed (Daly and Evans 2006, 2). While a concrete definition of Digital Archaeology remains elusive, some key aspects are apparent. Digital Archaeology is not and should not be, a secret knowledge and it exists to help archaeologists perform good archaeology (Daly and Evans 2006, 7). This can be done through creating texts, photos, videos, 3D, virtual, or augmented reality reconstructions, in addition to video games and music to visualize and communicate past ways of life (Morgan and Eve 2012, 521). Determining to whom the term 'digital archaeologist' applies is more abstract than an absolute definition for the concept. "We are using technology to haunt the present with the past. We are a consortium of academics, professionals, students, and avocational archaeologists and we want to share" (Morgan and Eve 2012, 521). They are the parties who adopt, modify, test, improve, and disseminate.

Whether Digital Archaeology is a school of thought, field, or subdiscipline within archaeology is contested due to the broad nature and uses of the term. Digital Archaeology is the term most frequently used, but archaeological computing, archaeological informatics, computer archaeology, archaeological informatics, and archaeological information science have all been used in the past to describe this concept

(Huggett 2012, 14; Llobera 2011). For consistency, Digital Archaeology will be the term applied to this concept, although ultimately, the terms used are quite arbitrary at this point in time. Within the last 50 years, no fewer than six terms have been used within archaeology to describe the incorporation of computational tools in archaeology, with varying degrees of frequency and success. While Digital Archaeology will be used, this is not done in order to discredit or reject other proposed or past terms but done for consistency and simplicity.

The distinction between Digital Archaeology as a field/school of thought and as a tool/approach may become quite important. Zubrow argues that there are two distinct perspectives; Digital Archaeology as "a-theoretical" and exists only to provide tools, similar to dating techniques, versus Digital Archaeology where the developments within Digital Archaeology influence the creation of theory (Zubrow 2006, 9). Digital Archaeology, as a field, therefore, requires engagement with the theory and a reflection or evaluation of the methods where Digital Archaeology as a tool does not. This is an important topic of debate within the field but lies outside the scope of this project.

Morgan and Eve suggest four criteria which should be met in order to do 'good archaeology' (2012, 527-528). The first is an increase in transparency, followed by inclusivity, openness, and the digital context. Inclusivity allows for multiple perspectives and is less hierarchical and in theory, would result in more well-rounded interpretations. Evaluating openness and how much data can be shared ensures that the information they are sharing does not limit future research, but also does not put cultural objects or locations in harm's way. Lastly, it is important to pay special attention to the multiple context digital objects inhabit.

Digital Archaeology has been heavily critiqued. Llobera argued, "computer methods rarely lead to new archaeological knowledge" (Llobera 2011, 219). The argument that Digital Archaeology can be more ambitious and seek to develop innovative tools and methodology (Huggett 2015, 83) is a valid argument but does not negate the necessity for Digital Archaeology as a field in its own right. Many encourage caution when adopting new technologies until it can be determined that they meet our scientific standards and are not simply consumer fads (Lull 1998, 379).

One of the many benefits of digital methods is that it allows for digital representations of the real-world, including the physical environments, sounds, and images (Zubrow 2006, 9). In addition, real-world processes can be modelled and simulated in a safe environment, where the virtual world remains separate and distinct

from actuality (Zubrow 2006, 9). Regardless, the use of computers has irrevocably transformed the field of archaeology (Huggett 2015, 80).

3.1.2 Sustainability in archaeology

In 2005, a non-profit, Heritage Preservation, found that 20% of collections in the USA were in need of better care, and 40% of collections had an unknown status (Bawaya 2007, 1025). The collections crisis is not limited to North America, nor is it a new problem (Bawaya 2007, 1025). The problem has unfortunately been exacerbated by staggering amounts of data (Marquardt *et al.* 1982, 417). Collections, be they in museums or storage, are only useful if they are maintained and protected (Marquardt *et al.* 1982, 409). The goals of sustainable archaeology are simple and few. The first is to prolong archaeology's vitality indefinitely which is done by minimizing the adverse effects while continuing to conduct research (Ferris and Welch 2014, 231). The next goals are to recognize that archaeology is part of cultural heritage and to prioritize service to society, instead of archaeology strictly for academic interests (Ferris and Welch 2014, 231). While the archaeology itself can be considered its own distinct discipline, the conservation, display, and dissemination of the materials collected are deeply entwined with heritage. Other goals are to promote sustainable designs via 'reduce, reuse, recycle' and to shift the archaeological discourse towards more inclusive outlets in order to consider alternative perspectives (Welch and Ferris 2014, 231-232). While this idea may be a little extreme, overall it shares many similarities with open archaeology. Both concepts seek to share the data that is collected so that it can be reused; both are trying to preserve the digital data that exists; both are interested in straying from strictly academic ideas and publishing and are moving towards a multi-disciplinary approach. Open Archaeology as it applies to this project is Sustainable Archaeology and Sustainable Archaeology is Open Archaeology.

3.1.3 Proprietary vs. FOSS software

The term software is used to describe a wide range of procedures, instructions, applications, and programming languages which control the hardware (physical components of the computer) (Bouras *et al.* 2013, 100). The system software comprises the compiler and the Operating System (OS). The compiler reads the human-readable instructions and translates them into a computer-readable language (Muffatto 2006, 24). The OS is most simply described as the interface that the user interacts with (Muffatto 2006, 24); examples include Microsoft Windows, Linux, and macOS. Application software is then the programs that perform specific functions (Muffatto 2006, 24). and will

frequently be referred to as "programs," where software will be used to describe both application software and OS.

The types of software that are relevant to this section are applications/ programs. Software can be divided into the five categories based on rights and licenses: public domain, FOSS, freeware, shareware, and proprietary software (tab. 1).

Table 1. A brief description and examples of the various types of software, after Muffato 2006, 35-37.

Category	Description	Example
Public Domain	Author gives up all intellectual rights	HTML
Free/Open Source (FOSS)	Open access to the source code, credit must be given	Linux
Freeware	Freely distributed, no source code available	Adobe Reader
Shareware	Free to download, fees for extended features or prolonged use	Apogee
Proprietary	Protected, paid,	Microsoft Windows

This project is particularly interested in FOSS programs. The term FOSS was coined by Richard Stallman in 1984 and stands for "Free and Open Source Software" (Costa *et al.* 2012, 449; Muffatto 2006, 7; Reyna and Simoes 2016, 7). In order to be considered FOSS, the software must follow the four freedoms of FOSS as well as be non-discriminatory against persons, groups or fields, distributable, and have a technologically neutral licence (Bouras *et al.* 2013, 101). The four freedoms are as follows: the freedom to use the software for any purpose, the freedom to the source code, the freedom to distribute, and the freedom to improve or modify the source code and share the results (Muffato and 2006, 36; Reyna and Simoes 2016, 8). The "Free" part of FOSS refers to the four freedoms, not the cost of using the programs, although many FOSS programs are free to download and use (Reyna and Simoes 2016, 8). FOSS is then protected by a concept called "copyleft" (derived from the term "Copyright") (Muffatto 2006, 8; Reyna and Simoes 2016, 8). While software designers could put their software in the public domain copyrighted, this would allow a user to convert the software into a proprietary software (https://www.gnu.org). Copyleft protects these programs by making it illegal to redistribute the software except

as free software (https://www.gnu.org). This is done by copyrighting the program and then stating the four freedoms in the distribution terms (https://www.gnu.org).

FOSS programs are of great benefit to many disciplines. The use of open source software has become much more commonplace in recent years (Duarte *et al.* 2017, 3182). These programs are user tested which allows the developers to fix bugs, add features and maintain a dynamic pace based on the real-time requirements of the users (Reyna and Simoes 2016, 8-9). The access to the source code allows users to understand the complex algorithms which are extremely relevant in GIS applications (Reyna and Simoes 2016, 9). This creates an active community (Reyna and Simoes 2016, 8) which is more willing to contribute time to making tutorials or to modify and improve the software for a variety of purposes. In addition, the free cost of FOSS programs makes it a low financial risk if the user is trying to decide between programs (Bouras *et al.* 2013, 101). The term "open" is becoming increasingly attractive, due to its ties to accountability, transparency, a plurality of opinion, and scientific repeatability (Costa *et al.* 2012, 449). It is important to note that the concept of "open" does not just apply to software. "Open access" publications, for example, are publications that are available to the reader without having to pay a fee or subscription (Costa *et al.* 2012,449).

Archaeologists tend to use the software that is available, regardless of cost. While working at an institution (i.e. university), it is not uncommon for the department to have purchased software on a license which can be accessed from any computer in the institution. Outside of institutions, proprietary software is often downloaded illegally. "It is common knowledge that some archaeologists have thousands and sometimes tens of thousands of dollars' worth of illegally downloaded software to perform everyday tasks and do not hesitate to publish results and visualizations gained from using this illegal software. Whether or not the archaeologist has a philosophical commitment to Open Source and Creative Commons, it is in their interest to prevent the catastrophic data loss that is possible with proprietary formats and illegitimate software" Morgan and Eve 2012, 532).

3.1.4 An abundance of data

The abundance of data within archaeology has been referred to as the 'data deluge' (Bevan 2015) as well as the 'data explosion' (Bennett *et al.* 2014). The term 'big data' has occasionally been used in reference to archaeology and is defined as digital datasets that are so immensely large that they present extraordinary challenges in regards to storage, analysis, and visualization (Bevan 2015, 1473). While archaeological data

rarely reach amounts that would categorize the data as big data (Bevan 2015, 1473; Verhagen 2018, 20), but it is messy data (Verhagen 2018, 20), which has the same issues with storage, analysis, and presentation. Regardless of the term used, it refers to the vast amounts of data, which have been collected since the technological revolution in archaeology. There is more data than ever and it is more easily accessed than ever before thanks to digital methods. In order for archaeologists to take advantage of this data, a paradigm shift is needed in order to evaluate the data and interpret the archaeological evidence (Bennett *et al.* 2014, 896). Propositions for these shifts can be seen in the digital archaeology literature and in the movement for sustainable archaeology.

Spatial data has become increasingly accessible and in the improvements in quality and coverage have contributed to their increased use (Opitz and Herrmann 2018, 19). The geospatial revolution has had a profound effect on archaeology, where much of the research now revolves around temporal and spatial data (Chase *et al.* 2012, 12916-12917). In addition, the number of free data sources for remote sensing data has made the data accessible to non-experts (Opitz and Herrmann 2018, 19) and projects with little or no funding. While analogue photos are useful, they are subject to degradation; digitization of these images preserves the contents (Lambers 2018, 114). Bevan stated, "it [archaeology] faces floods of new evidence about the human past that are largely digital, frequently spatial, increasingly open and often remotely sensed" (2015, 1473). This perfectly summarizes the current state of the data deluge within archaeology.

3.1.5 Open (source) archaeology and data re-use

Similar to the technological revolution, archaeology has been progressing through an information revolution over the last two decades (Edwards and Wilson 2015, 1). This revolution has been driven by a demand for being 'open', in reference to FOSS, open access to data and open ethics (Edwards and Wilson 2015, 1). It is a response to the archaeological grey literature, which is jargon-laden and inaccessible (Morgan and Eve 2012, 522). This idea of openness has manifested itself in archaeology in two distinct ways. Open source archaeology draws its name from computer sciences and refers to open source software (Edwards and Wilson 2015, 1). It tends to embrace FOSS programs, not just for the software, but also for the repository of knowledge for the tool (Edwards and Wilson 2015, 1) which is not present in proprietary software. Open archaeology refers to open publishing and free access to datasets (Edwards and Wilson 2015, 1). This includes free access to journal articles and conference proceedings, as well as raw datasets, such as excavation reports, databases, and archives (Edwards and Wilson 2015, 2). The trend

towards openness, which is often associated with transparency, can be seen in many scientific and social disciplines, as well as in politics and policy-making (Edwards and Wilson 2015, 2). Employing openness is not an easy task; the cost of archaeological research is a key issue (Edwards and Wilson 2015, 2). There are other concerns over releasing sensitive information to the public, such as georeferenced images of sites, which could allow looters to locate the site. There is a pressing need to engage with the discourse within open archaeology, open science, and open data in order to establish best practices for data storage (Opitz and Herrmann 2018, 26),

Since archaeological data has become available online or in digital formats, the relationship archaeologists have with the data has changed (Huggett 2015, 6). Not all "open data" is the same; in many cases, data is only partially open and can be sorted into a hierarchy of openness (Huggett 2015, 7). The first level of openness provides online access to datasets and is only limited by Internet access (Huggett 2015, 7). This is followed by data that is available to download but is limited due to concerns of bulk downloads (Huggett 2015, 7-8). The third level is data that can be downloaded but with restrictions pertaining to the use and reuse of the data and the fourth level is data that has no exclusions or restrictions and often falls under Creative Commons licenses (Huggett 2015, 8). Open data allows for the sharing of data which allows for collaboration and progress. Sharing data is one of the main benefits of open data, which has largely manifested in the distribution of textual outputs of archaeological research (Moore and Richards 2015, 30), which is not only convenient but also cost-effective.

The ability to reuse data is extremely appealing to archaeologists, since it is a sustainable practice, especially financially, and allows others to retest and verify results (Opitz and Herrmann 2018, 26). However, data reuse in archaeology has only appeared relatively recently in the literature. The majority of the time where data reuse is featured in academic writing, the publications often emphasize the positive outcomes without describing the issues (Huggett 2015, 11). With more archaeologists relying on digital methods and embracing openness, it is not unrealistic to predict that data reuse will become a more common practice. However, reusing data is a complex task (Huggett 2015, 12).

"Re-use of data requires a close understanding of the context of data collection and of the vocabulary used to describe the observations. The archaeologist of tomorrow needs training not so much in methods of data collection, but in data analysis and re-use" (Naylor and Richards 2005, 90).

The main issue with data re-use is the lack of context, which can be caused by the variability in recording procedures and variability between archaeologists (Faniel *et al.* 2013, 298). Other gaps can be attributed to missing information such as how the data was collected, the specifications of the instruments, what methodologies were used and what strategies were used (Huggett 2015, 12). Regardless, data is still used, and the researchers either find alternative means of recovering this metadata or ignore its absence (Huggett 2015, 12-13). The sharing and re-use of data may provide unexpected results, in the form of new research questions that were not originally envisioned (Moore and Richards 2015, 35). However, concerns about the quality of data are ever increasing, since there are many datasets with gaps in the metadata, or minimal or no documentation (Moore and Richards 2015, 35).

One result of this trend towards open archaeology is an increase in informal data dissemination. It is not uncommon for archaeologists or projects to maintain a blog where they write in plain language and share information, particularly videos or images, which can be used or viewed by anyone (Morgan and Eve 2012, 522). This has been called the 'digital village' (Morgan and Eve 2012; Zubrow 2006, 10). Unfortunately, since there is no standardization within the digital village that archiving the comments, conversations, and posts are impossible and are incompatible with traditional publishing methods, such as journal articles (Morgan and Eve 2012, 522). However, the digital village is a multilingual, multi-authored forum, which allows for unhindered communication (Morgan and Eve 2012 522).

3.2 Technical framework

3.2.1 Remote Sensing

Remote sensing describes non-invasive data collection methods and is most often used in reference to aerial and satellite imagery. For archaeology, remote sensing techniques have a history of being used for research due to the many advantages (Tapete 2018, 1) and successful history for site detection and the mapping of archaeological traces in the landscape (Lambers 2018, 109). Excavation is a destructive process where remote sensing allows the site to be investigated without direct contact, thus preventing risk, reducing cost, and allows archaeologists to revisit the site for further studies at a later date (Lambers 2018, 110; Tapete 2018, 1). In addition, remote sensing in an archaeological context can be used to investigate cultural landscapes, monitor sites, and monitor the impact that disasters (natural or otherwise) have had on sites (Lasaponara and Masini 2011, 1995; Tapete 2018, 1). The increase in availability of remote sensing data and the increase in coverage has led to a new wave of research which has taken place on a landscape or regional scale (Bennett *et al.* 2014, 896). It is the potential with investigating cultural landscapes with which this thesis is concerned.

Aerial photography has been used since the end of the 19th century when it was the most common method for surveying the surface and near-surface remains (fig. 7) (Lasaponara and Masini 2011, 1995). More recently, multispectral imagery has been used to improve positive identifications of textures, moisture, content, roughness, topography, terrain, vegetation, lithological and geological cover, among others. (Lasaponara and Masini 2011, 1995). As of 2004, unmanned aerial vehicles (UAVs) have been used in archaeology to gather remote sensing data (Lambers 2018, 113). Humans impact the environment through planning, modifying and engineering the space around their settlements, which is often visible in remote sensing data (Traviglia and Torsello 2017, 1).

Recently, the use of satellite imagery (fig. 7) by archaeologists has become increasingly important due to improvements in spatial resolution and analytical methods (Lambers 2018, 543; Lasaponara and Masini 2011, 1995). Archaeologists have used satellite imagery since 1972 (Danti *et al.* 2017, 1) when the Landsat satellite released images that were publically available (Lasaponara and Masini 2011, 1995).

One of the criticisms of the use of remote sensing is that it lacks a shared and standardized methodology (Tapete 2018, 2). Most remote sensing data is not collected for archaeological purposes, but rather for general purposes including: land-use studies,
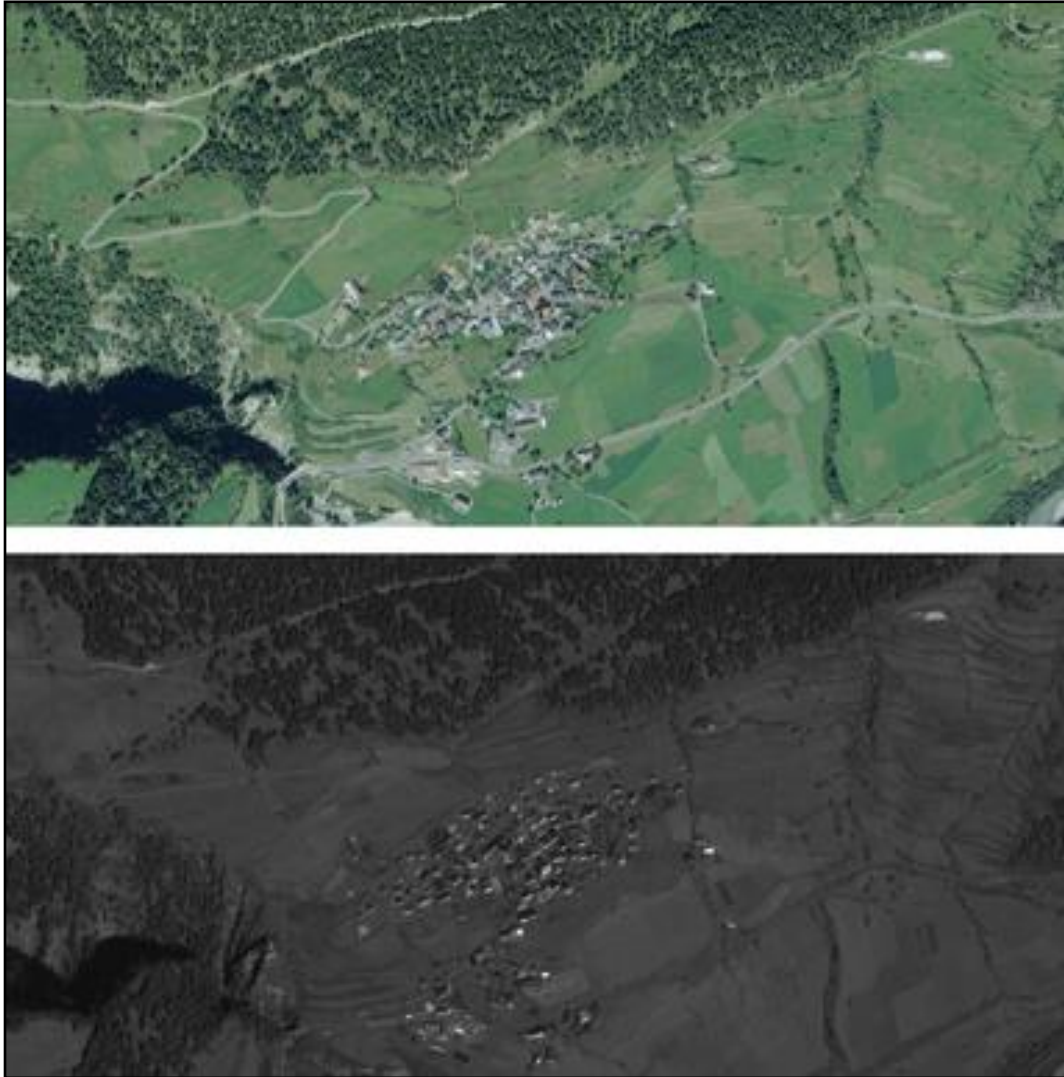
Figure 7. Top: orthomosaic photo of Ramosch derived from aerial imagery (Swisstopo). Bottom: Satellite imagery of Ramosch, panchromatic band (GeoEye).

land development/construction, and general surveys. The availability and cost of remote sensing data is constantly shifting and new analytical tools are constantly updated and created, making it very difficult to make a standardized methodology that would be relevant for more than a few years at a time. Another criticism is that the use of these technologies has produced a need for expertise and dissemination (Tapete 2018, 1) on a topic that did not exist 30 years ago in the capacity that it does today. In addition, there is a growing need for the simplification of data inspection (Traviglia and Torsello 2017, 2). The theoretical debate surrounding the use of remote sensing and the use of landscape within archaeology is quite dormant when compared to the debate and reflexivity of GIS (Verhoeven 2017, 3).

Despite these criticisms, the last ~25 years of geospatial technologies have greatly benefited archaeology (Hritz 2014, 230)[3]. It has allowed archaeologists in the Near East to overcome practical limitations without compromising their research questions (Hritz 2014, 230). Pappu *et al.* used satellite imagery to investigate cultural landscapes in India (2010, 2316). Lambers and Reitmaier used satellite imagery to investigate the Swiss Alps above the tree line, an environmental context in which this technology had not been previously used by archaeologists (2013, 543). Argyriou *et al.* studied the abandonment of higher elevation sites on Crete by using remote sensing and GIS to understand the relationship between the archaeological sites and the landscape (2017, 2). North American archaeologists have been relying on remote sensing since its revolution during the mid-1990s with a current focus in geophysical survey, mapping, and the relation with elevation (Johnson and Haley 2011, 39). Satellite imagery is being used to produce reports of cultural heritage damage in Syria and Northern Iraq, a project that began in 2014 and covers 1100 unique cultural heritage sites (Danti *et al.* 2017, 7).

3.2.2 GIS in an archaeological context

GIS is a useful tool for archaeologists to explore archaeological and cultural landscapes due to the development of enhanced tools used for spatial analysis and high-performance computing techniques (Hritz 2014, 267) and was introduced to archaeology over 30 years ago (Verhagen 2018, 11). GIS allows archaeologists to engage with both existing, real-world data and alternative worlds (Llobera 2012, 497). GIS is most simply defined as a computer application designed to perform specific functions related to spatial information (Wright *et al.* 1997, 347). Geographic information is the link between property and location, with the possibility to link it to a point in time (Goodchild 2010, 4). GIS is a spatially referenced database which is defined by subsystems for data management, verification, input, output, storage, display, and conversion (Ebert 2004, 319). It removes the traditional buffers between photogrammetry, remote sensing, geodesy, cartography, surveying, geography, computer science, spatial statistics and other related fields and allows the various types of data to be explored within the same workspace (Wright *et al.* 1997, 348).

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[3] For a more complete history of the use of remote sensing in archaeology, see Lambers 2018. For more information on the theoretical aspects of the use of remote sensing in archaeology, see Verhoeven 2017.

One of the many benefits of GIS is that it has the capability to be applied to both qualitative and quantitative datasets (Garnett and Kanaroglou 2016, 144). The use of specialized software requires a specific level of understanding, and GIS programs, such as ArcMap (https://www.esri.com) or QGIS (https://qgis.org) are no exception (Garnett and Kanaroglou 2016, 145). Since archaeologists have always been focused on spatial dimensions of humans, GIS and archaeology seem like the perfect match of technology and application (Ebert 2004, 319).

In the 1980s, GIS applications became extremely successful and the development shifted from academic environments to private and corporate companies (Pickles 1997, 368). Over the course of the last 35 years, GIS merged with other spatial information processing and imaging technologies and became generalized, therefore entering the domain of 'big science' (Pickles 1997, 368). Unfortunately, the rapid progress has led to problems with the consolidation and legitimacy of GIS as a science or field in itself (Pickles 1997, 369). Those who argue for GIS as a tool believe that it is only a tool applied when doing geography based sciences where GIS as a science believes that it is a method for testing spatial theories (Wright *et al.* 1997, 349).

The GIS workspace places the dataset within a virtual space which corresponds with a real location on Earth. This is done by projecting the data using a Coordinate Reference System (CRS). Data can be collected in the real world using a GPS (Global Positioning System) to give the data an exact location on Earth which can then be visualized within the GIS workspace. Alternatively, data can be georeferenced by matching overlapping features between a dataset with known coordinates and a dataset without. It is important to note that a single GIS program includes all the possible functions, and can be supplemented with extensions, scripts, plugins or add-ons (Orengo 2015, 65). This is now seen as an essential tool in archaeology and a GIS approach enables pluralism within research (Verhagen 2018, 11-13) as various models drawing on a variety of variables. One of the restrictions is that the software is not created specifically for archaeologists, therefore, depending on the software, the needs of the archaeologist may not be met (Lake *et al.* 1998, 27).

3.3.3 Open source GIS

The potential for open source GIS in archaeology is enormous. VGI (Volunteer Geographic Information) is a concept that utilizes the widespread engagement of people without formal qualifications (Reyna and Simoes 2016, 1). One of the main criticisms of GIS in archaeology is that it can be quite inaccessible to those unable to afford formal

training. This idea, while not without its own problems, can be used to diminish this knowledge gap.

Open source GIS programs have some evident advantages within archaeological contexts (Orengo 2015, 66). While it is true that many archaeologists lack the programming skills to directly study, manipulate, and change the source code, making the code open allows for public scrutiny and improvements (Orengo 2015, 67). Scientific research demands openness due to nature of scientific inquiry, which requires research to be open to scrutiny (Orengo 2015, 67) that should include the source code of the programs, functions, and calculations performed by software. Proprietary software is not open to public scrutiny and therefore prevents the understanding of the processes involved (Orengo 2015, 67). Another advantage is the high cost of proprietary software which is often outside of the budgets of archaeologists (Oregno 2015, 67). In addition, the open source code allows for effective plugins or add-ons to be built by users with the same needs (Orengo 2015, 68). Certain tools and capabilities are more relevant for archaeologists within GIS environments, such as least-cost path, viewshed analysis, hillshade, slope, and numerous other visualization techniques that can be applied to numerous kinds of data. While a large online community is beneficial, the lack of a central organization can lead to outdated scripts and abandoned open source GIS developments are common due to lack of funding, particularly in archaeology (Orengo 2015, 69-70). The dependency of the online community can be a blessing or a curse, where long-term support, availability and consistency of documentation are dependent on the vitality of the community (Orengo 2015, 70).

Chapter 4: Methodology

4.1 Software and specifications

4.1.1 Software

QGIS 1.8.0 Lisboa, released in 2012, was the main software used to complete this thesis, along with the GDAL Georeferencer, OpenLayers plugin (1.1.0) by Sourcepole, Freehand Editing 0.2.6 created by Pavol Kapusta and GdalTools (version 1.2.29) plugins. All of the plugins are available through the QGIS repository connected to the program. While this is not the most current version of the program, it was the version on the computer used to complete this project. QGIS was chosen, as opposed to ArcMap for a variety of reasons. QGIS is a FOSS program and as such adheres to the four freedoms as defined by Stallman (Duarte *et al.* 2017, 3182). This is important because it allows for better transparency; the source code for all the processes and tools are openly available. QGIS was developed in 2002 by Gary Sherman (Duarte *et al.* 2017, 3183) and has since grown to include a large online community. The QGIS online community is active in helping other users to problem solve and troubleshoot, which is a very appealing trait when working on a project of this nature. QGIS is free to download, as are the plugins. While the Leiden University Faculty of Archaeology provides access to ArcMap, the price of the software can be a significant barrier for anyone who wishes to replicate the project or methodology (Garnett and Kanaroglou 2016, 145). Most importantly, QGIS and the plugins are able to perform most of the required functions. The main functions include data manipulation and visual interpretation as well as the ability to read and display the data collected. GDAL is used to georeference the images, OpenLayers is used to add simple basemaps to some of the figures, and Freehand Editing was used to digitize the terrace walls as curved lines.

4.1.2 Computer specification

A desktop computer located in the digital archaeology computer lab at Leiden University was used to complete the project. A Dell Optiplex 3020 running Windows 7 Enterprise (2009) with a 64-bit operating system and Intel core i3 was used. While it is not the most robust or current system, it was usually sufficient.

4.2 Workflow and data

4.2.1 Understanding the data

All the data used was collected prior to my involvement with the project, and therefore I was not a part of the collection processes. Understanding the data was quite time-consuming; this process took place between February and April of 2018 and almost 120 hours. Originally, the dataset collected amounted to 114GB but throughout the course of the data processing phase has been reduced to approximately 45GB, not including the QGIS files that were generated throughout the project.

4.2.2 Swisstopo[4]

Historical maps

The first dataset explored was that which was downloaded from Swisstopo directly (appendix 2a). Four historical maps (fig. 8; appendix 1a) were downloaded as PDFs through the "A journey through time - maps" online portal (fig. 8). This portal shows a map of Switzerland with an interactive timeline that allows the viewer to choose a year with the slider or allow the map to progress through time via the play button. Using the print function on the left-hand toolbar you are able to save a section as a PDF. Starting in 1897, four maps were selected, approximately 30 years apart when available, in 1926, 1956, and 1998 at a scale of 1:50,000 and an orientation of A4 landscape. This scale was chosen because it is the smallest scale that included the entirety of the Zone 1 and Zone 2. Many of the maps are regional so while the entire map of Switzerland may change every year, the map used in the Lower Engadine does not. In many cases, the changes are purely stylistic changes or changes in the spelling of the place names, as opposed to the addition or subtraction of features. The four years (1897, 1926, 1961, 1991) selected are those that demonstrated the largest amount of change within this time period.

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[4] All of the information on Swisstopo can be found at https://www.swisstopo.admin.ch/. A complete list of the datasets used and the corresponding links can be found in the appendix 2a. The website is available in English, German, French, and Italian.
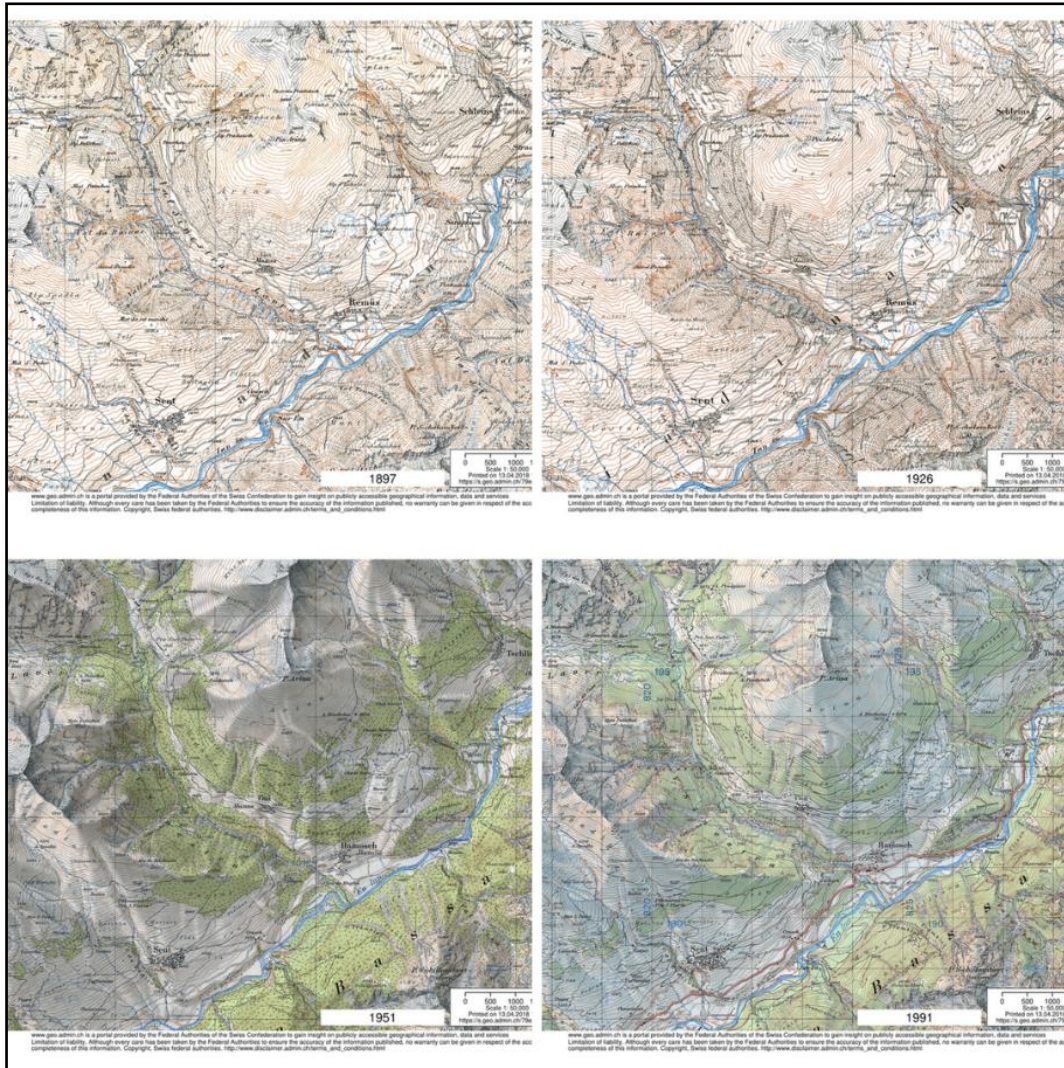
Figure 8. Swisstopo's "A Journey Through Time – Maps". Top left: map of study area in 1897; Top right: 1906; bottom left: 1951; bottom right: 1991. Scale of 1:50,000.

After downloading the maps, they were converted to PNG files using http://pdf2png.com/. This is a free online file converter that supports files up to 50mb (each pdf file was roughly 20mb) and the resolution of the images is not compromised during conversion. The files were then downloaded as ZIP files and unzipped using 7-Zip (https://www.7-zip.org/). These were then imported into QGIS as a raster layer and clipped to remove the border and then georeferenced using the georeferencer GDAL plugin, which is found under the raster toolbar at the top of the window. Ten ground control points (GCP) were used for each map and the points were taken from the canvas by looking at the orthomosaic photo and finding features that would be in the same position on each dataset, such as road intersections or bridges. Ten GCPs was found to be more than sufficient to georeference the images; an accurate translation could be achieved with as few as six points, using a linear transformation type and a nearest neighbour resampling method with no compression. Once the maps were georeferenced

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in QGIS, they were saved as a GeoTIFF, which stores the spatial data within the file. The most recent map is from 2003 and was previously georeferenced and supplied by the Terraced Landscapes project.

Aerial imagery

The second dataset used from Swisstopo was four aerial images dating from 1985, 1997, 2003, and 2011 (fig 9). They were downloaded from "A journey through time - aerial

Figure 9. Screenshot of Swisstopo's "A journey through time – maps" portal. The panel on the left allows you to toggle between maps, share, and print (or save) maps. The slider is located at the top of the window.

images" online portal (appendix 1b, 2a). These are the only years during which different aerial images were taken of the region, with black and white photos from 1985 and 1997, and full-colour images from 2003 and 2011. These were downloaded at a scale of 1:50,000 and converted from PDFs to JPEGs using http://pdftoimage.com/, which were then unzipped using 7-Zip. The same georeferencing procedure was followed, again using ten GCPs. PNGs and JPEGs use different algorithms to create the files. The resolution of the aerial images was originally too low to use for any identification; thus JPEGs are sufficient.

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Some data is lost during the compression but the file size is smaller and since the spatial resolution is poor to begin with these images cannot be used to visually identify terraces or irrigation systems but can be used to compare changes in the landscape of a regional scale.

Topographic Landscape Model: swissTLM3D

It is unclear what Swisstopo defines as a landscape model, although it simply appears to be a digital map where each feature (roads, rivers, etc.) appears as a separate vector layer. The first is titled "swissTLM3D". This data contains height information as well as x and y coordinates, however, the height data is not seen since QGIS only works in 2D. This model contains data for the entirety of Switzerland, marking the location of 15 million landscape features, across eight topics. These topics cover roads and tracks, public transport, buildings, area, land cover (fig. 10), hydrography, single point objects, and place names, which is divided into 32 vector layers. Of these topics, the layers for roads and tracks, public transport, buildings, hydrography, and single point objects are relevant. Unfortunately, the dataset does not differentiate between these topics so all 32 layers
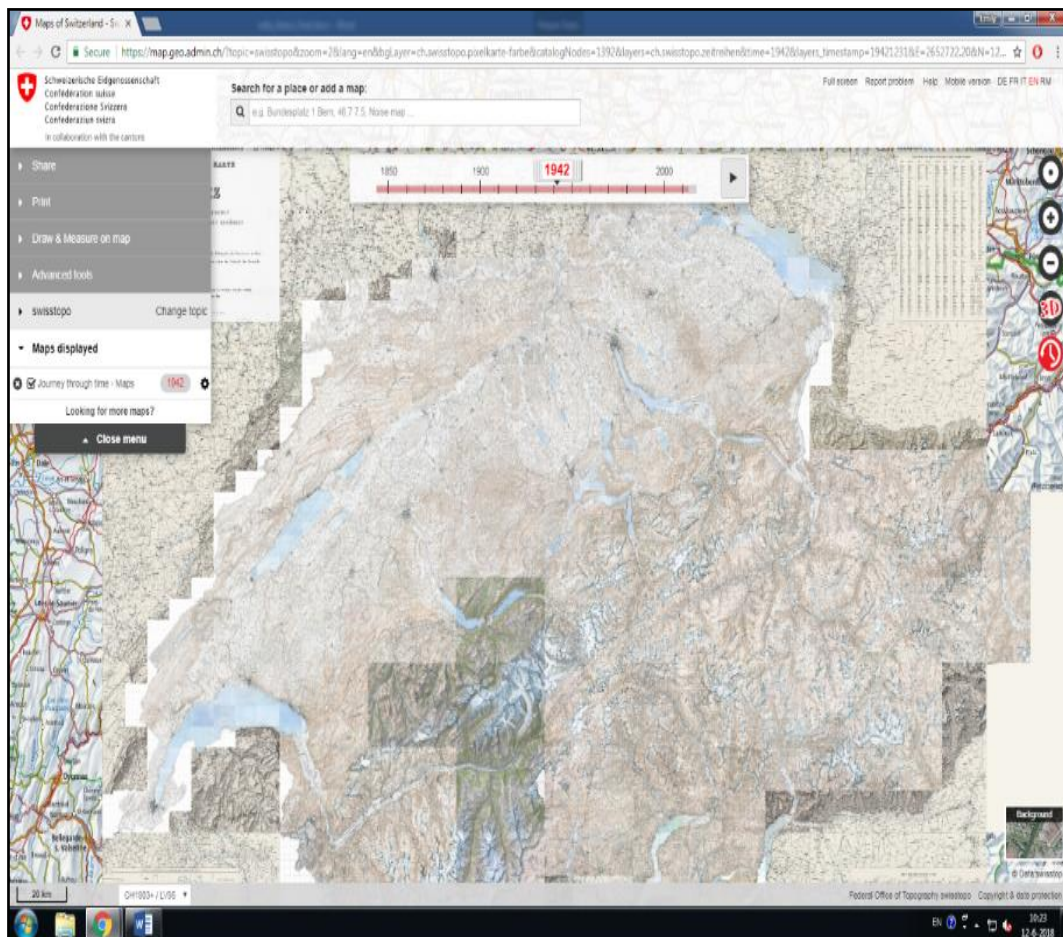

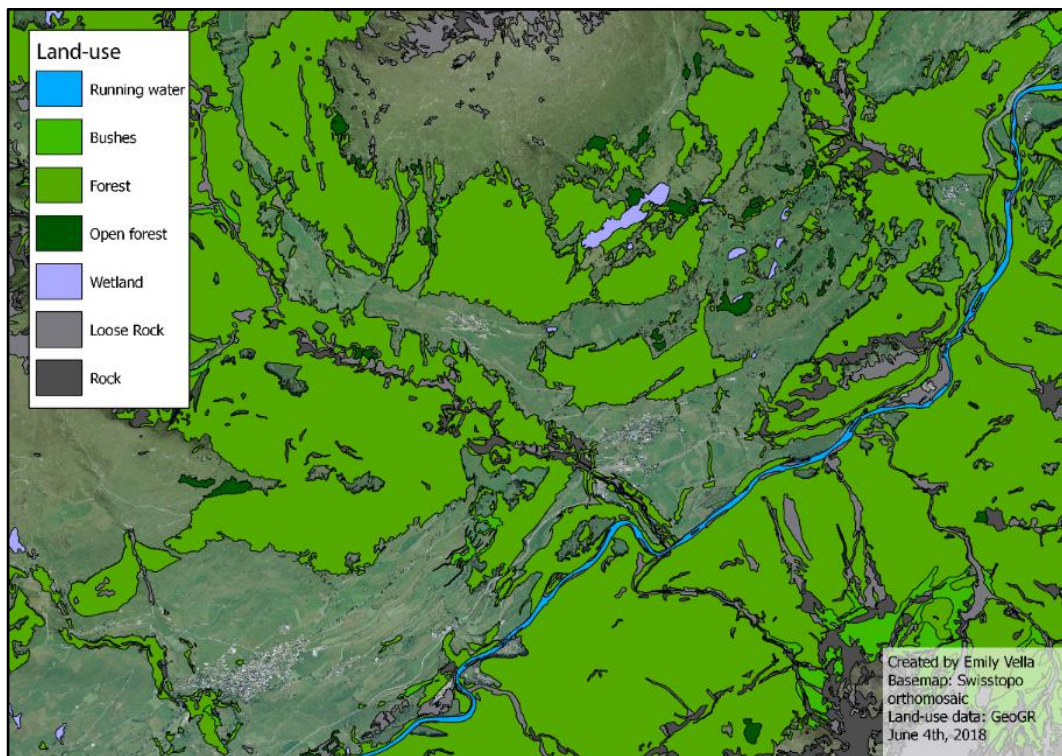Figure 10. Screenshot of Swisstopo's "A journey through time – maps" portal. The panel on the left allows you to toggle between maps, share, and print (or save) maps. The slider is located at the top of the window.

were imported into QGIS and inspected. Layers were combed individually and deleted if they were irrelevant or if the data fell outside the study area. Of the 32 layers, 14 layers

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were kept, most notably, layers for rivers, streets, and buildings. Since the dataset included all of Switzerland, the layers were edited to only include the features within the study area. This was achieved by toggling on editing (pencil icon found on the bottom of the attribute table window), selecting the features outside of the study area and then deleting them from the dataset. One of the most useful layers contained the land cover (fig. 10), including the forested areas, wetlands, and rock covered lands.

Swiss Boundaries

A dataset with all of the internal boundaries of Switzerland is freely available. The data was last updated in the early months of 2018, the exact time is unknown. The data was downloaded as a ZIP file and unzipped using 7-Zip. The folder contained the data in many different formats, including both the older LV03 and newer LV95 CRS. The LV95 shapefiles were imported into QGIS. Four of the five layers are relevant. The dataset is in German and was translated using wordreference.com and by using the attribute table to determine what each feature was indicating. The layers "BEZIRKSGEBIET", "HOHEITSGEBIET," "KANTONSGEBIET," and "LANDESGEBIET" were translated and renamed to "region", "municipality", "canton", and "swiss_borders". These are not fully accurate translations based on the naming conventions, but they are accurate to the information conveyed in the dataset. This dataset is useful because it provides the current official political borders of Switzerland and has been used to standardize the terminology used for the various regional classifications (ex. region vs. municipality vs. community). In addition, this dataset is useful for visualizing the data within the larger framework of the canton and country, as well as for generating maps that provide better geographic context than other more specific datasets.

4.2.3 GeoGR[5]

The GeoGR data was found on their website http://www.geogr.ch/. This website is only available in German and Italian, therefore the Google Translate extension (https://translate.google.com/) for Google Chrome (https://www.google.com/chrome/) was used and proved to be a sufficient, although imperfect, method of translation. On the left-hand side of the webpage, there is a link titled "shop" where the user can login or

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[5] All of the dataset described in this section can be found on http://www.geogr.ch/. A complete list of datasets and the corresponding links can be found in appendix 2b. These will also be cited under "Internet sources."

create a new account. A free account is required in order to download data[6]. The tab at the top of the page titled "products" was used to browse through the database. After browsing and previewing the datasets in the online viewer a variety of products were selected to be downloaded and explored further. All the data was downloaded as an ESRI shapefile in the "Swiss Grid projection system, CH190+/LV95," which is abbreviated to LV95.

Cadastral Survey (Amtliche Vermessung)

The Cadastral Survey includes the locations of roads, buildings, mountains and rivers. The selection tool in the online previewer only allows a selection area of 200ha, therefore three datasets were downloaded, using the "select by community" option to download datasets connected to Ramosch, Scuol, and Tschlin and were downloaded as ESRI shapefiles. The website took approximately 15 minutes to process the request and prepare the files to be downloaded, which were downloaded as a ZIP file. After unzipping the folders, the shapefiles were imported into QGIS. All three datasets had the same shapefiles therefore only one needed to be explored in order to find the relevant information, which was achieved by looking at the attribute table. The attribute table was in German and http://www.wordreference.com was used to translate the data. In the event that the data could not be translated due to naming conventions (ex. abbreviations), the layer was compared to the orthomosaic photo to see what features overlapped in order to determine what that particular layer was attempting to depict.

In order to view the land types, the layer style (found in the properties menu) was changed from single to categorical. Under the drop down tab, the heading "Beschreib" (description) was selected and then classified. This generated a list of all the different land types in the community. Of the 20 different classifications, 10 were kept based on relevancy. Classifications were only deleted when they were deemed irrelevant or redundant to the study, such as a classification marking all the traffic islands, which is already covered by the streets classification.

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[6] The site must be in German or Italian in order to download data. Translating the page to English somehow prevents downloading.

Crop areas 1992 (Fruchtfolgeflächen)

This dataset shows all the crop rotation areas as of 1992 (fig. 11) and was downloaded for the entire Canton of Grisons as an ESRI shape titled 'fff1992_shape' appearing in QGIS as polygons. The name of the layer was then changed to crop_areas_1992. The layer was edited to only include the crop areas that appear within Zone 1 and 2. This was accomplished by selecting the features using the rectangular selection tool to select all the features outside of the area. The attribute table was then opened and toggled into edit mode (pencil icon found on the bottom of the attribute table window) and then these features were deleted.
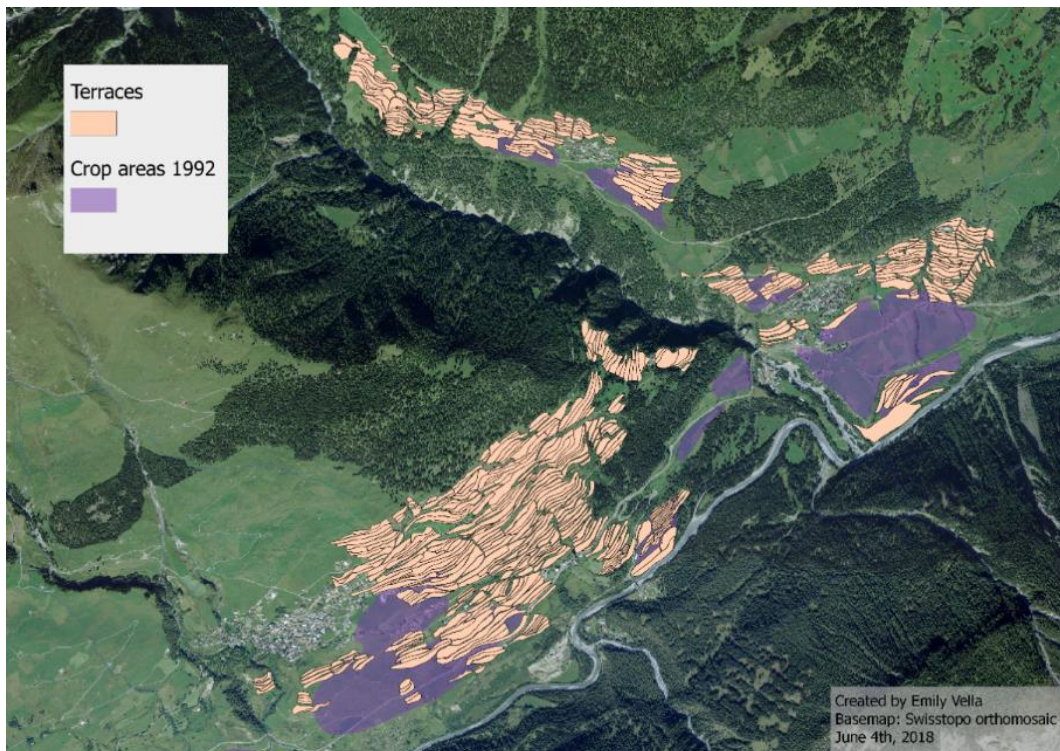
Figure 11. Zone 1 terraces and crop areas as of 1992 (GeoGR). More often than not these areas do not overlap. LV95.

Water Protection Map (Gewässerschutzkart)

The water protection map was last updated in 2015 and documents the location of water sources that host viable drinking water and are protected according to the laws on land development (fig. 12). The dataset for the Canton of Grisons was downloaded in LV95. Using the same procedure as the Crop areas 1992 dataset, the water protection map was edited to include only the features located within the study area. After inspecting the attribute tables of the six layers, the naming conventions used were not helpful, nor was a comparison to the other datasets. The website included a link to a PDF of metadata for this dataset which included a very brief description of the classifications and naming conventions used (http://map.geo.gr.ch/gis-tools/). The metadata is only

available in German and was translated into English using Google Translate. While the translation was imperfect, they were sufficient at determining the basic use for each layer.
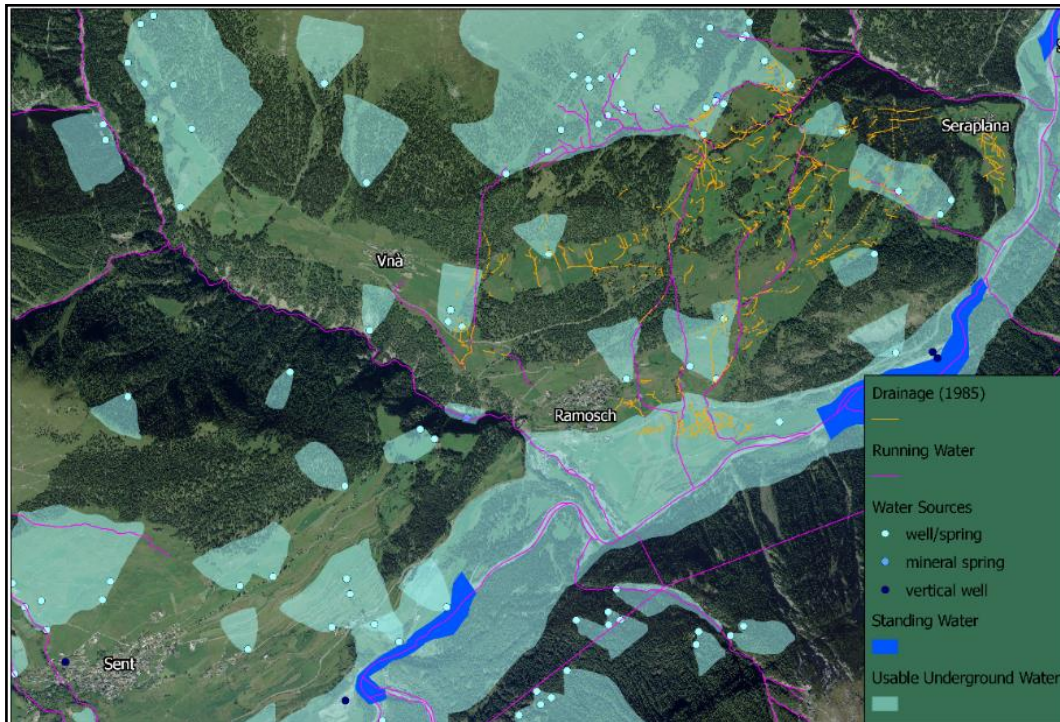
Figure 12. Confirmed water sources in the study area. The drainage systems were documented in 1985 (Raba 1996), where the other sources were documented in 2015 (GeoGR). Basemap: Swisstopo orthomosaic.

swissALTI3D (DTM)

SwissALTI35 is a digital terrain model (DTM) created by Swisstopo and reprocessed by GeoGR at a spatial resolution of 2m. The original model is available from Swisstopo for a significant price (486 CHF or 418 Euros as of June 7th, 2018, for Valsot) but is free from GeoGR. The model was created using LiDAR data and then converted to the DTM, without buildings and vegetation. It is available by the tile, five of which were downloaded to cover the extent of the study area. This data was then used to create a hillshade model (fig. 13) of the area. This was done in QGIS by uploading the images as a virtual raster catalogue and by using the "DEM (Terrain Model)" tool in the raster toolkit. The default settings were kept. Using the same process, aspect, slope, and a colour relief were generated (appendix 3).

This data was not obtained until after the terraces were digitized. The hillshade model clearly shows the outlines of the terraces, perhaps even better than the orthomosaic photo. The digitized terraces in Zone 1 where compared to the terraces visible in the hillshade model. Only 1 terrace located in array 2 seems to have been misidentified and was immediately removed from the studies. 27 new terraces were

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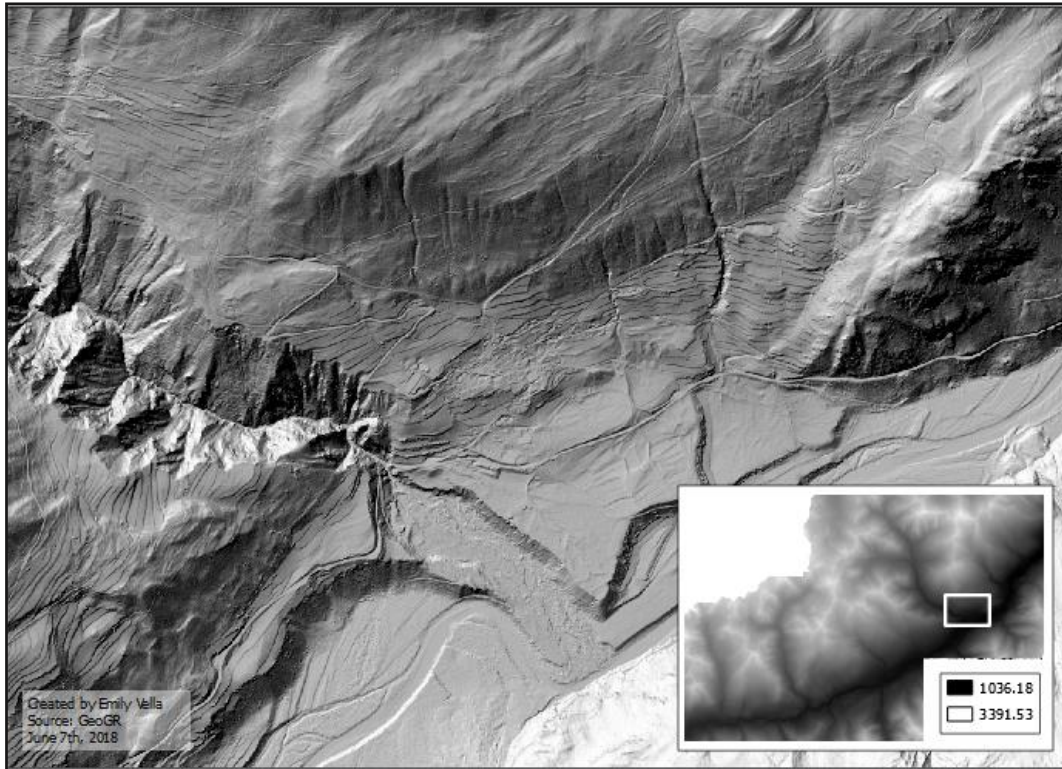
Figure 13. Hillshade model of A1 and parts of A2 and A3. The terraces are clearly visible since the hillshade shows the differences in elevation. Inset shows the DEM from which the hillshade was derived. GeoGR 2018, LV95.

identified, all of which were touching existing terraces but not clearly defined in the orthomosaic. These terraces were added to the existing clusters. Assuming that all of the terraces can be identified in the hillshade model, the percent error of the orthomosaic photo is 3.7%.[7]

4.2.4 Terraced Landscapes/Silvretta Geodata

GeoEye

The GeoEye imagery is satellite imagery taken from a commercial satellite and purchased by the Silvretta Project. The satellite was launched in 2008 and provides a spatial resolution of 0.41m (panchromatic) (Lambers 2018, 6). The imagery is available in five different spectral bands: panchromatic, blue, green, red, and near-infrared (fig. 14; appendix 4). The dataset that was received included all five spectral bands, each with five different tiles (GeoTIFF files), two of which covered the research area. In order to view

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[7] Percent error was calculated using the formula ((orthomosaic terraces − DTM terraces)/DTM terraces)*100, where orthomosaic terraces = 691 and DTM terraces = 718. Therefore, ((691-718)/718)*100 = 3.7%.

the images in QGIS, the contrast enhancement in the properties panel must be set to "Stretch to MinMax," otherwise the images appear as a black tile.

The GeoEye imagery is projected using the WGS84/UTM CRS. Due to a bug in QGIS 1.8., satellite imagery cannot be reprojected, nor can it be georeferenced using the georeferencer plugin. This issue is not present in later versions of QGIS, however, I did not have the administrative permissions to download another version of QGIS onto the faculty computers. Another solution is to convert the files from a GeoTIFF to a JPEG or by exporting the GeoTIFF as a TIFF using photo-editing software. This process will remove the previous georeferenced data from the file and allow QGIS to read the file as a regular raster file, which will permit the user to georeference the image using the georeferencer plug-in. This can be done using GIMP (FOSS)(https://www.gimp.org) or Photoshop (proprietary software)(https://www.adobe.com). Due to the lack of administrative permissions, GIMP could not be downloaded. The faculty has a license for Photoshop CC 2017 and this solution was tested. This solution was unsuccessful for two reasons. Simply exporting as a JPEG using the default options, specifically a resolution of 72 pixels per inch (ppi) significantly lowered the resolution of the image, rendering it unusable. Secondly, any attempt to increase the resolution to a usable resolution significantly increased the file size, which the computer was unable to process. For example, an increase to 300ppi increased the file size from approximately 1.3GB to almost 23GB. After numerous attempts, all resulting in Photoshop crashing, it was determined that this is most likely a hardware issue since this version of Photoshop is known to be quite stable, with export limitations commonly set by the computers processing power, as opposed to the software capabilities.

In theory, the images could be georeferenced using the georeferencer plug-in and a more recent version of QGIS. QGIS georeferences using a default contrast enhancement setting of "no stretch" which would make the images appear as a black rectangle and impossible to georeference. This can be solved by changing the contrast enhancement setting under "render" in the options setting window to "Stretch to MinMax" and saving as the new default.

In order to georeference the imagery ArcMap 10.2.2 was used. The software had been previously purchased and installed by the faculty at Leiden University. While this is not a FOSS program, the bug that prevents the imagery from being georeferenced in QGIS does not exist in this program. The images were imported into a new canvas and georeferenced against the SwissImage orthomosaic in LV95. The data was then exported
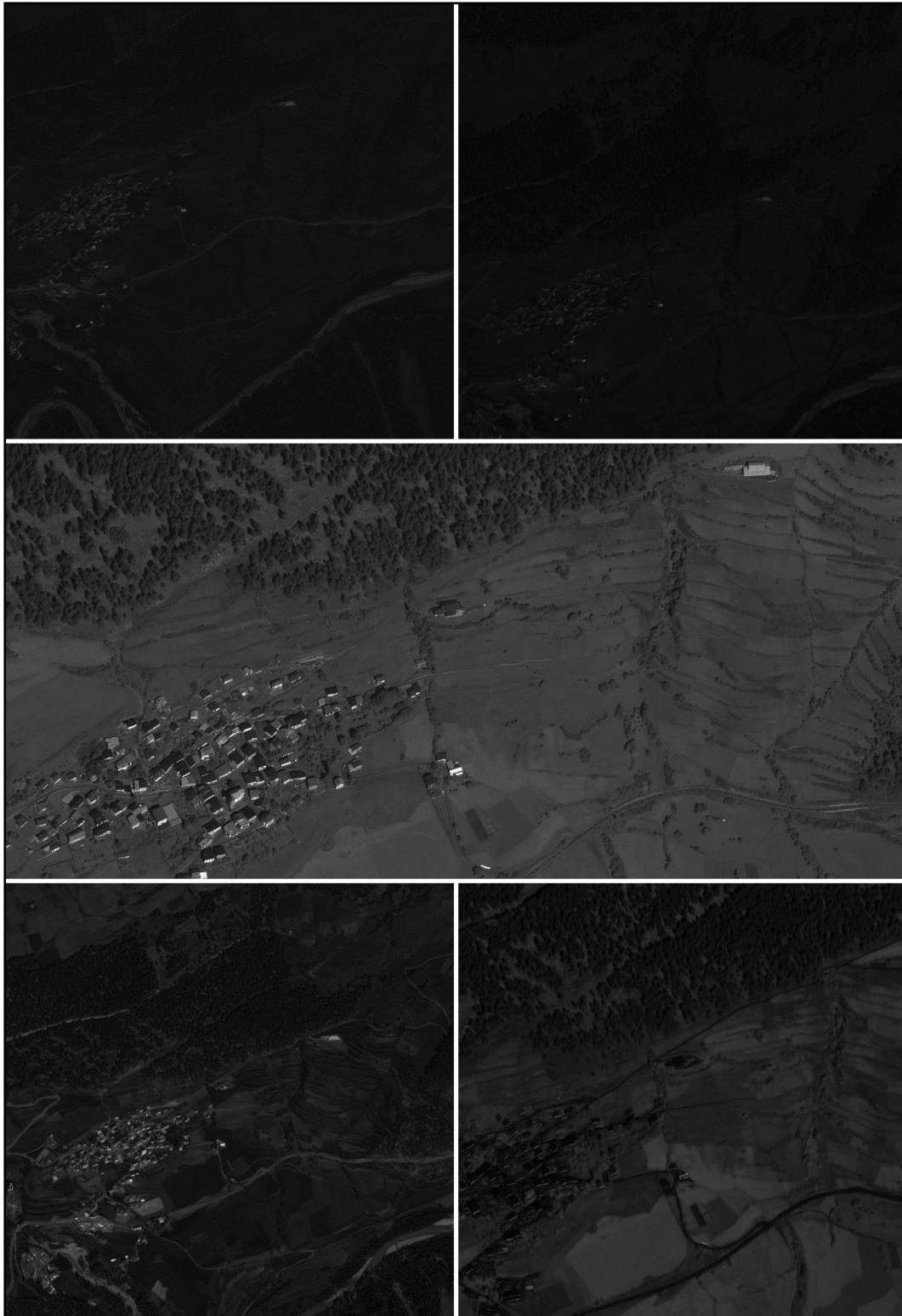
Figure 14. Comparison of GeoEye bands. Top left: blue; top right: green; middle: panchromatic; bottom left: red; bottom right: near infrared. All bands visualized in greyscale. GeoEye.

from ArcMap as a new GeoTIFF and then imported into QGIS, where the new georeferenced information was compatible with the CRS. This solution was both effective and efficient, however, it was used as a last resort. Due to the hardware and administrative permissions, the ideal solutions were not possible at this point in time.

Once the images were imported into QGIS with the correct CRS, it became clear that the data was extremely useful. Lines in the landscape are easily visible and this has made the images extremely useful for confirming the location of terraces that had been previously documented.

Swisstopo: DHM

The DHM (fig. 15) is available from Swisstopo with a height matrix of 25m. This is available as a shapefile and available for purchase by community. This data was previously purchased by the Silvretta Project who have allowed me to use the data for this thesis. The first shapefile is a line layer, which shows the contour lines of the region. The original layer covered a much larger area than was necessary. The layer was edited by turning on editing, selecting the "Select Features by Rectangle" tool to select the unnecessary areas, and deleting the features. Due to a large number of features and software and hardware limitations, the program would stop responding during any attempts to clip the layer to the study area. For this reason, the features had to be deleted from the attribute table in batches of approximately 1000-2000 features. The resulting layer was slightly larger than

Figure 15. The DHM (contour lines) overlaid on a the Hillshade model and DTM (GeoGR). Obtained from the Silvretta Project who previously downloaded the data from Swisstopo.

Zone 2 since the continuity of the lines extended outside of the borders of the research area and could not be deleted without losing the data inside the research area. The second shapefile is a point layer. The same process was followed in order to edit the data

to the shape of the research area. Where line data is continuous, point data is not, therefore the layer was edited to match the contours of the research area.

Swisstopo: Map

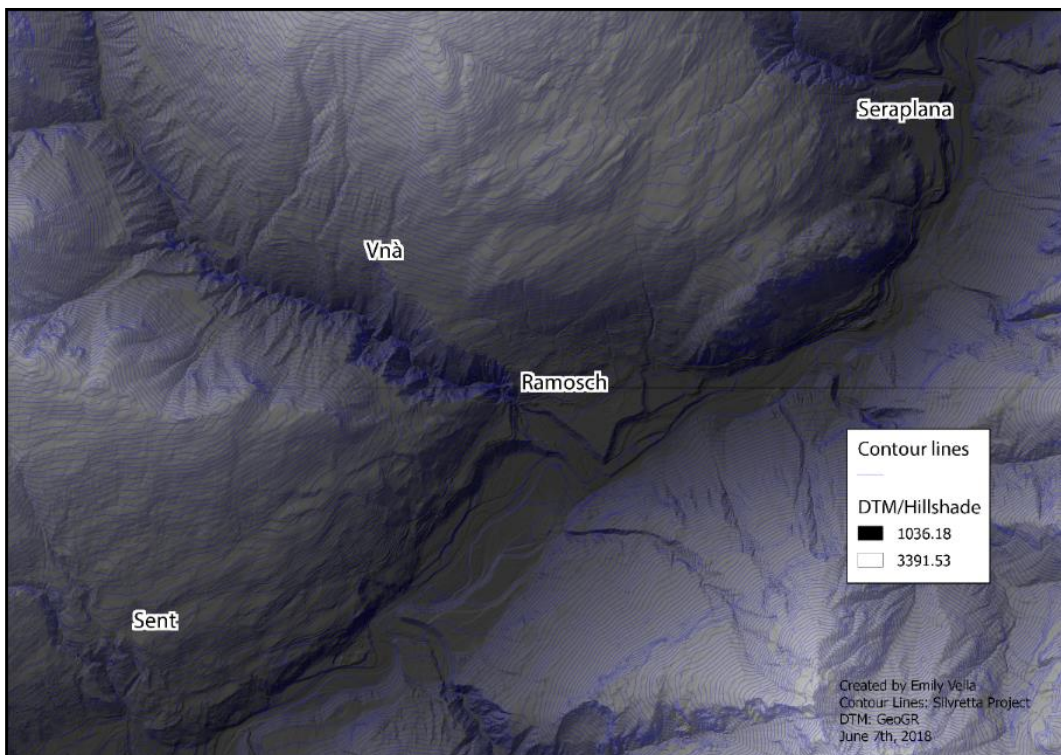The project had previously downloaded the most recent (2008) general map of the area that shows all the roads, rivers, and landmarks. This was most likely downloaded from the Swisstopo "A journey through time - maps" portal since the map from 2008 perfectly matches the map received from the project. The map was received as a GeoTIFF and did not have to be edited or clipped in any way.

Swisstopo: SwissImage

SwissImage is a series of orthomosaic photos which combines aerial photographs taken by Swisstopo in 2008. This data is available for purchase from Swisstopo but was received from the Terraced Landscapes project since it had previously been purchased. These images have a resolution of 25cm, however, edges are not always clearly defined due to shadows. A large number of tiles were received (approximately 16GB worth of data), of which 20 tiles, or 10GB of the data was used. These tiles were imported into QGIS using the "Build Virtual Raster (Catalogue)" option under the Raster toolbox. This was done to combine the tiles into one (virtual) layer. Another option is to merge the files into one raster, but this process takes significant amounts of processing power which the computer did not have. Merging files is known to be a long process, and creating a virtual raster (catalogue) is much quicker, and just as effective for viewing the data as a single layer.

One of the issues with this dataset is that the CRS information was incorrect, or there was another CRS bug in the program. In QGIS, the CRS was set to LV95, however, this projected the layer far away from where it should be, in comparison to the GeoGR and other Swisstopo data. Reprojecting the data in CH1903/LV03, however, placed the layer in the correct position. Therefore, the SwissImage layer has been projected in LV03, while the other datasets are projected in LV95, but they are all perfectly aligned.

Vector Data

This dataset contained 16 vector layers. Each layer was named using an unknown naming convention and no metadata was associated with the dataset. Swisstopo has a dataset titled "Vector 25" which is the name of the folder I received. It is likely that the data is derived from the Swisstopo dataset, however, this is an assumption that cannot be proven without the metadata of the data I received or by comparing both datasets. In

order to determine what this dataset contained, the attribute table for each layer was examined and the shapes were compared to the SwissImage orthomosaic. This dataset had the same CRS issue that SwissImage did, and was corrected by projecting it in LV03.

Only the layers that had features in Zone 1 were kept, which cut the dataset in half. Of these 7 layers, only the paths and trails layer and the road layer were kept. Layers that were deleted included buildings and land cover, which were redundant due to having already been covered by other datasets. Since it is difficult to determine if has been modified, the roads and trails layers were kept to ensure that any changes in paths were documented.

4.3 Methodology

4.3.1 Digitizing the terraces: Zone 1

The first step towards documenting the terraces was to locate them on the various datasets. When I began the process, the terraces were most easily visible on the SwissImage orthomosaic. A new shapefile layer was created in QGIS, as a polygon layer in LV95. The first field in the attribute table was labelled "unit" and categorized as a unique number. Two more fields were added, "Cluster", and "Array". After accepting the settings, the new layer was generated. After toggling into edit mode, the pen tool was used to draw an outline around the boundary of each terrace. They were each given a unique unit number, starting at 0. In total, 692 terraces were digitized in Zone 1, which was later updated to 726 with the additional terraces found using the hillshade model. In the event that a building, rock, tree, or other feature was located along the edge of a terrace the feature was not included in the terraces. However, if the feature was located in the middle of a terrace it was included within the area of the terrace. In many cases an edge of the terrace was not easily distinguished in the orthomosaic. In this instance, the visible line was extrapolated to the closest edge to close the feature. Polygons were chosen since the interest is in the entirety of the terraces, not just the terrace walls or divisions. In addition, the boundaries were difficult to pinpoint since they were often quite thick. Later, a line layer was created to document the walls based on the DTM so that this data is not lost if the walls begin to decay but this layer not be used in further analysis of the terraces within the context of this thesis due to time constraints.

After the terraces were digitized, they were grouped into clusters. The terraces do not exist in isolation but bordered other terraces with similar morphology, orientation, size, or colour. In order to be considered a cluster, the terraces had to share a border and be of similar morphology. Exceptions were made in cases where modern features, such as roads, cut through a terrace or when the topography or landscape clearly influenced the size or shape of terraces in a cluster. For example, near the tree line, the morphology is shaped by the location of forests, which have caused the terraces to follow the non-linear shape of the forests as a boundary, causing variations in size. In the event that a cluster of terraces was located on the border between Zone 1 and Zone 2, the terraces located in Zone 2 were digitized as Zone 1 terraces. Cluster numbers will be abbreviated to C(n) where n is the number of the cluster(s) being discussed. The terraces were then grouped together, where the group was given a unique number under the "cluster" field,

starting at 1. The edits were then saved and the editing was toggled off after inspecting the attribute table to ensure that there were no inconsistencies or accidental duplications. 60 clusters were identified. A cluster is defined as a group of at least 3 terraces with similar features (shape, orientation, size) and are in close proximity to each other. In the event that fewer terraces were located together, they were grouped with the closest cluster. The clusters were largely determined by the modern landscape, with features like pathways and roads dividing terraces. For this reason, it is difficult to look at clusters in close proximity as individual systems. Therefore, they have been grouped into 3 arrays in an attempt to view the terraces as a larger system with time depth as opposed to a modern construction.

Upon looking at the terraces as a whole, 3 larger arrays were evident, arbitrarily labelled Arrays 1, 2, and 3. Array 1 contains C1-13 and is located near Ramosch. Array 2, located the farthest north near Vnà, and contains C14-26. Array 3 contains the most clusters and is located on the western edge of Zone 1 (Scuol) and contains C27-59. The arrays are separated by spatial distance as well as landscape features, such as forests, ridges, towns, and elevation.

4.3.2 Digitizing the terraces: Zone 2

There are many terraces located within Zone 2. Since they lay outside the main research area, they were digitized with less rigour. A new shapefile was created, using only the cluster field. In this zone, only the clusters were digitized, not each individual terrace. It is important to note that these terraces do exist and often share similar morphology but they lie outside the research area and thus do not require the same level of detailed documentation. A more complete documentation of these terraces may be a relevant topic to explore in the future but lies outside of the scope of this project.

4.3.3 Terrace Shapes

A spreadsheet was created to describe the shape of the terraces and clusters. The spreadsheet contains the data from the attribute table in addition to three new fields: terrace_shape, cluster_structure, and cluster_relation. This field terrace_shape describes the shape of the individual terrace, which can be described as rectangular, curvilinear, or irregular (fig 16). The second column is labelled "cluster_structure", which describes the individual cluster structure, which can be described as regular, interlaced, or irregular (fig. 17). This describes the average shape of the terraces within the cluster. The last field is labelled "cluster_ relation," which describes the relationship between the cluster and the

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cluster(s) near it. These options are delineated, fractured, and disjointed (fig. 18). A delineated cluster is a cluster that is clearly separated from other terraces by a significant distance, often created by forest segments or settlements. A fractured cluster is a cluster in close proximity to another cluster where there appears to be a potential continuation of terraces but have been separated by smaller modern features, such as roads or rocks but the boundaries are clearly defined. A disjointed cluster describes a cluster which is not as clearly distinguishable from its surrounding clusters but displays slight differences in terrace morphology. In this case, a single cluster cannot be discussed in isolation, since the division is subjective, based on the resolution of the data available, the modern landscape, and human error. The spreadsheet was then joined to the attribute table of the terraces layer (appendix 6).
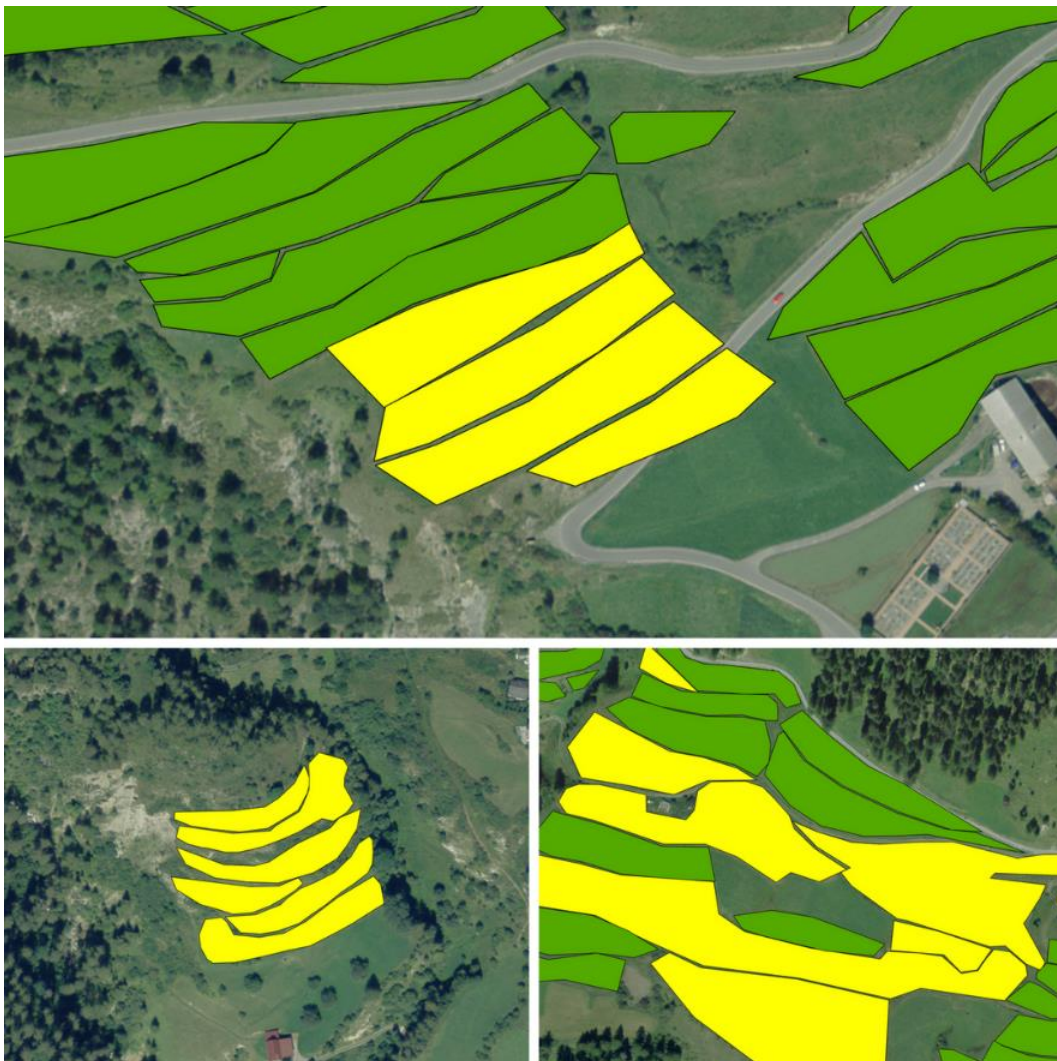
Figure 16. Top: rectangular terraces (yellow). Bottom left: curvilinear terraces (yellow). Bottom right: irregular terraces
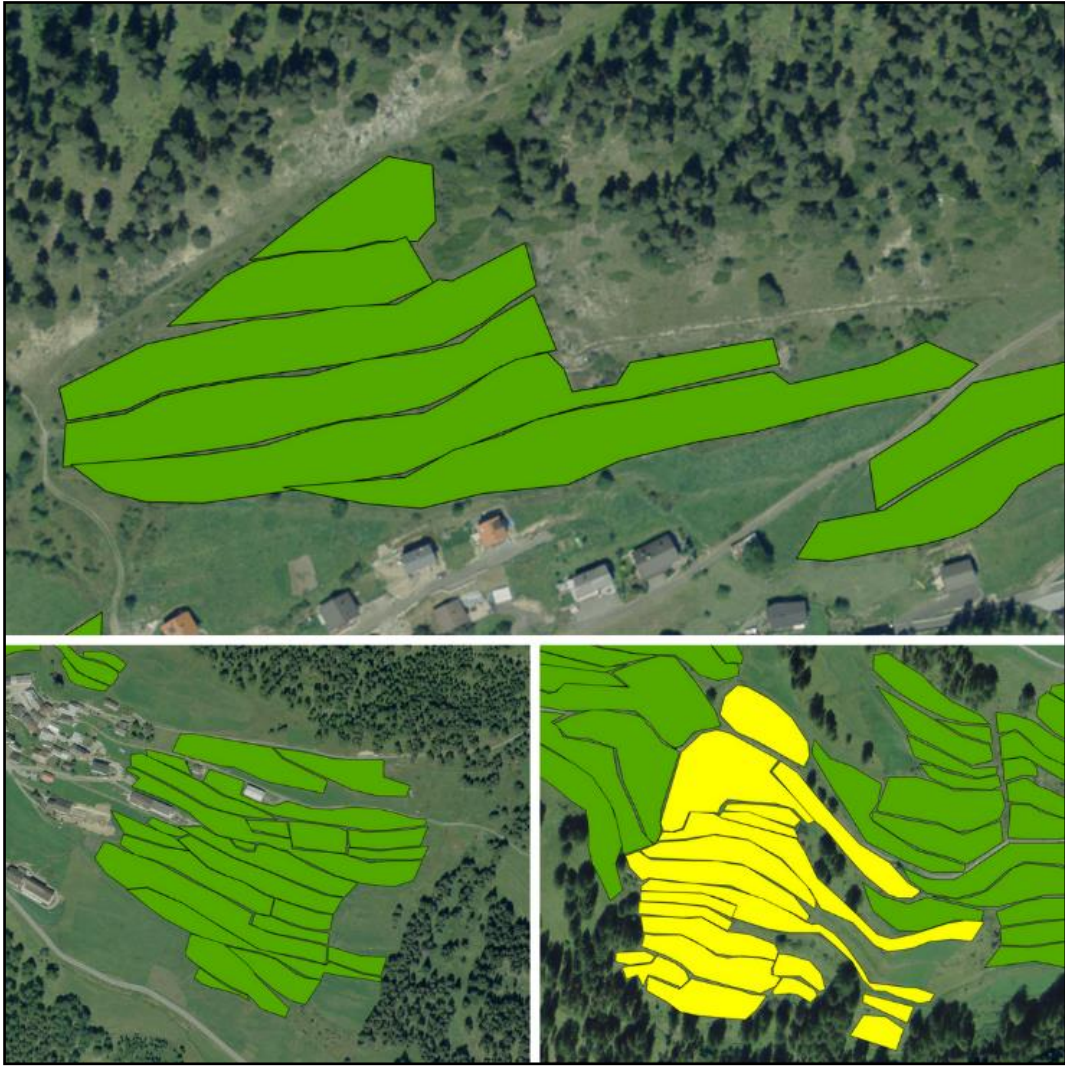
Figure 17. Top: Regular cluster. Bottom left: interlaced cluster. Bottom right: irregular cluster
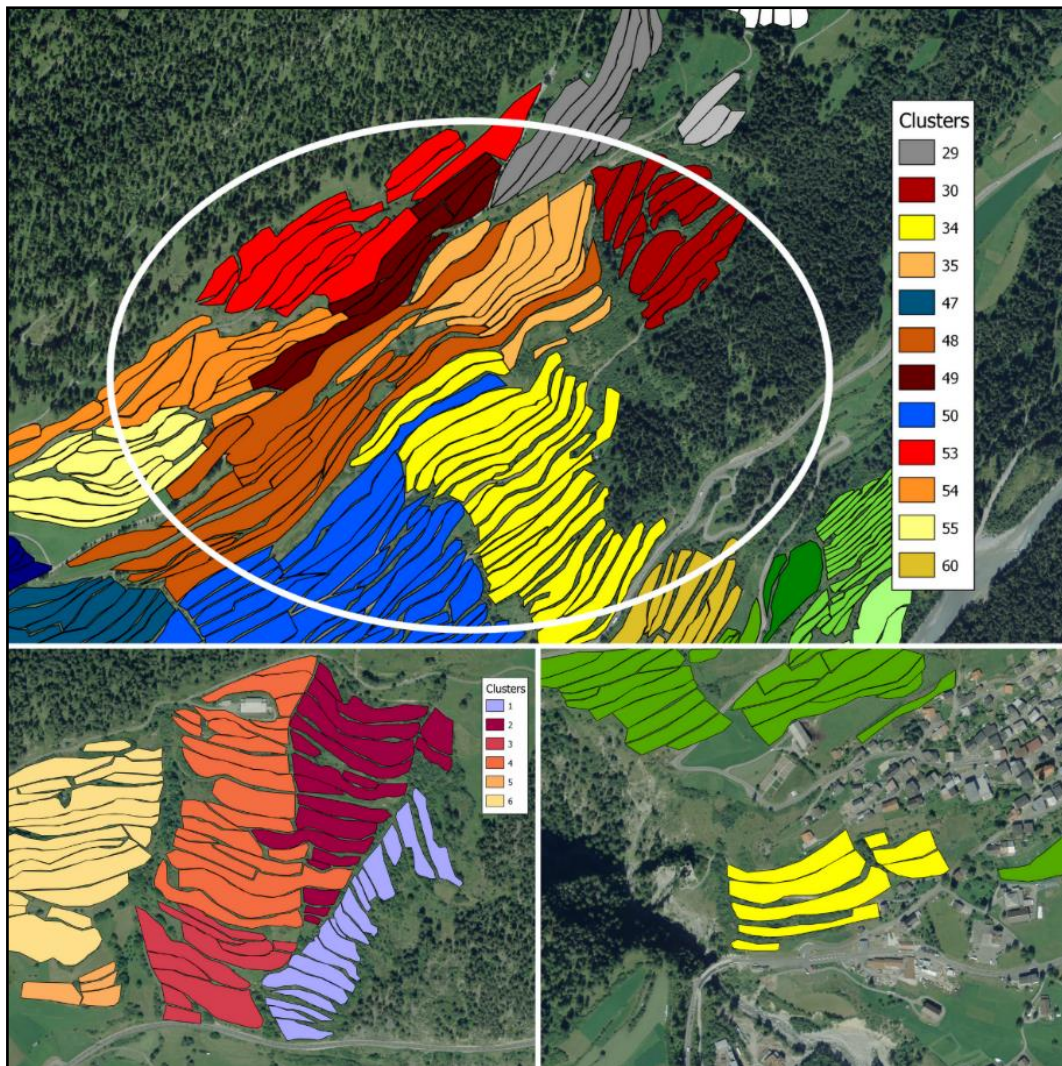
Figure 18. Top: Disjointed cluster. Clusters are difficult to distinguish. These clusters have been separated by size and shape of the terraces within. A certain level of subjectivity is involved. These often show high levels of continuity with the neighbouring clusters

Bottom left: Fractured clusters. The terraces show moderate continuity with the neighbouring clusters but are separated by breaks in the terraces, caused by irrigation, roads, pathways, or other features in the landscape.

Bottom right: Delineated cluster (yellow). The boundaries of the cluster are clear. These clusters are separated from other clusters by distance, elevation, or orientation. and show no continuity.

Chapter 5: Results and Analysis

The terraces clusters have been sorted into four arrays. Arrays 1-3 (abbreviated to A1, A2, and A3) are each distinct groups of terraces separated by large distances, landscape features, and settlements. It is likely that these arrays are separate entities from each other based on these distances. Array 4 (A4) has been used to discuss the terraces east of Ramosch, which were documented in 1996 by Raba based on aerial imagery from 1985. Arrays 1-3 can be seen in figure 19. Based on these divisions, it is a reasonable inference that the inhabitants of Ramosch, Vnà, and Sent are the caretakers of A1, A2, and A3, respectively.
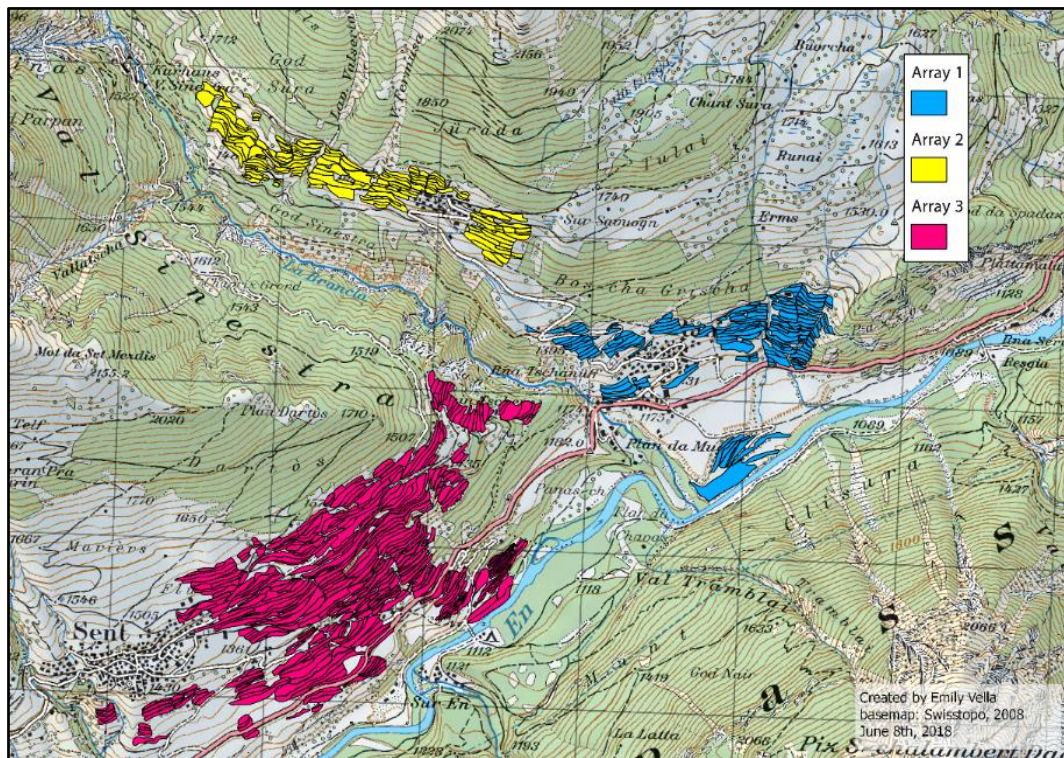
Figure 19. Digitized terraces divided into arrays based on location.

5.1 Array 1

5.1.1 Terrace Morphology and Orientation

Array 1 (fig. 20) contains clusters 1-13 (151 terraces) and is shaped in a slight arch, with the majority of the clusters located near Ramosch. Based on the toponyms from the Swisstopo map from 2008, specific boundaries for the array can be distinguished. *Boscha Grischa* acts as the northern boundary, where Road 27 (unmarked in Swisstopo map; name derived from https://www.google.nl/maps) acts as a general southern boundary. C13 located further south, where the Inn River acts as the boundary. However, these terraces are outliers in the area. *Paxxa* is the eastern boundary and *Rńa Tschaniif* is the western boundary. Based on the 2008 map, the terraces range from 1100-1400m. a.s.l.
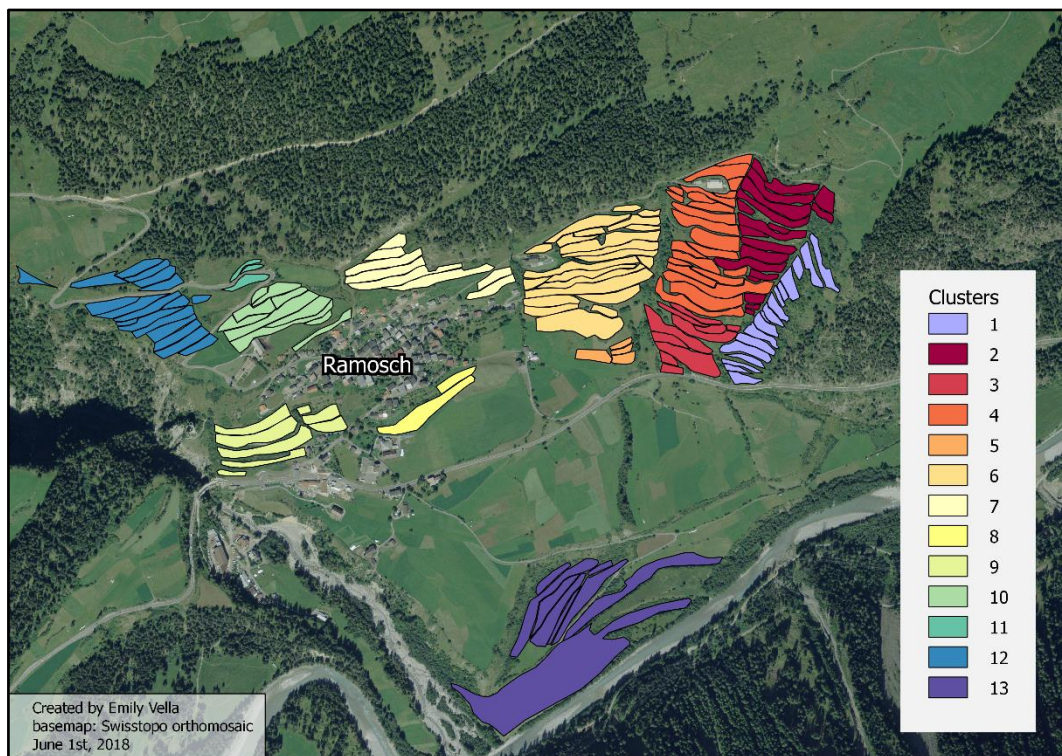
Figure 20. Clusters in array 1.

Clusters 1-6 (C1-6) are located on the eastern side of the array and are oriented from northeast to southeast. C7 has a fairly straight north to south orientation. C8-13 are oriented from northwest to southeast. The majority of terraces in this array are curvilinear, closely followed by irregular and then rectangular terraces. In general, the cluster structures are fairly regular, with some irregular and a few interlaced structures (statistics found in appendix 6).

C1 is separated from C2 by landscape features, which the maps depict as running water. C2 and C4 are separated by what are most likely modern or manmade features. These clusters may have once been part of the same cluster, due to the shapes of the terraces, which indicate continuity between the neighbouring clusters. C3 has been separated from C4 due to a variation in terrace size, although it is likely that C3 belongs to the same system as 2 and 4.

C5 and C6 are at slightly different orientations than those they border. They are part of the same system but have been separated due to a variation in terrace shape and size. C7 is very regular and clearly conforms to the landscape features, bordered by forest to the north and Ramosch to the south. A road separates the cluster from C10 to the west and a barrier of trees separates it from C6 to the east. Due to the variation in elevation between the bordering clusters, this cluster is most likely its own system.

C10-12 are located at the same elevation and are of a similar cluster structure. A road passes through C11 and C10 and twice through C12. It is most likely that these terraces are part of the same system, due to the modernity of the breaks. C8, 9, and 13 are located to the south of Ramosch. Clusters 8 and 9 are located in close proximity to Ramosch. Since it is most likely that water is brought to the terraces from a higher elevation, it is unlikely that the water source for these terraces will be identified due to the presence of Ramosch. C13 is located at the southernmost edge of the research area, far removed from the other clusters in this array. C13 appears to conform to the modern landscape features and is most likely a modern system. This cluster is clearly an outlier based on elevation and proximity to Ramosch.

5.1.2 Proximity to water sources

Numerous underground water sources are located in this region (fig. 21). The groundwater from the Inn River is present at higher elevations and theoretically accessible, reaching the lowest terraces of C1, 2, and 9. However, there are no known access points to this water source. Three underground water sources (identified as spring)) are located at a higher elevation to C1-4 and are likely used for irrigation in this area.

The ridges separating C1 from C2 has been identified as a waterway, which would most likely be used to irrigate these clusters. This waterway begins much further north and two points converge at the most northern spring in this area. This waterway would most likely be used to irrigate these clusters. The visible line separating C2 from C4 has

been identified as a drainage path in 1996[8]. This pathway is slightly broken and could be another segment of the waterway that irrigates C1 or this could be used exclusively as drainage during periods of high precipitation. However, the 2008 map designates this as simply a waterway, which continues down and reaches C13.

C5 and C6 are sandwiched in between two running water sources and it is impossible to tell which source irrigates the terraces. However, both water sources appear to have the same source of origin. C8 and C9 have no apparent water source. A well or spring is located at the southern edge of cluster 7 but it is more likely to be used by Ramosch than to be carried up the terraces to irrigate those to the north. A path through the forest to the north may exist to carry water to these terraces from the same water source as clusters 5 and 6. A series of broken drainage and water lines appear to connect clusters 10, 11, and 12 to a water source north of array 2.
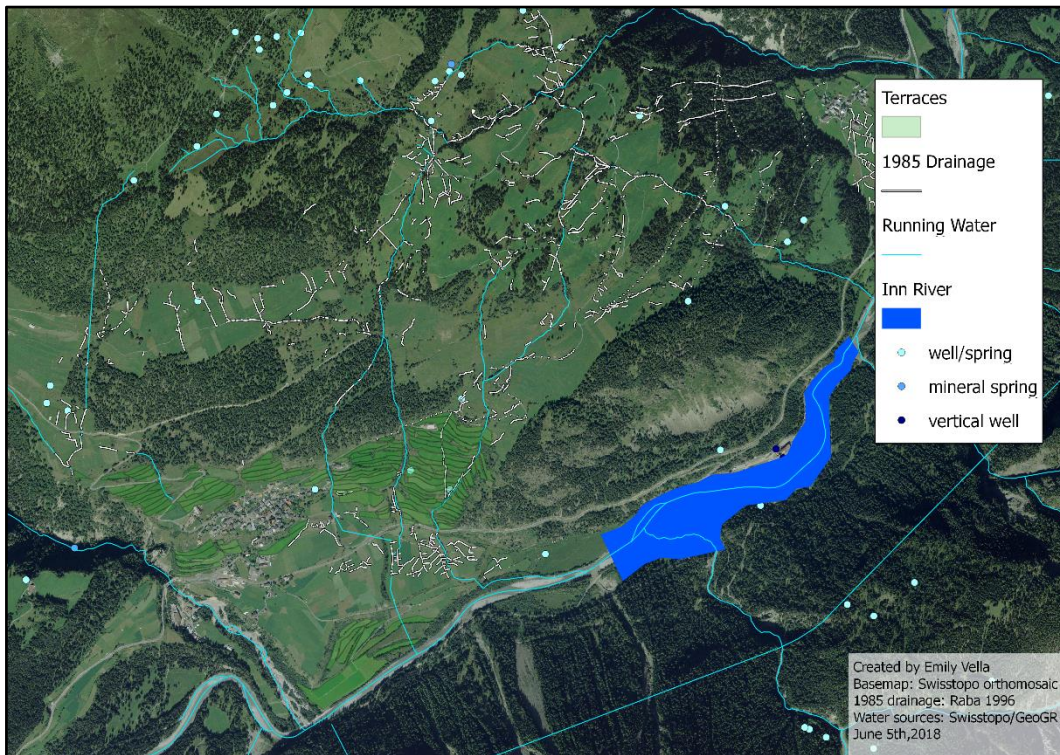
Figure 21. Array 1 terraces and waterways.

5.2 Array 2

5.2.1 Terrace morphology and orientation

In general, the terraces are oriented northeast to southeast and are fairly regular in size (fig 22). *God Sura* and *Jürada* (toponyms for the forested area above terraces) act as the northeastern boundary, where *God Sinestra* acts as the southwestern boundary. The southeastern boundary of this array is *Boscha Grischa,* while *Kurhaus V. Sinestra* acts as the northwestern boundary. Vnà separates cluster 14 from the rest of the clusters; otherwise, the breaks in the clusters appear to be due to natural landscape features, such as ridges and forested areas. Based on the 2008 map, the clusters have an elevation of 1400-1712m a.s.l.
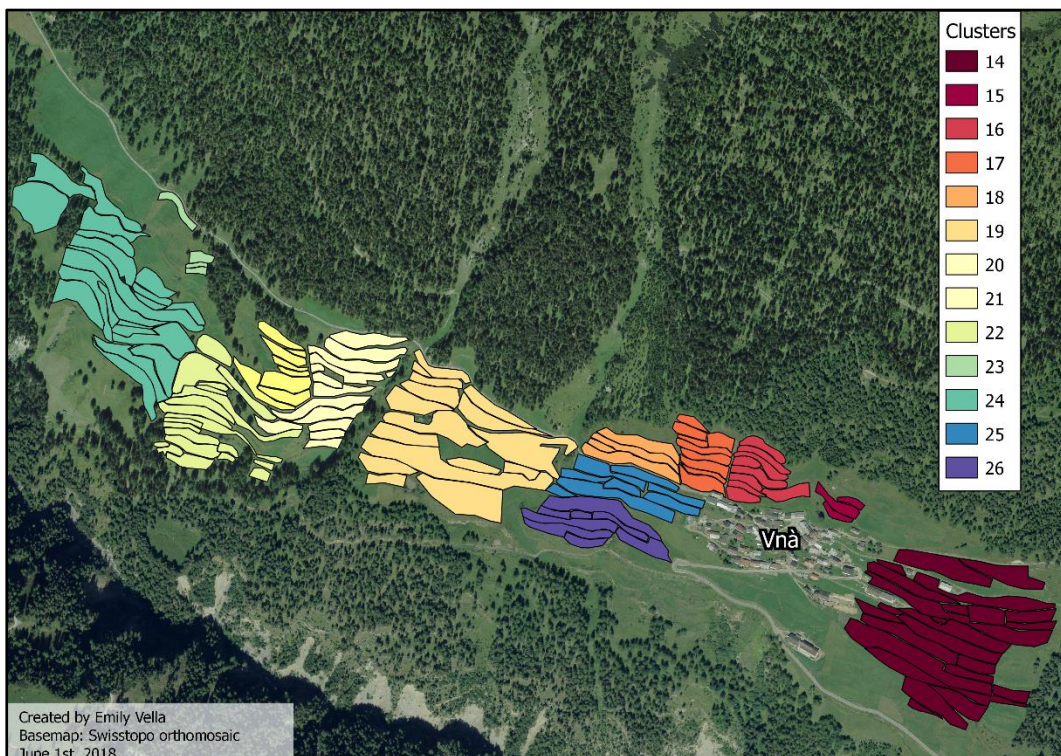
Figure 22. Terrace clusters in array 2.

The terraces in C14 conform to the roads and demonstrate a wide range in size. These terraces are more difficult to distinguish in the landscape when compared to the others in the array, which can be attributed to lack of use or a less extreme variation in elevation between the terraces.

Cluster 15 lies to the north of Vnà and is surrounded by markings in the landscape that could be more terraces belonging to the cluster, but this is unclear. The northwestern edge of the cluster is in close proximity to cluster 16 and due to the hypothesis that there

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are more terraces in the vicinity that are either no longer used or not visible in the imagery, it is likely that these clusters are part of the same system.

Clusters 16, 17, 18, 19, 25, and 26 have been described as fractured terraces, a road separates C18 and 25, and C17 and C16 are separated by a path, but otherwise the separations between the clusters are for superficial reasons (i.e. changes in shape), not based on changes in the landscape. C15-19, 25, 26 should be considered part of the same system. C20-24 are on the other side of a ridge, separating them from C19. While the other clusters in this array are fairly regular or standard in size and shape, these clusters are extremely irregular. There is a large variation in size and shape both across the clusters and within. The majority of terraces in these clusters are curvilinear or irregular with curvilinear aspects. Due to the close proximity, lack of landscape features separating the clusters and regular irregularity, these clusters are likely part of the same system.

5.2.2 Irrigation and water sources

There are no clear water sources for the clusters in A2 (fig. 23). Two water sources are located at a much higher elevation to C15, 16, 17, 18, 19, 25, and 26. A clear path through the dense vegetation from these sources to the terraces is visible. but they have not been previously documented as a waterway. It is believed that this is an error in the water systems datasets. It is impossible to tell if both or only one water source is used. A similar issue is encountered with the other clusters in the array. No waterways have been documented near these clusters. The closest water source is located to the north of C19. The ridge that separates clusters 20 and 19 could be a location where the waterway splits in two in order to irrigate both systems, or it could diverge towards one side of the ridge. Clusters 23 and 24 are located above an underground water source and there are two known access points within close proximity to these clusters. Due to the elevation and orientation of the terraces it is most likely that these sources irrigate C23 and C24 while the previously mentioned waterway north of C19 irrigates C19 and C20. Since this is a hypothesis based strictly on proximity, with no evidence of waterways in the region, this is a low certainty proposal and should be investigated further.
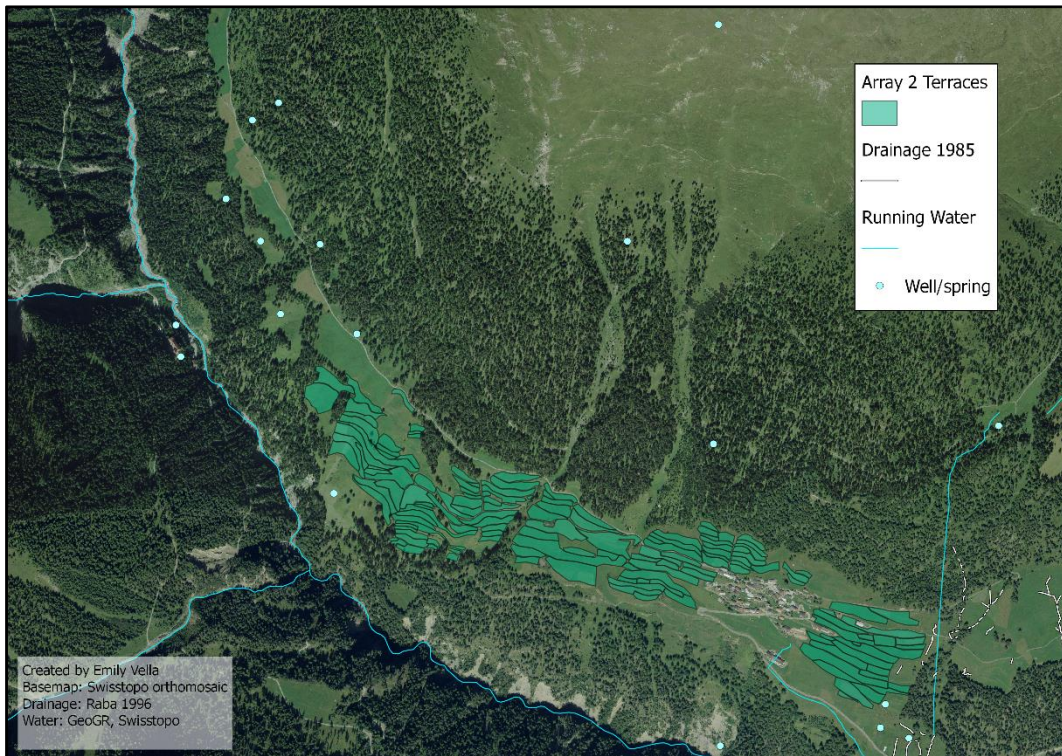
Figure 23. Array 2 and the documented waterways.

5.3 Array 3

5.3.1 Terrace morphology and orientation

The terraces in A3 (fig 24) are oriented from northwest to southeast and are by far the most complex set of clusters. The northeastern boundaries of this array are *Dartòs* and *Val Sinestra.* Road 27 acts as a general southeastern boundary, with the Inn River as the absolute boundary. *Panasch* and *Bain Tschern* border A3 on the northeast and Sent act as the southwestern boundary. Overall, the landscape shows a large amount of homogeneity. The clusters are fractured and disjointed but in general are of similar widths with varying lengths. The similarity in widths can be attributed to the steady slope of the region. The northern edge of this array is defined by the tree line, while the frequency on the lower edge is influenced by elevation. Some areas have agricultural fields where terracing is not needed due to the relative flatness of the terrain. These fields are typically located to the south of Sent. It acts as the western border of this region, with the exception of five clusters (38, 39, 40, 41, 58), which are located to the south of the town. These terraces are located at elevations between 1200-1600m a.s.l. based on the 2008 map.
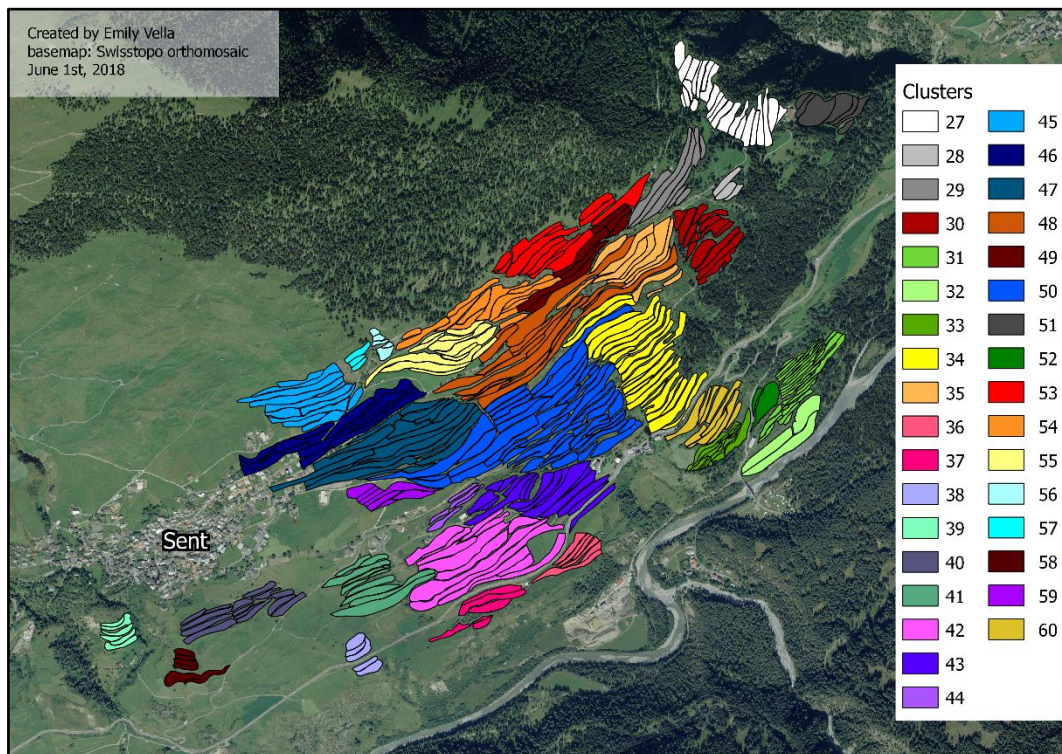
Figure 24. Clusters in array 3.

Two exceptions include clusters 27/51, and cluster 31. Clusters 27 and 51 are separated from each other by a building and are located at the northeastern edge of array 3. These terraces are relatively thin, since they are shaped on almost all sides by dense forests. While the other clusters are fairly linear in that that they are all oriented in the same direction, cluster 27 begins to curve towards the east to the point where the last terrace is oriented from east to west. Cluster 51 is oriented west by northwest; the reason for this change in orientation is unknown. Cluster 31 contains terraces that are extremely thin compared to every other cluster in the entire study region. The reason for this extreme change in size is unknown and does not appear to be due to a change in slope. Due to the high level of homogeneity in this region, the number of terrace systems is unknown but approximated at three.

5.3.2 Irrigation and water sources

Few waterways have been documented in this area (fig. 25). Due to the close proximity of terrace clusters and lack of waterways, it is difficult to hypothesize which water sources irrigate which clusters. C39 is located directly on top of an underground water source, with an access point to the southern edge. A waterway passed on the eastern side of the cluster and it is unknown if these terraces are irrigated by one, the other, or both. There are no visible lines connecting C39 to the next closest terraces, 58 and 40. C39 likely exists as its own small system.

The Inn River acts as the southern boundary for C31 and 32. There are two access points to an underground water source near C27 and C51 and are likely the sources of irrigation for these clusters, suggesting that these clusters are part of the same system. Due to the forest surrounding these clusters, it is unlikely that any other terraces are irrigated from this water source.

The remaining clusters are in too close proximity to each other to advocate for a separation of systems based on water sources. There are too many terraces across too wide a region for them to be irrigated by a single water source, but these sources and the extent of their use is unknown. Four access points to underground sources are present within this network of terraces that could be used for irrigation but their extent is unknown.
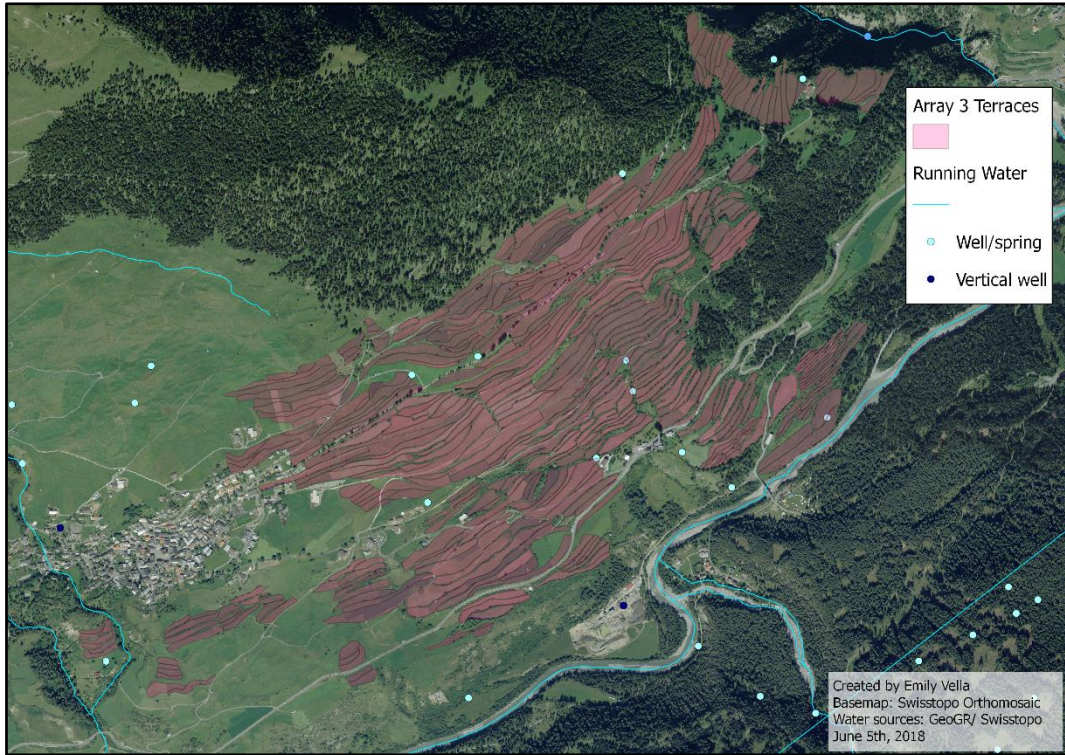
Figure 25. Array 3 waterways and terraces.

5.4 Array 4

The terraces in A4 were documented in 1996 based on the low-resolution 1985 aerial images from Swisstopo. These terraces are located the furthest away for a settlement when compared to the terraces in the other arrays. Since 1985, the forest has continued to reclaim this land as it reverts back to the natural vegetation it would have supported prior to human intervention. Based on the regrowth in this area and the 2003 aerial imagery, it took approximately 20 years for the terraces to become completely obscured. In addition to the regrowth, it appears that the terraces disappeared due to a change in elevation. The slope map (fig. 26) shows that this area has very little slope, meaning that terraces are no longer relevant in this area, and it is likely that the terrace walls have deteriorated to create this flattened landscape.
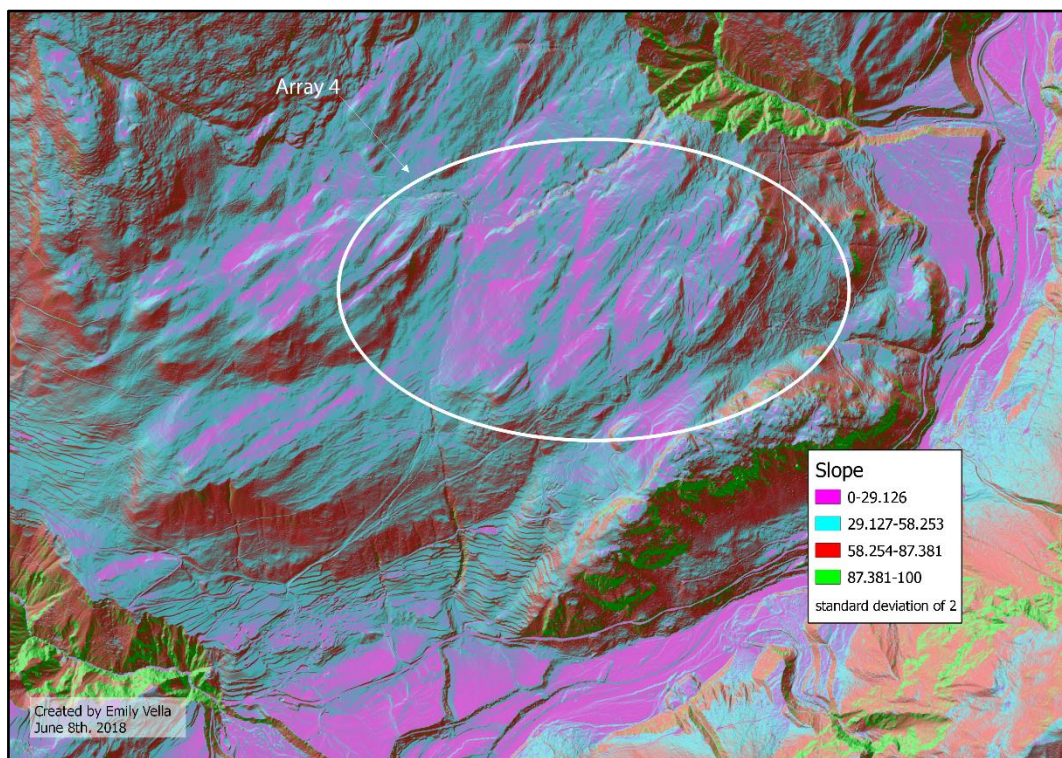
Figure 26. Slope map of array 4.

5.5 Changes in the Landscape

5.5.1 Historical maps

When comparing the map from 1897 to the map from 2008, it is difficult to distinguish any substantial differences. Ramosch was previously labelled Remüs, with Ramosch in a smaller font underneath. The lines showing the contours of the landscape are quite obvious, making it difficult to see other features, such as roads and waterways. Some waterways, particularly those surrounding Ramosch are documented on this map but are not seen on later maps. These waterways have been digitized and added to the water systems dataset under the name "new_waterways_1897" (fig. 27). These waterways cannot be used at present to analyze the modern terrace systems until they are investigated in the field. The discrepancies between the areas where the 1897 waterways and recent data come close to overlapping in some areas and this should be investigated further to determine if the discrepancies are different waterways or are the same just documented differently. The town of Sent was smaller, having since expanded eastwards. The forest edges appear to be the same.

The differences between 1897 and 1926 appear to be purely aesthetic. It is difficult to distinguish if changes in road and river thickness are due to variations in their sizes, or simply stylistic choices made by the cartographer. This map uses fewer, and
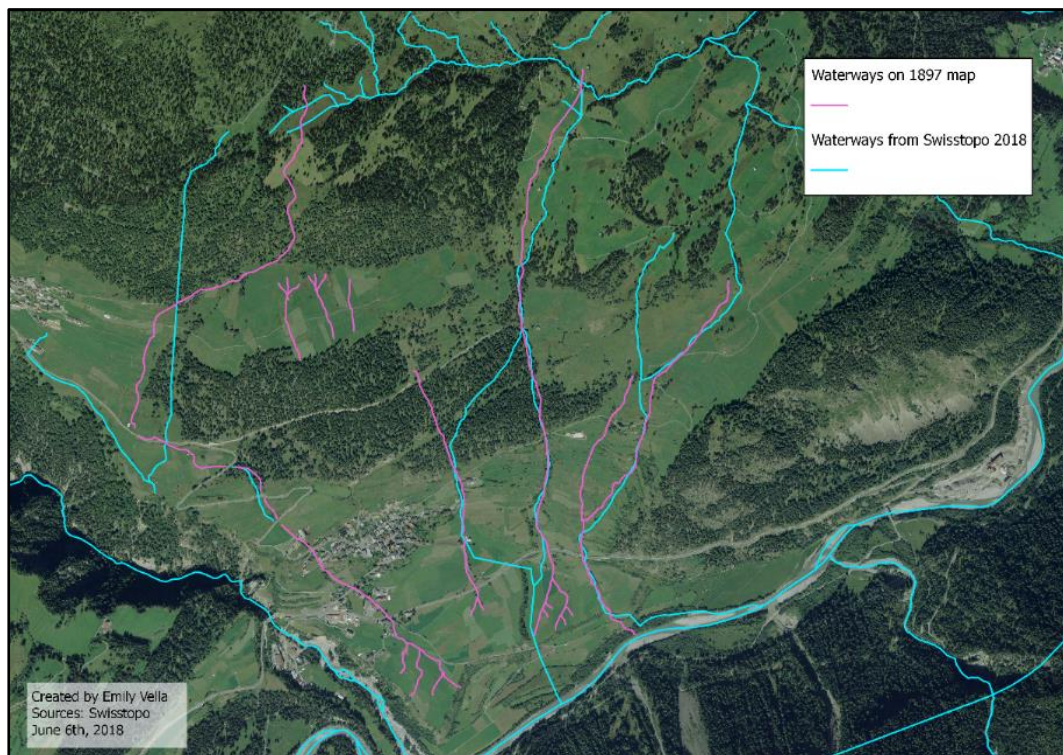
Figure 27. New waterways

thinner contour lines and darker lines to signify roads and rivers, which makes this a more comprehensible map. An unlabeled road near the northeastern end of Zone 1 is a new addition, which occurred sometime after the creation of the map in 1897.

1951 is the first year that the map uses colour, as opposed to shading and symbols, to indicate the location of the forested areas, which makes the edges clearer. Some of the forests, particularly near the northern edge of Zone 1 have been broken into smaller forested areas, although it is difficult to tell if this is due to a change in stylistic approaches or a change in the landscape. Ramosch, Sent, and Vnà appear to be the same size, where Seraplana has expanded slightly. The new road that was new in the 1926 map is no longer present. The earlier maps contained blue shading around the rivers to the northeastern corner of Zone 1, many of which have since disappeared. The most likely interpretation of this shading based on the colour is that there were water sources, that have since dried up or are no longer accessible, although again this could simply be a difference in aesthetic choices.

Between 1951 and 1991 Sent and Ramosch have expanded, based on the number of buildings marked on the maps. Some of the blue shading, which disappeared in 1951, seem to have reappeared, but not to the same extent in which they were present in 1926. Three new roads have appeared near Sent. These roads create connections between some major roads and were most likely built to relieve traffic while making the town more accessible.

Between 1991 and 2008 Sent has continued to expand eastwards, but no new roads are present in this region. One of the roads that passed through the forested area north of Ramosch has disappeared, otherwise there are no differences between the two maps since the forest edges, roads, and waterways remain the same.

5.5.2 Aerial photographs

Based on the data collected on the terraces in 1985 combined with the aerial photographs and historical maps the landscape has changed moderately. The path of the Inn River has changed slightly, but in general remains in the same location. The largest impact of the landscape has been the development of new roads and settlements.

Near A2 the landscape does not appear to have changed significantly. Since 1990, three houses on the southeastern edge of Vnà have been expanded and some pathways have thickened, most likely due to increased traffic, either by foot or by vehicles. The forest edges have not changed, indicating these edges were maintained. The terraces at the northernmost edge (clusters 23-24) are not visible on the aerial photograph. This may be due to the low resolution of the image or indicates that they are modern terraces. Similar statements can be made about A1. Other than the addition of a few buildings on the outskirts of Ramosch, there seem to be no major developments. Since 1990, a new path was constructed on the southern edge of the study area (C13), which was most likely created to transport vehicles to the fields. These terraces, however, are still visible. It is harder to distinguish the terraces in C9-12, although this is most likely due to the poor resolution of the image. The remaining clusters and forest edges appear to be unchanged.

Between 2003 and 2008 the road passing through the forest between A1 and A2 greatly expanded, cutting a clear path through the trees. The structure near the end of the path predates 2003, therefore this change is most likely caused by increased maintenance and/or a change or increase of use, most likely by a larger vehicle. All the terraces are present from 2003 onwards. The area around array 3 has not changed, and all the terraces are visible but difficult to distinguish due to the low resolution of the image.

Potential terraces located near the eastern edge of Zone 1 are somewhat visible in this image due to changes in colour. Unfortunately, the poor resolution makes them difficult to distinguish. It is possible that these terraces form another array, which has either disappeared since 2003 due to a variety of possible processes or are simply not visible in the orthomosaic. Terraces in this area were documented in 1985, some of which are visible but many are not. Therefore, it is more likely that these terraces fell out of use between 1985 and 2003, although it is possible that this occurred much earlier, and have become obscured due to natural processes.

The 2008 imagery and the orthomosaic photo appear identical and are likely derived from the same aerial images. The aerial images are of a significantly lower resolution and as such could be used as an alternative to the orthomosaic photo.

The most noticeable difference between the orthomosaic and the aerial photographs from 2014 is the deforestation located at the northeastern area of array 3. The deforestation appears to originate at the northern edge and cut through the forest. It is unlikely this was done intentionally for the construction of infrastructure. This deforestation is not visible in current Google Map satellite images taken in 2018. This change appears to have been temporary and the cause remains unresolved.

5.6 Zone 2

5.6.1 Terrace morphology and orientation

For comparison, the terraces in Zone 2 were briefly examined (fig. 28) and have been divided into 52 preliminary clusters. These clusters are much more spread out when compared to the clusters in Zone 1. An array can be seen in the terraces near Tschlin and Chasura. This array appears to be defined by the surrounding forests and waterways, but it is unclear how they are irrigated.

The remaining clusters are located to the east of Sent and end at Ardez. These terraces are too sparsely populated to create an array and it is unlikely that more than a couple clusters are part of the same system. These terraces are located at lower altitudes compared to those in Zone 1 and are often located further away from settlements. These terraces could be of interest in any further studies on this topic in the region, but cannot feasibly be included within the framework of this thesis. Nevertheless, it is important to note that these agricultural terraces exist outside of Zone 1. The divisions between the zones are rather arbitrary when put in this context but necessary in order to limit the scope of the study.
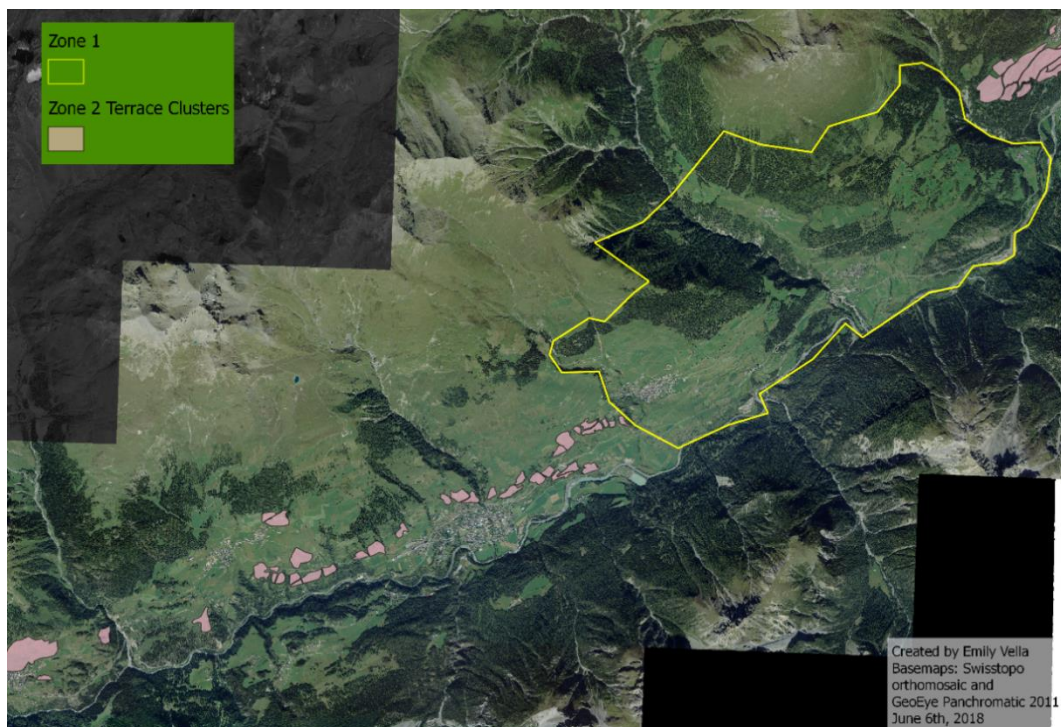
Figure 28. Zone 2 terraces.

5.7 Proposed terrace systems

It is clear that certain terrace systems exist and it is almost certain that each cluster acts as a system. 'System' refers to groups of terraces that are likely of the same age and are likely managed using the same strategies. System is used to describe any similarities which allow the terraces to function in tandem, either by proximity, use of the same water source, or by similar management strategies. The arrays could also be considered a system based on the proximity each one has to a unique settlement. In addition, each array has a different orientation and elevation range.

Another way to determine terrace systems is to rely on the water sources. The water sources can only be determined with any certainty for A1. As water is a necessity, these systems rely on the continuation and protection of this water source, and if they were to become unviable for any reason this could cause the terraces to be abandoned.

The last clear division exists in the level of preservation. This can be determined by how visible the terraces are in the landscape. While this can aid in determining which terraces are still in use and which are not, it is an imperfect system. Not all terraces are created the same. For example, a steeper slope would require stronger terrace walls, perhaps made out of stone, which would be more obvious in the imagery as opposed to a gentler slope where smaller dividers (walls or shrubbery) would be used. By cross-referencing the slope to the distance from the closest town, assuming that those further away would fall into disuse before those closer, the cause of the low distinguishability can be estimated. Based on these criteria, a number of systems (in no particular order) can be discerned.

The first system is the entirety of A4 (fig. 29). These terraces documented based on data from 1985 and are no longer visible in the Swisstopo orthomosaic. Three of the terraces are distinguishable in the GeoEye imagery when compared to the 1985 data; this number is insignificant. All the terraces in A4 have fallen into disuse, as evidenced by the lack of distinguishability in the landscape, lack of water sources, and distance from any towns. This is further evidenced by the forest regrowth which is documented in areas of land abandonment.

The second system contains C1-7 and C13 in A1 (fig. 29). These terraces are all regularly structured and in close proximity. C1-7 all face the same approximate orientation. There are obvious water sources, but it is difficult to distinguish through which paths the water follows, therefore the water systems cannot be distinguished any

further. The water appears to flow down from C1-7 to irrigate the lower fields and C13, which could indicate that these are the same system.

C8-12 are on the western side of A1 and have the same approximate orientation (NW to SE), which is different from the other terraces in A1. There is no clear water source for these terraces, but it is possible that they are irrigated from sources at a higher altitude on *Piz Arina*.

The terraces in A2 can only be categorized as one system (fig. 29). The water sources are unclear and all the documented terraces have the same orientation. The regrowth between C19 and C20 could indicate a division between the two management systems, but there are no other visible differences, therefore they will be considered the same system until proven otherwise. Interestingly, there appears to be worked land north of this system, outside of Zone 1, which seems to be affected by regrowth. It is possible that there was a previous terrace system north of C24 (fig. 29) which fell into disuse and has since been affected by regrowth. This regrowth is significant when compared to A4, and therefore likely fell into disuse prior to A4.

Systems within A3 are difficult to distinguish. The clusters are highly disjointed and there is no clear water source for many of the terrace clusters (fig. 29). C39 is interesting, since it is isolated by vegetation from all other terraces. In addition, this cluster sits almost perfectly on top of an underground water source. This cluster can be considered to be its own unique system (fig 29). C27 and C51 are isolated by vegetation, with a potential water source located near the building that is located between the two clusters. C27 and C51 will be considered a separate system based on management strategies (fig. 29). C33 and C31 are unique clusters. They are significantly thinner than the other terraces within the study area. These are worthy of note as they indicate a different management strategy, but since they are located in close proximity to the other terraces and face the same orientation they will be considered as part of this larger system. C38, C40 and C58 are separated from other terraces by distance, not vegetation or features. It remains unclear if these clusters are separate systems or not.
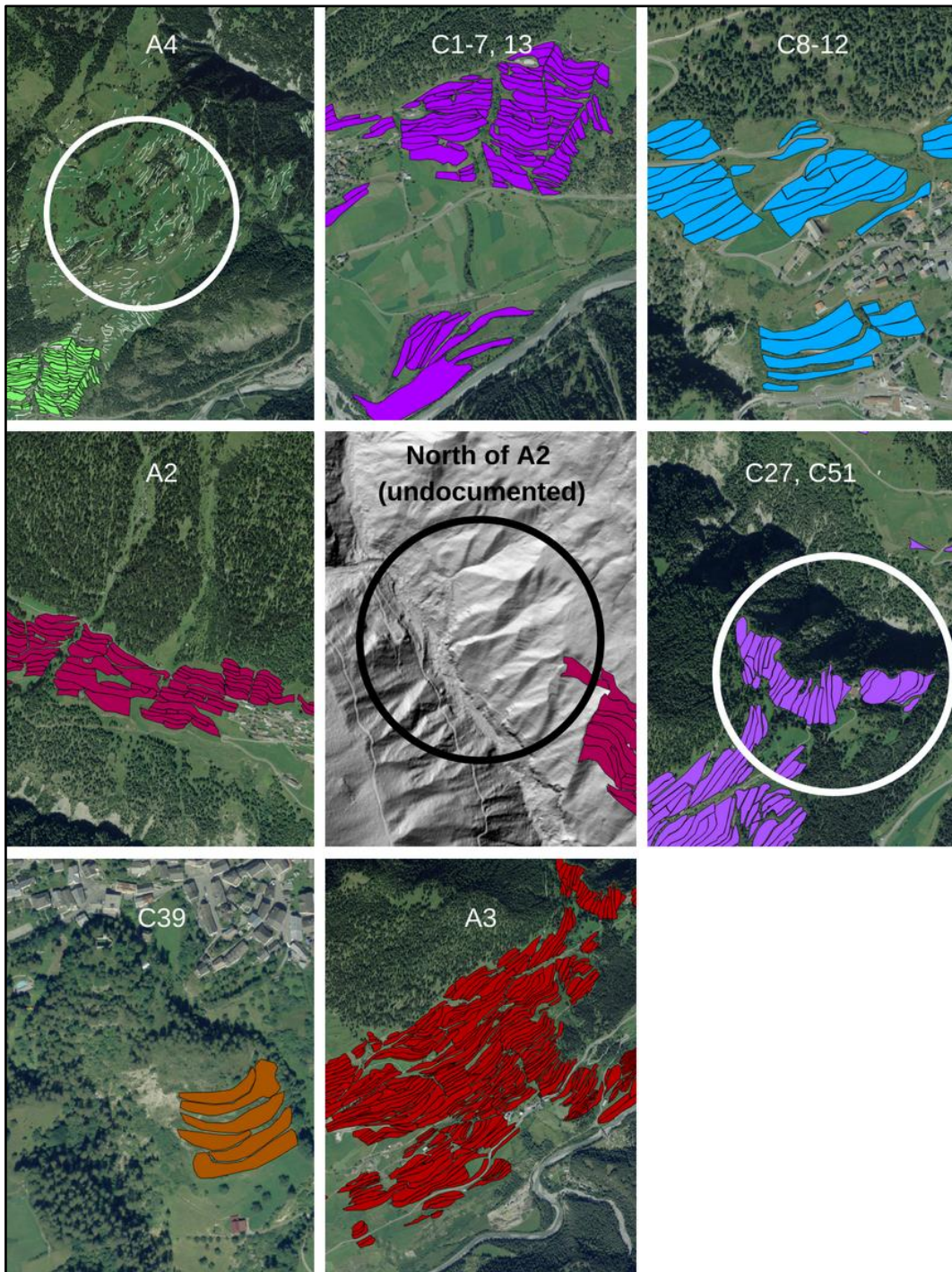
Figure 29. Proposed terrace systems.

Chapter 6: Discussion

6.1 Digging through data

What to do with data is perhaps one of the most frequently asked questions within Digital Archaeology. Unfortunately, there is no concrete answer to this question due to the wide range covered by the term data. Zubrow stated, "The data issue is that digital analysis and representation have insatiable data appetites. There is never enough data" (2006, 21). After completing this project, one aspect is strikingly clear: more data is not synonymous with good data.

For the purpose of this section, data is defined strictly as visual data, including both vector and raster files. After sifting through a few dozen datasets and even more layers, only a handful of layers were actually used. Since the datasets were not created for the purpose of this project, they often required editing in order to simplify the data to include on the features within the study area.

The most difficult and time-consuming aspect of this project was sifting through the large amounts of data. The process of going through the datasets, both online and obtained through the Silvretta Project, was completed manually and quite arduous. This process had to be streamlined, and the most efficient process for data lacking metadata can be found in figure 30. The process can be divided into two sections: finding the data and understanding the data.

6.1.1 Finding the data

Finding the data was made easier with Swisstopo and GeoGR. Luckily, these sources were made known during the early stages of this project. In many cases, however, resources like these may not be available or may be outside of a project or individual's budget. When looking at sources online, it is difficult to tell based simply by the description of the data would be useful. The ability to preview the data online before downloading was extremely helpful and is a function offered by both Swisstopo and GeoGR. Once a dataset appeared to have potential based on the title or description, the first step to determine if it is a usable source is to determine if the data overlaps with the research area. This immediately rendered some datasets unusable. The online previewer was invaluable by allowing less time to be spent downloading the datasets, some of which

are quite large and could take a significant amount of time. Finding relevant data was difficult since the second and third-party data collected lacked metadata or descriptions.
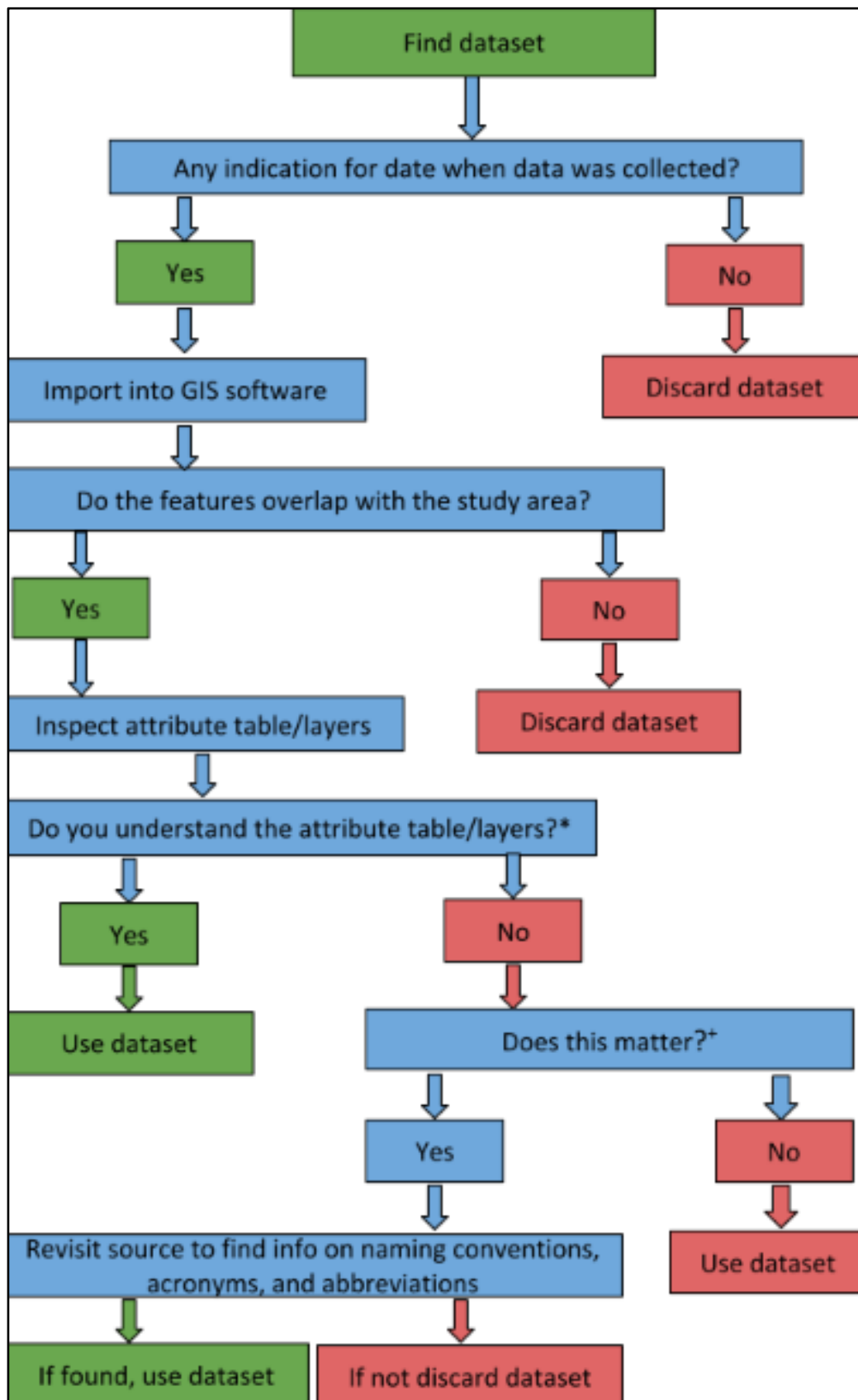
Figure 30. Workflow to determine if third-party dataset is usable.
* Reasons include language barriers and naming conventions
[+] In some cases, not all fields of the attribute table will be relevant, such as understanding the alphanumeric ID given to a particular plot of land by the government, as long as the land-use and boundaries are known.

6.1.2 Understanding the data

Understanding data without metadata is no easy feat. The biggest challenge with the data was that the attribute tables were often indecipherable. Many of the field names and classifications used were written in various unexplained naming conventions. If a data source cannot be understood, it cannot be used. The most important information that must be conveyed is what the data is showing, and when the data was collected. Often the datasets came with large attribute tables, including the dates the data was collected, the names of who collected the data, the year it was published, the areas of the polygons, descriptions, or various ID numbers which are only applicable to the original purpose of the data (fig. 31). While some of this information can be useful in understanding the data, too much data can become overwhelming.

	OBJECTID	BEREICH_KU	BEREICH	GEW_ID	BEARBEITUN	STAND_GSK	SHAPE_Leng	SHAPE_Area
0	753	Ao	GewÄ¤sserschu...	0000:0000:000052760000	20070125	20150826	1039.42583636573	10721.0825962
1	768	Ao	GewÄ¤sserschu...	0000:0000:000056090000	20080826	20150826	3870.99494801803	774818.371772389
2	810	Ao	GewÄ¤sserschu...	0000:0000:000056080000	20070124	20150826	428.76738219009	5477.20194889683
3	811	Ao	GewÄ¤sserschu...	0000:0000:000008020000	20070124	20150826	10280.6144476482	237413.801557391
4	817	Ao	GewÄ¤sserschu...	0000:0000:000000440000	20070124	20150826	7539.02168677488	280299.839868808
5	818	Ao	GewÄ¤sserschu...	0000:0000:000000440000	20070124	20150826	6206.37122130404	408300.611203361
6	822	Ao	GewÄ¤sserschu...	0000:0000:000000440000	20070124	20150826	2878.41909245232	147772.593138002
7	823	Ao	GewÄ¤sserschu...	0000:0000:000000440000	20070124	20150826	3764.76775537666	310218.526793861
8	824	Ao	GewÄ¤sserschu...	0000:0000:000000440000	20070124	20150826	12311.7642980243	843795.787130167

Attribute table - GEWSCHUTZ_BEREICH_AO :: 0 / 9 feature(s) selected

Figure 31. Example of an attribute table from a layer from the Water Protection Map, GeoGR. The BEREICH_KU, GEW_ID, SHAPE_leng, and SHAPE_Area were not relevant to this project and therefore the naming conventions and units of measurement did not need to be understood.

6.2 FOSS versus proprietary

FOSS programs are not inherently better than proprietary software. The most important factor when choosing a software is that it is capable of completing the necessary tasks. That being said, the gap between the capabilities of FOSS and proprietary software, particularly where GIS is concerned, is small enough that personal preference can play a role in choosing the software. One of the key differences between the software types are the points in development when the versions released. Proprietary software is often built behind closed doors and tested extensively within the company. Proprietary software is often quite costly and with a fee attached, and the providers must deliver a working, bug-free program to maintain their user-base. FOSS programs, on the other hand, rely on the user-base for input and the early versions are often released as beta versions to the community. This creates a discrepancy between the usability of the early versions of each program, where proprietary software tends to be quite useable, where FOSS programs require further troubleshooting. Of course, this is not true for all programs but summarizes the basic trends. QGIS 1.8 is an early version, unstable, and unreliable and is not recommended for use in research. Later versions of QGIS are much more stable and a promising alternative to ArcMap.

The use of FOSS programs for the sake of attaching the phrase FOSS to the project, or for a personal belief system in FOSS is simply a misguided practice. Using "digital toys" just because they are novel, available, or trendy (Zubrow 2006, 22) is not a useful practice. The largest benefit is that FOSS allows the researcher to be completely open with the processes the data underwent which may become an important pillar to Open Science and Open Archaeology. FOSS provides greater transparency and better licensing terms over proprietary software. With FOSS programs, researchers can work without fear of changes in licensing or losing access to the program due to changes in subscription methods. This advantage that FOSS has should not be downplayed, and will likely become essential in the coming years or decades. However, this is not the most important factor when choosing a software.

The most important factor when choosing a software, regardless of FOSS, proprietary, or any other category, is functionality. Researchers must use the best software available with the resources at hand. Replicability of studies is important and QGIS as a free program eliminates the financial barriers for others to test research, but QGIS should not be chosen unless it, along with plugins, are able to perform all the tasks required. As this thesis demonstrated, FOSS is not always the right choice; some functions

such as adding scale bars and north arrows to maps and georeferencing satellite imagery could only be completed in ArcMap. While it is true that these bugs were fixed in later versions, these versions were not available at the time the research was completed.

This project tested how far one can get in research using only FOSS (or at least free) programs and free or open data. Admittedly, QGIS was unimpressive, but also extremely outdated. A recent version of QGIS compared to a recent version of ArcMap would have yielded much better results, where the gap between QGIS and ArcMap is much smaller and the advantages that FOSS has over proprietary would be a factor. Simply, QGIS 1.8 was not capable of completing all the tasks. The three issues that remain unresolved within QGIS 1.8 (scale bar, georeferencing imagery, CRS discrepancy) do not affect the outcomes of the interpretations. Scale bars convey important information, but this did not have an impact on the study. The georeferencing issue was fixed using ArcMap, but the project could have been completed without the use of the GeoEye imagery. The use of both LV95 and LV03 was an inconvenience but had no impact on the study.

It is likely that FOSS programs will continue to grow in popularity, but I must caution that one does not use FOSS simply because it is the current trend or fad; the best available software must be used based on availability, budget, and terms and conditions that are compatible with the research and publishing goals. In terms of open data and Open Archaeology, FOSS can only help the field to move towards these more sustainable and less hierarchical ideals.

6.3 First, second, and third-party data

6.3.1 The use of second and third-party data

If data can be collected for the purpose of the research project, this is preferable to using third-party data. This gives the project better control over many aspects of the data, including spatial and spectral resolution, the regional extent that the data covers, and the features that are documented (although technical and financial restrictions apply). This can also ensure that important features to the project, which may be considered irrelevant to a third-party, are included. However, this can be a costly and redundant endeavour. Ultimately, the goal is to get the right data for the right price. The archaeological record is a constantly threatened, non-renewable resource that is spatially scattered and can benefit from open sharing (Bevan 2015, 1480), but this should be accompanied with the recognition of first, second, and third-party data.

Second and third party data are usable data sources for scientific investigation, but only if the following statements apply:

1. The data has been collected by a known or reputable source.
2. Licensing or terms and conditions of the data source are known (and permission to use/publish is granted).
3. The original purpose of the data is known.
4. The date of data collection is known
5. The data can be tested, in some way, for accuracy whenever possible.

What constitutes a reputable or known source is subject to the researchers' discretion. Obvious examples of reputable sources include any sources where the data and research is peer-reviewed and is held to a certain standard and monitored. This includes data that has previously been used in research, such as the data received from the Silvretta Project. The obvious reputable sources include government organizations, commercial satellite imagery providers, university-affiliated research projects, museum archives, curated archives, and material published in journals. A known source is any source that is not held to any official standards of quality but can be essential and is widely accepted. Examples of known sources in the context of spatial data in archaeology can include toolboxes, plugins, scripts, or add-ons published online by users, which can range from known experts to anonymous users.

Having knowledge of the licensing terms for data use and reproduction in publications is absolutely essential. Credit must be given to the original creators of the

data. At a time where the number of terms and conditions for data vary greatly across datasets and are often combined with datasets of other types of licensing, understanding the different licensing terms is crucial. So much data is available online and can be easily downloaded, but this does not mean that the data can legally be used.

Knowing the purpose for which the data was collected is essential, but the actual purpose is less important. The reason the data was collected is important because this influences the spatial and spectral resolutions, extent, and provides a reason why particular features have been documented or excluded. As long as the purpose, features, extent, and resolutions are compatible with the research then the data can be used.

Knowing when the data has been collected is extremely important for remote sensing data since the landscape can change significantly within a short period of time. In addition, remote sensing data collected during different seasons, or even different times of day can affect the results from the imagery. Most importantly, without knowing the year during which the data was collected, outdated (and potentially incorrect) data could be used in research. Maps capture a specific moment in time (Zubrow 2006, 19) and knowing what moment(s) are being conveyed are extremely important.

Statement 5 applies largely to spatial data and is the least important. If the data comes from a source where it is unknown, if it should be trusted, the ability to test the accuracy becomes important. This can be done by visually comparing the dataset to a known dataset. For example, a dataset contains a vector layer, which is supposed to map out the roads in an area to any contemporary maps (Google Maps for example). Some datasets, such as underground features, cannot be visually compared and cannot, therefore, be tested for accuracy. This data should, therefore, come from highly reputable sources who have released substantial metadata.

Data can be understood without certain metadata but should be used with caution. The metadata that is required depends on the nature of the study. For this study, the year that the data was collected is important in noting changes in the landscape, where the tool and methods used to collect the data are inconsequential. This is not to say that archaeologists should not record what equipment they are using in their research, but to say that the absence of this information should not hinder most projects.

This begs the question: if the data is available, and the source is reputable, should the data be used for archaeological research? The answer is a resounding yes, but only if it is relevant, and only if it can be understood. No data was collected in the field for the purposes of this project, but an entire database of geodata was available from a reputable source for free. Just because the data was not collected for the purpose of investigating

the terraces, does not mean that it is not useful data. The location of roads, paths, and waterways was invaluable information and to travel to Ramosch and collect the data myself would have been an exercise in redundancy.

One of the issues with data collected only for archaeological purposes is that it often focuses on too small of a region to be useful for other projects. For example, a thesis on these terraces was based on aerial images from 1985. Unfortunately, this data only covers a small extent of Zone 1, adding to the patchwork of the data used in this project. Additionally, a high-resolution 3D model and DEM was created for Mottata during a previous field season of the Terraced Landscape project. This model was created using aerial photographs collected with a UAV and stitched together using Agisoft Photoscan. This model, while of superior resolution to the orthomosaic, could not be used since the area covered was insignificant when compared to the research area.

6.3.2 Distinguishing between data

The distinction between first, second, and third-party data is extremely important but a topic rarely, if ever, considered within the field of archaeology. True, the distinction between raw data and other data is sometimes made but this is not enough. The relationship between the researcher and the data is extremely important. First-party data is raw data that the archaeologist has collected in the field, either through excavation or survey (including remote sensing and geophysical prospection). The planning and decisions made on how, when, where, and why to collect the data, as well as by whom, are made by the researchers within the framework of their project and technical and financial frameworks.

Second-party data is raw data that has been collected for archaeological purposes that was collected prior to the researchers' involvement. One example from this thesis was the use of the 1996 data on the terraces published by Raba. The data was highly relevant and well collected for similar purposes, but I have no relationship with the data. If data was missing, I would have no frame of reference to be able to fill the gap and this is why this distinction is important. If a date was missing from a database or a feature was accidentally misidentified by someone who had simply checked the wrong box, I am unable to correct these mistakes and I am less likely to notice them. In a perfect world, everyone would produce error-free datasets, but this is simply not the case. Between human error, time constraints, and technical issues there are bound to be errors which are less likely to be caught by someone who was not involved in the collection process.

Lastly, third-party data is general-purpose data. This includes basic maps, satellite imagery, and any of the other data downloaded from Swisstopo or GeoGR. The amounts of data available and the amounts of data archaeologist collect is staggering and these distinctions are important. However, this hierarchy does not mean that third-party data should not be used. This project could not have been completed without third-party data and could have potentially been completed using exclusively third-party data. Know my relationship with the data can help the reader to understand the decision I made with how to treat the data, and what biases may have occurred.

6.4 Terrace systems and changes in the landscape

Eight terrace systems have been proposed (fig. 30). A4 has been designated its own system where the terraces are no longer visible. These are likely older terraces, which could no longer be used due to soil conditions, distance from Ramosch, or a lack of a modern water source. Two systems are located in A1, based on the orientation of the terraces and the water sources. The homogeneity of these terraces indicates that while the current management may rest with different people, they were likely originally built by the same group. Two systems are located in A2. One system includes all the visible terraces, the majority of which are north of Vnà and are likely still in use. The clusters are somewhat difficult to distinguish from one another, as many of the terraces are irregular or curvilinear. The second system in A2 lies to the north of the documented terraces and is categorized by the remains of land which appears to have been used for agricultural activities but are no longer in use, as evidenced by the forest regrowth. Three systems have been proposed in A3. One system comprises the majority of the clusters, the majority of which are disjointed. The other two systems comprise 3 clusters (C27 and C51; C39) simply based on vegetation barriers between the clusters.

Based solely on remote sensing data, Swisstopo, and GeoGR, this is the furthest these systems can be categorized. It is simply impossible to distinguish a chronology for the terraces outside of those that are no longer used and those that are currently used. Arguments could be made for a chronology based on terrace shape or cluster but this would simply be conjecture. For example, the regularity of the terraces in A1 could indicate that they were all constructed at the same time, with a construction plan in mind, versus the irregularity of A3, which could indicate that the terrace system grew as the population grew and as farmers were able to care for larger plots due to advances in technology.

6.5 Critique of QGIS

QGIS 1.8.0 is not recommended for use in archaeology-related endeavours. The software is outdated and unstable, leading to extremely inefficient workflows. After three years, computer technologies are said to become obsolete (Zubrow 2006, 18), and QGIS 1.8 is far older than three years. Later versions of the software exist to resolve the issues of the earlier versions; therefore, it is recommended to use the latest available version of QGIS (currently 3.0 Girona). All of the issues encountered with the software could eventually be resolved based on the resources available at the time of the study.

Many minor issues were encountered throughout the project, which were previously presented in the Methodology chapter. One notable issue is the obvious missing scale bars from the figures. QGIS 1.8 is unable to generate scale bars for datasets outside of the default UTM coordinate system. Maps of the terraces have been (re)created in ArcMap with scales in appendix 5 in order to resolve this issue.

Due to the nature of QGIS (and many FOSS programs), the community is active in improving the software and providing solutions. Online forums, such as StackExchange Geographic Information Systems (https://gis.stackexchange.com/), have users ranging from beginners to experts who are active in asking questions and providing comprehensible solutions and expertise for both QGIS and ArcMap. One of the benefits of QGIS over ArcMap is that there are often many more solutions available for a problem. The users will post the solutions and workflows that worked for them to solve the same or similar problems. In ArcMap, there is typically only one possible workflow that will lead to the solution. The variety of solutions is especially appealing for archaeologists who are limited by a variety of factors, ranging from availability of the Internet in the field (limiting software updates and access to toolboxes) to restrictions imposed by the institution(s) with which they are employed or associated.

6.6 A Note on working at an institution

One of the limitations that researchers in all fields face are the restrictions placed upon them by the institution, often tied to financial or legal implications. The term institution is used as an umbrella term for universities, colleges, CRM companies, government organizations, non-profits, private research companies, and any other organization existing for educational, professional, or social functions that contain centralized resources. In terms of resources, this thesis is concerned with hardware and software restrictions placed by the University of Leiden.

The term restriction is often viewed to have a negative connotation, but this is not always the case. These restrictions to specific brands and external companies are necessary for the institution to follow a budget and ensure that the agents are provided with the necessary tools to complete the tasks they were hired to complete. The University of Leiden does not require a thesis to be completed using their equipment, however, any equipment not owned by the university is an additional cost for students and often employees. Equipment can be extremely costly which can create a barrier between those who are able to afford it and those who cannot. In terms of software, the use of free programs, such as QGIS can alleviate this cost for both individuals and institutions.

The largest restriction identified during the course of this project is the software that is available. QGIS 1.8.0 Lisboa is the only version of QGIS available on the computers. Only employees of the ICT Shared Service Centre are able to update or install software, and students are unable to request software changes. This is a common restriction placed by institutions for practical and financial reasons. New versions of software are released frequently and it is unrealistic to expect institutions update the software with each new update, especially when the newer versions of the software may be incompatible with the current hardware. FOSS has the advantage over proprietary software since it is usually free, which increases the likelihood for the approval of an update request.

Chapter 7: Conclusion

Land development has not impacted the preservation of the terraces and urbanization is not a threat to the terraces and archaeological sites. If land abandonment continues in this region, the terraces will continue to be obscured by vegetation. This will require different methods in order to document the terraces, either the use of LiDAR to see through the vegetation, geophysical prospection to see below the surface, or pedestrian survey in the field. The larger threats to the preservation of the terraces are natural processes and events, such as rockslides, avalanches, and erosion.

Currently, eight terrace systems have been proposed based on the second and third-party data, based on proximity to other terraces and water sources, orientation, and shape. Six of the eight systems are still in use and require further research to determine a chronology. The separation between systems is very difficult to distinguish in Zone 1, but the terrace clusters in Zone 2 are more spread out and it would be relevant to determine if these clusters could also be categorized into systems.

I would not recommend the use of QGIS 1.8 for any purpose. However, this should not reflect upon the use of FOSS in archaeology. More recent versions of QGIS have improved greatly over the earlier versions. Instead of choosing a software for the licensing terms, it should be chosen for the capabilities of the program based on the needs of the project. In the event that both proprietary and FOSS programs are both able to complete the necessary tasks, FOSS programs are almost always the better financial option and the access to the source code is an unparalleled advantage. The decision for FOSS over proprietary must be made on a case by case basis to ensure that the best available software is used.

More data is not synonymous with good data. Anyone can spend years of their life on the Internet looking for sources related to their topic and continue to find more information and datasets, but not all of the data will be relevant. The most efficient method for dealing with large amounts of spatial data that is lacking metadata is to first examine the attribute table and then visually compare the data to a known dataset, such as a map or satellite imagery. Not all aspects of the data need to be understood in order to use the data, but a timeframe of its collection date and what it is showing is crucial. The methods used to collect the data are useful and can help one to better understand the data but in many cases, the data can be understood without it. The distinction between first, second, and third-party data sources is important because the relationship

between the researcher and the data plays a role in potential biases, but all levels of data sources are acceptable for use within archaeology to each researchers' discretion.

There is a large potential for future work in this area. One of the main factors influencing terraces that was not covered in detail is slope. In order for terrace walls to be visible in imagery, there must be a discrepancy in height, which can present itself as a change in colour or the presence of shadows, in addition to being able to identify the walls. It would be interesting to study these terraces using a 3D, or rather 2.5D, model to visualize the terraces. The topography of the mountain landscapes would lend itself well to a 3D visualization method. Another avenue to study could be to continue investigating the waterways and irrigation systems in this region. This could be done by first identifying the modern irrigation channels in the region and potentially older systems as well. Lastly, it would be relevant to continue to study the terraces in the remainder of the Lower Engadine, as seen in Zone 2 of this study. The study area included only a small sample of the terraces in the region and it would be interesting to see if the terraces continued to be constructed as systems or if the management strategies changed across the Lower Engadine.

This thesis has demonstrated that archaeological research can be completed without fieldwork, and with no funding. This supports Sustainable Archaeology and the concepts of data reuse and data recycling. It is possible to complete research using pre-existing datasets. This coincides with the goals of Open Archaeology and Open Science, to make data more freely available. In order to do "good" archaeology using open data, a more concrete methodology is needed and this thesis has presented one possible workflow. As Digital Archaeology, Sustainable Archaeology, and Open Archaeology continue to develop, the relationship between researchers and data will become exceedingly important and should continue to be discussed and reflected upon.

Abstract

The use of computer applications has irrevocably changed the way archaeology is done, as well as redefined what it means to do "good" archaeology. This has brought about numerous methodological questions concerning the use of data, data sources, and the software used in analyses. This thesis seeks to explore some of these issues, including the re-use or borrowing of data, open source data, and the use of FOSS programs within archaeology.

In order to answer these questions, the spatial relationship between the terraces in the Swiss Alps was investigated. The study area is located in the area surrounding (and including) Ramosch in the Lower Engadine, Switzerland. These terraces have been in use since at least the Middle Ages, and could potentially date to the Bronze Age. The terraces were documented based on remote sensing data and digitized in QGIS 1.8. The spatial relationship of the terraces is primarily determined by the viability of the land for agriculture (soil composition and sunlight), followed by the distance from modern settlements, modern features in the landscape (i.e. buildings, roads, and waterways), and access to water.

This research shows that it is possible to do archaeological research by recycling data from third-party sources. All of the data used in this project was obtained for no cost. The spatial resolution of the general purpose data and recycled data was more than adequate and the lack of metadata was not a major obstacle. The largest hindrance with using data collected by others for an alternative purpose is finding the right data and gaining access to this data. The processes of understanding the data without metadata can be completed by comparing the unknown datasets to those that are known.

The use of FOSS programs is extremely beneficial. The low cost, easy accessibility and large online communities have helped the FOSS movement to thrive. The ability to share information unhindered by licensing and terms and conditions promotes the continuation of accessible research. However, FOSS is not inherently better than proprietary software. The primary requirement for the use of a program should be its ability to perform all the required functions necessary for good research.

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Appendix 1: Swisstopo "A journey through time"

1a. Maps

1926

0   500   1000   1500m
Scale 1 : 50,000
Printed on 13.04.2018 11:43
https://s.geo.admin.ch/79ea2c1ed7

1951

0   500   1000   1500m
Scale 1: 50,000
Printed on 13.04.2018 11:43
https://s.geo.admin.ch/79ea2c6239

1991

0   500   1000   1500m
Scale 1 : 50,000
Printed on 13.04.2018 11:44
https://s.geo.admin.ch/79ea2cb986

1b. Aerial images

1990

0   200   400   600m
Scale 1 : 20,000
Printed on 23.04.2018 15:59 CEST
https://s.geo.admin.ch/7a1e28938d

1997

2003

Scale 1 : 100,000
Printed on 09.04.2018 11:10
https://s.geo.admin.ch/79d574ecb3

0   1   2   3km

2008

2011

Scale 1 : 100,000
Printed on 09.04.2018 11:11
https://s.geo.admin.ch/79d5757ef0

0   1   2   3km

Schwaizerische Eidgenossenschaft
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In collaboration with the cantons

Appendix 2: Links to datasets

2a. Swisstopo

Name and access date	Link
A journey through time – maps (webpage) **Accessed 9 April 2018**	https://www.swisstopo.admin.ch/en/maps-data-online/maps-geodata-online/journey-through-time.html
A journey through time – maps (portal) **Accessed 9 April 2018**	https://map.geo.admin.ch/?topic=swisstopo&zoom=1&lang=en&bgLayer=ch.swisstopo.pixelkarte-farbe&catalogNodes=1392&layers=ch.swisstopo.zeitreihen&time=1864&layers_timestamp=18641231&E=2611250.00&N=1122625.00
A journey through time – aerial images (webpage) **Accessed 9 April 2018**	https://www.swisstopo.admin.ch/en/maps-data-online/maps-geodata-online/journey-through-time-images.html
A journey through time – aerial images (portal) **Accessed 9 April 2018**	https://map.geo.admin.ch/?lang=en&topic=swisstopo&bgLayer=voidLayer&X=185466.05&Y=647539.98&zoom=1&layers=ch.swisstopo.swissimage-product&time=1979&catalogNodes=1430&layers_timestamp=1979
Orthomosaic photo (25cm) (SWISSIMAGE 25 cm) **Accessed 12 June 2018** (dataset not downloaded)	https://shop.swisstopo.admin.ch/en/products/images/ortho_images/SWISSIMAGE
swissTLM3D **Accessed 3 April 2018**	https://shop.swisstopo.admin.ch/en/products/landscape/tlm3D
swissBOUNDARIES3D **Accessed 17 May 2018**	https://shop.swisstopo.admin.ch/en/products/landscape/boundaries3D
swissALTI3D **Accessed 15 May 2018** (dataset not downloaded)	https://shop.swisstopo.admin.ch/en/products/height_models/alti3D
DHM25 / 200m **Accessed 5 June 2018** (dataset not downloaded)	https://shop.swisstopo.admin.ch/en/products/height_models/dhm25200

2b. GeoGR

Name of dataset (as referenced in text)	Citation method preferred by GeoGR	Link
Cadastral survey	Amtliche Vermessung (AV), Kanton Graubünden, 03.2018	https://geogr.mapplus.ch/shop/prod_av_geo_lv95
Reprocessed SwissALTI3D	Digital Höhenmodelle – SwissALTI3D-AV, Kanton Graubünden, 06.2018	https://geogr.mapplus.ch/shop/prod_swissalti_tiff_lv95_k
Crop areas 1992	Fruchtfolgeflächen 1992 (fff),Graubünden, 02.2018	https://geogr.mapplus.ch/shop/prod_lw_fff
Water protection map	Gewässerschutzkart, Graubünden, 04.2018	https://geogr.mapplus.ch/shop/prod_gw_gsk

Appendix 3: swissALTI3D visualizations

3a. DTM

Elevation
■ 1036.18
□ 3391.53

N

3b. Slope

Slope (degrees)

■ (magenta)	1.74602
■ (cyan)	19.4686
■ (red)	37.1912
■ (green)	54.9139

N
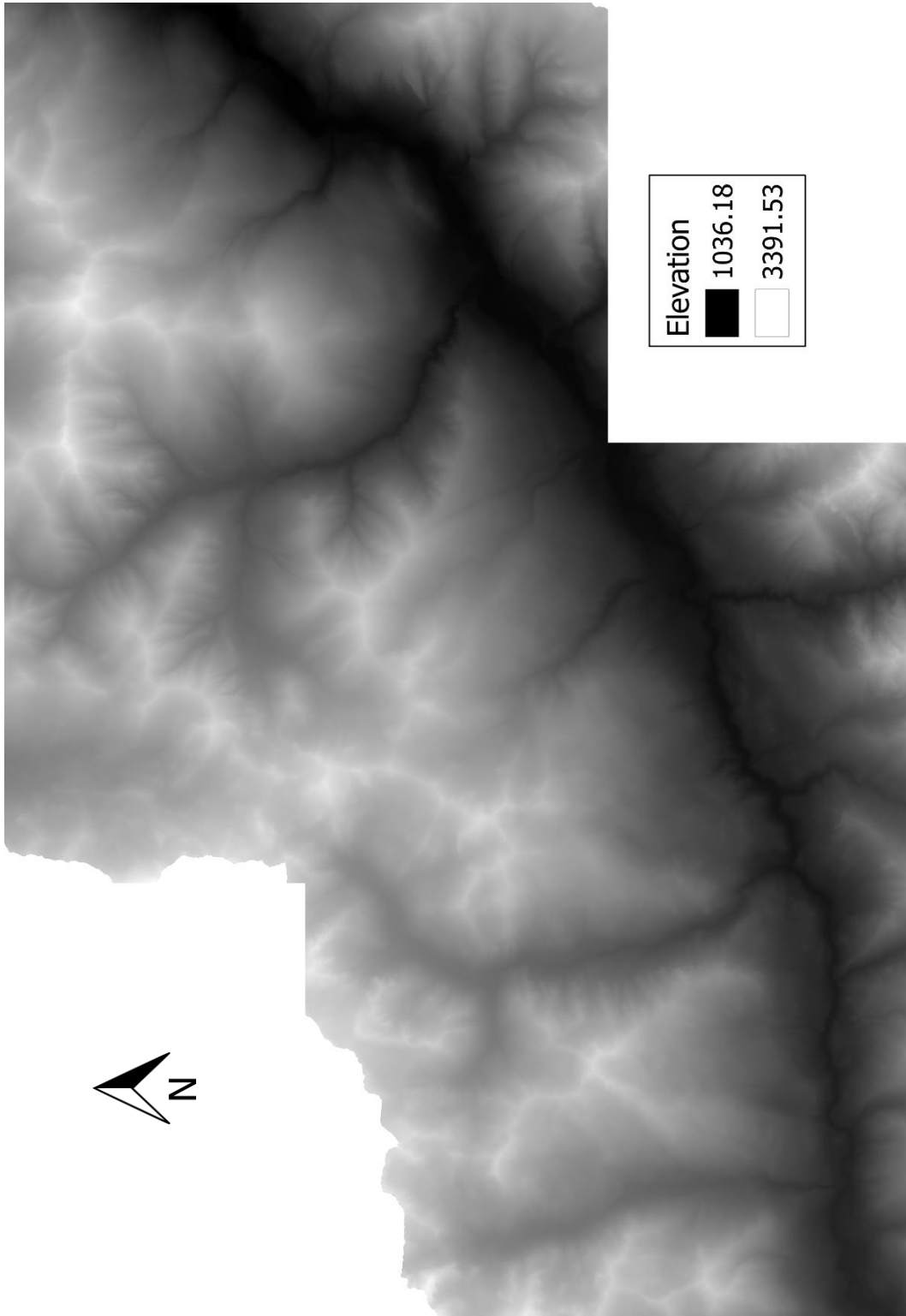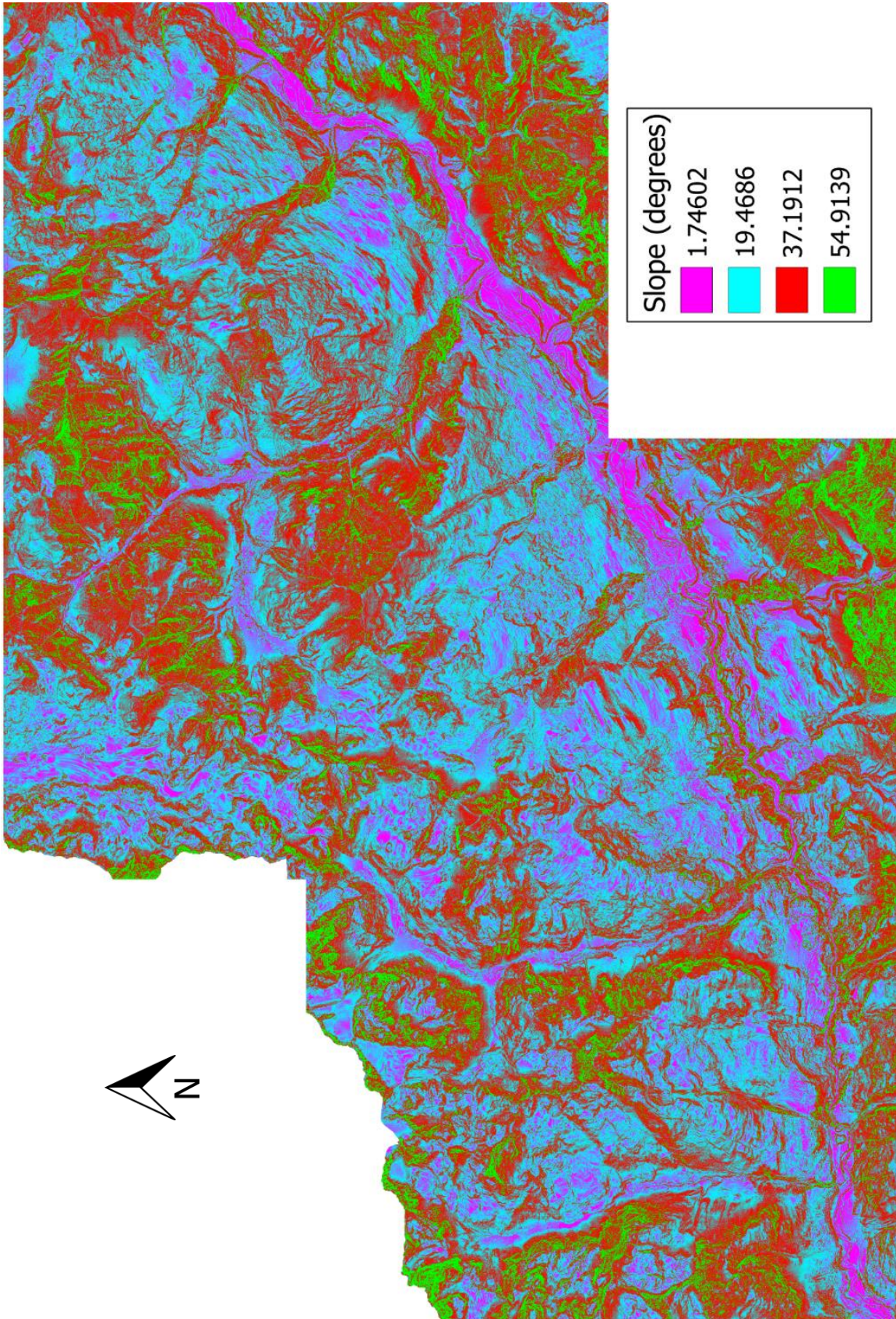
3c. Hillshade
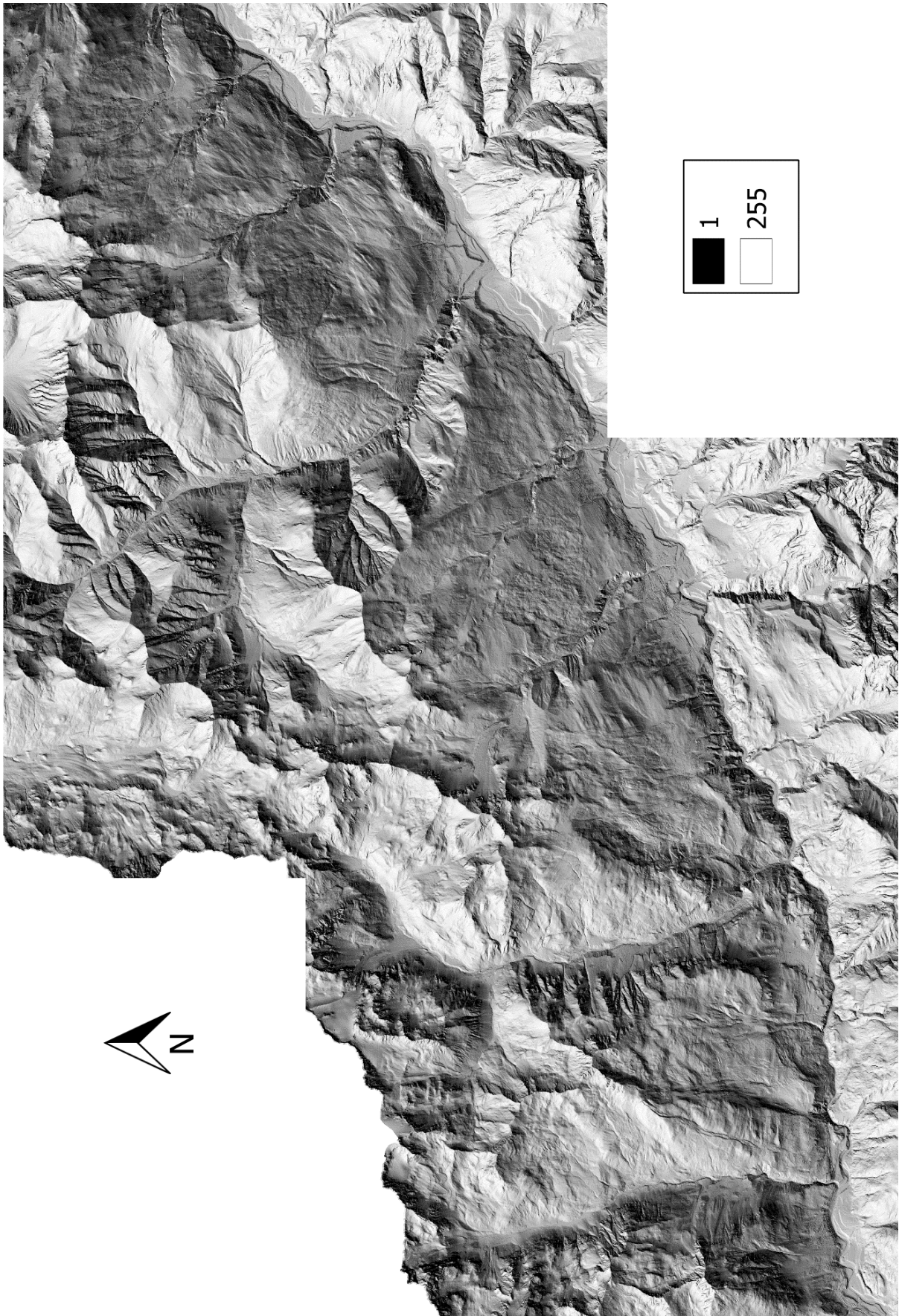
3d. Colour relief

3e. Aspect

Aspect

▆	0.000000
▆	119.999807
▆	239.999613
▆	359.999420

N
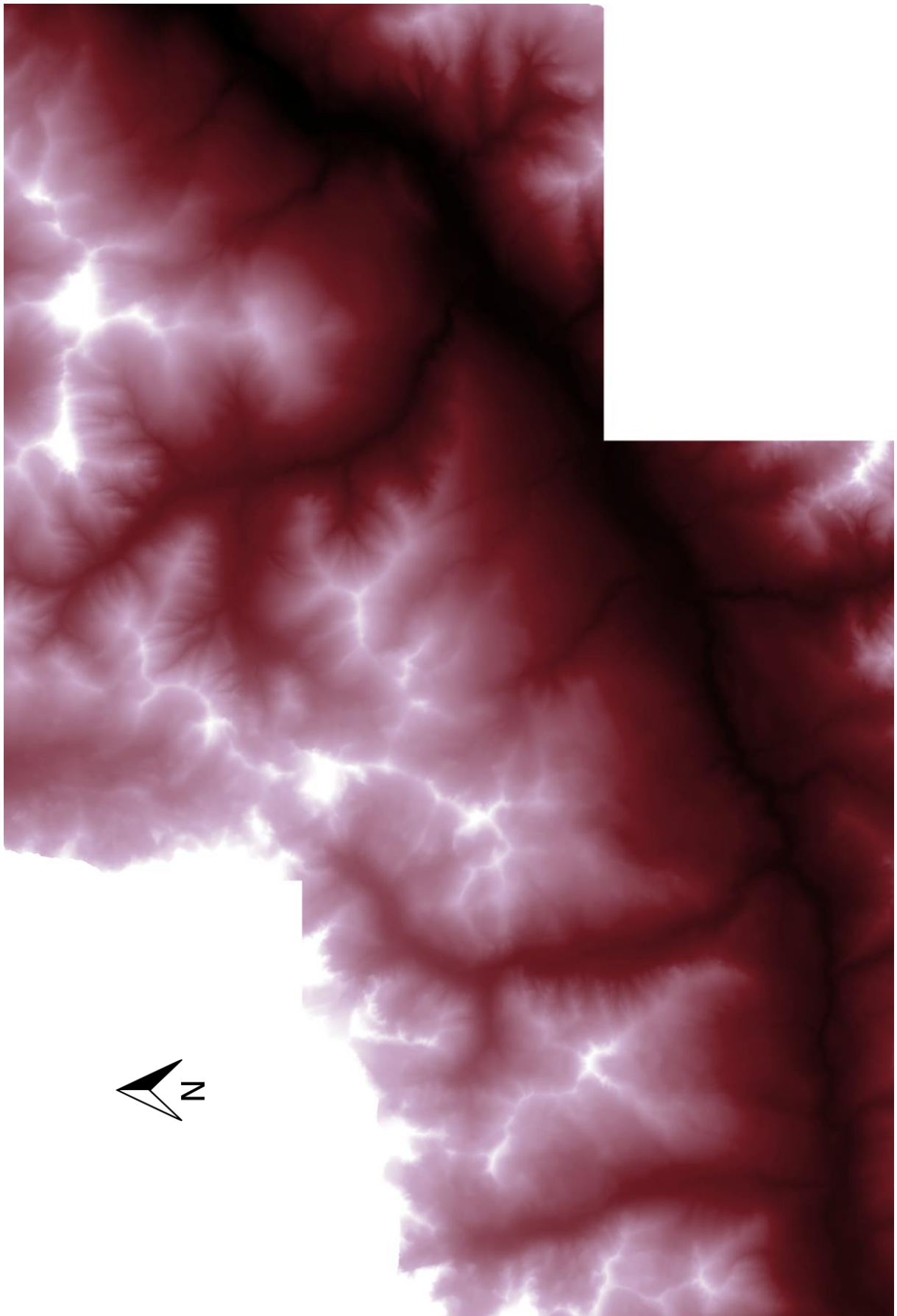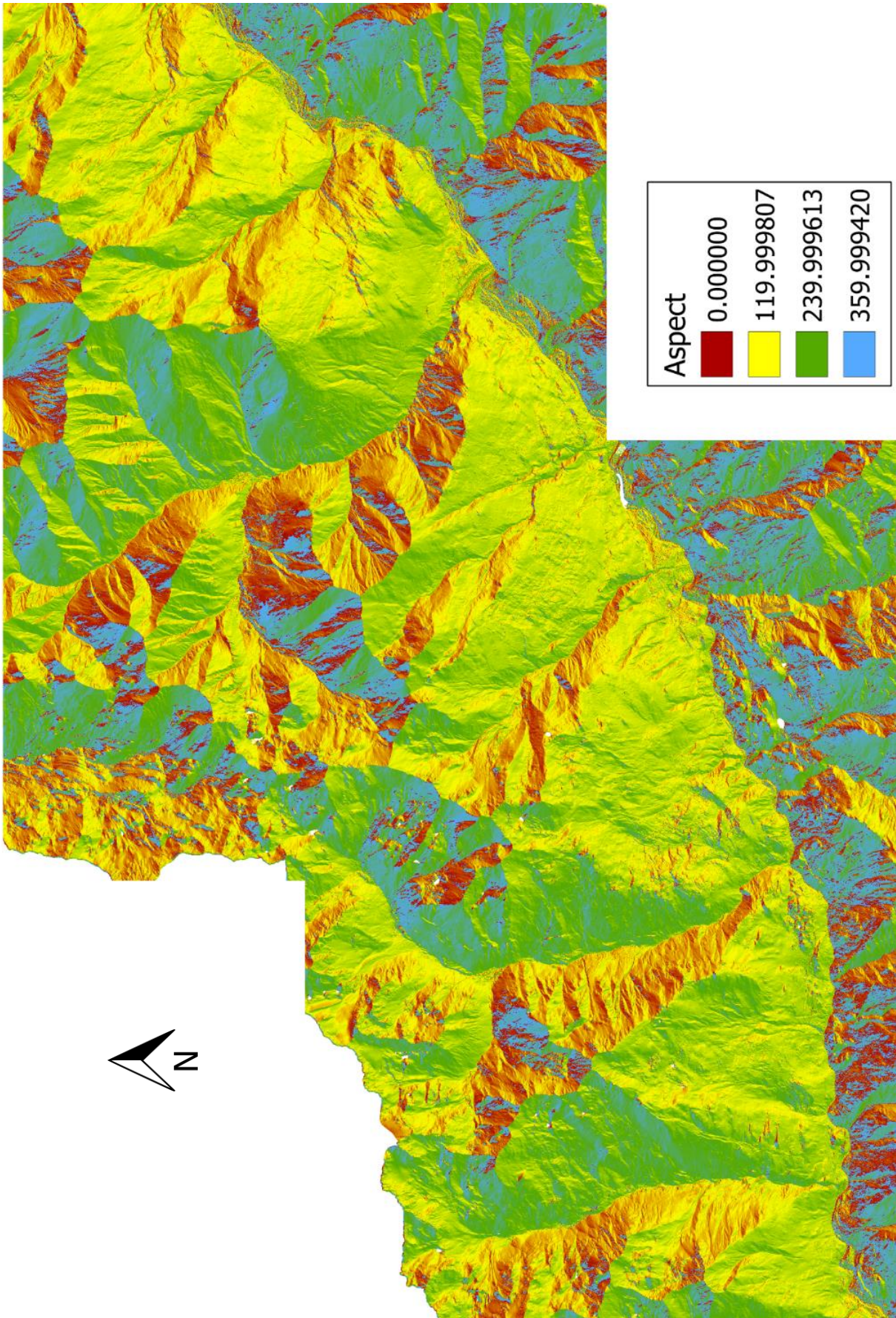
Appendix 4: GeoEye Imagery

4a. Panchromatic
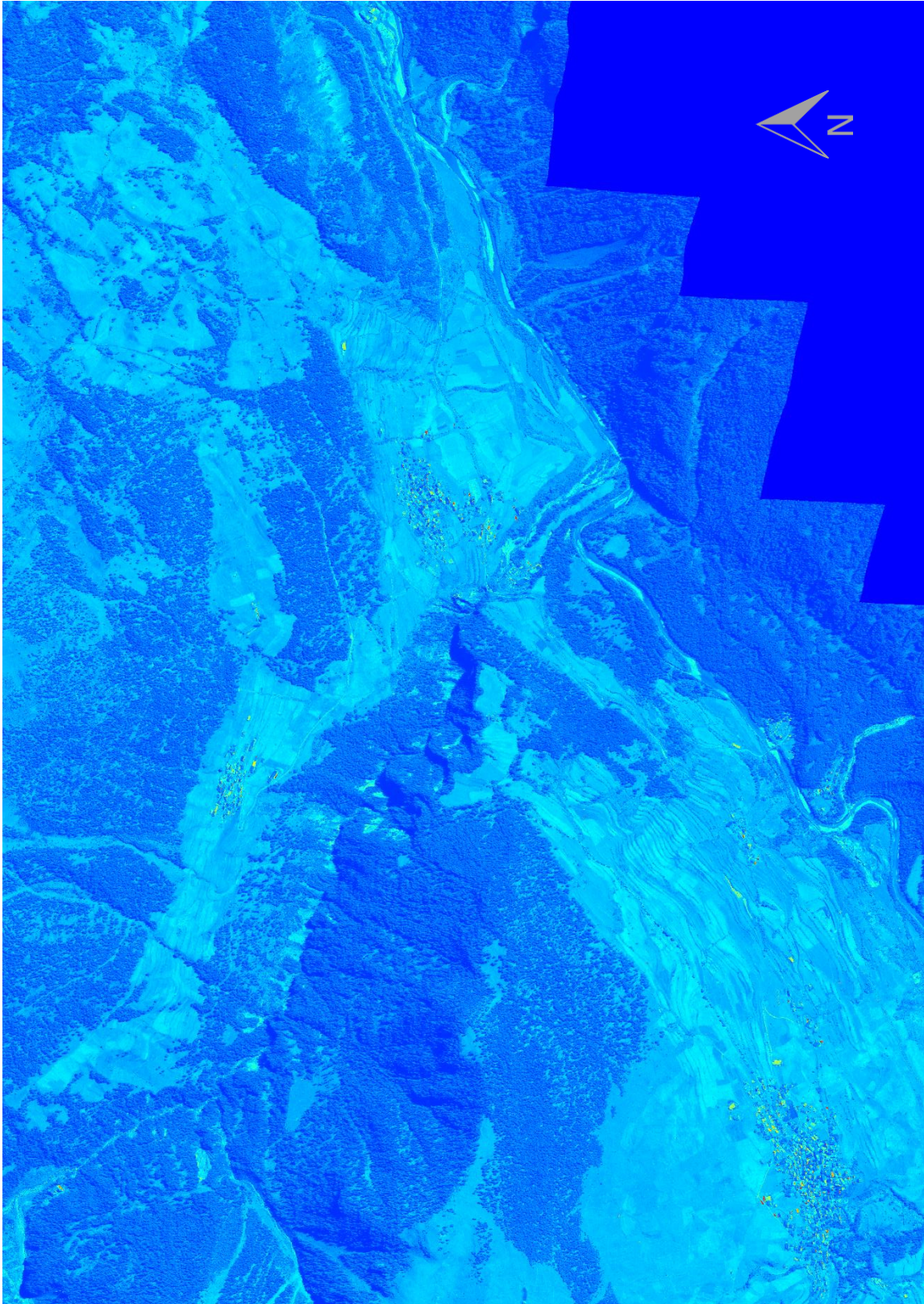
4b. Near Infrared

4b. Near Infrared
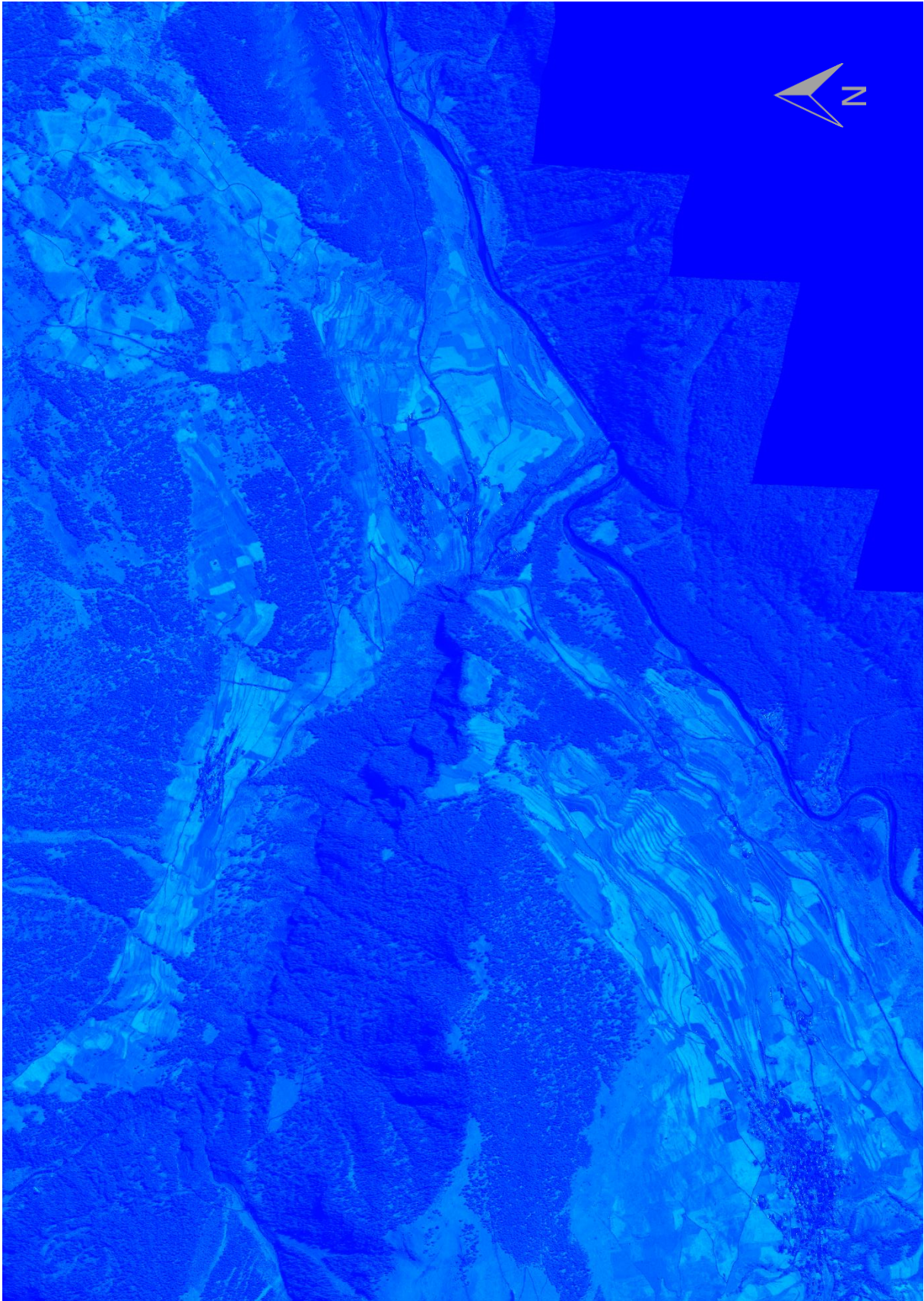
4c. Blue
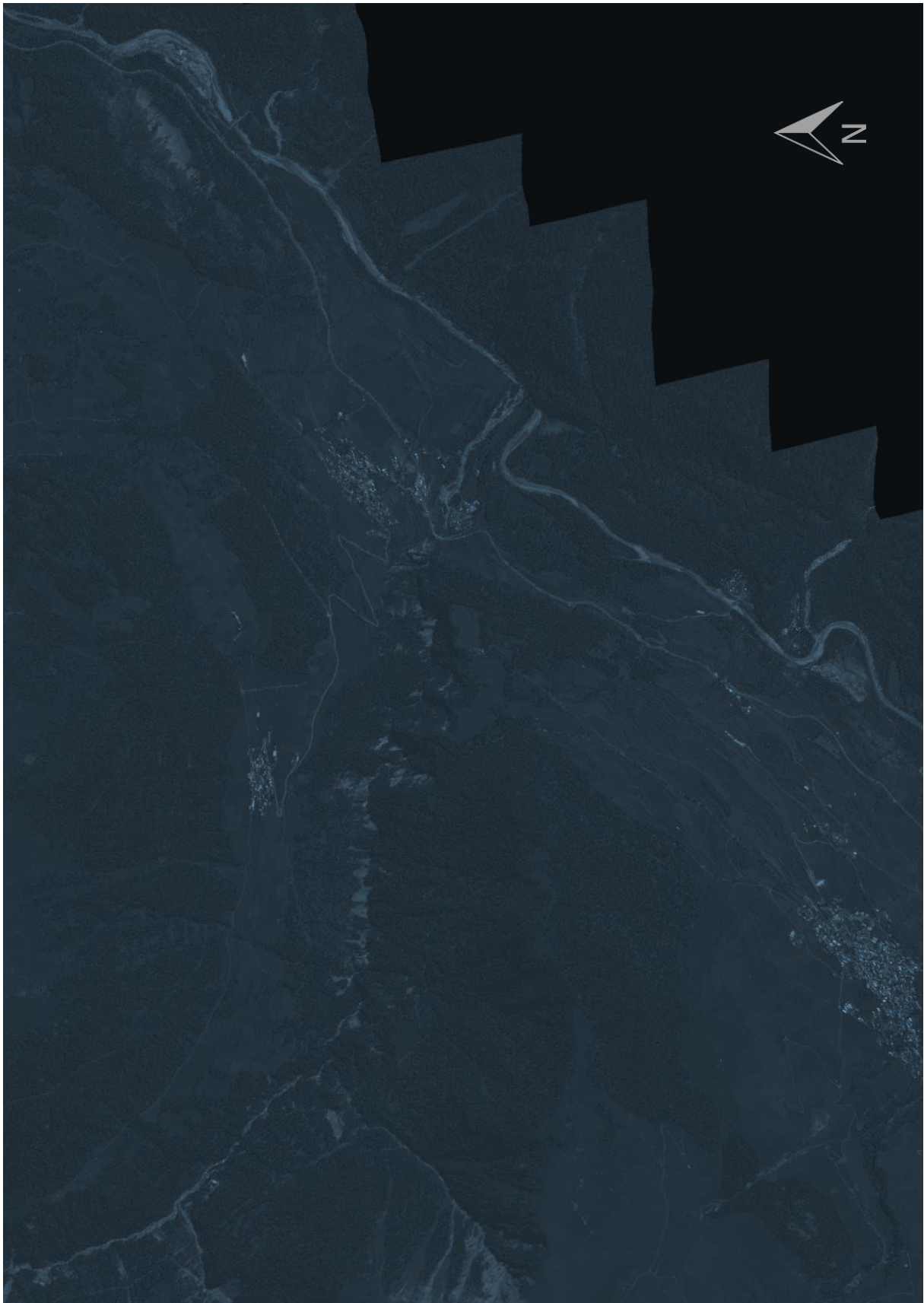
4d. Red
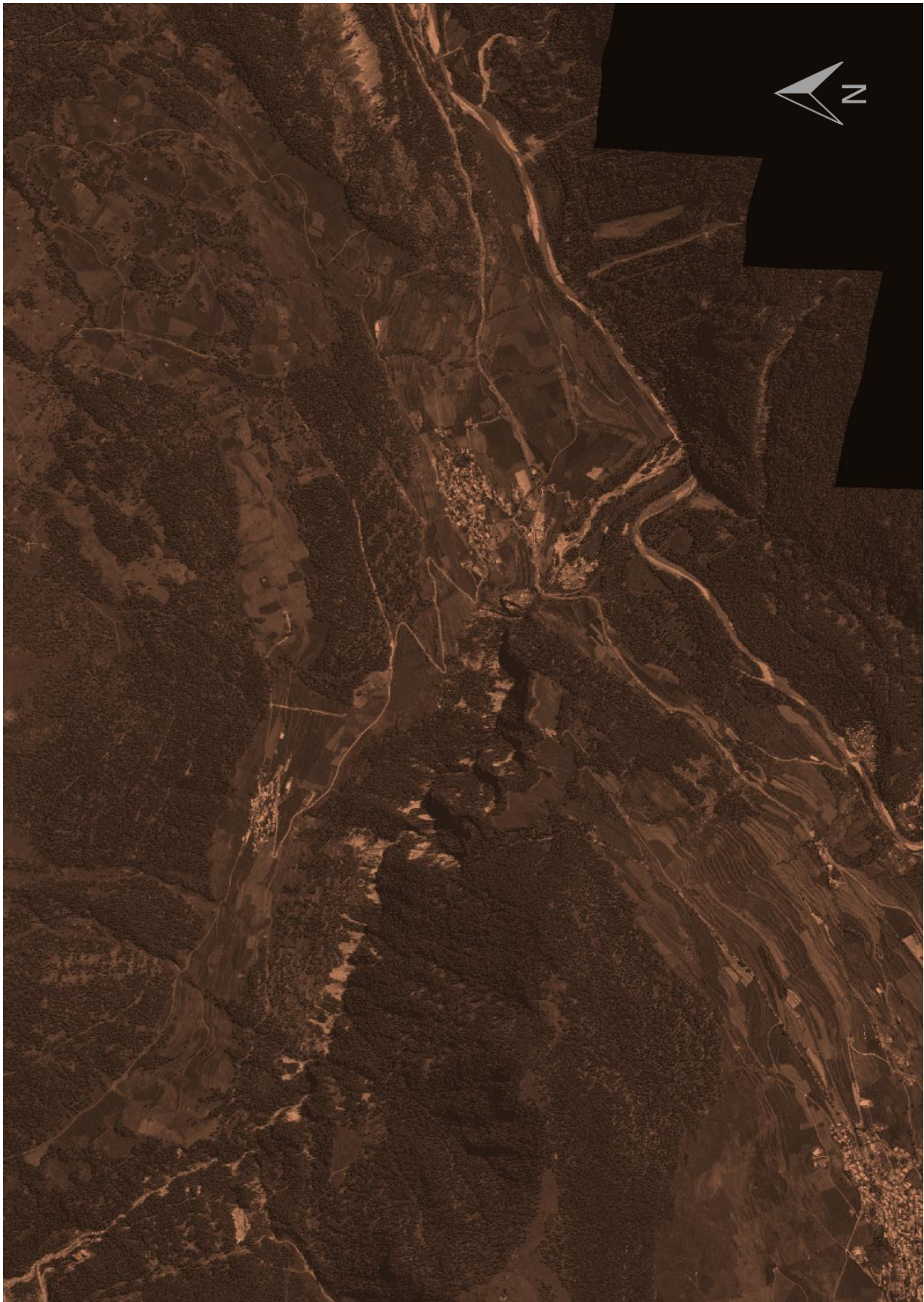
4e. Green
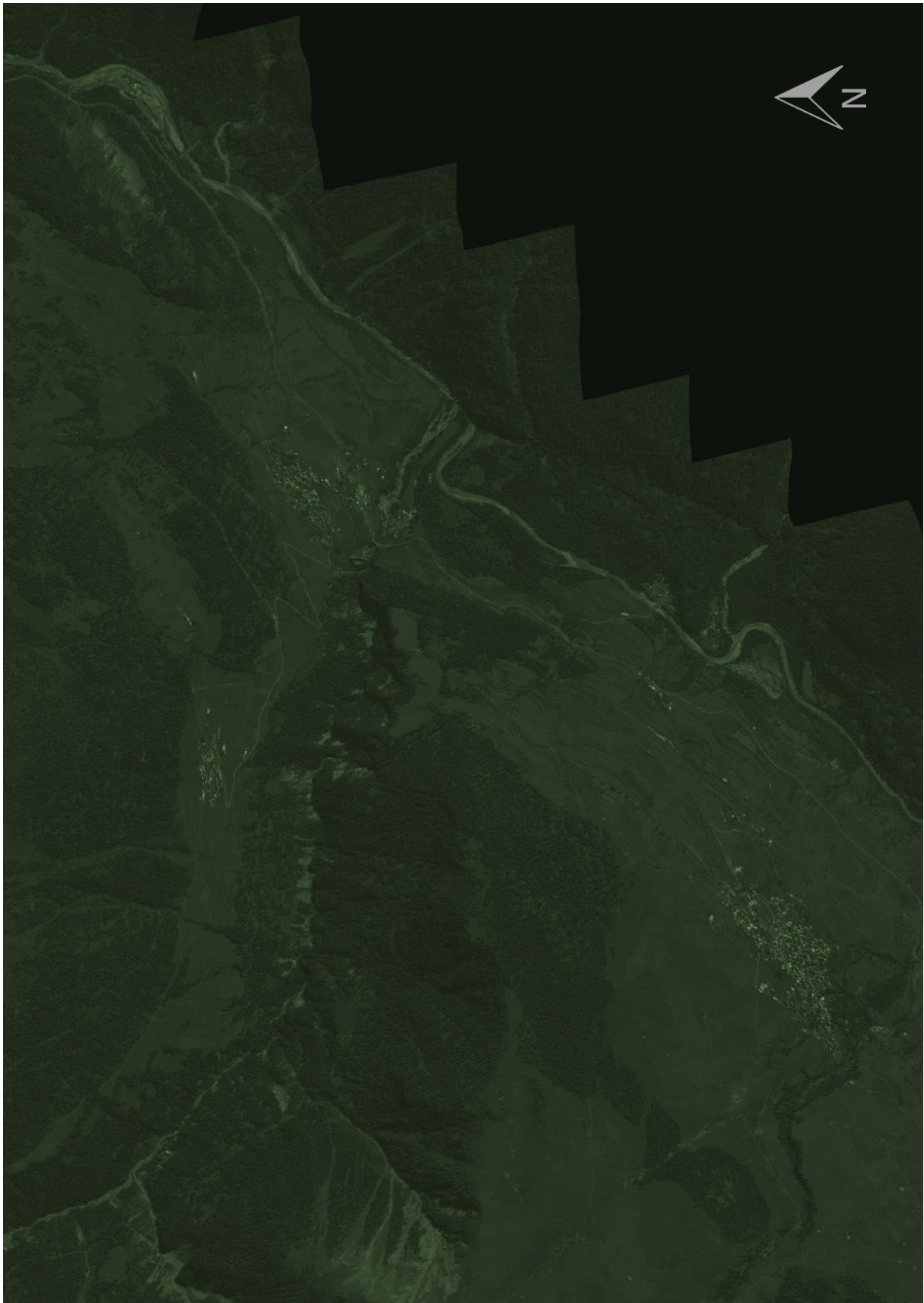
Appendix 5: Terrace Maps in ArcMap

Array 2
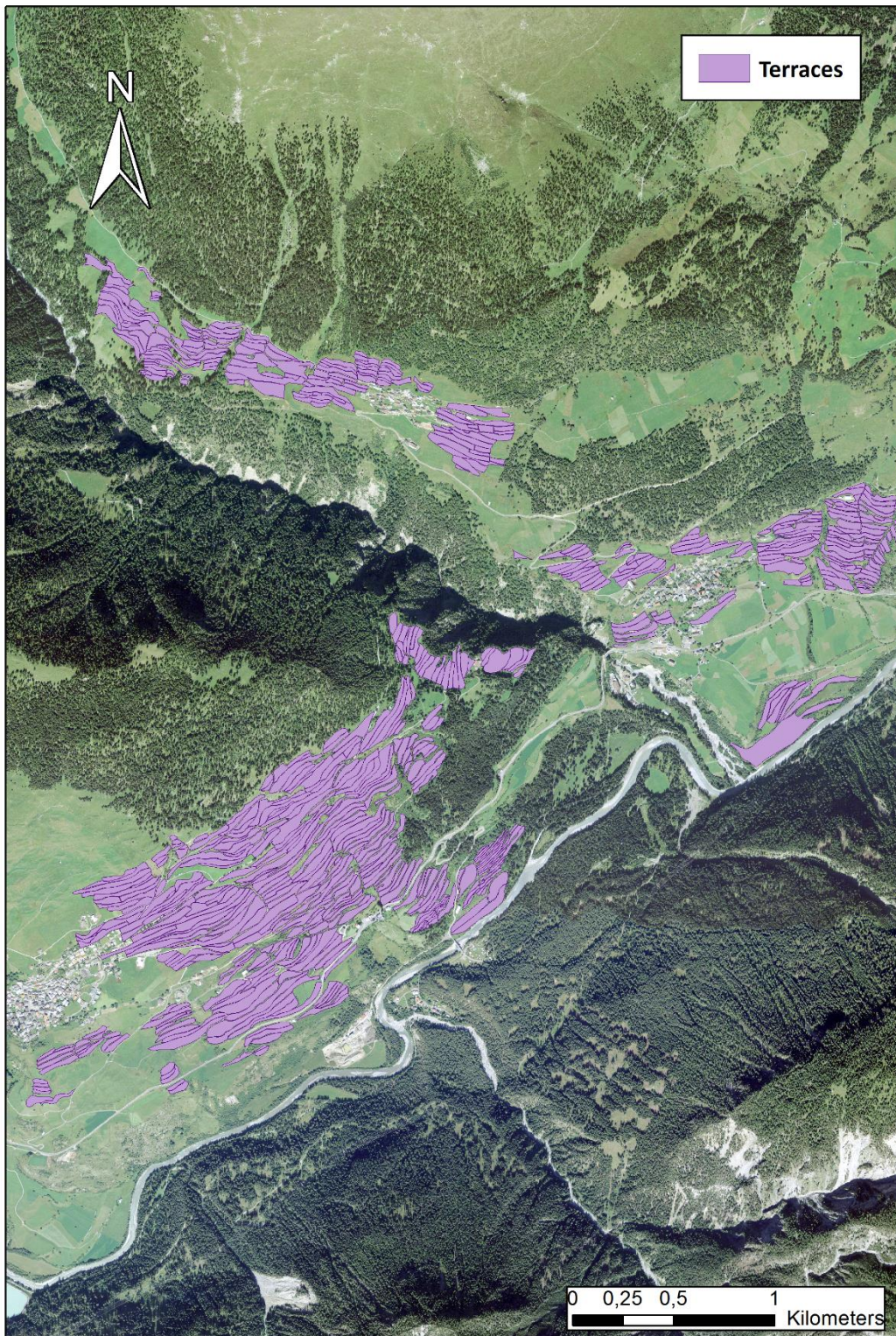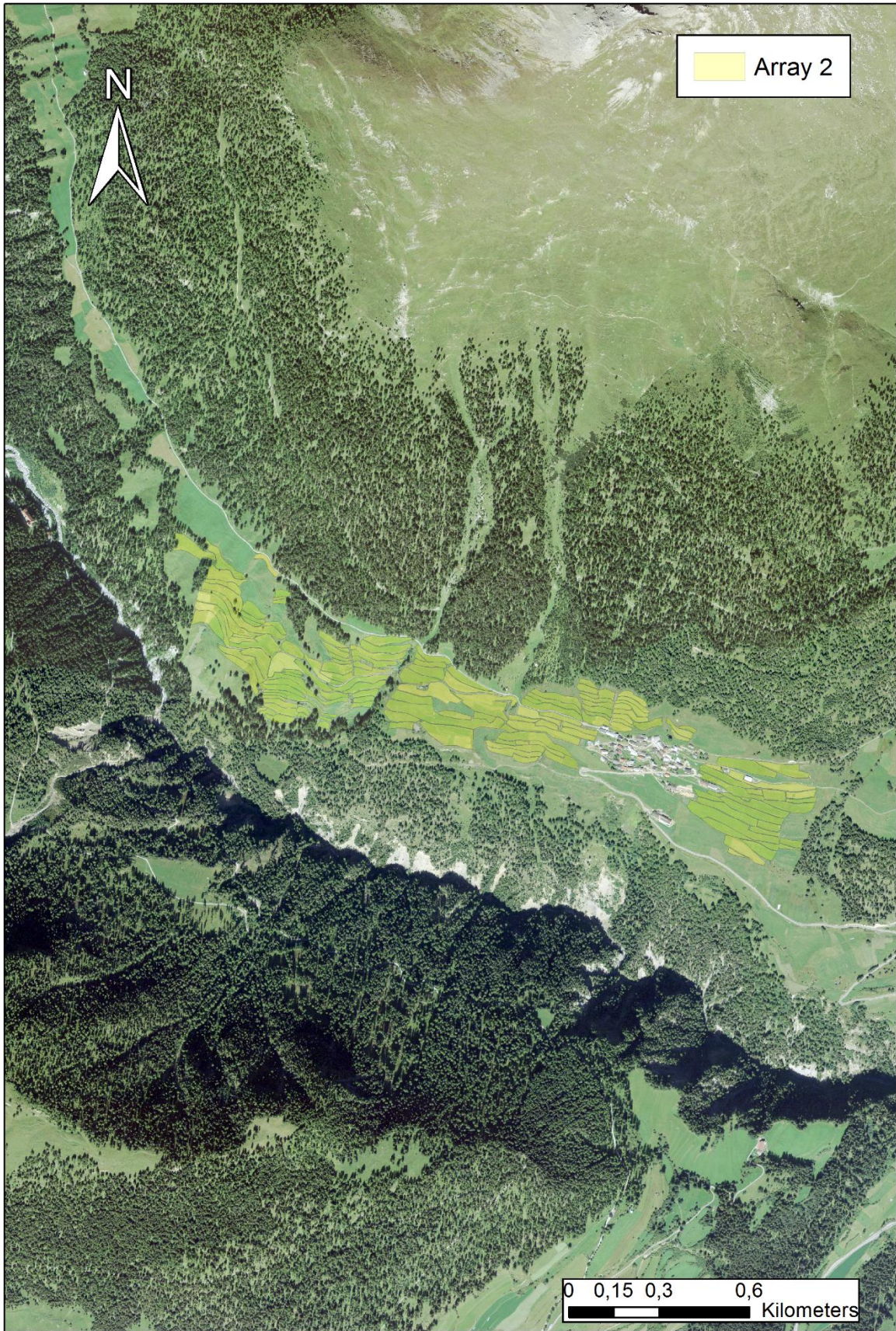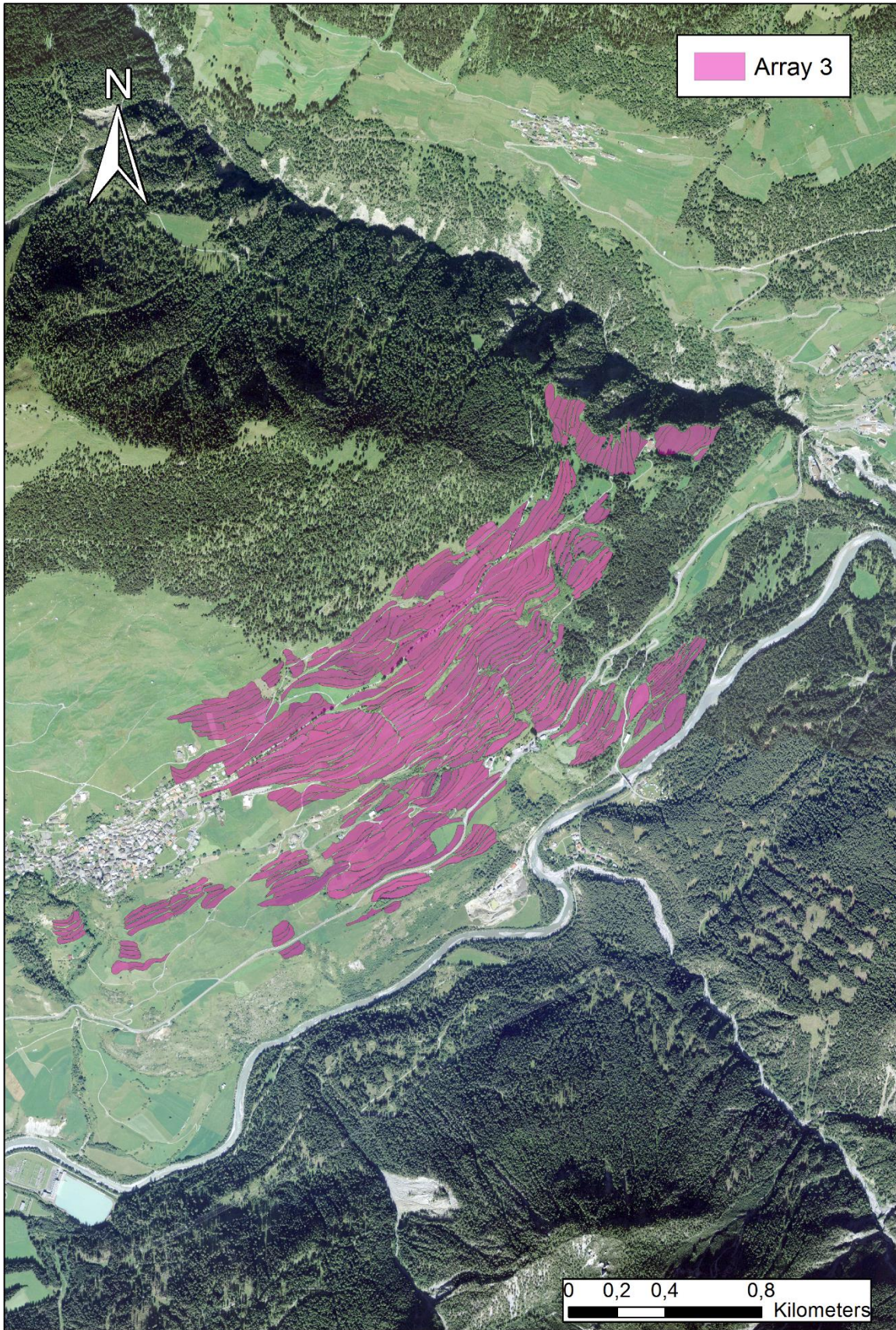
Appendix 6. Terrace statistics and attribute table

6a. Terrace statistics: All terraces

Terrace Shape	Number	Percent
Rectangular	107	14.9
Irregular	252	35
Curvilinear	371	51.6
Cluster Structure		
Regular	536	74.6
Irregular	185	25.7
Interlaced	191	26.6
Cluster Relations		
Disjointed	258	35.9
Delineated	153	21.3
Fractured	319	44.4

6b. Array 1 statistics

Terrace Shape	Number	Percent
Rectangular	59	37.3
Irregular	56	35.4
Curvilinear	43	27.2
Cluster Structure		
Regular	80	50.6
Irregular	7	4.4
Interlaced	71	44.9
Cluster Relations		
Disjointed	29	18.3
Delineated	44	27.8
Fractured	85	53.7

6c. Array 2 statistics

Terrace Shape	Number	Percent
Rectangular	34	27.2
Irregular	58	35.4
Curvilinear	89	37.4
Cluster Structure		
Regular	79	43.6
Irregular	56	30.9
Interlaced	46	25.4
Cluster Relations		
Disjointed	44	24.3
Delineated	27	14.9
Fractured	110	60.7

6d. Array 3 statistics

Terrace Shape	Number	Percent
Rectangular	30	7.6
Irregular	139	35.2
Curvilinear	223	57
Cluster Structure		
Regular	192	49.1
Irregular	122	31.2
Interlaced	77	19.6
Cluster Relations		
Disjointed	185	47.3
Delineated	82	20.9
Fractured	124	31.7

6e. Terrace attribute table

FID	Cluster	Array	terrace_shape	cluster_structure	cluster_relation
256	1	1	irregular	regular	fractured
257	1	1	irregular	regular	fractured
258	1	1	curvilinear	regular	fractured
259	1	1	irregular	regular	fractured
260	1	1	rectangular	regular	fractured
261	1	1	rectangular	regular	fractured
262	1	1	rectangular	regular	fractured
263	1	1	curvilinear	regular	fractured
264	1	1	curvilinear	regular	fractured
265	1	1	curvilinear	regular	fractured
266	1	1	curvilinear	regular	fractured
267	1	1	curvilinear	regular	fractured
268	1	1	curvilinear	regular	fractured
269	1	1	curvilinear	regular	fractured
270	1	1	rectangular	regular	fractured
271	1	1	irregular	regular	fractured
272	1	1	irregular	regular	fractured
217	2	1	irregular	interlaced	fractured
218	2	1	irregular	interlaced	fractured
219	2	1	curvilinear	interlaced	fractured
220	2	1	curvilinear	interlaced	fractured
221	2	1	curvilinear	interlaced	fractured
222	2	1	irregular	interlaced	fractured
223	2	1	irregular	interlaced	fractured
224	2	1	curvilinear	interlaced	fractured
225	2	1	irregular	interlaced	fractured
226	2	1	rectangular	interlaced	fractured
228	2	1	rectangular	interlaced	fractured
231	2	1	curvilinear	interlaced	fractured
233	2	1	curvilinear	interlaced	fractured
234	2	1	irregular	interlaced	fractured
241	2	1	rectangular	interlaced	fractured
242	2	1	rectangular	interlaced	fractured
243	2	1	rectangular	interlaced	fractured
254	2	1	irregular	interlaced	fractured
255	2	1	rectangular	interlaced	fractured
205	3	1	rectangular	interlaced	disjointed
245	3	1	curvilinear	interlaced	disjointed
246	3	1	rectangular	interlaced	disjointed
247	3	1	rectangular	interlaced	disjointed

248	3	1	irregular	interlaced	disjointed
249	3	1	curvilinear	interlaced	disjointed
250	3	1	curvilinear	interlaced	disjointed
251	3	1	curvilinear	interlaced	disjointed
252	3	1	irregular	interlaced	disjointed
253	3	1	irregular	interlaced	disjointed
206	4	1	irregular	interlaced	fractured
207	4	1	irregular	interlaced	fractured
208	4	1	irregular	interlaced	fractured
209	4	1	irregular	interlaced	fractured
210	4	1	curvilinear	interlaced	fractured
211	4	1	irregular	interlaced	fractured
212	4	1	irregular	interlaced	fractured
213	4	1	irregular	interlaced	fractured
214	4	1	curvilinear	interlaced	fractured
215	4	1	rectangular	interlaced	fractured
216	4	1	curvilinear	interlaced	fractured
227	4	1	irregular	interlaced	fractured
229	4	1	curvilinear	interlaced	fractured
230	4	1	irregular	interlaced	fractured
232	4	1	irregular	interlaced	fractured
235	4	1	irregular	interlaced	fractured
236	4	1	rectangular	interlaced	fractured
237	4	1	curvilinear	interlaced	fractured
237	4	1	curvilinear	interlaced	fractured
239	4	1	irregular	interlaced	fractured
240	4	1	curvilinear	interlaced	fractured
244	4	1	curvilinear	interlaced	fractured
204	5	1	rectangular	regular	delineated
685	5	1	rectangular	regular	fractured
686	5	1	rectangular	regular	fractured
687	5	1	rectangular	regular	fractured
182	6	1	rectangular	regular	fractured
183	6	1	curvilinear	regular	fractured
184	6	1	irregular	regular	fractured
185	6	1	rectangular	regular	fractured
186	6	1	irregular	regular	fractured
187	6	1	rectangular	regular	fractured
188	6	1	irregular	regular	fractured
189	6	1	curvilinear	regular	fractured
190	6	1	irregular	regular	fractured
191	6	1	curvilinear	regular	fractured
192	6	1	irregular	regular	fractured
193	6	1	irregular	regular	fractured
194	6	1	curvilinear	regular	fractured
195	6	1	irregular	regular	fractured
196	6	1	curvilinear	regular	fractured
197	6	1	curvilinear	regular	fractured
198	6	1	curvilinear	regular	fractured
199	6	1	irregular	regular	fractured
200	6	1	rectangular	regular	fractured
201	6	1	curvilinear	regular	fractured

202	6	1	irregular	regular	fractured
203	6	1	rectangular	regular	fractured
174	7	1	irregular	regular	delineated
175	7	1	rectangular	regular	delineated
176	7	1	rectangular	regular	delineated
177	7	1	rectangular	regular	delineated
178	7	1	irregular	regular	delineated
179	7	1	curvilinear	regular	delineated
180	7	1	curvilinear	regular	delineated
181	7	1	curvilinear	regular	delineated
693	7	1	irregular	interlaced	fractured
697	7	1	rectangular	interlaced	fractured
683	8	1	irregular	irregular	disjointed
684	8	1	curvilinear	irregular	disjointed
530	9	1	curvilinear	interlaced	disjointed
531	9	1	curvilinear	interlaced	disjointed
532	9	1	curvilinear	interlaced	disjointed
533	9	1	rectangular	interlaced	disjointed
534	9	1	rectangular	interlaced	disjointed
535	9	1	curvilinear	interlaced	disjointed
536	9	1	curvilinear	interlaced	disjointed
537	9	1	curvilinear	interlaced	disjointed
165	10	1	irregular	interlaced	delineated
166	10	1	irregular	interlaced	delineated
167	10	1	irregular	interlaced	delineated
168	10	1	rectangular	interlaced	delineated
169	10	1	irregular	interlaced	delineated
170	10	1	rectangular	interlaced	delineated
171	10	1	curvilinear	interlaced	delineated
172	10	1	curvilinear	interlaced	delineated
173	10	1	curvilinear	interlaced	delineated
688	10	1	curvilinear	interlaced	delineated
164	11	1	irregular	irregular	delineated
689	11	1	curvilinear	irregular	delineated
690	11	1	curvilinear	irregular	delineated
698	11	1	irregular	irregular	delineated
699	11	1	irregular	irregular	delineated
148	12	1	curvilinear	regular	delineated
149	12	1	curvilinear	regular	delineated
150	12	1	curvilinear	regular	delineated
151	12	1	curvilinear	regular	delineated
152	12	1	irregular	regular	delineated
153	12	1	curvilinear	regular	delineated
154	12	1	curvilinear	regular	delineated
155	12	1	irregular	regular	delineated
156	12	1	irregular	regular	delineated
157	12	1	irregular	regular	delineated
158	12	1	curvilinear	regular	delineated
160	12	1	rectangular	regular	delineated
161	12	1	rectangular	regular	delineated
162	12	1	rectangular	regular	delineated
163	12	1	rectangular	regular	delineated

691	12	1	irregular	regular	delineated
692	12	1	irregular	regular	delineated
694	12	1	irregular	regular	delineated
695	12	1	rectangular	regular	delineated
696	12	1	rectangular	regular	delineated
538	13	1	rectangular	regular	disjointed
539	13	1	curvilinear	regular	disjointed
540	13	1	rectangular	regular	disjointed
541	13	1	irregular	regular	disjointed
542	13	1	rectangular	regular	disjointed
543	13	1	rectangular	regular	disjointed
544	13	1	irregular	regular	disjointed
545	13	1	curvilinear	regular	disjointed
546	13	1	rectangular	regular	disjointed
124	14	2	irregular	interlaced	delineated
125	14	2	rectangular	interlaced	delineated
126	14	2	rectangular	interlaced	delineated
127	14	2	irregular	interlaced	delineated
128	14	2	curvilinear	interlaced	delineated
129	14	2	rectangular	interlaced	delineated
130	14	2	rectangular	interlaced	delineated
131	14	2	curvilinear	interlaced	delineated
132	14	2	curvilinear	interlaced	delineated
134	14	2	irregular	interlaced	delineated
135	14	2	irregular	interlaced	delineated
136	14	2	rectangular	interlaced	delineated
137	14	2	curvilinear	interlaced	delineated
138	14	2	rectangular	interlaced	delineated
139	14	2	curvilinear	interlaced	delineated
140	14	2	rectangular	interlaced	delineated
141	14	2	rectangular	interlaced	delineated
142	14	2	irregular	interlaced	delineated
143	14	2	irregular	interlaced	delineated
144	14	2	rectangular	interlaced	delineated
145	14	2	irregular	interlaced	delineated
146	14	2	curvilinear	interlaced	delineated
147	14	2	irregular	interlaced	delineated
121	15	2	curvilinear	regular	fractured
121	15	2	curvilinear	regular	fractured
122	15	2	curvilinear	regular	fractured
122	15	2	curvilinear	regular	fractured
123	15	2	curvilinear	regular	fractured
123	15	2	curvilinear	regular	fractured
700	15	2	rectangular	regular	fractured
701	15	2	rectangular	regular	fractured
11	16	2	curvilinear	regular	fractured
18	16	2	curvilinear	regular	fractured
104	16	2	curvilinear	regular	fractured
104	16	2	curvilinear	regular	fractured
105	16	2	curvilinear	regular	fractured
105	16	2	curvilinear	regular	fractured
106	16	2	curvilinear	regular	fractured

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106	16	2	curvilinear	regular	fractured
107	16	2	curvilinear	regular	fractured
107	16	2	curvilinear	regular	fractured
108	16	2	curvilinear	regular	fractured
109	16	2	curvilinear	regular	fractured
109	16	2	curvilinear	regular	fractured
110	16	2	curvilinear	regular	fractured
111	16	2	curvilinear	regular	fractured
111	16	2	curvilinear	regular	fractured
120	16	2	curvilinear	regular	fractured
120	16	2	curvilinear	regular	fractured
87	17	2	curvilinear	regular	fractured
87	17	2	irregular	regular	fractured
88	17	2	rectangular	regular	fractured
88	17	2	rectangular	regular	fractured
89	17	2	rectangular	regular	fractured
89	17	2	rectangular	regular	fractured
90	17	2	rectangular	regular	fractured
90	17	2	rectangular	regular	fractured
91	17	2	curvilinear	regular	fractured
91	17	2	curvilinear	regular	fractured
92	17	2	curvilinear	regular	fractured
92	17	2	curvilinear	regular	fractured
93	17	2	curvilinear	regular	fractured
93	17	2	curvilinear	regular	fractured
94	17	2	curvilinear	regular	fractured
94	17	2	curvilinear	regular	fractured
95	17	2	curvilinear	regular	fractured
95	17	2	irregular	regular	fractured
83	18	2	curvilinear	regular	fractured
83	18	2	curvilinear	regular	fractured
84	18	2	curvilinear	regular	fractured
84	18	2	curvilinear	regular	fractured
85	18	2	rectangular	regular	fractured
85	18	2	rectangular	regular	fractured
86	18	2	curvilinear	regular	fractured
86	18	2	curvilinear	regular	fractured
67	19	2	curvilinear	irregular	fractured
68	19	2	irregular	irregular	fractured
69	19	2	curvilinear	irregular	fractured
70	19	2	irregular	irregular	fractured
71	19	2	irregular	irregular	fractured
72	19	2	irregular	irregular	fractured
73	19	2	rectangular	irregular	fractured
74	19	2	irregular	irregular	fractured
75	19	2	curvilinear	irregular	fractured
76	19	2	curvilinear	irregular	fractured
77	19	2	rectangular	irregular	fractured
78	19	2	irregular	irregular	fractured
79	19	2	curvilinear	irregular	fractured
80	19	2	irregular	irregular	fractured
81	19	2	irregular	irregular	fractured

82	19	2	irregular	irregular	fractured
43	20	2	irregular	regular	fractured
44	20	2	curvilinear	regular	fractured
45	20	2	curvilinear	regular	fractured
46	20	2	irregular	regular	fractured
47	20	2	irregular	regular	fractured
48	20	2	rectangular	regular	fractured
50	20	2	irregular	regular	fractured
59	20	2	curvilinear	regular	fractured
60	20	2	curvilinear	regular	fractured
61	20	2	rectangular	regular	fractured
62	20	2	rectangular	regular	fractured
63	20	2	rectangular	regular	fractured
64	20	2	curvilinear	regular	fractured
708	20	2	irregular	regular	fractured
709	20	2	irregular	regular	fractured
51	21	2	curvilinear	regular	fractured
52	21	2	irregular	regular	fractured
53	21	2	curvilinear	regular	fractured
54	21	2	curvilinear	regular	fractured
55	21	2	curvilinear	regular	fractured
56	21	2	curvilinear	regular	fractured
57	21	2	irregular	regular	fractured
58	21	2	irregular	regular	fractured
22	22	2	irregular	irregular	fractured
23	22	2	curvilinear	irregular	fractured
24	22	2	curvilinear	irregular	fractured
25	22	2	rectangular	irregular	fractured
26	22	2	curvilinear	irregular	fractured
27	22	2	curvilinear	irregular	fractured
28	22	2	curvilinear	irregular	fractured
29	22	2	irregular	irregular	fractured
30	22	2	curvilinear	irregular	fractured
31	22	2	curvilinear	irregular	fractured
32	22	2	curvilinear	irregular	fractured
34	22	2	irregular	irregular	fractured
35	22	2	irregular	irregular	fractured
36	22	2	irregular	irregular	fractured
37	22	2	irregular	irregular	fractured
38	22	2	irregular	irregular	fractured
42	22	2	irregular	irregular	fractured
65	22	2	rectangular	irregular	fractured
66	22	2	rectangular	irregular	fractured
0	23	2	curvilinear	regular	delineated
1	23	2	curvilinear	regular	delineated
2	23	2	curvilinear	regular	delineated
3	23	2	curvilinear	regular	delineated
4	24	2	irregular	irregular	disjointed
5	24	2	irregular	irregular	disjointed
6	24	2	irregular	irregular	disjointed
7	24	2	irregular	irregular	disjointed
8	24	2	curvilinear	irregular	disjointed

9	24	2	curvilinear	irregular	disjointed
10	24	2	curvilinear	irregular	disjointed
11	24	2	curvilinear	irregular	disjointed
12	24	2	curvilinear	irregular	disjointed
13	24	2	rectangular	irregular	disjointed
14	24	2	rectangular	irregular	disjointed
15	24	2	irregular	irregular	disjointed
16	24	2	irregular	irregular	disjointed
17	24	2	irregular	irregular	disjointed
18	24	2	irregular	irregular	disjointed
19	24	2	irregular	irregular	disjointed
20	24	2	curvilinear	irregular	disjointed
21	24	2	irregular	irregular	disjointed
39	24	2	irregular	irregular	disjointed
40	24	2	irregular	irregular	disjointed
41	24	2	curvilinear	irregular	disjointed
96	25	2	curvilinear	interlaced	disjointed
97	25	2	rectangular	interlaced	disjointed
98	25	2	irregular	interlaced	disjointed
99	25	2	curvilinear	interlaced	disjointed
100	25	2	curvilinear	interlaced	disjointed
101	25	2	rectangular	interlaced	disjointed
102	25	2	curvilinear	interlaced	disjointed
102	25	2	irregular	interlaced	disjointed
103	25	2	irregular	interlaced	disjointed
112	26	2	curvilinear	interlaced	disjointed
113	26	2	curvilinear	interlaced	disjointed
114	26	2	curvilinear	interlaced	disjointed
115	26	2	rectangular	interlaced	disjointed
116	26	2	curvilinear	interlaced	disjointed
117	26	2	irregular	interlaced	disjointed
118	26	2	curvilinear	interlaced	disjointed
119	26	2	irregular	interlaced	disjointed
702	26	2	irregular	interlaced	disjointed
703	26	2	irregular	interlaced	disjointed
704	26	2	rectangular	interlaced	disjointed
705	26	2	irregular	interlaced	disjointed
706	26	2	irregular	interlaced	disjointed
707	26	2	irregular	interlaced	disjointed
499	27	3	irregular	regular	fractured
500	27	3	rectangular	regular	fractured
501	27	3	rectangular	regular	fractured
502	27	3	irregular	regular	fractured
503	27	3	irregular	regular	fractured
504	27	3	rectangular	regular	fractured
505	27	3	irregular	regular	fractured
506	27	3	curvilinear	regular	fractured
507	27	3	irregular	regular	fractured
508	27	3	rectangular	regular	fractured
509	27	3	irregular	regular	fractured
510	27	3	rectangular	regular	fractured
511	27	3	curvilinear	regular	fractured

512	27	3	curvilinear	regular	fractured
513	27	3	curvilinear	regular	fractured
514	27	3	irregular	regular	fractured
515	27	3	irregular	regular	fractured
516	27	3	irregular	regular	fractured
517	27	3	rectangular	regular	fractured
518	27	3	rectangular	regular	fractured
519	27	3	irregular	regular	fractured
520	27	3	irregular	regular	fractured
521	27	3	irregular	regular	fractured
522	27	3	irregular	regular	fractured
451	28	3	curvilinear	regular	delineated
452	28	3	curvilinear	regular	delineated
453	28	3	rectangular	regular	delineated
441	29	3	curvilinear	regular	fractured
442	29	3	rectangular	regular	fractured
443	29	3	curvilinear	regular	fractured
444	29	3	curvilinear	regular	fractured
445	29	3	curvilinear	regular	fractured
446	29	3	curvilinear	regular	fractured
447	29	3	curvilinear	regular	fractured
273	30	3	irregular	interlaced	fractured
274	30	3	curvilinear	interlaced	fractured
275	30	3	irregular	interlaced	fractured
276	30	3	irregular	interlaced	fractured
277	30	3	irregular	interlaced	fractured
278	30	3	curvilinear	interlaced	fractured
279	30	3	irregular	interlaced	fractured
280	30	3	rectangular	interlaced	fractured
281	30	3	curvilinear	interlaced	fractured
282	30	3	curvilinear	interlaced	fractured
283	30	3	irregular	interlaced	fractured
284	30	3	curvilinear	interlaced	fractured
285	30	3	rectangular	interlaced	fractured
286	30	3	curvilinear	interlaced	fractured
287	31	3	curvilinear	regular	delineated
288	31	3	rectangular	regular	delineated
289	31	3	irregular	regular	delineated
290	31	3	curvilinear	regular	delineated
291	31	3	curvilinear	regular	delineated
292	31	3	curvilinear	regular	delineated
293	31	3	curvilinear	regular	delineated
294	31	3	curvilinear	regular	delineated
295	31	3	curvilinear	regular	delineated
296	31	3	curvilinear	regular	delineated
297	31	3	curvilinear	regular	delineated
298	31	3	curvilinear	regular	delineated
299	31	3	irregular	regular	delineated
300	31	3	curvilinear	regular	delineated
301	31	3	curvilinear	regular	delineated
302	31	3	rectangular	regular	delineated
303	31	3	curvilinear	regular	delineated

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304	31	3	curvilinear	regular	delineated
305	31	3	irregular	regular	delineated
306	31	3	irregular	regular	delineated
307	31	3	curvilinear	regular	delineated
308	31	3	rectangular	regular	delineated
309	31	3	curvilinear	regular	delineated
310	32	3	curvilinear	interlaced	delineated
311	32	3	irregular	interlaced	delineated
312	32	3	curvilinear	interlaced	delineated
315	33	3	irregular	interlaced	fractured
316	33	3	curvilinear	interlaced	fractured
317	33	3	curvilinear	interlaced	fractured
318	33	3	curvilinear	interlaced	fractured
319	33	3	irregular	interlaced	fractured
320	33	3	irregular	interlaced	fractured
321	33	3	irregular	interlaced	fractured
322	33	3	curvilinear	interlaced	fractured
323	33	3	irregular	interlaced	fractured
324	33	3	irregular	interlaced	fractured
325	33	3	curvilinear	interlaced	fractured
326	33	3	curvilinear	interlaced	fractured
327	33	3	irregular	interlaced	fractured
328	33	3	irregular	interlaced	fractured
329	33	3	irregular	interlaced	fractured
339	34	3	curvilinear	regular	disjointed
340	34	3	curvilinear	regular	disjointed
341	34	3	curvilinear	regular	disjointed
342	34	3	curvilinear	regular	disjointed
343	34	3	irregular	regular	disjointed
344	34	3	curvilinear	regular	disjointed
345	34	3	curvilinear	regular	disjointed
346	34	3	curvilinear	regular	disjointed
347	34	3	curvilinear	regular	disjointed
348	34	3	curvilinear	regular	disjointed
349	34	3	curvilinear	regular	disjointed
350	34	3	irregular	regular	disjointed
351	34	3	irregular	regular	disjointed
352	34	3	irregular	regular	disjointed
353	34	3	irregular	regular	disjointed
354	34	3	curvilinear	regular	disjointed
355	34	3	curvilinear	regular	disjointed
356	34	3	curvilinear	regular	disjointed
357	34	3	curvilinear	regular	disjointed
358	34	3	curvilinear	regular	disjointed
359	34	3	curvilinear	regular	disjointed
360	34	3	curvilinear	regular	disjointed
361	34	3	curvilinear	regular	disjointed
365	34	3	curvilinear	regular	disjointed
362	35	3	irregular	regular	disjointed
363	35	3	curvilinear	regular	disjointed
364	35	3	curvilinear	regular	disjointed
416	35	3	curvilinear	regular	disjointed

419	35	3	curvilinear	regular	disjointed
421	35	3	curvilinear	regular	disjointed
422	35	3	curvilinear	regular	disjointed
427	35	3	curvilinear	regular	disjointed
429	35	3	curvilinear	regular	disjointed
460	35	3	curvilinear	regular	disjointed
590	36	3	curvilinear	regular	delineated
591	36	3	curvilinear	regular	delineated
592	36	3	curvilinear	regular	delineated
593	36	3	curvilinear	regular	delineated
594	36	3	curvilinear	regular	delineated
595	36	3	curvilinear	regular	delineated
584	37	3	curvilinear	irregular	fractured
585	37	3	curvilinear	irregular	fractured
586	37	3	curvilinear	irregular	fractured
675	37	3	irregular	irregular	fractured
676	37	3	irregular	irregular	fractured
677	37	3	irregular	irregular	fractured
678	38	3	irregular	regular	delineated
679	38	3	curvilinear	regular	delineated
680	38	3	curvilinear	regular	delineated
681	38	3	rectangular	regular	delineated
682	38	3	curvilinear	regular	delineated
547	39	3	curvilinear	regular	delineated
548	39	3	curvilinear	regular	delineated
549	39	3	curvilinear	regular	delineated
550	39	3	curvilinear	regular	delineated
551	39	3	curvilinear	regular	delineated
552	39	3	curvilinear	regular	delineated
559	40	3	curvilinear	interlaced	delineated
560	40	3	curvilinear	interlaced	delineated
561	40	3	curvilinear	interlaced	delineated
562	40	3	rectangular	interlaced	delineated
563	40	3	curvilinear	interlaced	delineated
564	40	3	curvilinear	interlaced	delineated
565	40	3	curvilinear	interlaced	delineated
566	40	3	curvilinear	interlaced	delineated
568	40	3	rectangular	interlaced	delineated
569	40	3	curvilinear	interlaced	delineated
570	40	3	irregular	interlaced	delineated
571	40	3	curvilinear	interlaced	delineated
572	40	3	irregular	interlaced	delineated
573	41	3	curvilinear	regular	fractured
574	41	3	curvilinear	regular	fractured
575	41	3	curvilinear	regular	fractured
576	41	3	curvilinear	regular	fractured
577	41	3	irregular	regular	fractured
578	41	3	irregular	regular	fractured
579	41	3	curvilinear	regular	fractured
580	41	3	irregular	regular	fractured
581	41	3	irregular	regular	fractured
582	41	3	curvilinear	regular	fractured

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583	41	3	curvilinear	regular	fractured
587	42	3	curvilinear	regular	disjointed
588	42	3	curvilinear	regular	disjointed
589	42	3	irregular	regular	disjointed
596	42	3	irregular	regular	disjointed
597	42	3	irregular	regular	disjointed
598	42	3	curvilinear	regular	disjointed
599	42	3	irregular	regular	disjointed
600	42	3	irregular	regular	disjointed
601	42	3	irregular	regular	disjointed
602	42	3	irregular	regular	disjointed
620	42	3	irregular	regular	disjointed
621	42	3	irregular	regular	disjointed
622	42	3	irregular	regular	disjointed
603	43	3	curvilinear	regular	disjointed
604	43	3	curvilinear	regular	disjointed
605	43	3	curvilinear	regular	disjointed
606	43	3	curvilinear	regular	disjointed
607	43	3	irregular	regular	disjointed
608	43	3	curvilinear	regular	disjointed
609	43	3	curvilinear	regular	disjointed
610	43	3	curvilinear	regular	disjointed
611	43	3	curvilinear	regular	disjointed
612	43	3	curvilinear	regular	disjointed
613	43	3	curvilinear	regular	disjointed
614	43	3	irregular	regular	disjointed
615	43	3	curvilinear	regular	disjointed
616	43	3	irregular	regular	disjointed
617	43	3	irregular	regular	disjointed
618	43	3	curvilinear	regular	disjointed
619	43	3	irregular	regular	disjointed
623	44	3	irregular	irregular	delineated
624	44	3	curvilinear	irregular	delineated
625	44	3	curvilinear	irregular	delineated
626	44	3	curvilinear	irregular	delineated
627	44	3	rectangular	irregular	delineated
663	45	3	irregular	interlaced	delineated
664	45	3	curvilinear	interlaced	delineated
665	45	3	curvilinear	interlaced	delineated
666	45	3	irregular	interlaced	delineated
667	45	3	curvilinear	interlaced	delineated
668	45	3	curvilinear	interlaced	delineated
669	45	3	irregular	interlaced	delineated
670	45	3	curvilinear	interlaced	delineated
671	45	3	curvilinear	interlaced	delineated
672	45	3	curvilinear	interlaced	delineated
673	45	3	curvilinear	interlaced	delineated
674	45	3	irregular	interlaced	delineated
648	46	3	rectangular	interlaced	fractured
649	46	3	curvilinear	interlaced	fractured
651	46	3	irregular	interlaced	fractured
653	46	3	curvilinear	interlaced	fractured

654	46	3	irregular	interlaced	fractured
655	46	3	irregular	interlaced	fractured
656	46	3	curvilinear	interlaced	fractured
657	46	3	irregular	interlaced	fractured
658	46	3	irregular	interlaced	fractured
659	46	3	irregular	interlaced	fractured
660	46	3	irregular	interlaced	fractured
661	46	3	curvilinear	interlaced	fractured
662	46	3	curvilinear	interlaced	fractured
413	47	3	irregular	irregular	disjointed
414	47	3	curvilinear	irregular	disjointed
415	47	3	curvilinear	irregular	disjointed
635	47	3	irregular	irregular	disjointed
636	47	3	irregular	irregular	disjointed
637	47	3	curvilinear	irregular	disjointed
638	47	3	curvilinear	irregular	disjointed
639	47	3	curvilinear	irregular	disjointed
640	47	3	rectangular	irregular	disjointed
641	47	3	irregular	irregular	disjointed
642	47	3	irregular	irregular	disjointed
643	47	3	curvilinear	irregular	disjointed
644	47	3	irregular	irregular	disjointed
645	47	3	irregular	irregular	disjointed
646	47	3	irregular	irregular	disjointed
647	47	3	curvilinear	irregular	disjointed
650	47	3	irregular	irregular	disjointed
652	47	3	irregular	irregular	disjointed
409	48	3	irregular	irregular	disjointed
410	48	3	irregular	irregular	disjointed
411	48	3	curvilinear	irregular	disjointed
412	48	3	curvilinear	irregular	disjointed
418	48	3	curvilinear	irregular	disjointed
423	48	3	curvilinear	irregular	disjointed
424	48	3	curvilinear	irregular	disjointed
425	48	3	curvilinear	irregular	disjointed
426	48	3	irregular	irregular	disjointed
427	48	3	irregular	irregular	disjointed
428	48	3	irregular	irregular	disjointed
429	48	3	irregular	irregular	disjointed
430	48	3	curvilinear	irregular	disjointed
431	48	3	curvilinear	irregular	disjointed
432	48	3	irregular	irregular	disjointed
433	48	3	rectangular	irregular	disjointed
434	49	3	irregular	interlaced	disjointed
435	49	3	curvilinear	interlaced	disjointed
436	49	3	irregular	interlaced	disjointed
437	49	3	rectangular	interlaced	disjointed
438	49	3	rectangular	interlaced	disjointed
439	49	3	curvilinear	interlaced	disjointed
440	49	3	curvilinear	interlaced	disjointed
366	50	3	curvilinear	irregular	disjointed
367	50	3	curvilinear	irregular	disjointed

368	50	3	curvilinear	irregular	disjointed
369	50	3	curvilinear	irregular	disjointed
370	50	3	curvilinear	irregular	disjointed
371	50	3	curvilinear	irregular	disjointed
372	50	3	curvilinear	irregular	disjointed
373	50	3	curvilinear	irregular	disjointed
374	50	3	curvilinear	irregular	disjointed
375	50	3	curvilinear	irregular	disjointed
376	50	3	curvilinear	irregular	disjointed
377	50	3	curvilinear	irregular	disjointed
378	50	3	curvilinear	irregular	disjointed
379	50	3	curvilinear	irregular	disjointed
380	50	3	irregular	irregular	disjointed
381	50	3	irregular	irregular	disjointed
382	50	3	curvilinear	irregular	disjointed
383	50	3	curvilinear	irregular	disjointed
384	50	3	curvilinear	irregular	disjointed
385	50	3	curvilinear	irregular	disjointed
386	50	3	curvilinear	irregular	disjointed
387	50	3	curvilinear	irregular	disjointed
388	50	3	curvilinear	irregular	disjointed
389	50	3	irregular	irregular	disjointed
390	50	3	curvilinear	irregular	disjointed
391	50	3	curvilinear	irregular	disjointed
392	50	3	curvilinear	irregular	disjointed
393	50	3	irregular	irregular	disjointed
394	50	3	curvilinear	irregular	disjointed
395	50	3	curvilinear	irregular	disjointed
396	50	3	irregular	irregular	disjointed
397	50	3	curvilinear	irregular	disjointed
398	50	3	irregular	irregular	disjointed
399	50	3	curvilinear	irregular	disjointed
400	50	3	curvilinear	irregular	disjointed
401	50	3	curvilinear	irregular	disjointed
402	50	3	curvilinear	irregular	disjointed
403	50	3	curvilinear	irregular	disjointed
404	50	3	curvilinear	irregular	disjointed
405	50	3	curvilinear	irregular	disjointed
406	50	3	curvilinear	irregular	disjointed
407	50	3	rectangular	irregular	disjointed
408	50	3	rectangular	irregular	disjointed
710	50	3	irregular	irregular	disjointed
523	51	3	curvilinear	regular	fractured
524	51	3	curvilinear	regular	fractured
525	51	3	irregular	regular	fractured
526	51	3	irregular	regular	fractured
527	51	3	curvilinear	regular	fractured
528	51	3	curvilinear	regular	fractured
529	51	3	irregular	regular	fractured
313	52	3	irregular	regular	fractured
314	52	3	curvilinear	regular	fractured
462	53	3	irregular	regular	disjointed

463	53	3	curvilinear	regular	disjointed
464	53	3	curvilinear	regular	disjointed
465	53	3	curvilinear	regular	disjointed
469	53	3	irregular	regular	disjointed
470	53	3	irregular	regular	disjointed
471	53	3	irregular	regular	disjointed
566	53	3	curvilinear	regular	disjointed
567	53	3	curvilinear	regular	disjointed
568	53	3	irregular	regular	disjointed
454	54	3	curvilinear	irregular	disjointed
455	54	3	curvilinear	irregular	disjointed
456	54	3	curvilinear	irregular	disjointed
457	54	3	curvilinear	irregular	disjointed
458	54	3	curvilinear	irregular	disjointed
459	54	3	irregular	irregular	disjointed
461	54	3	curvilinear	irregular	disjointed
472	54	3	irregular	irregular	disjointed
473	54	3	irregular	irregular	disjointed
474	54	3	irregular	irregular	disjointed
477	54	3	irregular	irregular	disjointed
482	54	3	irregular	irregular	disjointed
483	54	3	irregular	irregular	disjointed
484	54	3	irregular	irregular	disjointed
475	55	3	curvilinear	irregular	disjointed
476	55	3	curvilinear	irregular	disjointed
478	55	3	curvilinear	irregular	disjointed
479	55	3	irregular	irregular	disjointed
480	55	3	irregular	irregular	disjointed
481	55	3	irregular	irregular	disjointed
485	55	3	curvilinear	irregular	disjointed
486	55	3	irregular	irregular	disjointed
492	55	3	curvilinear	irregular	disjointed
493	55	3	irregular	irregular	disjointed
494	55	3	irregular	irregular	disjointed
495	55	3	curvilinear	irregular	disjointed
487	56	3	irregular	regular	fractured
488	56	3	irregular	regular	fractured
489	56	3	curvilinear	regular	fractured
490	56	3	irregular	regular	fractured
491	56	3	irregular	regular	fractured
496	57	3	curvilinear	regular	fractured
497	57	3	irregular	regular	fractured
498	57	3	curvilinear	regular	fractured
553	58	3	irregular	regular	delineated
554	58	3	curvilinear	regular	delineated
555	58	3	curvilinear	regular	delineated
556	58	3	curvilinear	regular	delineated
557	58	3	curvilinear	regular	delineated
558	58	3	curvilinear	regular	delineated
628	59	3	irregular	irregular	fractured
629	59	3	rectangular	irregular	fractured
630	59	3	rectangular	irregular	fractured

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631	59	3	irregular	irregular	fractured
632	59	3	rectangular	irregular	fractured
633	59	3	irregular	irregular	fractured
634	59	3	curvilinear	irregular	fractured
330	60	3	rectangular	regular	fractured
331	60	3	irregular	regular	fractured
332	60	3	curvilinear	regular	fractured
333	60	3	curvilinear	regular	fractured
334	60	3	irregular	regular	fractured
335	60	3	rectangular	regular	fractured
336	60	3	curvilinear	regular	fractured
337	60	3	irregular	regular	fractured
338	60	3	irregular	regular	fractured
711	60	3	curvilinear	regular	fractured