Modeling Prehistoric Paths in Bronze Age Northeast England

by

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List of Abbreviations

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ACS	Accumulated Cost Surface
ADS	Archaeological Data Service
DEM	Digital Elevation Model
GIS	Geographic Information System
LCP	Least Cost Path
LP DAAP	Land Processes Distributed Active Archive Center
LiDAR	Light Detection and Ranging
SRTM	Shuttle Radar Topography Mission
US	United States (of America)
UK	United Kingdom

Abstract

Numerous studies within the last 200 years have shed light on the socioeconomic patterns of the Beaker culture during the Bronze Age, particularly in the United Kingdom. However, with the expanding role of GIS in the field of archaeology, there is an increasing amount of spatial data on this cultural group, allowing opportunities for analysis that can begin to describe inter- and intrasite spatial connections. The geographic connections of pathways, for example, can illustrate the corridors of cultural exchange that gave rise to and sustained the Beakers for over 1,000 years. Using Least Cost Path analysis, this thesis aimed to model such spatial connections in Northeast England.

The study generated 66 anisotropic LCPs that modeled possible path connections between sites. The first 18 LCPs served as the primary LCPs between sites – within clusters and between clusters. Three assessment tests were conducted to validate these LCPs. First, for each primary LCP, another LCP was generated traveling in the reverse direction. Second, new segments that utilized pairs of nearby sites, approximating the alignment of original pairs, were generated; the new segments also included a primary and a reverse LCP. Finally, areas with high LCP coincidence were compared to aerial images for coincidence with paths or features. The study found that the LCPs were mostly coincident or near coincident. However, varying degrees of local variation in the trajectories of many LCPs were evident. Four areas with high LCP coincidence or near coincidence were selected for aerial imagery comparison which showed LCPs generally following watercourses. Generating LCPs can model human movement during the Bronze Age; however, datasets that describe the environmental conditions of the period as well cultural datasets that spatially delineate territories and taboos are needed in order to more

accurately understand the efficacy of these LCPs and the costs associated with prehistoric travel in the region.

Chapter 1 Introduction

The past continues to be present in our open landscapes. Prehistoric peoples created pathways between sites and between regions which can sometimes describe the interactions of local and regional groups, including social relationships and economic behavior (Kline 2009; Teeter, Martinez, and Richardson 2013). However, modern developments have masked many prehistoric trails. The northern portions of the United Kingdom (UK), for example, are rich in Bronze Age sites but are now dominated by agricultural land that has erased the physical connections between settlements; these connections would otherwise describe how certain objects in the era, such as jet, were transported from one site to another. This thesis aims to model the connections of Bronze Age settlements in northeast England according to paths of least resistance using natural topography.

Some paths of travel in modern times are possible iterations of past trails. Paths form due to repeated use over time, and many paths endure by conforming to new travel technologies and demands of trade (Kline 2009; Colton 1941). In 2015, a gold route between England and Ireland was found to have served the area since 2500 BC (Mendoza 2015). In the United States, prehistoric trade paths connecting coastal California areas to the American Southwest became railroad routes and highways (Colton 1941). Colton (1941, 318) has stated: “Although individuals on foot may traverse Arizona and New Mexico from one point to another from in almost any direction, yet the bulk of the movement would follow certain lines of geographical least resistance”. The key to understanding the consistent choices that people make in terms of the routes to take lies in the shape of the landscape and their associated costs to the human traveler.

To generate the model, Least Cost Path (LCP) analyses was employed. LCPs are a set of calculations that use the slope data of an area, often with other variables such as hydrology and land cover, to determine the possible routes with the least cost to the traveler, from a starting point to a destination (Herzog 2014). In short, LCPs follow Colton's (1941) logic of optimal lines of travel.

1.1 Background and Motivation

Bronze Age England is well documented but sizeable opportunities for research remain. Concepts of socioeconomic patterns of the era tend to be derived from southern cultures, while some evidence points to variation throughout the region, particularly in terms of settlements (Brück 2008). The use of multiple roundhouses in the south, for example, differ from the single household structures in the remainder of the region. In landscape studies, spatial organization of settlement and burial features as well as the relationship of material sources to sites lack analysis that would show and compare regional variations (Brück 2008).

British prehistoric sites are generally spatially consistent over time. Much physical evidence of the Bronze settlements and burials are largely the final iteration of a construction process (Frieman 2012). Settlements were occupied, abandoned, and reused or repurposed over several hundred years, if not thousands, as in the case of agricultural field systems in the Thames Valley from Early to Late Bronze Age (Yates 1999). More famously, the Stonehenge monument was built in a process lasting over 1,000 years (which encompassed the Neolithic and Early Bronze Age), with stones transported from Wales, approximately 140 miles away (Mendoza 2015; Parker Pearson, 2013). In 2016, Mike Parker Pearson has posited that Stonehenge was originally built in Wales and brought along through an eastward movement as descendants of the monument’s dead relocated it to its current site to bring an end to inter-regional conflict (Knapton 2016). Hence, despite changes in settlement patterns, a line of enduring paths can be drawn between two or several sites and features that can begin to spatially describe the diffusion or localization of socioeconomic behavior, the proximity of sites to source materials, and the organization and cosmography of local land use – core habitation areas, farming and craft production, and ceremonial/spiritual.

1.1.1. Least Cost Path analysis

LCPs model the spatial connections between points across a landscape (Mitchell 2012). Examples of the multiple applications of LCP in different, disparate fields include transportation planning – modeling roads and railways; utility planning – modeling the flow of gas and electricity distribution networks; and ecology – modeling the behavior of animals (Mitchell 2012).

LCPs involves three algorithms to search for the least-cost path. The first is the Cost Surface Raster. The raster provides the “cost of traveling through each cell” (Esri 2016c). It typically involves variables such as the distance and slope values across a study area. It can include any variable that facilitates or obstructs movement (White and Surface-Evans 2012). In transportation, cost variables may include monetary costs of construction along a route over another, for example (Mitchell 2012). In ecological studies, land use layers may be essential to analyzing the cost of migration for some animals (Lee, Chon, and Ahn 2014). Whatever the case, in GIS software such as ArcGIS, all layers will need to be reclassified to equal intervals to generate comparable scales. Once the algorithm is run, the cost is calculated and the cost surface is created in which each cell in the raster is assigned a cost value.

The second output is the Cost Distance Raster which "calculates the least accumulative cost distance for each cell" to an origin point (Esri 2016e). To process this raster requires the cost surface generated above and a given origin point run through the Cost Distance tool. This generates the Cost Distance Raster and the Backlink Raster. Once the cost distance raster is generated, an algorithm backtracks from the destination point to the origin using the lowest values in the cost distance raster. These rasters are required to run the Cost Path tool which provides the third and final output - a path of least cost between the two points (Esri 2016e).

1.1.2. Least Cost Path in archaeology

In archaeology, LCPs can demonstrate the movement of people across space, and often have been used to model prehistoric pathways (Herzog 2014). While LCP calculations have been available since 1957, cost surface analysis have been applied to archaeology since 1972 (Herzog 2014; Rahn 2005; Lee and Stucky 1998). The methods used in the field to collect spatial data have varied and continue to vary, but the cost surface is often generated from the values of slope and its relationship with other variable(s) that informed or shaped the decisions prehistoric peoples made in choosing paths to get from one place to another (Rahn 2005). Indeed, Herzog (2014) compiled archaeological LCP studies in rural areas and found that of the environmental variables, slope tends to be the primary layer used in most research. This is not surprising particularly since during prehistoric periods the primary mode of transport was on foot; hence, an increase in slope would have increased the cost in time and energy for the traveler (Kondo and Seino 2009).

LCPs have increased in complexity over time. LCPs can be executed anisotropically or isotropically in which the calculations either consider the directionality of travel, as in the former, or do not, as in the latter (White and Surface-Evans 2012). The cost of travel in isotropic calculations is the same whether or not the traveler changes direction. Anisotropic methods assume that directionality has implications for the cost of travel. The increase or decrease in the slope of a route or part of a route may affect the cost of movement into and out of a point in space (White and Surface-Evans 2012). Walking uphill has greater cost than walking downhill. LCPs can also be implemented with partial anisotropic calculations. In a study of movement during the Mayan Classic period, for instance, the method factored a greater cost to movement coming from the west due to the direction of trade (Doyle, Garrison and Houston 2012). However, despite the use of slope in many archaeological LCP studies, most LCPs are implemented isotropically (Herzog 2014).

There are other methods to employing LCPs. Rahn (2005) observes that GIS technology has improved in sophistication and archaeological LCAs can expand on or do away with slope altogether. Analyses can include data on social attitudes towards specific points on a landscape as in Llobera (2000), or improved algorithms for calculating the "visibility" relationships of cells, which is often referred to as viewshed analysis (Rahn 2005; Lee and Stucky 1998). In the latter case, paths are chosen according to how visible a cell is from other cells.

1.2 Study Area

Northeast England is located just south of England's border with Scotland, and includes Northumberland, the largest county, and Newcastle upon Tyne, its largest city (Figure 1). The study area is roughly 280-380 miles from London. It is comprised primarily of rural, agricultural lands interlaced with modern roads and highways, with the River Tyne and its tributaries cutting through the southern end on a west to east orientation and emptying into the North Sea.

Figure 1 Study Area – Northeast England. *Sources*: Esri, USGS, NOAA.

While farm and grazing lands dominate the area, they are superimposed on a relatively diverse topography that can impact the routes of a traveler. In the north, the Cheviot Hills flank (and transcend) the Scottish border. Low rolling hills create some relief to the flat agricultural topographic textures across the remainder of the region. Some sites skirt the coastal edges to the east. The diversity in elevation and slope in the contours of the surface shape the corridors by which pathways would have been used to connect prehistoric people from one geological formation to the next.

1.2.1. The Beaker Culture

The Bronze Age brought new technology and cultural practices across the British Isles (where the Bronze period lasted the longest). During the Late Neolithic and through the Early, Middle, and Late Bronze Ages, the region was populated by people primarily associated with the Beaker culture, so called due to the assemblage of artifacts found during this period that included beaked drinking vessels (Crawford 1912). The earliest of these artifacts date back to approximately 2,750 BC (Dyer 2002). In the literature, much has been discussed about whether the Beakers were native or immigrants from continental Europe, but Parker Pearson (2013) suggests that they were likely founded by a small number of immigrants rather than successive groups of immigrants moving into the British Isles throughout the period as previously thought. Dyer (2002) states that during Neolithic and into the Chalcolithic period (Late Neolithic through Early Bronze), people in the area engaged in trading with peoples of continental Europe that resulted in the spread of cultural ideas and exchange of material goods. In Parker Pearson’s study of strontium and oxygen isotopes in tooth enamel, less than seven (out of 360 subjects) were likely to have grown up outside of Britain. Thus, what defines the Beaker phenomenon is the diffusion of Beaker technology and other cultural hallmarks rather than the spread of a specific group of people.

1.2.1.1. Cultural Diffusion

The geospatial distribution of Beaker settlement sites is discontinuous across Europe as well as in England. Research into this cultural group has included different ideas on how Beaker culture had spread, but there is generally a lack of evidence of directionality of its diffusion across Europe; some typological variants of certain artifacts like pottery, for example, are sometimes contained to one small area (Linden 2007; Czebreszuk 2004; Waldren 2003; Brodie 1997). In other words, there are no known origins of Beaker technology or ideas. Since the shift from thinking of the Beaker culture as a people to one of a cultural package, the origin of the Beaker phenomenon has become less important; studies are now focused on the spread of cultural material (Czebreszuk 2004).

Patterns of material exchange are well established. Jet necklaces, for example, have been exchanged between prehistoric communities in the British Isles since the Neolithic, with Whitby (approximately 75 miles south of Newcastle upon Tyne) as one of its major sources (Frieman 2012; Sheridan and Davis 2002). In Northern England, a form of jet was used with a source in Scotland (Sheridan and Davis 2002). An Early Bronze Age burial in southern England near Stonehenge, known for having the greatest amount of artifacts from the period, including copper material with Spanish and French origins (Stevens 2008; Fitzpatrick 2002).

Beaker cultural diffusion may have been driven by trade, marriage, and war. Linden (2007) proposes that more research is needed to examine the modes of cultural transmission such as marital exchange, for example, in which a partner leaves their native village for their spouse’s, as such arrangements can have implications for cultural diffusion across time and space. Brück (2006) explains that the Bronze Age was predicated on an economy of gift and commodity exchange and argues that marriage operated in a way that promoted the mechanism of the flow of goods between groups as well as the flow of people between groups; to this extent, people and goods are interchangeable.

Increasingly, since the 2000s, studies employ chemical analysis on human remains to determine patterns of migration. Isotope analysis of tooth and bone in a Bavarian study have demonstrated significant patterns of migration during the Bronze Age that have implications on movement by marriage (Price, Grupe, and Schröter 1998). In southern England, isotope analysis of adult subjects showed that they migrated 150-200 km, from their childhood to their final residence (Evans, Chenery and Fitzpatrick 2006).

1.2.1.2. Burial Practices

Beaker burial practices reflect cultural change from the Neolithic to the Bronze Age (Figure 2). The round barrows, or mounds, of single inhumations are a departure from the multiple inhumations found in the burial mounds and monuments of the Neolithic (Bruck 2004b; Dyer 2002). However, the number of human remains in a round barrow can sometimes vary (Jones and Quintell 2014; Bruck 2008). In Fowler’s (2012) compilation of approximately 350 Chalcolithic and Bronze Age burial studies in Northeast England, 22 had at two to three sets of human remains; one contained 24. It is important to note that the data also includes instances of burials in which the number of those interred could not be determined and more in which the number is unknown or unrecorded. It is not a surprise that these burial studies have inadequate data; many British archaeological studies over the last two centuries concerning the Bronze Age were poorly recorded excavations (Linden 2007; Brück 2008).

Figure 2 Beaker artifact samples – pottery and flint tools and arrowheads.
Source: Worcestershire Historic Environment and Archaeology Service.

Burials also feature material deposits that define the period. The first excavations of Beakers barrows around or near Stonehenge by Richard Colt Hoare and William Cunnington in

1808 not only included beaker vessels but also the first bronze and copper axes and daggers found in England (Parker Pearson 2013; Dyer 2002; Crawford 1912). In excavations since, artifacts have also included those made of gold and jet. Fowler's (2012) compiled dataset includes jet necklaces and buttons, which may have served as heirlooms or relics; bronze knives and dagger blades as well as barbed and tanged arrowheads – tools and weapons often associated with warriors; gold earrings, and an iron spearhead; various types of beakers and other vessels that usually dominate grave artifact assemblages; and even items made of gold and iron. While the social positions of the dead have been defined by their associated artifact deposits in archaeological research, there are studies that argue that artifacts may have also been offerings or contained offerings by mourners that further expand identities and social ties (Woodward et al. 2005; Brück 2004b; Barrett 1990). This illuminates the ceremonial aspects of Beaker burials that have particular geographic importance.

To mourn the dead includes several activities that involve community members and various features of the local geography. Mourning revolves around preparations for burial rites and a procession to the grave site. Later in the Bronze Age, for example, when cremation was more widely practiced than inhumations, burials involved a procession to the pyre, deposition of artifacts, preparation and interring of ashes, occurring along the origin and destination of the ritual (Barrett 1990). Sometimes, artifacts might have been deposited in geologic features outside of graves such as rivers; in some cases, human bones, or entire graves were deposited or built at settlement boundaries (Brück 2006; Barrett 1990).

1.3 Research Objectives

While numerous studies of the British Bronze Age have been conducted over the last 200 years, a gap in knowledge continues, particularly in spatial analysis. Through LCP modeling, connections and movement between sites and features of Bronze Age Northeast England can be spatially described. The objectives of this thesis were to:

- Demonstrate the feasibility of using LCP analysis to model pathways between sites and features in Bronze Age Northeast England.
- Identify possible pathways from settlements to burials within clusters of sites.
- Identify possible pathways between clusters of sites.

1.4 Thesis Organization

This thesis includes four remaining chapters. Chapter 2 explores the significance of GIS and using LCP in the field of archaeology as well the processes and datasets typically used in such endeavors. Chapter 3 describes the datasets acquired and the methods employed to generate LCP paths in this thesis study. Chapter 4 explores the results of executing all of the LCPs involved in the study as well as the validity assessments that were conducted. Finally, Chapter 5 discusses the significance of the results and their implications for future LCP studies in the region.

Chapter 2 Background and Related Work

This chapter begins with an overview of the current role of GIS in archaeology and the applications of LCP analysis. A discussion on the types of data necessary to run archaeological LCPs, including variables and the cost surface raster follows. The chapter concludes with a look into the different validity assessments implemented in previous studies.

2.1 GIS and Archaeology

GIS has become increasingly central to archaeological work. There is no one exacting definition of GIS, but it often involves computerized hardware and software in which digital spatial data can be collected using GPS units, stored and managed in a geodatabase, and processed, analyzed, and visualized using software with automated statistical formulas (Arias 2013; Kline 2009; Kvamme 1999). These different components can be connected with compatible software formats to facilitate the flow of data from one digital architecture to another. For example, digital data can be collected in the field using Trimble or Garmin units (common brand names of GPS devices in North America) and uploaded as shapefiles into ArcGIS, a major spatial data software developed by Esri. In ArcGIS, the spatial data can be housed in a geodatabase and then processed and/or analyzed using ArcMap, a mapping interface within which a few hundred geoprocessing and spatial analysis tools can be employed (Esri, 2016b). The implications for archaeology are vast. For instance, processing and storing data from the field to a geodatabase can be done in a matter of hours whereas manually processing the data can take several days, or even months. Through GIS, the capacity and ability of archaeological projects in managing and analyzing data over the last three decades has been transformed from slow and manual to quick and simultaneous processes with greater flexibility for scale in map visualizations (McCoy and Ladefoged 2009; Kvamme 1999).

The increasing use of GIS has led to prospecting, predictive modeling, and behavioral modeling since the 1980s (McCoy and Ladefoged 2009). Prospecting aims to locate archaeological sites, particularly buried features, typically by geophysical survey and remote-sensing methods; predictive modeling utilizes the association of environmental elements to known archaeological sites to estimate the probability for certain human activities to occur; and behavioral modeling, which typically uses spatial statistics to analyze artifacts, features, and associated environmental variables and to extrapolate human social behavior. It is also in behavioral modeling under which archaeological LCP analysis falls (McCoy and Ladefoged 2009).

2.1 LCP Overview

On its own, LCP analysis simply calculates movement and generates a path with the lowest cost from one point in space to another. It is in this simplicity and in choosing the appropriate variables to solve a particular problem that it owes its applicability to the number of fields that employ it. In the prehistoric archaeological context, it can model the way people interacted with their environment, or more specifically, how people consistently chose the paths to traverse an area.

2.1.1. LCP Studies in archaeology

As mentioned, LCP analysis can generate possible paths between two points across an area. It considers the cost of time and energy for human travel, which makes it valuable to archaeological studies for a number of reasons, including the potential for: (1) identifying prehistoric trails; (2) identifying additional sites along a path; and (3) understanding the cultural significance and meaning of the spaces associated with the path, and of the path itself. There have been numerous archaeological studies that have employed LCPs to these ends.

One of the primary goals of archaeological LCPs is to identify prehistoric trails. Melmed and Apple (2009) modeled seven possible continuing paths from existing prehistoric trail segments. The study suggests with greater environmental constraints, the accuracy of the LCP analysis increases, which is the case with Schild's (2016) thesis which executed LCPs to determine the least cost Bronze Age trading route in an area of Southern Turkey while demonstrating the appropriateness of using LCPs to find possible prehistoric routes. Teeter, Martinez, and Kennedy Richardson (2013) conducted a study of historic and prehistoric trails in Santa Catalina Island, California that employed ethnographic data from which possible potential trails were identified and the area on and around the trails surveyed. The survey results were then later tested by LCP analysis. Surveys have found additional sites and artifacts. Kline (2009) conducted LCP analysis to map out the network of footpaths in Lost Valley, California, using several sets of start and end points. The study found various foothpaths crossing and fanning out in the valleys with many following drainages.

Other studies are discussed or referenced in the following sections and subsections as they relate to a particular subject or topic. Some of these have been compiled in notable works such as in White and Surface-Evans (2012) which features various approaches to LCP analysis; Herzog (2014) which explores the shortcomings of executing LCPs, including the use of cost layers for interpreting cultural variables in multiple studies.

2.2 Gathering Data

Prehistoric routes are not only cultural but topographic in nature. To model prehistoric routes, spatial datasets that characterize the local landscape and cultural points of reference are key. The model must also necessarily present the origin and destination of a traveler and the consistent choices travelers have made over what routes to take over time. These choices, theoretically involves minimizing time and energy (White and Surface-Evans 2012). The topographic dataset(s) must be able to provide values from which the variables of cost can be derived. Since these variables typically involve elevation and slope, LCPs of prehistoric routes relies on two primary types of datasets: (1) Digital Elevation Models (DEMs) that describe the shape of the terrain; and (2) cultural site points that represent archaeological sites. When applicable (and available), datasets of other variables that influence travel within a study area may also be included in or factored into the analysis.

2.2.1. DEMs

DEMs represent the surface of the Earth and are essential to LCP analysis. They can be used as the primary base raster upon which all geospatial calculations are performed. In addition, the elevation attributes of DEMs can be used to generate slope data, which in turn can be used as a variable to generate a cost surface raster. To select the appropriate DEM for use in a project, the advantages and disadvantages of data sources and structures of a DEM must be weighed.

Data sources for DEM surfaces include ground survey, existing topographic maps, and remote-sensing. Ground surveys can be expensive and time consuming but can yield data with high accuracy; and digitization of existing topographic maps can be less costly but yield considerably less accuracy than other methods (Nelson, Reuter, and Gessler 2009). Remote sensing methods such as photogrammetric land-surface models (aerial imagery) can produce high resolution photographs of the surface and high levels of accuracy but sometimes require greater data storage and processing time; and LiDAR, which can be costly and require high post-processing time, but, when used in ideal conditions (fair weather), can yield data with sub-meter accuracy (Wilson 2012; Nelson, Reuter, and Gessler 2009).

DEM datasets are structured in three ways: triangulated, contour, and grid (Hutchinson 2008; Wilson and Gallant 2000). Triangulated irregular networks (TINs) are derived from surface specific point elevation data through ground survey and photogrammetric stereo models (Hutchinson 2008). TINs represent the surface with triangulated elements joined at the vertices and configured in varying sizes and density to approximate terrain variation; it enables the DEM to efficiently handle breaks in the terrain and other irregularities (Wilson and Gallant 2000). TINs can be applied to LCP analysis, especially in relatively small areas as using TINs is computationally intensive (Antikainen 2013).

Contour data structures are usually derived from existing topographic maps, and sometimes from aerial images (Hutchinson 2008). The structure employs polygons that reflect the contours of the topography, and essentially renders the spaces between the contour lines as smooth spaces (Hutchinson 2008; Wilson and Gallant 2000). These spaces and lines can produce errors in the DEMs, resulting in impressions of a terraced surface and other related anomalies or errors, also referred to as “artifacts” (not to be confused with the archaeological definition of the same term) (Lock and Pouncett 2010).

The gridded DEM is a surface raster comprised of square cells and are typically derived from aerial imagery (Hutchinson 2008). Each cell is attributed with an elevation value that altogether creates the relief or shape of the Earth’s surface. Gridded DEMs are simple and easy to use; however, unlike TINs, these structures sometimes cannot efficiently incorporate discontinuities in the terrain (Wilson and Gallant 2000). Nonetheless, their structural simplicity makes for relatively easier computation across relatively larger areas, and thus more suited to the scale of this thesis' analysis (Hutchinson 2008).

Various gridded DEMs at different resolutions can be acquired through numerous sources. Since the 1990s, elevation data collection has grown in sophistication, resulting in finer and more accurate datasets (Wilson 2012; Nelson, Reuter, and Gessler 2009). The U.S. Geological Survey, for example, offers two commonly used global DEMs in archaeology (as well as other fields) to analyze large areas: The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) and the Shuttle Radar Topography Mission (SRTM). Millions of images were processed to comprise the ASTER GDEM's 22,702 1° x 1° tiles, with the newest version (ASTER GDEM V2) available at a 30 m resolution (U.S. Geological Survey 2014). ASTER GDEM V2, released in 2011, contains significantly less discontinuities and artifacts than the first iteration (U.S. Geological Survey 2011b; Krieger, Curtis, and Haase 2010). Data collected from the space shuttle Endeavor comprises the SRTM DEM, for which a 30 m resolution released in 2014 (U.S. Geological Survey 2015b). SRTM differs from ASTER's optical-based data collection: ASTER must collect cloud-free images or mask clouds in post-processing in contrast to SRTM's radar system which can penetrate through cloud masses (U.S. Geological Survey 2015a). However, SRTM's relative shortcomings lie in discontinuities in higher elevation rugged terrains due to the angles that it takes; these discontinuities present themselves as gaps or voids in the DEM which in SRTM's latest (and perhaps final) 30 m iteration, were primarily filled by ASTER data as ASTER's stereoscopic data collection features a nadir view (U.S. Geological Survey 2015a).

Since ASTER's Version 2 (V2) release, a few published archaeological studies feature comparisons between ASTER and SRTM. Aside from the obvious resolution differences between the 30 m ASTER and the initial 90 m SRTM, some discrepancies occur in their vertical and horizontal accuracies (Wilson 2012; Nelson, Reuter, and Gessler 2009). Rademaker, Reid, and Bromley (2012) observe a significant vertical bias in the ASTER DEM over SRTM in their study of Paleoindian sites within the mountainous area of Nevado Coropuna in Peru. In fact, in the U.S. Geological Survey's (2011a) ASTER validation study over the continental U.S. (CONUS), ASTER GDEM V2 provided higher or lower elevations than SRTM depending on land cover type. In Doyle, Garrison, and Houston's (2012) Mayan study, three LCPs were executed using the 30 m ASTER, 90 m SRTM, and a 5 m AIRSAR DEM. The study identified only the areas within the differences between LCPs generated by the ASTER and AIRSAR as the most probable prehistoric pathways. The ASTER and AIRSAR LCPs appear more consistent with each other than with the coarser SRTM. As the 30 m resolution SRTM was published in 2014 (approximately two years prior to this writing), very few comparisons with ASTER GDEM V2 have been published. Preferences may lie in the field in which analysis is conducted, the size and location of a study area, and the context/framework of a particular study.

2.2.2. Bronze Age cultural data: Settlement and burial site points

The objective of gathering archaeological data for this thesis is to acquire points representing the origins and destinations of human movement. There are various sources of spatial data from the U.K. that can be utilized, as there have been numerous archaeological studies of the Bronze Age since the early 1800s. Choosing cultural datasets for analysis to model a relatively large area requires the most comprehensive collection of spatial data of known sites available from a reliable source. Fortunately, there is an open source website that provides archaeological data from the U.K., the Archaeological Data Service (ADS).

ADS includes studies of the U.K. and the region by British archaeologists. Beginning in 1996, the website acts as a clearinghouse for research data as well as an archival site for data that are not associated or housed in any other web-based repository. A quick search for Bronze Age data can yield several tens of thousands of studies, both with spatial data and without. This extensive collection is largely due to the larger number of site-specific archaeological studies that have been conducted over the years. This means that to analyze an appropriate set of sites over a large region is to conduct an exhaustive search of all sites with spatial data, organized according to research subject, and determine their applicability for analysis. A dataset of settlement point data was compiled from these varied sources.

Additionally, one study available on ADS involves a sweeping collection of Bronze Age sites in a relative large region. Fowler (2012) provides a compilation of data from mortuary studies in Northeast England area that includes 137 burial sites (cairns and barrows) with a few hundred inhumation and cremation deposits along with their associated artifacts.

2.2.3. Other cost variables

While slope has been the primary factor used in most archaeological LCP studies, numerous studies have used other variables in determining travel costs. Variables such as vegetation, hydrology, and land cover can play a role in the choices people make in terms of paths for travel. A study on communication routes in the Mediterranean region, for example, factored in avoidance of swamps and other areas prone to flooding (Fiz and Orengo 2008; Bell, Wilson, and Wickham 2002). In their multi-criteria study of prehistoric movement in Michigan, Howey (2007) utilized both vegetation land cover and waterways cost layers.

Using different variables and methods can make a difference in the outcome of an LCP analysis. Zakšek et al. (2008) conducted a viewshed analysis in which a layer was created by recalculating the slope with directionality and aspect to account for path visibility. The authors ran their model and an isotropic LCP analysis (with only slope as cost) for comparison. The study found significant differences – the isotropic path was the shortest and the lowest route, while their model generated lines with better visibility along routes with some gentle slopes. Ultimately, reconstruction of human path selection continues to present challenges.

2.3 Generating a Cost Surface

The cost surface is a raster with each cell containing the total cost value of all variables involved in an LCP analysis (Esri 2016c). As mentioned in Chapter 1, to qualify all variables for analysis, they must be reclassified to the same range of values and at the same intervals in order to perform meaningful calculations. If a given range is 1-8, then the range of values in each of the rasters must only contain values within that range wherein the higher the classification the greater the cost value. In Bell, Wilson, and Wickham (2002), for example, marshes were given the highest classification of 12, whereas grasslands, which are usually flat or offer very little slope, were given the lowest rating.

The values of corresponding cells are then added to estimate the total cost for each cell in the cost surface raster. For example, if the value of a cell in a slope raster is 5 and the corresponding cell in another cost variable raster is 3, then that same cell in the cost surface raster is 8 (Esri 2016c) (Table 1).

Table 1. Sample cost surface calculations.

	Variable 1	***Variable 2***	**Total Cost**
Set 1	5	3	5 + 3 = 8
Set 2	2	7	2 + 7 = 9

When applicable, variables can also be weighted according to their estimated influence, such as in Doyle, Garrison, and Houston (2012), as mentioned in Chapter 1. In ArcGIS, the weights are expressed in percentages (Table 2):

Table 2. Sample cost surface calculations with weighted variables.

	Variable 1	****Influence (40%)***	***Variable 2***	****Influence (60%)***	**Total Cost**
Set 1	5	5 x .4 = 2	3	3 x .6 = 1.8	2 + 1.8 = 3.8
Set 2	2	2 x .4 = .8	7	7 x .6 = 4.2	.8 + 4.2 = 5

2.3.1. Anisotropic Modeling: Tobler's hiking function and Naismith's rule

In most LCP analyses, the cost is framed in terms of time and/or energy. In isotropic modeling, the accumulated cost surface (ACS) is produced by averaging the cost of movement from one cell to the next as an LCP algorithm finds its way to each cell from a source/origin point and an LCP is then generated by selection of a string of cells with the lowest values between the source and the destination (Herzog 2014). However, the cost of moving into a cell may differ depending on slope and the direction of travel, as in anisotropic modeling (Tobler 1993). For example, a hiker may pass a point along a mountain peak trail faster on their return from the top than from the bottom. Tobler (1993) produced a function, referred to as Tobler's Hiking Function, that added 0.05 to slope in an exponential formula to describe the directional discrepancy in walking velocity. Another commonly used rule is Naismith's Rule which suggests 4 km/hour and 600 m/hour of ascent on slopes greater than 12°, subtracting 10 minutes from a 300 m downhill trek on 5°-12° slopes, and an additional 10 minutes on downhill slopes greater than 12° (Yang et al. 2014; Magyari-Sáska and Dombay 2012). In Magyari-Sáska and Dombay (2012) which compared the time rates for each formula, Tobler's Hiking Function estimated shorter times than the refined Naismith's Rule.

Using these rules may depend on the software by which an LCP analysis is conducted. Naismith's Rule can be run using GRASS software while Tobler's Hiking Function can be used with ArcGIS.

2.4 LCP Algorithm

After the generation of an ACS, an algorithm searches for a string of lowest values that in turn produces the LCP. The most enduring LCP algorithm is Dijkstra's (1959), which conducts a sweeping search for the least cost path in all directions, regardless of accumulating distance, until it reaches the destination point (White and Surface-Evans 2012; Husdal 2000; Dijkstra 1959). Due to such an exhaustive search, LCPs produced by the algorithm tend to be longer than the true optimal path for it does not search for alternative shorter routes that would cost less in time to travel (Herzog 2014). Another algorithm used in archaeological LCP analyses is the A* which includes a similar algorithm to Dijkstra but the search parameters must be set by the user, and thus limiting LCP returns to within those parameters (White and Surface-Evans 2012).

2.5 Validity Assessment

Some methods for validating archaeological LCPs exists, but none are necessarily considered standard practice (Schild 2016). Ground truthing, visual comparison with aerial images, introducing minor errors, and changes in variables have been implemented (Schild 2016).

Ground truthing is a practice by which archaeological LCPs can be tested by surveys and existing archaeological data (White 2012). A survey would involve a search for artifacts and/or features along the LCP. Melmed and Apple (2009) used ground truthing to validate LCPs with varying results due to the relatively uniform topography of the study area. On the other hand, Teeter, Martinez, and Kennedy-Richardson (2013), implemented the inverse process and used LCPs to validate archaeological data.

Kline (2009), who looked at probable prehistoric trails by running LCPs, superimposed the network of LCP paths over satellite imagery and visually confirmed a relationship between LCP paths and sites. White (2012) performed ground truthing (although not from running LCPs but from identifying anomalies in aerial imagery) and observed that the efficacy of this method depended on the degree of landscape modification since prehistoric times. However, Kline (2009) posits that many of the modern trails, roads, and rails evolved from prehistoric trails.

Validating an LCP model can also include changing the parameters of an analysis such as the cost variables and the source and destination points. Schild (2016) used a sensitivity analysis introducing random points, relocating the source and destination, and re-running the analysis. Rademaker, Reid, and Bromley (2012) validated their study by changing the walking speed parameters of foragers. In short, the scope of validity assessments is diverse and depends on the needs of the study and its archaeological contexts.

Chapter 3 Methods

This chapter describes of the methods employed in generating LCPs between cultural sites in Northeast England. The method involved: (1) acquiring and preparing DEMs; (2) identifying clusters within the study area and selecting sites for analysis; (3) generating the cost surface and the LCPs; and (4) validating the analysis. All processes described were performed in ArcGIS 10.4, referred to, henceforth, simply as ArcGIS.

3.1 Data

3.1.1. Acquiring and preparing the cultural dataset

To model a matrix of prehistoric routes, employing a cultural dataset with site points is ideal. The cultural datasets were acquired from ADS. The first dataset was downloaded in Microsoft Excel .csv format (Fowler 2012). It is a large collection of data from different archaeological mortuary studies in the study area from the last 200 years (Fowler 2012). The data was comprised of individual points spanning 2,100 years from 3360 BC. to 1260 BC. The objects in the dataset are instances of inhumations and cremations tabulated along with their associated burial features (e.g. cists, cairns, pits), artifact deposits, location type, estimated age range, elevation, and source of data. Sites excluded from this collection are those that are too difficult to date. Since the dataset is a record of each inhumation and/or cremation, there was redundancy in the number of burial sites – some sites include more than one set of human remains. A new dataset was then derived from the original to only contain the unique locations of these burial features (n=137).

This thesis primarily utilized the location attribute of each site. The British National Grid was used for spatial reference in the original dataset, so the new burial sites dataset was first transformed to the geographic coordinate system (GCS) OSGB 1936 (i.e. Ordnance Survey Great Britain 1936) as it was exported into ArcGIS, and then projected to the British National Grid datum. Note that projecting coordinates from OSBG 1936 to another datum can cause significant errors to global projected coordinated systems (PCS) and other projections because the datum is confined to Britain only (Ordnance Survey 2015). The data was incorporated into the geodatabase and added to ArcMap.

To provide greater accuracy, the dataset was further reduced to reflect a more relevant spatiotemporal range. In the raw data, Bronze Age artifacts appear with increasing frequency and diversity beginning in 2200 BC. The material types, for example, include bronze, jet, and lead ore that were not found in the burial sites prior to 2200 BC. Therefore, sites were selected in the burial site layer that fall within the 2200-1260 BC range, with 1260 BC as the most recent of the burials. After the sites were selected, they were imported into the geodatabase as a new feature class. The final iteration of the dataset totals 46 burial sites.

The second dataset is comprised of settlement points that was manually compiled from ADS (Appendix A). The ADS website includes a feature called “Archsearch” that serves as a metadata catalog with over 1 million archaeological studies and resources. A search for Bronze Age settlements in Archsearch yielded numerous site points. Each resource page supplies a small amount of information on the particular site, including a brief description, the coordinates, and historical period. Sites described or deemed as Bronze Age settlements in the Northeast England region were selected for inclusion in the dataset. Each site point was entered into a .csv file in Microsoft Excel with a simple set of attributes, consisting of Site name, National Grid reference (NGR), and Easting and Northing coordinates (Appendix A). Sites without names in the catalog were given one after their civil parish. A total of 59 settlement sites was collected and imported into ArcGIS as a feature class with the same projection as the burial dataset.

3.1.2. Generating the origin and destination points

Generating the origin and destination points first required a process of selection. Two steps were employed to generate the origin and destination points. First, clusters of sites were identified from a visual evaluation of site points in ArcMap (Figure 3). Clusters are sets of sites with each one within three kilometers of their nearest neighbor. Second, adjacent segments of origin and destination points were then assigned for LCP analysis from these clusters.

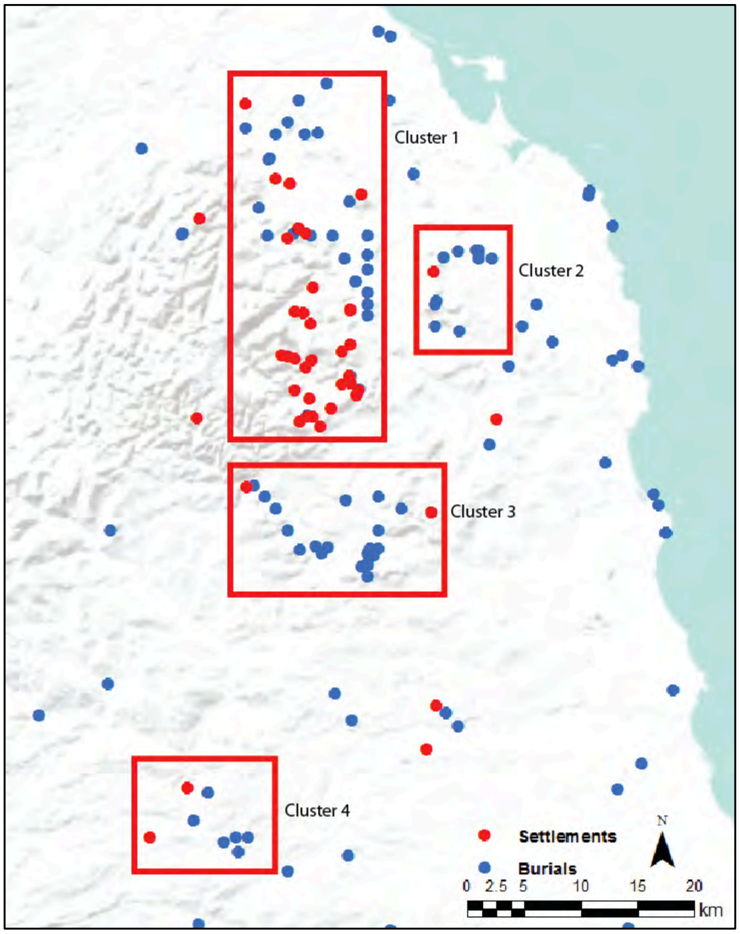

Figure 3 Overview of selected clusters of settlement and burial sites. *Sources* (basemap): Esri, USGS, NOAA.

Four clusters were selected, with each cluster broken down into segments (Table 3). In the north central portion of the study is Cluster 1 (Figure 4). Cluster 1 includes 35 settlement sites and 20 burial sites with a north-south orientation spanning approximately 30 km (Figure 4). Five pairs of origin and destination points, or segments, were chosen for LCP analysis. Hazeltonrig and Knock Hill comprise Segment 1; Knock Hill and Brands Hill comprise Segment 2; Brands Hill and Harehope Hill comprise Segment 3; Harehope Hill and West Plain Henge comprise Segment 4; and West Plain Henge and Lookout Plantation comprise Segment 5.

Table 3. Clusters and Segments.

	Origin Site	Destination Site
Segment	*Cluster 1*	
1	Hazeltonrig	Knock Hill
2	Knock Hill	Brands Hill
3	Brands Hill	Harehope Hill
4	Harehope Hill	West Plain Henge
5	West Plain Henge	Lookout Plantation
	Cluster 2	
1	Cheviot Walk Wood	Blawearie cairn
2	Blawearie cairn	Hepburn Crag Plantation
3	Hepburn Crag Plantation	Rosemoor Cairn 1
	Cluster 3	
1	Alwinton	Kirkhill Cremation Cemetery
2	Kirkhill Cremation Cemetery	Great Tosson Quarry
3	Great Tosson Quarry	Debdon Whitefield
	Cluster 4	
1	NW High Carry House	Warkshaugh Farm
2	Warkshaugh Farm	Reaverhill Farm

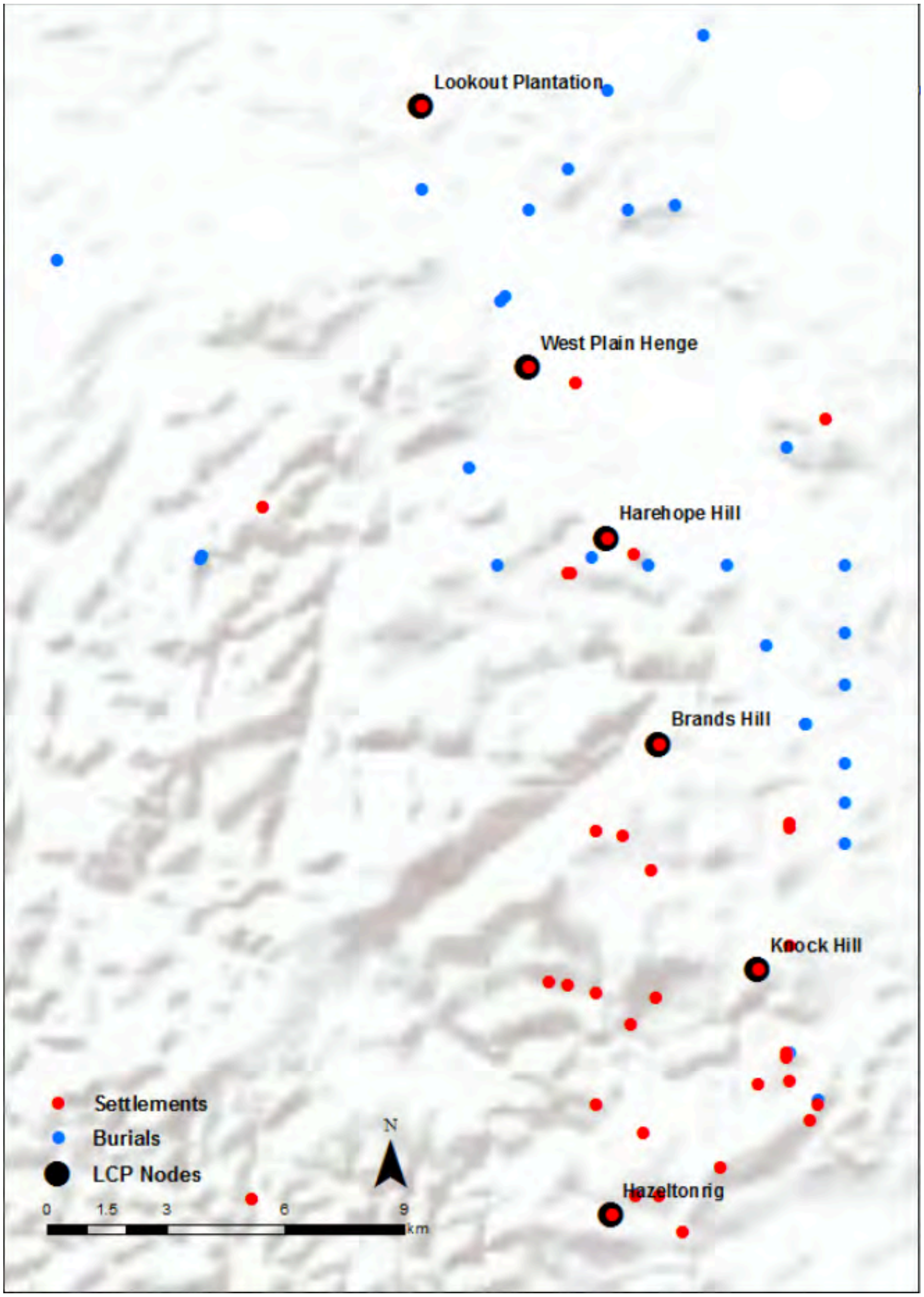

Figure 4 Cluster 1 with origin and destination points (LCP nodes). *Sources* (basemap): Esri, USGS, NOAA.

Cluster 2 included one settlement and twelve burial sites with an approximately SE-NW orientation, from the Cheviot Walk Wood site to the Rosebrough Moor site (Figure 5). Three origin-destination pairs were selected for analysis.

Figure 5 Cluster 2 with origin and destination points (LCP Nodes). *Sources* (basemap): Esri, USGS, NOAA.

Cluster 3 included two settlement sites and 21 burial sites, with a semi-circular alignment and a slight E-W orientation, from Alwinton to Debdon Whitefield (Figure 6). Three origin-destination pairs were selected for analysis.

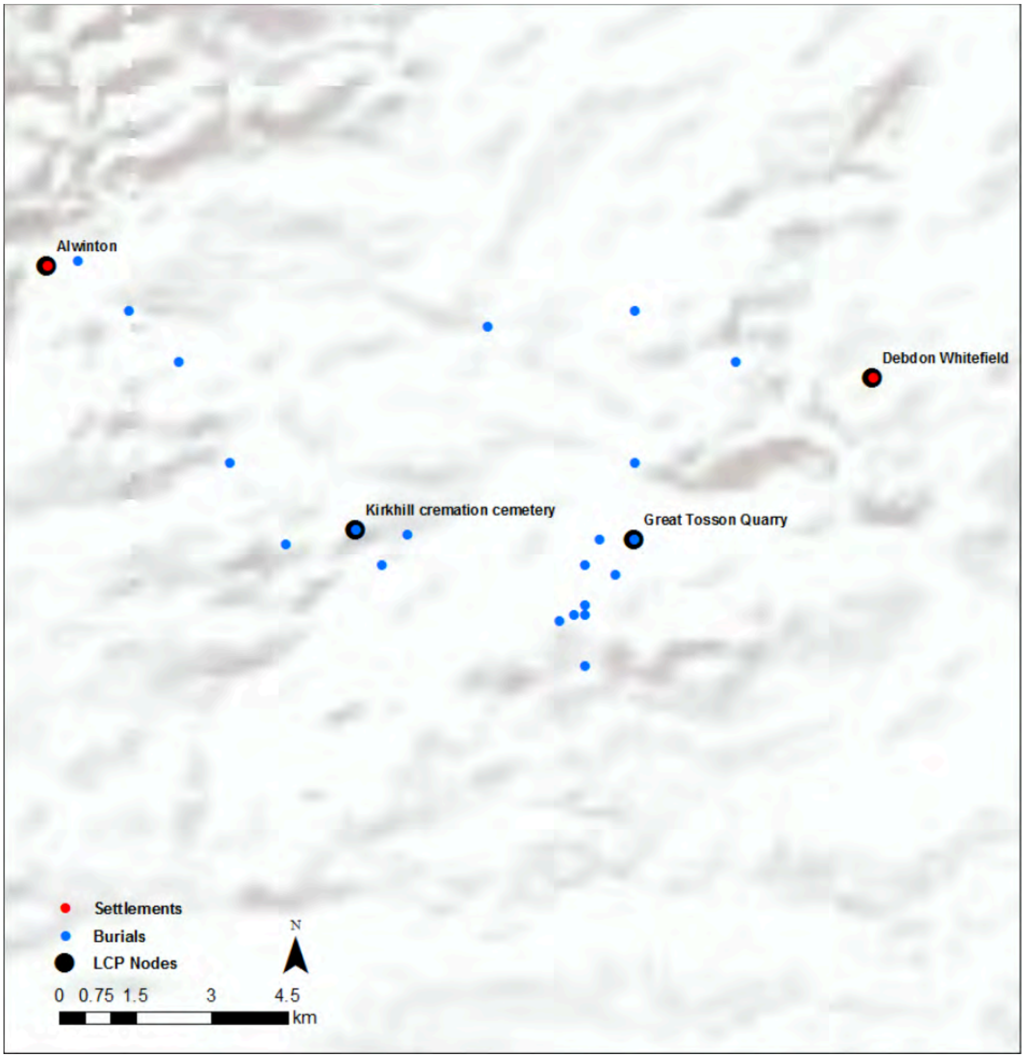

Figure 6 Cluster 3 with origin and destination points (LCP Nodes). *Sources* (basemap): Esri, USGS, NOAA.

Cluster 4 included two settlement and six burial sites with a NE-SW orientation from the High Carry House site to Reaverhill Farm (Figure 7). Three origin-destination pairs were selected for analysis. All of the origin-destination pairs in the four clusters were converted into a feature class in ArcGIS.

Figure 7 Cluster 4 with labeled origin and destination points (LCP Nodes). *Sources* (basemap): Esri, USGS, NOAA.

Finally, to model connections between clusters, origin and destination points for paths between clusters were also selected (Figure 8). The five pairs listed in Table 4 were chosen for analysis.

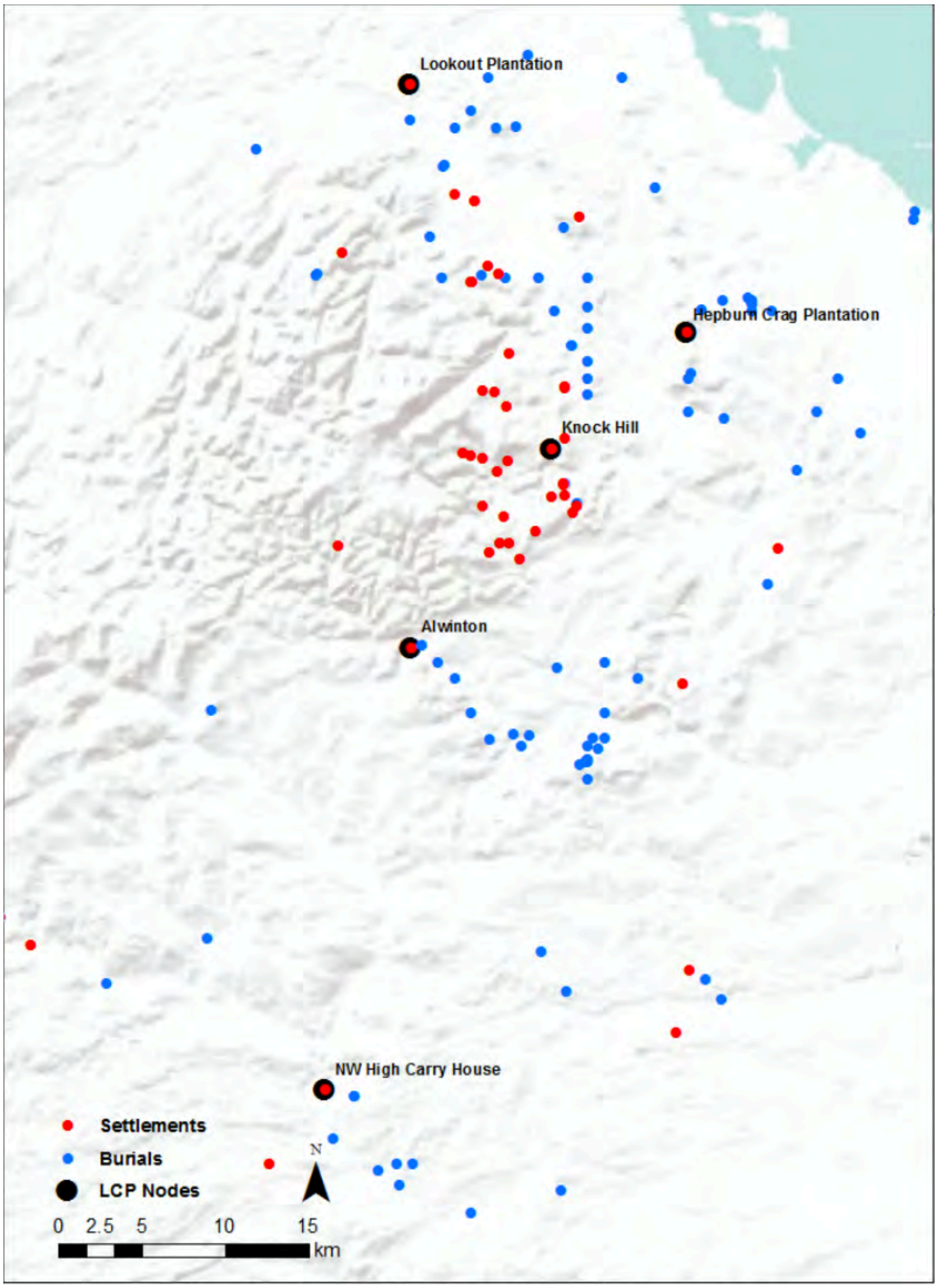

Figure 8 Inter-cluster origin and destination points (LCP Nodes). *Sources* (basemap): Esri, USGS, NOAA.

Table 4. Inter-cluster segments.

	Origin Site	Destination Site
Segment	*Inter-cluster 1*	
1	High Carry House	Alwinton
2	Alwinton	Knock Hill
3	Knock Hill	Hepburn Crag Plantation
4	Knock Hill	Lookout Plantation
5	Hepburn Crag Plantation	Lookout Plantation

3.1.3. Acquiring the DEM

The DEMs were acquired from the U.S. Geological Survey Land Processes Distributed Active Archive Center website (LP DAAP; http://gdex.cr.usgs.gov/gdex/) that provides free spatial data for registered users. After selecting the study area in an interactive map, the 30 m SRTM and ASTER GDEM V2 datasets were chosen for download in a compressed folder (Figures 9 and 10). The folders were then imported into ArcGIS by unzipping the file and saved in a local drive that stores all relevant raw spatial data for the project. The DEMs were then imported as a raster feature class into the project geodatabase and visualized in ArcMap. The 30 m SRTM with voids filled was chosen for analysis as “artifacts” were demonstrably less than in the 30 m ASTER GDEM. Recall also the vertical bias in ASTER, as discussed in Section 2.2.1. Once in ArcGIS, the DEMs were clipped and reprojected for the study area at hand. This step meant that each DEM was projected from WGS84 to the British National Grid to match the datum of the cultural dataset, OSGB 1936 (as was discussed in Section 3.1.1).

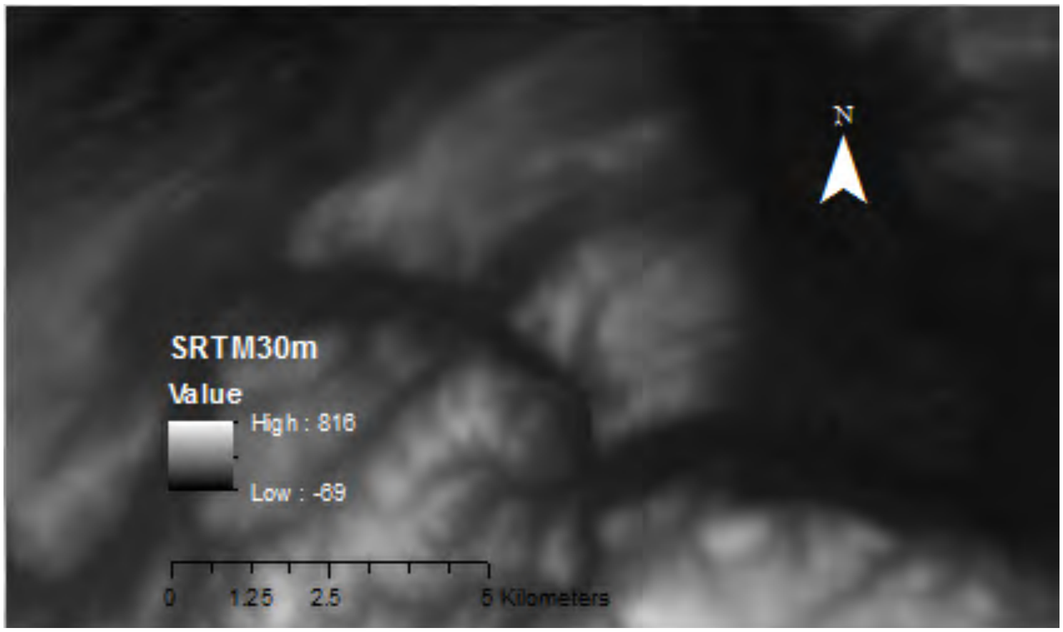

Figure 9 SRTM 30 m resolution, with elevation values in meters. *Source*: U.S. Geological Survey Land Processes Distributed Active Archive Center (LP DAAP; http://gdex.cr.usgs.gov/gdex/).

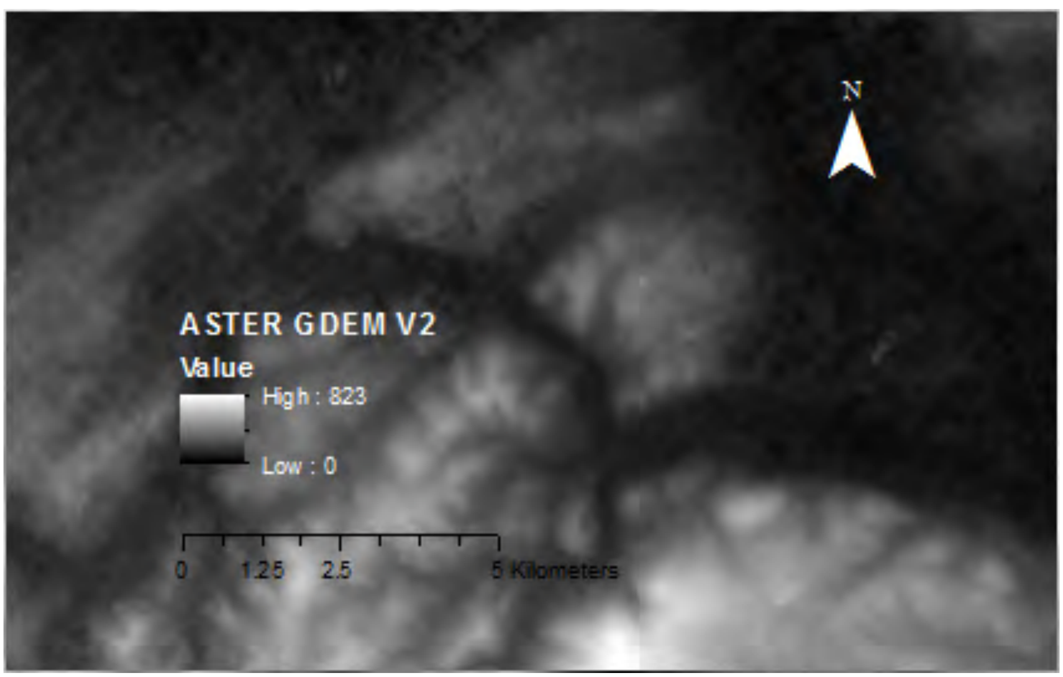

Figure 10 ASTER GDEM V2 30 m resolution, with elevation values in meters. *Source*: U.S. Geological Survey Land Processes Distributed Active Archive Center (LP DAAP; http://gdex.cr.usgs.gov/gdex/).

3.1.4. Creating the slope raster

Prior to creating the slope raster, the DEM was resized (Figure 11). The original SRTM30 was much larger than necessary to cover the study area. This would result in slower processing times. Thus, a smaller version was derived from the larger DEM.

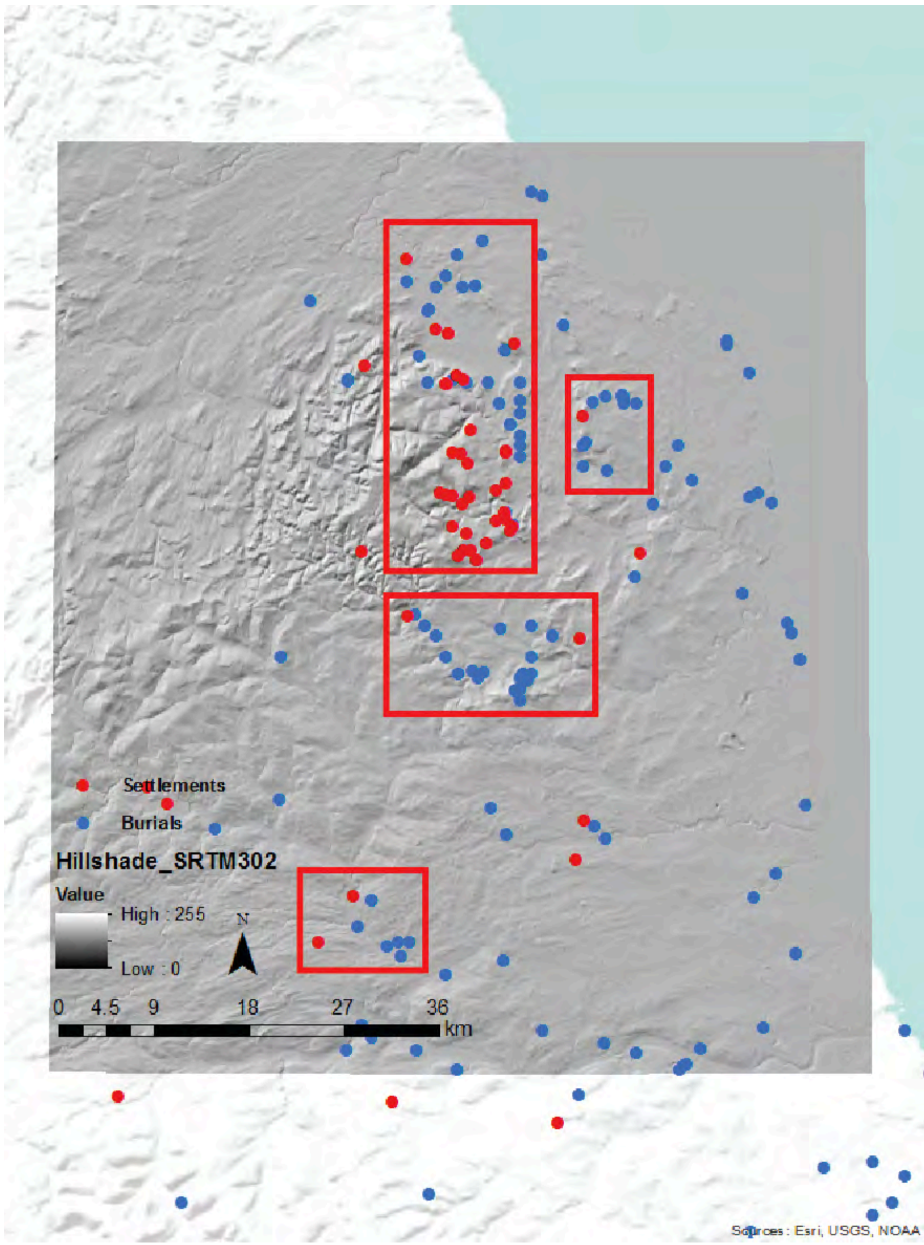

Figure 11 Clusters in smaller DEM (with hillshade effect; values in meters) derived from the larger SRTM DEM. *Sources* (basemap): Esri, USGS, NOAA.

In ArcGIS, a temporary polygon feature class was created to reflect an area extent large enough to include all four clusters. Using the "Clip" tool, the new area polygon was utilized as the output extent. The Clip tool creates a new raster by extracting a smaller area from a source raster using specific inputs of extent (X and Y maxima and minima) (Esri 2016a). In this case, the tool drew the extent from the area polygon.

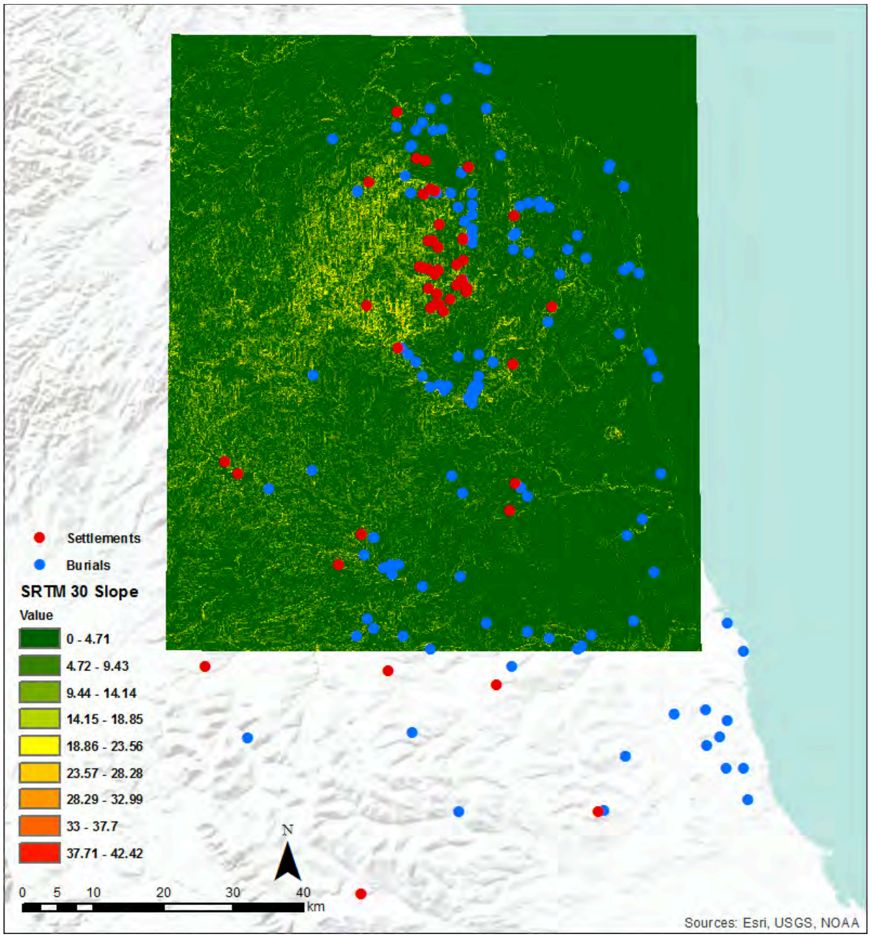

Figure 12 Slope raster (with values in degrees) with cultural sites. *Sources* (basemap): Esri, USGS, NOAA.

The slope surface was one of the components required for the production of a cost layer, which in turn, was key to generating LCPs. Once the new DEM was created, the slope raster was generated using the "Slope" tool in the ArcGIS Spatial Analyst toolbox (Figure 12). The Slope tool creates a continuous grid of cells, with each cell given a slope value calculated from changes in elevation from one cell to the next (Esri 2011). In this case, the output measurement of the raster is expressed in degrees.

3.2 Methodology

Due to the high number of LCPs (n=66) produced, the study employed two models for the execution of the Path Distance and Cost Path tools using the ModelBuilder application in ArcGIS. A model in ModelBuilder includes the entire package of tools, inputs, and outputs to solve a particular spatial problem (Allen 2011). A model can be built as a workflow using a visually friendly interface that does not require any knowledge of coding; rather, the architecture of the model only needs the specific inputs, tools, and the desired output.

Prior to building the models, the environmental settings for the model properties were customized. Customization minimizes errors and offers greater efficiency in processing data. In the Processing Extent environment, the SRTM30 DEM (Figure 12) was chosen as the Snap Raster. This meant that the model only processed data which fell within the extent of the DEM. Any additional data that extended beyond this extent were out-of-bounds and not included in the analysis. Next, the raster cell size in the Raster Analysis Environment was set to 30 to match the cell size of the DEM. And, finally, the current workspace was set to the project geodatabase so the workspace became the default output location for any new data layers.

Once the DEM, the derived slope, and the cultural dataset were prepared, the generation of a cost surface, and finally, generation of the least cost path – was assembled in ModelBuilder (Figures 16 and 17). The process is sequential, with each step a requirement for the next.

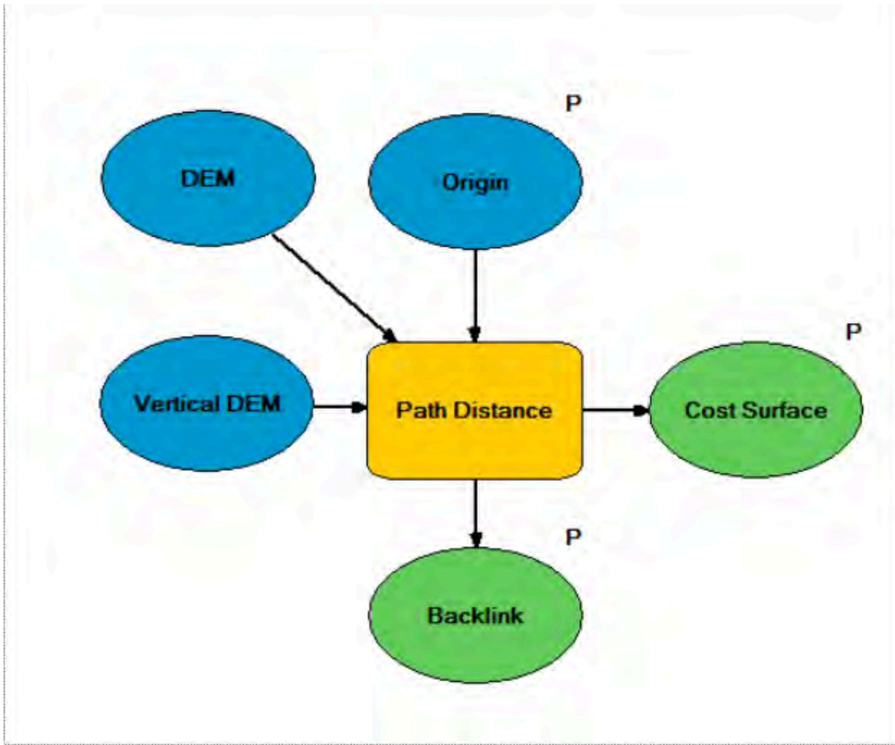

Figure 13 The Path Distance model, with the origin, cost surface, and backlink surface indicated as a model parameter (P).

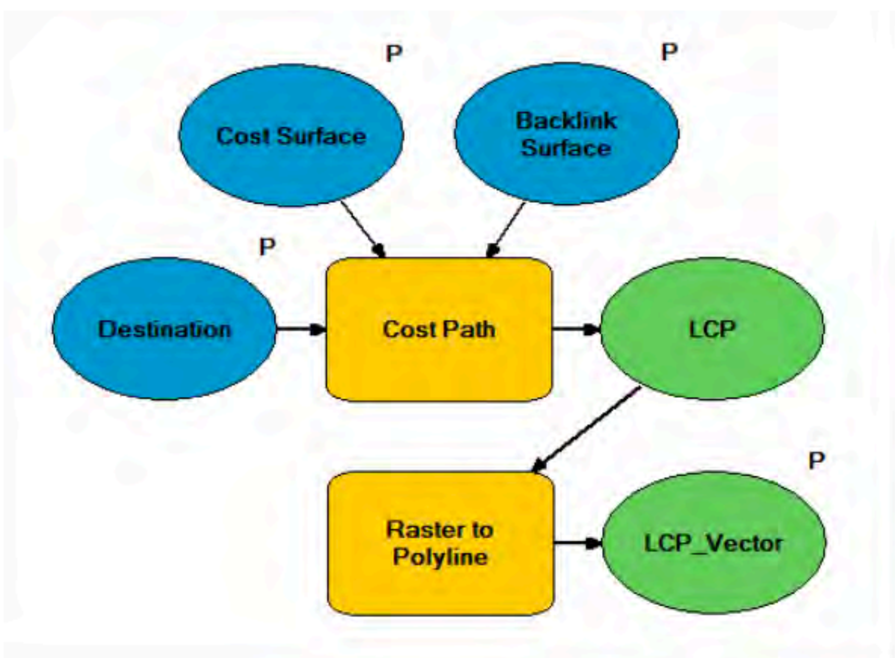

Figure 14 The Cost Path model, with the destination, cost surface raster, backlink surface raster, and the converted LCP raster (LCP_Vector) indicated as a model parameter (P).

3.2.1. Executing the Path Distance tool

The "Path Distance" tool is executed after creating the slope surface. The tool required origin points for the input feature source data (Tables 3 and 4) and the DEM as the input surface raster which the tool used to measure surface distance (Figure 15; Esri 2016f). The SRTM 30 m DEM was also used as the input for the vertical raster. This functions to generate the slope. The tool produced the cost surface raster and the output backlink which were required to run the Cost Path tool. Each time a segment is run, a new origin point for that segment is used as input.

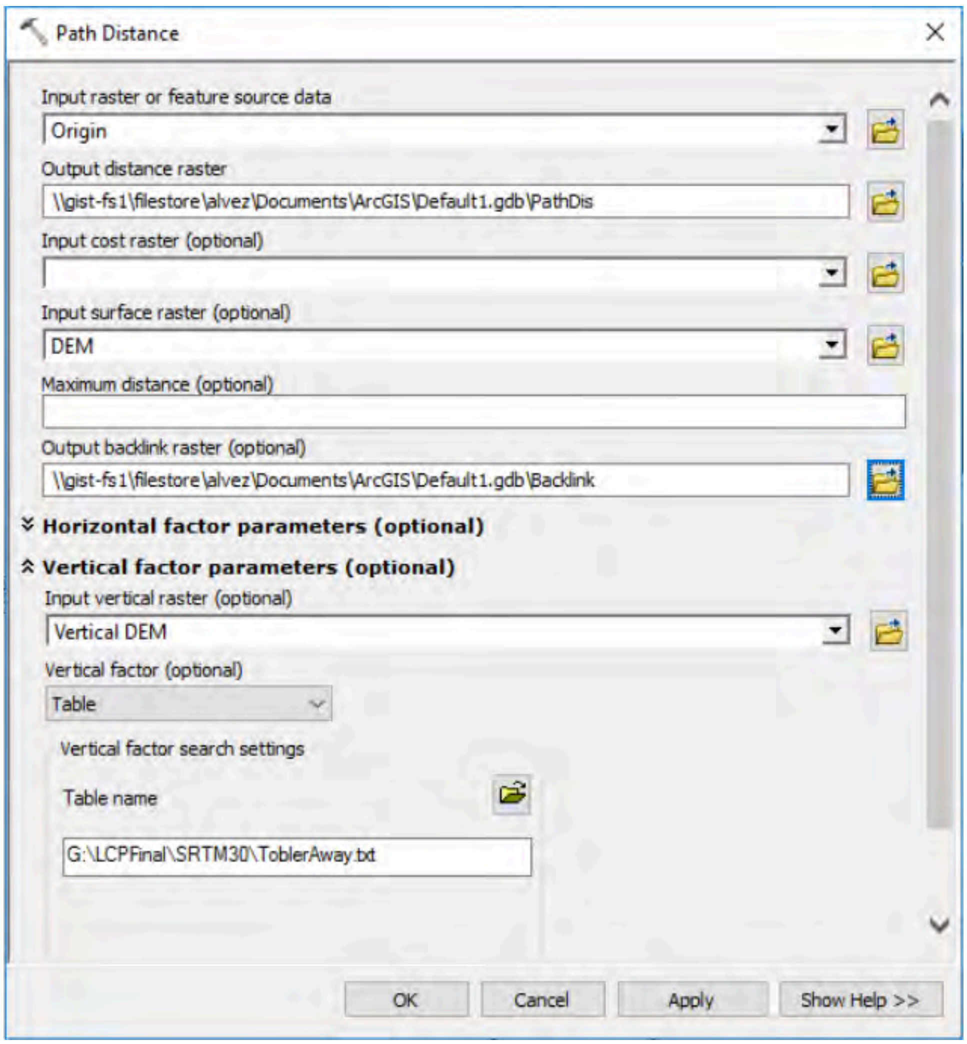

Figure 15 Path Distance tool inputs.

Due to the diversity of the terrain and range of slope, an anisotropic analysis was used. This was calculated using Tripcevich's (2009) vertical factor table, which takes the reciprocal of Tobler's (1993) formula: TIME (HOURS) TO CROSS 1 METER or the reciprocal of Meters per Hour =0.000166666*(EXP(3.5*(ABS(TAN(RADIANS(slope_deg))+0.05)))) (Table 5). The table can be interpreted as a vertical factor parameter. The resulting surface, or cost surface, was comprised of values reflecting the cost of moving from one cell to the next throughout the extent of the DEM from the origin. When paired with a destination point in the Cost Path Tool as the input cost raster, each resulting LCP was in the direction towards the destination from the origin.

Table 5. Tripcevich's (2009) vertical factor table (abbreviated).

Slope (deg)	Vertical Factor
-90	-1
-80	-1
-70	2.099409721
-50	0.009064613
-30	0.001055449
-10	0.00025934
-5	0.000190035
-4	0.000178706
-3	0.000168077
-2	0.000175699
-1	0.000186775
0	0.000198541
5	0.000269672
10	0.000368021
30	0.001497754
50	0.012863298
70	2.979204206
80	-1
90	-1

3.2.2. Generating LCPs

To generate the LCP, the "Cost Path" tool was employed. The tool required three data layers as input. These were the destination points (see Tables 3 and 4) as well as the cost surface and the output backlink produced from executing the path distance tool (Figure 16). Like the origin points in the execution of the Path Distance, the input for the destination data changes with each new segment tested in the model. Once the Cost Path tool is run, it creates a raster of LCP as the output. To better visualize the LCPs, the tool "Raster to Polyline" was employed to convert the LCP raster to a vector format.

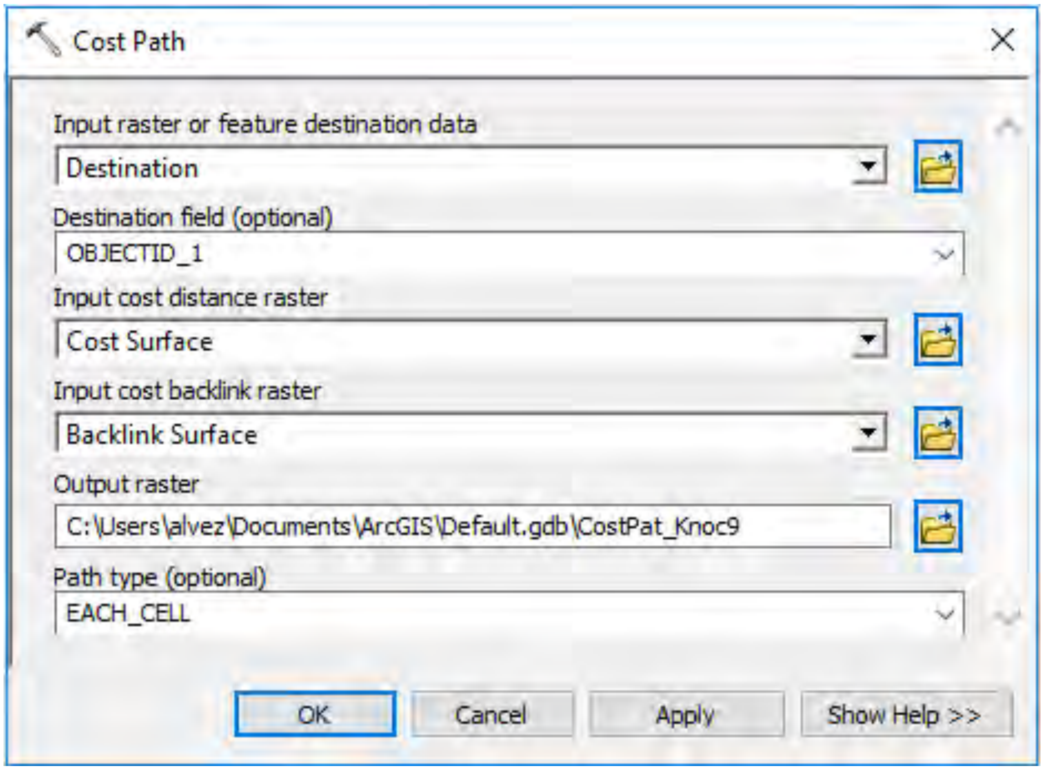

Figure 16 Cost Path tool inputs.

3.2.3. Conducting the validity assessment

Three forms of validity analysis were performed. The first validity assessment generated reverse LCPs for the original cluster and inter-cluster segments (see Tables 4 and 5). Since each LCP is anisotropic, a path distance analysis would result in a cost surface raster that accounts for the costs associated with traveling from particular origins. This means that the values in a cost surface raster may be different when an LCP is executed from the opposite direction. The second validity assessment included generating new segments, referred to as modified segments, for each of the clusters using new sets of origin and destination points that approximated the alignment of the original segments. For comparison, each new segment was selected using sites close to the original nodes (Table 6). In addition, reverse LCPs were also generated for the new segments. Henceforth, the original LCP and its reverse counterpart are referred to as the original set, and the modified LCP and its reverse counterpart are referred to as the modified set. The third assessment compared all LCPs to aerial images of paths for coincidence or proximity. A multiple ring buffer consisting of 0.5, 1, and 1.5 km bands was generated to estimate proximity.

Table 6. Modified segments used for sensitivity assessment.

	Origin Site	Destination Site
Segment	*Cluster 1*	
1	Alnham 3	Reavely Hill
2	Turf Knowe	Humbleton Hill
3	Humbleton Hill	Cheviot Quarry
4	Cheviot Quarry	Lookout Plantation
	Cluster 2	
1	Cheviot Walk Wood	Millstone Hill
2	Hepburn Crag Plantation	Rosebrough Moor Cairn 2
	Cluster 3	
1	Farnham	Hedley Wood
2	Holystone Common	Great Tosson Quarry
3	Spital Hill	Debdon Whitefield
	Cluster 4	
1	NW High Carry House	Reaverhill Farm
	Inter-Cluster	
1	Wark Manor House	Farnham
2	Farnham	Alnham
3	Alnham	Millstone Hill
4	Millstone Hill	Lookout Plantation
5	Reavely Hill	Lookout Plantation

Chapter 4 Results

This chapter describes the results from performing the tasks specified in the preceding chapter. The first two sections detail the LCPs executed within clusters and between clusters. Each section also includes comparisons with reverse LCPs and LCPs generated from modified segments as part of the validity assessments. It is important to note that LCPs in the original configuration and reverse LCPs were generated from the same set of nodes and are thus treated as a set in a segment, referred to here as original sets. LCPs from modified segments have no more than one common node with the original sets, if at all, and are thus discussed as a separate measure of validity. Moreover, modified LCPs come as a set in a segment, with another path generated from the opposite direction, referred to here as modified sets.

For map visualizations, LCPs are superimposed on the SRTM30 DEM in hillshade effect, with the exception of the aerial imagery in the last section that compares selected segments with original and modified LCPs to check the coincidence with visible geologic features.

4.1 Executing LCPs

The study generated a total of 66 LCPs in 18 original and 15 modified segments for all 33 source/destination nodes, approximating a network of paths cutting through clusters and connecting selected sites between clusters (Figure 17).

Original sets showed some divergence from each other but overall they indicated consistency/coincidence or near coincidence in all four clusters. Clusters 1, 2 and 4 showed some divergence. In Cluster 4, for example, Segment 1 diverged by 0.5 km or more. Cluster 3 presented the least amount of divergence, with < 0.3 km divergence throughout.

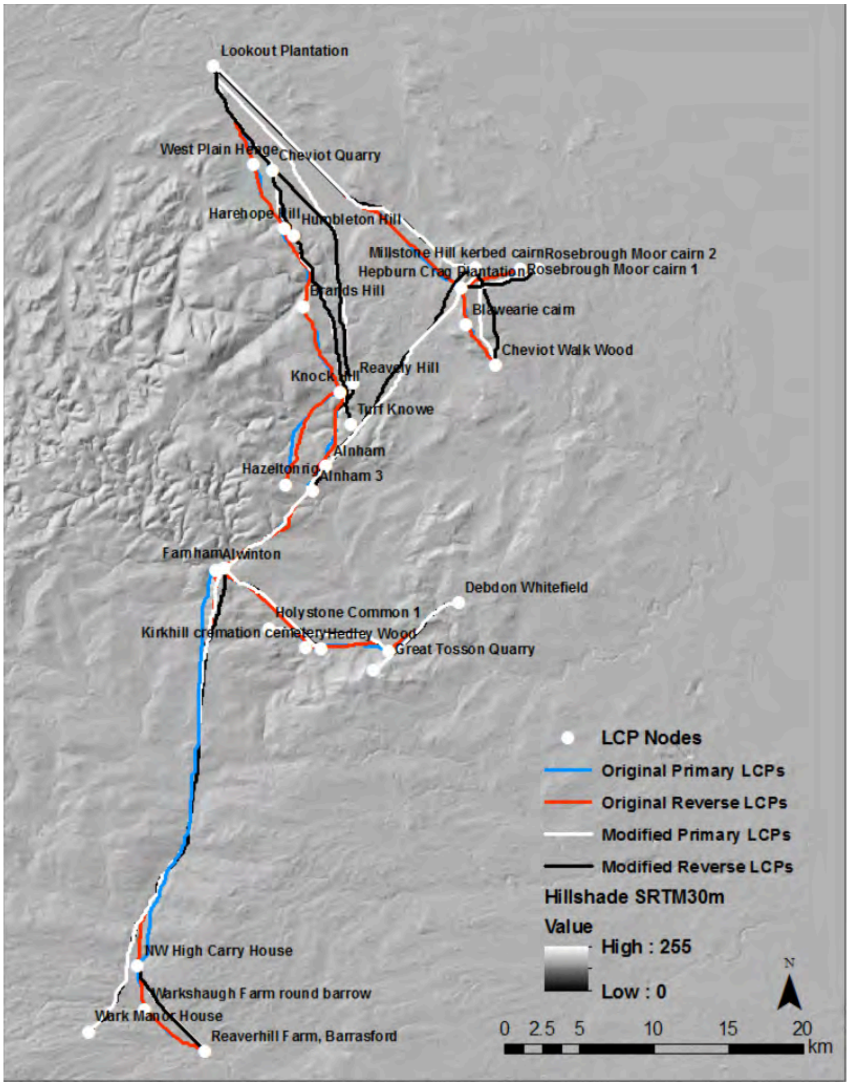

Figure 17 Overview of cluster and inter-cluster primary and modified LCPs.

LCPs from modified sets, however, sometimes diverged to a greater extent from the original LCPs, and from each other within a segment. Modified Segments 2 and 3 in Cluster 3 for example, diverged by more than 1.5 km. On the other hand, the modified LCPs produced just one exact path of coincidence in Modified Segment 1. By running the Intersect tool in ArcGIS, sections of exact coincidence within segments were identified. (In maps throughout this chapter, these are referred to as intersections, rather than coincidence, after the tool).

4.2 Cluster LCPs

4.2.1. Cluster 1

LCPs were generated for the five segments of Cluster 1 (Figure 18). Overall, the original sets were consistent with each other, exactly coinciding along several sections, particularly the northern portion of Segment 1 and the southern portion of Segment 4 (Figure 19). Segment 1 also produced the most divergence, > 0.6 km, in its southern portion.

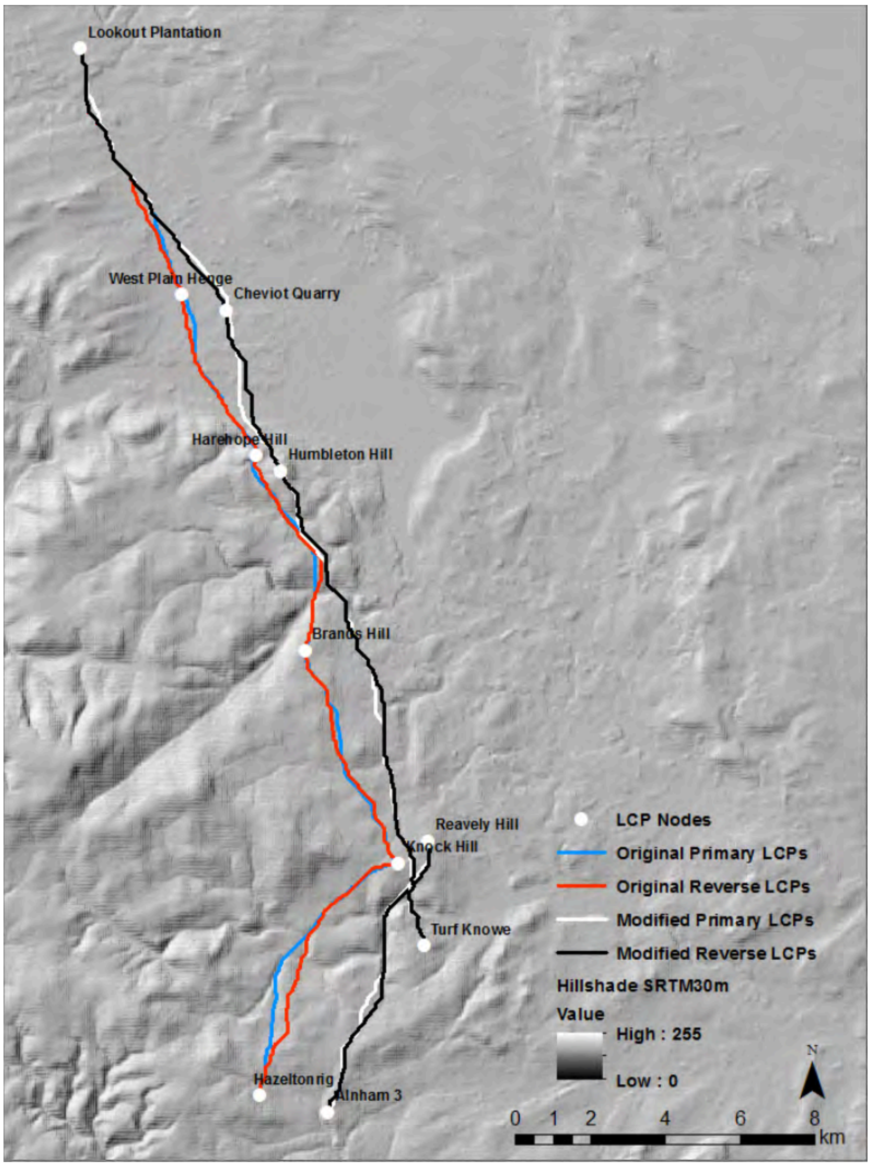

Figure 18 Overview of Cluster 1 LCPs with original and modified segments.

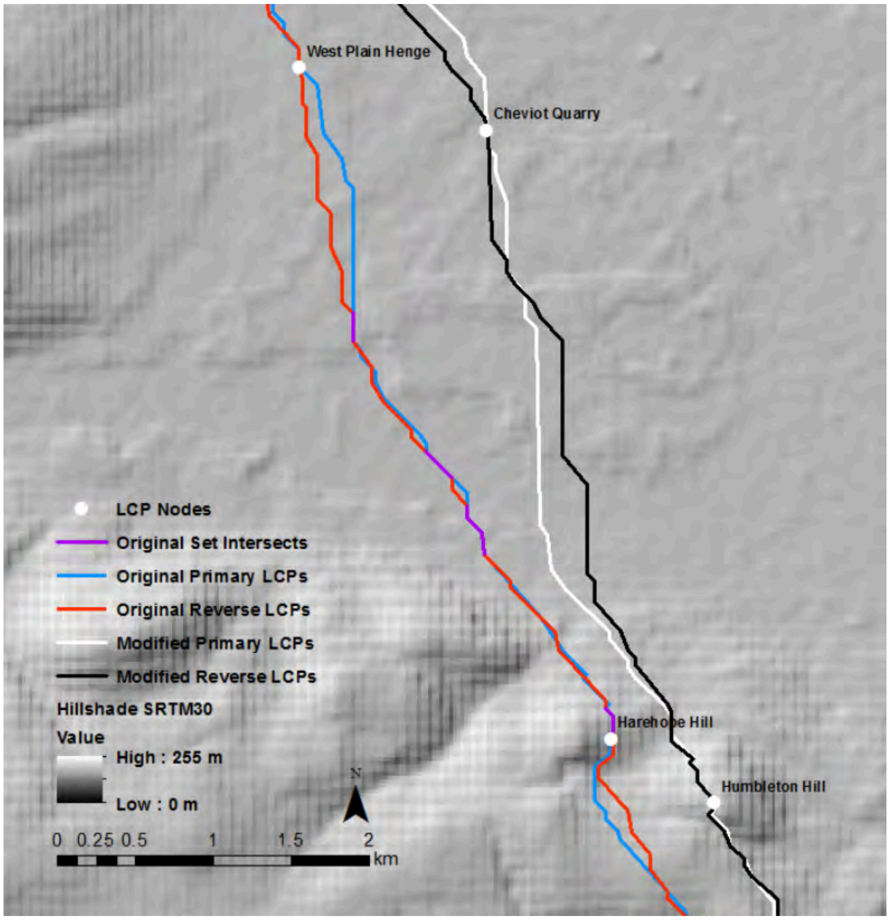

Figure 19 Detail of Cluster 1 – Segment 4 (Harehope Hill – West Plain Henge).

Modified LCPs in Cluster 1 were also generally consistent within each segment but sometimes diverged from each other, although to a lesser degree than the original sets. Modified Segments 1 and 3 showed the greatest divergence but only by < 0.4 km. However, the primary and the reverse LCPs in Modified Segment 4 exactly coincided with their counterparts in Segment 5 in the northern portions of the segments (Figure 20). Additionally, the modified sets varied in proximity and coincidence with the original sets. Modified Segment 1 followed a low cost corridor approximately 3 km from the original set and never coincided. Modified Segment 2 steered away from the alignment of the original Segment 2, following a more direct route until it nearly coincided with Segment 3 along a narrow corridor. Modified Segment 3 roughly paralleled the original Segment 4 and was never coincident or near coincident.

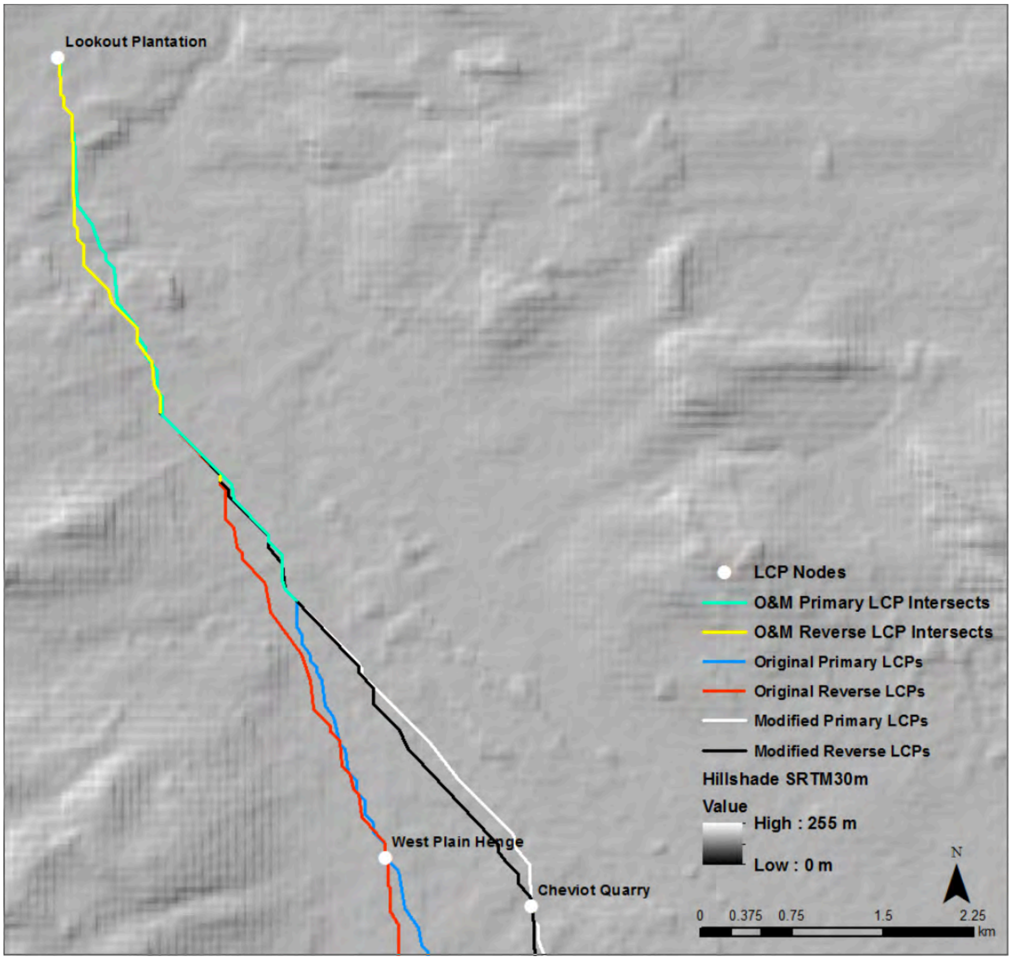

Figure 20 Detail of Cluster 1 – Segment 5 (West Plain Henge – Lookout Plantation) and Modified Segment 4 (Cheviot Quarry – Lookout Plantation).

4.2.2. Cluster 2

Three original and two modified LCP sets were generated in Cluster 2 (Figure 21). Segments 1 and 2 were mostly consistent and showed the most intersections, while Segment 3, presented the greatest divergence. However, the divergences along Segment 3 were < 0.5 km at their widest. In addition, the original primary LCP of the segment exactly coincided with its counterpart in Modified Segment 2 all along its eastern section. Divergence also characterized

Modified Segment 1, by approximately 1 km at its widest, particularly in the southern portion where there is greater topological variation. While each modified set shared a common node with the original sets, it was only at these points where intersections occurred.

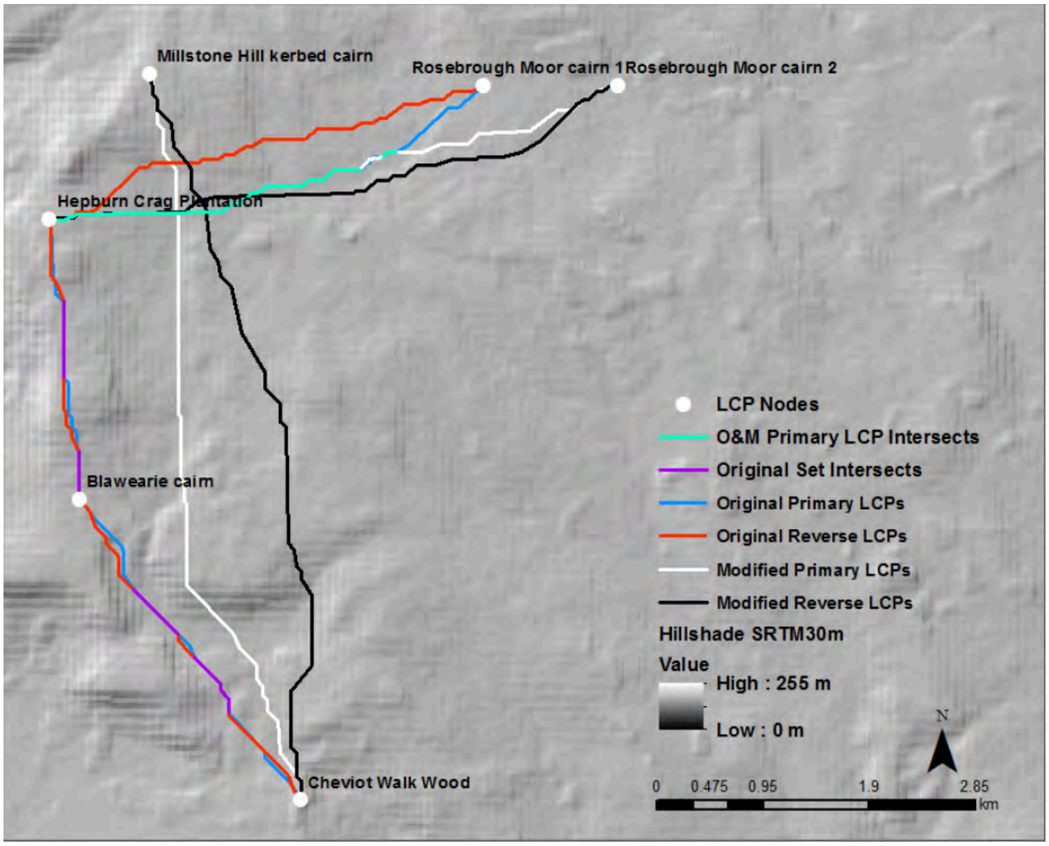

Figure 21 Overview of Cluster 2 - Segment 1 (Cheviot Walk Wood – Blawearie Cairn), Segment 2 (Blawearie Cairn – Hepburn Crag Plantation), and Segment 3 (Hepburn Crag Plantation – Rosebrough Moor Cairn 1), with Modified Segment 1 (Cheviot Walk Wood – Millstone Hill) and Modified Segment 2 (Hepburn Crag Plantation – Rosebrough Moor Cairn 2).

4.2.3. Cluster 3

Three original and three modified segments comprised Cluster 3 (Figure 22). All segments were consistent, with LCPs coinciding in several sections throughout the cluster. Segment 1 and Modified Segment 1 ran parallel (< 0.3 km apart) from each other along a low cost corridor, coinciding or near coinciding near the northwestern nodes of Alwinton and

Farnham. Segment 2 and Modified Segment 2 also ran parallel but to a wider degree (nearly 1 km apart) until all LCPs connect at the Great Tosson Quarry site.

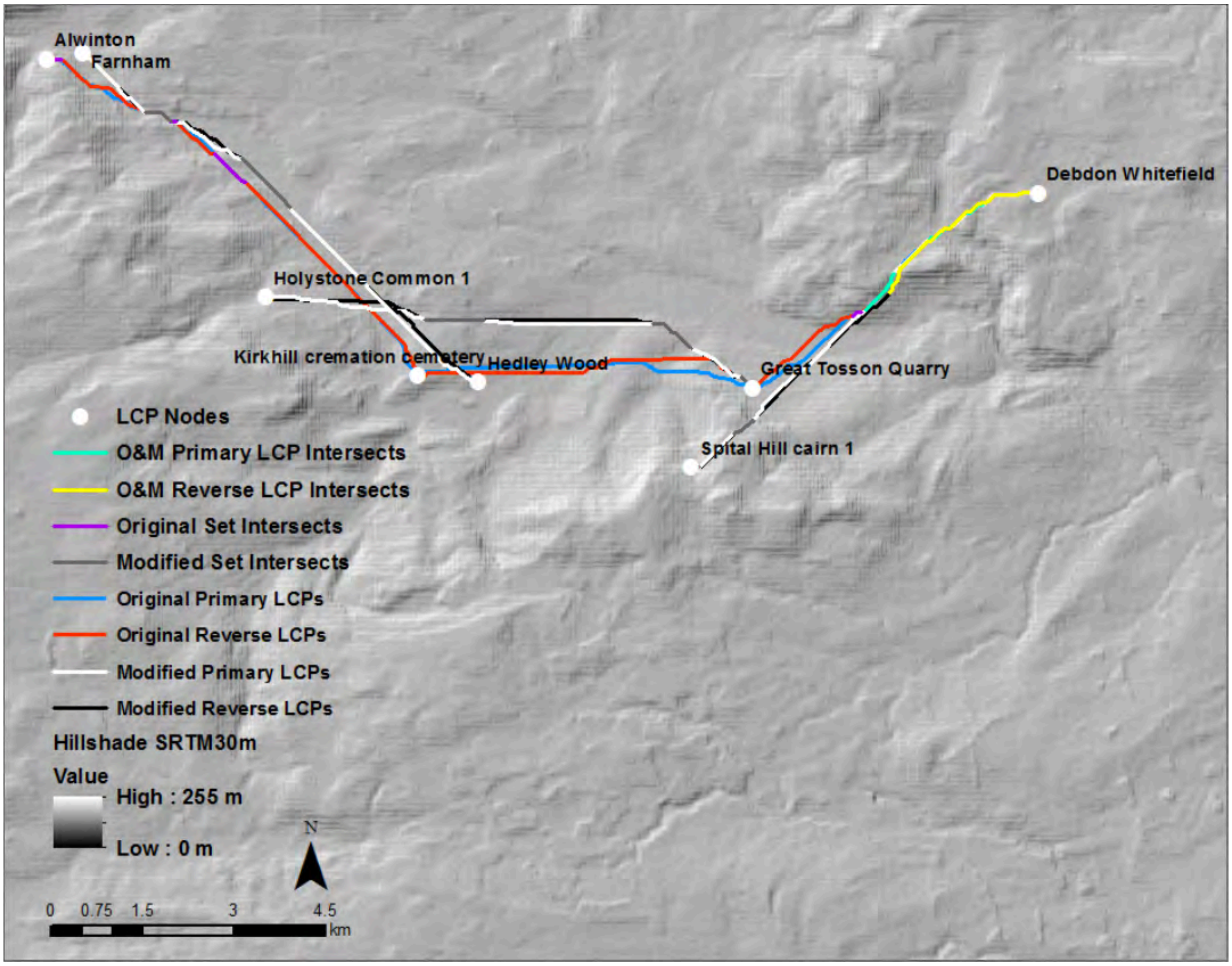

Figure 22 Overview of Cluster 3 LCPs – Segment 1 (Alwinton – Kirkhill Cemetery), with Modified Segment 1 (Farnham – Hedley Wood); Segment 2 (Kirkhill Cemetery – Great Tosson Quarry), with Modified Segment 2 (Holystone Common 1 – Great Tosson Quarry); and Segment 3 (Great Tosson Quarry – Debdon Whitefield), with Modified Segment 3 (Spital Hill Cairn 1 – Debdon Whitefield).

Segment 3 and Modified Segment 3 showed most LCPs in exact coincidence (Figure 23). LCPs of Segment 3 were divergent but ran closely parallel as they traverse a valley. They became coincident or near coincident in the higher elevation, northeastern portion of the segment. LCPs from Segment 3 and Modified Segment 3 also coincided in this portion, with the primary and reverse LCPs exactly coinciding with their counterparts all the way to Debdon Whitefield (Figure 23).

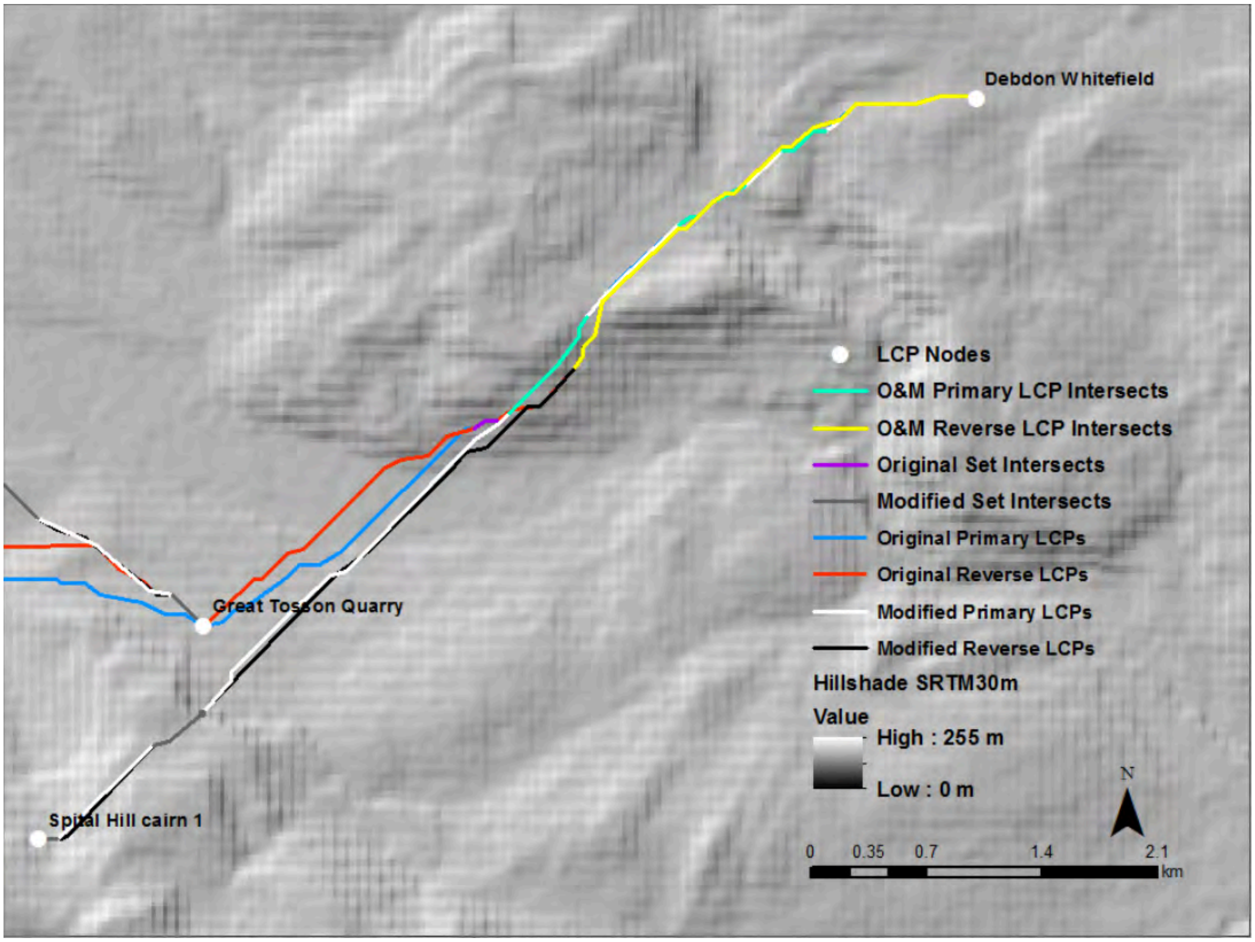

Figure 23 Detail of Cluster 3 – Segment 3 and Modified Segment 3, with sections of exact coincidence of LCPs from both segments in their northeastern portions by Debdon Whitefield.

4.2.4. Cluster 4

Cluster 4 was comprised of two original segments and one modified segment (Figure 24). All segments were consistent with each other, with Segment 2 exactly coincident throughout most of its run. Segment 2 showed the most divergence but < 0.2 km at its widest.

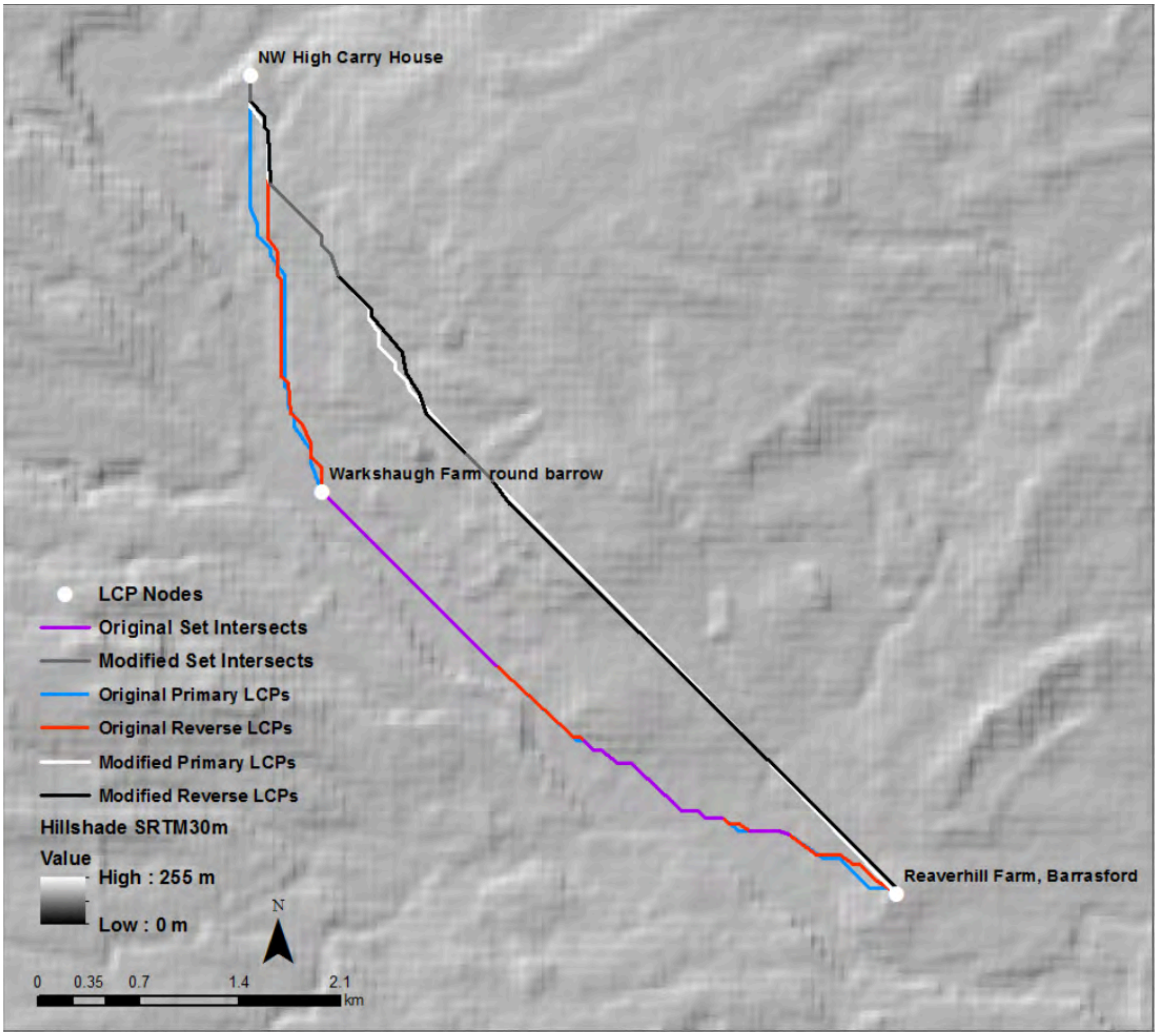

Figure 24 Overview of Cluster 4 LCPs – Segments 1 (NW High Carry House – Warkshaugh Farm) and 2 (Warkshaugh Farm – Reaverhill Farm) with Modified Segment 1 (NW High Carry House –Reaverhill Farm).

A long, narrow topographic depression that runs along all nodes likely contributed to the largely consistent stretch of Segments 1 and 2. This consistency began approximately at the middle of Segment 1 and continued all the way to Reaverhill Farm. However, Modified Segment 2 took a more direct route between NW High Carry House and Reaverhill Farm.

4.3 Inter-cluster LCPs

LCPs were generated for the five original and five modified segments connecting the four clusters (Figure 25). The original and modified segments were mostly consistent, with many LCPs exactly coinciding. However, some divergence occurred.

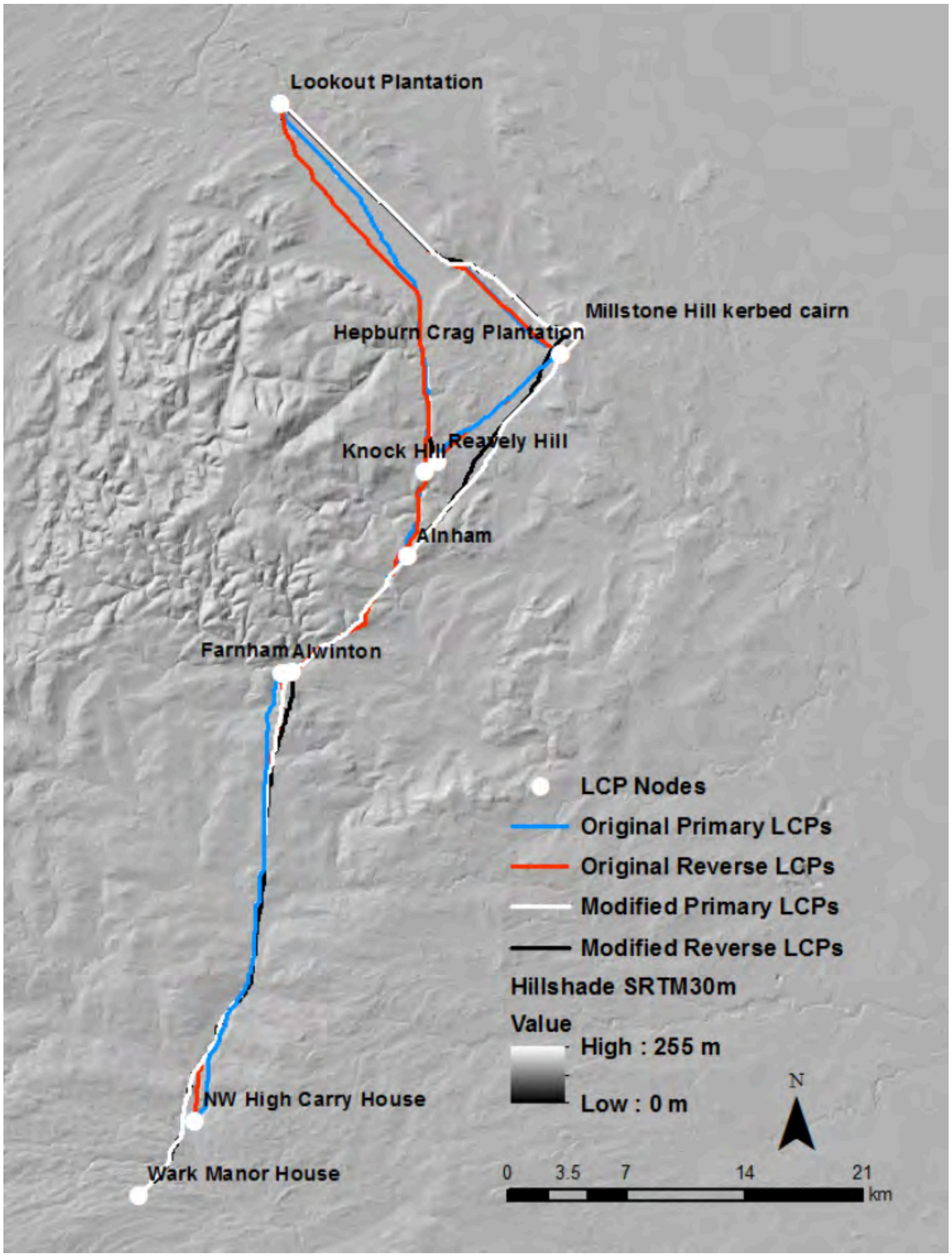

Figure 25 Overview of Inter-cluster LCPs.

Consistency characterized the original segments of the inter-cluster LCPs. For example, in its nearly approximately 30 km run between the nodes of NW High Carry House and Alwinton, Segment 1 was mostly consistent, particularly in the middle of the segment, along a long narrow corridor (Figure 26). The segment was also consistent with Modified Segment 1 (Wark Manor House – Farnham), with the primary and reverse LCPs from each segment exactly coinciding with their counterparts in some sections. Marked divergence occurred in both segments by their nodes.

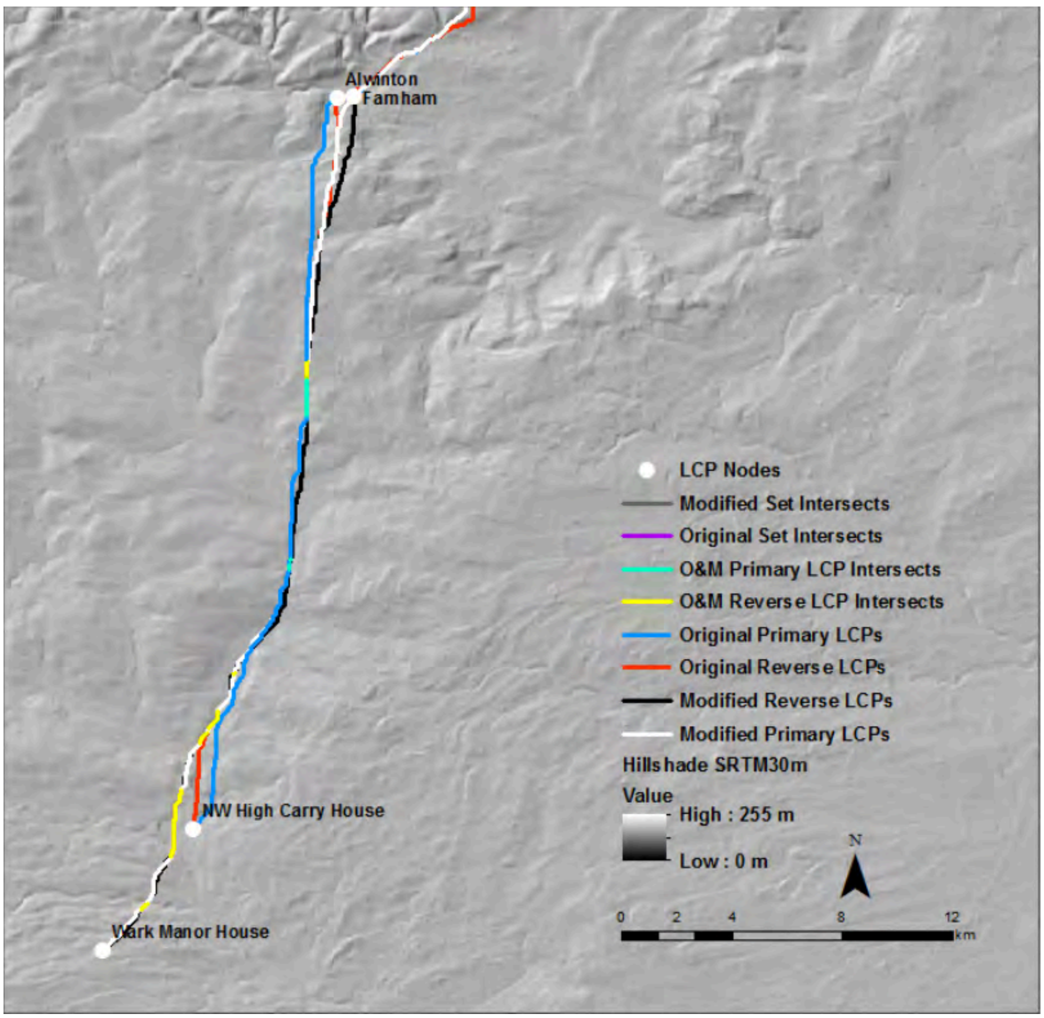

Figure 26 Detail of Inter-cluster Segment 1 (NW High Carry House – Alwinton) with Modified Segment 1 (Wark Manor House – Farnham).

The remainder of the original and modified segments were coincident or near coincident, with some divergence. Segment 4 and Modified Segment 4 exhibited the widest divergence by as much as 1.3 km. However, the primary and reverse LCPs from the two segments exactly coincided with their counterparts in a valley between their nodes (Figure 27). In contrast, Segment 5 and Modified Segment 5 ran along the same corridor and included primary and reverse LCPs that exactly coincided with their counterparts; however, all LCPs were consistent with the exception of the southeastern portion of the segments where they ran parallel and < 0.7 km apart.

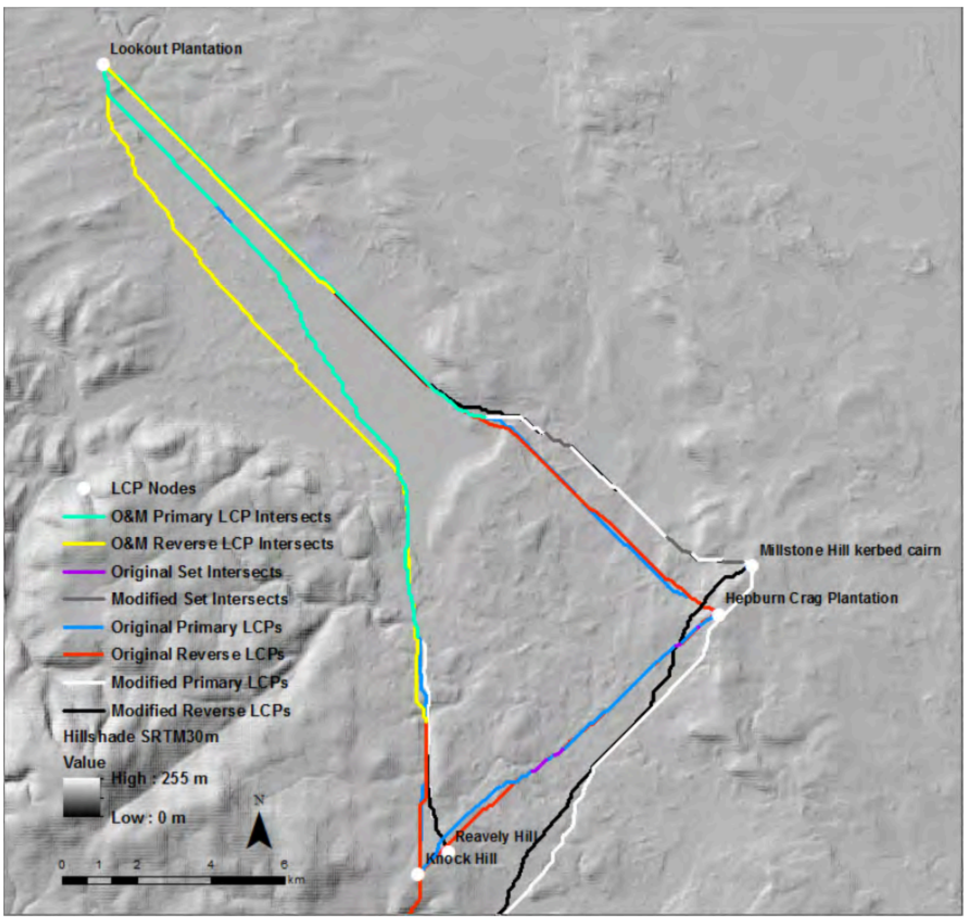

Figure 27 Detail of Inter-cluster Segment 4 (Knock Hill – Lookout Plantation) with Modified Segment 4 (Reavely Hill – Lookout Plantation, Segment 5 (Hepburn Crag Plantation – Lookout Plantation) with Modified Segment 5 (Millstone Hill – Lookout Plantation).

4.4 Aerial Imagery Comparisons

Due to their high coincidence of LCPs, four areas were selected for comparison with aerial imagery: (1) Cluster 3 – Segment 3 with Modified Segment 3; (2) Inter-cluster Segment 1 with Modified Segment 1; (3) Inter-cluster Segment 2 and Modified Segment 2; and (4) Inter-cluster Segment 4 and 5 with Modified Segment 4 and 5, and Cluster 1 – Segment 5 with Modified 4. Watercourses were found in three of the areas. One area that included a river system flowing through from which the distances to the LCPs was measured using the multiple ring buffer tool in ArcGIS.

Cluster 3 – Segment 3's original set and the corresponding modified set are largely consistent, particularly in the northeastern sections of the segments where the primary and reverse LCPs exactly coincided with their counterparts (Figure 28). The LCPs intersect the river just once as they cross the bottom of the valley, with the original primary LCP nearly coinciding with a modern bridge. The segments cut through the northwestern edge of a small village and exploited a low cost corridor on the northern side of a small hill between the river and Debdon Whitefield. While the southeastern section of the primary segment diverged, the LCPs were no more than 0.3 km apart. The divergence occurred at the bottom of the valley, between the Great Tosson Quarry site and the edge of the village. This divergence was perhaps due to what appears to be a relative uniformity of elevation in this particular area. However, it is possible that subtle changes in the topography may have caused the LCPs to favor one corridor over the other. Note that despite the divergence in the original segment in this area, the modified segment remained consistent with only a marked divergence by the village edge where it diverged along with its counterpart.

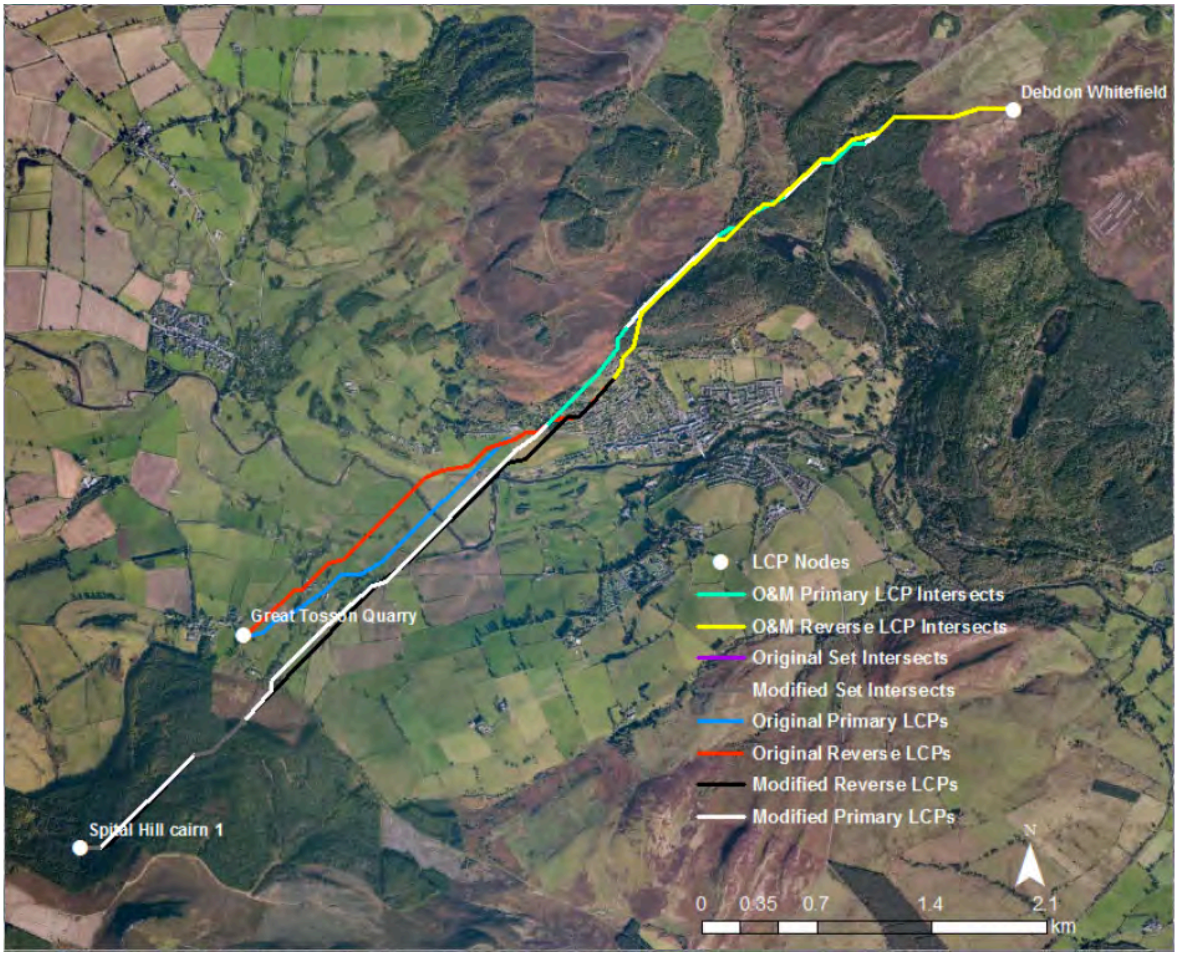

Figure 28 Cluster 3 – Aerial of Segment 3 (Great Tosson Quarry – Debdon Whitefield) with Modified Segment 3 (Spital Hill Cairn 1 – Debdon Whitefield). *Sources* (basemap): Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

The LCPs of inter-cluster Segment 1 with its corresponding Modified Segment 1 were mostly consistent and nearly coincident, particularly in the southern portion of each segment (Figure 29). The segments cut through agricultural lands and closely followed a river. A few modern structures were found along the river, but no recognizable village existed. The LCPs intersected the river several times along their routes.

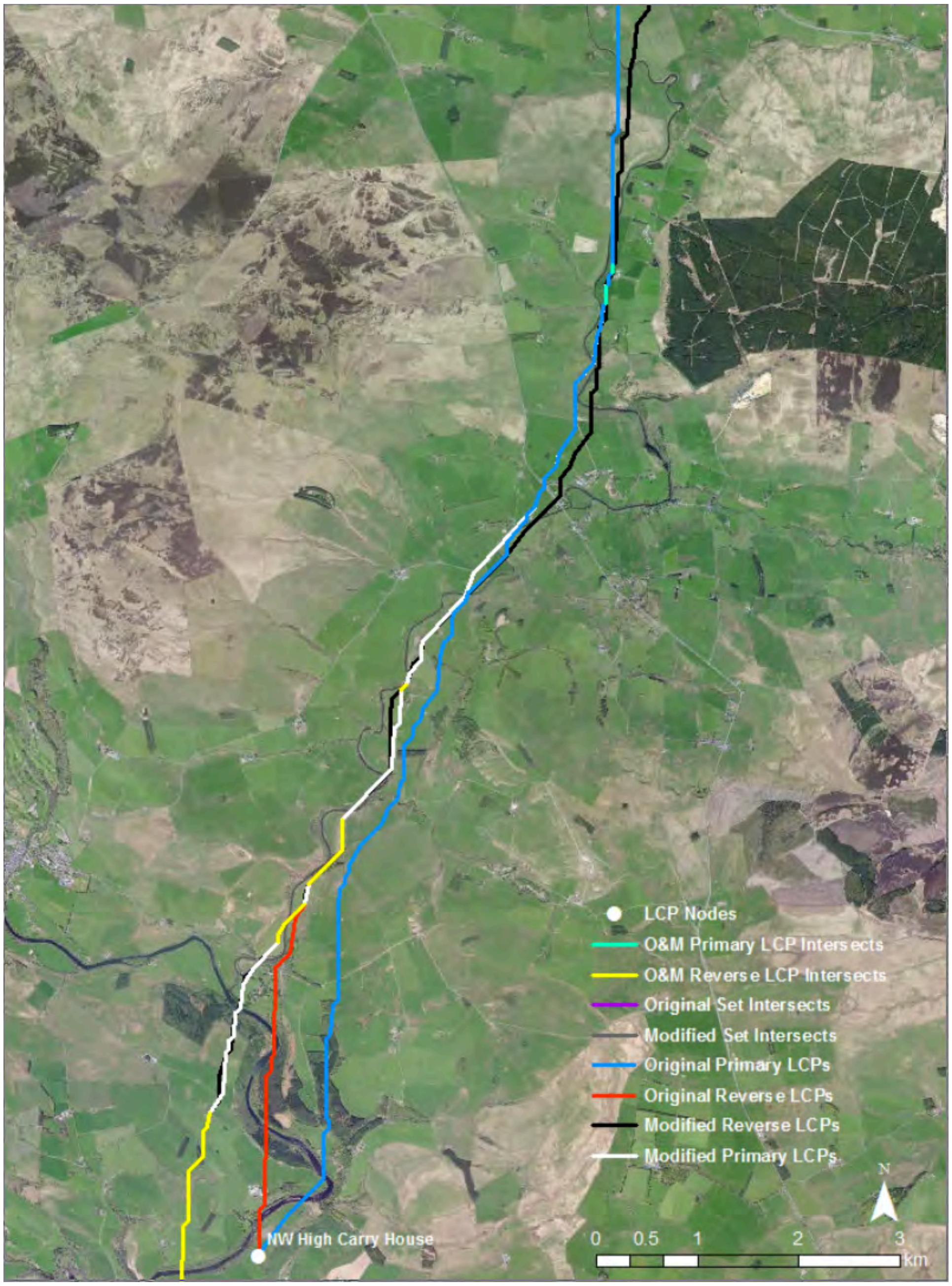

Figure 29 Aerial of the southern portions of Inter-cluster Segment 1 and Modified Segment 1. *Source* (basemap): Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

The southern section of Inter-cluster Segment 2 was mostly consistent with Modified Segment 2 (Figure 30). Specifically, the primary LCP of Segment 2 was exactly coincident with its modified counterpart, as were the reverse LCPs. Some divergence occurred within each segment, but for < 0.4 km. The LCPs traversed a corridor where a hilly formation met flat agricultural lands.

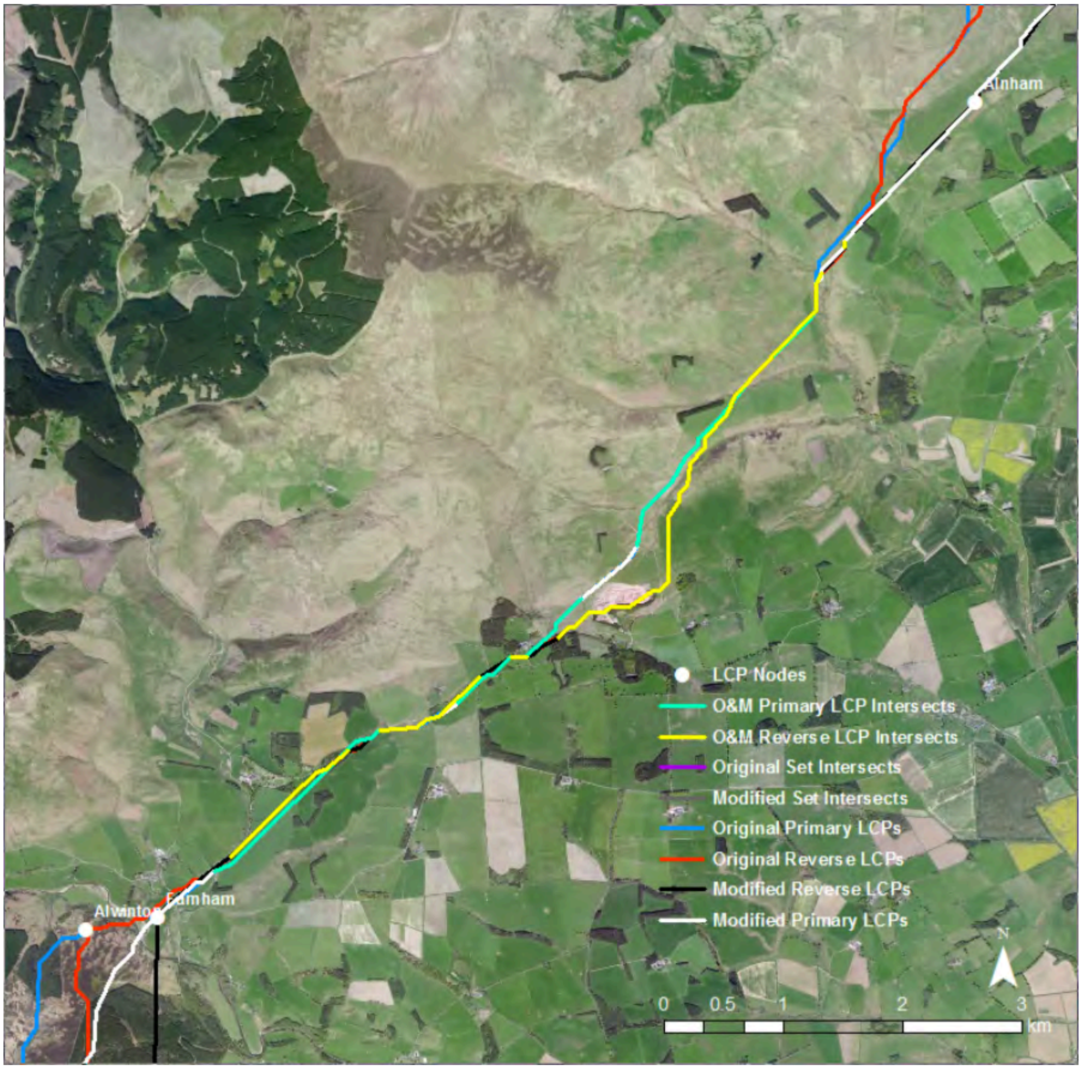

Figure 30 Aerial of the southern section of Inter-cluster Segment 2 (Alwinton – Knock Hill), with Modified Segment 2 (Farnham – Alnham). *Source* (basemap): Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Inter-cluster Segments 4 and 5 with Modified Segments 4 and 5 join Cluster 1 – Segment 5 with its corresponding Segment 4 along a stretch of a wide corridor cut through by a river

(Figure 31). The corridor is also agricultural but modern buildings and small villages dot the landscape close to the river. Multiple LCPs exactly coincide within this corridor, including two pairs of primary LCPs and two pairs of reverse LCPs. A multiple ring buffer was generated from the primary LCP of Cluster 1 – Segment 5. The buffer showed that all LCPs were within 1.5 km of the intersected feature (Figure 32). However, Inter-cluster Segment 5 and Modified Segment 5, which took a direct route between their nodes, extend outside of the buffer near the Hepburn Crag Plantation and Millstone Hill sites.

Figure 31. Aerial of Inter-cluster Segments 4 and 5 with Modified Segments 4 and 5; Cluster 1 – Segment 5 with Modified Segment 4. *Sources* (basemap): Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

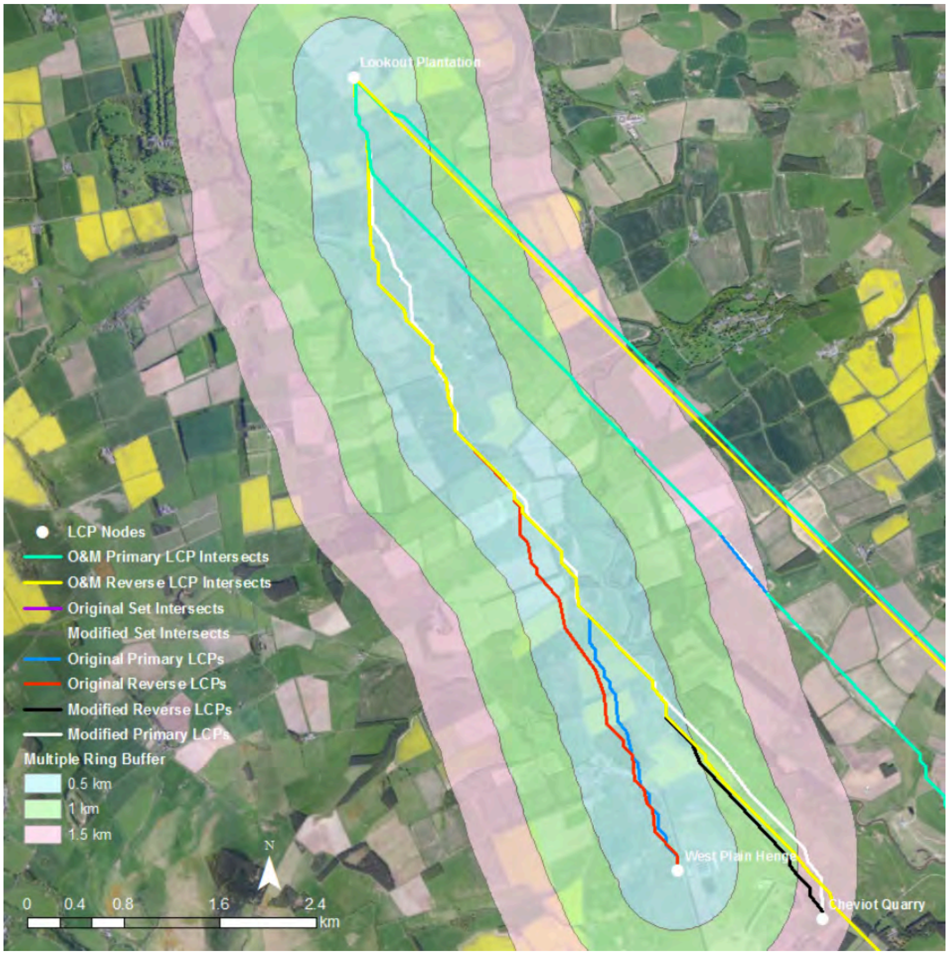

Figure 32. Inter-cluster – Aerial of Inter-cluster Segments 4 and 5, Modified Segments 4 and 5; Cluster 1 – Segment 5 with Modified Segment 4, with multiple ring buffer (30% transparency). *Sources* (basemap): Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Chapter 5 Discussion and Conclusions

Degrees of local topographic variation shaped the generated LCPs, and the results of this thesis have only begun to describe a network of paths during the Bronze Age in Northeast England. The study generated relatively consistent original sets of LCPs that, on their own, already point to possible corridors of prehistoric travel. However, the addition of the modified sets as another kind of validity test provided another dimension to this analysis, particularly when existing nearby sites were used as nodes. They demonstrated the contiguity or lack of contiguity of the paths in connecting with other sites in a cluster as well as between clusters, and hence, challenges to or confirmation of the validity of the primary LCPs. Through this level of validation, four areas were identified with a high likelihood of having supported prehistoric paths. This chapter explores the significance of the patterns that emerged from generating LCPs, the significance of using only one variable (slope) in the study, and finally some concluding comments with directions for future research.

The modified sets demonstrated that topographic variations at the local scale can impact the route of an LCP. In Cluster 2, for example, Modified Segment 1 was highly divergent (1 km apart at its widest) in its southern portion by the Cheviot Walk Wood node (see Figure 21). Immediate north of the node is a small depression flanked by varying degrees of slope as the area transitioned to higher elevation. It appears that the divergence of the modified set was due to this variation, with the primary LCP favoring a route along a corridor to the west than the reverse which followed a corridor to east. A narrow strip of small hills between these corridors preserved the divergence until both LCPs met at the Millstone Hill node.

Variation can lead to divergence even in wide, open spaces that appear to have largely uniform elevations and/or slopes. The northern portion of Inter-cluster Segment 4 and its modified counterpart follow a wide open corridor with some relatively minor undulations (see Figure 27). Recall that Segment 5 and Modified Segment 5 ran parallel with the Segment 4 and Modified Segment 4 along the same corridor and were coincident or nearly coincident all along the area. However, a cursory look at the hillshade DEM showed that there is a cluster of small formations in between the divergent LCPs that appear to be of higher elevation, effectively creating shallow corridors of low cost values on either side. The fact that the trajectory changes as a result of the slightest variations in relief is consistent with the effects of local variations discussed above; even in wide open spaces that offered few restrictions, significant divergence can occur.

While modified sets in the study served to test the validity of the original primary LCPs, they also generated low cost paths that can serve as possible prehistoric routes. Indeed, multiple routes between sites are a possibility in this region. For example, the northeastern part of Segment 1 in Cluster 1 was coincident or nearly coincident by Knock Hill, and hence, this is a route with a high likelihood for serving as a location of prehistoric paths (Figure 33). However, its counterpart, Modified Segment 1, exploited a deeper, more restrictive corridor to the east, following a more or less parallel path to the other segments. Settlement sites dominate this portion of the dataset, with the nearest ones such as Cat Crag in the west and Chesters Burn in the east > 0.5 km away from the closest parts of the LCP segments. More travel would have occurred along paths connecting settlements, and these sites could possibly be served by these segments, which means that either one is viable and warrants further study or ground-truthing.

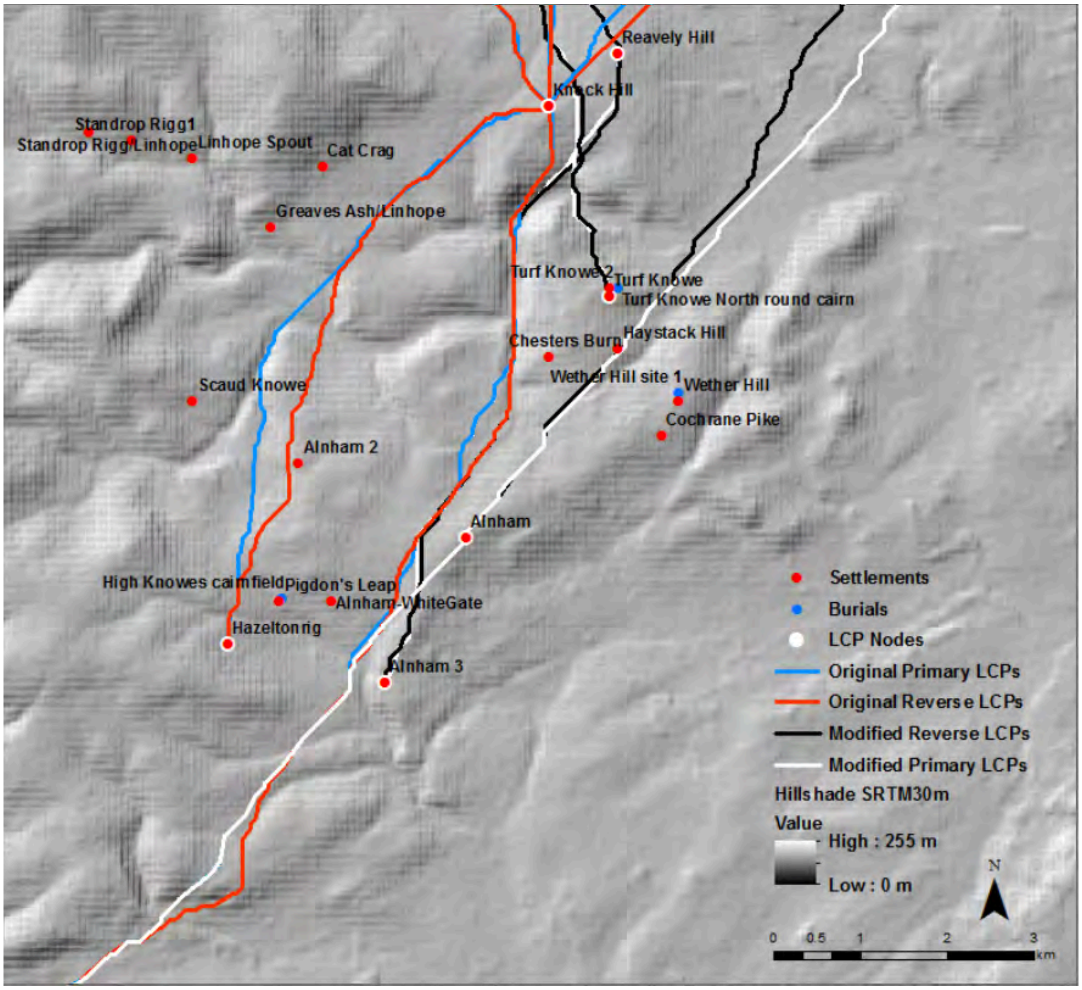

Figure 33 Cultural sites and LCPs in the southern portion of Cluster 1, with Inter-cluster Segment 2.

Rivers and streams offer persistently low cost corridors throughout their courses and emerged as areas with the highest prevalence of LCP coincidence in the study. Logically, LCPs, when given the opportunity, exploit the low cost values in topography associated with watercourses and the adjacent valley bottoms. This is evident in the examples of aerial imagery comparisons discussed at the end of Chapter 4. Indeed, High Carry House, the southern node of Inter-cluster Segment 1, is also a node in Cluster 4 (see Figure 29), in which all three segment nodes lie adjacent to the stream. All original segments ran parallel with the general flow of the water. This is consistent with Kline (2009) who found many generated LCPs following drainage systems.

Since the only variable utilized in the study is slope, then only the values of slope guide the LCPs. Indeed, many LCPs crossed streams and rivers due to the absence of the added costs that may accompany the portrayal of rivers in a hydrological dataset. But the study chose to forgo the use of hydrology and other variables for several reasons. In terms of hydrology, modern datasets do not necessarily describe the conditions of the Bronze Age. Early Bronze Age was also the onset of a wetter climate that, in turn, also transitioned into a warmer period at the start of the Iron Age (Brown 2008). Hence, different hydrological datasets at finer temporal lenses need to be combined with cultural datasets within the same temporal ranges. Additionally, the watercourses within the study area are minor rivers and streams that may have been welcome features for prehistoric travelers; they may have even been a necessity (Colton 1941).

Smaller rivers and streams did not hinder movement in the Bronze Age. The Beakers built small bridges to allow for crossings (Bruck 2004a). The settlement site of Alwinton, for instance, is located just across a river from the burial site of Farnham; a hydrological dataset would have likely triggered LCP algorithms to find other low cost avenues and the LCPs would not have been as consistent as the first segments of Cluster 4 (Figure 34). In terms of land cover, some increase in deforestation relative to the Neolithic also characterized the period with the continued dependence on agriculture, effectively creating patches all around what was then a largely wooded terrain (Dyer 2002). If it was possible to derive such hydrological and land cover datasets from existing climate studies during the Bronze Age (see Brown 2008), future LCP studies in the region would greatly benefit from the inclusion of these data layers.

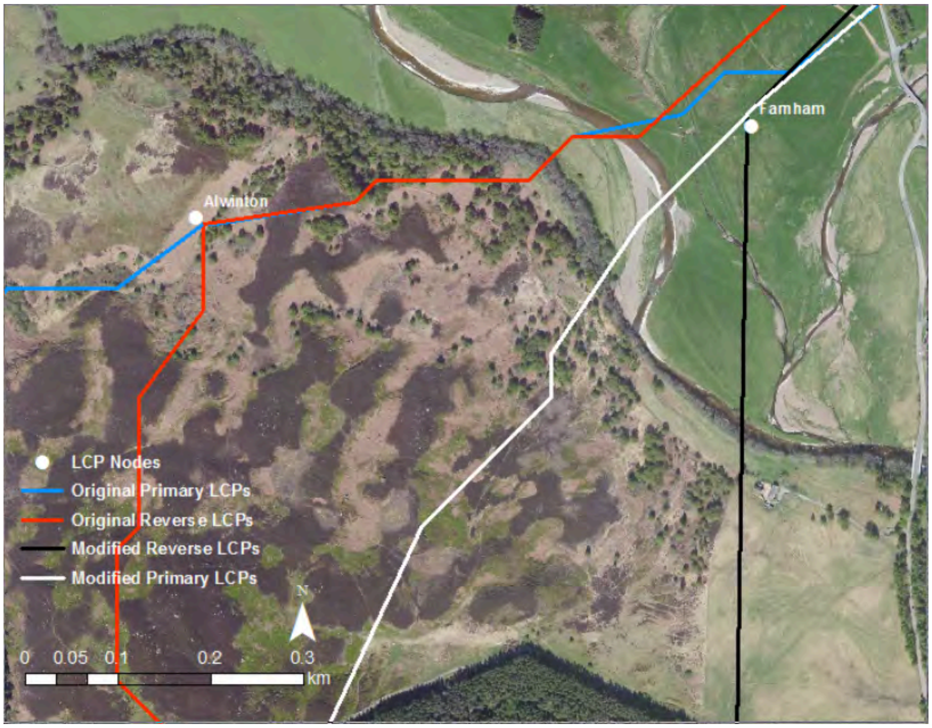

Figure 34 Alwinton and Farnham sites, with LCPs crossing a watercourse. *Sources* (basemap): Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

This thesis generated 66 LCPs that demonstrated how sites may have been connected through a network of paths. While numerous, the number of sites involved is small amount relative to the number of sites remaining in the dataset. Nonetheless, the thesis showed that possible prehistoric paths can be modeled using LCPs when three types of validation are employed to test the primary LCPs; these assessments produced areas with varying levels of likelihood for having hosted prehistoric trails. These methods are particularly applicable to analysis of areas with multiple sites.

While slope was the only variable used as a proxy for cost, some error may have been introduced as a result of the calculation method. ArcGIS calculates slope using a 3 x 3 cell moving window and assigns the value of a center cell to cells without considering the elevations of cells just outside of these 3 by 3 cell moving windows or neighborhoods (Esri 2016d). This can result in local anomalies and using a larger window may yield more accurate slope values and least cost paths across the land surface.

Moreover, the additional processing to produce the SRTM 30 m DEM may have also introduced residual errors that affect slope calculations, and ultimately the computed paths between nodes. Data from the ASTER and the lower resolution GMTED were used to fill some of the voids in the previous SRTM version (USGS 2015a). Filling the voids can result in a smoother terrain that can also affect LCP trajectories, given the LCP algorithm's sensitivity to small and subtle changes in the topography.

More studies should be implemented to deepen our understanding of prehistoric movement in Northeast England. In addition to finding appropriate and finer temporal datasets, other methods can be employed to further validate LCPs. In the archaeological context, interfacing LCPs with the presence of cultural material would substantiate computed paths – either with recovered artifacts and features with spatial data or through ground truthing with surveys and excavations. Furthermore, human social behavior is not always determined by the environment. Future studies must also employ ethnographic and similar data to incorporate territorial boundaries and taboos that would inform the path choices of a traveler.

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Appendix A: Settlement Data Record Sources

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