GIS AND ARCHAEOLOGY:
BISON HUNTING STRATEGIES
IN SOUTHERN SASKATCHEWAN

A Thesis Submitted to the College of
Graduate Studies and Research
In Partial Fulfillment of the Requirements
For the Degree of Master of Arts
In the Department of Archaeology and Anthropology
University of Saskatchewan
Saskatoon

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Abstract

Between 1988 and 1989, an intensive archaeological survey of a small drainage known as Roan Mare coulee in southern Saskatchewan was conducted by Dr. Ernest Walker (Walker 1990). Among the 120 archaeological sites in the area, seven bison kills and a vast array of associated drivelines were identified. This study focuses upon the spatial interaction amongst the kills, the drivelines and the local environment in relation to the bison hunting strategies used on the Northern Plains. This is done by modelling where bison are likely to move in the terrain as well as how the topography obstructs their line of sight.

As this problem covers a large spatial area and multiple different data sources, Geographic Information Systems (GIS) are integrated into the research design in the form of Least Cost Path and Viewshed analyses. Both archaeological data from Walker's survey and environmental data such as elevation and water sources served as the input datasets required by ArcGIS's spatial analysis tools. The results of the Least Cost Path analyses were compared visually to both the location and orientation of the driveline evidence, while the viewshed results were compared to the trap's location at the valley edge.

The results of this research showed that the drivelines found at Roan Mare coulee appear to be following the general orientation of the landscape at the broadest scales, and likely served to funnel bison over large distances. There also appear to be several locations on the landscape that are amenable to moving bison to several different sites. The viewshed evidence shows the smaller scale nuances between bison vision and the terrain in a hypothetical drive event. The differences in the viewable area available to the bison at each site likely played a role in the chosen strategy employed when that site was used. It is hoped that this style of research can be continued with higher quality data and additional variables to help clarify many of the subtleties found in a Plains bison drive.

Acknowledgements

I wish to extend my thanks to my supervisor, Dr. Ernest Walker for introducing me to the study area of Roan Mare coulee, but also for his continued support, guidance and camaraderie. I want to thank my committee members, Dr. Margaret Kennedy and Dr. Christopher Foley for their support, guidance, and valuable insight which helped shape this thesis into what it is today. I would also want to thank several of the other faculty and staff of the Department of Archaeology and Anthropology at the University of Saskatchewan, including Dr. Elizabeth Robertson, Dr. Clinton Westman, Dr. Pamela Downe, Dr. Glenn Stuart, Dr. David Meyer and Deborah Croteau. Aside from offering both academic and personal advice, they made me feel welcomed as both a newcomer to Saskatchewan and the world of academia.

I would like to thank the agencies which helped fund this research. These include the Saskatchewan Archaeological Society, the Saskatchewan Heritage Foundation, Saskatchewan Lotteries and the Social Sciences and Humanities Research Council of Canada. I also wish to thank several of the people who provided assistance in making this project a reality. This includes the local land owners in the Roan Mare coulee study area: Barry Stefan, the Nyhus family and the Hlavka family. I owe a great deal of gratitude to my brother, Chris Larsen for his volunteered knowledge and assistance during the topographic survey portion of this research. I wish to thank DMS Survey in Saskatoon for providing the survey equipment and also John Leonard at ISC for providing many of the DEM's and aerial imagery. I also wish to thank Nathan Friesen at Saskatchewan Heritage for his assistance and interest in the project.

I would like to thank my friends and family. I extend my gratitude to the other graduate students whom I have gotten to know over the years. Special thanks go to Karin Steuber, Adam Splawinski, Nadia Smith, Maria Mampe, Brent Kevinsen, Erika Cole, Julie Martindale and Loni Williams. I also want to thank my siblings: my brother, sister, brother-in-law and of course my niece and nephew. I give special thanks to my mother, Karen, and father, Michael, for their support and understanding through this project. They encouraged me to keep going during my darkest hour when I felt like giving up.

Lastly, I would like to commend Officer Teal of the United States Border Patrol. His bravery and quick thinking in the line of duty helped protect the USA potato industry from the threat of dirty Canadian rocks. Remember: "Say 'NO' to Nematode!"

Table of Contents

List of Tables

List of Figures

Chapter 1
Introduction

Bison jumps exist as some of the largest sites found on the Northern Plains. Over the years, bison jumps and drives have been well studied in hundreds of manuscripts and site reports (Brink 2008; Cooper 2008; Kehoe 1973; Reher and Frison 1980). Many of these research projects have focused on the material evidence found on the killing floor. These bone beds have the greatest concentration of material culture relating to the jump's operation. Through analysis of the faunal elements several important conclusions about the hunters' subsistence patterns such as the intensity of butchering or the seasonality of the kill can be gleaned. The stratigraphy of the deposits provide information about how frequently the kill was used, while the typology and radiocarbon dates show what time periods the kill was in operation.

However, one aspect of bison jumps that is often neglected or taken for granted in these projects is the interactions between the human hunters and their environment that were enacted to bring the bison to the killing floor in the first place. The process of luring or manipulating bison to the trap is a very complex process involving several factors revolving around the hunters' ability to predict bison behaviour as a herd and their reaction to changes in topography or environmental stimuli (Rollans 1987). Plains groups were able to manoeuvre bison over vast distances as evidenced by driveline networks that are expansive in length and complexity. These driveline structures facilitated the coordinated movement of the bison from their milling areas to the trap, and can range in size from a few metres to several kilometres (Brink and Rollans 1990; Medicine Crow 1978; Walker 1990). As these sites and features cover such widespread areas, studying the spatial relationships manually exhibits a laborious chore.

Geographic Information Systems (GIS) have been used by archaeologists to study spatial patterning in archaeological data for the past 30 years (Lieff 2006). GIS can be thought as spatial databases, where an entry's spatial information can be queried and analyzed alongside other recorded attributes. Projects in archaeology have ranged in size from mapping artefact concentrations in a site (Kvamme 1996) to postulating probable routes used by early hunter gatherers when populating North America (Anderson and Gillam 2000). GIS have also been used in Plains archaeology in recent years to study sites, material and activities related to large scale bison hunting (Byerly et al. 2005; Carlson 2011; Cooper 2008; Lieff 2006; Middleton 1998; Mills 2009). One of the aims of this project is to expand upon this limited area of research.

1.1 Project Overview and Goals

In the late 1980s an intensive archaeological survey was conducted by Dr. Ernest Walker from the University of Saskatchewan. The target area was a small drainage known as Roan Mare coulee, which was a small tributary of the Big Muddy Valley located in southern Saskatchewan. Through the course of the survey, Walker identified 120 archaeological sites in the small valley and its surrounding uplands as well as a wide array of stone cairn drivelines. Of 120 sites, seven were identified as bison kills and were most likely jumps associated with the driveline network (Walker 1990). Unfortunately, the sites were never excavated outside of a limited number of test units and surface collections. Many of the analyses typically used to study and compare bison jumps are inoperable without the wealth of material evidence that the bonebeds provide. The evidence that is available is the vast collection of drivelines and their spatial distribution across the landscape.

The goal of this thesis is to move beyond Walker's (1990) survey by studying the spatial interactions between the drivelines and the kill site locations with the predicted routes of travel hunters would have led bison through during a Plains drive event. This is done through the use of GIS, where the standard theories of how hunters manoeuvred bison through the landscape can be modelled through Least Cost Path analysis. In doing so, three research objectives are to be met:

1. Do the calculated least cost paths reflect the intended pathways of movement predicted by the driveline structures?
2. Are particular areas or direction more amenable to manoeuvring bison than others? Do these directions differ between different sites?
3. Are routes shared or reused when directing bison to different kill sites in Roan Mare coulee?

Alongside these objectives, a fourth and related goal is sought. An important part of any Plains bison drive is how bison react to stimuli. If bison are unable to identify the oncoming trap in a drive, this increases the hunters' chances for success. Using the Viewshed tools in GIS, the area visible to a bison can be recreated at different points along the least cost paths. This helps approach the fourth research objective:

4. Is the natural topography effective at obscuring the jump edge from the bison in the final stages of a drive?

1.2 Chapter Overview

This thesis is organized into eight chapters, three of which provide much of the background information and related literature to familiarize the reader with the study area, how a Plains bison jump is operated and how GIS is used in archaeology. The later chapters provide the reader with how the analyses were conducted, their results and how they address the research objectives listed above. The thesis concludes with possible avenues where the research can be continued in the future.

Chapter Two provides a synopsis of both the environmental and archaeological background of the study area. The environmental portion highlights the biophysical conditions present in the Big Muddy Valley and Roan Mare coulee by extension. The study area's floral and faunal resources are examined along with its current climate conditions, soil distribution and geomorphic and geologic history. The chapter continues with a summary of both Walker's archaeological survey methodology and his results. This serves to introduce the reader to what types of sites are found in Roan Mare coulee and how they are distributed. The chapter also provides additional exploratory data analysis to highlight some of the trends for the site types outside of the bison kills.

Chapter Three is a review of the various factors that are involved and influence the outcome of a Plains bison drive. The seasonal and herd behaviours of the bison are investigated along with what roles they play in a drive's operation. All portions and stages typically found in a plains bison drive such as the gathering basin, the drivelanes, the killing zone and the processing areas are all summarized. The kill sites in Roan Mare coulee are critiqued to see if they share the environmental conditions typically present at the various stages of a drive.

Chapter Four is concerned with how Geographic Information Systems are used and researched in archaeology. It begins with a summary of what GIS are and introduces several terms and types of data that are used in later sections with which the reader may not be familiar. A variety of case studies are offered to the reader, each highlighting one of several ways GIS have been approached in archaeology since their adoption in the early 1980s. The case studies are arranged not only by the research topic, but also by the spatial extent being examined which ranges from small site level analyses to projects that span continents. This is done to convey to the reader one of the benefits GIS can offer an archaeologist is the ability to work with a variety of different data sources across a vast area.

Chapter Five outlines the methodology undertaken to meet the research objectives identified above. The pertinent datasets are identified and include how and where they were collected. This also includes the terrain data created specifically for the viewshed portion of the project, providing an overview of the topographic survey used to collect these data and how they were transformed into a workable terrain model. Overviews of how the Least Cost Path and Viewshed analyses function in a GIS and how they are applied to the archaeological data in Roan Mare coulee are also examined. The chapter concludes by outlining the assumptions pertaining how the data are used to reflect theories on bison behaviour and past human hunting strategies.

Chapter Six presents the results of both the Least Cost Paths and Viewshed processes for each jump. Alongside each least cost path map is a table reflecting the associated costs of each path depicted. A brief summary notes how the paths and their costs have changed through each iteration of the process. Select viewsheds are displayed to convey the overall change in viewable area for bison along each of the routes nearest the jump.

Chapter Seven readdresses the results provided in the previous chapter in light of the four research objectives. The least cost paths for each site are evaluated for how they reflect the driveline evidence, both noting areas where the technique worked well and areas where conflicts arose. The similarity and preferred directions of travel between each site are also evaluated, noting both large and small scale trends. Locations that show a high amount of traffic are mapped and identified and interpretations of what these areas represent archaeologically are given. The viewshed evidence is also critiqued as to how well the topography obscured the trap from the bison and whether this constitutes an effective trap. Finally all the research objectives are analyzed as a whole, shedding light on some of the bison hunting strategies present in Roan Mare coulee.

Chapter Eight provides an overview of all the chapters prior to it and summarizes the conclusions made regarding the research objectives this thesis approached. From there, a number of future research options and avenues are presented. These include future work on the model presented here, a return to Roan Mare coulee for additional archaeological study, and the application of Least Cost Path and Viewshed analyses to other regions of the Northern Plains.

Chapter 2
Environmental and Archaeological Background of the Study Area

2.1 Environment of Big Muddy Valley

2.1.1 Location

The Big Muddy Valley is situated in south-central Saskatchewan, within the northern Great Plains. The Big Muddy Creek's head waters begin southeast of Willow Bunch Lake and travel southeast to drain into Big Muddy Lake. Big Muddy Creek then continues to flow out of the southern edge of Big Muddy Lake southward toward Montana. The Big Muddy Creek rests within the much larger Big Muddy Valley. While the creek abruptly stops just north of the United States border, the valley extends south into Montana, where it eventually joins the Missouri river system, whose waters join with the Mississippi and drain into the Gulf of Mexico. The valley also extends north and west of the creek's headwaters, connecting with Willow Bunch Lake. The trench extends north and west of this location, into the Lake of Rivers and Wood Mountain areas respectfully, but the Big Muddy Valley usually corresponds to the area just south of Willow Bunch Lake (Ellis et al. 1969: Plate 1). This large expanse of valley trench is the reason the Big Muddy Creek Watershed, as defined by the Saskatchewan Watershed Authority (2007), extends so far away from the Big Muddy Valley itself. The study area will also revolve around two tributaries of the Big Muddy Valley known as Roan Mare and Hole in the Wall coulees.

2.1.2 Climate and Local Weather

Ellis et al. (1967:14) define the overall climate in the Big Muddy area and surrounding uplands as a cool, semi-arid continental type. This means the area experiences a wide range of temperatures throughout the year (Ellis et al. 1967:14), which will average to a low mean yearly temperature. The semi-arid climate is created by a low mean precipitation in the area. Parizek (1964:13-14, Fig. 4) notes that yearly precipitation ranges from 10-15 inches (254-381mm), and Ellis et al. (1967:15) provide averages between 15 and 15.5 inches (381-393.7mm). Climate histories from Ceylon and Coronach recorded from 1971 to 2000 show similar trends (Environment Canada 2010a; 2010b). Data from Ceylon shows an average annual precipitation of 386.3mm, with average daily temperatures between -12.5^{oC} to 18.6^{oC} for January and July respectively (Environment Canada 2010a). Coronach averages 414.1mm precipitation annually, with a January-July average daily temperature spread between -12.8^{oC} and 18.7^{oC} (Environment Canada 2010b). Both the stations (Environment Canada 2010a; 2010b), and Ellis et al. (1967:15), show that the majority of precipitation falls between May and August while snowfall only contributes to about 30% of the total precipitation. The closest wind data for the area is from the town of Weyburn, located about 75km northeast of Big Muddy Lake. The Weyburn station records winds from the northwest as most frequent from September to February, while southeast winds are more frequent from March to August (with the exception of July, where northwest winds prevail) (Environment Canada 2010c). The growing season, measured in frost free days, ranges between 99 and 115 days on average (Ellis et al. 1967:15).

2.1.3 Geology

Klassen (1986:138-139, Fig 2.15) shows the Big Muddy Valley residing in an area underlain by Tertiary age deposits, which are relatively young compared to the bedrock found as one travels northward through Saskatchewan. The Big Muddy Valley itself cuts into the Tertiary layers and exposes Late Cretaceous age strata in some locations. Five major bedrock layers in the Big Muddy Valley and surrounding area are identified by Parizek (1964). These include the Bearspaw, Eastend, Whitemud, Ravenscrag, and Wood Mountain formations. Whitaker (1978) and Postnikoff (2009) both note a sixth layer, the Frenchmen formation, resides between the Whitemud and Ravenscrag strata, and can be found in the study area.

The Bearspaw formation underlies all other formations and dates to the Late Cretaceous period. It consists mostly of dark grey to dark brownish grey clay and silty shales which are noncalcareous (Parizek 1964:14). The formation also includes beds of fine sand and silt as well as yellowish bentonite beds. The Bearspaw formation is found closer to the modern surface as one travels north of the study area, but portions are found under the surface deposits within the Big Muddy Valley and near the town of Bengough (Whitaker 1978).

The Eastend formation rests on a gradational contact with the Bearspaw formation and also dates to the Late Cretaceous period, and can range in from 20 to 140 feet (6.1 - 42.7m) in thickness (Parizek 1964:16). The formation consists of greenish-grey, yellow and brown layers of interbedded sand silt and clay. Thin beds of ironstone and concretions of sandstone and ironstone are also present in the Eastend. Times and Stationary (1975:5) note that the upper layers are kaolinized. Portions of the Eastend formation can be found in outcrops along the Big

Muddy Valley (Parizek 1964:16). The Whitemud formation consists of thin beds of sandy clay and silt and beds of white to light grey silt, which are overlain by a mix of white, grey, pale mauve and black carbonaceous clay with silt beds (Parizek 1964:16; Times and Stationary 1975:5). It is found in outcrops along the Big Muddy Valley, and can be up to 45 feet (13.7m) thick.

Parizek (1964) divides the Ravenscrag formation into two sections: the Upper and Lower Ravenscrags, following identifications by Fraser et al. (1935). Parizek (1964:16) explains that the Lower Ravenscrag dates to the Late Cretaceous, contains dinosaur fossils and lacks lignite beds, while the Upper Ravenscrag is of Paleocene age (Tertiary), contains lignite beds and lacks dinosaur remains. However, Postnikoff (2009) notes that the Late Cretaceous Frenchmen formation is often misidentified as being part of the Ravenscrag formation (citing Fraser et al. [1935] as an example). The two formations are near identical in colour and mineralology, and the identifying traits Postnikoff (2009) uses to differentiate the two: the presence or absence of dinosaur fossils and lignite, are used by Parizek (1964) to differentiate the Upper and Lower Ravenscrags. Thus it is likely that Parizek's Lower Ravenscrag is actually the Cretaceous Frenchman formation, while the Upper Ravenscrag is the Paleocene Ravenscrag formation. Thus the nomenclature used by Postnikoff (2009) will be used for this study when referring to Parizek's Lower and Upper Ravenscrag.

The Frenchman formation is usually very thin or non-existent in the study area and rests on an unconformity with either the Whitemud or Eastend formations where the Whitemud had been eroded away earlier (Parizek 1964:16). The Frenchman formation is typically not found in areas where the Whitemud is at its thickest. It can be found in outcrops within the Big Muddy Valley (Postnikoff 2009:13), and again can be best identified by the presence of dinosaur remains and lack of lignite (Parizek 1964; Postnikoff 2009). The contact between the Frenchman and the Ravenscrag represents the K-T boundary for the region (Postnikoff 2009:9-10). The Ravenscrag formation consists of a mix of different bed units. The deeper areas contain crossbedded layers of feldspathic sand and greenish grey and yellow sandy clay beds (Parizek 1964:16). Above these layers are yellowish-brown beds of clay, silt, shales and fine sands. Upper units are cream coloured sandy clay, silt and clay beds (Parizek 1964:17). Bands of ironstone and sandstone can also be found within the Ravenscrag formation. The Ravenscrag formation can be up to 500 feet (152.4m) thick, and can be found exposed in several areas of the

Big Muddy Valley, along with the lignite deposits which run through it (Parizek 1964; Times and Stationary 1975).

The Wood Mountain formation is found in isolated locations along the plains surrounding the Big Muddy Valley (Parizek 1964: Fig 5; Whitaker 1974). The formation dates to the Miocene period, and consists of cobble sized gravels with crossbedded yellow and brown sands and thin clay beds (Parizek 1964:17). The gravels are usually composed of chert and quartzite, while petrified wood and bone are also present. The formation rests on a disconformity with the Ravenscrag.

Capping these formations are quaternary deposits. The uplands are dominated by glacial till and drift, while alluvial deposits are found in the valley bottom. Klassen (1989:141, Fig 2.17) shows that the drift thickness in the area is usually no thicker than 30 m deep, while Drew (1982) notes that the drift averages around 10m in thickness. The drift is a mix of loose Canadian Shield gravels, local carbonites, well rounded Tertiary gravels, and a mix of sands, silts and clay (Parizek 1964:24). The texture of the till is usually dominated by clay loam, but clay textures are also present (Parizek 1964:24-25, Fig 12). The alluvium in the Big Muddy Valley is generally a clay texture, with some clay and mixed loams in certain areas (Ellis et al. 1969:55).

The groundwater in the study area is closely tied to the geology. The Big Muddy Valley is part of the greater Eastend-Ravenscrag aquifer, which spans most of southern Saskatchewan (Maathuis 1999:128, Fig 3). Several ground water horizons area found in the study area, most of which are confined to the Ravenscrag formation. The formation's mix of permeable sandy beds with near impermeable clay and lignite strata provides the means for groundwater to flow within the formation along the resistant beds as reliable groundwater horizons. MacKay et al. (1936a; 1936b; 1936c) mapped known groundwater horizons across the Big Muddy Valley and surrounding areas. While many sections of these horizons can only be tapped into by deep wells, MacKay et al. (1936a: 1936b; 1936c) note that several of these horizons lay exposed along the Big Muddy Valley and other small tributary valleys creating natural springs. Concretions and dissolved minerals in the soil and bedrock can make some of the water from the springs either saline or alkaline, and MacKay et al. (1936a: 1936b; 1936c) determine sources which are fit for human use and consumption. During pre-contact periods, it is likely that these springs would have been utilized by mobile hunters in the area for personal use or for processing bison carcasses when other water sources were not readily available. MacKay et al. (1936a: 1936b;

1936c) show that horizons can be found along the valley edges in various locations between elevations of 2150 and 2520 feet above sea level (655.3 - 768.1m). The quantities of water attainable from individual springs varies, but can range to meet the water needs of up to 300 heads of stock, which is more than enough to satisfy the requirements of mobile hunters or a herd of their bison prey.

2.1.4 Soils

The soil properties and characteristics of the Big Muddy Valley and surrounding area are classified by Ellis et al. (1969). The Big Muddy Valley and proximal uplands occupy four physiographic sub sections, as defined by Ellis et al. (1969: Plate 1): Hardy Hills, Coteau Lakes Dissected Plain, Buffalo Gap Dissected Plateau and Big Muddy Channel. The Hardy Hills lie on the Missouri Coteau, and are dominated by strongly rolling glacial till moraine with features such as kames, outwash plains and lacustrine plateaus (Ellis et al. 1969: Table 1). The Coteau Lakes Dissected Plain is made up of slightly to moderately dissected till moraine with undulating outwash plains. The Buffalo Gap subsection is made up of slightly to moderately dissected uplands while local alluvial fans and bed rock plateaus are found. Finally the Big Muddy Channel consists of mostly of eroded valley walls with a flat alluvial flood plain along with alluvial fans. Most of the drainage of these sub sections drain internally, towards the Big Muddy valley, into the Coteau Lakes or into Beaver Creek.

Three dominant soil types are present in the Big Muddy Valley and surrounding uplands (Ellis et al. 1969). Brown Chernozems are found across the uplands and include the Ardill, Fife Lake and Haverhill associations. Regosols are confined to the exposures along the valley walls. Gleysols are along the valley bottom within the Big Muddy Association. Also included are depositions of hillwash or alluvium. The Ardill association is typically found on the northern side of the Big Muddy Valley. It is dominantly Orthic Brown, ranges from clay to clay loam in texture, and its parent material consists of mixed glacial till and Cretaceous shales (Ellis 1969:18). The areas closest to the edge of the Big Muddy Valley contain a significant presence of Calcareous Browns and Orthic Regosols alongside the dominant Orthic Browns, due to the high slope and dissection of the valley edge (Ellis et al. 1969:20).

The Fife Lake association is another Brown Chernozem which is predominately located on south and west of the Big Muddy Valley. The association is predominately Orthic Brown, varies in texture including clay, clay loam, mixed loam and sandy loam, and the parent material is a mix of glacial till, Tertiary bedrock and lignite coal (Ellis et al. 1969:22-24). The soils of this association which are closest to the valley edge are much more calcareous due to the increased slope and dissection (Ellis et al. 1969:25).

The Haverhill association is the last Brown Chernozem, and is located mostly surrounding Big Muddy Lake to the north, east and southeast. Like the other Chernozemic associations, the Haverhill is Orthic Brown dominant. The association's parent material is derived from glacial till, and the texture is predominately loam, with clay loam and mixed loam also being present (Ellis et al. 1969:28). Like the other Cheronzems, the Haverhill soils adjacent to the Big Muddy Valley are affected by its topography. The high slopes and erosion surfaces of the valley edge lead to Calcareous, Regosolic, and sometimes Gleysolic soils being developed alongside the dominate Orthic Browns (Ellis et al. 1969:29-30).

The Exposure association serves as one of the buffers between the Gleysolic valley bottom and the Chernozemic uplands, and consists of exposed Tertiary and Cretaceous bedrock and thin, poorly developed Regosols. The area is highly sloped and heavily eroded (Ellis et al. 1969:54). Hillwash also lines the valley edges and consists of colluvium and eroded sediment from the upper slopes (Ellis et al. 1969:60). Its texture varies depending on the colluvium's origin, and can consist of either Chernozems or Regosols, with Regosols dominant in upper slopes, and Chernozems dominant lower down (Ellis et al. 1969:60). The Alluvium complex is composed of small pockets of recently developed pond or alluvial deposits (Ellis et al. 1969:59). This association is usually restricted to the valleys and mouths of tributary streams. Within the Big Muddy Valley, the majority of the Alluvium forms either weak Chernozems which are highly gleyed and Solodized, or weak Gleysolic and Solonetzic dominant soils (Ellis et al. 1969:59-60).

Gleysolic soils make up the valley bottom and are referred to as the Big Muddy association. The Gleysols are finely textured and poorly drained, being composed of transported clay shale bedrock and poorly drained alluvial deposits, creating clay, clay loam and mixed loam textures (Ellis et al. 1969:54-55). Some of the soils are highly saline due to the poorly drained, clay rich deposits. The high clay and salt content restricts plant growth and limits which species can develop.

The high clay content of the valley bottom restricts proper drainage in the area. This causes the deposits to be highly saturated for long periods of time, making it difficult to traverse. Jolly (1983:57) refers to this sediment as “alkali gumbo,” and local ranchers had to be careful not to let livestock get too close to the water under these conditions. Cattle could easily become stuck in the mud and be left to die unless pulled out with a strong horse (Jolly 1983). If cattle are so easily mired, then other large mammals such as bison could be as well. Although prey could be easily trapped in these conditions, Frison (2004:117-118) explains that the removal and butchering of the carcass would be too strenuous to be an effective hunting practice. Therefore, it is unlikely to find many kill sites in the valley bottom that utilized this technique.

Soil stoniness also can play a role in site location. Friesen (1999) determined that tipi ring sites in Grasslands National Park were not found in locations where soil stoniness was low or nonexistent. He attributed this to the lack of large cobbles or boulders in the immediate area to use for quick construction. Since the majority of the soil associations mentioned above are based on glacial till which contains a range of stone sizes including cobbles (Ellis et al. 1969), only the alluvial based Big Muddy association will be lacking sufficient amounts of cobbles. The uplands would ensure a robust supply of field stones for the construction of driveline cairns.

2.1.5 Glacial History and Geomorphology

Glacial processes played a large role in shaping the study area's landscape. As mentioned above, glacial till and drift overlay bedrock of various depths. These deposits were laid during several episodes of glacial retreat and re-advancement over the last 20,000 years. Glacial activity also carved the Big Muddy Valley trench, as it served as a meltwater channel during later glacial periods. Parizek (1969) provides a brief summary of the glacial history of the study area, while Christiansen (1979) provides the glacial history for the rest of southern Saskatchewan.

The Big Muddy Valley lies between the Harptree end moraine to the north and east, and the Poplar end moraine to the south and west. Each moraine was formed during individual ice advances. The Poplar moraine was deposited during an ice advancement that overrode the Missouri Coteau and the present Big Muddy Valley. This corresponds to Parizek's (1964:29-31, Fig 20) Phase 2 of glacial advancement and Christiansen's (1979:918, Fig 10) Phase 1. The majority of the meltwater flowed through Rockglen Channel and new channels were formed near Big Beaver. Christiansen (1979: Fig 10) provides a date of 17,000 BP for this phase, so the

Poplar end moraine was likely formed during or around this period. The Big Muddy Valley was opened during Parizek's (1964:29, Fig 21) Phase 3, when ice had retreated/re-advanced to just north east of the valley. It was during this ice frontal position that the Harptree moraine was deposited (Parizek 1964:29). This frontal position is very similar to Christiansen's (1979:919, Fig 11) Phase 2, which he dates to 16,500 BP. Portions of the Harptree moraine are dissected by meltwater channels draining westward into the Big Muddy Channel during subsequent re-advancement phases (Parizek 1964).

The large trench which constitutes the Big Muddy Valley was eroded as a glacial meltwater spillway during glacial retreat. As mentioned above, the Big Muddy Channel was opened approximately 16,500BP as a spillway channel for waters melting from the receding Laurentide glacier at the end of the Wisconsinan glaciation. As it does today, the Big Muddy Valley would transport water into the Missouri River system. Schumm and Brakenridge (1987:232-233) suggest that the headwater valleys of the Missouri were greatly influenced by meltwater. Proglacial lakes would collect along the ice edges, and would be dammed by ice or moraines. When these dams burst, outwash channels would flood rapidly and carve deep, wide valleys. This was the case for the Big Muddy, draining glacial lakes such as Lake Willows, Lake Kincaid, Old Wives Lake, and Lake Bigstick (Parizek 1964: Fig 22, Fig 25; Christiansen 1979: Fig 11, Fig 12). After 15,500BP, the ice sheet had retreated north past the Missouri drainage divide, causing all melt water to travel northward (Christiansen 1979: Fig 13).

After being cut off from source water from the ice edges, the Big Muddy spillway would have changed considerably in response. Schumm and Brakenridge (1987) describe the effects that such changes have on a river. As river discharge decreases, channel size decreases in turn, with a drop in both channel depth and width. The sediment load of the river will also shift as discharge changes. Sediment size and quantity decrease as river discharge decreases, which shifts dominance from bedload to suspended load, as the stream has less power to move larger sediments. River sinuosity will increase as discharge decreases. Thus, as water quantity was reduced during glacial retreat, the stream within the Big Muddy Channel shrank in size and sediment load, while increasing in sinuosity (Schumm and Brakenridge 1987:225, Fig 4). This led to the present state of the Big Muddy Creek, a low discharge and highly sinuous stream placed within a very wide and deep valley. Since the Big Muddy Creek in its present state could not have carved the valley in which it resides, it is known as an underfit or misfit stream.

2.1.6 Paleoclimate

Approximately 10 km north of the Big Muddy Lake is a large playa known as Salt Lake or Ceylon Lake. Teller and Last (1990) summarize the lithology, mineralogy, and salt concentrations of the saline lake sediments to recreate the fluctuating depositional and hydrological conditions through time. Teller and Last (1990:Fig 3) note the lake's water levels steadily declined after being cut off from glacial outwash and eventually drying up around 8000 BP. The lake would remain dry between 8000 and 4000 BP, save for two periods of slightly higher lake levels around 7500 and 6500 BP. These drops in lake levels are interpreted to be in response to a period of increased aridity (Teller and Last 1990: 222). Lake levels would rise past 4000 BP, but never return to their early Holocene quantities. If the lake levels in Salt/Ceylon Lake are taken as a proxy for changes in the local climate, then the Big Muddy Valley area has fluctuated in aridity throughout the Holocene. These fluctuations can be seen in several other lakes found across the Northern Plains (Laird et al. 2007).

2.1.7 Non-Glacial Geomorphic Influences

The present landscape of the Big Muddy Valley has been influenced by other geomorphic forces since glacial retreat. Although many of the streams in the drainage are very weak, fluvial forces slowly continue to shape the valley sides and bottom through cycles of erosion and deposition. Due to combined effects the high clay content in soils, thin quaternary deposits and intense summer rainfall events lead to large quantities of water flowing overland. Over time this will incise new or extend existing rill and gully systems in the hillside. The thin soil development is also susceptible to eolian processes which can easily erode or redistribute sediment across the landscape. Valley edges are also susceptible to colluvial erosion and mass wasting events. For example, rotational slumping has been known to occur in the area (Bengough Historical Book Committee 2005:838), when underlying sediments along the valley edge become destabilized by subsurface water.

Subsurface water also plays a considerable role in shaping the topography of the study area through piping. Drew (1982:303) estimates that over 50% of the drainage of upland buttes and slopes is performed through piping. After rainfall events, water will slowly percolate through the soils until it reaches less permeable strata, such as Ravenscrag bedrock. The water will then flow along the barrier to an exposure on the hillside and continues to flow overland downhill. Over time these pathways, with the assistance of burrowing animals, will carve out a network underground pipes and channels (Drew 1982: Fig 16.7). The outlets from these pipes will expand to large cave openings in the valley walls if given enough time. Eventually these pipes will collapse, creating new gullies or expanding existing ones. Collapsed pipes can also leave hoodoos along the valley wall.

2.1.8 Flora and Fauna

Times and Stationary (1975:8-12) provide an overview of plant and animal species found in the study area. The plants found in the Big Muddy Valley consist mostly of resistant short to medium prairie grasses. Broomweed (*Gutierrezia sarothrae*) and Prickly Pear Cactus (*Opuntia*) are found mostly on the dry southern slopes. Grasses include Bluestem (*Andropogan scoparius),* Blue Grama (*Bouteloua gracilis),* speargrass (*Stipa comota),* and June grass (*Koeleria cristata*), all of which will grow on different slopes depending on available moisture. Shrubs are able to grow in areas of increased moisture retention. Creeping Juniper (*Juniperus horizontalis),* low Juniper (*J. communis*), Saskatoon berry (*Amelachier alnifolia*) and snowberry (*Symphoricarpos sp.*) are all example of shrub vegetation found in the area. In the valley, trees such as Aspen (*Populus tremuloides*), American Elm (*Ulmus americana*) and Green Ash (*Fraxinus pennsylvanica subintegerrima*) grow along north or north-east facing slopes. Saline soils will restrict plant growth, especially with shrubs, to species which are more saline tolerant.

The fauna of the area are typical to those in a semi-arid grassland environment. Tiger salamanders (*Ambystoma tigrinum*), grass frogs and garter snakes (*Thamnophis elegans terrestris)* are common amphibian and reptile species in the area. Birds consist of waterfowl such as surface and diving ducks, and birds of prey such as the prairie falcon and red-tailed hawk (*Buteo jamaicensis).* Vultures, golden eagles (*Aquila chrysaetos)* and burrowing owls (*Athene cunicularia*) are also known to be found in the area. Rodents, such as mice, shrews, voles and ground squirrels are abundant to the area. Carnivores in the area include coyotes (*Canis latrans*), red fox (*Vulpes fulva*), long tailed weasel (*Mustela frenata*), badger (*Taxidea taxus*) and skunks (*Mephitis mephitis*). Grey wolves (*Canis lupus*) were also present during the early homesteading period (Jolly 1983). Modern ungulates include the mule and white-tailed deer (*Odocoileus hemionus and O. virginianus*), and the pronghorn (*Antilocarpa americana*), while bison (*Bison bison*) were more abundant in pre-contact periods.

Friesen (1999) identifies that the presence of grass species such as blue grama, speargrass and western wheatgrass has a strong association with pre-contact habitation sites in Grasslands National Park. He explains that these grass species make up a significant portion of a bison's diet. Babin et al (2011) expands on this idea that bison prefer grasses that offer the greatest instantaneous caloric value and identifying grama and speargrass as such grasses. Since bison would gather in locations where these grasses were abundant, pre-contact hunters could use this vegetation to predict where bison were to congregate. Thus Friesen (1999:151-152) attributed the association between grass species and habitation sites as representing an aspect of pre-contact hunting strategy. Within the Big Muddy study area, the vegetation found there would be highly attractive to both bison and bison hunter alike.

2.2 Archaeological Research in Roan Mare Coulee

2.2.1 The 1986 Assessment

This thesis project is largely an extension of the work performed by Dr. Ernest Walker during the late 1980s. In 1986, Walker was asked by the Heritage Branch of Saskatchewan Culture, Multiculturalism and Recreation to assess the Sabin Buffalo Jump (DhNe-1) for archaeological and tourism potential. The Sabin Jump had been known to local land owners in the area for several decades and had been first recorded by Thomas Kehoe in 1962. Through the course of the assessment, a lack of bison bone was noted from the auger holes and backhoe trenches at the base of the jump (Walker 1988). A short distance from the jump, materials including lithic tools and fire-broken rock were uncovered in shovel tests. Walker (1990: 31-38) attributes this discrepancy in faunal and lithic remains to a lack of deposition in the local area, given the steep slope of the talus deposit below the jump. After a kill, the bison bone would lie uncovered on the surface and be exposed to the elements. Given enough time, the faunal deposits would decompose while the hardier stone materials would be left behind.

During this assessment of the bison jump, Walker was informed by local landowners and residents of other archaeological sites in the area. This included the Roan Mare Coulee Tipi Ring site (DhNe-25), a mass accumulation of stone circles in the uplands opposite the Sabin jump. Three hundred forty-eight tipi rings, 50 associated structures and 46 stone cairns were mapped during the course of the investigation (Walker 1988). From this accumulation, four separate sites have been identified: DhNe-26 which includes a large boulder alignment and nearby ceremonial structures, DhNe-27 a homestead consisting of a large cellar depression surrounded by an elliptical trench, DhNe-28 which consists of 28 tipi rings on a small spit of land between drainages which show little evidence of burial, and finally DhNe-25 comprises the remaining stone circles and cairns in the region (Walker 1990: 43-55).

Walker's 1986 evaluation of the area also included a large stone effigy known as the Minton Turtle (DhNe-2). As the common name implies, the effigy resembles a turtle and its shell. Like the Sabin jump, the effigy has been known to local land owners for several years. The turtle rests on a small stretch of upland which is surrounded by small drainages and gullies, slightly east of where Roan Mare Coulee joins with the larger Big Muddy Valley. From the effigy, the view can stretch several kilometres across the Big Muddy, most notably to the east, south and west. Local topography obscures sight northward, but a sizable portion of Roan Mare Coulee's western uplands can still be seen to the northwest. An intrusive burial beyond the central cairn is also present (Walker 1988: 28).

The success of the 1986 project prompted Walker to return to the area to lead a more intensive research survey of Roan Mare Coulee. The project was conducted over the summers of 1988 and 1989 with a total area of nine square miles investigated. The survey portion was completed in 1988, identifying 120 archaeological sites (Figure 2.1), and 1989 focused on controlled test excavations in predetermined areas (Walker 1990: 1-2). The goals of the research were to build an intensive understanding of both the archaeological variety in the study area, as well as the sites' relation to their environment and locations (Walker 1990: 10).

2.2.2 The 1988-89 Survey: Design and Biases

Walker's investigation was approached by a saturation sample design, where the entirety of the nine square mile study area is surveyed equally (Walker 1990: 10). While 100% saturation of a target area is a lofty goal, it is ultimately unattainable as error can emerge from a variety of factors during the course of a survey. The discovery probability of a survey can be affected by several factors from sites and their environment, as well as the survey design and strategy (Schiffer et al. 1978: 4). Each factor has different roles to play in how sites are discovered and how they contribute to the overall archaeological diversity of the area.

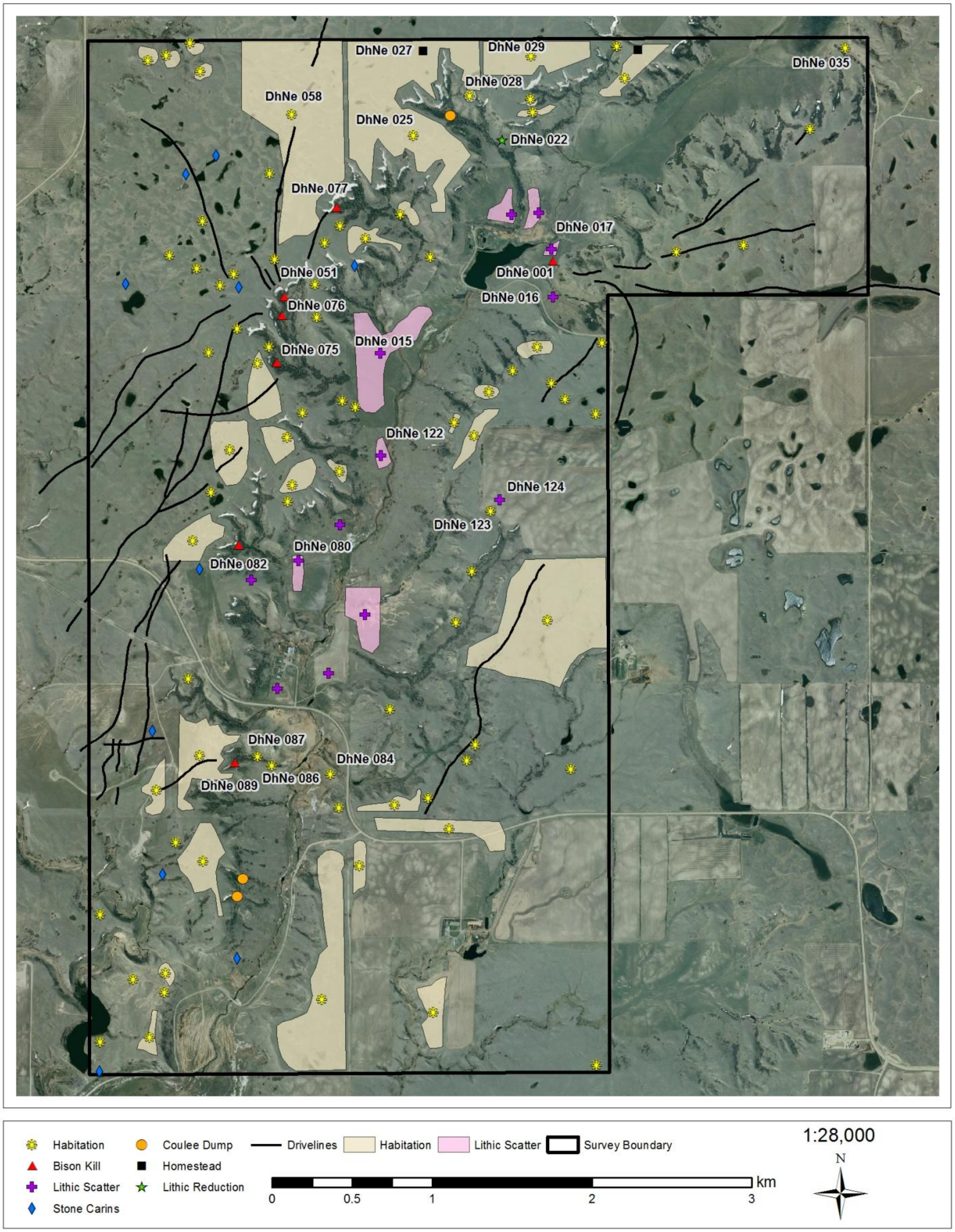

Figure 2.1: Map of Walker's 1988-89 Survey. Labelled sites are those mentioned in this chapter.

Abundance refers to how much archaeological evidence there is in a given area, and typically discovery probability increases with abundance (Schiffer et al. 1978: 4). Different site types have different abundances, and this can also be seen in the Roan Mare survey (Figure 2.1**)**. Habitation sites are grossly abundant while small lithic scatters are less so. The saturation survey allowed for information from less abundant sites to be included in the data as they are less likely to be hit in a probabilistic survey design.

Clustering is the degree in which similar archaeological evidence is spatially separated, and is inversely proportional to discovery (Schiffer et al. 1978: 4). Clustering also varies based on site type. Again, the saturation design allows for identification of highly clustered sites which may be missed by other sampling techniques.

Obtrusiveness refers to how well a site type is at being identified by a given method or technique of the survey (Schiffer et al. 1978: 6). For example, buried sites show low obtrusiveness to techniques that do not employ sub-surface testing. On the other hand large tipi ring accumulations and drivelines would be highly obtrusive to fieldwalking in transects.

Visibility is the extent to which archaeological evidence can be detected by a surveyor in a given environment (Schiffer et al. 1978: 6). Much like obtrusiveness, visibility can vary from different site types, but also between different environments and ecozones. In the Roan Mare Coulee example, the open grassy uplands creates high visibility for stone features such as drive lines or cairns, which would be less likely to be seen in the shrub vegetation near the water courses. Subsurface artefacts become more visible in tilled fields as they are churned up to the surface. The different visibility of different archaeological evidence can change how site types are defined. Walker (1990: 25) makes note of this between sites DhNe-123 and 124. DhNe-123 consists of an isolated tip ring, while 124 is a small lithic scatter in a neighbouring tilled field. He suggests that 124 may have been another tipi ring site that was disturbed by ploughing. Since a large portion of the study area is used for forage ranching, it may have led to an over identification of stone features, as the grasses were short enough to identify the stone arrangements more clearly.

Accessibly is the degree to which the surveyors can reach particular areas to assess them (Schiffer et al. 1978: 8). Restraints from factors such as vegetation, topography and available infrastructure can reduce how effectively a study area is covered. For the Roan Mare Coulee project, accessibility was not a large factor. The majority of the terrain can be covered on foot or horseback, and the remote areas were never far from an access road.

Survey design and identification strategies

As mentioned above, the methodology of a survey can favour some sites over others based on their obtrusiveness. Walker preformed the survey in transects with two to as many as 12 field assistants spaced 20m - 25m apart (Walker 1990: 10). This strategy has the chance of overlooking small debris scatters between each observer, while larger stone features can be easily identified. This discrepancy is accounted for in that "once a locus of cultural activity was identified, it was flagged and a random surface collection of artifactual material proceeded" (Walker 1990: 10-11). Sites were identified by evidence of human alterations to the environment or in the case of artefact scatters; an arbitrary cut-off of 20 artefacts was required to be considered a site (Walker 1990: 11-12). Evidence for buried sites prompted the use of random shovel testing and particular sites were chosen for controlled test excavations in 1989 (Walker 1990: 11).

When all the factors affecting discovery probabilities of a survey are considered together, the results of the Roan Mare Coulee Project are indeed biased to some degree. High abundance, visibility and obtrusiveness along with moderate clustering favoured the discovery of large sites with stone features (rings, cairns and drive lines). Smaller site types, such as lithic scatters and reduction areas are less favoured due to low abundances and visibility with higher clustering. However, the intensive strategy does improve the chances of discovery of these small sites, which could be missed in more probabilistic designs. Shovel testing does aid in the identification of buried sites but this is only done if evidence for burial is identified beforehand. Also note that small portions of the coulee are underwater by modern dams and reservoirs, so these areas have no discovery potential due to low obtrusiveness, visibility and access. Overall, the intensive survey did cover as much area as possible and identified a large number of sites. Just note that no survey is unbiased or 100 percent complete.

Survey Results

Walker's survey breaks down into the following site types:

Table 2.1: Breakdown of sites in Walker's 1988-89 surveys (Adapted from Walker [1990, Table 4]).

Site Type	Number	Recorded Features
Lithic Scatter	13	NA
Habitation	81	1379 Rings 228 Cairns
Bison Kill	7	NA
Lithic Reduction	1	NA
Boulder Alignment	1	NA
Stone Carins	12	22 Cairns
Coulee Dumps/Bait Traps	3	NA
Homestead	2	NA
TOTALS	**120**	**1379 Rings** **250 Cairns**

As seen in Table 2.1, the majority of the sites in Roan Mare Coulee are habitation sites which include a large number of tipi rings. Several of these sites contain multiple rings, as seen in Table 2.2, suggesting that these locations were occupied by more than one family or repeated occupation by different groups through time. Many of the large sites seen in Figure 2.1**,** such as DhNe-25 and its neighbours cover vast areas and contain high quantities of tipi rings within. The lone tipi ring sites (n = 14) are found typically away from the major accumulations of sites. Walker (1990: 129-130) provides two possible scenarios for this discrepancy: the sites are simple transient camps for a small group on route to a new area, or specialized activity sites due to their isolated and sometimes topographically restrictive locations.

Table 2.2: Tipi ring distribution amongst habitation sites.

Number of Rings	Number of Sites	Total Rings	Cairns
Single	14	14	3
Greater than 1	67	1365	225
TOTALS	81	1379	228

For the multiple ring habitation sites, the number of rings range from two to 320 per site. Walker (1990: 131) mentions that the lower end of the range represent single occupations, while the larger accumulations are multiple sites amassed together and reflect repeated occupations. This is confirmed by Table 2.3 and Figure 2.2 which highlight the discrepancies in the tipi ring site data. Table 2.3 breaks down the number of sites based on their ring counts while displaying their total and cumulative percentages of the site and ring totals. It also includes three measures of central tendency, and through their comparison one can conclude the allocation of tipi rings among sites is not normally distributed. Figure 2.2 is a classic Lorenz curve made by plotting the final two columns of Table 2.3 against one another. It highlights that the majority of stone rings are found in a scant number of sites, while the majority of sites hold a disproportional quantity of rings.

Examining the data from Table 2.3 and Figure 2.2 shows that several of the habitation sites with multiple rings in Roan Mare are small accumulations. With 2 rings as the mode and 8 rings as a median, the preference for smaller accumulations is apparent. In fact, sites with 8 or fewer rings comprise more that 50% of the total habitation sites. Also, while the mean of 20 is very much skewed by DhNe-25 as an outlier, it still supports evidence for smaller accumulations, as sites with 20 or fewer rings comprise more than 75% of the site data. The preference for smaller accumulations strengthens Walker's conclusions that the larger sites are simply aggregations of many different sites across multiple occupations. The reason these aggregations were identified as large individual sites may come back to Schiffer et al.'s (1978) survey factors. The abundance of tipi rings and upon the uplands, combined with their high visibility and obtrusiveness to the survey technique would have made it difficult to separate out different occupations by location alone. In fact Walker (1990) repeatedly mentions that some of the site boundaries for DhNe-25, 29 and 58 are based on the legal sections and are thus arbitrarily derived. Rather, they represent one massive aggregation of several smaller sites across this area of the survey.

Also of note for the tipi ring sites is that the large majority of them (n= 76) are located upon the undulating uplands surrounding the coulee proper. Very rarely do the habitation sites reside within the valley bottoms, either the main channel or the fingerling drainages flowing into it. DhNe-31, 35, 84, 86, and 87 are the only sites Walker (1990) confirms being found in the valley bottom. This dichotomy between the uplands and lowlands could be suggestive of preferential settlement patterning or simple survey error. Walker (1990: 131) suggests that DhNe-31 in particular may represent a winter occupation where shelter was sought in the more enclosed valley from the elements. This would have also brought people closer to wood resources found in the valley bottoms, allowing for quicker and more efficient timber harvest for

Table 2.3: Tipi Ring Distribution for Multi-Ring (>1) Habitation Sites.

Ring Count Class (A)	Sites per Class (B)	% Sites = (B/C) * 100	% Rings = ([A x B]/D) * 100	Cumulative % Sites	Cumulative % Rings
2	16	23.88	2.34	23.88	2.34
3	3	4.48	0.66	28.36	3.00
4	5	7.46	1.47	35.82	4.47
5	3	4.48	1.10	40.30	5.57
6	3	4.48	1.32	44.78	6.89
7	2	2.99	1.03	47.76	7.91
8	4	5.97	2.34	53.73	10.26
9	1	1.49	0.66	55.22	10.92
10	6	8.96	4.40	64.18	15.31
12	1	1.49	0.88	65.67	16.19
14	2	2.99	2.05	68.66	18.24
16	1	1.49	1.17	70.15	19.41
17	3	4.48	3.74	74.63	23.15
20	1	1.49	1.47	76.12	24.62
21	1	1.49	1.54	77.61	26.15
24	1	1.49	1.76	79.10	27.91
28	1	1.49	2.05	80.60	29.96
29	2	2.99	4.25	83.58	34.21
32	2	2.99	4.69	86.57	38.90
37	1	1.49	2.71	88.06	41.61
47	1	1.49	3.44	89.55	45.05
60	1	1.49	4.40	91.04	49.45
61	1	1.49	4.47	92.54	53.92
68	1	1.49	4.98	94.03	58.90
76	1	1.49	5.57	95.52	64.47
82	1	1.49	6.01	97.01	70.48
83	1	1.49	6.08	98.51	76.56
320	1	1.49	23.44	100.00	100.00
Site Total (C)	**67**				
Ring Total (D)	**1365**				
Mean (D/C)	**20.37**	**Median**	**8**	**Mode**	**2**

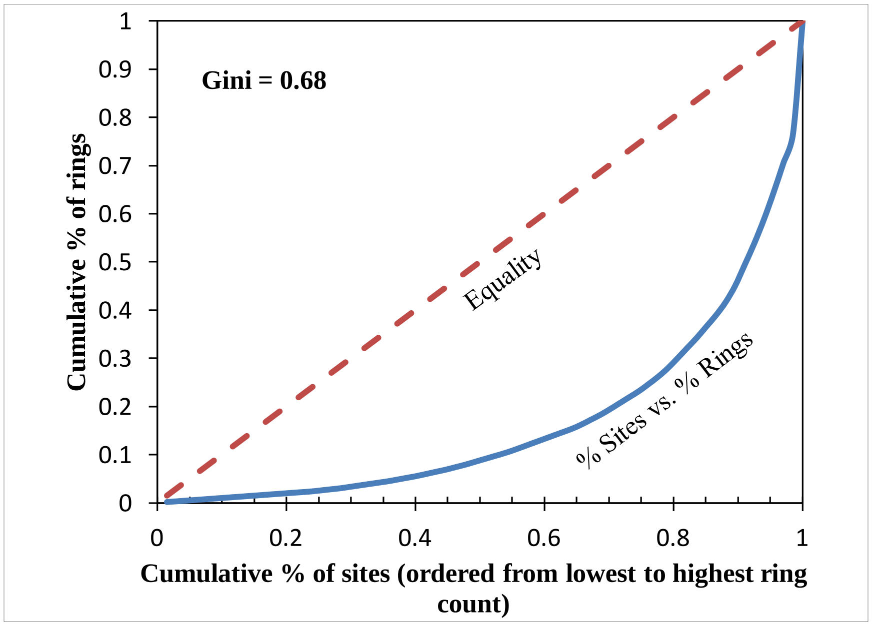

Figure 2.2: Lorenz Curve of Tipi Ring Allocation per Habitation Site (multi-ring).

firewood. However, the absence of tipi rings in the lowlands may also be a visibility issue. It is much easier to plant crops in the valley bottom due to its flatter terrain and ease of access. Thus several large portions of the valley floor have been ploughed and tilled. This activity may have destroyed tipi ring scatters, rendering them unrecognizable by archaeological surveyors. Erosional and depositional forces are also more numerous in the valley compared to the uplands due to the migration of the underfit stream so habitation sites have a higher chance to be destroyed or buried in the channel. Ultimately the likely outcome is a combination of all these scenarios; selective settlement in the uplands and taphonomic forces removing habitation sites from being visible in the valley bottoms.

One of the other prominent stone features found during the course of the survey were the numerous stone cairns. These features are typically composed of a large pile of field stones, built up to various sizes. Twelve out of the 120 sites, or 10% of the total, contain stone cairns with no other stone features present. These 12 sites account for 22 of the cairns identified during the course of the survey. The remaining 228 are found in association with tipi rings, thus are included under the habitation site class (Table 2.1 and 2.2). In fact, as can be seen in Table 2.4, a slim majority of habitation sites have at least one associated cairn within them. The association of cairns with tipi rings could suggest that they share a relationship to the camp structure in the area (Walker 1990: 132). On the other hand, one possible explanation is that more cairns are found at larger tipi ring accumulations by the sheer fact that more area is covered. So the issue may be a side effect of the survey design, the cairns are found with large tipi ring clusters because they cover larger areas and both features are very obtrusive to the transect technique. Figures 2.3 and 2.4 show there is a slight positive correlation between tipi ring and cairn quantities. However, with the R^2 values of 0.7816 and 0.4486, it is likely both situations are at work, some cairns may be associated with the camping strategy while others may just fall in the large site areas by chance.

Table 2.4: Breakdown of Cairn Counts among Habitation Sites.

Subclass	Site Count	Ring Count	Cairn Count	% Sites	% Rings	% Cairns
Pure Habitation	40	226	0	49.38	16.39	0.00
Hab with Cairns	41	1153	228	50.62	83.61	100.00

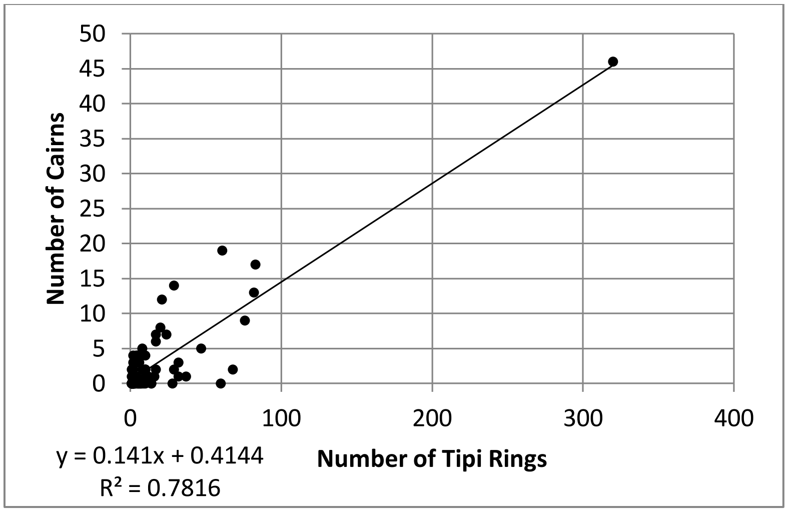

Figure 2.3: Number of Cairns vs. Number of Tipi Rings at Habitation Sites in Roan Mare Coulee.

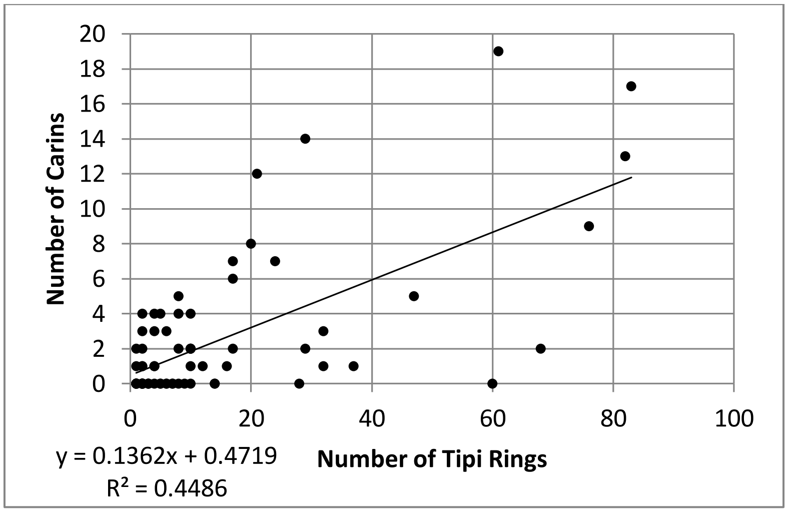

Figure 2.4: Number of Cairns vs. Number of Tipi Rings at Habitation Sites in Roan Mare Coulee (DhNe 25 removed).

Some miscellaneous site types found during Walker's survey include the remains of two homestead cellar pits, one of which is DhNe-27 mentioned earlier with the elliptical trench. A small lithic reduction station was found at DhNe-22 resting upon the valley slope, and included evidence of several stages of lithic preparation (Walker 1990:41-42). Given the location on the slope and nearby exposures of glacial gravels, the site may have served as known lithic source of the tan and grey quartzite tool stone. The large boulder alignment at DhNe-26[1] is also an interesting feature. Its function is unknown and hard to determine, but likely held strong ceremonial value. This hypothesis is strengthened by the discovery of a small circular stone

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[1] This site is not shown on Figure 2.1, as it is classified as a Site of Special Nature and thus cannot be displayed.

feature south of the alignment. Walker (1990:48) determined this as the remains of a sweat lodge, thus ceremonial activity was very likely practiced in the area. Also, it should be noted that several large stone features are found in the rest of the Big Muddy area, such as the Minton Turtle mentioned above, but also the Big Beaver Bison Effigy (DgNh-3), the Pat Gilles Ceremonial Circle (DgNg-1) and the Dick Giles Turtle Effigy (DgNg-2). The abundance of these large boulder structures should be a strong indication of the importance of the Big Muddy area in prehistory.

Certainly the largest sites found during the survey are the seven bison kills: DhNe-1, 51, 75, 76, 77, 82 and 89. Each of these sites is found adjacent to a steep incline, separating the prairie uplands from the valley bottoms. The first kill, the Sabin Bison Jump, is the anomaly of the group. DhNe-1 is the only kill located on the eastern margin of Roan Mare coulee, suggesting the bison moved east to west over the cliff face. The others, as seen in Figure 2.1, skirt the western valley edge, prompting an eastern run instead. DhNe-1 is also unique amongst the group in that it is only the kill which terminates upon an escarpment of exposed Ravenscrag bedrock. The remaining six all terminate upon shallower valley edges. These edges are still quite steep and do create swift changes in elevation, but they do not have the sheer drop created by the bedrock exposure.

Aside from the drop point and the killing surface below, DhNe-1 has nine associated stone features known as drivelines which aid in its operation and function. Drivelines are simple accumulations of single stones and small cairns laid out in a linear fashion across a landscape. Since DhNe-1 is the only bison kill on the eastern edge of the valley, it is assumed that all drive lines upon the eastern uplands are associated with it. As shown in Figure 2.1, these drive lines extend for several kilometres to the northeast, east, and south. Some of these drivelines are lost in ploughed areas, but continue on after leaving agricultural fields (Walker 1990: 28). From these drivelines form two main drivelanes, one from the north and east, and the other from the south and southwest (Walker 1990: 28). These drivelanes serve to funnel bison from the gathering basin toward the jump, slowly narrowing the gap between separate lines as the terminus approaches. Smaller sub-lanes will eventually join much like a stream network farther from the gathering area. Driveline and drivelane functions will be examined in further detail in Chapter Three.

The drivelines and drivelanes on the western uplands are much more complex than their eastern brethren. There are at least 21 different drivelines that make up the network of lanes in the western part of the study area (Figure 2.1). With so many lines amassed and often overlapping in such a small area, it is hard to determine which lines are associated with which drop off point. Each kill has at least one set that are oriented towards their respective terminus, except for DhNe-77. Walker (1990:94) suggests that this kill shares the drivelines leading to DhNe-51, including one that joins the two coulees that serves as a barrier for overshooting either drop off. Sharing or reusing drivelines for separate kills is a likely scenario, especially in the case of DhNe-51, 75, and 76, which are all clustered into the same coulee system. The preference and reuse of popular drivelines in this cluster of sites is one of the foci of this research and will be revisited in later chapters.

The material data for each kill are limited to some surface collections, shovel test samples and a handful of test units Walker conducted during the survey. DhNe-1, as mentioned above, shows a lack of faunal information due to unfavourable preservation, while lithic data can be found further down slope. Neighbouring sites DhNe-16 and 17 show evidence of comminuted bone of unidentifiable origin and a bison first phalanx (Walker 1990: 38). These sites also contain fire broken rock, lithic debitage, cores, retouched tools and a Prairie and Plains Side Notched projectile point respectively.

The Ironhorse Bison Jump (DhNe-51) contained a wealth of material culture including lithic, faunal and ceramic items. The kills on the western edge of the valley have different depositional conditions than found at the Sabin Jump, thus more information is preserved. Walker (1990: 65-66) notes that the valley below the jump point contains three terraces with the top most containing three distinct bone beds below the surface. Bone from these beds was identified as bison and contained a mix of burned and unburned elements. The other terraces yielded similar quantities of bone as well as a small pecking hammer (Walker 1990: 66). The date of these beds is unknown, but projectiles found in the lower parts of the coulee suggest Plains Side Notched and earlier Sandy Creek occupations. Evidence for the Plains Side-Notched occupations is strengthened by *in situ* artefacts discovered in two controlled 1x1m test excavations, including another projectile point and pottery sherds (Walker 1990: 70-77). Certainly more excavations are required at DhNe-51 to understand its history of use in antiquity.

Located west of DhNe-51, in a small offshoot of the same valley is DhNe-76, another multiple component bison kill. A long spit of upland running southeast separates 51 from 76, but the two valleys join downstream before entering into the greater Roan Mare Coulee (Figure 2.1). Given the density of bison bone emerging from shovel tests, Walker also opened a 1x1m test excavation at this site like at DhNe-51 to assess the stratigraphy (Walker 1990: 84). Unlike DhNe-51, the statigraphy at DhNe-76 did not contain discernible strata, rather a large mass of greasy black silt. Walker (1990: 86-93) identified two probable occupations, the lower of which contained three Plains Side Notched projectiles, giving a similar age to DhNe-51 and other kills in the area. This layer also contained a small ash filled pit in its northeast corner. The only diagnostic from the upper occupation was a glass trade bead, suggesting the site could have been used as late as the Early Contact period on the Plains. Pottery, lithic debitage and tools and a multitude of bison bone were also found in both cultural layers. As there were no stratigraphic breaks down to depths of 70 cm, further excavations should be conducted at DhNe-76 to properly assess the statigraphy and potential older occupations.

The only other kill site to receive a test 1x1m excavation during Walker's survey was DhNe-82 to the south. DhNe-82 rests in a separate coulee from DhNe-51 and 76 mentioned above, as seen on Figure 2.1. DhNe-82 yielded much less cultural material than its northern brethren. Whether this deficiency of information is due to a lack of use, different taphonomic forces or simple sampling error has yet to be determined. Nevertheless, the test excavation did hold a small sample of burned and unburned bone, fire broken rock, and some lithic debitage (Walker 1990: 115-116). Notably a large core of Swan River chert was excavated, along with a sample of red ochre. No diagnostic artefacts or pottery were excavated, so the age of the site cannot be completely verified. Downstream of this kill however is a large lithic scatter, DhNe-80, and could represent the processing area of the kill (Walker 1990: 115). DhNe-80 will be elaborated upon below.

The remaining kill sites, DhNe-75, 77, and 89, did not receive test units, so their information comes from surface collections and shovel testing. DhNe-77 contains both burned and unburned fractured bone, fire broken rock, a Plains Side Notched Point and lithic debitage, much like the other kills in the area (Walker 1990: 94). Of particular note for this site is evidence for Mortlach pottery, which dates to the Late Precontact Period on the Plains (Walker 1990: 94) and overlaps with Plains Side-Notched material, further strengthening the evidence for

Late Period occupation of sites in this area. DhNe-75 is nestled between DhNe-51 and 76 as they all share the same coulee drainage. DhNe-75 is separated from DhNe-51 by a small jut of land extending into the valley (Figure 2.1). It shares the same types of material culture as the other kills such as fire broken rock and burned bone fragments. It lacks debitage aside from a lone chert flake, but two whole elements were recorded: a bison right tibia and a burned second phalanx (Walker 1990: 83). DhNe-89 is the final and southernmost kill in the study area. Walker (1990: 118) mentions that this particular valley has been used to shelter cattle and thus has experienced higher levels of disturbance than other kills. No debitage, pottery or fire broken rock were recorded, only a large quantity of bison bone and a pecking hammer.

The final sites recorded by Walker in Roan Mare coulee were lithic scatters, of which 11 were found. The majority of these scatters are located along the valley bottom. The function of these sites could be a multitude of different things including tool workshops, former habitation sites, bison processing areas, etc. As the name implies, the majority of the artefacts from these sites are lithic tools, cores, debitage and fire broken rock. Faunal remains are found only at five sites, DhNe-15, 16, 17, 80 and 122, three of which are downstream of a nearby bison kill. Pottery was also found at DhNe-15 and 80. The variety of different artefacts at these two sites could be a result of favourable preservation not found at the other sites, or specialized activity occurring during their occupation.

DhNe-15 is a large expansive lithic scatter site located in the centre of the valley that runs north-south with a small arm extending to the northeast (Figure 2.1). Walker (1990: 23) notes that portions of this site along the creek’s edge had been cultivated years prior and had since been reseeded for grass. Thus the site has been marred by ploughing and other disturbing factors associated with agricultural fields. Nevertheless, the site does hold a substantial quantity of lithic debris including cores, debitage flakes, spalls, scrapers, and retouched flakes. The diversity of different material types is particularly interesting with the assemblage including Rocky Mountain quartzites, Swan River chert, feldspathic siltstone, grey and brown chalcedonies, fused shale, banded jasper, and some unspecified chert (Walker 1990: 23). As mentioned above, the site does contain faunal and ceramic evidence in the form of bison tooth fragments and a single body sherd respectively. Walker (1990: 24) acknowledges that no subsurface deposits were found. This may be due to the fact that the lower deposits may have been churned upward due to the aforementioned ploughing. The big attraction to this site is that it is immediately downstream of four of the bison kills mentioned above, where their respective valleys join with the main channel. This association will be discussed later.

DhNe-80, while smaller than DhNe-15, holds vastly more information. The site rests on the western bank of the creek, near the mouth of another small coulee and south of DhNe-15. Like its predecessor, DhNe-80 contains a plethora of archaeological material including lithic, faunal and ceramic remains and is found in an agricultural field. Unlike DhNe-15, the site contains subsurface components revealed through shovel testing and test excavations. Walker (1990: 111) identified 4 separate occupation levels and evidence for buried soil horizons. DhNe-80 contains the largest and broadest assemblage of diagnostic artefacts of any site in the survey, both in terms of quantity and time range. Surface collections contained 14 projectile points including two Plains Side Notched, three Prairie Side Notched, and two Pelican Lake style points. Two other projectiles show evidence of side and corner notching, and the remaining five cannot be identified (Walker 1990: Table 1). The lithic material is consistent with that found at DhNe-15, but also includes silicified peat, agate, petrified wood and obsidian. Other cultural items include retouched flakes, scrapers, hammerstones, bifaces, awls, a pipe bowl fragment, eight Mortlach style ceramic sherds, and a small quantity of fragmented bone along with some larger bison elements (Walker 1990: 97-103).

2.2.3 Site Interactions and Summary

The archaeology of Roan Mare Coulee is both diverse and intertwined. Site types range from bison kills to habitation areas, ceremonial locations to small lithic scatters. As mentioned above the most abundant site types are the stone ring habitation sites. Well over 1300 rings were recorded in the region, the bulk of which rest in six large accumulations (Table 2.3). The majority of the ring sites are found on the prairie uplands, adjacent to the valley edge. Lithic scatters, the second most populated site class, on the other hand primarily occupies the valley bottoms. This bias is likely a result of the difference in destructive forces between the uplands and basins. Ploughing is more prevalent on the valley floor which can obscure stone rings, but upturn buried artefacts. Artefacts such as lithic debitage and small debris typical of the lithic scatters have been found at habitation sites in other parts of the study area. This suggests that the site type classes can overlap and that sites can have multiple functions and activities occurring within them, even if evidence for these activities are not apparent.

The association of cairns with several stone rings at habitation sites is another example of function overlap. As elaborated earlier, stone cairns existing by themselves are found only at 12 sites, while 41 habitation sites contain at least one cairn. These associated cairns can be found either removed from the tipi rings or contained within their structure (Walker 1990: Figure 16) and might be associated with the camp structure. While larger tipi ring scatters do not generally mean more cairns will be found within their boundaries, they do show slight positive correlation. As these large scatters of tipi rings are likely just large palimpsests of smaller occupations built up over time, the cairns held within could have originally been isolated and had tipi rings built up around them. It is only through excavation and proper mapping of the individual features in these large accumulations can arguments of contemporaneity and association be properly addressed.

Another cross-site association is found between the habitation areas and the bison kills. The most obvious is the clustering of large tipi ring scatters just uphill of the large kills on the western side of the study area (Fig 2.1). Four of the seven kills have habitation sites encroaching upon their drop-off locations, with DhNe-1, 51 and 75 being the exceptions. Walker (1990: 44) notes that evidence for tipi rings decreases with distance from the valley edge, and the large accumulations may be a result to the proximity to the kills. However, this association is both intuitive and counter-intuitive. Remaining close to such large food and resource locations offered by the kill sites is certainly advantageous, but camping right over the main drive lanes during an active bison drive would lead to disaster. Thus the contemporaneity between these kills and adjacent tipi ring scatters is called into question. What could be the case is that the habitation areas were used during communal bison hunts, but not during ones where the adjacent kill was being utilized. This could explain why 1, 51 and 75 have much smaller habitation sites nearby, as there is little room to set up camp and still be out of the way. Again, since the large accumulations are likely palimpsests, they could be built up over several different hunting events in the valley.

One connection between the kills and habitation sites involves small tipi ring scatters located adjacent to drivelines. Given the large distances covered by these lines and their expansive breadth across the landscape, these drive lines would likely take several days to construct. Walker (1990: 59, 131-132) suggests that these habitation sites may have functioned as work camps, areas of occupation between working days constructing the drivelines. He also mentions that the proximity could simply be coincidental, or the location was chosen by campers as a ready source of stone, cannibalizing rocks from the drivelines to form the tipi rings (Walker 1990: 131).

The final association found between different site types is the proximity between kills and lithic scatters found downstream. Six of the seven kills have a lithic scatter located downstream of the killing floor, where each coulee opens into the larger Roan Mare valley (Figure 2.1). This association is strengthened in that each of these scatters contains faunal remains, suggesting they may have served as processing areas for the kills. Walker (1990:135-136) arrives at this conclusion, but notes that continued excavation is needed to verify or refute it. The exception to this scheme is DhNe-89, where no true lithic scatter site was identified near the kill. This absence is a tad misleading, as the habitation site DhNe-86 did contain some lithic artefacts on the surface. But with no fauna evidence, the connection is harder to make between these two sites. The connection between a bison jump and its processing area will be discussed in greater detail in the next chapter.

Many of the associations between different sites mentioned above have rested upon the issue of contemporaneity, in that each site should be similar enough in age so that the assumptions can be given credibility. Walker (1990) does not mention that any radiocarbon dates were obtained, so diagnostic artefacts and features will have to be relied upon for determining age of occupations. A summary of the valley's cultural history is given in Figure 2.5. As the graph shows, the majority of the diagnostic material dates to the Late Precontact Period, roughly spanning the time between 2000-200 r.c.y BP (Walker 1990: 12; Walker 1992: 120). The high amount of Late Period evidence ties in nicely with the bison kill sites, as large scale communal bison hunting techniques flourished during this time period on the Plains (Kornfeld et al. 2010: 268)**.** Within the Late Period, the Plains Side Notched-aged (550 - 200 r.c.y. BP [Dyck 1983: 129]) material has been found at the most sites, including projectile points and Mortlach style pottery. It could be that the area was used more frequently during this time period, but it is also the youngest material in the assemblage and would be found more frequently near the surface of sites. While many of the sites (n = 110) in the study area yielded no diagnostic artefacts, the tipi rings found at certain sites can give an approximate age. Kornfeld et al. (2010: 401) mentions that stone circles have been found on the Plains dating to the Middle Prehistoric Period and sometimes into Paleoindian times as well. However, they note that the majority of rings end up dating to the end of the Middle Prehistoric, Late Prehistoric and Early Contact Periods. With the abundance of tipi rings and diagnostic artefacts, it would be safe to say that the majority of sites found in Roan Mare Coulee date to the Late Prehistoric Period, with preference for later occupations. Certainly earlier occupations should be present in the valley as a few of the diagnostics suggest, and would most likely be found in the buried levels of the bison kills where deposition is favourable. Again, only controlled excavations and further research in the area can verify this claim.

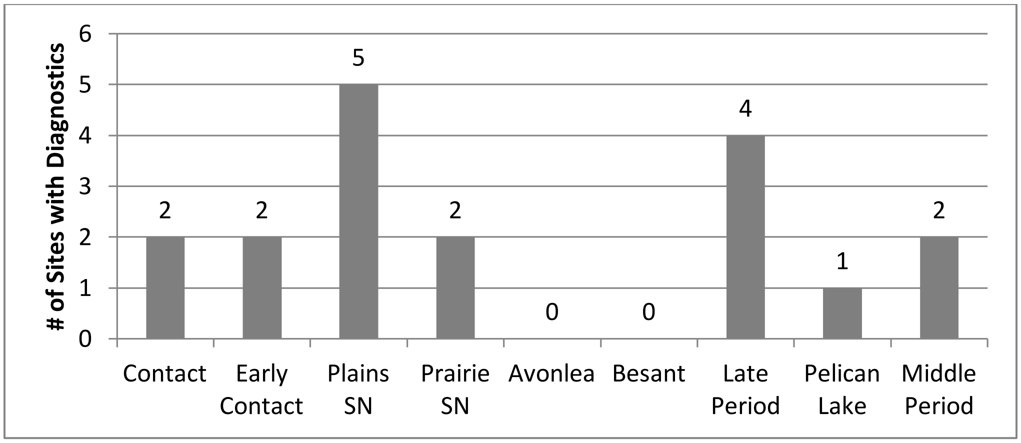


Figure 2.5: Frequency of Sites with Diagnostic Artefacts for Various Typologies. Note that Late and Middle Period groupings represent the sites which contain material from the respective period, but are not diagnostic enough place in the more specific groups (e.g.: body sherds).

In summary, the investigations conducted by Walker between 1988 and 1989 lead to the identification of a plethora of archaeological sites and areas of activity. The survey was biased towards large obtrusive features such tipi ring scatters and cairns and this is reflected in the results. However, the survey did lead to the discovery of smaller and less obvious sites, such as lithic scatters and procurement areas. The addition of test excavations in 1989 also broadened the understanding of buried archaeological components at certain sites, namely the bison kills and select lithic scatters and habitation sites. Although the tipi ring sites are the most numerous and easiest to identify in the survey, they are only a small part of the total assemblage and integrations of archaeological sites found at Roan Mare Coulee. While the issue of contemporaneity between particular sites still needs to be settled, the majority of information points towards occupations which highlight the end of the Late Prehistoric Period on the Plains. Overall, Roan Mare Coulee contains a wealth of identified archaeological data as well as high potential for future research in the area.

Chapter 3
Bison Jump Anatomy and Operation

Communal bison hunting has been evidenced on the Plains as early as 10,000 BP (Reeves 1990: 175), with kill counts exceeding 150 animals in particular locations such as the Olsen-Chubbock (Wheat 1972) and Jones Millar Sites (Stanford 1978). Driver (1990: 12) defines a communal hunt as a group of hunters (>2) actively cooperating with one another in a predetermined plan of action. One of the best examples of communal bison hunting on the Plains is the bison jump. Many archaeologists have overlapping and differing views as to what features are required in a functional bison jump (Brink 2008, Byerly et al. 2005; Cooper 2008; Frison 2004; Kornfeld et al. 2010; Polk 1979). The most common requirements are as follows: a large open area capable of sustaining large bison herds, a large but not overly steep slope or cliff to run animals off, a means of funnelling the bison from the range to the slope, and lastly an accessible killing floor and processing areas. No jump will be completely identical in their operation and variations on the previous factors are commonplace. However, one factor is found at each and every jump site found on the Plains; the proper understanding of how this factor behaves is crucial if all the other parts are to be used correctly. This factor of course is the prey of the hunt, the North American Plains Bison.

3.1 Bison Physiology and Seasonal Behaviour

The Plains bison (*Bison bison bison*) is a large ungulate whose typical habitat consists of short grass prairie and montaine valleys. The bison holds the title of being the largest land mammal in North America (Brink 2008: 27). This title is well earned as a typical male averages about 1.7m (70 in.) from hoof to shoulder while females are typically 25-30% smaller (Soper 1964: 373). Male and female weights range between 650 – 900kg and 450 – 650kg respectively (Brink 2008: 46-50). This discrepancy between weights is an example of the sexual dimorphism apparent in the species. Bison size and health not only vary between sexes, but also by the season as well.

Bison are highly influenced by changes in the season, both individually and as a herd. First, bison are highly mobile. Herds migrate across the landscape in a fairly predictable fashion as the seasons progress. Reeves (1990: 171) divides the year into two periods, Overwintering and Summer based on bison migration movements known as the seasonal round (Brink 2008: 60).

The Overwintering period, as the name implies, extends from October to May and it involves herds descending upon the fringes of the Plains and hilly areas. During the fall, the new calves will have grown to over 100kg and become healthy enough to survive through the coming winter (Brink 2008: 45). Bulls and cows will have just completed the rut a few weeks prior and cows will have reached their peak fat content (Driver 1990: 14; Speth 1983: 2). The fat content of bulls on the other hand will have dropped significantly during this time. Herds will have started to disperse back into smaller groups following the rut as they move towards wintering habitats (Brink 2008: 62). However, once at their winter ranges, herds reconvene into larger groups for the remainder of the season (Morgan 1980: 158, Figure 5). Over the winter, bison would survive off of fat reserves and loose forage such as exposed grasses and even trees and shrubs (Kornfeld et al. 2010: 42). This period is especially taxing upon the pregnant cows as the bison gestation period finishes near the end of spring. When spring arrives, herds start moving out of sheltered areas back onto the Plains in phases; generally males first while cows stay to give birth (Brink 2008: 64; Kornfeld et al. 2010:41), with the birthing phase occurring as early as April and as late as June (Roe 1970: 94). Males typically retain higher fat reserves in the spring compared to females, where their condition is the lowest for the year (Speth 1983: 2).

As the spring continues, bison make their way back towards their summer ranges (Morgan 1980). Spring ends with grasses green and water sources still plentiful. Reeves (1990: 172) argues that accessible water becomes more restricted as the Summer period progresses and this serves as the impetus for bison movement across the Plains. Peden (1976) also shows that the maturation rates of different grass species found on the Plains could also dictate bison movement. In the midsummer, smaller herds converge together for the rut. The rut is restricted to the summer as it is the only time the ecosystem is bountiful enough to support that many bison in one place (Brink 2008: 61), and any large deviations in time may lead to calve births out of season into inhospitable climates (Kornfeld et al. 2010: 162). After the rut, the cycle comes full circle with the beginning of fall and bison moving back to winter habitats.

The seasonal migration patterns and behaviour in bison would certainly be well known and utilized by their hunters. While Roe (1970) concludes that bison would not likely follow the same regular, highway-like courses during their annual migrations, Driver (1990: 13) notes that, if any communal hunt is to be successful, the prey must be predictable in some fashion. Thus bison should be predictable in occupying a general area at specific times of the season, as opposed to specific locations year after year. Driver also observes that based on ethnographic evidence, hunters in higher latitudes tend to coordinate hunts in the fall. This was done on the Plains to take advantage of concentrated bison herds, secure the best quality hides, and obtain animals at their peak fat content (Driver 1990: 15). The desired procurement of fat and proper hides is also supported by Brink (2008) while Speth (1983) notes that fat is easily metabolized and aids in digestion of proteins. However, bison were not exclusively hunted during the fall. Reeves (1990: 171) states that bison can be taken all through the Overwintering period, and Walker (1974) confirms with ethnographic evidence that communal hunting did not occur solely in the fall, but would have carried onward through the winter.

Meanwhile, Cooper (2008: 231-233) found that the distribution of kill sites on the Plains containing seasonality evidence is fairly even between fall, winter, and spring, with winter being the most represented season. In fact, kills occurred most frequently in March, a period when bison would be nutritionally drained after a taxing winter (Cooper 2008; Speth 1983). While winter kills are more frequent on the Plains, Cooper does show that their assemblages are typically much smaller than those found at fall kills. Winter shows a 50/50 split between large and small bonebeds while fall sites favour larger kills, representing 63% of the sample (Cooper 2008: 234-235). As far as bison jumps are concerned, they are the most frequent site type for fall season kills, and fall shows the largest quantity of jumps represented through the entire year (Cooper 2008: 236). Thus while the hunting of bison is not restricted to the fall season and can occur throughout the year, jump kills are more often found during this time of the year and more animals are dispatched per event. This ties nicely with Walker's (1974: 3) argument that the operation of a bison jump would be more difficult in winter conditions, necessitating that different hunting techniques would be employed in this season.

To summarize, the movement, physiology and herd behaviour of bison on the Great Plains was largely influenced by the changing of the seasons. The nutrition and fat content of bison would fluctuate through the year and would vary between males and females. Herd size would also fluctuate: clustering in winter, dispersing in spring, highly clustered in late summer and early fall for the rut, and dispersing again in late fall as they moved towards their wintering climes. The herd sizes were also a response to the movements between summer and wintering ranges, associated with food (Peden 1976) or water (Reeves 1990) availability. For a large scale communal bison hunting event to be successful, these seasonal variations had to be known and planned for by the hunters. The synchronization of the large herd congestion (Driver 1990) along with the peaking of fat content in females (Brink 2008; Speth 1983) would have made the fall season an attractive option to operate a large scale hunt event such as a jump. This would explain why jumps are so frequent and massive in scale in the fall (Cooper 2008). However, having the herds in large enough size and in the right location would only be the first step in the operation of a bison jump. Several stages remain in getting the prey to the final killing floor, each of which relied upon hunters anticipating and utilizing bison behaviour correctly.

3.2 The Gathering Basin

As established above, bison herds will congregate at the height of summer and into the beginning of fall for the rut. Slightly after this period would be the opportune time to coordinate a massive bison jump kill as the herds are still abundant and starting to move towards the winter ranges. However, the bulls have started to remove themselves from the cow/calf herds making it easier for hunters to direct the larger herd movements. Having bulls in crowd, especially during the rut, makes the group behaviour too unpredictable to move the heard properly (Brink 2008: 66). Nevertheless, the first requirement of a bison jump is a suitable area behind the jump edge to hold and sustain a large congregation of bison around the beginning of fall. This area is typically referred to the gathering basin/area (Brink 2008; Brink and Rollans 1990; Byerly et al. 2005; Rollans 1987). The term gathering basin is an apt one as it alludes to the idea of a hydrological basin that serves to move water from a large area into a confined one. The same is true for a bison population; hunters wish to gather herds from larger areas into select paths and move them towards the drop off.

Brink (2008) elaborates upon the specific environment found in and around Head-Smashed-In Buffalo Jump (DkPj-1) in southwestern Alberta, and how these elements contribute to gathering basin and the success of the bison kill. He notes that DkPj-1 rests upon the border of two topographic zones where the fringes of the Plains meet the foothills of the Rocky Mountains at the Porcupine Hills (Brink 2008: 65). The prairie to the east of the jump would serve as a suitable summer habitat for bison while the valleys and drainages west of the cliff provide shelter in winter months (Brink 2008: 65). Brink defines the gathering basin for DkPj-1 as the large watershed for Olsen Creek that flows a few kilometres west of the cliff. He also notes the abundance of blue grama (*Bouteloua gracilis*) and fescue grasses in the area which serve as nutrient food sources in the fall and winter months (Brink 2008: 65). The connection of blue grama in the gathering basin correlates with both Peden's (1976) and Babin et al.'s (2011) findings that grama fills a sizable portion of bison diet and serves as a ready source of calories.

The abundance of permanent water is another important factor in the attractiveness of a gathering basin and bison jump. Polk (1979) performed a locational analysis of 146 bison jumps found within the Northern Plains in an attempt to find similarities and correlations between jump locations and the nearby environment. Many of his results were inconclusive or not statistically significant with the exception of two factors. He concluded that "...the most critically important variables to occur in association with site locations are (1) the direction in which jump sites face, and (2) water features," (Polk 1979: 105). He explains that jumps may be found near water features so hunters can capitalize on bison tendency to cluster in and around water sources (Polk 1979: 106). This argument is strengthened by Reeves's (1990: 172) conclusion that bison movement would be motivated by deplenishing water supplies on the Plains. Having a viable source of water in a jump's gathering basin would be an attractive local for a large herd of bison at the end of summer.

The availably of quality grass and water sources permits the gathering basin to hold a large quantity of bison required for driving. Reher and Frison (1980: 45) note that a "critical prey density" must be achieved if a large scale hunt is to be undertaken. If the herd sizes are too small and dispersed, the bison's movements are less predictable and harder to mobilize. Thus, if a large bison jump is to be successful, a minimum number of bison are needed to be maintained in the gathering basin. Reher and Frison (1980: 46) estimate that 100 – 300 animals would be typical, but up to 500 to 1000 would be required if multiple kills were to be repeated in a short period of time. As this critical density requirement is directly related to the environmental conditions of the gathering basin, drier years on the Plains would be less amenable to maintain a communal bison kill. Cooper (2008) identifies that the frequency of communal bison kill sites from 900 – 1549 CE drops on the Great Plains during drier years and increases in wetter years. So a healthy and lush gathering basin would be one of the first required factors needed to operate a successful bison drive.

3.3 The Drive: Linking the Gathering Basin to the Killing Floor

With a suitable habitat in place to hold and maintain a large heard of bison, the next step in operating a bison jump is to move the animals from the gathering basin into the trap some distance away. This bison drive process would take several days to set up and operate, long before the actual kill would occur. Arthur (1975) mentions that fire would often be used by hunters to influence herd movements into desirable locations. These controlled burns could be set to create attractive patches of grass in later seasons (Brink 2008: 119; Arthur 1975: 25), or to create smoke to ward bison towards a trap (Arthur 1975: 23). Brink (2008: 119-121) mentions that if this second tactic were used, it would have been a very rare occurrence. He attributes this assumption to the unpredictability of fire in a dry, grassy environment. A poorly controlled blaze could do as much harm as good to the communal hunt; scattering the bison rather than congregating them. Lott (2002: 85) also notes that grasses burned in the fall were problematic in that they do not have time to recover before spring, leaving bare zones that are not favourable to bison. Nevertheless, the ultimate goal of the fire was to move scattered herds from the surrounding area into a desired locale in the gathering basin.

Once the bison are congregated, they must then be led out of the gathering basin in a controlled and organized manner towards the trap. These paths are known as the drivelanes and they were choice corridors designed to traverse the topography with several dozen bison in tow. Drivelanes are created by the natural topography and consist of trails moving and weaving between local high points. These lanes can be augmented with drivelines, which are elongated archaeological structures composed of a series of stone cairns. The two features, cultural and topographic work in tandem as a funnelling mechanism, which hunters used to manoeuvre the bison towards the trap.

The drivelanes need to be designed to capitalize on bison behaviour. Rollans (1987: 7) elaborates on the effectiveness of a drive event:

> “The secret of an effective drive practice is making the game want to go in the direction of the trap. The hunters must ensure that the most convenient route available to animals, and the one which appears to hold the only chance for escape, is the route toward the trap. The animals cannot be aware of the impending danger until it is too late for them to change their course”

This is where the terrain features play an important role. Moving a herd in a small syncline between two hill crests will block bison sight of both hunter movements and the oncoming drop. The slopes on the flanks also play to the "convenient route" part of the strategy as bison are less inclined to tackle difficult terrain (such as a hillslope) when easier passage is available (Rollans 1987:32). Ideally, these corridors are ones the bison already use; familiar paths taken between water and food sources in their daily routine (Arthur 1975; Brink 2008:136; Rollans 1987: 34). Polk (1979: 106) also connects the terrain requirements of the drivelanes with his association between bison jumps and water sources. He argues that the jump-water location correlation could be attributed to small creeks and streams found behind a jump edge. The small coulees and drainages created from these water courses would be advantageous to herd bison into since they create a natural chute of topographic relief.

The direction of the movement is also important. Obviously one would want to move towards the escarpment, which Polk (1979) found were traditionally found on north to east facing slopes in bison jump sites. Exceptions to this trend are to be expected, but the north/east orientation of bison jumps is quite substantial. Thus, movement between the gathering basin and the killing floor would be in a northeastern direction. This direction takes advantage of another characteristic important to bison; their strong sense of smell (Arthur 1975; Rollans 1987; Brink 2008). Rollans (1987: 34) notes from interviews with bison handlers that the animals prefer to walk into the wind. This is done habitually so the bison can identify oncoming danger from upwind via smell, and adjust course accordingly. To a hunter this behaviour can be turned around and work to their advantage. Arthur (1975:89-90) says that the wind direction was best when it blew toward the trap in Assiniboine bison drives. He continues in saying that small crews of hunters would stay behind the herd while moving them towards the kill (Arthur 1975: 90). Their scent would be blowing downwind to the bison, creating a sense of danger and thus influencing their movement. Meanwhile the real threat, the trap and its large collection of humans a few miles away, was undetectable because it lay downwind of the bison and their noses. Bringing this back to Polk's (1979) assessment of the north-east orientation of bison jumps connects them with wind direction. In the Northwestern Plains, wind direction primarily blows from the west to the east due to the Rocky Mountains' influence on weather systems. So bison jumps would correlate well with eastern slopes as this would place them downwind through most of the year; a useful orientation for hunting.

Thus the topography in a bison drive's backfield plays a major role in its operation. It serves to keep the bison blind, both visually and olfactorily, to the hunters' movements and their approaching doom. However, the topography can differ between different drives and no system provides the perfect channel to connect the gathering area to the trap. The terrain can be augmented in the hunters' favour through the use of stone cairns and drivelines. The stone cairns can serve a variety of different functions based on their size, shape and location on the landscape. Rollans (1987) postulates several different functions that cairns can hold in the operation of a bison drive. She concludes that broadest utility that drive lines serve is to mark the boundaries of the lanes in which the bison were led (Rollans 1987: 109). That is, the bison's corridor would be flanked between two separate lines of cairns. The two lines will form a V- shape on the landscape, tapering and constricting the area between them closer to the jump. These lines are known to extend for long distances, up to several kilometres across the landscape (Brink 2008; Brink and Rollans 1990; Frison 2004; Kornfeld et al. 2010; Reher and Frison 1980; Rollans 1987).

Rollans (1987) breaks down this overarching proposition into smaller, more specific functions of the cairns and drivelines. She concludes that drive lines could be used to limit bison movement out of or near the edge of the lanes in a variety of different methods. All of these sub-prepositions assumed the use of perishable material not found in the archaeological record (Rollans 1987: 111). The most plausible method of deterring movement was the use of "deadmen" or "scarecrows" at the cairn locations. These items would likely be small piles of brush and sticks held upright by the stones, upon which leaves or flags would blow in the wind (Brink 2008; Brink and Rollans 1990; Rollans 1987). These deadmen would not create a physical barrier to bison movement, but a psychological one. Bison are particularly fearful of the unknown if they aren't given time to investigate the anomaly and the flags' erratic movement in the wind would provide added mystery (Rollans 1987: 118-119). Thus, the drivelines would be avoided out of fear of these devices. The illusion didn't need to be overt either, as Rollans (1987:119-121) explains:

> "It must be remembered that the lines of scarecrow structures need not have provide a strong psychological barrier to bison movement because the bison had an apparently clear route of escape ahead of them. As long as the route toward the trap remained attractive (i.e. the lane was not too narrow and the trap was concealed) the bison would have no impetus to test the lines."

Rollans (1987) provides other propositions which have weaker plausibility and more conditional acceptance than the deadmen theory to explain driveline function. She notes that some cairns may have served both as blinds and stations for hazers allowing them to conceal their movements and enter the drive at known times and locations (Rollans 1987: 122). This would have been particularly effective at the end of the drive, where the bison were aggravated into a controlled stampede to the trap (Brink 2008: 138). This action is mentioned in ethnographic accounts of bison drives (Arthur 1975: 92; Kehoe 1967: 79), giving additional support for this function. Finally, Rollans (1987: 121) acknowledges that the cairns could also serve as guides for the drivers leading the bison between the gathering basin and the jump, especially with the added visibility of the deadmen. As long as the drivers could see the markers on either side of them, they were moving the bison in the correct direction.

The movement of bison across the landscape towards the jump edge was intended to be slow and gradual process, only riling them into a run at the last possible moment (Brink 2008). Bison are incredibly fast animals and often competed with the agility of horses (Arthur 1975: 37; Lott 2002: 41). A full stampede from start to finish would exhaust the drivers and hazers long before the bison. Due to the V-shape of the drive lanes, the distal portions are open and less confined giving the rushing animals more avenues of escape while fewer people are available to control their movement. On the other hand, the confined end allows for more people to gather and work together providing greater control (Brink 2008: 141). Brink (2008) also explains that herd diversity is in play as well. A full stampeding herd will move as a cohesive unit for a time, but over large distances the weaker individuals will not be able to keep stride with the stronger animals splitting the group (Brink 2008: 140). This would lower yield of the final kill from the full herd to only a handful or none at all (Brink 2008:141). Thus the full stampede was reserved until the very end of the drive as it presented fewer options for bison movement in the confined area, increased the effectiveness of human participants and kept the herd in a stable group for longest duration.

As the bison were lead towards the jump, the drivelines would slowly converge into smaller corridors. The bison would have fewer options for movement within the channel and as the perceived threat of the deadmen drew closer on the flanks, the hazers upwind would still present fear of moving backwards and the path ahead still appeared safe. The stampede may have already been started as several hunters appear from their blinds to startle the bison (mentioned above). However, as the jump approaches, the danger of the plummet has to be removed or downplayed lest the bison realize this as the greater threat and rapidly change course. The topography and drivelines can obscure the drop for some time, but there would be a period when this is no longer available. This is why many believe that a quick turn integrated into the end of the drive lane system is an important factor in a successful drive (Brink 2008; Byerly et al. 2005; Kornfeld et al. 2010). The goal of the turn is to run the bison parallel to the valley edge, then quickly forcing a turn through the use of the cairn markers and humans making commotion (waving arms and blankets, shouting) from the sides. This impromptu turn would have the bison to be led directly over the slope without having time to react, slow down, or change direction. If the lead cows did manage to stop in time, the momentum from the massive and constricted herd behind them would be too overpowering and force them over the edge (Brink 2008: 152).

The quick turn would not be needed at all kill sites however. If the topography allowed, the drop could be obscured from sight almost up to the precipice. Frison (2004: 81-83) notes this occurring at the Two Medicine Jump in Montana, and the Chugwater and Vore bison jumps in Wyoming. The local topography blends with the background scenery so well that the drop in elevation is invisible until too late. Brink (2008: 144) also notices this optical illusion occurring at Head-Smashed-In Buffalo Jump. At the Boarding School Bison Drive site in Montana, Kehoe (1967: 88) remarks that the bison would have to climb a small bluff before being able to see the sharp slope that lay ahead of them. Whatever the case, the key to the final portion of the drive was to manoeuvre the bison as fast as possible into the trap while maintaining the illusion that it was still the safest route to take.

3.4 The Kill and Processing Areas

Once the entire process of manoeuvring the bison from the gathering basins, through the funnelling drive lane network and past the final stampede, the hunters are successful in bringing the animals into their trap. This trap in a jump style kill is usually a vertical cliff face or a very steep slope in which the bison either fall over or tumble down respectfully. This fall needs to be powerful enough to kill or severely wound the animals, but not so strong that the meat and animal hide becomes too badly damaged (Byerly et al. 2005: 605). A bison drive can also terminate into a pound style kill. In a pound/corral kill, the bison are driven out of the drive lane into a narrow chute and into a small man-made pen (see Rollans 1987: Figure 2). Once in the pound, the bison can be dispatched with weapons from the successful hunters. While pound kills and jump kills are found exclusive of one another, the distinction between them can be blurred at times, since the method of driving the bison into each remains relatively the same (Brink 2008: 86).

Small corrals have been known to be used at the bottom of jump sites, especially those with less pronounced slopes (Arthur 1975; Cooper 2008; Kehoe 1967). In fact, Polk (1979) included kill sites containing corrals and slopes lower than 45° in one of his possible criteria for selecting bison jump sites. The corrals in these kills would have been useful in containing the bison that the gentler slopes did not kill (Frison 2004: 80), as Brink (2008: 163) makes it clear that hunters would not want survivors escaping. Thus if a large drive line system is found leading up to a significant slope, the possible existence of a corral cannot be ruled out before excavating. Of course if the drive terminates at a sheer cliff face, the drop can be enough to kill the bison outright without need for containment. Jumps that utilize a sheer drop are found across the Great Plains (Cooper 2008; Polk 1979), but a few examples include Head-Smashed-In Buffalo Jump in Alberta (Brink 2008), the Kobold Buffalo Jump in Montana (Frison 2004), and the Sabin Buffalo Jump in Saskatchewan (Walker 1990). Polk (1979) notes that some cliffs utilized in bison jumps can exceed 50m in height, though they are very rare. Also, Cooper (2008: 127) mentions that most recorded cliffs found at bison jumps are less than 20m high. In either case, sheer cliff or steep gradient with a corral, the hillslope remains the primary means of injuring or dispatching the bison. This should separate the confusion with drives and pound kills that end in relatively open terrain, or run up a valley into a natural corral.

Once the animals have been killed, the task now remains for the hunters to process the corpses. The first step is to actually access the carcases down slope from the drive. Frison (2004) notes that several optimal locations exist on the Plains which offer ideal slopes and gathering basin topography, but show no evidence of use. He argues that while the terrain would be effective at killing bison in these locations, the killing floors were inaccessible. There was no way for hunters to reap their spoils and harvest the meat and hides. Thus communal hunts are futile if the processing area cannot be accessed.

The hunters cannot delay too long after a successful hunt to start processing the remains, lest rotting and decomposition set in. Brink (2008: 174-178) notes that this was especially important due to the insulator effect of bison hides. A massive mound of freshly killed bison would hold onto a large quantity of heat and encourage spoilage. The initial processing would have followed a well regimented process in order to meet the pressures presented by a limited time window and a copious work load. The main goals of this initial processing were to remove the hides and stomach contents to dissipate heat and then butcher the carcasses into smaller and more manageable primal cuts. After this procedure, it is hypothesized that the killing floor would be set ablaze to sanitize the area and cut down on odours (Brink 2008: 167).

Following the initial processing, the butchered elements would be carried by the hunters to a nearby location to further break down the carcass. This secondary processing can be rather time consuming and requires more room to work, so the processing site should be some distance away from the base of the slope and in more open terrain. The site should also be in close proximity to water resources, as the processing phase does require copious amounts of water (Brink 2008: 180-181). This requirement further supports Polk's (1979) correlation between jump locations and proximity to water sources. During this phase larger bones are broken open for marrow removal, bones are placed in boiling pits to extract grease, meat is cut up and dried for preservation, and if the hides were still present, they would be removed for tanning on a later date (Brink 2008). Thus the archaeological evidence for such activities would include highly processed, smashed, and burned bone from marrow and grease extraction, high quantities of lithic debitage created from resharpening stone knives and abundant fire-broken rock. The presence of intact boiling pits and hearths are also a possibility depending on the level of disturbance the site has faced.

The extraction of grease and marrow is helpful in utilizing the full nutritional content of the bison. When dried, bison meat is very lean as the fat has been rendered out alongside the water content. Thus fat stores must be created to add back to the meat to make it more nutritious and palatable (Brink 2008: 188). This process is extended further with the development of pemmican, in which the meat is heavily pounded to break up muscle fibres and later fat, grease and berries are incorporated into it (Brink 2008; Reeves 1990). The resulting mixture is nutrient dense, providing a source of protein, fat, carbohydrates and vitamins, while being resistant to spoilage for long periods of time. Brink (2008: 229) acknowledges that the creation of pemmican could be performed either at the processing site, or at a later time away from the hunting camp. Reeves (1990: 170) acknowledges the evidence for pemmican creation as early as 2800 BCE, with the practice being common place at the beginning of the Late Period on the

Plains. He argues that the use of pemmican along with the adoption of the bow and arrow during this time would have spurred both population and cultural growth on the Plains (Reeves (1990: 190).

3.5 Assessing Roan Mare Coulee Kills as Bison Jumps

Given all the information presented above concerning what processes and structures go into a bison jump, it is best to see how the sites mentioned in Chapter Two reflect the ideal. These sites are of course DhNe-1, 51, 75, 76, 77, 82, and 89. Starting with the gathering basin, the sites on the western side of the valley will all likely share the same basin, whereas DhNe-1 utilizes the eastern basin by its lonesome. As mentioned in the previous chapter, blue grama grass is known to grow in the Big Muddy area, so the presence of it should be expected in the gathering basins. Water availability is likely the limiting factor in the carrying capacity of the gathering basins. Polk (1979) notes that while water sources of any type are found in association with bison jumps, permanent water is more desirable. Many of the water sources listed on the topographic maps of the area are seasonal or intermittent, consisting of small soughs and first order streams. Even the Big Muddy Lake is classified as intermittent, as it is not very deep and shore line can fluctuate from season to season. The southern bison kills would likely draw on the lake as the primary water source for bison to congregate, while the northern kills would rely on the intermittent streams and ponds to the west and north just on sheer proximity. DhNe-1 has several intermittent sloughs and streams to the north, east and south to utilize. However, one should note that even though the majority of water sources are non-permanent, it has been shown that ground water does play a major role in the hydrology of the area. These springs could keep the streams and ponds replenished for much longer in the year. Overall, the gathering basins are viable areas to maintain a sizable bison population with water availability being the critical factor.

In terms of the drive lanes, each kill has two or more cairn drive lines associated with it, with the possible exception of DhNe-77. The orientation of these drive lines suggest that bison were driven from several different locales in the greater gathering basin, depending on the kill location. DhNe-82 seems to have been used by hunters to draw bison northward from the Big Muddy Lake, running parallel to the valley edge before making a wide turn east towards the jump edge. However, unlike the other jumps, the drivelines do not extend to DhNe-82's jump edge. DhNe-89 has very small drive line lengths, oriented slightly to the west-southwest. DhNe-

89 could have been used to drawn bison from the lake, or from the creeks and sloughs to the west in Hole in the Wall Coulee. Hunters using DhNe-51, 75 or 76 appear to have led bison from several different directions, ranging from north to the southwest. Some of these lanes follow the valley edge until the final reaches where the characteristic turn is made at the end. The drive lane for DhNe-77 is hard to determine as it has only one driveline leading directly to it. A mentioned in the previous chapter, Walker (1990: 94) suggests that it would share the north east drive lane with DhNe-51. The viability of this scenario will be assessed in the cost path analysis of each kill. Finally, DhNe-1 appears to drive bison from the north, east and southwest. The northern and southern drivelines skirt the valley edge for long stretches before switching direction once the desired upland area was reached.

As can be seen in Figure 2.1, many of the drive lines and jumps are oriented to the east, in agreement with Polk's (1979) assessment of bison jumps. As mentioned above, this orientation is often tied to the predominate wind direction in the area. In Chapter Two, it was mentioned that northwestern winds were most prevalent from September to February (and also July). This would make these lanes ideal for fall and winter hunts. For DhNe-1, the drivelines eventually move west towards the jump edge. While the west orientation may not be the norm on the Northern Plains (Polk 1979), note that southeastern winds are common between March and August in the region. A possibility is that DhNe-1 could have been used for spring and summer hunts. Cooper (2008: 236) shows that while jumps dominate the fall season compared to other hunting techniques, they are still utilized in other seasons.

For the jump slopes, the angles never exceed 21° or 38% grade (Figure 3.1) in the areas in close proximity to the drops. However, given the coarse nature of these data (pixel size of 30m), this only gives a rough estimate of the actual landscape. For instance, the sheer drop seen at DhNe-1 would yield a slope of up to 90° if measured over a few metres, but these local changes get blurred out at the 30m scale. Nevertheless, the western bison jumps are located on some of the shallower slopes in the valley, while the highest slopes in the area show no evidence of bison procurement. The fingerling drainages that the western jumps terminate in may have served as natural corrals, containing the wounded bison long enough to be dispatched. Wooden corrals could also have been constructed, but evidence for this can only be gleaned through further excavation. Also of note is that these jumps tend to terminate into the larger and more open valleys. This could suggest that accessibility was a concern. These valleys would provide more room to begin the initial processing in rather than the smaller, V-shaped coulees found in other areas of the drainage. Since fear of spoilage was a well known reality (Brink 2008), having more space to work allowed the corpses on the bottom of the kill pile to be reached quickly.

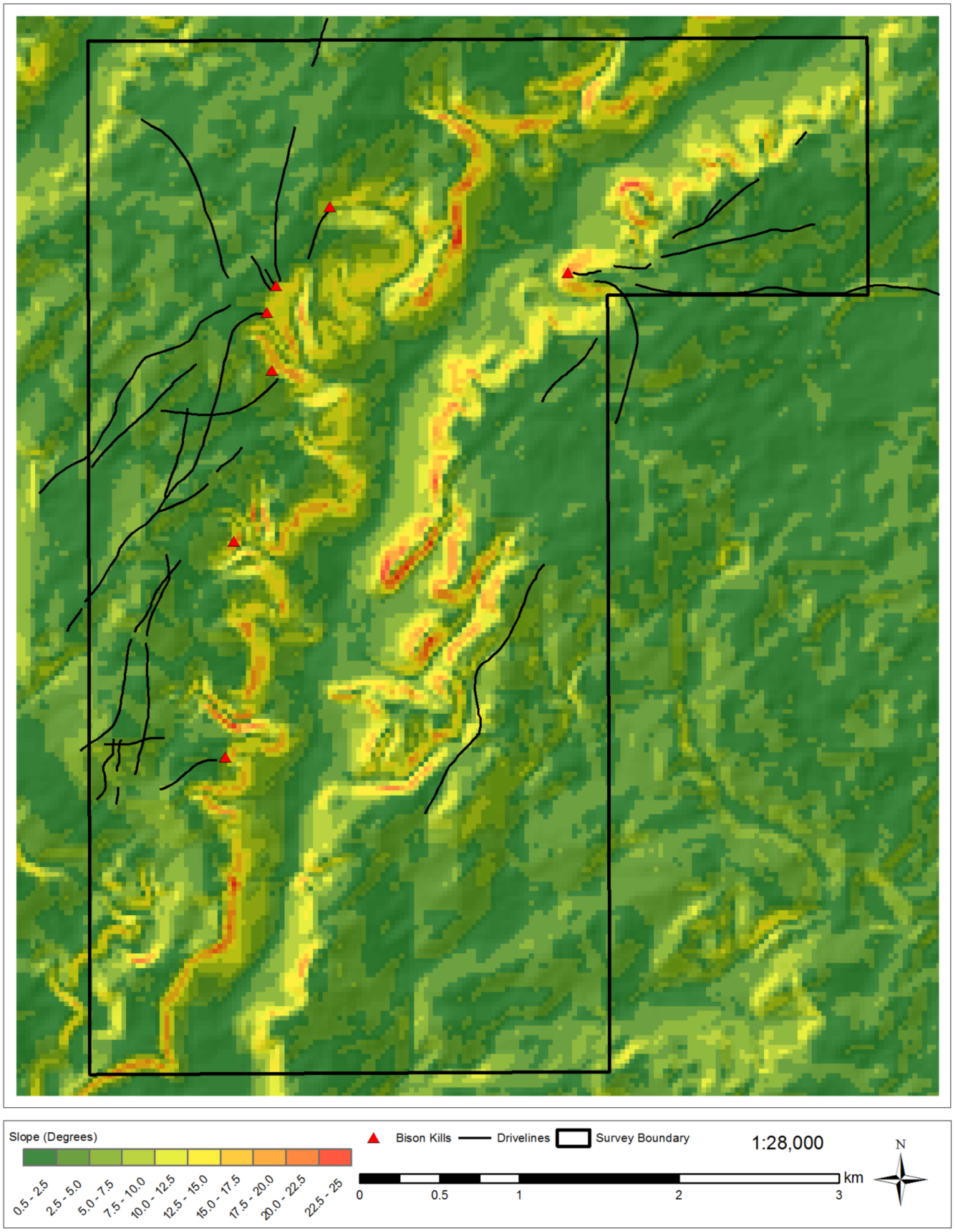


Figure 3.1: Slope Values in Close Proximity of Bison Kills (Pixel size = 30m).

The processing areas for the individual jumps were alluded to in Chapter Two as consisting of the variety of lithic scatters found in the valley bottom. DhNe-1 was matched with DhNe-16 and 17, DhNe-51, 75, 76, and 77 were connected with DhNe-15 and DhNe-82 associating with DhNe-80. These sites do meet several of the requirements of a successful processing site for a bison jump. They are all located in the more open terrain found further downslope and away from the killing floors. They all show evidence for fire-broken rock and faunal remains with highly comminuted bone found at DhNe-16 and 80. All four are also located near sources of water, chiefly the central creek that runs through Roan Mare Coulee. As mentioned before, the majority of water sources in this area are seasonal but groundwater springs could help sustain these water courses longer into the year. However, excavation is needed both at the lithic scatters and the bison jumps to further assess the connection between them. Additional support of these inter-site relationships would include similar age in material remains, evidence for bone boiling pits and hearths, and lack of other processing areas between the bone beds and the lithic scatters. At this moment the association between the jumps and lithic scatters is plausible but not confirmed.

3.6 Summary

It should now be apparent that operating a communal bison jump is a vast undertaking involving the efforts of several individuals in each step of the process. The entire practice predicates on the understanding of bison behaviour when moving through a landscape, and capitalizing on that behaviour to achieve the hunters’ goals. This thesis will focus on the topographic effects on bison movement via the least cost path analyses and how they relate to the observed drivelines.

Chapter 4
Geographic Information Systems Applications in Archaeology

Geographic Information Systems (GIS) have been useful tools in the study of archaeological sites and data since the mid 1980's (Lieff 2006). Use of GIS allowed the capabilities of spatial analysis of archaeological material to broaden, as they allow for larger and denser data sets to be used that would otherwise be unapproachable with hand drawn maps (Ebert 2004: 335; Mills 2009: 29). This chapter seeks to provide an overview of what GIS are and provide examples and case studies of how they are commonly used in the context of archaeology.

4.1 Overview of GIS and its Components

"A Geographic Information System (GIS) is a computer system for capturing, storing, querying, analyzing, and displaying geospatial data" (Chang 2008: 1). At its core, GIS software is similar to any other database software such as Microsoft Access, since these programs provide systems for data storage, queries, analysis and display. Such programs are widely used in archaeological research to assist the recording and registration of artefacts within a site or multiple sites across a landscape. What sets GIS software apart from other database programs is that it utilizes *geospatial* data, where each record can have inherent spatial properties of a location on the Earth's surface (Chang 2008: 1). This spatial property literally adds extra dimensions of information to each piece of input data and expands the level analysis that can be conducted. Geospatial data are often represented in GIS in one of two forms: vector data and raster data. Each data model has unique data structures, implementation and uses in GIS.

Vector data are best at representing discrete features: individual features on the Earth's surface that are only found where they are observed (Chang 2008: 5). Depending on the feature being represented and the level of detail, vector data are divided into three forms: points (0-dimensions), lines (1-dimension) and polygons/areas (2-dimensions). Vector data stores their spatial data in the form of *x*,*y*-coordinates for points, or connecting several coordinate pairs together to create lines and polygons. Examples of points could be individual artefacts found at a site, lines could be large drivelines near a bison jump and polygons could be used to define the boundaries of an individual site. Of course as the dimensions increase, so does the applicable information. Measures of length and direction are available to lines, while perimeter and area measures can only be applied to polygons. Finally, the data represented using either points, lines or polygons will change depending on the research objective and scale. For example, when looking at a few sites over a small area, polygons can be used to differentiate the boundaries for each site. But when comparing several sites over a large area, sites could be represented simply as points.

Raster data are the other common data model for geospatial information used in GIS and are best used for continuous features (Chang 2008: 5). Continuous features are those that found across the Earth, but can vary depending on location and a variety of other factors. The best example of a continuous feature is elevation: each location on Earth has an inherent value which changes as one moves across the surface. Raster data are laid out in a two dimensional grid, with rows and columns of individual cells. Each cell records a value of whatever is being recorded and all cells are of a uniform size (1x1m, 30x30m, etc.). When the entire grid is viewed, the variations amongst groups of cells can be observed. For example, the slope values in Figure 3.1 are displayed as a raster grid where colours have been categorized to represent high and low values.

Both data models rely on a coordinate system and projection to discern their spatial information. A projection is a means of transforming the spatial information found on a round Earth into a two dimensional map (Chang 2008: 38). A projection may either utilize a Geographic Coordinate System that uses latitude and longitude or a Projected Coordinate System specific to the chosen projection to create *x* and *y* coordinate values (Chang 2008; Conolly and Lake 2006). A datum is also selected in a projection and serves to define the origin, the model of Earth's shape being referenced (known as a spheroid), and the separation of the Earth and spheroid at the origin (Chang 2008: 22). Since the transition from a three dimensional object into a two dimensional plane creates distortion, there is no perfect way to project the Earth with equal accuracy. As such, the projection, datum and spheroid are to be kept uniform and controlled across all data in a project. With a proper projection and coordinate system in place, both vector data and raster can be located on the Earth, and distances between different coordinates and grid cells can be calculated.

Once the datasets are properly projected together, the data exploration and analysis functions of a GIS come to the forefront. With several datasets together, the data can be analyzed in a spatial context. Most GIS software packages organize data sets into series of layers which overlay one another; improving visual inspection and interpretation of data. Spatial queries can be run to select or eliminate data based on spatial criteria. Examples include distance to particular features, locations not found in certain polygons, or lines that intersect with polygon boundaries. Raster data also excels at these particular tasks, so long as cell locations and size are standardized through all data sets. If so, a stack of raster datasets can host a wealth of information for each cell represented.

4.2 Benefits of GIS to Archaeology

Now that the basic form and function of GIS has been defined and elaborated upon, how are these tools beneficial to archaeological research? GIS offers a multitude of advantages to research and management of archaeological material. While there are a variety of individual tools available in a GIS software package that are useful for specific research interests, there are three overarching advantages that benefit the archaeologist. These benefits are useful to the all branches of archaeology such as the academic, consultant or government heritage bodies. They are listed as follows:

1. Ability to work at a variety of different scales, local or regional
2. Data management and visualization capabilities with added spatial element
3. Spatial analysis functions and tools

These three factors do not exist in a vacuum from one another, but rather they intertwine and complement each other. This breakdown is inspired by Ebert’s (2004: 320) hierarchy of GIS applications. While Ebert’s hierarchy is based on the level in which the available tools of a GIS are utilized, this scheme just serves to look at how GIS integration into archaeology can be beneficial.

4.2.1 Levels of Scale

Archaeological data and evidence of human activity in space can span a wide range of scales. For example, the lone flintknapper can create a very concentrated area of artefacts in a site when forming a tool (Kvamme 1996). The distribution of different tools and artefacts across a site could suggest areas where specific tasks were preformed (Middleton 1998; Mills 2009). The disappearance of archaeological material shows the boundaries of that particular site. Comparing the material found at a site in the context of its local environment implies how a site's occupants interacted with their nearby surroundings (Leiff 2006). At a larger scale, interactions between several different sites on a landscape can be identified as nodes in a culture's subsistence system (Dalla Bona and Larcombe 1996). Seasonality evidence across a variety of sites can be linked to seasonal migration patterns at a very broad scale (Cooper 2008). Finally, evidence of exotic materials not found locally could be inferred as evidence for extremely long distance travel or trade at the continental scale. For purposes of easing interpretation, archaeologists break down different scales into different levels of scope. For example, Farley et al. (1990) uses classes such as continent, state, and project level to divide different points of scale, while Wansleeben and Verhart (1995) prefer to divide areas into macro, core, micro and site regions. Each level of scale will determine what data can be used and what information can be obtained from them (Farley et al. 1990: 146; Wansleeben and Verhart 1995: 155).

For this volume, the following scheme will be used and referenced: everything within a site's boundaries will be referred to as the *microscale*, a site and its surrounding environment along with interactions with nearby sites will be known as the *mesoscale*, site interactions across large distances is the *macroscale*, and activity that spans a continental breadth is the *megascale*. These generalizations are summarized in Table 4.1. Examples of size and citations for applicable research are provided. Keep in mind that no classification scheme will be perfect, and many projects will straddle the division between the classes.

Table 4.1: Overview and definitions of different levels of scale used in this chapter.

Level	Description	Approximate Area	Example Size	References
Microscale	Analysis within an individual site	Varies by site size	Small tipi ring cluster	Leiff 2006 Middleton 1998 Mills 2008
Mesoscale	Analysis of site(s) in a local area, usually sharing a similar environment	~1000m^2 – 1000km^2	Individual valley (low) National Park (high)	This volume Bell and Lock 2000 Byerly et al. 2005 Dalla Bona and Larcombe 1996 Freisen 1999 Krist and Brown 1994 Kvamme 1992
Macroscale	Analysis of multitude of sites over a broad area and different environments	~1000km^2 – 10000km^2	Borden Block (low) Southern Saskatchewan (high)	Bikoulis 2009 Moors 2007 Whitley and Hicks 2002
Megascale	Analysis of sites over an entire biophysical region or continent	>10000km^2	Province of Saskatchewan (low) North America (high)	Anderson and Gillam 2000 Cooper 2008

As one can see in the example above, human activity can be interpreted at a variety of different scales. By its nature, GIS can operate at any of these spatial extents and beyond. However, this does not mean scales are interchangeable. The information available to be utilized should represent the scale at which the research is focused. As a result of this, the level of detail decreases as the scale increases. This reduction of data quality is useful as it decreases file storage and processing demands. As such, fine scale data should not be used for large scale projects and coarser data should not be used in smaller scale tasks. Lock and Harris (2000: xix) note that sometimes data of an ideal scale cannot be obtained, so archaeologists should be wary of how these constraints affect their interpretations.

4.2.2 Data Management and Visualization

Ebert (2004: 320) notes that data management applications comprise the majority of GIS use in archaeology. The data management applications of a GIS are just as the name implies; simple means and methods to organize and manage archaeological data in a fairly systematic manner. As highlighted earlier, GIS is an information system with a spatial component. Thus it has the tools to create, organize, search and remove data to fit the whims of the researcher. Harris and Lock (1990: 39) note that archaeological data often has a vital spatial component; information that would be lost or distorted when stored in a nonspatial information system. They continue by adding that hand drawn maps and sketches holding spatial information are difficult to update or alter in response to changes or additions of new data. Thus the integration of both data sources into a GIS program saves time and resources without the risk of data loss. The ability to handle large quantities of information is beneficial to any scale of research, from cataloguing individual site assemblages to maintaining a working data base of all sites recorded across a province or state.

Another management advantage for archaeology is provided by how GIS programs display and organize data visually. Depending on the project, archaeologists will often have to coordinate several different data sources at once. Since GIS software organizes data into layers, each of these data sources would be displayed as such. These layers can be added or removed from the GIS based on the researcher’s interest. Thus an archaeologist can be working with all their data at once without cluttering the map. They will be able to select and organize the layers so only the applicable information is displayed for interpretation. At the microscale the layer system also provides another benefit. Archaeological sites can be composed of several different occupation layers through time and artefacts are often organized as such. Due to the layer organization, an archaeologist can isolate specific occupations for further study, or compare data through multiple occupations to investigate changes in spatial distributions through time.

4.2.3 Spatial Analysis Functions and Tools

Within each GIS software package lies a multitude of tools and programs designed to analyze spatial data. Accessing these analysis tools is the highest yet least utilized method of integrating archaeological information with GIS according to Ebert (2004: 320-321). These tools move beyond displaying, exploring and organizing data and instead use that data to create and test hypotheses and theories. Often new spatial and non-spatial data are created from these programs, and the output from one tool serves as the input for another. Ebert (2004) divides spatial analysis into two groups: those that focus on point locations (point procedures) and those that focus on broader areas and surfaces (areal procedures). There is overlap between the two, but Ebert makes the distinction upon what is the focus: the objects within a parcel of land, or the parcel of land itself (Ebert 2004: 323).

There are a multitude of tools and functions in a GIS package that are utilized by archaeologists in research. Such include: spatial statistics, predictive modelling, surface interpolation, viewshed analysis, site catchment analysis, cost-path analysis, cluster and density analyses, and locational analysis. This is not an exhaustive list of all possible GIS tools useful to the archaeologist and only serves as an example. These examples will be elaborated upon in the case studies to follow and these projects often make use of several different sets of tools.

4.3 Examples of GIS Archaeological Projects

4.3.1 Microscale

Middleton (1998) provides an excellent overview of the value created by Geographic Information Systems when used to the interpreted a complex archaeological excavation. His thesis also serves as a great guide on how to properly integrate and convert archaeological data into the spatial and non-spatial data used by a GIS. Middleton takes the information collected over five years of excavation at Head-Smashed-In Buffalo Jump (DkPj-1) and performs a variety of "intrasite analyses" upon both the faunal and lithic material found there (Middleton 1998: 83).

For the lithic analyses, he employs both visualization and data exploration tools to identify trends in the data. For example, by querying and separating data from specific levels and cultural phases into individual maps, he was able to identify areas of artefact concentration and zones that were disturbed by looting and augering that affected the site; a trend that would not be visible using tabular data alone (Middleton 1998: 116). Middleton (1998: 136-143) also utilized thematic mapping of the faunal material and was able to highlight large horizontal and vertical concentrations of burned elements amidst a plethora of other faunal data. The concentrations highlighted in the thematic map correlated with the excavator's in-field identifications of a large refuse pile and a small hearth feature. Overall, Middleton's work offers an exemplary illustration of GIS's ability to organize and filter large and complex datasets into packets that are easier to manage for interpretation.

Lieff (2006) focuses on a different set of site-level analyses to interpret site use and probable activities that would have taken place. Lieff's work also shows the breadth of uses GIS offers to many different research areas and topics in archaeology; focusing on both a bison kill site in Alberta and a deeply stratified tell in Israel. It also serves as a strong tutorial on how to integrate GIS into excavation planning and data collection in the field. At the Fincastle Kill site (DlOx-5), Lieff compiles the year's worth of excavation records into a digital format, mapping the site's extensive bone bed. He uses these data sets with spatial analysis tools such as Inverse Distance Weighting Interpolation and Kernal Density to glean possible spatial correlations between the lithic and faunal material (Lieff 2006: 52). He found that the highest concentrations of lithic and faunal material were positively correlated to one another, both horizontally and across several vertical levels. He hypothesizes the correlation represented the tool resharpening taking place throughout the butchering process of the bison bone (Lieff 2006: 58-59).

Lieff (2006) broadens the analyses conducted at the Fincastle site to incorporate the terrain immediately surrounding the kill and how it may have been utilized in hunting strategies. Lieff attempts to reconstruct what areas a bison can see when entering the site using viewshed analysis and uses this information to predict possible locations for the human hunters to hide out of sight. This analysis required the creation of a fine scale Digital Elevation Model (DEM), the data for which were collected from a topographic survey of the site (Leiff 2006: 40). Leiff (2006: 51) concluded that although the viewshed analysis did identify possible hiding spots for a hunter's ambush, several more factors such as wind direction, paleoenvironment and the vertical viewing angle for a bison still need to be accounted for in the model. Nevertheless, it remains a strong example of how the use of viewsheds can strengthen the interpretation of hunting methods used at a kill site on the Northern Plains.

Finally, Lieff (2006) concludes his overview of GIS applications in archaeology with a visualization exercise (Ebert 2004) of material and structures recovered during excavations at Tel Bet Shemesh in Israel. Using the field level records, level maps and measured elevations, Lieff creates a 3D model of structures, features and artefacts across two of the site`s blocks. Thanks to the field records, Lieff separates materials into their respective occupations and relative time periods and reflects this thematically in the 3D model. In doing so, the model user can quickly identify errors created in record keeping as incorrect material would stand out as a marked colour change from its neighbours (Lieff 2006: 94). By ensuring proper recording and digitizing procedures, Lieff (2006: 95) concludes that such a model can be utilized and updated in real time alongside an ongoing excavation and such an advantage is a terrific reflection of GIS`s data management and analysis capabilities.

Mills (2009) continues Lieff's work on the Fincastle kill site by bringing more geostatistical approaches to the fold. Combining the data from Lieff (2006) with additional data collected over two more years of excavations at the site, Mills focused her statistical analyses on the entire excavated area rather than the eastern portions of the site. Mills (2009: 8) uses a variety of spatial statistic tests and measures such as Nearest Neighbour analysis, Quadrat analysis, Kernal Density estimation, K-means analysis, Ripley's K function, Moran's I test and Getis-Ord General G_i to analyze levels of clustering or dispersal found within the archaeological material. By applying these tests to the spatial information of the lithic and faunal material from the excavations and comparing the results, Mills highlights several spatial trends in the data that would not be discernible visually if looking at the complete dataset. For example by comparing the results from the kernal density tool of burned bone and fire broken rock, it was noted the highest densities of both material were found in close proximity to one another, suggesting an activity area where secondary butchering took place (Mills 2009: 126). Like Middlton (1998) and Leiff (2006) she concludes that GIS is a powerful tool for the interpretation of spatial relationships found at archaeological sites, and that the combination of spatial statistics and distribution maps can help the interpreter identify specific activity patterns (Mills 2009: 130).

4.3.2 Mesoscale

Moving outside the spatial relationships experienced within a site to those that exist between different sites as well as between sites and their local environments is the mesoscale of analysis. Friesen's (1999) thesis provides an example this style of research by conducting a locational analysis between sites and a variety of environmental variables found in Grasslands National Park in southern Saskatchewan. Using a site database of over 1000 known archaeological sites found in the Park, Friesen uses each site's location upon a continuous environmental variable as a testable attribute of that site. By running this information through single and two sample chi square tests, he identifies positive and negative trends in the site data between certain classes of the given environmental variable. His environmental variables include slope, aspect, distance to permanent and seasonal water sources and drainages, local geology, level of erosion, and soil stoniness (Friesen 1999: 80-90). Beyond these raw environmental and topological variables, Friesen also incorporates how biological elements may have an effect on where sites are located or found. By comparing distances from different vegetation types as well as locations where bison are likely to forage, Friesen adds elements of how vegetation can promote or hinder site visibility (Schiffer et al. 1979) as well as how subsistence strategies have a role in where sites are typically found. Overall, Friesen's work exemplifies GIS's role in spatial data analysis, this time focusing on the relationships between sites and their environments.

A popular vein of research in archaeology that relies heavily on GIS is archaeological site predictive modelling (Ebert 2004: 323; McCoy and Ladefoged 2009: 270-271). The research is split into two separate methodologies: deductive and inductive (Dalla Bona 1993; Ebert 2004; McCoy and Ladefoged 2009). The inductive approach is very much the natural extension of Friesen's (1999) locational analysis in that it uses the environmental relationships of known sites to predict where sites may be located in an unknown area. Thus the observations of where sites are traditionally located are then used to determine where other sites will be found. It is the more widely used method and many projects rely heavily upon statistical tests to highlight environmental relationships (Ebert 2004: 324). Deductive models work from a "theory first" methodology rather than the "observations first" inductive models. So rather than relying on where sites are observed in a given environment, site locations are hypothesized from theories regarding human subsistence and settlement patterns. This means that the resulting model is explanatory as it provides explanations as to why the chosen environmental variables are used to find sites based on decisions humans make when entering an area. Ebert (2004: 323-324) notes that in practice there is no pure deductive or inductive model, as many of their concepts do overlap. In either case, GIS facilitates both by being able to connect and manage site data with several different environmental variables.

An example of an inductive model is Kvamme's (1992) study of site distribution in Piñon Canyon, Colorado. Kvamme's (1992: 21) research utilizes logistic regression to analyze the distribution of archaeological sites found in a sample area of Piñon Canyon upon the base assumption that human activity is non-random. Eighty-seven open air sites were used as the model creation sample which translated into 220 50x50m raster cells in the GIS. He compares these site present cells to 461 site absent cells; pixels systematically sampled to represent the normal background environment (Kvamme 1992: 28). Thus, the site-environment interactions could be compared to the control sample of natural environmental change expressed across the study area. Kvamme (1992: 25-27) employs six major environmental variables to compare site locations to their background: topographic slope, hill aspect, local relief, view data, shelter index (the index of how open/enclosed an environment is) and distance to water sources. Using said variables, the logistic regression modelling scheme divided the sample area into two zones, M and M'. Zone M represented areas that were environmentally similar to locations with sites, and sites were four times more likely to occur in this zone than the M', thus showing the successfulness of the model (Kvamme 1992: 34).

The success mentioned above is not without folly, however. Kvamme (1992) notes that the measures of success were based upon data that formed the model. That is, they show how well the model can predict the sites that were used to build it. So it is no wonder that the model preformed so well: it was predicting what it already knew. Kvamme anticipates this problem by testing the model against a new site sample survey in the same area. The new survey was conducted completely independent of the original using different crews, investigators and institutions; although it was slightly biased as it relied upon the model's prior assessment (Kvamme 1992: 34). The use of this new sample as a test allows for a true measure of the model's predictive capabilities, even with the slight bias. Kvamme (1992: 36) showed that the model was successful in predicting the new sites 23% better than chance. Overall, Kvamme's research provides a well explained and step by step example of the employment of logistic regression modeling of archaeological site distribution within a GIS. Most importantly, Kvamme's testing the model against an independent sample is critical to the operation of an inductive modeling process, as it allows for an unbiased assessment of the model's accuracy.

While Kvamme's (1992) paper showcases a successful example of inductive modeling where site locations and environmental variables found in a study area are used to infer site/environment relationships using statistical tests, deductive modeling works in reverse: taking theories on human/environment interactions and transposing them upon a study area to predict sites. This allows the researcher to explain using theories why sites are predicted where they are, though Kvamme (1992: 37) remarks that variable selections in empirical models needs to make anthropological sense if they are to be used correctly. Dalla Bona and Larcombe's (1996) work in northern Ontario provides an example of the deductive modelling process in action. Dalla Bona and Larcombe (1996: 252) aim to summarize the Centre for Archaeological Resource Prediction (CARP)'s efforts at predicting human land use in the Ontario boreal forest in attempts to subvert destructive effects of the lumber industry. Rather than use existing site records and empirical tests to identify site/environment interactions, Dalla Bona and Larcombe harness information gleaned from ethnographic accounts and previous research to summarize seasonal human activity in a boreal forest environment. This allows them to identify that different subsistence strategies were enforced between the summer and winter, and both would be expressed upon the landscape differently. With these different strategies in hand, Dalla Bona and Larcombe are able to create two separate models: one that reflects winter activities and one for summer ones. For example, both models use proximity to lakes as an environmental variable. However, the summer model focuses on larger order lakes for its deciding factor, while the winter model relies on smaller lakes due to the change in subsistence strategy between the two seasons (Dalla Bona and Larcombe: 264-266). When integrated with the environmental data in a GIS, the resulting maps for each season stand in stark contrast to one another. Combining the two permits a more holistic view of human activity in the boreal forest and more explanative conclusions of where sites are to be located.

Moving away from predictive modeling, another popular vein of research integrating GIS with archaeology is least-cost path/catchment analysis (Ebert 2004: 328; McCoy and Ladefoged 2009: 273). The goal in these kinds of studies is to identify movement routes and accessibility between sites or across an environment where sites are found. Each works upon tools common in GIS software packages that assign cost or friction values to a raster grid. Each value reflects the inherent cost or impediment to traversing that square (Chang 2008: 378). Costs can reflect a variety of different measures such as time (Whitley and Hicks 2002), potential energy (Bell and Lock 2000; Bell et al. 2002), currency expenditure, or simply exist as unit-less quantities. Algorithms in the software attempt to recreate movements by calculating the sequence of pixels that accumulate the least total cost. The mechanics behind least-cost path analyses will be discussed further in Chapter Five.

In archaeology, the most common application of least cost path analysis is to recreate possible travel routes used by humans in antiquity. This practice is especially prevalent in Old World archaeology, where models are often created and compared to known road systems. Bell and Lock (2000) use such techniques in investigating path selection between hill forts in Oxfordshire, England. Bell and Lock (2000) argue that such hill fort sites are located where they are thanks to the influence of a well travelled path known as The Ridgeway. Since the study area resides in particularly hilly terrain, Bell and Lock (2000: 99) conclude that The Ridgeway was utilized because it was the least-costly pathway based on changes in slope. That is, the route calculated by the GIS closely followed the recorded route of The Ridgeway, and often ran directly through the hill forts themselves. Being an optimal route, historic and prehistoric sites were set up along the Ridgeway to take advantage of its efficiency, even if visibility between the sites and route was minimal (Bell and Lock 2000: 99).

Degree of slope is often the most common determinant of friction in least-cost studies done in archaeology (Conolly and Lake 2006; Ebert 2004; Wheatly and Gillings 2002). An important point to take away from Bell and Lock (2000)'s analysis is their emphasis on anisotropy, where costs and frictions can change based on the direction one travels. This is often employed in mountainous or hilly terrain due to the aforementioned reliance on slope to determine costs, as movement uphill will have different weights than movement on the same slope in a downhill direction. This effect would be less prevalent in flatter areas, but other anisotropic factors that influence travel could be in play such as prevailing winds or stream currents.

Krist and Brown (1994) offer a different means of utilizing least-cost path tools in an archaeological context. Rather than focus on human movement patterns and routes through a landscape, they instead look at caribou movements and how archaeological sites might interact with such paths. Krist and Brown (1994: 1129) seek to apply GIS tools and methods to aid in understanding environmental and cultural patterns, and do so by modelling caribou migration paths in Northern Michigan during the Paleoindian time period. Like Bell and Lock (2000) the authors use hillslope as the main contributor to movement cost, making use of previous research of how caribou herds interact with sloped terrain. They note that caribou have a tendency to walk perpendicular along steep slopes since the accumulated cost of a normally difficult pixel (>8˚) can be negated by moving at right angles to that slope. By doing so, they are able to simulate anisotropic movement of caribou based upon which direction they were moving, either northwesterly or southeasterly (Krist and Brown 1994: 1132).

With the least-cost caribou paths in hand, Krist and Brown (1994) then create viewsheds from the various archaeological sites found in their study area. They hypothesize that sites were located where they were so hunters could maximize their viewsheds overlooking the caribou trails (Krist and Brown 1994: 1133). They note that caribou could easily be seen from high points near the sites at key locations such as river valley crossings. Like Bell and Lock (2000), Kirst and Brown (1994) combine the results of both cost path and viewshed analysis packages in GIS software to aid their interpretations of past settlement patterns and human-environment interactions. This study is also very similar to Dalla Bona and Larcombe's (1996) inductive model methodology, using inferences about human subsistence strategies to predict site locations.

Byerly et al. (2005) follow Krist and Brown's (1994) lead by using cost-path and viewshed analysis tools to recreate animal movements in an archeological context. Investigating the Bonfire Shelter bison kill site in Southern Texas, Byerly et al. (2005) combine GIS and zooarchaeological data to test the hypothesis that the site was operated as a bison jump during the Paleoindian Period. Byerly et al. (2005: 599-605) acknowledge that Bonfire Shelter possessed many of the attributes found in several bison jumps across the Great Plains, but lacked a network of drivelines above the cliff face. As discussed in Chapter Three, the driveline and drivelane system was crucial to a bison jump's operation, so Byerly et al. (2005) attempt to simulate the possible routes using least-cost path analyses that reflect an ancient bison's movement. Their results were positive, showing that a strong central corridor from the north could have served as a possible route (Byerly et al. 2005: 603). They take their analysis a step further by recreating bison viewsheds at several locations along the route, much like that done by Lieff (2006). Through the viewshed process, Byerly et al. (2005: 604-605) determine that a bison's chances of seeing the cliff edge too soon was minimal along these least cost paths, thus further cementing the likelihood of the route being used in a bison jump event. However, despite the strong evidence from the GIS analyses, the zooarchaeological investigations showed little evidence that would suggest the kill was operated as a bison jump (Byerly et al. 2005: 625-626). Nevertheless, Byerly et al. (2005)'s investigation is a prime example of the usefulness of GIS in archeological studies, especially for sites so closely tied to environmental variables such as bison jumps.

4.3.3 Macroscale

Moving away from individual and small clusters of sites of the microscale and mesoscale, we enter into the macroscale. Not only are we now looking at several different sites, but the sites are located across great distances and different environments. Showcasing an example of this grandeur of scale as well as another example of cost-path analysis is Bikoulis's (2009) analysis of Anatolian social networks. Bikoulis (2009: 76-77) utilized least-cost pathways to connect areas such as the Amuq and Konya Plains in south central Anatolia to see if the Göksu valley served as a popular route for travel during the Late Neolithic and Early Chalcolithic and into the Early Bronze Age. Two main routes were identified from the least cost analysis, one through a common and well know pass in the Taurus Mountains and the other moving between the Göksu Valley and Cilician Plain (Bikoulis 2009: 122). However, the second route travels through an area of the Taurus Mountains known to be well arid. Bikoulis (2009: 124-125) notes that despite the area being highlighted for its ease in topography, other factors such as limited access to water deny its usefulness for human travel. This is an important point about using GIS in archaeology, especially in modeling and simulation (see Ebert 2004). GIS software will output information, but will not critique it. It is up to the archaeologist to judge if the data output from a GIS make sense in the area and time period they are studying.

Bikoulis (2009) adapts his least-cost pathways between sites into a series of social networks, with sites comprising vertices and the paths representing edges of the network. He divides sites down into three time slices: The Chalcolithic, Early Bronze I-II and Early Bronze III, creating a social network for each period. Comparing the three, Bikoulis (2009) is able to note changes through time and highlight when particular regions rise and fall in prominence. When looking at sites from the Göksu Valley, their centrality role in the network (the ability to control network flow) only becomes prominent in the Early Bronze III period, holding relative obscurity in earlier periods (Bikoulis 2009: 130). Bikoulis (2009: 90) acknowledges that the least cost paths were an important component of the network analysis, as they allowed for sites to connect over long distances all while being controlled by "effort."

Whitley and Hicks (2003) showcase another use and modification of least-cost path analysis for use in archaeology. Beginning with datasets created for predictive modeling use in cultural resource management (CRM) archaeology, the researchers examine other uses for the data in "...exploring, identifying, and interpreting more complex sociocultural themes using GIS software" (Whitley and Hicks 2003: 77). These research goals lead them to explore possible historic and prehistoric travel corridors through Northern Georgia using least cost path analyses. In doing so, Whitley and Hicks (2003) divided their paths into primary and secondary pathways. The primary pathways represented the most efficient routes to traverse the landscape, connecting the systematically selected origin and destination locations along the study area's perimeter (Whitley and Hicks 2003: 82). Each path was then allocated its own *costshed*: the area of cost-corrected terrain that each path services. The costshed is synonymous with a watershed which refers to the given area that a particular river drains. In this case, the costshed reveals the area where it is most efficient to travel to and upon a particular primary pathway. From here, the secondary pathways are determined as they are the most efficient pathways that move within a given costshed. In the watershed analogy, the secondary pathways would be the first order streams that flow into the primary pathway's "river." Whitley and Hicks (2003: 83) associate these secondary pathways with the arteries that facilitate travel between resource gathering areas and the central routes for travel (primary paths). By creating the network of primary and secondary pathways with their respective costsheds, Whitley and Hicks (2003) manage to create a model of human movement in their study area.

The paths and networks Whitley and Hicks (2003) created do not exist in a vacuum; their locations are compared with known archaeological site locations to critique their possible association. The associations were evaluated based on cost distance through the Chi-square statistic against a set of random background locations. Archaeological sites are divided into relative time periods, ranging from the Paleo-Indian period into historic occupations (Whitley and Hicks 2003: 85-89). Comparing the results between the primary and secondary pathways highlights the site selection patterns of the time period, either preferring to be closer to travel routes (primary), or resource extraction (secondary). These preferences can be tracked through time, showing how site selection behaviours and decisions changed through the prehistoric and into the historic period. Whitley and Hicks (2003: 77) admit this study was purely exploratory, seeking to raise more questions than answers and their conclusions will require additional research to verify.

The last GIS-focused research worth mentioning from the macroscale is Moors (2007)'s study of ceremonial and habitation sites in Alberta. Like Whitley and Hicks (2003), Moors (2007) reconstructs travel routes and trails that may have been used in antiquity. However, he does so using a drastically different methodology and theories. What makes Moors (2007)'s research unique is that he performs his analysis through the theoretical lens of *landscape archaeology* and integrates this theoretical paradigm into GIS. He works against the common empirical views of the environment and landscape, where access and availability of physical resources determine where people settle in that environment. Such views are the cornerstone of settlement studies and predictive modeling scenarios such as Friesen (1999), Kvamme (1992), and Dalla Bona and Larcombe (1996) mentioned above. Instead, Moors (2007) investigates how the natural landscape transitions into the cultural and spiritual landscapes of the *Siksikaitsitapi* (Blackfoot) worldview, and how site locations and interactions reflect such landscapes.

Moors (2007) centres his thesis around the *Siksikaitsitapi*'s movement across their spiritual landscape as a reflection of their seasonal round. Moors (2007: 28-29) acknowledges that a cultural/spiritual landscape is made up of named places experienced when traveling through said landscape. These named places would be frequently returned to for ceremonies and would be used as location markers to discern where the individual is. Noticing the high concentration of ceremonial sites as well as habitation sites around confluences of the Bow, Red Deer and South Saskatchewan rivers, Moors (2007) focused his research into two study areas in this region, each containing at least one prominent and well known medicine wheel within. Moors (2007) argues that since these medicine wheels (Majorville and British Block) would be well established places on the cultural landscape in prehistory, as people would be returning year after year as they followed the seasonal round. The routine visitation should be seen archaeologically as clusters of tipi rings and ceremonial sites near each medicine wheel. He found that in both study areas that tipi rings tend to cluster along linear features in the landscape, such as river valleys, meltwater channels and hill complexes. The medicine wheels tend to be situated on the most prominent locations along these linear features, indicating they are located near important and well travelled paths in the landscape (Moors 2007: 164-165). Other ceremonial sites such as circle camps and bisected tipi rings tended to cluster near the medicine wheel in the Majorville study area, supporting their important role in the spiritual aspect of the landscape (Moors 2007: 167). Thus by looking at tipi ring concentrations in respect to the *Siksikaitsitapi*'s spiritual associations with place, Moors (2007) was able to identify routes of repeat travel and visitation, just as Friesen (1999), Kvamme (1992) or Whitley and Hicks (2003) had done. However, Moors (2007)'s work is unique because it breaks away from traditional GIS applications in archaeology by utilizing a landscape rather than a cultural ecology approach.

4.3.4 Megascale

Most GIS studies in archaeology focus on the previous three scales, such as analyzing the spatial distributions of artefacts in an individual site, locations that are favorable to sites along a river valley, or how site locations indicate movement and social complexity in a larger region. Still there are a few researchers that push the limits of scale, covering broad areas, environments and types of sites. These megascale studies are not focused on specific locations or regions, but are rather the summation of such regions. The two case studies mentioned below cover vast areas: one combining the data recorded across the several states and provinces that make up the Great Plains, while the other goes even larger, crossing multiple countries and two continents.

The Great Plains study analyzes the characteristics of different bison kills and strategies recorded from Saskatchewan to Texas. Cooper's (2008) dissertation compared and contrasted the similarities and differences of every recorded bison kill site identified on the Great Plains to see how their general trends reflected five different substance models. She defined the five models to describe when, how and why bison were hunted on the Great Plains by summarizing the general views and theories presented in archaeological, anthropological, ecological and other literature (Cooper 2008: Table 5-1). While not the focus of her research, GIS played an important role in Cooper (2008)'s assessment of these models, namely for its data management, visualization and analysis capabilities. Cooper (2008: 215-218) monitors the spatial distribution of various types of bison kills, such as jumps, pounds and arroyo style traps, noting that jumps and pounds typically cluster in the Northwestern Plains, while arroyo kills are more spread out across the entirety of the Great Plains. She attributes this distribution to the terrain changes across the Plains, where the Northwestern Plains offer more cliffs and valleys that are better suited for jumps, while arroyo topography is more ubiquitous (Cooper 2008: 215-217). However, this ubiquity may stem from her inclusion of coulee kills with more traditional arroyos (Cooper 2008: 190). The spatial distribution of seasonality of kills is also studied. Within the northern plains, where seasonality evidence more prevalent, Cooper (2008: 240) finds that the mean centre of site distribution shifts eastward as seasons progress from winter to fall, suggesting a preference to hunt on the open plains in the summer and fall and in the foothills during winter and spring. Finally, Cooper (2008: 210-212) models through Inverse Distance Weighting that the size of bison kills changes not only across space, but through time as well. From 500 to 1700 C.E. large bone bed sizes were being found further and further south into the Central Plains, while kill sizes in the Northwestern Plains shrank (Cooper 2008: Figure 7-7). However, this may be a side effect of how Cooper defines her assemblage sizes, which are based on the quantity of bone pieces procured from each site (Cooper 2008: 209) instead of the total number of animals killed or spatial extent of the bone beds. This southern expansion of assemblage size may also be a result of the lack of kill sites in the southern Plains in the earlier time periods (See Cooper 2008: Figure 7-4). Inevitably by combining the spatial, seasonal, climactic and temporal data of all the bison kills in the Great Plains, Cooper (2008: 313-315) concludes that no single model explains the variation in bison hunting seen in the archaeological record. She also notes that even at a regional scale that no model adequately fits the evidence of bison kills (Cooper 2008: 315). The record is simply too diverse and variable to summarize with a single hunting model.

The last case study that will be looked at is indeed the largest in scale. Anderson and Gillam (2000) probe the possible migration routes that would have been taken by the first humans entering North and South America during the Late Pleistocene. Seeking to assess the variety of different theories of how Paleoindian groups may have travelled across the New World, Andreson and Gillam turn to least cost path analysis tools in GIS. Like the other least cost models mentioned above, Anderson and Gillam (2000: 47) built their friction surface using slope as the major inhibiting factor. However, since their work is set during the late Pleistocene, they combined their slope data with the locations of continental ice sheets that would have served as barriers to movement, giving a more realistic model of possible travel corridors. Anderson and Gillam (2000: 47) test three possible entry locations into the new world: Western Alaska, the mouth of the Colorado River, and the Isthmus of Panama and calculate the least cost paths from these locations to 45 archaeological sites across North and South America. While the different points of entry did create similar paths in the grand scheme, subtle differences are apparent. The most notable difference is seen in the order and direction that certain sites were reached in western North America. The Alaskan entry favours north-south primary paths and east-west secondary pathways, while the Colorado entryway shows the opposite with east-west primaries and north-south secondaries (Anderson and Gillam 2000: 48-51).

Anderson and Gillam (2000) note that the likelihood of any of the paths or points of entry being used in antiquity cannot be tested nor verified on their data alone. Such a thing would require continued archaeological research of sites dating to this time period across North and South America. Instead, they use their hypothesized paths to model various demographic and dispersion scenarios of a founding population spreading into the New World. Using a variety of different variables, Anderson and Gillam (2000: 54) found that a starter population of 25 people can reproduce and spread across the entire landmass in a period anywhere from 600 and 5000 years, with 2000 years reflecting parameters found in modern hunter-gatherer groups. Two dispersion models are put forth: the string of pearls model where a new population moves adjacent to the original after fission and the leap frog model where the new population moves a substantial distance after fissioning from the parent group. Anderson and Gillam (2009: 59-60) acknowledge the distribution of fluted points across the United States follows closer to the leap-frog scenario, and each of the major cost paths pass along high densities of fluted points. They conclude that the first groups into the Americas likely travelled in a leap-frog manner across the continent in a similar fashion to those predicted by the least cost paths when south of the ice sheets.

The case studies presented above are only a small sample of the kinds of roles GIS can play in archaeological research. However, a continued debate in the archaeological community is the question if GIS is "theory neutral" (Conolly and Lake: 2006: 3), in that it can be used outside of a theoretical framework or will not inherently establish its own. Neglecting these arguments could lead to a researcher making false interpretations, using GIS incorrectly or establishing unseen and unwanted biases into the data.

4.4 Theoretical Considerations

The first consideration stems from how explanation is conducted and approached when using GIS as a tool in archaeology. Maschner (1996b) describes the two approaches as deductive and inductive. As mentioned above these two schemes are generally used when comparing different techniques in archaeological predictive modeling (Dalla Bona 1993; Ebert 2004; McCoy and Ladefoged 2009). However, Maschner (1996b: 302) notes that these theoretical approaches extend beyond the realm of predictive modeling into all GIS based applications, suggesting that many of the studies that make use of the exploratory data analysis functions in a GIS can be thought of as inductive. In this sense, Kvamme (1992), Middleton (1998) and Mills (2009) would all fall under the inductive banner, as they draw conclusions from observations and interactions between archaeological material and their environments. On the other hand, several of the other case studies (Anderson and Gilliam 2000; Bell and Lock 2000; Bikoulis 2009; Byerly et al. 2005; Cooper 2008; Dalla Bona and Larcombe 1996; Moors 2007; Whitley and Hicks 2002) follow the more deductive path, testing hypotheses against archaeological observations and critiquing the outcomes.

However, the division between these two approaches is never this simple. Kvamme (1992)'s research did begin as inductive modelling of site potential, but the conclusions and generalizations he made were then tested against new independent data, moving to a more deductive approach. While some of Friesen's (1999) locational analyses based on topography were inductive in nature, he also supplies and tests his own hypothesis of how site locations reflect a bison forage model. Maschner (1996b: 302) notes that many of the deductive studies performed during his time had grown out of former inductive processes. Overall, GIS plays two roles: an exploratory and visualization tool that allows the researcher to draw conclusions from their data (e.g.: "the debitage tends to cluster along the northern boundary") but also an analytical tool which the researcher can use to answer important spatial questions (e.g.: "what can a human see from this medicine wheel?"). Often the two tools are intertwined and will work in tandem with one another.

The second theoretical debate regarding GIS use in archaeology is that the use of spatial technologies fosters an environmental determinist bias (Conolly and Lake 2006; Lock and Harris 2000; Maschner 1996a; McCoy and Ladefoged 2009; van Leusen 1996; Wheatly and Gillings 2002). Environmental determinism of course is the idea that "...races, cultural diversity, cultural stability and change could be explained by the environmental conditions under which these traits developed" (Erikson 2010: 108). Thus, the environment where you find archaeological material played a pivotal role in its creation and determined where it was found. Obviously, the locational and predictive modeling sides of GIS are the most often criticized of this bias (McCoy and Ladefoged 2009; Wheatly and Gillings 2002) as they are the ones that attempt to connect site locations with specific environmental variables. This is especially prevalent in the inductive modeling scheme. Such approaches remove the agent from the dialogue between the agent and their environment by basing all site patterning on the interaction between environmental observations.

There are a few reasons why the environmental deterministic bias has been so prevalent in GIS-focused archaeological research for the last 20 years (Allen et al. 1990; Lock and Stancic 1995; Maschner 1996a; McCoy and Ladefoged 2009). Van Leusen (1996:181-182) points out that cultural variables that influence spatial decisions are either unknown or unmappable. On the other hand, environmental variables are often preferred not because they have increased importance over cultural ones, but according to Maschner (1996b: 303) they are often the only data that are available. Ebert (2004: 324-325) notes that aspect, slope and distance to water have become the "usual suspects" list of predictors, as they often are used again and again in different projects. Ebert (2004: 327) continues in saying that one of the greatest failings of inductive models is their lack of non-environmental predictor variables. So how does an archaeologist shy away from the norm and integrate cultural factors into a GIS?

The most common approach is to reconstruct the cognitive processes of past humans as they interacted with and within their environments. This school of thought is very common in European archaeology (Gaffney et al. 1995; Harris and Lock 1995; Lock and Stancic 1995; Ebert 2004; McCoy and Ladefoged 2009). Such studies often employ viewshed/line-of-site tools as a means of recreating a social landscape (Ebert 2004: 330), modeling past behaviours (McCoy and Ladefoged 2009: 272) or studying cognition (Maschner 1996; 305). By recreating what an agent could (or could not) see, the user can glean insight into the agent's decision making process and in turn use this new information as a cultural variable in their analysis. Obviously the line-of-sight method is not without its flaws (see Wheatly and Gillings 2000; Wheatly and Gillings 2002; Conolly and Lake 2006), but when connected with environmental data, the results offer a much more robust view of human subsistence strategies, settlement patterns and other interactions between an agent and their environments. In the examples above, Kirst and Brown (1994), Dalla Bona and Larcombe (1996) and Bell and Lock (2000) all integrate both cultural and environmental factors into their spatial analyses, providing them with a more holistic view of past human behaviours.

Ultimately the level that environmental determinist biases can influence research is left up to discretion of the researcher. Van Leusen (Gaffney and van Leusen 1995; van Leusen 1996) acknowledges that an environmental determinist mindset can sometimes be of great benefit to archaeologists. He advocates that environmentally focused models have great use in the CRM side of archaeology, where time and monetary limits may not allow for broader cultural variables to be assessed (Gaffney and van Leusen 1995: 369). Such environmentally determinist models can serve as a "first approach" (Gaffney and van Leusen 1995: 371), filtering out the "obvious relationships" (Gaffney et al. 1995: 211) and perhaps highlighting areas of future research. Such areas would be outlier sites that do not fit the environmental determinist view and where more culturally oriented spatial variables may be expressing themselves (van Leusen 1996: 183). However, Gaffney counters this stance by saying that human agency and belief systems are rather pervasive and would be ignored or overlooked by van Leusen's methods (Gaffney and van Leusen 1995: 375). So again, the role and impact of possible environmental biases will vary from archaeologist to archaeologist. Nevertheless, any GIS lead archaeological researcher must acknowledge and account for environmental determinist biases that may manifest in their methodology.

4.4 Summary

The use of Geographic Information Systems has been a great boon for archaeology. GIS is not a simple program to make maps with, nor is it a simple information system for data querying and storage. It is in fact the marriage of both programs combined with the added functionality brought in by the wealth of spatial data analysis tools and processes developed over the years. Since its adoption in the 1980's, GIS has expanded the level and depth of spatial analyses available to the archaeologist. Many note that the much of the research and application regarding archaeological GIS has been centered around predictive modeling and prospecting for purposes of CRM (Ebert 2004; McCoy and Ladefoged 2009). However, research has broadened over the years to accommodate a variety of spatial analytical tools and methodologies, such as cost path analysis, viewsheds, density and cluster analyses and social network analysis to name a few. GIS offers a host of benefits and opportunities to archaeological research, a small sample of which were seen above. These benefits and tools will be utilized in this project to examine the spatial dynamics that play a crucial role in the operation of a Plains bison jump.

Chapter 5
Methodology and Data Collection

Integrating archaeological data into a GIS is a process involving several steps. This thesis follows the methodology outlined in Byerly et al. (2005), Lieff (2006), Carlson (2011) and Surface-Evans (2012) and is divided into two major and related foci of research. The first is least cost path analysis and the second is viewshed analysis. These processes can share similar data between one another, but also require specialized data for their individual functions. In fact, the results of the cost path procedure are used as input data in the viewshed tool. A general overview of each tool is provided below, as well as the pertinent information on the data utilized by the GIS software. One important point to note is that all datasets are projected into Universal Transverse Mercader (UTM) projected coordinate system using the North American 1983 Datum (NAD83), as this was the base projection for the elevation data and the aerial imagery. This is done to avoid errors that arise from working in multiple projections.

5.1 Data Acquisition and Creation

5.1.1 Environmental and Topographic Data

The non-archaeological data include three major datasets. The first was the digital versions of the 1:50,000 NTS Topographic Maps of Canada for the study area (NTS sheets 72H02 and 72H07). These topographic maps were used primarily for their hydrology data, which included the waterbody polygon and watercourse polyline layers. The data from the topographic maps were primarily used for visualization and map making purposes. These datasets are publicly available from GeoGratis, a collection of geospatial data provided by the Government of Canada (Natural Resources Canada 2012).

The second major data set was a collection of orthorectified aerial imagery created by the Saskatchewan Geospatial Information Collective (Saskatchewan Geospatial Information Collective 2013; ISC 2012). These images were composed of three visual bands representing the red, green and blue wavelengths of the visual spectrum. Thus when combined, the band display as a truecolour image. Each image encompassed an area equal to one legal township (6x6 mile) in size with a cell size of 0.6m. Five of these township images were used in the course of the study: 04T21R2W, 03T21R2W, 03T22R2W, 02T21R2W and 02T22R2W.

These images were a great benefit as they provided a recent overview of the study area. While primarily used for visualization purposes, they also were used to update the hydrological data not present on the topographic maps. The images were collected in early spring of 2009, thus they represent a moister time of the year. As such, several seasonal water bodies and sloughs dot the upland portions of the landscape. These places of open water served as a dark contrast to the grassy vegetation in neighbouring areas and were easy to identify (Figure 5.1). Drier sloughs could still be identified by a colour shift resulting from a change in vegetation or wetter soil. The sloughs were digitized into polygons and were added to the waterbody layer of the topographic map. The digitization was based on the operator's experience and judgement and does not represent the complete hydrology of the region, only a representative sample thereof. For example, waterbodies that show evidence of human modification, such as a dammed valley or dugout, were not digitized. This was done in an attempt to best represent the pre-contact environment of the area as these modifications would not be found at such a time. Discretion was also given for very small water sources. As these data would later be converted into 30x30m pixels, such small sloughs would be grossly overemphasized and skew the data.

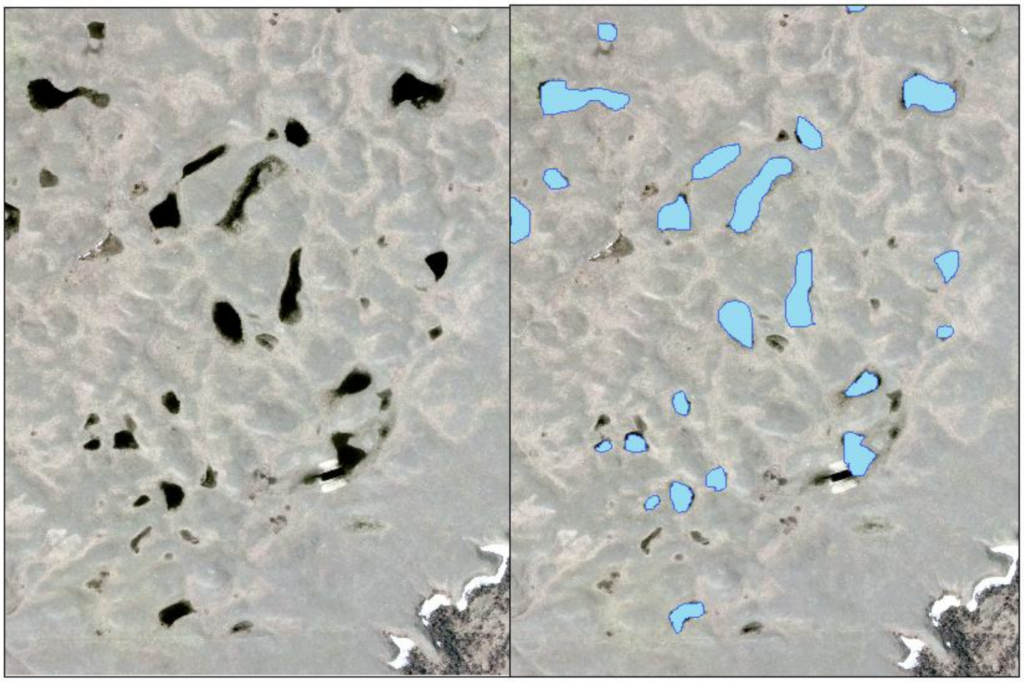


Figure 5.1: Identification of waterbodies from imagery. Dark zones (left) represent standing water, which are digitized into water polygons (right).

The third and most important of the environmental datasets collected was a series of Digital Elevation Models (DEM) that represent the changes in elevation experienced across the landscape. These elevation models were created from the township ortho-images mentioned above. Information Services Corporation (ISC) notes that these DEMs were created using points laid in a 100m grid along with breaklines that denote sharper changes elevation. These breaklines represent a variety of features such as tops of stream banks, ridge lines and road edges (John Leonard, personal communication 2010). The use of breaklines allows for a better representation of changes of terrain, especially near areas of high relief such as a stream valley. ISC quotes a horizontal and vertical accuracy of ±3m of this data (John Leonard, personal communication 2010). The DEMs have a resolution of 30x30m pixels and reflect the townships mentioned above. Along with these DEMs, the SaskGrid 3.0 shapefile was also collected from ISC (ISC 2012). These spatial data provided the boundaries for the legal sections, and were used to draw the boundaries of Walker's (1990) study area seen in Figures 2.1 and 3.1.

Since the cost path analysis step of this research relies heavily on these elevation data, it is important that they are an accurate representation of the topography of the study area. The use of breaklines helps increase the accuracy, but also raises an important point worth mentioning. The breaklines used in the DEM creation also reflect the presence of manmade roads effect on topography. Much like the dammed lakes and dugouts mentioned earlier, these roads were not present on the landscape during the pre-contact period. This does create a small bias in the data that will give false elevations near a built-up roadway. However, when compared to the pixel size of 30m and vertical precision no smaller than a metre, the effect of a 10m road allowance is not expected to be very significant. Nonetheless, it is a point worth mentioning should the end product of the cost path analysis mysteriously follow modern roads.

The 30x30m resolution does lend itself to challenges when working in some portions of the study area and in the viewshed analysis stage. While a finer resolution of elevation data would be highly favourable, such options either were not feasible or created worse problems in other ways. Light Detection and Ranging (LiDAR) remote sensing systems offer powerful and high resolution elevation data, often down to 1x1m pixel size. LiDAR was originally considered as a possible data source, but such data are very expensive to acquire in Saskatchewan and was therefore ultimately unattainable. Another source of elevation data that are commonly used by archaeologists come from contour lines on topographic maps. GIS software is often used to interpolate a model of the terrain by using contour lines as locations of known elevation. The interpolation process is beneficial as it allows the user to set a desired resolution. While this practice was common in earlier GIS based studies, it has fallen under some harsh criticism in recent years. Conolly and Lake (2006: 104-106) note that there is no well established method of converting contour data into a working DEM and will often create unwanted errors with the data. One example they highlight is so called "tiger-striping" where DEM derivatives will appear as bands radiating across the surface; artefacts left behind by the original contours. They also note that in areas where contours are further spaced, the interpolator has less information to fill in the void, creating plateaus that do not reflect the natural environment. This example is highlighted in Figure 5.2 which compares the 30x30m DEM with one created from topographic contours with a 10x10m resolution. Even though the resolution is much higher on the contoured data, the upland areas show very little variation in terrain, adopting a more step-like layout. Since the cost path analysis looks primarily at the upland areas, the 30x30m data provides a better representation of the knob and kettle terrain of the landscape.

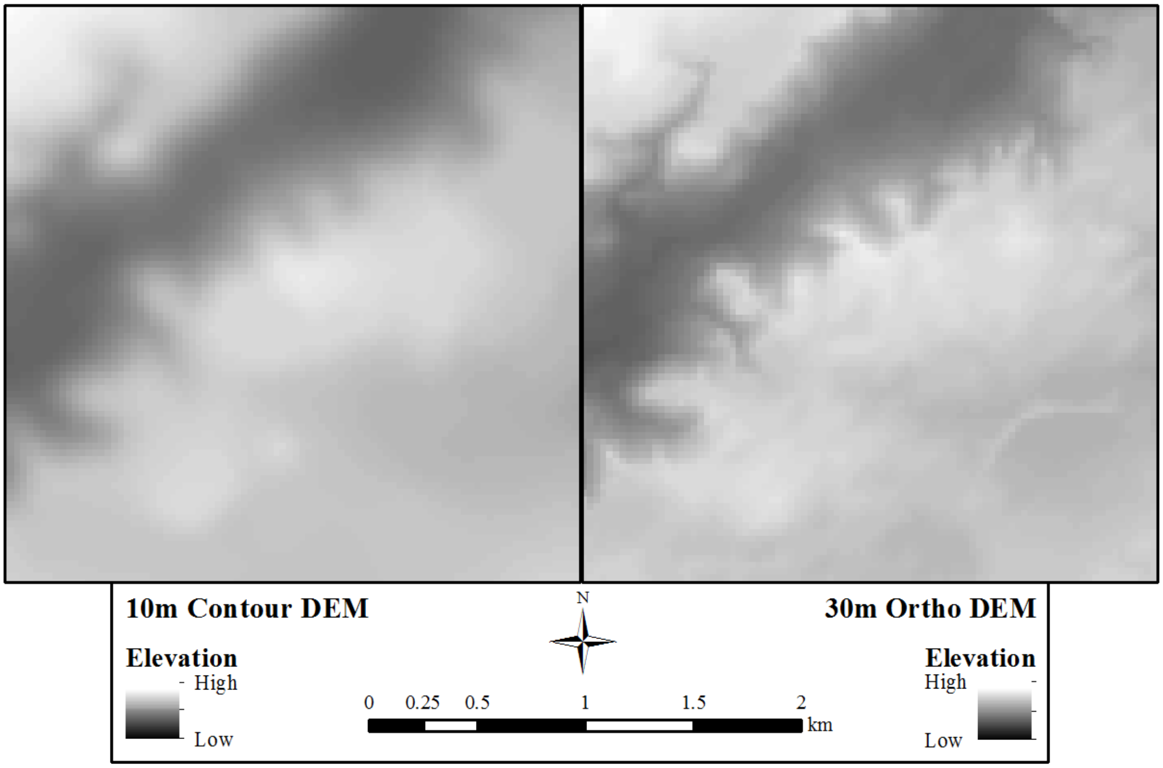


Figure 5.2: Comparison of a DEM created from contour lines (left) vs. one from digital imagery (right). Note that even though the contour model is of higher resolution, the upland areas have a washed out appearance, completely missing the esker found in the southeast corner.

A second DEM was created for the specific use in the viewshed analysis which would be focused on the areas immediately behind the bison jumps. The 30x30m data would be too coarse for this style of analysis, especially for the smaller areas that needed to be covered. The new DEMs were derived from elevation points collected in during a topographic survey. Only two bison jumps were surveyed in this fashion as the process is rather time consuming and thus it was not feasible to look at all seven. DhNe-1 and 51 were selected because they are found at opposing sides of the valley and they have the most drivelines associated with their immediate proximity. These sites were also the most easily accessible and generally lacked modern disturbances such as major roads and oil pads. Again, this tries to follow Byerly et al.'s (2005) approach, as they to needed to conduct a topographic survey to perform their viewshed analysis. The methodology of the survey is found below.

5.1.2 Topographic Survey

To create the finer scale DEMs used in the viewshed analyses, a systematic survey was conducted to record the range in elevations for two of the bison jumps as mentioned above. The survey was conducted in the spring of 2012 by a two-man team using a Triumph real-time kinematic (RTK) GPS receiver (Figure 5.3). The ground system involved one stationary base unit and two rover units with data collectors. The rovers were used to record spatial coordinates (easting, northing and elevation) along transects every nine metres. Since the target resolution of the DEMs were to be 10x10m (see below), a nine metre interval was chosen to decrease the chances of overshooting the 10 metre window. Extra coordinates were recorded when the sample design did not reflect the terrain. For example, if a low spot of a small gully fell between two normal points, a third point would be recorded at that location. This was to ensure the samples better reflected the change in terrain. Using the RTK receiver afforded increased accuracy and precision of recorded spatial information over a typical handheld GPS device. While root mean square (RMS) error would vary from point to point, vertical and horizontal error never exceeded ±0.03m, and was most often kept below 0.02m. Compared with a handheld GPS having ~3m horizontal accuracy in the best scenarios, the RTK provides at least a hundred fold reduction in error.

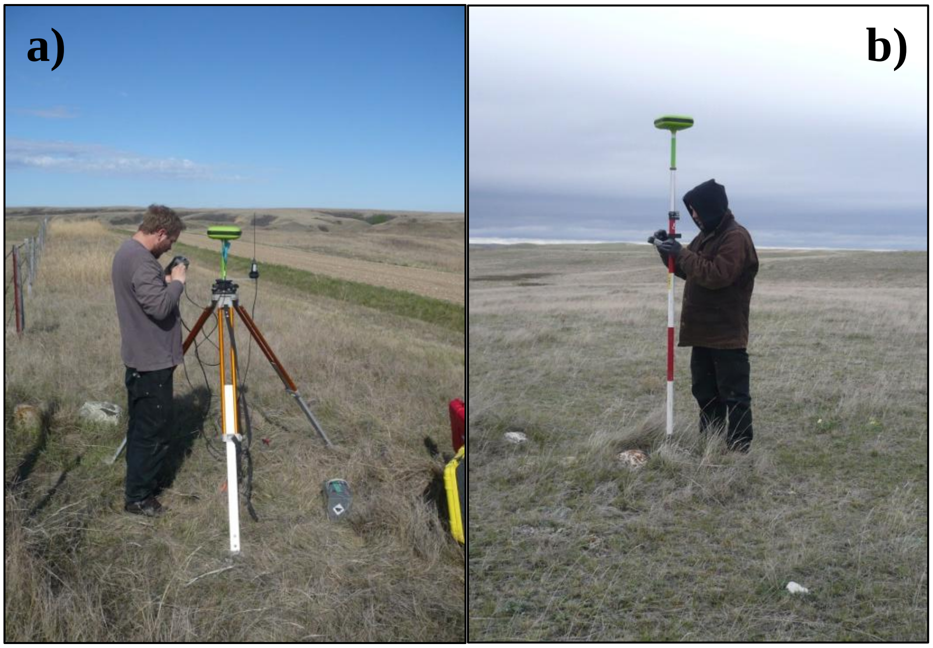


Figure 5.3: RTK GPS in use. a) Base station b) Rover used for transects.

The boundaries for the survey were different for each area. The aim was to follow Byerly et al.'s (2005) example, where their topographic survey enveloped an area approximately 400m behind the edge of the jump. This worked for the Ironhorse bison jump (DhNe - 51) and the survey targeted a near-circular area with a 400m radius around the jump edge. This was not the case for the Sabin bison jump (DhNe-1), where the 400m area only encompassed the small spur of land that extends off of the main upland area. The small area would not encapsulate the variety of possible paths that may have been utilized in a hunting event. Thus the survey area was extended backwards to up to 1km from the cliff face to provide a better representation of the possible avenues used. The valley edges served as the other boundaries for the survey. These were chosen for two reasons. The first is that the viewshed analysis was only concerned with the upland areas, as paths originating in the valley bottom would not fit the bison jump strategies described in Kehoe (1973), Arthur (1975), Rollans (1987) or Brink (2008). Second, the valley bottoms would not serve as line-of-sight blockers to the bison moving on the uplands, so they could be realistically ignored. The edges of the valley were recorded where the hillslope showed a drastic change downhill and were left to the judgement of the collector. These break-in-slope records maintained the nine metre sampling interval wherever possible as well as recording any noticeable undulations created by the valley edge. A second set of records were collected a few metres upslope from the break-in-slope data to better reflect the quick changes in slope experienced near the valley edges. A visual example can be found in Figure 5.4.

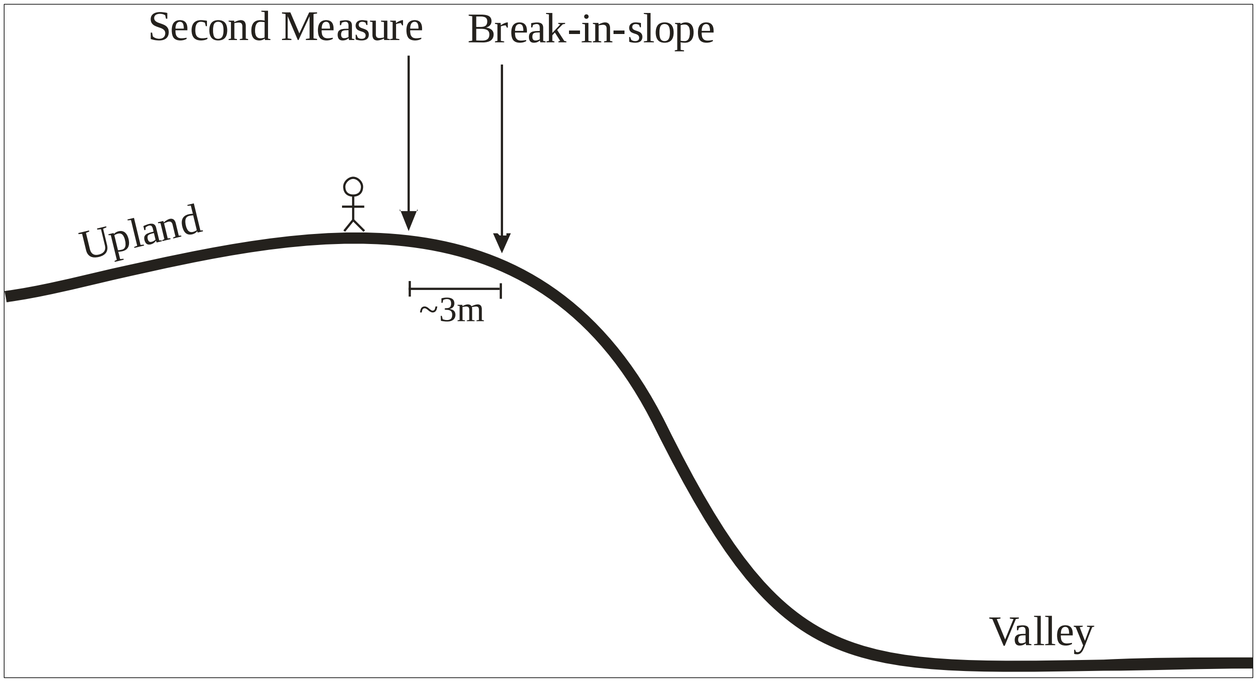


Figure 5.4: Overview of where the break-in-slope measures were taken.

It should be noted that some of the upland areas were cut from the survey since, like the lowland areas, they did not reflect the bison jump strategy and would not serve as line-of-sight blockers. For example, a large spit of land north of the Sabin site was excluded, as it was surrounded on three sides by steep valley walls and was only connected to the upland by a narrow chokepoint approximately 20 meters wide. It seemed unlikely that bison would be lead from this isolated landform, past the choke only to swerve back into another landform to their doom. This was also the case at the Ironhorse site, where the eastern side of the circle abruptly stops, as no bison were likely to be led from this direction being enclosed on all sides by valley walls.

The result of the topographic survey was the collection of over 10,000 data points, each with horizontal and vertical coordinates recorded at ±3cm accuracy. As a side note, some additional archaeological sites and materials were identified as part of this survey. These were found in areas not covered by Walker (1990), and include a habitation site, a cairn cluster and new drivelines. The summaries of these sites are listed in Appendix C.

5.1.3 Archaeological Data

The archaeological data collected by Walker (1990) were digitized into shapefiles in ArcGIS 10. As these site data represent discrete objects on the landscape, they are best represented in a vector data format. Figure 2 in Walker (1990) was scanned and added into ArcGIS. The image was georeferenced to overlay upon the township aerial images. From there, it was a simple process of digitizing the areas Walker identified as sites in his nine square mile study area. Larger sites such as DhNe-15 and 25 were recorded as polygons, while smaller sites were marked as points. Sites represented as polygons had their centroid calculated and merged with the other single point sites. This ensured the entire 120 site catalogue could be accessed from a single point shapefile. A sample of sites was groundtruthed with a handheld Garmin GPSmap 62s device to ensure the georeferencing process was done correctly. The ±3m accuracy was not as large of hindrance in this case as it would have been in the topographic survey, since many of these sites are rather large.

Aside from site locations, Walker also recorded the presence and orientation of drivelines in the area during the course of his survey. These too were digitized from survey maps into ArcGIS. The locations of these drivelines are important to the cost path analysis step, as they will serve as a relative visual aid that highlight the desired areas to move in due to their importance in the bison drive. However, there are some problems with the drivelines as they are presented in Figure 2.1 and Figure 2 in Walker (1990). Firstly, they appear as solid lines in several locations which is misleading from the reality of the situation. These lines, as discussed in Chapters Two and Three, are small ranks of stone cairns on local topographic highs. This means there are prominent gaps from hilltop to hilltop. Thus they do not represent a solid boundary for bison movement, as the exact locations of the cairn clusters are not known. Second, the drivelines are bound to what Walker was able to survey. There are likely drivelines located beyond the study area, but that cannot be known for sure. Fortunately one driveline was discovered during the topographic survey portion of this research in areas Walker did not reach. This new information alleviates the problem somewhat, but it is still an important point to consider. Thirdly, some of the drivelines were likely destroyed due to agricultural practices, noted by hashed lines in Walker (1990). Walker estimated the location of these missing lines by association with other lines in the area. Thus there is an overlying assumption that drivelines likely existed in these areas, but cannot be fully confirmed. The final consideration comes from the digitization process. The georectified drive lines from Figure 2 in Walker (1990) have an inherent zone of error associated with their location in the GIS. On average, the digitized lines were approximately 30m off horizontally from where the groundtruth samples were collected in the field. Since the least cost path analysis uses 30m data, this error is not of great concern, but is accounted for as a 30m buffer around each driveline.

5.2 Viewshed DEM Creation

The DEM used in the viewshed portion of the analysis was built from the topographic data collected in 2012 for the Sabin and Ironhorse sites using an Inverse Distance Weighting (IDW) interpolator. IDW interpolation has been used by both Byerly et al. (2005) and Lieff (2006) to create finer scale elevation models for their viewshed analyses. Beyond being used in related research, IDW was chosen because its interpolated values will never exceed the minimum and maximum values in the base data (Chang 2008: 334), unlike other interpolators such as splines. This means the modelled surface will never surpass the limits of the topographic data collected in the field. The IDW interpolator operates in a similar fashion to the First Law of Geography where "...everything is related to everything else, but near things are more related than distant things" (Tobler 1970: 236). Thus, when interpolating a surface, the IDW tool depreciates the weight of the inputs as distance to them increases. The standard formula (Chang 2008:334) is as follows:

$$Z_0 = \frac{\sum_{i=1}^{s} Z_i \frac{1}{d_i^k}}{\sum_{i=1}^{s} \frac{1}{d_i^k}}$$

where Z_0 is the elevation at location zero, Z_i is the elevation at location i, d_i is the distance between locations i and zero, and k is a weighting variable that controls the amount of influence distance has on the outcome, with 2 being the norm.

Before the IDW was run upon the survey data, a few corrections needed to be made. When the data was collected, several sloughs were not traversed and thus not sampled due to the presence of standing water. While the IDW tool would fill in these areas based on surrounding points, it may lead to an overflattening of the slough and not represent the dip in terrain. To alleviate this issue, the Mean Centre tool was used to calculate a new point that averaged the coordinates and elevations from points surrounding each slough. To simulate the depression in terrain, the elevations of these mean centres were each dropped by 0.03m so they would be lower than their surroundings. The 0.03m value was obtained by calculating the average change in elevations found in other slough and depression areas that were recorded due to a lack of standing water. The change in elevation at these locations averaged to about 0.028m, which was rounded to 0.030. Overall, these corrections lead to four sloughs being corrected in the Sabin data while the Ironhorse data had three such corrections. The modern access road was also not surveyed and represents a gap specific to the Sabin points. However, no corrections were made to this location since unlike the sloughs we cannot know if the natural terrain in this void was higher or lower than its surroundings. Likely the proximity to the valley edge would suggest the terrain sloped downhill in that direction and would be interpreted as such by the IDW.

With the data filled in, each set of points was fed into the IDW interpolator. A cell size of 10x10m was chosen as this reflected the sampling strategy in which the elevations were collected. A cell size smaller than 10m would yield a finer resolution of data, but may create unwanted errors in areas between the surveyed points (Lieff 2006). A 10x10 metre grid would always ensure that at least one sampled point would be represented by each cell. The resulting DEM's are shown in Figures 5.5 and 5.6.

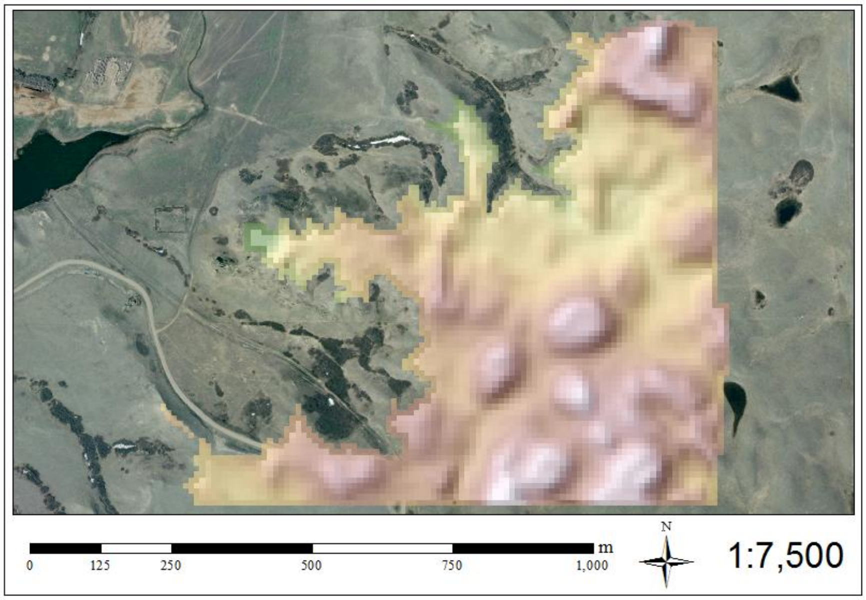


Figure 5.5: 10m DEM created for the Sabin Jump (DhNe-1).

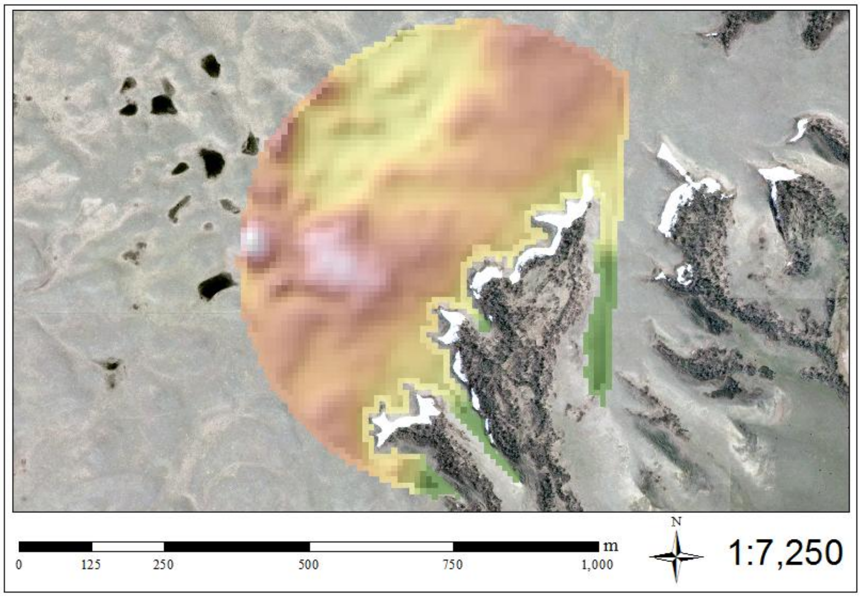


Figure 5.6: 10m DEM created for the Ironhorse Bison Jump (DhNe-51).

5.3 Least Cost Path Analysis

Chapter Four provided a number of examples of how least cost path analysis has been used in previous archaeological research. While they all operated in different study areas and have different goals for the tool, each least cost path study required three essential components. These components are a *destination* location, an *origin* location, and a *cost raster* that connects them. The cost raster (also referred to as friction surface [Wheatly and Gillings 2002; Whitley and Hicks 2003] or cost of passage maps [Conolly and Lake 2006]) represents the inherent impedance or cost of traversing each cell. This can be measured in absolute values such as caloric output, monetary loss, units of time, or simply reflect relative differences chosen by the user. They all work on the basic premise that a lower value always preferable. For example, a cell with a cost of "2" is more arduous to cross than a cell with a value of "1," and both are easier to pass through than a "3" cell.

As mentioned in Chapter Four, costs that derive from slope values are most often employed in archaeology. This is typically conducted by transforming a slope raster using a formula that meets the user's needs. For example, Bell and Lock (2000) use the simple formula of $energy = \tan(\theta)/\tan 1$ to transform slope into the relative change of potential energy experienced as one changes elevations. Whitley and Hicks (2003) on the other hand monitors slope's effect on travel time, using Tobler's (1993) hiker function of: $speed = 6\exp(-3.5|\%slope + 0.05|)$. While such formulae have been shown to work in many scenarios, ideally the cost raster should reflect the environment where it is being utilized. Wheatly and Gillings (2002: 155) elaborate on this matter by suggesting that an equation derived for Himalayan hiking would not provide an appropriate estimate for movement in a rainforest.

Carlson (2011) utilized least cost paths to investigate what roles topography and human agency played in the operation of eight different bison jumps across the northern Plains. Thus, the environmental settings she encountered are very similar to those found at Roan Mare Coulee, namely large open areas of relatively flat prairie interrupted by sections of high relief at the valley edge. Her methods are also centered on assumptions about bison behaviour rather than humans, particularly their preference to take the path of least resistance (Carlson 2011: 74). This makes her method ideal for use in this study. Her method is very simple to understand and operate. She divides her slope raster into nine classes using the natural breaks/jenks method found in ArcGIS and assigns each a value from one to nine as the slope values increase (Carlson 2011: 77). This sets a preference for travel in areas that are flatter and less sloped, fitting our assumption of bison behaviour.

One major concern this cost raster creates is it is a *relative* measure rather than an absolute. What this means is that the values used may not reflect the actual impedance slope has upon bison movement as measured in caloric consumption or time. Since such data is lacking, the best information are the relative accounts and interviews regarding bison heard behaviour seen in McHugh (1958), Kehoe (1973), Rollans (1988) or Brink (2008). Thus any measure of the costs of such movement in GIS will be *relative* in nature, not absolute. Since Carlson's (2011) method reflects these generalizations of bison behaviour, it still is the best tool for the task.

Another issue of this relative scale and the lack of how slope affects bison movement is the inability to fully model anisotropy. As mentioned in Chapter Four, anisotropy includes how the direction of travel affects the severity of the costs encountered while moving. In the case for slope, costs associated with a 5° incline would be different if the individual was moving uphill vs. downhill. This difference in costs has been well studied in humans (Tobler 1993; Minetti 1995) and has been applied in many least cost path studies in archaeology (e.g.: Krist and Brown 1994; Bell and Lock 2000; Llobera 2000). Carlson (2011: 74-75) acknowledges this inability to model anisotropy in her analysis and counters it by noting that in the bison hunting strategy employed, any change in slope, up or down, is going to be more costly than flat terrain.

Two changes are made to Carlson's (2011) method for use in this thesis. The first is to move away from ordinal level of the data. Rather than assign arbitrary ranked classes to break up slope, the raw slope values will be used for the friction costs (Rissetto 2012; Surface-Evans 2012). This was done to ensure more reliable comparisons between different paths. This alteration keeps with the same idea behind Carlson's design since lower slopes will still be ideal, but allows for the data to better integrate with the Cost Distance tools in ArcGIS. These tools see friction values as ratio data rather than ordinal. For example, a cell with value of 8 is seen by the GIS tools as being four times more costly to traverse than a cell value of 2. To put it another way, an individual accumulates the same cost moving across four value 2 cells as they would crossing a single 8 cell. This is not the case in with the original ordinal data, where the only discernible information is that a value of 2 is preferable to that of 8. As such, if we need to compare the different paths, the comparisons made using the raw slope values hold more clout than those based off of arbitrary class divisions. This issue is magnified if the class divisions are unique to each jump. The jenks method may classify a slope of 3˚ as "2" cost for one jump, but as "3" cost for another. The raw values allow for equal definitions of cost across the study area.

The second break from Carlson's (2011) process of creating a cost raster concerns the small sloughs found across the upland zones in the study area. In her original methodology, Carlson (2011) allows no special privileges or detriments for movement through small water bodies. Such sloughs appear as flat terrain on the DEM, and thus would be least costly to move in. However, these areas may contain standing water during some periods throughout the year. Normally waterbodies would be an attractive area for bison to congregate, but during a hunting event the water would pose a hindrance to movement. Even when dried out, it is likely that the clay rich sediments would be waterlogged and may cause bison to become mired within them. Add in the fact that such sloughs promote the growth of local shrubs and this break in vegetation could also serve as a detractor to travel. For these reasons, the digitized sloughs mentioned above were converted to 30x30m pixels and were overlain upon the cost surface. Using MapAlgebra, the cost pixels that also contained sloughs were multiplied by 1.5 to reflect these additional costs. The modifier of 1.5 was chosen as an average between terrain coefficients used to reflect "light brush" and "swampy bog" by Soule and Goldman (1972: 708). This modification makes otherwise flat areas on the DEM slightly less appealing, but not so much as to completely restrict movement through them.

A side effect of the two deviations from Carlson's cost surface is the cost assignment to areas of 0˚ slope. Since the cost values match the values recorded for slope in degrees, a 0˚ degree area would have a cost of zero. Zero costs are not permissible within the Cost Distance tools in ArcGIS. Add to the fact that the 1.5 multiplier for the sloughs would be irrelevant since anything multiplied by zero remains zero. To counter both these issues, all 0˚ ≤ slopes ≤ 1˚ were reclassified as "1." This helps keep the slough multiplier working as intended and ensures that the flatter areas of land are still the lowest cost.

With these issues in mind, a cost raster was created for all areas to be used in the cost path analysis. The area was defined by the greatest spatial extent of the origin locations. Byerly et al. (2005) used a distance of four kilometers away from the jump edge to define their origin locations. They created 16 origins in all, one for each cardinal direction and created a least cost path for each. This way they could compare which directions were more efficient to traverse which indicates the more likely used route(s). Following their methodology, a four kilometre buffer was created surrounding each jump edge and points were made for each cardinal direction for a total of 112 (16 for 7 jumps) at the 4km level. Origins at three, two and one kilometre distances were also created to see if relative efficiencies changed at different scales for particular directions. This resulted in 448 total origins across all jumps and scales to calculate least cost paths for.

The final data required for a least cost path analysis are the destination locations. Since each bison jump is looked at individually, each jump required a destination point. These locations of course reflect the likely location on the valley edge where the bison were driven over. For some jumps, such as DhNe - 1, 51 and 89, these locations were easy to determine from the map as drivelines lead straight up to the valley edge. The others were either recorded in the field during the groundtruthing and survey portions, or estimated from the comparison of a variety of different data sources including the position and orientation of the drive lines, aerial imagery of the valley edges, topographic maps and Walker's original recorded locations of the bone beds. These points served as the stopping location for each cost path created.

With the cost surface and destination locations known, the Cost Distance tool in ArcGIS is run using both as inputs. Two raster surfaces are output: the cost distance raster (also referred to as an accumulated cost surface in Conolly and Lake [2006]) and a back link raster. These two rasters are a result of applying a spreading function based on the cost surface to the destination point. The values in each cell in the cost distance raster represent the sum of all links between the cell and the destination that accumulated the least total cost. The costs for each link are calculated as such (Chang 2008: 379):

$$C_{link} = 1 \times \left[\left(C_i + C_j\right)/2\right] \ \ OR \ \ C_{link} = 1.414 \times \left[\left(C_i + C_j\right)/2\right]$$

The cost of each link is the average of the two cells, and if the link is diagonal, the average is multiplied by √2 or 1.414. This process is repeated again and again for each cell, with the costs being recalculated at each iteration to determine the least costly sum. The backlink classifies each cell into eight categories that identify which neighbouring cell is the least costly to move between. With these two rasters and the origin locations, the Cost Path tool creates the least cost path between each origin and the destination.

Once the least cost paths are created for all directions, distances and jumps, they will be critiqued both visually and by comparing the differences in their relative costs. The visual analysis will involve comparing the paths to the locations of the drive lines in an attempt to discern if the most cost effective routes can be identified archaeologically. That is, were the most efficient routes to move bison through the topography identified and marked by the ancient hunters through the use of drive line networks? Figure 5.7 provides examples of how the different location and orientations of the least cost paths and the drivelines could either support or conflict with one another. Another avenue of interest is the possible overlap of paths for different destinations. The use of a particular path by two or more of the bison jumps would suggest that these portions of the landscape were useful in moving bison during separate hunting events.

Since each created path will have a calculated cost associated with it, comparing these costs will help determine which paths and directions are more favorable to move bison through based on the topography. The different directions will be ranked on their relative costs, numbering between 1 and 16. This comparison of costs will also be conducted between different distances to see if particular paths remain popular at different scales. Finally, the costs will be compared between jumps if possible to determine if certain directions change favorability in different parts of the valley. These last two comparisons will be conducted using the statistical measure known as Kendall's tau (Thomas 1986). Since each set of 16 starting locations were systematically rather than randomly sampled, Kendall's tau cannot be used as a correlation coefficient (Thomas 1986: 401), but will instead be a measure of the how the ordinal ranks between the two samples differ for each direction.

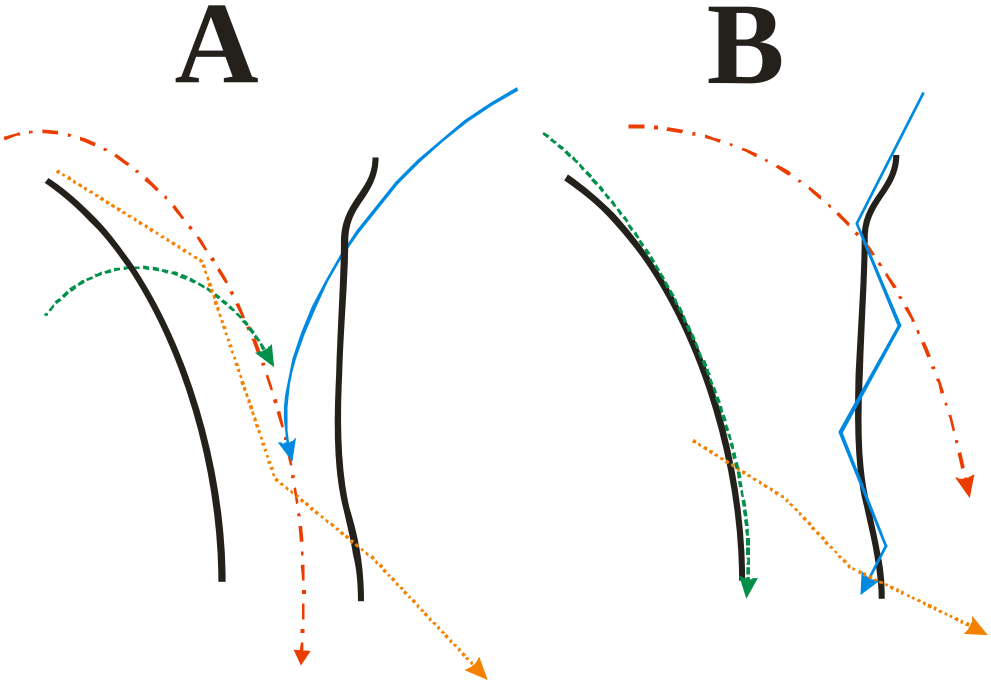


Figure 5.7: Comparison of possible outcomes of LCP Analyses and their relation to drivelines. (A) Shows "good" examples where the calculated least cost paths follow the orientation of the drivelines with minimal overlap. (B) Least cost paths here poorly reflect the drivelines, either quickly darting across them, or straddling and hugging one of the lines.

5.4 Viewshed Analysis

Viewsheds utilize a terrain model, such as a DEM to depict what areas are visible and invisible to an observer at a particular location, based on line of sight. Shifts and alterations in the local topography may block the viewable area that an observer can see. For example, standing in a pit with high walls would yield a very small viewshed, while standing on a hill top allows for greater distances to be visible and thus creates a larger viewshed. As mentioned in Chapter Four, viewsheds have been well used in archaeology, often in conjunction with least cost paths. Of particular note is Byerly et al.'s (2005) and Lieff's (2006) work using viewsheds in the context of a bison hunt on the Plains.

The methods employed by Byerly et al. (2005) will again be emulated here in the creation and analysis of viewsheds at the Sabin and Ironhorse sites. The least cost paths created from the previous step are overlain upon the newly created 10m DEM. Each path is segmented into 30 metre intervals corresponding to the cell centres of the 30m cost path raster. This makes it easier to create viewsheds upon the corners of turns and junctions with other paths. A point file is made of these cell centres and used as the observer location inputs for the viewshed tool. Each point was assigned a new attribute field titled "OFFSETA," all of which contained a value of 1.5. This value is used as variable in the viewshed analysis for the height of the observer. In this case it corresponds to 1.5 metres, the average shoulder height of a female bison (Soper 1964). Since the shoulder is about on level with the height of the eye, it served as good proxy.

From there a viewshed is created for each point in each cost path for each jump, 117 in total (64 for Sabin, 53 for Ironhorse). Each viewshed raster is a binary set of values, marking "Visible" and "Non-visible" areas. While this illustrates what terrain the bison can and cannot see during their run, the crucial factor being investigated is if the bison can see the terminus of the jump. As mentioned in Chapter Three, if the drop off is revealed too early, then the bison may have time to identify the trap and escape. So the viewshed stage qualitatively assesses how well the topography works to hide the plunge in each path scenario.

5.5 Assumptions Concerning the Data and Methodology

For this research to continue and operate as outlined above, a few assumptions regarding the nature of bison behaviour, human hunting strategies, the data used and the archaeological applicability of these data needed to be made. Often times the best data are not available, or certain theoretical viewpoints do not integrate well with certain methods of analysis. This section is here to simply state the underlying conditions and assumptions that are made through the course of this thesis.

5.5.1 Bison Behaviour and Hunting Strategies

As outlined in Chapter Three, the operation of a bison jump required the forethought, planning and cooperation of many individuals. As such, a thorough understanding of the terrain and how bison respond to it was often necessary to ensure success. The key role of topography in the use and operation of such kills is one of the main research goals of this thesis. Thus, the assumption one can easily make is that topography is the *only* factor that determines the success of a bison jump. This of course is not the case. The group's experience, the irritability of the bison, weather and certain ceremonial practices are just a few of the other variables that play a role in the event. These items are very hard to recreate in archaeology let alone in a GIS, as they may not be readily visible or understood. Topography and terrain on the other hand are very quick and easy to integrate into a GIS. So while the use of and roles of topography in a bison jump are the focus here, they are far from being the only relevant factors.

The author also makes some broad assumptions regarding bison behaviour and their movement across the landscape. Again, as Chapter Three summarized, bison are fairly predictable animals and this predictability was a core ingredient during a mass kill. For this thesis, the assumption is made that bison will follow the path of least resistance when moving through terrain, opting for easier paths and topography at all times. This assumption is reflected in the cost path analysis, where flatter and unchanging ground is preferred to sharp changes seen in highly sloped areas. However, as predictable as bison are, they are known to have bouts of erratic behaviour (McHugh 1958; Rollans 1987; Brink 2008). So there would be occasions in the past where bison would not have taken the path of least resistance. Thus, this research assumption looks at the best case scenario, where the hazers' and other hunters' actions kept the bison upon the most ideal path in regard to the topography.

The final issue regarding the bison specifically is in regard to their physiology. As mentioned above, there is a lack of data regarding how the bison interact with specific angles of hillslope. So again, we must go with the generalization of bison preferring gentlest slopes and least costly terrain. This is most likely a gross simplification of herd mobility, but the lack of pertinent data dictates few other options. The viewshed step also generalizes the physical limitations of bison. Following Byerly et al.'s (2005) example, the only condition regarding the bison's vision accounted for is height. Other variables, such as differences in viewing angle and azimuth, are kept to the defaults. This means that in this simulation a bison can look in all directions, horizontally and vertically for unlimited distances. Viewsheds typically reflect the perspective of a sole viewer and would not account for an entire herd of animals. Thus, if the vision of the entire heard is considered, the 360˚ view becomes much more plausible. Still, the viewshed portion does take some liberties when concerning the bison's visual capabilities but does so to compensate for a group rather than an individual.

5.5.2 Present Data Representing the Past

One of the most glaring suppositions made in any GIS related archaeological research is that spatial data collected in the present can be used as a substitute for the past environment. However, these issues are often unavoidable as a one hundred percent reconstruction of the former landscape is a daunting challenge and often the data needed for such a proposal are lacking or outright non-existent. Even faced with such voids in the records, the researcher should strive to have the best recreation of the past and acknowledge possible biases present day data may cause. For example, the natural lakes and ponds were integrated into the spatial analyses as they were likely present in the past, while the dammed waterbodies were removed. On the other hand, some modern skews are inescapable and are outlined below.

In regards to the cost path analysis, the accuracy of the DEM's is of greatest concern. First and foremost, the elevation models reflect the topography seen today, including the location of hills, ponds, lakes and valleys. The assumption made in this thesis is that the current terrain is contemporaneous enough to recreate past mobility. This is a minor issue in Roan Mare Coulee for two reasons. As outlined in Chapter Two, Roan Mare Coulee is an extremely low energy environment, so the knob and kettle terrain of the highlands would be very slow to change though history. The second reason comes from the small time window. The majority of the archaeological material found in the valley comes from the very end of the Late Period and early Contact Period on the Plains, roughly 550 years ago. During this time, climactic conditions were fairly similar to what we see today (Laird et al 2007; Teller and Last 1990). So the slow rate of change and lack of time to act have led to the assumption that erosional forces in the uplands are negligible. The most pressing concern regarding the change in topography would be the condition of the valley edge as headward erosion has most likely been at work. This would of course diminish the available area to run bison across, as well as change the location of the edge where bison would have been run off. However, it is impossible to assess how far the edge would have extended while the bison jumps were in use, or what shape the edge would have taken. So alas, the current valley edge will have to be used in the lack of the historically accurate terrain. This oversight will create a small, but unavoidable bias as a result.

The same issues regarding the contemporanity of the terrain experienced by the least cost path analysis also present themselves in the viewshed stage. Vegetative cover that may have existed in the past is also missing. While it is likely that the flora of the area was very much like what is found today, taller shrubs and bushes could obscure certain areas from sight, and thus change the area visible to a bison. So while the role topography plays on bison vision is the focus here, it does not mean it is the only variable. Only that it is the best available source of information.

5.5.3 Environmental factors vs. Human Agency

The last major concern pertaining to this thesis is its theoretical framework. This research leans towards optimal foraging theory and an ecological approach to understanding past human activity. Least cost path analysis by its design seeks out the optimal routes based on the most efficient means of crossing the landscape. Then we assume that the bison are going to take the path of least resistance and the hunters will capitalize on this behaviour. And our final goal is to assess how these jumps were used based upon strictly environmental variables, as these are the most readily available data to integrate into a GIS. So while the chosen framework meshes well with the methods employed, it does not reject other theoretical stances of study and factors contributing to a bison jump.

There is certainly a ceremonial element at play in ethnohistoric accounts of a bison hunt's operation. Kehoe (1973: 179) mentions that several portions of a bison drive are deeply steeped in ritualistic activity to insure better success. He notes that amongst the Blackfoot, holy women began the drive process after four nights of ritual prayer and song to garner the power to call the bison to the drive, while the runners would receive blessings to aid them in their tasks (Kehoe (1973: 180-181). Medicine Crow (1978) emphasizes that ceremonial elements were also important in the operation of a Crow bison drive. Such factors, although very important in the success and understanding of the drive are ultimately hard to recreate or simulate in the GIS. The ceremonial influences the people and the landscape have on the operation of a bison jump cannot be mapped, measured or quantified by a computer, nor should they be. That is why there is a focus upon the physical realities and limitations of the terrain, as this data works in the confines of the GIS. So this thesis acknowledges that while physical environmental factors are under scrutiny here, immeasurable ceremonial features are also at work in the operation of a bison drive.

Another factor not addressed here is the hunters' skill and role they play in the success of a bison drive. Without the human agents, bison would not willfully stampede themselves off a cliff whist following the most ideal route. It is assumed here that hunters would want to capitalize on the bison's predictability, leading them through areas well traversed by the animals and these areas would correspond to the least cost paths. However it is likely that the hunters may not have followed the least costly routes exactly as the GIS predicts. Unforeseen factors may have led them to focus their attention along different tracks. Sudden changes in wind direction or bison temperament may have influenced the hazers to break away from the idyllic path. Another example could be the crossing or approach of sacred areas deterring use of otherwise good terrain to move bison in. So we must acknowledge that while the cost path analysis calculates a single set of possible routes, small deviations from those paths are to be expected and would not be followed precisely.

In the end, many of these assumptions and the biases they create extend from the use and creation of models. Models by their nature are a representation of reality, not reality itself. They either embody a simplified version of a complex system, or an ideal scenario where everything is operating under the best of circumstances. Therefore, skew and bias are to be acknowledged and expected in models, and the researcher should do their best to minimize their effects if possible.

5.6 Summary

This chapter illustrates the methods and means by which the results seen in the following pages were obtained. The data set presented here are a combination of environmental and archaeological data sources, collected both by the researcher and other parties. The main analytical tools of least cost paths and viewsheds have been outlined as to their intended function and purpose. Like in all research biases can appear throughout the process either from the raw data, the tools of analysis or the theoretical framework employed. Attempts to subvert these skews have been taken at every stage while unavoidable biases have been identified and acknowledged by the researcher.

Chapter 6
Presentation of Results

This chapter provides an overview of the results from both the least cost path and viewshed analysis steps. The pertinent information from the associated figures and tables will be summarized here and this information will be used, evaluated, and interpreted in the next chapter. For the least cost path analysis, only paths that originated west (east and south for DhNe-1 paths) of the Roan Mare coulee valley edge will be shown in the figures. The complete maps with all 16 paths can be found in Appendix A. For the viewshed data, only a selection of key locations, such as entry, turns and junction points for each path will be displayed here. Many of the viewsheds not seen here can be found in Appendix B.

6.1 Hypothesized Drivelines

As mentioned in Chapter Five, three sets of cairns south of Walker's (1990) study area were identified during the topographic survey. Due to the time limits of the survey, only a single coordinate for each line was collected and their general orientations were recorded. Each driveline was oriented in a NW-SE direction, and one was found just NW of the other two. Taking this information into account, a set of hypothesized drive lines were made in the GIS, connecting each of the southern series of cairns to the northern one, creating a "V" shape pointed to the northwest (Figure 6.1). While this crude representation is rather small, it will be taken into account in the assessment of the least cost paths for DhNe-1.

6.2 Least Cost Path Analysis

6.2.1 Relative Costs

As the accumulated costs for each path do not reflect an absolute value such as caloric expenditure, they remain *relative* to one another. As such, each path is assigned a rank based on how its cost relates to the others calculated for that jump and distance. These will help highlight what directions are more favorable or less favorable to travel within. These ranks are only for the paths that fit the upland criterion, and the complete rankings for all 16 paths can be found in Appendix A. The actual costs are noted in the tables found on the maps.

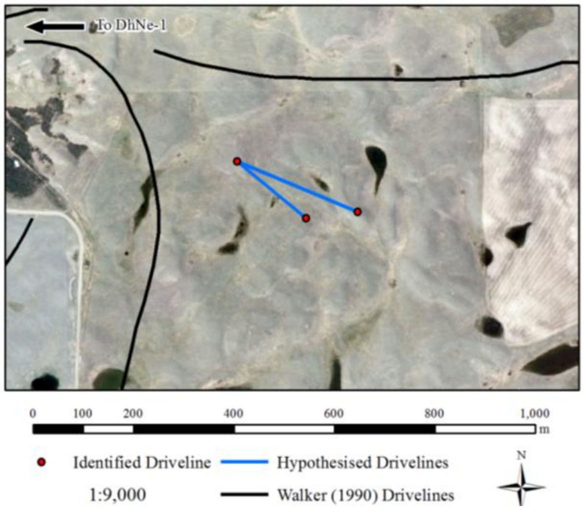


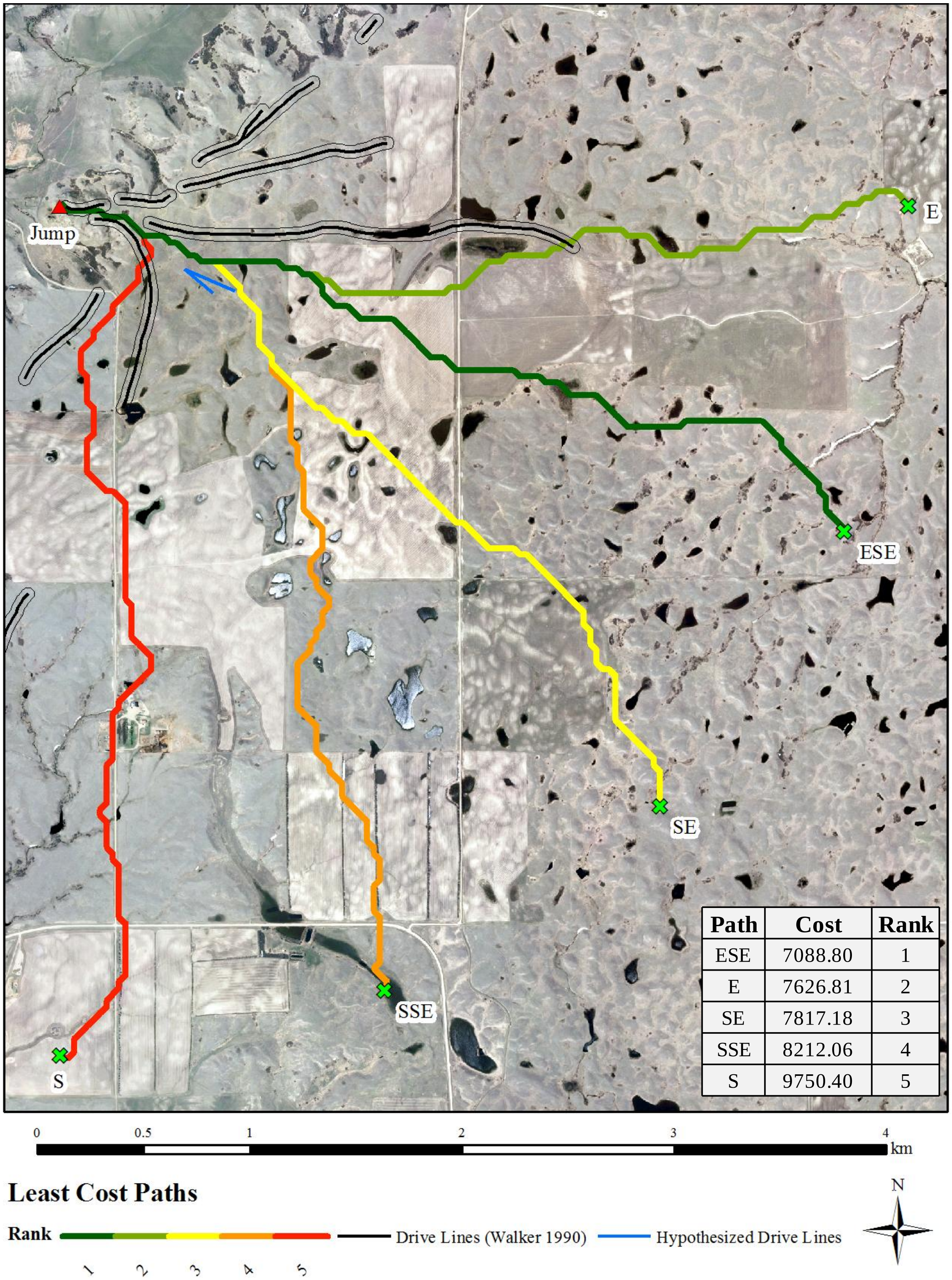
Figure 6.1: New drivelines found near DhNe-1. Blue line connects identified coordinates together.

6.2.2 DhNe-1

Four Kilometre Level

The Sabin Bison Jump is the outlier among the other kills found in Roan Mare coulee as it is the only one found on the eastern side of the valley. As such, its drivelanes and drivelines are not shared among the others and exist solely for its use. At the 4km interval, only five of the 16 origin locations created a least cost path along the uplands behind the jump. The other nine were excluded as they created courses that followed valley bottom and reached the jump face from the opposite direction. Most surprising of these was the East-Northeast origin, as drivelines do extend in that direction. However, the 4km distance extended beyond the uplands, placing the origin in the Roan Mare Coulee as it turns to the north and east. The other distance intervals will make up for this deficiency.

As seen in Figure 6.2, the ESE direction is the most cost effective route by a fairly wide margin, followed by the East route. It is interesting that the East route jogs to the south just as it meets the long stretch of driveline found to the west. This could be skew of the nearby agricultural field, which sports a much flatter terrain than that found between the drivelines. The most costly route is the southern leg, which seems to follow the modern road for quite some distance before veering west and later east again. While on this detour from the road, the southern path moves right in between two drivelines before rounding the valley edge and joining the other paths on the small spit of land the jump rests upon. While this path is obviously skewed by the modern road, it hints that the drivelines follow the topographic least cost route.



Path	Cost	Rank
ESE	7088.80	1
E	7626.81	2
SE	7817.18	3
SSE	8212.06	4
S	9750.40	5

Figure 6.2: Upland least cost paths for DhNe-1, 4km extent.

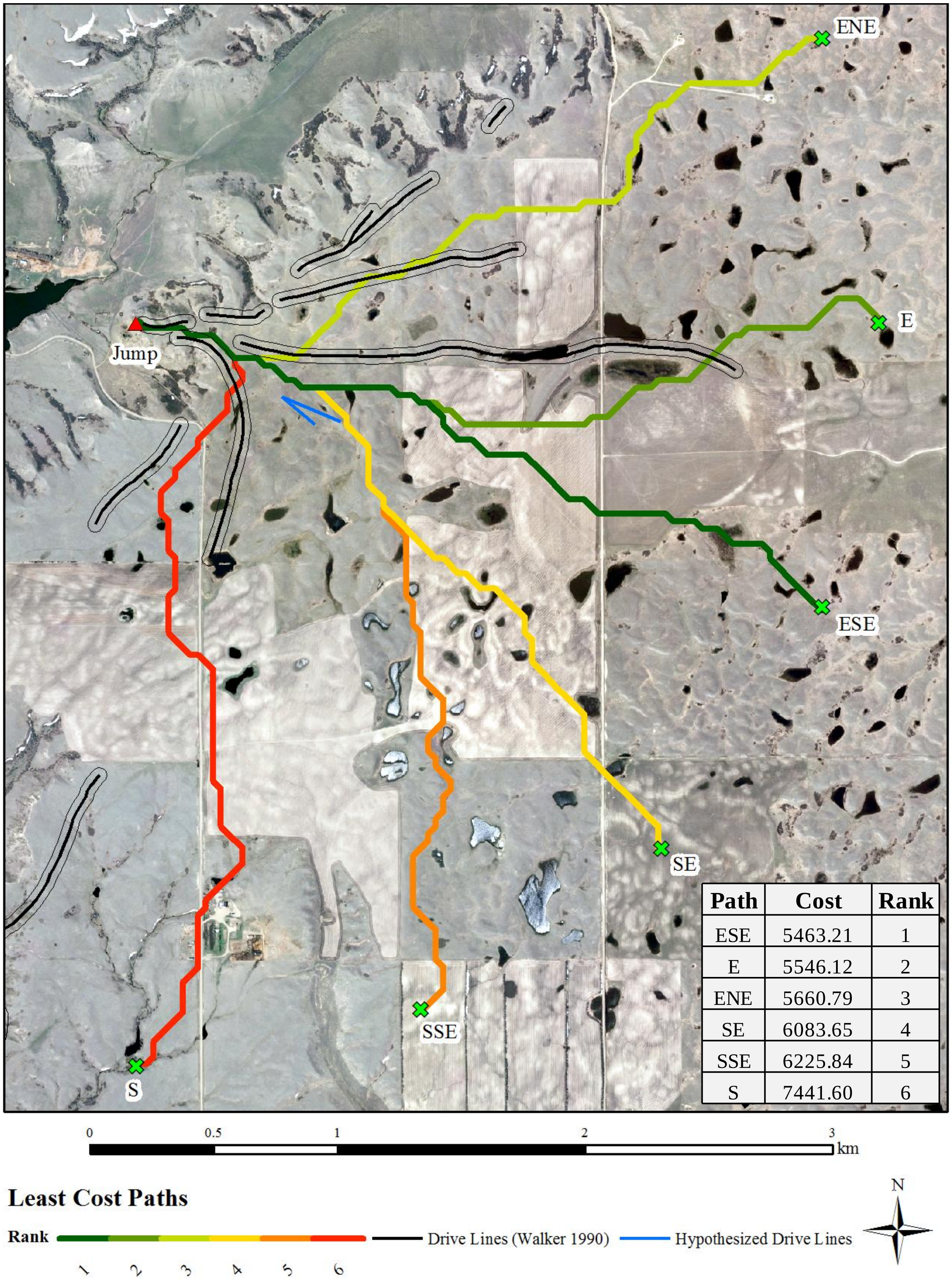
The other four paths join up between one of the drivelines identified by Walker (1990) and those identified during this study, with the E/ESE routes meeting with the SE/SSE. It is a shame that these paths rest in large areas not surveyed as it would be interesting to see if they associate with any other driveline features for the majority of their lengths. The paths do tend to hug the drivelines as they near the jump along the extruding spit of land, but this is likely due to the lack of room to maneuver on the smaller landform, especially when operating in 30m intervals.

So at the longest iteration of the least cost path analysis, we see two major routes approach the jump and finally merging into one approximately 500 metres before the jump edge. One route enters from the south while the other enters from the southeast, comprising paths from the East to the South-southeast. Both of the major routes travel between the drivelines near the end of their runs. At the 4km level, the northern and southwestern most drivelines are not utilized by the least cost paths.

Three kilometre level

The most obvious difference between the 3km and 4km maps is the inclusion of a path from the East-Northeast. Figure 6.3 reveal that this ENE path is the third most efficient of the six. The East-Southeast and East paths again take the first and second spots in terms of efficiency and the South direction is again the least preferable. So realistically the rankings do not change with the addition of the ENE pathway, suggesting there were no major topographic changes between the three and four kilometre radii.

One thing to note about the 3km scale is the path selected by the ENE origin. While it does travel between two of the northernmost drive lines, it quickly heads south and moves southwestward along the middle driveline for about 750m. It then darts across the next drivelane to connect with the southeastern least cost paths. This odd behaviour does not match what we see with the southern drivelanes where the least cost paths run in the middle of their channels. This is obviously a case where the topographic path of least resistance conflicts with the archaeological evidence.



Path	Cost	Rank
ESE	5463.21	1
E	5546.12	2
ENE	5660.79	3
SE	6083.65	4
SSE	6225.84	5
S	7441.60	6

Figure 6.3: Upland least cost paths for DhNe-1, 3km extent.

Two kilometre level

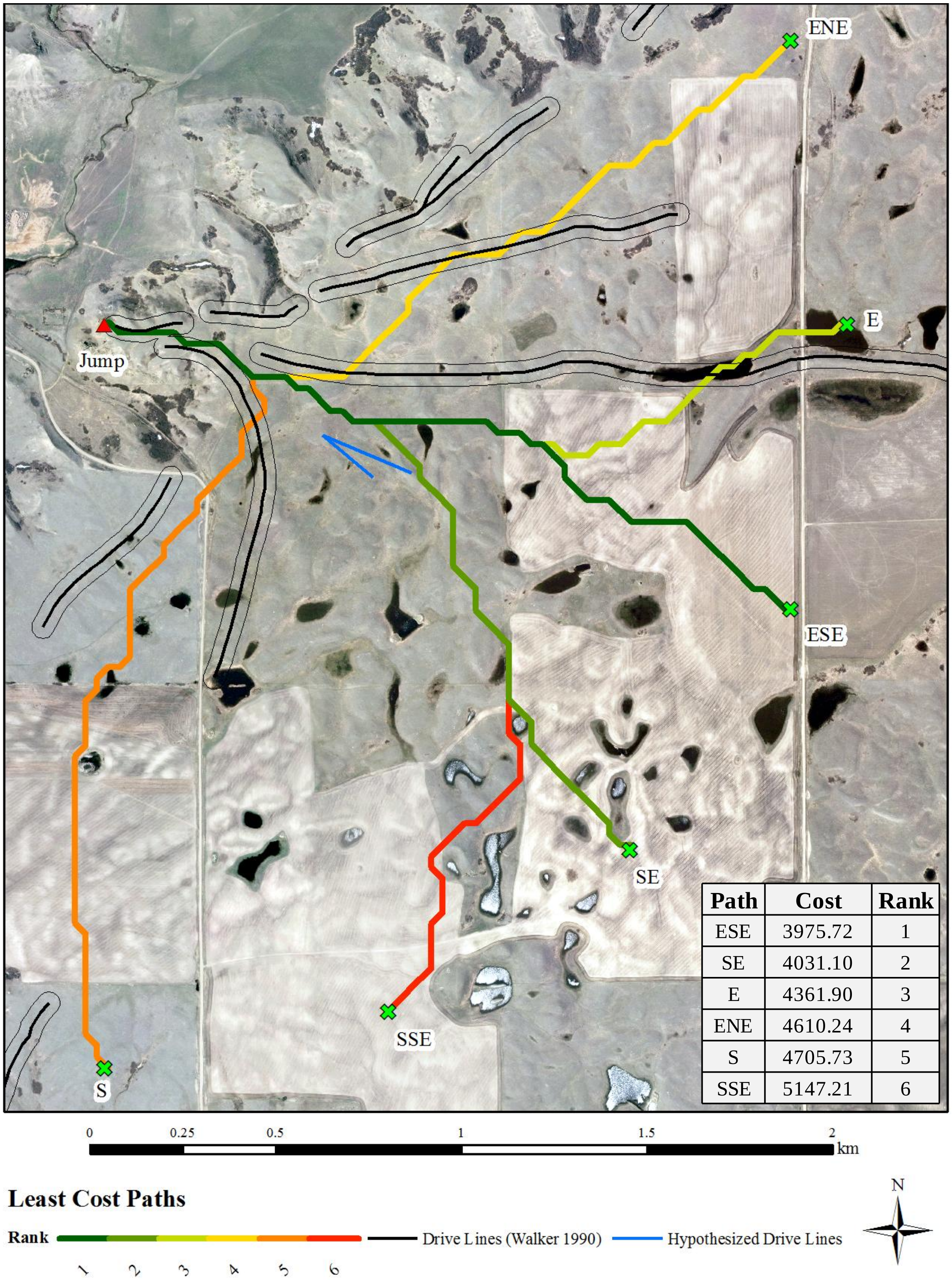
As we narrow our focus to the two kilometre scale, we see a great deal of change in the efficiency ranks between the separate paths. As witnessed in Figure 6.4, the East-Southeast pathway still is the most efficient. From there the rank order differs from the 3km and 4km groups. The second most efficient path is now the Southeast route, followed by the East and East-Northeast. The most costly upland route is now the South-Southeast, usurping the Southern course. These changes in rank indicate a change in the topography between the two and three kilometre scales. The SE increasing in rank indicates that it has now passed out of an area of higher cost terrain it had to travel through during the longer distances. The opposite is true for the SSE, where it has been removed from an area that is easier to traverse and now has to move through more difficult terrain.

Along with the changes in relative efficiencies, the calculated paths show minor shifts as well. The ENE, E, and ESE show little change, as all three quickly rejoin the paths used at the 3km scale. The SE and SSE paths are changed slightly, as they now join approximately 250m southeast of their former location. The South is no longer following the road and is instead placed slightly west, where it highlights a new least cost path which runs relatively due north until it meets the drive lane as before and curves eastward. Overall, these are small changes and still show the same general means of approaching the jump edge.

At this juncture, there is still no indication that the northeastern and eastern drivelanes follow a topographic least cost route through the landscape. Both the ENE and E origins quickly divert to the southwest to join with the other least cost paths. The southwest and southeastern drivelanes do show evidence for following topographically efficient routes, as several of the calculated least cost paths move within them.

One kilometre level

The 1km radius adds a new origin from the SSW, which is also the most costly path. The least costly paths return to similar ranks seen at the three and four kilometre stages, with ESE once again the most efficient, followed by the E and ENE (Figure 6.5). The greatest change in routes appears from the SSE, where instead of veering east and connecting with the SE, the new path now heads northward directly through the drivelines and merging with the S path. This shift in the direction of approach between the 1km and 2km scales suggests that a small



Path	Cost	Rank
ESE	3975.72	1
SE	4031.10	2
E	4361.90	3
ENE	4610.24	4
S	4705.73	5
SSE	5147.21	6

Figure 6.4: Upland least cost paths for DhNe-1, 2km extent.

topographic barrier exists between the 1km and 2km SSE origins. One side facilitates a southwestern approach, while the other diverts movement to the southeast.

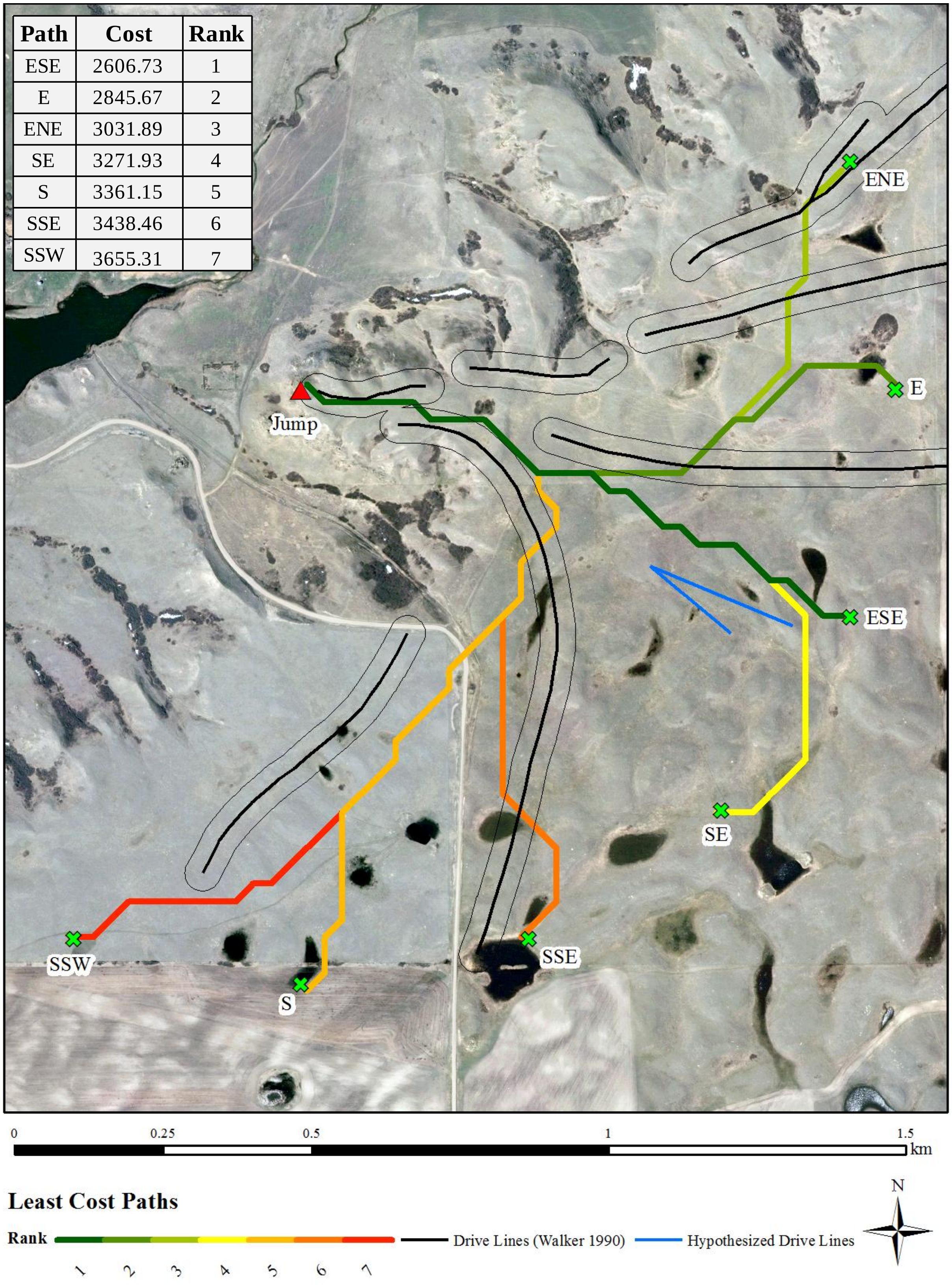
The eastern origin also shows a small alteration in its calculated path. Instead of diverting south to merge with the ESE as before, it now moves southwestward and joins with the ENE. This change is not as dramatic as seen with the SSE, as it still rejoins with the same main approach albeit in a new location.

So while the smallest scale of measure is used to highlight all possible routes into the final stages of the drive, there is little variation between what is seen here and what is seen at the larger distances. Two major routes (Southeast and Southwest) merge into one single lane about 500 meters before the cliff face from a general southeastern direction. There is a third main route from the Northeast, but the least cost paths that originate from this direction consistently deflect south or southwest out of the drivelanes to join with the Southeast. The least cost path analysis for this jump shows mixed support for the drivelanes highlighting the most cost effective routes through the landscape. There are instances where it works well such as the southwest and southeast drivelanes, but also instances where the cost paths conflict with the driveline evidence.

6.2.3 DhNe-51

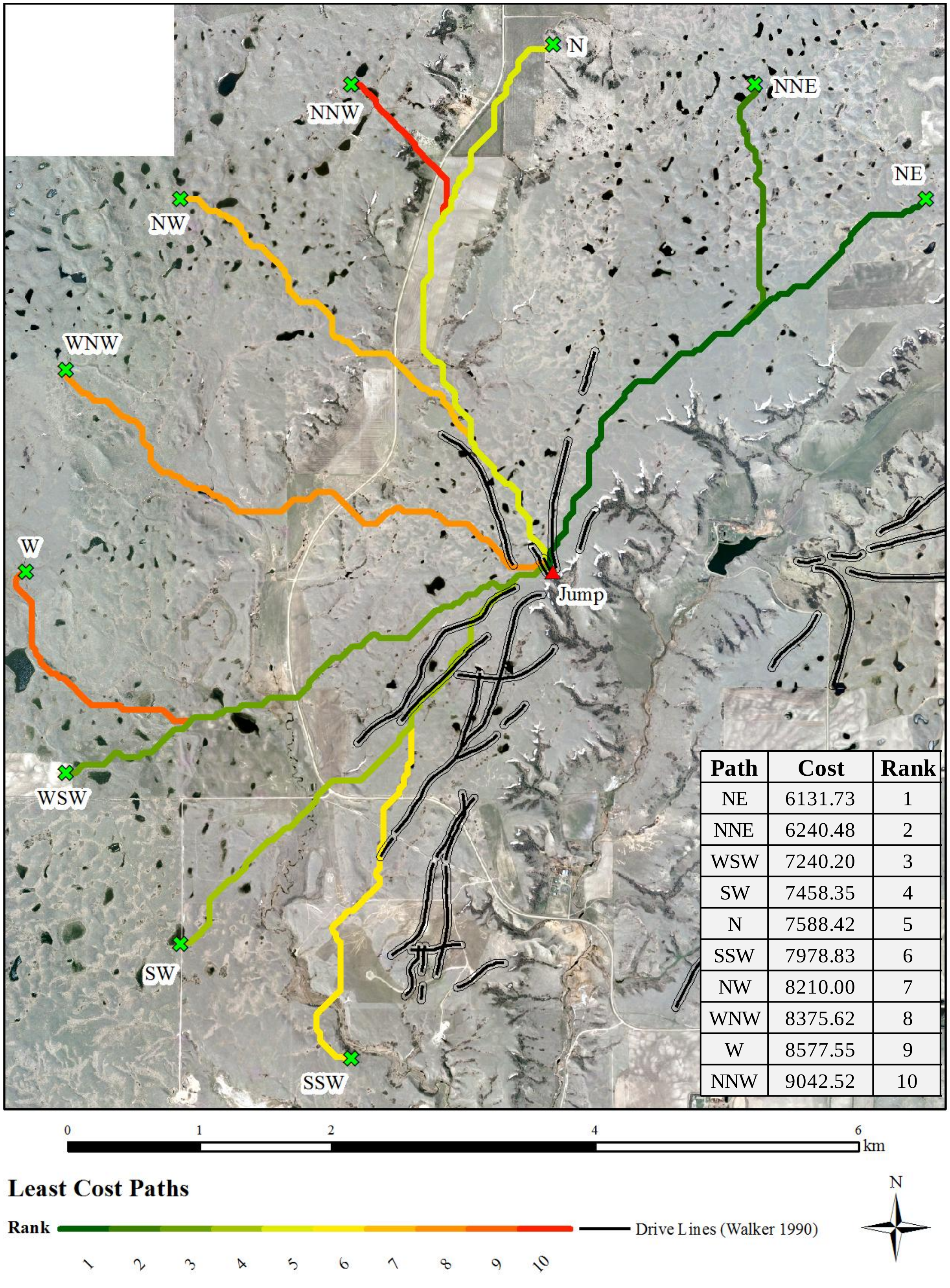
Four kilometre level

At the first iteration of the least cost path analysis, 10 of the 16 origin locations created paths along the upland area behind the Ironhorse Bison Jump. Figure 6.6 identifies the NE path as the most efficient route to the jump edge, followed by the NNE. These two paths merge northeast of the bison jump and move southward directly between the two north-south oriented drivelines. Surprisingly, the next two most efficient routes come from the Southwest and West-southwest , beginning all the way past Hole in the Wall coulee. These routes both travel in a general Northeastern direction with the WSW remaining outside the drivelines until the last few moments. The SW path moves within the southern drivelines, but also moves along the centre most cairn line for most of its length before veering north to connect with the WSW. While these southwestern paths do show drastic increase in costs compared to the previous two, they may highlight some underlying preferable terrain that may be utilized by other jumps.



Path	Cost	Rank
ESE	2606.73	1
E	2845.67	2
ENE	3031.89	3
SE	3271.93	4
S	3361.15	5
SSE	3438.46	6
SSW	3655.31	7

Figure 6.5: Upland least cost paths for DhNe-1, 1km extent.



Path	Cost	Rank
NE	6131.73	1
NNE	6240.48	2
WSW	7240.20	3
SW	7458.35	4
N	7588.42	5
SSW	7978.83	6
NW	8210.00	7
WNW	8375.62	8
W	8577.55	9
NNW	9042.52	10

Figure 6.6: Upland least cost paths for DhNe-51, 4km extent.

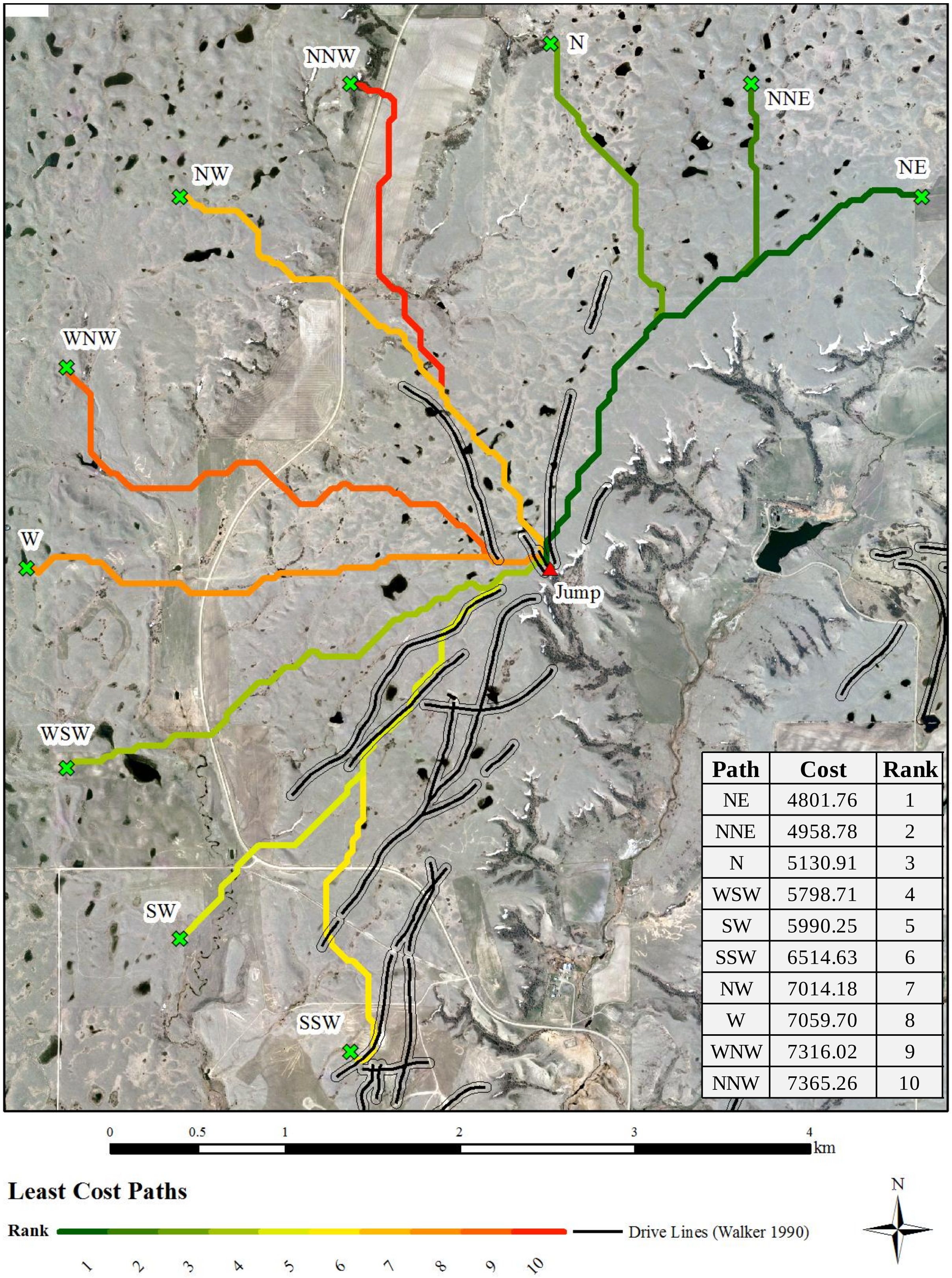
The remaining paths generally move within the drivelines with the exception of the WNW and W routes. The W path quickly joins with the WSW, while the WNW route takes its own approach across Hole in the Wall coulee, only joining with the other paths in the final 500m of the drive. The South-Southwestern route avoids the southeastern drivelines and instead moves north to join with the southwest path. The northwestern origins (NW, NWN and N) travel down Hole in the Wall coulee and climb through a small valley to the uplands where they promptly move down through the northwestern drivelines and towards the jump. These chosen routes are poor choices for manoeuvring bison due to the rapid changes in terrain. However, they do show eventual use of the drivelanes that will bear fruit at the shorter intervals.

As the four major routes approach the jump (Northeast, Southwest, Northwest and West), they all converge into one single route shortly before the edge. However, this convergence only occurs in the final 50m before the jump edge as opposed to the final 500m seen at DhNe-1. This is likely due to the open nature of the landform nearest the drop. The escarpment at the DhNe-1 lies at the end of a long spur of land extending off the upland. Since it is flanked on all sides by difficult terrain, there are few options to move from multiple directions so converging early into one single route is logical. Since the valley edge nearest DhNe-51 is more open, the paths are less restricted and are less likely to converge until the very end.

In summary, the 4km least cost paths highlighted four general routes into the jump, the Northeast, Northwest, Southwest and West. The most efficient of these three major routes is definitely the Northeast, while the other paths have a mix of low and high costing routes. The Northeast and Northwest major routes are the best at following the drivelines, while the Southwest route either skirt the outside edges of the drive lanes or travels along the centre line of cairns. This overlap indicates where topographic variables contradict the driveline's placement. The path could be reflecting a different lane from one of the other combinations of drivelines, or an area where greater human involvement was required to direct bison movement.

Three kilometre level

Like at DhNe-1, there are some subtle changes between the four and three kilometre radii least cost paths seen at DhNe-51. The most notable is the new route and cost rank for the Northern origin, as seen in Figure 6.7. The origin is now placed outside of Hole in the Wall coulee and creates a new route through the upland because of it. What is interesting is that



Path	Cost	Rank
NE	4801.76	1
NNE	4958.78	2
N	5130.91	3
WSW	5798.71	4
SW	5990.25	5
SSW	6514.63	6
NW	7014.18	7
W	7059.70	8
WNW	7316.02	9
NNW	7365.26	10

Figure 6.7: Upland least cost paths for DhNe-51, 3km extent.

instead of moving south and reconnecting with the path it had forged in the 4km example, the North path now heads southeast to connect with the two northeastern paths. The new Northern route is ranked third in terms of cost, following the NNE and NE pathways which are still the two most efficient. These three are followed by the WSW and SW paths, again suggesting the popularity of these directions of travel.

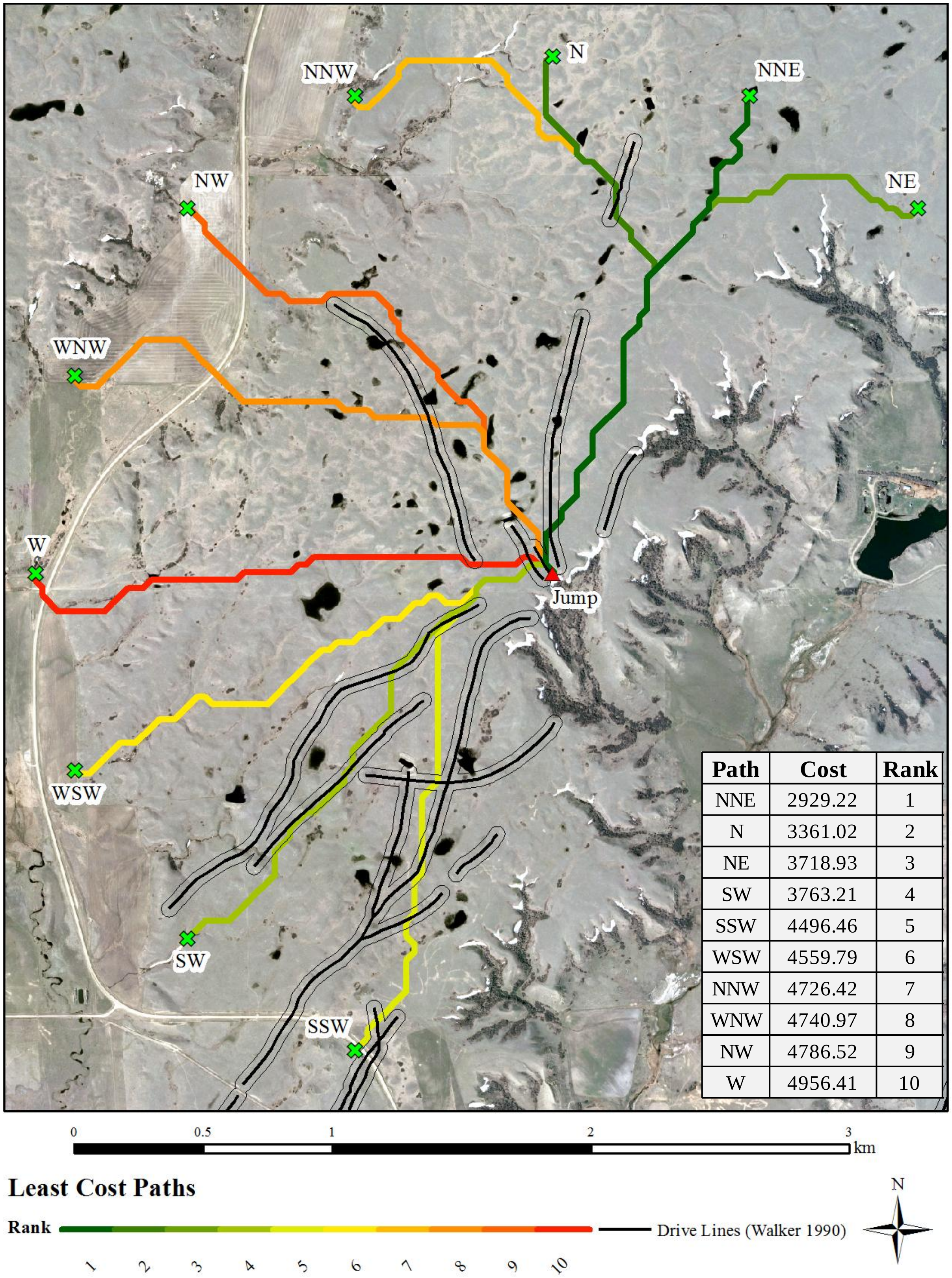
Another noticeable change is that the W route now moves eastward rather than south, connecting with the WNW rather than the WSW. This likely indicates another topographic barrier lies between the three and four kilometre W origins which dictates the preferred direction of travel. This new route also increases the W's relative rank, switching places with the WNW.

The main routes from the Northeast, Northwest, West, and Southwest are still intact and follow the same paths through the drivelines they come across. The addition of the Northern path to the Northeastern main route further solidifies its place as the most efficient as it is comprised of the top three least cost paths. The Southwest comes in second, having lost the rather low ranking West path.

Two kilometre level

There is considerable difference between the two and three kilometre levels in terms of the relative efficiencies of the different paths. As seen in Figure 6.8, the NE origin is no longer the least costly path, which is now held by the NNE, and followed by the N origin. This alteration in the top ranked paths could be attributed to the unfortunate placement of the 2km NE origin, which is located near the valley edge and thus would accumulate greater costs associated with this proximity (Figure 6.8). The SW path could also have benefited by its placement as its origin is now located outside Hole in the Wall coulee and would no longer have to climb out of the valley. The North origin also makes a noted detour to reconnect with the NNE path, as it now travels south along the west side of the northernmost driveline before swerving east near its end, creating a small amount of conflict in the process.

Three routes received glaring alterations: the NNW, WNW, and SSW. Instead of moving sharply northwest and following the course set by the SW origin, the new SSW route now treks northward across several drivelines. Some crossing of drivelines is expected as the SSW origin is encapsulated on all sides by the cairn lines and such lines have no association with this



Path	Cost	Rank
NNE	2929.22	1
N	3361.02	2
NE	3718.93	3
SW	3763.21	4
SSW	4496.46	5
WSW	4559.79	6
NNW	4726.42	7
WNW	4740.97	8
NW	4786.52	9
W	4956.41	10

Figure 6.8: Upland least cost paths for DhNe-51, 2km extent.

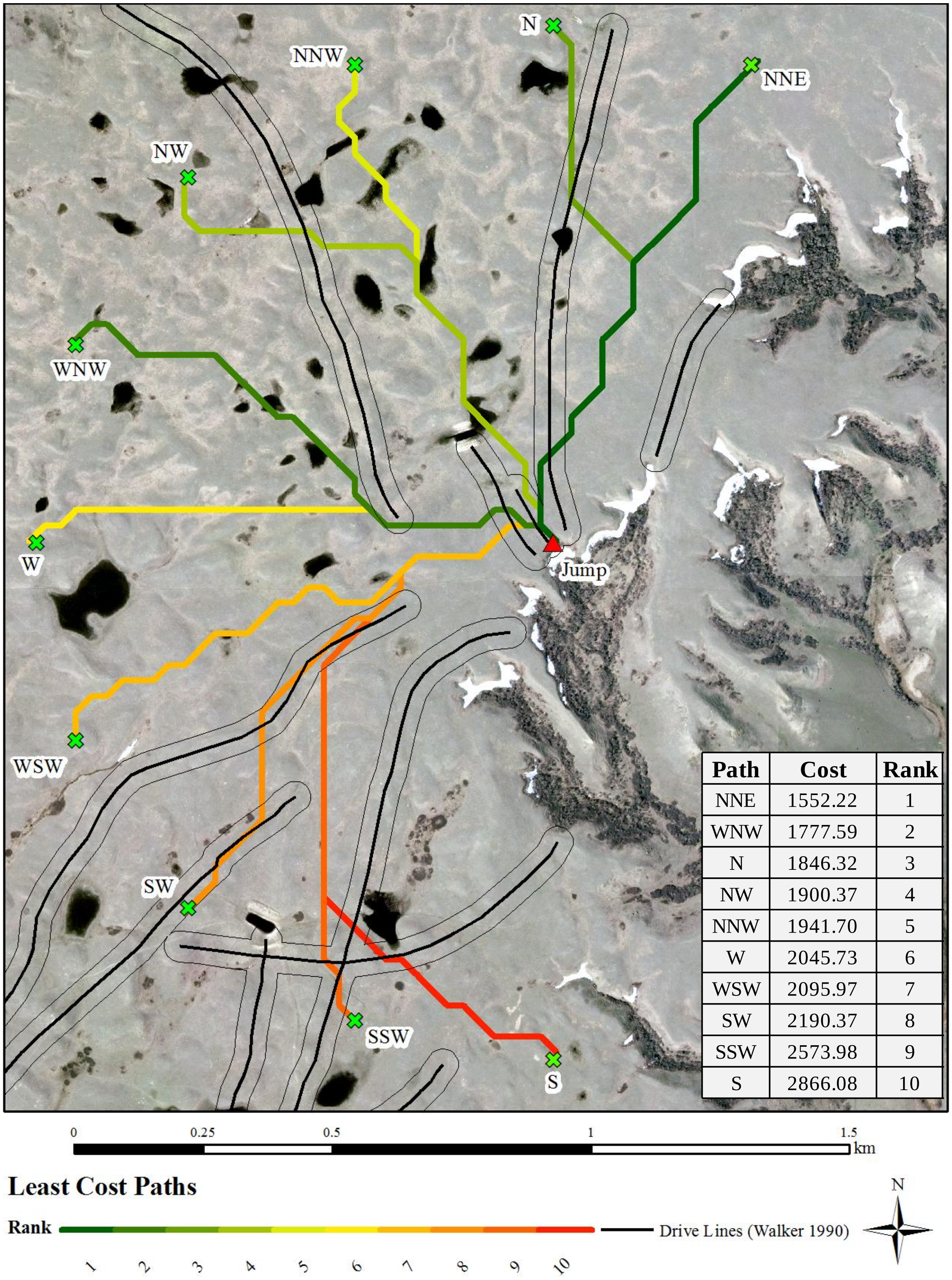
particular jump given their orientation. The path does begin moving within a drivelane for an appreciable duration northward before reconnecting with the SW path at the drivelane's end.

The 2km NNW path now heads eastward away from Hole in the Wall coulee and merges with the N path to approach the jump from the Northeast main route. This change is interesting as it was expected to move with its fellow northwestern paths out of Hole in the Wall coulee and approach through the Northwestern drivelane. The small drainage south of the 2km NNW origin may have been a deterrent to this course of action, deflecting it to the east instead.

The last major change we see with the path orientation is that the WNW now connects with the NW path within the Northwest drivelane. It abandons the route it has used at the three and four kilometre levels. However, as we will see at the one kilometre scale (Figure 6.9), this shift is temporary. The WNW returns to the western main path at the 1km scale, so the alteration seen here is likely due to the placement near the small drainage on the east side of Hole in the Wall coulee. This small drainage facilitates movement out of the coulee and is located on the opposing side of the topographic barrier that separates the Northwest and West main routes. As mentioned above, the placement of the WNW, NW and NNW origins at the previous extent made them poor candidates for routes to lead bison within, due to the high slopes that were twice encountered. While the new placements are in more favorable positions, their costs still reflect the high slopes they must pass through.

One kilometre level

Arrival at the one kilometre extent shows sweeping change to the calculated least cost paths. As seen in Figure 6.9, the all the origins that were formerly located in Hole in the Wall coulee are now found on the uplands behind the DhNe-51. As such, they no longer cross areas of high cost represented by the valley edge of Hole in the Wall. This change in terrain provides much lower accumulated costs and thus changes the relative cost ranks. This is especially true for the western and northwestern origins (W, WNW, NW, and NNW).



Path	Cost	Rank
NNE	1552.22	1
WNW	1777.59	2
N	1846.32	3
NW	1900.37	4
NNW	1941.70	5
W	2045.73	6
WSW	2095.97	7
SW	2190.37	8
SSW	2573.98	9
S	2866.08	10

Figure 6.9: Upland least cost paths for DhNe-51, 1km extent.

The W, WNW, NW and NNW all rise in relative rank compared to those seen at the two kilometre level, while the southwesterly paths have dropped in turn. The NNE still holds the least costly route but is now followed by the WNW while the N origin is relegated to third position. The most costly route now comes from the South origin, a newly introduced direction. The South path is preceded by the SSW and SW both of which are following relatively the same courses seen at the 2km scope.

What we see in this upheaval of the relative ranks between the one and two kilometre extents is a switch between the middle and worst ranked main routes. The Northeast main artery is still the most cost effective, being maintained by the 1st and 3rd best paths. However, the Northwestern approach now holds the middle spot, moving well within the northwest oriented drivelines. The Southwestern route accumulates higher relative costs than the other two, so it serves as the least effective main path to the bison jump. This switch of course can be attributed to the presence of higher cost terrain just south of the jump as seen in the original cost raster (Figure 6.10). While the Southwestern paths have always crossed this during the other iterations, the costs seen here pale in comparison to those at the north end of Hole in the Wall coulee. Since the Northwest routes no longer cross this break in terrain, their accumulated costs drastically drop and allow for movement in this direction to be a much more viable option.

While the West main route consists of the second and sixth least costly paths, it lacks evidence for movement through the drivelines. Unlike the southeastern paths seen at DhNe-1 where the lack of supporting driveline evidence is due to the lack of survey in the area, here the areas west of DhNe-51 were thoroughly surveyed by Walker (1990) and no driveline evidence was identified. So while movement from this direction shows moderate potential in terms of topography, the lack of driveline evidence suggests that movement from this area was not preferable when compared to the other main arteries.

6.2.4 DhNe-75

Four kilometre level

Moving south from DhNe-51, we arrive at DhNe-75. As mentioned in Chapter Two, DhNe-75 rests on a separate arm of the same coulee system used by DhNe-51 and 76. This close proximity may warrant the sharing of many of the drivelines and least cost paths calculated for the other jumps. While all the jumps used the same cost raster to calculate their least cost paths,

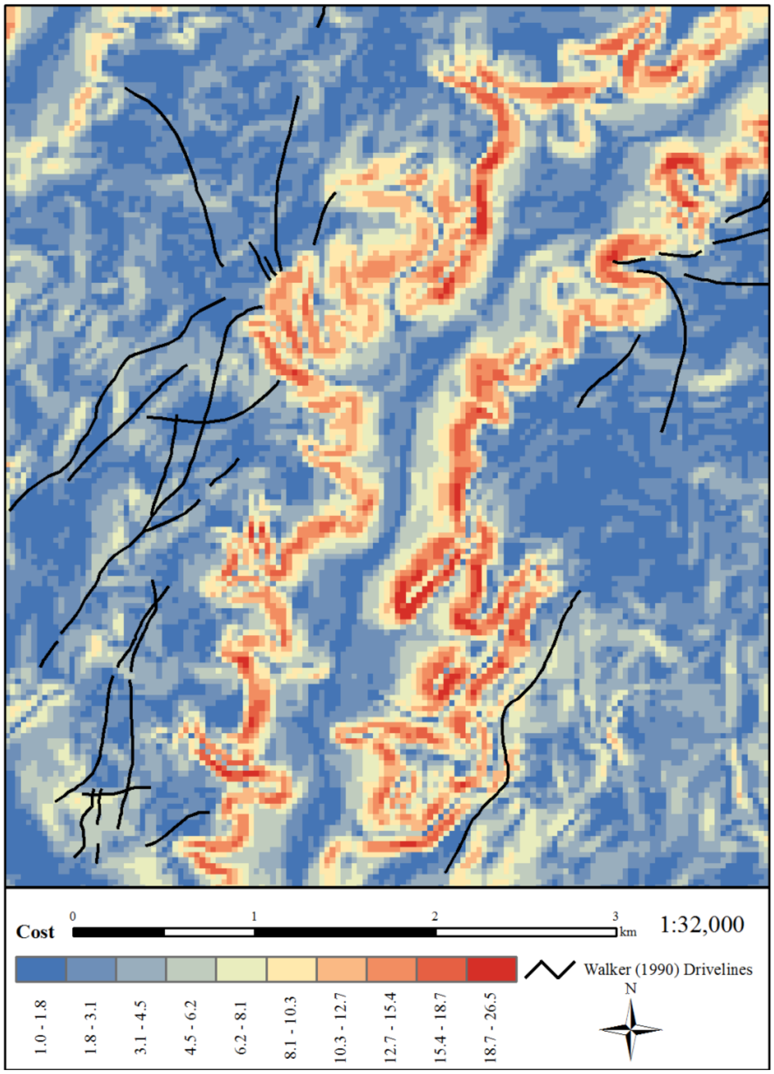
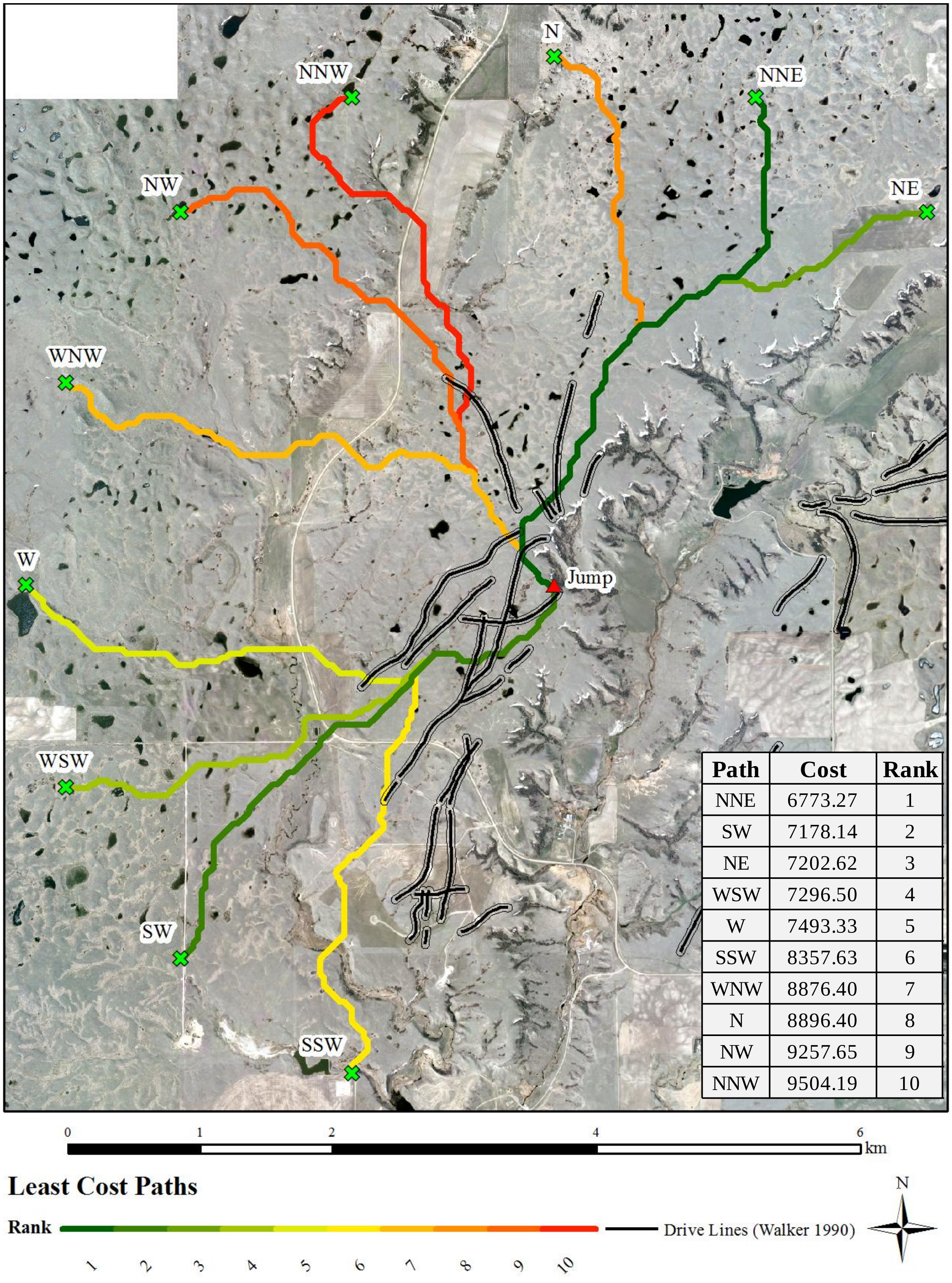


Figure 6.10: Cost raster used in least cost path analysis. Note the locations where the costs quickly change.

each had separate source and destination locations. We shall see if these different variables create noticeable shifts in the calculated least cost paths.

Figure 6.11 summarizes the results of the least cost path calculations for DhNe-75 at 4km distances. Like DhNe-51, 10 of DhNe-75's 16 origins yielded an upland location. Also like DhNe-51, the path efficiencies show a preference to the Northeast and Southwest orientations as NNE, SW, NE and WSW are the top four ranks. The West path follows in fifth position and thereafter we see a large spike in costs for the remaining routes. This is expected because the



Path	Cost	Rank
NNE	6773.27	1
SW	7178.14	2
NE	7202.62	3
WSW	7296.50	4
W	7493.33	5
SSW	8357.63	6
WNW	8876.40	7
N	8896.40	8
NW	9257.65	9
NNW	9504.19	10

Figure 6.11: Upland least cost paths for DhNe-75, 4km extent.

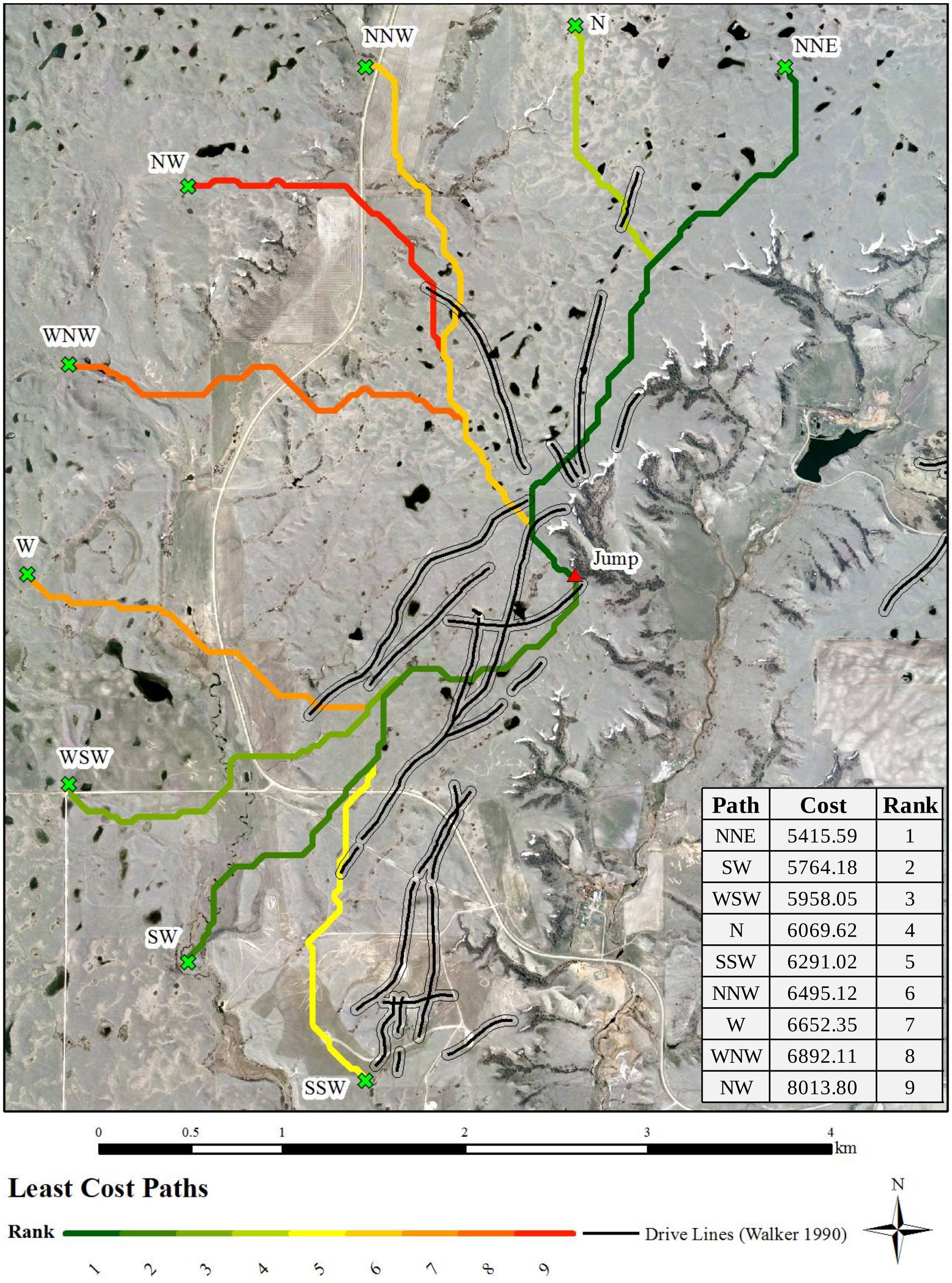
three Northwestern origins have to climb into and out of Hole in the Wall coulee as they did at DhNe-51, drastically increasing their cost. The SSW, ranked sixth, has to cross two small drainages as it moves north, leading to a larger cost of travel. Finally the North path, while not following the same tracks as its Northwestern brethren, was unfortunately placed at the head of a coulee. So again the high costs associated with the valley edges are the main contributors to the lower ranks seen in these least cost paths.

As the individual paths begin to merge, they end up creating two main routes of access leading into the final stages of the jump. These two are the Southwest route, comprised of paths between SSW and W, and the Northwest route made up of all paths between WNW and NE. This Northwest artery is made up of two subsections, the Northwest origins which are generally high costing, and the North/Northeast which encompasses less costly paths. The Northwest subsection rarely does follows the drivelines, either remaining in the area void of drivelines to the west or cutting straight across them as the jump approaches. The Northeast subsection follows paths similar to those used in DhNe-51 while following the northeastern most driveline for about a kilometre before turning west. After this, the path cuts across the other drivelines it meets before swinging around the head of the valley and approaching from the northwest.

The paths making up the Southwestern artery also appear to follow the drive lines in their area. All four paths meet near the mouth of the drive lanes and proceed in a northeasterly direction towards the jump. Due to the complexity of the drivelines seen nearest the DhNe-75 jump, it is expected that some of the drivelines would be crossed, which is what we see in Figure 6.11. So aside from the areas where the path crosses the drivelines by necessity, the Southwestern artery provides a fine example where the drivelines showcase the easiest routes through the topography.

Three kilometre level

Like what we saw at DhNe-51, the three kilometre extent allows for the Northern path to jump several places in cost rank as it no longer has to contend with Hole in the Wall coulee's valley edge. In fact, this North least cost path follows a very similar route used by the North origin in the 2km extent for DhNe-51. This North path jumps in rank from 8th to 4th position after this transition. The NNE and SW still remain as the top two ranking paths, while WSW



Path	Cost	Rank
NNE	5415.59	1
SW	5764.18	2
WSW	5958.05	3
N	6069.62	4
SSW	6291.02	5
NNW	6495.12	6
W	6652.35	7
WNW	6892.11	8
NW	8013.80	9

Figure 6.12: Upland least cost paths for DhNe-75, 3km extent.

moves into third position. The NE was excluded from Figure 6.11 as its origin was unfortunately within the head of a sub-drainage of Roan Mare coulee, disqualifying it from use.

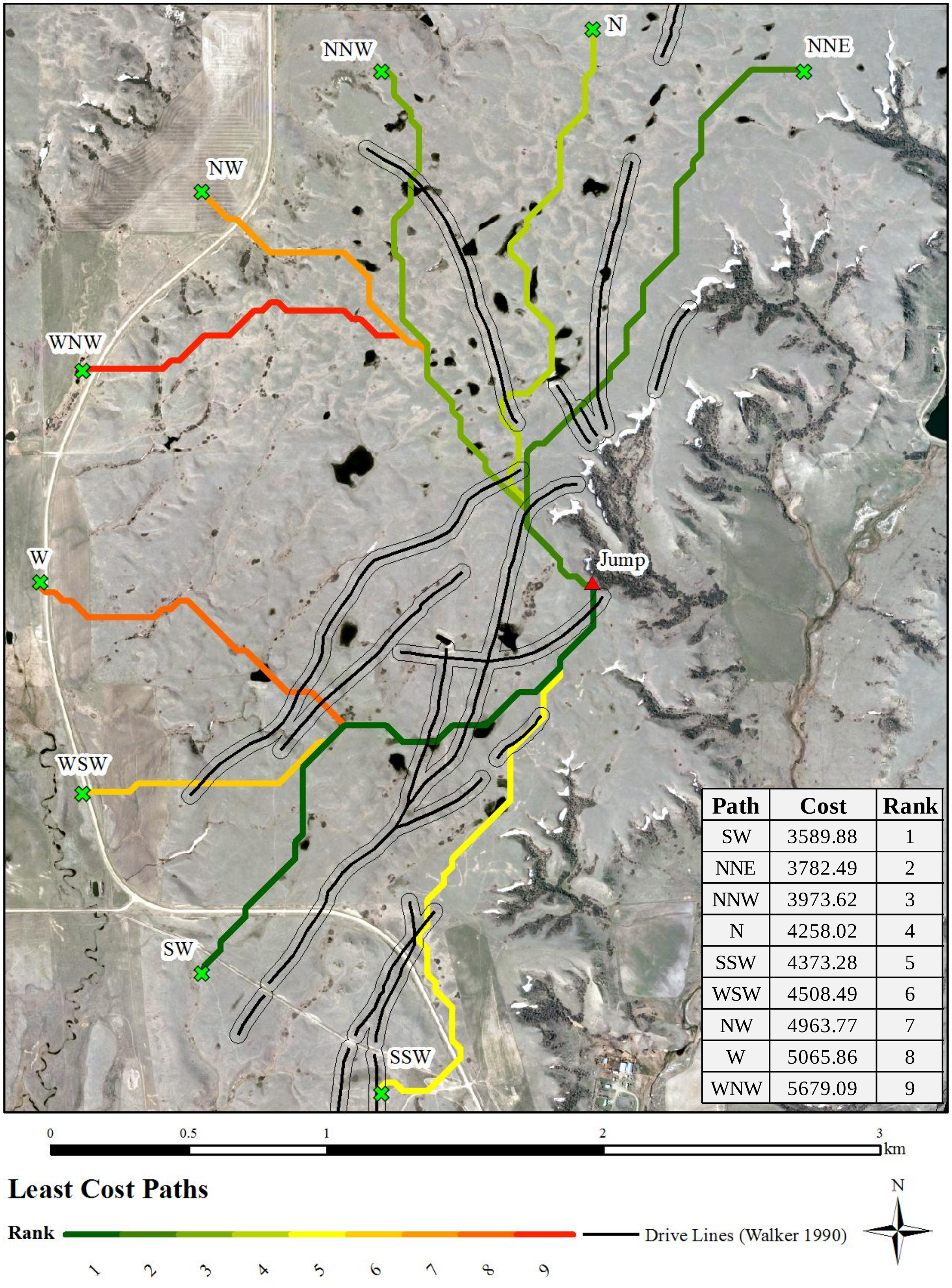
There are also some transitions in the lower ranks as well. The West path drops from fifth to seventh, while the North-Northwest route increases from last to sixth. This increase in rank is likely due to the NNW origin's new location within Hole in the Wall coulee. This new location affords easier accumulated costs compared to the W, WNW and NW paths as it only has one valley edge to traverse instead of two.

While the relative ranks of the least cost paths saw noticeable transitions, the paths themselves varied very little between the four and three kilometre scales. The most visible changes that did occur can be seen in the North and Southwest paths. As mentioned before, the North path now heads south then east to connect with the NNE, rather than east then south. The SW path now originates in Hole in the Wall coulee so it now heads more eastward and merges with the SSW first rather than the WSW, while running roughly parallel to its former route. The Southwest paths still merge at the same location, only in different pairings. This subtitle variation over such a small distance suggests that this area could have several different avenues for moving bison within, while only having minute differences in cost between them.

Two kilometre level

The entry into the 2km scale for DhNe-75 marks obvious changes to both the orientation and ranks of the calculated least cost paths from the 3km extent. For the first time, the SW origin is now the least costly path to traverse, switching rank positions with the NNE. Again, this is most likely due to the absence of having to cross Hole in the Wall coulee. The same can be said for the increase in rank for the NNW origin which trades ranks with the WSW, exchanging 3rd for 6th (Figure 6.13).

Two new least cost paths are created from the 2km N and SSW origins. The North path now moves south-southwestward through the Northwest drivelines. It is strange that this new North origin does not seek to connect with more efficient routes found nearby such as the NNW or the NNE. Instead it adopts a similar path seen used by the northwestern origins from DhNe-51, moving directly through this drivelane. The reuse of the same least cost paths used for other jumps strengthens the argument that the nearby drivelines highlight effective topographic routes to move bison within.



Path	Cost	Rank
SW	3589.88	1
NNE	3782.49	2
NNW	3973.62	3
N	4258.02	4
SSW	4373.28	5
WSW	4508.49	6
NW	4963.77	7
W	5065.86	8
WNW	5679.09	9

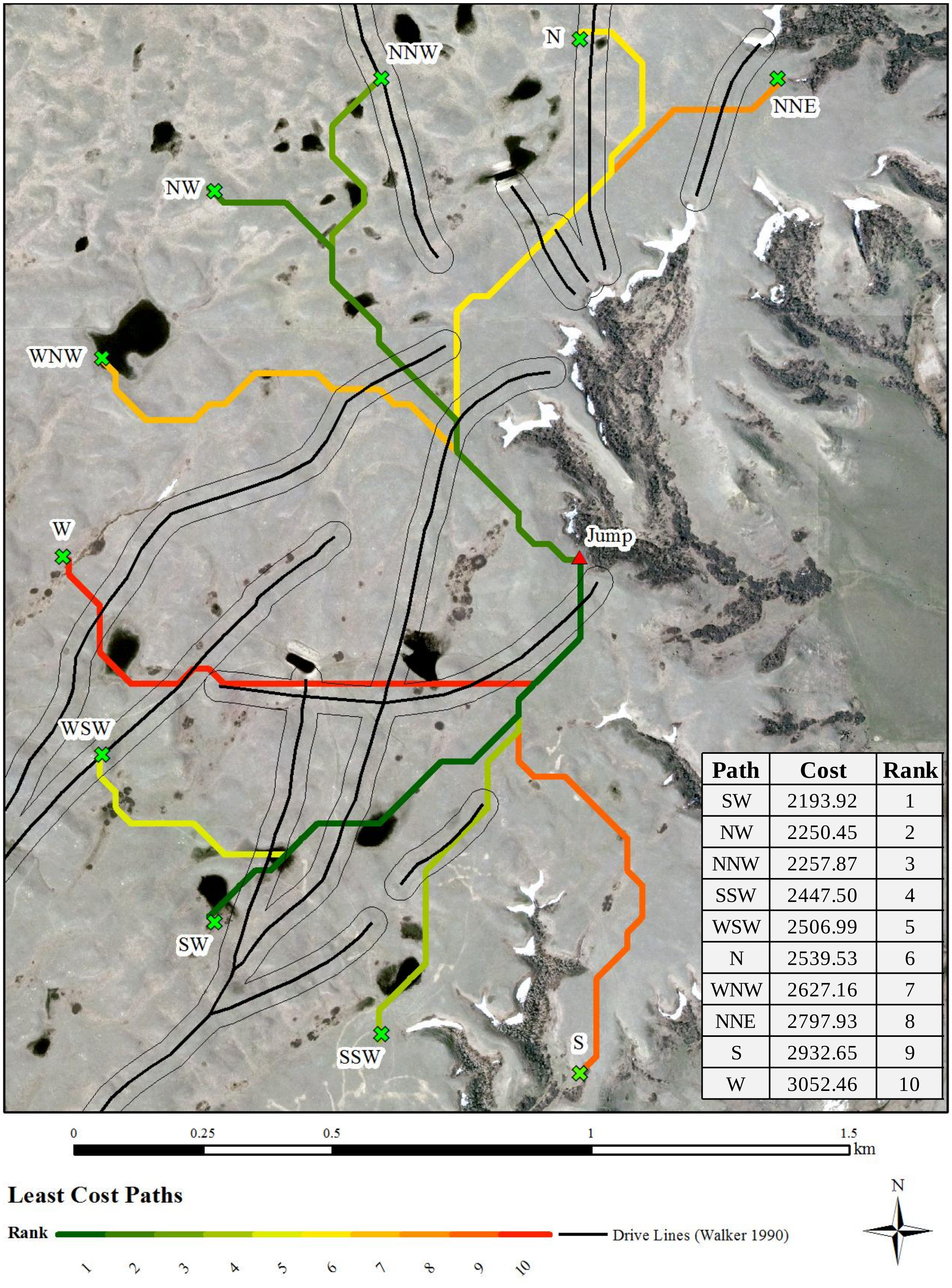
Figure 6.13: Upland least cost paths for DhNe-75, 2km extent.

The SSW also creates a new least cost path to the jump edge. Rather than heading westward to connect with the other southwest paths, the new path skirts the valley edge to the northeast. It does reconnect with the Southwest main route once it passes the drivelines to the west of it, approximately 300m before the end of the drive. This diversion from the previous path could be due to a large topographic high between the two and three kilometre SSW origins. The three kilometre path deflects away to the west, while the two kilometre route quickly moves east to lower terrain. This area of higher cost is topped by two criss-crossing drivelines, perhaps indicating this topographic barrier. There is also a chance that this new path has been skewed by the modern road, as it does run parallel to it for about 500m early on before moving northward.

One kilometre level

With the 1km scale, we see the northwestern paths (NW, NNW) increase in rank, while the northeastern (N, NNE) ones drop in relative efficiency. In this scenario, the SW path is still the least costly path to traverse but is now followed by the NW instead of the NNE as seen at the two kilometre extent. The N and NNE paths drop in rank to 6th and 8th respectfully, so movement from those directions are much less cost effective at this scale. The two lowest ranks are the new South and West least cost paths. The South path's high rank could be as a result of the close proximity of its origin to the valley edge, as it joins fairly low costing paths from the southwest near the end of its run. The West path on the other hand takes a most unexpected course. Instead of following the small drainage to the northeast and connecting with the WNW, the path moves south then due east to connect with the Southwest main artery. In doing so, it crosses all drivelines and drivelanes it comes across. This is likely due to the large patch of high costing terrain between DhNe-51 and 75 mentioned above. This new West path is simply avoiding this area of high cost by running parallel to the area's southern extent.

It can also be seen that the new North origin has resumed heading eastward rather than down through the Northwestern drivelines as seen at the two kilometre scale. This could signify that the middle driveline marks a topographic divide through the terrain. Such a divide would section off the separate drivelanes from one another until the eventual approach of the valley edge. Such a division would be expected given the bison drive strategies described in Chapter Two.



Path	Cost	Rank
SW	2193.92	1
NW	2250.45	2
NNW	2257.87	3
SSW	2447.50	4
WSW	2506.99	5
N	2539.53	6
WNW	2627.16	7
NNE	2797.93	8
S	2932.65	9
W	3052.46	10

Figure 6.14: Upland least cost paths for DhNe-75, 1km extent.

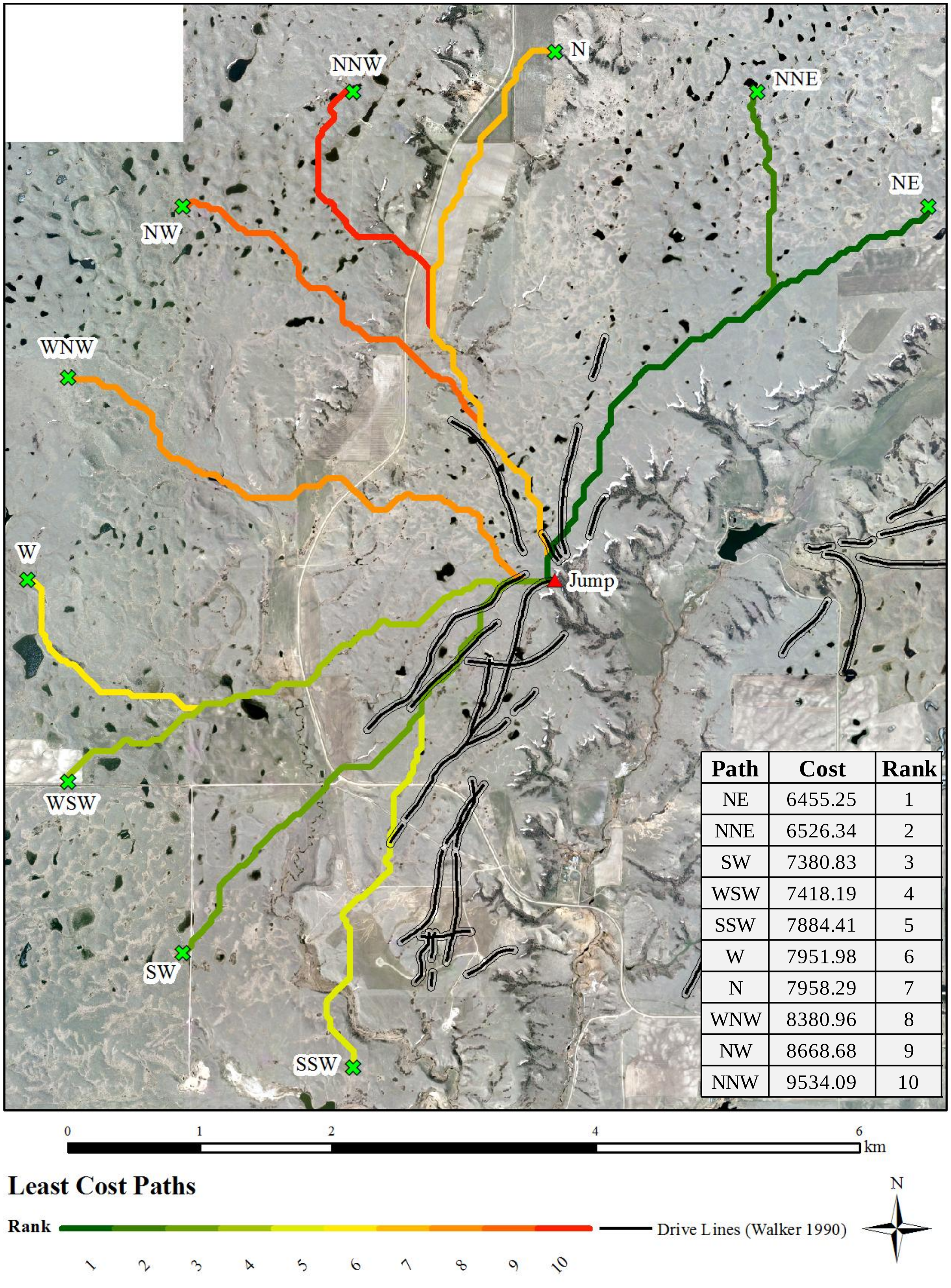
When comparing the one kilometre level to the four kilometre, we see both similarities and differences. We still show two primary routes that terminate at the end of the jump, one from the Northwest and the other from the Southwest. The Northwest route is still made up of two smaller subsections consisting of the Northwestern (WNW-NNW) paths and the Northeast (N, NNE). Unlike the 4km level where the Northeast was much less costly than the Northwest, the situation is somewhat reversed at 1km. Thus, like DhNe-51, entry from the Northwest becomes a fairly cost effective route once Hole in the Wall coulee is no longer in consideration. However, unlike DhNe-51, these Northwestern paths show no evidence for movement through drivelines at any scale.

6.2.5 DhNe-76

Four Kilometre level

The least cost paths calculated for DhNe-76 shares many of the paths used in DhNe-51, but the ranks of these paths are akin to those of DhNe-75. This is to be expected as the close proximity means it should share characteristics of both. Much like DhNe-51 and 75, the Northeastern paths for DhNe-76 are ranked first and second least costly. The Southwestern (SSW to W) paths then follow by holding ranks third through sixth as seen with DhNe-75. The remaining paths from the Northwest fall into the most costly ranks amongst the upland routes as expected. Again, these northwest paths would be ill suited to move bison along due to the repeated changes in slope.

The assemblages of paths merge into two major routes of access. One approaches from the north, consisting of paths from the NW through to the NE that merge approximately 200m from the jump edge. These subsections show good evidence for least cost movement within the drivelines utilizing the drivelanes north and northwest of the jump. The second major approach is from the West, consisting of the least cost paths between the SSW and WNW origins. The SSW and SW paths merge and move through the drivelines south of the jump. They proceed along these drivelines to termination where they then veer to the east and move straight to the jump edge. These two paths have the same issues with the center and northern tips of these drivelines that were seen with DhNe-51 as they share the same paths. The WSW, W and WNW approach from outside the drivelines, meeting with the other paths in the last 250m of the drive.



Path	Cost	Rank
NE	6455.25	1
NNE	6526.34	2
SW	7380.83	3
WSW	7418.19	4
SSW	7884.41	5
W	7951.98	6
N	7958.29	7
WNW	8380.96	8
NW	8668.68	9
NNW	9534.09	10

Figure 6.15: Upland least cost paths for DhNe-76, 4km extent.

From the 4km perspective, the two major routes of access mentioned above have very clear cut groups of ranks. The North main artery is a mix of both the best and worst costing paths which is again due to interference from Hole in the Wall coulee. As referred to above, the subsections of the route follow the drivelines admirably. It is likely that DhNe-75 will follow a similar pattern seen at DhNe-51, where the Northwest paths will become more cost effective at shorter intervals. On the other hand, the West main route is constituted by all the middle ranking paths with the exception of the WNW. This favoritism for movement from the Northeast with the Southwest following close behind has been an ongoing trend in the other western bison jumps we have viewed thus far. It will be interesting to see if this trend continues into the smaller scales and amongst the remaining sites.

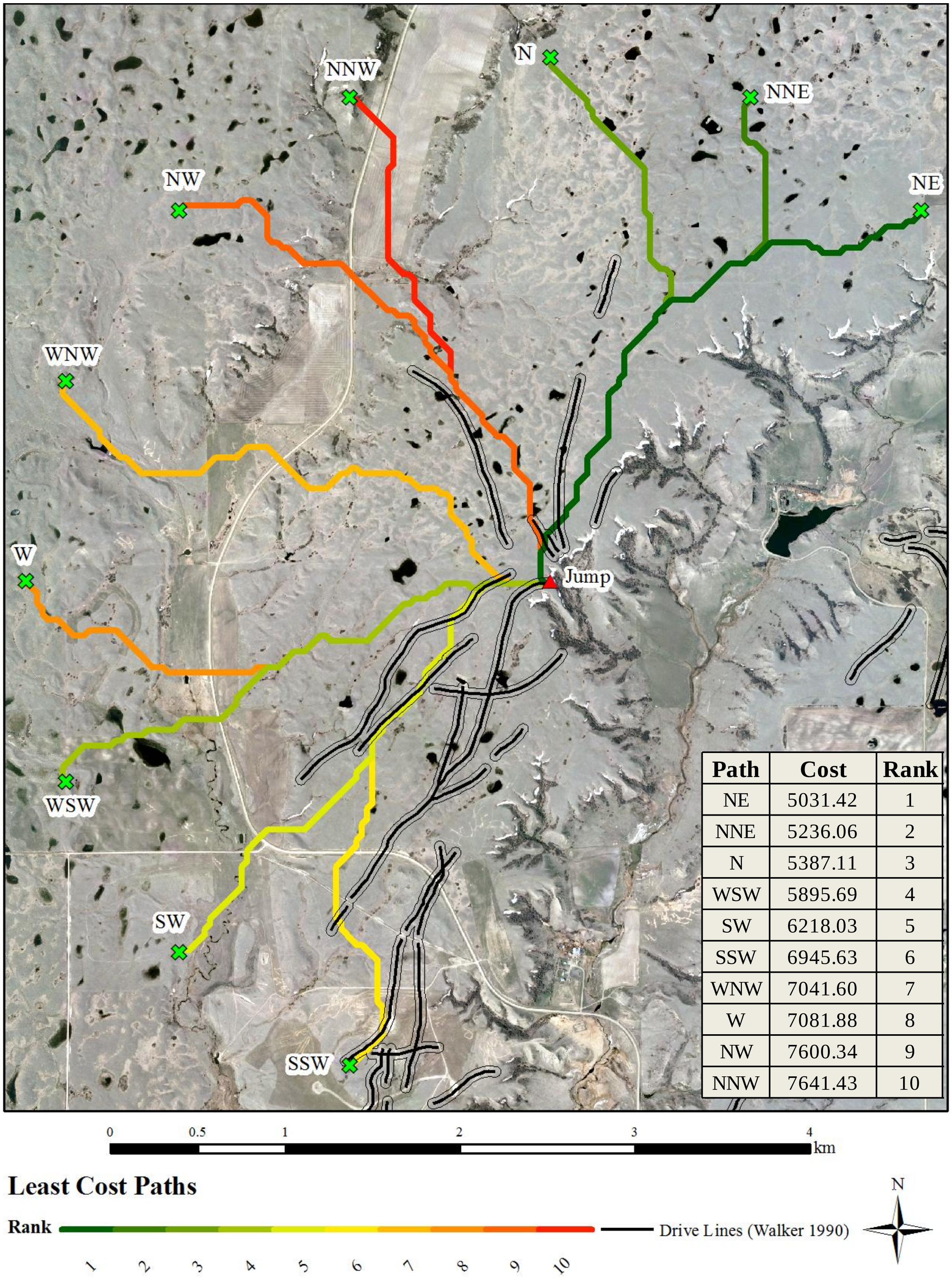
Three kilometre level

Like what was seen at the 4km extent, the 3km least cost paths calculated for DhNe-76 mirror those seen at same scale for DhNe-51. The most obvious change from DhNe-51 is seen in the West path. Instead of heading due east across Hole in the Wall coulee, DhNe-76's W path moves southeast to connect with the WSW. The North path once again joins the Northeastern paths as it increases in rank to third position. From there, the remaining paths follow a similar rank order to what they had for the 4km level. The WSW and SW exchange positions while the West origin drops in rank to 3rd last. Outside of these changes, there is little difference in what was seen at the 4km scale or for DhNe-51.

Two kilometre level

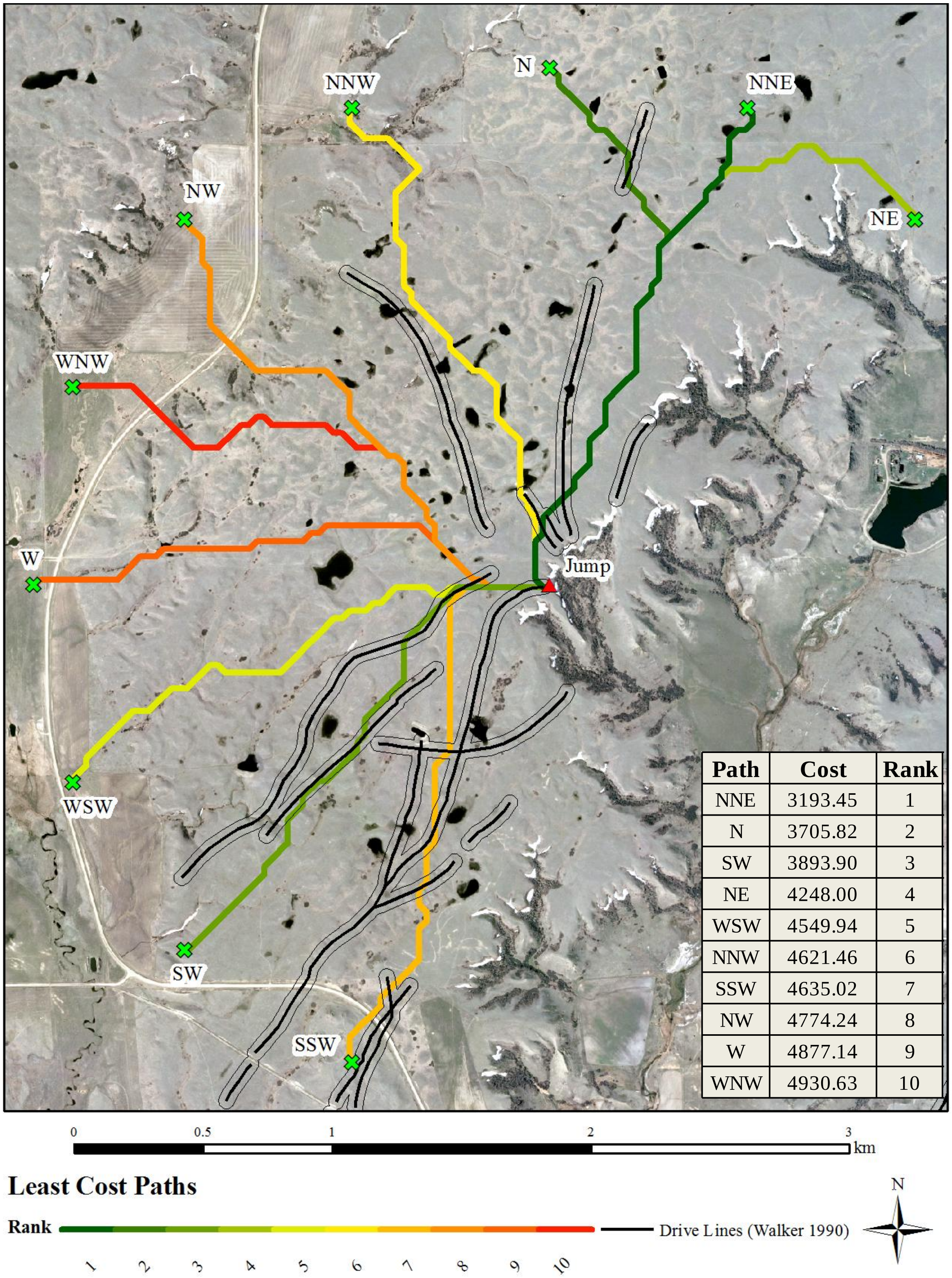
As the distance from the origins to the destination decreases, the likeness between the least cost paths for DhNe-51 and 76 also appears to diminish. Of course we still do see some similarities between the paths for the two jumps. This is especially evident in the southwestern paths, where the SSW, SW, WSW and W for DhNe-76 follow the exact same routes as their compatriots from DhNe-51. The only real variation they show is near the end of their run where change direction towards their respective jump termini.

The major differences can be seen with the Northwestern paths (WNW, NW, and NNW). In Figure 6.8, we saw the NNW path climb out of Hole in the Wall coulee and join with the Northeastern pathways. Here the NNW instead travels south as it had at the larger scales,



Path	Cost	Rank
NE	5031.42	1
NNE	5236.06	2
N	5387.11	3
WSW	5895.69	4
SW	6218.03	5
SSW	6945.63	6
WNW	7041.60	7
W	7081.88	8
NW	7600.34	9
NNW	7641.43	10

Figure 6.16: Upland least cost paths for DhNe-76, 3km extent.



Path	Cost	Rank
NNE	3193.45	1
N	3705.82	2
SW	3893.90	3
NE	4248.00	4
WSW	4549.94	5
NNW	4621.46	6
SSW	4635.02	7
NW	4774.24	8
W	4877.14	9
WNW	4930.63	10

Figure 6.17: Upland least cost paths for DhNe-76, 2km extent.

moving within the Northwestern drivelane (Figure 6.17). Meanwhile, the WNW and NW paths which occupied this corridor for the DhNe-51 now defect to the west moving outside the drivelines and connecting with West main artery. Granted the WNW has always moved outside the drivelines for DhNe-76, but it is now joined by the NW instead of the other way round seen with DhNe-51. This is just an example where subtle changes in the destinations and sources lead greatly different least cost paths.

One kilometre level

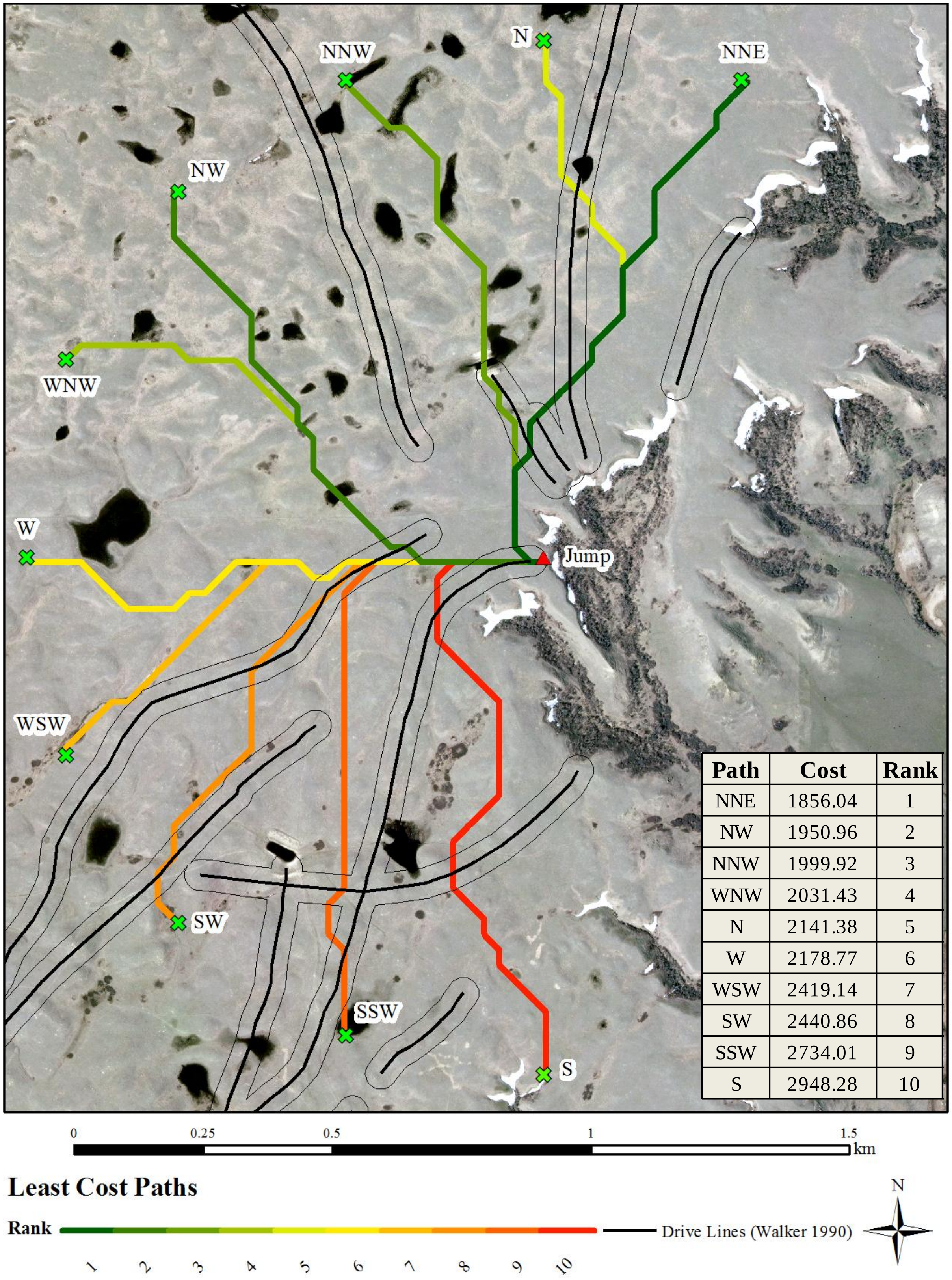
In the final extent for DhNe-76, we see a similar layout of the least cost paths to those seen at DhNe-51. The southwestern access has diminished in rank while the reverse is seen with travel from the Northwest. The lack of arduous terrain, such as the edge of Hole in the Wall coulee is the reason for this rank promotion. The NNE once again is the most efficient route, followed by the NW, NNW and WNW in that order.

From the Southwest, we see a fluorescence of individual paths. Instead of several paths merging together early on, each origin from S to WSW move parallel to one another and meet the West route individually. Of these, only the SSW and SW show any semblance of moving within the drivelanes, as they follow the paths forged in the earlier iterations of the least cost path analysis. This too may be a result of the area of high cost found at the end of these drivelines. It is easier for each path to detour around the area and join up on the east-west oriented route that skirts the northern edge.

6.2.6 DhNe-77

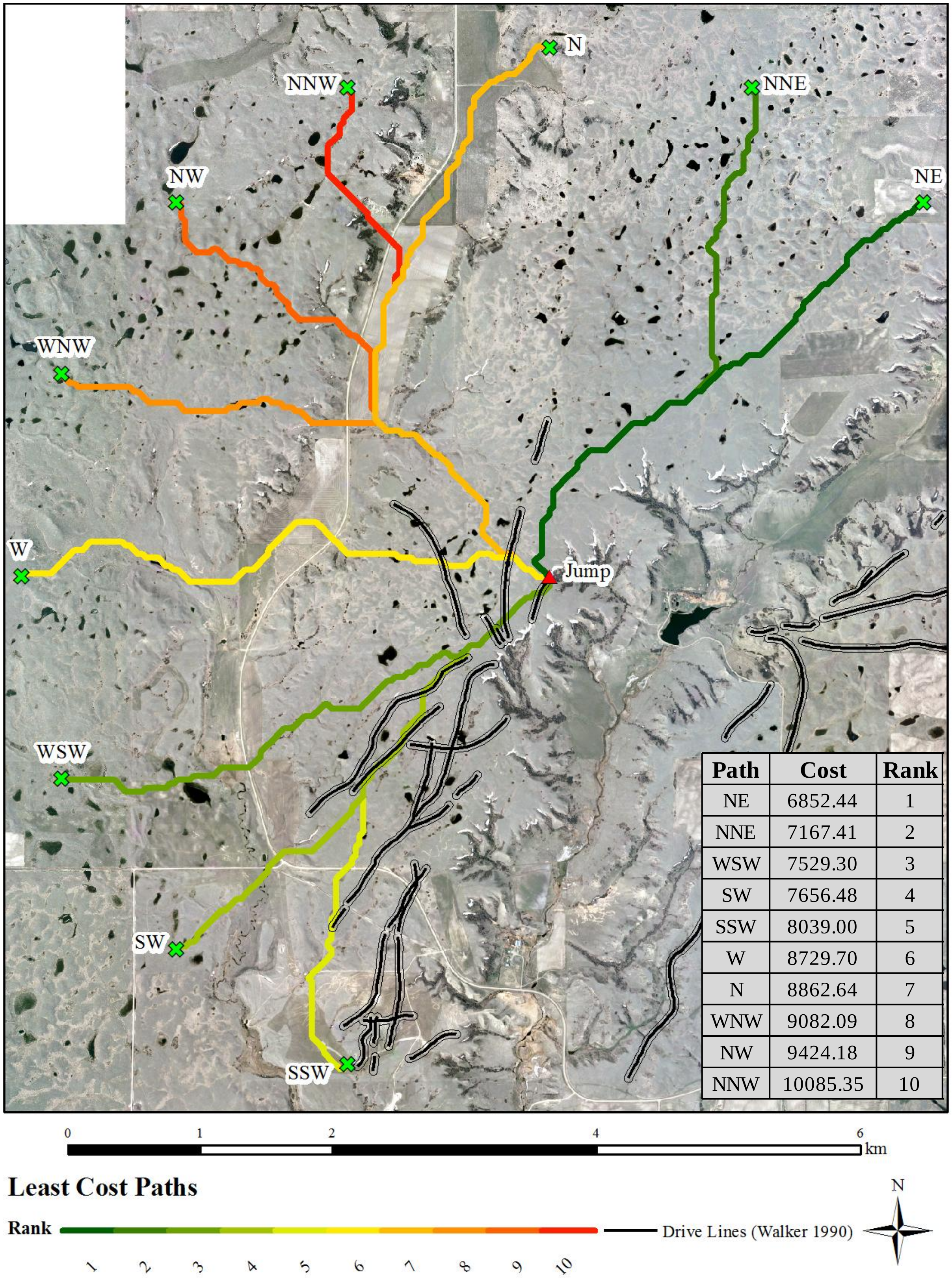
Four kilometre level

Moving northward we arrive at DhNe-77 and it is the northernmost bison jump in Roan Mare coulee. As mentioned in Chapter Two, the only driveline that Walker (1990) connected to this jump was the small one stretching the gap between it and DhNe-51. Through the least cost path analysis, we hope to identify if optimal movement to this site involved other driveline systems found over the valley.



Path	Cost	Rank
NNE	1856.04	1
NW	1950.96	2
NNW	1999.92	3
WNW	2031.43	4
N	2141.38	5
W	2178.77	6
WSW	2419.14	7
SW	2440.86	8
SSW	2734.01	9
S	2948.28	10

Figure 6.18: Upland least cost paths for DhNe-76, 1km extent.



Path	Cost	Rank
NE	6852.44	1
NNE	7167.41	2
WSW	7529.30	3
SW	7656.48	4
SSW	8039.00	5
W	8729.70	6
N	8862.64	7
WNW	9082.09	8
NW	9424.18	9
NNW	10085.35	10

Figure 6.19: Upland least cost paths for DhNe-77, 4km extent.

From the outset, the 4km least cost paths create three main arteries of access: the Southwest, Northwest and Northeast. The Northeast is the most efficient as it is comprised by the two highest ranked paths. It is followed by the Southwest, holding the 3rd through 5th positions. The Northwest encompasses the remaining five paths which are the lowest ranked.

Several paths for DhNe-77 follow the same courses used by the jumps mentioned above. The SSW, SW and WSW paths are identical to those used by their corresponding origins for DhNe-51. The W path here closely follows portions of the WNW paths from DhNe-51, 75 and 76. The most variation we see from the paths for other jumps is from the Northwestern paths. The portions found within Hole in the Wall coulee are very similar, but the DhNe-77 paths divert from their cousins after they climb out of valley moving East-southeast across the uplands. Even with this variation, the crossing of two steep valley walls makes the WNW-NNW unlikely places to drive bison from.

At the four kilometre level, there is minimal evidence for paths moving to DhNe-77 using the driveline network. The Northeastern route shows no driveline use, mostly due to residing outside Walker's (1990) survey area. The Northwestern paths do move through the outer recesses of the Northwest drivelane in a general southeasterly fashion, but head east at approximately the halfway point. The West least cost path shows no sign of driveline use. The most prevalent use of drivelines is from the Southwest and South-southwest where the paths are overlapping with routes seen for the other sites. This of course means they have the same issues with the central and western drivelines found there. As the southwestern paths pass DhNe-76 towards their destination, they show little influence from the first drivelines they come across. Passing DhNe-51, the paths turn northeast allowing some minor movement through a drivelane before crossing the eastern driveline and move northward.

What is unfortunate is that according to the aerial image, this north turn taken but the Southwestern route moves the bison through a small gulley and up the side of the jump edge. This is best seen in Figure 6.22. Since this irregularity with the bison hunting model is only seen in the final few pixels of the least cost path analysis, it is likely this is a side effect of the 30x30m cell size being unable to indentify this small topographic change. Nevertheless, while these Southwest paths are good at remaining on the uplands for the majority of their lengths, their reliability as possible avenues to drive bison are more problematic than the Northeastern courses.

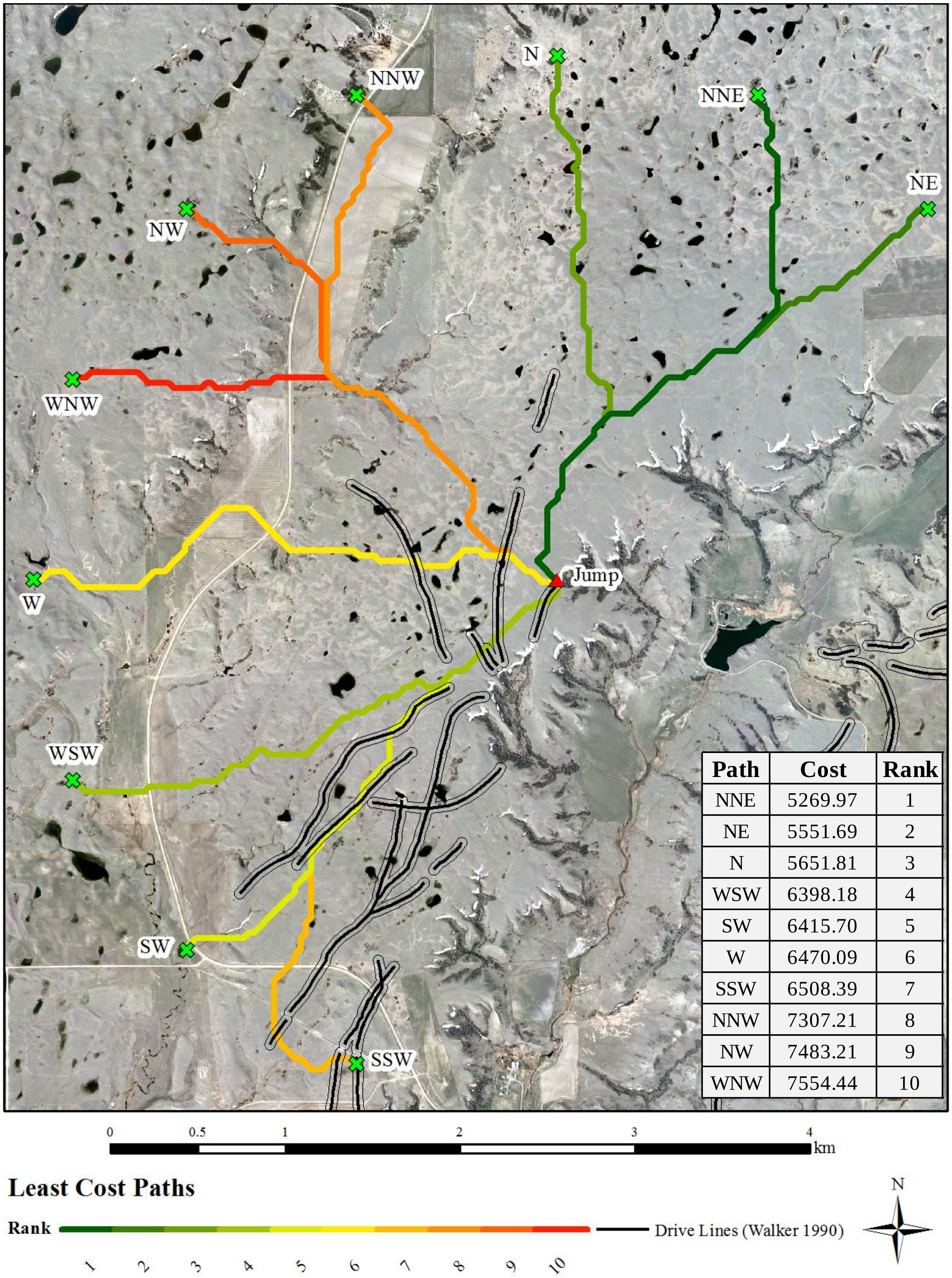
Three kilometre level

The three kilometre paths for DhNe-77 closely resemble what we have seen at the four kilometre level as well as the other bison jumps in the area. The North path has once again moved outside Hole in the Wall coulee and this change has prompted the new least cost path to join the Northeastern paths rather than the Northwest. Again, as seen with DhNe-51 and 76, this new path leads to an increase in relative rank. So the Northeastern main route now holds the top three least costly paths. The South-Southwest drops in rank likely due to the SSW now being placed in an area of higher cost. This can be seen in its rather unusual route where it moves southwest away from the jump edge out of this rough terrain and then makes a hairpin turn to connect with the SW path. Outside of these subtle changes, the new level of scale adds little else that has not been seen at the 4km or other bison jumps.

Two kilometre level

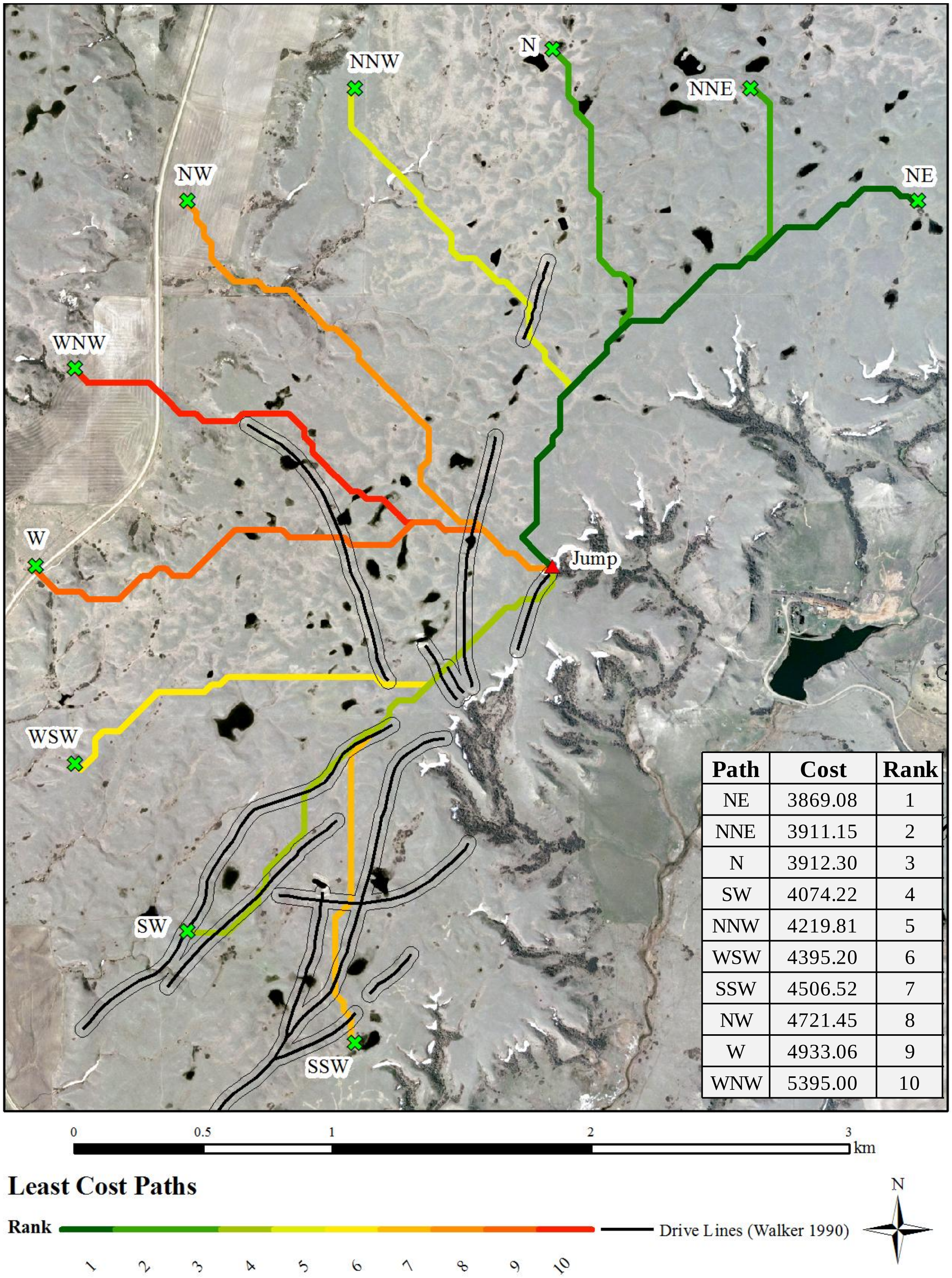
In the two kilometre scale we see changes to both the path choice and cost rank of several routes to the jump edge. The NNW, like the N before it at the 3km level, has moved out of Hole in the Wall coulee and now travels southeast to the connect with the Northeastern paths. In fact it follows a very similar path to that used by the North origin at the 2km extent of DhNe-51, holding close to northernmost driveline then swinging southeastward in the gap between drivelines. This shift away from the Northwestern main route to the Northeast has been seen before in DhNe-51 and may indicate a topographic divisor in the northern reaches of the Northwestern drivelane. The SSW also takes a new pathway to the jump edge, following the route that runs northward through the Southwestern drivelines near DhNe-75. This route saw use in both DhNe-51 and 76.

The top three paths (NE, NNE, and N) remained the same with the exception of NNE and NE switching ranks. Following in fourth is the SW which replaces the WSW. The NNW now occupies the fifth spot, a sizable increase thanks to its new origin location. The South-Southwest holds its position in 7th while other West and Northwestern paths remain as the most costly routes as they still must travel out of Hole in the Wall coulee.



Path	Cost	Rank
NNE	5269.97	1
NE	5551.69	2
N	5651.81	3
WSW	6398.18	4
SW	6415.70	5
W	6470.09	6
SSW	6508.39	7
NNW	7307.21	8
NW	7483.21	9
WNW	7554.44	10

Figure 6.20: Upland least cost paths for DhNe-77, 3km extent.



Path	Cost	Rank
NE	3869.08	1
NNE	3911.15	2
N	3912.30	3
SW	4074.22	4
NNW	4219.81	5
WSW	4395.20	6
SSW	4506.52	7
NW	4721.45	8
W	4933.06	9
WNW	5395.00	10

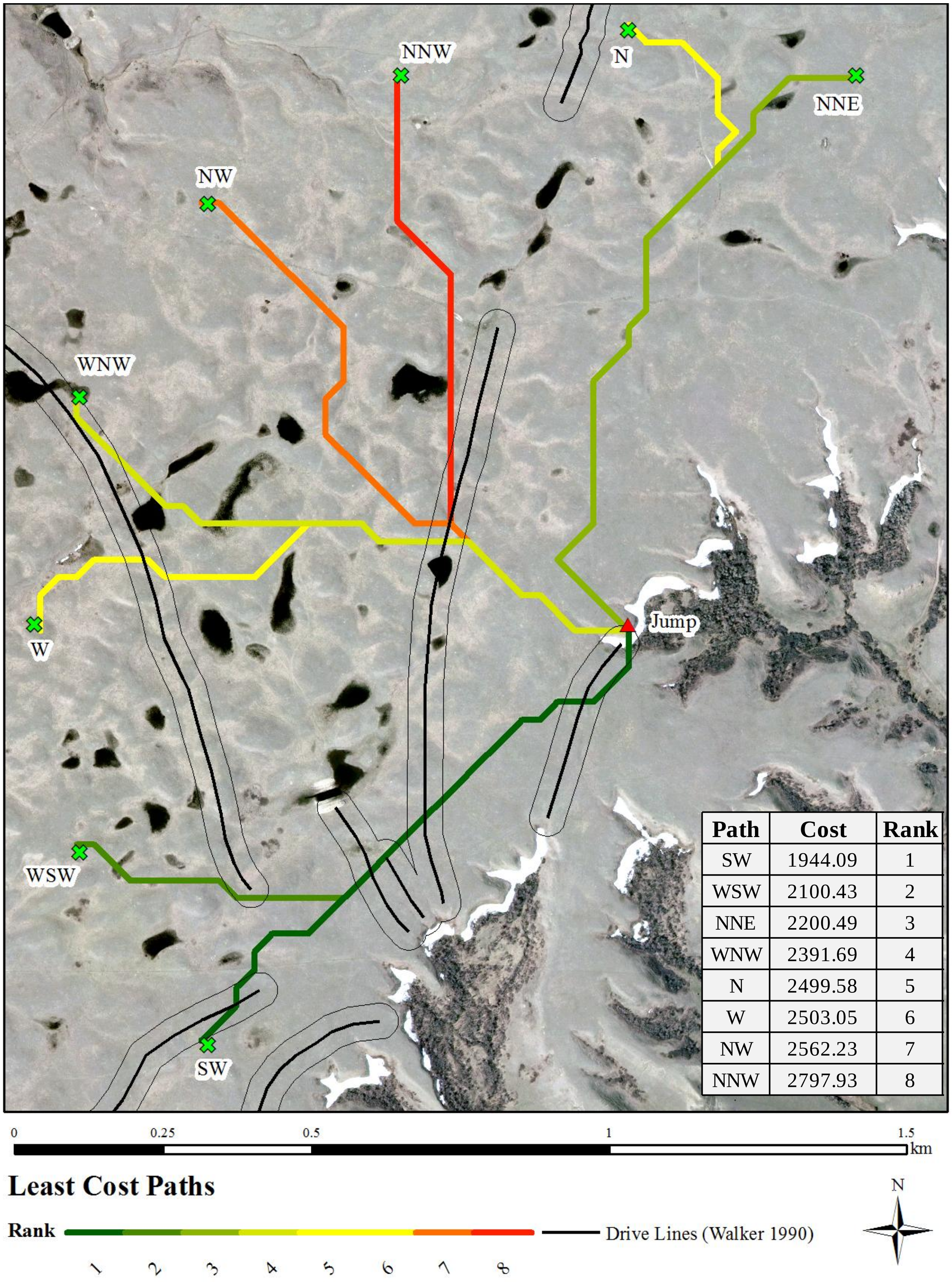
Figure 6.21: Upland least cost paths for DhNe-77, 2km extent.

One kilometre level

Arriving at the one kilometre paths marks a striking difference from the 1km levels of neighbouring DhNe-51 and 76. During the transition from two to one kilometre at those sites, the Northeast routes remained dominant whilst the Southwestern and Northwestern routes switched ranks. As seen in Figure 6.22, the Southwestern routes now hold the two highest ranks. This usurps the Northeast's dominance through the larger least cost path iterations. From there, the ranks waffle back and forth between the Northeast and Northwest, with the NNE placing third and WNW reaching fourth. The NW and NNW hold the highest costing paths of this extent. As mentioned before, the Southwest route does cross the tip of the valley edge during its approach. So even though they rank as the most efficient, the paths themselves are suspect.

Overall, there is little evidence for use of the drivelanes at this scale of measure. Since this scale has few drivelines orientated in a SW/NE direction, the best evidence for the Southwest route using drivelanes is found at the greater distances. There were no other drivelines found along the edge of the valley during Walker's (1990) survey, so the Northeast route has no defined drivelane to compare to. The Northwest route forms a fan like shape from its paths within the Northwest drivelane. This indicates the terrain here being able to facilitate a multitude of different paths and funnel them to a single location necessary for the drive. Unfortunately this funneling point is along the driveline edge, rather than the exit.

Walker (1990) hypothesizes that this site shares the drivelanes used for DhNe-51. Comparing the least cost paths for both jumps, it does appear the two sites overlap at several instances, especially in the northeast and the southwest. However, this assumption could be extended to several other jumps nearby, as there is a large amount of path overlap with them as well. So from the least cost path evidence, it is likely that bison driven to DhNe-77 would share similar routes used to bison driven to DhNe-51.



Path	Cost	Rank
SW	1944.09	1
WSW	2100.43	2
NNE	2200.49	3
WNW	2391.69	4
N	2499.58	5
W	2503.05	6
NW	2562.23	7
NNW	2797.93	8

Figure 6.22: Upland least cost paths for DhNe-77, 1km extent.

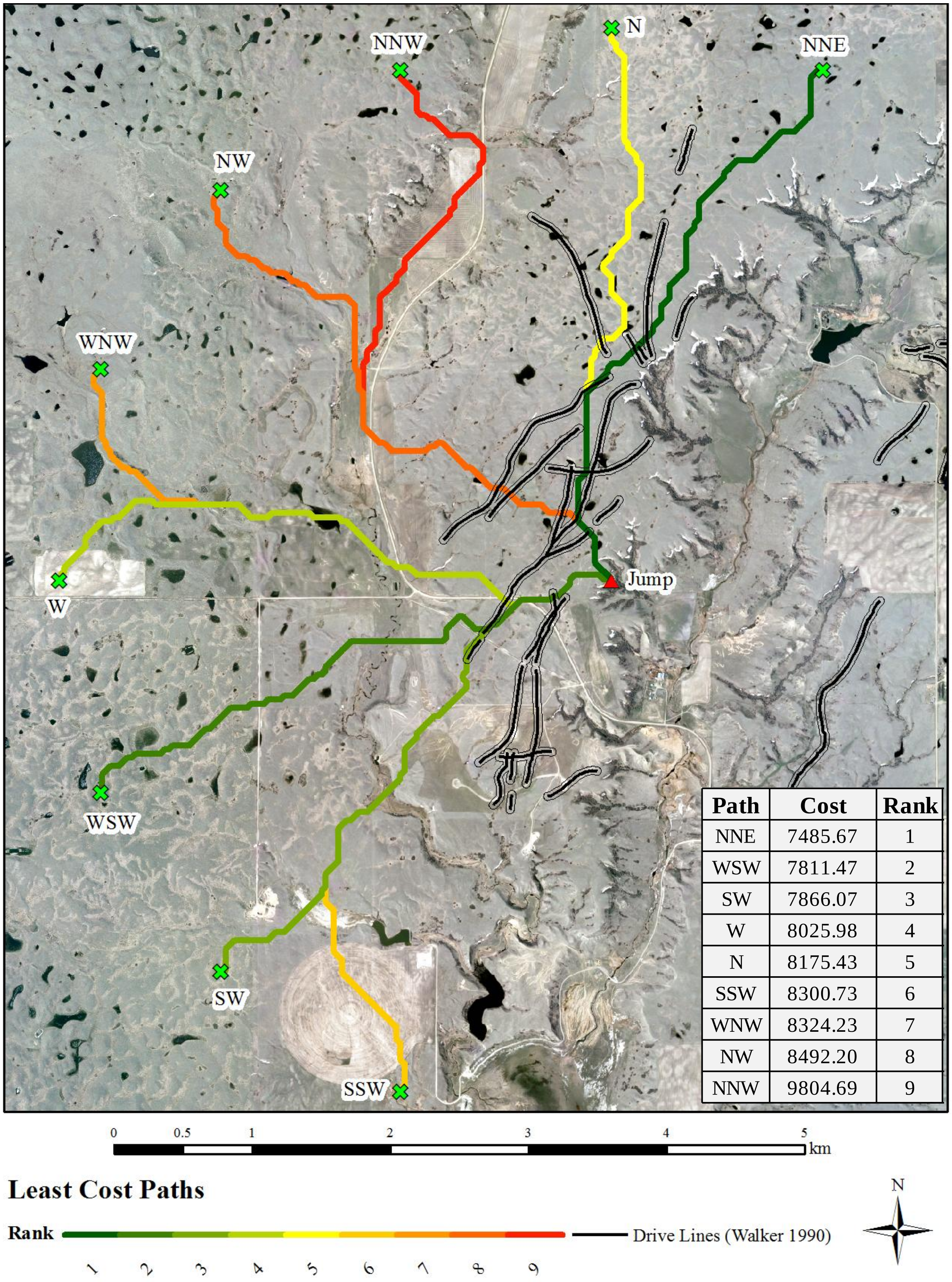
6.2.7 DhNe-82

Four kilometre level

Moving away from the northern bison jumps, we arrive at DhNe-82 to the south. Being removed from the four jumps in the north allows for new routes and paths through the terrain to be established and evaluated. Nine of the 16 origins for the 4km level created routes on the upland outside of Roan Mare coulee (Figure 6.23). The North-Northeast tops the nine as the least costly route. The ranks then shift to the Southwestern paths, with WSW, SW and W taking second, third and fourth least costly paths respectfully. The ranks continue to drop with the N, SSW and WNW following. The NW and NNW are at the bottom ranks as we have seen with previous least cost paths from this area.

The nine calculated paths merge into two major routes as the jump edge approaches. The first is the West route, comprised of paths from SSW through to the WNW. The five paths each cross Hole in the Wall coulee, with the WNW merging with the W and SSW with the SW early on. They all meet near the southern tip of a driveline and move to the Northeast. Once past this driveline, the combined paths follow the general direction and orientation of the drivelane they now reside within in a zig-zag pattern. The second main path approaches the jump from the Northwest, and like at DhNe-76 it can be split into two general subsections.

The first subsection includes the Northeastern paths (N, NNE) and this route is very much an amalgam of several popular paths calculated for the previous jumps. The two paths meet approximately 2/3rds of the way through their course near DhNe-76. The North path occupies the Northwest drivelane, adopting a route seen used for several of the other jumps. The North-Northeast path does the same by taking the adjacent drivelane, again repeating paths we have seen before. After merging, the route takes a path due south through the nearest drivelines before pitching to the southwest in the final 500m of the drive. It is also at this point that the Northeast paths merge with the other subsection from the Northwest. The two Northwest paths move down from their origins into Hole in the Wall coulee and progress south through the valley bottom. The combined path then moves east out of the valley and on to the uplands. It proceeds to then move southeast, transecting all drivelines and drivelanes it comes across until it finally merges with the Northeast to approach the valley edge.



Path	Cost	Rank
NNE	7485.67	1
WSW	7811.47	2
SW	7866.07	3
W	8025.98	4
N	8175.43	5
SSW	8300.73	6
WNW	8324.23	7
NW	8492.20	8
NNW	9804.69	9

Figure 6.23: Upland least cost paths for DhNe-82, 4km extent.

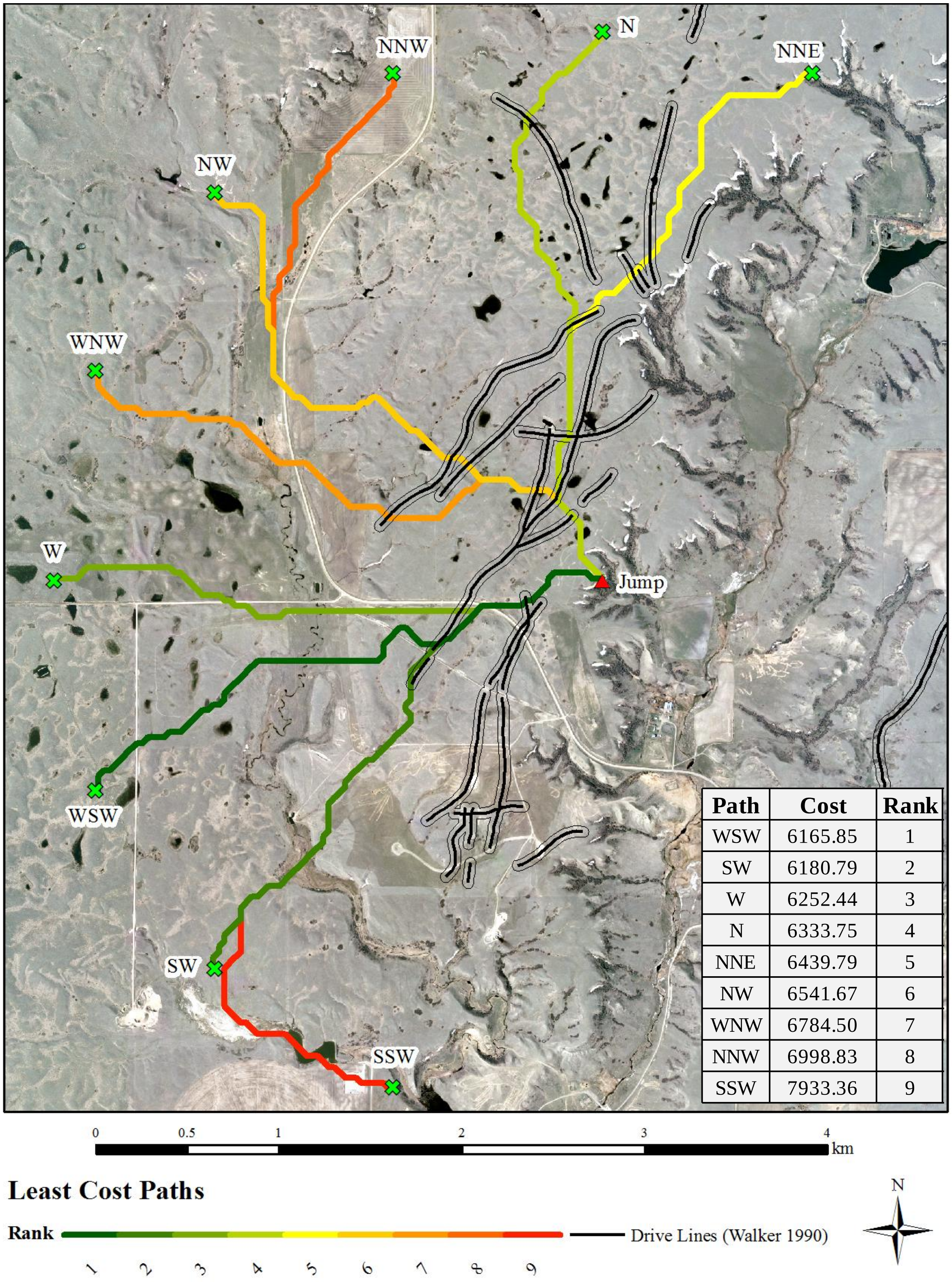
Three kilometre level

The two most noticeable changes between the four and three kilometre scales are the changes in the top ranked paths and the changes to the West, West-northwest and North paths. To begin the NNE is no longer the highest ranked path. The WSW, SW and W paths now hold the 1st, 2nd and 3rd ranks, indicating that movement from this area is much more efficient than the Northeast. The N is now placed fourth while the NNE is demoted to fifth. This is a side effect of the new origin being placed so close to the valley edge and incurring higher costs. The Northwestern pathways (WNW now included) are still ranked poorly as a result of moving through Hole in the Wall coulee for extended durations. The SSW is the lowest rank also due to poor placement at the edge of a narrow, but steep valley tributary to Hole in the Wall coulee.

The West, West-Northwest and North paths now take different pathways compared to their 4km counterparts. The placement of the new West origin permits it to take a new course heading east through Hole in the Wall coulee instead of its former southeasterly orientation. Also of note about this change is that the new route runs parallel to the modern road and likely represents a bias in the data. The new North path also takes an interesting meander. Now beginning at the mouth of the Northwest driveline, the route chooses to move outside the drivelane instead of immediately rejoining its former route. We have seen this deflection before with the North-Northwest paths from DhNe-75, so this change is not completely unexpected. This can also be said for the new WNW path, which transfers from one main route to the other. The 3km WNW path no longer joins with the W and instead follows a path used by DhNe-76. This path was used by the West 3km origin for DhNe-76, where it moves east through Hole in the Wall coulee and northeast on the uplands. It is not until meeting the Northeastern routes does the DhNe-82 path stop following this previously established course.

Two kilometre level

As we transition from the three to the two kilometre distances, several variations within the path ranks and orientations become apparent. To begin, the North path is now the most efficient route and is followed by the North-Northwest in second. The Southwest is demoted to third and the West-Southwest drops to fourth from first. This change in ranks has once again shifted the popularity between the Northeast and Southwest routes of access. Movement down from the north along the uplands is once again more efficient than from the southwest, aside



Path	Cost	Rank
WSW	6165.85	1
SW	6180.79	2
W	6252.44	3
N	6333.75	4
NNE	6439.79	5
NW	6541.67	6
WNW	6784.50	7
NNW	6998.83	8
SSW	7933.36	9

Figure 6.24: Upland least cost paths for DhNe-82, 3km extent.

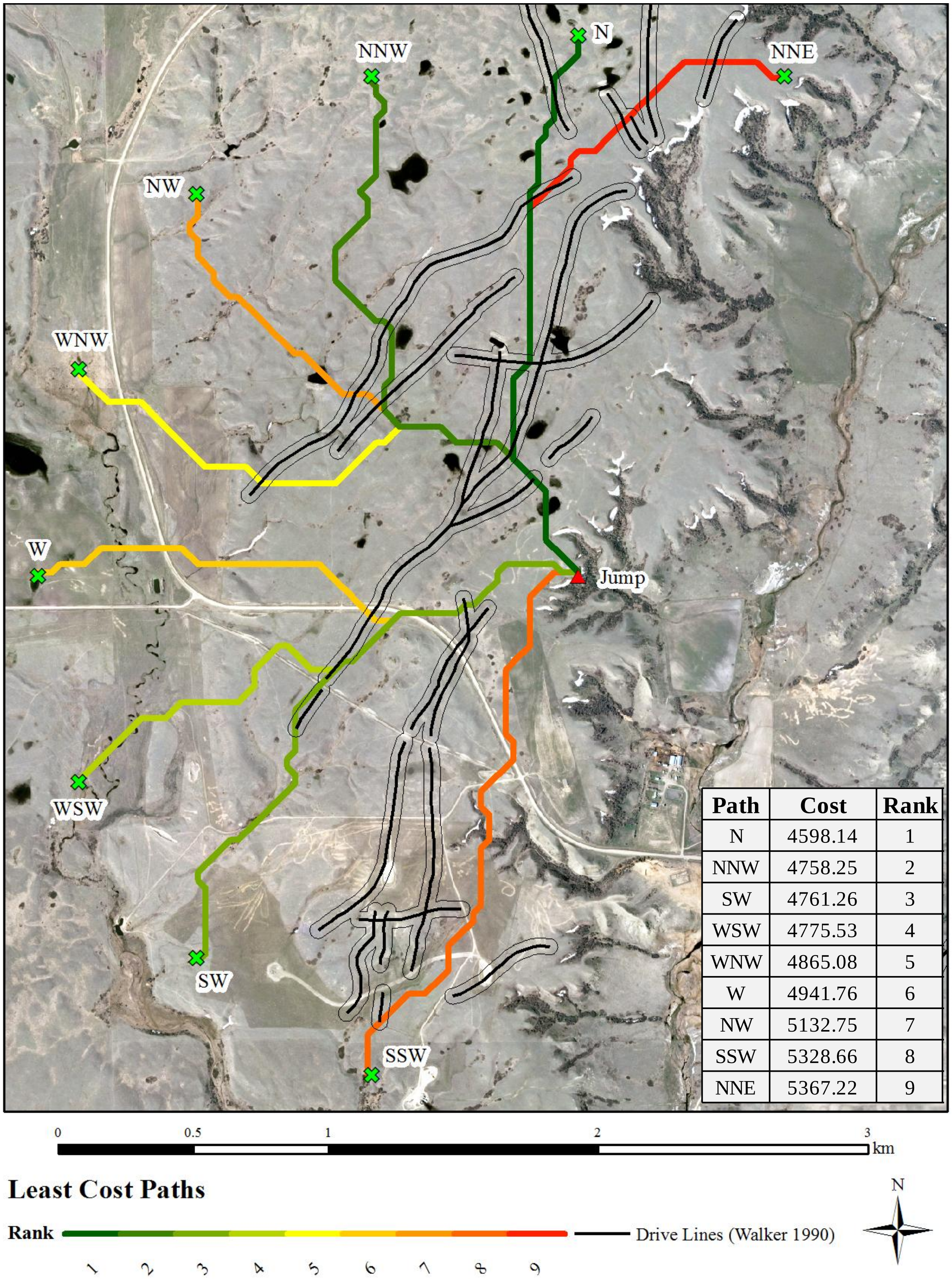
from the NNE which is a victim of poor placement near the valley edge. The two other Northwest paths change rank in opposite directions where the WNW increases to 5th from 7th, while the NW drops from 6th to 7th. This is likely due to the NW having to run perpendicular to some of the small drainages on the east side of Hole in the Wall coulee, while the WNW encounters very few of such gullies.

Overall, the majority of paths from this extent quickly followed and rejoined the paths used at the three and four kilometre iterations. However, two new paths created in this batch of least cost analysis are worth noting. The NNW origin created a new route through the uplands that up until this juncture had not been seen during the other least cost analysis steps. This new path moves in a general south direction with a small detour around a set of hills between it and the drivelines. Once it passes this group of hills, it enters into and transects a thin drivelane southward where it meets with the NW path before crossing the second driveline.

The second new path originates from the SSW. Rather than move to the northwest and connect with its neighbour, the new SSW path heads to the northeast. Early on, it moves through a series of East/West oriented drivelines that are likely connected to DhNe-89 before rerouting to the north. Running parallel to the valley edge and the drivelines to the west the path continues in a general north-northeast direction. Strangely, it moves across the headwater channels of a small drainage between DhNe-82 and 89. This could be a similar situation to what was seen at DhNe-77, where the change in slope in this area could not be resolved by the 30m pixels. Also of note is that while this path shares the same path seen in DhNe-76 near the modern road, it diverts from this northwestern route early to the northeast instead. This is likely due to the close proximity to the destination making the new route preferable to one previously established.

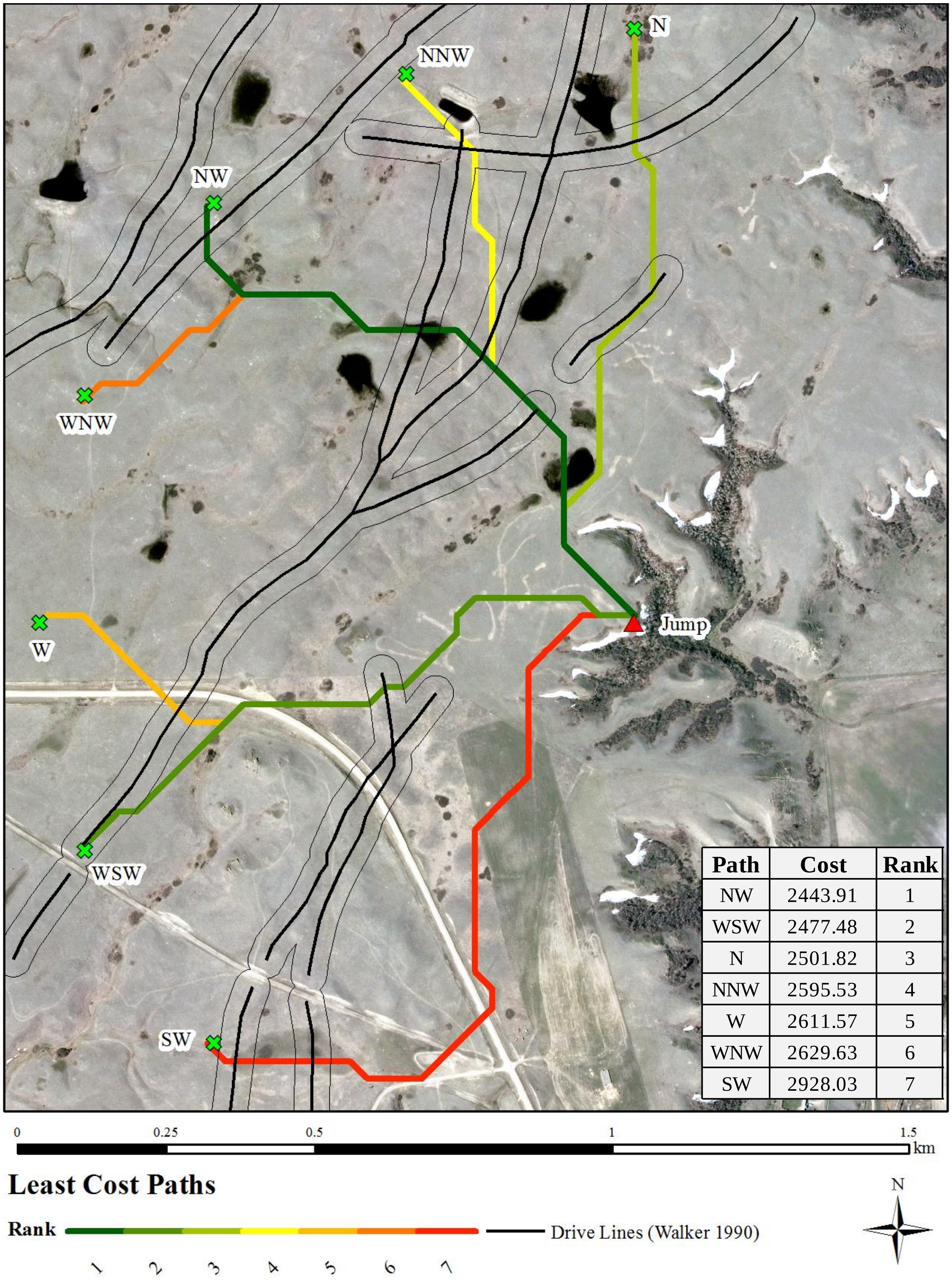
One kilometre level

At the shortest scope, we have one new path created by the new North origin. This new path travels south while cutting across a drivelane and then proceeds to tilt to the southwest moving on top of a small driveline. After following the driveline for 200m, the path veers south again to affix itself to the Northwest main path. This is very much the same route taken by the SSW origin at the two and one kilometre scales for DhNe-75, but moving in the opposite direction. The other northern paths quickly reconnect with their predecessors while the NW becomes the least costly route on the uplands.



Path	Cost	Rank
N	4598.14	1
NNW	4758.25	2
SW	4761.26	3
WSW	4775.53	4
WNW	4865.08	5
W	4941.76	6
NW	5132.75	7
SSW	5328.66	8
NNE	5367.22	9

Figure 6.25: Upland least cost paths for DhNe-82, 2km extent.



Path	Cost	Rank
NW	2443.91	1
WSW	2477.48	2
N	2501.82	3
NNW	2595.53	4
W	2611.57	5
WNW	2629.63	6
SW	2928.03	7

Figure 6.26: Upland least cost paths for DhNe-82, 1km extent.

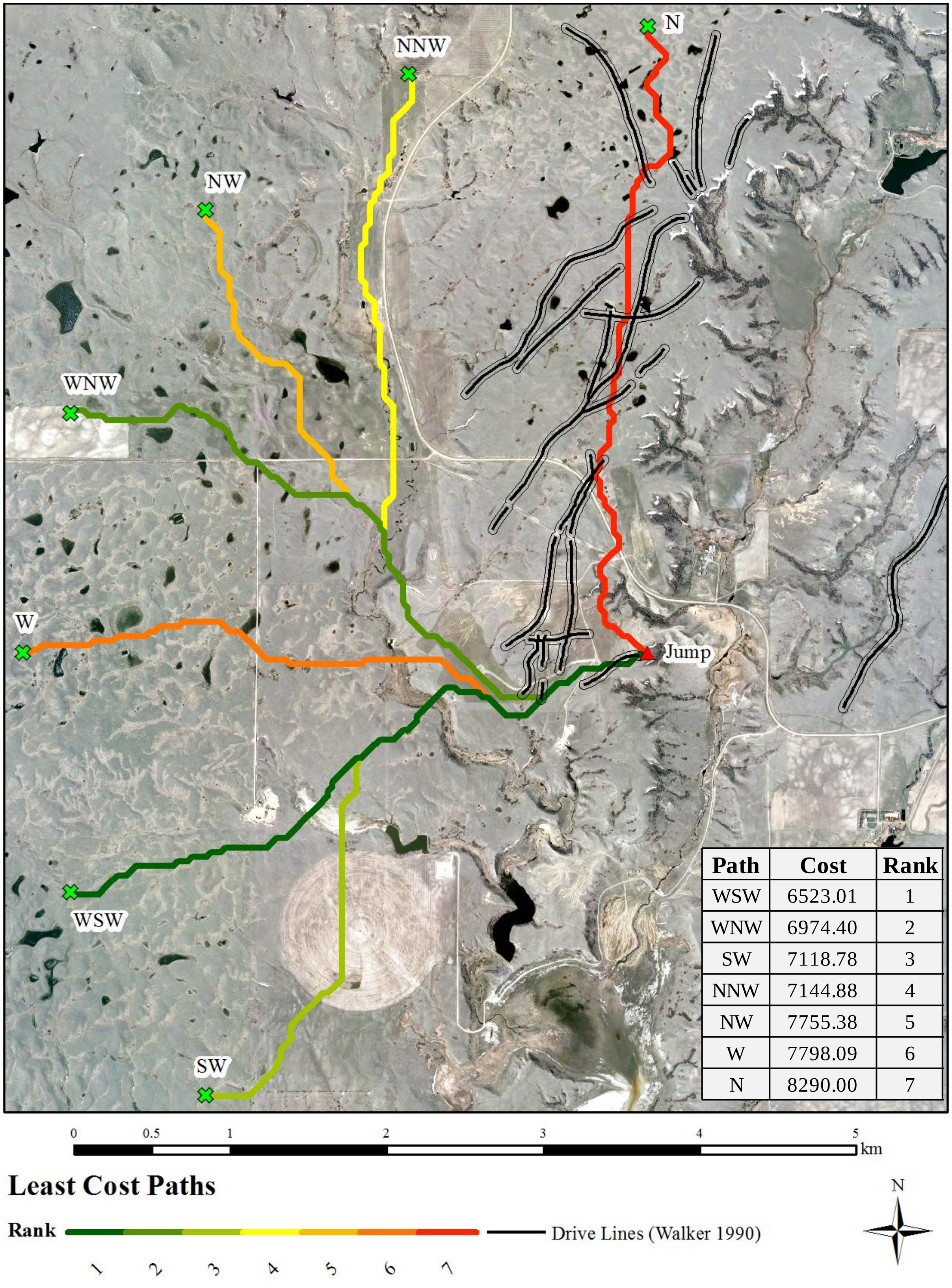
The West approach has diminished to consisting of two paths at this level, the WSW and W origins. The WSW is the second least costly route of the seven, while the W is ranked fifth. The SW path now diverts east continuing with the path created by the SSW from the 2km level and is the most costly route due to its starting location being placed in an area of high cost terrain. Ultimately this new route from the south counts as a third main approach to the jump, as it only reconnects with the West route in the last 100 metres of the jump edge.

6.2.8 DhNe-89

Four kilometre level

The final and southernmost bison jump in Roan Mare coulee is DhNe-89. Seeing as how it is the most distant of the western jumps, we would expect that it would be the least related in terms of its least cost paths. Of the original 16 origins, only seven yielded least cost paths that began and travelled upon the upland areas. As seen in Figure 6.27, the paths bifurcate into two major routes that approach the jump, the North and the West. The North main route consists of the lone North least cost path. Like at DhNe-82, this North path appears as a fusion of many of the least costly routes used for previous jumps and shows strong use of the drivelanes nearest DhNe-51, 75 and 76. Unfortunately, while these routes that comprise this one were highly ranked for the northern jumps, the N origin holds the worst rank for DhNe-89.

The West main route holds the remaining six least cost paths and forms a fan-like shape extending north through Hole in the Wall coulee and out beyond the upland area to the west. This main route is formed by the meeting of two smaller subsections from the Northwest and Southwest. The Southwest subsection is made up of the SW, WSW and W least cost paths, each ranking 3rd, 1st and 6th respectfully. The SW and WSW merge on the uplands after crossing a tributary drainage to Hole in the Wall coulee and move in a general northeast direction. The W path then merges with them shortly after crossing Hole in the Wall coulee. The Northwest subsection is comprised of the WNW, NW and NNW paths, each ranking 2nd, 5th and 4th respectfully. It is odd how the NNW path which travels primarily in the valley bottom of Hole in the Wall coulee accumulates more cost than the WNW path that moves across the uplands. This discrepancy indicates that the area the WNW occupies is generally flatter and easier to move bison through than the Hole in the Wall valley. The three paths meet as the valley begins to



Path	Cost	Rank
WSW	6523.01	1
WNW	6974.40	2
SW	7118.78	3
NNW	7144.88	4
NW	7755.38	5
W	7798.09	6
N	8290.00	7

Figure 6.27: Upland least cost paths for DhNe-89, 4km extent.

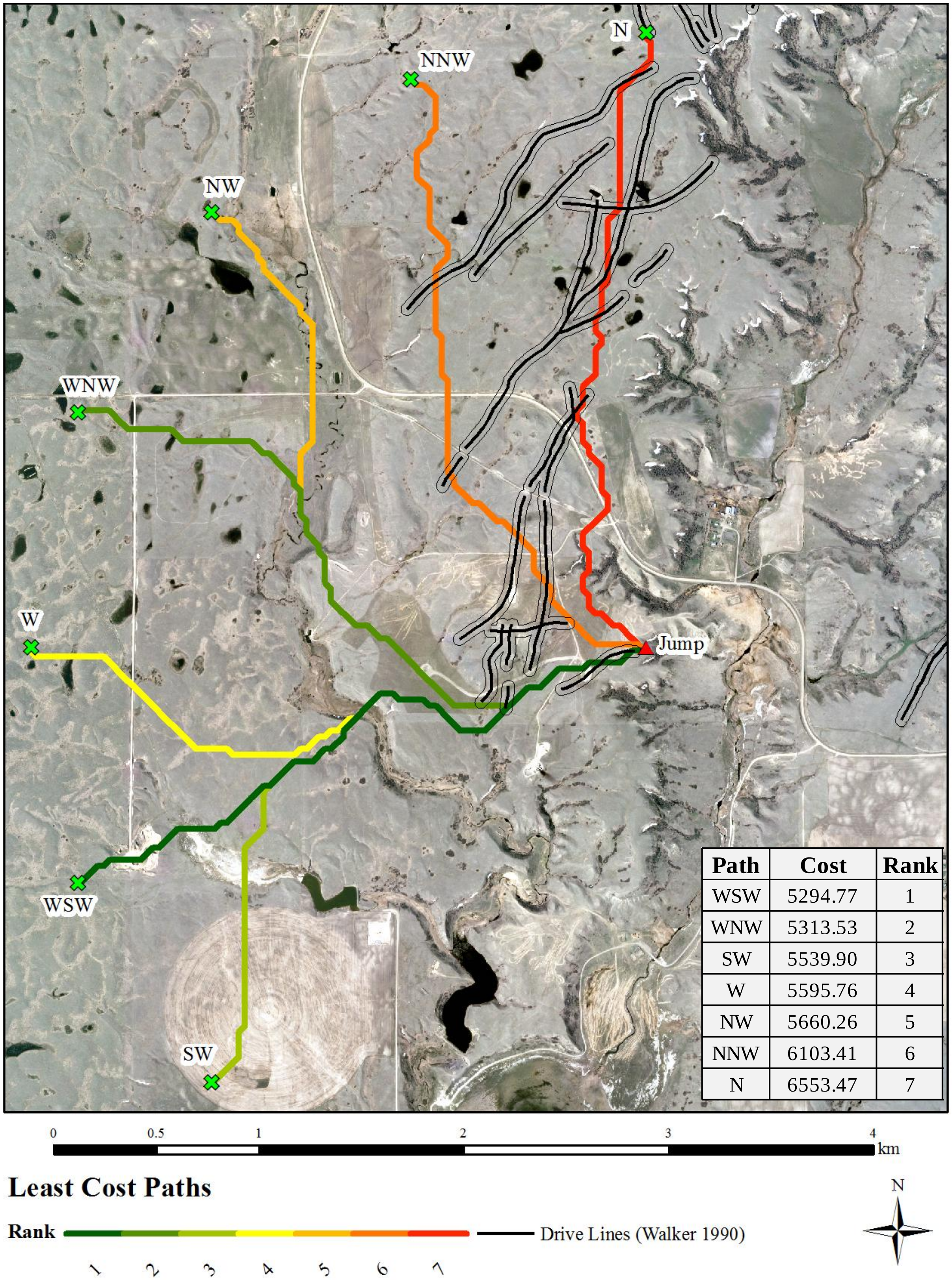
narrow and they move southeast onto the upland area. They veer around the high cost terrain to the east and north, eventually merging with the Southwest paths.

As seen in Figure 6.27 the West main route has one flaw. After the six paths have merged together, they travel eastward and travel within the east-west oriented drivelane nearest the jump for a short duration. However, they continue eastward across the southern driveline just as it jogs to the north. The paths run parallel to this driveline and only return to it at its termination. This detour is peculiar, as these are the only drivelines associated with this particular jump and move around a small complex of hills to the north. Obviously there is a small change in the topography that makes the southern path more preferable.

Three kilometre level

Approaching the three kilometre scale we see in Figure 6.28 there are now three main routes of access to the jump edge, adding the Northwest route to the roster. The West main route is still the strongest of the three holding the top five least costly paths. Within this route, the WSW and the WNW both retain their positions as first and second ranked paths, while the W increases in rank from sixth to fourth. While this increase is likely contributed to by the equal drop in rank by the NNW, the new W path also merges with the other Southwest paths at a different location. The paths now meet prior to crossing Hole in the Wall coulee rather than after, so the 3km W origin may have been placed in a less costly area of terrain which dictates its new rank and choice of path.

The new NNW path and subsequent Northwest main route create a course that has been relatively unused by the previous bison jumps. This new path travels due south over the uplands and straight across the mouth of a well used drivelane. After passing this drivelane, the path veers to the southeast crossing two other drivelines in the process. As the path nears its destination, it curves once again to the east in the final 250m of the drive. Even though the overall route is the second most costly and shows little use of drivelanes it comes across, it does highlight something interesting near the jump edge. This path approaches from the west without merging with the other two main routes (it does merge with the North in the last 42m). It shows that the terrain immediately west of the bison jump is amenable to movement. Therefore the deflection of the West main route to the south as mentioned above may have been a result of a rather subtle change in cost, rather than the area being completely unapproachable by any means.



Path	Cost	Rank
WSW	5294.77	1
WNW	5313.53	2
SW	5539.90	3
W	5595.76	4
NW	5660.26	5
NNW	6103.41	6
N	6553.47	7

Figure 6.28: Upland least cost paths for DhNe-89, 3km extent.

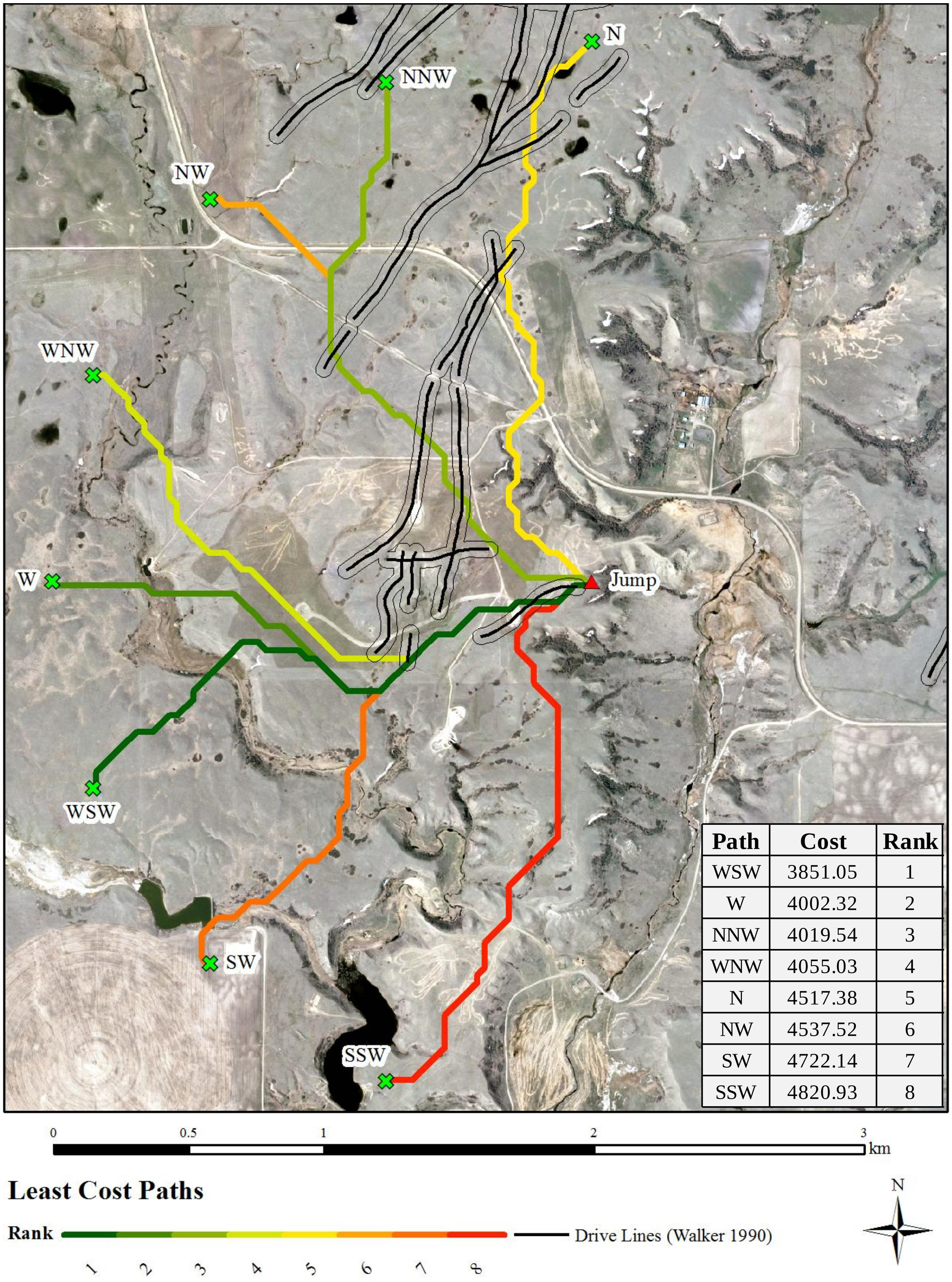
Two kilometre level

At the two kilometre extent, a new least cost path from the SSW is exposed. Unfortunately it is also the worst ranking path among the eight. This is not unexpected, as the topography south of DhNe-89 becomes constricted and pinched out between Roan Mare and Hole in the Wall coulees. The close proximity to two high costing valley edges inflates this path's cost to the highest level.

The WSW once again is the least costly path of the assemblage. The W path is now ranked second and the WNW drops to fourth. This decrease is likely a result of the West path having a smaller portion of Hole in the Wall coulee to cross than the WNW. Surprisingly, the NNW rises in rank from sixth to third. This increase indicates that the route is no longer traversing high costing terrain, namely the areas north of the driveline network. The better terrain offered in this new area may be what is attracting the NW path out of Hole in the Wall coulee rather than continuing south. The North path also increases in rank for similar reasons; it no longer has to traverse the patch of high cost terrain between DhNe-75 and 76. The SW path drops from third to seventh least costly. The new path has to cross two deeply incised stream valleys to reconnect with the other routes. The WSW also must cross these valleys, but does so at areas where the valleys are more open and splayed, decreasing their cost.

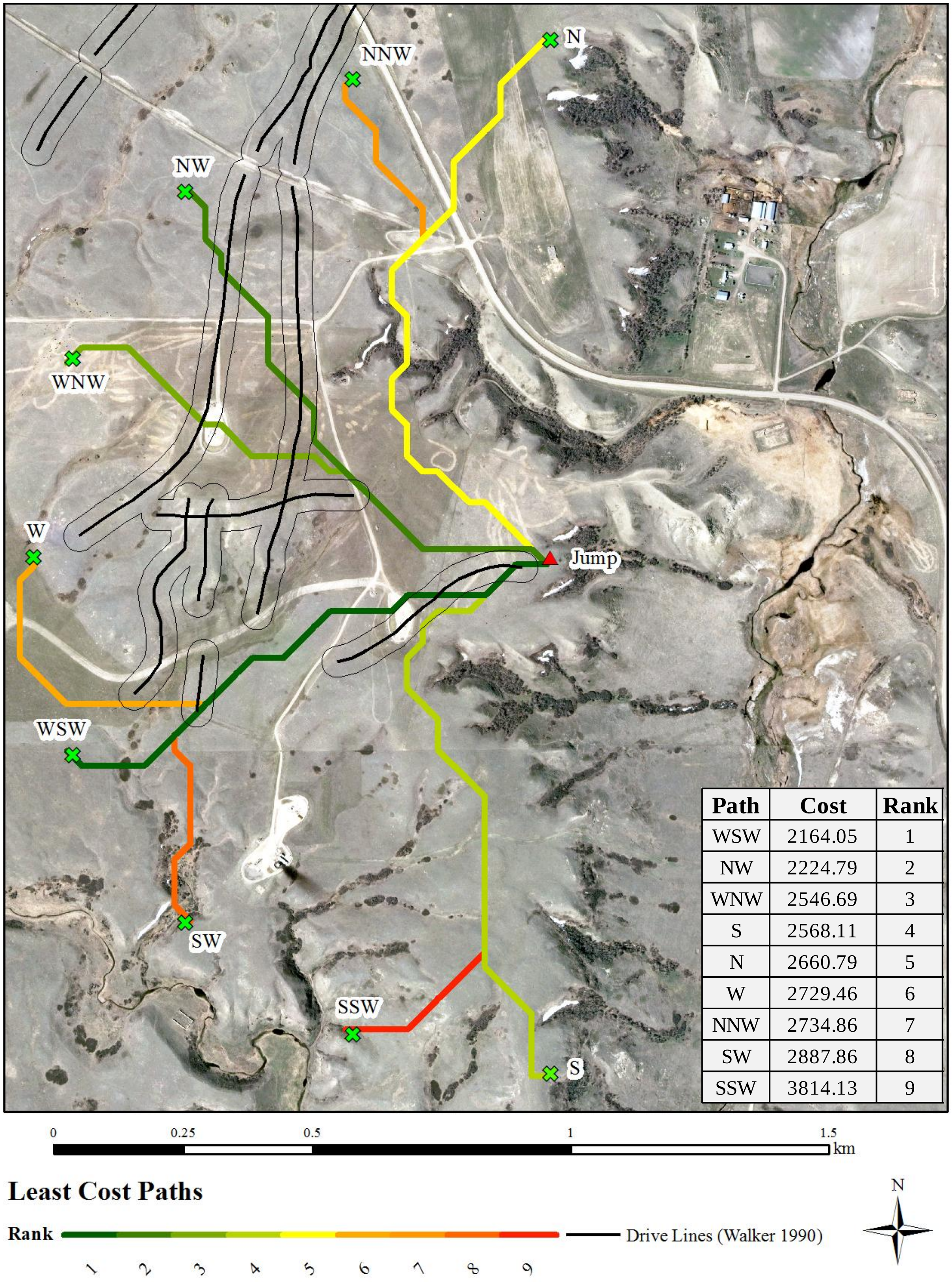
One kilometre level

The final series of least cost paths constitute the one kilometre distances from DhNe-89. The WSW has maintained its position as the top ranked path. It is now followed by the NW and the WNW which constitute the Northwest main route. The new South path is placed fourth, as it has been placed past the narrowest portion of the southern uplands. This allows it some increased flexibility to avoid the areas of higher cost. The same cannot be said for the SSW path, which has fallen in a tributary of Hole in the Wall coulee and incurring increased costs from the higher slopes. The NNW path has defected to the North main route, and is now placed south of the drivelines. This switch between main routes is due to crossing a topographic boundary. There is a chance that this boundary is marked by the drivelines but is impossible to say at this juncture.



Path	Cost	Rank
WSW	3851.05	1
W	4002.32	2
NNW	4019.54	3
WNW	4055.03	4
N	4517.38	5
NW	4537.52	6
SW	4722.14	7
SSW	4820.93	8

Figure 6.29: Upland least cost paths for DhNe-89, 2km extent.



Path	Cost	Rank
WSW	2164.05	1
NW	2224.79	2
WNW	2546.69	3
S	2568.11	4
N	2660.79	5
W	2729.46	6
NNW	2734.86	7
SW	2887.86	8
SSW	3814.13	9

Figure 6.30: Upland least cost paths for DhNe-89, 1km extent.

It is at this scale that the avoidance of the drivelines nearest the valley edge is most visible. The Western main path does not follow the eastern driveline as it curves northward. This could mean that the terrain to the north is less accessible than to the south. We can see this in back in the original cost raster seen in Figure 6.10. However, the Northwestern main path easily moves through this area, and since its introduction in the three kilometre scale it has steadily risen in rank. This suggests that the rougher terrain is experienced in the earlier sections of the path and not at the uplands nearest the jump. These two main routes, the West and the Northwest show that there are several topographically viable options for reaching the drive's destination.

6.3 Viewshed Analysis

As outlined in Chapter Five, the least cost paths created for DhNe-1 and 51 are used as viewing locations in the viewshed analysis. For clarity, the paths will be grouped into the main routes that were identified for each site creating four routes for DhNe-51 and three for DhNe-1. However, since all the routes in DhNe-1 meet and approach the jump together, this combined path will also be evaluated. Each route is being assessed as to when the bison herd could see the jump edge. As explained in Chapter Three, the revelation of the trap should be held off as long as possible to ensure the bison do not identify the danger and escape the drive (Figure 6.31).

Figure 6.31: Example of how terrain blocks line of sight. The viewer is facing West towards the jump edge, but the hills do not reveal any information that the valley approaches. (height ~1.6m).

6.3.1 DhNe-1

Southern Route

The Southern route into DhNe-1 consists primarily of paths originating from the S origins, but also the SSW and SSE origins at the 1km distance interval. The route enters the Sabin10m DEM at two locations (Figure 6.31 a, b). From both these locations, the bison can see very little beyond the terrain immediately in front of them. Two hilltops can be seen to their northeast, but the majority of their upcoming path and the valley edge remain obscured. As the two paths merge (Figure 6.31 c) the viewshed opens up and exposes more visible area. These areas are the small dips between some of the larger hills in the area. The spur of land upon which the jump edge rests remains obscured save for a small hilltop along the northern valley edge.

Moving northward, the route dips into a small depression and decreases the viewable area (Figure 6.31 d). Here, the southern edge of the spit of land is now in view, but the jump edge remains obscured. In Figure 6.31 e), the path has now climbed upon one of the larger hills in the area. This new vantage point extends the visible area to many of the surrounding hills and swales. Most importantly, portions of the approaching landform to the northwest are once again visible. We see this landform alternates between portions of visibility and obscurity, suggesting an undulating terrain. Again the destination cell is hidden from sight at this location. Finally, the path dips into a second depression as it moves north as seen in Figure 6.31 f). Many of the areas that were visible 72 metres back are now concealed. The target continues to be unseen as well as the majority of the remaining path. This means the bison only had the briefest of glimpses of what laid before them as the crossed the preceding hill.

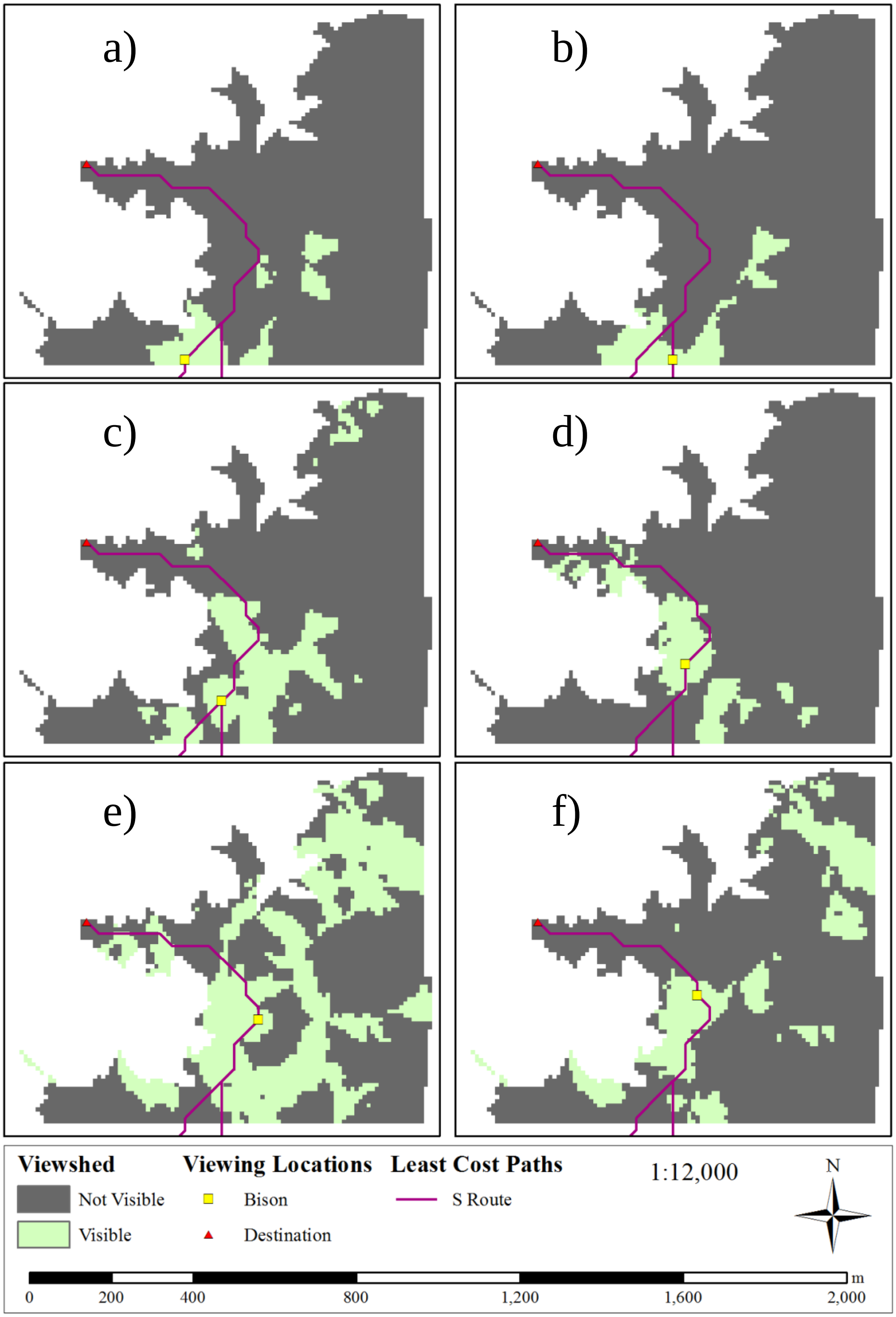


Figure 6.32: Sample of viewsheds from Southern route of DhNe-1.

Southeastern Route

The Southeastern approach consistently held the most efficient paths throughout the least cost path analysis phase. Three paths enter the 10m DEM and merge shortly thereafter (Figure 6.32 a, b, c).   Each of these entry points have a very limited viewshed restricted by the nearby hill complex to the west. Only the tops and sides of said hills are discernible as well as a few of the larger hills to the north. The northernmost entryway (Figure 6.32 c) represents the popular route utilized by the ESE and E origins at the four, three and two kilometre levels, while the other two entryways (Figure 6.32 a, b) constitute the pathways used by the SE and SSE origins at said extents as well as the SE and ESE 1km origins. The three paths eventually merge (Figure 6.2 d) atop one of the eastern hills. While this hilltop offers a greatly increased viewing area compared to the entry locations, the two taller hills to the northwest limit vision in this direction beyond 200 metres.

As the path continues, it moves into the space between the topographic highs which serve to block line of sight as seen by the diminished viewshed in Figure 6.32 e). However, moving 84 metres to the northwest and onto the side of one of these hills causes the viewshed to explode, offering a vast area of the upland area to become visible (Figure 6.32 f). This new viewing location lies right before this route merges with the Northeast and allows for much of the anticipated path ahead to be seen as well. It should be noted that even with this large viewable area, the upcoming spit of land has remained relatively invisible save for the tops of some topographic highs found upon it. No portion of this landform has come into view up to this point in the route. This means that the final stages of the drive would have remained concealed for a long duration.

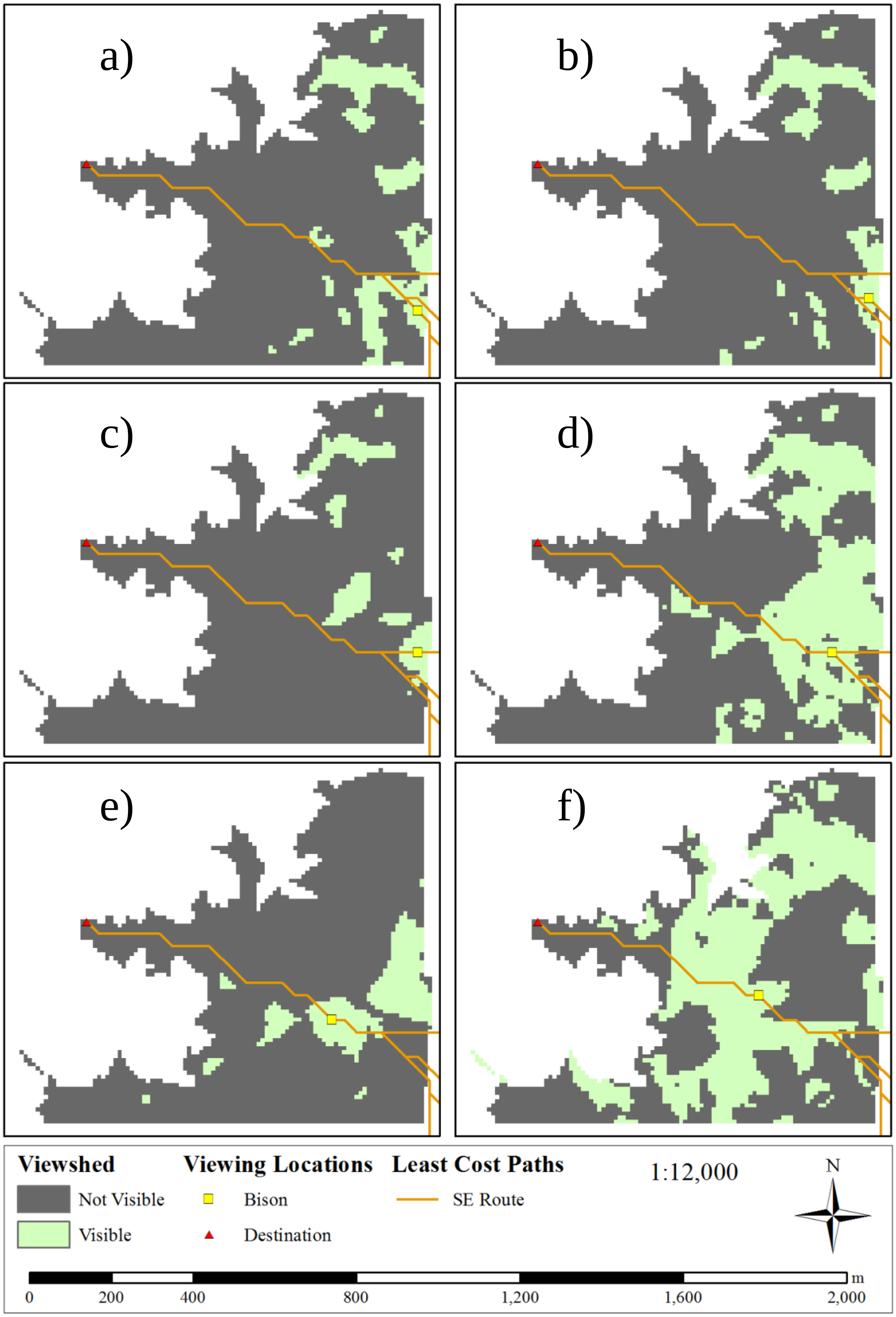


Figure 6.33: Sample of viewsheds from Southeastern route for DhNe-1.

Northeastern Route

Like the Southeastern route, the Northeastern route consists of paths entering the 10m DEM from three different locations (Figure 6.33 a, b, c). These paths constitute the ENE paths created at the three, two and one kilometre viewing extents as well as the E 1km path. The northernmost entryway (Figure 6.33 a) has a sizable viewshed as it enters on the southern side of a hill overlooking a large basin. With no opposing terrain, there the bison can see the majority of this open area, vision only being blocked by the hills to the south. This includes a large portion of the bison's future movement along this course. The second entryway 120m south (Figure 6.33 b) is placed within the basin and suffers a reduced viewshed thanks to the surrounding higher topography. The third entry sits upon the northern face of a small hill on the eastern margin of the DEM (Figure 6.33 c). This hill blocks sight of the low lying areas immediately northwest of the viewer, but does permit visibility to the areas found to the west which the bison will soon be approaching.

The three entry paths merge at the location highlighted in Figure 6.33 d). From this vantage point, the bison have dropped into the swale between two hills and have a reduced visible area as a result. Areas to the northwest and southeast are highly visible from this locale, but the route leads to the southwest where visibility is much more limited. Extending further to the southwest, the path bends to the west across the terrain to merge with the Southeast route. Vision to the west is very restricted at this turn as it is located at the base of a hill (Figure 6.33 e). From this point, much of the oncoming path is left in mystery to the bison. The path crosses over the hill obtaining viewsheds similar to those seen in Figure 6.32 f) due to the proximity of the two routes along this hill. The two routes meet after crossing this hill in the low lying inter-hill area as depicted in Figure 6.33 f). What is important about this viewshed is that the view towards the trap to the west is once again blocked.

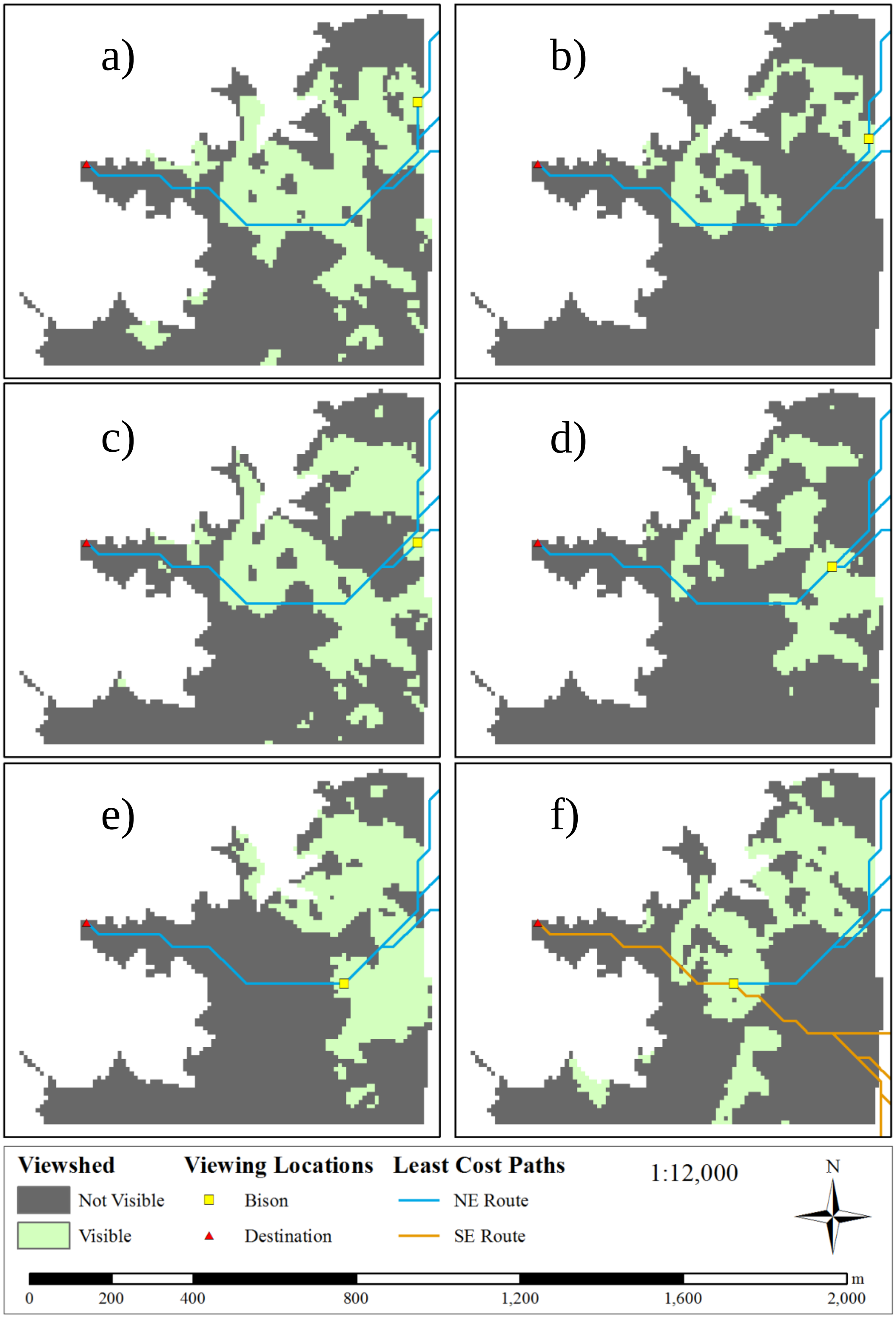


Figure 6.34: Sample of viewsheds from Northeastern and Southeastern routes for DhNe-1.

Merged Routes

The three separate paths discussed above merge together before moving onto the enclosed landform. The viewshed for this merger point is depicted in Figure 6.34 a). We see the viewable area extend for great distances to the southwest, northeast and east as the terrain is more open in each of these directions. Vision to the southeast is more restricted in part due to the small hill that lies in that direction. To the northwest, vision of the combined paths' direction is also restricted due to an elongated hill that extends north to south. This hill is the primary reason why the landform has remained invisible to all the previous viewing locations. As the bison move 84 metres to the northwest, they begin to climb this hill and part its veil, opening up the terrain to the west (Figure 6.34 b). However, even from this locality the jump edge still eludes the sight of the viewer. This problem persists as movement continues to the west. A small depression lies on the lee side of the hill causing the greatly reduced viewshed seen in Figure 6.34 c). Vision increases slightly as the bison head west, but a second line of sight blocker is found between the viewer and the jump edge. This obstruction continues to remove vision to the west (Figure 6.34 d). As if to add insult to injury, crossing this rise does not bring the destination into sight as a third and final obstruction remains ahead of the bison (Figure 6.34 e). It is not until the final 72 metres (Figure 6.34 f) that the jump edge is seen for the first time.

In summary, the undulating terrain found in the uplands nearest DhNe - 1 has played a restrictive role of the visibility of the bison being manipulated towards it. The paths through the terrain have alternated between periods of high and low visibility, but the invisible nature of the jump edge has remained constant. Even in the final 500 metres of the drive, the trap location stays obscured until the last possible moment.

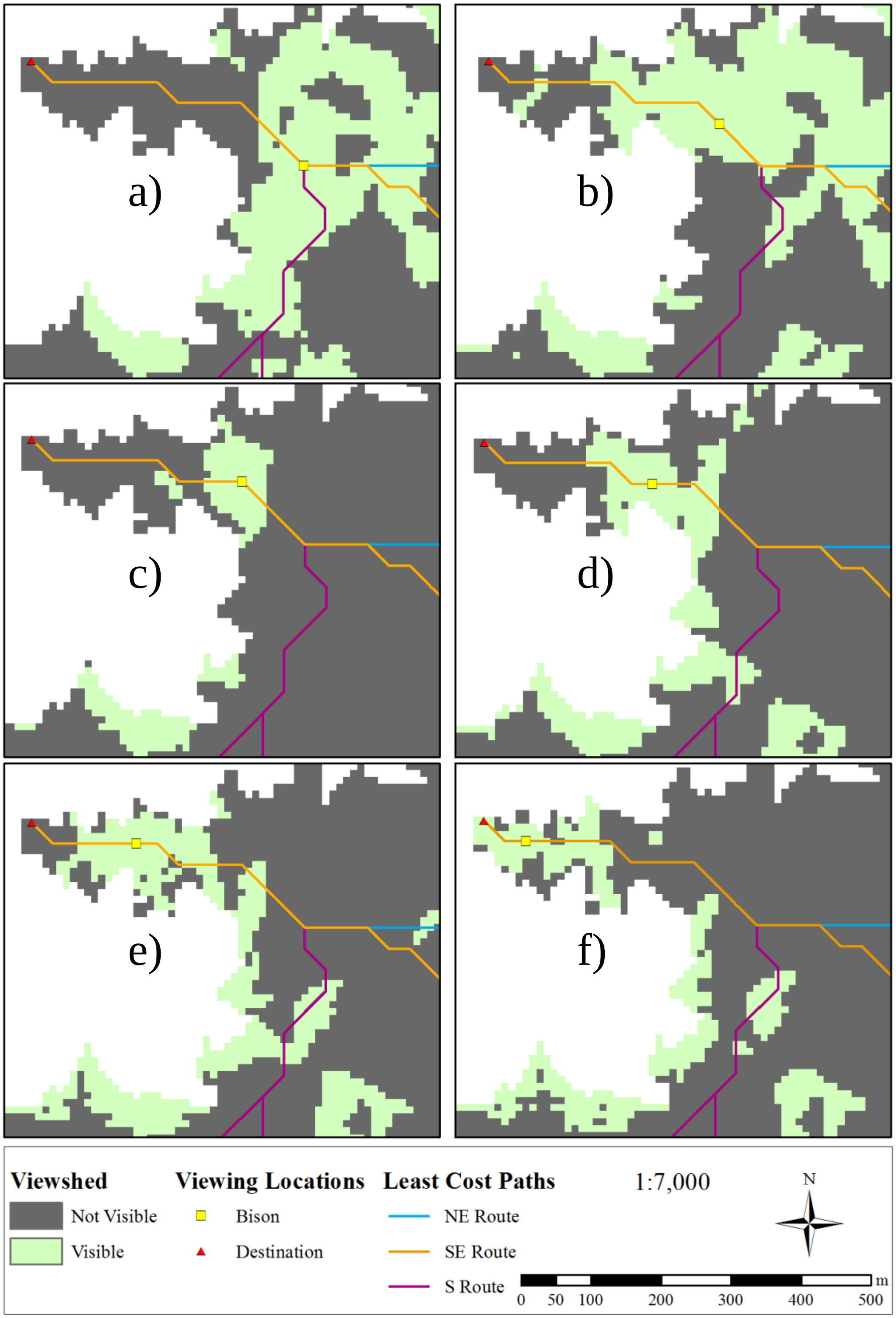


Figure 6.35: Sample of viewsheds along the final stages of a bison drive at DhNe-1.

6.3.2 DhNe-51

Southwestern Route

The Southwestern paths in the least cost path analysis phase generally held the second tier of ranks behind their northeastern counterparts at the four, three and two kilometre distances. The Southwestern route enters the Ironhorse 10m DEM at three locations shown in Figure 6.35 a), b) and c) which roughly showcase the WSW, SW and SSW paths respectfully. These three images portray the limited view that is obtained when entering from this direction. Two large hills to the northeast block most of the information from that direction, while depressions to the south sink too low to be visible. As the paths merge in Figure 6.35 d), the viewshed decreases as the bison now rest directly in the shadow of the hill complex. The viewable area does expand greatly as we move to position e), thanks to the rise in elevation. However, even with this much larger viewshed, the trap remains obscured from this location due to a small topographic chute immediately northwest of the drop off point.

Moving to location f), much of the terrain obscuring the jump edge is now visible. While the drop itself remains hidden in a thin 20-30 metre wide patch, the rest of the drive is in plain sight. It is likely that the "quick turn" technique (Brink 2008; Byerly et al. 2005; Kornfeld et al. 2010) mentioned in Chapter Three would be a viable option here, since both the valley edge and the flat terrain to the northeast are identifiable to the bison at this location. The bison could be run parallel to the visible valley edge towards the "safer" areas to the northeast, but quickly steered into the valley at the right moment by the hunters. Being 102 metres from the drop off point, the stampeding herd would cover this distance in approximately 7.34 seconds.

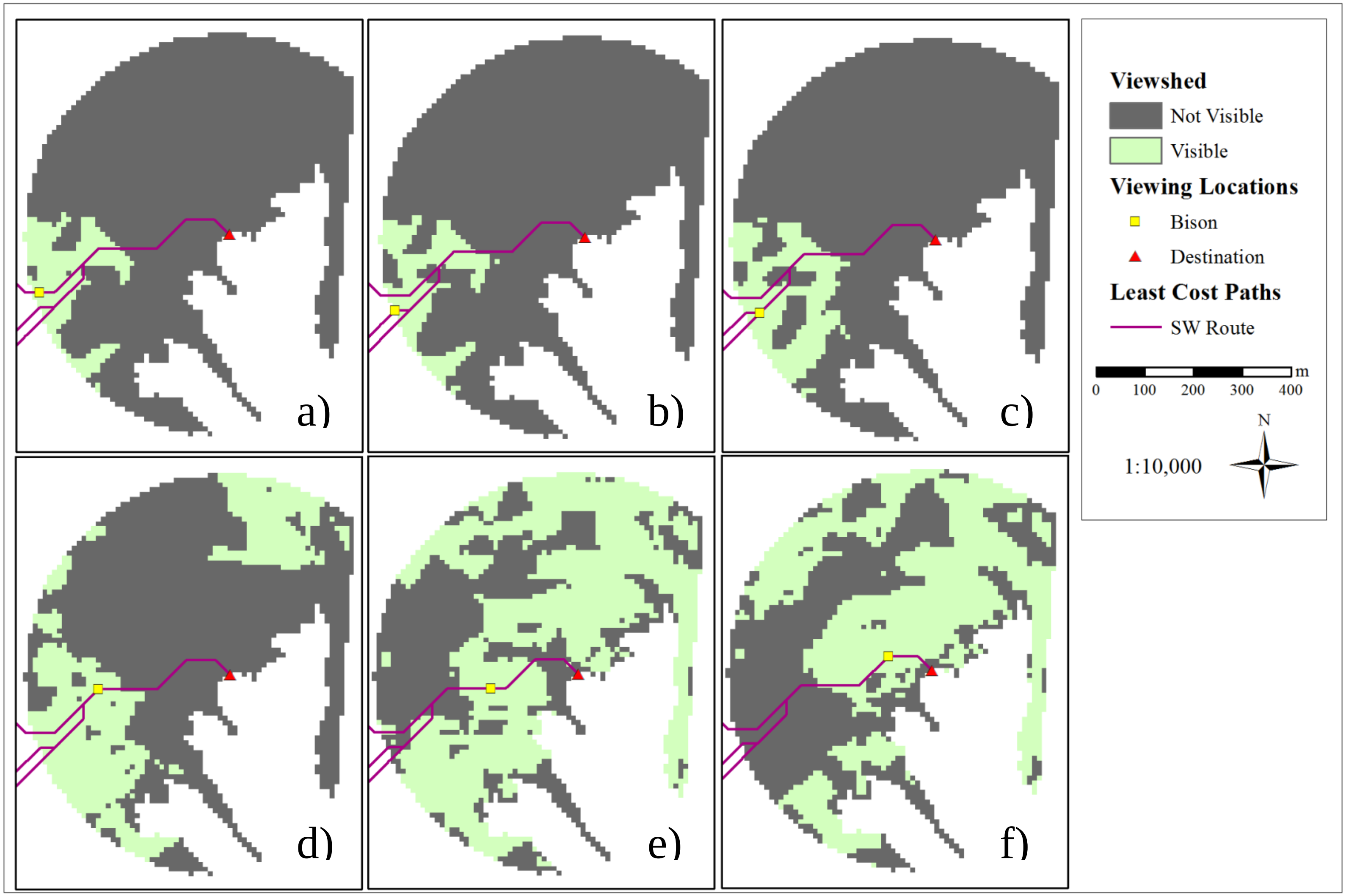


Figure 6.36: Sample of viewsheds from the Southwestern route for DhNe-51

Western Route

The Western route is definitely the least populated of the four, consisting only of the 3km, 2km 1km paths from the W origins and the 4km, 3km and 1km paths from the WNW origins. It also shows the least amount of evidence for use of the drivelane network of the four routes found at DhNe-51. There are two points of entry into the 10m DEM showcased in Figure 6.36 a) and b). From these two vantage points, much of the area to the northwest is open sight, while zones to the east and southeast are hidden. The viewable area reflects a wide local basin which holds several small sloughs. The restricted visibility to the south and east is thanks again to the two small hills mentioned above, which the Western route enters north of. After the paths merge, the route veers south and then east across one of these hills. This change in topography can be seen by comparing Figure 6.36 c) with d) where the first view is restricted by the base of the hill, but the second is much more expansive. From location d), the next 200 metres of the path is exposed to the bison's view.

With this said, the entirety of the valley edge including the drop off point stays hidden from sight. This obstruction is due to the topography sloping towards the valley in the final 50-60 metres around the valley edge. Even as the bison approach closer such as at location e) in Figure 6.6, the dip in terrain continues to veil the valley edge from sight. This veil is pierced only when the bison are standing right above drop in Figure 6.36 f). Like with Figure 6.35 f), the drop point itself stays blocked but the many of the remaining metres of the drive are now visible. It is likely that extra visibility would make the trap identifiable to the bison, even with the drop point obscured. Unfortunately, it occurs in the last 72 metres of the path, which the stampeding herd would cross in 5.18 seconds.

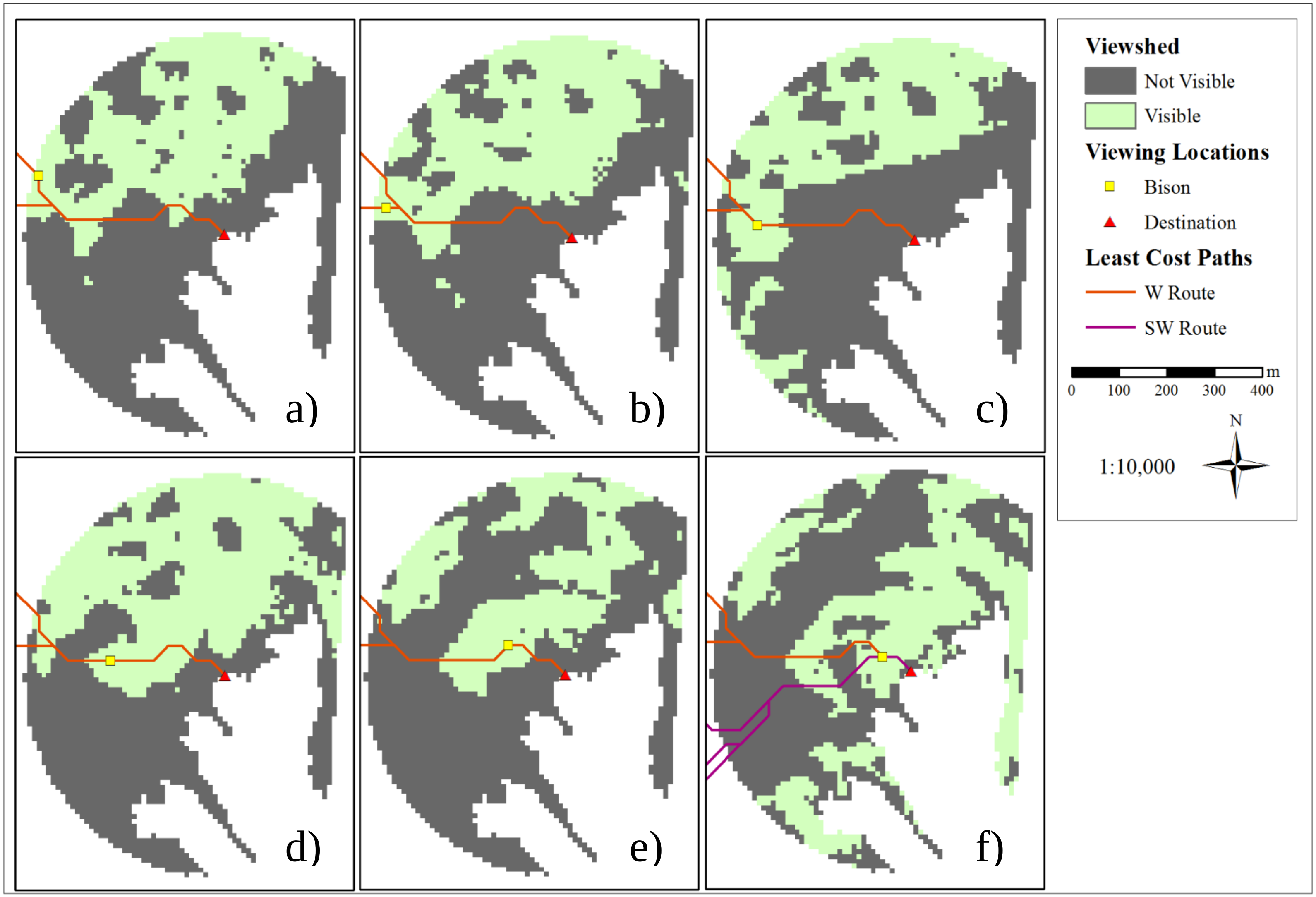


Figure 6.37: Sample of the viewsheds from the Western and Southwestern routes for DhNe-51

Northwestern Route

The Northwest route was made up of the highest costing paths for the 4km, 3km, and 2km extents during the least cost path analysis stage. However, as shown above, they became relatively cost effective paths once their origins passed Hole in the Wall coulee at the 1km level. The contributing paths merge into the single route before meeting the 10m DEM, so only one point of entry exists from this direction (Figure 6.37 a). The route enters the large topographic sink seen in the northwest portion of the DEM. As such, the sink offers a broken viewshed to the bison. The sloughs and other depressions obscure their depths, and the rises in terrain to the east and south block view of the valley. As the bison move within this depression area (Figure 6.37 b, c), the viewable terrain changes as different sloughs fall in and out of obscurity. All the while the bison remain blind to the valley edge to the east.

Climbing out of the depression and upon the plateau to the east presents a greater viewable area as witnessed in Figure 6.37 d). The greatest expansion of the viewshed is towards the northeast and southwest. Viewable area does expand slightly to the east as well, but is again blocked by the topographic dip surrounding the valley edge. Moving closer does little to alleviate the problem, as Figure 6.37 e) shows the non-viewable area stays relatively unchanged. As the Northwest route merges with the Northeast, the obscured terrain does recede (Figure 6.37 f). However, a slim band around 20-30 metres wide continues to block vision of the drop point. This is similar to what was seen in Figures 6.35 f) and 6.36 f), so it is likely the trap would be fully realized by this point, even if the drop itself is missing. This too occurs at the 72 metre mark.

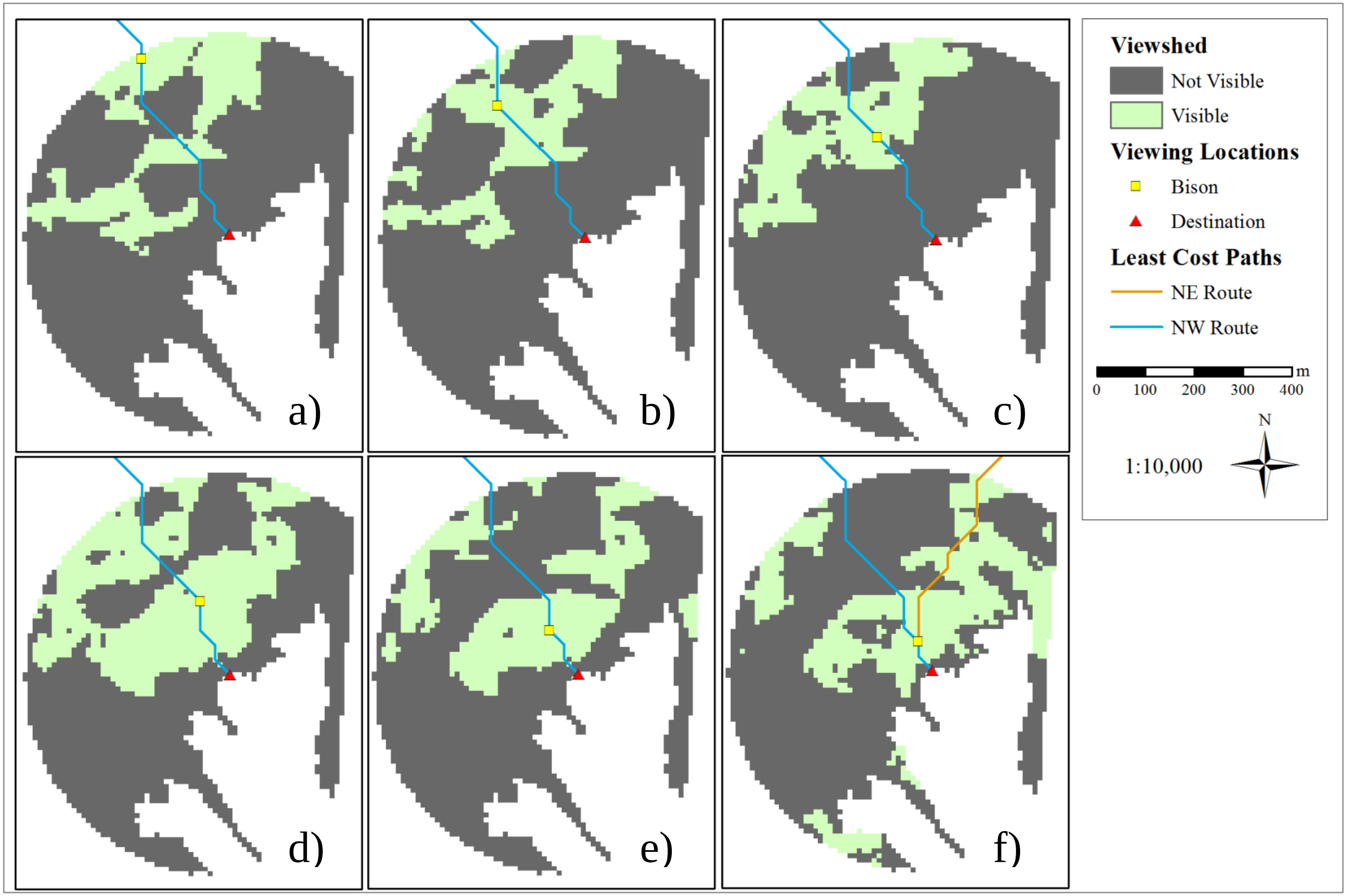


Figure 6.38: Sample of the viewsheds from the Northwestern and Northeastern routes for DhNe-51

Northeastern Route

The Northeastern route consistently held the top ranked paths throughout all iterations of the least cost path analysis. It also showed some of the best and most consistent evidence of movement through the drivelane system. The route's entry into the 10m DEM is shown in Figure 6.38 a), and expresses a very large and expansive viewshed. This large viewable area results from the fact that the route travels upon a plateau of flat land that bisects the lower areas to the east, west and south. This raised ground causes interesting results with the viewsheds. The plateau's breadth allows for the majority of its area to be visible for long distances, but also forces the adjacent low lying terrain to be lost in its shadow. This is what creates the thin band of invisible land along the valley edge. The valley edge continues to be obscured as the bison move along the plateau from viewing locations a) through d) in Figure 6.38.

Figure 6.8 e) shows the view from where the Northwestern and Northeastern routes merge and was previously seen in Figure 6.37 f). Thirty metres south from there is where all four routes meet and join as one, as shown in Figure 6.38 f). From this location, the valley edge around the destination is much more visible while the drop itself still remains in one of the few obscured pixels. However, like with the West, Southwest, and Northwest routes, the fact that bison are being lead headlong into the valley edge should be more than apparent to them at this point even if the drop point itself remains concealed,. So with this caveat in mind, the trap location becomes known to the bison in the last 72 metres of the drive when approaching from the NW or NE and between 72 and 102 m from the W or SW.

In summary, the topography surrounding the valley edge does not reveal the trap for any of the calculated routes until the very last opportunity to do so. The two high hills along the western margin and the plateau that runs down the middle of the 10m DEM were the major reasons why this secret was hidden so well. The rise in terrain created by the plateau and hills impeded the vision of those who stand behind them. Once the bison were upon the plateau landform, its expansive nature swallowed up the visibility of the adjacent valley and the trap that lay within. This secret is held until the final 70 - 100 metres of the drive, where the bison would only have seconds to react.

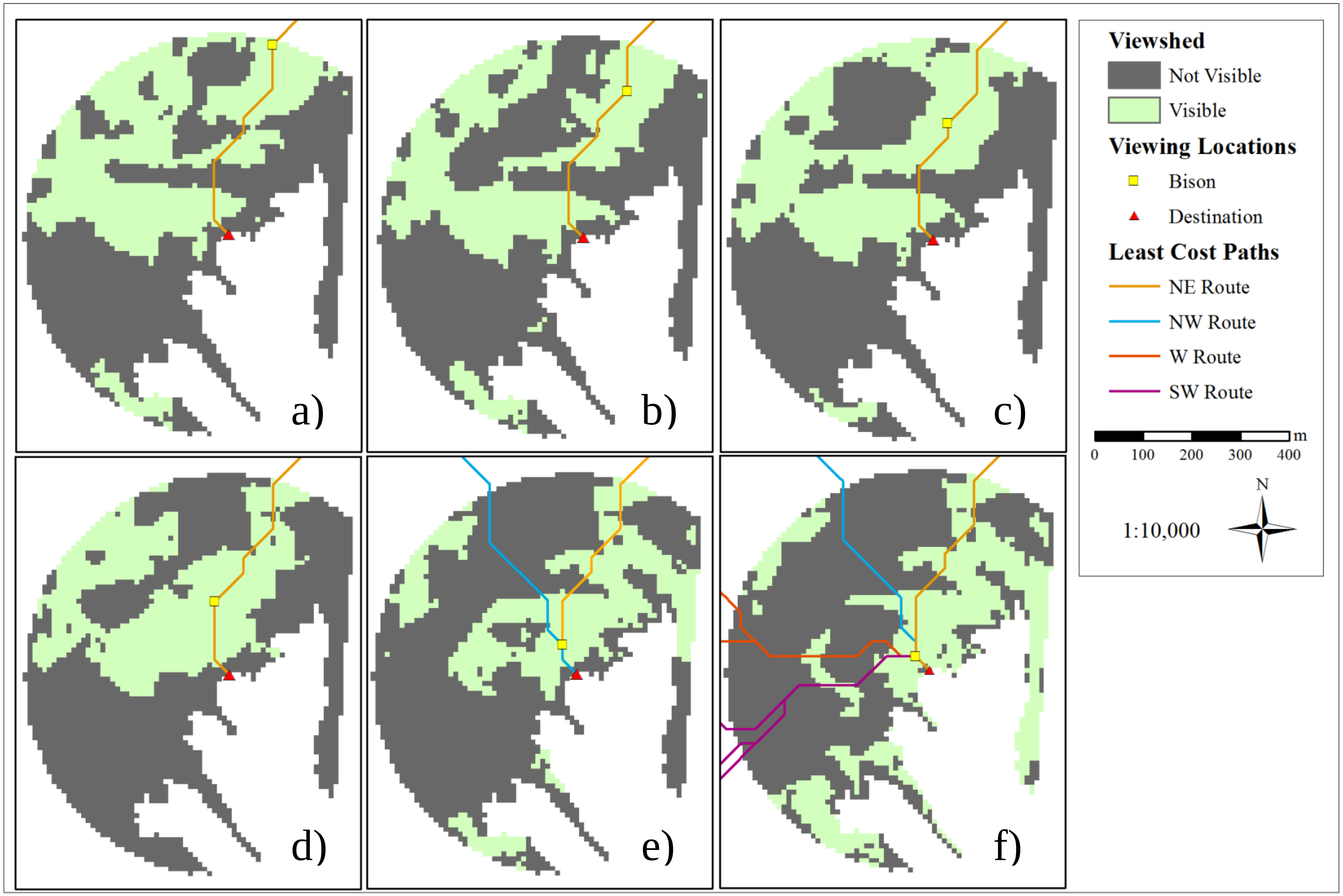


Figure 6.39: Sample of viewsheds from the Northeastern route and final viewshed from all routes for DhNe-51

Chapter 7
Interpretations and Discussions

7.1 Usage of Drivelines

In Chapter Three, it was established that the common interpretations regarding drivelines is that they facilitate the movement of bison from the gathering basin to the kill area in a Plains bison drive. Rollans (1987) also suggested that when herding and manipulating bison movement, it is favorable to travel along a path of least resistance through the landscape. Combining the two ideas, driveline structures should be found surrounding the locations in the terrain that are easiest for bison to traverse. Using Least Cost Path Analysis tools in ArcGIS, these paths of least resistance were simulated and presented in Chapter Six and Appendix A.

Reviewing the calculated least cost paths shows mixed support for the driveline evidence. There were cases where the cost paths followed the drivelanes to their final jump destinations, but also an assortment of cases where the chosen paths completely conflicted with the archaeological evidence. This was expected as the least cost paths had 16 different directions to travel from while the driveline positions were fixed. These conflicts helped identify routes that were incompatible with the common interpretations of how bison drives are operated.

7.1.1 DhNe-89

DhNe-89 has seven drivelines in its immediate proximity and the least cost paths show the most success with the two east-west oriented lines. As mentioned in Chapter Six, the paths from the west (SW-NNW) would move through this east-west oriented drivelane as they arrive at the opening, but would not veer northward when the drivelines did so. This conflict is likely a result of a small topographic difference, as we see the "avoided" area is quite amenable to bison movement. At this stage in the drive (<500m), the bison would likely have been stirred into a stampede and the hunters would have been stationed along the driveline edges as a means to deflect this detour. This drivelane also has a very broad reach. Movement south and around the valley edge from Hole in the Wall coulee is an easier route than the more direct path over the uplands at the 4km extent. The low costs from the Northwestern origins are examples of this.

The remaining five drivelines found near this site are oriented to the north and seem to be clustered around an area of higher costing topography. This is why many of the least cost paths bypass this area, or cut across perpendicularly through the better terrain in the middle. We also see some use of drivelanes found further afield. The North and North-Northeast origins make use the northernmost drivelines found in the study area, as well as one of the NE/SW oriented drivelane as they pass around DhNe-76. The NNW 2km path also makes minor use of the widest portion of this drivelane as well while it heads south. However, once removed from these areas the least cost paths neglect the other drivelanes they encounter on their route to the jump. While these alternate paths highlight popular areas to travel within, they lack the driveline evidence in their final stages to be desired routes in a bison hunting event. Bison were unlikely to be led from these areas to DhNe-89.

7.1.2 DhNe-82

An interesting conundrum is raised at DhNe-82. The most obvious drivelane associated with the site approaches from the southwest and curves slightly eastward before terminating. What is interesting is that this is one of the few jumps where a driveline does not continue right up to the edge or at least the final 100 metres of the valley. Given what we know of how bison jumps operate, drivelines play a pivotal role in these final stages. So is this early terminating drivelane a viable approach to the jump, or a happenstance creation between two separate sets of drivelines?

From the least cost path analysis, several paths collect and move within this lane, but do not move exactly parallel to the lane's orientation. Movement through this area is relatively favorable at the widest extents, usually holding the 2nd, 3rd or 4th least costly paths and the 1st among the 3km origins. Entry into the lane does not begin at the mouth, but off to the side to the west. However, the paths do quickly merge at this point of entry or shortly thereafter, suggesting a general funnelling mechanism. So the least cost paths do show that entry accessing the jump through this drivelane was probable. Perhaps the intricacies this route provides could be gleaned if higher resolution elevation data were available.

The least cost paths also identified a possible alternate route from the West/Northwest that exhibits minor conflicts with the driveline data. At the shorter extents, movement from these directions generally follow the driveline networks; moving northeast within one then east for a short duration in another. Like the southwestern approach no drivelines from this direction extend to the valley edge. This limits the information available in the final phases of the drive.

Similar movement from the north is less likely as their progress south moves against the general funnel shape of the drivelane. They travel from narrow to wide rather than wide to narrow.

7.1.3 DhNe-77

Assessing DhNe-77's use of the driveline network may be the most challenging of the seven bison kills found in Roan Mare Coulee, as it has only a single cairn line directly connected with it. Many of the least cost paths calculated for DhNe - 77 mirrored and followed routes used to reach its neighbours DhNe-51 and 76. This was especially true for movement from the northeast and southwest. This fits with Walker (1990)'s hypothesis that hunters using DhNe - 77 would reuse the northeast drivelane from DhNe - 51. The hypothesis also holds weight if the clause is extended to the southwest drivelanes or to DhNe - 76. Entry from the northwest shows the most individuality from the other jumps nearby. There is some marginal evidence for the least cost paths following the drivelane found here, but they all divert to the east around the midway point. The cost paths are showing that an easier route is available to the east than the one offered by following the drivelane to termination then abruptly turning to the northeast.

7.1.4 DhNe-76

The drive and movement options seen at DhNe-76 are very similar to those found at DhNe-77. While DhNe-76 benefits by having substantially more drivelines in its immediate vicinity, many of its paths to the northeast and southwest are shared with DhNe-77, and they too overlap with the paths destined for DhNe-51 that lay between them. With that said, DhNe-76's usage of drivelanes is more closely akin to 51 than to 77, as both use the northwestern drivelane to its fullest extent.

The area of greatest concern stems from the SW and SSW routes. While these paths travel through the southwestern drivelines, they raise many conflicts while doing so. The two main issues are the two regions of overlap with the central driveline and the northwestern edge of this drivelane. These regions of overlap are also shared by other jumps that use this route, not only DhNe-76. These two issues likely stem from the same source: an area of high costing terrain approximately 400m southwest of DhNe-76 and west of DhNe-75 (Figure 6.10). This high cost area rests at the northeastern end of the central driveline that is being overlapped. The least cost paths that traverse this area are forced to move around it to the west. The SSW 2km path does travel through some of this high cost area, but still detours around the places where costs are highest.

This westward deflection is what is causing the regions of overlap. We can see in Figure 6.10 that the area east of the central cairn line contains a sizable area of low cost terrain, which is capped by the area of higher cost. The alternative is to head east, which is ridden with costly terrain extending off the valley edge or to the west where the central driveline resides. This driveline likely rests upon a set of hilltops overlooking a small trough which the 30m raster blurs together. Since movement to the east is still blocked by the costly zone, travel continues along the northern fringes of the drivelane, even after the obstructing terrain is passed. Needless to say, this is an area where the hazer's influence would likely trump or overrule where the topography is leading the bison.

7.1.5 DhNe-75

DhNe-75 shows the most independence from the other sites at the 1km scale where its local topography holds the most sway. At the broader scales, DhNe-75 shares many of the paths that the jumps to the north use to traverse the upland areas. Its northeastern paths follow in the northeastern drivelane just as seen at DhNe-51, 76 and to an extent, 77. Travel within the northwestern drivelane is also observed by one of the least cost paths, following a similar route used by DhNe-76. However, there is a lack of complementary driveline evidence for travel past DhNe-76. This is where the least cost paths from the Northwest and Northeast swing around the edge of the valley and approach from the northwest. Since movement runs parallel to the valley edge, any drivelines that are encountered are quickly transected.

The routes from the southwest on the other hand show some of the best evidence for the use of drivelanes seen from the least cost path analysis. The mouth of the southwestern drivelane highlights a perfect topographic funnel. The West through South-southwest paths from the two broadest scales all congregate in the early stage of this drivelane and follow it as it narrows to the east. Unfortunately the easternmost driveline disappears approximately 750 metres from the end of the drive. The least cost paths do follow the general curve of the driveline to their west during this period, so there is at least some evidence supporting this choice of direction as opposed to the northwestern access mentioned above.

Given what we know about bison jumps, it odd that this driveline does not extend to the final stages before the jump terminus. This has also been seen at some of the other jumps such as DhNe-76 and 82, where a single driveline extends to the valley edge while the other abruptly stops. One possible explanation is that the stones that would have been located here may have been pilfered and reused elsewhere. Another possibility could be that perishable material, such as wood, bison chips or bramble would have been piled up and used as drivelines in these void areas. Sampling error is also possible, but these features would be very obtrusive to Walker's survey methodology as mentioned in Chapter Two. This is a question that cannot be fully resolved without further study.

7.1.6 DhNe-51

DhNe-51 is one of the few jumps in the study area that has a set of three drivelines in the last 100 metres of the drive. As mentioned above, the other sites either lack these features or have a solitary driveline meet the terminus. The need for additional stone features may indicate that more control was required at this site than the local topography could provide. Another explanation is that these drivelines were constructed during the last bison drive operated in the area and could not be removed and recycled at another location. In any case, the least cost paths are surprisingly responsive to the direction and orientation of these final drivelines. Granted the 30 metre buffer around the drivelines diminishes the accuracy of this statement, but the paths are funnelling into a topographic feature found just before the valley edge.

The least cost paths from DhNe-51 show consistent use of the drivelines located to the northeast, northwest and southwest of its terminus. The southwestern approach holds the same issues mentioned above with running atop drivelines at certain locations. An item of note is that at the 4 and 3km levels, it is mildly more efficient to travel *outside* these drivelines using the WSW route. This condition is also true for travel towards DhNe-76 at three kilometres and DhNe-77 at four and three kilometre levels. The difference in accumulated costs between these two options is generally slim, so small non-topographic variables may be need to be relied upon to encourage movement into the drivelane system.

The northeastern drivelane appears to be the passage of choice for several of the least cost paths originating north and northeast of the jump edge. This is true not only for DhNe-51, but also for all the bison jumps located south of this location. The paths that traverse this area create few conflicts with the drivelines they are contained within. The only instance where the least cost paths "straddle" a driveline occurs along the southern tip of the northernmost driveline in the study area. This overlap is minor in comparison to what is witnessed in the southwest, but may still suggest an area where human involvement would be required to steer bison away from the driveline. Aside from this overlapping area, the northeast driveline is a very popular route of travel. The popularity of travel through this region will be further addressed below.

7.1.7 DhNe-1

While one of the most visually impressive jumps in the region, DhNe-1 may also have the most modern skew affecting its least cost paths. This skew comes from the ploughed agricultural fields that dot the landscape behind the jump. These fields offer much flatter terrain than the nearby grazing plots. Since the least cost paths rely on slope to calculate costs, the flatter terrain found in these fields means they are easier to traverse. This skews both the direction and accumulated costs for several of the least cost paths calculated for DhNe-1. The southeastern and eastern paths that traverse these fields exhibit lower costs than those found among the northeastern or southern routes. These fields also explain why the four, three and two kilometre East paths are quick to deflect south away from the drivelane, as the flat areas offer the ability to travel great distances with minimal effort.

The saving grace for DhNe-1 can be found within the 1km extent as none of the calculated paths move through an agricultural field (save for the first 30m of the S path). Here we do see that the least cost paths do travel within two of the outlying drivelanes to the south and southeast. The lane between them goes unused and may just be overpowered by its neighbours' more effective ways of traversing the terrain. The drivelines that lead on to the final landform do show some contention with the least cost paths nearest the jump edge, but this is likely a side effect of the 30m data having few options to manoeuvre while on this small piece of land.

As for the east-west oriented drivelane, the E and ENE origins for DhNe-1 show little association with it and quickly abandon the drivelane for the southeastern one. However, this drivelane does yield a topographic least cost path which travels within its boundaries. The East origins for the 4 and 3km extents of DhNe-51 take a sinuous route that manoeuvres through the high cost terrain found to the north and south (Figures A5 and A6). They steer into a small tributary gully of Roan Mare coulee found northeast of DhNe-1 and continue across the valley bottom and up the western slope to reach their destination. Why do the paths from DhNe-51 take this route, while the paths for closer DhNe-1 do not? Aside from the aforementioned agricultural fields to the south, a small area of high cost terrain can be found near the drivelane's exit (see Figure 6.10). This increase in slope is likely due to the transition from the hummocky terrain of the uplands into the valley edge. The DhNe-1 paths divert around this area to the south, while the DhNe-51 routes divert into the tributary to the north. This area of slightly higher cost terrain combined with the flatter fields to the south explains why the least cost paths neglected this elongated drivelane. If travel were to occur within the lane, it would resemble a path like the one calculated for DhNe-51.

7.1.8 Summary

The network of drivelines found in Roan Mare coulee do appear to moderately highlight the topographic paths of least resistance through the landscape. Some of the best examples of this include the northeastern paths from DhNe-51 and 76 and the southwestern pathways seen at DhNe-75. These examples show little conflict with the drivelines that surround them and usually involve several of the least costly routes calculated for their respective jumps. In these cases, the drivelines reflect one of the hypothesised uses in a Plains bison drive: highlighting favorable drivelanes to manoeuvre bison within (Brink 2008; Brink and Rollans 1990; Rollans 1987).

With that said, there are also a number of instances where the least cost paths contend with the driveline evidence. These contentions range from the least cost paths cutting straight across a drivelane, traveling atop or next to driveline markers for extended durations, or generally avoiding an obvious route to the jump edge identified by drivelines. The easiest conclusion to draw about these conflicts is that the drivelines in question are not associated with that particular jump destination. For example, the NNW routes at DhNe-89's three and two kilometre levels cross several drivelane systems which are oriented away from the jump. A second explanation arises from the limitations of data accuracy and resolution inherent in any model. The Cost Distance tools can only select from eight directions when proceeding and can only do so in 30 metre intervals. This is likely the culprit for several of the driveline conflicts that are in close proximity to the destination. For example, the landform which DhNe-1 rests upon is rather small and surrounded on three sides by difficult terrain so the least cost paths have limited options for movement and are bound to overlap with the drivelines.

Carlson (2011) proposes that places where topographic least cost paths and archaeological evidence were in disagreement are locations where human agency was required to correct the bison's' trajectory. This is the likely scenario where the least cost paths are overlapping the drivelines or when particular sections of drivelanes are left unused. The topography is leading the bison in directions that clash with the drive's mechanisms so influence from the human agents would be required at these locations to provide an alternative. This would likely be the tactic employed when using the east-west and northeast drivelane at DhNe-1, or where the cost paths do not follow the final curves of the drivelines seen near DhNe-76 or 89.

Overall, the least cost paths do not reflect the orientation of the drivelines in all the cases investigated. Many of the places where conflicts arose were happenstance; drivelines that were crossed were unlikely to be associated with that site. However, some of the cases where the drivelines do appear to be associated with the chosen jump do not match the least cost paths. It is hoped that improving both the data resolution and how the cost raster is derived will solve these issues. Factors other than topography such as the intervisiblity between a bison and the drivelines as well as wind direction need to be added to the least cost calculation to better model a bison drive scenario, while an improvement in spatial resolution could identify smaller changes in topography not observable at 30m intervals.

7.2 Comparison of the Sites

Kendall's Tau

As we saw in the previous chapter, the seven bison jumps in Roan Mare Coulee shared many similarities and differences in terms of their least cost paths. Tables 7.1 through 7.4 summarize the results of the Kendall's tau calculations between each jump. This will serve as a rough measure of similarity between the path rankings found at each jump. That is, do the two jumps value movement from particular directions in the same fashion? The values range between -1 and 1, with 1 indicating perfect similarity and -1 being perfect inverted similarity (directions ranked high by one are ranked low by the other). Values closer to 0 suggest no meaningful similarity between the two sets of ranks. Keep in mind since these samples were not randomly selected (systematic placement of origins from known bison jump locations), the measures of statistical significance of these coefficients would be mute. They just serve as a comparison between the rankings of different directions found at different sites.

Table 7.1: Kendall's tau values for 4km least cost paths.

4 kilometres							
Borden #	1	51	75	76	77	82	89
1	-	-0.267	-0.300	-0.200	-0.150	-0.300	-0.733
51	-0.267	-	0.817	0.883	0.867	0.600	0.383
75	-0.300	0.817	-	0.867	0.800	0.700	0.433
76	-0.200	0.883	0.867	-	0.883	0.633	0.350
77	-0.150	0.867	0.800	0.883	-	0.583	0.283
82	-0.300	0.600	0.700	0.633	0.583	-	0.433
89	-0.733	0.383	0.433	0.350	0.283	0.433	-

Table 7.2: Kendall's tau values of 3km least cost paths.

3 kilometres							
Borden #	1	51	75	76	77	82	89
1	-	-0.133	-0.317	-0.233	-0.200	-0.417	-0.583
51	-0.133	-	0.700	0.917	0.867	0.500	0.233
75	-0.317	0.700	-	0.700	0.733	0.533	0.383
76	-0.233	0.917	0.700	-	0.833	0.550	0.333
77	-0.200	0.867	0.733	0.833	-	0.500	0.333
82	-0.417	0.500	0.533	0.550	0.500	-	0.633
89	-0.583	0.233	0.383	0.333	0.333	0.633	-

Table 7.3: Kendall's tau values of 2km least cost paths.

2 kilometres							
Borden #	1	51	75	76	77	82	89
1	-	-0.300	-0.450	-0.333	-0.300	-0.650	-0.667
51	-0.300	-	0.717	0.900	0.850	0.550	0.267
75	-0.450	0.717	-	0.783	0.733	0.600	0.417
76	-0.333	0.900	0.783	-	0.917	0.550	0.300
77	-0.300	0.850	0.733	0.917	-	0.533	0.250
82	-0.650	0.550	0.600	0.550	0.533	-	0.683
89	-0.667	0.267	0.417	0.300	0.250	0.683	-

Table 7.4: Kendall's tau values of 1km least cost paths.

1 kilometre							
Borden #	1	51	75	76	77	82	89
1	-	-0.567	-0.550	-0.550	-0.517	-0.400	-0.433
51	-0.567	-	0.400	0.833	0.667	0.517	0.500
75	-0.550	0.400	-	0.517	0.567	0.567	0.567
76	-0.550	0.833	0.517	-	0.583	0.633	0.533
77	-0.517	0.667	0.567	0.583	-	0.450	0.483
82	-0.400	0.517	0.567	0.633	0.450	-	0.633
89	-0.433	0.500	0.567	0.533	0.483	0.633	-

The first point that can be identified from the statistic values is that several of the jumps such as DhNe-51, 75, 76 and 77 share a high level of similarity in their ranks. As these sites are all clustered together with three of them all sharing the same tributary valley, the close association is due to spatial autocorrelation. This is a situation in geography where the proximity of two observations has an effect on the variable being observed. Many continuous variables such as elevation are positively spatially autocorrelated; that is similar values are found close to one another. Since our cost raster was ultimately derived from elevation, sites in close proximity will share similar costs of travel to reach them. While spatial autocorrelation is the bane of a predictive site location modeller (Kvamme 1992), here it is logical that the path to one site should be of similar difficulty as a path to a nearby site if routes originated in the same general area.

With that said, similarity between the sites is not always spatially dependant. Take for instance the negative values between DhNe-1 and the western jumps. While DhNe-1 may be in relatively close spatial proximity, the orientation of the valley edge creates the differences we see. The paths to the east and south east are more accessible on DhNe-1's side, whereas they are extremely poor routes for the other sites due to the high cost of traversing the valley edge. The value of this negative coefficient changes through the different distances and among different sites. The highest value comes from DhNe-89 at the 4km extent. This high coefficient is a sign that the two jumps have near opposite directions as their highest and lowest ranks. We see this when looking back at the cost tables, where DhNe-1 favors southeastern routes, while DhNe-89 favors the northwest. As northwestern routes become more favored at the shorter extents for DhNe-51, 75 and 76, their respective coefficients also increase in opposition. These negative values all indicate that the directional strategies for moving bison to DhNe-1 would be very different than those for the sites on the western side of the valley.

When comparing the western jumps we see that all the sites are at least moderately (≥ 0.50) similar to one another across the larger distances, with the exception of DhNe-89. The high level of similarity is likely inflated thanks to Roan Mare coulee causing the eastern and southeastern paths to consistently be the most costly ranks for all jumps. DhNe-89's variation manifests from its favoring of the southwest and northwest origins over the northeast. The northern jumps are restricted in their respective northwest travel by Hole in the Wall coulee and lack a consistent passageway to avoid the high cost terrain found there. DhNe-89 has an advantage in this case since its local terrain provides a low cost corridor to funnel movement from the northwest around the valley edge and approach from the southwest at the greater distances. This is most apparent at the 4km extent, where the NNW path from DhNe-89 does not take the direct route overland, whereas all the other western jumps are forced to cut across the upland. The opposite is true for travel from the northeast. The northern jumps gather along the pivot point where Roan Mare coulee turns to the northeast. This allocates more upland area for the northern sites in this direction, but the valley clips the NE access for southern sites like DhNe-89 and increasing their cost. Suffice to say, the bison hunting strategies employed at DhNe-89 are largely dissimilar to what would be seen at DhNe-51, 75, 76 and 77.

The spatial autocorrelation does diminish at the shorter and shorter distances. For example, the 4km DhNe-75 shows very strong coefficients with the sites to the north, and somewhat strong (0.70 - 0.79) similarity to DhNe-82. These similarities begin to dissipate as the travel distance decreases. This is expected as the shorter distances place extra weight on local topography, which is less likely to overlap with neighbouring sites. To use DhNe-75 as an example again, it is the only site that is situated on a northeast facing slope. This local characteristic becomes more and more pronounced as travel distance decreases. Obviously this scenario is not in effect between DhNe-51 and 76 which have the shortest spatial proximity. Without extenuating circumstances such as resting on different valley aspects, the popularity of particular directions of travel will be nearly identical for these two.

DhNe-82's path ranks generally hold moderate similarity to the other western jumps. The highest achieved tau value for DhNe-82 is with DhNe-75 at the four kilometre level. This is likely due to their close proximity, overlapping each other's topography at the larger intervals. As distances decrease, the tau coefficients do increase between DhNe-82 and DhNe-89, being strongest at the 2km extent. DhNe-82 typically ranks the North-Northeast and Southwest routes very high just as the northern jumps. However, DhNe-82 is in an advantageous position where travel from the West is a much easier process than for sites further north. This means the West and West-Southwest paths typically rank higher at DhNe-82 than their counterparts at DhNe-51, 75, 76, and 77. Much like DhNe-89, the valley edge clips the NE origin from being a favorable upland path at DhNe-82, resulting in a very poor rank. So when DhNe-82 is compared to the jumps to the north, the mediocre tau value is the result largely due to the differences in rank between the NE and W paths.

7.3 Most Efficient Paths

While Chapter Six overviewed the least costly paths in a site by site basis, combining the paths for all the western jumps yields interesting results. Figures 7.1 through 7.4 graphically summarize the top four paths for each site and plot each direction's popularity. As seen in Figure 7.1a), the four kilometre extent creates a bimodal distribution, peaking at the NNE/NE and the WSW/SW directions. A closer inspection shows that while the WSW/SW option is more frequently chosen, the majority of the 1st and many of the 2nd ranks are concentrated at the NNE/NE end. This is a result of the spatially autocorrelated northern jumps all travelling through the flat terrain found to the north. The WSW/SW cluster is mainly populated by 3rd and 4th ranked paths.

Since the four kilometre extent is the most expansive of those under study it is little surprise that the lower quartile of paths created for it follow a SW/NE orientation (Figure 7.1 b). The upland area on the western edge of Roan Mare coulee naturally follows this alignment. Hole in the Wall coulee blocks the terrain to the west and pinches out the landform to the south with help from the Big Muddy Valley. The terrain does open up at the fringes of these areas, but there is little room to manoeuvre outside of the SW/NE corridor once upon the upland adjacent to the jumps. The terrain naturally forms a bottleneck as one moves from these outskirts towards the jumps. Since the drivelines found here also follow this general orientation, the hunters would have capitalized on this phenomenon as part of their bison drives.

The three kilometre extent keeps the same general layout seen in Figure 7.1 b), but broadens in the north and restricts in the southwest (Figure 7.2 b). The popularity of the North direction comes from 3rd and 4th positions. We saw this preference for the 3km North origins in Chapter Six among the northernmost bison jumps as a result of being removed from Hole in the Wall coulee. The diminishment of the SW's frequency is likely a by-product of the new North's popularity. As the north origins increased in relative rank, the SW's were demoted to positions outside the lower quartile. The NNE/NE portion still holds many of the 1st and 2nd least costly paths. The WSW and SW do grow in their proportion of 1st and 2nd ranked pathways on account of DhNe-82 now favoring such directions. So while movement from the North through Northeast is the least costly, there is still strong favoritism for the WSW and its neighbours as secondary routes of access at the three kilometre extent.

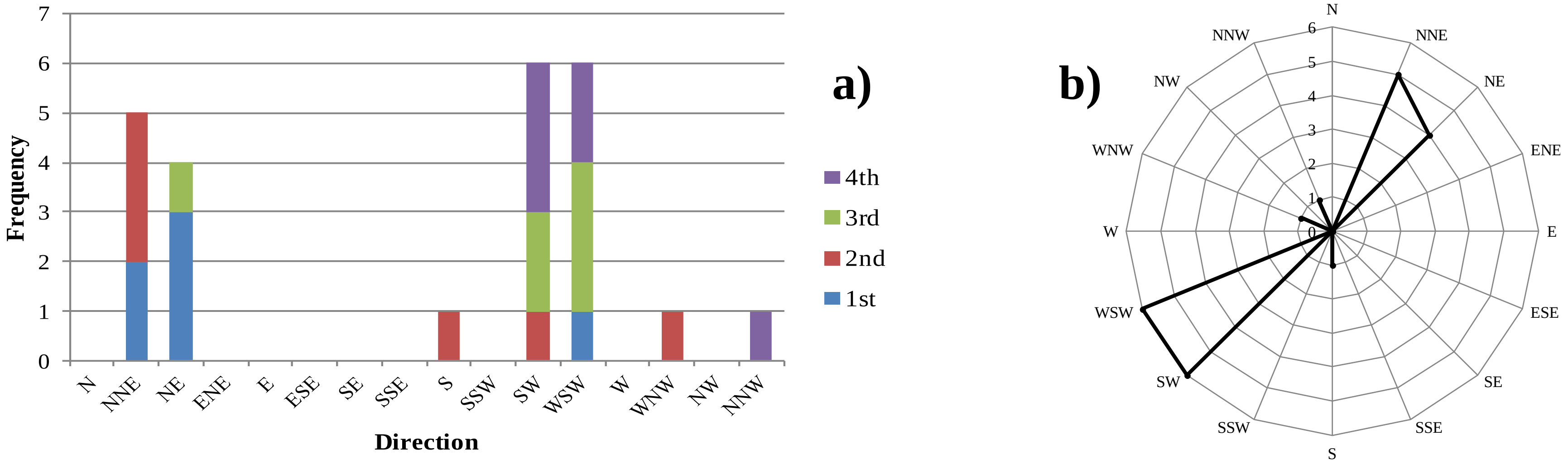


Figure 7.1: a) Frequency of top 4 paths from all western jumps, 4km. b) Radar graph of directional frequencies.

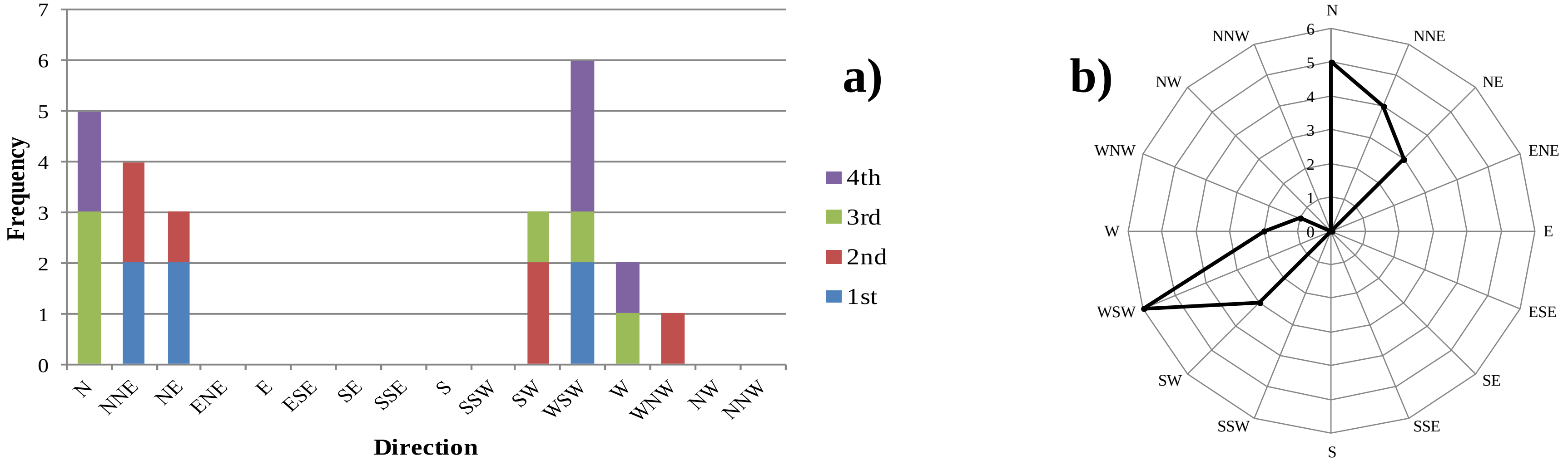


Figure 7.2: a) Frequency of top 4 paths from all western jumps, 3km. b) Radar graph of directional frequencies.

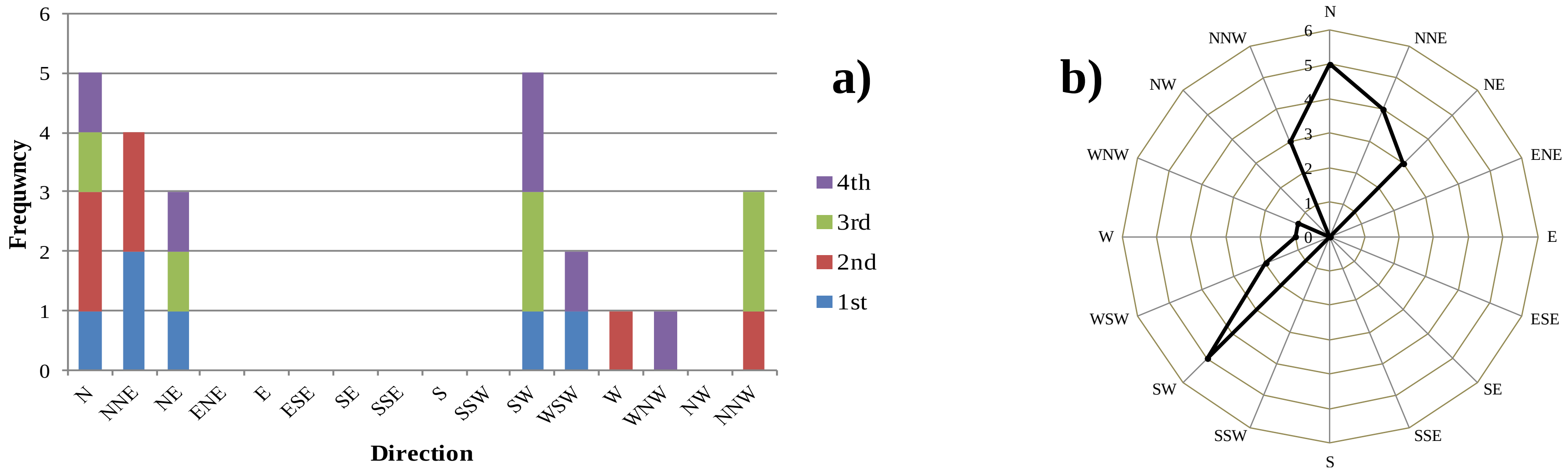


Figure 7.3: a) Frequency of top 4 paths from all western jumps, 2km. b) Radar graph of directional frequencies.

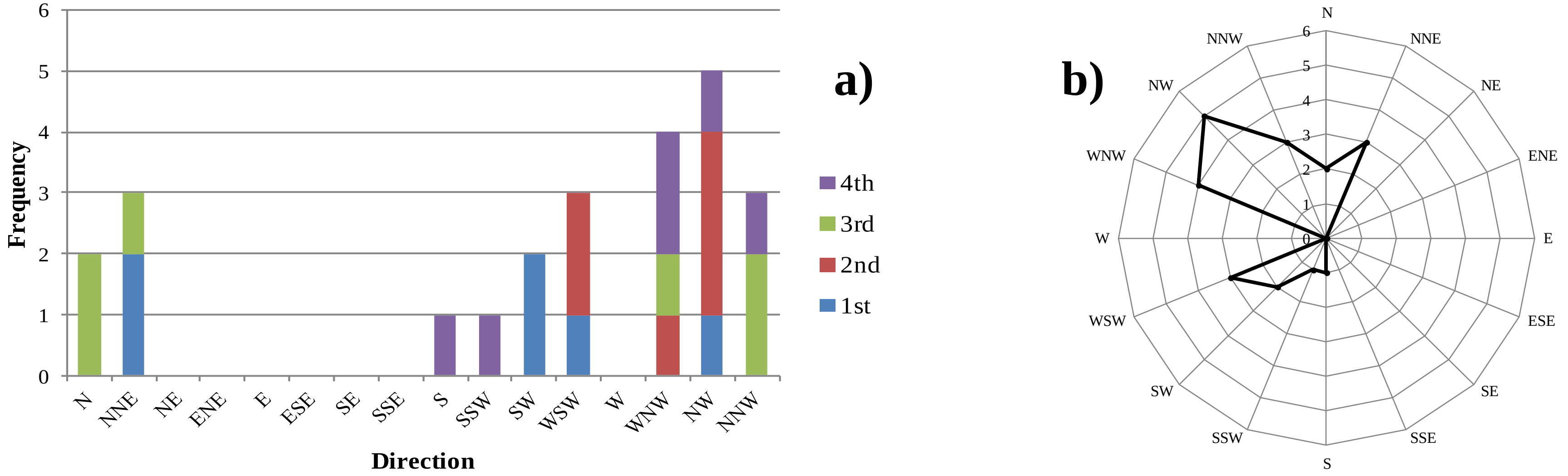


Figure 7.4: a) Frequency of top 4 paths from all western jumps, 1km. b) Radar graph of directional frequencies.

The two kilometre extent begins to mark the shift from global topographic influences to more local ones. Comparing the frequency graphs found in Figure 7.3 to their predecessors shows a widening influence of North and North-Northwest. Meanwhile, the popularity of the southwestern paths continues to be eaten away (Figure 7.3 b). This is a result of the trends we witnessed in Chapter 6 where the northern jumps DhNe-51, 76, and 77 continued their favoritism towards the N, NNE and NE routes. While this occurs, the three other jumps begin to spread their top ranked paths between the Northeast, North, Northwest and Southwest. This fluorescence of possible pathways is a result of the two neighbouring valleys having a diminished effect on the least cost paths at these sites. Routes which travel through Hole in the Wall coulee experience gentler slopes and fewer paths have to divert around the undulations of Roan Mare coulee's valley edge to reach southern sites.

Since the one kilometre extent has the least amount of overlap between the separate jumps, its frequency distribution shows the most local variation. The most noticeable difference is the drastic popularity shift from the Northeast to the Northwest (Figure 7.4 b). As Hole in the Wall coulee no longer holds sway, travel from the Northwest becomes much more cost effective. This can be seen in Figure 7.4 a), where five of the six sites hold a Northwestern (WNW-NNW) path in either 1st or 2nd position. DhNe-77 sidesteps this trend as it is advantageously placed near flat terrain to the southwest and northeast and these directions occupy many of the top spots. The deflation of the southwestern paths is also a result of the Northwest's popularity. The southwest is largely ignored by DhNe-51 and 76 and the jumps to the south offer their first or second positions to the southwest then shift much of their attention to the northwest. Again, the DhNe-77 site bucks this trend for the reason stated above. The frequencies shown in Figure 7.4 a) portray the open nature of topography found nearest the jumps. Access from directions that were not feasible at the broader extents are now popular routes of entry.

The popularity of these Northwest paths at the one kilometre level are not all what they seem. Many of these routes, as shown in Chapter Six, stand opposed to the driveline evidence. For example, the NW and NW routes for DhNe-75 rank second and third respectfully. Yet as witnessed in Figure 6.14, they cut straight across the two nearest drivelines and show no other use of such features. At DhNe-76, the low costing WNW and NW paths move within the area void of drivelines, while the WNW at DhNe-51 does the same. Obviously there are cases where some driveline use is observed. The WNW and NW from DhNe-89 cut across two sets of drivelines on their approach before moving straight into the only drivelane associated with the jump. The NW path from DhNe-82 does move along an east oriented drivelane for a short duration before turning south to the terminus, but the drivelane it uses is oriented more towards DhNe-75 than 82. So even though the topography nearest the jumps is more open with several new routes that are more amenable to movement, the driveline evidence supports paths that are continuations of the least costly routes at longer distances. The drivelines at these distances would also likely be manned by additional hunters, which would further dissuade movement from these other directions.

7.4 Path Sharing

Figure 7.5 shows the locations where the calculated least cost paths from separate sites overlap. Since DhNe-51, 75, 76 and 77 show the most amount of spatial autocorrelation, their paths also overlap the most. Thus for clarity, only paths with four sites or greater contributing were displayed. This map also excludes DhNe-1 from the collection as it is the only jump on the eastern side of the valley.

Firstly, it may seem superfluous in Figure 7.5 to include the paths found in Roan Mare coulee as they would not reflect the hunting strategy explained in Chapter Three. However, they help highlight the *environments* where the most overlap occurs. Since the cost surface is derived from slope data, the least cost paths will cluster in areas where low costing terrain is flanked by higher costs such as the bottom of Roan Mare coulee and small tributary drainages. We can apply this corridor idea to areas where we also see path sharing.

If we treat the overlapping process as a means to highlight natural corridors, the paths on the upland show the most overlap in a general NE/SW orientation. We also see several of the shared paths fall within the driveline network. If the drivelines flank areas identified as natural corridors, such an association fits well with Rollan's (1987:109) broadest function of drivelines: highlighting the boundaries of lanes where bison were to be led. We see this in the northeast, northwest and southwest oriented drivelanes encircling DhNe-51, 75, 76 and 77.

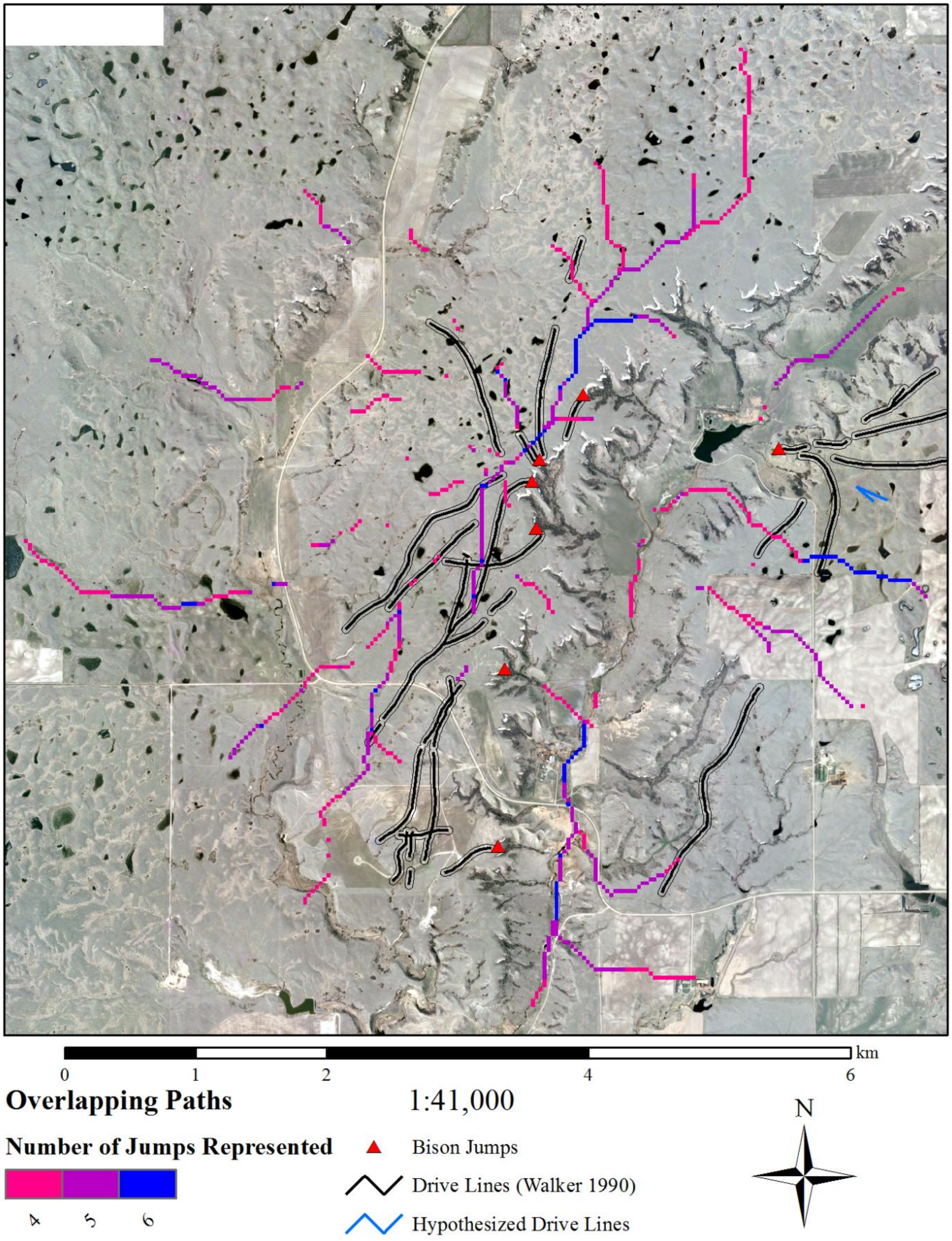


Figure 7.5: Overlapping least cost paths from western sites.

One of the densest concentrations of paths is found immediately behind DhNe-51, 76 and 77. The least cost paths in this region anchor into a thin strip of flat terrain flanked to the northwest by knob and kettle topography and Roan Mare Coulee to the southeast. This strip of land may be the best example of a restricted travel corridor. For DhNe-51, 76 and 77, travel in this corridor is mandatory as access to their jump faces are simple detours from the main route. In this sense, its popularity may be a side effect of the spatial autocorrelation found here. The southern jumps also utilize this route and its ease of passage explains why access from the North and Northeast rank so well for DhNe-75 and 82, even if travel beyond this area conflicts with drivelines.

There are of course regions where we see little to no amounts of path overlap. The areas to the south near DhNe-82 and 89 for example have no paths shared by four or more jumps in their vicinity. This is a result of the influence from both Roan Mare and Hole in the Wall coulee. The southern origins from the northern jumps would often detour around this area, preferring to move through Roan Mare or swing to the northwest and follow the drivelines away from Hole in the Wall. We also see small patches of overlapping paths in the area void of drivelines found west of DhNe-51 and 76. While several least cost paths traverse this region, the lack of overlap shows that movement through the area is highly variable and inconsistent. This may be why we see a lack of drivelines in this area. Since there is no well established corridor through the terrain in this area, the bison would have several possible routes to choose from. This increases the challenge of manoeuvring the animals in a specific direction and would in turn increase the effort required for a successful drive.

7.5 Viewshed Analysis

In the examples provided in Chapter Six, we saw the topography played an effective role in the limiting a bison's visual information in the final stages of drives leading to DhNe-1 and 51. DhNe-1's more hummocky topography would constantly cause fluctuates in the bison's viewshed; expansive views atop hills would be swallowed up as the animals were driven into the inter-hill areas. DhNe-51 held similar results, but its more homogenous terrain yielded fewer fluctuations. Viewsheds from this area usually stayed open once revealed and would not flip between large and small like those seen at DhNe-1.

Both jumps had an effective line of sight blocker in place that obscured the drop edge. DhNe-1 required bison to be led upon a narrow spit of land to reach the drop and the undulating topographic relief found on this landform blocked sight at three different locations. At DhNe-51, a wide plateau of flat terrain extended from the northeast to the southwest where it was capped by two hills. The hilly terrain obscured sight from the Southwest and West, while the plateau blocked vision from bison entering from the low-lying areas to the Northwest. Once upon this plateau, its breadth obscured vision downhill towards the jump edge until the last 78 metres of the drive.

Both these events neglect the human element of the drive unfortunately. As the cairn locations were not surveyed alongside the topography due to time constraints, their presence on the landscape could not be accurately projected. Several authors (Arthur 1975; Brink 2008; Medicine Crow 1978; Rollans 1987; Schaeffer 1978) note the important role the hunters and driveline structures played in deflecting bison movement in the final moments of a bison drive. The built-up cairns and humans stationed behind them would have offered an obscuring factor to the landscape from the bison's perspective. For example, the Northeast access for DhNe-51 travels along the flat plateau mentioned above. The viewshed evidence (Figure 6.38) shows that much of the plateau beyond the jump was openly visible. Given what we know about bison behaviour, this continued flat terrain would be a much safer option than turning south towards the sloping terrain. It is likely that the drivelines nearest the jump edge at DhNe-51 would have been erected and stationed with hunters to hide this favorable terrain.

While the viewshed analyses were generally successful in measuring the topographic effects on bison vision, they do highlight a failing of the least cost path analyses. This effect is more pronounced in the DhNe-1 10m DEM. As mentioned above, the viewsheds would fluctuate on account of the paths continuously traveling up and down hills found in the area. However, this stands in opposition to the idea of bison following the path of least resistance through the terrain. It would not be advantageous to lead bison continuously up and down hills given what was proposed in Chapter Three regarding bison behaviour in a hunting scenario.

This problem stems from the transition between the 30m data used for the cost paths and the 10m data created for the viewsheds. The 10 metre data offers a higher spatial resolution which allows it to resolve these hills in greater detail than the 30 metre raster can. As the 30m cost surface was created from the 30m DEM, it either could not resolve these finer topographic changes or averaged them with the surrounding terrain. This is why the least cost paths move from hilltop to hilltop: there was little information that a sizable dip existed between them. This is one of the inherent pitfalls in any model: the trade-off between data resolution and data simplicity. It is for this reason that further research with least cost paths in this study area would be beneficial if greater resolution data were obtained.

7.6 Bison Jumping at Roan Mare Coulee

Through the use of least cost path analysis, we have seen that the drivelines found in Roan Mare coulee do follow topographic paths of least resistance at the broadest scales. On the western side of the valley, a SW/NE orientation is seen both in the drivelines and the least costly routes to the jump edges at the largest scales of measure. Corollary to these observations is the clustering of separate least cost paths into corridors along the upland areas. The orientation of these corridors also follow a general NE/SW direction with the most clustering found west of DhNe-82, southwest of DhNe-75 and west/northeast of DhNe-51. This high level of clustering shows use and reuse of certain areas of drivelanes for travel to multiple sites.

Since several sites use the same paths to connect themselves to the gathering basins, why would hunters go to one jump when another is closer on the same route? For example, entry to DhNe-51 from the northeast must pass DhNe-77, so would it not be advantageous to simply run the bison into DhNe-77 instead? First, the selection of a jump will likely depend on where the bison herds are congregating when the group enters the valley. If the herds are congregating near the sloughs southwest of Roan Mare coulee then logically leading them to DhNe-75 would be better choice than DhNe-77 and the vice-versa if the herds ware found to the northeast. There also may be particular portion of the valley that is chosen to set up camp due to availability of water or an inherent ceremonial value that will determine the final destination.

The placement of the kill sites in relation to one another offers a variety of options to the hunters to ensure success depending where the bison may be congregating. The reuse of the drivelanes facilitates this plethora of options, where two different jumps could make use of the same gathering basin. If the same drivelines are used by different jumps, it may serve as a means of conserving energy and resources. The drivelines would serve as a naked template that could be quickly augmented and stationed with hunters to lead the herd to the chosen jump face once the bison's location had been established. Use of a different jump location would only require a change in the final driveline structures specific to that one site, while the reused structures could remain constant with minimal augmentation.

For example, we see two instances where two jumps use a particular route then divert at a driveline to their respective destinations. The first and most apparent one is between DhNe-75 and 76. The two jumps utilize the widest portion of the drivelane southwest of them, highlighted by the "v" shaped zone of path overlap (Figure 7.5). At the apex of this "V" shape, the paths destined for DhNe-75 veer to the east into the adjoining drivelane, while the remaining paths continue northward in the original drivelane. Here the topography allows the hazers a choice of the potential destination from the same general gathering area. A similar situation is seen from the Northwest. DhNe-51 and 76 utilize the same paths within the northwestern drivelane and only divert to their respective sites once they reach the central driveline that bifurcates the lane into eastern and western halves. Hunters stationed along this central cairn could direct the bison to the desired location when they came into range. However this assessment is not as clear cut as the previous example, as the DhNe-76 route does straddle the 30 metre buffer around the central cairn line.

Another possibility the reuse of drivelines presents is the simultaneous operation of several different drives in quick succession. Medicine Crow (1978) notes that the Crow in southern Montana were known to drive bison to separate jumps using the same drivelines. He refers to such areas as "Combination kills" where different kill sites in close proximity could be operated simultaneously (Medicine Crow 1978:253). Given that DhNe-51, 75 and 76 all share the same tributary valley and processing area, it would be little work to retrieve the bounty from each killing floor if they were all run in succession. On the uplands, the area encircling this valley creates a restricted corridor for movement behind DhNe-51 and 76, allowing for easier control of bison into the drive. The locations of the jumps around this valley encourage a breadth of possible directions the hunters can draw bison from. DhNe-75 appears strongly suited to draw bison from the southwest, while DhNe-51 offers a closer position to collect bison from the northeast or northwest. DhNe-76 is a near mirror to DhNe-51 (Tables 7.1-7.4) so it too could adequately obtain bison from the northeast and northwest, or serve as an alternative destination from the southwest given how the drivelanes from that direction curve towards it. DhNe-77 could also be used in conjunction with these three sites by its overland proximity, but its killing floor rests in a separate valley than the others so moving people between them would be much more troublesome.

DhNe-82 and 89 are unlikely associated with the "combination kill" between DhNe-51, 75 and 76 mentioned above and may have been separate additions to the bison hunting strategies employed at Roan Mare coulee. The least cost paths for DhNe-89 show that the most popular routes funnel from the west via the tail end of Hole in the Wall coulee. Any paths that pass through the drivelines to the north are either very high costing, move against the tapering shape of the drivelanes or outright bisect drivelines in their entirety. DhNe-82 adopts a similar pattern, where movement from the north conflicts with the tapering and orientation of the drivelane nearest DhNe-76. However, the southwestern drivelane for DhNe-82 incorporates the southern drivelines used by DhNe-75 and 76 in its structure, and some of DhNe-82's viable paths even utilize the early portions of this other drivelane. So there is definitely a mutual benefit between DhNe-82 and the trifecta of jumps to the north, even if they do not share the same valley or processing site.

Finally, DhNe-1 covers the eastern half of the valley. As stated in Chapter Three, the driveline evidence shows bison could be drawn from the northeast, east and south while the new driveline adds a southeastern option. Furthermore, approach from any of these directions is met with undulating topography that hides the trap from the bison's sight. Granted the least cost paths have been skewed by the agricultural fields, the vast array of sloughs and ponds to the southeast and northeast would serve as suitable places for bison to gather. The paths that lack this bias show that the southern and southeast drivelanes do reflect a path of least resistance though the terrain, while the east-west drivelane likely follows a topographic route similar to DhNe-51's East path.

7.7 Summary

It appears that archaeological bison jump sites at Roan Mare coulee are distributed to take advantage of the Northeast/Southwest orientation of the upland areas. This NE/SW orientation offers several long range topographic paths of least resistance connecting possible bison milling areas to the jumps themselves. However at finer scales, the topographic evidence often conflicts with the archaeological evidence found in the driveline features. So while topography does play a supportive role in determining what areas bison are most likely to be led within in the broadest sense, there are certainly more variables at work such as the hunter's influence in the final stages of the drive. While improvements to the data quality such as that used in Carlson (2011) will help remove some sources of error, Carlson also encountered instances where the topographic conditions alone did not reflect the archaeological evidence. It is hoped that further study into these factors could provide a means to properly integrate their roles into GIS and provide a more holistic model of a bison drive.

Chapter 8: Conclusions

8.1 Research Objectives

Through this thesis, four research objectives were presented concerning the integration of GIS software and the seven bison jump sites found within Roan Mare coulee. These objectives were approached and analyzed using both Least Cost Path and Viewshed tools found in ArcGIS 10.1, attempting to address the role of environmental interaction inherent to a Plains bison drive. The results of these analyses are summarized below.

The first objective compared the driveline structures found within Roan Mare coulee against the calculated least cost paths which simulated a bison's desire to follow a path of least resistance through the landscape. If the least cost paths closely followed the driveline evidence, this would be in agreement with Rollans' (1987) broadest interpretation of drivelines functioning to highlight the lanes in which to manoeuvre bison within. There were a few cases where the design worked as intended, with several paths funneling together into and following the drivelanes to their destinations with few conflicts. These events worked best at the larger extents (four and three kilometres), where a greater number of topographic influences could help shape where the paths headed. Ultimately however, the least cost paths provided only episodic support for this idea at the shorter extents (two and one kilometres). It is likely that several of these issues can be smoothed out with better quality of data, both for the topographic DEM and the driveline locations. Another solution would be to make the cost raster more robust by incorporating different variables important to a drive outside of the favoritism of flat terrain.

The second objective identifies which areas are the least costly to manoeuvre bison through, and if these preferences are shared between the jumps. At the larger scales, there is a definite favoritism of movement from both the Northeast and Southwest among the western jumps. The shorter scales on the other hand show greater support of favorable movement shifting from the North to the Northwest. These differences are a result of the restrictive influences created by Roan Mare coulee and the northern end of Hole in the Wall coulee. Movement through these areas incur high costs, while moving through the upland area between them is less costly by comparison. The fact that the majority of the drivelines found on the western side of the valley are oriented in a NE-SW direction suggests that the natural restrictions created by the two valleys were utilized by the hunters to drive bison from long distances.

The third objective provides further support for this idea of a preferable NE-SW corridor. Objective three was tasked with recognizing particular paths through the terrain could be used to reach several different jumps. Overlaying the paths for all six western jumps permitted the identification of areas where bison movement was the most concentrated and consistent. The result was a semi-continuous corridor spanning from the northeast of Roan Mare coulee to the southwest of Hole in the Wall coulee. While the northeastern end may be slightly skewed by spatial autocorrelation, the corridor does show that the topography of the upland areas encourages movement in these directions. This again matches the general orientation and location of many of the drivelines found on the western side of Roan Mare coulee.

While the previous three objectives show evidence for the least cost paths and their derivatives matching the archaeological evidence at the broad scales, the fourth objective takes a closer look at topography's role in the final stages of two jumps. The viewshed data shows that the topography effectively blocks bison vision when approaching the traps found at DhNe-1 and 51. DhNe-1's knob and kettle terrain offers a variety of hills that obstruct vision until the bison are on the required landform where they are surrounded by either sharp slopes or manned drivelines. DhNe-51's more open terrain is less visually restrictive, but the drop edge is obscured by the beginning of the valley slope. The more open nature of DhNe-51 may require the utilization of the "quick turn" technique (Brink 2008; Byerly et al. 2005; Kornfeld et al. 2010) to quickly run the bison into the final chute when approaching from either the Northeast or Southwest, as the views are more expansive from these directions. While the driveline data was not accurate enough to incorporate into these analyses, the viewshed process did allow for some further understanding of the nuances and subtleties of the final stages of these two bison drives.

Overall, the first three research objectives show the driveline data tend to reflect the larger scale topographic influences such as the valley edges and would support moving bison from longer distances. The diminishment of available water sources at these short distances supports the idea that the hunters would have been driving bison from farther away, with exception given to the northwesternmost drivelane. At shorter scales, the less restrictive upland terrain leads to a fluorescence of different available paths, several of which contend with the driveline placement. This fluorescence shows that the existing driveline structures and local topography have to be relied upon to dissuade bison from changing course to more flavorful areas and hide the trap. It is hoped that these factors can be accounted for in future models.

8.2 New Methods and Changes to Existing Techniques

While the research objectives listed above helped highlight some of the underlying associations between the bison jumps and the topography in Roan Mare coulee, their impacts are restricted to the bounds of the study area. However, this is not the case for many of the techniques adopted or created in this volume. These techniques can be expanded to new study areas beyond Roan Mare coulee, where least cost path analyses are being applied to bison hunting sites on the Plains.

The cost surface, while not completely matching the driveline evidence does provide a strong upgrade from the one employed in Carlson (2011). Of course, while both methods offer means of identifying topographic least cost paths, the model developed here is the better choice when working with multiple sites in the same area. Carlson's jenks method allows for the local topography unique for each jump to influence the costs of movement. Since each site defines its costs differently based on the slopes encountered in its local area, the cost for a given slope value may be different between two sites. This would mean that topography favorable at one site is not favorable at another. The cost raster employed here which, uses the raw values of slope, resolves this deficiency by using a standardized definition of cost. Thus, it provides a suitable alternative to Carlson's (2011) method if a similar project were to be conducted elsewhere on the Plains, especially if comparisons between sites are part of the research interests.

Comparisons between sites, particularly the favourability of movement from certain directions, have not been addressed in previous bison hunting focused applications of least cost paths. The accessibility of sites has been investigated before in human mobility studies (Llobera 2000), but is particularly useful in a bison hunting scenario as well, as it allows the researcher to qualitatively assess which areas are more favorable to move bison through. Carlson (2011) did investigate several sites, but each was analyzed in isolation of the others. Byerly et al. (2005) did show that the cost of movement to Bonfire Shelter was not equal in all directions, and noted certain directions were more amiable than others. However, this was done for only a single site. Through the methods such as the Kendall tau measure and ranking the accumulated costs for each direction, the author was able to identify how movement from different directions changed not only as one approaches a jump, but also between different jumps. The Kendall tau measure also showed how directional preference between sites can be strongly influenced by spatial autocorrelation. These comparative measures would be very beneficial to future least cost applications of GIS to bison kills, as they help identify similarities and differences among different sites within a study area

To summarize, the new methods presented in this thesis are best suited at examining multiple bison hunting sites in the same area. The use of raw slope values as proxies for cost grouping them into classes allows for topography to be defined equally for all the sites in the study area. Meanwhile the individual ranking system allows for each site to be represented and compared fairly, so sites near flatter terrain will not overshadow sites near more rugged terrain. Finally, the ranks allow the user to identify areas that are consistently preferable to move through across several different sites and scales. Thus, the techniques employed here move beyond previous work done by Byerly et al. (2005) and Carlson (2011) regarding the integration of least cost path analyses into the study of bison hunting strategies.

8.3 Further Research

8.3.1 Roan Mare Coulee and the Big Muddy Valley

While this thesis did shed some light on the large scale interactions found between a site and its environment, there is still a great amount of research potential available in Roan Mare coulee and surrounding areas. The first of which would be continued archaeological survey and excavation. Walker (1990) showed that many of the bison jumps offer well defined statigraphy and evidence of bone beds. Further excavation of these sites would open several additional avenues of research. The most pertinent to the ideas presented in this thesis would be a comparison of the bonebeds found at DhNe-51, 75 and 76, as they all share the same valley. If these jumps were used in conjunction with each other, perhaps additional evidence for or against the idea can be found in the archaeological deposits. Alongside this, further excavation of these kills may yield information if corral structures were used in the hunting strategy.

Archaeological excavations should also be conducted for DhNe-77 to see if the zooarchaeological data supports its classification as a bison jump. The least cost path analysis did support Walker's (1990) hypothesis that this jump would share drivelines with its neighbours, but this may be a side effect of the spatial autocorrelation. Remember that Byerly et al. (2005) surmised that Bonfire Shelter had all the applicable characteristics of a bison jump according to their GIS research, but it was the zooarchaeological evidence that dismissed this conclusion. A similar situation may be occurring at DhNe-77, where the least cost path data trends towards this idea but needs the bonebed materials to provide additional support. If the evidence suggests the bison were not lead over the edge, it would explain the lack of driveline evidence for this kill.

Moving away from the bison jumps, Roan Mare offers a variety of other archaeological site types to focus research upon. On possible vein of study that involves GIS would be the mapping of the 1300+ tipi rings identified in the study area. Many of the sites were so plentiful in stone circles that site boundaries were hard to define, such as DhNe-25, 29 and 58. Through GIS tools such as nearest neighbour, kernal density or *k*-means analysis, one could identify where the tipi rings are clustering and perhaps even break down these larger sites into more representative groups. Another possible analysis for the tipi rings would be a landscape study in relation to the many ceremonial sites found in and around the Big Muddy Valley, similar to Moors' (2007) work in central Alberta.

Finally, it would be interesting to investigate the Big Muddy Valley's role within the greater northern Plains. Sites on the American side of the Big Muddy and neighbouring Coteau show artefacts ranging from the Paleoindian Period to the Historic Period (Jerde and Joyes 2009). The valley is also situated between several large river systems found in the Northern Plains including the Missouri, the Souris, the Qu'appelle and the South Saskatchewan, so it may have served as an important travel corridor between these areas.

8.2.2 Least Cost Path and Viewshed Analysis for Bison Kills

Through this thesis, Cost Distance and Viewshed tools in ArcGIS have been used to study probable routes taken by bison in a precontact Plains bison jump. Previous research in this particular application of GIS to bison hunting is limited. Many of these project have met with mixed success (Byerly et al. 2005; Carlson 2011), or were simply created for visualization purposes (Lieff 2006). There is great potential in this line of study, as it provides a larger understanding of the kill sites in relation to their surroundings. It also provides a means of studying bison jumps with minimal destruction to the site that comes with excavation. However, as noted through this thesis, topography cannot be the sole variable to predicting bison movement.

Unfortunately, adding new variables into least cost paths is not an easy process. Kanter (2012: 234) notes that "...cost-path studies are extremely sensitive to small changes in variables, especially when we're working with small regions or topographically diverse but less extreme landscapes." Thus if one were to add a new variable to an existing set, or change the weight a particular variable holds, the chosen paths may drastically shift in both cost and location. This problem compounds if the variables or weights are arbitrarily rather than empirically assigned (Kanter 2012). If paths can shift so rapidly, what is deemed "correct?" Kanter (2012:235) notes that statistical validation is and will continue to be a significant challenge to least cost path applications.

In light of this grim portrayal of building more complex least cost path models, Branting (2012: 218) notes that more sophisticated algorithms can yield impressive results. If modeling bison movement in a drive event is to continue, the first steps may be to incorporate more empirical measures anisotropy into the cost rasters. When modeling humans, several archaeologists (Llobera 2000; Conolly and Lake 2006) turned to human physiological studies such as Minetti (1995) to derive their cost surfaces in terms of energy expenditure. Similar work with bison may be difficult, so the data may have to rely on observing what slopes bison prefer to travel upon in the wild. For instance, Babin et al (2011) monitored a bison herd in Grasslands National Park with GPS radio collars to determine which vegetation communities they were likely to congregate at. A similar research project could focus on the terrain the bison traverse while moving from one area to another.

Many of the non-topographic factors can be addressed through a new research design. A new dynamic or simulation modelling scheme can be implemented where new variables can be added to the model and be compared. The weight/friction value for each variable can also be altered to identify which combination best reflects the driveline evidence. For example, Rademaker et al. (2012) use different coefficients in a standard backpacker's equation to reflect changes in the agent's walking speed, personal mass, or any loads they may be carrying. They found that walking speed was the most active variable in determining the model's result (Rademaker et al. 2012: 38). So by comparing the effects each variable has on the base topographic least cost paths, the researcher can identify which factors and weights yield the best results in following the drivelane network.

Finally, it would be of great merit to gather more topographic data in Roan Mare coulee so viewsheds could be created for the other jumps in the study area to assess how their topography interacts with the bison hunting strategy. Extending from this would be a controlled survey of all the drivelines, with proper mapping of individual cairns. With these data, the drivelines could serve as greater controls in both the least cost path and viewshed assessments. The cairns could be integrated into the viewshed process to simulate line of sight blockers, or assess how high an obstruction would have to be built to restrict vision. Vision from humans at the farther ends of the drivelines could be integrated into the least cost paths to serve as preferred areas of travel, whereas the drivelines themselves can serve as movement barriers. Of course this kind of analysis would require a much finer scale of DEM to work with the cost paths. Lastly, incorporation of other elements such as vegetation's effect on vision have long been desired in human viewshed studies (Tschan et al. 2000; Wheatly and Gillings 2000) and would be equally advantageous here.

8.2.3 Least Cost Paths for the Northern Plains

Least cost paths have been used in archaeology to predict and recreate human movement and settlement patterns (Anderson and Gillam 2000; Bell and Lock 2000; Bell et al. 2002; Rissetto 2012; Whitley and Hicks 2002). An interesting avenue of research would be an analysis of human movement and settlement across the northern plains utilizing least cost paths. One option is to calculate preferred corridors of bison movement between their summer and overwintering habitats (Morgan 1980; Reeves 1990). The analysis would continue as a combination of Krist and Brown's (1994) and Whitley and Hicks (2002) research, comparing precontact archaeological site distribution to these preferred bison travel routes. Do we see many sites cluster along these routes, or do more specific site types such as kills populate these areas? If seasonality data are available for these sites, they may serve as a stepping stone towards reconstructing a seasonal round. Given how important the seasonal behaviour of bison were to movement patterns precontact groups in the Northern Plains, this would be a very interesting line of macroscale research.

Least cost paths may also be extended to the study of breaks in the ecological homogeneity of the Great Plains. These islands and patches (Kornfeld and Olsen 2003) or areas of high diversity and uniqueness (Wiseman and Graham 2007) serve as areas where a variety of different resources can be found together making them attractive locations to settle. Creation of least cost paths using these patches as sources and destinations would allow archaeologists to hypothesise the likely routes taken when movement between the patches was required. Costs of travel can also be augmented when resources are available along the way, serving much like the linear islands proposed by MacDonell and Wandsnider (2003). The lack of recognition for corridors between these islands was one of Wilson's (2005: 149) major concerns regarding Kornfeld and Olsen's (2003) book, so the least cost path analysis could fill this role nicely.

8.3 Conclusions

Least Cost Path and Viewshed analyses offer a relatively new and intuitive way of studying bison kills. They serve as non-destructive avenues of research of some of the largest sites that can be found on the Great Plains. However, the techniques and data requirements in their use need to be expanded upon beyond simple topographic variables and relative measures of bison movement. They also cannot be completely free of bias, as the researcher creates skew by choosing the variables and weights of the cost surfaces, while the inherent limitations of the modern landscape are not so easily removed from the model. Thus, the researcher needs to play an active role in critiquing the results, ascertaining why the paths or viewsheds are laid out the way they are and whether they reflect the chosen hunting strategy.

With that said, least cost paths and viewsheds provide information about a hunting event that cannot be addressed by traditional archaeological excavation of the cultural deposits. The reverse is also true, important information regarding the kill's age, seasonality and use can only be found in the bonebeds and not in computer recreations of the prey's final moments. The two processes should be used in tandem as they complement each other. It is hoped that integrating the two will lead to a broader understanding of the human activity at bison kill sites through both time and within the surrounding environment.

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Appendix A
Least Cost Paths

Below are the maps portraying all the least cost paths created for each bison jump. The paths are ranked one through sixteen, so the ranks seen here may not match the ranks seen in the upland paths shown in Chapter Six. All the paths found in these maps (aside from the ones calculated for DhNe-1) were overlain to create Figure 7.5. The tables compiling the path costs and ranks for each site can be found at the end of this appendix. The items in these tables marked in bold are the upland paths shown in Chapter Six. These tables were also used to calculate the Kendall tau coefficients seen in Chapter Seven.

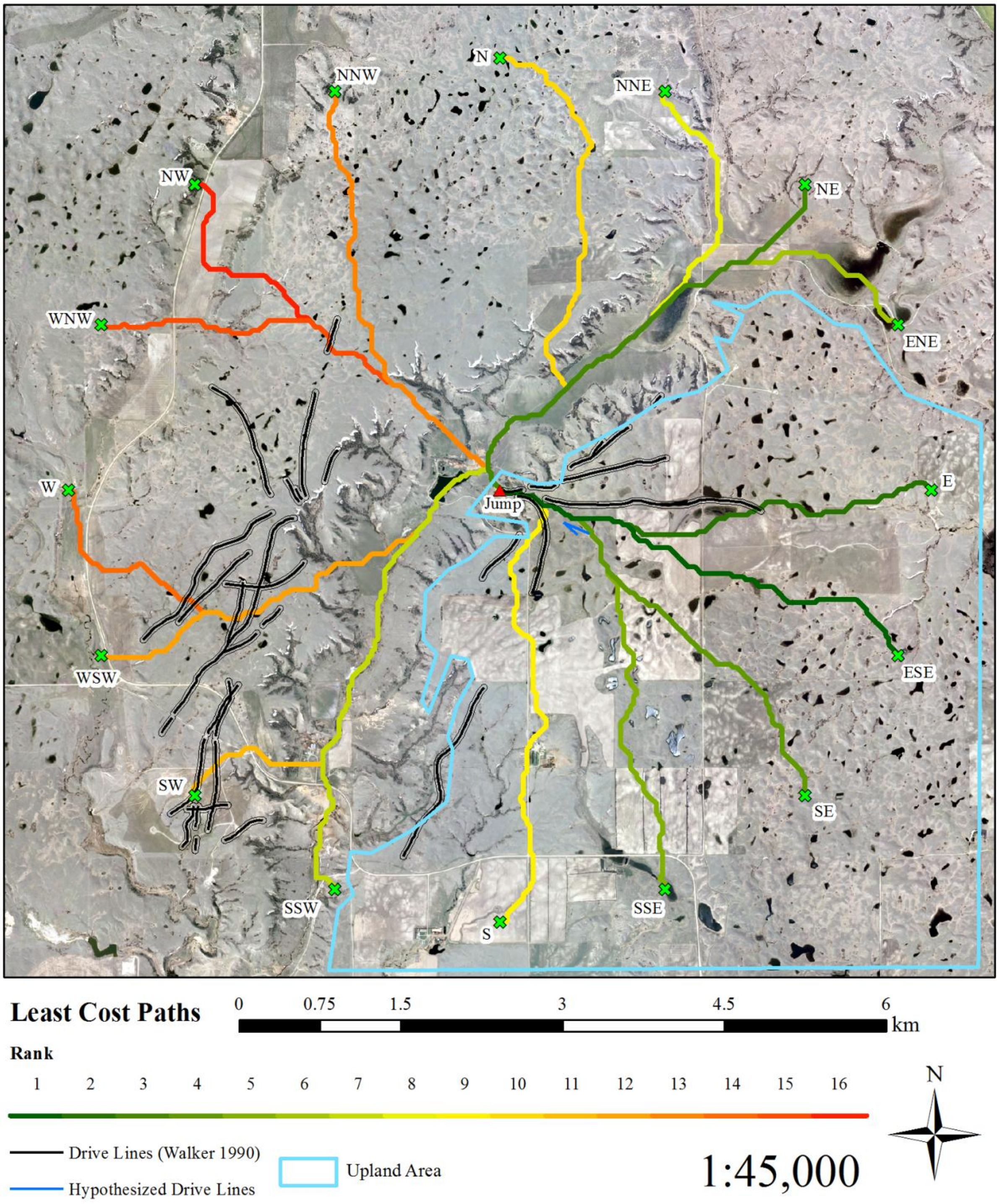


Figure A1: All 4km least cost paths for DhNe-1.

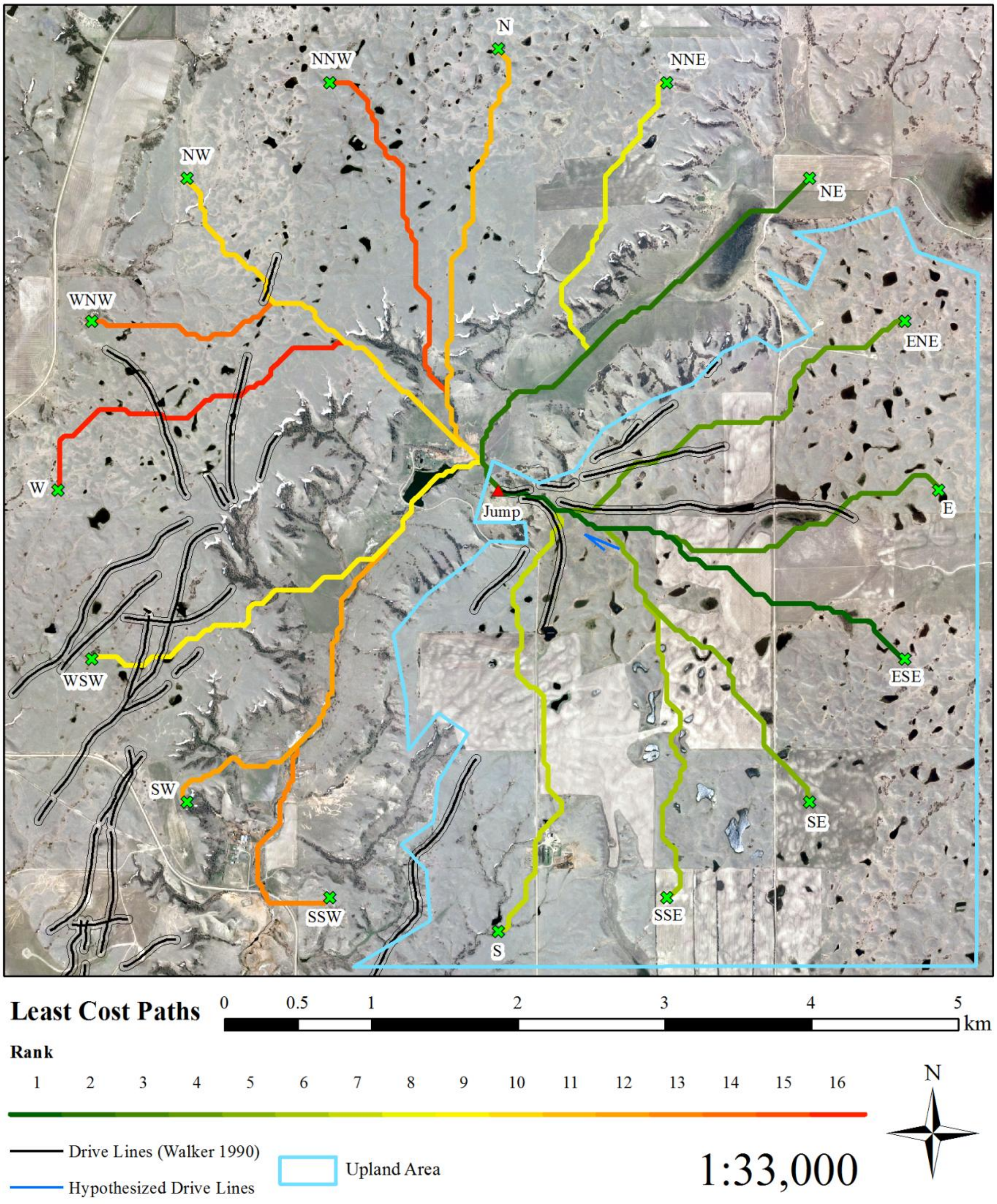


Figure A2: All 3km least cost paths for DhNe-1.

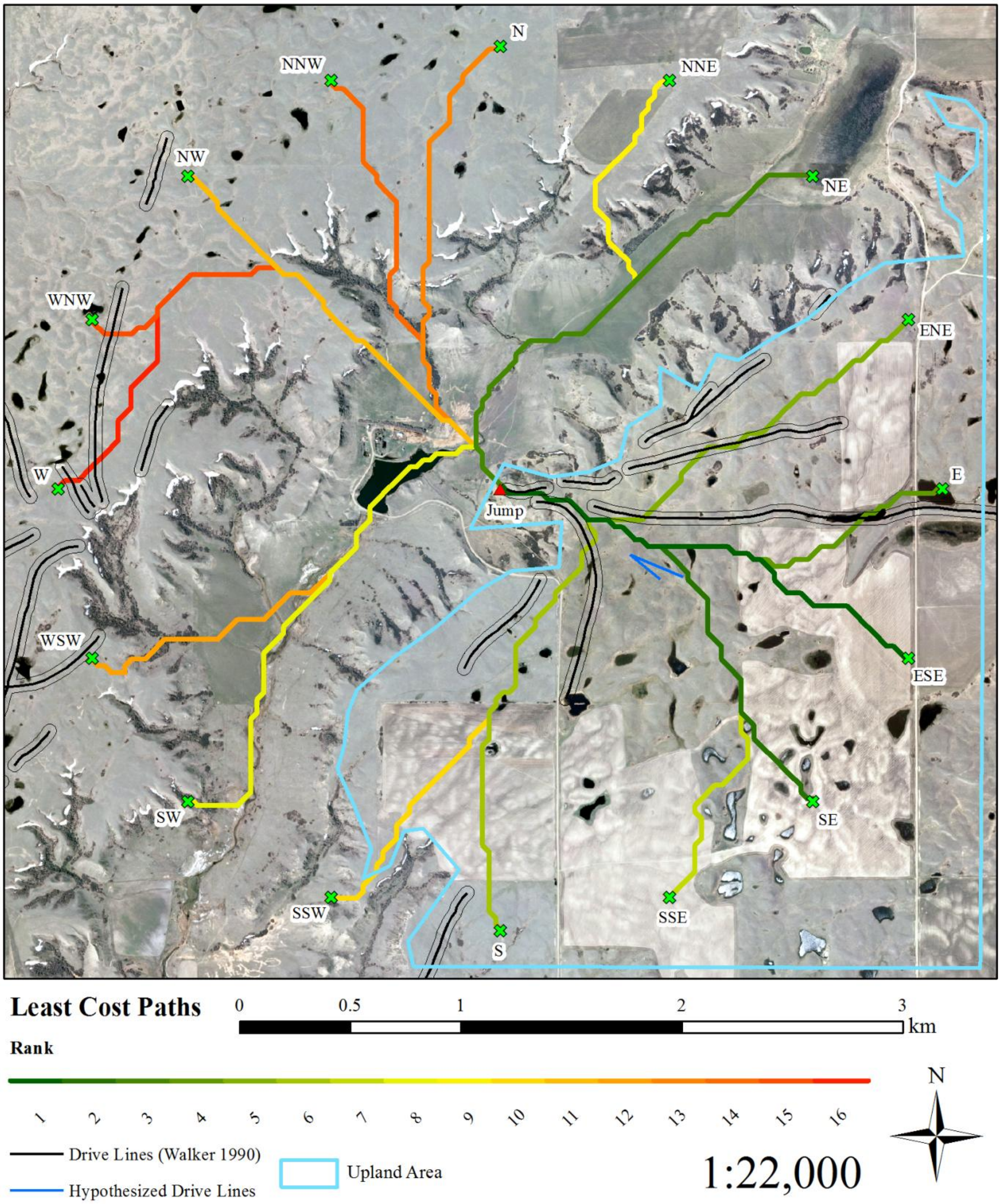


Figure A3: All 2km least cost paths for DhNe-1.

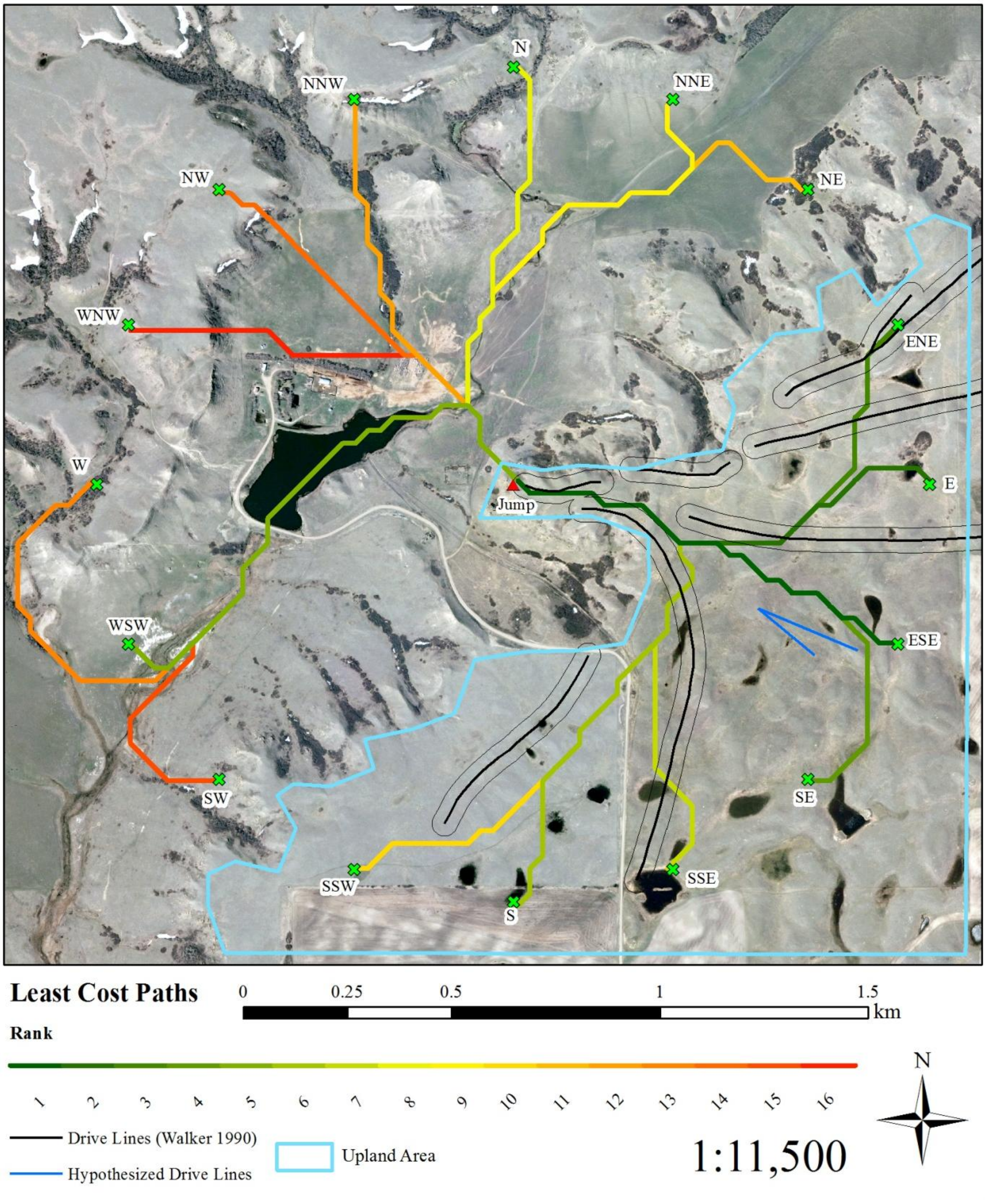


Figure A4: All 1km least cost paths for DhNe-1.

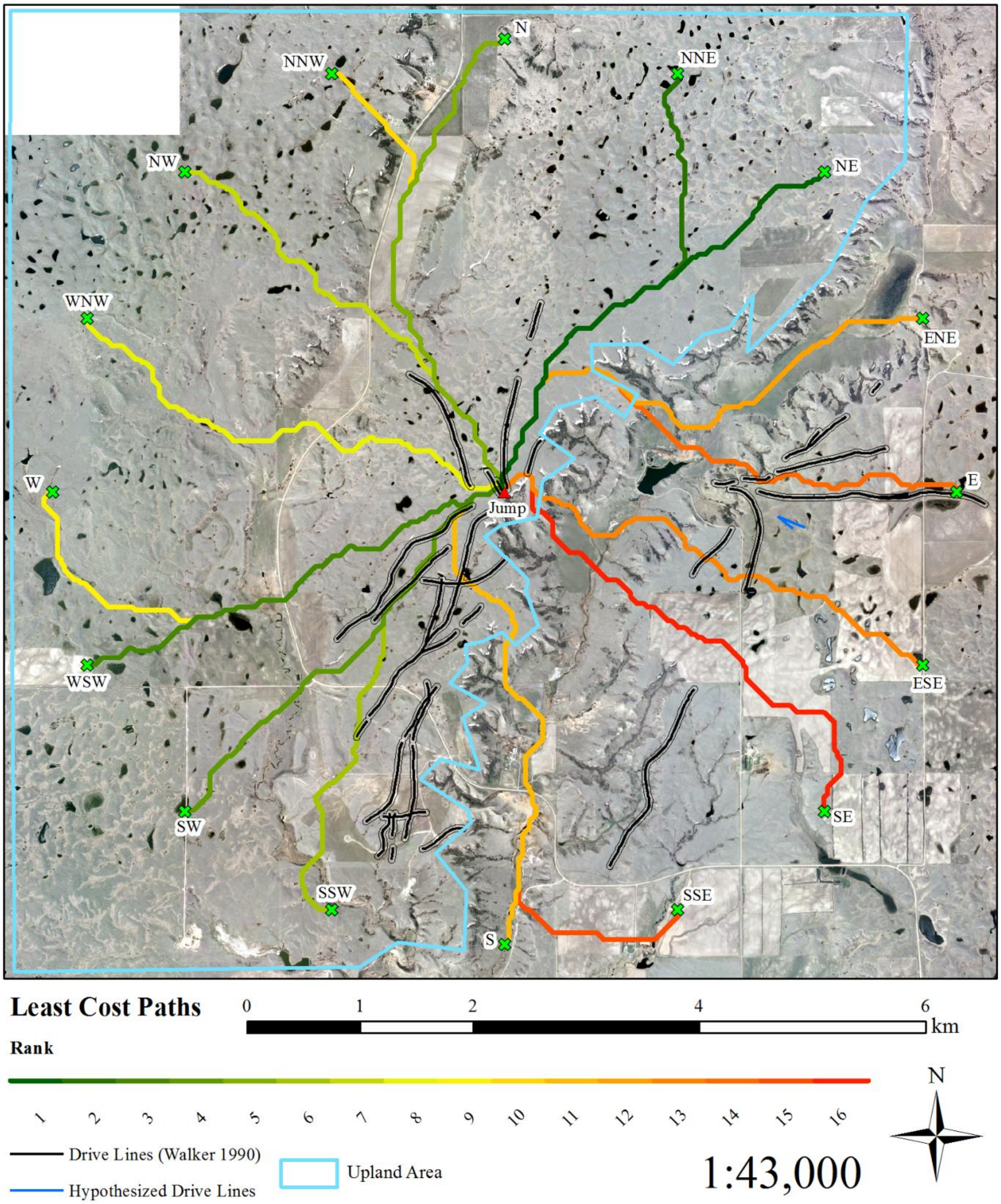
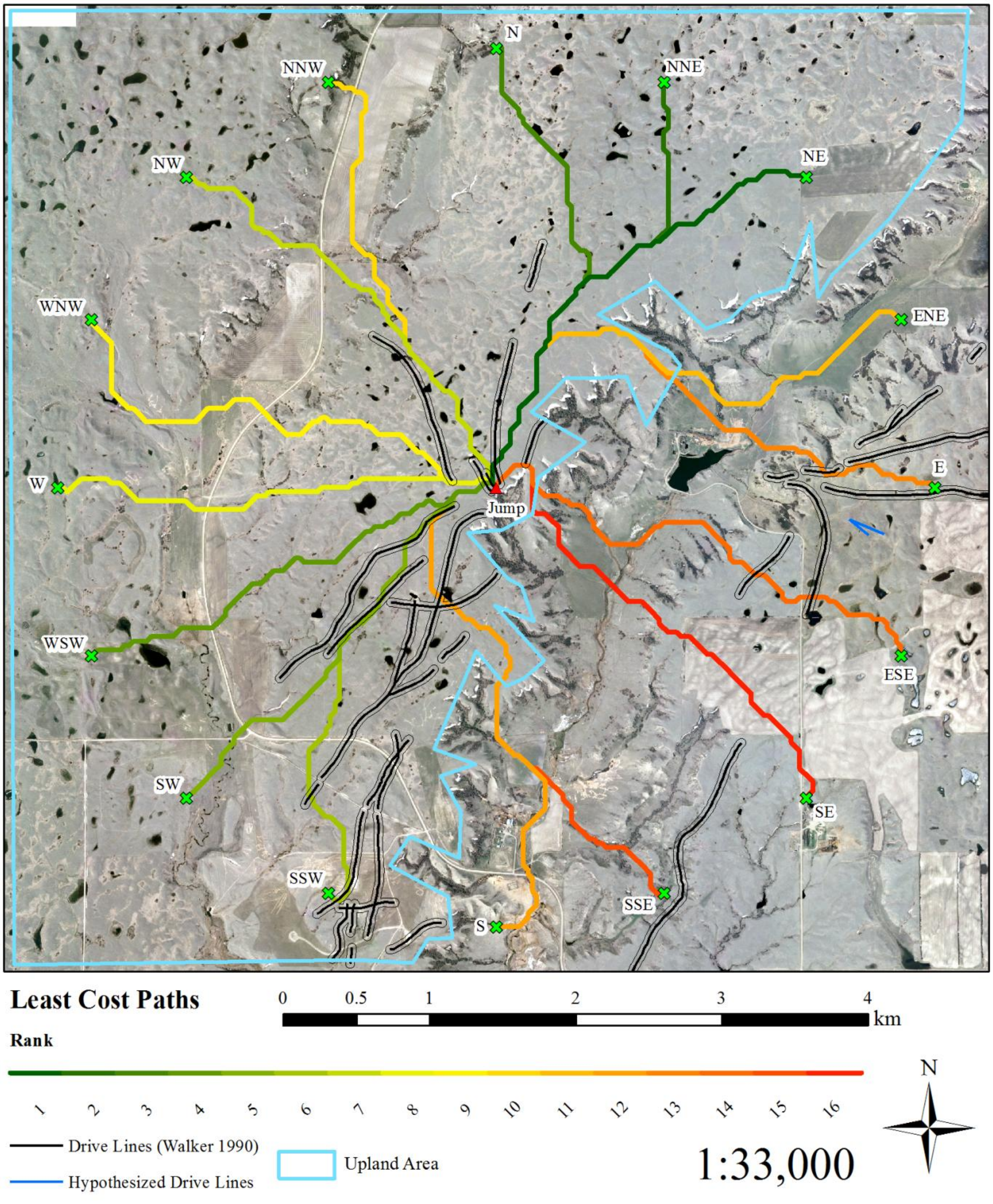


Figure A5: All 4km least cost paths for DhNe-51.



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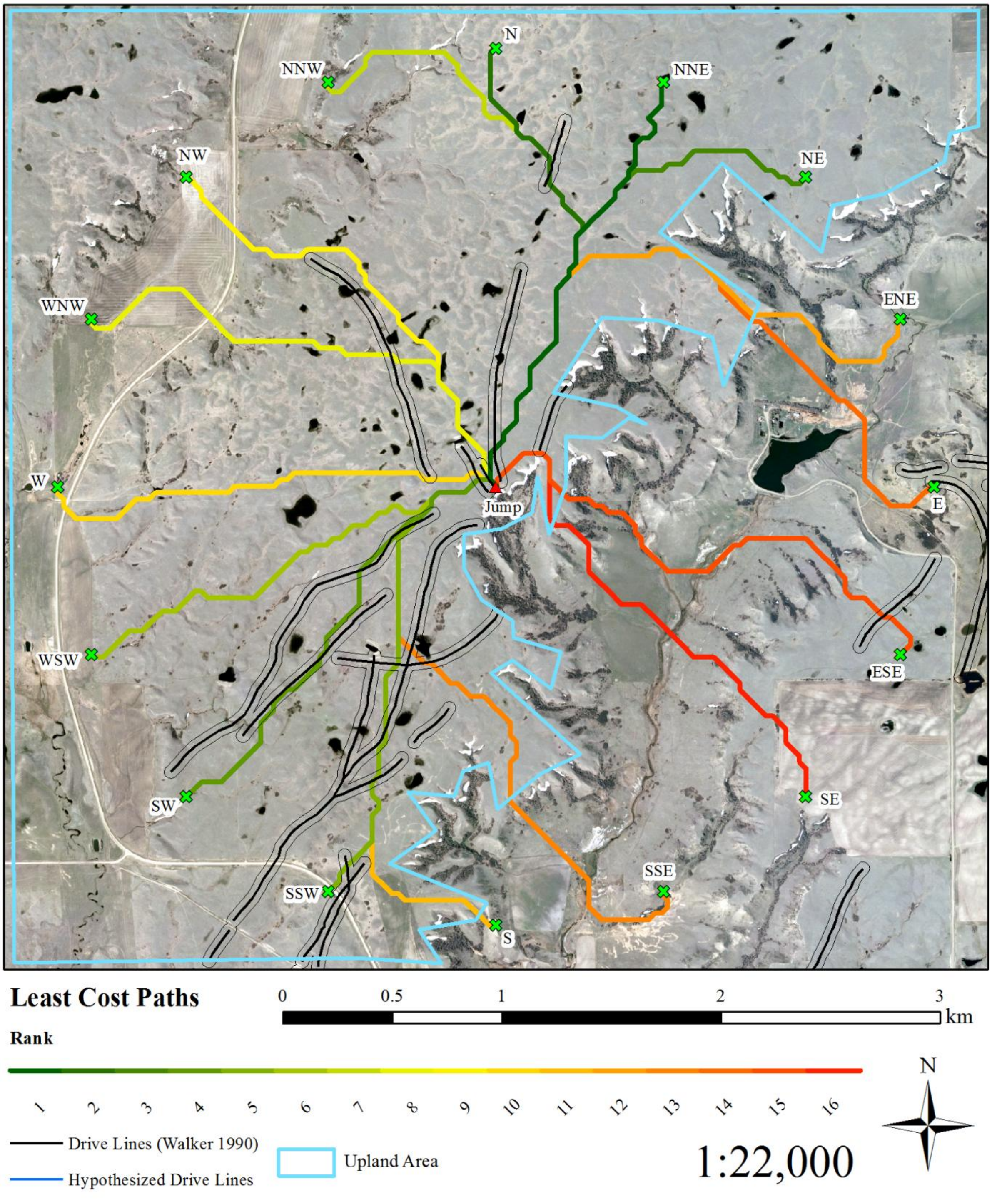


Figure A7: All 2km least cost paths for DhNe-51.

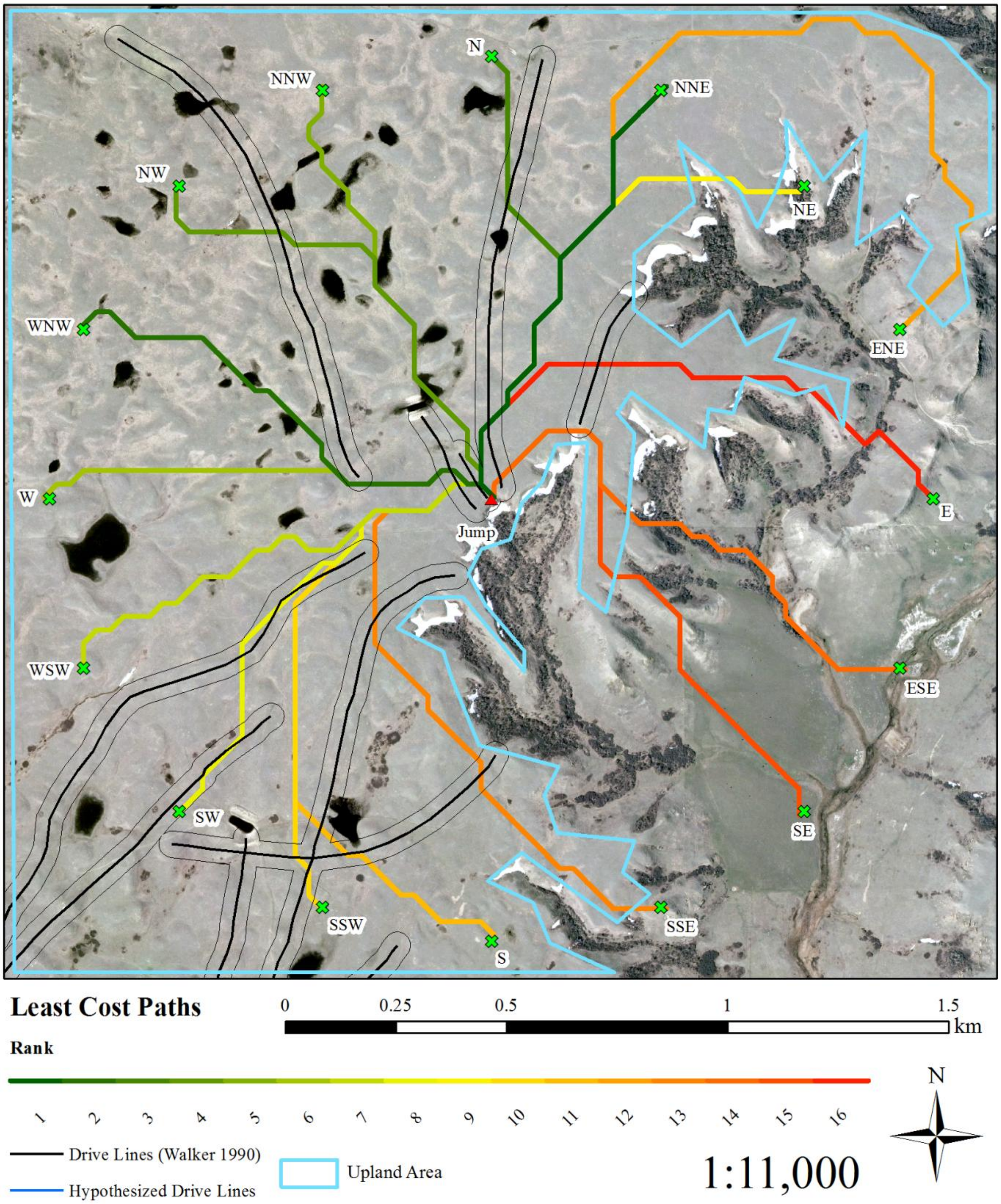


Figure A8: All 1km least cost paths for DhNe-51.

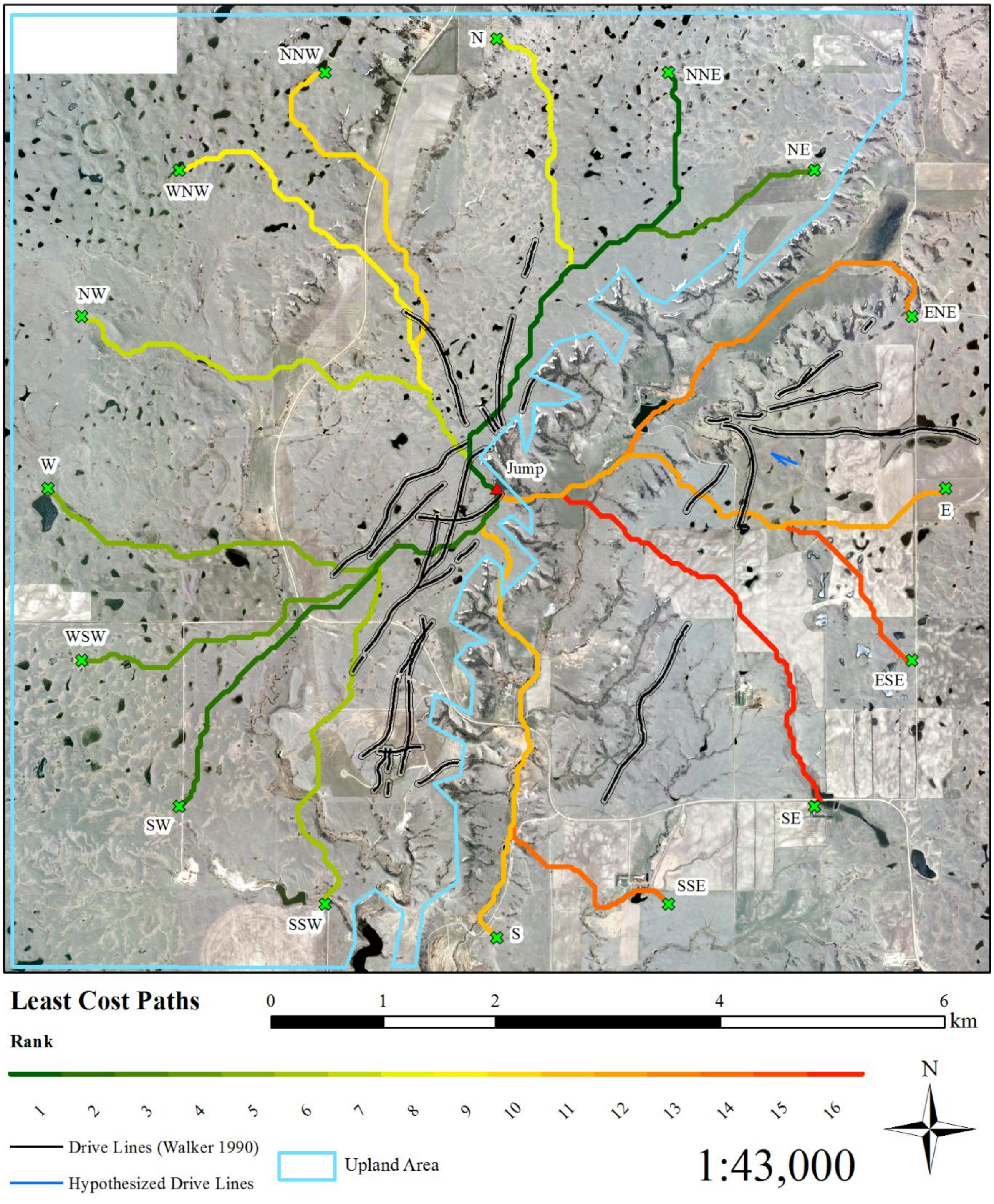


Figure A9: All 4km least cost paths for DhNe-75.

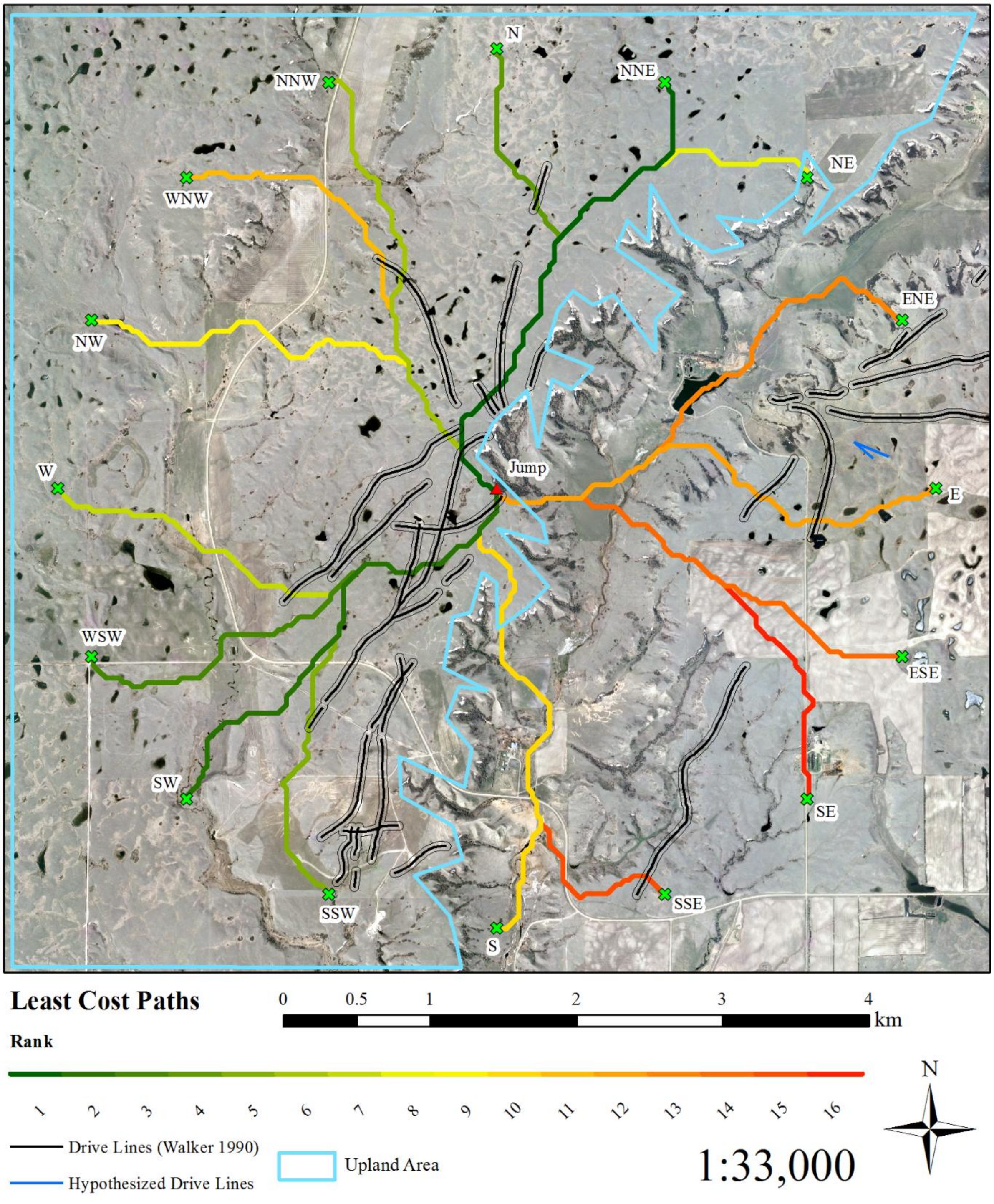


Figure A10: All 3km least cost paths for DhNe-75.

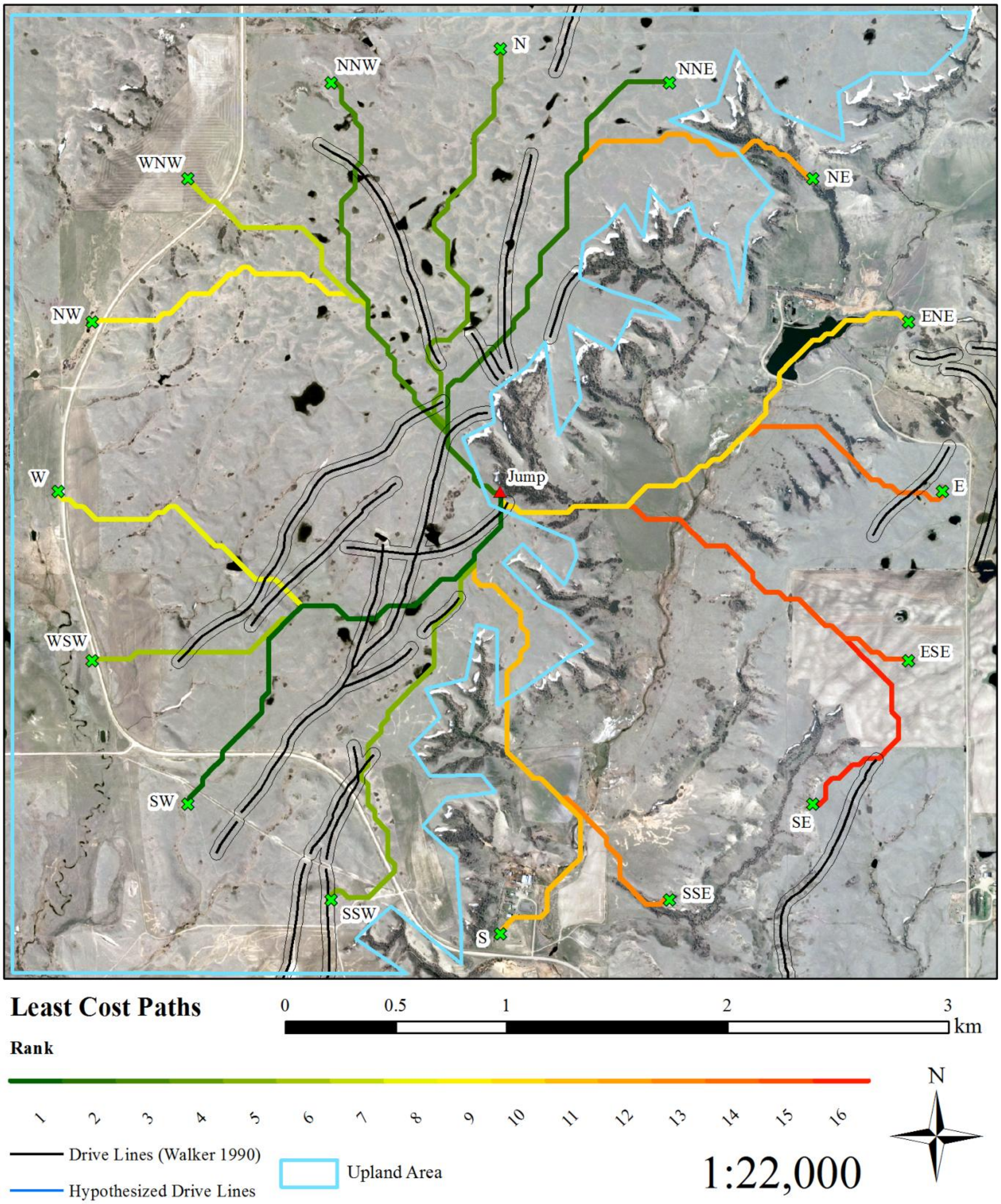


Figure A11: All 2km least cost paths for DhNe-75.

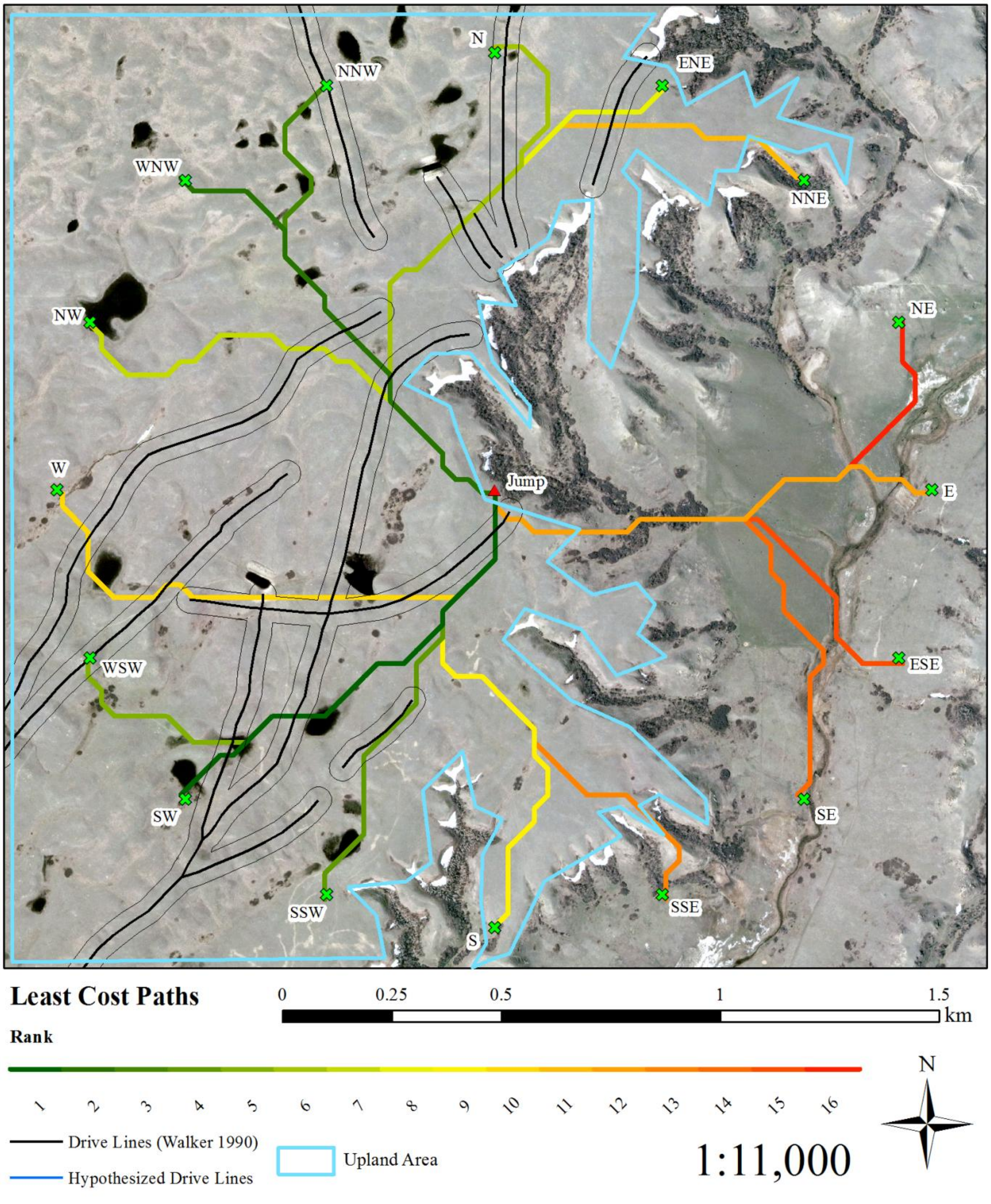


Figure A12: All 1km least cost paths for DhNe-75.

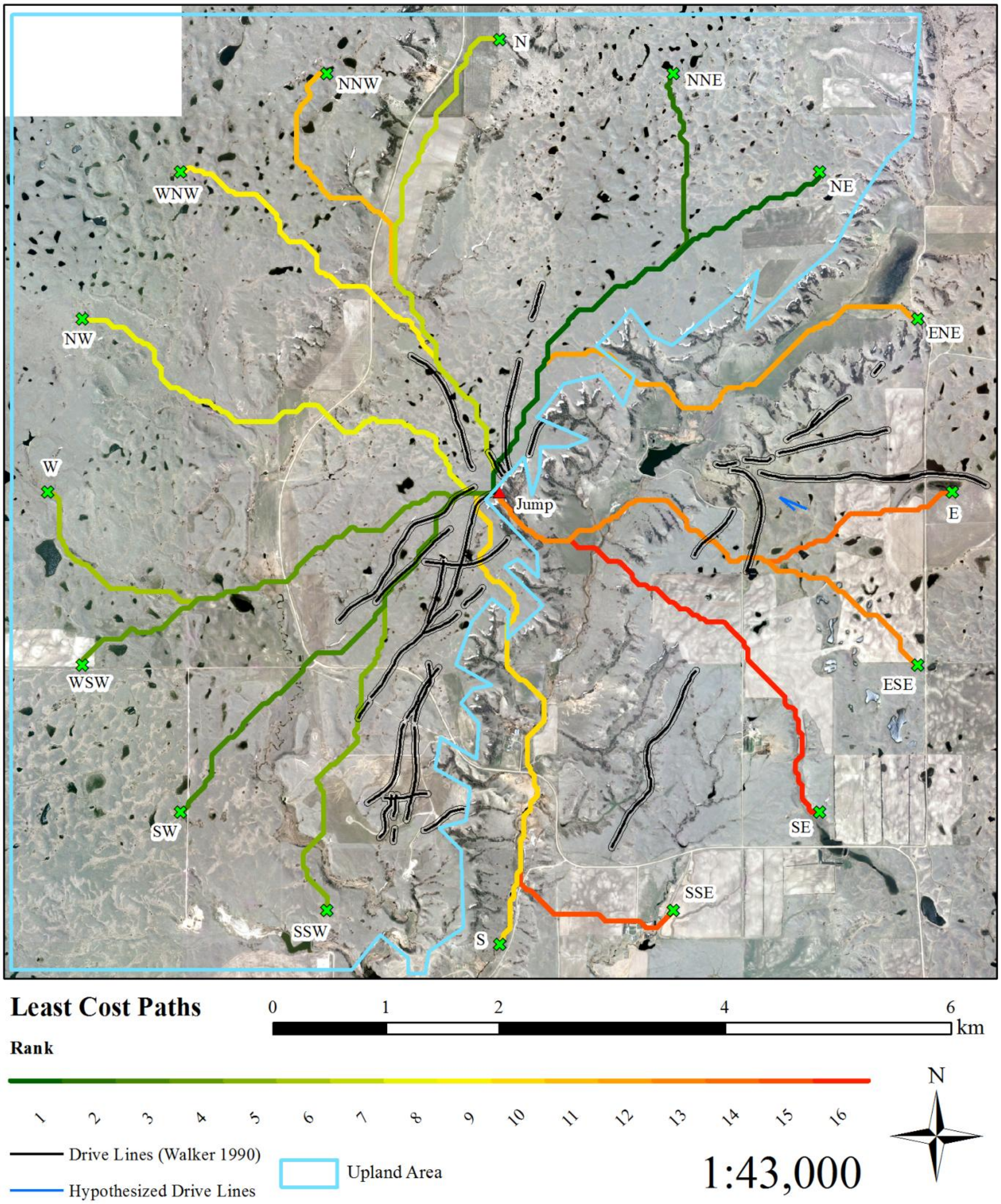


Figure A13: All 4km least cost paths for DhNe-76.

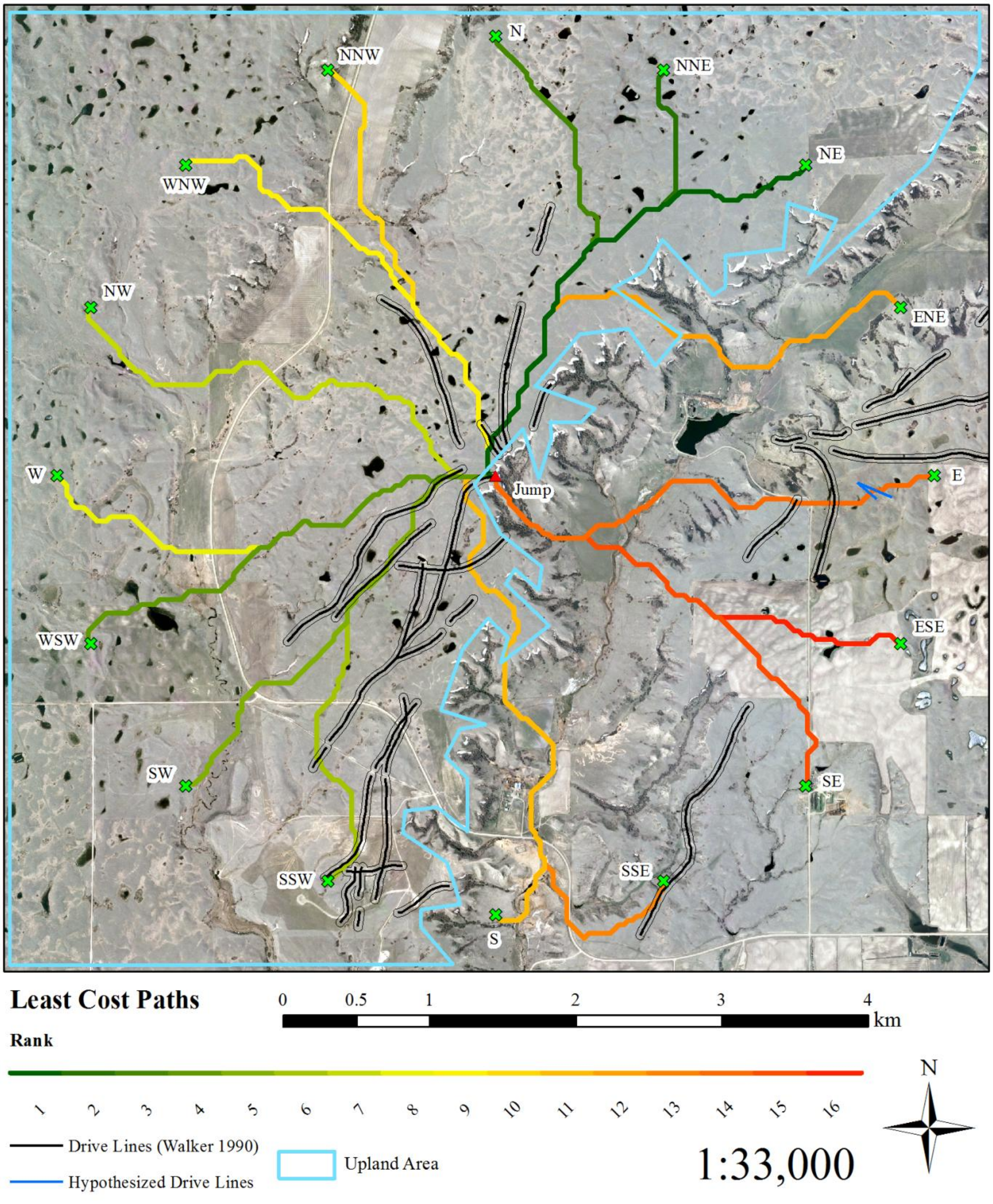


Figure A14: All 3km least cost paths for DhNe-76.

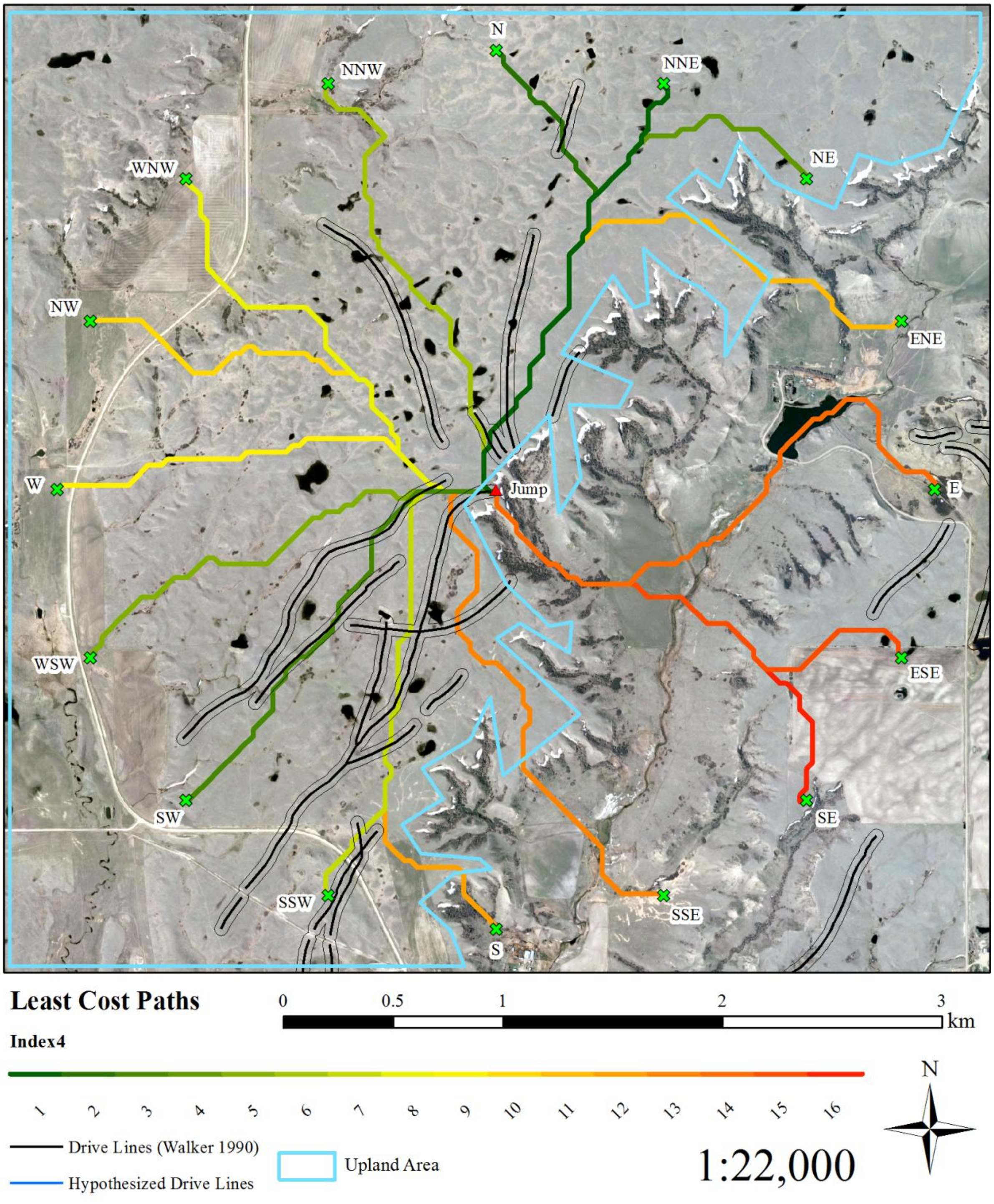


Figure A15: All 2km least cost paths for DhNe-76.

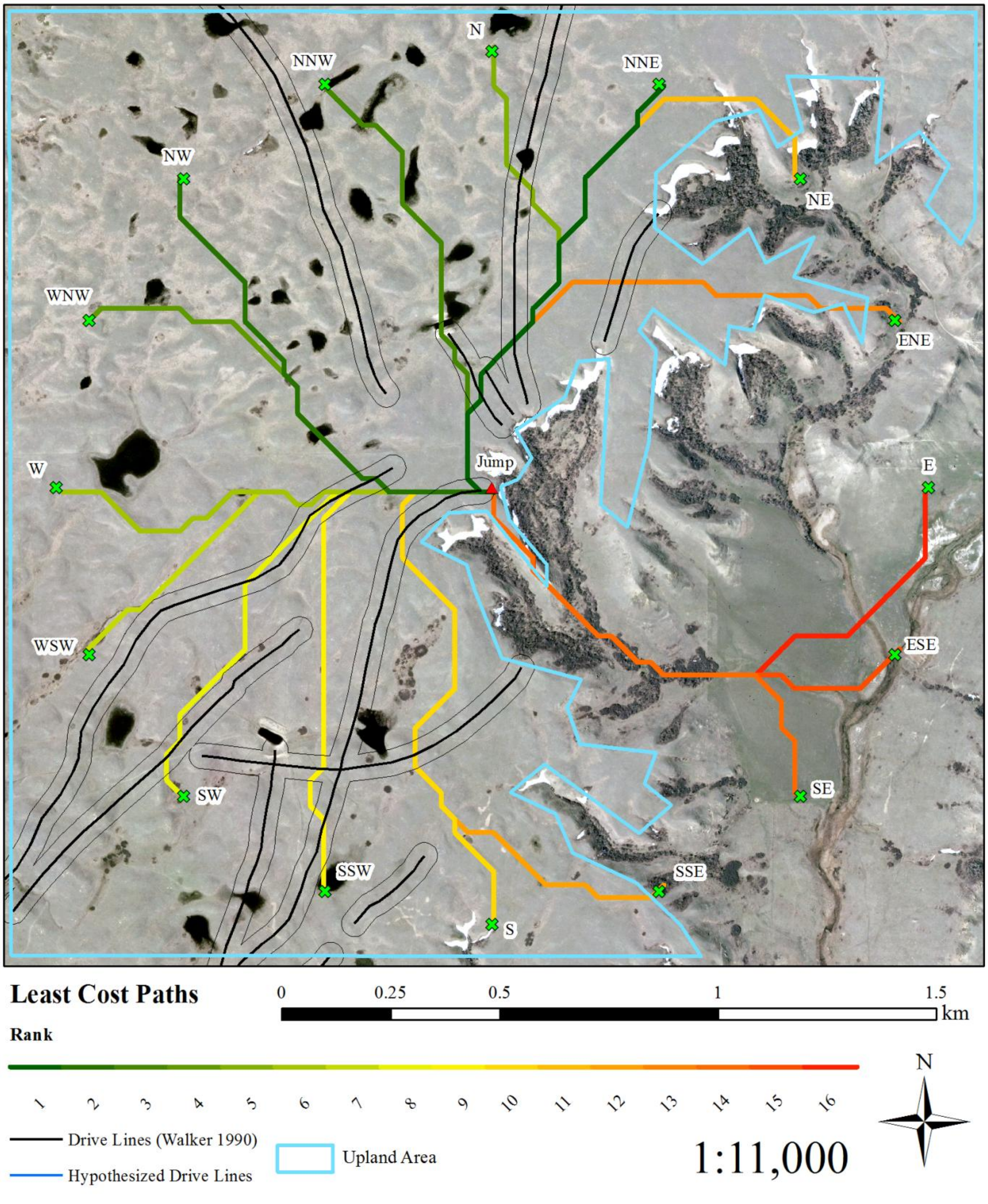


Figure A16: All 1km least cost paths for DhNe-76.

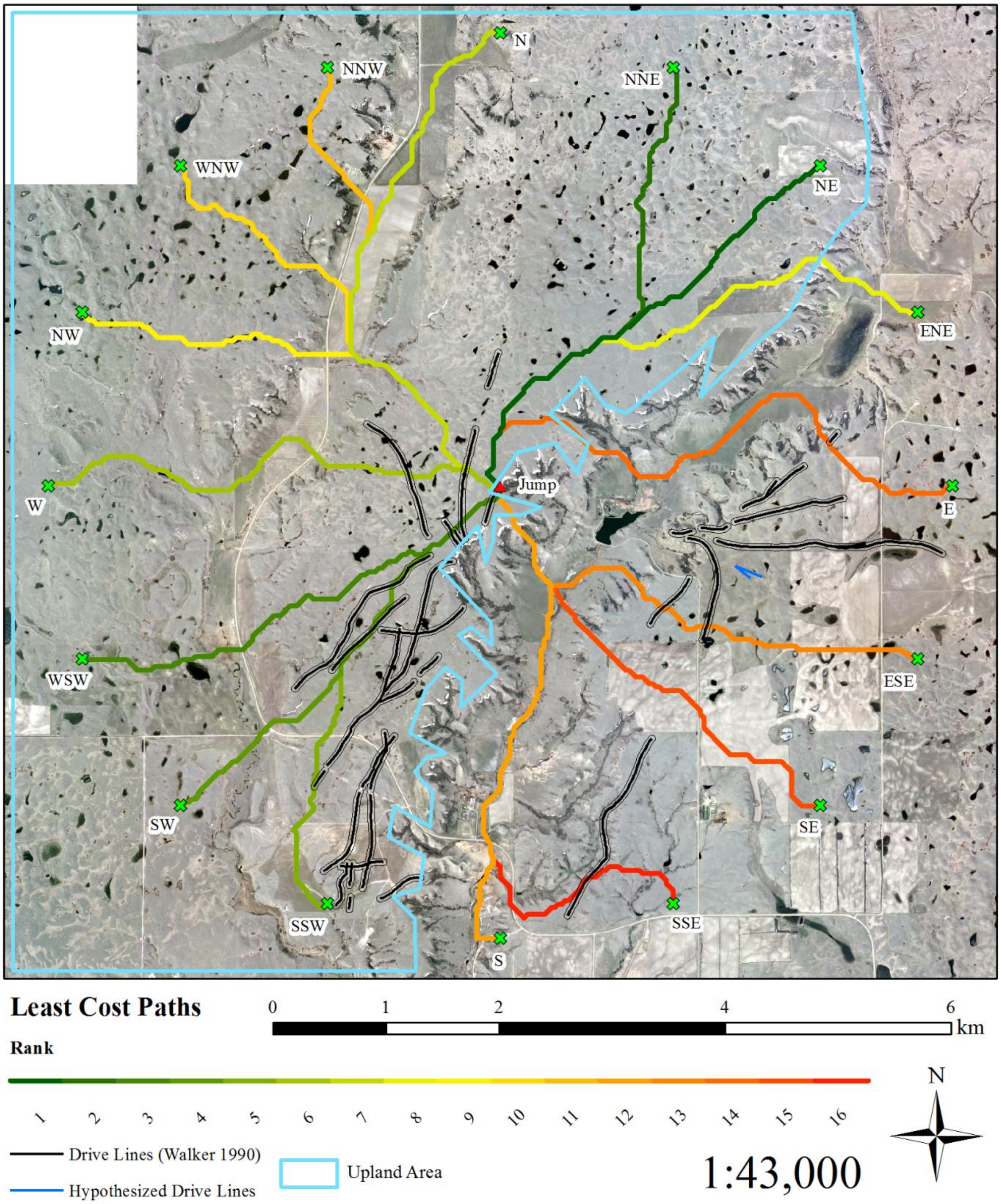


Figure A17: All 4km least cost paths for DhNe-77.

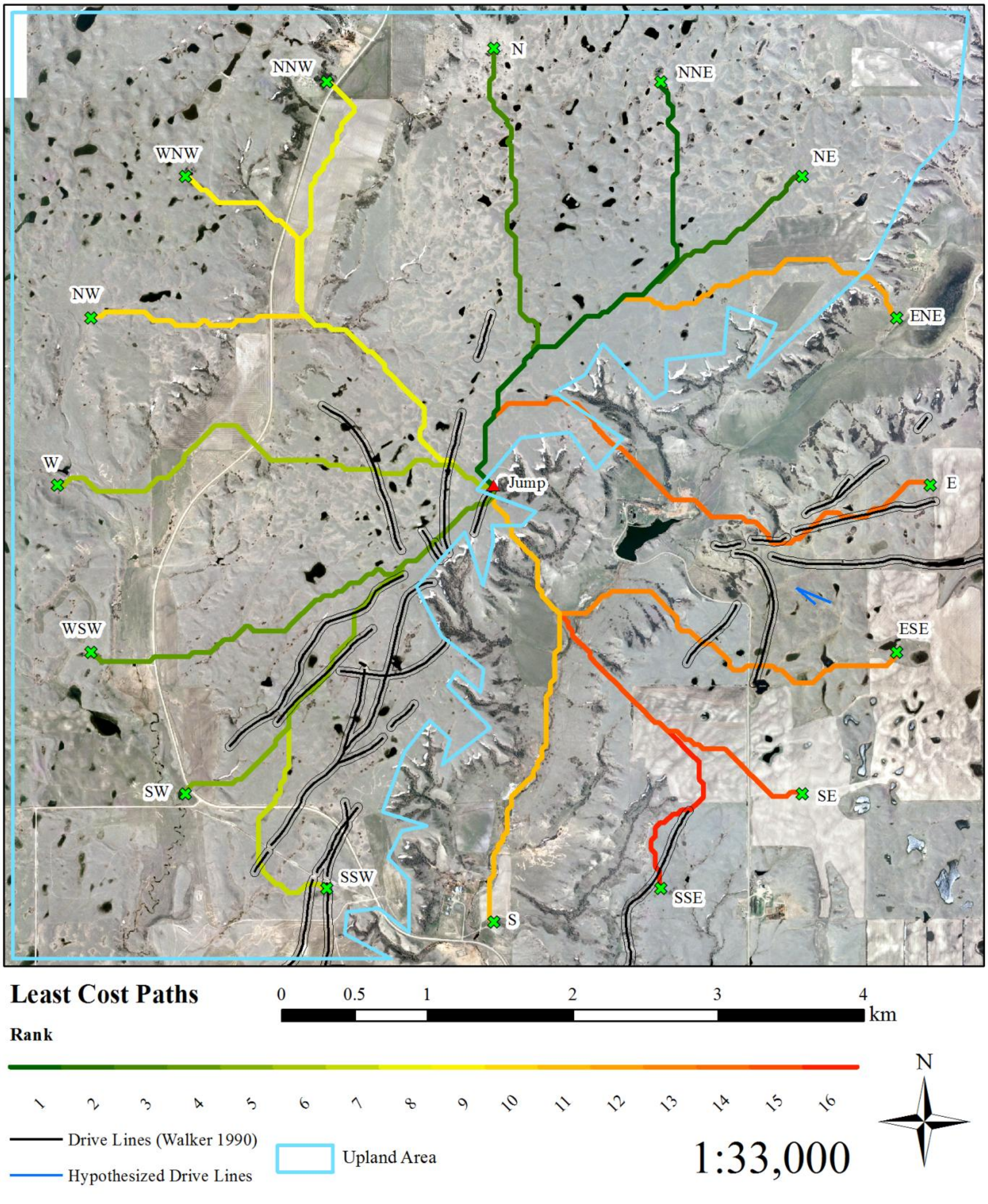


Figure A18: All 3km least cost paths for DhNe-77.

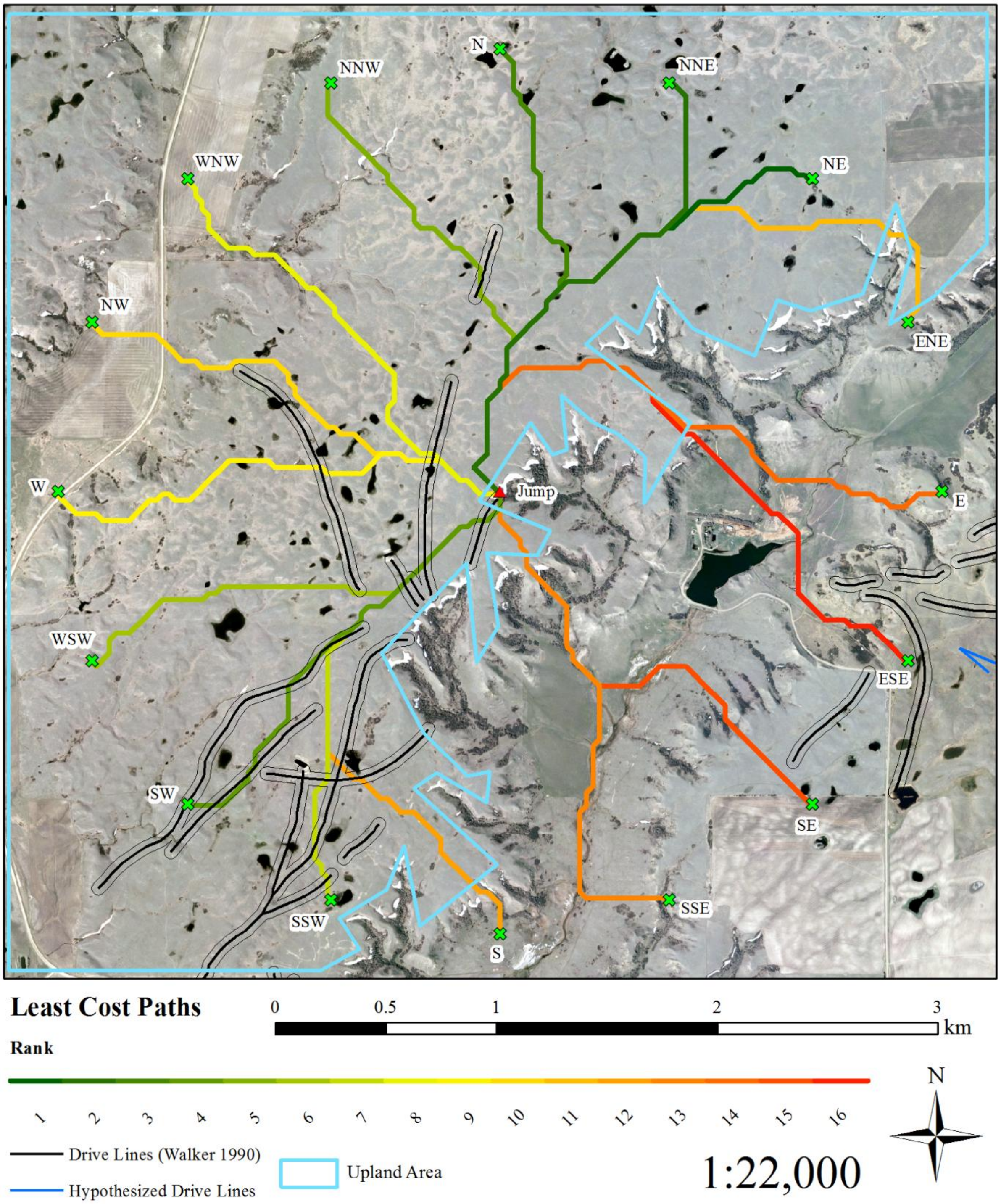


Figure A19: All 2km least cost paths for DhNe-77.

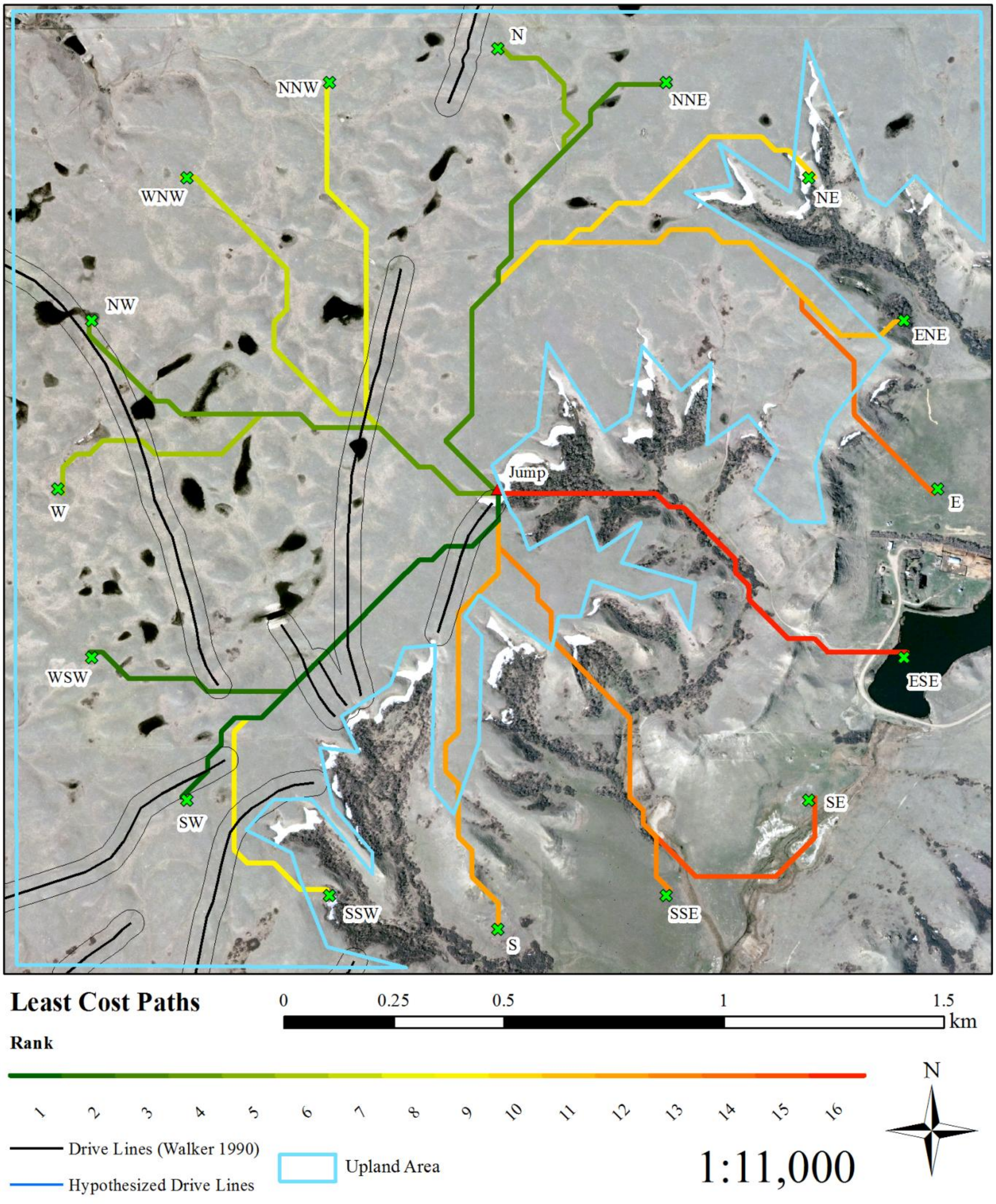


Figure A20: All 1km least cost paths for DhNe-77.

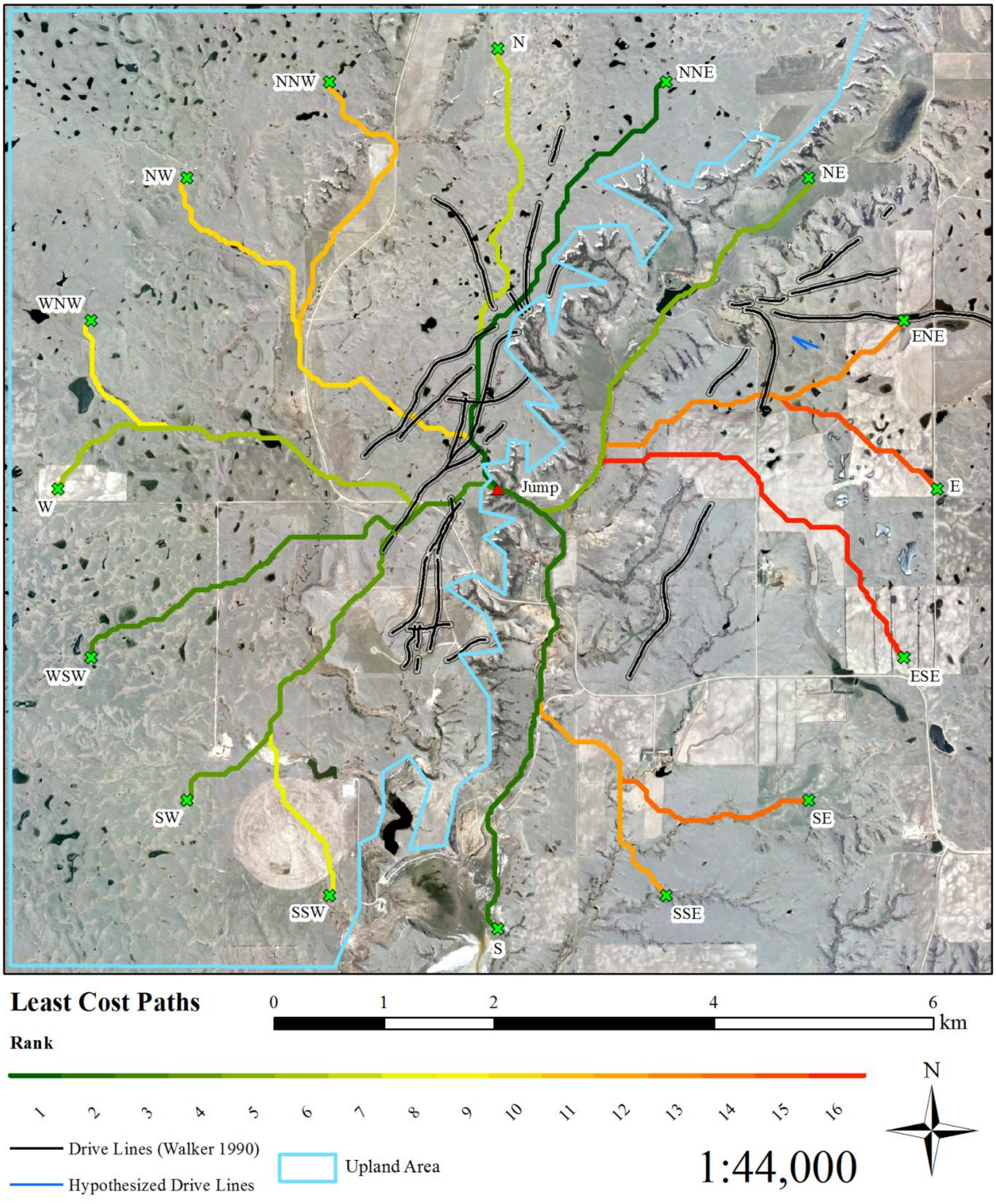
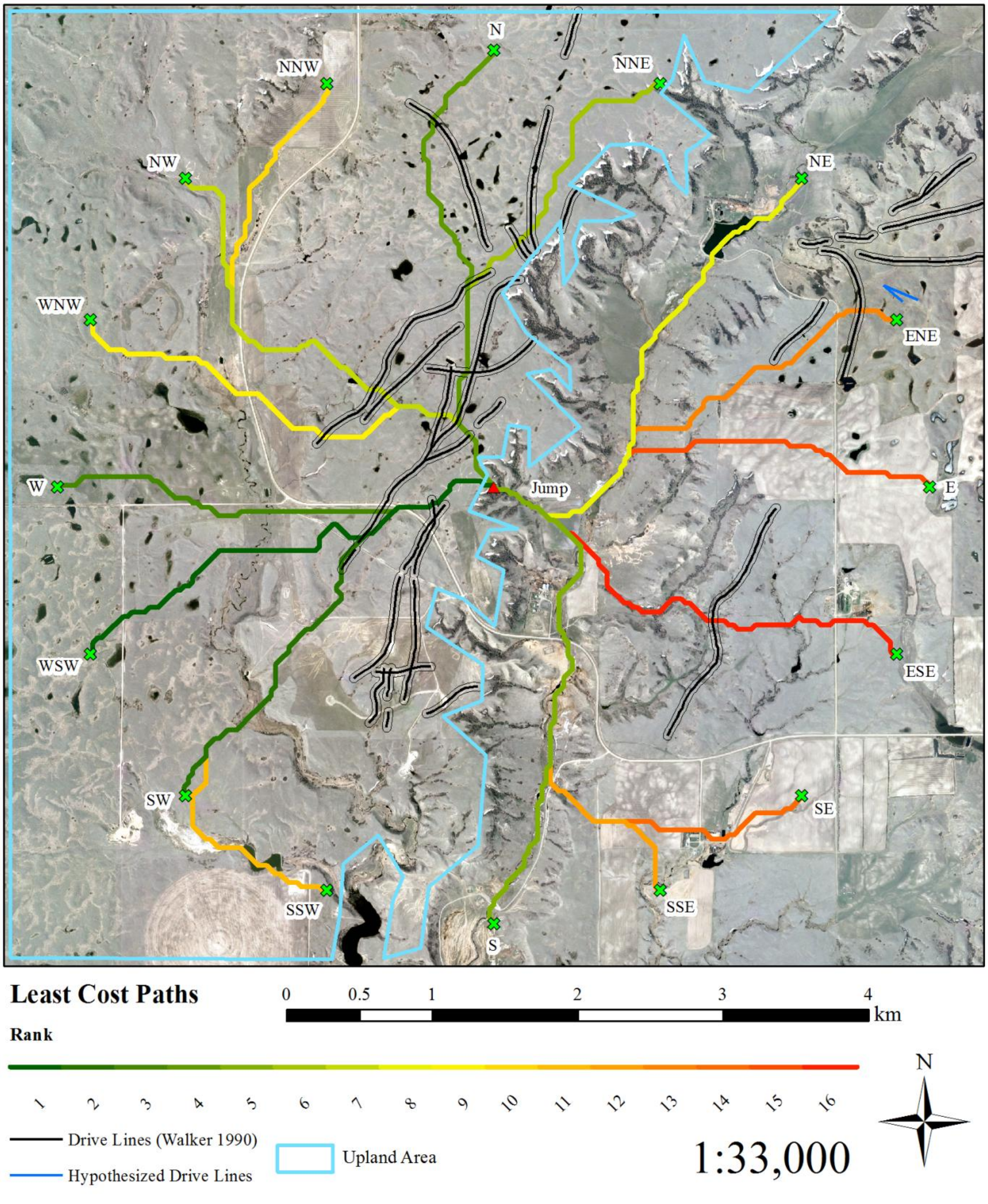


Figure A21: All 4km least cost paths for DhNe-82.



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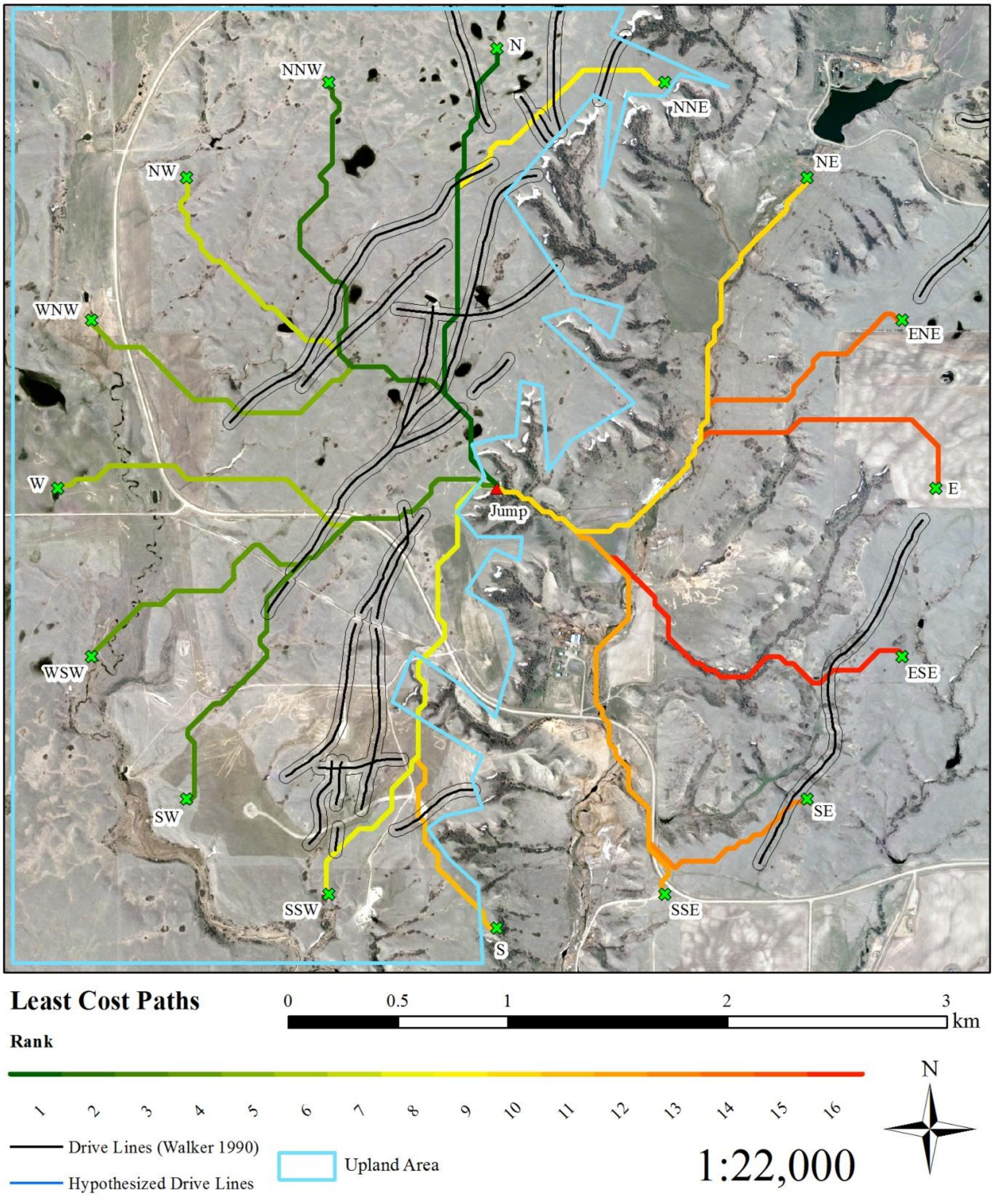

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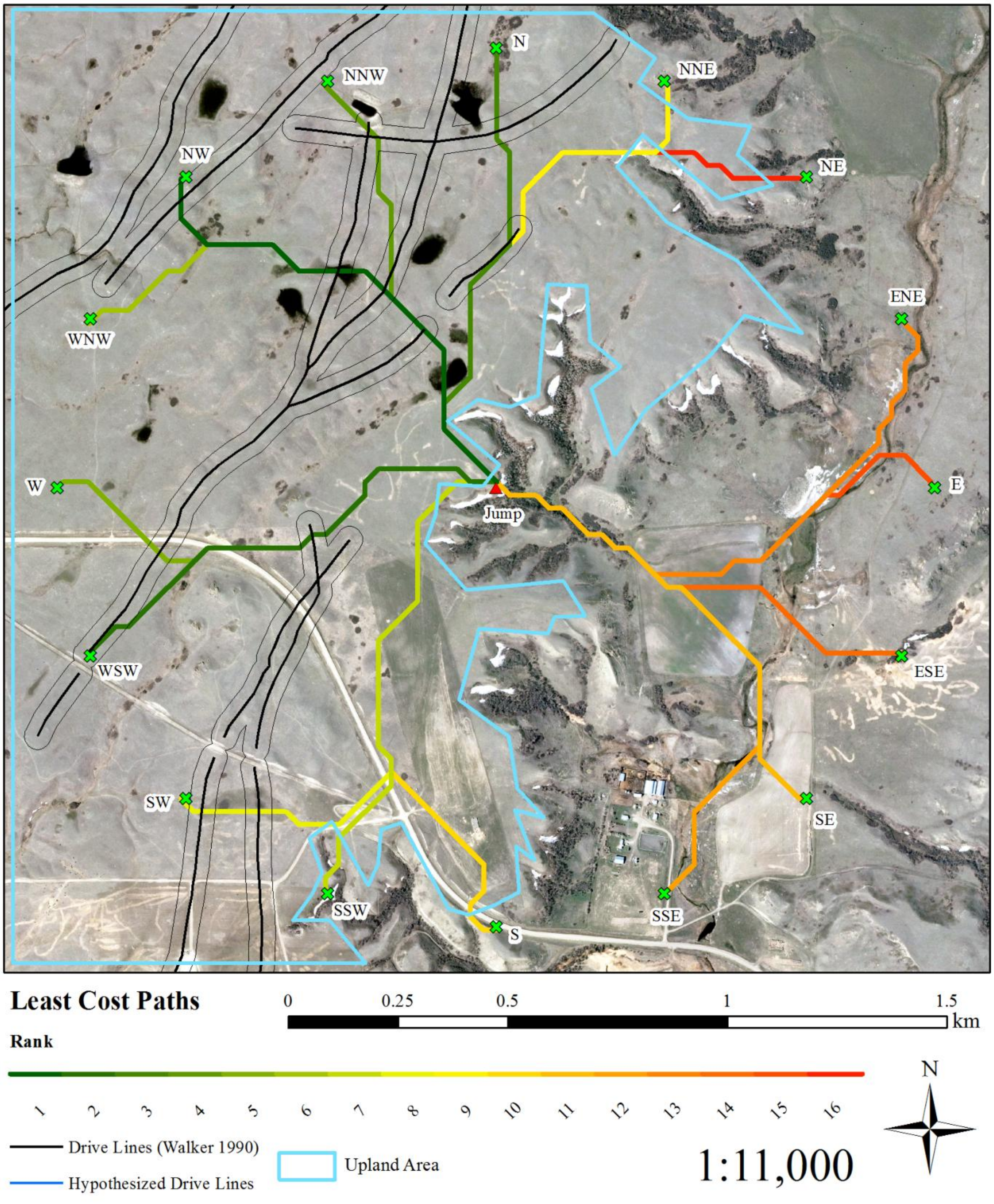

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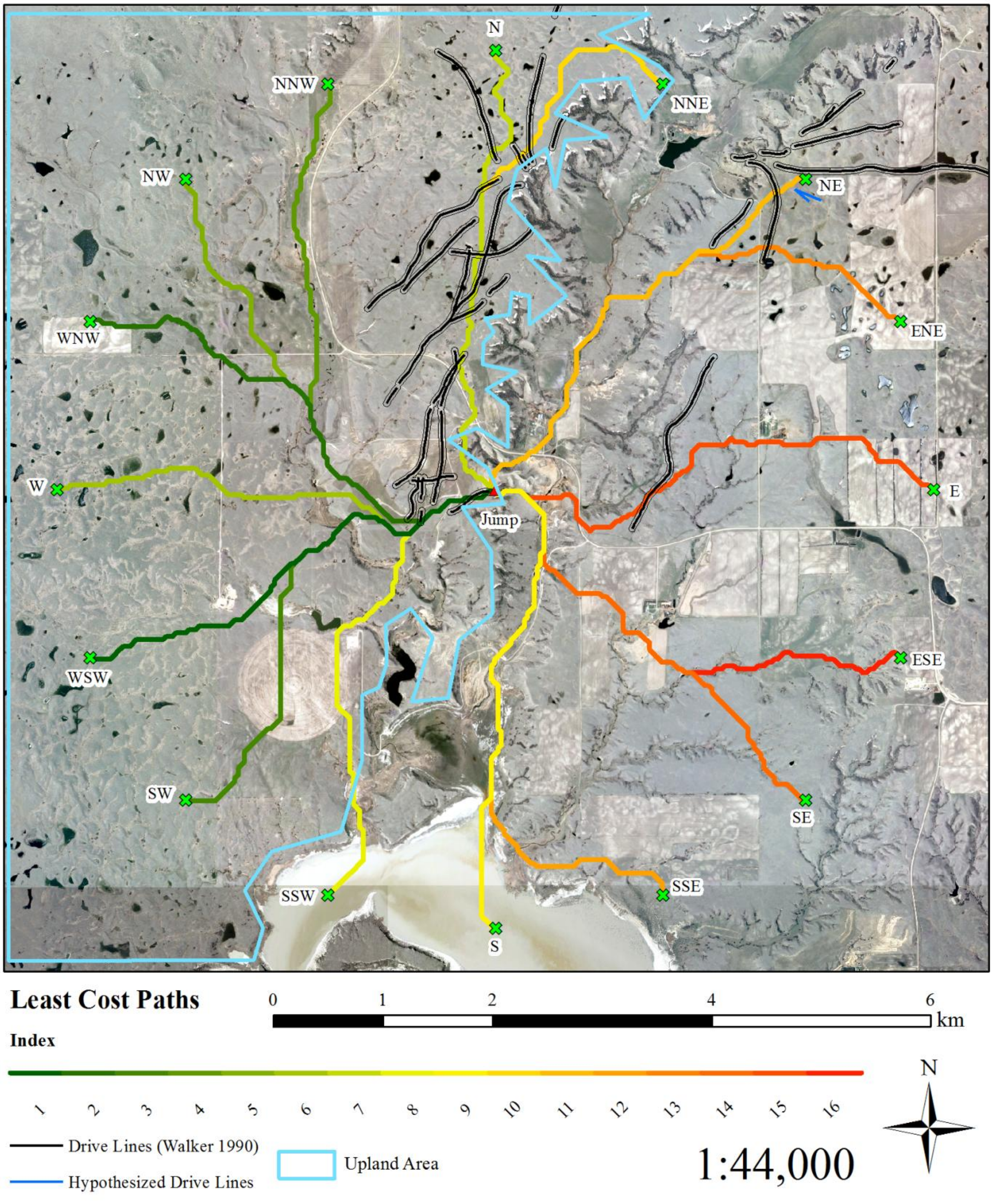

Figure A25: All 4km least cost paths for DhNe-89.

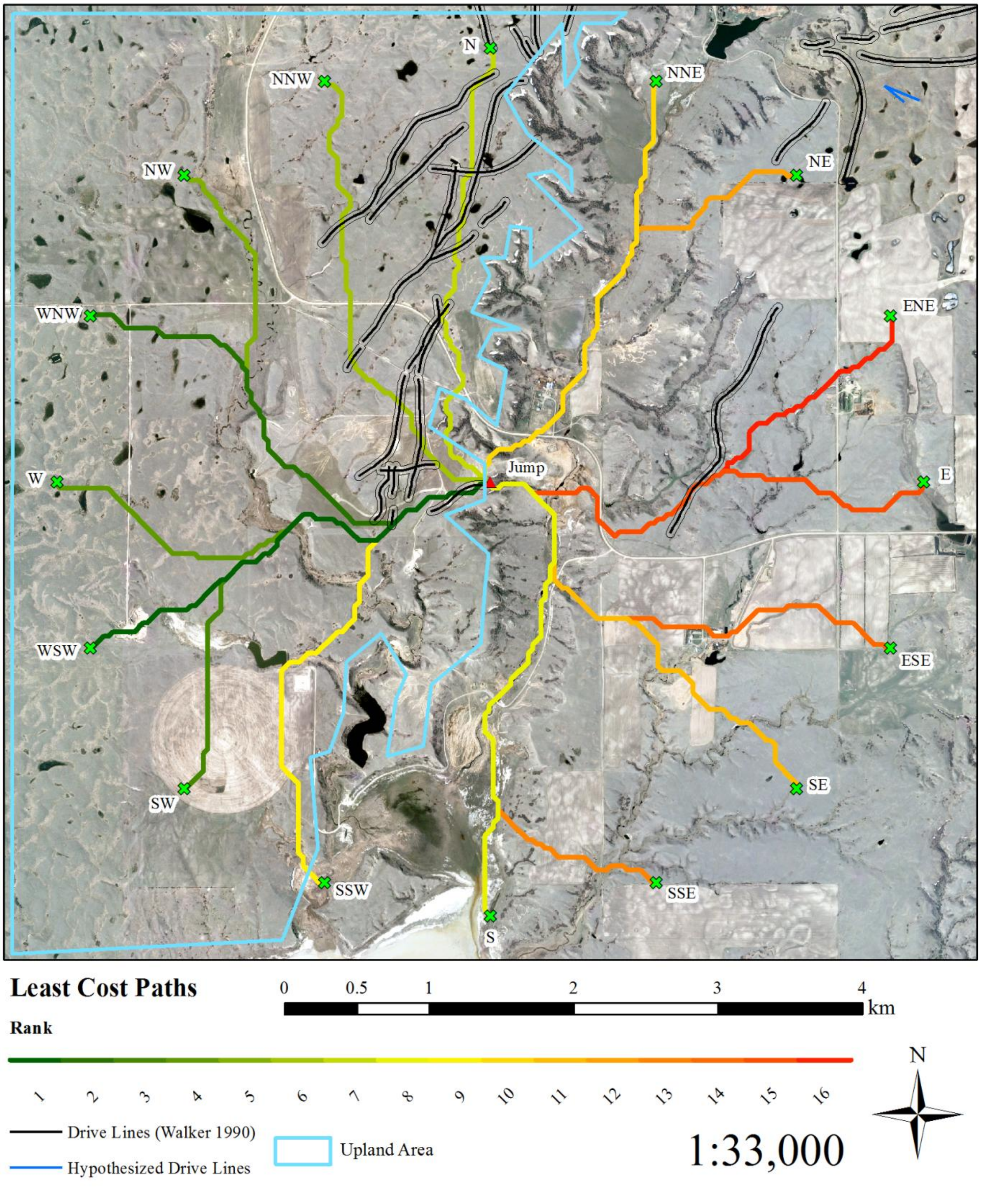

Figure A26: All 3km least cost paths for DhNe-89.

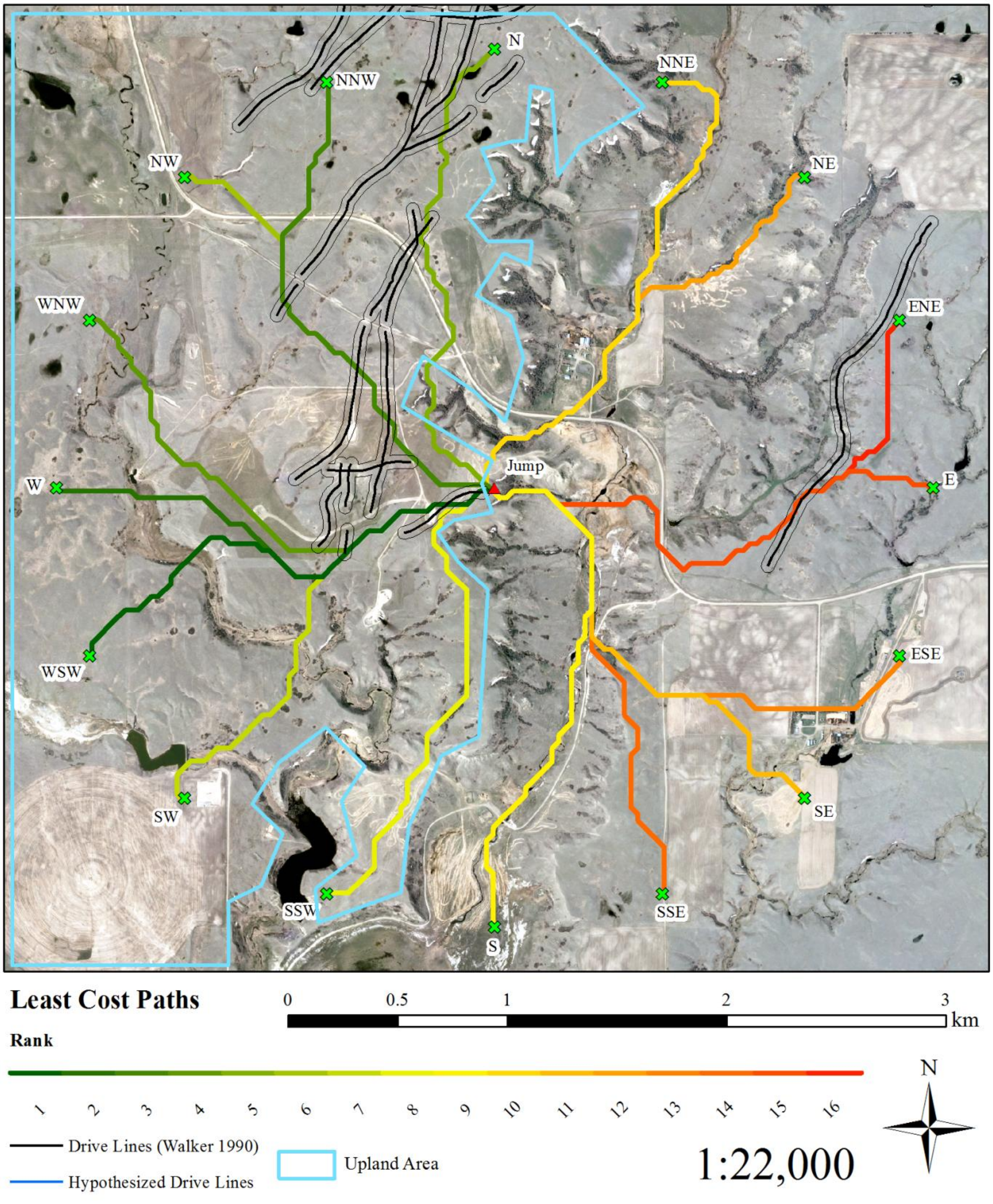

Figure A27: All 2km least cost paths for DhNe-89.

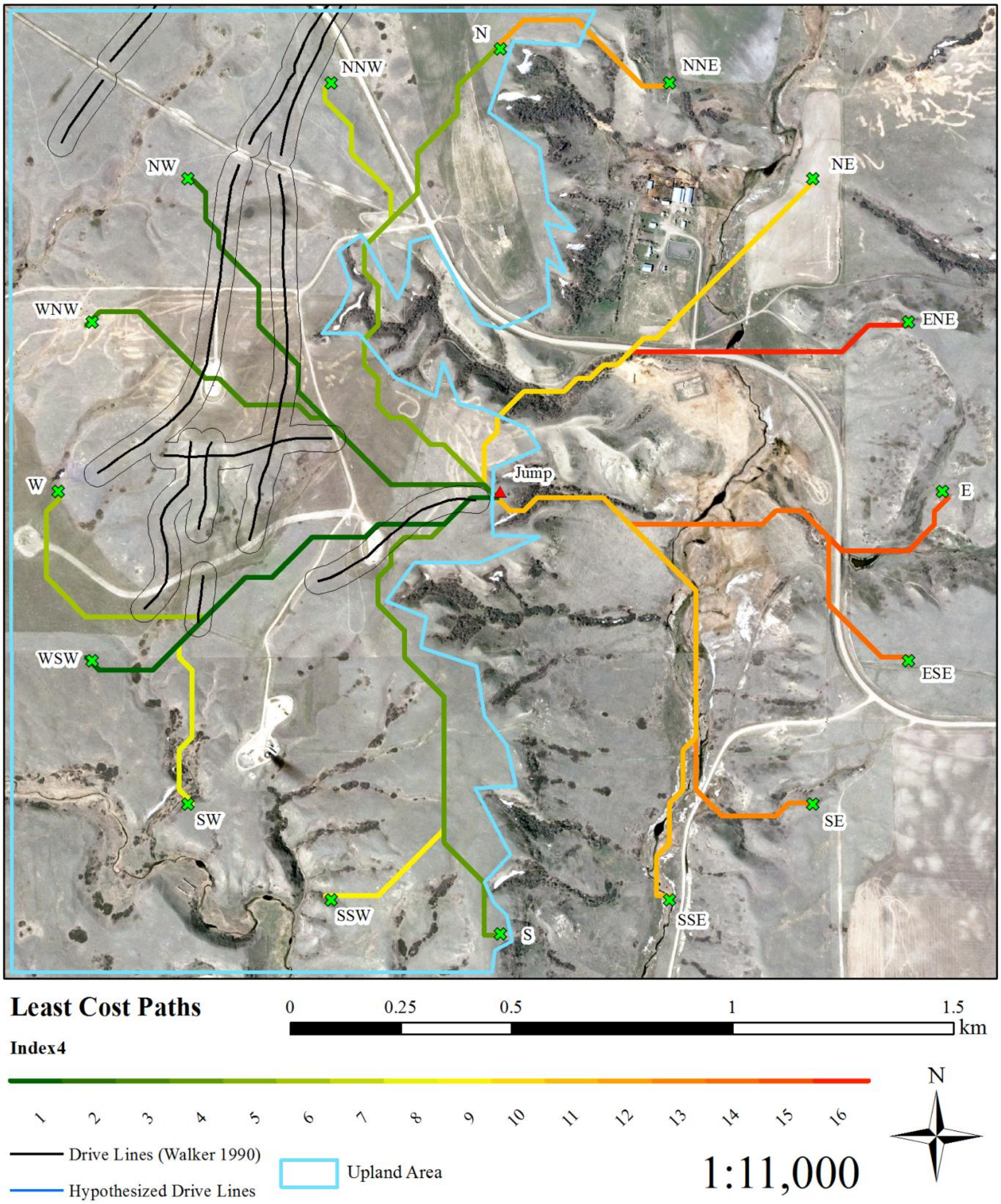

Figure A28: All 1km least cost paths for DhNe-89.

Table A1: Costs and ranks for DhNe-1 paths for a) 4km b) 3km c) 2km and d) 1km.

Path	*Cost*	*Rank*
ESE	**7,088.80**	**1**
E	**7,626.81**	**2**
NE	7,682.00	3
SE	**7,817.18**	**4**
SSE	**8,212.06**	**5**
ENE	8,317.98	6
SSW	8,502.88	7
NNE	8,730.79	8
S	**9,750.40**	**9**
N	10,108.29	10
SW	10,117.57	11
WSW	10,435.52	12
NNW	11,478.98	13
W	11,727.06	14
WNW	12,035.28	15
NW	12,945.29	16

a)

Path	*Cost*	*Rank*
ESE	**5,463.21**	**1**
NE	5,499.50	2
E	**5,546.12**	**3**
ENE	**5,660.79**	**4**
SE	**6,083.65**	**5**
SSE	**6,225.84**	**6**
S	**7,441.60**	**7**
NNE	7,707.35	8
WSW	8,186.04	9
NW	8,392.72	10
N	8,463.90	11
SW	8,644.99	12
SSW	8,775.59	13
WNW	8,854.48	14
NNW	8,896.39	15
W	9,678.90	16

b)

c)

Path	*Cost*	*Rank*
ESE	**3,975.72**	**1**
SE	**4,031.10**	**2**
NE	4,128.79	3
E	**4,361.90**	**4**
ENE	**4,610.24**	**5**
S	**4,705.73**	**6**
SSE	**5,147.21**	**7**
SW	6,023.08	8
NNE	6,290.28	9
SSW	6,476.58	10
NW	6,779.46	11
WSW	6,862.60	12
N	6,969.88	13
NNW	6,986.54	14
WNW	7,446.16	15
W	7,852.73	16

d)

Path	*Cost*	*Rank*
ESE	**2,606.73**	**1**
E	**2,845.67**	**2**
ENE	**3,031.89**	**3**
SE	**3,271.93**	**4**
WSW	3,292.55	5
S	**3,361.15**	**6**
SSE	**3,438.46**	**7**
N	3,508.62	8
NNE	3,511.20	9
SSW	**3,655.31**	**10**
NE	3,708.31	11
NNW	4,293.41	12
W	5,021.78	13
NW	5,108.72	14
SW	5,206.27	15
WNW	5,985.41	16

Table A2: Costs and ranks for DhNe-51 paths for a) 4km b) 3km c) 2km and d) 1km.

Path	*Cost*	*Rank*
NE	**6,131.73**	**1**
NNE	**6,240.48**	**2**
WSW	**7,240.20**	**3**
SW	**7,458.35**	**4**
N	**7,588.42**	**5**
SSW	**7,978.83**	**6**
NW	**8,210.00**	**7**
WNW	**8,375.62**	**8**
W	**8,577.55**	**9**
NNW	**9,042.52**	**10**
S	9,214.64	11
ENE	9,794.32	12
ESE	12,163.01	13
E	12,381.64	14
SSE	12,751.99	15
SE	13,810.88	16

a)

Path	*Cost*	*Rank*
NE	**4,801.76**	**1**
NNE	**4,958.78**	**2**
N	**5,130.91**	**3**
WSW	**5,798.71**	**4**
SW	**5,990.25**	**5**
SSW	**6,514.63**	**6**
NW	**7,014.18**	**7**
W	**7,059.70**	**8**
WNW	**7,316.02**	**9**
NNW	**7,365.26**	**10**
ENE	7,921.07	11
S	8,549.70	12
E	10,720.74	13
ESE	10,987.97	14
SSE	11,331.50	15
SE	11,767.20	16

b)

c)

Path	*Cost*	*Rank*
NNE	**2,929.22**	**1**
N	**3,361.02**	**2**
NE	**3,718.93**	**3**
SW	**3,763.21**	**4**
SSW	**4,496.46**	**5**
WSW	**4,559.79**	**6**
NNW	**4,726.42**	**7**
WNW	**4,740.97**	**8**
NW	**4,786.52**	**9**
W	**4,956.41**	**10**
S	6,268.63	11
ENE	6,542.72	12
SSE	8,509.74	13
E	9,363.84	14
ESE	9,752.90	15
SE	9,831.80	16

d)

Path	*Cost*	*Rank*
NNE	**1,552.22**	**1**
WNW	**1,777.59**	**2**
N	**1,846.32**	**3**
NW	**1,900.37**	**4**
NNW	**1,941.70**	**5**
W	**2,045.73**	**6**
WSW	**2,095.97**	**7**
SW	**2,190.37**	**8**
NE	2,475.34	9
SSW	**2,573.98**	**10**
S	**2,866.08**	**11**
ENE	4,564.57	12
SSE	4,612.42	13
ESE	5,449.35	14
SE	5,482.78	15
E	5,943.70	16

Table A3: Costs and ranks for DhNe-75 paths for a) 4km b) 3km c) 2km and d) 1km.

Path	*Cost*	*Rank*
NNE	**6,773.27**	**1**
SW	**7,178.14**	**2**
NE	**7,202.62**	**3**
WSW	**7,296.50**	**4**
W	**7,493.33**	**5**
SSW	**8,357.63**	**6**
WNW	**8,876.40**	**7**
N	**8,896.40**	**8**
NW	**9,257.65**	**9**
NNW	**9,504.19**	**10**
S	9,570.58	11
E	10,974.09	12
ENE	10,986.61	13
SSE	11,523.98	14
ESE	11,633.09	15
SE	13,238.16	16

a)

Path	*Cost*	*Rank*
NNE	**5,415.59**	**1**
SW	**5,764.18**	**2**
WSW	**5,958.05**	**3**
N	**6,069.62**	**4**
SSW	**6,291.02**	**5**
NNW	**6,495.12**	**6**
W	**6,652.35**	**7**
NE	6,882.73	8
WNW	**6,892.11**	**9**
S	7,544.78	10
NW	**8,013.80**	**11**
E	9,764.64	12
ENE	9,906.63	13
ESE	10,240.94	14
SSE	10,396.07	15
SE	11,473.58	16

b)

c)

Path	*Cost*	*Rank*
SW	**3589.88**	**1**
NNE	**3782.49**	**2**
NNW	**3973.62**	**3**
N	**4258.02**	**4**
SSW	**4373.28**	**5**
WSW	**4508.49**	**6**
NW	**4963.77**	**7**
W	**5065.86**	**8**
WNW	**5679.09**	**9**
ENE	5897.30	10
S	6428.14	11
NE	6636.84	12
SSE	6974.46	13
E	8379.19	14
ESE	8571.59	15
SE	9789.54	16

d)

Path	*Cost*	*Rank*
SW	**2,193.92**	**1**
NW	**2,250.45**	**2**
NNW	**2,257.87**	**3**
SSW	**2,447.50**	**4**
WSW	**2,506.99**	**5**
N	**2,539.53**	**6**
WNW	**2,627.16**	**7**
NNE	**2,797.93**	**8**
S	**2,932.65**	**9**
W	**3,052.46**	**10**
NE	4,344.80	11
E	4,484.58	12
SSE	4,601.28	13
SE	4,636.63	14
ESE	5,175.72	15
ENE	5,370.64	16

Table A4: Costs and ranks for DhNe-76 paths for a) 4km b) 3km c) 2km and d) 1km.

Path	*Cost*	*Rank*
NE	**6,455.25**	**1**
NNE	**6,526.34**	**2**
SW	**7,380.83**	**3**
WSW	**7,418.19**	**4**
SSW	**7,884.41**	**5**
W	**7,951.98**	**6**
N	**7,958.29**	**7**
WNW	**8,380.96**	**8**
NW	**8,668.68**	**9**
S	9,158.34	10
NNW	**9,534.09**	**11**
ENE	10,043.59	12
ESE	12,204.37	13
E	12,239.87	14
SSE	12,249.96	15
SE	13,404.92	16

a)

Path	*Cost*	*Rank*
NE	**5,031.42**	**1**
NNE	**5,236.06**	**2**
N	**5,387.11**	**3**
WSW	**5,895.69**	**4**
SW	**6,218.03**	**5**
SSW	**6,945.63**	**6**
WNW	**7,041.60**	**7**
W	**7,081.88**	**8**
NW	**7,600.34**	**9**
NNW	**7,641.43**	**10**
S	8,487.86	11
ENE	8,862.31	12
SSE	10,886.50	13
E	10,936.00	14
ESE	11,278.13	15
SE	11,713.95	16

b)

c)

Path	*Cost*	*Rank*
NNE	**3,193.45**	**1**
N	**3,705.82**	**2**
SW	**3,893.90**	**3**
NE	**4,248.00**	**4**
WSW	**4,549.94**	**5**
NNW	**4,621.46**	**6**
SSW	**4,635.02**	**7**
NW	**4,774.24**	**8**
W	**4,877.14**	**9**
WNW	**4,930.63**	**10**
ENE	6,889.20	11
S	6,935.66	12
SSE	7,304.87	13
E	9,017.73	14
ESE	9,574.39	15
SE	9,837.49	16

d)

Path	*Cost*	*Rank*
NNE	**1,856.04**	**1**
NW	**1,950.96**	**2**
NNW	**1,999.92**	**3**
WNW	**2,031.43**	**4**
N	**2,141.38**	**5**
W	**2,178.77**	**6**
WSW	**2,419.14**	**7**
SW	**2,440.86**	**8**
SSW	**2,734.01**	**9**
S	**2,948.28**	**10**
SSE	3,731.53	11
NE	3,881.85	12
ENE	4,639.98	13
SE	5,201.47	14
ESE	5,259.48	15
E	6,091.68	16

Table A5: Costs and ranks for DhNe-77 paths for a) 4km b) 3km c) 2km and d) 1km.

Path	*Cost*	*Rank*
NE	**6,852.44**	**1**
NNE	**7,167.41**	**2**
WSW	**7,529.30**	**3**
SW	**7,656.48**	**4**
SSW	**8,039.00**	**5**
W	**8,729.70**	**6**
N	**8,862.64**	**7**
ENE	9,039.32	8
WNW	**9,082.09**	**9**
NW	**9,424.18**	**10**
NNW	**10,085.35**	**11**
S	10,558.38	12
ESE	12,416.25	13
E	12,497.53	14
SE	13,048.32	15
SSE	14,006.84	16

a)

Path	*Cost*	*Rank*
NNE	**5,269.97**	**1**
NE	**5,551.69**	**2**
N	**5,651.81**	**3**
WSW	**6,398.18**	**4**
SW	**6,415.70**	**5**
W	**6,470.09**	**6**
SSW	**6,508.39**	**7**
NNW	**7,307.21**	**8**
NW	**7,483.21**	**9**
WNW	**7,554.44**	**10**
S	8,278.60	11
ENE	8,362.93	12
ESE	11,033.67	13
E	11,107.90	14
SE	11,156.95	15
SSE	12,302.22	16

b)

c)

Path	*Cost*	*Rank*
NE	**3869.08**	**1**
NNE	**3911.15**	**2**
N	**3912.30**	**3**
SW	**4074.22**	**4**
NNW	**4219.81**	**5**
WSW	**4395.20**	**6**
SSW	**4506.52**	**7**
NW	**4721.45**	**8**
W	**4933.06**	**9**
WNW	**5395.00**	**10**
ENE	5555.53	11
S	7158.60	12
SSE	9360.51	13
E	9660.57	14
SE	9686.49	15
ESE	9948.78	16

d)

Path	*Cost*	*Rank*
SW	**1,944.09**	**1**
WSW	**2,100.43**	**2**
NNE	**2,200.49**	**3**
WNW	**2,391.69**	**4**
N	**2,499.58**	**5**
W	**2,503.05**	**6**
NW	**2,562.23**	**7**
NNW	**2,797.93**	**8**
SSW	3,168.54	9
NE	3,405.87	10
ENE	4,067.69	11
S	4,704.80	12
SSE	5,255.80	13
E	5,699.95	14
SE	5,784.02	15
ESE	6,318.52	16

Table A6: Costs and ranks for DhNe-82 paths for a) 4km b) 3km c) 2km and d) 1km.

Path	*Acc. Cost*	*Rank*
NNE	**7,485.67**	**1**
S	7,693.62	2
WSW	**7,811.47**	**3**
SW	**7,866.07**	**4**
NE	7,967.00	5
W	**8,025.98**	**6**
N	**8,175.43**	**7**
SSW	**8,300.73**	**8**
WNW	**8,324.23**	**9**
NW	**8,492.20**	**10**
NNW	**9,804.69**	**11**
SSE	10,878.99	12
ENE	10,904.10	13
SE	11,245.73	14
E	11,284.94	15
ESE	12,441.23	16

a)

Path	*Cost*	*Rank*
WSW	**6,165.85**	**1**
SW	**6,180.79**	**2**
W	**6,252.44**	**3**
N	**6,333.75**	**4**
S	6,410.42	5
NNE	**6,439.79**	**6**
NW	**6,541.67**	**7**
NE	6,738.44	8
WNW	**6,784.50**	**9**
NNW	**6,998.83**	**10**
SSW	**7,933.36**	**11**
SSE	8,176.31	12
ENE	9,790.70	13
SE	9,815.76	14
E	10,166.90	15
ESE	11,175.45	16

b)

c)

Path	*Cost*	*Rank*
N	**4,598.14**	**1**
NNW	**4,758.25**	**2**
SW	**4,761.26**	**3**
WSW	**4,775.53**	**4**
WNW	**4,865.08**	**5**
W	**4,941.76**	**6**
NW	**5,132.75**	**7**
SSW	**5,328.66**	**8**
NNE	**5,367.22**	**9**
NE	5,395.68	10
S	5,405.44	11
SSE	6,634.66	12
SE	7,580.20	13
ENE	8,254.38	14
E	8,623.98	15
ESE	9,194.23	16

d)

Path	*Cost*	*Rank*
NW	**2,443.91**	**1**
WSW	**2,477.48**	**2**
N	**2,501.82**	**3**
NNW	**2,595.53**	**4**
W	**2,611.57**	**5**
WNW	**2,629.63**	**6**
SSW	2,740.04	7
SW	**2,928.03**	**8**
NNE	2,998.53	9
S	3,276.71	10
SE	3,773.73	11
SSE	3,815.62	12
ENE	3,826.65	13
ESE	3,875.70	14
E	4,256.66	15
NE	4,810.63	16

Table A7: Costs and ranks for DhNe-89 paths for a) 4km b) 3km c) 2km and d) 1km.

Path	*Cost*	*Rank*
WSW	**6,523.01**	**1**
WNW	**6,974.40**	**2**
SW	**7,118.78**	**3**
NNW	**7,144.88**	**4**
NW	**7,755.38**	**5**
W	**7,798.09**	**6**
N	**8,290.00**	**7**
SSW	8,432.87	8
S	8,475.87	9
NNE	9,742.22	10
NE	11,351.28	11
SSE	11,362.76	12
ENE	12,090.81	13
SE	12,254.66	14
E	13,011.37	15
ESE	13,138.61	16

a)

Path	*Cost*	*Rank*
WSW	**5,294.77**	**1**
WNW	**5,313.53**	**2**
SW	**5,539.90**	**3**
W	**5,595.76**	**4**
NW	**5,660.26**	**5**
NNW	**6,103.41**	**6**
N	**6,553.47**	**7**
S	6,852.85	8
SSW	6,980.16	9
NNE	7,270.86	10
SE	9,668.48	11
NE	9,919.60	12
SSE	10,028.43	13
ESE	10,031.26	14
E	10,992.05	15
ENE	11,116.52	16

b)

c)

Path	*Cost*	*Rank*
WSW	**3,851.05**	**1**
W	**4,002.32**	**2**
NNW	**4,019.54**	**3**
WNW	**4,055.03**	**4**
N	**4,517.38**	**5**
NW	**4,537.52**	**6**
SW	**4,722.14**	**7**
SSW	**4,820.93**	**8**
S	5,467.38	9
NNE	6,423.90	10
SE	7,400.19	11
NE	7,650.88	12
ESE	7,790.03	13
SSE	7,841.41	14
E	8,363.89	15
ENE	9,140.52	16

d)

Path	*Cost*	*Rank*
WSW	**2,164.05**	**1**
NW	**2,224.79**	**2**
WNW	**2,546.69**	**3**
S	**2,568.11**	**4**
N	**2,660.79**	**5**
W	**2,729.46**	**6**
NNW	**2,734.86**	**7**
SW	**2,887.86**	**8**
SSW	**3,814.13**	**9**
NE	4,219.48	10
SSE	4,249.19	11
NNE	5,051.17	12
SE	5,452.54	13
ESE	5,655.93	14
E	5,921.66	15
ENE	6,178.51	16

Appendix B
Viewsheds

Below are the many of the viewsheds not seen in Chapter Six for both the Sabin and Ironhorse sites. As many adjacent cells present redundant viewsheds, every second viewing location is presented. In a bison drive scenario, these would result in time slices between approximately four and six seconds of running time at top speed (50km/hr). Deviations from this scheme were given where necessary to avoid re-showing viewsheds found already in Chapter Six.

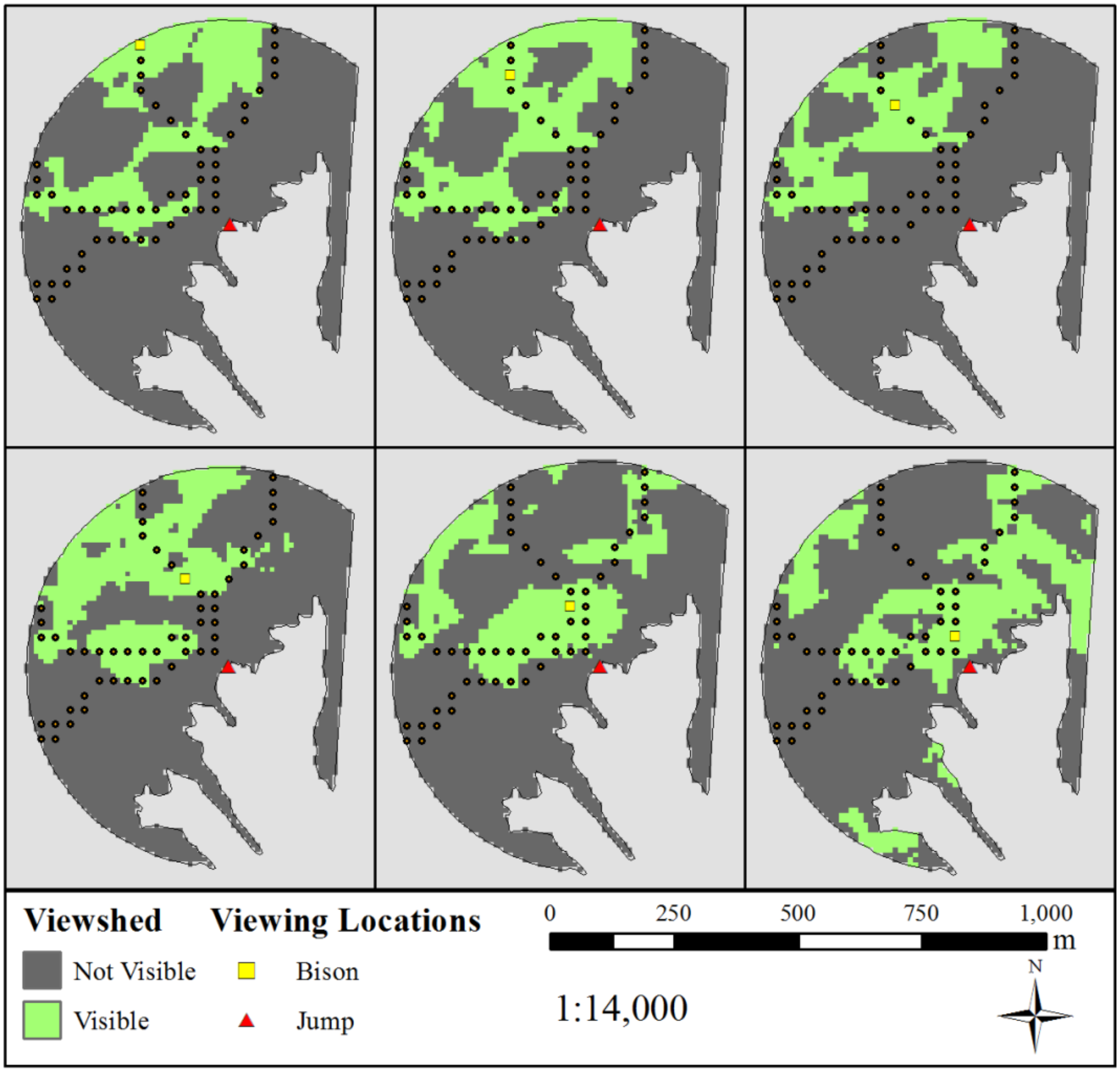

Figure B1: Viewsheds from the NW route for DhNe-51.

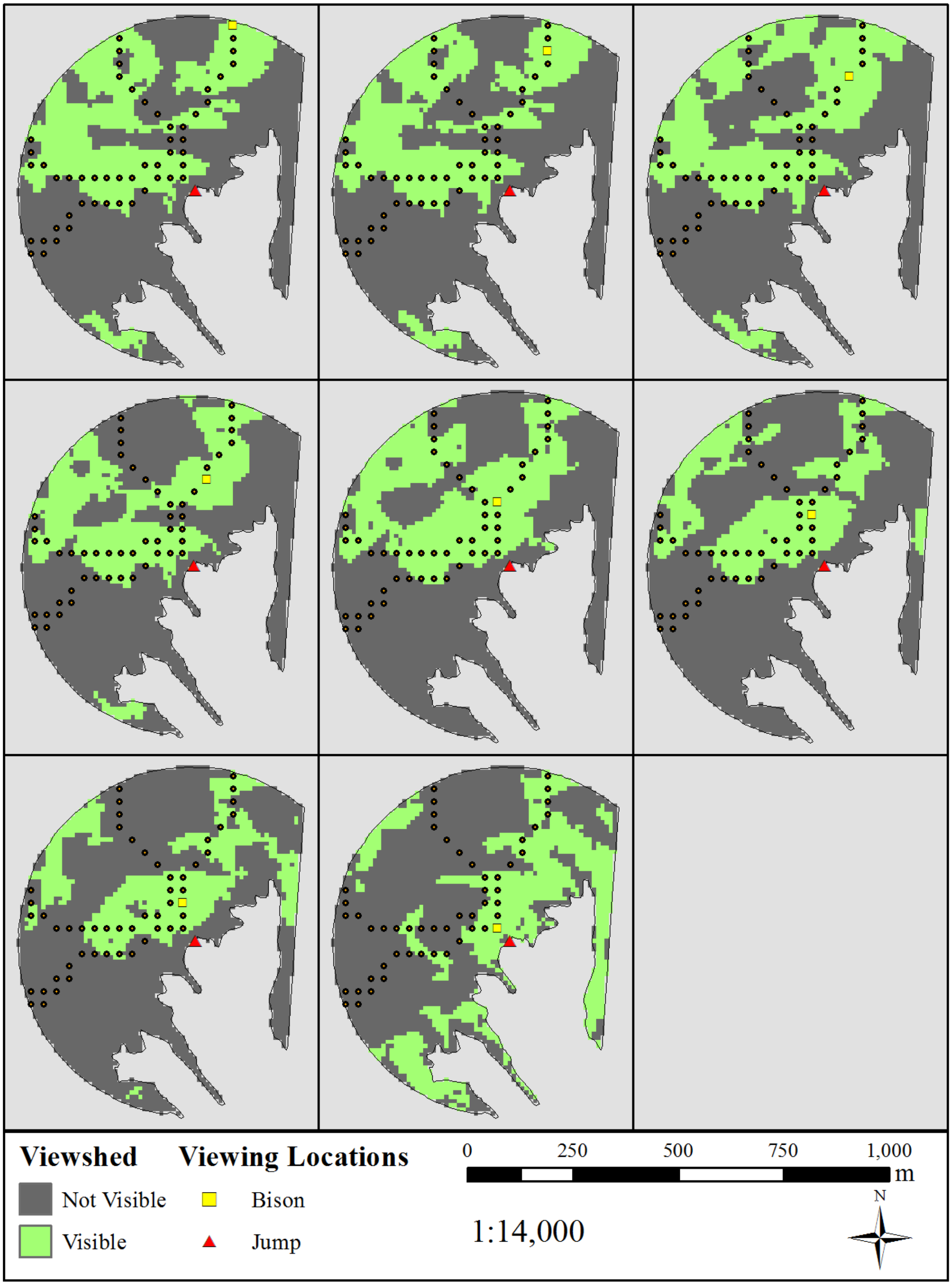

Figure B2: Viewsheds from the NE route for DhNe-51.

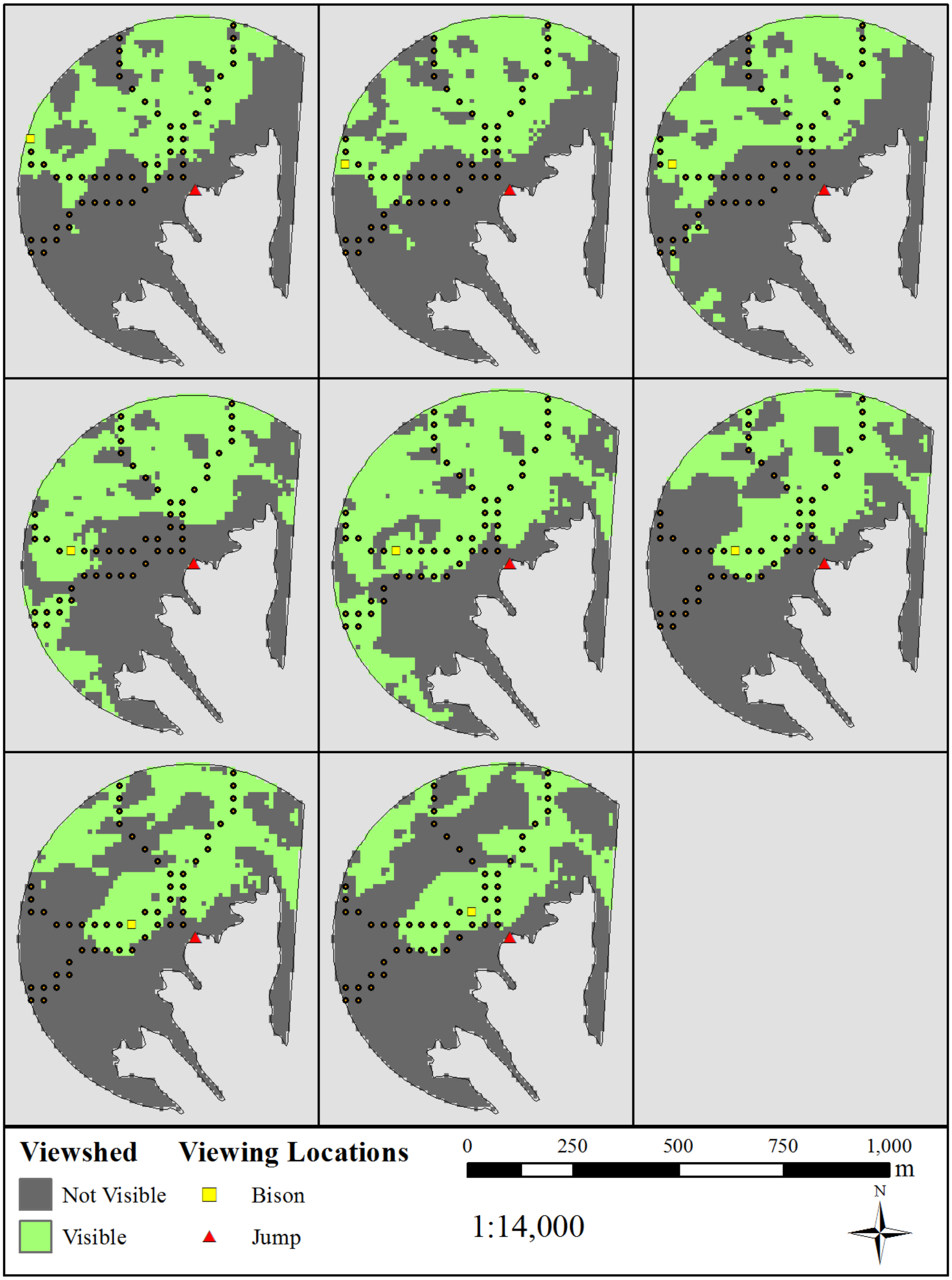

Figure B3: Viewsheds from the W route for DhNe-51.

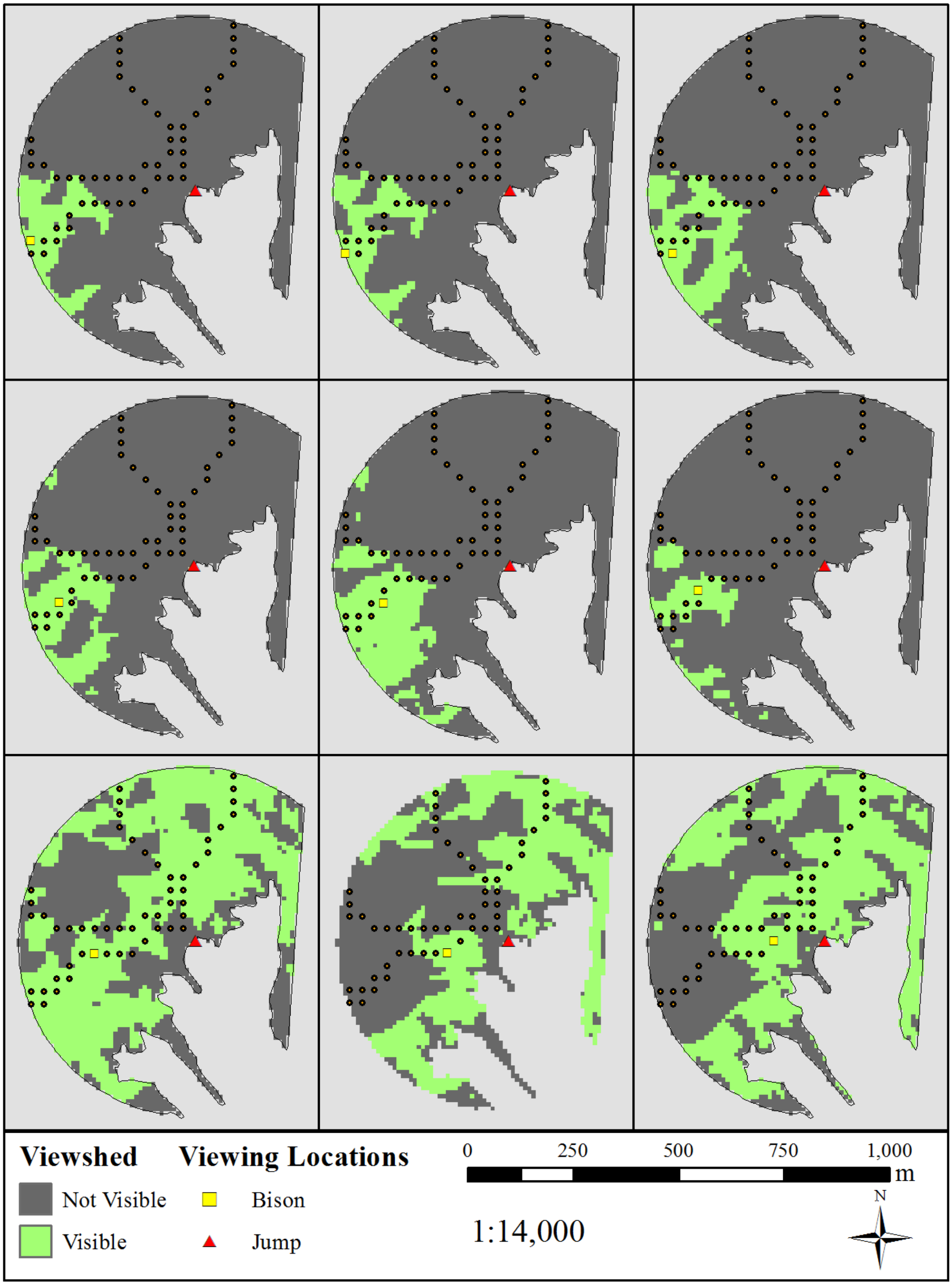

Figure B4: Viewsheds from the SW route for DhNe-51.

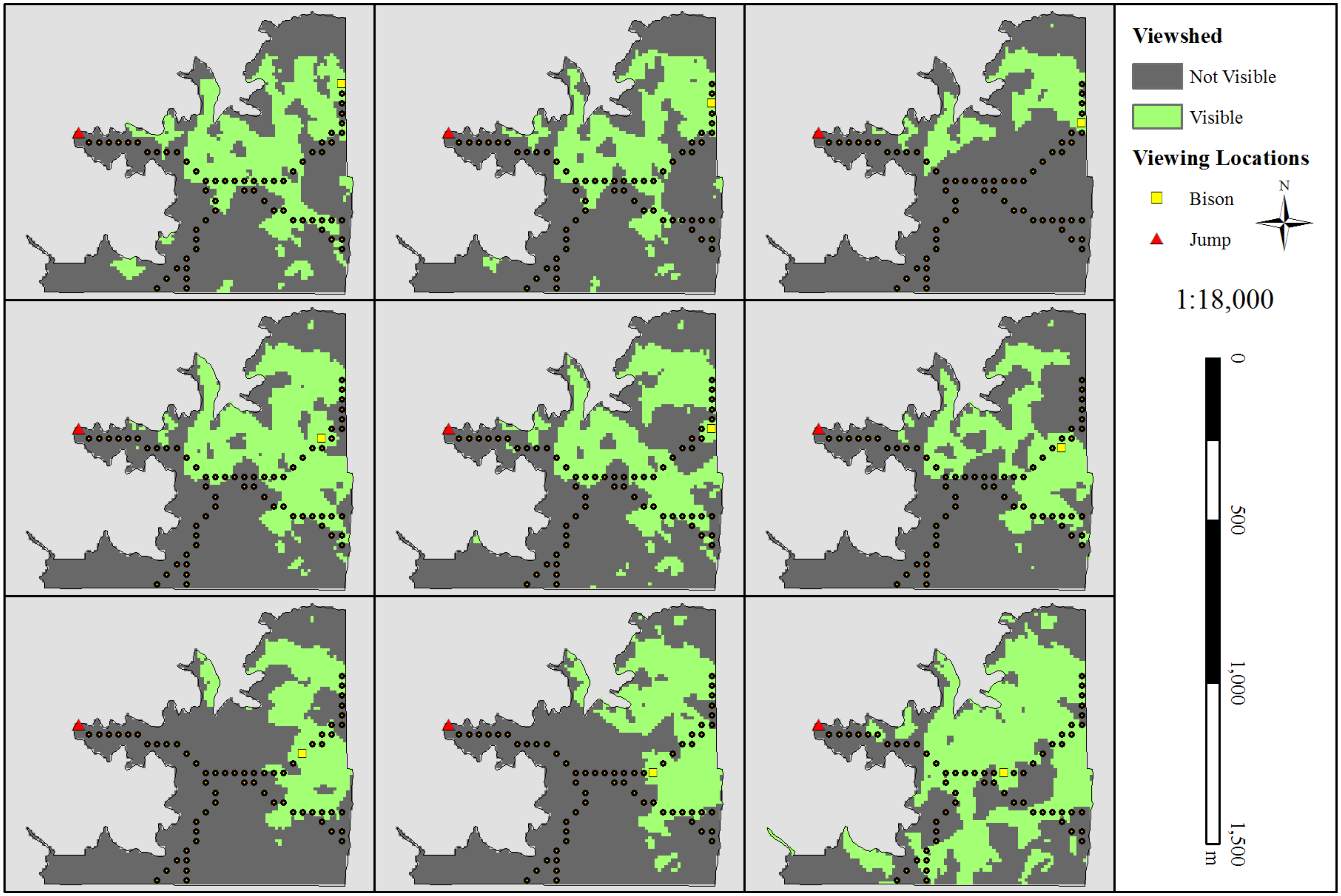

Figure B5: Viewsheds from the NE route for DhNe-1.

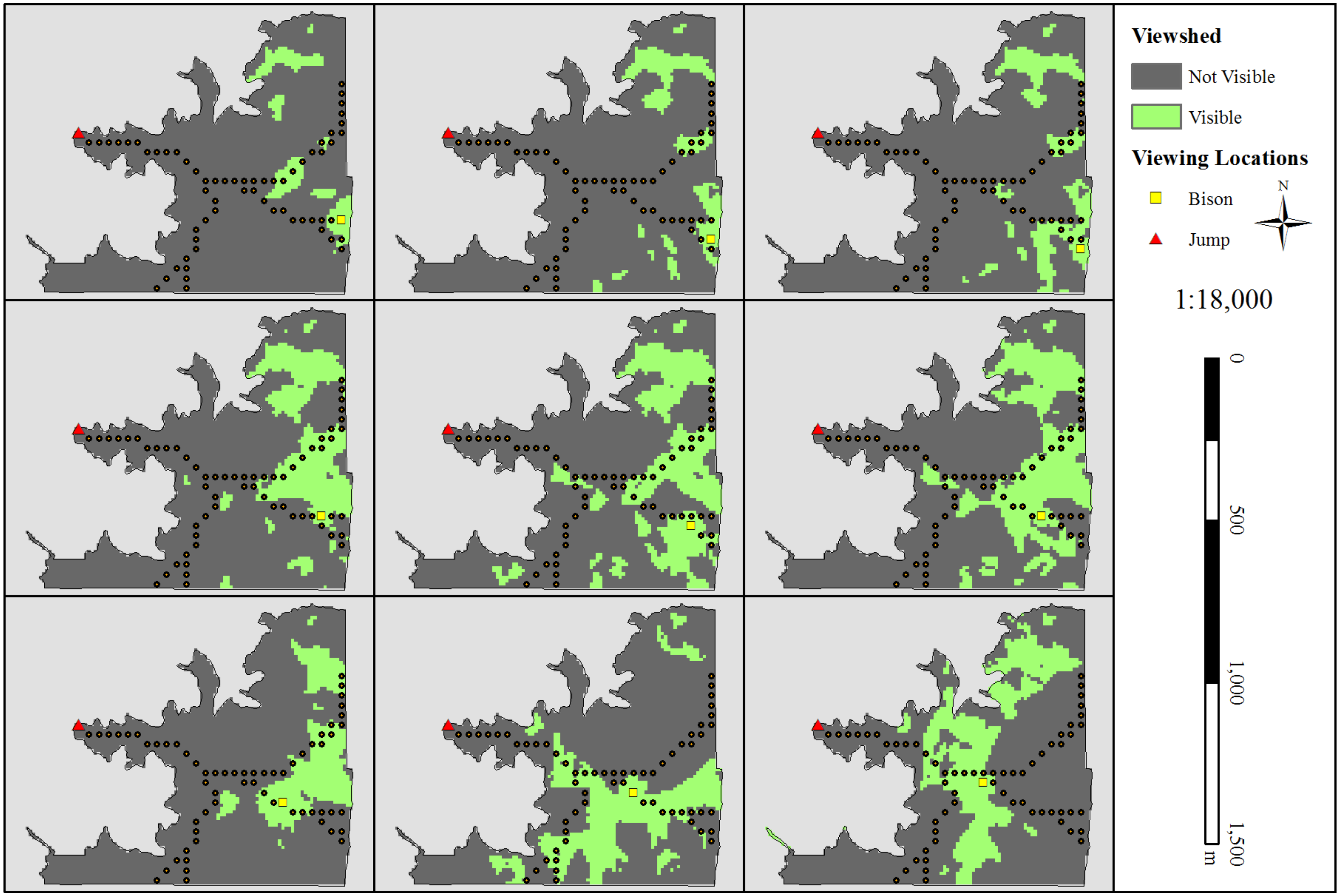

Figure B6: Viewsheds from the SE route for DhNe-1.

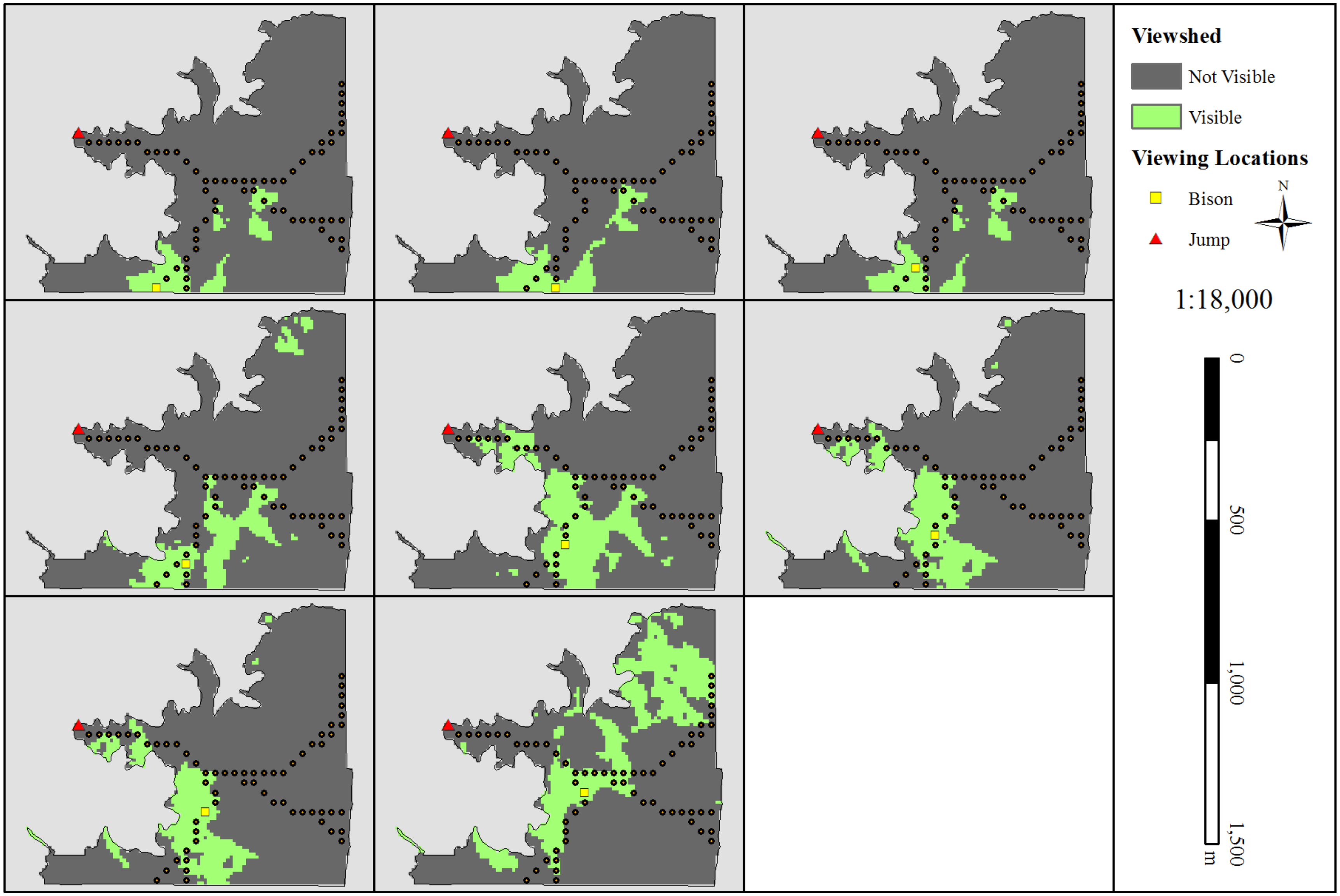

Figure B7: Viewsheds from the S route for DhNe-1.

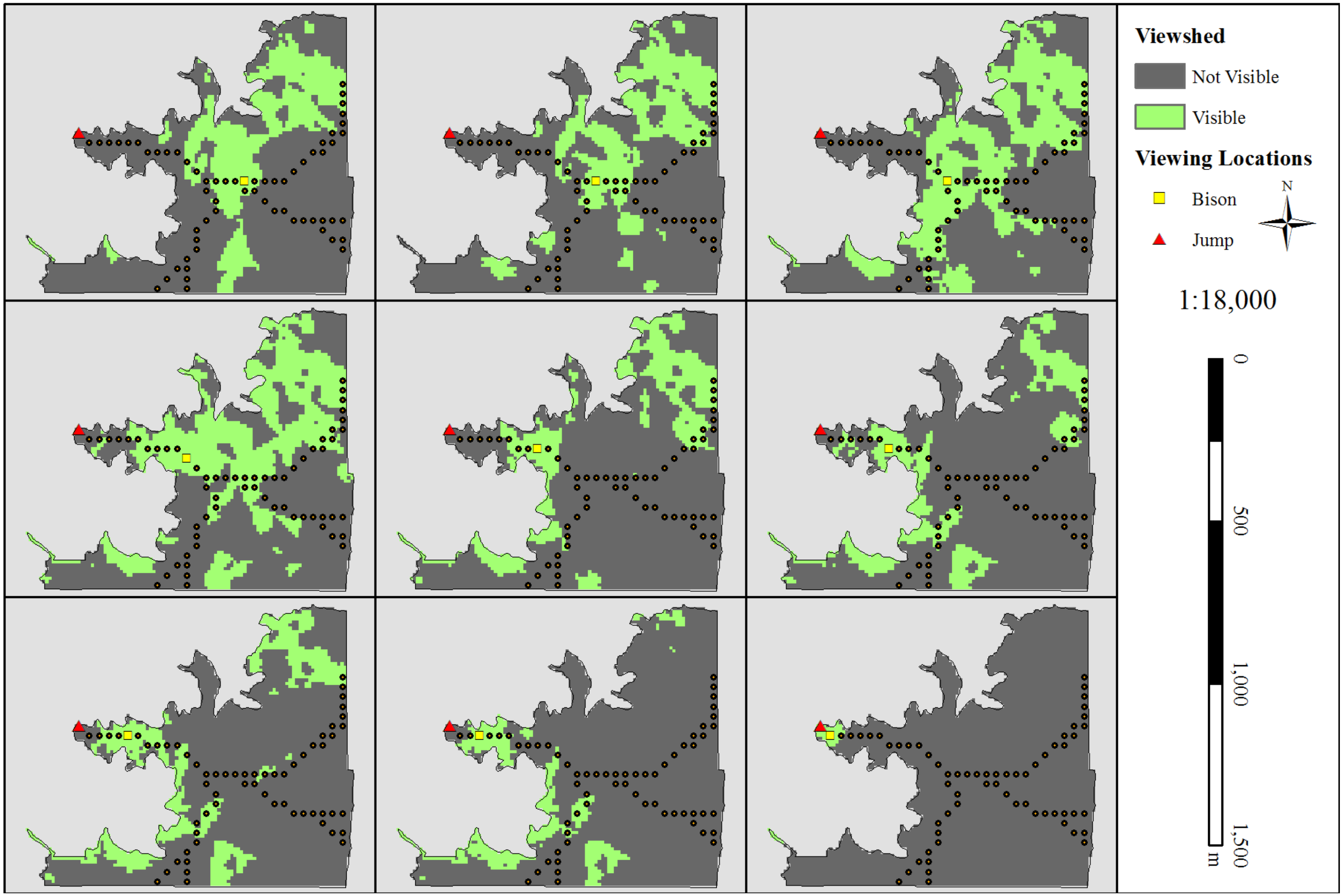

Figure B8: Viewsheds from the combined routes for DhNe-1.

Appendix C
Identified Sites

Through the course of this research, a handful of new archaeological sites and features were identified. As part of the researcher's due diligence, each site had a Saskatchewan Archaeological Resource Record (SARR) filed with Saskatchewan Parks, Culture and Sport. Brief summaries of the observed sites are found below. Borden numbers have yet to be assigned.

HITW1 **Hole in the Wall Coulee Site 1** **Single Feature, Cairn**

Site consists of a single cairn that rests upon the upland edge overlooking the Hole in the Wall coulee to the east. Cairn is located on a small piece of land where the upland valley wall pinches to a single tip pointed south.

HITW2 **Hole in the Wall Coulee Site 2** **Recurrent Feature, Camp Site**

Seven stone circles were identified on the upland portion of western valley edge of Hole in the Wall coulee. Upland area is bisected to the south by a small tributary valley to the south, and Hole in the Wall to the East. These stone rings are thought to be tipi rings, thus classifying the location as a precontact habitation site.

HITW3 **Hole in the Wall Coulee Site 3** **Single Feature, Camp Site**

A lone stone circle is found on the uplands just off the eastern valley edge of Hole in the Wall coulee. Site is found approximately 300 metres north of the site cluster DhNe-39, 40, 41 and 42. The site is interpreted as a single occupation habitation site.

NRMC2 **North Roan Mare Coulee Site 2** **Recurrent Feature, Camp Site**

Four stone circles were identified surrounding a small seasonal slough. Two circles rest on a knoll on the eastern side of the site, overlooking the pond. The remaining two circles lie in the low lands on opposite sides of the slough. The site likely a habitation site built up over successive occupations drawn to the water source. Site is just north of DhNe-25 and likely is an extension of that site's expanse of tipi rings

NRMC3 North Roan Mare Coulee Site 3 Single Feature, Camp Site

Lone stone circle found on top of a local hill in the knob and kettle terrain found northwest of Roan Mare Coulee. Likely an extension of the DhNe-25 tipi ring site found to the south.

82VO27 Survey Spike Site Recurrent Feature, Cairn

Two small stone cairns were identified while recording a land survey control point for township 03-21-2W. The site rests on a prominent hill that overlooks Salt Lake to the north and portions of Roan Mare Coulee to the south and southwest. The two cairns were estimated at 75cm in diameter and may be portions of a larger unidentified feature.

ERMC1 East Roan Mare Coulee Site 1 Multiple Features, Camp Site

Two stone circles and two small cairns were observed on a knoll southeast of Roan Mare coulee. The features were observed on the northern edge of this hill. The stone circles were spread 30 metres apart and the cairns were located in the space in between. The relationship between the cairns and stone circles is unknown.

DR501 Driveline 1 Alignment/Configuration, Drive Line

A set of small cairns were observed on a local topographic high that were oriented in a NW/SE line. These were interpreted as a driveline feature associated with DhNe-1, and likely associate with DR502 to the east and DR503 to the north

DR502 Driveline 2 Alignment/Configuration, Drive Line

A set of small cairns were observed on a local topographic high that were oriented in a NW/SE line. These were interpreted as a driveline feature associated with DhNe-1, and likely associate with DR501 to the west and DR503 to the north.

DR503 Driveline 3 Alignment/Configuration, Drive Line

A set of small cairns were observed on a local topographic high that were oriented in a NW/SE line. These were interpreted as a driveline feature associated with DhNe-1, and likely associate with DR501 and DR502 to the south.