A GIS ANALYSIS OF
ARCHAEOLOGICAL TRAILS AND SITE CATCHMENTS IN THE GRAND CANYON, ARIZONA

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ABSTRACT

A GIS ANALYSIS OF ARCHAEOLOGICAL TRAILS AND SITE CATCHMENTS IN THE GRAND CANYON, ARIZONA

SEAN L. TEETER

The topography of the Grand Canyon presents challenges to human movement in the form of long, continuous, vertical barriers and generally steep and rugged terrain. These conditions constrain human movement both energetically. In addition, the topography of the Grand Canyon creates accessibility issues. This thesis explores the implications of these conditions on prehistoric populations. A comprehensive trail dataset was compiled based on the distribution of trails and routes known to modern day hikers. Comparison of the resulting dataset to archaeological sites and constructed trail features indicates a high correspondence between prehistoric and modern routes. The resulting dataset, in turn, indicates that accessibility of the Grand Canyon influenced prehistoric travel costs and decision making strategies. Subsequent Geographic Information Systems (GIS) analysis using ESRI ArcGIS Pathdistance tools compares the predictions of three formulae for the estimation of archaeological site catchments based on measures of energy expenditure and travel time, including 1)Tobler’s (1993) Hiker Function, 2) Hill’s (1995) method, and 3) The “Pandolf Equation” (Pandolf et al. 1977) and downhill correction factor (Yokota et al. 2004). Analysis indicates that the Pandolf equation is poorly suited to application in the Grand Canyon environment, and that Tobler’s Hiker Function may provide a reasonable “upper bound” estimation of archaeological site catchments, while Hill’s method provides a reasonable “lower bound” estimation. With these results in mind tentative conclusions are drawn concerning the effects of higher effective distance on prehistoric populations in the Grand Canyon.

Acknowledgements

I am very thankful for the opportunity to study the trail systems of the Grand Canyon, and I would like to acknowledge the help of many people in this project. First, I would like to thank my committee. Dr. Smiley, my committee chair, created the opportunity to work on this project and guided it from a vaguely defined independent study, to book chapter, and finally to its present form. Dr. Downum offered his critical insight into the project at all stages. Dr. Vannette provided perspective from outside of archaeology, and Mark Manone provided technical GIS expertise necessary to the completion of the project.

I would like to thank the staff of Grand Canyon National Parks cultural resources program, including Ellen Brennan and Ian Hough, as well as park ranger Todd Seliga. Without the cooperation of the Park, this project would not have been possible. Ellen and Todd were willing to sit down with me to answer questions even in the early stages when I could hardly tell someone the difference between the Redwall Limestone and Coconino Sandstone. Ellen, Todd, and Ian all offered insight based on their experience navigating the trails and routes of the Grand Canyon.

I would also like to thank the Grand Canyon buffs that I interviewed for this project. Jim Ohlman, Scott Thybony, Rich Rudow, and Glen Rinck all offered their perspective based on thousands of miles of trekking experience in the Grand Canyon overy many decades. Scott Thybony was willing to sit down with me in person, and shared some great stories. Jim Ohlman provided long and detailed answers to my questions, for which I am very thankful.

Special thanks goes to the GIS experts that helped me throughout this project. I would like to thank Dr. Nicolas Tripcevich, Matt Taliafero, and Brian Wood for answering my questions. Dr. Patricia Kramer also helped me with technical questions regarding the use of predictive formulae of energy expenditure.

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Table of Contents

List of Tables

List of Figures

Chapter 1

Archaeological Trail Systems of the Grand Canyon: Distance, Roughness, Accessibility

The Grand Canyon's various geologic strata, subject to differing rates of erosion, geologic faulting, and in some instances volcanic activity, form a labyrinth of imposing cliffs, talus slopes, and isolated plateaus nearly 278 miles long. During seasonally high water, crossing the Colorado River would have been extremely hazardous for prehistoric groups. This thesis explores a range of travel possibilities and limitations for prehistoric human populations presented by the extraordinarily rugged terrain of the Grand Canyon.

Understanding prehistoric life in the Grand Canyon demands that archaeologists understand the challenges presented by the Canyon's terrain in day to day activities, such as subsistence tasks. Modern-day Canyon trekking enthusiasts, such as the remarkable Harvey Butchart, have taught us that travel is possible across hundreds of main trails and lesser-known routes in and out of the Grand Canyon. However, issues discussed in this thesis, such as accessibility and the energetic constraints presented by rough terrain, likely imposed unique restrictions on prehistoric populations.

This thesis examines three general themes related to prehistoric travel in the Grand Canyon. First, I examine the general structure of Grand Canyon trail networks as well as the problem of establishing whether particular trails known to us today were used in pre-history, as well (Chapter 3). Second, I examine the accessibility of the Grand Canyon (Chapter 4). By accessibility, I mean the particular challenges faced by prehistoric peoples in navigating large and continuous vertical obstacles such as the

Canyon Rim, Redwall Cliffs, and Granite Gorge, etc. Third, I examine the costs, in time and energy, of prehistoric human movement in the Canyon (Chapters Five and Six). Because the horizontal distance that people can cover in a day is constricted by steep and rugged terrain, archaeological catchment areas surrounding sites in the Grand Canyon were probably restricted in size compared to adjacent areas of the Southwest. Accordingly, understanding the costs of movement in the Canyon may provide a window into the nature of various aspects of prehistoric life, such as subsistence, isolation, and exchange.

Research Area

This study examines the area between Lee's Ferry and Havasu Canyon (Figure 1.1), or roughly one half of the Grand Canyon. This area includes Marble Canyon, the eastern Grand Canyon, and smaller portions of what is variously considered as either the central or western Grand Canyon. This research area encompasses enormous differences in topography, and is large enough, I believe, to have relevance for subsistence models that address different parts of the Canyon. I provide additional explanation of the research area in Chapter 2.

Verification of Known Trails and Routes as Archaeological Features

Perhaps one of the most tangible benefits of this study includes the verification of known trails and routes in the Grand Canyon as cultural resources. By following the methods outlined by Wilson (1999) it is possible to assert with a relatively high

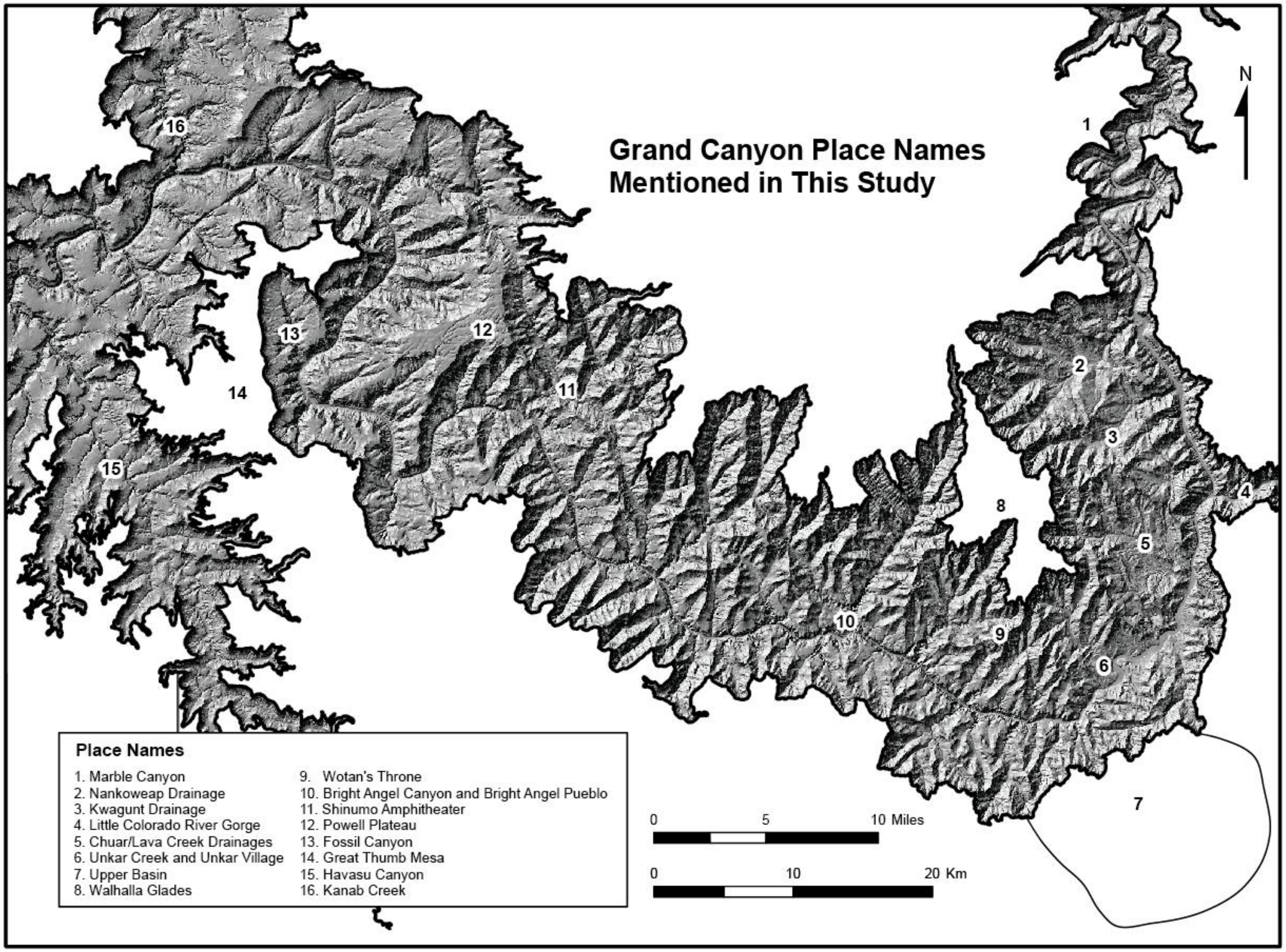

Figure 1.1. Project area overview, with Grand Canyon place names mentioned in the study (Not captured: upper Marble Canyon).

degree of confidence the prehistoric use of trail systems. However, routes identified in this study may not always coincide with a discernible path on the modern ground surface.

As stated by Wilson (1999), several studies examining on the trail systems of the Southwest have approached various topics such as subsistence uses, canyon morphology, and cultural significance. However, only Wilson (1999) has conducted an archaeology-specific trails study for the Grand Canyon region. Anderson et al. (1997a, 1997b, 1997c, 1997d) establish prehistoric use of many of the well-known Grand Canyon National Park (GCNP) trails, such as historical reports of decaying log ladders near the Redwall Limestone section of the modern Bright Angel Trail (Anderson et al. 1997a). I argue, based on multiple characteristics of Grand Canyon trails, that most, if not all of the 500 plus trails and routes identified in the current study received at least limited prehistoric use. Although current knowledge of Grand Canyon trails by no means duplicates exactly the Grand Canyon's prehistoric trail network, the locations of archaeological sites and presence of prehistoric trail modifications within the Canyon allow us to infer that many currently known routes were used prehistorically. For instance, Wilson (1999:33-34) states that two of the primary considerations important in determining whether or not a trail was used prehistorically include, " 1) Archaeological remains are present on or near the suspected trail" and "2) The topography affords passage of human beings within reasonable limitations." There is hardly a known trail or route within the Grand Canyon that does not meet these criteria. Accordingly, current documentation of trails and routes within the Grand Canyon allows us to examine and understand an extensive network of prehistoric trails.

Accessibility

While each of the Canyon’s many strata presents unique considerations for foot travel, the Canyon's geologic layers most resistant to weathering comprise extended vertical barriers to movement often hundreds and sometimes thousands of feet in height. For Colonial Spaniards, historic miners and explorers, and modern day thrill seekers, the Grand Canyon has presented a formidable obstacle. At least one popular volume is dedicated solely to the documentation of fatal accidents that have occurred in the Canyon through various means (Ghiglieri and Myers 2001). Until Lee’s Ferry became a regular crossing point in the 1850’s, the only reliable places to cross the Colorado included Pierce Ferry, at the Canyon’s western edge, and Hall’s Crossing at Hite, Utah, locations separated by 300 miles (Baars 1983:34-35). Since the addition of Lee’s Ferry, the list of river crossings has come to include the Glen Canyon, Hoover, and Navajo Bridges, respectively. However, hundreds of miles still separate these places, and the area north of the Grand Canyon, the Arizona Strip, remains one of the most isolated regions in the continental United States.

Until the recent phenomenon of canyoneering, westerners have had a poor record of negotiating the Canyon’s obstacles. In 1540, Don Garcia de Cardenas and a small company of men tried, but failed, to locate a route from the rim, near the Palisades of the Desert, to the river (Butler and Myers 2007: 89). Over three-hundred years later, the renowned geologist Clarence Dutton, “… proclaimed …that a total of four routes from rim-to-river existed within the gorge.” (Butler and Myers 2007:6) And yet, in roughly thirty years of exploration, the well-known Grand Canyon hiker and explorer Harvey Butchart (Figure 1.2, Harvey Butchart’s map) located no fewer than 116 rim-to-river routes (Benti 1997:18), primarily during weekend excursions from Flagstaff. The example of Butchart thus raises the question: How many routes within the Canyon were known to the prehistoric occupants of the Grand Canyon, who grew up and made a living within its walls, were probably in excellent physical condition, and were aided by the collective knowledge of generations? Would the Canyon have presented a significant barrier at all?

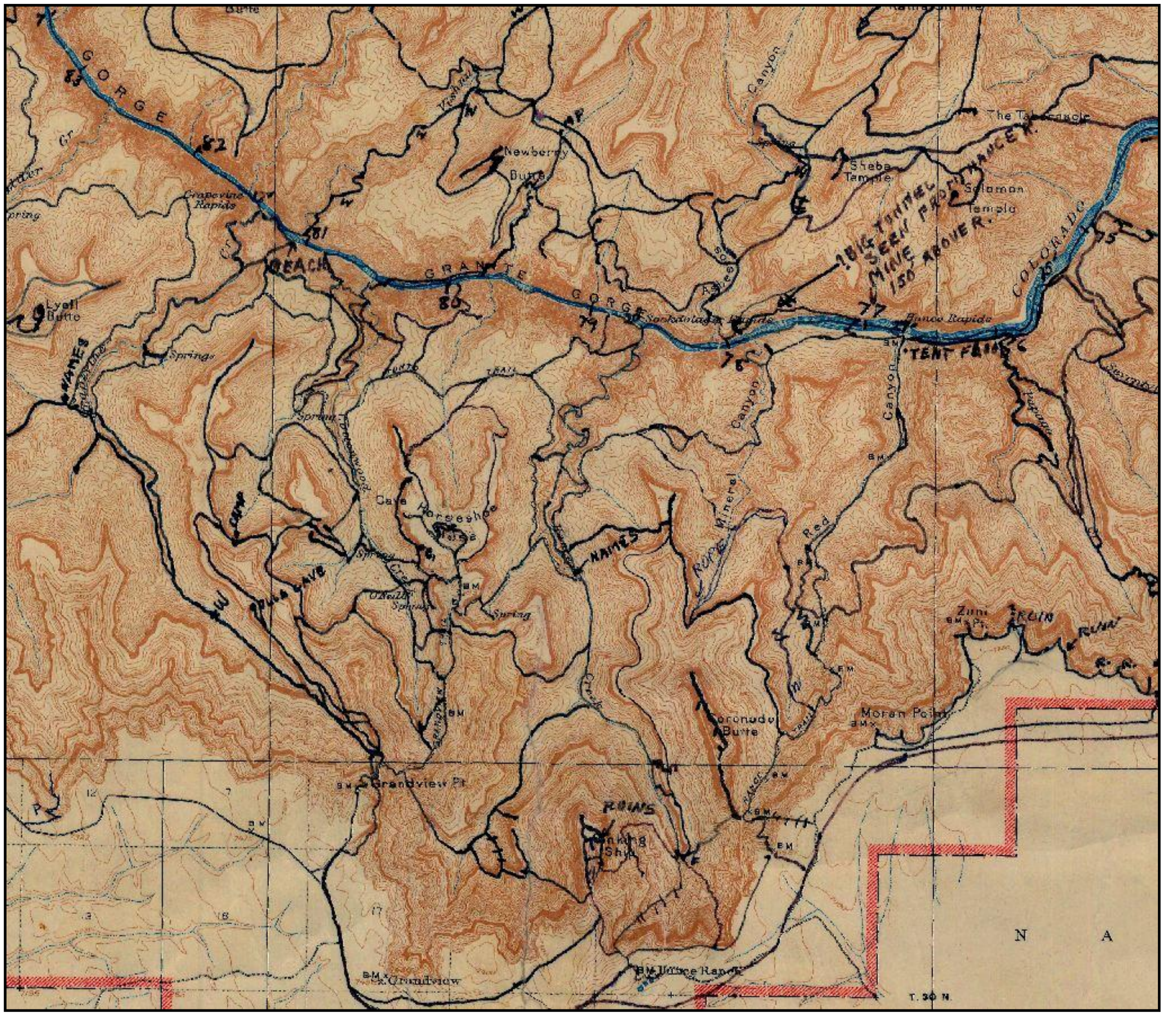

Figure 1.2. A Particularly well-travelled portion of Harvey Butchart's Matthes-Evan's Grand Canyon map. Black lines indicate routes travelled by Butchart.

Based on the preceding characterization, the second theme that I examine is the accessibility of the Grand Canyon to its prehistoric inhabitants. I contend that, although the prehistoric inhabitants of the Grand Canyon were familiar with their surroundings, the Canyon did, in fact, constitute a unique barrier. Although Euler and Chandler (1978) have stated that the Canyon did not present a barrier to movement, I contend that the Canyon's physiographic variability denies us the ability to categorize the entire Canyon simply as "accessible." In addition, the concept of accessibility obligates us to define the purpose of a hypothetical prehistoric groups' use of the Canyon. For instance, we might ask, "was the population in question merely entering the Canyon? Were "they" attempting to cross the Colorado River, or go to a specific place? Or, were "they" using the Canyon on a regular basis for agriculture, hunting, or religious purposes? These sorts of questions show us that accessibility, as a factor, may be much more acute with a specific purpose in mind, resulting in a limited set of travel options. For instance, one extraordinary route in Marble Canyon known as "The Wormhole" (Figure 1.3) descends through a cave in the top of the Redwall limestone, opening onto an extended free climb down to the river. Certain areas, such as Fossil Canyon, or Wotan's Throne, likely could have been accessed in an extremely limited number of ways. The Enfilade Point route which leads into Fossil Canyon, as an example, took Harvey Butchart ten years of diligent searching to locate (Butchart 1997:160).

Routes, such as those mentioned above (Enfilade Point, Wormhole, etc.), are typically separated by miles of inaccessible cliffs, and sometimes contain constructed features designed to aid in the passage of large vertical barriers. Although I do not claim to possess a complete catalog of prehistoric trails, the current trails database, and the apparent separation of routes which allow passage over cliffs indicate that prehistoric people repeatedly used a finite number of trails in order to gain entry into the Canyon. While knowledgeable individuals and groups may not have been greatly inhibited in their passage into the canyon, the ways in which they did so were confined to a limited number of paths. Awareness of this condition, as well as the general constraints placed on groups by rough terrain, allow us to gain a more complete understanding of prehistoric life-ways in the Grand Canyon.

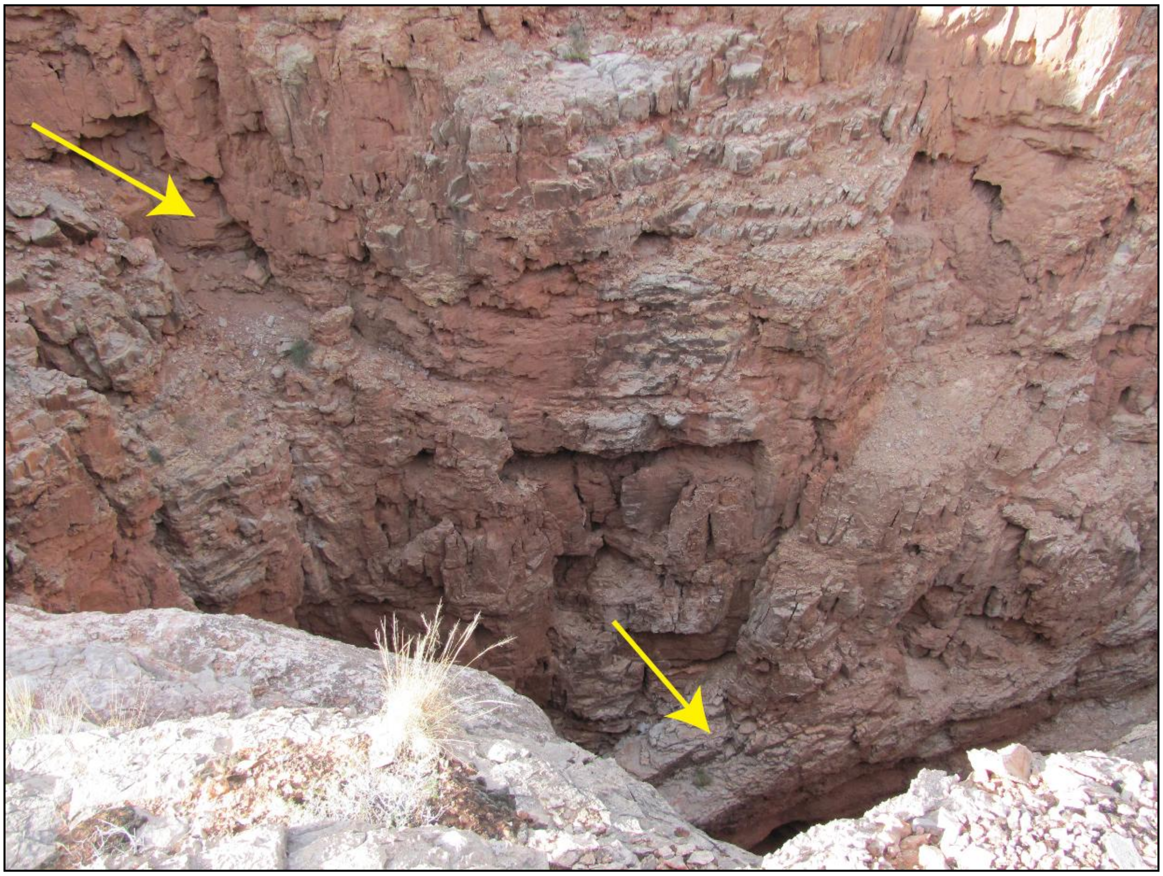

Figure 1.3. The “Wormhole” route requires one to perform exposed lateral climbing as well as crawl through a series of tunnels.

Distance

In addition to the circumstances mentioned above, I contend that in order to refine subsistence and settlement models in the Grand Canyon, archaeologists need to conceptualize distance from new perspectives. The distance between archaeological sites and resources, sometimes characterized as a straight line distance, actually entails costs and decision making strategies (Taliafero et al. 2010:546). For instance, Wilcox (1996), in the Chaco Canyon region, conceptualizes the distance between archaeological sites in terms of concentric circles radiating out from specific locations in order to understand the spatial relationship between sites. Although this technique may be satisfactory in areas of limited vertical relief, it will not accurately account for distance in the Grand Canyon. Specifically, I argue that by conceptualizing distance according to variables such as travel time and energy expenditure, it is possible to more accurately understand the implications of constraints placed on prehistoric groups by rough terrain.

As Neff (2011) indicates, various subsistence models have been presented by scholars of Grand Canyon archaeology over the last 30 years (Effland et al. 1981; Schwartz et al. 1980, 1981; Sullivan 2002; Fairley 2003). Such models contend that in different regions of the Canyon, the Canyon's prehistoric occupants relied on varying degrees of mobility, seasonality, and agriculture, at different points in time. The study of prehistoric trails and travel considerations in the Canyon is related to these models, because all of the models imply either "transhumance" (the movement of populations from one region of the Canyon to another) or logistical forays into the Canyon (Neff 2010:3). For instance, the "Biseasonal Model" presented by Schwartz et al. (1980, 1981) suggests that in portions of the eastern Canyon, prehistoric groups seasonally occupied areas along the rim, such as the Walhalla Glades (summer months), and areas along the river corridor (winter months). In the "Cross-Canyon" model (Sullivan et al. 2002) populations moved from one rim to another at different times of the year, or between years. Models presented by Effland et al. (1981) suggest that logistical forays into the Canyon occurred. An accurate conception of the effects of distance between rim and river regions, the accessibility of the Canyon, and the true "roughness" of the Canyon, are critical for evaluating further implications or feasibility of such models. Here, my aim is not to explicitly support a single model of subsistence within the Canyon. Archaeologists must introduce multiple viable models to compensate for the Canyon's vast size, considerable physiographic variability, and breadth of temporal occupation. Rather, I aim to provide perspective through which the various subsistence models may be assessed.

By using techniques derived from Geographic Information Systems (GIS) it is possible to conceptualize distance within the Canyon more accurately. In order to demonstrate this point, I use three mathematical models that predict travel time and energy expenditure. These models include 1) Tobler's (1993) estimation of speed as a function of grade, 2) The "Pandolf Equation" (Pandolf et al. 1977), a model of metabolic energy expenditure, and the downhill correction factor developed by Yokota et al. (2004), and 3) An estimation of "energy equivalence" developed by Hill (1995, cf. Herhann and Hill 1998, Hill 2000). I create estimations for travel costs using these formulae with the Pathdistance tool provided by ESRI ArcGIS (versions 9.3 and 10).

The GIS analysis is presented in Chapter Six, and contains two components. The first component provides an assessment of the usefulness of the formulae listed above in the rugged environment of the Canyon. As will be demonstrated, the different models of human energetics produce markedly different results in the same geographic locations. Accordingly, archaeologists must be discerning in future use of such models in similar studies. In the second portion of the GIS analysis, Pathdistance tools are used to make tentative statements regarding the implications of the higher effective distance on life within the canyon, discussing issues such as the comparative roughness of the Grand Canyon, and the implications of difficult terrain on subsistence tasks.

As stated above, one question addressed by the GIS analysis is, “How rough, comparatively, are the catchment areas surrounding archaeological sites in different regions of the Grand Canyon?” By comparing the hypothetical catchment areas of various regions of the Canyon to one another, as well as other areas of the Southwest, I provide a comparative basis for evaluating the effects of the rough terrain of the Grand Canyon on human subsistence tasks. A second question is, “What was the energetic cost of travelling between the rim, and river?” This question has implications for the catchments of sites located in rim or river regions in terms of their hypothetical use of distant water and subsistence resources in rim to river foraging. A third question is, “How isolated were sites in the Grand Canyon in relation to one another?” The analysis of these questions can be viewed in terms of site catchment, or cost surface analysis, the implications of which could potentially be integrated into central place foraging models.

Finally, this study examines additional methods for creating increasingly complex cost surfaces and site catchment estimation in the Grand Canyon (Chapter 6). One of these methods provides a means of predicting the travel cost along any one specific trail in ESRI ArcGIS. As the section on accessibility will show, although some areas of the Canyon allow a relatively high freedom of movement, access between vertical barriers required the use of specific access points, which can greatly affect the cost of movement between points. In a second method, vertical barriers such as the Redwall Limestone are digitized, insuring that the Pathdistance algorithm will not traverse steep walls in unrealistic ways. These methods demonstrate the degree to which seemingly disparate topics, such as accessibility and terrain roughness are interrelated as travel concerns. The methods introduce the possibility that network analysis, or the development of more complex cost surfaces may offer greater understanding of prehistoric travel constraints. Although the application of network analysis is outside the scope of this thesis, consideration of such concepts may provide a promising direction for future research.

Theoretical Perspective

The theoretical framework most closely associated with this thesis is Human Behavioral Ecology (HBE, Chapter Five). As stated by Winterhalder and Kennet (2006:13) HBE attempts to, "assess the costs and benefits of alternative courses of action under a range of environmental conditions." Although typically characterized as a distinct, self-identified perspective (Hegmon 2003), HBE seems to fall within the boundaries of processualist approaches. For instance, Winterhalder and Smith (2000:52) describe HBE as a, "hypothetico-deductive research strategy and its neo-Darwinian theoretical sources. HBE derives testable hypotheses from mathematical or graphical models anchored in basic principles of evolution…emphasizing generality." Therefore, this thesis can be described as evaluating the likelihood of prehistoric subsistence strategies by concerning itself with costs and benefits of prehistoric travel options, while adhering to principles of scientific archaeology.

As a theoretical approach, HBE utilizes a combination of concepts derived from ecology and micro-economics, such as resource procurement costs (usually in reference to food resources) and caloric yield, to understand the economies of foraging and horticultural societies. HBE began with the original goal of providing a solid theoretical framework to the cultural ecology envisioned by Julian Steward in the 1950's. HBE "began in the 1970's with the application of optimal foraging models to hunter-gatherer decisions concerning resource selection and land use" (Winterhalder and Smith 2000:51). HBE derives generally from evolutionary ecology; when applied to human behavior evolutionary ecology becomes HBE.

What sets HBE apart as a theoretical perspective is an explicit set of models and definitions, as summarized by Winterhalder and Kennet (2006). Although I will not go into great detail regarding these models here, it is relevant to state that HBE relies on the assumption that humans optimize resource use. Although understood that resource use will not be perfectly optimal, human resource use may be described as, "constrained optimization."

As will be described in the subsequent chapters, the Pathdistance function of ArcGIS relies on Least Cost Path Analysis (LCPA). In this thesis, the costs of travelling within the Canyon are calculated as the accumulative costs of travelling along a set of least cost paths. These calculations are then used to define likely resource procurement areas, as well as the boundaries within which prehistoric societies would have conducted agricultural activities from a residence. According to this characterization, least cost methods are used to define site catchments of varying size. Therefore, this thesis not only identifies with HBE, but relies methodologically on the assumptions of site catchment analysis. The relationship between site catchment analysis and HBE are further discussed in Chapter 5.

There are several caveats associated with the application HBE to this study. First, As Neff (2010) points out, least-cost path analysis is an atemporal exercise because it illuminates broad patterns of movement that may be applicable to various periods of time. Taliafero et al. (2010) demonstrate this principle by using least cost paths to compare obsidian procurement over a several thousand year period, from the Late Archaic Period to the Mimbres Classic Period. This condition is both potentially useful and problematic. The condition is useful in the sense that it is applied to long periods of time. The condition is problematic in that it does not examine a specific site in detail, meaning that the specificity required by models within HBE is not possible. For example, it is difficult for a study applied to a several thousand year period to meet the optimization assumption. Thus, although Taliafero et al. (2010) weigh the costs and benefits of travel time in reference to obsidian sources, they do not identify their study with any formal HBE model, such as central place foraging or diet breadth .

This thesis shares the potential problem highlighted above, because it identifies movement patterns through all time. However, because the vast majority of archaeological fieldwork conducted in the Grand Canyon thus far relates to the Grand Canyon's Late Formative (1000 – 1200 A.D.) In addition, constructed trail features date exclusively to Puebloan times or later. Therefore, this thesis may be viewed as having its greatest explanatory power for the late Puebloan occupation of the Grand Canyon.

Summary

Many previous studies have shown that the Canyon was visited and inhabited by a wide range of prehistoric and Historic-period Native Americans. This study will show, on one hand, that prehistoric inhabitants of the Canyon used specific knowledge and physical ability to adeptly navigate the Canyon; on the other, it will show that the Canyon's extreme topography likely placed unique limitations on the subsistence tasks of the various prehistoric groups that lived there.

Chapter 2

Background: Geologic Obstacles and Cultural History

Introduction

This chapter provides a foundation for study of the archaeological trail systems in the Grand Canyon, examining the Canyon's geology and cultural history. The greatest and most apparent hazards encountered in attempting to travel the Canyon are geologic obstacles. Large continuous cliffs create impossible barriers which can only be circumvented with the aid of specific knowledge and experience. By contrast, rapid elevation change creates a diverse community of edible plant resources, perhaps made even more attractive by their proximity to the Colorado River. Therefore, the Canyon appears to provide incentives for negotiating ubiquitous geologic hurdles. The first portion of this chapter describes the geologic strata most problematic for human movement. The second portion of the chapter summarizes the Canyon's culture history, paying attention to subsistence and settlement models developed by Effland et al. (1980), Schwartz et al. (1979, 1980, 1981), Sullivan et al. (2002), Fairley (2003), and Huffman (1993). In reviewing these models I highlight the implications of each model for the study of prehistoric travel considerations in the Grand Canyon.

Geologic Setting

It would be difficult to discuss the considerations of foot travel in the Grand Canyon without at least a cursory examination of geology. This subject has, however, been discussed at length elsewhere, so this review will not be extensive. Here I provide a brief synopsis of the most recognizable of the Canyon's geologic strata, paying attention to details important for prehistoric human foot travel within the Canyon.

The Canyon's oldest geologic strata (1,700 mya or older), or basement layers, include The Vishnu Schist and other igneous and metamorphic rocks characteristic of the Canyon's three inner gorges (Figure 2.1). The Precambrian layers (Baars 1983:7), underlie the Grand Canyon Series – the flat lying sedimentary rocks that form the Canyon's most recognizable layers. For the majority of the length of the Canyon, the Grand Canyon series sits directly upon Vishnu Schist, although younger Precambrian strata which comprise the Grand Canyon Super Group (ancient folded layers including Dox Sandstone and the Kwagunt Formation, amongst several others), are visible in various portions of the eastern Canyon. For the majority of the areas in which the Vishnu Schist and other igneous rocks are exposed at river level, which includes the Canyon's three inner gorges, the Vishnu Schist constitutes a steep, sheer, sharp realm, sometimes a thousand feet in height. It is a serious obstacle for foot travel, with limited access points.

Directly overlying the Precambrian strata are the Canyon's three Cambrian (500 – 570 mya) strata, consisting of the Tonto Group (Middleton and Elliot 2003). These strata, formed by the eastward advance of a vast Cambrian sea, include the Tapeats Sandstone, Bright Angel Shale, and Muav Limestone. The oldest, the Tapeats Sandstone, lies directly on the Vishnu Schist and forms steep, brown cliffs, with an average thickness over 200 ft. The Tapeats was formed as the result of deposition along an ancient beach. As the sea moved eastward, lithified marine mud was deposited over the Tonto sand, forming the Bright Angel Shale (average thickness 450 – 640 ft.). Finally, this eastward advance deposited the Muav Limestone (average thickness 100 ft.), which is the most

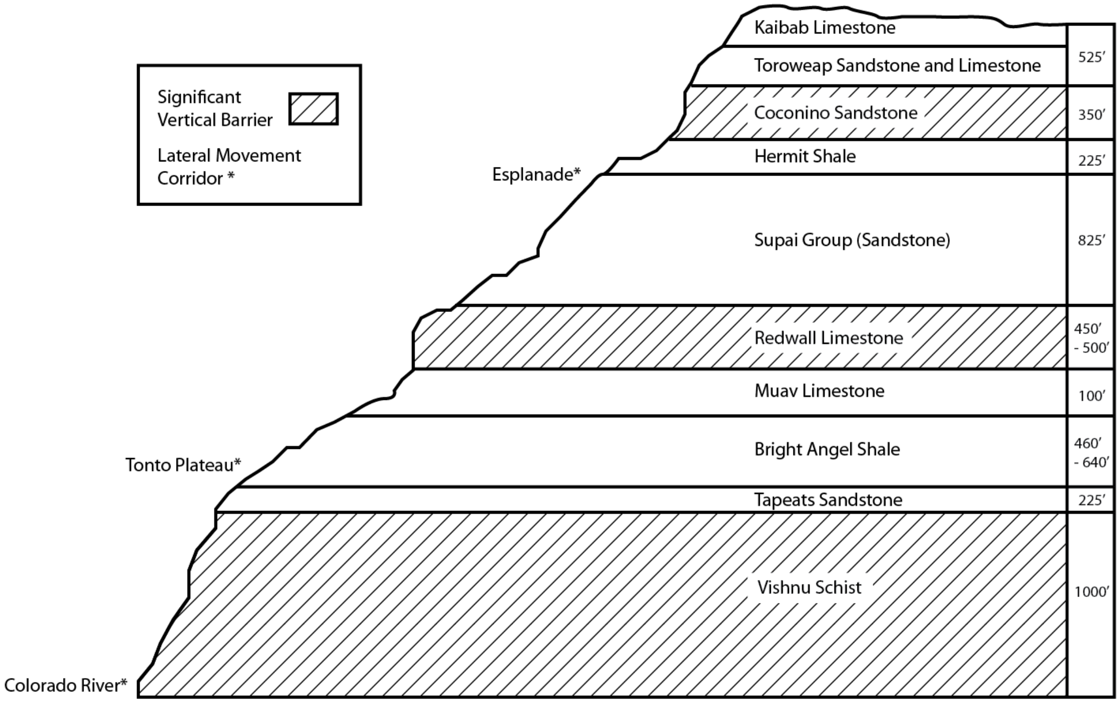

Figure 2.1. Generalized geologic profile of the Grand Canyon, highlighting lateral movement corridors and major vertical barriers.

erosion-resistant of these layers and which “caps” the Tonto group (Baars 1983:16). The juxtaposition of the softer Bright Angel Shale between the more resistant Tapeats Sandstone and Muav Limestone resulted in the formation of the Tonto Plateau, a wide bench, which provides the primary corridor of lateral movement in the eastern Grand Canyon (Figure 2.2). In the areas of the Canyon encompassing the Upper Granite Gorge, the Tonto Plateau would have formed an important middle ground between the rim and river, and the most important means of horizontal movement through Canyon. When John Annerino (1998) ran ultra-marathon distances in two separate runs (including a seven day stretch below the South Rim, and nine day 250 mile run below the North Rim) below the rim of the Grand Canyon he ran predominantly along the Tonto Plateau.

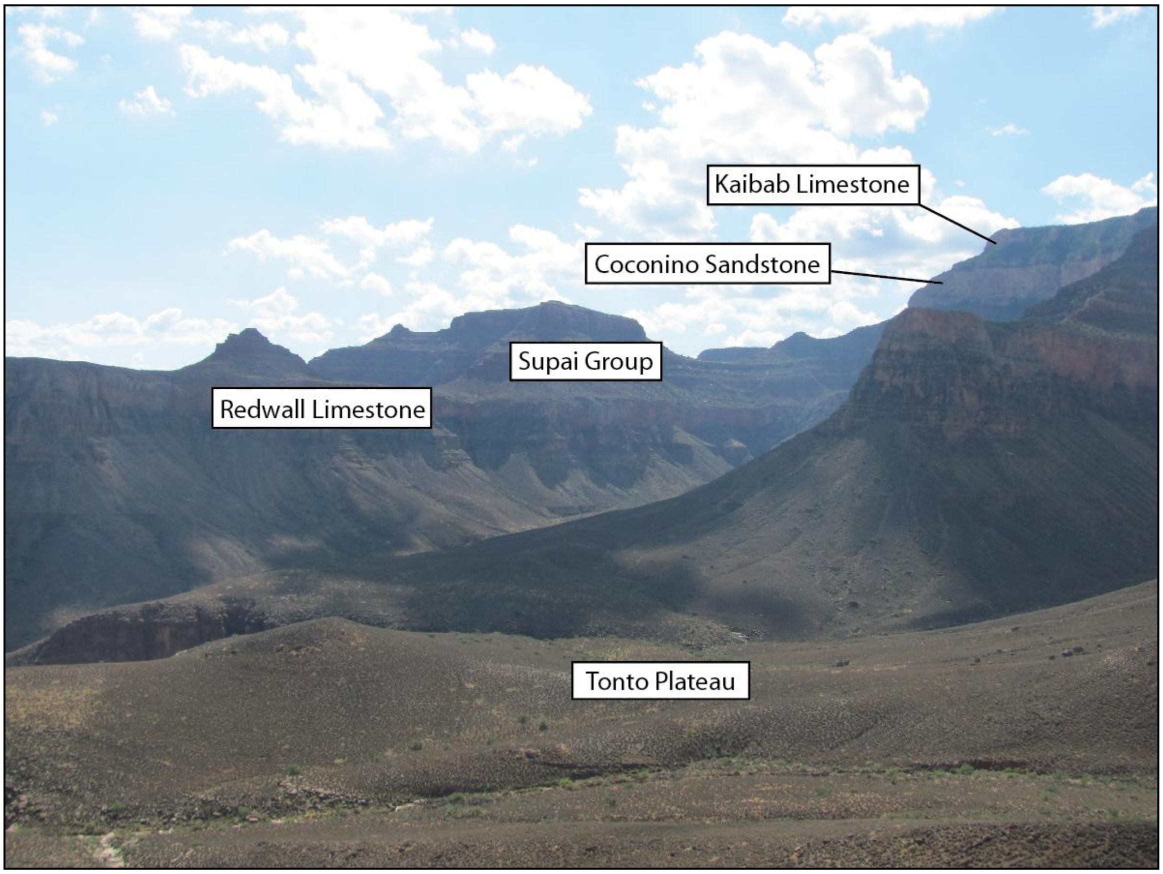

Figure 2.2. Some of the major strata of the eastern Grand Canyon, emphasizing the Tonto Plateau in the foreground.

Following an unconformity, or period of erosion or non-deposition, the Redwall Limestone was deposited by a Mississippian (325–355 mya) sea of shallow depth (Beus 2003). This limestone layer is gray, but appears "painted" red by downward-flowing material from the erosion of overlying red layers of the Supai group. The Redwall (Figure 2.3), typically over 400 ft. high and sometimes as high as 800, creates one of the most imposing and ubiquitous barriers to travel, because the massive cliff is continuous throughout the length of the Canyon. Fortunately for Grand Canyon travelers, the Redwall is susceptible to faulting. Conventional wisdom, as well as the following analysis, shows that there is, in fact, a tight correspondence between faults and Redwall routes, although exceptions to the rule may exist in cases that involve more technical climbing.

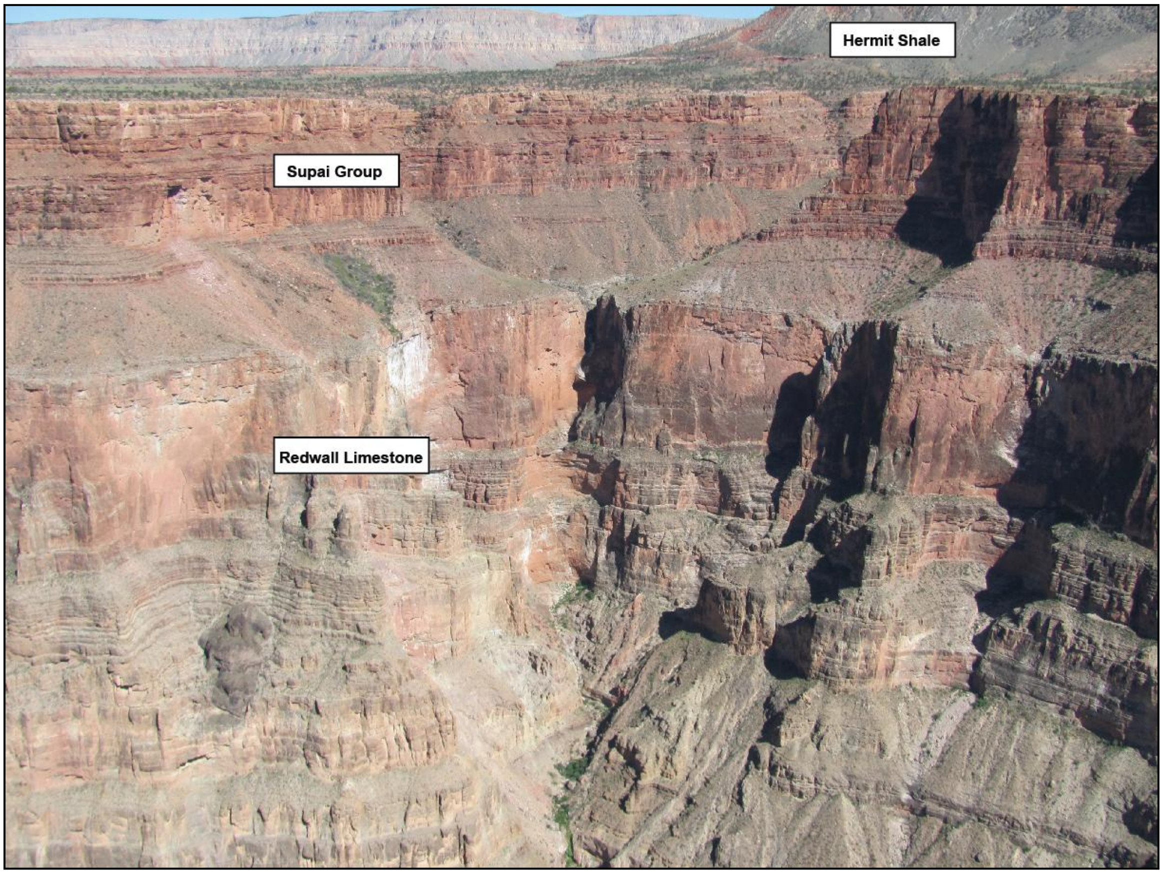

Figure 2.3**.** Geologic strata of the Grand Canyon as seen from Toroweap overlook, emphasizing the Redwall Limestone.

The remainder of the Canyon's strata are late Pennsylvanian (290 – 325 mya) or Permian (230 – 290 mya) in age. The first of these layers includes the Supai Group (approximately 825 ft thick), actually composed of four members deposited in, "continental, shoreline, and shallow marine" environments (Blakey 2003:136) the floodplains of ancient streambeds. The layers vary from limestones to shales to sandstones, and appear red because of high iron content. The youngest of the four layers, the Esplanade Sandstone, forms a wide bench, especially characteristic of the western Grand Canyon (Figure 2.4). Although the Supai forms a thick stratum, the individual beds of sandstone are relatively thin and blocky, which allows them to be bypassed by travelers. The loose nature of large portions of the Supai can form a hazard. In addition, "the Supai has the nasty tendency of allowing easy passage through one ledge or ledge-sequence, followed by the need to traverse one way or the other in order to locate the next line-of-passage" (James Ohlman, personal communication 2011).

The next layer, the Hermit Shale (the first of the Canyon's Permian strata), was deposited in a floodplain environment, has an average thickness 350t, and sits atop the Esplanade. Hermit Shale typically allows easy vertical movement, but is laborious during traverse (Butler and Myers 2007:86).

The Coconino Sandstone, another of the Canyon's most distinct strata, was formed by eolian processes and the solidification of massive sand dunes (Middleton et al. 2003). This buff-to-white colored layer averages 350 ft. in thickness, although in some areas is over 600 ft. thick (Middleton et al. 2003: 164). Hence, the Coconino forms another major obstacle to vertical movement into and out of the Canyon. Although Grand Canyon hikers often characterize the Redwall limestone as the greatest barrier in rim-to-river travel, veteran Grand Canyon hiker James Ohlman (personal communication 2011) has said that there are perhaps two to three times as many usable routes through the

Redwall than through the Coconino – a statement largely confirmed by this study, for the eastern

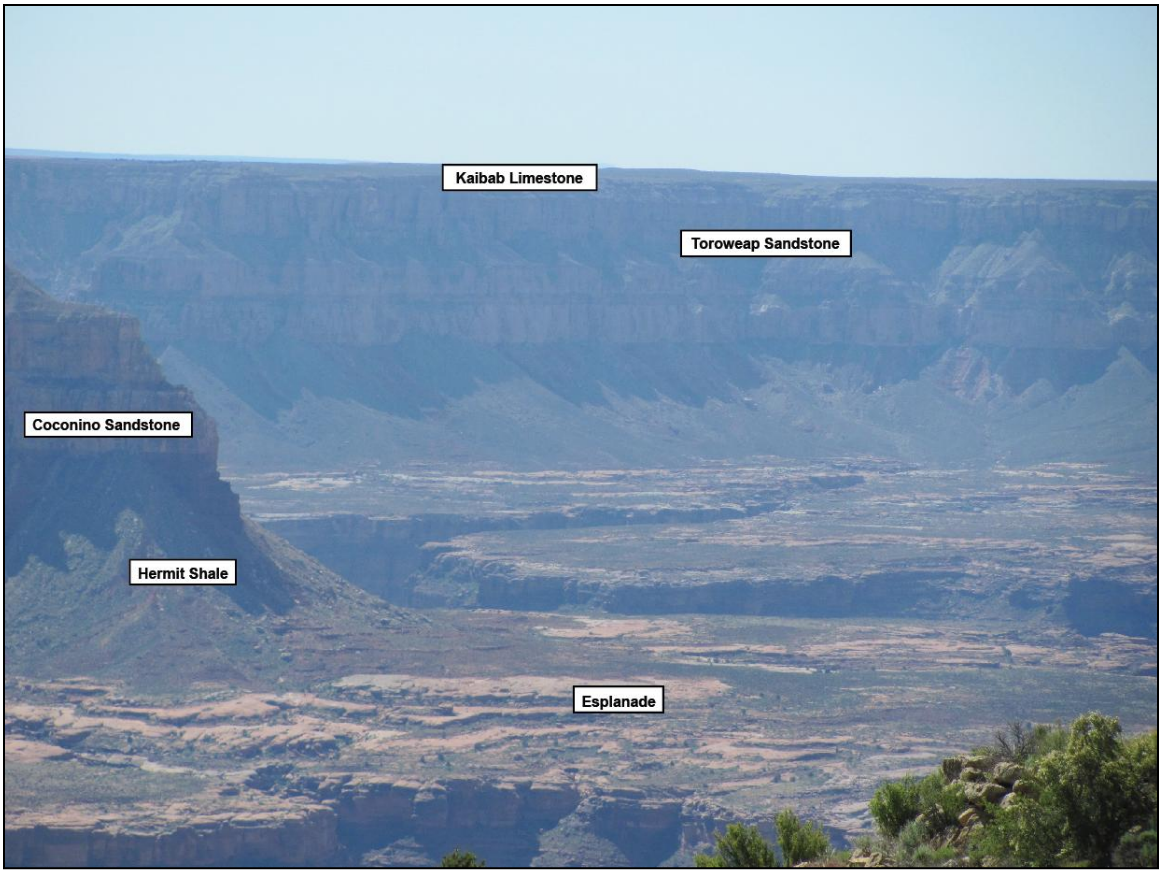

Figure 2.4**.** The Esplanade (foreground), the youngest member of the Supai Group, provides a relatively flat plain used for lateral movement in the canyon. The Esplanade is especially characteristic of the western Grand Canyon, and appears as a major corridor of lateral movement in Reach 7 of this study.

Grand Canyon. The Coconino is, after all, a continuous cliff only slightly less thick than the Redwall. On the other hand, as another veteran Canyon hiker, Rich Rudow (personal communication 2011) has pointed out, in the western Grand Canyon, the Coconino does not present a significant barrier at all, as thickness may be less than ten feet. In areas of

Marble Canyon to the north, as well, the Coconino decreases in thickness (Middleton et al. 2003:164).

The final two major strata in the Grand Canyon include the Toroweap and Kaibab formations. These formations are principally composed of limestone, although the lower portions of the Toroweap may include large amounts of sandstone. According to Butler and Myers (2007:86), although the Kaibab may present a three hundred foot cliff, it, " …is often fractured, which sometimes makes it passable without a rope." One of the major concerns in travelling through the Toroweap is its brittle nature, which makes climbing particularly precarious (Butler and Myers 2007: 86).

From this cursory discussion of Grand Canyon geology, several important characteristics regarding foot travel in the Grand Canyon become clear. Generally speaking, three of the Canyon's strata pose severe obstacles to vertical human movement: Vishnu Schist, Redwall Limestone, and Coconino Sandstone. Additional vertical barriers include the Kaibab and Toroweap formations, Supai Group, Tapeats Sandstone, and Muav Limestone, although these layers can be negotiated more regularly (this is not to say that these layers do not present any difficulty). Four geophysical features facilitate horizontal movement, including the River Corridor, Tonto Plateau, Esplanade, and the Canyon rim (the rim is easily superior to any other feature for lateral movement). It is additionally possible to move laterally through many layers of talus, although compared to the aforementioned strata, this is difficult, slow going work. The Precambrian layers (excluding members of the Grand Canyon Supergroup), although rarely sheer, are steep and treacherous enough to block or inhibit horizontal river-level travel in areas where Precambrian strata are exposed adjacent to the river, especially in Upper Granite Gorge.

While the aforementioned observations of the Canyon are generally true, important differences exist between specific regions of the Canyon. Large regions of the Canyon contain overwhelming physiographic similarities, and differences. One method of dividing these areas is through the "reach" concept developed by geologists and used by Fairley (2003). In this method, areas of the Canyon that exhibit similar river level geology are grouped together. Schmidt and Graf (1988) developed a 12-reach classification of river level geology that was adopted by Fairley (2003). In this chapter, I focus on Reaches 1 – 9 of the same system. Reach 1 begins at River Mile 0 at Lee's Ferry, and Reach 9 ends at mi. 160, just past Havasu Canyon. I find the system useful because it not only defines where river level travel is practical, but each "reach" typically corresponds to additional corridors of lateral movement. For instance Reach 6, Upper Granite Gorge, corresponds almost exclusively to the Tonto Plateau as a corridor for lateral movement. Finally, differences in river level geology correspond to wide and narrow reaches, affecting the speed and depth of the river. This may have been of concern to prehistoric travelers. Of the river reaches examined in this study, Supai Gorge, Redwall Gorge, Upper Granite Gorge, Aisles, Middle Granite Gorge, and Muav Gorge, are narrow (Reaches 2, 3, 6, 7, 8, 9); Lower Marble Canyon and Furnace Flats are characterized as wide (Schmidt and Graf 1988:7).

A summary of river level geology and lateral travel corridors by reach is provided in Table 2.1. Here, I briefly describe changes in travel considerations as one moves down the river starting at Lee's Ferry. For more detailed information the reader should consult Fairley (2003:15-25). Starting at Lee's Ferry, one encounters a gentle, open area, but this condition quickly fades as one moves through the Canyon's upper strata. As one encounters the Supai Group, river level travel becomes impossible (Fairley 2003:19), although Supai ledges can be traversed away from the river. Although it is possible to travel along the River briefly downstream of Rider Canyon (Fairley 2003: 19) the appearance of the Redwall around mile 23 eliminates this travel option. As in the case of the Supai, the top of the Redwall offers a new corridor of lateral movement, which may be preferable to Supai traverse. As the Cambrian strata appear, river travel once again becomes feasible, and as the Canyon opens up at the end of Marble Canyon, travel options proliferate. As stated by Ohlman (James Ohlman personal communication 2011) on may travel along the river, Butte fault (aka Horse Thief Trail), or high saddle route, depending on destination. The Canyon then maintains a relatively gentle, open character until the next major topographic feature, the Upper Granite Gorge, appears at Hance Rapid. Throughout the course of the Upper Granite Gorge, the Tonto Plateau provides the primary means of lateral movement, as river level travel is not practical. Finally, at the end of Upper Granite Gorge, the Esplanade widens out, becoming the primary corridor of lateral movement throughout the remainder of the study area, although river travel is possible on either side of the Middle Granite Gorge. The limitations discussed above are addressed again in Chapter Four.

A departure here from Fairley's (2003) use of the reach system is that I go on to use it in order to characterize differences in distance between rim and river, between different areas of the Canyon. However, because the rim line does not parallel the course of the river, matching river reaches to rim line is an imperfect process (Figure 2.5). Tables 2.2 and 2.3, and Figure 2.6 provide summary statistics on rim-to-river distance (straight line distance) on the North Rim and South Rim of the Canyon, respectively. Due to the slanted nature of layers in the Grand Canyon Series, the north-side canyon floor and walls above the river are generally wider and less steep (Fairley 2003:19). The high standard deviation in many of the Canyon's reaches reflects the marked undulation of the rim line. The Canyon's width, in conjunction with extreme vertical relief, creates conditions in which greater energy is required to traverse an equal straight line distance.

Table 2.1. Primary and Secondary lateral movement corridors (Adapted from Fairley 2003)

Reach	Start	End	Name	River Level Geology	River Travel Practical	Primary Travel Corridor	Secondary Travel Corridor
1	0	11.3	Permian Section	Kaibab, Toroweap, Coconino	Y	Rim	River level talus
2	11.3	22.6	Supai Gorge	Supai group	Y/N	Supai Talus Slope	Rimline. Continuous river travel impossible
3	22.6	35.9	Redwall Gorge	Redwall Limestone	N	Top of Redwall	Supai traverse
4	35.9	61.5	Lower Marble Canyon	Muav Limestone, Bright Angel Shale, Tapeats Sandstone	Y	River, Butte Fault	Redwall, Supai , High Saddle Route
5	61.5	77.4	Furnace Flats	Grand Canyon Super Group	Y	River, Tonto Plateau	Supai or RedwallTraverse
6	77.4	117.8	Upper Granite Gorge	Precambrian Schist	N	Tonto Plateau	Redwall or Supai Traverse
7	117.8	125.5	Aisles	Tapeats Sandstone	Y	Esplanade	Supai or redwall traverse
8	125.5	139.9	Middle Granite Gorge	Precambrian Schist	N	Esplanade	Supai or redwall traverse
9	139.9	159.9	Muav Gorge	Muav Limestone	Y	Esplanade	Supai or redwall traverse

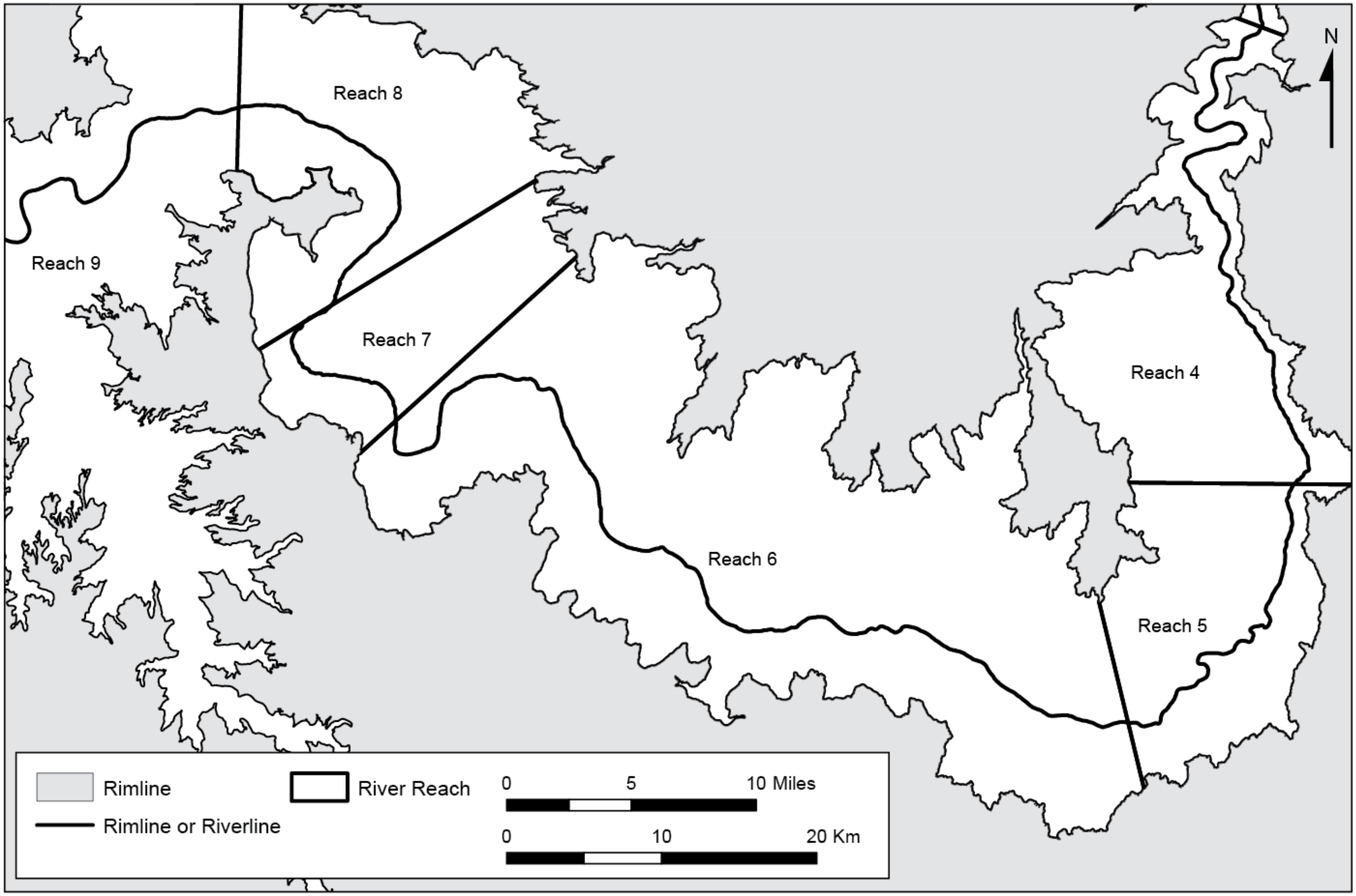

Figure 2.5. River reaches analyzed in this study. Not Pictured are Reaches 1-3 in Marble Canyon

Table 2.2 Straight Line Distance from North Rim to River

Distance to North rim by reach	Minimum	Maximum	Mean	Standard Deviation
1	0.00	2.28	0.46	0.57
2	0.30	5.82	1.80	1.36
3	0.46	7.47	2.66	2.15
4	0.84	13.16	5.88	4.28
5	6.71	10.77	8.48	1.22
6	5.29	21.76	11.64	3.34
7	14.62	17.63	16.09	0.85
8	5.75	17.46	11.11	3.19
9	1.57	23.84	10.65	6.45

Table 2.3. Straight Line Distance from South Rim to River

Distance to South rim by reach	Minimum	Maximum	Mean	Standard Deviation
1	0.00	2.17	0.92	0.73
2	0.21	7.91	2.06	2.06
3	0.53	5.20	1.84	1.13
4	0.60	4.82	1.67	0.89
5	0.91	6.85	3.48	1.44
6	2.32	7.87	4.78	1.22
7	2.04	3.96	3.06	0.52
8	2.08	6.41	4.10	1.28
9	2.13	25.90	12.95	5.52

Culture History

In this section I briefly outline what is known of Grand Canyon prehistory, following the chronological placement of Fairley (2003). I pay attention to aspects of previous work in which subsistence models contain implications for the study of prehistoric trails and transportation within the Grand Canyon. As one may imagine, essentially all of these models pertain to the Formative Period, which denotes semi-sedentary ceramic using populations. However, spatial patterning evident in Archaic and

Pre-Formative site locations (Smiley 2011; Smiley and Smiley 2011) may also be relevant to the current study (See below).

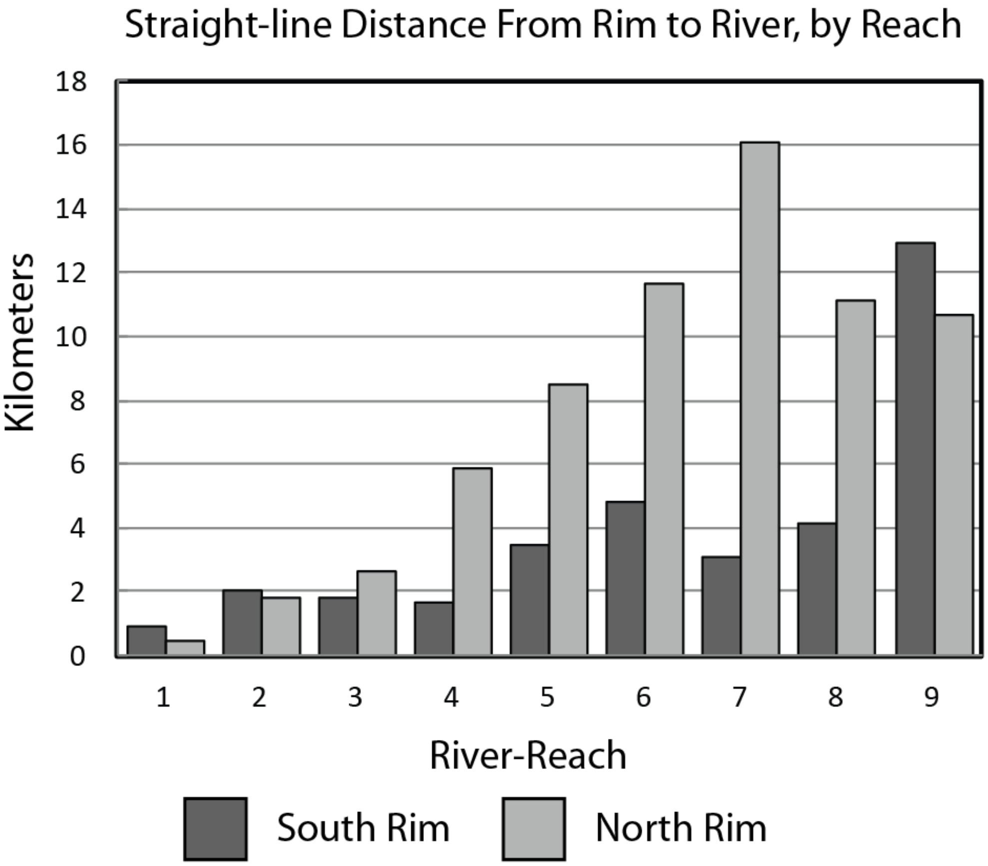

Figure 2.6**.** Differences in the mean “straight-line” distance between the rim and river, for river reaches used in this study. Note the considerable difference between drainages on the north and south rims

Paleoindian Period

Evidence for a Paleoindian occupation of the Grand Canyon region specifically, and the Southern Colorado Plateau in general, consists of a slowly growing body of isolated projectile point finds. The southern Colorado Plateau region lacks well dated sites, such as the kill sites and bison drives found in the southern Southwest and High Plains regions of the United States. However, recent studies of Paleoindian sites across the southern Colorado Plateau, such as the Rainbow Forest site (Wandler et al. 2011), Lime Ridge site (Vance 2011), and Badger Springs site (Hesse et al. 1999) can be taken as examples of expanding evidence for the Paleoindian occupation of the area. In addition, Smiley (2011:8) points out that the apparent clustering of isolated Clovis Point finds in the vicinity of Flagstaff is likely related to the concentration of urban land use in that area. So, perhaps we may expect that as additional areas of GCNP are surveyed, we find increasing evidence of Paleoindian use of the Canyon.

Within the park itself, two Paleoindian points have been found so far. This information has been summarized by Smiley (2011:8) as follows:

> The first of the finds is the Desert View Clovis fragment made on chert from the Washington Pass area of the Chuska Mountains (Hollenshead 2007:9) The Little Nankoweap Folsom point (C:09:0164), came to light as an isolated find by Roberta Serface, an archaeologist working with Steven Emsie's project on Archaeology and Paleontology of Caves in the Grand Canyon in May of 1993 (Serface 1993). Huckell identified the point in 1993 as a Folsom broken in manufacture and made on brown Tolchaco chert from along the Little Colorado River.

The combination of climatic evidence and isolated point finds indicates a possible utilization of the area similar to regions containing more substantial evidence of Paleoindian occupation. Nevertheless, the limited nature of these finds leaves us with little to work with in terms of the application of data to the study of prehistoric trails and transportation. However, the possible association of these points with known trails and routes, including routes into Little Nankoweap Canyon, and the Tanner Trail (near Desert View), offers evidence of the great antiquity of prehistoric trail networks in the Grand Canyon.

The Archaic (10,000 – 1000 B.P.)

In some respects, the Early Archaic Period (8000 – 5000 B.C.) mirrors the Paleoindian occupation of the Canyon. A limited number of projectile point finds derived from surface contexts indicates the presence of Early Archaic hunter-gatherers. Well-dated cave sites, such as those found in the Glen Canyon region are absent from Grand Canyon. However, in contrast to the Paleoindian period, Early Archaic sites are far more numerous, as Smiley (2011:15) has recorded 48 Early Archaic points in GCNP – discounting sites that contain chronologically unreliable Elko points.

According to Fairley, evidence of the Early Archaic comes in the form of Mojave/Silverlake points, Pinto points, Northern Side Notched points, and Elko Corner and Side Notched points (2003:78-79). Smiley (201115-20) adds Bajada points to this list, as well as groups Pinto and San Jose points into a single Early Archaic category. According to this convention, Early Archaic points are grouped into broader categories including Western stemmed (Silverlake and Bajada), bifurcate stemmed (Pinto/SanJose), notched (Northern Side Notched), and Elko (Smiley 2011:15-20). Additional evidence of the Early Archaic includes the Grand Canyon Linear rock art style, which may occur as early as 8000 B.C. (Comstock 2011:20).

In reference to subsistence models, Fairley (2003: 78) cautiously proposes that archaeologists may draw upon Early Archaic evidence in Glen Canyon to inform our understanding of the Grand Canyon Early Archaic. This line of reasoning implies that early foragers, dependent on a diverse array of plant and animal species, may have lived in lower elevation zones of the canyon while strategically exploiting resources from different elevations within, and outside the canyon, and that cave sites may have functioned as winter base camps. This seems plausible, although without stratified cave sites, and the extreme unlikelihood of finding undisturbed open-air sites dating to the Early Archaic, evidence of this model remains unconfirmed. The feasibility of foraging from different locations, such as the from the River level or from the Canyon rim, will be explored within the context of cost equivalent distances in Chapter Six.

Lesser counts of projectile points both regionally and within the Grand Canyon point to reduced habitation or use of the Canyon during the Middle Archaic (5000 – 3000 B.C.). Smiley (2011:25) counts 24 sites containing Middle Archaic projectile points in the Canyon, compared to 48 Early Archaic sites. Point types from this era include Hawken, Sudden Side-Notched, and Rocker Side Notched points, respectively (Smiley 2011: 22). Evidence of decreased population on the Colorado Plateau, and in the Southwest in general, is largely accepted as a result of increased temperature and decreased moisture during the Altithermal (Fairley 2003: 79). However, as Smiley (2011:22 – 25) has pointed out, areas south of the Grand Canyon such as the Coconino Plateau, and areas east of the Grand Canyon such as Black Mesa show some evidence of continued occupation through the Middle Archaic. In addition, Geib (1996; quoted in Fairley 2003) has pointed out that lack of evidence for the Middle Archaic may be the result of a higher mobility foraging style. At this point it is only possible to assume a reduction, but not complete abandonment of the Canyon during this period. The Middle Archaic is also evidenced by the presence of the Glen Canyon Linear rock art style (Comstock 2011:23).

Fairley (2003:81) attributes various point types as evidence of the Late Archaic (3000 – 1000 B.C.), including Gypsum, McKean, San Rafael Side-notched, and Elko-eared. However, Smiley (2011: 26) states that the only type abundant enough to draw conclusions from is the Gypsum point. The Gypsum typology essentially includes a variety of contracting stem projectile points, sometimes referred to by different names. Perhaps the most interesting aspect of Gypsum points is their apparent association with the Grand Canyon Split-Twig Figurine Complex (Smiley 2011: 30), although this association is extremely uncommon. Evidence of the Late Archaic also comes by way of several radiocarbon dates obtained as result of paleoflood research. Dates from the upper Marble Canyon range between 2508 – 2289 B.C., while dates obtained much farther downriver range 1260 – 1141 B.C. (Fairley 2003:82).

The most oft reported evidence of the Late Archaic takes the form of the Grand Canyon split-twig figurine complex. Archaic peoples built figurines from a single twig of willow. Early reports (Wheeler 1939, 1949) mention discoveries of the phenomenon by CCC crews working in Crystal Creek drainage on the north side of the Colorado, as well as early discoveries by river parties in Stanton’s Cave. Subsequent work by Farmer and DeSausure (1955) expanded the sample of caves containing split-twigs to include several sites below the south rim. Schwartz et al. (1958) provided the first radiocarbon dates and formal archaeological excavation of split-twig caves, and subsequent work by Euler

(1965, 1984) in Stanton's Cave increased the sample of figurines substantially. Finally, the work of Emslie et al. (1995) resulted in the most recent discoveries of Grand Canyon split-twig caves, and brought the total number of known Grand Canyon Split Twig Caves to 14 (Smiley 2011: 43).

Smiley (2011: 43) states that a reliable time span for the split-twig complex ranges for 1700 years between 2900 and 1200 B.C., although the two-sigma range on radiocarbon ranges over 2500 years. Split-twig caves are often difficult to access, sometimes requiring climbing gear, and contain the remains of extinct species (Emslie et al. 1995) Split-twig caves are essentially devoid of associated artifacts, although Tse-an-Kaetan produced a number of interesting finds, including a wad of human hair hanging from the ceiling, an un-typed projectile point, and a torch (Schwartz et al. 1958). The dearth of associated materials has lead researchers to assume a primarily ritual, or, "magico-religious" function for the caves (Schwartz et al. 1958). Recently Coulam and Shroedl (2004) argued that the figures represent increase totems. Due to the apparent ritual, rather than subsistence use of split-twig caves, the most relevant aspect of prehistoric transportation addressed by this thesis is accessibility. The hard-to-reach and dangerous settings of split twig caves attest to the ability of prehistoric people to access difficult parts of the canyon.

Recent work by Smiley (2011: 38) has recognized significant spatial patterning of Archaic sites above the south rim of the Grand Canyon, in well-surveyed areas near Grand Canyon village. Archaic sites, including sites from the Early, Middle, and Late Periods, evince a clear pattern of spatial clustering. This clustering pattern is not apparent on the Kaibab National Forest south of the Grand Canyon (Lyndon 2005; cited in Smiley

2011). In addition, these south rim clusters occur in close proximity to known Grand Canyon trails and routes. Accordingly, Smiley (2011:38) has made the inference that Archaic peoples chose site locations for, “proximity to Grand Canyon access, whether to the benches below the Rim, Colorado River, or North rim…” This pattern is highly relevant to this study because it substantiates my subsequent characterization of Grand Canyon accessibility, and may hold implications in the nature of rim-to-river foraging activities.

The Preformative (1000 B.C. – 400 A.D.)

As Fairley (2003:82-83) points out, naming conventions used in other regions of the Southwest, including Early Agricultural, Basketmaker II, and Terminal Archaic, contain implications that cannot be verified in the Grand Canyon, such as cultural connectivity with later Puebloan people, or dominant subsistence strategies. These implications cannot be substantiated because of an overwhelming lack of evidence related to this period of time in the Grand Canyon. Smiley and Smiley (2011:2-3), while in agreement with Fairley’s characterization, state that some of the most generalized characteristics of Basketmaker II probably hold true in reference to the Grand Canyon Preformative, including:

> The Baskemakers were preceramic farmers of corn and squash who frequently lived in rock shelters as well as open-air settlements with permanent dwellings. The Basketmakers buried their dead in their own settlement and social context and used the atlatl and dart as a weapons system. Finally, the Basketmakers

> maintained a significant level of residential mobility in their adaptation to the difficult and stochastic climatic regime of the Colorado Plateau

Accordingly, although the cultural affiliations of the Grand Canyon Preformative are unknown, they probably shared in common some of the most basic characteristics of early horticulturalists around the Southwest mentioned above.

Tangible evidence of agricultural origins in the Canyon is meager. Radiocarbon dates from the Striped Alluvium include cluster between 3200 and 2700 B.P., and between 400 B.C., and 400 A.D. (Fairley 2003:84). However, these finds contain no associated cultural materials or plant remains (Fairley 2003:84). The finding by Davis et al. (2000) that corn pollen was found to be associated with a hearth dating to 1300 B.C. appears to be problematic (Fairley 2003:84; Smiley and Smiley2011: 37). This is due to the ability of corn pollen to mix between stratigraphic levels in alluvial contexts.

Additional evidence of Preformative occupation takes several forms. Comstock (2011) "analyzes four rock art styles dating to the Preformative period, including Preformative A and B, and Snake Gulch and Cave Valley styles" (Smiley and Smiley 2011: 24). These sites come from diverse regions of the canyon, and as Smiley and Smiley (2011:23) state, may indicate the presence of Preformative ethnic diversity and, "a considerable temporal span." In addition to rock art sites, Smiley and Smiley (2011: 26-29) provide a tabular summary of sites in GCNP that contain the following characteristics: 1) Typed (typed by field crews) BMII projectile points, either in mixed (three sites) or unmixed (one site) contexts, 2) Side-notched points, which may or may not be BMII (two sites), 3) Corn-cobs in absence of ceramics (two sites), 4) Storage cists in chronologically mixed context (1 site), and 5) Sites designated as BMII on a site form without further explanation (1 site). Finally, two sites, the Greenland Lake site, and the Little Jug site, deserve additional attention as either tested or excavated sites.

Only one site contains excavated evidence of the BMII/BMIII time frame, the Little Jug site (Smiley and Smiley 2011: 24 – 32). The site is located in the western Grand Canyon, in the eastern Tuweep Valley. Excavations during the 1970's (Thomson and Thomson 1978) produced numerous pithouses, and a rather intense BMIII occupation, evinced by multitudes of potsherds. Importantly, "six radiocarbon dates place the earlier occupation between A.D. 100 and A.D. 320" (Smiley and Smiley 2011: 29). BMII features at the site included pithouses, bell-shaped cists, and rock –lined cists, similar to those described by Earl Morris at Talus village (Smiley and Smiley 2011: 29 – 30). An additional site, the Greenland Lake site, was partially tested by Schwartz et al. (1981). Surface artifacts included BMII projectile points and debitage. The site is located in the eastern Canyon at the northern end of the Walhalla Glades, and sits at a source of permanent water, perhaps an important hunting location.

In the absence of substantial numbers of excavated Preformative sites, scholars have pointed to environmental characteristics of the Grand Canyon similar to other parts of Arizona. For instance, Smiley and Smiley (2011:39 -49) have pointed to the remarkable similarities between northern Black Mesa, and the Grand Canyon's south rim, including 1) Similarities in elevation between the Grand Canyon South Rim and Black Mesa Archaeological Project (BMAP) project area (1900 – 2200 meters), 2) Similarity in elevation between the Grand Canyon North Rim and very northern edge of Black Mesa, 3) Hydrological similarities, including a lack of permanent standing water in both study areas, as well as the prevalence of northeast to southwest trending drainages, 4) Similar vegetative regimes, 5) the presence of dramatic escarpments on the edge of both study areas, 6) Similarity of soil type, including the presence of thin sandy loams overriding bedrock, and finally, 7) the prevalence of low slope topography. Based on these similarities, Smiley and Smiley (2011) infer that future investigations of the Grand Canyon Preformative may include predictive models based on the distribution of sites on Black Mesa, which predominantly requires special attention to stream and drainage buffer zones.

In contrast, Fairley (2003:85) has pointed to similarities between the basin and range province, in the area of the Gila and lower Colorado Rivers, as well as early radiocarbon dates, and the presence of a San Pedro point, as potentially implicating the spread of agriculture through north-migrating southern populations. Fairley states (2003:85):

> On the Colorado Plateau, alluvial bottomlands along the Colorado River within the Grand Canyon offered the requisite features desired by early desert farmers: an aggrading floodplain next to a perennial river in a low-elevation, warm desert environment.

I acknowledge that these environmental zones are not mutually exclusive to specific models of Preformative archaeology in the Grand Canyon, and in fact Smiley and Smiley (2011) expect that Preformative groups occupied river corridor as well as the rimlands. However, as environmental considerations weigh large in potential future studies of this era, it is appropriate to ask the question, “Were the Preformative occupants of Grand Canyon immigrants from the south, or analogs to BMII populations farther to the east?” In terms of the influence of topography and accessibility to Preformative peoples, I assume that there would have been an influence similar to that of later formative and earlier agricultural peoples.

The Formative (1600 – 800 B.P.)

As stated by Fairley (2003:87) the formative can be defined as the period of time in which people, “lived in substantially constructed dwellings, tended gardens of cultivars such as corn and squash, and produced ceramics.” Here, I follow Fairley’s (2003) convention of dividing the Formative into an early and late period. The Early Formative includes Basketmaker III (400 – 800 A.D.) and Pueblo I (800-1000). The Late Formative includes the Pueblo II period (1000 – 1200 A.D.).

Whereas Smiley and Smiley (2011) located slightly over a dozen instances of Preformative archaeological sites, Fairley’s (2003) search of Grand Canyon site files returned only 12 instances of Lino type ceramics (in other words, the quantity of evidence regarding both Periods is similar), the hallmark of BMIII occupation. However, as Fairley (2003:89) points out, the low number of sites may indicate archaeologists’ bias towards Kayenta Anasazi ceramic types as indicators of this time period, as we have no other known diagnostics for non Kayenta Anasazi groups during this time period. In addition to the Lino ceramic sites, there are a number of radiocarbon dates, including those reported on by Jones (1986) at sites in Tuna creek, Deer Creek, and at the Beamer

Cabin site. Finally, the Little Jug site, mentioned earlier as evidence of Preformative period occupation, carries over into Formative times.

As with preceding periods, evidence of Pueblo I occupation remains scarce in the Canyon. Current information suggests that Cohonina groups preceded the Kayenta Anasazi in the Canyon. Schwartz et al. (1980) first made this assertion based on the presence of Kana-a Black-on-white sherds in association with San Francisco Mountain Gray Wares at some sites on Unkar delta, although Fairley (2003:91) has called this evidence, “meager.” The, “Cohonina First” hypothesis appears to have been substantiated, however, by the discovery of an assemblage dominated by early Cohonina ceramics underneath a PII occupation at site AZ: C:13:10, upstream from Unkar delta (Fairley et al. 1994:104). Cohonina ceramics are abundant above the Canyon rim to the south as well (Fairley et al. 1994).

In contrast to every time period discussed thus far, evidence of the Late Formative (1000 – 1200) A.D., or Pueblo II occupation, is widespread and, as Fairley (2003:92) points out, the most common focus of study for archaeologists. Among the different Ancestral Puebloan branches, surface scatters indicate that Cohonina dominate to the west on top of the south rim, and Kayenta assemblages are more common to the East (Fairley 2003:92). In terms of subsistence models, several have been suggested. As Neff (2010) points out, this is due to the apparent benefit of changing environmental zones as a consequence of rapid change in elevation. Although these models are typically constricted to a specific region of the canyon, they all imply that seasonality played a role in prehistoric peoples’ yearly round, and seem to imply that seasonality was more important to people living in the Grand Canyon than contemporaneous Puebloan people elsewhere (Neff 2010:1) Neff has additionally pointed out that some models are synchronic over the 1000 – 1200 A.D. time span, whereas others are diachronic over the same time span.

One of the first seasonal settlement models to be introduced was Schwartz et al.'s (1980, 1981) "bi-seasonal" model (Neff 2010). This model states that after 1050, the inhabitants of Unkar delta and perhaps other river level sites began to farm seasonally in the Walhalla Glades (Fairley 2003:93, Schwartz et al. 1981). Sites on the Walhalla Glades dating to this time period are smaller compared to river level sites, typically lack hearths, and completely lack kivas, indicating summer occupation by a smaller subset of the Unkar Delta or Unkar Canyon population. An important aspect of this model is the role of apparent increased rainfall after 1050 A.D., in this region of Arizona; Schwartz et al. (1981:124) hypothesized that the area could not be effectively farmed otherwise. Equally important, perhaps, are the reasons for which there are thought to be cultural ties between the sites on Walhalla Glades and in the canyon, including similarity in agricultural features, architecture, and ceramic tradition. The last criterion, ceramics, has recently been questioned by Neff (2010:5). Neff states that differences in the proportion of grayware ceramics indicate that sites on the Walhalla glades were more closely tied to elements of the Virgin Anasazi, primarily located to the north and northwest.

Following the work of Schwartz et al., a number of scholars have gone on to develop models of Grand Canyon settlement that account for greater geographic areas. Effland et al. (1981) drew on ethnographic analogy, archaeological evidence from Powell Plateau, and the characterization of the Grand Canyon as a marginal environment to create several subsistence models. All of these models predict reliance on hunting and gathering as well as agriculture. For instance, Effland et al. (1981:41) note that the Havasupai would often rely on agriculture for only 10 percent of their diet, and that in years of poor harvest the Havasupai would simply expend more energy foraging. I make this point in order to highlight the fact that these models should be considered flexible with respect to the subsistence activities that may have predominated from one year to the next.

The first of the models proposed by Effland et al. (1981) is based on traditional Havasupai subsistence, and applies to the western Grand Canyon south of the Colorado River. This model emphasizes the harvesting of agave during the spring, and foraging and hunting above the south rim during the fall and winter, followed by summer agricultural activities. The second model, similar to the Havasupai model is the Paiute model (Effland et al. 1981:43-44), and it applies to the western Grand Canyon north of the Colorado River. This model implies agricultural activities during the summer, the gathering of mesquite, wild grasses, and Pinyon during the fall, and settled villages during the winter. Spring activities would include agave harvesting. These two models do not apply to the eastern canyon on the south rim, or the Powell Plateau area. In these areas Effland et al. (1981) emphasized seasonal movement above the rim with some agriculture and resource procurement below the rim. In addition, these scholars drew an analogy between the Tarahumara of northern Mexico and the inhabitants of Unkar and the eastern Canyon north of the river, as the Tarahumara historically inhabited lower elevation areas of Copper Canyon and farmed in higher elevation zones. On final point regarding these models is the assumption that sites on the north rim were located in proximity to trails that allowed canyon access (Effland et al 1981: 43). This idea coincides with Euler and Chandler's (1978) assertion that trails are an important component determining the location of archaeological sites.

Similar to Effland et al. (1981), Huffman (1993) and Fairley (2003) have combined western, central, and eastern Canyon models of subsistence, creating more comprehensive, synthetic models. These models rely primarily on physiographic differences between regions of the canyon, and largely agree with the settlement models proposed earlier. For instance, Fairley (2003:94) states plainly that, "some settlement strategies are more practical for specific areas of the Grand Canyon than for others." Under this assumption, a summer-upland, winter-lowland model makes sense for the eastern canyon, whereas in central canyon areas, such as Powell Plateau, year round occupation of the rim with seasonal forays into the canyon for farming and foraging makes sense. In the western canyon, late winter and early spring foraging in the canyon may have supplemented year round subsistence on the rim.

Huffman (1993:154) outlined in considerable detail elements of the Canyon's physiography that he refers to as system components. Differences in system components are hypothesized to have contributed to differences in subsistence strategies between the eastern and western Canyon. Although the western extent of the study area on the north rim for this thesis is Kanab Creek, points made by Huffman for areas west remain pertinent for portions of the central canyon. In the eastern Canyon, system components include the north rim, river deltas, and connecting side-canyon corridors (Huffman 1993:155). Because agricultural features are similar in these different areas, and the sites in different areas appear to have been contemporaneous, it is hypothesized that they were part of a unified agricultural strategy. However, as Huffman (1993:158) and Schwartz et al. (1979) have pointed out, the level of communication between north rim drainages is unknown due to travel considerations, or to put it another way, the consequences of a higher “effective distance” between north rim drainages is unknown. Two factors contribute to high effective distance between locations of the Canyon, including 1) the effects of steep terrain, and 2) the effects of topographic obstacles, such as cliffs, side drainages, and if travel to the south rim is considered, the Colorado River. The ramifications of high effective distance between north rim drainages create uncertainty as to the nature of trade and interaction between people living in these drainages. This concept will be addressed in Chapter 6. To summarize, Huffman’s (1993) eastern Canyon subsistence system basically coincides with that of Schwartz et al.; major habitations along the river were inhabited year round, while a segment of the population relocated to the north rim in order to take create a second harvest, which may have performed differently due to differences in rainfall and soil between rim and river areas.

In the western Canyon, Huffman characterized system components based off of the results of the Kanab Plateau Project as well as previous management driven surveys (1993:161). In the western Canyon, major system components include the Esplanade, plateaus, and surrounding uplands including the Uinkaret Mountains, while minor components included riverine environments at the mouths of side canyons (Huffman 1993:161). According to this view, inhabitants of the western Canyon practiced a, “Top Down” approach, living permanently above the canyon rim, with, “logistical movement from permanent habitations to various plateau and canyon resources. In the following chapters, I will examine the energetic differences involved in rim-to-river foraging strategies in the eastern and western canyons.

A final settlement model that has been proposed relatively recently is Sullivan et al.'s (2002), "Cross-Canyon Model." This model states that the inhabitants of the Grand Canyon's Upper Basin moved around the Upper Basin in a seasonal round, and relied very little on agriculture. Sullivan (1986, 1995, 1996) has stated often that the Cohonina of the Upper Basin relied little to none on agriculture, apparently in contrast to the views of other scholars (Schwartz 1989). The central thesis of this model is that, depending on the severity of the spring drought, Upper Basin peoples would cross the river during late spring or early summer in order to hunt and gather on the north rim (Sullivan et al. 2002: 61). According to Sullivan et al. (2002:61), "The cross-canyon model explains the extent of the canyon's trail system." I consider this characterization of trails to be erroneous, a point which will be discussed in Chapter Three

Historical Adaptation to the Canyon

In addition to the various hypothetical models of prehistoric subsistence, I would like to add additional perspective from the Historic and Protohistoric periods, which has been summarized by Fairley (2003:96 – 102). This information serves to demonstrate the variability of prehistoric subsistence between geographic areas of the canyon, and in some instances even within bands. In addition, this section highlights the pressures introduced by Euroamerican settlers, and the effect this may have had on subsistence strategies.

Historical Navajo use of the Canyon resulted in part from pressured introduced Euroamericans during the American-Indian Wars of the 19th century. During the 1850's, Navajo bands took refuge in the Canyon, and one band lived with the Havasupai during this period as guests in Cataract Canyon. In addition, Navajo utility wares have been found near Hance Creek, in the eastern Grand Canyon. Like the Navajo, Hualapai and Southern Paiute bands sought refuge from Euroamerican pressures related to mining and agriculture during the late 1800's, spending more time in the inner Canyon than they would have as part of a traditional seasonal round. According to Isabel Kelly's (1964) ethnography of the Southern Paiute, the Southern Paiute practiced a subsistence round that included winter and spring base camps along the base of the Kaibab plateau, spring harvesting of agave in the eastern Canyon, and summer occupation of House Rock valley in order to tend small gardens, with additional hunting during the fall on the Kaibab Plateau. However, as Fairley (2003) points out, Mormon settlement north of House rock valley probably pushed the Southern Paiute out of prime agricultural land. Moreover, excavation data along the Colorado River indicates variability in the Southern Paiute seasonal round contrary to Kelly's (1964) description. Finally, some Pai bands lived in within the Canyon during the winter, while others lived on the surrounding plateaus.

The above summary shows that historic native American use of the Canyon was influenced by events taking place in the broader scheme of American history, and that even during this time frame, use of the Canyon was highly variable over time and space. Therefore, as archaeologists, it is important to realize that subsistence models based on historical Native American use of the Canyon, although informative, probably do not offer perfect prehistoric analogs. These subsistence models do, however, highlight themes, such as dispersed settlement patterns, and seasonal agave harvest that can widely be assumed to be feasible subsistence adaptations within the context of prehistoric land use.

Conclusion

This chapter has provided an overview of the Grand Canyon's geology, and what is known of the Canyon's cultural history, juxtaposing what we perceive to be the limitations of the Canyons topography with the history of human occupation. A couple of salient points include:

1) The Canyon's topography creates an issue of accessibility. Archaeological evidence in support of this point comes from the apparent clustering of Archaic sites around routes on the south rim (Smiley 2011), Euler and Chandler's (1978) hypothesis that one of the most important factors influencing site location is the location of trails, and Fairley's (2003) characterization of the river corridor around Granite Gorge as the area least populated with archaeological sites.
2) The Canyons topography creates an issue of effective distance. This has been highlighted by Huffman's (1993) and Euler et al.'s (1979) discussion of the level of communication between north rim drainages in the eastern Canyon. We may also assume that rough terrain had an influence on foraging activities, as well as the size and distribution of agricultural catchments.
3) The Canyon's trail system arose as a response to cross-canyon foraging (Sullivan 2002).

Clearly, issues related to prehistoric trails or travel considerations have weighed in the minds of most scholars of Grand Canyon prehistory. From this point I go on to address the verification of archaeological trails in the Grand Canyon. This verification provides a jumping off point an informed discussion of issues related to accessibility and effective distance, which are inter-related factors.

Chapter 3

Evidence for Prehistoric Use of Known Trails and Routes

Introduction

This chapter examines the current evidence for archaeological trails in the Grand Canyon. One previous study (Wilson 1999) identified several trails or trail complexes within the Grand Canyon as prehistoric. Based on the criteria outlined by Wilson (1999), I believe that it is possible to characterize the majority of known trails and routes as having received prehistoric use, although many routes will not correspond to an actual discernible path on the modern ground surface. This is possible due to the relative ubiquity of archaeological sites in the Grand Canyon as well as the basic features of the Canyon's topography. The Canyon's side drainages and plateau systems create natural travel corridors that correspond to routes travelled by modern hikers; these routes, in turn are generally consistent with descriptions of prehistoric and ethnographic trails systems in the greater Southwest. Finally, comparing the juxtaposition of archaeological sites and constructed trail features to trails allows for reasonable designation of modern routes as prehistoric features.

Characteristics of Regional Trails and Paths; Implications for the Grand Canyon

In the volume, "Landscapes of Movement" (Snead et al. 2009), several authors characterize the form, function, and meaning of prehistoric and historic trail and path systems in the southwestern United States. Case studies include Hopi (Fergusen 2009), Ancestral Puebloan (Snead 2009), Southern Paiute and Chemehuevi in the Mojave Desert

(Fowler 2009), and O'odham Trails (Darling 2009). Similarities in the trail systems of these groups may reflect similarities in the scales of the societies considered. Generally, the groups involved consist of small-scale societies ranging in residential population size between tens of members and hundreds of members living under similar environments in the arid Southwest. Characteristics of trail systems mentioned above provide useful analogs for the prehistoric trail systems of the Canyon.

Figure 3.1. Stacked rocks, or steps, near the Canyon's south rim. A number of the stones in this picture are deeply embedded, allowing the interpretation of these steps as a prehistoric feature

Figure 3.2. People debate whether or not this log ladder was placed by prehistoric peoples or Bass-era miners. Regardless, it provides a useful analogy of how log ladders may have facilitated movement through the vertical barriers of the Grand Canyon.

In the examples cited above, trail and path networks are created through repetition of use, meaning that as people walk over the same landscape through time, trails form naturally by the continual depression of the ground surface by through the act of walking. Additional labor is not typically invested in the creation of trails, although as Snead (2009:54) points out in the Pajarito trail system of northern New Mexico, steep sections of terrain may be modified to include hand and toe holds, or staircases. Such

Figure 3.3. Formal steps, or stairs, occur in at least one place within the Canyon.

modifications also occur in the Grand Canyon (Figures 3.1 – 3.4). Trails often conform to cost-efficient routes over the landscape, such as valley floors and drainages, and contain extended linear segments, which often jump minor obstacles to maintain linearity (Fergusen 2009:27). In the arid Southwest, trails also tend to reflect the distribution of springs. Trails usually perform both secular (resource allocation, trade) and religious functions. Fergusen (2009:30-31) lists additional variables that may aid in the ground-truthing of archaeological trail systems.

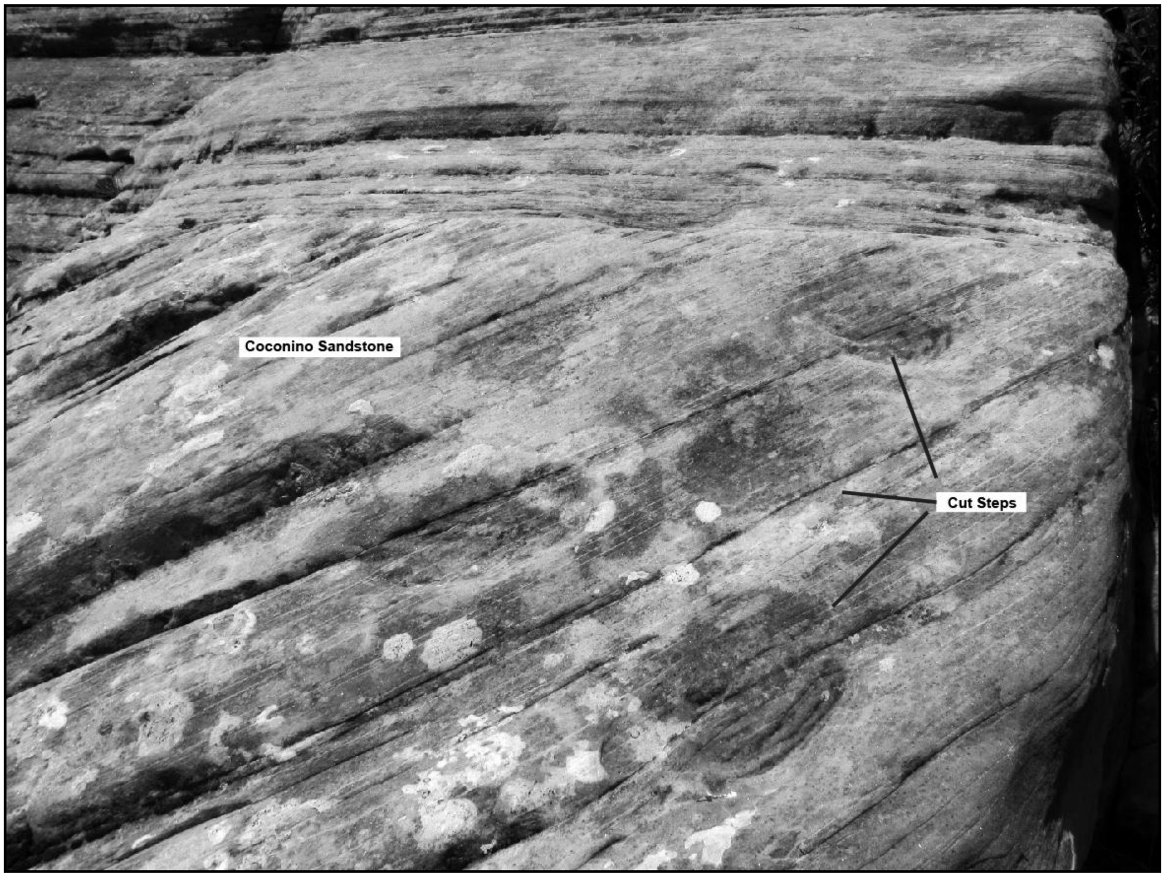

Figure 3.4**.** Cut, or “Moki” steps, such as these, facilitate movment in several routes in the Grand Canyon.

Wilson (1999: 33-35) also lists general, as well as, specific characteristics of trails that can be used to verify prehistoric use. Generally, trails may be 1) Located near archaeological sites, and 2) topographically feasible. More specifically, trails may 1) Include the presence of constructed features along trails, “designed to facilitate passage over the landscape, i.e., toe-holds, steps, ramps, and ladders, 2) Be discernable on the ground surface visually or through remote sensing, 3) Contain archaeological material especially indicative of trail systems, such as, “linear artifact scatters, caches, rock art” (Wilson 1999: 34, Figure 3.5), 4) extend from/to a resource area or between sites, and 5) be ethnographically corroborated.

It is significant that Wilson (1999: 27 –29) also differentiates among types of trails present in the Grand Canyon, including routes, animal trails, informal trails, formal trails, and corridors. The difference between these types of linear features is a function of the level of use. *Routes* represent topographically possible means of travel. *Informal trails* include trails that are not improved, but are conceptualized in the minds of people. *Formal trails* include trails that exhibit constructed features, i.e., steps, handholds, or ladders. A *corridor* is a, “definable space, generally linear in nature bounded by environmental or topographical conditions on two sides parallel with the linear axis. Within this bounded space, networks of transportation, communication, trade, etc. connect various elements.” (Wilson 1999: 29)

Figure 3.5. This pictograph, clearly associated with a room block, marks the top of an exposed descent through the Coconino sandstone. Sites such as this can be conceptualized as nodes in an ancient network of trails.

Implications

So far, I have outlined two important characteristics of pedestrian movement in the Grand Canyon; 1) General geologic or topographic features of the Grand Canyon that may inhibit or facilitate foot travel (Chapter 2), and 2) general characteristics of indigenous and prehistoric trails in the greater Southwest and Grand Canyon regions. From here, it is possible to synthesize such variables to create a more nuanced picture of prehistoric travel within the Grand Canyon.

As mentioned previously, several of the Canyon's geologic strata present significant barriers to vertical movement. These barriers include the Vishnu Schist, Redwall Limestone, and Coconino Sandstone. It is in negotiating these layers that we are likely to encounter opportunistic use of the landscape as well as modifications to natural features such as cut or constructed steps, ladders, and stairs. In other words, we will encounter the characteristics of informal and formal trails defined by Wilson (1999). Perhaps the most famous of these is the "Bridge of Poles" near Nankoweap in Marble Canyon. The Bridge of Poles spans a gap in the Muav Limestone, leading to a technical climb to the top of a route which has only been completed in modern times by climbers using rappelling equipment. This example brings up another point regarding vertical barriers, which is that prehistoric peoples appear to have been undeterred by exposed climbing. Several routes in the Canyon involve extended climbing which, after repetition, may have become routine (Rich Rudow, personal communication 2010). In fact, with very few exceptions, climbing routes to the tops of the Canyon's summits exhibit some evidence of prehistoric use, either in the form of pottery, projectile points, or cairns (James Ohlman, personal communication 2011). So, while routes that span vertical barriers may have clustered around faults, such routes also involved creative use of natural features and construction of features that would assist in maneuvering around obstacles. Because of these limitations, we may expect that rim-to-river routes, or movement that required considerable elevation change required repeated use of specific access points. An additional point of evidence in this regard is the fact that many sites are located in intermediate areas between the rim and river, such as at Indian Gardens in

Bright Angel Canyon, which indicates frequent use of routes that provide access over vertical barriers.

Lateral movement within the Canyon also occurred in zones specified by geologic strata, such as along the Tonto Plateau, Esplanade, River Corridor, and along the top of the Redwall Limestone. These areas, especially the broader plateau regions, exhibit characteristics of travel corridors. Movement along such topography probably was constrained by access to water, especially in the summer months. I assume that prehistoric people knew about and opportunistically used seasonally available water as well as springs and creeks. Additional barriers to lateral movement, especially in the eastern Grand Canyon, include the multitude of side drainages and fault zones. This aspect of the canyon highlights an ironic circumstance: While geological faults enable vertical travel, they also, "are real barriers to lateral movement. The problem here being loose breccia zones, or shear faces where faulted strata are widely offset from side to side." (James Ohlman, personal communication 2011). As stated in Chapter 2, we might also break down lateral travel corridors in the Canyon by specific regions. For instance the use of the Tonto plateau as a corridor of horizontal movement mostly corresponds to Upper Granite Gorge.

In this study, I make several assumptions based on the aforementioned examples. I assume that the prehistoric occupants of the Grand Canyon created trails by repetitious use, and that most foot travel was restricted to trails in order to maximize travel efficiency. For instance, hikers often characterize off trail travel in the Canyon proceeding at 1 mph or less. In reference to trails being created by repletion of use, I would like to point out that the majority of what are assumed to have been prehistorically used trails do not typically correspond with an actual discernible path on the modern ground surface. Erosional characteristics of the Canyon prevent the long term preservation of most trails. In addition, modern use of the canyon, and the trails created by game and rangeland animals obscure what may be de facto prehistoric trails. Thus we often depend on route information to identify trails that probably received a great deal of prehistoric use. Therefore, we may reason that what may only appear as a topographically feasible route today may have functioned as an informal trail prehistorically, especially when such routes are associated with archaeological materials. I assume that prehistoric trails mirror topographic features, including the Canyon's many drainages, faults, and plateaus. Where possible, for example on the plateaus, trails will tend to be linear. Prehistoric trails in the Canyon undoubtedly served both secular and religious purposes, as Hopi ethnographies describing the salt pilgrimage attest.

The Grand Canyon Trails Database

The trails database used in this study results from the compilation of several sources, including popular guidebooks and GIS data provided by Grand Canyon National Park. GIS data provided by the Park generally contribute precise locations for major Park trails. Guidebooks used in this study include the 1997 compilation of Harvey Butchart's classic hiking guides, as well as the works of Steck (2002) and Martin (2010). Although numerous volumes exist on the topic of Grand Canyon hiking, these references typically include the maps necessary for reasonably accurate digital recording. The exception to this rule is of course Butchart (1997), however, a digital version of Butchart's Matthes-Evan's map allowed reasonably accurate digitization of the numerous trails and routes described in his guides. Because Butchart's map can be accessed publicly through Northern Arizona University, the dataset provides a synthesis of public, verified, and mapped data. The map is not, by any means, an "absolute" list of routes completed in the Grand Canyon. Known routes that cannot be accurately mapped are not included in the database.

It would be difficult if not impossible to verify and accurately map every route completed by Grand Canyon hikers over the years, although I acknowledge that collaboration with Canyon experts would very likely fill in some data gaps. For instance, Butchart (1997:261) states that he barely explored routes to or from the Esplanade below Powell Plateau. Because neither Steck (2002) nor Martin (2010) discuss trails in the Powell Plateau area, the dearth of routes there simply represents a gap in the available data. Hence, individuals familiar with the Powell Plateau area could probably fill a large gap for that region. I should also point out that there are several routes mentioned by authors that I am aware of, but which have no corresponding map, and therefore are not included in this portion of the study. Nonetheless, the dataset used in this study is probably the most complete Grand Canyon trails database compiled in a GIS for the central and eastern Grand Canyon. In any case, I doubt that the number of prehistoric or modern-day routes not included in this dataset is large enough to significantly change the implications for prehistoric use in the Canyon. There are probably not many "effective" routes that are not included in this study (Chapter Four).

The addition of the Butchart map represents the greatest contribution to this compilation of trails, and the one which makes the database comprehensive. Not only did Butchart hike extensively in the Grand Canyon, he specifically sought out new access points between rim, Redwall, and river. In addition, Butchart often collaborated with Park Archaeologist Robert Euler, using Euler's knowledge of archaeological sites to infer the potential of prehistoric use of routes, and he regularly made note of archaeologically significant features. I assume that this collaboration was influential to Euler and Chandlers' (1978) assertion that Canyon access was a major factor in determining the location of archaeological sites. Butchart's exploration typically occurred in areas as yet unexplored by archaeologists, which allows us to make inferences about the prehistoric use of trails in remote areas. Readers interested in the life and contribution of Harvey Butchart to our understanding of the Grand Canyon should consult *Grand Obsession: Harvey Butchart and the Exploration of the Grand Canyon* (Butler and Myers 2007).

The current database includes 501 trails or routes compiled from the aforementioned sources. The attribute table associated with the routes layer includes some sort of reference information for each route (although descriptions by Harvey Butchart are famously minimal) as well as attributes used to support the following analysis; presence/absence fields indicate whether or not a trail contains constructed prehistoric features or other archaeological materials, as well as information as to whether a route is accessible only by rope; whether a route crosses the Redwall, and if a route encounters the river, and, finally, the river mile measure. In order to provide context to the large number of trails recorded in this analysis, it is important to point out that routes that follow the Esplanade and Tonto Plateau are partitioned in order to maintain reference information (Figure 3.6). No guide book describes the entire length of these areas in one description. In addition, the current distribution of routes often mirrors the dendritic pattern of stream distribution in the Canyon (Figure 3.7). Thus, one might group the 500 plus trails and routes by stream or amphitheater association.

Identification of Archaeological Trails in the Grand Canyon

The identification of trails and routes in this study as likely candidates for prehistoric use comes from both direct and indirect evidence. The most direct form of evidence on prehistoric use includes modified trail features, such as steps, grooves, or ladders, although such features are relatively rare. The next is a presence/absence category used during the creation of the trails database, which identifies whether or not

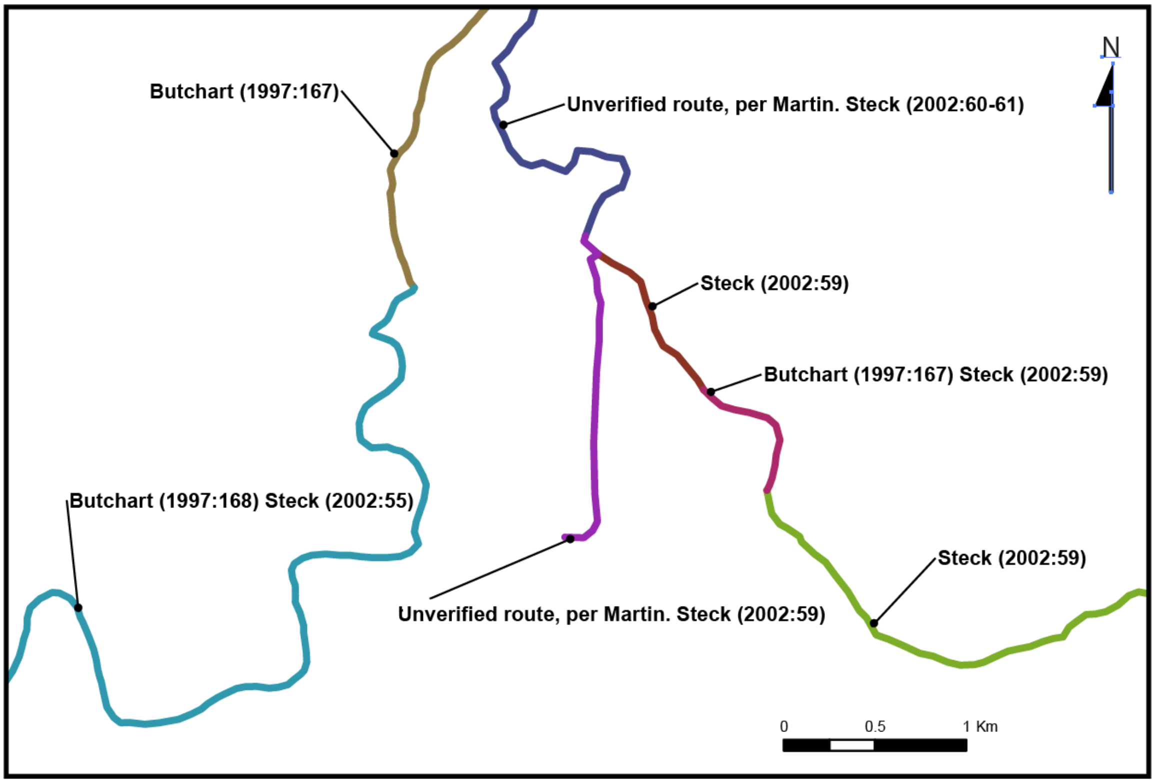

Figure 3.6. Trails that follow travel corridors, such as the Tonto Plateau or the Esplanade, are broken apart to maintain reference information. Many of the trails in the database result from this convention.

the authors of guide books identified particular trails as prehistoric based on their own experiences, that is, whether or not they, the book authors, encountered archaeological sites, rock art, or other evidence while travelling the routes. This category is particularly important because not all of the archaeological resources mentioned in guides are recorded in the GCNP archaeological site database, due to lack of survey in the remote regions of the Canyon. In addition, I find this category slightly stronger than the next because archaeological evidence was encountered while actually travelling a route. The next category, which is circumstantial, consists of trails or routes in close proximity to archaeological sites. I included trails and routes associated with archaeological sites within 50, 100, 200, and 300 meter buffer zones. Finally, prehistoric use of trails and routes can be inferred based on another type of circumstantial evidence: the simple topographic feasibility of a route. For the Grand Canyon region this line of evidence is particularly strong. To summarize, evidence for prehistoric use of routes in the Grand Canyon proceeds in order from strongest prehistoric association to weakest as follows:

1. The trail contains modified features, such as steps, ladders, etc.
2. A guidebook author identified the trail as prehistoric based on archaeological evidence.
3. The trail is within a buffer zone of a known archaeological site.
4. The trail is topographically feasible. This especially includes routes that facilitate movement over major vertical barriers or between eco-zones.

Beginning with topographic evidence, the simplest qualifier is one mentioned by Wilson (1999:34), “The topography affords passage of human beings within reasonable limitations.” Given the following discussion regarding accessibility, a strong argument can be made that any route which affords passage over major vertical barriers was potentially used prehistorically. Considering the Canyon’s enormous size, the number of possible ways into the Canyon is low, even though it ranges in the hundreds. This simple criterion includes all known trails and routes, although there is no way to speculate on the degree or amount of use experienced by a trail based on this evidence. We could, potentially, expand this set of trails to include routes that *seem* feasible. For example, we

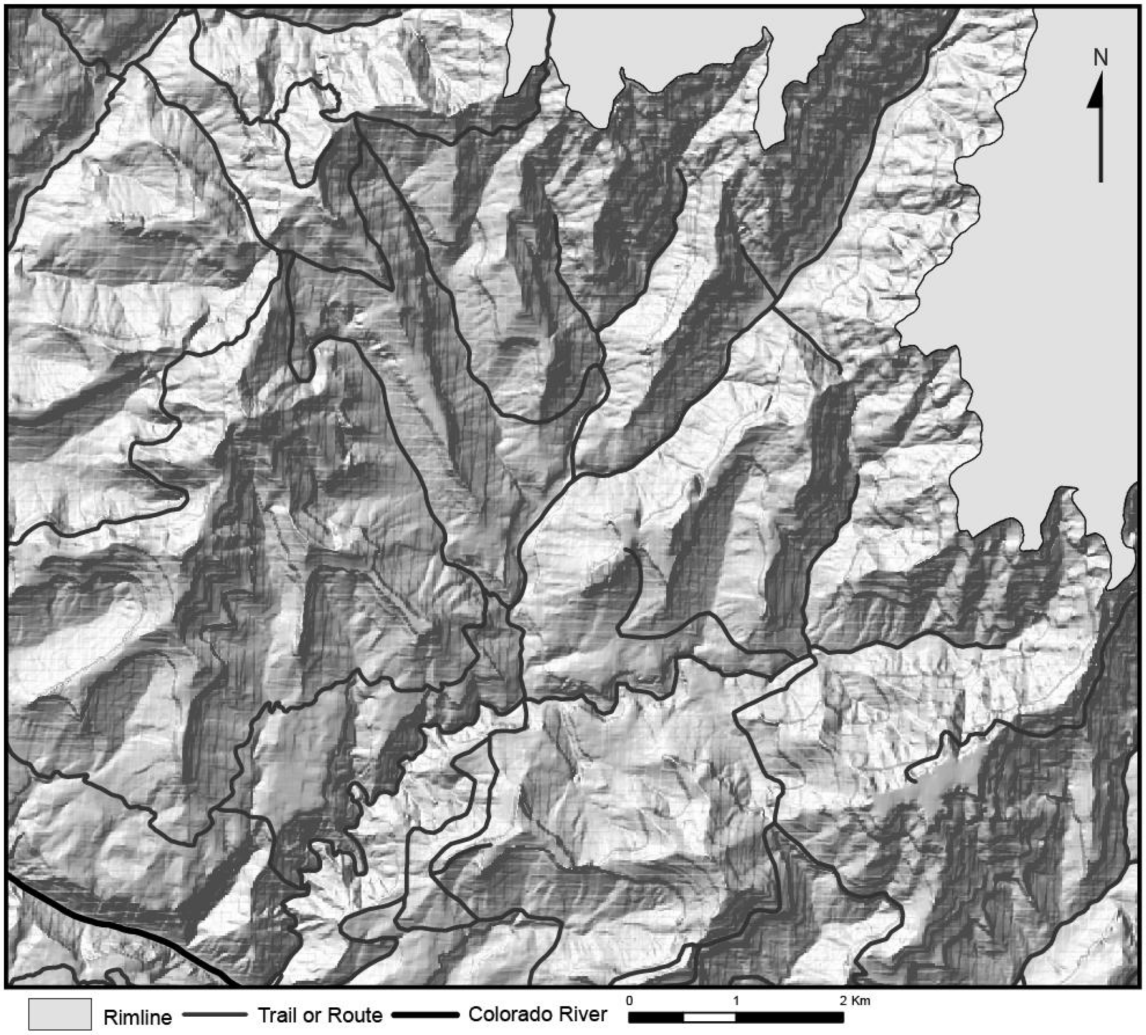

Figure 3.7**.** This figure illustrates characteristic of most trails in the Canyon to follow the dendritic pattern of streams, as well as other topographic features, such as the Tonto Plateau.

can typically expect traverse along the top of the Redwall to have been possible, even if we are unaware of anyone have performed a Redwall traverse in a specific area of the Canyon. However, I make no attempt to speculate on the number of *possible* trails and routes. At any rate, this exercise would not expand our knowledge of routes that provide accessibility into the Canyon.

A second type of topographic evidence mentioned by Wilson (1999:34) obtains in cases in which, “The proposed trail leads either from an archaeological site to another or to a resource such as a water source, ritual or ceremonial area, hunting grounds, or foraging area, etc.” Given the variability of biotic zones in the Grand Canyon, the presence of the Colorado River, and the possibility that prehistoric groups used surrounding plateau regions for subsistence tasks, circumstantial evidence tends to support the conclusion that any trail that affords passage through a major vertical barrier received prehistoric use.

The next type of circumstantial evidence is archaeological. Habitation sites and agricultural features can be viewed as destinations (Figure 3.5). In addition, specific types of archaeological sites, such as pot drops, caches, cairns, and rock art are known through ethnographic analogy and archaeological trails studies to be especially indicative of travel corridors. By examining the association of archaeological sites with known trails and routes, a greater degree of certainty is ascertained. Of over 500 routes included in the archaeological trails database, 302 are within 300 meters of an archaeological site, 252 within 200 meters, 168 within 100, and 111 lie within 50 meters. At the 50- or 100-meter buffer range, an archaeological site is potentially located directly on top of a route.

So, 282 of 501 routes, or slightly over half, are within 300 meters of an archaeological site. It is important to point out, however, that there are several circumstances related to the trails dataset that make a simple association of trails and routes even stronger. First, less than 10 percent of Grand Canyon National Park has been surveyed. Therefore, routes that we might expect to be spatially associated with archaeological sites sometimes are not for lack of archaeological investigation. For example 18 routes or route segments in Upper Nankoweap Canyon, where archaeological sites have been noted, were not identified as prehistoric in this analysis due to lack of survey. Second, as indicated above, routes along the Tonto Plateau are divided in order to maintain reference information. 14 of these segments are unassociated, even though I doubt that any portion of the Tonto was not travel in prehistory. Third, 22 routes occur on Havasupai Land, outside the range of the archaeological site database. Similarly, eight unassociated exist on the East Side of Marble Canyon, on the Navajo Reservation. Fourth, 20 of the routes identified by guidebooks (see below) as prehistoric were not identified through spatial queries. Finally 27 routes that provide access into the Upper Granite Gorge were not spatially associated. I assume that the lack of association between routes into the Upper Granite Gorge is related to the goals of management surveys, due to the fact that these routes provide access through a major vertical barrier, as well as to the Colorado River. In sum, it would be impossible to identify the 84 routes listed above through spatial queries for various reasons. When added to the number of routes associated with archaeological sites at the 300 meter buffer zone (366 of a possible 501, note that three routes that occur on Havasupai land also were identified as prehistoric based on the testimony of guidebook authors), the association between archaeological sites and routes appears stronger.

Based on the work of Wilson (1999), prehistoric trails identified through association with archaeological sites can probably be assigned to the category of "Informal Trail" although specific route study is necessary to further classify such trails. Eventually, archaeological survey will likely confirm the prehistoric nature of trails not currently known to have prehistoric associations.

A large number trails exhibit evidence of prehistoric use based on the testimony of the authors who wrote the guidebooks which I have used to compile the trails database. The association of such sites as prehistoric essentially includes any of the circumstantial archaeological evidence listed above (presence of habitations, artifact scatters etc.), but with the qualitative difference that these resources were encountered in the direct path of travel. Whereas a site at the 50 meter buffer zone is practically on top of a route, these resources quite literally are. The literature review conducted in this inventory identified 90 such routes. 20 of these routes are not associated with any site in the current site database. Of the 20, only three sites occur in Havasupai, outside the bounds of GCNP. Accordingly, these associations may provide clues as to where future archaeological survey should be conducted.

The final category of association includes trails that exhibit constructed features that, "allow or significantly facilitate passage across the terrain." (Wilson 1999:29) The number of such routes is surprisingly low, at seven. However, at least twelve additional routes exist within the defined project area, but do not meet the criterion of having been accurately mapped. As expected, these routes facilitate movement primarily through the

Coconino Sandstone and Redwall Limestone, but also through the Toroweap and Supai layers.

Conclusion

This chapter has shown that the Grand Canyon’s topography, along with the association of archaeological materials, allow the inference that most, if not all known routes in the Grand Canyon received some prehistoric use (Figure 3.8). Based on this information, I believe it is necessary to briefly pose several questions regarding future research, resource management.

1. How might the current dataset be expanded?
2. What implications does the current dataset contain from a cultural resource management perspective?”
3. What are the implications on the assumption that the Grand Canyon trails network arose as a response to cross canyon foraging (Sullivan et al. 2002).

Expansion of the Trails Dataset

Several approaches may allow the current trails dataset to be expanded substantially. First the same methods applied to the eastern Grand Canyon in this study could be used in the western Canyon. Although one of the vital sources of data, Harvey Butchart’s Mathes-Evans maps, does not extend into the western Canyon, publicly available maps and data contain a great deal of information related to the western Canyon. Second, for the entire Canyon, the dataset can be expanded to include routes that are not public and mapped, as are all routes included in this study. For example, it would be possible to collaborate with experts on Grand Canyon hiking, such as those consulted in this study, to expand the dataset. Another related resource, and I believe a worthy avenue of research would be to consult Harvey Butchart's hiking logs. Although time consuming, the simple consultation of Butchart's published hiking guides has provided important information related to the archaeological association of trails and routes. Within the thousands of pages of Butchart's hiking logs, publicly available through the Colorado Plateau Archive, is undoubtedly a wealth of information.

Finally, as previously indicated, it may be possible to expand the dataset to include routes that seem *possible.* For example, traversing along the top of the Redwall Limestone and Esplanade is generally possible, although the entire length of these travel corridors may not have been traversed in actuality. While the assumptions involved in this process may prove problematic in some instances, this exercise would likely be an important component of network analysis, if any future researcher were to use the trails dataset for such a purpose.

The Trails Dataset and Cultural Resource Management

From a management standpoint, the simple knowledge that most were travelled prehistorically may not provide any clear management directive, because prehistoric routes are so numerous, and the level of prehistoric use for many trails remains vague or limited. However, a potential solution to this problem lies in ranking ranking trails based on the type and detail of evidence for prehistoric use. Of the formal trails identified in this study, only one was described by Wilson (1999). Because these are the trails that contain potentially sensitive features, they should be addressed first. From there, the knowledge that at least 20 routes contain evidence of prehistoric association based on guidebook authors alone (routes not associated with sites in the current archaeological site database through spatial queries) may provide an additional management concern, because public information may in fact provide a “road map” to sensitive sites and features. From this point, routes within the closest proximity to archaeological to archaeological sites might be investigated.

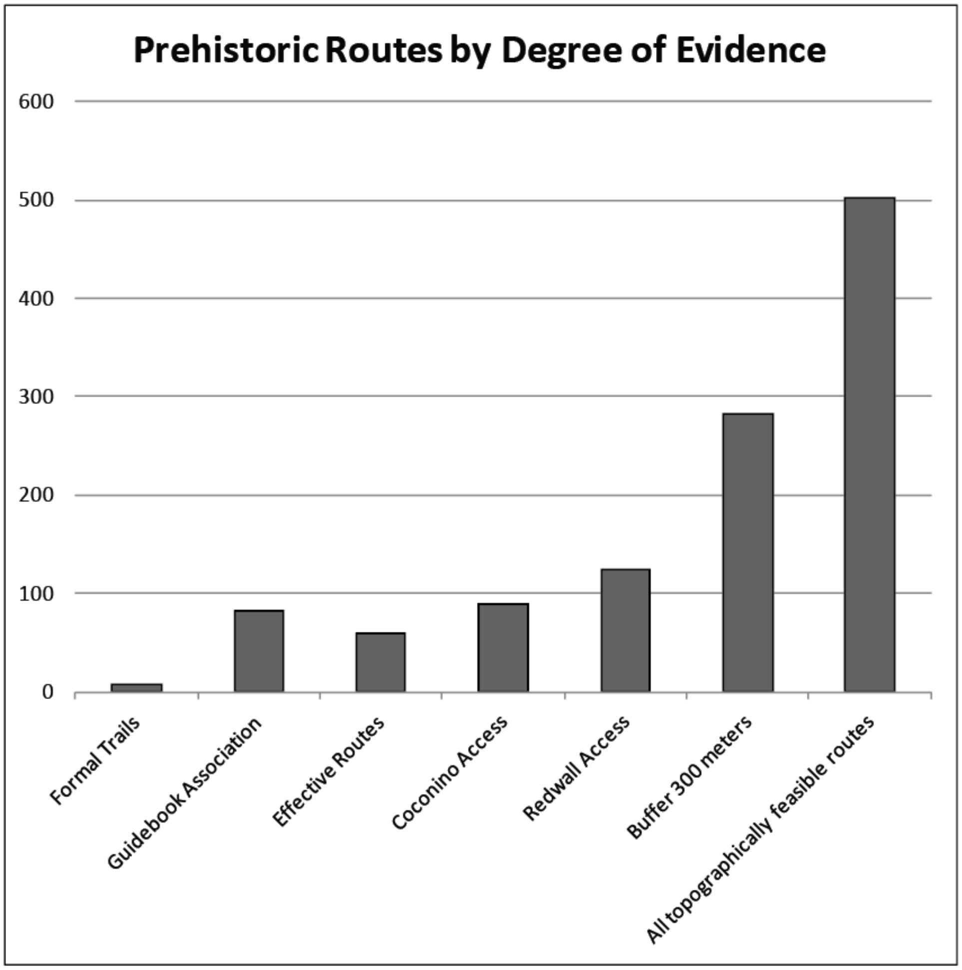

Figure 3.8. Prehistoric routes according to the degree, or type, of evidence by which they exhibit prehistoric use.

The Trails Dataset and Cross-Canyon Foraging

A final point which deserves consideration in this chapter is the claim, mentioned in Chapter Two, regarding prehistoric trails in the Canyon and the "Cross Canyon Hypothesis." Sullivan (2002:61) states that, "The cross-canyon model explains the extent of the canyon's trail system." In my opinion, although the prehistoric trail system is clearly extensive, there is little evidence to support this assumption. For example, if the trails database were to support this characterization, one of the following conditions related to the Cohonina occupation of the Grand Canyon would have to be true: 1) Prehistoric trails in the Grand Canyon arose as a response to Cohonina phase rim-to-rim travel. This condition implies that the trails in question exist as discernible paths on the modern ground surface distinguishable from the topography of the Grand Canyon, and 2) Prehistoric trails in the Grand Canyon are primarily related to Cohonina sites.

Both conditions are clearly false. Figure 3.8 shows that, although there are various ways to associate trails and routes with prehistoric land use, the most prevalent factors are topographic feasibility and access over barriers such as the Coconino Sandstone and the Redwall Limestone. Figure 3.9 provides an example of a route that provides access over two vertical barriers (Coconino Sandstone, and Redwall Limestone), the Old Hance Trail. Last maintained in 1895, the Old Hance is only distinguishable on the ground in a couple of short segments. The route is defined by a massive scree slope that covers all geologic strata from the Kaibab Limestone down through the Redwall Limestone. There is nothing about the route that denotes a specific occupation with the potential exception

Figure 3.9**.** The Old Hance Trail (last maintained in 1895), like many routes in the Grand Canyon, is formed primarily by a scree slope and fault line, rather than prehistoric modification.

of archaeological sites within a buffer zone. The route is simply a *possible* way of traveling through a series of vertical barriers. It cannot, therefore, have arisen in response to cross canyon travel by Cohonina forager-farmers. Many routes that provide access over vertical barriers are similar.

Thus, only the latter condition (prehistoric routes are primarily related to Cohonina sites) can validate the claim that the Grand Canyon Trails database arose as a response to the cross-canyon model. Given the prevalence of Kayenta Anasazi archaeological sites and lithic scatters in the eastern Grand Canyon, any of the 50 primary paths identified by Euler and Chandler (1978) or “effective routes” (Chapter Four) are likely associated with such sites. Although these routes are also associated with Cohonina sites, this relationship is not exclusive, and clearly does not pertain over the entire expanse of the prehistoric trials network. Therefore, I disagree with the claim that routes arose as a result of the cross-canyon foraging model.

Chapter 4

Canyon Access

Introduction

In this chapter, I examine the issue of accessibility of the Grand Canyon, paying attention to physiographic characteristics described earlier. As mentioned in the introductory chapter of this thesis, Grand Canyon explorers and adventurers considered the Canyon to be a barrier to movement for almost four-hundred years. This thinking, in turn, influenced archaeologists. The Canyon's accessibility or lack thereof, is a topic that interested scholars, especially in the early years of archaeological investigation (Taylor 1958; Euler and Chandler 1978:73). For instance, Taylor (1958) considered accessibility to be the cause of low site densities in the Canyon's narrow reaches, and Fairley (2003) appears to support this interpretation. However, at this time, only Euler and Chandler (1978) formally compare the locations of archaeological sites to trails in a systematic, Canyon-wide manner.

As a result of the meeting of the Southwest Anthropological Research Group (SARG) in 1976, Euler and Chandler (1978) became interested in the locations of archaeological sites compared to features of the natural environment, including access to water, trails, subsistence resources, and protection. Euler and Chandler (1978:73) maintained that the Canyon did not present a barrier to movement for prehistoric people, but also hypothesized that proximity to trails was the second most important factor in determining the location of archaeological sites in the Grand Canyon. For instance, Euler and Chandler (1978:76) indicate that nearly all routes into the canyon are accompanied by an archaeological site on the rim.

If routes that lead into Havasu Canyon are excluded, the number of primary foot trails (50) providing access to the canyon identified by Euler and Chandler is exactly the same as the number of "effective routes" (see below) identified by this study. In my opinion, it is problematic to identify accessibility, or proximity to trails, as one of the most important criteria determining the location of archaeological sites, while at the same time advancing the idea that the Canyon did not create some sort of barrier.

Resolution of this issue lies in taking a more detailed look at the concept of accessibility. Specifically, the way in which accessibility is defined, and how might that definition influence the way we regard the concept (Figures 4.1, 4.2). While the canyon is certainly accessible by a simple definition, the effect of the limited distribution of access points on prehistoric life-ways remains vague.

Accessing the Canyon

Defining Canyon Access

A simple definition of Canyon access would include any route that enters the Canyon. Examined in finer detail, access could include routes over the Coconino Sandstone or Redwall Limestone, as well as routes that access the Colorado River. In addition, one could define access as a means of entry to flat-lying areas likely important for subsistence tasks, such as the Esplanade in the western Canyon, or the Tonto Plateau in the east. Accessibility to single location might also be conceived of as an issue. The majority of these definitions require that a route or trail provide passage over at least one

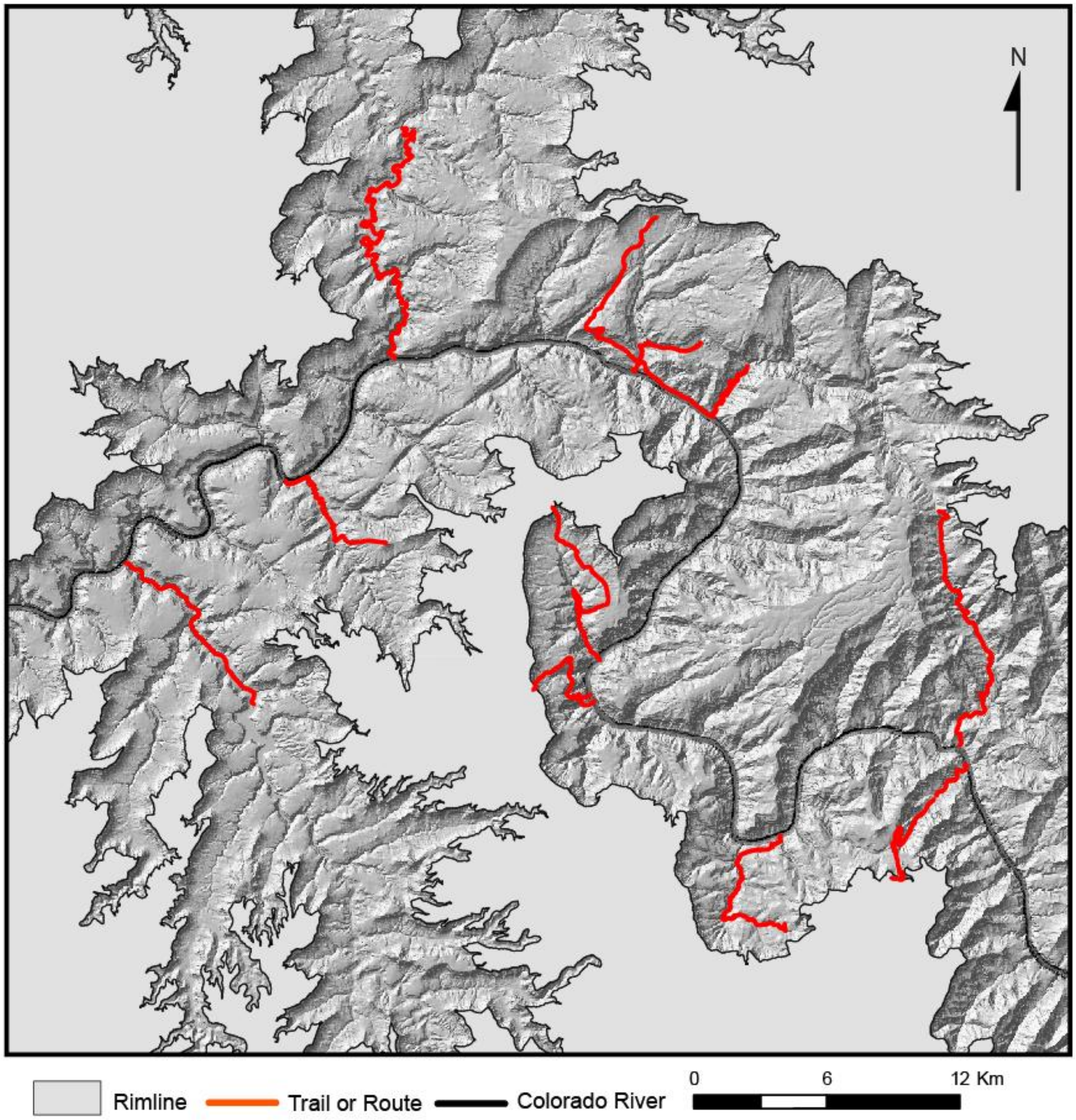

Figure 4.1**.** Accessibility issues. This map shows all verifiable routes that provide access to the Colorado River between the Bass Trails (easternmost routes) and Havasupai (westernmost route), a distance of 60 river miles. There are six routes on the south of the river, and five on the north.

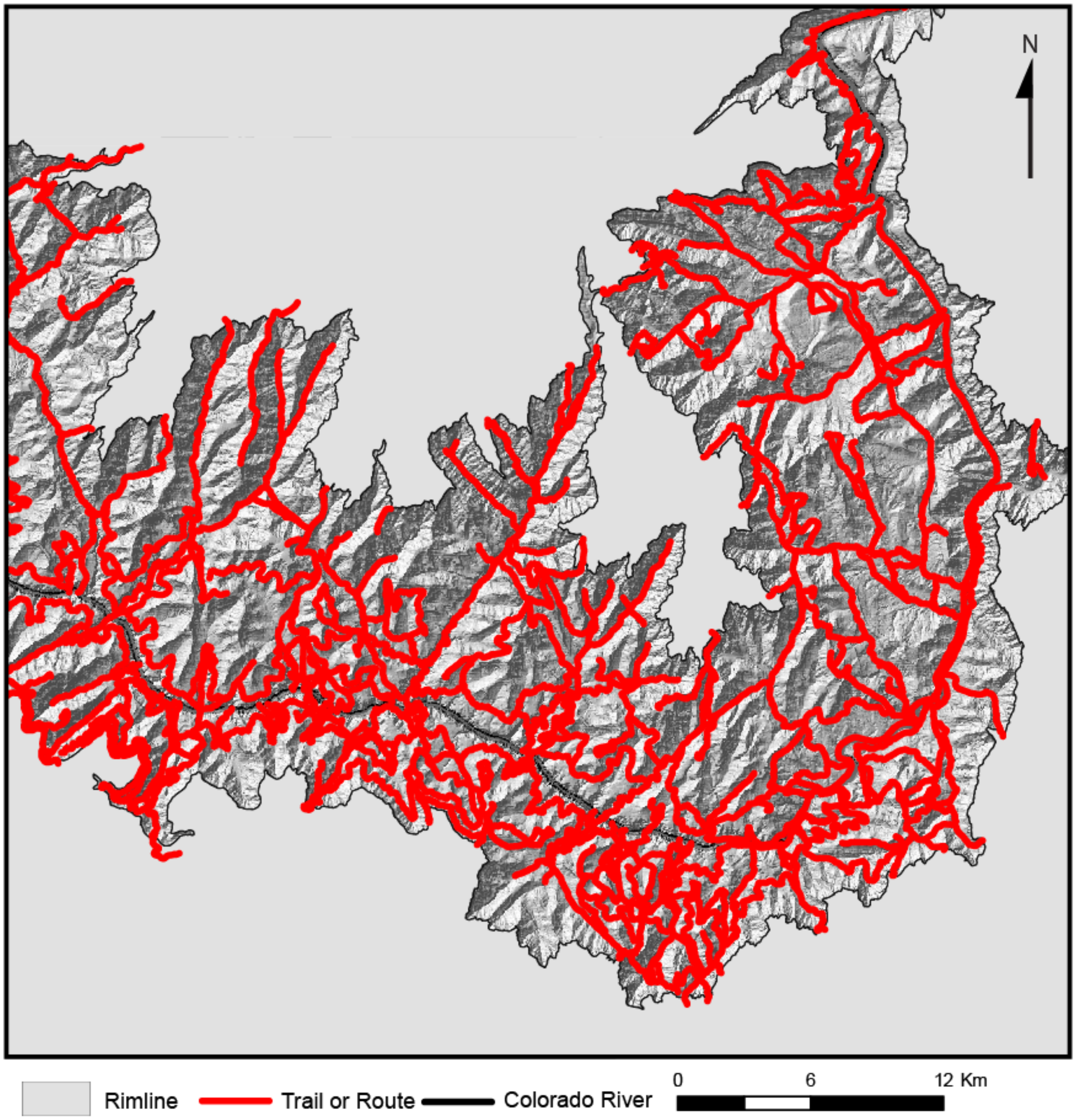

Figure 4.2. Accessibility, alternatively defined (in reference to figure 3.1). Looking at the range of travel options over the eastern Grand Canyon gives the impression that accessibility is not a travel concern.

of the major vertical barriers discussed above.

Simple access to the Canyon from the rim will include routes through the Coconino Sandstone. In the western Canyon, such routes allow travelers free range over the Esplanade. In the eastern Canyon, however, simple access through the Coconino Sandstone represents a less likely goal, because in the east the traveler typically reaches only a series of steep Supai and Redwall cliffs. River crossings present another accessibility issue. In order to access the river, or the Tonto Plateau, one must pass through not only the Coconino Sandstone, but the Redwall Limestone. In any of the Canyon's three granite gorges, an individual must also work through steep Precambrian strata. Accordingly, with the exception of the Esplanade, meaningful Canyon access may require navigation of at least two, if not three major vertical barriers. With these considerations in mind, I examine the problem of accessing the Canyon and I discuss the distribution of routes through relevant geologic strata on the North and the South Rims. I pay attention to differences between the eastern and western study area, Upper Granite Gorge, and Marble Canyon.

Canyon Access

The current database identifies 90 routes through the Coconino Sandstone (Figure 4.3); 31 on the north rim, 31 on the south rim, eight on the west side of Marble Canyon, 11 on the east side of Marble Canyon, and nine in Havasupai. The routes are spread over roughly 650 undulating miles of rim line (excluding the rims of Kanab Creek and Havasu Canyon). Average spacing of routes through the Coconino occurs roughly every 14 miles in Marble Canyon, and about every eight miles for the North and South rims. I use average spacing only because it would be difficult to create more meaningful statistics. Although the rim line distances separating routes are lengthy, such distances may not be meaningful measures of distance between routes, because people with pre-existing knowledge of trails would be unlikely to follow the rim from one access point to another. Instead, travelers would likely cut across "inland" of the rim as the shortest travel route. Suffice it to say, however, that the distribution of Coconino routes clusters in some areas, leaving noticeable gaps in the distribution of routes. A couple of the most obvious gaps in route regularity exist between the Little Colorado River and Eminence Break Fault, as well as between North and South Canyons in Marble Canyon (For more information see Table 4.1, Figure 4.3 bar graph).

This study identified 124 routes through the Redwall, well over the number of Coconino routes. Applying the same measure of routes-per-rim mile, Redwall routes are spaced every five and a half miles; about every 10 miles in Marble Canyon and between three and four miles for most of the rest of the Canyon. A major difference between Redwall and Coconino route spacing, however, is that whereas one may walk inland between routes through the Coconino, this option is not available for passage through the Redwall. One may, however, walk inland along the Tonto level, but this is much less desirable than walking inland above the rim. From the perspective of travelling through the Redwall from the rim, on may only pass this barrier by traversing along a Supai ledge or along the top of the Redwall. Therefore, the rim line distance is probably a more accurate indicator of distance between Redwall routes, which implies that people

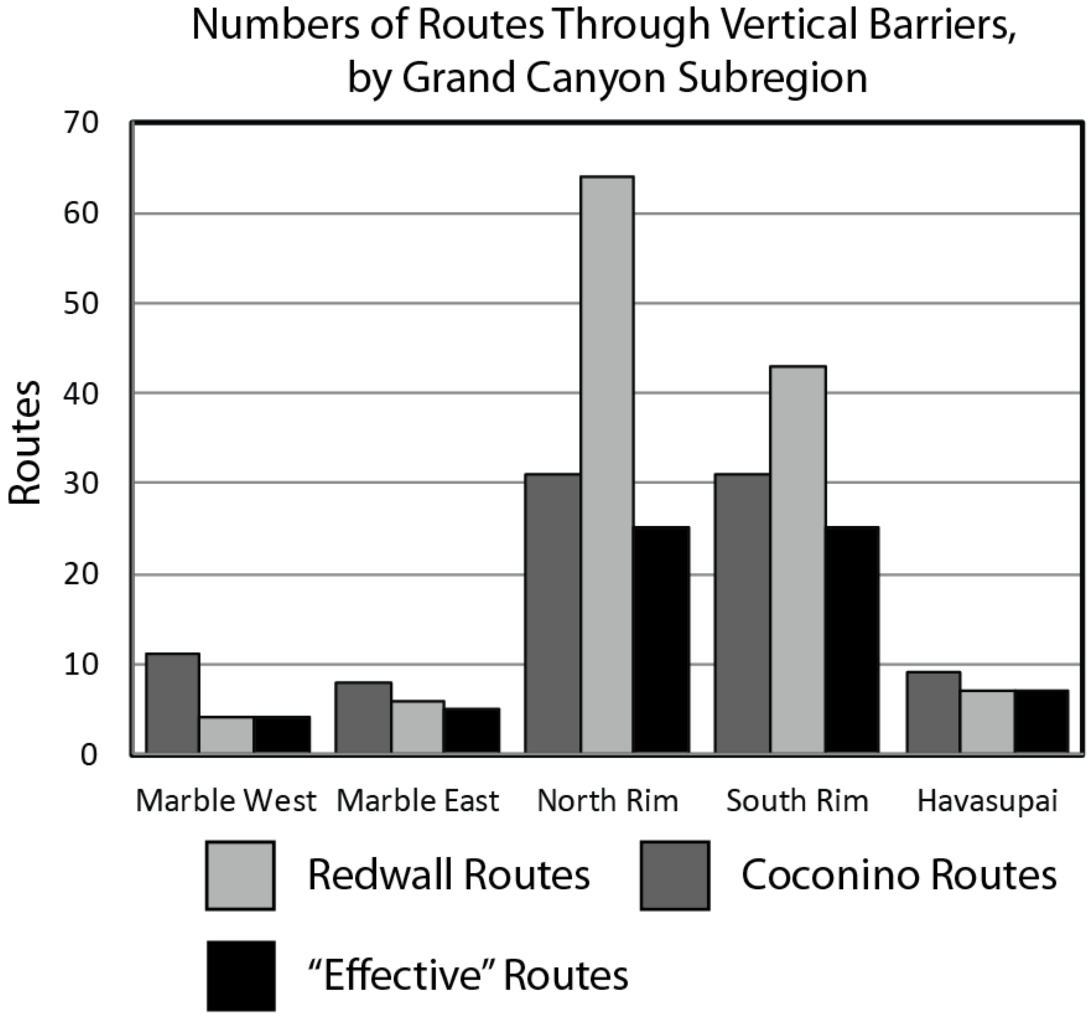

Figure 4.3. This bar graph depicts the number of Coconino, Redwall, and "effective" routes between regions of the Grand Canyon.

may "feel" the distance between Redwall routes to a greater degree. In addition, movement concerns are created by the clustering of Redwall routes. Most of the Redwall routes identified in this study occur in the eastern project area. A very sparse set of routes exists in the west.

Table 4.1. Canyon Access

	Coconino Routes	Redwall Routes	Effective Routes	River Miles	Rim Miles
Marble West	11	4	4	51	107
Marble East	8	6	5	51	174
North Rim	31	64	25	88	193
South Rim	31	43	25	88	176
Havasupai	9	7	7	-	323
Total	90	124	66	-	-

This disparity, that is, the clustering of Redwall routes in the east, along with the occurrence of Coconino routes that apparently dead end in the Supai, reduces the accessibility of the Tonto Plateau in the eastern Canyon, and the river in the western Canyon. For any particular region of the Canyon, every Redwall route must be matched by a Coconino route, or vice versa, to effectively provide access to either the river or the Tonto Plateau. For instance, in the area around Grandview, three routes through the Coconino provide access to 12 Redwall routes. The accessibility of this area is thus limited to the three “effective” routes. Similar situations exist elsewhere. Four Coconino routes dead end in the Supai west of Nankoweap, and of at least 21 Redwall routes between Nankoweap Creek and Unkar Creek, only five Coconino routes provide access from the Redwall to the rim. Accordingly, simply tabulating the numbers of access points (90 Coconino routes, 124 Redwall routes) gives an inaccurate picture of the Canyon’s accessibility. The total number of effective routes is limited to 25 on both the North and South rims – reduced from 64 North Rim, and 43 South Rim routes through the Coconino. In Marble Canyon there are six effective routes on the north (after the Redwall starts at mile 23.5) and four on the south, although these routes often include a long traverse along the top of the Redwall.

An additional consideration of Canyon access includes passage to the river. Beginning in Marble Canyon after the start of the Redwall Limestone (Reach Three), access to the river is defined by access through the Redwall. Beyond Reach Three, it is usually possible to move laterally along the river in Reaches Four and Five. However, getting to the river is confined to a limited number of routes (19 routes). In Reach Six (Upper Granite Gorge), river level travel is not practical, and access is further confined by the presence of the Vishnu Schist and other igneous rocks. In fact, river access in Reach Six is unique, because one must travel through the older Precambrian rocks as well as the Coconino Sandstone and Redwall Limestone. We might expect the same situation to occur in the Middle Granite Gorge (Reach Eight), however, the near complete lack of Redwall routes into Reach Eight makes access through the Precambrian layers of that region a moot point. In Reaches Seven and Nine, river access is defined by the number of Redwall routes, which are extremely few in number.

The effective route problem exists in the Upper Granite Gorge as it does in areas discussed previously, because numerous Tapeats breaks provide passage to the river in a more limited number of areas. For example, three or four Tapeats breaks may provide access to a several routes through the schist which all terminate at a single location on the river. On the north side of the river, 42 Tapeats breaks give access to 17 distinct locations along the river. On the south, 45 Tapeats breaks give access to 27 locations on the river.

An additional issue related to canyon access is crossing the Colorado River. Numerous crossing points have been documented. Often, the juxtaposition of routes on opposite banks of the river provides insight into areas of likely Prehistoric river crossings. However, in contrast to previous barriers mentioned in this study, river crossings were probably only problematic at times of high water, such as during periods of spring runoff. Due to this situation, it is difficult to identify these locations in a comprehensive manner because of the artificially high river level maintained by Glen Canyon Dam. The artificially high river level may obscure the visibility of some crossing points.

The degree to which seasonally high water may have inhibited river crossings is unknown. However, a potential implication is that, areas in close proximity to rapids would present unlikely crossing points. Another potential implication is that, if one subscribes to the “Cross-Canyon” model envisioned by Sullivan et al. (2002), then the late-spring, early summer crossing of the Colorado River implied by the model may have constituted a unique travel concern.

Earlier, the idea of geologic faulting was mentioned with respect to breaks in the Redwall and Coconino strata. Those familiar with the Canyon have long understood the connection between fault lines and routes. In order to quantify the relationship, I compared the number of Redwall routes and Coconino routes intersected by fault lines at the 1:62,500 geologic mapping scale. My examination revealed that 95 Coconino or Redwall routes corresponded to a major fault. The list includes 15 Coconino routes on the North Rim and 23 on the South Rim (48 and 74 percent), and 37 Redwall routes on the north and 23 on the south (57 and 53 percent). This simple examination confirms not only a strong relationship between faults and routes, but a particularly strong connection between routes and the faults that might be termed “major players.” Further investigation at a smaller geologic mapping scale would undoubtedly reveal a greater, if not nearly complete correspondence between the routes identified in this study and the thousands of faults that exist in the Grand Canyon.

Implications

The number of effective access routes into the Grand Canyon totals in the dozens. These routes are spread over hundreds of miles of rim, and many are separated by hours of walking. This leaves us with two perhaps conflicting views of Canyon accessibility. On one hand a well-informed individual may never have been more, and often would have been much less, than a few hours walk from an access point. On the other hand, there are a limited number of places, along hundreds of miles of rim where access is possible at all. Although the number of access points that could be created through cultural modifications such as ropes and ladders will forever be unknown, it is likely that accessibility was tied to a small number of trails that were used repeatedly. At least 43 of the Redwall routes identified in this database received prehistoric use based on testimony of the authors of the guidebooks. If social determinants, such as trail “ownership” were added to the list of factors impeding access to the Canyon for competing prehistoric groups, enormous areas would have become inaccessible (for some people). Minimally, the limited amount of access probably created choke-points, or locations that constricted the flow of people and everything else into and out of the Canyon. Any clustering of archaeological sites around fault lines is potentially related to this issue (See Smiley 2011).

In the introduction of this chapter, I introduced to the idea that the movement goals, whatever they may have been, undoubtedly influenced the relevance of accessibility issues for prehistoric groups. Recently, Llobera et al. (2011) have written about to the process of movement. The authors state that movement, as a basic human process, is ordered. Movement is ordered by the (Llobera et al. 2011: 843):

> Creation of sequences that link locations across the landscape (Ingold, 2000: 53 - 60, 2009: 29 – 43). Indeed it is through these sequences that a landscape is taken in, understood or appropriated, and that social rules are frequently enacted across the landscape. This is particularly true when approaching certain locations on the landscape during specific moments in time (Barret 1994).

The authors then go on to state that locations, such as access points, anchor people to specific places on the landscape. Surely, the anchor points, or choke points, created by geologic strata in the Grand Canyon caused prehistoric groups to move along a predictable number and sequence of paths. The authors of this study (Llobera et al. 2011) go on to define a focal mobility network through the use of hydrological modeling. Similar processes have been used by Neff (2010), and Whitley and Hicks (2003), to determine likely networks of trails on large landscapes, or in the case of Neff (2010), cityscapes. The ability of GIS techniques to effectively model movement in areas that might be defined as hilly, compared to the extreme relief of the Grand Canyon, allows us to infer that prehistoric movement in the Grand Canyon was highly patterned throughout all time. This characterization would than agree with Euler and Chandler's (1978) finding that trails are a significant predictor of site location in the Canyon.

Scholars such as Llobera et al. (2011) and Neff (2010) go on to study the connectivity of nodes and arcs in predicted transportation networks, indicating the degree of accessibility of different areas of the networks in relation to each other. In the future, this sort of modeling may be possible in the Grand Canyon, although at the current point in time trails and routes are digitized from known route information, rather than created through hydrologic or least cost modeling (as in the studies mentioned above). Such modeling techniques, in conjunction with advice from experienced Grand Canyon hikers, could eventually create a trails network comprehensive enough to define what Llobera et al. (2011:845) term an "accessibility signature." An accessibility signature is the created by ranking routes based on their topological relationships to one another. According to this classification scheme, the higher the number of routes that connect to a given location, or "arc" within a network, the higher the accessibility signature will be. Although it would be possible to conduct such analysis with the current trails dataset, the number of feasible, but undefined routes – routes that afford movement but do not provide access over large vertical obstacles – would introduce inaccuracy into the model.

Another way of approaching the issue of accessibility as "destination based" is to examine anecdotal evidence provided by Harvey Butchart (1997:160). In one example, Butchart describes the discovery of the Enfilade Point Route, a route which contains constructed trail features. Butchart became interested in the area when:

> Archaeologist R.C. Euler told of a Supai Indian named Walin Burro, who said that the Indians used to farm near the mouth of Fossil Bay…… [Burro] gave the impression that there should be a shorter way to reach the river at Fossil Bay than the obvious one down the Bass Trail and along the Tonto – more than a two day walk for a good hiker…

After searching for the route on separate trips over the course of about ten years, Butchart located this route, which contains multiple lines of evidence for prehistoric use – and which is exceedingly exposed (For a lively description of this route consult Butler and

Meyers 2007). The relevant point regarding accessibility, here, is the fact that a single route could potentially save two days of travel if a specific origin and destination were defined. Butchart (1997:163) also describes the major advantages of travel between Kanab Creek and Havasupai, where the use of a specific route could also save a full day of travel. Similar situations may exist elsewhere, such as in the most inaccessible areas of Marble Canyon. For instance, there is a 20 river-mile section of Marble Canyon between South Canyon and Nankoweap, in which the only known routes contain constructed prehistoric trail features – neither of were digitized for the purposes of this thesis, as the requisite maps do not exist.

Summary

The preceding characterization of the Canyon's accessibility issues may seem overwhelmingly complicated. Mainly this occurs due to the difficulty involved in creating a generalized description of an area as large and diverse as the Grand Canyon. The Canyon's variable river level geology, the changing "behavior" of the Redwall Limestone between the eastern and western canyon, the differing prevalence of the Tonto Plateau and Esplanade as lateral movement corridors and resource procurement areas, and the unique considerations involved in navigating the Upper Granite Gorge combine to form a complex landscape of movement. Summarily, the variability of the Canyon negates a binary accessible/inaccessible, or barrier/not barrier characterizations. In addition such depictions also mask the ordered movement patterns that become apparent when we examine travel concerns from a diverse set of origins and destinations, and especially when the differences in travel options represent not only hours, but days of travel. Nevertheless, several generalizations about movement concerns are as follows:

1. There are access issues involved in navigating through the Coconino Sandstone, Redwall Limestone, and Granite Gorge.
2. There exists an east/west dichotomy in travel concerns. The Redwall Limestone is the most significant barrier in the western half of the study area (downstream of the Bass trail corresponding with the appearance of the Esplanade). The Coconino Sandstone is the most significant barrier in the eastern study area.
3. In the Canyon's narrow reaches, especially Reach Three, the north half of Reach Four, and all of Reaches Six, Seven, Eight, and Nine, access to the river is constricted enough to be characterized as a significant travel concern. However, in Reaches Seven, Nine, and Four, river level walking is mostly possible.
4. Accessibility of the Canyon rim is particularly problematic in Reaches Four and Five on the south side of the Canyon. This includes the areas between Eminence Break and the Little Colorado River, and the area between the Little Colorado River and Desert View.
5. The source (the area from which one sets out in travel) and the destination are important in understanding accessibility issues. This concept is important in understanding travel within the Canyon as ordered movement.

Chapter 5

The Theory and Method of Site Catchment Analysis in the Grand Canyon

Introduction

The remainder of this thesis examines problems related to effective distance in the Grand Canyon. Ethnographic studies have shown that specific subsistence tasks, such as foraging and farming, are likely to have taken place within a maximum single day boundary range of a home-base. These distances have been recorded for many societies around the world (Chisholm 1979). However, because the rough terrain of the Grand Canyon requires a greater investment of energy to exploit an equally sized territory, foraging and farming activities may have been constricted within the Canyon relative to other regions. Therefore, understanding the consequences of effective distance is important in evaluating settlement and subsistence models. Currently, the only method used to account for this problem is found in Schwartz et al. (1979:82). The authors estimated the amount of time necessary to walk from place to place in the Canyon, such as from Bright Angel Pueblo to adjacent drainages, based on personal experience hiking in the Canyon. Although informative, anecdotal evidence of this nature is difficult to apply on a Canyon wide basis.

I suggest that GIS tools, such as the Pathdistance tools available in ESRI ArcGIS offer a solution to this problem. These tools provide a method for delineating archaeological site catchments based on variables such as travel time and energy expenditure. Spatial characteristics of catchments, such as the size, shape, and comparative roughness (Chapter Six), can then be recorded in order to gain insight into the differences that exist between the Grand Canyon and other regions. The methods described above are best understood in the context of the *method* of Site Catchment Analysis (SCA), and the *theoretical perspective* of Human Behavioral Ecology (HBE).

Site Catchment Analysis: A Brief Overview

As a method practiced within archaeology, SCA has antecedents both within and outside of anthropology. Perhaps the earliest notable attempts to understand the spatial relationship between the distribution of resources (plant and animal resources, water, etc.) and home-sites includes the 19th century works of scholars such as Von Thunen and Weber (Roper 1978:122). Early anthropological interest in the topic is evidenced in topics such as, "The culture area concept (Kroeber 1939), the concept of horizon (Wiley and Philips 1958: 33), and the notion of settlement pattern (Willey 1953)" (Roper 1978:119).

Perhaps as a result of these general precursors, the method of site catchment analysis in archaeology appeared in the late 1960's and early 1970's. The term "site catchment" was coined by Vita-Finzi and Higgs (1970). The term catchment derives from geomorphology, a term which denotes an area of common hydrological drainage (Roper 1978:120). In archaeology, the term catchment simply refers to the area from which the site's inhabitants procured resources. Site catchments might further be categorized by type. For instance, archaeologists may be interested agricultural catchments, foraging catchments or the catchments related to a specific resource such as water or chipped stone. Binford (1982) characterized different sized catchments in terms of logistical or collecting foraging strategies (single or multi-day procurement tasks). In addition, archaeologists have developed the concept of a hierarchy of resource needs (Jochim 1976; cited in Roper 1978:121). This implies that some resources, such as water or shelter, may take greater precedence in choosing site location than others, and that the seasonal distribution of resources will have a further complicating effect.

Despite agreement about general terms, an array of methodologies has arisen for the delineation of site catchments. The first method, employed by Vita-Finzi and Higgs in 1970, involved walking out from the archaeological site in question in different directions and recording the position at different time intervals. The difference in distance covered on each vector for an equal amount of travel time was meant to account for differences in terrain, and the authors defined a one-hour walk as within the agricultural catchment area, and a two hour walk as within a foraging catchment area. The result of this method is a series of isochrones (time contours) that delimit the range one may be expected to walk in a given amount of time from a particular site.

An alternate method, employed by Flannery (1976) involves working backwards from the materials recovered at an archaeological site in order to delimit the catchment. For instance, if a given type of plant were recovered at the site, one would then look to the surrounding environment to find out where the plant can be found. This method also included trade items and items that occurred at considerable distance of the site, meaning that these catchments were, in a sense “absolute” catchments. While this method emphasizes the fact that a given population might depend on a far flung trade network to survive, extremely large catchments might be less informative as to the structure of daily farming and foraging activities.

An additional method was employed by researchers working for the Dolores Archaeological Program (Kohler et al. 1986). These researchers used rainfall estimates based off of tree ring and paleoclimatic data to estimate the yield of prehistoric fields located in proximity of archaeological sites. These hypothetical yields were in turn compared to estimates of nutritional need. The researchers predicted that Anasazi farmers would not place fields at a distance greater than required to meet the nutritional need, and therefore drew the agricultural boundary at the point where necessary agricultural yield was met to feed the estimated population. This ranged between .24 and 1.66 km from the sites in question. Hunt (1992) compiled GIS layers that have implications for the agricultural potential of land, such as soil type, bedrock and surficial geology, elevation etc. In this method the size and shape of an agricultural catchment is determined by an assessment of crop suitability. Finally, as stated by Roper (1978), if one is fairly confident about the contemporaneity of a number of sites in a region, a site catchment can be defined based on the midpoint between sites.

Perhaps because the methods described above are analytically intensive, or in the case of performing actual walks out from archaeological sites to determine isochrones is labor intensive, most scholars interested in site catchment analysis simply draw circular catchments around sites. For instance, Wilcox in the Chaco Canyon region (1996) conceptualizes the distance between archaeological sites in terms of concentric circles radiating out from specific locations in order to understand the spatial relationship between sites. Although this technique may be satisfactory in areas of limited vertical relief, it will not accurately account for distance in the Grand Canyon. These zones are based on ethnographic analogies, such as those provided by Chisholm (Roper 1978:123), in which the average distance travelled, or average time taken to get to fields or foraging areas, have been recorded. There are at least two problems with this method including, 1) These figures cannot be universally applied, and 2) The method does not account for terrain variation (Roper 1978). In reference to the first problem, the safest solution seems to be to use the maximum distance derived from ethnographic analogy – that is, the case in which modern foragers or farmers travelled the farthest to their foraging areas or fields. However, as stated by Roper (1978:124), practitioners of this method must be explicit in the source of the distance figures used, and assumptions made. The response to the second problem has received some recent attention from archaeological GIS studies, and is the focus of the remainder of this study.

Theoretical Application of Site Catchment Analysis

As stated by Roper (1978:135) SCA by itself is more of a method than a theory. Evidence of this can be seen in the different ways that SCA has been applied. For example Varien (1999), and Hill (Hill 2000; Herhahn and Hill 1998) use similar GIS methods to define site catchments, but with very different goals in mind. In the former study (Varien 1999), SCA is used to study community aggregation. Contemporaneous sites are seen as within one another's interaction sphere when they share catchment areas, which are variously defined as agricultural catchments, foraging catchments, or as defining the limit of distance that a person could travel and return in one day. This study uses post-structural theory to understand the social processes involved in community aggregation. Herhahn and Hill’s (1998) study, on the other hand, uses site catchments to delineate the distance people are likely to have travelled in one day to field locations. These catchments are then compared to slope and soil models in an effort to understand the agricultural potential of a site within a given range from a home base. The study works from the standpoint of Human Behavioral Ecology, emphasizing cost-benefit analysis and ecologic constraints.

These two case studies demonstrate a couple of the possible ways in which researchers have recently applied SCA to solving various problems. However, more often than not, studies emphasize the latter, rather than the former theoretical approach. Generally speaking, SCA is used as a tool within ecological and environmental archaeology as a means of understanding resource use in cost-benefit analysis. In this study GIS approaches are particularly appealing because they offer the possibility of modeling catchments based on *cost surfaces,* rather than soil types, directional walks, or concentric circles.

Human Behavioral Ecology: Overview and Basic Concepts

In reference to site catchment and cost surface analysis, this study emphasizes concepts derived from HBE. As a theoretical approach, HBE utilizes a combination of concepts derived from ecology and micro-economics, such as resource procurement costs (usually in reference to food resources) and caloric yield, to understand the economies of foraging and horticultural societies. Therefore, as a theoretical approach that hinges on conceptualizations of cost, HBE may provide a useful means of analysis of comparative site catchments in the Grand Canyon. Although, HBE traditionally analyzes foraging societies, the application of HBE to agricultural societies has occurred in several instances (Winterhalder and Kennett, 2006).

Winterhalder and Smith (2000) summarize the history and goals of HBE. HBE began with the original goal of providing a solid theoretical framework to the cultural ecology envisioned by Julian Steward in the 1950's. HBE "began in the 1970's with the application of optimal foraging models to hunter-gatherer decisions concerning resource selection and land use." (Winterhalder and Smith 2000:51) HBE derives generally from evolutionary ecology; when applied to human behavior, evolutionary ecology becomes HBE. Earlier approaches, as evinced by Wilmsen (1973) provide a rationale for the use of principles derived to understand animal behavior in the study of human societies. Evolutionary approaches to human behavior also include evolutionary psychology and dual inheritance theory, not to mention evolutionary archaeology, which shares a vague theoretical relationship with HBE approaches to archaeology (Winterhalder and Smith 2000:51). Evolutionary ecology is the study of "evolution and adaptive design" (Winterhalder and Smith 2000:51) at the level of the ecosystem. Since the 1970's, researchers have applied HBE to a variety of anthropological and archaeological scenarios, including "children's foraging, conservation biology, demographic transitions, domestication and agricultural origins, the evolution of menopause, field processing and central place foraging, life history, male-female division of labor, mating tactics and fertility decisions, and resource intensification" (Winterhalder and Smith 2000:51).

Although characterized as a distinct, self-identified perspective (Hegmon 2003), HBE seems to fall within the boundaries of processualist approaches. For instance, Winterhalder and Smith (2000:52) describe HBE as a, "hypothetico-deductive research strategy and its neo-Darwinian theoretical sources. HBE derives testable hypotheses from mathematical or graphical models anchored in basic principles of evolution…emphasizing generality."

What sets HBE apart as a theoretical perspective is an explicit set of models and definitions, as summarized by Winterhalder and Kennet (2006). First and foremost, HBE relies on the assumption that humans optimize resource use, an assumption grounded in optimal foraging theory. Although understood that resource use will not be perfectly optimal, human resource use may be described as, "constrained optimization" (Winterhalder and Kennet 2000:11), or tending towards optimization. HBE practitioners base this assumption on the idea that hunter-gatherers display efficiency in subsistence tasks, and that efficiency in subsistence tasks allows greater amounts of time for other activities. Jochim (1976) explains that hunter-gatherer researchers can assume rational decision making principles to hold true in the same way as in market based societies. The uncertainty involved in subsistence tasks requires hunter-gatherers to make calculated decisions leading to optimization of resources. Jochim (1976:15-45) provides numerous ethnographic examples illustrating hunter-gatherer desire to make least-cost decisions, and illustrates how site location may be predicted based on the seasonal nature of resources. Diehl and Waters (2006:70, in reference to Kelly 1995:54-57), go further, stating specific condition that lead to a greater likelihood for optimization of resources:

> 1) there is a threat of starvation, (2) specific nutrients (calories in most studies) are in short supply, (3) constraints limit the amount of time available for obtaining food, (4) subsistence activities expose people to risk, or (5) surplus food or time

> may be used to enhance reproductive fitness. When optimization occurs one expects rational decision-making to favor the use of the most efficient food acquisition systems. It is not necessary to assume a priori, that this was likely to be the case. It is sufficient to show that resources were used commensurate with their ranking based on their energy returns, that diet breadths changed through time in ways consistent with optimization models.

In order to operationalize the optimization assumption, HBE relies on a set of economic concepts that “transcend their scholarly origins in microeconomic attempts to explain the functioning of market-oriented economies” (Winterhalder and Kennet 2006:11). In the order provided by Winterhalder and Kennet (2006:11-12), these concepts include marginal value, opportunity costs, discounting, and risk sensitive behavior. In keeping with the theme of this study, I will attempt to characterize these concepts in terms of resource use in the Grand Canyon.

Marginal value states that the value of a commodity changes over time, regardless of the intrinsic value of that resource. Marginal value plays a part in determining when the pursuit of one resource will be abandoned in favor of another. For instance, while gathering ten agave stalks might provide an attractive resource procurement goal, 100 agave stalks might not be desirable because a number of them would not be immediately useful. The benefit of collecting agave diminishes as a number of them have been obtained and the transport cost increases, even though the quality of the resource remains equal. In a highly mobile subsistence system, one item may contain a high value, while the tenth iteration of the same item contains zero value.

Opportunity costs, closely related to marginal value, are the costs associated with choosing one activity over another. In terms of Grand Canyon resource use, the time spent obtaining agave comes at the cost in time of some other subsistence task. So, while one searches for agave or cactus pads, one cannot tend their fields, hunt elk, or fish. According to Winterhalder and Kennet (2006:12), the weighing of opportunity costs and marginal value allows researchers to understand the decision making process.

Discounting refers, "to the situation in which we assign a future reward less value than if it were available immediately and with certainty." (Winterhalder and Kennet 2006:12) For instance, while a high value hunting item, such as elk may be preferred to smaller species like rabbit, it may not be preferred if it has to be obtained at great cost. The increased payoff may not seem worthwhile if it comes at the delay of travel time, especially if one needs to process an animal quickly to avoid spoiling meat, or starvation. Finally, the concept of risk-sensitive behavior addresses the idea that an optimal resource may be one with a low associated risk of procurement. In terms of hunter-gatherer subsistence activities, although the encounter of a specific, high value resource (i.e. elk, pinyon nuts) may be likely, it cannot be guaranteed.

By highlighting the aforementioned concepts, Winterhalder and Kennet (2006:13) emphasize that HBE attempts to, "assess the costs and benefits of alternative courses of action under a range of environmental conditions." HBE models contain not only the aforementioned concepts but additional features, including, "an alternative set, constraints, some form of currency, and a goal." (Winterhalder and Kennet 2006:13). The alternative set consists of the range of possible actions. Constraints include the exogenous (such as the natural distribution of resources) and endogenous (cultural constraints, technology) variables that structure resource use. Currency includes any measure of cost (time required for procurement, caloric potential of a resource, prestige). A goal is the desired effect of a behavior, or the aspect of an activity that conceivably requires optimization.

All of the above concepts and definitions operate within specific foraging models, the most common of which are defined by Winterhalder and Kennet (2006:14-16). Models include the diet breadth, patch choice, patch residence time, habitat selection, central place foraging, and settlement location models. Several of the models differ mainly in scale, but all deal with decision making in resource use. Resources range from a single unit of a type of plant or animal, to a resource patch, or even an entire ecosystem. While describing these models in detail would be time consuming, suffice it to say that they utilize the above concepts to solve differing questions relating to decision making strategies of resource use.

Of these various models, perhaps the ones most relevant to SCA are central place foraging models – although there is no reason why the other models could not be applied to questions of Grand Canyon subsistence. Central place foraging assumes the group in question to be a fixed-base operator, making forays out from a base camp to procure subsistence goods. Such considerations will have effects on where foragers decide to place their residence, as the place of residence will determine the value of subsistence resources. The feasibility of utilizing a particular resource can be measured by determining the rate of delivery to the central place; a resource must yield sufficient energy to offset round trip travel costs. The longer the trip from the central place, the greater the value of the resource in question must be in order to justify the trip.

Further context for central place foraging can is provided by a case study, from the Cumberland Escarpment of eastern Kentucky. Gremillion (2006) identified two ecological zones that contain potential for agriculture, including floodplain alluvium and the hillsides adjacent to rock shelter habitations. The best soils for farming include floodplain alluvium. Yearly flooding restocks floodplain zones each year with silt, providing a consistently good setting for agricultural production. However, floodplains occur at a greater distance from rockshelters compared to potential hillslope farming areas. Hillslope farming would have provided suitable farming land, but contains risks associated with erosion and over-exposure to sunlight, in addition to less agricultural potential related to lower nutritive soil content. The question posited by the central place model is, "Does the greater soil potential of floodplain alluvium outweigh greater travel costs incurred by travelling to floodplain areas?"

In order to analyze this question, Gremillion examined various factors related to agricultural potential of wild and cultivated varieties of *Chenopodium Berlandieri*, and *Iva Annua,* plant species found in rock shelters in the study area. Assessing the agricultural potential of the different potential agricultural zones required a serious of analogies and calculations. First, Gremillion estimated the soil potential of different prehistoric soil conditions. The fact that prehistoric and modern soil conditions may have differed is simply acknowledged as a given because the difference probably impossible to account for. Based on modern yields of corn in floodplain alluvium in the area and adjacent hillsides, Gremillion determined that floodplain alluvium would contain twice the agricultural potential of hillside slopes. Next, Gremillion calculated the carrying capacity of an individual returning from a field to the rock shelter. Based on a combination of ethnographic evidence in the Great Basin related to conical burden baskets and modern recommendations for hiking weights, Gremillion determined that a load of 15 kilograms would be a conservative maximum load assumption. Subsequently, Gremillion calculated the energy content per basket load of harvest by subtracting the plant waste material, such as stems, that could not have been eaten but would have been carried. Finally, Gremillion estimated the processing time and agricultural labor investment based off of the most pertinent ethnographic analogy, quinoa farmers in the Andes of South America.

Because this thesis examines the implications of rough terrain as a travel constraint, the most relevant aspect of the aforementioned study is the way in which it accounts for travel costs. Travel costs are a significant model component, and are measured both in travel time and energy expenditure. While Gremillion acknowledges that it would be possible to create a highly realistic estimate of travel cost, the author chooses a more generalized method for a variety of reasons (Gremillion 2006: 57-58). These costs are based on single studies that estimate travel speed (Winterhalder and Goland 1997) and energy expenditure (Ainslie et al. 2002) as fixed rate values. Therefore, although the methodology for estimating travel costs in this study is much different than this thesis, the study shows the utility of travel cost estimates in HBE models. In addition, the study shows the utility of HBE outside of the foraging scenarios in which they were originally envisioned. Small scale agricultural societies dealt with many of the same environmental constraints, costs, currencies, and goals in their subsistence strategies, so the utility of the framework in assessing subsistence strategies remains compelling.

Application of SCA and HBE Models to the Current Study

For several reasons, the development of comprehensive HBE models, such as central place models, is outside the purview of this thesis. For example, knowledge of relative agricultural productivity of different soil types, or the expected post-processing yield of plants in the canyon is not available. In addition, as the focus of this thesis is prehistoric travel and transportation in general, this thesis does not address a specific time period, or subsistence model. Furthermore, even if the preceding conditions were met, this study does not address a specific archaeological assemblage or site. Therefore, the application of site catchment analysis to HBE models must remain generalized for the current study. Nevertheless, I believe that it is beneficial to keep the backdrop of models derived from HBE in mind for several reasons.

First, as a region, and for various reasons, the Grand Canyon has experienced relatively little archaeological excavation over the years. Yet, the region is home to a multiplicity of subsistence models. The cross-canyon, Havasupai, Paiute, Powell Plateau, and Bi-Seasonal models, as well as synthetic models (Fairley 2003, Huffman 1993) models, and Smiley and Smiley's (2011) Pre-formative model, were all introduced in Chapter Two. However, with the exception of Smiley and Smiley's (2011) Pre-formative model, based off of the subsistence models of the Basketmaker II phase on northern Black Mesa, none of the models contain any criteria through which they can be verified. In addition, none of the current models address Archaic subsistence.

Second, the models mentioned above consist either predominantly, or at least partially, of foraging models. The Powell Plateau, Havasupai, and Paiute models emphasize foraging with some agriculture. For example, if one takes as a precondition

Effland et al.'s (1981) characterization of Havasupai subsistence as being composed of 10 percent agriculture, then this point seems clear. The cross-canyon model is essentially a foraging model, as Sullivan (1986, 1995, 1996) has consistently downplayed the role of agriculture in the Cohonina economy. Only Pueblo II period agricultural models, such as the bi-seasonal model (Schwartz et al. 1981), can be conceived of as predominantly agricultural in nature. Because HBE has shown success in addressing the economies of foraging or mixed foraging/agricultural societies, HBE would seem to hold promise in evaluating these models.

Third, because of the extreme vertical relief of the Grand Canyon, which causes great ecological variability over short horizontal distance, as well seasonal variability in resources use, we have seen interest in understanding prehistoric subsistence strategies as integrated Rim-to-River systems (Huffman 1993). In response to this situation, Huffman (1993) has defined system components that could be used in the creation of testable models of GC subsistence. Given this as well as the preceding statements, it seems that studies of Grand Canyon subsistence may be well suited to application of models derived from HBE, in which transportation costs are included in cost benefit analysis.

What I attempt to provide here is further delineation of components necessary for construction of models derived from HBE. As stated by Smith (1983:626), optimization analysis must specify, "a currency (such as energy), a goal (such as maximizing foraging efficiency), a set of constraints (factors that limit the range of options for the duration of the process studied, and a set of options (choices left open to the actor)." Huffman's (1993) system components (rim, river, side canyons etc.) correspond to constraints. The trails database, and the accompanying discussion of accessibility options (Chapters Three and Four), can be seen as providing additional clarity to the constraints of movement in the Grand Canyon. Foraging goals would be specific to any of the aforementioned models, while foraging options would be associated with the spatial and seasonal variability of flora and fauna in the Canyon. The following analysis (Chapter Six) refines estimations of the currency by examining different formulae used to predict travel time and energy expenditure.

GIS Methods for defining Site Catchments and Cost Surfaces

Due to the nature of terrain in the Grand Canyon, the amount of energy expended through the physical act of walking is greater than on a flat surface (Figure 5.1). Accordingly, an understanding of the effect of terrain on energy expenditure is perhaps more important, but less tractable, than in other regions. Recently, there has been interest in defining the effects of variable terrain as travel costs, but the range of specific GIS techniques and formulae used to estimate energy expenditure or travel time are perhaps as variable all of the previously mentioned techniques for estimating site catchment boundaries combined. In addition, the applicability of formulae used to estimate energy expenditure on extreme slopes is unknown due to the varying conditions under which the formulae were created. As further analysis in this paper will show, there is considerable variability in the predictions of different formulae for estimation energy costs. In this section I provide a brief overview of the ways in which various researchers have performed cost surface analysis. I provide basics of raster analysis, as well as relevant formula that have been used to model costs, paying attention to the three different

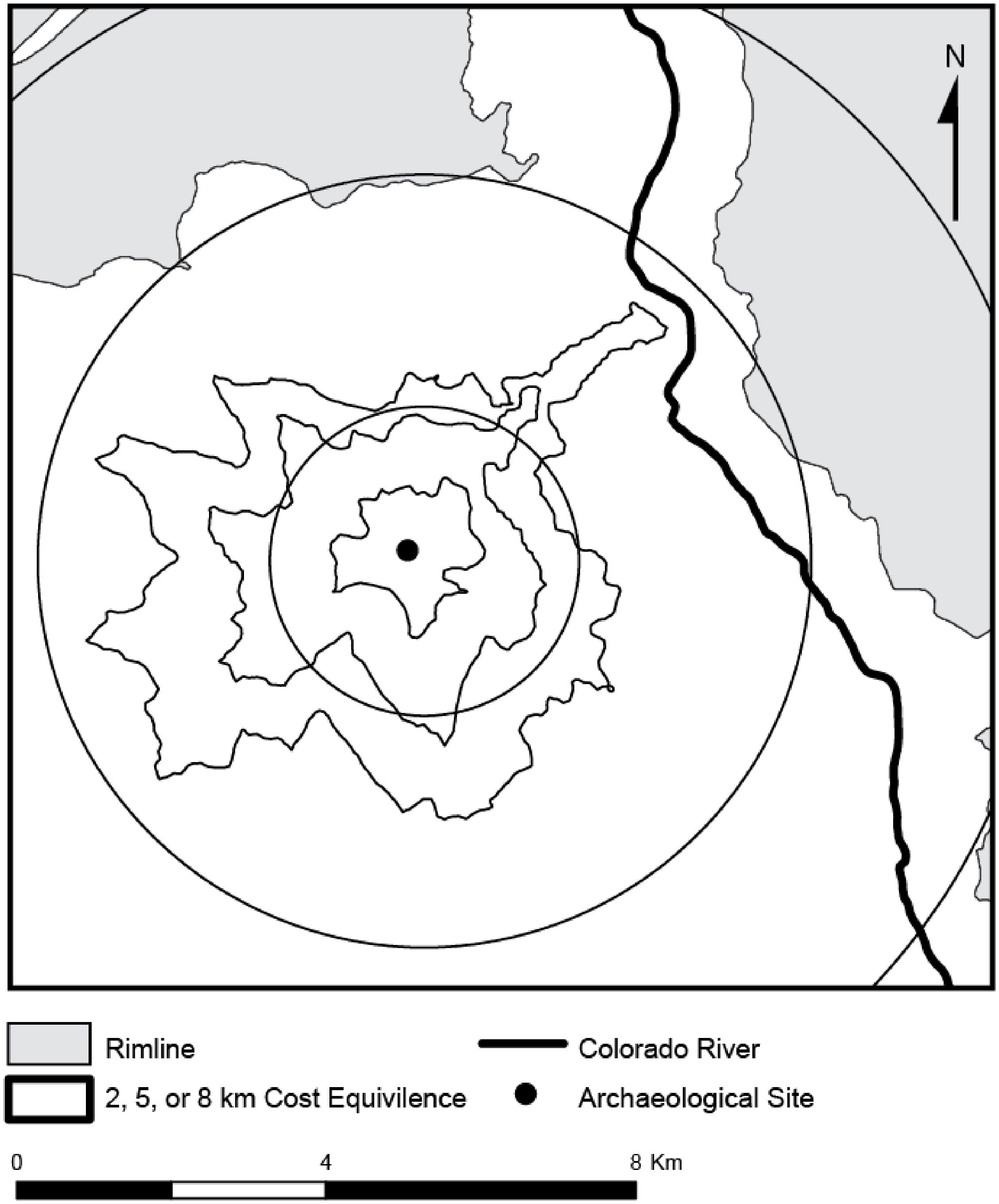

Figure 5.1. A comparison of the difference between straight line, and energy equivalent distance, using the formula derived by Hill (1995).

formulae that are used. I then examine ethnographic examples of the distance between archaeological sites and resource use in order to define what we would expect to be important catchment sizes.

GIS Methodology

The analysis performed in Chapter Six is conducted using the Pathdistance Tool, an application of the Spatial Analyst Extension in ESRI ArcGIS. Pathdistance predicts the cost of travel from a source (such as an archaeological site or resource procurement area) to every other cell in a raster grid along a least cost path. In a GIS analysis, a given geographic area is digitally represented by rows and columns of cells of equal size. The total area containing all the cells is called a “raster.” GIS analysts also refer to rasters as “grids.” Each raster or grid cell has an assigned value. In the most common instance, values represent elevations for each cell and form a topographic model of terrain called a digital elevation model or DEM. Raster cell values can also represent travel costs in a grid in which each cell value is calculated by the amount of energy required to reach the cell from some defined point. Travel, or movement costs, in turn, demonstrate the difficulty or ease of human movement across the grid. Just as a raster composed of cells that denote elevation above sea level can also be said to be an "elevation surface" a raster composed of cells that denote travel cost can be said to be a "cost surface."

An important analytical tool in GIS, least cost path (LCP) applications, help analysts identify the most likely avenues of movement on a landscape based on the routes that require the least “cost” to negotiate. Differences in energy expenditure occur while climbing steep slopes, walking across contours on steep slopes, or walking down steep slopes. Accordingly, "energy cost" should be easy to grasp intuitively. A "cost path" is simply a route across terrain for which the energy costs have been calculated. A "least cost path", as should also be intuitively clear, is the route calculated to require the least energy expenditure. To “run” a least cost path analysis, an analyst identifies starting and ending points and the application calculates the most likely (energy inexpensive) pathways for travel between the points.

Using the Pathdistance tool, each cell in the output grid represents the cumulative cost of movement along a least cost path from the source. A compelling aspect of Pathdistance, compared to other methods that may be used to predict cost of movement, is the fact that Pathdistance assigns costs to cells based on a measure of directionally dependent slope between cells. This measure of slope can then be used to assign a cost to movement at a specific angle of movement, which may be derived from equations that predict the cost of movement at a given grade.

In the analysis that follows, the reader should keep in mind the great range of variation in individual human travel capacity. As stated by Aldenderfer (1999:15) mathematical formulae that predict variables such as travel time cannot be applied uncritically. For instance, prehistoric populations in the Grand Canyon could only travel only on foot, may be carrying commodities or children, and have a wide range of travel distances and motivations.

Time as Currency

As stated above, the first method used in SCA was to conduct a series of timed walks outward from the archaeological site in question (Vita Finzi and Higgs 1970).

Because this method is labor intensive, it has not been commonly applied. If one were to image conducting this form of site catchment estimation for multiple sites in an archaeological region of interest, conducting the analysis could quickly become unmanageable. Therefore, due to the interest in time as currency in the field of geography, multiple formulae have been created to predict travel time as a function of grade, including Tobler's (1993) Hiker Function, which is based off estimates of walking speed developed by Imhof (1950). The function appears as follows:

$$V = 6e^{-3.5|S+.05|}$$

Where, V is walking speed in km/hr, e is the base of natural logarithms, and S is slope in degrees. The equation predicts that a pedestrian will travel at a maximum speed of 6 km/hr on a slightly negative slope and that speed will rapidly decrease as slope increases in a positive or negative direction. Tobler's Function is non-isotropic (Figure 5.2), in that it predicts different speeds for positive and negative slope values.

Aldenderfer (1998) tested the predictions of Tobler's Hiker Function against observed walking speeds in the mountainous environment of the Andes, finding that the function predicted walking speeds reasonably well. However, the weight of loads carried by participants in Aldenderfer's study appear to have resulted in lower speed estimates, and the Hiker Function cannot account for differences in load. In addition, frictional differences in surface types, such as the difference between walking over asphalt, along dirt paths, or across rocky terrain also affect travel speed. According to Tobler (1993) off path travel times can be estimated by multiplying any walking speed by a factor of 0.6.

Roughness of terrain may modify walking speed in a predictable way, but in the present, study I assume that most travel occurred on trails, and I, therefore, do not modify the equation. In addition, in the following analysis (Chapter Six) the Pathdistance algorithm is prevented from choosing slopes over forty degrees.

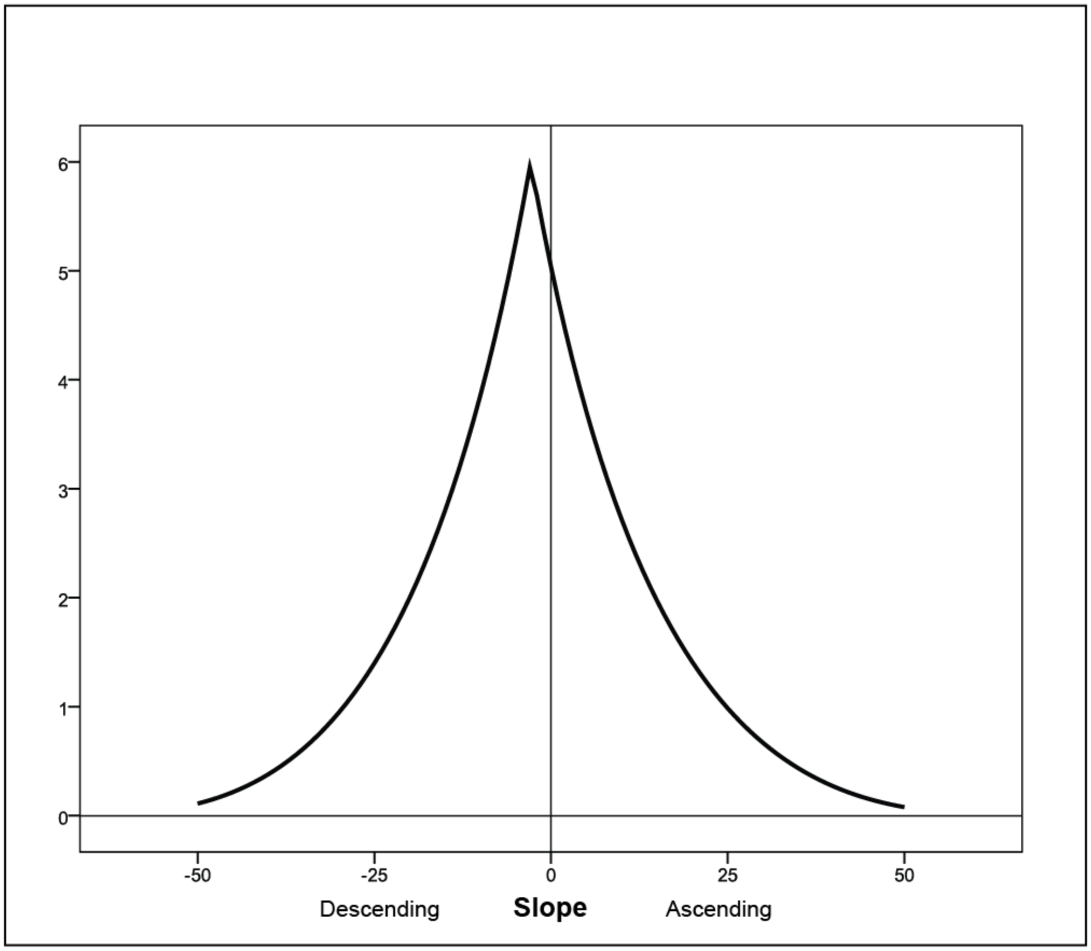

Figure 5.2**.** A graphical depiction of the differences in walking speed predicted by Tobler's (1993) Hiker Function (slope measurement is degree).

Recently, Taliafero et al. (2010) integrated the Hiker Function into a GIS to compare the travel time between archaeological sites and raw obsidian providing a comparative framework for examining travel time in the process of resource procurement. Taliafero et al. (2010) provide an example of a HBE approach to societies of varying scale in the Mimbres region of western New Mexico. However, HBE studies rarely examine the procurement of non-subsistence goods, though procurement of such items entails cost based analysis similar to studies of subsistence. For instance, costs involved in the procurement of lithic raw materials, such as obsidian, would include the, "the distance to sources, time, labor, and material support to collect process, and transport it" (Taliafero et al. 2010:538). In addition, Whitley and Hicks (2003) used the Hiker Function to mediate the slope of terrain in least-cost path analysis. Understanding that time is a function of distance *and* velocity allows one to calculate the time required to cross a raster cell of a given size. For instance, time can be expressed as:

$$T = D/V$$

where T is time, D is distance, and V is velocity. The formula allows us to convert the Hiker Function into a measure of time in the following way:

$$T = \frac{e^{-3.5|S + .05|}}{6000}$$

Where the denominator represents meters per hour. As a result, it is possible to calculate the time required to cross one meter of distance at a given slope. After running the Pathdistance tool, it is then possible to create isolines, or travel contours as discussed above, that depict equal units of travel time. In any given direction from the travel contour reference point, the travel radius will lengthen on easy terrain and shorten on rougher terrain. The major drawback in applying this formula to archaeological analysis in the Grand Canyon is the fact that the equation deals poorly with extreme slopes.

Energy as Currency

Energy provides an alternative measure of travel currency to time. In the method used by Hill (1995; cf. Herhan and Hill 1998; Hill 2000), mechanical work (expressed in joules) is calculated based on Cotterel and Kamminga's (1990) formula for travel over a horizontal distance, which is added to the work required to elevate the traveler over a change in vertical distance. The formula used to calculate horizontal work is presented here:

$$MGP^2/8L$$

where M is mass, G is gravity, P is pace length, and L is leg length. Herhann and Hill (1998) use measurements derived from Gamble (1949) to estimate body characteristics for modern Puebloan people, which I follow in the subsequent analysis: weight 65 kg, leg length 78.5 cm (These parameters are also used in application of the Pandolf Equation, see below). Essentially, this formula predicts the amount of work required to move a center of mass up and down (such as in the rise and fall of a human footstep) and forward one pace. In order to predict the work incurred by vertical motion, Hill (1995,) uses this formula:

$$(MG)*(\sin (S))*(D)$$

Where M is mass, G is gravity, S is slope in degrees, and D is distance (base distance/ cosine of slope, aka hypotenuse). By adding the horizontal and vertical work together, the total mechanical work for travelling over a unit of distance is derived. From this point onward, this method is referred to as Hill's Formula. The method gives us an isotropic model. An isotropic model predicts equal costs for travelling over positive, or uphill, and negative, or downhill, slopes (Figure 5.3) of energy expenditure when walking on a grade. This is the formula used by Hill (1998) and Varien (1999) to define site catchments, for various research purposes. However, the GIS methodology in the aforementioned studies used to create cost surfaces is much different than the one used in this study. Despite differences in methodology, I believe that the generalized nature of the formulae is compelling for use in high slope environments. For this reason, I propose that this model is the best fit for measuring large catchments in the Grand Canyon, which invariably require travel over steep slopes.

The Pandolf Equation and Yokota's Downhill Correction Factor

In several instances, researchers (Whitley and Hicks 2003; Taliafero et al. 2010) have cited the ability of GIS to model caloric expenditure, but, as stated by Aldenderfer, "It has proved difficult to measure energy expenditure and work effort empirically in the field or in "realistic" work settings" (1998:11). Hence, the use of energy expenditure, as a variable used to calculate cost surfaces, and to negotiate least-cost paths, is often mentioned, but rarely utilized. Notable exceptions include Hill (1995), as discussed above, and Wood and Wood (2006), who modeled the energy expenditure of least-cost paths through use of the Pandolf Equation (Pandolf et al. 1977). A major difference between the formulae utilized by Hill and that of Wood and Wood is that the Pandolf Equation accounts for negative slope values. In addition, it is particularly alluring for a couple of reasons. First, the equation specifically accounts for the load a person may be carrying, and the frictional differences of various types of terrain, which may allow one to predict the caloric cost of a specific subsistence scenario. Thus, the formula is more specific than either the Hiker Function or Hill's method. Second, the formula can predict

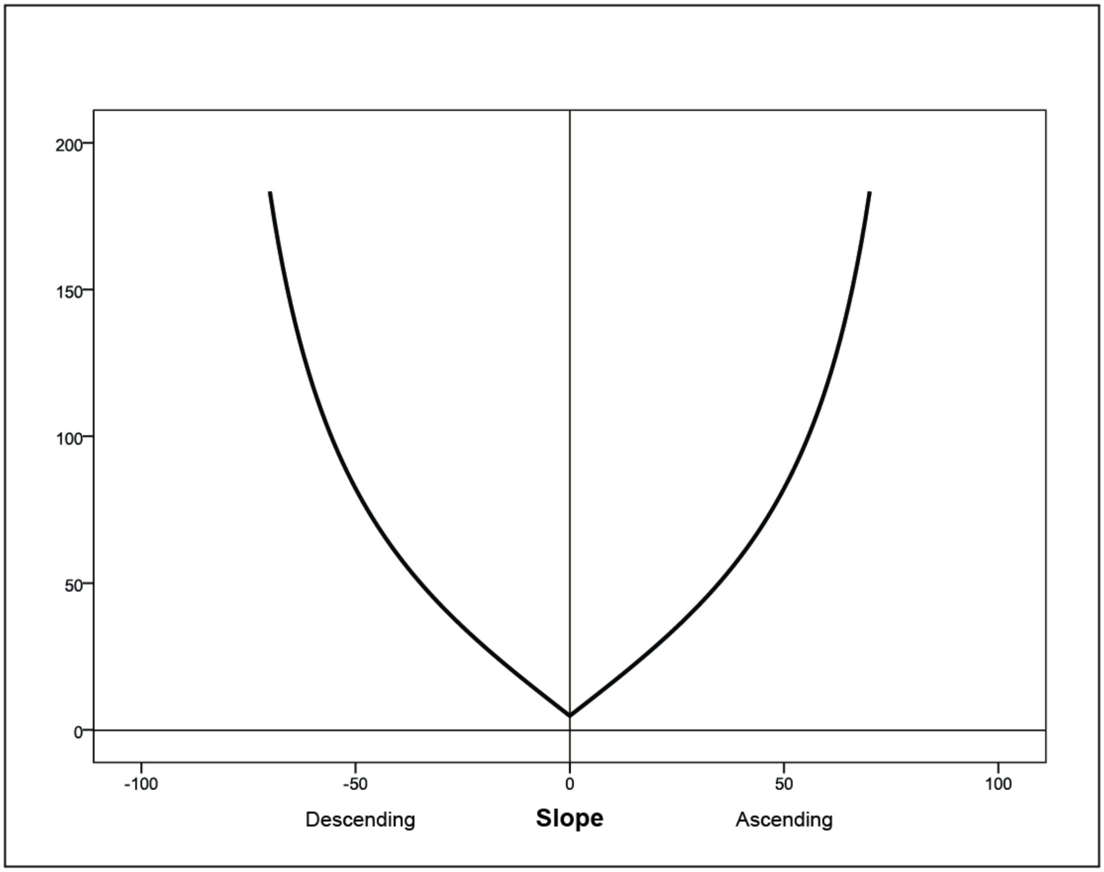

Figure 5.3. Graphical depiction of the formula for estimating the energetic equivalence of walking over graded slopes, derived by Hill (1995).

the number of calories that a person burns in a hypothetical trip. This is appealing because calories are a unit of energetic expenditure employed in many HBE models. Initially, the principal weakness of the Pandolf Equation was its inability to account for costs of downhill movement incurred as one prevents themselves from slipping. Yokota et al. (2004) created a downhill correction factor for the Pandolf Equation, which is used on negative slopes. Below are the Pandolf Equation (M) and its correction factor (CF) for travel over negative terrain (Wood and Wood 2006; LaFreniere 2009)

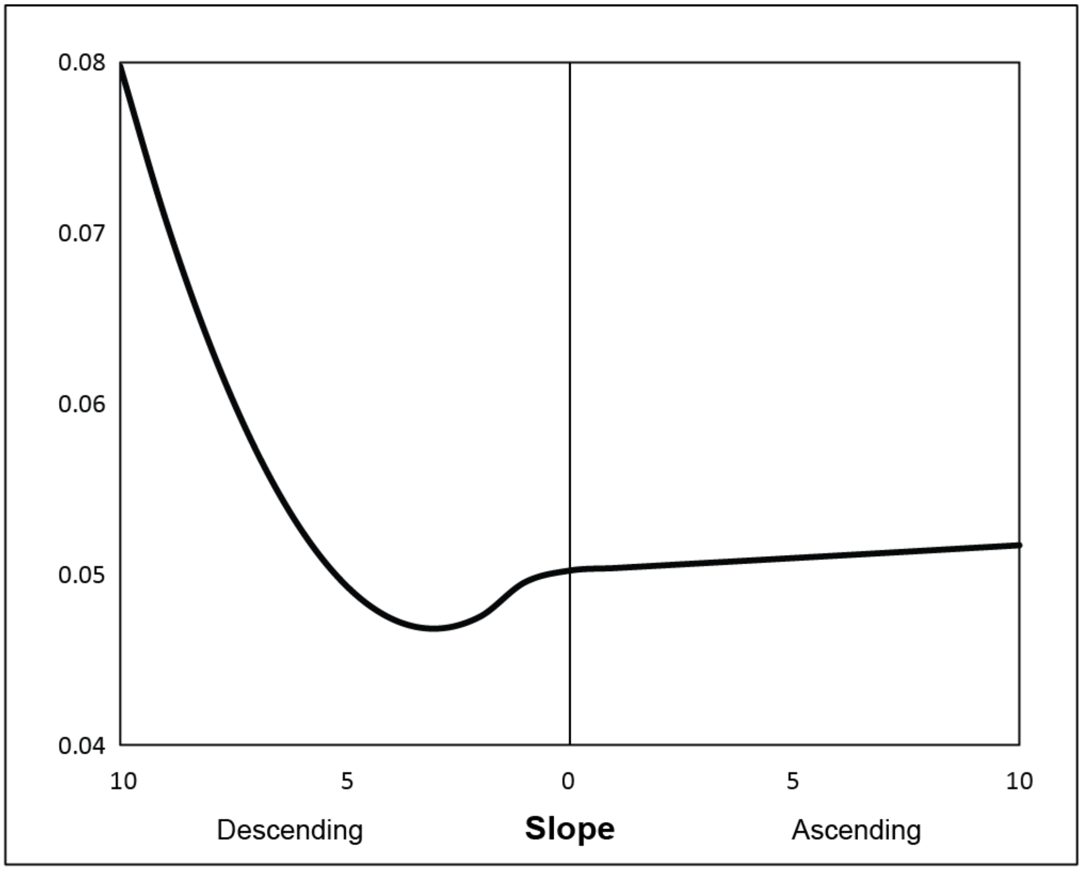

Figure 5.4. Graphical depiction of the Pandolf Equation, with the fixed speed parameter set to 1.11 meters per second (4 km per hour).

$$M = 1.5w + 2(w + l)((l/w)^2 + ŋ(w+l)[1.5v^2+35vg]$$

$$CF = M - ŋ[(g(w+l)v/3.5) – ((w+l)(g+6)^2/w)+(25-v^2)]$$

Where M = metabolic rate in watts, w is weight, ŋ is the coefficient of friction, l is load, v is velocity in meters per second, and g is gradient in percent. This equation allows one to create a truly anisotropic measurement of cost. Figure 5.4 shows caloric expenditure as predicted by the Pandolf/Yokota equation. One may note, however, that the Pandolf equation quickly loses accuracy on steep negative grades. Also, the Pandolf equation requires a fixed velocity (Patricia Kramer, personal communication 2010) which as I show in the following chapter, causes it to work poorly in this application. Kramer (personal communication 2010) recommends setting this parameter between 1.4 and 1.8 meters per second, however, these estimates seem unrealistic as a travel speed in the Grand Canyon. Therefore, I use 1.11 mps (4 km/h).

In a case study outside of archaeology, LaFreniere (2009) successfully applied the Pandolf/Yokota equations to a study of water procurement in rural Southeast Asian villages. This study showed that energetic expenditure predicts the ways in which people use water to a much better degree than straight line measures of distance sometimes applied by international development agencies. In other words, the amount of energy that people expend procuring water causes people to drink less, use less water for cooking, washing dishes, consumption, etc. Although this case study is not archaeological, it demonstrates how differences in energetic expenditure related to procurement tasks influence behavior.

Summary

In this section, I have described the use of three different formulae to predict the travel costs in various applications. Each formula contains inherit strengths and weaknesses for application in GIS due to the parameters under which each formula was developed, including data on human travel parameters gathered from treadmill tests, which have a lower frictional cost than walking over open terrain or even walking on a dirt path, and data gathered in tests that included a lower range of slope gradients than found in the real world. The reader should keep in mind the extremes of elevation and roughness of the terrain in the Grand Canyon.

In addition, various supplementary models exist that predict energetic expenditure, some of which have been applied to archaeological analysis. Drennan (1984a, 1984b) used a model derived from Phillips (1954) to determine the extent of trade networks for subsistence resources in Formative and Classic Period Mesoamerican urban centers. The model predicted average caloric cost for different activities by attaching a breathing apparatus to indigenous farmers while they performed various tasks. Thus, the calculation of energetic expenditure was derived by multiplying the amount of time spent performing a task by this average expenditure rate, a method which does not account for movement along a given grade. Ullah (2011) used another formula of energetic expenditure, and performed a study quite similar to the analysis performed in the following chapter, using the GRASS program suite. Kramer (2010) and Minetti et al. (2002) derived additional equations for predicting energetic expenditure, although Kramer's equations appear somewhat complicated for archaeological application. Minetti et al. (2002) created an equation predicting the cost of walking or running at extreme grades, and I would suggest that subsequent analysis test the applicability of that equation. Finally, Hare (2003) suggested the use of an isotropic equation derived from Ralston (1958).

I imagine that additional formulae can be found in the literature of fields such as exercise science and physiology. Despite the abundance of formulae, specific conditions must be met for any given formula to be applicable to the Pathdistance tool. These conditions include either a measure of distance-per-cost-unit or a measure of velocity. The models used here satisfy the necessary conditions without introducing variables that are overwhelmingly complicated for archaeological application, such as human heart rate or gender. I consider consistency between the results of the applications of the models to be indicative of the relative roughness of terrain (See Chapter Six), but would only tentatively agree to the accuracy of specific predictions of energy expenditure or travel time. The acknowledgement that there is as of yet no “unified equation” for energy expenditure reinforces necessity of the current project goal of comparing the results of different formulae when applied specifically to the Pathdistance Tool within ESRI ArcGIS.

Developing Expectations

In order to provide a reference point for predictions made by the aforementioned formulae, it is necessary to develop expectations about the distance for the types of activities that occur in a cost-equivalent area of a given size. The most basic starting point for developing expectation might be to ask the question, “How much distance can a person cover in a day?” One way to conceptualize this problem is in terms of human running capacity. Numerous examples demonstrate the remarkable running ability of members of indigenous groups worldwide, as well as in the Southwest. The Tarahumara, occupants of Copper Canyon, sometimes referred to as Mexico's "Grand Canyon" in northern Mexico are known to run hundreds of miles without stopping (McDougal 2010). More relevant to this study, however, are the running traditions of indigenous groups of the American Southwest. Mauss, in *Techniques of the Body* (1973:82), reported meeting a Hopi runner who had run 250 miles without stopping. The Navajo, Apache, and Havasupai, all have long held running traditions. The examples of indigenous long-distance runners are comparable to modern-day ultra-runners, such as John Annerino, who ran great distances within the Grand Canyon. Annerino ran approximately the length of the former NPS boundary over a period of several days below the North and South rims. Annerino's documented feat suggests that it is possible, if not likely, to infer that the prehistoric inhabitants of the Grand Canyon were capable of covering enormous distances in a single day, within the Canyon.

While such running capability may have been used, as Wilcox (1996:243) suggests, to exert a threat radius, that is, an assertion of territoriality, or for various other purposes, it is unlikely that the majority of daily subsistence activities occurred within such parameters. For normal prehistoric subsistence activities, distances travelled are expected to have been much shorter, and the general ranges for such activities have been recorded by ethnographers. Varian (1999) has summarized the results of several such studies including Chisholm (1970), Arnold (1985), and Stone (1991a). With respect to the distances that agriculturalists are willing to travel from a settlement to a cultivated field, Chisholm found that distances of 1 kilometer or less were normal, and that distances of 3 to 4 kilometers presented an upper limit. For example, Kofyar farmers of Nigeria typically travel less than 700 meters (Stone 1991b). Arnold (1985) contends that an upper limit for distance to fields would be around eight kilometers, and that the distances travelled to gather materials used in ceramic manufacture, were similar.

The Grand Canyon, however, was occupied by both foraging and farming societies. The distances travelled by foraging societies to resource procurement areas are very likely to have been greater than distances travelled by agriculturalists to fields. Lee (1969) states that distances of 10 kilometers were recorded for !Kung Bushman in the Kalahari Desert environment of South Africa. In Drennan's (1984a, 1984b) studies of distance as related to subsistence based trade in pre-Colonial Mexico, a distance of 36 kilometers was set as the maximum distance a person could travel in an 8-hour work day, carrying a 30 kg pack – an estimate that, in my view, is likely to represent the upper limits of prehistoric human endurance. However, a probable outlier, would include the Papago, who travelled round trip distances of 48 km (Castetter and Bell 1942:42 cited in Ritterbush 1981) for water procurement. Such a consideration might be important when considering the hypothetical use of the Colorado River from various areas of the canyon or along the rim.

In his analysis of Mesa Verdean archaeology, Varian (1999) defined 2 km cost-equivalent polygons (see Chapter Six for definition of cost-equivalence) as the maximum extent of travel likely for agricultural subsistence. Varian defined 7 km as the maximum distance likely for non-agricultural site-related activities and 18 km as the maximum distance a person could travel away from a base camp in and return in a day (half of Drennan's [1984a, 1984b] estimation of 36 km as a max distance (max one-way) for a heavily burdened traveler). Varian based his estimates on ethnographic analogs, such as those mentioned above.

At this time, the methods and productivity of agricultural activities within the Grand Canyon remain unknown. Perhaps an analogy could be constructed based on the Havasupai, who are known to have farmed at Indian Gardens below the South Rim, on the floor of Fossil Canyon, and in other areas, if estimates of agricultural yields could be determined based on such scenarios.

Based on Varian's ethnographic analogy cited above, as well as on my interest in examining differences in the areas of energy-equivalent polygons between predictions created by different mathematical models, I stipulate 2, 5, and 8 km catchments as units of analysis for the first portion of the analysis undertaken in Chapter Six. These values can be thought of as low, medium, and high agricultural catchments or catchments for other non-agricultural subsistence areas. In addition, large catchments will be created when examining the costs of travelling between the Canyon rim and Colorado River.

Summary

This chapter has examined issues ranging from the application of SCA to HBE, as well as the methodology and formulae used to develop cost surfaces by various authors. In the next chapter, these concepts are applied to different regions of the Grand Canyon in order to provide an inductive examination of effects of rough terrain on prehistoric populations, the variation in catchment size according to different formula, and the effects of accessibility on the estimation of catchments.

Chapter 6

Comparison of Formulae for Delineation of Archaeological Site Catchments and Cost Surfaces

Introduction

This chapter explores the implications for the use of three mathematical formulae for the construction of site catchments and cost surfaces in the Grand Canyon. In Chapter Five, I introduced several formulae used by various authors to construct either archaeological site catchments or cost surfaces. I discussed three of the formulae in detail, including Tobler's (1993) Hiker Function, Hill's (1995) formula, the Pandolf Equation (Pandolf et al. 1977) and the Yokota (Yokota et al. 2004) downhill correction factor. In this chapter, I compare these formulae for the construction of archaeological site catchments and cost surfaces in the Grand Canyon.

Previous studies (Hill 1995; Varien 1999; Taliafero 2010) have applied a single formula for the construction of site catchments or cost surfaces. However, as I point out in Chapter Five, several formulae have been used by different authors. Therefore, a circumstance has arisen in which it is unknown which formula, if any, is better suited to the estimation of archaeological site catchments. Moreover, the extreme terrain of the Grand Canyon, may exaggerate differences in formulae because it is in high slope environments that the largest differences between the different formulae occur. Thus, GIS methods, such as the use of the ESRI ArcGIS Pathdistance tool, may allow the possibility of estimating site catchments, but the variability of formulae used create an uncomfortable circumstance for the application of such methods. As I show in this chapter, the predictions of each formula vary greatly.

Based on this characterization, I perform an inductive analysis, in which the size, shape, and "roughness" of site catchments in the Grand Canyon, created through the use of different formulae, are compared. This comparison provides an informed perspective for the investigation of questions related to the problem of effective distance in the Grand Canyon. In addition to the comparison of the use of different formulae, I tentatively use these formulae to investigate the following questions:

1. How rough, comparatively, is the terrain of the Grand Canyon compared to corresponding regions of the Southwest?
2. What are the potential consequences of high effective distance between the Grand Canyon Rim and River regions? Alternatively, what are the consequences of high effective distance in understanding integrated rim-to-river subsistence strategies?
3. What is the relative isolation of sites in the Grand Canyon?

Finally, I will introduce two potential methods that can be used to better account for the effects of accessibility on site catchment estimation. The first method involves calculation of costs incurred travelling a specific route. This method may eventually be combined with some sort of network analysis to provide a more fine grained assessment of prehistoric travel in the Canyon, and to identify specific routes associated with particular prehistoric activities. The second method involves blocking areas of high slope completely. The second method may be beneficial because although the equations used in this analysis make it unlikely that the algorithm will “choose” extremely high slope cells or routes, cell resolution will inevitably force the algorithm through barriers where usable routes may not exist or will allow the algorithm to unrealistically traverse to the tops of cliff edges. There are potential advantages and disadvantages in the use of any of the methods discussed in this chapter.

Grand Canyon Catchment Areas

The first portion of this analysis compares the predictions generated by the formulae mentioned previously. Because topographic variability exists between regions of the Grand Canyon. I have selected several locations from which site catchments are estimated. Five Canyon side drainages were chosen for analysis. These include the North Rim drainages/canyons of Nankoweap, Chuar, Unkar, and Bright Angel, and the Shinumo Amphitheater, respectively. The eastern drainages of Nankoweap, Chuar, and Unkar contain large portions of relatively gentle, open terrain, while the catchment areas of the Shinumo Amphitheater and Bright Angel Canyon are more constricted. These locations provide comparison between locations in Reaches Four (portions of Reach Four below Marble Canyon), Five, and Six. In addition to these drainages, areas outside of the Grand Canyon were chosen to provide insight into the differences in terrain roughness between the Grand Canyon and other regions of the Southwest. These areas include a portion of the Tsegi drainage (surrounding the site of Keet Seel) in northeastern Arizona, Mesa Verde (surrounding Cliff Palace), and the Grand Canyon’s Upper Basin.

In order to compare catchment sizes in different areas, and to provide a comprehensible metric, I use a unit of measurement called a cost-equivalent kilometer, which is borrowed from Varian (1999) who describes the concept of "cost-equivalent distance." As stated by Varian, "The concept of cost-equivalent distance accounts for the fact that crossing a deep, 1-kilometer-wide canyon, for example, consumes much more energy than does walking 1 kilometer across nearly level terrain" (Varian 1999:151). A cost-equivalent kilometer, in turn, is defined in this study as the energetic cost of travelling 1 kilometer over flat ground. A cost-equivalent kilometer is shorter on steep terrain than a kilometer measured in straight-line distances (Figure 5.1). Cost-equivalent distances are measured both in travel time and energy expenditure. Related to the concept of the cost-equivalent kilometer is the cost-equivalent polygon. For the remainder of this analysis the terms cost-equivalent polygon and site catchment are used interchangeably. I define a 1 km cost-equivalent polygon as a boundary around a site defining the distance a traveler must go from a defined origin point to expend the equivalent of one cost-equivalent kilometer.

The rougher the terrain, the smaller the cost-equivalent polygon in question will be, because cost is accumulated more quickly over an equivalent amount of horizontal distance. Accordingly, differences in size between cost-equivalent polygons will denote differences in terrain roughness. A comparison of the size of energy-equivalent polygons surrounding sites in different parts of the Canyon, as well as sites in the greater Southwest, provides an indicator of differences in terrain roughness. For each formula used in the analysis, the cost-equivalent distance is slightly different. In the use of Tobler's Hiker Function, a one cost-equivalent kilometer is equal to the amount of time that the equation predicts it will take to walk one kilometer on flat ground (slightly under 12 minutes). In the use of Hill's (1995) formula, a one kilometer cost-equivalent kilometer is equal to the amount of energy that the equation predicts it will take to walk 1 kilometer on flat ground (roughly 48,000 joules), and so on.

Based on the ethnographic analogies discussed in Chapter Five, as well as interest in examining differences in the areas of cost-equivalent polygons between predictions created by different mathematical models, I stipulate two, five, and eight kilometer cost-equivalents as units of analysis for the first portion of this analysis. These values can be thought of as low, medium and high, agricultural catchments or more simply just as catchments of different sizes. It is much more informative to examine catchments of several different sizes than to define a single maximum distance for agricultural catchments, because this allows observation of the way in which catchments change as a function of size in different parts of the Canyon.

Within each of the Grand Canyon drainages and the comparative regions in the greater Southwest, energy-equivalent polygons of two, five, and eight kilometers were created using each of the formulae discussed above. In each region, catchments were created around a single site. Although it would be possible to compare the catchments of multiple sites in all of the drainages examined here, thereby creating a more balanced measure of terrain roughness for all drainages, such an undertaking is outside of the scope of this project. Instead, sites were chosen that are expected to accord catchments that are minimally rough, in an attempt to avoid overstating terrain roughness of the Grand Canyon. Thus, the sites used for this portion of the analysis occupy the gentlest terrain of

Table 6.1. Comparative Catchment Area, Surface Area, and Ratio for All Drainages Used in this Analysis

Pandolf et al. 1977 and Yokota et al. 2004

CE	Bright Angel			Chuar			Nankoweap			Shinumo		
	Km2	SA	Ratio	Km2	SA	Ratio	Km2	SA	Ratio	Km2	SA	Ratio
2	5.72	6.71	1.17	11.74	12.19	1.04	10.8	11.49	1.06	8.77	10.17	1.16
5	33.77	39.88	1.18	49.79	54.5	1.09	59.15	66.71	1.13	30.96	37.41	1.21
8	84.81	102.46	1.21	102.51	117.01	1.14	135.85	160.05	1.18	139.72	170.29	1.22
CE	**Unkar**			**Keet Seel**			**Mesa Verde**			**Upper Basin**		
	Km2	SA	Ratio	Km2	SA	Km2	SA	Km2	SA	Km2	SA	Ratio
2	6.53	6.81	1.04	6.04	6.33	1.05	13.07	13.32	1.02	21.68	21.69	1.00
5	40.15	44.65	1.11	47.97	51.66	1.08	64.71	67.20	1.04	141.62	141.74	1.00
8	86.36	98.84	1.14	143.84	155.46	1.08	165.29	171.54	1.04	303.63	305.79	1.01

Hill (1995)

CE	Bright Angel			Chuar			Nankoweap			Shinumo		
	Km2	SA	Ratio	Km2	SA	Ratio	Km2	SA	Ratio	Km2	SA	Ratio
2	1.42	1.59	1.11	2.72	2.75	1.01	2.14	2.21	1.03	0.97	1.04	1.07
5	5.74	6.86	1.19	14.43	15.01	1.04	11.23	11.96	1.06	6.52	7.17	1.10
8	14.51	17.44	1.20	37.20	39.26	1.06	26.73	29.18	1.09	20.07	22.85	1.14
CE	**Unkar**			**Keet Seel**			**Mesa Verde**			**Upper Basin**		
	Km2	SA	Ratio	Km2	SA	Ratio	Km2	SA	Ratio	Km2	SA	Ratio
2	2.76	2.78	1.01	1.20	1.32	1.10	5.68	5.76	1.01	12.11	12.11	1.00
5	20.44	21.20	1.04	12.24	13.20	1.08	25.62	26.34	1.03	81.92	81.94	1.00
8	47.74	51.02	1.07	39.99	42.63	1.07	53.00	54.97	1.04	182.61	182.84	1.00

Tobler (1993)

CE	Bright Angel			Chuar			Nankoweap			Shinumo		
	Km2	SA	Ratio	Km2	SA	Ratio	Km2	SA	Ratio	Km2	SA	Ratio
2	3.00	3.46	1.15	5.83	6.01	1.03	5.32	5.63	1.06	2.99	3.23	1.08
5	20.61	24.20	1.17	34.10	36.02	1.06	29.53	32.26	1.09	22.69	25.94	1.14
8	66.65	77.70	1.17	83.98	92.30	1.10	73.66	83.82	1.14	54.64	64.18	1.17
CE	**Unkar**			**Keet Seel**			**Mesa Verde**			**Upper Basin**		
	Km2	SA	Ratio	Km2	SA	Ratio	Km2	SA	Ratio	Km2	SA	Ratio
2	2.76	2.78	1.01	4.74	5.10	1.08	11.94	12.21	1.02	12.11	12.11	1.00
5	20.44	21.20	1.04	40.09	42.99	1.07	56.05	58.32	1.04	81.92	81.94	1.00
8	47.74	51.02	1.07	108.23	116.98	1.08	135.54	141.01	1.04	182.61	182.84	1.00

Note: CE = Cost Equivalence, SA =Surface Area, Ratio is SA/Km^2

each drainage. The only possible exception to this rule is in Bright Angel Canyon Bright Angle Canyon where catchments surround Bright Angel Pueblo. In addition, catchments within the Grand Canyon are cut off at the Colorado River, because I consider it unlikely that river crossings occurred on a daily basis. Differences in, size, shape, and roughness (see below), are taken as indications of the differences in the predictions of each formula (Table 6.1).

Caveats

Before additional discussion, I must set out several caveats for using the methods selected here. First, two of the formulae estimate energy use, while one estimates time. Time and energy are different currencies, and we have no reason to assume that one will be a perfect indicator of the other. For example, it is possible that a human traveler could maintain a high walking speed on sloped terrain, therefore expending less time, but more energy for a lower distance. Therefore, it is reasonable to assume that different sized equivalence polygons could be created for different currencies. This is a methodological problem that makes comparison of different formulae somewhat difficult.

Second, because Pathdistance is a computationally expensive application, this portion of the analysis was conducted using 90 meter DEMs. In my experience, using smaller scale DEMs over large geographic areas can result in erroneous calculations of cost surfaces. The use of large scale DEM's, in turn, may inflate calculations of square area, as boundary cells cover greater area, and reduce precision of the analysis.

Third, sizeable differences in estimations of area^2 for equal energy-equivalence will occur even between catchments that do not appear to vary greatly on visual examination, or which exhibit slightly different sized "radii". This is due in part to the fact that calculations of area increase in an exponential manner as distance from the source is increased. For instance the difference in area^2 between a circle of radius 3km and one of 4 km is 22 km^2. This effect is especially exaggerated in larger catchments.

Likewise, this point must be kept in mind when examining the differences in square area between catchments. This point would have implications for researchers interested in determining agricultural yield of a catchment.

Finally, as mentioned in Chapter Five, each formula contains inherent strengths and weaknesses for application in the Grand Canyon due to the conditions under which the formulae were derived. For example, formulae may have been developed through treadmill tests (Pandolf/Yokota), observations on taken on smooth paths (unmodified Hiker Function), or without any empirical testing at all (Hill). Therefore, it is reasonable to assume some gap between the predictions made by the formulae and application in the Grand Canyon.

Comparison of Grand Canyon Catchments

Comparison of Catchment Shape

In this section I evaluate the implications for use of the formulae for site catchment analysis by examining the shape of catchments predicted by each formula. This portion of the analysis revolves around a couple of assumptions regarding how the Pathdistance algorithm should behave in relation to the topographic obstacles presented by the Grand Canyon. Essentially, these formulae should be sensitive to topography, meaning that the catchments predicted by the use of each formula should be irregularly shaped in relation to the distribution of cliffs and hill slopes in the Grand Canyon. It should be difficult for the algorithm to jump over cliffs, although the algorithm will inevitably do so as it is able to unrealistically traverse cells along cliff faces. The problem of unrealistically jumping cliff faces will be addressed later; in this section, when this occurs it is not excessively problematic because we are able to see general costs of movement over the landscape without assuming that we know all routes that provide accessibility, and we are also not required to digitize hundreds of miles of travel barriers (e.g. Coconino Sandstone or Redwall Limestone). The only barrier to movement specified here is the Colorado River.

Figures (6.1 – 6.15) depict 2, 5, and 8 kilometer catchments around sites in each region of the Grand Canyon (Figures 6.16, and 6.17 provide comparative look at catchments in the relatively flat lying Upper Basin). Figures 6.1, 6.2, and 6.3, depict catchments around a site in Nankoweap Canyon. In the case of the catchments predicted by Hill's method (Figure 6.2), and the Hiker Function (Figure 6.1), highly irregular catchments are predicted, as the catchments are funneled between Nankoweap Mesa and the North Rim. The Pandolf/Yokota catchment, however, is much more circular, and seemingly less sensitive to topographic obstacles. Particularly irksome is the fact that the 8 km cost equivalent polygon created by the Pandolf/Yokota catchment jumps over the canyon rim without rapidly accumulating cost. This pattern essentially repeats itself in other regions of the canyon. For instance, the catchments predicted by Hill's formula which surround Bright Angel Pueblo (6.10) are particularly constricted and irregular, while those predicted by the Pandolf/Yokota are almost circular. This is not to say that the Pandolf/Yokota catchments do not reflect topography at all. For example, Figure 6.9, shows a fair amount of variability around the Colorado River. Nevertheless, the simple examination of catchment shape is perhaps the first indication that the Pandolf/Yokota formula is poorly suited to predict catchment areas in rough terrain.

Catchment Size

This section compares each formula used in for the creation of archaeological site catchments according to the different predictions of size. Comparison of catchments by size is summarized in Table 6.1. The reader may also visually compare the difference in catchment size by examining differences in catchments predicted by different formula for each drainage (note that the scale is necessarily different on figures depicting catchments predicted by Pandolf/Yokota because the catchments are so much larger). In addition, Figure 6.18 compares the differences in 8km cost equivalent polygons created by each equation around Bright Angel Pueblo.

Clearly, there are large differences between the estimates created by the different formulae. When examining Table 6.1 one must keep in mind the caveats mentioned earlier, especially the exponential accumulation of area^2 vs. linear increase in radius length. That said, the reader will undoubtedly notice the large differences that occur - in fact, the Pandolf Equation often predicts area^2 values as much as 10 times greater than through Hill's method. Thus, archaeologists must use discretion when choosing mathematical models for the estimation of site catchments, and especially in the creation of cost surfaces. Differences in predictions made by the various formulae are great enough that they cannot be uncritically applied. This is especially true when comparing larger catchments.

As in the discussion of catchment shape, it is important to develop reasonable expectations for predictions for catchment size in order to evaluate the use of each formula. For this reason, it is especially useful to compare one formula that provides estimations of travel time, as opposed to energy expenditure because it is possible to

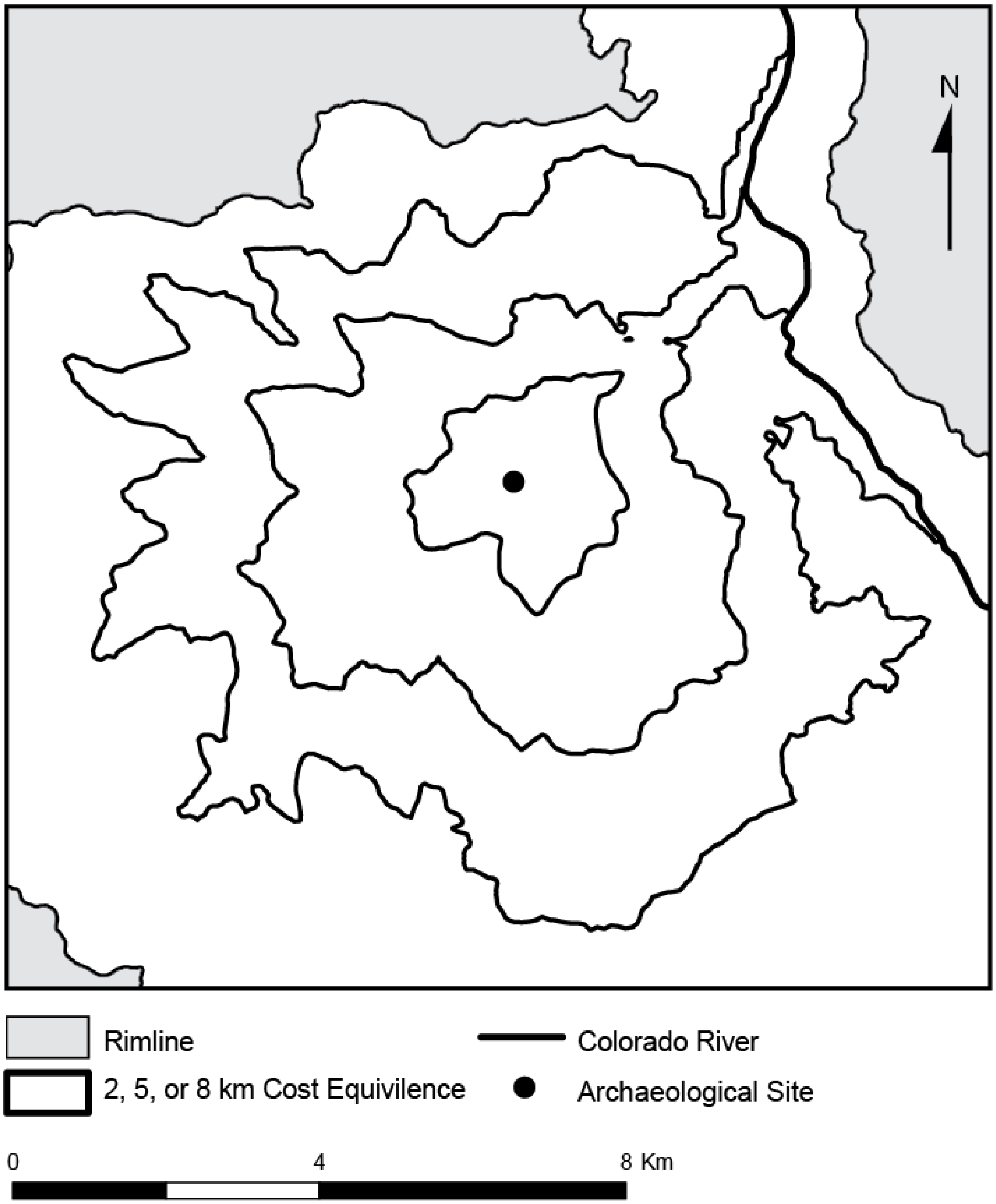

Figure 6.1. The 2, 5, and 8 km cost equivalent polygons for Nankoweap Canyon predicted by Tobler's (1993) Hiker Function.

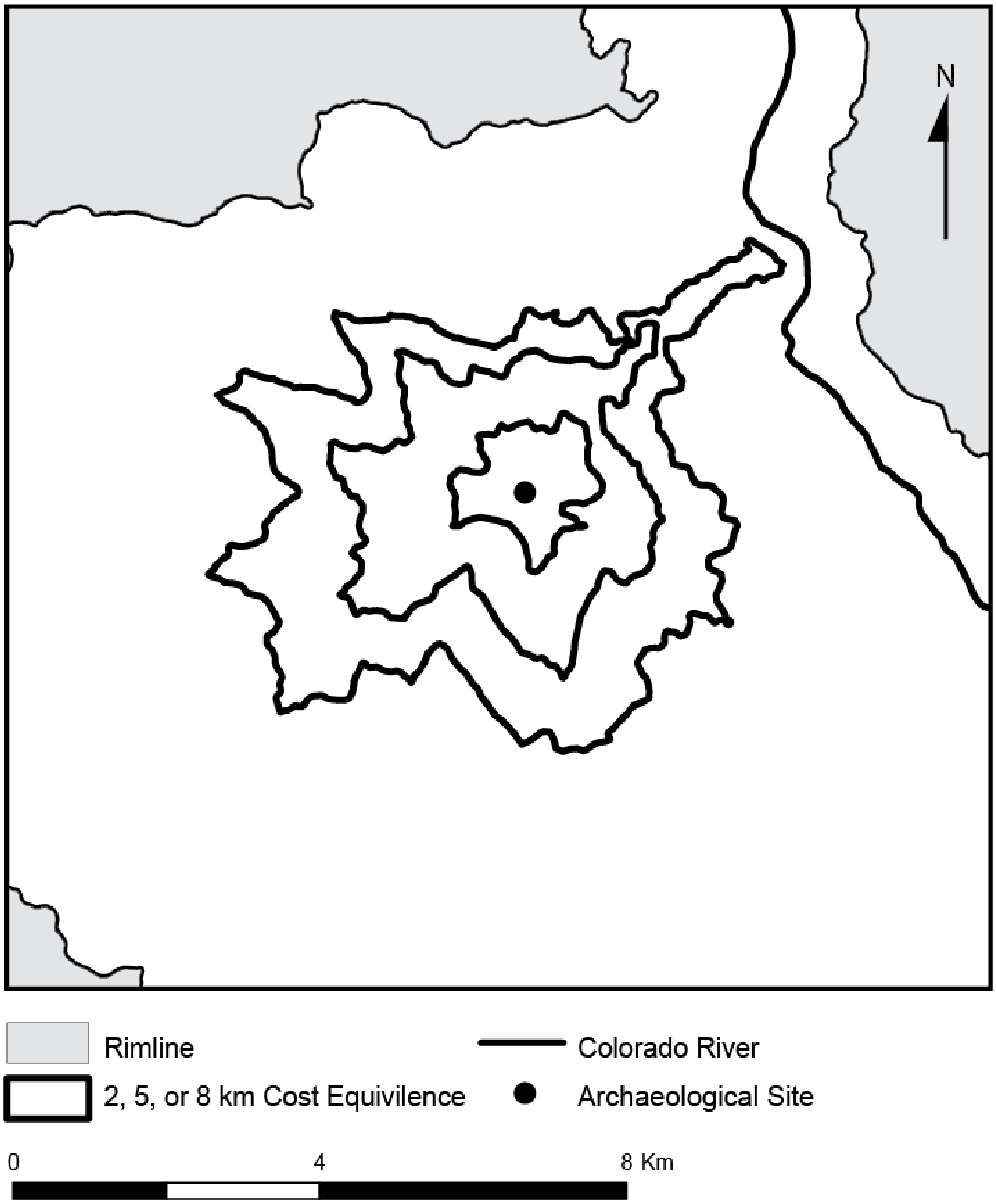

Figure 6.2. The 2, 5, and 8km cost-equivalent polygons for Nankoweap drainage predicted by Hill's (1995) formula.

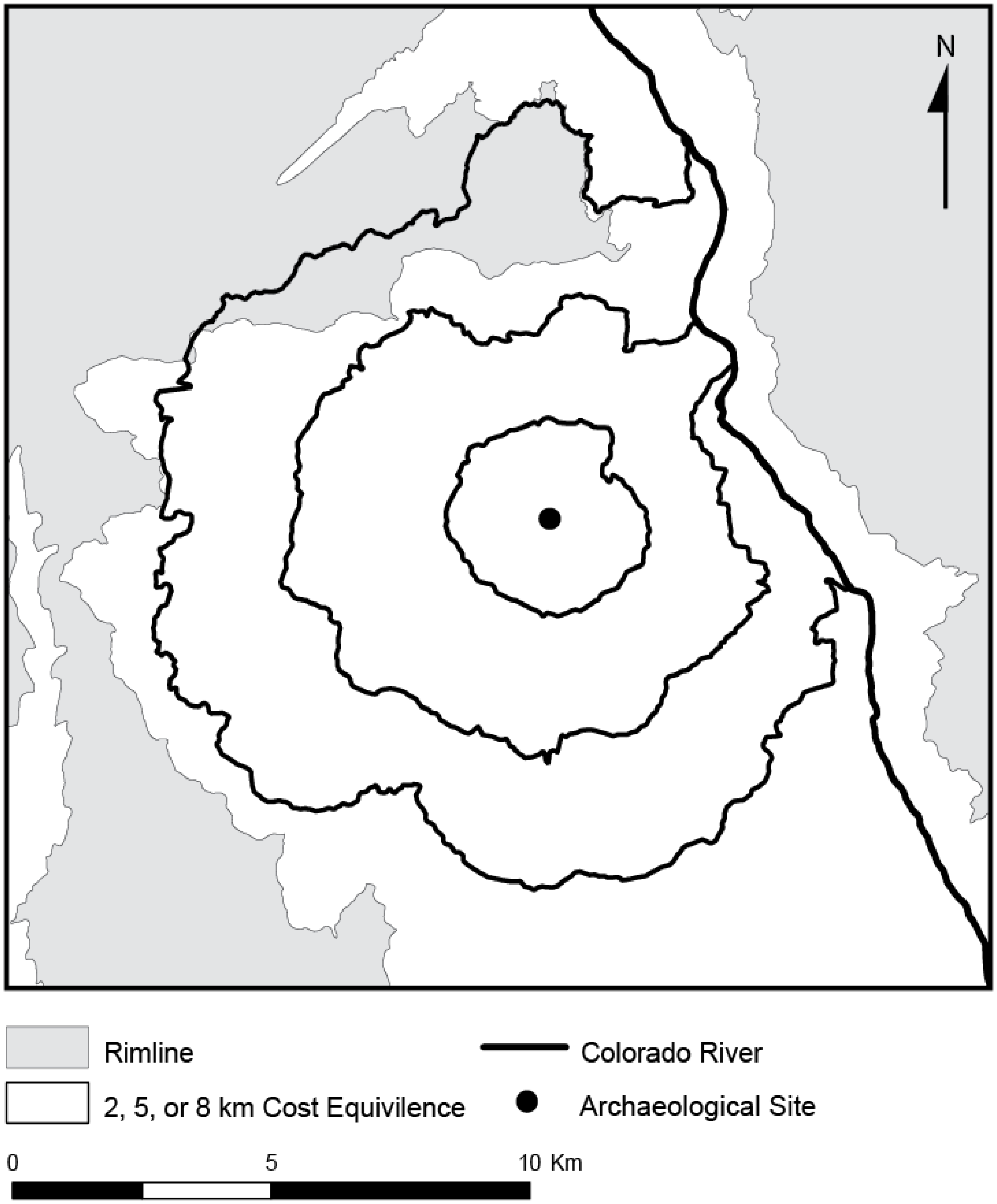

Figure 6.3. The 2, 5, and 8 km cost-equivalent polygons for Nankoweap drainage predicted by the "Pandolf Equation" (Pandolf et al. 1977) with the Yokota et al. (2004) downhill correction factor.

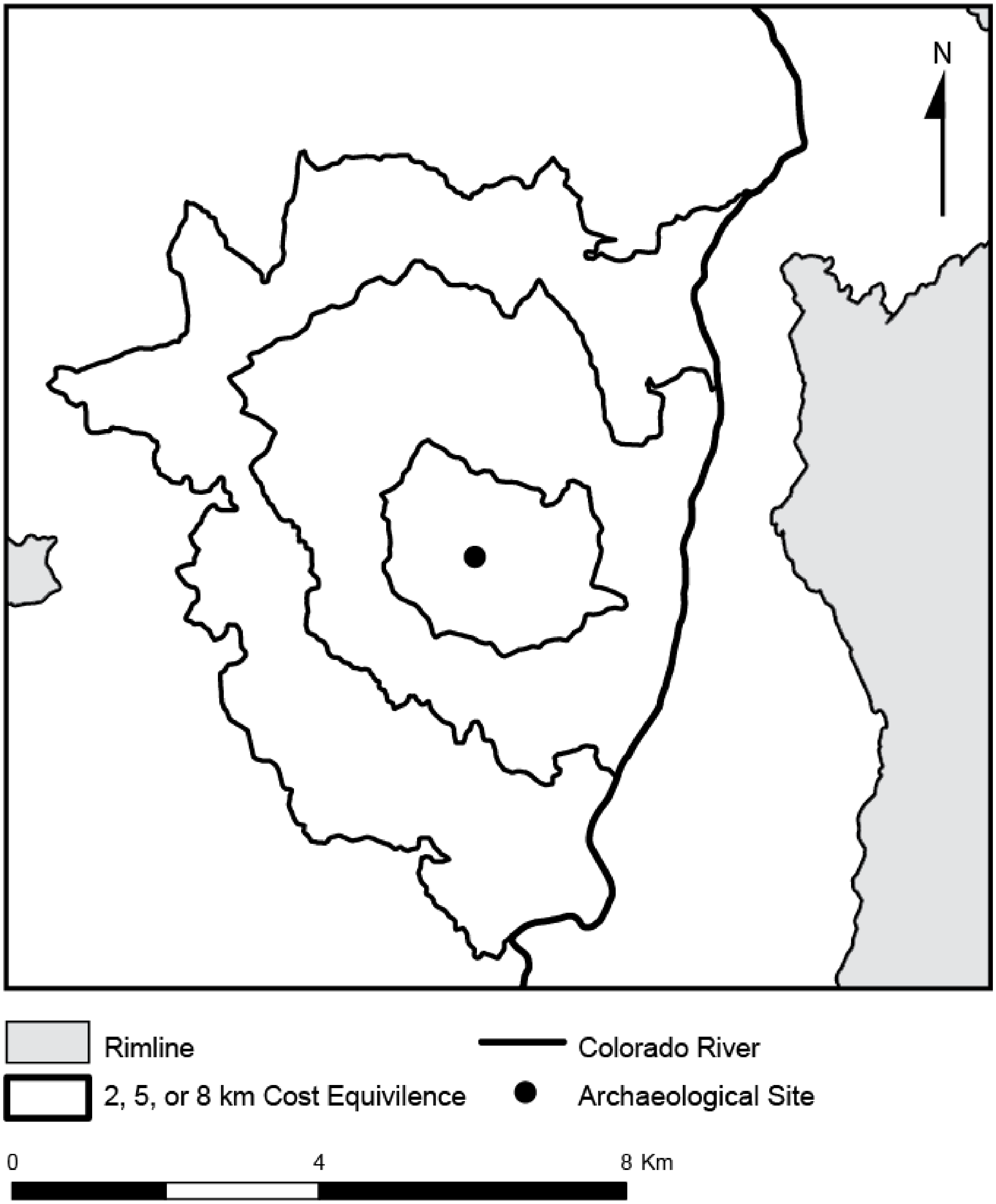

Figure 6.4. The 2, 5, and 8km cost-equivalent polygons for Lava/Chuar drainage predicted by Tobler’s (1993) Hiker Function.

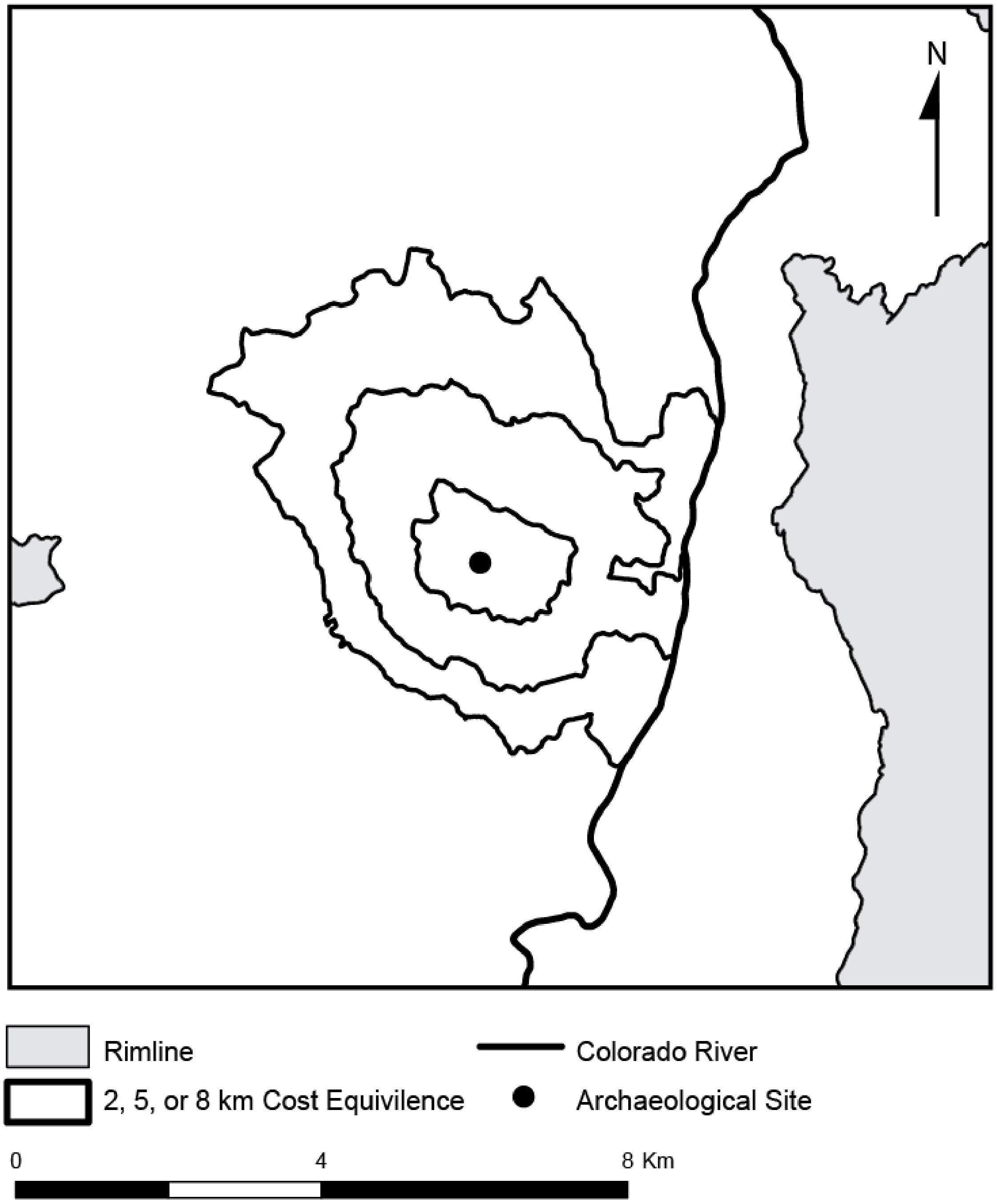

Figure 6.5. The 2, 5, and 8km cost-equivalent polygons for Lava/Chuar drainage predicted by Hill's (1995) formula.

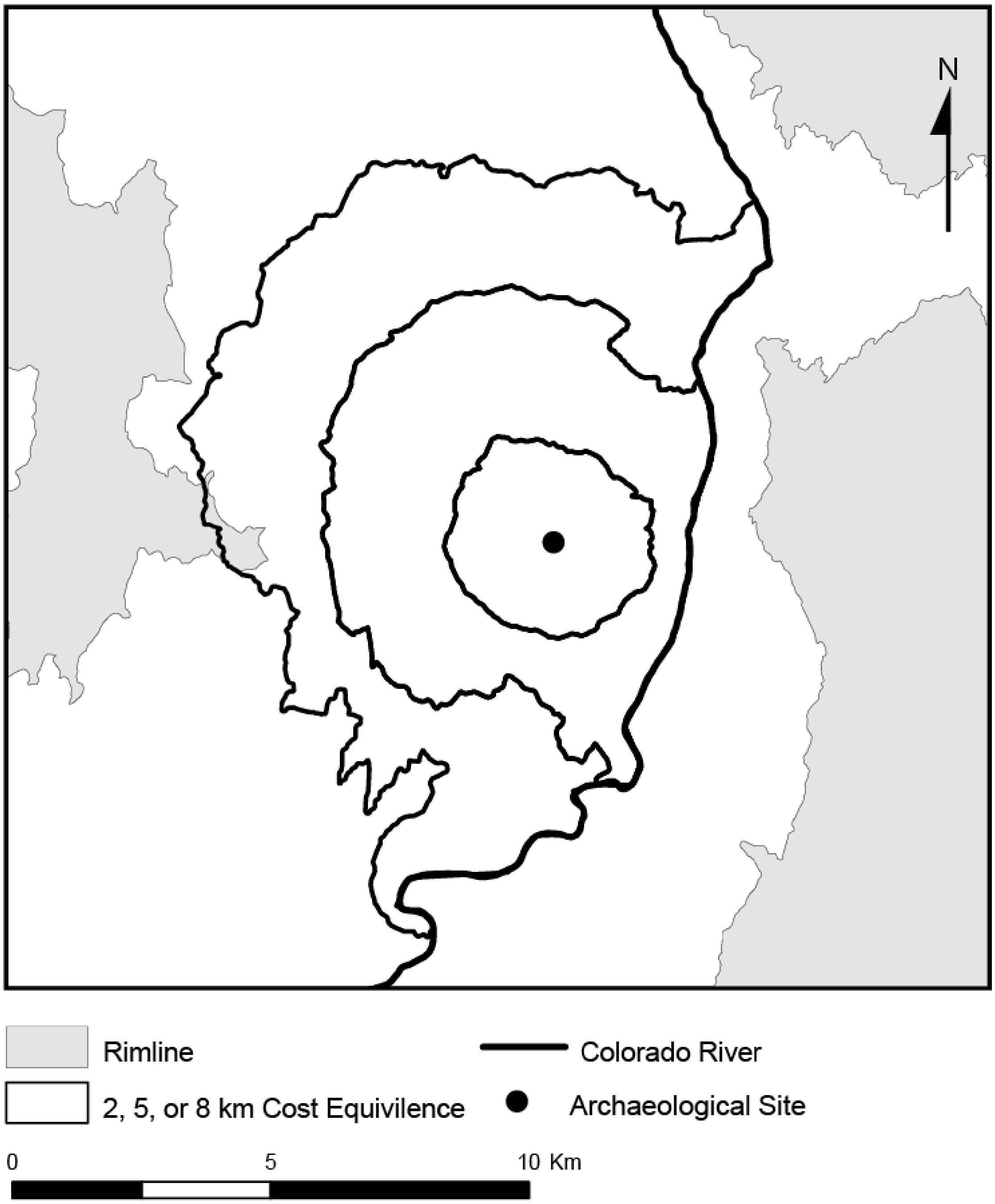

Figure 6.6. The 2, 5, and 8km cost-equivalent polygons for Lava/Chuar drainage predicted by the "Pandolf Equation" (Pandolf et al. 1977) and the Yokota et al. (2004) downhill correction factor.

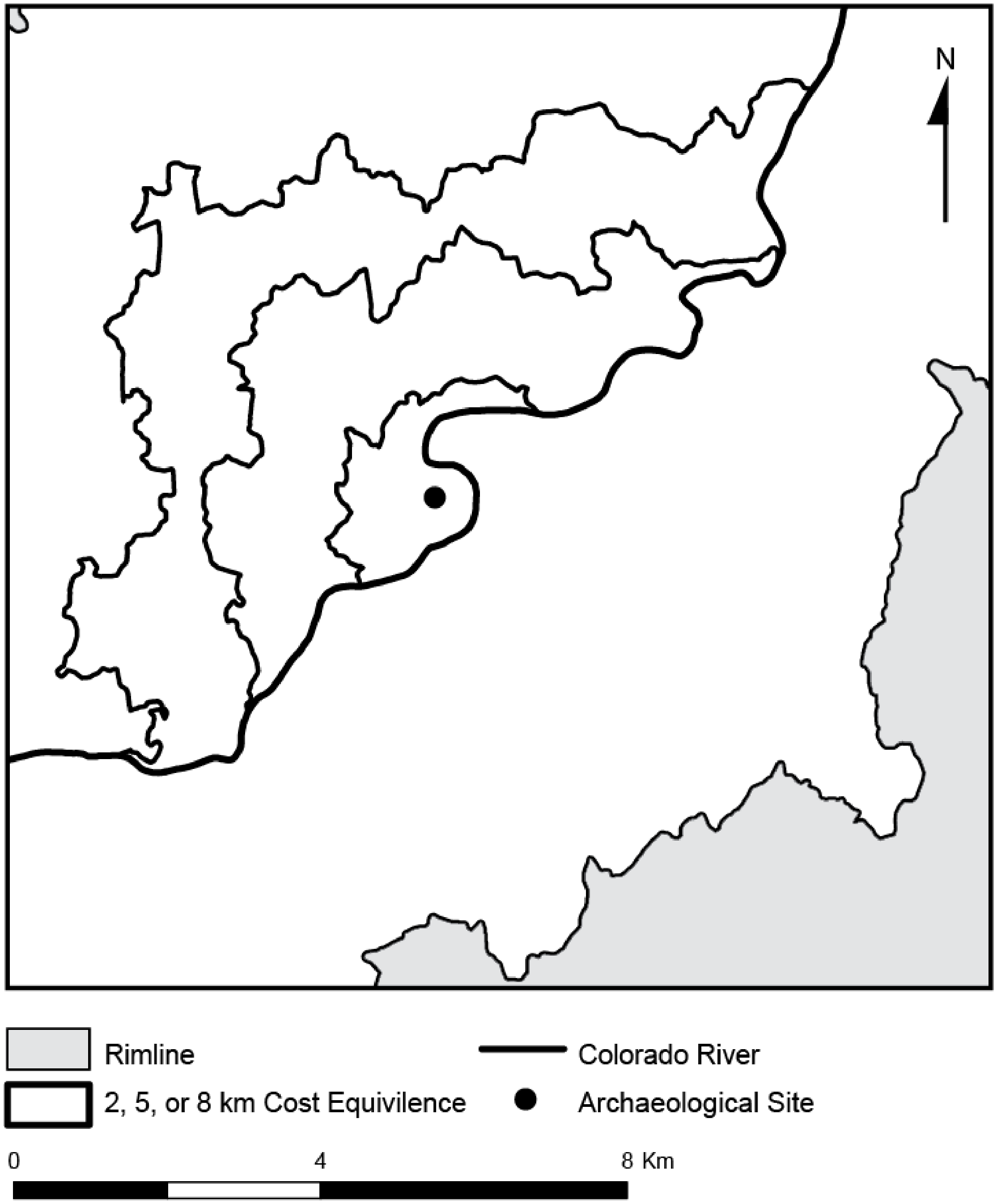

Figure 6.7. The 2, 5, and 8km cost equivalent polygons predicted for Unkar Pueblo by Tobler's (1993) Hiker Function.

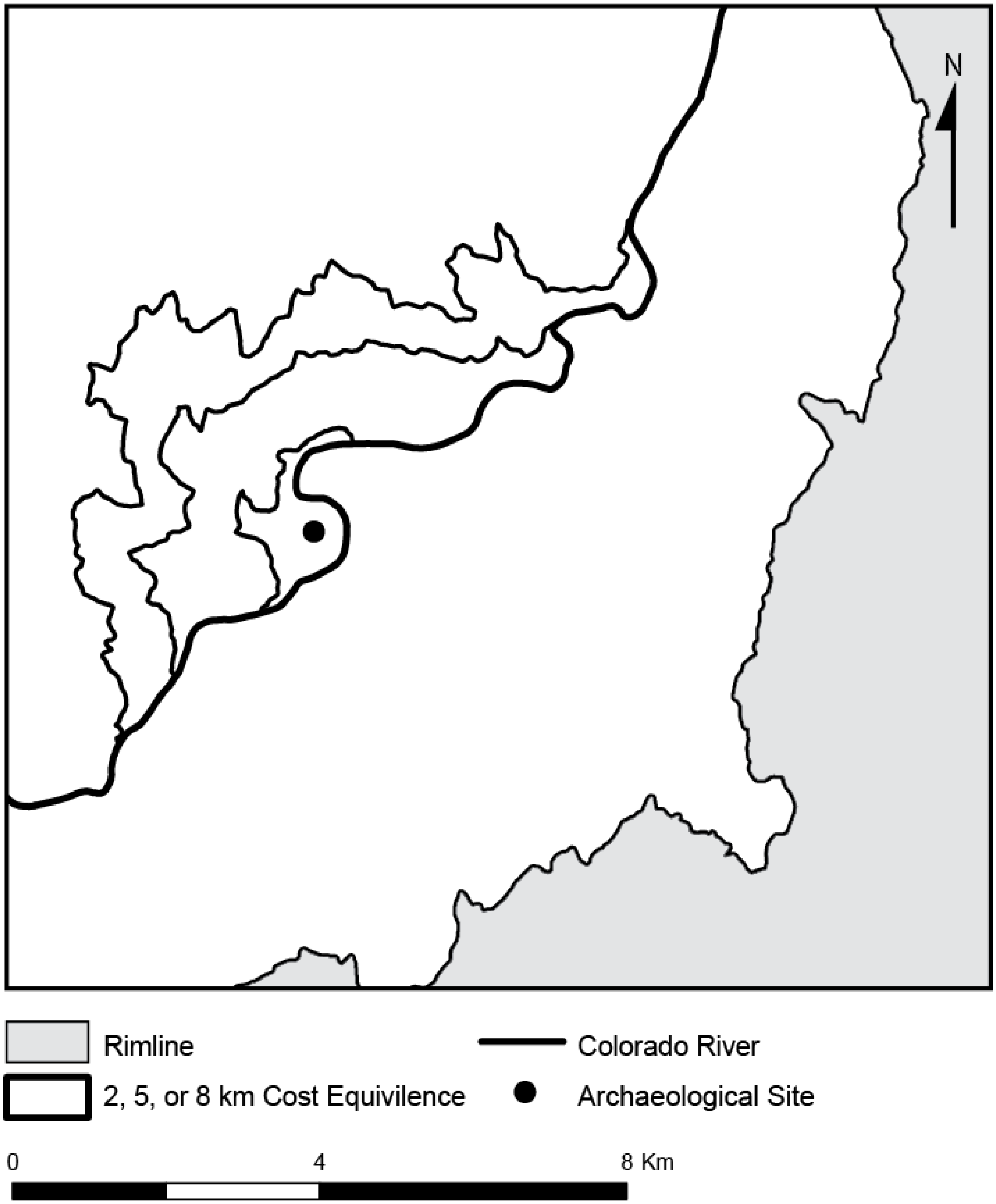

Figure 6.8. The 2, 5, and 8km cost-equivalent polygons for Unkar Pueblo predicted by Hill's (1995) formula.

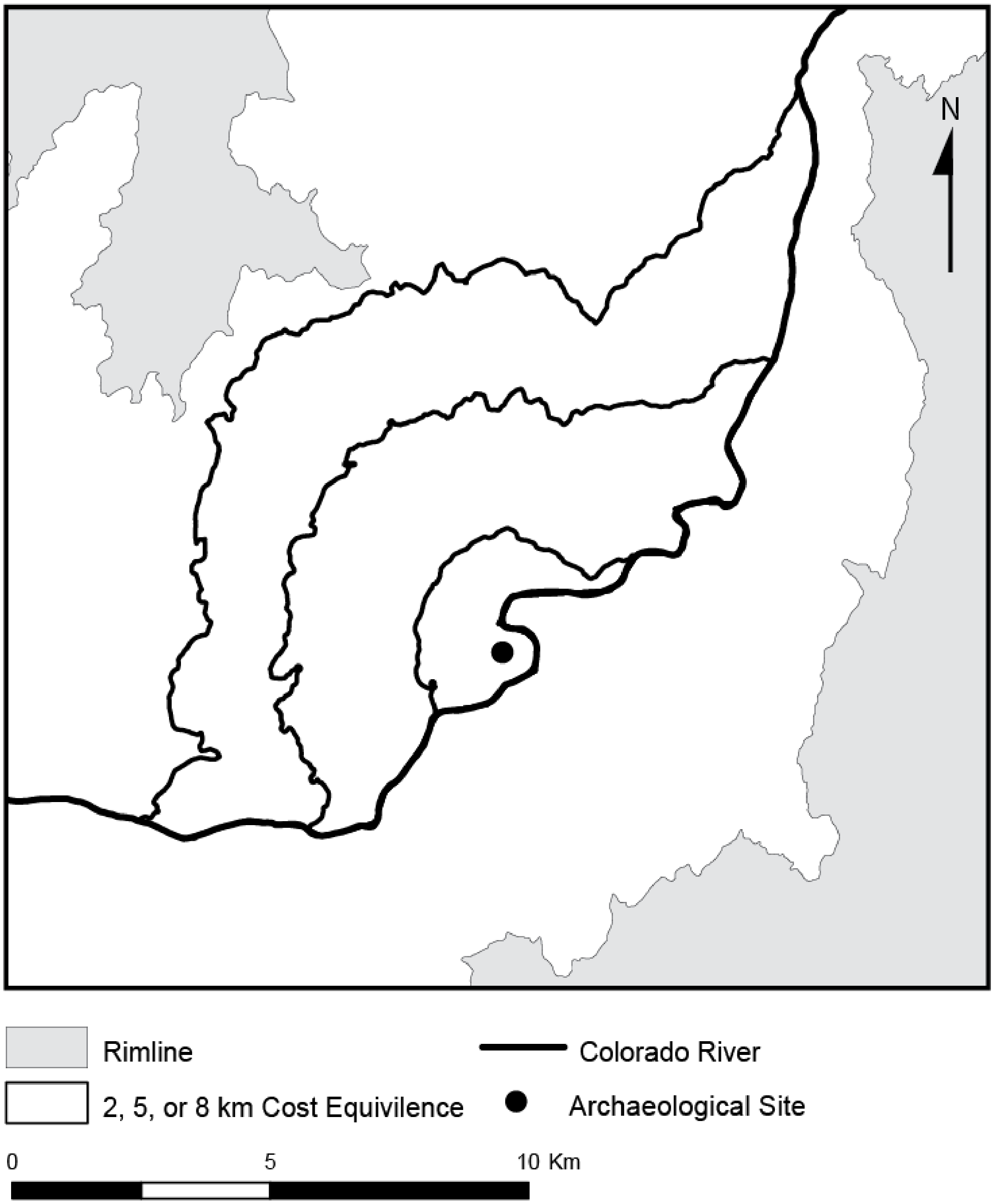

Figure 6.9. The 2, 5, and 8 km cost-equivalent polygons for Unkar Pueblo predicted by the "Pandolf Equation" (Pandolf et al. 1977) and the Yokota et al. (2004) downhill correction factor.

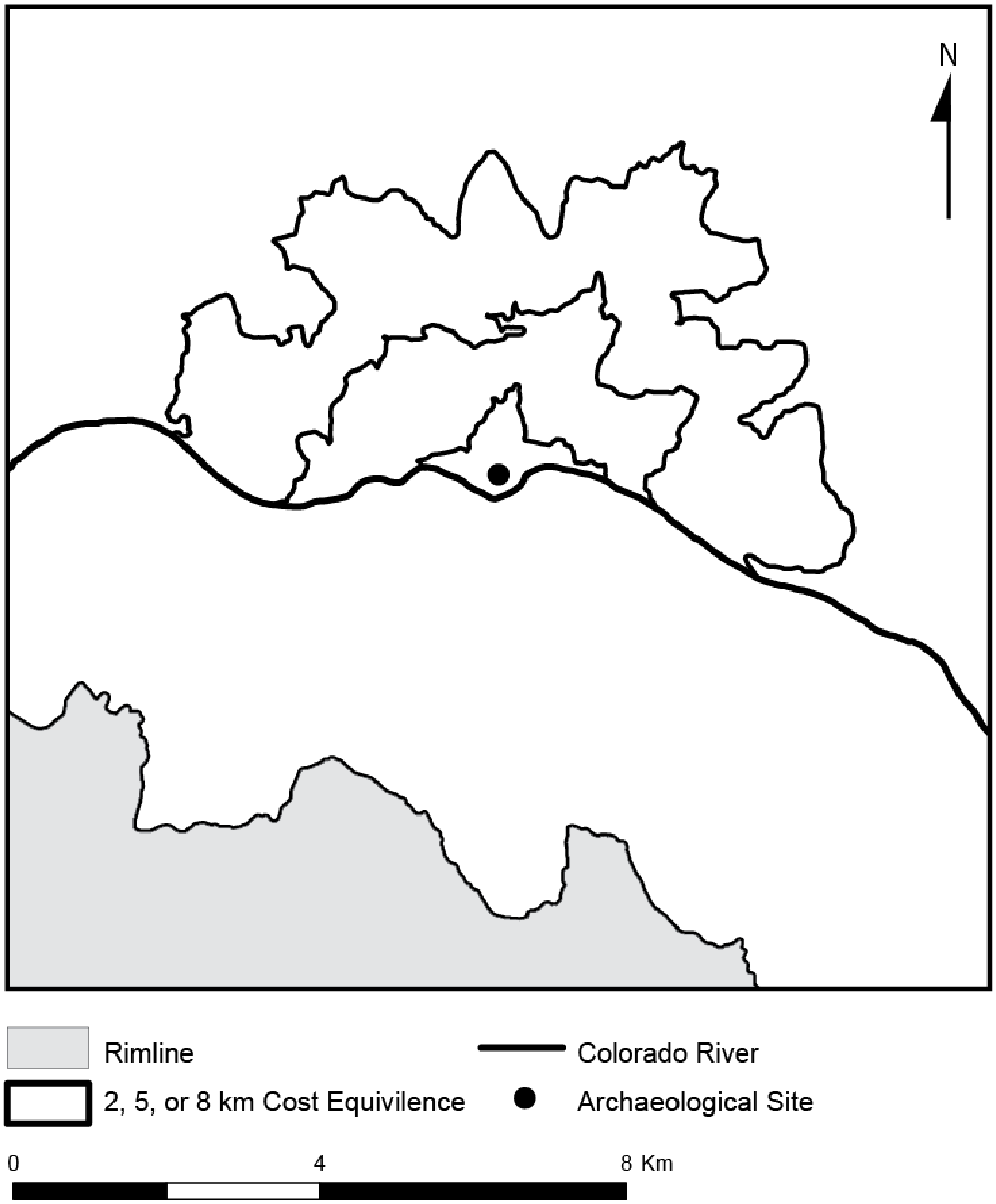

Figure 6.10. The 2, 5, and 8km cost-equivalent polygons for Bright Angel Pueblo predicted by Tobler’s (1993) Hiker Function.

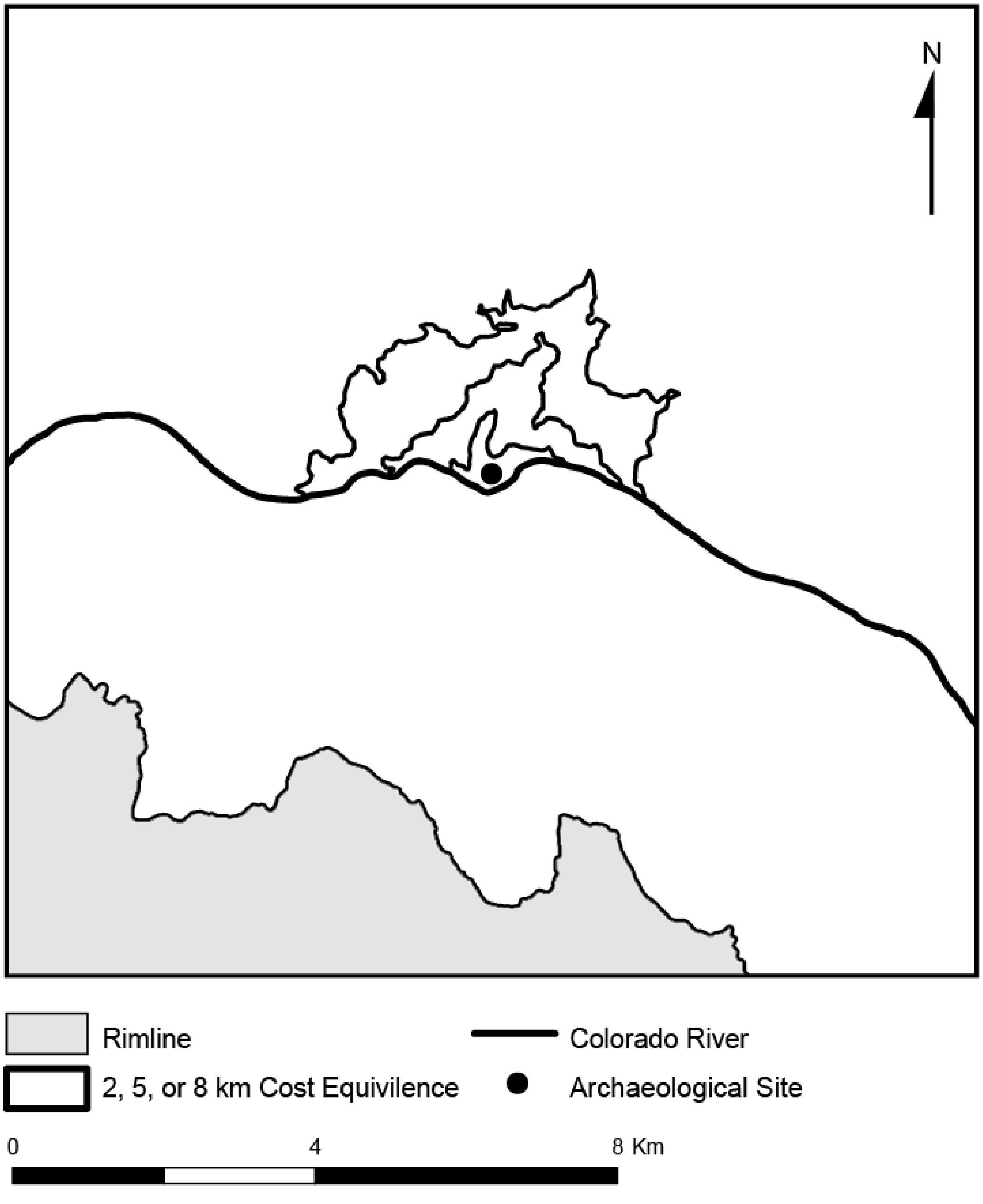

Figure 6.11**.** The 2, 5, and 8km cost-equivalent polygons for Bright Angel Pueblo predicted by Hill's (1995) formula.

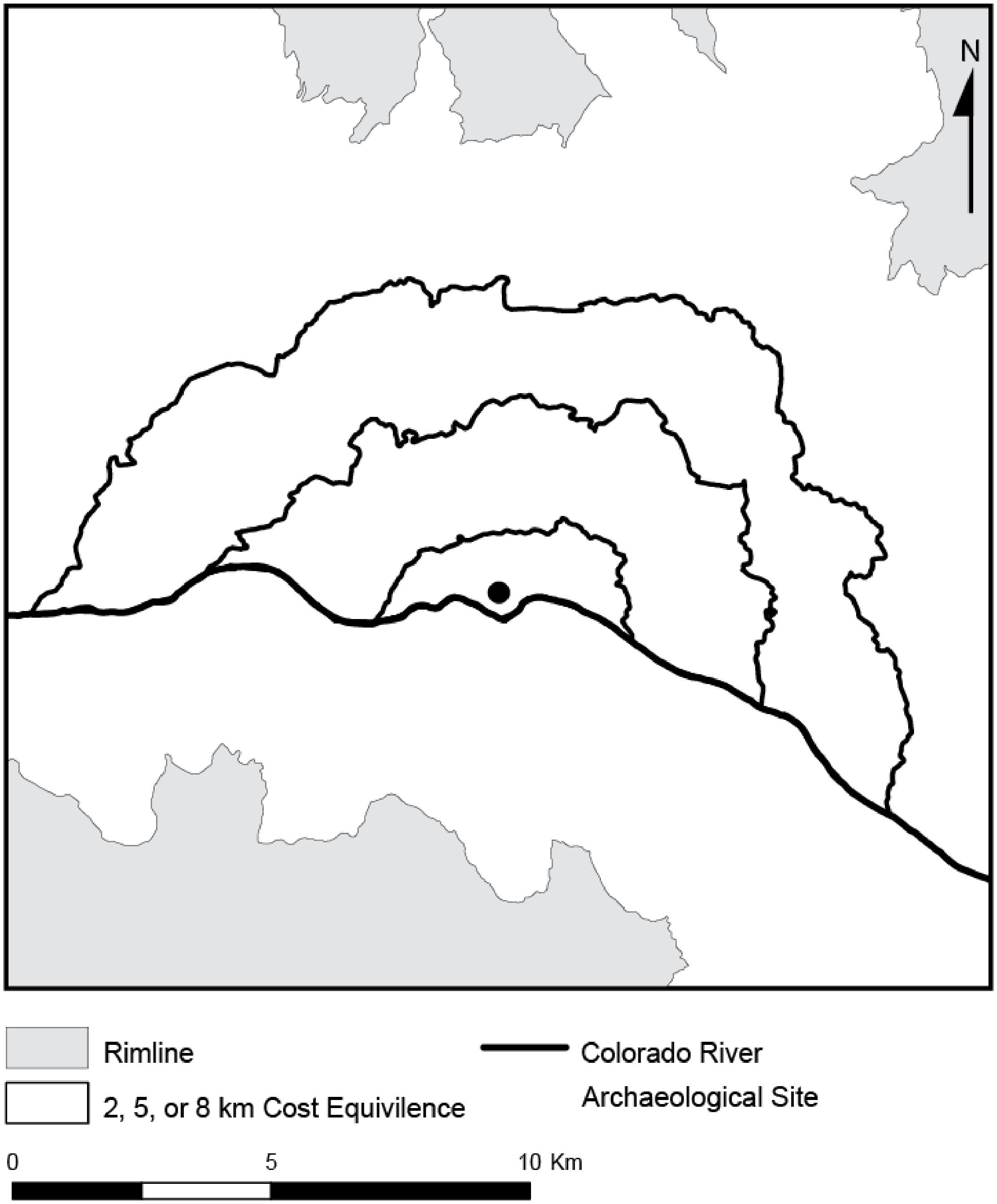

Figure 6.12**.** The 2, 5, and 8km cost-equivalent polygons for Bright Angel Pueblo predicted by the "Pandolf Equation" (Pandolf et al. 1977) and the Yokota et al. (2004) downhill correction factor.

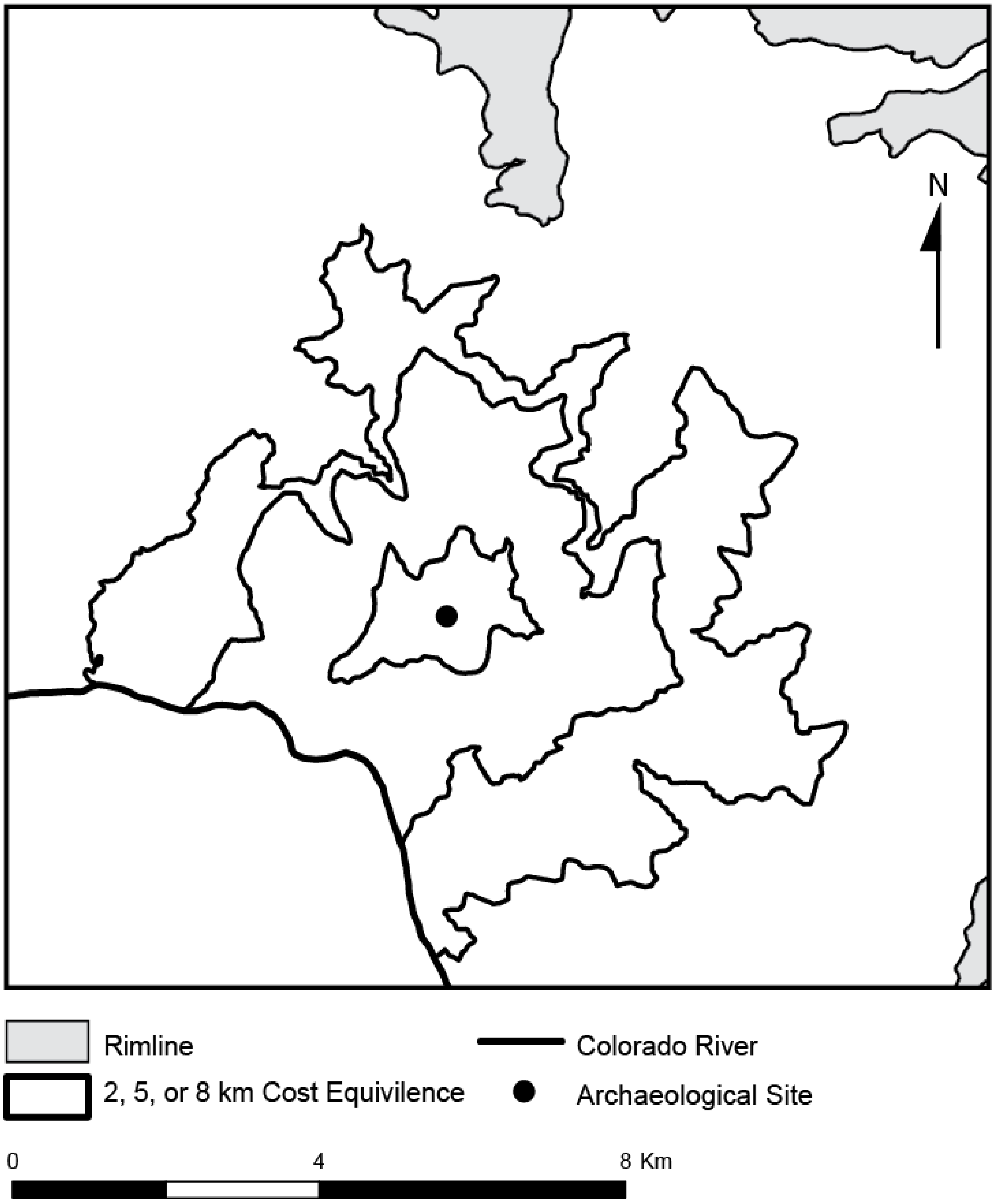

Figure 6.13**.** The 2, 5, and 8km cost-equivalent polygons predicted for the Shinumo Amphitheater by Tobler's (1993) Hiker Function.

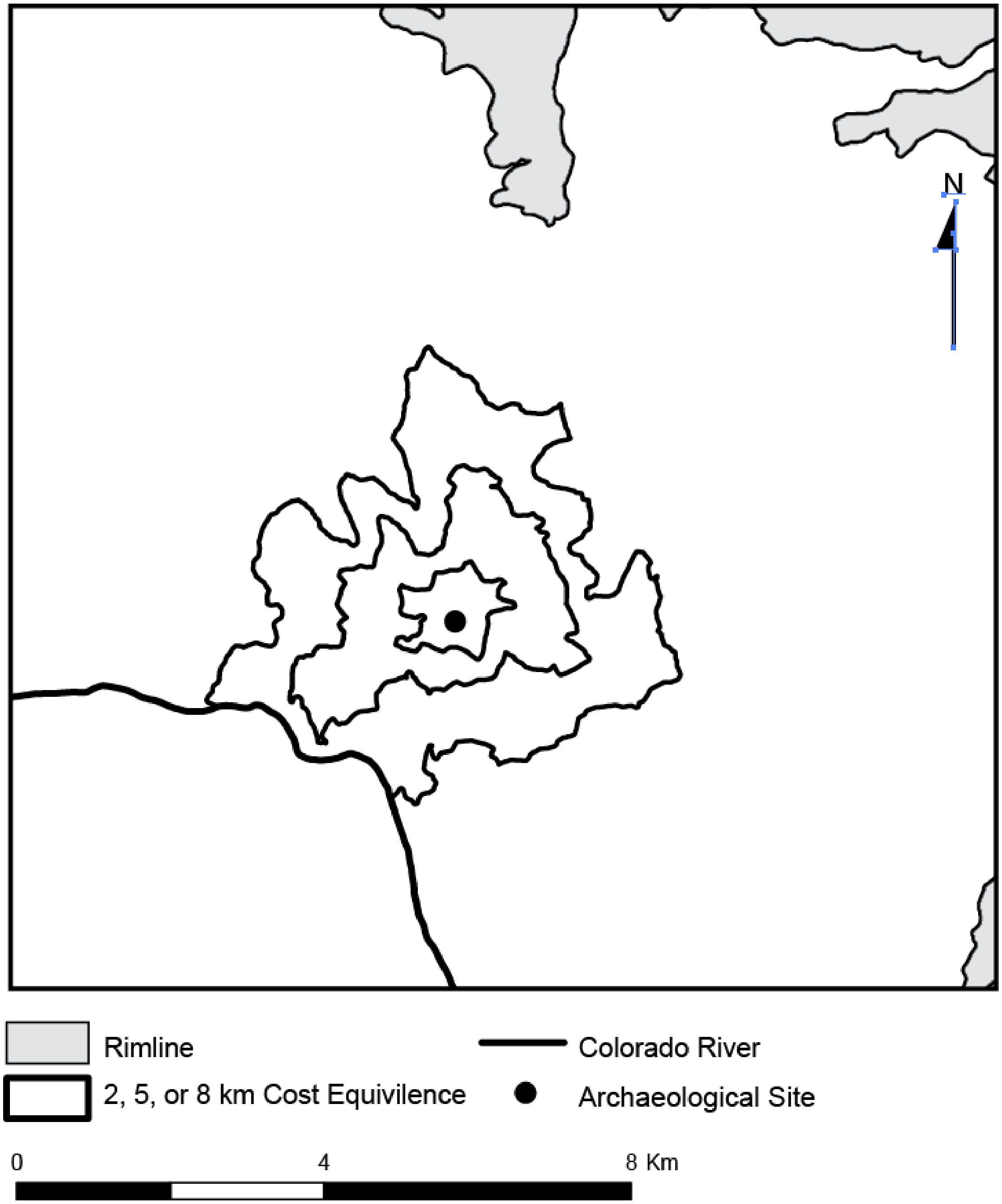

Figure 6.14. The 2, 5, and 8km cost-equivalent polygons in the Shinumo Amphitheater predicted by Hill’s (1995) formula.

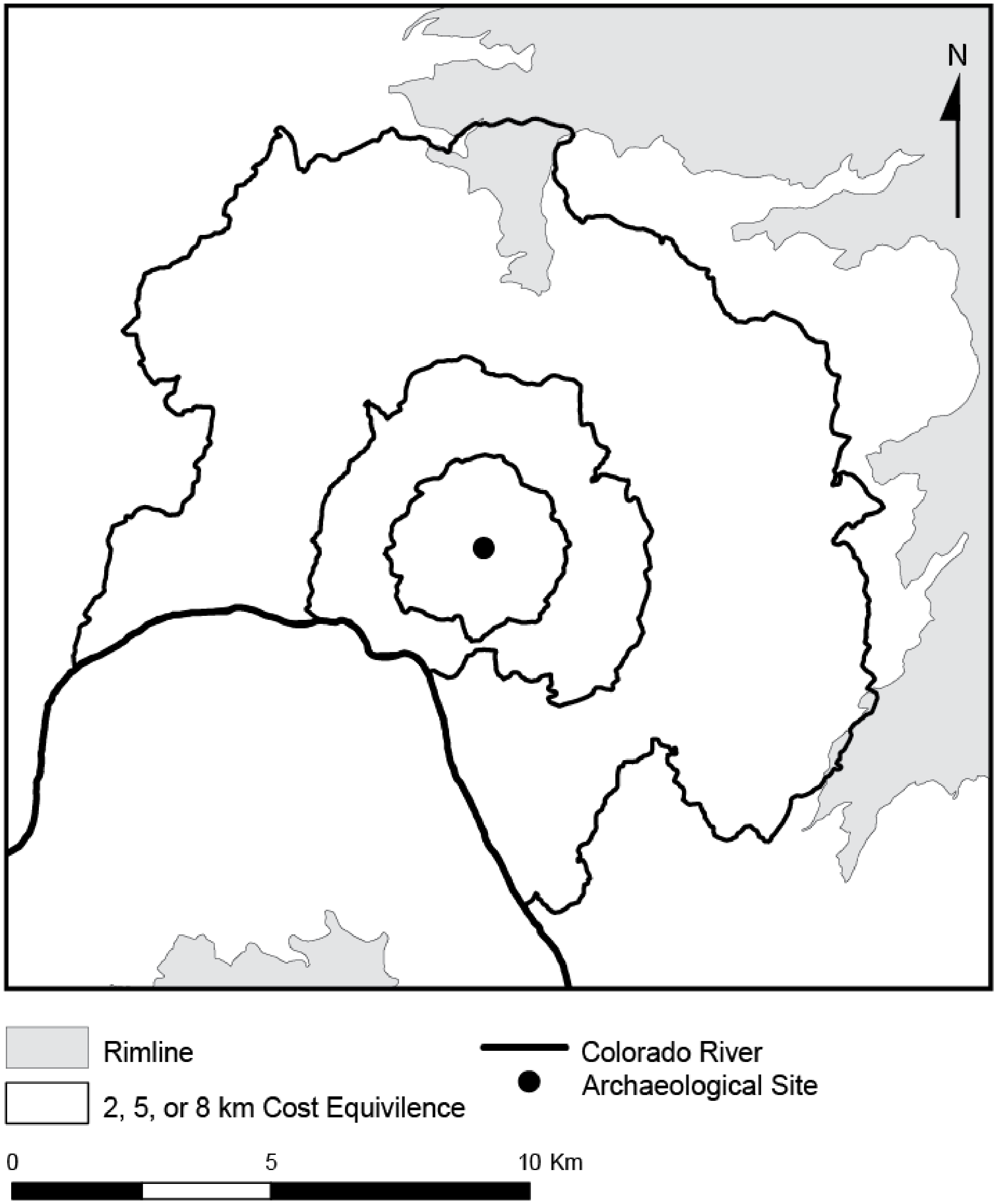

Figure 6.15. The 2, 5, and 8km cost-equivalent polygons predicted by the "Pandolf Equation" (Pandolf et al. 1977) and the Yokota et al. (2004) downhill correction factor.

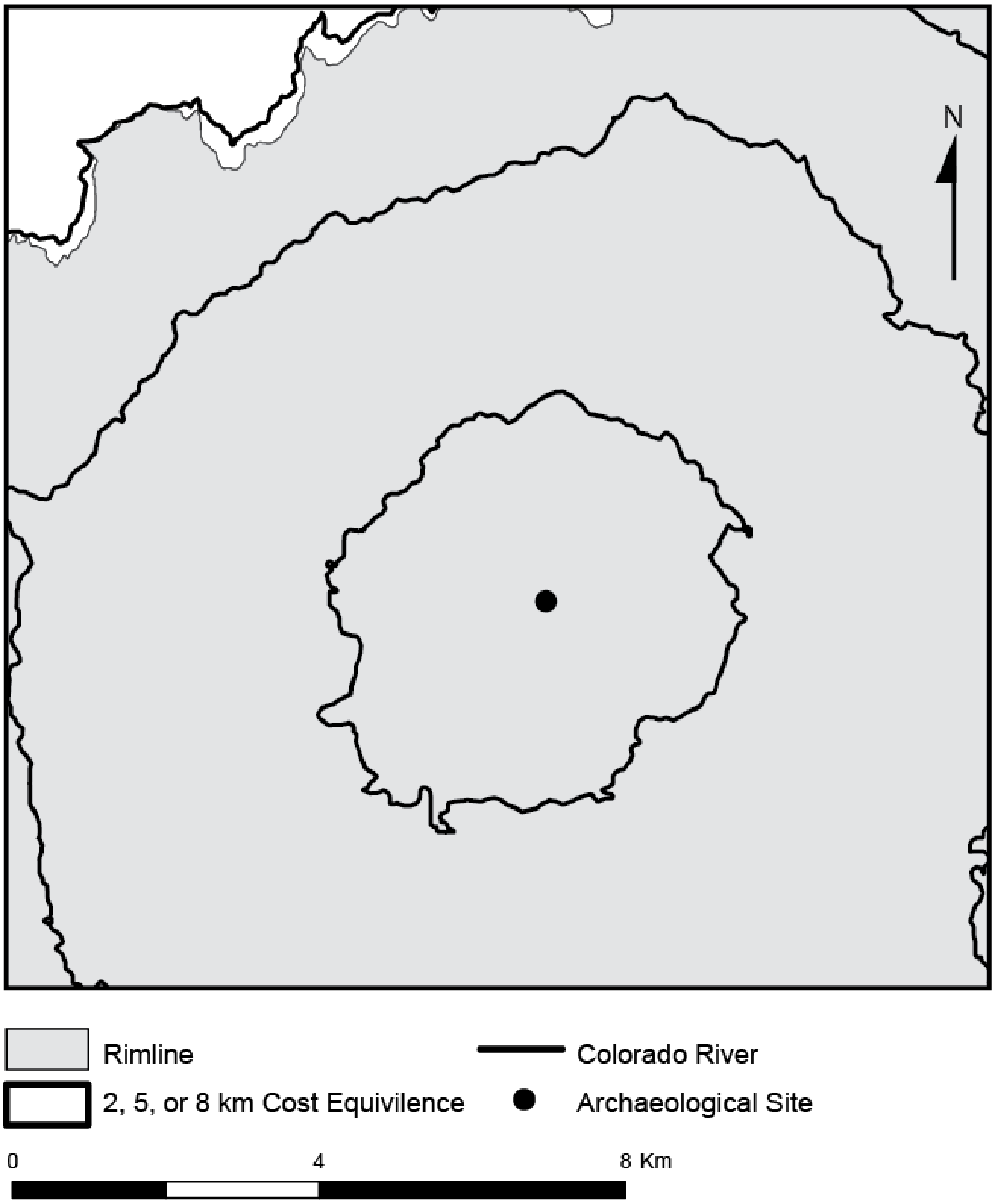

Figure 6.16. The 2, 5, and 8 km cost-equivalent polygons for the Grand Canyon's Upper Basin predicted by Tobler's (1993) Hiker Function.

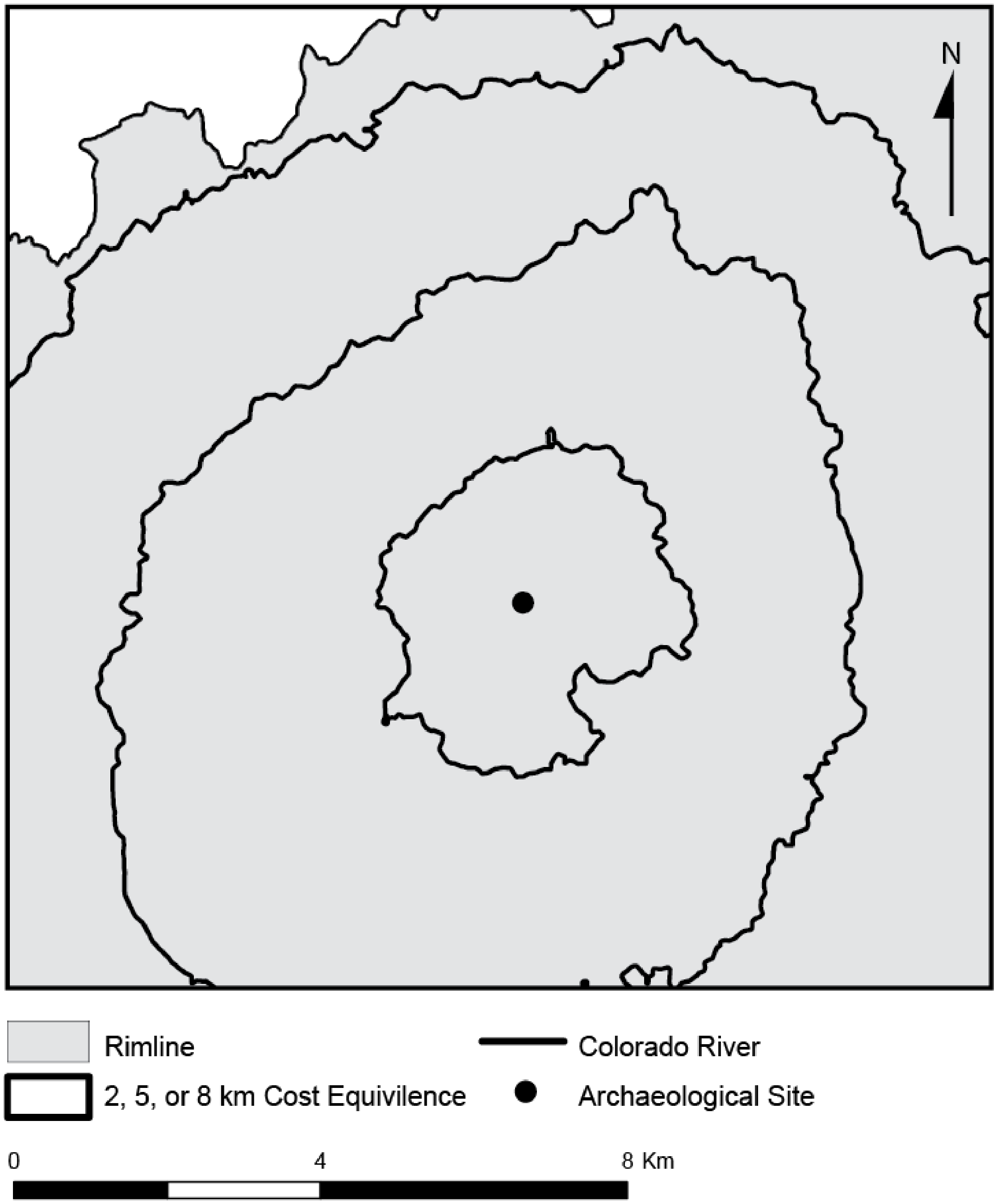

Figure 6.17**.** The 2, 5, and 8km cost-equivalent polygons predicted for the Grand Canyon's Upper Basin by Hill's (1995) formula.

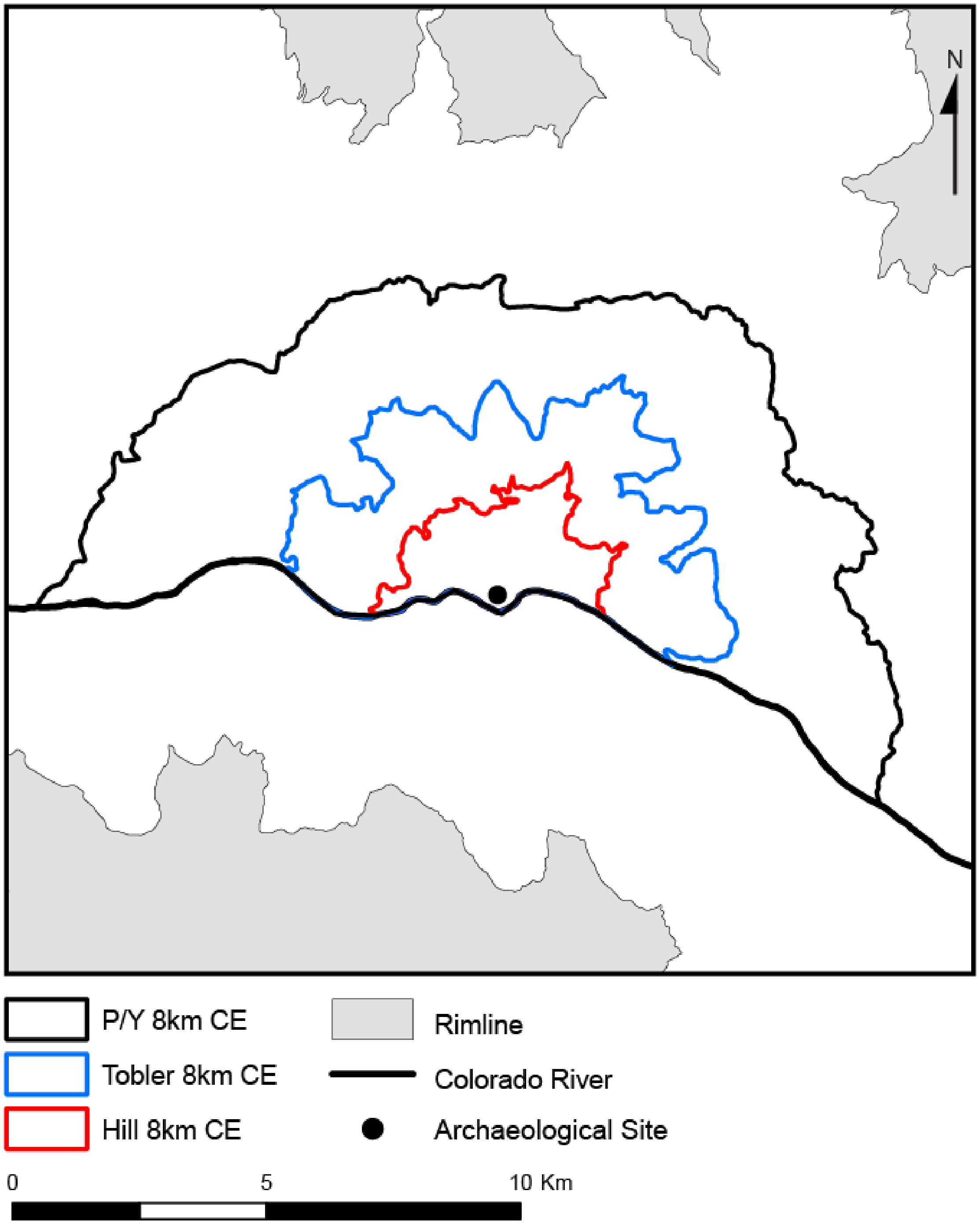

Figure 6.18. This figure depicts the differences in cost-equivalent polygons created by the various formulae used in this analysis around Bright Angel Pueblo (P/Y = Pandolf/Yokota).

evaluate predictions of travel time based on personal experience hiking in the Grand Canyon. The Hiker Function (Tobler 1993) satisfies this requirement.

As the predictions for walking speed used to create the Hiker Function were derived from people walking relatively quickly on smooth, solid ground, it is not unreasonable to assume that these predictions should represent an upper bound in estimation of site catchments. Aldenderfer (1999) found that villagers hiking in the rugged environment of the Andes consistently walked slightly slower that predictions created through the Hiker Function. In addition, the Hiker Function predicts that one may walk from the river near Bright Angel Pueblo to the North Rim in slightly under four hours – a fast estimate that is perhaps influenced by the fact that the Hiker Function (as well as any of the formulae used here) does not account for fatigue or rest. Thus, the Hiker Function likely provides estimates of travel time that are fairly accurate for a fast hiker travelling on trails, but unreasonably fast for off trail travel.

In my opinion, the preceding characterization of the Hiker Function and the predictions that it generates using the methods outlined in this study provide sound reasoning for the use of the Hiker Function as an upper bound in the creation of site catchments. This characterization, in turn, provides a reference point for evaluation of Hill’s (1995) formula as well as the Pandolf Equation (Pandolf et al. 1977) and downhill correction factor (Yokota et al. 2004).

Hill’s (1995) formula predicts cost-equivalent polygons that are consistently much smaller than those predicted by the Hiker Function. As Tobler (1993) states, the predictions of the Hiker Function can be modified by a factor of .6 in order to create a reliable estimate of off-trail travel time. Although modifying the Hiker Function in this manner is not conducted in this analysis, I expect that the predictions of such modification would result in estimates very similar to those predicted by Hill's (1995) formula. Therefore, use of Hill's formula appears to provide a reasonable method for delineating "lower bound" catchments delineated by off trail travel. Unfortunately, this measure of energy expenditure cannot be converted into a more useful currency, such as calories.

The Pandolf Equation (Pandolf et al. 1977) and downhill correction factor do not appear to create reliable cost surfaces of site catchments in the rugged terrain of the Grand Canyon. First, the catchments predicted through the use of this formula are much larger than those predicted through use of the Hiker Function. In fact, the formula often predicts catchments that are similar in size to perfectly circular catchments (For instance, one may measure the length of the "radii" of the catchment predicted by the Pandolf Equation in Figure 6.21). In my opinion, the slow differences in energy accumulation predicted for increasing grade, and the fixed-velocity parameter of the Pandolf equation (Chapter Five), create unreliable predictions of caloric expenditure in this application. This does not mean that the Pandolf equation is necessarily inaccurate in low slope environments; rather the Pandolf equation cannot be applied reliably to the high slope environments of the Grand Canyon. Thus, despite the potential utility of the Pandolf Equation, such as the ability to create cost surfaces that predict caloric expenditure, and the ability to account for additional parameters such as frictional coefficients and varying load, I recommend that archaeologists avoid use of the Pandolf Equation in similarly rough environments.

The Comparative Roughness of Archaeological Site Catchments in the Grand Canyon and the Greater Southwest

Having assessed the utility of different formulae within the GIS environment, I now move on to examine the questions outlined in the beginning of this chapter. The first of these questions is, “How rough, comparatively, is the terrain of the Grand Canyon compared to adjacent regions of the greater Southwest?” While differences in catchment size and shape should be intuitively clear, I have created my own methods for defining terrain roughness. I believe these methods account well for differences in roughness between catchments, as opposed to traditional archaeological methods for estimating the terrain roughness of an individual site, or a larger region geographic region.

In this study, terrain roughness is calculated by deriving the ratio of surface area to planar area (Beasom 1983; Berry 2002). Two regions, one with a markedly undulating surface and one with a flat surface, will have different surface area/planar area ratios. The region with the undulating surface will have a greater surface area and higher surface area/planar area ratio. Accordingly, higher a surface area/planar area ratios correspond to greater terrain roughness. In order to compare differences in terrain roughness between site catchments in this study, I calculate the ratio of surface area to planar area with a TIN (Triangulated Irregular Network) model in ArcGIS. A triangulated irregular network is a model of terrain rendered by adjacent triangles.

Figures 6.19 – 6.21 and Table 6.1 depict differences in terrain roughness between catchments in this study, according to the different formulae. Examination of these bar graphs displays several interesting patterns. First, there is a general increase in terrain roughness as catchment size increases. This pattern is evident in all catchments except for those of the Upper Basin and the Tsegi drainage. In the Upper Basin, where terrain remains mostly flat regardless of the distance one travels from the archaeological site in question, there is no change in terrain roughness. In the Tsegi drainage, changes in roughness for catchment size depend on the formula used. In the case of Hill's formula, Tsegi Canyon roughness increases with catchment size because the smaller catchments predicted by this formula do not escape the canyon walls, whereas the large catchments predicted by the Pandolf Equation decrease in roughness after one escapes the Tsegi drainage and emerges onto the top of the Shonto Plateau. The catchments predicted by the Hiker Function remain somewhat even in roughness.

Within the Grand Canyon, however, catchment roughness consistently increases with catchment size regardless of the predictive formula (the only exception is in the catchments surrounding Bright Angel Pueblo). This pattern reflects the fact that as one moves away from the flat lying drainage bottoms, a would-be traveler encounters the vertical barriers characteristic of the Canyon's upper strata. This pattern, therefore, indicates that prehistoric inhabitants of the Canyon would have been energetically "trapped" within the Canyon for purposes of day-to-day subsistence strategies (aka "collecting" strategies), or would at least have experienced difficulty conducting single day foraging activities outside of the Canyon.

Another interesting pattern is that the relatively open eastern canyon does not appear to experience greater terrain roughness than other rugged regions of the Southwest, such as Mesa Verde or the Tsegi, in smaller catchments. In fact, the Tsegi appears to have been rougher than these areas. Therefore, the terrain of the Grand Canyon is not likely to have presented any abnormal difficulty in the day to day travel concerns of prehistoric peoples living seasonally or year round in these areas. Even the Tsegi drainage, however, does not match constricted areas such as the catchment of Bright Angel Pueblo in Upper Granite Gorge, or the rough catchments of the Shinumo Amphitheater. Also apparent is the large difference in catchment size between flat lying areas such as the Upper Basin. The results of the ratio calculation analysis are consistent with predictions based on the area² of catchments alone (Figures 5.31, 5.32). The flat-lying portions of Nankoweap, Chuar, and Unkar drainages are similar, if perhaps slightly rougher than a region such as Mesa Verde, but perhaps not as rough as the Tsegi drainage. However, even an area such as the Tsegi drainage is not as rough as the catchments predicted for portions of Upper Granite Gorge, or the Shinumo Amphitheater.

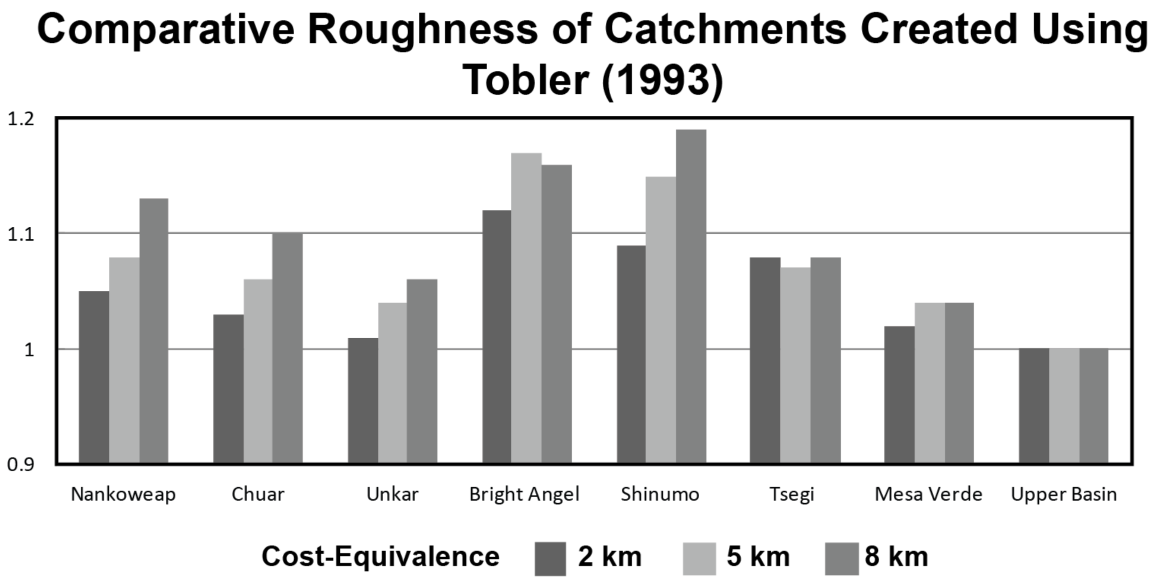

Figure 6.19**.** This bar graph compares the terrain roughness of catchments (cost-equivalent polygons creating using Tobler's (1993) Hiker Function.

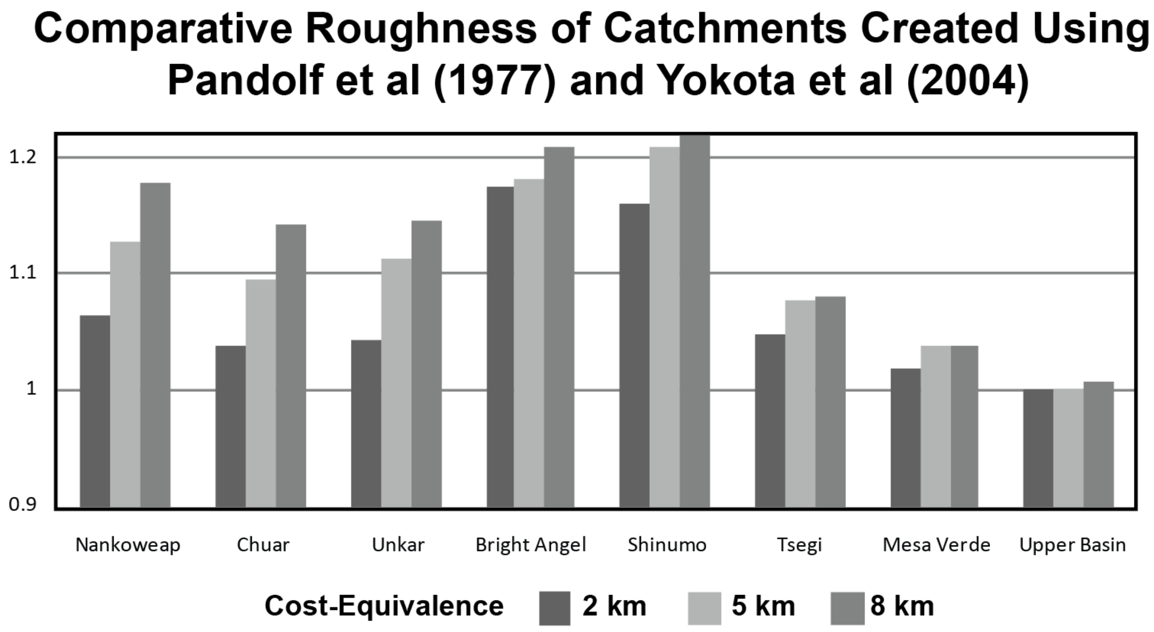

Figure 6.20**.** This bar graph compares the terrain roughness of catchments (cost-equivalent polygons created using the "Pandolf Equation" (Pandolf et al. 1977) with the Yokota et al. (2004) downhill correction factor.

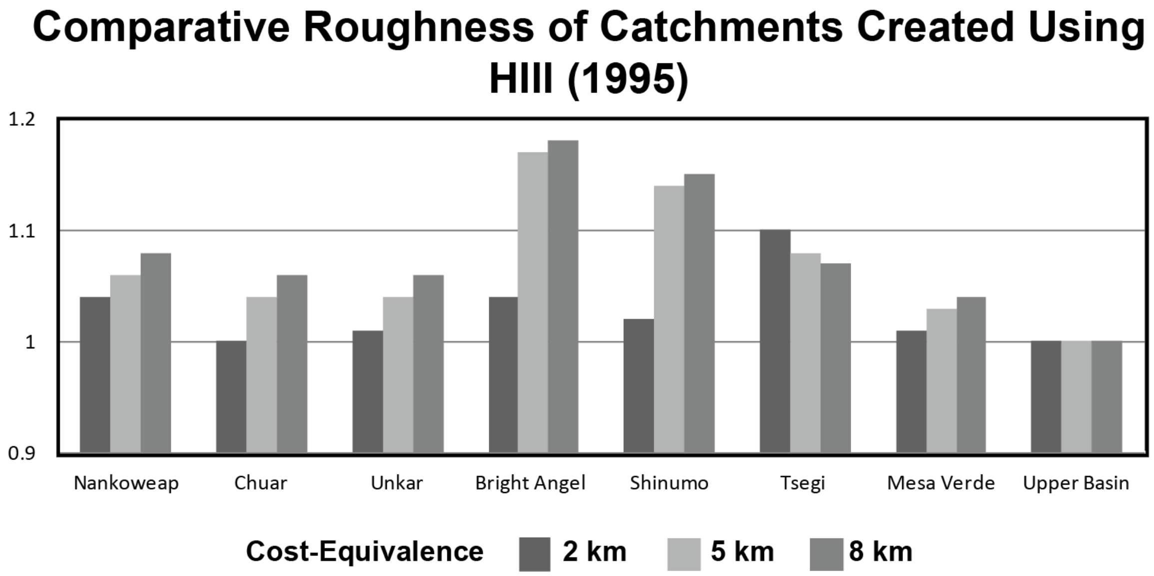

Figure 6.21**.** This bar graph compares the terrain roughness of catchments (cost-equivalent polygons created using Hill's (1995) formula, which estimates energy expenditure.

The predictions of the above calculations provide informative comparative measures of terrain roughness. However, the specific catchment of any site in Grand Canyon should probably be examined with greater scrutiny. For instance, allowing predicted catchments to cross the river might change estimations of terrain roughness. Because it is difficult to know the cost, in time or energy of making a river crossing, or the exact places in which river crossing would have been possible, I do not allow catchments to cross the river. If, during low water, it was possible to wade across the river in numerous places, perhaps simply adding a 10 minute cost (or energy equivalence of the cost of walking for 10 minutes) for river crossing might produce an accumulative cost that reasonably accounts for movement over the river. Conversely, if during high water, the inhabitants of a site such as Bright Angel Pueblo were limited to one side of the river, and, as previous discussion has indicated, if walking along the river in Upper Granite Gorge were impractical, then the catchment of such a site would be even smaller than that predicted here (the predicted catchments of Bright Angel Pueblo include considerable distances of river-level walking). I would be willing to conjecture that such a situation would be similar at the mouths of most of the drainages of Upper Granite Gorge.

Implications of Energy Equivalent Distances Between Rim and River Regions

In this section I examine the energetic costs of moving between rim and river in order to understand the potential for movement within the Canyon on a daily basis. An implication of constructed trail features and formal routes that facilitate vertical movement in the Canyon is that a great deal of movement took place across vertical barriers on a daily basis, with people potentially living, and “working” in different elevation zones of the Canyon. This section briefly examines the implications of energetic constraints on vertical movement in the Canyon between rim and river. Comparison of cost equivalence in movement between Rim and River to the ethnographic analogies discussed earlier may implicate the types of activities that took place at different places in the Canyon on a daily basis.

For this comparison, I examine the cost-equivalent distance between rim and river by reach, using Hill’s (1995) method. I choose this model for this portion of the analysis for the following reasons. 1) The model is more generalized and I believe more accurate in the environment of high slope gradients, and 2) Because Hill’s model is isotropic, it facilitates comparison between rim and river, as the cost calculated in movement away from the river will be equal to cost of movement towards the river. Isotropic analysis is sufficient to provide insight into energetic constraints in this situation.

In this comparison, the mean accumulative cost of least-cost paths from any point along the river to the least costly point along the rim is derived by extracting values from the rim line of the final cost surface. Statistics are performed on the extracted values. The only difference in use of the Pathdistance tool between this portion of the analysis and the preceding sections of this chapter is that the “source” for the Pathdistance tool is a polyline (the Colorado River) as opposed to a point (such as a single archaeological site). Statistics were derived by extracting values along the rim line from the resulting cost surface. These statistics are summarized in Tables 6.2 and 6.3, as well as Figures 6.22, and 6.23. These statistics can be compared to measurements of Euclidean distance between rim and river in Chapter 2 (Figures 2.2, 2.3, Tables 2.2, 2.3).

In comparison, the straight-line distance often accounts for less than half, and sometimes only as much as 10 percent of the energy-equivalent distance expended in traveling from Rim-to-River. This shows the necessity of using models of energy equivalence, rather than straight line distance, when comparing the distance between archaeological sites and subsistence resources in the Grand Canyon.

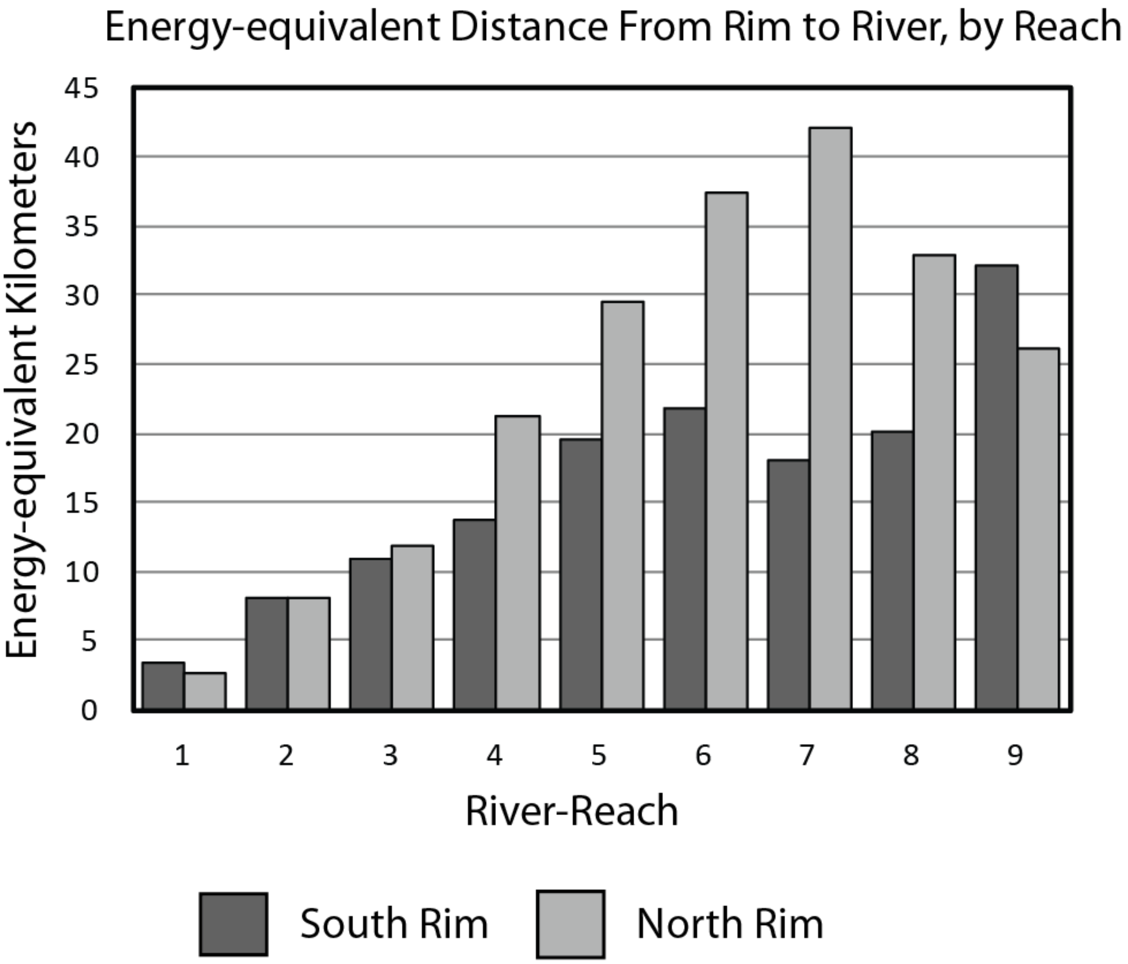

Figure 6.22**.** This figure compares the average cost equivalent distance between the north rim and Colorado River according to Hill's (1995) formula.

Furthermore, the cost-equivalent values, when juxtaposed with ethnographic examples of distance travelled for agricultural activities, suggest that rim and river regions are typically out of reach of one another for most daily subsistence activities. For instance, the mean energy-equivalent distance between Rim and River, for Reach Six on the North Rim is roughly 37 km, while the straight line distance is close to 11km (Table 6.2, 2.2). Therefore, one may tentatively assume that straight line distances convey about one third of the energetic cost of travelling between rim and river, for Reach Six. Accordingly, it is unlikely that populations living along the rim would tend farms in the River Corridor. Groups living along the River Corridor also would not likely forage or farm along the rim using any but a logistical strategy that involved sending foraging parties to the Rim, or from the Rim, to forage for some period of time. Even the minimum energy equivalence for any reach outside Marble Canyon is beyond the ethnographic analogy (10 km) for farming or foraging on the rim, for a group that resides on the river. In some instances, the estimated costs are barely even within estimated distances that someone could travel out and return in a single day. This implies that the model is accurate because while Rim-to-Rim hikes are common but difficult undertakings for modern hikers, modern day rim-to-rim hikers are supported by a considerable logistic complement entirely unavailable in prehistory.

Although this analysis indicates the unlikelihood of Rim-to-River foraging, the analysis also points to several hypothetically feasible subsistence strategies. For example, flat lying areas below the Rim, such as the Tonto Plateau and Esplanade, exist within range of feasible energy-equivalent distance for agricultural or foraging activities from a base on the Rim or River (although the Tonto Plateau is much farther removed from either the Rim or River than is the Esplanade). As a consequence, prehistoric groups could potentially have lived on the Rim while farming and foraging within the Canyon, or could have lived along the river farming and foraging the uplands. In addition, logistical strategies could have allowed those living along the Rim to farm the River.

Table 6.2. Energy Equivalent Distance From River to North Rim, Expressed in 1km Cost Equivalence.

Energy Equivalent distance to North Rim by Reach	Minimum	Maximum	Mean	Standard Deviation
1	0.00	3.55	1.80	1.08
2	1.86	8.50	5.47	1.41
3	4.39	12.32	8.04	1.86
4	1.86	24.47	14.38	0.00
5	18.48	21.88	20.00	0.79
6	17.70	34.05	25.34	3.17
7	26.96	30.76	28.51	1.00
8	13.95	30.45	22.24	3.47
9	10.05	31.18	17.67	5.15

Table 6.3. Energy Equivalent Distance From River to South Rim, Expressed in 1km Cost Equivalence.

Energy Equivalent distance to South Rim	Minimum	Maximum	Mean	Standard Deviation
1	0.00	4.01	2.36	1.21
2	1.09	10.49	5.52	2.12
3	5.29	9.99	7.36	0.93
4	6.45	11.45	9.26	0.97
5	8.76	16.85	13.22	2.28
6	11.34	19.31	14.75	1.65
7	11.04	13.20	12.28	0.60
8	7.57	16.25	13.64	1.10
9	10.14	33.43	21.75	5.42

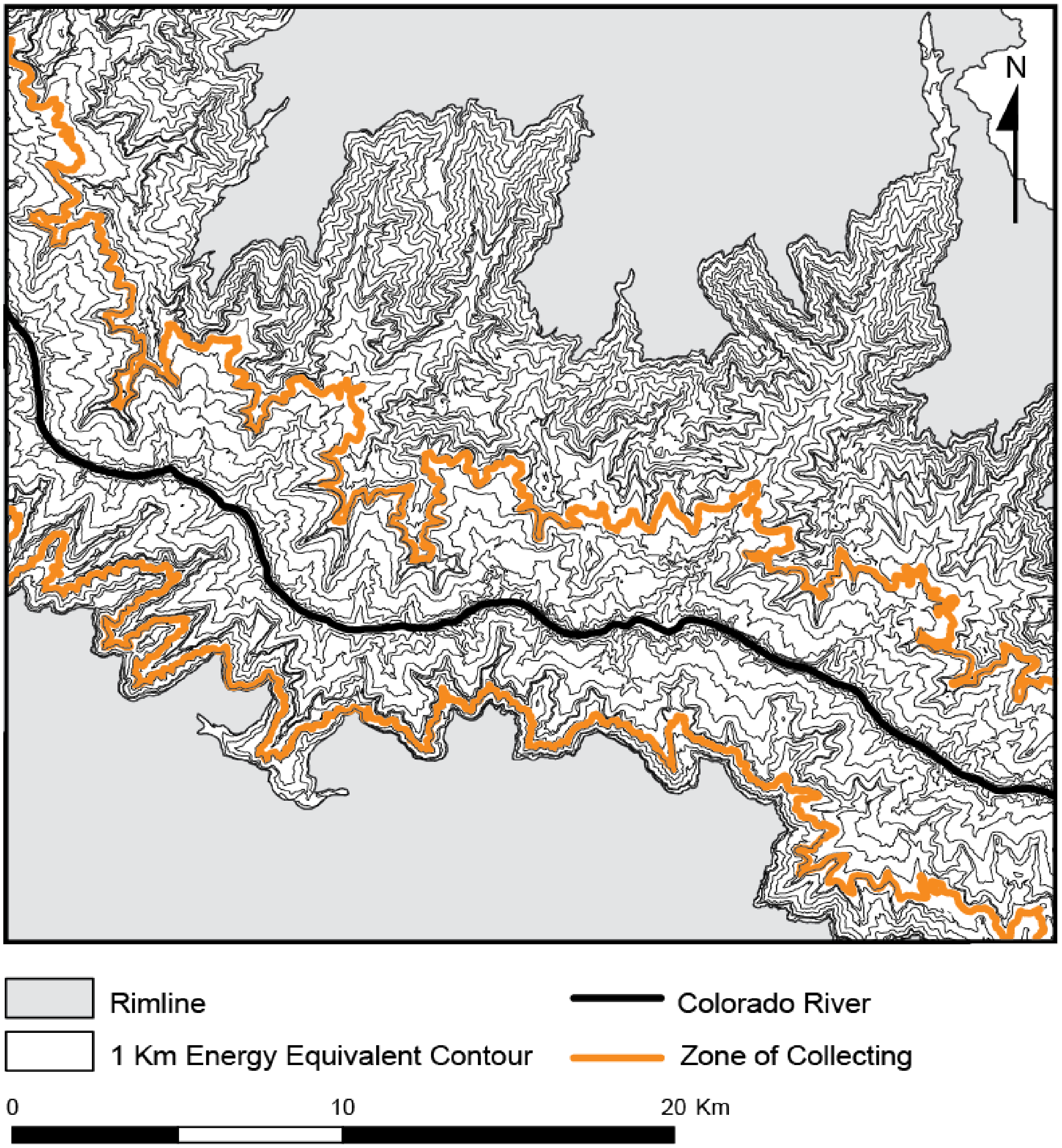

Figure 6.23**.** This figure depicts the cost equivalent distance predicted by Hill’s (1995) formula between any point on the river and any point on the rim, in a portion of Reach 6, Upper Granite Gorge. The orange line shows the 10km cost equivalence, which is taken as an upper boundary for single day foraging activities (collecting strategy).

Implications of Using Measures of Energy Equivalent Distance in the Study of Community Interaction

Having established the hiker function as a reasonable "upper bound" measure of cost equivalence, I will discuss the implications of the use of this formula in studying community interaction for the sites previously examined in this study. The question of the isolation of eastern canyon sites, such as Bright Angel Pueblo, is one that has been approached by Schwartz et al. (1981) as well as Huffman (1993). Both researchers wondered about down-the-line trade, or the use of the Walhalla Glades as a common distribution center centrally located between north rim drainages. For Example, Schwartz et al. (1979:82), in reference to Bright Angel Pueblo, stated:

> The Pueblo still seems to have been a semi-isolated settlement. Its nearest neighbors were probably the occupants of small sites in Clear Creek Canyon, the next side canyon emptying into the Colorado River upstream from Bright Angel Creek. These sites are several hours' walk away. The next nearest neighbors, also at least two hours away, were probably the small population living at Indian Gardens on the Tonto Platform south of the Colorado River. A visit there would have involved swimming the river….

Figure 6.24. shows the two, five, and eight km cost-equivalent polygons for each of the drainages discussed in this study. If we were to hold these cost-equivalent polygons in reference to Varien's (1999) characterization of sites sharing a 7km cost-equivalent polygon as cooperatively using local resources, the isolation of these sites may

appear clearer. Huffman wondered about the possibilities of down the line, or vertical exchange systems among the Grand Canyon's deltas. An example of down the line trade between Pueblos may have looked something like this (Huffman 1993:158) :

> Bright Angel Pueblo > Clear Creek > Unkar Delta > Basalt Canyon > Chuar Valley

Lightfoot (1979, cited in Huffman 1993:158) stated that local exchange of subsistence goods occurs within a boundary range of 20 – 50 km. However, the higher "effective distance" between drainages on the North Rim prevented Huffman from making definitive statements about the nature of the economies in the Grand Canyon on the basis of distance between sites.

If Figure 6.24 displayed the catchments of additional drainages adjacent to one another, it would perhaps be possible to examine these questions in greater detail. However, the figure still demonstrates a couple of points relevant to this discussion. First, only the eight km cost-equivalent polygons of Lava/Chuar and Unkar Drainages overlap. Smaller catchments, which more closely represent catchments that could be created through the use of Hill's formula, do not overlap. This perhaps demonstrates that there would have been a one drainage "limit" in daily interaction between drainages, even using the upper bound measurement. On the other hand, the 20-50 km cost-equivalent polygons very likely would have been in range of each other, indicating the possibility of subisistence based trade between many of the north rim drainages. Although the figure does not show cost-equivalent catchments of this size, it does clearly show how estimations of cost-equivalence could provide a valuable interpretive tool in answering

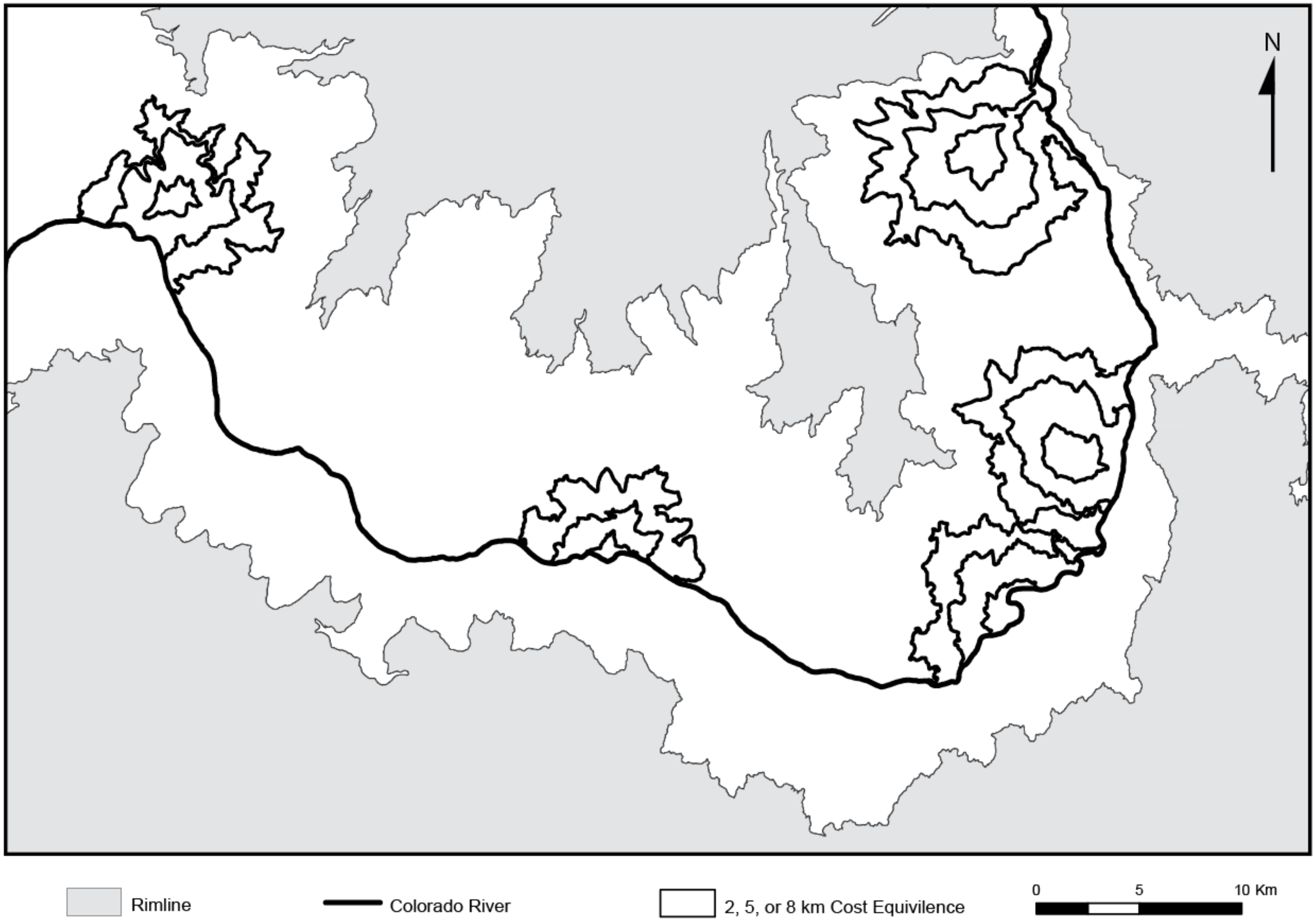

Figure 6.24. This figure shows all catchments created through the Hiker Function (Tobler 1993) in relation to one another.

these and related questions, as well as a useful metric in cost benefit analysis for understanding economies within the Grand Canyon.

This cursory examination cannot substantially challenge or support the possibilities raised by Huffman (1993) or Schwartz (1979). However, the utility of thesemethods in examining these questions is clear, and I would suggest that future studies revisit these problems, especially with more detailed cost surfaces, such as those discussed in the following sections (see below).

Additional Methods for Estimating Cost: Future Directions

Costs of Travelling Verified Prehistoric Routes vs. Estimated Catchment Areas

The methods described above provide insight into the costs of movement vertically within Grand Canyon, in a generalized way. It does so, however, without fully acknowledging the specific conditions imposed by the Grand Canyon's topography, as discussed in the first half of this study. In Chapter Four, I established that there are limited access points where it is possible to travel through vertical barriers. Often, these access points are encountered along least cost paths of travel. However, in some situations, the Pathdistance algorithm will choose to travel over an area where there is no known access point because it is possible for the algorithm to "traverse" or move laterally along the edges of cliffs, or high slope areas even though the vertical factor table stipulates that the algorithm cannot choose to travel directly into an adjacent slope greater than 40 degrees. So, in the preceding section, measurements should be taken as generalized, but not necessarily erroneous. For instance, travelling from Rim-to-River along the North Kaibab trail approximates travel along a least cost path, and the accumulative cost distance for this route represents an accurate Rim-to-River cost. In addition, in smaller catchments located in the relatively flat lying areas discussed earlier, such as the drainages of Nankoweap, Chuar, and Unkar, there are few barriers that are impossible to travel over. Nevertheless, in some places travelling along a least cost path specified by the algorithm is unrealistic. Therefore, we must ask the question: Does the energy expended travelling from Rim-to-River on a specific, verifiable route actually exceed, or fall below that predicted by the generalized model? At the current time, I can only suggest methods that may resolve this question in the future, when the costs of travel along specific trails can be fully integrated into a network analysis. Currently, Network Analyst tools provided within ArcGIS do not account for vertical movement. In addition, I cannot examine costs of travelling every specific trail and route identified in this study, but I have taken a test case from the area surrounding the Great Thumb Mesa in order to suggest how this question could be addressed in the future.

By extracting elevation data from a DEM that corresponds with a specific trail (Figure 6.25 shows the workflow involved in this process) it is possible to estimate the cost of travelling the trail. Using this technique in conjunction with Hill's (1995) isotropic (implying an equal cost for travel up or down slope) formula, the predicted cost of travelling the Tanner Trail (approximately 14.5 km) is the energy equivalent of travelling 35 kilometers on flat ground. In table 6.3, for example, the mean value in cost-equivalence for Reach Five on the South Rim is 19.1 energy equivalent kilometers, and in Table 2.2, the mean straight line distance rim-to-river distance is only 3.5 km. Accordingly, and as we can intuitively grasp from the relationship of the figures cited, even when energy costs are mediated by least cost paths, the roundabout nature of some trails in the Grand Canyon, whose paths are defined by Redwall and Coconino access points, has the consequence of increasing the total energy expenditure required to travel from one point to another.

In the example of the Tanner Trail, the cost of travelling the trail is greater than the mean Rim-to-River cost predicted by the generalized model for Reach Five. However, a number of routes in the vicinity of the Tanner trail, such as routes down Papago Creek, 75 Mile Canyon, or Cardenas Creek, could potentially minimize rim to river travel costs, bringing the estimation closer to the mean energy-equivalent distance predicted by the general model. Accordingly, we may expect that minimal travel costs can be achieved only by travelling specific trails out of a number of potential choices.

The implication is that the costs of travelling in the Grand Canyon might be more accurately modeled as a type of network analysis. In this scenario, routes in the trails database would contain directionally dependent travel costs, in which the cost of traveling a trail is equal to its energetic costs. Figures 6.26 and 6.27 show the costs, in travel time (in minutes), to travel up, down, or across any of the trails between rim and river for the area east of Great Thumb Mesa. I chose this area because routes through the Coconino and Redwall are sparsely distributed, making the relevance of the concept more easily understood. This area is also the region of the Canyon mentioned in Chapter Four, where Butchart (1997) searched obsessively for routes, ultimately finding the Enfilade Point route into Fossil Canyon. In addition, calculations were made using a 10 meter resolution DEM in order to minimimize deviation between digitized routes and the elevation grid. In the figure, the cost of travelling a route is the average of the uphill and downhill costs. The cost to get from one point to another here is equivalent to the accumulative cost of traveling along all of the routes to a destination. Because the time-based energetic equivalence of travelling one kilometer on flat ground is slightly under 12 minutes, the one kilometer cost equivalence of travelling between points can be calculated by adding the minutes incurred travelling a route and dividing by 12 (because this exercise uses the Hiker Function, such measures of energy equivalence cannot be directly compared to measures of cost equivalence in tables 5.2 and 5.3). When comparing the costs in these figures, keep in mind the assumptions of the Hiker Function. The Hiker Function does not account for rest, fatigue, friction, fear, or any other complication incurred due to travelling a complex vertical route.

When viewed in comparison to topography (Figure 5.35), one might imagine least cost paths travelling down many of the drainages in the region. However, the figure shows a very limited number of possible ways to get to the river. The message from figure 5.35 is that the costs incurred to travel to the least accessible areas on the map are high because they involve much circuitous navigation. Perhaps this would have provided the prehistoric inhabitants of the canyon with added incentive to seek out dangerous routes than minimize overall travel costs. One point of evidence in this regard is the fact that the Redwall routes in this section of the canyon are particularly harrowing. Due to the limited nature of accessibility in the Canyon, the scenario presented here may predict the costs of travelling in the canyon more accurately.

The methods discussed here would be useful in a network analysis in which the least costly path is chosen from a list of verified routes. The potential weakness, however, is that if the route list compiled through archaeological investigation is significantly different from the real world or “true” distribution of routes, then erroneous results will

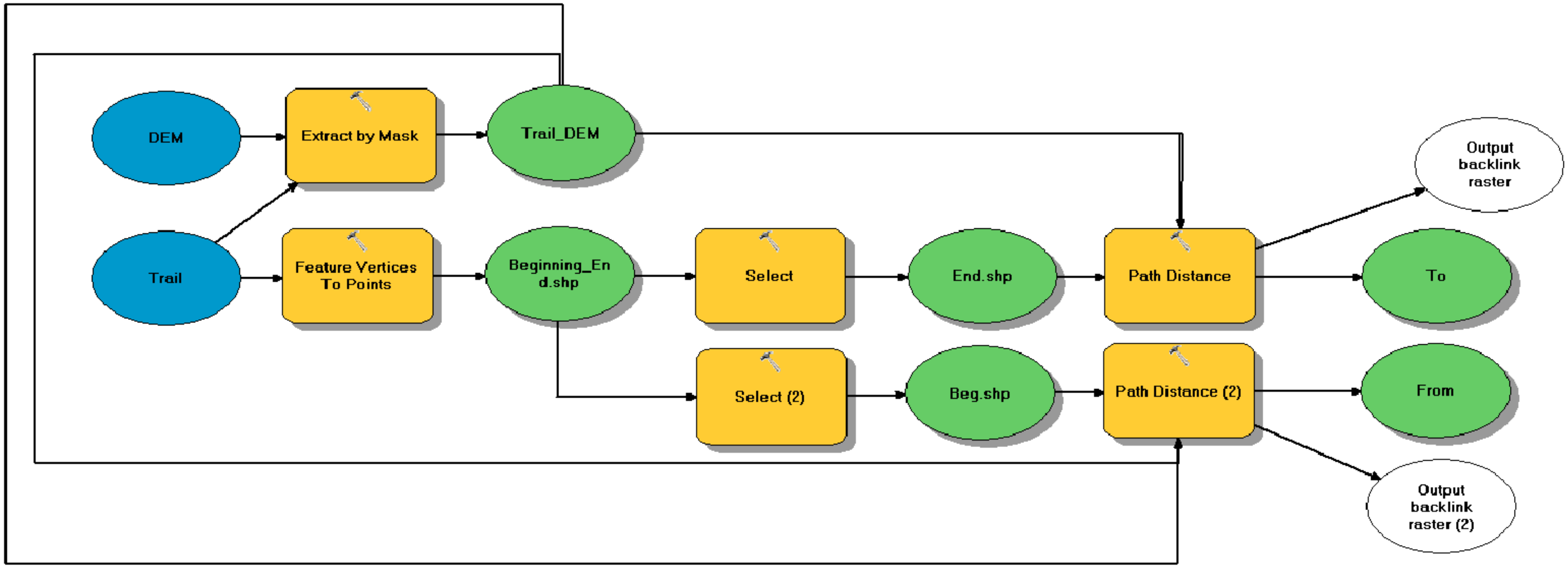

Figure 6.25. This figure depicts the steps necessary to calculate the energetic expenditure or travel time along a specified path. There are two final outputs . "To" and "From", which are raster files. Each of the outputs states the time or energy required to travel in one direction, an important component for anisotropic modeling. In addition, the model contains four parameters (required inputs), including a DEM (the elevation model for the study area) a trail (a shapefile or feature class which contains the location of the relevant trail), and two Path Distance parameters. These parameters specify the vertical factor table, which is a textfile that states the cost of movement on a specific slope degree

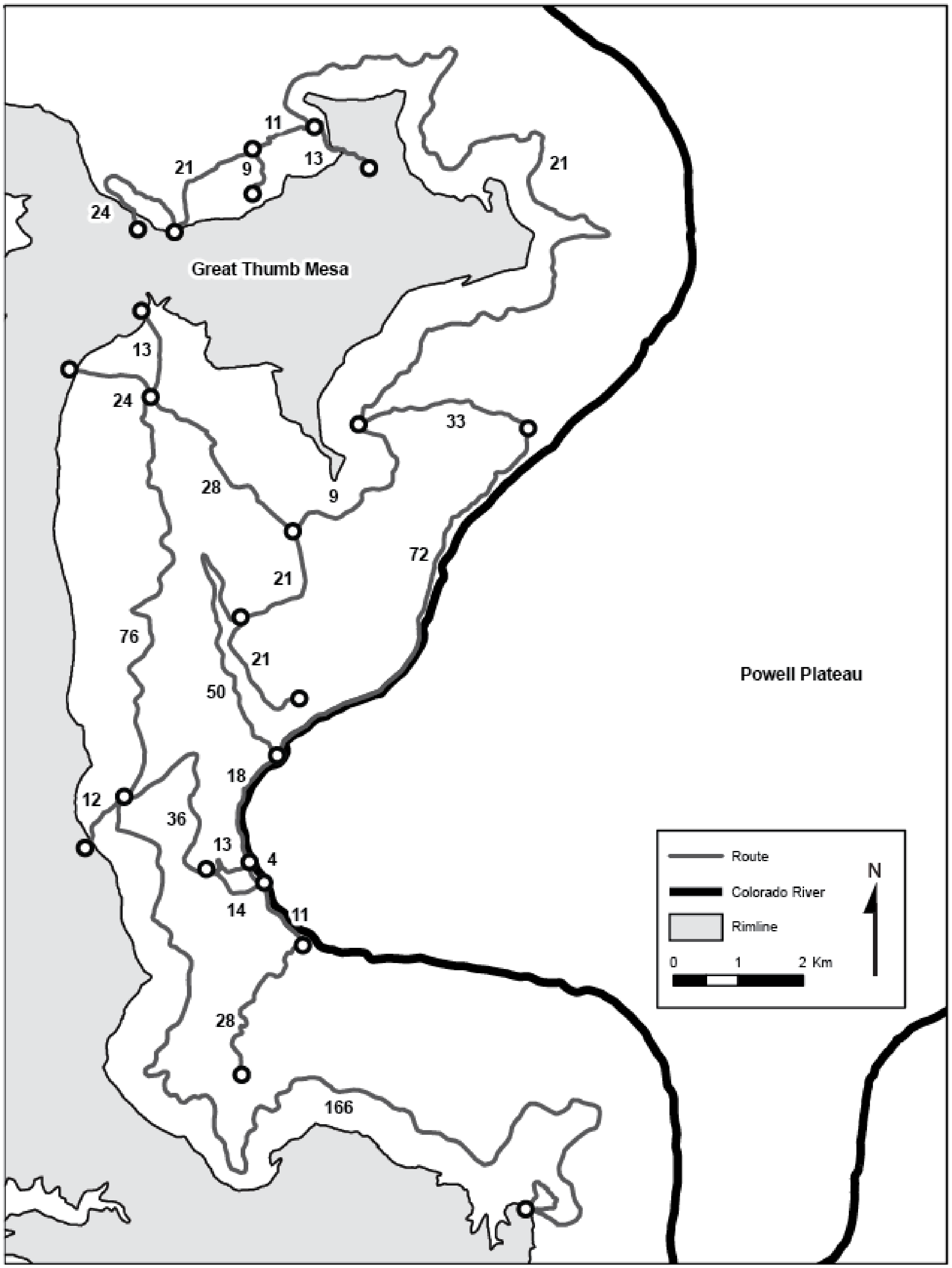

Figure 6.26. This figure shows the cost, in travel time, of travelling along a specific trail in the area around the Great Thumb Mesa. The numbers adjacent to each route depict travel time as an average of travel in either direction

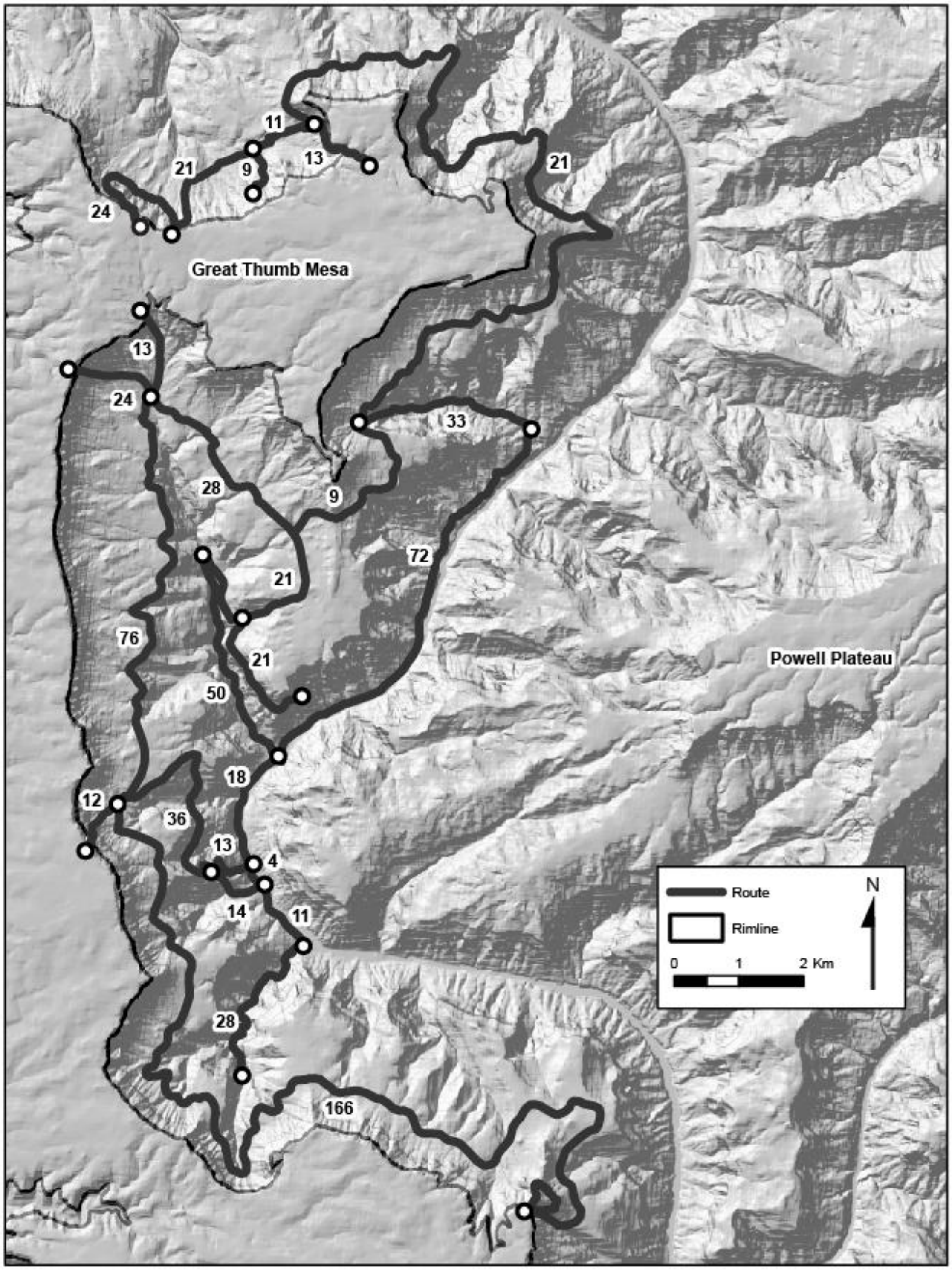

Figure 6.27**.** This figure shows depicts travel time along any one route in the area surround Great Thumb Mesa. The numbers adjacent to each route depict travel time as an average of travel in either direction, with the added dimension of topography compared to Figure 6.26.

paths between places, such as in rim to rim travel. For instance, starting with a known origin, such as the Upper Basin, it would be possible to select one or two efficient cross canyon routes to the North Rim. Those routes, in turn, could be compared to archaeological survey for evidence of annual or multi-year migration patterns.

Digitation of Vertical Barriers for More Accurate Catchment Assessment

The previous section provides methods that could potentially be used to more accurately determine the costs of point-to-point travel along a specific set of trails. It does not, however, more accurately define site catchments or cost surfaces, in which a would-be traveler might deviate from known paths for any number of reasons. A potential solution to this problem is to digitize barriers, such as cliffs, which can then be converted into raster layers and combined with DEM's. The digitized barriers can then be converted into nodata cells, which the Pathdistance algorithm is not permitted to choose. Therefore, it is possible to force the algorithm to go around, rather than potentially, and unrealistsically, traverse up cliff slopes. This method, then, presents the opposite problem – whereas previous portions of this analysis did not rely on the digitization of barriers an may therefore contain some error, this method assumes a perfect knowledge of access points.

Due to the fact that it is time consuming to accurately digitize the hundreds of miles of various cliff layers, and difficult to define cliff edges accurately using a simple slope model, I have chosen subregion for analysis, around the site used previously for analysis in Nankoweap Canyon. This region is large enough to demonstrate the.

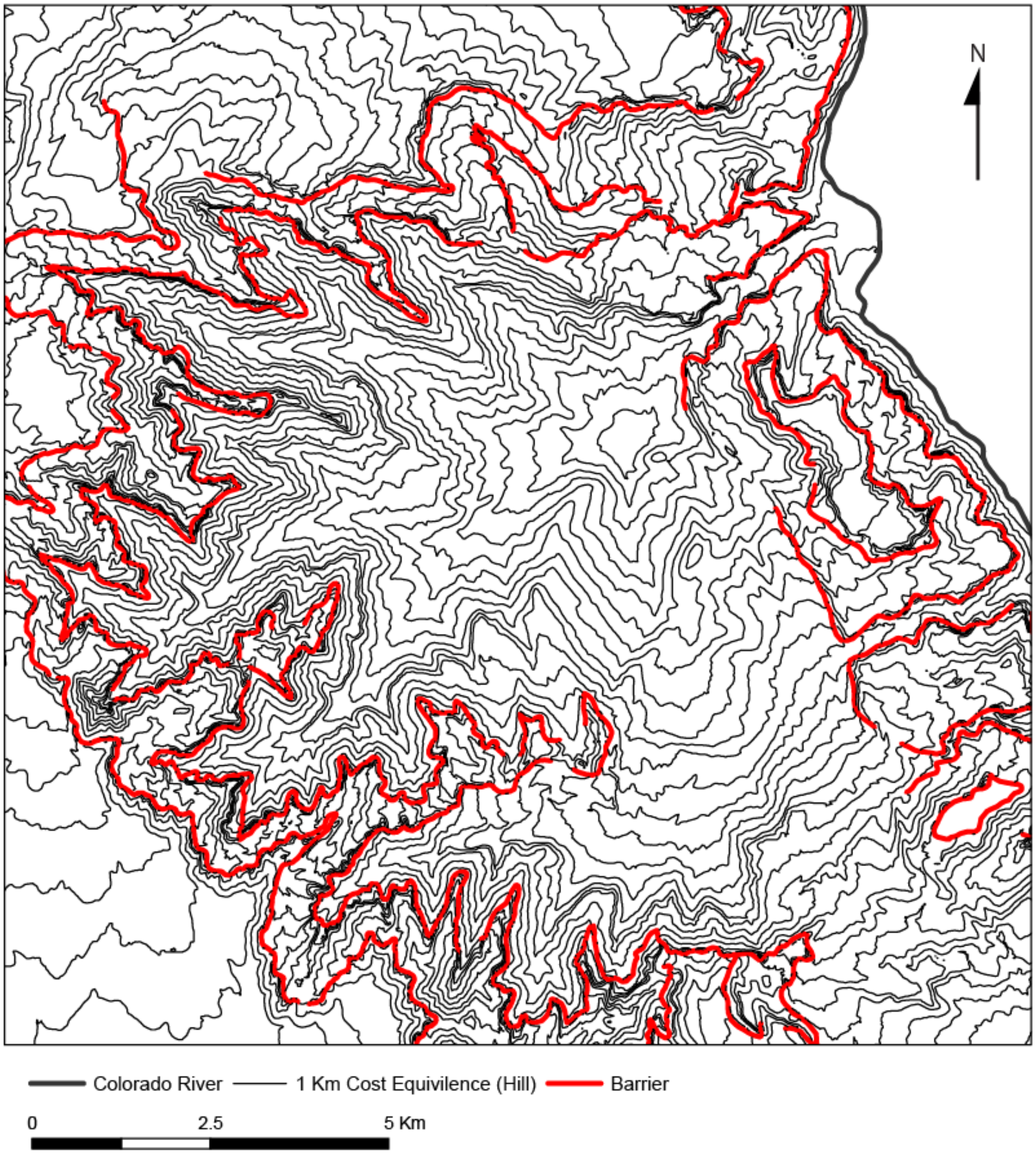

Figure 6.28**.** This figure shows the effects of more detailed cost surface modeling in the Grand Canyon. Note how cost-equivalent contours expand away from the source laterally along the tops of cliff edges, especially on top of the Walhalla Glades in the southwest corner of the map.

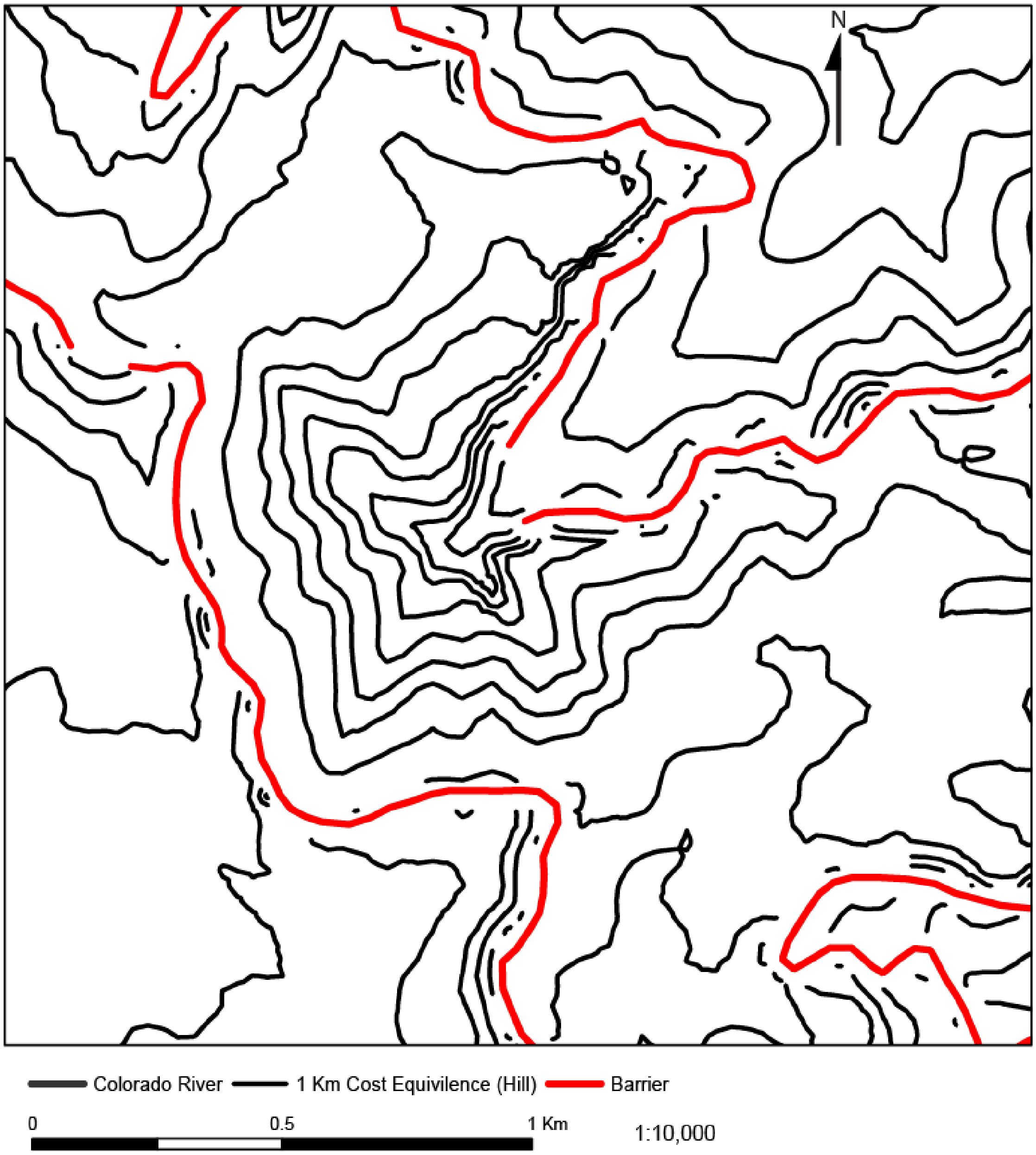

Figure 6.29. This figure provides a detailed view of Figure 6.28. The gap in the cliff in the middle of the figure represents a break in the Redwall Limestone. Note how cost-equivalent contours are funneled toward the access point, and then expand outward laterally.

implications of this sort of modeling without dealing with the additional barrier presented by Upper Granite Gorge in Reach Six.

Figures 6.28 and 6.29 provide examples of this type of modeling. In the figures, red lines represent digitized travel barriers, including the Redwall Limestone and Coconino Sandstone cliff faces. Gaps in the red lines represent known access points over the cliffs. These figures demonstrate several patterns not be readily evident in the previous portion of this analysis. In these figures, the isolines (representing cost-equivalent kilometers derived from Hill's [1995] formula) traverse along the tops of cliffs in order to access barriers, and are funneled towards access points. They then expand outward in all directions until they encounter, or "meet" isolines expanding out from a different access point (Figure 6.29). This method shows the relative isolation of locations on top of cliffs but intermediate between access points (although the actual cost may not be greatly different from the methods used previously). The methods described here provide a more detailed method for deriving site catchments.

Summary

This chapter has examined several themes related to the construction and application of archaeological site catchments in the Grand Canyon. First, I compared predictions made by various formulae designed to measure the cost, in time or energy expenditure, to determine the reliability of each formula. I determined that Tobler's (1993) Hiker function provides a reasonable upper bound for measures of cost equivalence. Using the Hiker Function as a reference point, I then determined that Hill's (1995) formula can be used as a reasonable lower bound, or off trail predictor of site catchment boundaries. Finally, I determined that the Pandolf equation (Pandolf et al. 1977) and downhill correction factor (Yokota et al. 2004) do not provide reliable estimates of cost equivalence in the rough environment of the Grand Canyon, despite the alluring possibility of modeling cost in calories or measuring load carriage.

With the aforementioned analysis in mind, I demonstrated several ways in which Pathdistance tools can be used to provide insight into prehistoric subsistence tasks in the Grand Canyon. First, I analyzed the comparative roughness of site catchments in the Canyon, finding that depending on the region of the Canyon analyzed, the catchments may be more or less rough than catchments located in adjacent regions of the greater Southwest. In addition, I found that catchments tend to increase in roughness the larger that they become, a byproduct of the fact that a would-be traveler inevitably encounters the major vertical barriers characteristic of the Canyon's upper strata. Second, I examined the cost of moving between rim and river, determining that these areas of the Canyon are typically out of reach of each other for single day (collecting) farming or foraging activities. Based on the preceding statements, it is likely that prehistoric inhabitants of the Grand Canyon, were, in some respects, energetically "locked in" to the canyon depending on the chosen settlement strategy. Finally I examined the isolation of sites examined in this study. Although inconclusive, this portion of the analysis demonstrated the potential utility of the methods described here in understanding questions of communication and trade within areas of rough topography, using cost-equivalent polygons as a metric.

Lastly, this chapter examined two potential methods for examining the cost-equivalent distance between archaeological sites and resources in greater detail. The first method involves extracting portions of a digital elevation model congruent with any particular trail, and calculating the cost of travelling the trail. This method could potentially be integrated into network analysis to understand more fully the costs of travelling on actual trails, instead of hypothetical least cost paths in the Grand Canyon. The second method requires the digitization of cliffs or other barriers, and converting these cells into NoData values. Because NoData values cannot be chosen by the Pathdistance algorithim, this method allows the possibility of eliminating unrealistic movement options, such as traversing along a cliff edge.

In future studies, I believe that the methodology described in this chapter can be compared to data derived from a single site in order to understand the subsistence and settlement options. It is only then that the models described in Chapter 5, such as Central Place Foraging, or other models subsumed within Human Behavioral Ecology will gain traction in archaeological studies of the Grand Canyon.

Chapter 7

Conclusions and Recommendations for Future Research

Conclusion

In many respects, this study has been very broad, examining several interrelated topics. These topics include distribution of trails and routes in the Grand Canyon, evidence of prehistoric use of known trails and routes, and accessibility problems presented by the resulting distribution of trails. From that point, this study assessed the accuracy of various mathematical formulae for the use of delimiting archaeological site catchments and cost surfaces, and discussed the implications of the use of such formulae in prehistoric subsistence models. The former research focus was the original goal of this study, however, it could not be undertaken without delving into additional topics. Thus, it is not possible to understand archaeological site catchments in the Grand Canyon without first examining the different formulae that researchers have used in site catchment estimation. In addition, it is not possible to understand site catchments in the Grand Canyon without some knowledge of the Canyon's accessibility issues. These issues, in turn, cannot be understood without a detailed understanding of the distribution of prehistoric trails and routes.

Fortunately, the environment of the Grand Canyon is particularly well suited to the study of prehistoric trail systems, and it is possible to define a comprehensive trails database with a high degree of accuracy for several reasons (Chapter 3). First, the topography of the Canyon presents a circumstance in which travel routes and corridors mirror topographic features, such as drainages, plateaus and geologic faults, through simple necessity. The exploration of the Grand Canyon by Harvey Butchart and others has demonstrated this fact. This finding coincides with the implications of recent studies (Snead et al. 2009) that have found that prehistoric routes typically mirror cost-efficient routes over the landscape. Thus, it is reasonable to assume that modern routes through the Grand Canyon mirror prehistoric movement options. This study compared this hypothesis to the distribution of archaeological sites and prehistoric trail features, such as steps and log ladders, finding various degrees of direct and circumstantial evidence of prehistoric use of the majority of approximately 500 trails in the current database.

The finding that most known trails and routes in the Grand Canyon contain evidence of prehistoric use was then important to the study of accessibility issues in the Canyon (Chapter 4). The key finding of this study related to the concept of accessibility is not whether or not the Canyon was accessible to prehistoric peoples; this question was resolved for practitioners of the western intellectual tradition when John Wesley Powell noticed prehistoric sites in the Canyon in 1869. Rather, the distribution of routes that provide access through the Canyon's most imposing strata must be conceptualized in reference to specific travel goals in order to understand their implications. For instance, accessibility concerns would be of little importance in the day to day subsistence tasks of sedentary farmers living in the open canyon bottoms of the eastern Canyon. On the other hand, accessibility issues would be of paramount concern in cross Canyon or Rim-to-River travel, for foraging or hunting activities that crossed over major vertical barriers, or for prehistoric people living in transitional areas. One implication of accessibility issues is that while there are many travel options within the canyon, there might only be one or two *good* options. Therefore, the distribution of access points in the canyon might be evaluated in comparison to a specific subsistence strategy, such as that hypothesized in the Cross Canyon Model (Sullivan 2002) in order to define a limited number of likely cross-canyon routes in a network environment.

One of the issues associated with the concept of accessibility is that limitations in accessibility can increase the distance between places by forcing the would-be traveler to follow circuitous travel routes. This condition, in conjunction with the higher energetic expenditure incurred by travelling over the steep terrain of the Grand Canyon, ultimately form the two key elements in cost surface estimation in the Canyon. With accessibility issues defined, it is then possible to investigate measures of energetic expenditure. However, because the terrain of the Grand Canyon is so extreme, it was unclear which, if any of the formulae used by previous authors in the estimation of cost surfaces through the use of ESRI ArcGIS or other similar GIS software, was appropriate for application in the Grand Canyon. This is especially apparent as no previous archaeological study has compared the implications of the use of different formulae in cost surface or site catchment estimation. Therefore, I compared the use of each formula at different sites in the Canyon, finding that the Tobler's (1993) Hiker Function provides a reasonable "upper bound" formula for the delineation of site catchments based on measures of cost equivalence, and that the formula used by Hill (1995) provides a good "lower bound" in the estimation of site catchments, or would be a reasonable formula to use in off trail movement. I found that the Pandolf Equation (Pandolf et al. 1977) and Yokota's downhill correction factor (Yokota et al. 2004) did not predict reasonable catchments based on cost equivalence, for various reasons.

Although I recommend that additional formulae be employed in similar analysis, as well as in additional environments of the Southwest, I believe that the formulae used in this study are substantially accurate to make some tentative statements regarding the effects of rough terrain on the prehistoric life ways of prehistoric peoples living in the Canyon. Minimally, measures of straight-line, or “as the crow flies” distance account poorly for the extreme topography of Grand Canyon. In the example of the Tanner Trail, the energetic equivalence of traveling from Rim-to-River was ten times that of the average straight line distance for the area surrounding the Tanner trail. By continuing to examine methods for assessing the energetic, rather than straight line distances, a greater appreciation of the costs of movement within the Canyon may be gained.

I must emphasize that the following statements are derived from an inductive analysis and must be verified through additional field methods at a later point in time. The first implication of this study is that the terrain of the eastern Grand Canyon drainages of Nankoweap, Chuar, and Unkar is probably not substantially rougher than other rough regions of the greater Southwest. However, it is doubtful that there are many areas in the Southwest that construe greater terrain roughness than the drainages surrounding Upper Granite Gorge, such as Bright Angel Canyon and the Shinumo Amphitheater. There was probably, therefore, a higher energetic cost in travel concerns in these areas that elsewhere, and the true implications of this finding are yet to be investigated.

Second, the formulae used in this thesis have implications for understanding the side drainages of the Grand Canyon as integrated rim-to-river subsistence systems. The energetic cost between these areas, taken in comparison to ethnographic analogy, implies that these regions would have been out of reach for each other for most single-day subsistence tasks. However, this study supports the notion that prehistoric peoples may have lived on the Rim and foraged in mid elevation zones of the Canyon on a single day basis, or that centrally located people could have enjoyed a range of subsistence options within the range of the ethnographic analogies considered in this study. In addition, this study supports the idea that subsistence strategies differed between the eastern and western Canyon, because there is large differences in energetic expenditure and accessibility issues between these regions. Specifically, the energetic distance between the Canyon Rim and the Esplanade (as this relates to the western Canyon) is much lower than the energetic distance between the canyon rim and the Tonto Plateau or Colorado River (as this relates to the eastern Canyon). In addition, the Esplanade contains a greater number of access points as the Coconino Sandstone decreases in thickness further west. One final point made in this study is that it is now possible to study the isolation and interaction of sites located in different areas of the canyon in a much more comprehensive way.

Future Directions

Expansion of the Trails Dataset

Most of the information consulted in creating the dataset used in this analysis is in some respects very basic, in that I was often limited to public, mapped trails, and elevation data. By consulting additional sources, such as modern Canyon hiking experts, the trails dataset might be expanded. The trails database could potentially benefit from the incorporation of unpublished routes, for example, beneath Powell Plateau, trails into the basins of Nankoweap, Kwagunt, and Chuar, as well as into Marble Canyon (James Ohlman, personal communication 2011).

Developing More Complex Cost Surfaces

In addition to expanding the trails dataset, it would be beneficial to examine additional costs to movement. Two mentioned briefly in this study include social factors, such as trail ownership, as well as conceptualizing the costs of travelling across the river in a more sophisticated manner. One might conceive of prehistoric groups crossing the from rim-to-rim in Marble Canyon by travelling down the Eminence Break Fault, across the Bridge of Poles, and up a modified route out of Buckfarm Canyon, but who would have had access to constructed trail features in a constricted environment? Would such routes have been available to everyone, or only to the members of a specific culture, band, clan, or family unit?

Final Thoughts

After documenting additional trails, and conceptualizing additional costs, trails may also inform us as to the ways in which daily life was structured. Somewhat absent from previous Canyon settlement models is the idea that people may have been moving vertically between strata on a regular basis. However, informal trails, and trails with constructed features, which facilitate movement between the rim, and flat lying areas of the inner Canyon, suggest that movement between strata was likely to have taken place on a daily basis. A contribution of this study has been an assessment of hypothetical feasibility for subsistence tasks within the canyon, such as rim-to-river foraging, and foraging between the Canyon's many strata. By comparing the costs of travel to more detailed archaeological analysis, the implications of prehistoric travel may be more fully understood.

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