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Modeling Ceramic Transport with GIS in East-central Arizona

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Modeling Ceramic Transport with GIS in East-central Arizona

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Table of Contents

List of Figures

List of Tables

Abstract

Pottery was central to the lives of ancient peoples in the American Southwest, having both mundane and special purpose functions. Some ceramic types were widely circulated well beyond where they were crafted. However very little investigation has been done on the processes or paths used to transport pottery within social networks. This project examines the movement of a central fourteenth-century pottery type in east-central Arizona. Using Geographic Information Systems (GIS), I analyze the physical and cultural landscapes in this area to identify possible corridors of human movement between known pottery-creator and -recipient villages. Building on existing knowledge of where pottery is produced, this project will focus needed attention on *how* ceramics were moved around the landscape and what trails were used to move them in the ancient Southwest.

Chapter 1: Introduction

Pottery was central to the lives of ancient peoples in the American Southwest. Most communities in the ancient Southwest produced utilitarian (undecorated) pottery for local use, but there was also a deep tradition of long-distance exchange of decorated pottery (Blinman and Wilson 1992). Southwest archaeologists have long relied on the exchange and movement of decorated pottery to infer cultural boundaries, migrations, and broader social networks (see Blinman and Wilson 1992; Triadan 1997; Triadan et al. 2002; Van Keuren and Cameron 2015; Van Keuren and Ferguson 2020; Whittlesey 1974; Zedeño 1998). However, very little investigation has been done on the processes or pathways used to transport pottery across geographic space. This project examines the movement of a prominent fourteenth-century pottery type in east-central Arizona. Using Geographic Information Systems (GIS), I analyze the physical and cultural landscapes in this area to identify possible corridors of human movement between where vessels were created and where they were eventually used and discarded. Building on existing knowledge of where pottery is produced, this project will focus needed attention on *how* ceramics were moved and what routes were used within landscapes of the ancient Southwest.

In an archaeological context, pottery is organized most generally into “wares”, which are broad categories characterized by similar technological attributes and geographic proximity, that are then further broken down into traditions and types (Carlson 1970: 1). Types are more specific groupings of pottery based on spatial and temporal proximity, as well as technological attributes such as paste (the characteristics of the clay cross section of a vessel), temper (non-clay inclusions that are mixed into clay to stabilize it), and surface treatment. A vessel can be undecorated (not painted or slipped), monochrome (slipped with one color), bichrome (decorated with two colors), or polychrome (decorated with more than two colors). Pottery traditions are a series of types that constitute a “socially transmitted developmental continuum through time” (Carlson 1970: 1).

Ancient peoples living at the edge of the Colorado Plateau in the A.D. 1300s utilized several decorated and undecorated pottery wares. The focus of this project is on Fourmile Polychrome, a red-slipped polychrome type of White Mountain Red Ware, which is a tradition of high-fired, red-slipped pottery that was first produced in the upland Southwest during the eleventh century A.D. (Carlson 1970). Fourmile Polychrome is the final type in the White Mountain series of White Mountain Red Ware and was produced at a handful of villages in the Silver Creek drainage of east-central Arizona from A.D. 1325 to 1375 (Carlson 1970). These villages, including Fourmile Ruin, Shumway Ruin, Showlow Ruin, and perhaps Tundastusa, can be seen in Figure 1. It has a light-colored paste and is tempered with sherd and quartz (Carlson 1970; Triadan et al. 2002). The type, primarily in bowl form, was circulated throughout Ancestral Pueblo and Mogollon villages in eastern Arizona during the 1300s (Triadan et al. 2002: 87-91). Using chemical sourcing studies, specifically neutron activation analysis to match the chemical makeup of ceramic pastes to clay sources, three likely production villages have been identified (Triadan et al. 2002; Van Keuren and Ferguson 2020). Although there is detailed evidence about where Fourmile Polychrome was produced and where it was circulated, we know little about the paths used to transport pottery or the methods that may have been used to move pottery long distances. That said, GIS has been used by researchers to explore similar questions of travel and exchange elsewhere in the Southwest (e.g. Caseldine 2021; Cutright-Smith 2013; Field et al. 2019; Luévano 2022; Phillips and Leckman 2017; Safi 2014; Teeter 2017). Fourmile Polychrome is an ideal case study to explore the movement of Ancestral Pueblo pottery across the landscape using similar methods; its extent is well delineated in both space and time and provenance research (namely chemical sourcing analyses) have pinpointed its narrow production zone (see Carlson 1970; Triadan 1997; Triadan et al. 2002; Van Keuren and Ferguson 2020).

The terminology used to describe the circulation of Fourmile Polychrome tends to over-emphasize the possibility of the type's explicit production for trade (see Whittlesey 1974; Van Keuren and Ferguson 2020; Zedeño 1998). Because of its widespread exchange outside of its production area, and specific characteristics and use wear patterns (the characteristics of abrasions found on pottery that can evidence what a vessel was used for and how often it was used), Fourmile Polychrome has been referred to as a "commodity" ware (see Zedeño 1998: 470), and is suggested to have been produced for trade (Whittlesey 1974). Whittlesey (1974: 110) posits that "Fourmile Polychrome appears to have been manufactured in terms of one economically significant factor of production, nestability" and further suggests that "It would seem desirable, in widely traded ceramics, to produce bowls which can be easily nested" (Whittlesey 1974: 108), assuming that Fourmile Polychrome was produced with the explicit intention of large-scale trade. More recent studies have clarified that Fourmile Polychrome was probably not produced solely for trade, as these bowls were used heavily in the villages they were produced in (Van Keuren and Cameron 2015), but the focus on economic value, in the language used to describe its circulation, remains (e.g., Triadan 1997; Whittlesey 1974; Van Keuren and Cameron 2015: 36). Also, gift exchange, in the form of informal down-the-line exchange or gifting of goods at ceremonies and feasts, has been proposed as a viable mechanism of pottery exchange in this region of the Southwest (Zedeño 1998), meaning that Fourmile Polychrome may not have been intentionally produced for large scale exchange as proposed by Whittlesey (1974). Finally, objects are not simply produced for functional reasons. Many things have both functional and decorative attributes, and objects are embedded in cultural knowledge and beliefs (Van Keuren and Cameron 2015). In fact, "household artisans may embellish a craft… particularly if that craft were central in the subsistence economy" (Hagstrum 1995: 293). The terminology that is used to describe objects should acknowledge the complex process of their creation and their social meaning.

In this study I use neutral terms to describe the sites involved in the circulation of Fourmile Polychrome to acknowledge the complex social meanings and processes involved in the creation of pottery, as well as the ambiguities in the social mechanism of its circulation. The role of the Fourmile, Shumway, and Showlow Ruins cannot be described fully by the term "producer". It is widely agreed upon that Fourmile Polychrome pottery was likely made in these villages (Triadan et al. 2002; Van Keuren and Ferguson 2020), however, pottery is not simply produced, its creation is a complex process that involves creativity and flexibility (Hagstrum 1995). Within the process of pottery creation, "meanings, experience, memory, and other processes are all in play as the 'social life' of a vessel begins" (Van Keuren and Cameron 2015: 30-31). Because of this, the sites where Fourmile Polychrome was made are referred to as "creator" sites here. The role of the other sites where Fourmile Polychrome is found, presumably having been transported from a creator village, is not that of a "consumer", a term which is used to describe these sites in some previous studies (see Van Keuren and Cameron 2015). This term reflects a view of Fourmile Polychrome as a commodity that was traded for economic benefits. While one hypothesis for the exchange of Fourmile Polychrome does involve a commodity-based mechanism, the other does not, and so a more neutral term is needed to reflect this ambiguity. Thus, the sites where Fourmile Polychrome is found, but was not produced, are called "recipient" sites in this paper. These terms cannot fully represent the complex inter-community relationships in this region. However, by being intentional about the terminology I use in this project, I hope to move away from the modern mindset of consumerism, which often distorts our views of pre-modern processes of cultural exchange and social connections, and better reflect the economic systems in place in this region of the ancient Southwest.

There are two main goals for this project. The first is to better understand the human energetic processes used to move pottery in the Southwest through a review of ethnohistoric and ethnographic resources, including literature and images. How was the pottery carried? How many pieces of pottery were transported at one time? How much weight would one person carry? The second goal of this project is to create a predictive geospatial model of movement across the landscape to better understand the possible pathways used to transport pottery. Where were the corridors of travel? How might travel have differed with or without pottery? And what were the energy costs of traveling these proposed pathways? Using various geospatial techniques within GIS I attempt to model these pathways, shedding light on the above research questions and expanding our understanding of the social dynamics of pottery circulation in this part of the fourteenth century Southwest.

In Chapter 2, I discuss the geographic features of east-central Arizona, the cultural context of the Silver Creek site cluster and the clusters below the Mogollon Rim during the early Pueblo IV (A.D. 1275/1300-1400), and a more detailed description of Fourmile Polychrome and its circulation. In Chapter 3, I detail the theoretical framework that structures my geospatial analysis, centered around cultural landscape theory, practice theory, and landscapes of movement. I also discuss mechanisms and social contexts of exchange and how pottery may have been carried in the past. In Chapter 4, I discuss the benefits and drawbacks of GIS, and the precedence of GIS use in Southwestern archaeology. My methods for geospatial analysis, including Least Cost Path (LCP) analysis, and Circuit Theoretic (CT) modeling can be found in Chapter 5. Then, in Chapter 6, I detail the results of the LCP and CT modeling, and of the validation tests for the predictive models. My discussion and interpretation of these results can be found in Chapter 6 as well. Finally, I summarize my findings and interpretations, and discuss possibilities for further research in Chapter 7.

Chapter 2: Background and Cultural Context

For humans, travel is a behavior that is influenced by a number of complex, interacting factors. These include but are not limited to: the terrain a person is traveling through and their familiarity with it, geographic barriers to travel, the locations of desired resources, and cultural boundaries and relationships (Darling 2009; Snead 2009; Snead et al. 2009). Because of this, in any study of movement through a landscape, a discussion of the geography of the region and the cultural context in which movement takes place is needed. Below is a geographic description of this project's study area, as well as a discussion of the cultures present in east-central Arizona during the late Pueblo III and early IV periods (roughly A.D. 1200s through 1300s).

Geography of East-central Arizona

Though the geography of a region does not necessarily dictate how people move through a landscape, geographic features still do play a role in that decision making process. Thus, for any study of travel, it is important to understand the general geographic features of a region. The study area for this project is roughly bounded by several important geographic features in east-central Arizona. The Colorado Plateau is to the north, with the northernmost sites included in this study on the edge of the Mogollon Rim. Travel on the Colorado Plateau along the Mogollon Rim is relatively easy, as it is not deeply dissected (Triadan and Zedeño 2004: 97). However, crossing the rim southward can be nearly impossible in places, as it ranges from a steep slope to a sheer cliff in certain areas, especially to the west (Triadan and Zedeño 2004: 96-98). South of the rim, the landscape transitions into a rugged mountainous region with heavily dissected terrain due to geologic faulting and volcanism (Reid 1989). Often referred to as the Arizona Mountains or Transitional Zone, the valleys, plateaus, and mountains in this region tend to run roughly north-south. Generally, east-west travel in this area is difficult because of the rugged terrain, but north-south travel is easier due to the natural movement corridors (Triadan and Zedeño 2004). The Salt River runs along the southern portion of the study area. To the east are the White Mountains, and north-south travel in this eastern portion of the study area tends to be more feasible than in the west, because the Mogollon Rim here is easier to traverse. To the south-west is the Tonto River valley. See Figure 1 for a map of this project's study area.

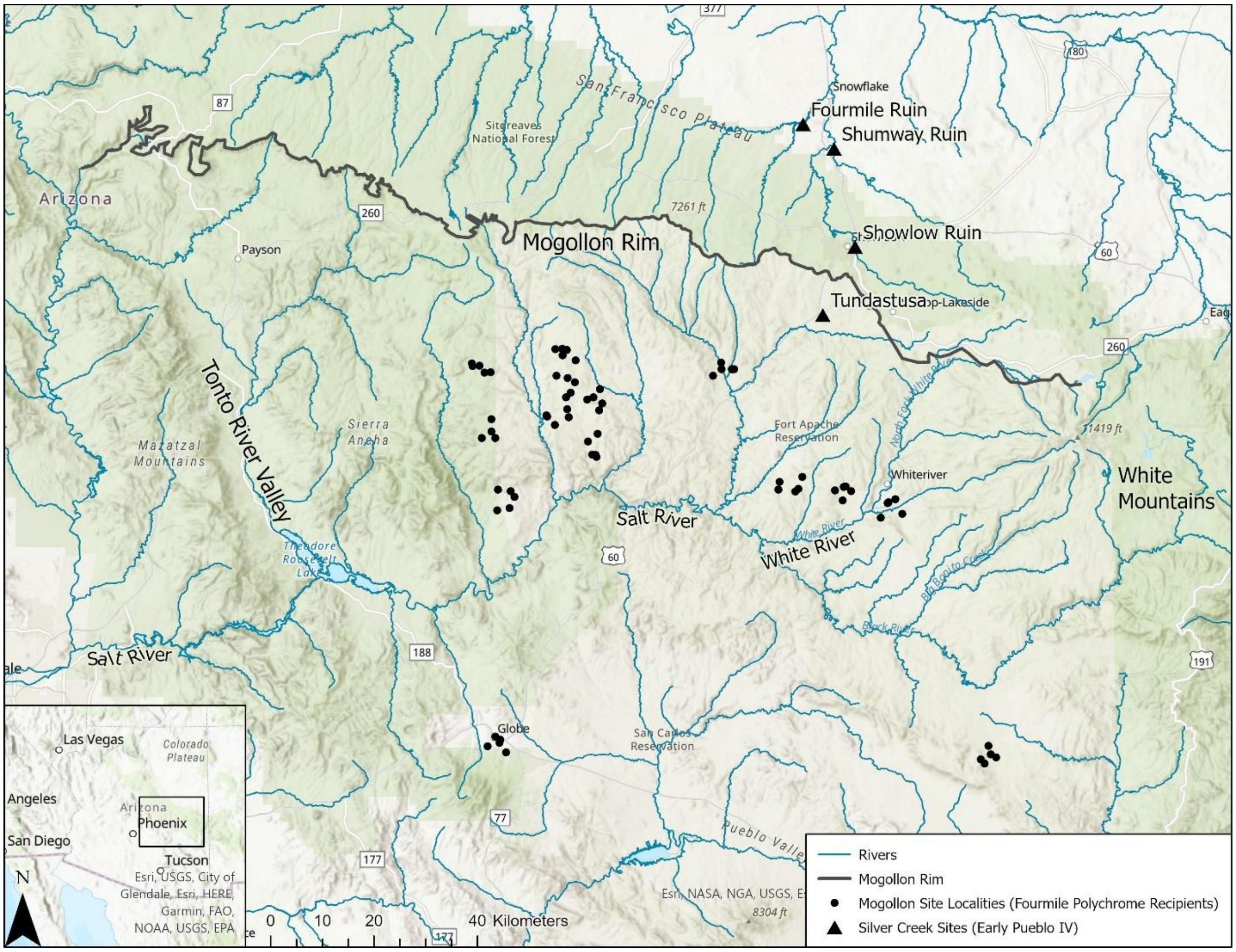


Figure 1: Map of project study area, notable geographic features, and archaeological sites.

Cultural Landscapes in the Pueblo IV period

The area below the Mogollon Rim (described above) is a transition zone, not only geographically, but also culturally. It represents the loose archaeologically-defined cultural boundary between the Mogollon culture in the south, and the Ancestral Pueblo in the north.

Temporally, this study is centered on late occupations of the region, during the early Pueblo IV period (A.D. 1275/1300-1400). Here and elsewhere in the northern Southwest, this was a phase of major reorganization of settlement patterns and migration between regions. The Four Corners region experienced major migrations out of the area (Dean 1996) and other areas experienced settlement growth and nucleation into clusters, which are groups of settlements that are spatially close to one another, have similar material cultures, and have significant spatial gaps in occupation between other groups of settlements (Adams and Duff 2004; Kaldahl et al. 2004; Triadan and Zedeño 2004). In the Silver Creek drainage and the Arizona Mountains, early settlements were small, highly dispersed, and most likely seasonally occupied before A.D. 1000. Then, south of the rim, there was aggregation into settlement clusters located near agricultural soils, and in Silver Creek populations aggregated into larger pueblos of more than 50 rooms. Finally, populations aggregated into large, dense pueblos before the region was largely depopulated by A.D. 1400 (Mills 1999; Reid 1989; Reid et al. 1996).

This project is focused on the circulation of pottery among villages in the Silver Creek drainage and settlements to the south in the rugged Transition Zone below the Mogollon Rim during the early Pueblo IV period because this was the primary distribution zone of Fourmile Polychrome (Carlson 1970: 69). The Silver Creek cluster was a group of Ancestral Pueblo settlements situated on the Colorado Plateau near the Mogollon Rim (see Figure 1). The area was sparsely occupied, with only small settlements of one or two households in the eleventh and twelfth centuries (Mills 1999). Larger pueblos were established in the late Pueblo III period and occupied throughout the early Pueblo IV period (Kaldahl et al. 2004; Mills 1999; Triadan et al. 2002). The Silver Creek cluster went through periods of major settlement reorganization, similar to other areas in the northern Southwest. Most of the population of Silver Creek consolidated into six large villages by the A.D. 1280s, depopulating the smaller villages in the area that were previously occupied (Triadan et al. 2002; Kaldahl et al. 2004). Around A.D. 1325, one or two of the large villages were depopulated and there was increased population and cultural diversity in the others due to population movement (Kaldahl et al. 2004). For the rest of the early Pueblo IV period (A.D. 1325-1375/1400), most of the residents of the Silver Creek cluster lived at four large villages above and just below the Mogollon Rim, before the area was then depopulated by the A.D. 1390s (Kaldahl et al. 2004). The settlement aggregation in Silver Creek was so significant and happened so quickly that "between the late 12th and early 14th centuries the Silver Creek area saw a doubling in the size of the largest settlement about every 50 years or the equivalent of every two generations" (Mills 1999: 505). This major change in settlement organization was also accompanied by changes in leadership strategies, social identity, and the organization of labor and craft production (Mills 1999).

Similar settlement changes occurred to the south. Mogollon occupation of the Arizona Mountains has been documented for the Pueblo II and early Pueblo III periods (approximately A.D. 600-1150), when mobile groups of hunter-gatherer-gardeners used the area for resource procurement and seasonal occupation. Settlements were highly dispersed groups of 5-10 pithouses (Reid 1989: 70-71; Reid et al. 1996: 76). By the late Pueblo III (A.D. 1150-1300), settlements began to cluster near fertile agricultural soils. Clusters took on a pattern of a number of smaller villages surrounding a larger settlement with ceremonial structures that served as a focal community (Reid 1989: 76; Reid et al. 1996: 77-78). During the 13th and 14th century this region transitioned from being sparsely populated and seasonally exploited to having areas of densely populated, sedentary communities. During the early fourteenth century settlement reorganization and migration from north of the Mogollon Rim led to further population aggregation (Reid 1989: 81; Triadan and Zedeño 2004: 98-99). With this settlement reorganization and population increase, the diversity of material culture also increased, implying the cohabitation of multiple cultural groups in these villages (Reid et al. 1996: 77-78; Triadan 1997: 94). The settlement clusters of the Arizona Mountains during the fourteenth century were also often arranged defensively, according to a geospatial analysis of cluster structure by Triadan and Zedeño (2004: 105). This hints at underlying tensions and conflict in the region during this period. This study also suggests a number of "access routes" throughout the Arizona Mountains (Triadan and Zedeño 2004: Figure 10.2), though no methods for generating these access routes are given. The settlement clusters of east-central Arizona seem to have conformed to the general trend of major reorganization and migration in the northern Southwest during the Pueblo IV period.

Fourmile Polychrome

This time period of major population shift and settlement reorganization correlates to the development of regionally distinctive pottery traditions and new networks of pottery exchange (Adams and Duff 2004: 5). One of these primary pottery types was Fourmile Polychrome, which diverged stylistically from previous White Mountain Red Ware types decorated in the early Pinedale style (Triadan et al. 2002). The type is defined stylistically by elaborate, asymmetric, iconographic imagery (see Figure 2), a trend away from the geometric designs on bowl interiors of earlier White Mountain Red Ware types (Carlson 1970; Van Keuren and Cameron 2015). Carlson (1970: 94) describes this stylistic development as a "radical departure from earlier styles" because of the "change of focus of decoration on bowl interiors from the walls to the center", as well as the asymmetric patterning and the appearance of "large biomorphic figures" within bowl interior decorations.

Figure 2: Two Fourmile Polychrome bowls (top) and three Pinedale Polychrome bowls (bottom, pre- A.D. 1275). Image adapted from Van Keuren and Cameron (2015: Figure 2).

This type also likely had a high social value in some areas, as Fourmile Polychrome bowls from recipient sites often exhibited less use wear and were more frequently repaired than at sites where this pottery was produced (Van Keuren and Cameron 2015: 38). Among decorated types, Fourmile Polychrome is ubiquitous at both Silver Creek villages and sites below the Mogollon Rim by the 1320s (Triadan et al. 2002). Previous research suggests that Fourmile Polychrome was produced at a few villages in the Silver Creek cluster (Triadan 1997; Triadan et al. 2002), and provenance research has further narrowed its likely production areas to three Silver Creek villages: Fourmile, Shumway and Showlow Ruins (Van Keuren and Ferguson 2020).

Van Keuren and Ferguson (2020) also suggested that the villages where Fourmile Polychrome was produced may have differed in their social relationships and exchange networks with “recipient” villages of this pottery, as vessels from different source groups tend to be found in different areas. There are three main compositional source groups of Fourmile Polychrome.

Two were produced at the sites of Fourmile Ruin and Shumway Ruin; one was circulated widely to the north and east, as well as south to the Arizona Mountains, and the other was more geographically limited (Van Keuren and Ferguson 2020: 11). The third compositional group is not found at Fourmile Ruin or Shumway Ruin, and so must have been produced at Showlow Ruin, Tundastusa, or both (Van Keuren and Ferguson 2020: 12). The pottery of this group was circulated primarily to the south, in the Arizona Mountains. The differing distributions of Fourmile Polychrome compositional groups implies that villages in the Silver Creek cluster varied in their exchange networks and relationships with other villages (Van Keuren and Ferguson 2020: 15), a hypothesis that is supported by previous research by Kaldahl and colleagues (2004: 94), who found that “The residents in particular Silver Creek villages traded with different villages outside the cluster, indicating heterogeneous external trade relations”, based on ceramic composition analysis.

Fourmile Polychrome was developed at a time of major social reorganization at Silver Creek and in the Arizona Mountains. Its distribution implies interesting differences in social ties and exchange networks within the Silver Creek cluster. While there is much information on ceramic circulation during the early Pueblo IV period in east-central Arizona (see Triadan 1997; Triadan et al. 2002; Whittlesey 1974; Zedeño 1998), there has been very little research done investigating the actual routes used to circulate pottery like Fourmile Polychrome. To fully understand the circulation of Fourmile Polychrome, questions of movement and pathways through the rugged landscape below the Mogollon Rim need to be considered.

Chapter 3: Landscapes of Movement and Exchange in the Prehistoric Southwest

Regional exchange studies and social network analyses are central topics in Southwestern archaeology (see Mills et al. 2013; Triadan 1997; Triadan et al. 2002; Whittlesey 1974; Zedeño 1998). There have been studies on the actual movement of people and things that facilitates exchange and the social dynamics that are inherent in the act of exchange in other parts of the Southwest (see Chapter 4 for a discussion of how GIS has been used to model movement in the Southwest), but the social, cultural, and experiential aspects of the movement of people and things has often been overlooked. The movement of people and things through a landscape relies on the features and cultural context of the landscape itself. How someone travels depends not only on the physical attributes of their surroundings, but also that person's cultural perceptions of the landscape. By applying landscape theories to geospatial analysis, we gain a better understanding of the cultural and ideological factors that influence travel, along with the physical factors. Landscape theories inform the choice and construction of GIS analyses to allow for a more complete model of past human behavior.

Landscapes of Movement

In the past three decades, landscape studies in the American Southwest have turned away from strictly empirical frameworks and have moved towards an understanding of landscapes as embedded with cultural ideas and meaning (Fowles 2010: 454). This project draws on cultural landscape theory and practice theory to build a theoretical framework that acknowledges the intensely cultural nature of landscapes and trail networks. Through the lens of these theories, the landscape is a complex network of interacting features connected by the worldview and activities of the people living within the landscape (Cutright-Smith 2013: 43-50). A landscape is formed and then further developed through the recursive relationship between human agency and structure (Snead, Erickson, and Darling 2009: 15-16). Structure is defined as the rules and resources (including the environment) that are used to inform daily interactions. Agency refers to the idea that all people are conscious agents drawing upon structure and culture to inform our actions. In practice theory, structure and agency are two sides of a reflexive relationship (Varien 1999). Humans create structure within a landscape, which, in turn, shapes the everyday lives of humans (Snead, Erickson, and Darling 2009: 15-16). In other words, a landscape is not a static entity that humans live on, it is an actively changing and growing network that holds cultural knowledge and beliefs (Cutright-Smith 2013).

Within the broader context of the cultural landscape are landscapes of movement, which are defined as networks of static elements in an environment that represent the active movement of humans (Snead 2009). They include elements of a cultural landscape that facilitate the movement of people and things (Snead, Erickson, and Darling 2009: 4), as well as geographical restrictions to movement. Trails and roads are features of the cultural landscape that allow archaeologists to study and understand landscapes of movement in the past. Trails link tangible spaces to the social places they are related to, and are created both intentionally and unintentionally through repeated movement (Darling 2009: 72). However, while corridors of movement, like trails, are often conceptualized as the network that links culturally important places within a landscape (Cutright-Smith 2013, Darling 2009), they are also places in and of themselves (Snead 2009).

Through inscription and materialization, that is, the marking of the landscape (both intentionally and unintentionally) and the construction of structures meant to shape the perception of space, movement across a landscape becomes part of the built environment and pathways are infused with meaning (Snead 2009). Human travel inscribes movement onto the landscape, forming the structure of trail networks. These trail networks can then be materialized through the intentional construction of structures that shape the cultural perception of the landscape like cairns, formal roads, and staircases, among other things. The inscribed and materialized structure of the trail system then structures human movement (Snead 2009). In this way, it is important to think about movement and travel as experiential. Travel is not simply a way to get from Point A to Point B, it is a journey, a specific experience that has important cultural and individual meaning. Movement and travel are related to cultural perceptions of the landscape and take into account the relationships between social and physical space, as well as cultural mobility patterns (Darling 2009: 63-64). Because of the experiential nature of movement, patterns of movement often look different depending on their purposes. For example, travel for religious purposes and travel for trade require different patterns of movement in relation to different elements of the built environment, even if they are both using the same trail network (Darling 2009: 64).

Within the framework laid out above, movement and travel are embedded within the complex interactions between cultural ideologies, physical landscape, and human agency. GIS based on physical geographic factors cannot reveal the full cultural context of landscapes, but it can be used to create frames of reference from which to start interpreting landscapes of movement. Considering economic systems and social mechanisms of exchange, and comparing results to known historic and prehistoric pathways used by Indigenous communities alongside the predictive models created using GIS is an important part of geospatial analysis of exchange systems, as it allows researchers to better understand the social context and experiential aspects of trade and travel that have been disregarded in past research.

Mechanisms and Social Contexts of Exchange

Different mechanisms of exchange have varied spatial patterns based on the complex sociocultural factors that affect them. According to Sahlins (1972), in general, exchange is based on cultural concepts of gift-giving and reciprocity. All exchanges lie on a continuum between pure gift, something freely given with no expectation of direct return, and negative reciprocity, in which one attempts to get something for nothing. At the centerpoint is balanced reciprocity, in which reciprocation happens within a finite period of time and is culturally equivalent to the goods received. Where an exchange falls along this spectrum depends on a number of factors, including social/kinship distance, rank and wealth, type of good, etc. (Sahlins 1972), and so to understand the movement patterns of an object, we first have to understand the social and political aspects of its exchange. As Sahlins says, “A material transaction is usually a momentary episode in a continuous social relation. The social relation exerts governance: the flow of goods is constrained by, is part of, a status etiquette” (Sahlins 1972, 185-186). Different degrees of social distance necessitate different types of reciprocity. For example, close kin often engage in generalized reciprocity, or pure gifting. An exchange with a complete stranger, on the other hand, may be one of negative reciprocity, like haggling (Sahlins 1972). According to Sahlins (1972: 182), in today’s economic system of market capitalism economic and social relationships are often separated, but in a gift-giving economy they are merged. However, this understanding of exchange does not fully recognize the relational work that shapes the exchange of goods. Instead, it must be acknowledged that social engagement is inherent in any type of exchange, transactional or otherwise (Harrison-Buck 2021: 569). By recognizing that interpersonal relationships drive exchange regardless of the economic model in use, a better understanding of the social dimensions of exchange can be reached.

Ceramics were a ubiquitous item in Southwestern cultures, and were often moved far from where they were produced (Blinman and Wilson 1992). Though pottery was exchanged between communities, it must be acknowledged that exchange was not the only mechanism of pottery circulation. At least some pottery movement can be accounted for by the short-term sedentism followed by migration practiced by many prehistoric communities in the area (Zedeño 1998: 465), as well as logistic procurement and raiding (Blinman and Wilson 1992: 67). In the Southwest, pottery would have been exchanged as part of an informal craft economy that circulated goods across inter-community networks. These craft economies were most likely powered by many different mechanisms of exchange, and the circulation of staple and prestige goods would have been integrated within larger economic systems (Bayman 1999). The mechanisms for pottery circulation in various regions likely differed, and probably evolved over time. Pots could have been exchanged as commodities, at informal fairs or markets (Blinman and Wilson 1992; Zedeño 1998). Circulation could also have been structured and facilitated by social relationships such as kinship or marriage (Blinman and Wilson 1992; Lightfoot 1979). There is also ethnographic and archaeological evidence of pottery gifting, particularly of bowls, at public ceremonies and feasts (Willis and Harry 2019; Zedeño 1998). None of these mechanisms for circulation are mutually exclusive. In fact, ceramic exchange in the Southwest was complex and nuanced, and could have involved any number of social mechanisms (Blinman and Wilson 1992).

There are currently two main hypotheses for the economic or social model that best represents the circulation of Fourmile Polychrome and other fourteenth century pottery in eastern Arizona. The first posits that vessels are “commodity pots” that were traded in more formal settings and in greater amounts. For instance, Whittlesey (1974) found that Fourmile Polychrome and other ceramic types “nonlocal” to Grasshopper Pueblo displayed more standardization (less stylistic and functional variability) than their “local” counterparts. It was also noted that Fourmile Polychrome bowls were highly “nestable”, suggesting that as many as seven or eight vessels could be nested for easier transportation (Whittlesey 1974: 110). This study implied that Fourmile Polychrome was produced in such a way to facilitate transport in large amounts. In a review of pottery exchange mechanisms, Zedeño (1998: 467-468) describes “commodity pots” as vessels defined by their “exchangeability”. Fourmile Polychrome is cited as a commodity ceramic type because of its differentiated uses in creator and recipient sites (Zedeño 1998: 470). It is important to note that this is not the same as a market-based economic model, as there is no evidence for market trade in the Ancestral Pueblo and Mogollon regions during this time period (though pre-Hispanic markets did take place in other parts of the Southwest; Fertelmes 2014).

The second theory is that painted ceramics like Fourmile Polychrome bowls were part of a more informal gift exchange that took place at feasts and ceremonies. The exchange of pottery as gifts and ceremonial offerings is well documented in the ethnographic and historical records, and the vessels obtained through these mechanisms were more likely to be bowls, because of their common use as ceremonial food containers (Mills 2007: 213; Zedeño 1998: 469). The majority of known Fourmile Polychrome vessels that were circulated throughout east-central Arizona are bowls (Van Keuren and Cameron 2015), and so a likely exchange mechanism is that they were gifted at ceremonies and feasts. Also, Fourmile Polychrome vessels from recipient sites often have much less use wear and were repaired more often than those from creator sites (Van Keuren and Cameron 2015). This implies that they had a high social value in some areas, as people may have been more careful not to damage the bowls and were more likely to repair them if they were broken (Van Keuren and Cameron 2015). The exchange of pottery at public ceremonies is also archaeologically documented for other wares in the Southwest, such as the Shivwits Ware in northwestern Arizona and southern Nevada (Willis and Harry 2019: 333). These hypotheses form the guiding theoretical principles for my geospatial models, as it is important to consider the social and economic mechanisms by which goods were exchanged when modeling their movement.

Carrying Pots

Recognizing how goods were carried is also essential to understanding the experience of movement across a landscape. In the ancient Southwest, there were no beasts of burden, so people had to carry things themselves while traveling. So how was pottery generally carried?

In the historic period, Pueblo communities tended to carry larger loads in blankets or baskets on their backs, with the weight of the load on the forehead using burden straps or tumplines (Malville 2001; see ethnographic examples in the Handbook of North American Indians Volume 9 1979). The use of baskets to transport pottery is also mentioned in ethnographic accounts. Ford (1972: 32) describes Tewa traders' travel preparations as follows: "Large willow wicker baskets were used to transport the goods. The flour was placed at the bottom with bread above, and the pottery and woven goods were tied to the top of the load". This method of transportation has been documented cross-culturally as well. For example, the Yanomamo people in Venezuela cushion their pottery during travel using bark, and transport multiple vessels in the same basket (Arnold 1985: 110). Similar methods of preventing breakage, such as "net bags, carrying frames, or by packing pine needles, grass, henequen waste, corn husks, or paper between pots tied in bundles" are often used during long-distance travel by multiple cultural groups (Arnold 1985: 110-111). Porters of the Tarascan state of Prehispanic Mexico are depicted carrying pottery in baskets supported on the forehead as well (Hirshman and

Stawski 2013: 12). Transporting heavy loads of goods supported on the forehead is seen throughout the modern, historic, and prehistoric world.

Figure 3: Image of a group of Zuni people carrying goods in blankets supported on the forehead (National Anthropological Archives, Smithsonian Institution BAE GN 04545).

The ethnographic record cannot act as a complete proxy for the behaviors of people in the prehistoric past. For example, the photo of the trading party above (Figure 3) shows burros that were used as pack animals. This would not have been the case during the pre-Hispanic period. However, it is reasonable to assume that people in the ancient Southwest may have carried goods for long distances using similar strategies to those shown in Figure 3. There is little evidence of

Figure 4: A Tohono O'odham woman carrying a pot using a head ring (National Anthropological Archives, Smithsonian Institution BAE GN 02267A).

Figure 5: A plaited yucca head ring (National Museum of the American Indian catalog number 8/9805).

these baskets and burden straps in the archaeological record due to poor preservation, but a few examples of baskets and burden straps have survived (see Plog 1979: Figure 5a). It is possible that larger loads of pottery could have been carried in this way, along with other goods.

A second plausible method of transporting pottery would have been balancing it on the head, using plaited yucca rings to help stabilize the load. Figure 4 shows an example of how a pot may have been carried on the head. Figure 5 shows an example of a plaited ring from the Tohono O’odham tribe. This method of carrying pottery is also documented in the ethnographic records of other cultural groups as well (Arnold 1999: 148-150). Some ceramic types, such as Fourmile Polychrome bowls, are nestable, whether by coincidence or design. Nesting makes it much easier to transport pottery (Whittlesey 1974: 108), as pieces take up less space and may be less unwieldy (Whittlesey 1974).

These two methods of transporting pottery are different energetically, and likely work best for different types of movement. Carrying a large load on the forehead using a tumpline or blanket would likely be more stable and efficient for very long trips. This method has also been documented ethnographically in very rugged landscapes. For example, Nepalese porters transport loads of 50 kilograms up to 250 kilometers in very mountainous landscapes using the tump-line method (Malville 2001). Transporting pottery on the head would likely be better for shorter trips and lighter loads. Also, ethnographically, pottery that is transported on the head tends to be water jugs with specific forms, such as a long neck to prevent spillage (Arnold 1985: 148-150). Because of these differences, it is likely that Fourmile Polychrome was carried in a load supported on the forehead using a tumpline and basket or tied blanket for the travel between creator and recipient sites because of the distance between the sites and the difficulty of the terrain.

As discussed in the section on landscape theories, travel is not just a way to get from one place to another, it is an experience that is infused with meaning (Darling 2009). In geospatial studies of movement, it is important to consider the social and experiential aspects of travel in addition to the geographic and energetic factors that are easier to model. Though these more social mechanisms and experiences can be difficult to represent with GIS models, they can be included in basic ways, like varying the amount of weight a hypothetical traveler is carrying based on the social mechanism for why they are traveling. These factors also can and should be considered in the interpretation of models of human movement, as they help to build a more nuanced understanding of the experience and cultural meaning of travel.

Chapter 4: Introduction to Geographic Information Systems (GIS)

Geographic Information Systems (GIS) are systems that facilitate the gathering, use, and analysis of spatial data (Bolstad, 2019). Space and place are often central to the human experience (Snead et al. 2009), and so geospatial analysis can provide key insights into the complex social and spatial dynamics of past cultures. GIS have become increasingly important tools in archaeological investigations of past behavioral patterns, as we attempt to understand the spatial dynamics of past cultural landscapes, and as GIS softwares and geospatial data become more accessible to researchers (Brouwer Burg, Peeters, and Lovis 2016). GIS can help archaeologists answer a myriad of questions about spatial patterns and trends in artifacts and features, past routes, and can be used in predictive/reconstructive modeling of past landscapes (Conolly and Lake 2006: 2). For this reason, as well as the perception of GIS as a consistent and accurate tool, geospatial analysis has become an integral part of archaeological research. However, the consistency and accuracy of these tools depends heavily on the knowledge of the user, and the methodologies and data that are used (Brouwer Burg 2017). GIS (like cartography in general) is not necessarily objective, because the user controls what formulas and factors are being used, and what data is fed into the analysis. The biases of the user can affect the outcome of an analysis and subsequently the visual product or map. This issue can be combatted using theories based in critical cartography, which can be helpful in deconstructing the power dynamics and cultural beliefs inherent in traditional Western cartography (Wood 2010: 120). For similar reasons, GIS cannot be used uncritically. Its weaknesses must be acknowledged along with its utilities.

Utilities and Limitations of GIS

As a way to better understand past spatial relationships and dynamics, archaeologists often use GIS to model past landscapes, behaviors, and interactions (Brouwer Burg, Peeters, and Lovis 2016). However, it must be acknowledged that these models are often a simplification and abstraction of reality (Branting 2012), and do not necessarily depict the reality of the past accurately (Brouwer Burg 2017). This becomes especially important to consider when using GIS to reconstruct past human behavior because past actions cannot be exactly replicated. This is due to the recursive relationship between the structural frameworks that humans build (which shape daily life) and the agency humans have to break from those structures (Snead, Erickson, and Darling 2009; Varien 1999). GIS and computer simulation models will never be able to perfectly replicate past human decisions, but they can act as hypotheses against which we can test real-world data to better understand past human behaviors (Crabtree 2015). When constructed carefully, models can be used as heuristics to compare with real-world data, which can reveal the complexities and theoretical implications of that data (Branting 2012; Brouwer Burg 2017; Brouwer Burg, Peeters, and Lovis 2016; Crabtree 2015).

Because models are simplified and abstracted from reality, uncertainty can enter them at any point in the generation process (Brouwer Burg 2017). Entry points for uncertainty can vary, but the most common entry points for methodological uncertainty are inherent errors in input datasets, the choice of model, and the determination of model fit to those datasets (Brouwer Burg 2017; Brouwer Burg, Peeters, and Lovis 2016). Uncertainty and error are things that should be acknowledged and controlled for at every point of the process of model creation. This can be done through sets of recursive analytical tests that are performed throughout the generation of a model. Verification tests determine how well a model does what it’s supposed to do. Calibration tests help to determine the input parameters that generate an output that approximates real-world data. Sensitivity analyses allow a user to understand how changes in input variables and parameters affect the output. Finally, validation tests determine how well a final model approximates reality (Brouwer Burg 2017). These tests of uncertainty become more difficult when creating models to answer archaeological questions in particular because archaeological data sets are inherently incomplete (Brouwer Burg, Peeters, and Lovis 2016). Very little past material culture actually survives in the archaeological record, and multiple natural and cultural processes can result in the same archaeological findings (Brouwer Burg 2017; Brouwer Burg, Peeters, and Lovis 2016). Thus, the acknowledgement and quantification of uncertainty in archaeological contexts is particularly essential to the generation of a sound model. Robusticity tests were built into the methods for this study by continually verifying and calibrating cost surfaces and models during construction, as well as by validating models using a number of historical maps.

GIS is particularly useful to archaeologists studying movement across landscapes. Least Cost Path (LCP) analysis is one of the most popular tools for modeling past movement. LCP analysis is based on the concept of cost-equivalent distance. The basic idea is that a cost-equivalent unit is the distance that “costs” the same as that unit on flat ground (usually energetically) (Varien 1999; Teeter 2017). Originally derived from ecological studies of movement within animal habitats, LCP analysis is based on the premise that to move through a landscape, an agent must expend a certain amount of effort, or “cost.” Cost can be measured in various ways, from the actual energetics expended in moving a particular distance, to time involved, etc. These models are based on cost surfaces, which are regular grids in which each cell is assigned a ‘cost’ that represents how difficult it is to move through that cell. The LCP is the path from one user-designated point to another that accumulates the lowest ‘cost’ on its route (Herzog 2014). That is, it is the most efficient path from Point A to Point B. LCP analysis is useful because in complicated geographic landscapes, straight-line distance does not accurately capture the true cost of movement from one location to another, nor does it accurately represent how a person would actually move through that terrain (Herzog 2014). LCP analysis is a way to better model the cost and reality of moving through a landscape. In most archaeological LCP studies, cost surfaces are based on elevation data, which can be used to calculate the slope, walking time, or energy expenditure for each cell (e.g. Herzog 2014; Herzog 2021; and Gowen and Smet 2020).

Circuit Theoretic (CT) modeling was developed out of electrical engineering, and has primarily been used to model migration corridors and gene flow within animal populations (Howey 2011), although there are a growing number of archaeological studies utilizing this GIS method (see Howey 2011; McLean and Rubio-Campillo 2022; Moreno-Meynard et al. 2022). CT analysis conceptualizes the landscape as a circuit of nodes that either impede or conduct the “electrical current” of movement (Howey 2011). The user inputs a cost surface file, representing the conductivity of each node or cell, and a file of focal nodes that the current flows from and towards. The program then generates a map showing the amount of current flowing through each cell, displaying, in the case of most archaeological studies, the corridors of high potential movement through a landscape. CT and LCP analysis complement each other well in studies of movement in the past, in that LCP analysis shows the one most efficient path between two points, and CT models show a number of relatively efficient paths. Utilizing both methods allows for a more complex understanding of movement within a region.

Like any tool, these techniques have their limitations. First, LCPs are based on the modern idea of path optimization (Lewis 2021), which operates under the assumption that all agents in the past moved through a landscape with efficiency as their singular goal. Although ancient pathways do often follow the most energy- or time-efficient routes (Herzog 2014), they could also have been affected by social or political factors that cannot be easily assumed or modeled today. Second, LCPs are heavily affected by both the cost model and the topographic data used (Herzog 2021), meaning that multiple cost models should be assessed and applied to fully understand the most appropriate pathway. Further, as discussed above, there are inherent errors in any input data that must be acknowledged and mitigated (Lewis 2021). Finally, LCP analysis only defines the single most efficient path through a landscape, ignoring natural and cultural variability in individual behavior, as well as the fact that the "optimal" route may not always be available or desirable (Howey 2011; McLean and Rubio-Campillo 2022). There are additional techniques that have been developed to mitigate this latter issue of singular route creation such as CT modeling.

CT analysis is a strong complement to LCP analysis in that it allows for multiple low-cost paths to be defined in the same model. However, CT modeling has limitations as well. CT models are isotropic, which means that they can't accommodate movement that has different costs in different directions. CT analysis is also restricted to generating random walk models, in which each movement is independent from the last, meaning there is no "memory" of past moves (McRae et al. 2008). Also, as CT models are focused on identifying multiple low-cost paths through a landscape, the one most efficient path can be under-emphasized (Howey 2011). Finally, both CT and LCP modeling are also affected by the presentist cultural concepts of the modeler, for example, a prioritization of travel time that arises from modern Western cultural ideals (Kantner 2012). When used in conjunction, CT and LCP analyses create richer understandings of past movement where scenarios in which multiple pathways are useful, and scenarios in which the single most efficient route takes priority can coexist (Howey 2011: 2534).

GIS Use in Southwestern Archaeology

The use of GIS in archaeology began in the 1990s and has increased exponentially in the years since (Conolly and Lake 2006). Geospatial analysis is particularly helpful in understanding the historical complexities of regional social networks, community boundaries, household and community mobility, trade, and trail networks, among other topics. The following selection of studies demonstrate the utility of GIS in studying community relationships, movement, and exchange in Southwestern archaeology, as well as general methodological trends that are relevant to this project.

GIS is useful in studying community boundaries and relationships between settlements. Varien's (1999) study is one of the first uses of cost-distance in the context of Southwest archaeology, using cost-equivalent distance to create boundaries between communities in Mesa Verde and better understand how those boundaries changed over time. Later, Kantner and Hobgood (2003) used multiple LCP algorithms to model hypotheses for the intended functions of the Chaco regional road system. They found that the road system in the Lobo Mesa area of the Chaco region focused on intra-community integration, and connected outlying communities to important geographical features (Kantner and Hobgood 2003). Teeter (2017) also emphasized the importance of cost-distance in his analysis of prehistoric travel into, out of, and through the Grand Canyon. This study found that trails in the Grand Canyon often follow cost-efficient routes, though they deviate in favor of straight-line pathways and to intersect with important resource locations, such as water sources. Cost-equivalent distance was used to create catchment areas for sites (the territory in which people probably stayed for day to day activities), and LCPs were generated to simulate travel routes through the canyon. LCPs were validated by comparing them to existing trails, and also by using buffers to identify archaeological sites near pathways (Teeter 2017).

Least Cost Path analysis is a popular methodology for studying the movement of people and things in the past, often expanding on social network analyses that have identified social connections between certain sites or regions (e.g. Mills et al. 2013). Safi (2014) identified four main migration corridors from Mesa Verde to the Rio Grande area, with the goal of better understanding the major migration between these two areas during the Pueblo III period. Using multiple start and end points allowed for the acknowledgement of spatial variation in these major routes, as well as the understanding that the routes predicted by GIS to be less traveled may actually have actually been more popular due to their proximity to large, well-known settlements and other cultural factors (Safi 2014). Caseldine (2021) used LCP analysis to study pathways within and out of Tonto Basin to find corridors of travel between sites. The LCPs for this study were generated from cost surfaces based on slope, walking time, and energy expenditure. The movement corridor models were then compared to each other and to military accounts of trails to validate the predictions (Caseldine 2021).

LCP analysis can also be used to understand exchange and trade. Field, Heitman, and Richards-Rissetto (2019) used multiple algorithms to generate LCPs testing different hypotheses for the creation and use of formal Chaco roads; one simulating the development of roads for timber transportation, and the other simulating the use of preexisting roads for timber transportation. They found a high correlation between modeled and real-world Chaco roads even when pre-existing roads were not considered as conduits to movement, suggesting that Chaco roads were built along efficient routes for timber transport (Field, Heitman, and Richards-Rissetto 2019). Luévano (2022) modeled LCPs between California and Arizona to better understand the exchange of shells between these two areas. A cost surface based on slope was used to generate pathways, which were validated using historically documented trails (Luévano, 2022).

These studies set a precedent for cost distance and social network studies in the Southwest. There are also a few clear methodological trends in these studies. Most researchers use multiple cost surfaces based on different variables to create multiple iterations of LCPs between the same sites to understand more general trends in movement rather than relying on a single LCP to predict trail location. Multiple start and end points are used to further increase the number of LCP iterations. Finally, these LCPs are then validated by comparison to each other, to known historical trails, and to archaeological data. This research forms a solid foundation for this study, which is set in rugged terrain in the Southwest, and my analysis used similar methods to those found here.

Chapter 5: Methods

Cost Surfaces

This analysis uses modern geographic data to create cost surfaces for movement models, as paleo-landscape reconstructions are not available for this area. Thus, this study assumes that the landscape of this study area looked the same in the past as it does today, which is likely not the case. Cost surfaces were created using the Raster Calculator tool in ArcGIS Pro 3.0.3. Four final cost surfaces were created, starting with the least complex, and moving to the most complex. The final cost surfaces represented slope, walking time (in hours), and energy expenditure (in kilocalories per meter). There were two energy expenditure cost surfaces, one representing a gift exchange scenario and the other a commodity exchange scenario. The slope cost surface was generated using the Slope tool based on a 30-meter resolution Digital Elevation Model (DEM) from the United States Geological Survey (USGS). This surface was then used to calculate the surface for walking time based on an equation from Gowen and de Smet (2020), which is a modified Tobler's Hiking Function (see Tobler 1993). Following the advice of Caseldine (2021), the function was broken up into smaller sections to make it easier to process. The equation is as follows:

$$T = \frac{R/1000}{6e^{-3.5|\tan(D\pi/180)+0.05|}}$$

Where

T = time (hours)

D = slope (degrees)

R = spatial resolution of DEM (meters)

The process for the energy expenditure cost surfaces required three different functions. First, walking time was converted into velocity (m/s) using the following:

$$V = 6e^{-3.5\left|tan(\frac{D\pi}{180})+0.05\right|} \cdot (C)$$

Where

V = velocity (m/s)

C = factor for converting km/hr to m/s (1000/3600 or 0.277778)

The bulk of this equation is Tobler's Hiking Function, which was calculated as a step in the Walking Time cost surface. This function converts Tobler's Hiking Function, which is in kilometers per hour to a velocity that is in meters per second. Then, this velocity is used to calculate the Metabolic Rate of Travel (MRT) with this equation:

$$MRT = 1.5W + 2(\frac{L}{W})^2 + \eta(W + L)\{1.5V^2 + 0.35V[tan(\frac{D\pi}{180})100]\}$$

Where

W = individual weight (kg)

L = external load (kg)

V = velocity (m/s)

η = terrain coefficient

D = slope (degrees)

Individual weight (W), which represents the weight of the hypothetical traveler in this model, was set at 45 kilograms, following Caseldine's (2021) methods. Velocity (V) is represented by the previously calculated velocity raster. Slope (D) is also represented by the previously generated raster. The external load (L), or the amount of weight the traveler carries, differs based on the exchange model represented by the cost surface. There were two factors in determining this number. The first was a base weight of 15kg, based on Malville's (2001: Table

2) study of Nepali porters. This weight represents food and personal belongings carried, which can range from 10-15kg. I chose 15kg to represent food, belongings, and any other goods carried to exchange. The second factor was the weight of the pottery. There is very little data on the weights of intact White Mountain Red Ware bowls. Six Fourmile Polychrome bowls from the Museum of Peoples and Cultures collection at Brigham Young University were weighed to create a representative sample based on rim diameter. Appendix A provides the weight data used here. The external load for the gift exchange scenario was calculated from the bowls with the largest and smallest rim diameters, reflecting the assumption that fewer bowls would have been transported in a gifting scenario. External load for the gift exchange scenario (L_G) was 16.9 kilograms. The external load for the commodity exchange scenario was calculated from the weights of all six bowls, based on Whittlesey's (1974) assertion that Fourmile Polychrome was produced with more formal exchange in mind, so up to seven or eight bowls could be nested to transport all at once. External load for the commodity exchange scenario (L_C) was 20.3 kilograms. The terrain coefficient (η) raster was created by reclassifying a section of the Southwest Regional Gap Analysis Project's land cover map using terrain coefficients from Safi's (2014) LCP analysis. It should be noted that there were gaps in this land cover data that can be identified in the final cost surfaces, however it was still the most complete dataset that I could access. The terrain coefficient table, the Fourmile Polychrome bowl weight and rim diameter table, and more detailed cost surface methods can be found in Appendix A.

Least Cost Path Analysis

The starting points for the LCP analysis were Fourmile, Shumway, and Showlow Ruins, as they are the likely locations of Fourmile Polychrome production (Triadan et al. 2002; Van Keuren and Ferguson 2020). The exact locations of these sites were used in the analysis; they are well known, and their locations have been previously published. In contrast, the endpoints were randomized points near some of the recipient villages of Fourmile Polychrome in the Transition Zone south of the Mogollon Rim; the latter were based on site locality data presented in previous publications (e.g. Triadan 1997; Triadan and Zedeño 2004). This randomization was done to protect the exact locations of sites on White Mountain Apache Tribe lands that are vulnerable to looting. Three-kilometer buffers were created around general site localities, and then five random points were generated within each buffer. These are the endpoints for the LCPs. Some known recipient sites, like those on the southern Colorado Plateau, were excluded to curtail the scope of the project. The site of Tundastusa is not included in either the creator or recipient categories because of the ambiguity of its role in this exchange system (Van Keuren and Ferguson 2020). LCPs were run individually between each creator site and each cluster of randomized recipient sites to increase the number of iterations, which helped elucidate corridors that LCPs moved through. See Appendix B for detailed LCP methods.

Circuit Theoretic Modeling

CT modeling for this project was done in Circuitscape, a freely available software program. Circuitscape has a number of modeling modes; the two that are most applicable to archaeological data are the Pairwise and Advanced modes (Howey 2011; McLean and Rubio-Campillo 2022). In the Pairwise mode, connectivity is iteratively calculated between all pairs of focal nodes in a single input file. Using the Advanced mode, a user inputs a file for current sources and another file for current grounds within a landscape, which are activated simultaneously to create a circuit (McRae et al. 2013). In this study, I used the Pairwise modeling mode for all CT models on the suggestion of Howey (2011). The focal nodes were 5-kilometer buffers around each site (both creator and recipient) to decrease the amount of computational power needed for the analysis. The resistance data was the four cost surfaces detailed above at a coarser resolution (300m instead of 30m), again to decrease the computational power needed. Though the cost surfaces used for the CT models were much coarser than those used for the LCP analysis, the accuracy of the resulting models was not affected greatly, as the coarser resolution still captured important landscape features (McRae et al. 2008). This analysis resulted in four final CT models against which the LCPs could be compared. See Appendix C for detailed CT modeling methods.

Validation of Modeling by Comparison of LCPs and Historical Trails

When corroboration through archaeological survey and excavation is not possible, comparison of LCPs to known trails or roads can serve as a way to "ground-truth" predictive models (Caseldine 2021; Herzog 2021; Kantner 1997). Since many modern roads and historic trails in the Southwest tend to follow the trajectories of prehistoric Indigenous trails (Colton 1964), I compared the outputs of my predictive models to historical trails and modern roads within the study area. The shapefile for modern roads was "All Roads Network 2020" for Arizona and was found on ArcGIS Online. Maps of historical trails and roads were georeferenced and digitized from Stein (1994), and included major Native American trails as evidenced through archaeological and ethnographic studies, routes used during the Mexican period and U.S.-Mexican War, military roads used during the Indian Wars, and trails used predominantly by Mormons for colonization (see Stein 1994: Figures 1, 3, 6, and 7). An 1869 map drawn by L. H. Webber and O. R. Potter (courtesy of Dr. Welch of Archaeology Southwest) was also georeferenced and the trails were digitized. Then, I calculated correlation factors between the real-world trails and modern roads and my LCPs to test the accuracy of my predictive models. A correlation factor is the percent that the predictively modeled LCPs overlap with known trails or roads (Field, Heitman, and Richards-Rissetto 2019; Gowen and de Smet 2020). The real-world pathways were buffered at 25, 50, 75, and 100 meters. The LCPs were then intersected with those buffers, and correlation factors were calculated by taking the sum of the intersection lengths and dividing it by the sum of the LCP lengths. This was done for each of the four sets of LCPs. See Appendix D for detailed validation methods.

Chapter 6: Results and Discussion

LCP and CT models

The GIS models constructed for this study show corridors of movement between creator and recipient sites of Fourmile Polychrome. Figure 6 illustrates how many of the LCPs follow similar pathways and deviate slightly from one another. The LCPs based on walking time deviate from the pattern seen in the other three groups, trending toward more direct routes between sites. The LCPs based on commodity exchange and gift exchange take very similar routes through the landscape, suggesting that the same pathways would have been used to circulate pottery, regardless of the economic model that that circulation was based on. The LCP models show a few general corridors of movement that many pathways move through. Almost all of the pathways to the two southernmost recipient sites move through the same corridor in the east of the study area, and the pathways to 2-3 other sites also follow this corridor for some distance before diverging. The other clear corridor in the LCP models follows the Mogollon Rim for a time, before dipping below it in the west of the study area to reach the western cluster of sites. In fact, there seems to be a continuous pathway roughly following the Mogollon Rim throughout this area. The geology of this region makes travel along the Mogollon Rim relatively easy, and the rim is easier to traverse in the east, than the west (Triadan and Zedeño 2004), so in terms of efficiency and ease of travel, these corridors are intuitive pathways.

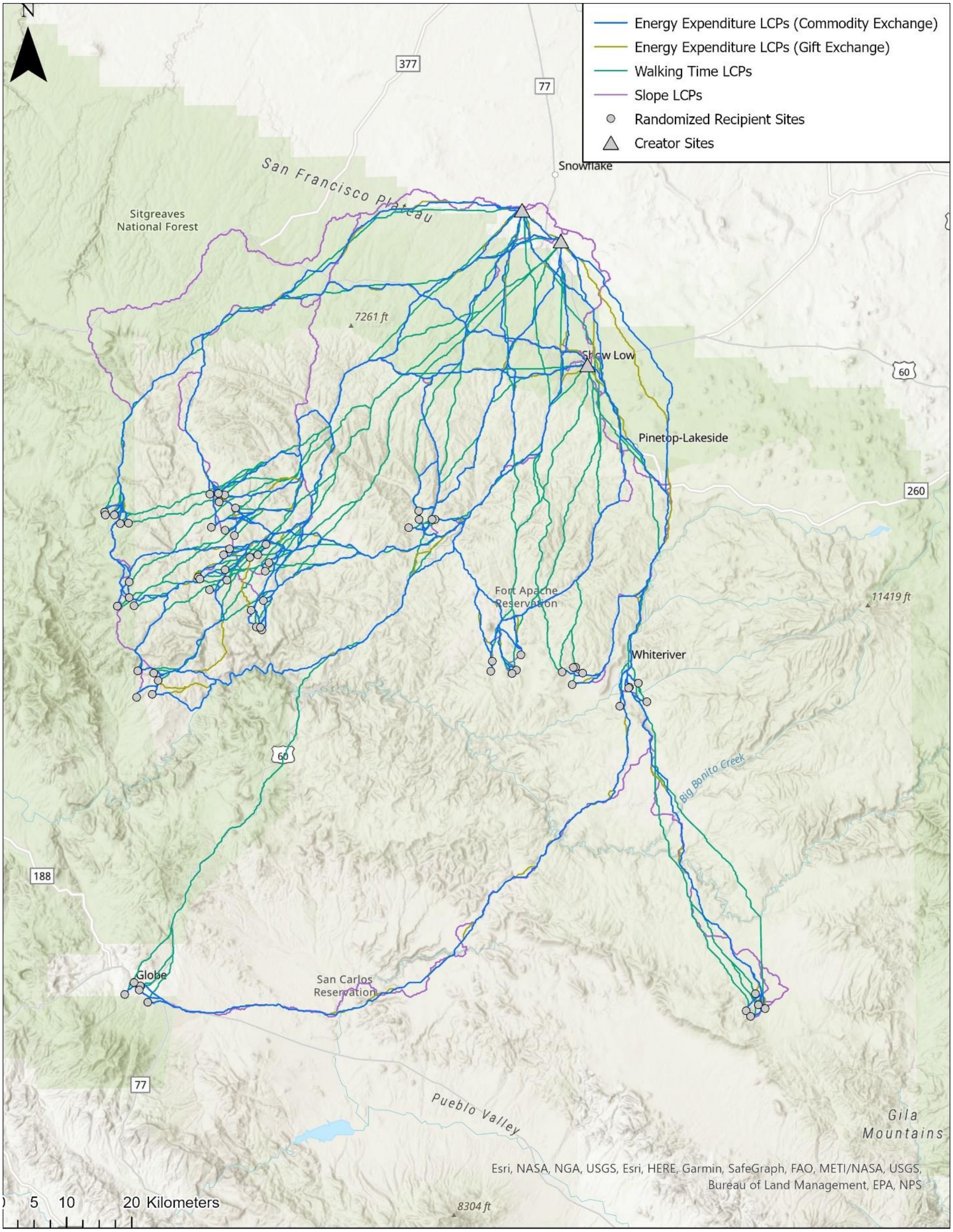
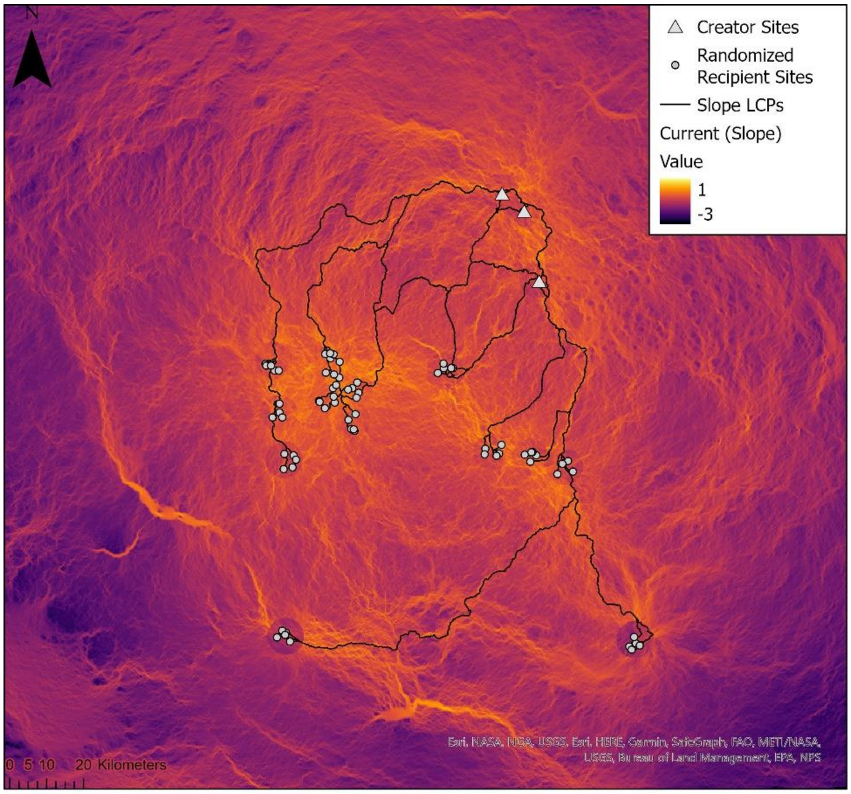
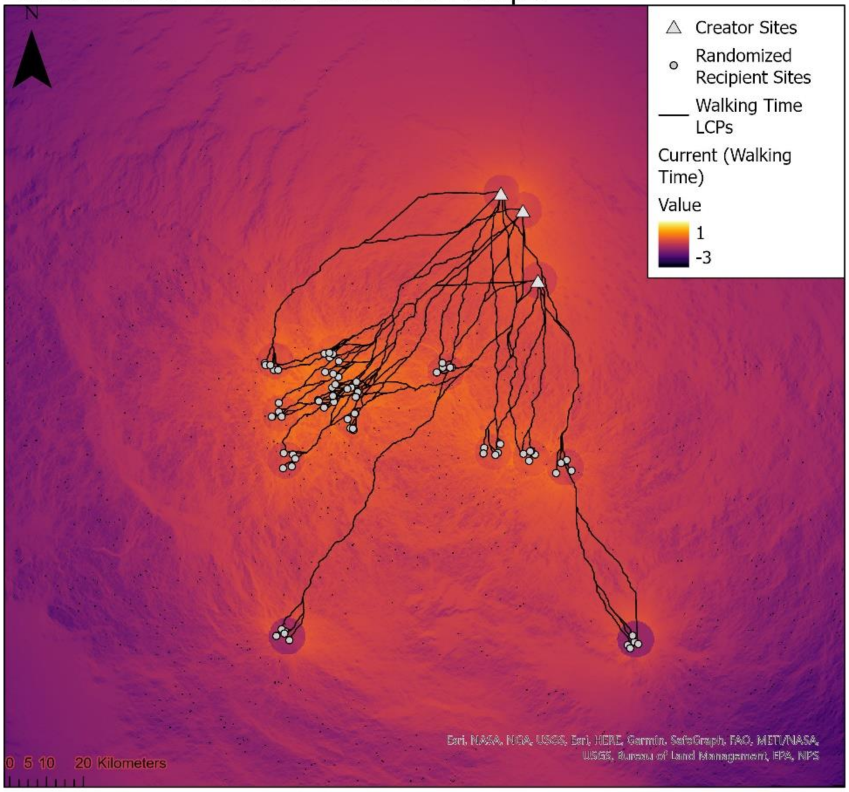


Figure 6: All generated LCP pathways.

The CT models have corridors of high potential movement that follow similar pathways to the LCPs, corroborating the LCP routes. However, there are also areas of high potential movement shown on the CT models that are not reflected in the LCP models (see Figures 7a and 7b), implying that there likely were other trails in the area that did not follow the trajectories of the LCPs. One of these corridors connects many of the recipient sites below the Mogollon Rim, something that the LCPs were not able to model because of their rigid start and end points. Another seems to roughly follow the Salt River in the south. A few of the LCPs follow this corridor of high potential movement briefly, but the CT models imply that trails could likely have followed the Salt River for longer stretches than those seen in the LCP models. The CT models for this region emphasize that LCP analysis can only show parts of a possible trail system because it only considers paths between two specific points, whereas CT analysis can use an interactive process to consider corridors of movement between multiple sites at once.

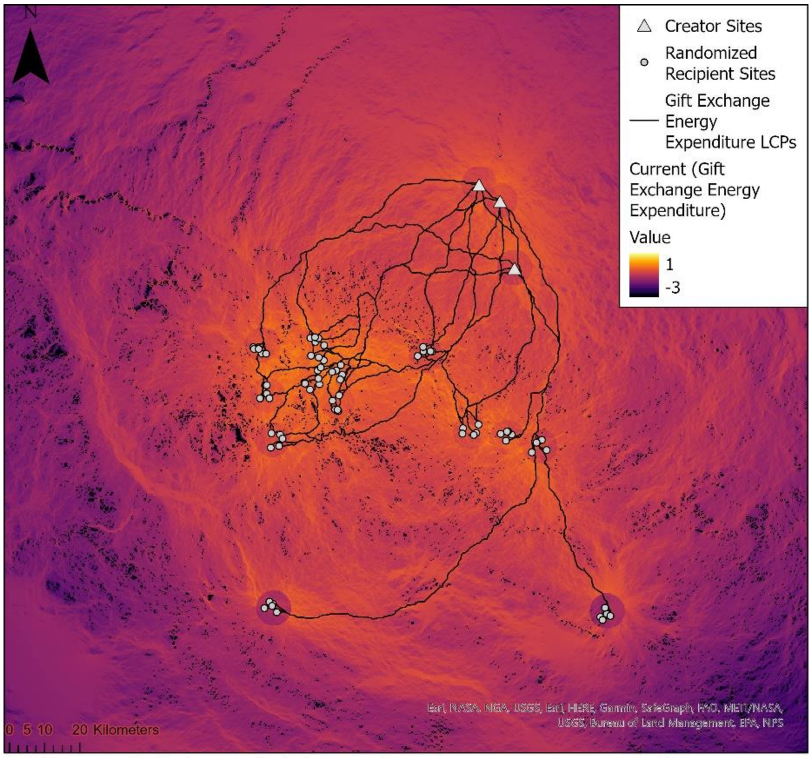


LCPs and CT model based on slope

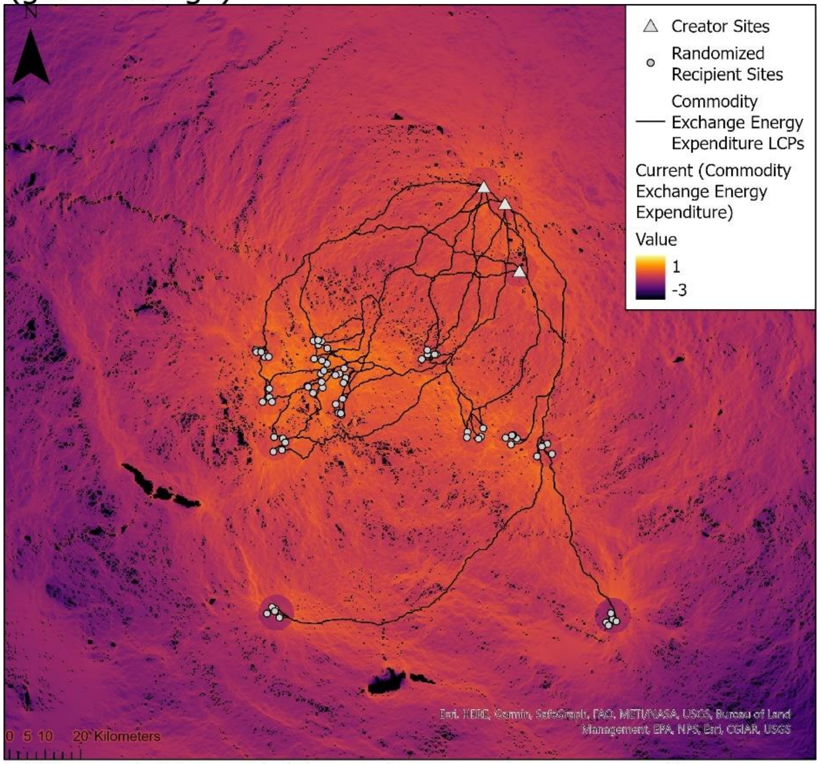


LCPs and CT model based on walking time

Figure 7a: CT models based on slope and walking time and corresponding LCPs.



LCPs and CT model based on energy expenditure (gift exchange)



LCPs and CT model based on energy expenditure (commodity exchange)

Figure 7b: CT models based on energy expenditure and corresponding LCPs.

Validation of LCPs with Correlation Factors

Correlation factors between LCPs and historical trails mapped by Stein (1994) were very low; the highest was 2.2% (see Table 1). There are a number of reasons that this could have happened. The first, is that the historical trails were georeferenced and digitized from an older, presumably hand drawn map of all of Arizona. The trails on Stein's maps are much more general than my LCPs, which are very granular, having a 30-meter resolution. The second is that my study area includes the White Mountain Apache Reservation. Though there is a project there to map historic trails (Van Keuren pers. comm.), that data is not available to the public. Because of this, I have low coverage of historical trails in the area of my LCPs. However, general trends in routes documented by Stein (1994) and my LCPs can still be found (see Figure 8). There seem to be two general routes running laterally, one along the Mogollon Rim, and the other along the Salt River. There is also one shared north-south route between the historical maps and the LCPs in the east of the study area. All three of these routes can be found in the LCP and/or CT models. These are the routes that are most likely to have been used in the past.

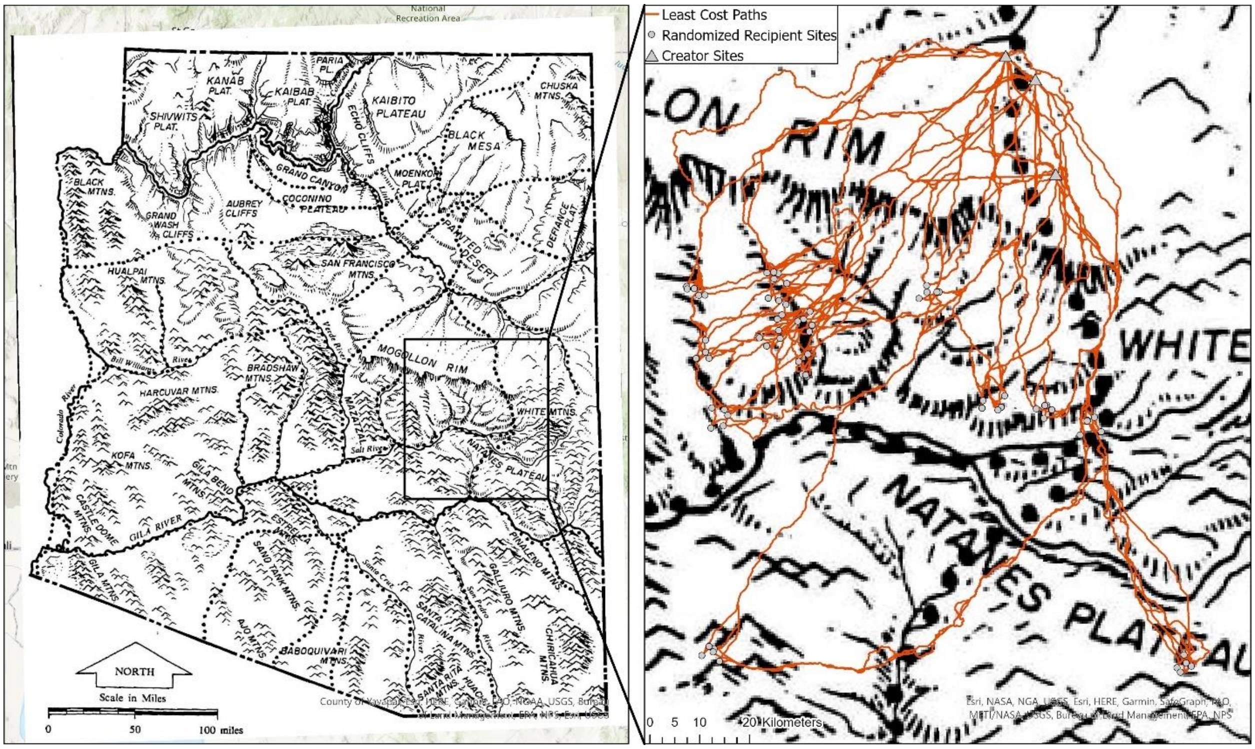


Figure 8: Indigenous trails as documented archaeologically and ethnographically (Stein 1994: Figure 1) compared to LCP models.

The correlation factors between the LCPs and the trails on the Webber and Potter (1869) map were similar to those from the Stein (1994) maps, the highest value being 1.8% (see Table 2). The low correlation factor values can be partially explained by the accuracy of the historical map. Again, it is not as granular as my LCPs, which means that the modeled pathways follow similar pathways to the historic trails, but they do not completely overlap. The accuracy of the map could also have to do with an error in georeferencing, which, in this case, was based on the locations of river confluences that still exist today. Although this got the historic map close to matching the modern landscape, I acknowledge that river beds likely have shifted slightly over the past approximately 150 years, and so there could have been errors in the georeferencing.This map covers a much smaller area than the Stein (1994) maps, but there are still some general trends that can be observed. A north-south corridor in the middle of the map (see Figure 9) can be found in both the documented historical trails and the LCPs. This corridor also moves through or comes close to three recipient site localities before arcing to the west to parallel the Salt River, a corridor documented in the Stein (1994) historical maps, and in the LCPs. There are also a few short east-west corridors that diverge from this central north-south corridor that are followed by both historical pathways and LCPs.

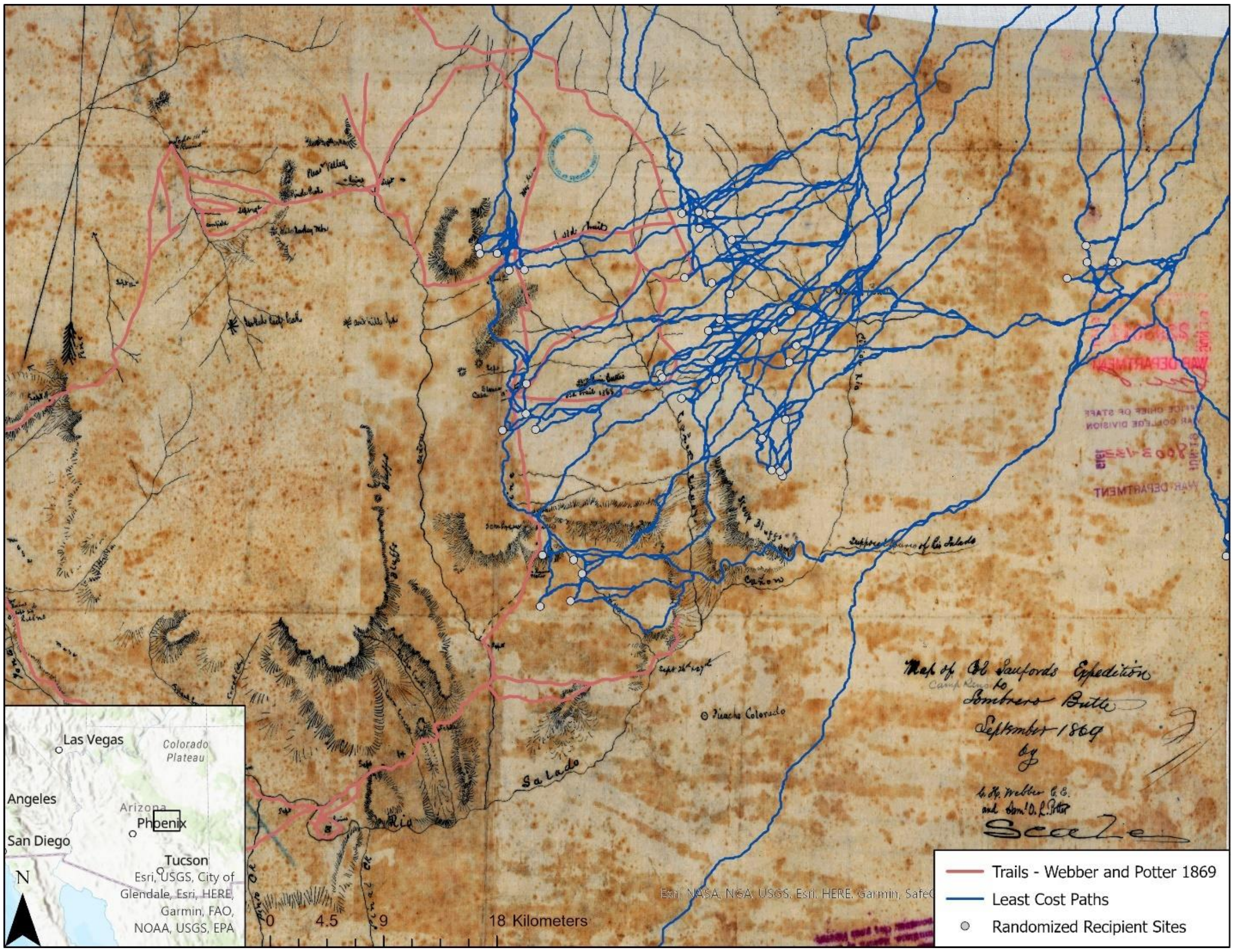


Figure 9: LCPs and trails digitized from Webber and Potter (1869) map (provided by John Welch of Archaeology Southwest).

Correlation factors between LCPs and modern roads were higher, but still not high enough to definitively conclude that they correlate, with the highest being 30.4% (see Table 3). This is most likely because the shapefile I used for the modern roads has much better coverage than the historical trail maps. However, it is possible that this higher correlation does not reflect that the LCP pathways would have been used as trails in the past, as the construction of modern roads focuses heavily on efficiency, as do the LCPs. Also, the LCPs based on slope consistently had the highest correlation factors with modern roads of each buffer category, which makes sense as there are slope restrictions on roads because of the mechanical descriptions of modern automobiles. Foot travel is still affected by slope, but not to the degree that automobile travel is.

Along with the error and granularity explanation for the discrepancies between the LCPs and real-world trails, there are also theoretical explanations. First, the GIS models generated for this study follow the assumption that at least part of the trail system of this area was created to circulate pottery and other goods, as they are generated without taking into account the lower cost of traveling existing trails or roads. Field, Heitman, and Richards-Rissetto (2019) explain that there is a difference between the *intent* of the creation of a trail or road system to be efficient for certain types of travel, and its *utility* for other types of travel. Because the models detailed here do not necessarily correlate with historical trail trajectories, perhaps the intent of the trail system in east-central Arizona was not to create efficient trade routes between these settlements, but the trail system was still utilized for that purpose.

Second, the LCP models represent one-to-one relationships and pathways between creator and recipient villages. Given the nature of the social mechanisms of exchange likely involved in the circulation of Fourmile Polychrome (that is, ceremonies/feasting or informal gift exchange; Zedeño 1998), the movement involved in these mechanisms could have looked more like many people converging on one location and then diverging, or, more informal down-the-line exchange. These different types of movements could have affected the pattern of the trail system, especially if a certain few villages tended to hold the biggest or most important ceremonies or feasts. Evidence of which villages may have been the hosts of ceremonies and which were not is ambiguous, and so the best way to model pathways for this project was on a one-to-one basis. However, the movement of an individual piece of pottery from where it was produced to where it was discarded likely was not as direct as is suggested by the LCPs in this study.

Finally, trails could have diverged from the most efficient pathways to travel between established contemporary sites or other resource locations. LCP path length ranged from approximately 47 to 252 kilometers, and probably would have taken between two and twelve days to travel depending on the amount of weight carried, and the distance between sites (see Malville 2001: Figure 1 for progression rates). A trip between any of these creator and recipient sites would have been a multi day trek. If there weren't established contemporary sites near the most efficient pathways, perhaps travel was diverted to nearby sites to spend the night. The trajectories of trails could also have been affected by the locations of already established shrines, or known locations of food or water. Regardless, the formation of trail systems is a complex, often iterative process (Varien 1999: 25-27), that is not dictated by any one factor. The pathway models laid out in this paper show broad movement trends through the Arizona mountains of east-central Arizona, and are a good heuristic tool for further archaeological survey and excavation to determine the locations and trajectories of prehistoric trails in this area.

Table 1: Correlation factors for LCPs and historical trails (from Stein [1994]).

Buffer width (m)	**Slope**	**Walking Time**	**Energy Expenditure (Gift Exchange)**	**Energy Expenditure (Commodity Exchange)**
25	0.0052	0.0070	0.0060	0.0049
50	0.0099	0.0109	0.0136	0.0115
75	0.0134	0.0182	0.0179	0.0167
100	0.0171	0.0223	0.0224	0.0218

Table 2: Correlation Factors for LCPs and historical trails (from Webber and Potter [1869]).

Buffer Width (m)	**Slope**	**Walking Time**	**Energy Expenditure (Gift Exchange)**	**Energy Expenditure (Commodity Exchange**
25	0.0042	0.0013	0.0017	0.0020
50	0.0083	0.0024	0.0031	0.0041
75	0.0129	0.038	0.0044	0.0056
100	0.0177	0.0049	0.0062	0.0072

Table 3: Correlation factors for LCPs and modern roads.

Buffer Width (m)	**Slope**	**Walking Time**	**Energy Expenditure (Gift Exchange)**	**Energy Expenditure (Commodity Exchange)**
25	0.0970	0.0852	0.0969	0.1011
50	0.1806	0.1572	0.1770	0.1805
75	0.2482	0.2169	0.2404	0.2435
100	0.3042	0.2653	0.2956	0.2986

Trail Systems and Social Networks

The major movement corridors detailed above also have an interesting relationship with the distribution of different compositional groups of Fourmile Polychrome and earlier White Mountain Red Ware as described by Van Keuren and Ferguson (2020). In southwestern provenance studies, individual compositional groups are assumed to represent localized pottery production zones (e.g., potter neighborhoods; Glascock and Neff 2003). The three major compositional source groups of Fourmile Polychrome are Groups 4, 5, and 7 in Van Keuren and Ferguson's (2020) neutron activation study. Pottery of the compositional Groups 5 and 7 are found at Fourmile Ruin and Shumway Ruin, the most likely sources of production for these groups. Pottery in Group 5 is found at other sites below the Mogollon Rim, and also to the north and east; pottery in Group 7 is very limited, geographically. Pottery of Group 4, however, is conspicuously absent at Fourmile Ruin and Shumway Ruin, and so must have been produced at Showlow Ruin or Tundastusa Ruin, or perhaps both villages. Pottery of this source was almost entirely circulated below the Mogollon Rim, and is especially prevalent at Mogollon pueblo sites in the southeastern portion of the study area for this project (Van Keuren and Ferguson 2020). According to Van Keuren and Ferguson (2020: 15) the distribution differences of these different compositional groups suggest "villages in the Arizona Mountains and points southward obtained Fourmile Polychrome mainly produced in the southern Silver Creek cluster; northern Silver Creek villages supplied Middle Little Colorado and other parts of the Upper Little Colorado". The different social relationships evident in the varied distribution patterns of Fourmile Polychrome detailed by Van Keuren and Ferguson (2020) have some interesting connections to the general movement corridors observed in this study. The major north-south corridor in the eastern portion of the study area runs through or close to Showlow Ruin, and can also be seen in Stein's (1994) historical maps, as well as in the modern road maps. This makes a strong case for this eastern corridor as a thoroughfare for the movement of Fourmile Polychrome between Showlow Ruin and sites below the Mogollon Rim, especially those to the southeast. Analyses of material culture have evidenced the social and cultural connections between sites in the Silver Creek cluster and those below the Mogollon Rim in the past (see Reid 1989; Triadan and Zedeño

2004; Whittlesey 1974), but the models generated in this study help to elucidate the physical and geographical connections between sites that facilitate social networks.

Chapter 7: Summary and Future Research

This GIS analysis adds to archaeological knowledge of how an important tradition of painted bowls were circulated in the fourteenth-century Southwest. The predictive trail models generated for this study show a few broad corridors of movement in east-central Arizona that likely were used in the circulation of Fourmile Polychrome. The three corridors with the strongest case for prehistoric use are an eastern corridor that runs north-south through the Arizona mountains, a corridor that parallels the Mogollon Rim, and a corridor that follows the Salt River in the south. These modeled corridors correlate with known historic trails in the area, and a few also overlap with the possible access routes in the Arizona Mountains mapped by Triadan and Zedeño (2004: Figure 10.2). The CT models and digitized historic trails detailed above imply the existence of a much more complex trail system connecting many of the sites that were not connected in the LCP models. Finally, this work provides further evidence for modeling intra-regional social relationships and exchange networks that have been detailed in ceramic provenance research (Triadan 1997; Triadan et al. 2002; Van Keuren and Ferguson 2020). Recent social network analyses and models of movement are often larger-scale and inter-regional in scope (e.g. Luévano 2022; Mills et al. 2013; Safi 2014); this project emphasizes the necessity for smaller-scale, intra-regional studies of exchange in addition to broader studies.

This study also focuses needed attention on landscapes and experiences of ceramic circulation. The connections revealed in studies of exchange networks are important; without them, studies like this likely would not be possible. However, research like this project, that goes beyond network analysis, is also necessary. It is important to consider how the connections inferred through the movement of objects manifest in physical space, as well the experience of moving through that space with goods. Another important aspect of the circulation of goods to consider is the social dimensions of exchange. In this project, I consider the trails that people may have used to move pottery in east-central Arizona. I also discuss how this pottery likely would have been carried by the people moving it either on their head as a single vessel, or in a blanket supported by the forehead as part of a larger load of goods. The experiences of the people traveling in this landscape are also important. The pathways generated in this study would have taken multiple days to travel. Future research could focus on where people may have stayed while traveling in this area, or whether there are important cultural features along the routes. Though this project is primarily a GIS analysis, in any study of space it is important to include discussions of aspects of travel that are not as easy to model geospatially.

This research raises many new questions about the movement and circulation of late White Mountain Red Ware, and the pre-Hispanic trail network in east-central Arizona. Further modeling could be done to validate the models in this study, and generate more accurate movement corridor models. This further analysis could include agent-based modeling, a social network analysis of ceramic similarity, and viewshed analyses factoring in land-cover and/or elevation changes. New iterations of least cost or circuit theoretic modeling could also be done with more refined and culturally specific methodologies, such as including cultural boundaries or important landmarks in analysis, as well as taking into account more objective factors that conduct or obstruct movement, such as the trajectories of game trails or the locations of objective dangers like predators.

The pathways modeled in this project can be used as a basis for field work, including survey and the application of remote-sensing technologies to locate archaeological traces of ancient trails (see Phillips and Leckman 2012). Are there established contemporary sites that are on or near these pathways? If there are, how far is it between sites? Would it be feasible to walk that distance in one day? If not, are there artifact scatters or signs of ephemeral sites that show that people were spending the night on the side of the trail? There is little published settlement data for sites just below the Mogollon Rim, largely because of the paucity of archaeological survey in this incredibly rugged terrain. However, answering these questions will further clarify the accuracy of the modeled pathways generated for this project, and will help to reveal the lived reality of the people who transported painted pottery between villages above and below the Mogollon Rim in the fourteenth century.

The research presented here also sets the stage for collaborative opportunities with the Indigenous communities that still live in this region. While working within the framework of cultural landscape theory, it is essential to consider Indigenous knowledge, which is rooted intimately in traditional use of and interaction with the land. Indigenous groups have an intimate knowledge of their native landscapes, both culturally and geographically (e.g. Darling 2009; Ferguson et al. 2009; Hedquist et al. 2021). Though no modern group can be used as an exact analog for the past, Indigenous knowledge can provide insight into how and why places are invested with meaning, and how places within a landscape are connected culturally (Cutright-Smith 2013). By utilizing Indigenous epistemologies and concepts of space, a more thorough and well rounded understanding of past cultural landscapes can be reached (Fowles 2010; Snead, Erickson, and Darling 2009). An Indigenous perspective is essential to understanding the rich cultural context that surrounded, and still surrounds this trail system.

Local Indigenous worldviews and perspectives on the landscape can also help to create more accurate GIS models by fulfilling the need for more culturally specific geospatial models (Supernant 2017). Though the Pueblo and Mogollon cultures of the fourteenth century and the modern White Mountain Apache Tribe are not technically part of a continuous cultural tradition, collaborative research with the White Mountain Apache Tribe could identify culturally important geographic features, cultural features, and resource areas that might have served as nodes of travel in the past. Collaborative ethnographic research and interviews with Indigenous communities could also identify cultural practices and landscape knowledge that could have altered the pathways that people traveled or the places they traveled to. Critical geography and counter-mapping projects, similar to the one undertaken by the Zuni to reclaim and depict their landscape as they see and understand it (see Steinauer-Scudder 2018), could also be undertaken. This project could also contribute to the collaborative research on historic trails on White Mountain Apache tribal lands developed by the White Mountain Apache Tribe in conjunction with Archaeology Southwest. As stated above, GIS models are a good heuristic tool for comparison with real-world data (Branting 2012; Brouwer Burg 2017; Brouwer Burg, Peeters, and Lovis 2016; Crabtree 2015). Perhaps the pathways generated in this study can be used as a starting point for field research to identify trail networks in the area. Trails and roads are often long-term features on the landscape that can connect different cultural traditions throughout time (Darling 2009: 64-65). Because of this, research studies on fourteenth century trail networks and historic Apache trail networks can be mutually beneficial.

This study is a start towards better understanding intra-regional ceramic exchange networks in this area of east-central Arizona and furthers research into ceramic provenance and social network studies by providing a more fine-grained view of movement and ceramic circulation in the Silver Creek area. It also discusses experiential aspects of movement in the past, and raises questions for future research, including collaborative research efforts with Indigenous communities in the region.

Appendix A: Cost Surface Methods

Slope

Slope was extracted from a 30 meter resolution DEM from USGS.

Walking Time

To calculate a raster of walking time in ArcGIS Pro's raster calculator, I used Gowen and Smet's (2020) modified Tobler's Hiking Function, seen here:

$$T = \frac{R/1000}{6e^{-3.5|tan(D\pi/180)+0.05|}}$$

Where

T = time (hours)

D = slope (degrees)

R = spatial resolution of DEM (meters)

On the suggestion of Caseldine (2021), I broke the function into smaller steps to make it easier for the program to parse. My steps are seen below.

A. $\frac{D\pi}{180}$
B. $tan(Step\ A)$
C. $Step\ B$+0.05
D. $|Step\ C|$
E. $-3.5 * Step\ D$
F. $e^{Step\ E}$
G. $6 * Step\ F$

a. This is the complete Tobler's Hiking Function, which predicts velocity in km/h.

H. Reclassify Tobler's Hiking Function Raster using the table seen below. This step is to simplify the values in the raster, because the range of values makes the raster visually difficult to interpret.

a. *Table 4: Reclassification values for Tobler's Hiking Function.*

Start	End	New Value
0	0.99	1
1	1.99	2
2	2.99	3
3	3.99	4
4	4.99	5
5	5.99	6

I. $\frac{0.03}{Step\ H}$

a. My DEM resolution is 30m, so $\frac{30}{1000} = 0.03$

b. This gave me my final walking time cost surface.

Energy Expenditure

I created two energy expenditure surfaces to reflect two different economic scenarios. The first recognizes gifting as the primary exchange model for Fourmile Polychrome (see Zedeño 1998). The second views a market economy as the primary exchange model (see Triadan 1997, Whittlesey 1974). To get the final energy expenditure surfaces, I had to work through three different functions.

A. Movement Speed
  a. $V = Tobler's\ Hiking\ Function\ *\ C$
    i. V = velocity (m/s)
    ii. C = factor for converting km/hr to m/s (1000/3600 or 0.277778)
B. Metabolic Rate of Travel (MRT)
  a. $MRT = 1.5W + 2(\frac{L}{W})^2 + \eta(W + L)\{1.5V^2 + 0.35V[tan(\frac{D\pi}{180})100]\}$
    i. W = individual weight (kg)
    ii. L = external load (kg)
    iii. V = velocity (m/s)
    iv. η = terrain coefficient
    v. D = slope (degrees)
  b. W = 45kg, following the methods of Caseldine (2021)
  c. I used two values for L, based on the two different economic models. There were two factors in determining this number. The first was a base weight of 15kg, based on Malville's (2001) study of Nepali porters (Table 2 in that article). This weight represents food and personal belongings carried, which can range from 10-15kg. I chose 15kg to represent food, belongings, and any other goods carried to exchange. The second factor was the weight of the pottery. There is very little data on the weights of intact Fourmile Polychrome bowls. Six pots from the

collection at Brigham Young University were weighed to create a representative sample based on rim diameter. The table is below.

i. *Table 5: Weight and rim diameter of Fourmile Polychrome bowls from Brigham Young University collections.*

Accession Number	Weight (g)	Rim diameter (cm)
2006.60.0032.001	1244.4	29
2006.60.0033.001	801.5	24
2006.60.0034.001	1034.2	26.5
2006.60.0036.001	1046	27
2006.60.0064.001	651.5	19
2006.60.0092.001	513.5	23

ii.

iii. The external load for the gifting scenario was calculated from the bowls with the largest and smallest rim diameters, reflecting the theory that fewer bowls would have been transported in a gifting scenario.

    1. L_{Gift} = 16.9kg

iv. The external load for the market scenario was calculated from the weights of all six bowls, based on Whittlesey's (1974) assertion that Fourmile Polychrome was produced so that up to seven or eight bowls could be nested to transport all at once.

    1. L_{Market} = 20.3kg

d. Velocity (V) is represented by the Movement Speed raster.

e. The terrain coefficient (η) raster was created by reclassifying a section of the Southwest Regional Gap Analysis Project's land cover map using terrain coefficients from Safi's (2014) LCP analysis.

    i. *Table 6: Terrain coefficients from Safi (2014: Table 1)*

Land Class Category	Terrain Coefficient
Barren, Playa, Desert Pavement, Desert Badland	1
Grassland, Prairie, Meadow, Forbland, Tundra	1.2
Scrub, Steppe, Shrubland	1.2
Forest and Woodland, Chaparral, Encinal, Greasewood Flat, Bosque, Savanna	1.5
Scree, Bedrock Canyon, Tableland, Volcanic Rockland, Shale Badland	1.6
Wetland, Marsh, Wet Meadow, Fen	1.8
Open Water	1.8
Dune/Wash	2

f. Slope (D) is represented by the Slope raster.

g. Again, this formula was broken into steps to make it easier to parse.

C. Energy Expenditure

a. $kcal = \frac{(0.000239)MRT}{V}$

   i. kcal = energy expenditure (kilocalories per meter)

   ii. V = velocity (m/s)

   iii. MRT = metabolic rate of travel (watts per second)

b. Once both MRT equations were converted to energy expenditure cost surfaces, they had to be reclassified to simplify values. Features like cliffs create massive outlier values, making it difficult to display the cost surfaces visually. They were reclassified based on the table below.

   i. *Table 7: Reclassification values for MRT raster.*

Start Value	End Value	New Value
Minimum value	0.1	0.1
0.1	0.2	0.2
0.2	0.3	0.3
0.3	0.4	0.4
0.4	0.5	0.5
0.5	0.6	0.6
0.6	0.7	0.7
0.7	0.8	0.8
0.8	0.9	0.9

0.9	1.0	1.0

c. This created the final energy expenditure cost surfaces.

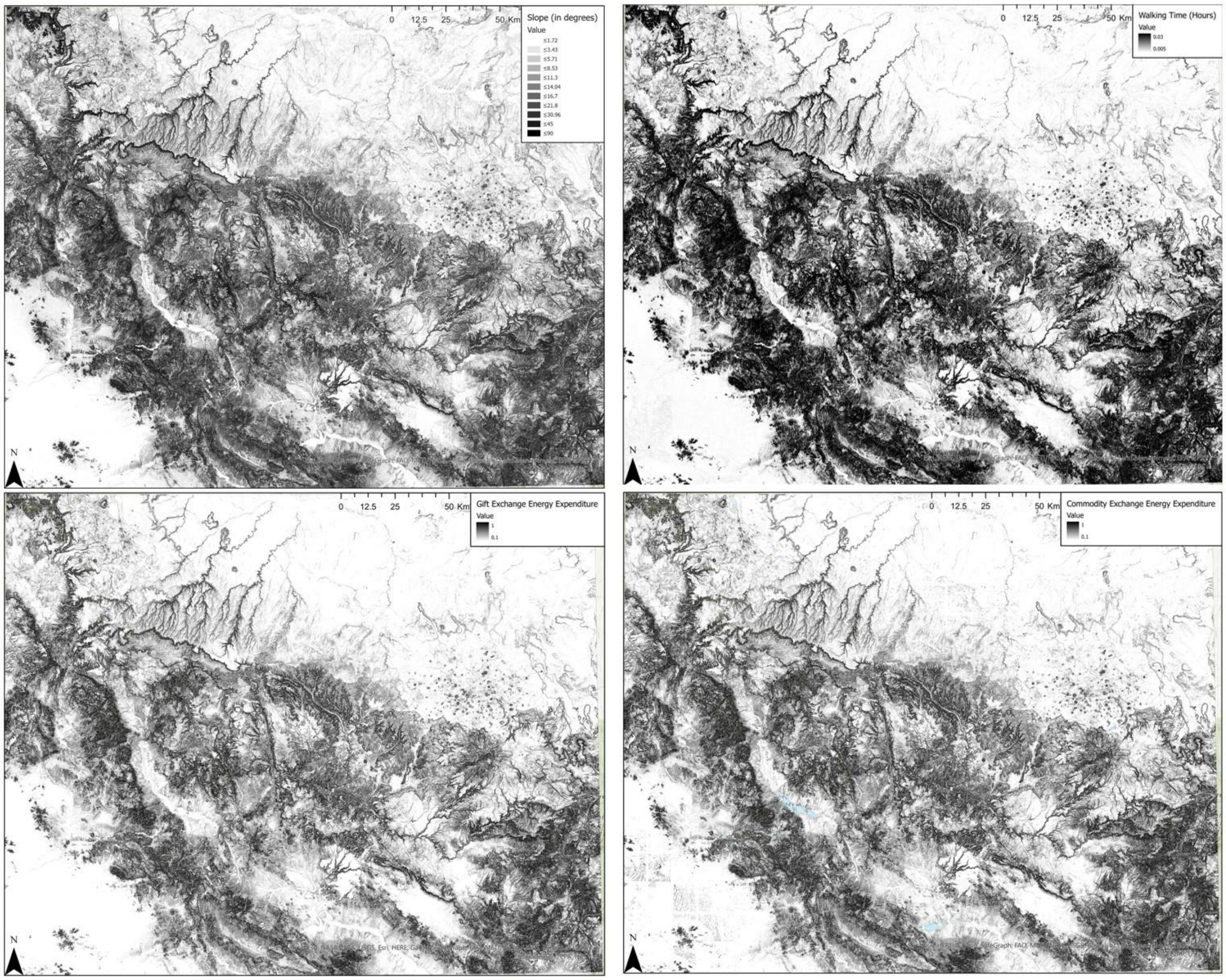


Figure 10: The four finished cost surfaces.

Appendix B: Least Cost Path Methods

The start points for the LCP analysis were Fourmile, Shumway, and Showlow Ruins, as they are the likely creator sites for Fourmile Polychrome (Triadan et al. 2002; Van Keuren and Ferguson 2020). Site location data was sourced from previous publications (see Spier 1919; Triadan 1997; Triadan and Zedeño 2004). The exact locations of these sites were used in the analysis; they are well known, and their locations have been previously published. The endpoints were randomized points near some of the recipient villages of Fourmile Polychrome below the Mogollon Rim; the latter were based on site locality presented in previous publications (e.g. Triadan 1997; Triadan and Zedeño 2004). This randomization was done to protect the exact locations of sites on White Mountain Apache lands that are vulnerable to looting. Below is a step-by-step explanation of the GIS methods used to generate LCP models for this project.

A. Site location data was imported into ArcGIS Pro 3.0.3 and the Copy Features tool was used to separate creator and recipient sites. Some known recipient sites, such as those north of the creator sites on the Colorado Plateau, were excluded to curtail the scope of the project. The site of Tundastusa was deleted from the dataset because of the ambiguity of its role in this exchange system (Van Keuren and Ferguson 2020).

B. Three-kilometer buffers were created around the general recipient site localities.

C. Then, five random points were generated within each buffer. These are the endpoints for the LCPs.

D. LCPs were run individually between each creator site and each cluster of randomized recipient sites to increase the number of iterations, which helped elucidate corridors that LCPs moved through. LCPs were run to each cluster and not to each point individually because of limitations on computational power and time.

Appendix C: Circuit Theoretic Modeling Methods

CT modeling for this project was done in Circuitscape, a freely available program. Circuitscape has a number of modeling modes; the two that are most applicable to archaeological data are the Pairwise and Advanced modes (Howey 2011; McLean and Rubio-Campillo 2022). In the Pairwise mode, connectivity is iteratively calculated between all pairs of focal nodes in a single input file. Using the Advanced mode, a user inputs a file for current sources and another file for current grounds within a landscape, which are activated simultaneously to create a circuit (Circuitscape User Guide). In this study, I used the Pairwise modeling mode for all CT models on the suggestion of Howey (2011). Below is the step-by-step process that was used to generate the CT models for this project.

A. The Pairwise modeling mode requires input files for the focal nodes and the cost surface to be used in the analysis. The focal nodes were 5-kilometer buffers around each site (both creator and recipient) to decrease the amount of computational power needed for the analysis. The resistance data was the four finished cost surfaces.
    a. Using the Resample tool in ArcGIS Pro, the resolution of the cost surfaces was made coarser (300m instead of 30m), again to decrease the computational power needed. Though the cost surfaces used for the CT models were much coarser than those used for the LCP analysis, the accuracy of the resulting models was not affected greatly, as the coarser resolution still captured important landscape features (McRae et al. 2008).
    b. Within the Circuitscape user interface, the option for “Write cumulative and max current maps only” was turned on to decrease needed computational power, and the options for “Log-transform current maps”, and “Set focal node currents to

zero” were turned on to allow for better visualization of corridors of high potential movement in the final model rasters.

c. Circuitscape output one raster for each cost surface that visualized current flow across the landscape.

Appendix D: Historical Trail Correlation Factor Methods

When corroboration through archaeological excavation or survey is not possible, comparison of LCPs to known trails or roads can serve as a way to “ground-truth” predictive models (Caseldine 2021; Herzog 2021; Kantner 1997). Since many modern roads and historic trails in the Southwest tend to follow the trajectories of prehistoric Indigenous trails (Colton 1964), I compared the outputs of my predictive models to historical trails and modern roads within the study area by calculating correlation factors, which are the percent that the predictively modeled LCPs overlap with known trails or roads (Field et al. 2019; Gowen and de Smet 2020).. The shapefile for modern roads was “All Roads Network 2020” for Arizona, and was found on ArcGIS Online. Below is the step-by-step process used to validate the LCP models through the calculation of correlation factors.

A. Maps of historical trails and roads were georeferenced and digitized from Stein (1994), and included major Native American trails as evidenced through archaeological and ethnographic studies, routes used during the Mexican period and U.S.-Mexican War, military roads used during the Indian Wars, trails used predominantly by Mormons for colonization, and the road system in Arizona around 1940 (see Stein 1994, Figures 1, 3, 6, 7, and 9).

B. The Webber and Potter 1869 map was georeferenced using river confluences as control points, and the trails were digitized.

C. The shapefile “All Roads Network 2020”, which shows all current roads in Arizona as of 2020, was brought in from ArcGIS Online, and clipped to the extent of the study area to decrease necessary computational power.

D. The real world pathways were then buffered at 25, 50, 75, and 100 meters using the Pairwise Buffer tool.

E. The LCPs were intersected with those buffers using the Pairwise Intersect tool.

    a. For the Webber and Potter map, the LCPs were first clipped to the extent of the georeferenced map because it only covered part of the total study area, unlike the other historical maps. These clipped LCPs were used later to calculate the correlation factors for the Webber and Potter trails.

F. Finally, correlation factors were calculated by taking the sum of the intersection lengths and dividing it by the sum of the LCP lengths. This was done for each of the four sets of LCPs and each of the three sets of real-world trails.

Appendix F: Supplementary Maps

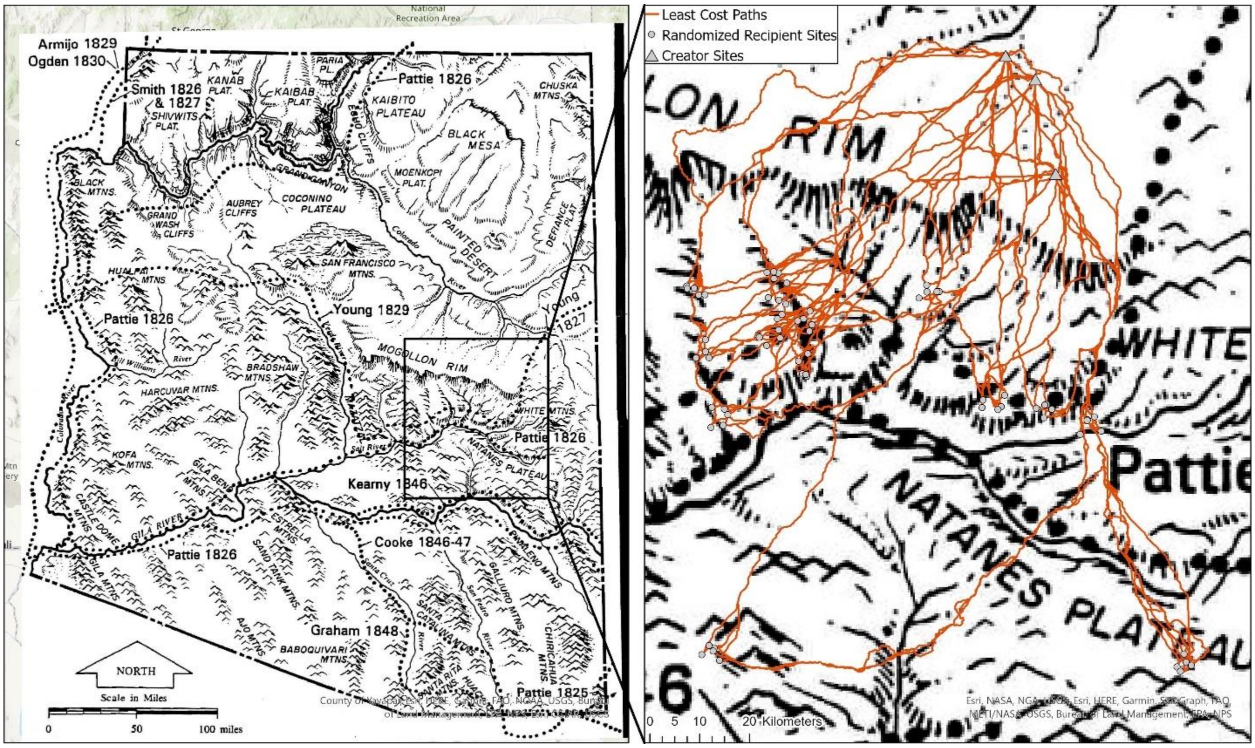


Figure 11: Stein (1994: Figure 3) Mexican War era trails and generated LCPs.

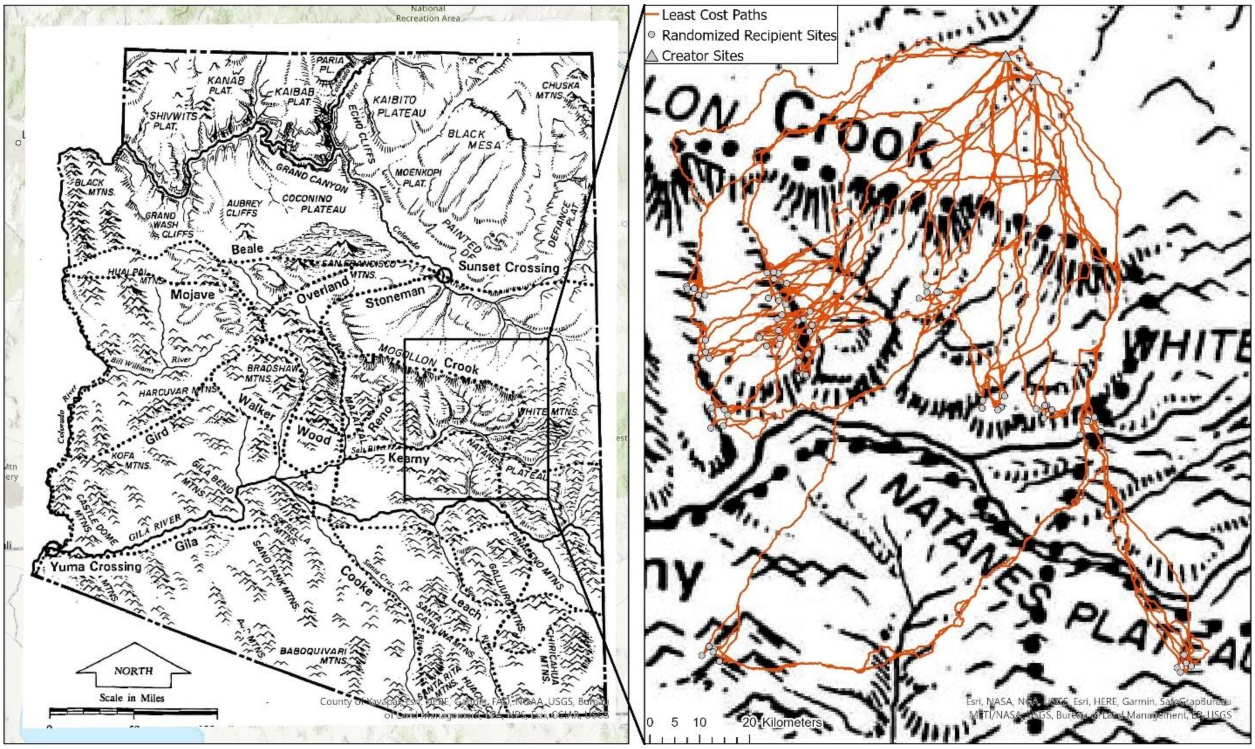


Figure 12: Stein (1994: Figure 6) military trails and LCPs.

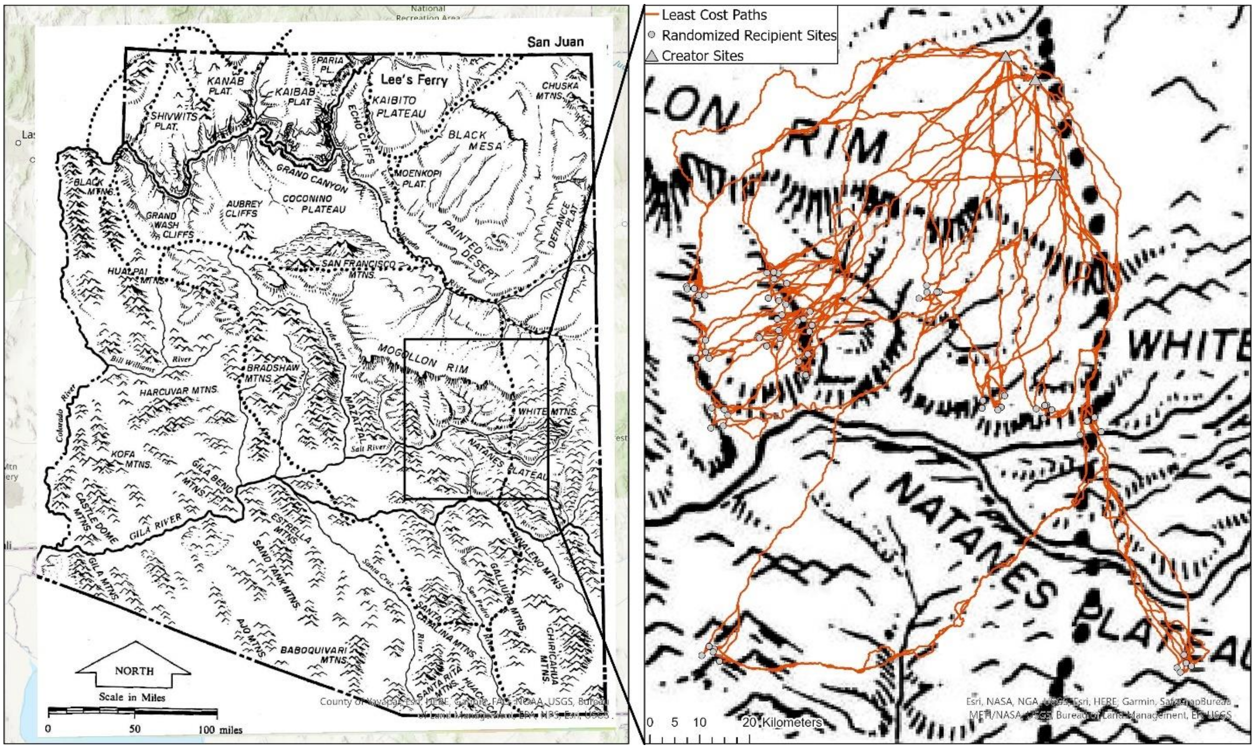


Figure 13: Stein (1994: Figure 7) Mormon Trails and LCPs.

References

Adams, E. Charles and Andrew I. Duff. “Settlement Clusters and the Pueblo IV Period.” In *The Protohistoric Pueblo World, A.D. 1275-1600*, edited by E. Charles Adams and Andrew I. Duff, 3-16. Arizona: The University of Arizona Press, 2004.

Arnold, Dean E. *Ceramic Theory and Cultural Process*. New York: Cambridge University Press, 1985.

Bayman, James M. “Craft Economies in the North American Southwest.” *Journal of Archaeological Research* 7, no. 3 (1999): 249-299. Bolstad, Paul. *GIS Fundamentals: A First Text on Geographic Information Systems, Sixth Edition*. XanEdu, 2019.

Blinman, Eric, and C. Dean Wilson. “Ceramic Perspectives on Northern Anasazi Exchange.” In *The American Southwest and Mesoamerica: Systems of Prehistoric Exchange*, edited by Jonathon E. Ericson and Timothy G. Baugh, 65-94. New York: Plenum Press, 1992.

Bolstad, Paul. *GIS Fundamentals: A First Text on Geographic Information Systems*. XanEdu, 2019.

Branting, Scott. “Seven Solutions for Seven Problems with Least Cost Pathways.” In *Least Cost Analysis of Social Landscapes: Archaeological Case Studies*, edited by Devin A White, and Sarah L Surface-Evans, 209-224. Salt Lake City: University of Utah Press, 2017.

Brouwer Burg, Marieka. “It Must Be Right, GIS Told Me So! Questioning the Infallibility of GIS as a Methodological Tool.” *Journal of Archaeological Science* 84 (2017): 115-120. https://doi.org/10.1016/j.jas.2017.05.010.

Brouwer Burg, Marieka, Hans Peeters, and William A. Lovis. “Introduction to Uncertainty and Sensitivity Analysis in Archaeological Computational Modeling.” In *Uncertainty and Sensitivity Analysis in Archaeological Computational Modeling*. Edited by Marieka

Brouwer Burg, Hans Peeters, and William A. Lovis: 1-20. Switzerland: Springer International Publishing, 2016.

Carlson, Roy L. *White Mountain Redware: A Pottery Tradition of East-Central Arizona and Western New Mexico*. University of Arizona Anthropological Papers. Tucson: University of Arizona Press, 1970.

Caseldine, Christopher R. "Least Cost Paths and Movement in Tonto Basin, Central Arizona." *KIVA* 88, no. 1 (2021): 1-30. https://doi.org/10.1080/00231940.2021.1996517.

Colton, Harold S. "Principle Hopi Trails." *Museum of Northern Arizona* (1964).

Conolly, James and Mark Lake. "Introduction and Theoretical Issues in Archaeological GIS." In *Geographic Information Systems in Archaeology*, 1-10. Cambridge: Cambridge University Press, 2006.

Crabtree, Stefani A. "Inferring Ancestral Pueblo Social Networks from Simulation in the Central Mesa Verde." *Journal of Archaeological Method and Theory* 22 (2015): 144-181.

Cutright-Smith, Elisabeth. "Mapping Ancestral Hopi Archaeological Landscapes: An Assessment for the Efficacy of GIS Analysis for Interpreting Indigenous Cultural Landscapes." Dissertation, University of Arizona, 2013.

Darling, J. Andrew. "O'odham Trails and the Archaeology of Space." In *Landscapes of Movement: Trails, Paths, and Roads in Anthropological Perspective*, edited by James E. Snead, Clark L. Erickson, and J. Andrew Darling, 61-83. Philadelphia: University of Pennsylvania Press, 2009.

Dean, Jeffrey S. "Kayenta Anasazi Settlement Transformations in Northeastern Arizona: A.D. 1150 to 1350." In *The Prehistoric Pueblo World, A.D. 1150-1350*, edited by Michael A. Adler, 29-47. Arizona: The University of Arizona Press, 1996.

Fertelmes, Craig M. “Vesicular Basalt Provisioning Practices Among the Prehistoric Hohokam of the Salt-Gila Basin, Southern Arizona.” PhD Dissertation, Arizona State University, 2014.

Field, Sean, Carrie Heitman, and Heather Richards-Rissetto. “A Least Cost Analysis: Correlative Modeling of the Chaco Regional Road System.” *Journal of Computer Applications in Archaeology* 2, no. 1 (2019): 136-150. https://doi.org/10.5334/jcaa.36.

Ford, Richard I. “Barter, Gift, or Violence: An Analysis of Tewa Intertribal Exchange.” In *Social Exchange and Interaction*, edited by Edwin N. Wilmsen, 21-45. Ann Arbor: University of Michigan, 1972.

Fowles, Severin. “The Southwest School of Landscape Archaeology.” *Annual Review of Anthropology* 39 (2010): 453-468. 10.1146/annurev.anthro.012809.105107.

Glascock, Michael D., and Hector Neff. “Neutron activation analysis and provenance research in archaeology.” *Measurement Science and Technology* 14, no. 9 (2003):1516-1526.

Gowen, Kyle M., and Timothy S. de Smet. “Testing Least Cost Path (LCP) Models for Travel Time and Kilocalorie Expenditure: Implications for Landscape Genomics.” *PLOS One* 15, no. 9 (2020). https://doi.org/10.1371/journal.pone.0239387.

Hagstrum, Melissa B. “Creativity and Craft: Household Pottery Traditions in the Southwest.” In *Ceramic Production in the American Southwest*, edited by Barbara J. Mills, and Patricia L. Crown: 281-299. The University of Arizona Press, Tucson, 1995.

Harrison-Buck, Eleanor. “Relational Economies of Reciprocal Gifting: A Case Study of Exchanges in Ancient Maya Marriage and War.” *Current Anthropology* 62, no. 5 (2021): 569-601. https://doi.org/10.1086/716726.

Hedquist, Saul L., Maren P. Hopkins, Stewart B. Koyiyumptewa, Lee Wayne Lomayestewa, and T. J. Ferguson. “Tungwniwpi Nit Wukwlavayi (Named Places and Oral Traditions): Multivocal Approaches to Hopi Land.” In *Footprints of Hopi History*, edited by Leigh J. Kuwanisiwma, T. J. Ferguson, and Chip Colwell, 52-72. Arizona: University of Arizona Press, 2018.

Herzog, Irmela. “Least Cost Paths - Some Methodological Issues.” *Internet Archaeology* 36 (2014). http://dx.doi.org/10.11141/ia.36.5.

Herzog, Irmela. “Issues in Replication and Stability of Least-cost Path Calculations.” *Studies in Digital Heritage* 5, no. 2 (2021): 132-155. https://doi.org/10.14434/sdh.v5i2.33796.

Hirshman, Amy J., and Christopher J. Stawski. “Distribution, Transportation, and the Persistence of Household Ceramic Production in the Tarascan State.” *Ethnoarchaeology* 5, no. 1 (2013): 1-23. https://doi.org/10.1179/1944289013Z.0000000002.

Howey, Meghan C.L. “Multiple Pathways across Past Landscapes: Circuit Theory as a Complementary Geospatial Method to Least Cost Path for Modeling Past Movement.” *Journal of Archaeological Science* 38 (2011): 2523-2535. https://doi.org/10.1016/j.jas.2011.03.024.

Kaldahl, Eric J., Scott Van Keuren, and Barbara J. Mills. “Migration, Factionalism, and the Trajectories of Pueblo IV Period Clusters in the Mogollon Rim Region.” In *The Protohistoric Pueblo World: A.D. 1275*-1600, edited by Andrew Duff, and E. Charles Adam, 85-94. Tucson: The University of Arizona Press, 2004.

Kantner, John. “Realism, Reality, and Routes: Evaluating Cost-Surface and Cost-Path Algorithms.” In *Least Cost Analysis of Social Landscapes: Archaeological Case Studies*.

Edited by Devin A. White and Sarah L. Surface-Evans, 225-238. Utah: University of Utah Press, 2012.

Kantner, John and Ronald Hobgood. “Digital technologies and prehistoric landscapes in the American Southwest.” In *The Reconstruction of Archaeological Landscapes through Digital Technologies*, edited by M. Forte and P. R. Williams, 117–123. BAR International Series 1151. Oxford: Archaeopress, 2003.

Lewis, Joseph. “Probabilistic Modeling for Incorporated Uncertainty in Least Cost Path Results: a Postdictive Roman Road Case Study.” *Journal of Archaeological Method and Theory* 28 (2021): 911-924. https://doi.org/10.1007/s10816-021-09522-w.

Lightfoot, Kent G. “Food Redistribution among Prehistoric Pueblo Groups.” *Kiva* 44, no. 4 (1979): 319-339.

Luévano, Terrence Bradley. “A GIS Model of Shell Exchange between Coastal Southern California and Northern Arizona.” Master’s thesis, University of Arizona, 2022.

Malville, Nancy J. “Long-Distance Transport of Bulk Goods in the Pre-Hispanic American Southwest.” *Journal of Anthropological Archaeology* 20, no. 2 (2001): 230-243. https://doi.org/10.1006/jaar.2000.0373

McLean, Andrew, and Xavier Rubio-Campillo. “Beyond Least Cost Paths: Circuit Theory, Maritime Mobility, and Patterns of Urbanism in the Roman Adriatic.” *Journal of Archaeological Science* 138 (2022). https://doi.org/10.1016/j.jas.2021.105534.

McRae, Brad H., Brett G. Dickinson, Timothy H. Keitt, and Viral B. Shah. “Using Circuit Theory to Model Connectivity in Ecology, Evolution, and Conservation.” *Ecology* 89, no. 10 (2008): 2712-2724.

McRae, Brad, Viral Shah, and Tanmay Mohapatra. “Circuitscape 4 User Guide.” *The Nature Conservancy* (2013). http://www.circuitscape.org.

Mills, Barbara J. “The Reorganization of Silver Creek Communities from the 11th to the 14th Centuries.” In *Living on the Edge of the Rim: Excavations and Analysis of the Silver Creek Archaeological Research Project, 1993-1998 (ASM Archaeological Series)*, 505-511. Tucson: University of Arizona, 1999.

Mills, Barbara J. “Performing the Feast: Visual Display and Suprahousehold Commensalism in the Puebloan Southwest.” *American Antiquity* 72, no. 2 (2007):210-239.

Mills, Barbara J., Jeffrey J. Clark, Matthew A. Peeples, W. R. Haas, Jr., John M. Roberts, Jr., J. Brett Hill, Deborah L. Huntley, Lewis Borck, Ronald L. Breiger, Aaron Clauset, and M. Steven Shackley. “Transformation of Social Networks in the Late Prehispanic US Southwest.” *Proceedings of the National Academy of Sciences* 110, no. 15 (2013): 5785-5790.

Moreno-Meynard, Paulo, César Méndez, Iñigo Irarrázaval, and Amalia Nuevo-Delaunay. “Past Human Mobility Corridors and Least-Cost Path Models South of General Carrera Lake, Central West Patagonia (46° S, South America).” *Land* 11 (2022): 1351-1374. https://doi.org/10.3390/land11081351.

Phillips, Shaun M., and Phillip O. Leckman. “Wandering the Desert: Least Cost Path Modeling for Water Transport Trails in the Jornada Mogollon Region, Fort Bliss, South-Central New Mexico.” In *Least Cost Analysis of Social Landscapes: Archaeological Case Studies*, edited by Devin A White, and Sarah L Surface-Evans, 46-66. Salt Lake City: University of Utah Press, 2017.

Plog, Fred. “Prehistory: Western Anasazi.” In *Handbook of North American Indians Volume 9*, edited by Alfonso Ortiz and William Sturtevant, 108-130. Washington, D.C.: Smithsonian Institution, 1979.

Reid, J. Jefferson. “A Grasshopper Perspective on the Mogollon of the Arizona Mountains.” In *Dynamics of Southwest Prehistory*. Edited by Linda S. Cordell and George J. Gutterman, 65-97. Washington, D.C.: Smithsonian Institution Press, 1989.

Reid, J. Jefferson, John R. Welch, Barbara K. Montgomery, and María Nieves Zedeño. “A Demographic Overview of the Late Pueblo III Period in the Mountains of East-central Arizona.” In *The Prehistoric Pueblo World, A.D. 1150-1350*, edited by Michael A. Adler, 73-85. Arizona: The University of Arizona Press, 1996.

Rice, Prudence M. *Pottery Analysis*. Chicago: University of Chicago Press, 2015.

Safi, Kristin N. “Using Least Cost Pathways to Understand the Processes of Migration from the Mesa Verde Region during the Pueblo III Period.” *Kiva* 80, no. 1 (2014): 28-44.

Sahlins, Marshall. *Stone Age Economics*. Chicago: Aldine Atherton Inc., 1972

Snead, James E. “Trails of Tradition: Movement, Meaning, and Place.” In *Landscapes of Movement: Trails, Paths, and Roads in Anthropological Perspective,* edited by James E. Snead, Clark L. Erickson, and J. Andrew Darling, 42-60. Philadelphia: University of Pennsylvania Press, 2009.

Snead, James E., Clark L. Erickson, and J. Andrew Darling. “Making Human Space: The Archaeology of Trails, Paths, and Roads.” In *Landscapes of Movement: Trails, Paths, and Roads in Anthropological Perspective,* edited by James E. Snead, Clark L. Erickson, and J. Andrew Darling, 1-19. Philadelphia: University of Pennsylvania Press, 2009.

Spier, Leslie. “Ruins in the White Mountains, Arizona.” *Anthropological papers of the AMNH* 18 (1919): 363-398.

Stein, Pat H. “Historic Trails in Arizona from Coronado to 1940.” SWCA Report, Arizona, 1994.

Steinauer-Scudder, Chelsea. “Counter Mapping.” *Emergence Magazine* (2018). https://emergencemagazine.org/feature/counter-mapping/.

Supernant, Kisha. “Modeling Metis mobility? Evaluating least cost paths and indigenous landscapes in the Canadian west.” *Journal of Archaeological Science* 84 (2017): 63-73.

Teeter, Sean. “Traveling Grand Canyon: Ancient Trail Systems.” In *The Archaeology of Grand Canyon: Ancient Peoples, Ancient Places*, edited by Francis E. Smiley, Christian E. Downum, and Susan G. Smiley, 137-177. Arizona: Grand Canyon Association, 2017.

Tobler, Waldo. “Three presentations on geographical analysis and modeling: Non-isotropic geographic modeling speculations on the geometry of geography global spatial analysis.” *National Center for Geographic Information and Analysis* 93, no. 1 (1993).

Triadan, Daniela. *Ceramic Commodities and Common Containers: Production and Distribution of White Mountain Red Ware in the Grasshopper Region, Arizona*. Anthropological Papers of the University of Arizona 61. Arizona: The University of Arizona Press, 1997.

Triadan, Daniela, Barbara J. Mills, and Andrew I. Duff. “From Compositional to Anthropological: Fourteenth-century Red-Ware Circulation and Its Implications for Pueblo Reorganization.” In *Ceramic Production and Circulation in the Greater Southwest: Source Determination by INAA and Complementary Mineralogical Investigations*, edited by Donna M. Glowi and Hector Neff, 85-97. Los Angeles: The Cotsen Institute of Archaeology, 2002.

Triadan, Daniela and M. Nieves Zedeño. "The Political Geography and Territoriality of 14th-Century Settlements in the Mogollon Highlands of East-Central Arizona." In *The Protohistoric Pueblo World, A.D. 1275-1600*, edited by E. Charles Adams and Andrew I. Duff, 95-107. Arizona: The University of Arizona Press, 2004.

Van Keuren, Scott, and Grace E. Cameron. "The Lives of Painted Bowls at Ancestral Pueblos in East-Central Arizona." *American Antiquity* 80, no. 1 (2015): 25-45.

Van Keuren, Scott, and Jeffrey R. Ferguson. "Tracing the Circulation of Iconographic-style Red Ware in East-central Arizona." *KIVA* 86, no. 3 (2020): 1-24. https://doi.org/10.1080/00231940.2020.1726126.

Varien, Mark D. *Sedentism and Mobility in a Social Landscape: Mesa Verde and Beyond*. Tucson: The University of Arizona Press, 1999.

Wilcox, David R., and Jim Holmlund. *The Archaeology of Perry Mesa and its World*. Flagstaff, AZ: Ralph M. Bilby Research Center (2007).

Whittlesey, Stephanie M. "Identification of Imported Ceramics through Functional Analysis of Attributes." *Kiva* 40, nos. 1-2 (1974): 101-112.

Willis, William M., and Karen G. Harry. "Settlement Patterns, Scheduling Conflicts, and Climate Variability: An Explanation for the Collapse of the Shivwits Ware Distribution Network." *Kiva* 85, no. 4 (2019): 331-344. https://doi.org/10.1080/00231940.2019.1689657.

Wood, Denis. *Rethinking the Power of Maps*. New York: The Guilford Press, 2010.

Zedeño, María Nieves. "Defining Material Correlates for Ceramic Circulation in the Prehistoric Puebloan Southwest." *Journal of Anthropological Research* 54, no. 4 (1998): 461-476.