REGIONAL NETWORK ANALYSIS SITUATING LOST VALLEY IN
THE INTER-SITE LANDSCAPE

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To my father, Richard McCall Hannah, a physician and master of the liberal arts who loved books and indulged himself frequently.
ABSTRACT OF THE THESIS

Regional Network Analysis Situating Lost Valley in the Inter-Site Landscape
by
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Master of Arts in Anthropology
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The purpose of this study is to analyze possible contact pathways through Lost Valley, San Diego County, California, using the methods of least-cost path analysis for both real and modeled travel corridors through the San Luis Rey Watershed. I conducted this study using ArcView 9.2 GIS (geographic information systems), digital elevation models, and aerial photography in order to show the most likely corridors of travel and trade using least-cost path modeling. In addition, I compared the modeled paths to real trail networks, for example those that show up in aerial photographs and/or those written about in the literature. This study demonstrates how prehistoric and protohistoric peoples traveled through the Lost Valley area and how contact networks were likely established and maintained. The modeled travel corridors are compared to the ethnographic and historic knowledge of the Cupeño who seasonally occupied Lost Valley.
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CHAPTER 1

INTRODUCTION

Archaeologists have traditionally studied evidence of trade and contact between sites by a comparison of artifact material and style, and on the distribution of these material goods through time and space (Renfrew and Bahn 1991), thus inferring contact through a theoretical network of trade or travel routes. Many current studies of obsidian and shell trade use chemical techniques to source the material, and obsidian hydration, or radiocarbon dating (for shell) to determine age. Old trails were also noted, studied, and accounted for in the past when the trails were still visible, well traveled, and well known (Colton 1941). Early in the study of American trade routes it was noted that shells were good markers of long distance trade routes in the southwest (Brand 1935).

Travel networks and trade routes can serve as important sources of data for archaeologists. Movement between geographic locations involved foot travel by Late Period inhabitants in the northern portion of San Diego County, in southern California. The network of footpaths created by pedestrian travel from region to region most likely remained consistent over time, so that the paths we see today while walking in these areas and what we see in aerial photographs were probably the travel networks used in the past. It is well documented that some of these footpaths became horse trails, then wagon paths, then rural roads, and then finally the modern highways of today. I intend to show that foot travel tends to follow the natural topography, which can be shown in modeled networks of travel paths. The method I use is experimental although not absent from the literature (see Chapter 2). The aim of this thesis is to model a network of least-cost paths (LCPs) in the study area to show how the natural topography affects the distance and direction of travel, and therefore the trade routes and potential contact routes for the Late Period inhabitants of the study area.

STUDY AREA

The location of interest for this study is Lost Valley, San Diego County, California. The prehistoric inhabitants of this area were, the Cupeño, a branch of the Uto-Aztecan
speaking people related linguistically to the Cahuilla to the north and east of their territory and the Luiseño to the west (Bright and Hill 1967; Hill and Nolasquez 1993). Culturally, the Cupeño also had contact and intermarried with the Ipai or Northern Kumeyaay, to the south, (APEC 1981; Bean and Smith 1978; Strong 1929). The territory of the Cupeño was exceptionally small, about 10 x 10 miles in size, encompassing the entire San Jose del Valle that lies to the north of the modern town of Warner Springs, and to the west and south of Lost Valley (APEC 1981; Bean and Smith 1978:588; Kroeber 1925:689). William Bright commented on the linguistic affinity of the Cahuilla and Cupeño when he concluded that “Cupeño is very close to Cahuilla, being perhaps an offshoot of it” while “Cahuilla, Cupeño, Luiseño, Serrano, and Gabrielino, with possible other extinct languages…form a genetic group which Kroeber [1907] called ‘Southern California Shoshonean,’”” or more conveniently “Takic” (Bright 1967:xxi). According to Victor Golla (2007:75), language differences between the Cahuilla, the Luiseno, and the Cupeño, were limited, indicating that movement of these peoples into the territory in which they were found at contact was “probably within the last millennium.”

**GIS Analysis**

In order to analyze prehistoric footpaths, which represent the network of trade and contact, the use of Geographic Information Systems (GIS) was paramount. GIS are computer programs (the combination of computer hardware, software, and database management systems) that accept spatial input in combination with attribute data (contained in a database) that have the capability of analyzing those figures via logic and statistics, and the functionality to illustrate that material by way of map outputs, thus turning data into information. GIS have become part of the archaeologist’s toolkit (Kvamme 2005; Moyes 2002).

A GIS application is relevant to this proposed study of prehistoric footpaths because one of its main uses is that of least-cost path analysis, that is usually applied to, for instance, a best route for the construction of a freeway, or hydrologic global functions such as those for watersheds, or drainage basins (DeMers 2002:81). Examples for the use of least-cost path analyses include modeled travel connections between mountain lion habitats (Gallo et al. n.d.), finding off-road routes for autonomous land vehicles (Stahl 2005), planning for
highway construction (Brumm et al. 2002), research on livestock trails (Ganskopp et al. 2000), research on urban landscape and trail making in the urban environment (Helbing et al. 1997), and an exploration of past regional landscape using cost surfaces (Howey 2007).

**Previous Research Theses**

Dr. Larry Leach, professor Emeritus, San Diego State University, conducted a field school in the study area of Lost Valley spanning the summer sessions between 1997 and 2003. The three research questions posed at the onset of the field schools were; (1) was Lost Valley occupied year round, rather than seasonally; (2) if occupation was seasonal, was it during summer and fall; and (3) if seasonally occupied, was it during the fall only to harvest seasonal foods available at that time of the year (Fleming 1999:4).

The harvest of the field schools has resulted in fodder for graduate students from San Diego State University, whom have produced several theses from the excavations, which are detailed in the next chapter.

**Problem and Solution**

The use of GIS to study the system of travel networks is of interest to archaeologists, however studies of this problem seem to be somewhat limited. To extend the work done on Lost Valley prehistory described in the next chapter, I created a model of trail networks around Lost Valley within a pre-defined buffer zone (a specified distance around a feature) of Lost Valley. Since I was interested in how Lost Valley fits into the established trail network, I chose to use evenly distributed start and end points around the edges of a block of digital elevation models (DEMs), rather than use known site locations as the start and end points of the LCPs. The relationship of the modeled LCPs was then compared to known site locations in one small area of the total study area to note correlation between the model and the sites. The work done within the constraints of this thesis is an important contribution to the body of knowledge that has been produced through hands on involvement with the material excavated from Lost Valley. Future study of the excavated material can be compared to excavation or surface collected material from sites located along the network of least-cost paths. Possible travel networks equal possible social networks.

The DEM is an integral part of spatial analysis, and also becomes a major part of the visual presentation, as site locations and the networks between them can be visualized in
relation to terrain. A DEM is “a sampled grid or raster-based representation of continuous topographic surfaces on portions of the globe” (DeMers 2002:83).

The following research questions are posed in order to lay a foundation for the regional spatial analysis of Lost Valley sites to gain insight into how they are connected to the surrounding area:

1. How is Lost Valley linearly connected to areas to the west and east, within portions of the San Luis Rey and Anza Borrego watersheds?
2. Is Lost Valley situated on a travel network from the Borrego Springs area following a least-cost path to sites west of Lost Valley?
3. How does the natural topography of the watershed function in defining travel or trade networks?
4. Is there a relationship between the modeled paths and the archaeological sites that have been documented and recorded?

LIMITATIONS AND CONSTRAINTS

Least-cost path analysis will delineate the most likely routes through Lost Valley from the west (through parts of the San Luis Rey Watershed) and the east (northern Anza-Borrego Watershed).

The focus of this thesis changed dramatically over time, from visualization of artifactual remains at the site level, to regional study of Lost Valley, to situating Lost Valley as part of a much larger region, and finally to trade and trails and modeling least-cost paths through or near the Lost Valley area to demonstrate how Lost Valley is connected with the surrounding area/territories via virtual trade routes or travel networks. There are several intertwining data sets with which to negotiate. First, the ethnographies of the prehistoric and protohistoric inhabitants of Cupeño territory and the surrounding tribes/groups/territories as described by Kroeber (1925) and Bean and Smith (1978); second, Native American trail systems and known trade networks from the literature; third, GIS in general and the use of GIS in archaeology, specifically the use of least-cost path in research; and fourth, theory and method that combines the use of GIS and archaeology.

SUMMARY OF CHAPTERS AND APPENDICES

The next chapter of the thesis will discuss the background of the project, including what is known about the people who once occupied Lost Valley (the Cupeño), and the natural history of Lost Valley. Following the background section, the literature review
(Chapter 3) provides an explanation of the uses of GIS in archaeology, especially least-cost path analysis. A section on the methods (Chapter 4) to be used in the study follows the literature review. This leads to the results and discussion section (Chapter 5) providing the results of the procedures described in the methods section and discussion of the meaning of the findings. Finally, Chapter 6 brings the thesis to a close with the addition of possible future research projects that evolved through this research. The Appendix includes summaries of the four initial projects that were completed in the beginning stages of research. These four projects are included because this project is the result of the evolution of ideas that led to the end product of this thesis.
CHAPTER 2

BACKGROUND

PROJECT

The end of the trail is literally Lost Valley, an oasis beautiful by any standard. Lost Valley is a high, remote sheltered valley located in the north-central portion of San Diego County, in southern California (Fig. 1). Mountains at the rim of the valley encompass a meadow that may be the remnant of a Pleistocene lake at the center of the valley floor. To the east, the mountains give way in steep descent to the desert oasis of Borrego Springs. The prehistoric inhabitants likely came to Lost Valley because of the abundance of oak trees of various species, spring water available year round, and the animals that were attracted to food sources found at this oasis.

Archaeological field schools were conducted at Lost Valley for seven summer sessions from 1997-2003 through San Diego State University (SDSU) under the tutelage of Dr. Larry Leach (then head of the Anthropology Department, now Professor Emeritus). I participated in the field school for the summers of 2002 and 2003, and also completed the preliminary laboratory work on the excavation materials from the 2002 and 2003 field sessions in the semesters following those field sessions. Laboratory work consisted of cleaning, sorting, identifying, and cataloging all the materials brought back from the field and was also conducted under the advisement of Dr. Larry Leach. For Dr. Leach, it is of the utmost importance that all materials that were collected, and that have now been cataloged, be analyzed and published as part of the archaeological record. Without publication and availability, there is no archaeological record.

In response to this call to action, several graduate students have used the materials from the excavations at Lost Valley as the foundation of their master’s theses. For example, George Kline wrote a thesis presenting the analysis of the contents of the excavations from Lost Valley (CA-SDI-2506, CA-SDI-2507, CA-SDI-2508, and VS-766C). In April 2008 he defended his thesis entitled “Metates to Merit Badges: The Contrasting Occupational Sequences of Lost Valley” (Kline 2008).
In addition, three other theses have been completed using the excavations as the data and knowledge base. “Life at 5000 Feet: An Archaeological Investigation of CA-SDI-2508 (Leaning Pines), Lost Valley, San Diego County, California,” a thesis by Kaylene Fleming (1999), presents a complete analysis of the artifacts excavated from the Leaning Pines site at Lost Valley. The Leaning Pines site is a stone’s throw from CA-SDI-2506, the Bog Site excavation (Kline 2008). Shasta Gaughen’s 2002 thesis, “The Ethnobotany of the Cupeño,” (Gaughen 2002), combines data from the field schools with interviews of Cupeño elders about plant use in the Lost Valley area. In 2005, John Simmons completed his thesis, “An Analysis of Function at Several Late Prehistoric Sites in Lost Valley, California” (Simmons 2005), in which he tested a hypothesis of the settlement systems of Lost Valley through statistical analysis.

**CULTURAL BACKGROUND: THE CUPEÑO PEOPLE**

According to ethnographic data, members of one of the Cupeño clans (*temewhaniticem*) made a seasonal trek from the main village at Cupa (or *Kupa*), near the modern town of Warner Springs, California, to Lost Valley (APEC 1981; Pignolio 1999;
Strong 1929). Oral tradition indicates that there were three original Cupeño clans: the *kavalim*, the *pumtumatūlnikteum*, and the *temewhanitcem* (Strong 1929:186, Table 8). Duncan Strong names three more clans that lived at Cupa and two more that occupied *Wilikal*; all five of these clans are of the wildcat moiety and are therefore related to the women who had to marry outside of their clan of birth. The three Cupeño clans are of the coyote moiety (Strong 1929:186, Table 8). I will show the relationships of these clans through the telling of the following story.

“The Cupas say they have lived in the vicinity of the hot springs in San Jose Valley from time immemorial and that it is their homeland and that of their ancestors...Yet there was a time when they first came to the area” (Almstedt 1981:33). The story of culture hero *Kisily Pewik*, from Cupeño oral history, is told in two versions in Hill and Nolasquez (1972). In the second version, Kisily’s mother is Diegueño, married to a Kavaly man at Cupa. Diegueños come to Cupa and kill all the people there (by burning them) except Kisily’s mother (as she is kin) and her newborn infant (Kisily). The Diegueños want to throw the infant into the fire but she stops them by telling them the infant is a girl (Kisily is a boy). The Diegueños want her to come back to their village with them (to the south). She says she cannot travel right then, but will catch up with them the following day (Hill and Nolasquez 1972).

As soon as the Diegueño warriors leave, Kisily’s mother with Kisily held tight, heads straight for Soboba (to the north). Soboba, then identified as a Cahuilla village, is where they live until Kisily is grown. As an adult he wishes to return to his homeland. Mother and son return to Cupa where he marries two Luiseño women. By these women he has one son by the first, and two sons by the second. Since reckoning is through the male line, all his children are of his moiety, which is coyote. This means that the two Luiseño women had to be of the opposite moiety, wildcat, for a proper marriage to take place. The sons become the heads of the three main clans of Cupeño origin: *kavalim* (Kavaly), *pumtumatūlnikteum* (Blacktooth), and *temewhanitcem* (Northerner) (Hill and Nolasquez 1972:41; Strong 1929:186).

This story is repeated through the literature in various versions as Cupeño oral literature. I believe there is some truth to the myth, thus the story is reviewed here to show the possible descent of the modern Cupeño from Kisily as the last surviving Cupeño. The story is informative in the way of trade, trading, relationships, and which directions of travel
were most likely for trade because of kin and clan alignments. For this thesis I modeled a series of the least-cost paths and compared one to a current aerial photo view provided by the Google Earth Internet program. This same method of comparison could be done selecting the locations of Soboba, Lost Valley, and Cupa for an interesting comparison of modeled travel between the villages and places named in the Cupeño oral literature.

**Trade and Trails Through Lost Valley**

Although it has been proposed that Lost Valley may have had permanent Cupeño occupation prior to contact (Fleming 1998:21), so far there is no conclusive evidence of year-round occupation. One of the things that may be shown with the least-cost path analysis is that the location of Lost Valley is not on any major travel or trade route, but out of the way, hidden (or lost) as it were. It is one of my hypotheses that in observing the locations of major village sites in the Shoshonean language region, major networks of travel paths traversed every major village.

David Prescott Barrows, in talking about the connection between the Cahuillas and the Chemehuevis, relates the following: “The route traveled between these two tribes is an almost direct trail running eastward from the Cabezon valley to the Colorado [River]. In places the path has been worn deep in the ridges of rock over which it passes. The Indians take about two days to make the trip” (1900:25). Other references to trails and routes through the Cahuilla territory are mentioned as follows: the Mojave desert was “crossed by the old Mormon road from Salt Lake City to San Bernardino, as well as the overland trail from Santa Fe, both roads meeting near the western side of the desert on the Mojave river” (Barrows 1900:25). San Gorgonio pass also was used to travel from the Banning area to the Colton area. The San Gorgonio pass is another location that can be found on a map and checked through inspection of aerial photographs in seeking information on the locations of trails that lead in and out of the surrounding canyons (Barrows 1900:25-26). Then, “[u]p the San Jacinto ridges, dark and gloomy with shadows, run the ancient trails by which the Coahuillas entered the mountains and became hillsmen, as well as men of the desert” (Barrows 1900:27).

Cahuilla well digging was an art that was appreciated by Barrows. The Cahuillas had their own way of digging a well so that a person could gradually walk down to the water level (Barrows 1900).
The desert climate is the reason for the scant vegetation, but that climate is also responsible for the fact the vegetation is rich in nutrients (Barrows 1900). Barrows also noted that the canyons contained much of the vegetal foodstuffs that women gathered and credits the women for their ability to find plant foods in the desert and near mountains for keeping the people healthy in an otherwise harsh environment.

**Natural History of Lost Valley**

The natural history of Lost Valley has been discussed in detail elsewhere and will not be repeated here. Previous accounts include Philip Pryde 1978, who focused on the natural history and climate of the San Diego region, and Jess McColloch (1984) who summarized evidence on the geology of Lost Valley. Kline (2008) focused on lithic resources from around Shingle Spring, but gave a general review of the natural history of Lost Valley. Fleming (1999) centered attention on site CA-SDI-2508, but provided a general review of the natural history of Lost Valley. Gaugen (2000) concentrated on the ethnobotany of the area. The firm APEC 1981 gives a review of the natural history of the Valley of San Jose at the head of the San Luis Rey Watershed. Andrew Pigniolo and colleagues (1998) provided a general review of the natural history of Lost Valley.

The two main villages of the Cupeño were *Kupa* (or Cupa) at Warner’s Ranch, and *Wilikalpa* (or *Wilikal*), which was four miles southeast of *Kupa* at what is now San Ysidro (Strong 1929:248). *Wiatava*, or Lost Valley, is located in the northeast corner of Cupeño territory, so that it is north and east of Warner Springs. The Cupeño clan, *temewhanitecem* (or Northerers), had control/ownership of *Wiatava* and used the valley for collection of acorns, seeds, berries, wild oats, and other foodstuffs. A map from Strong (1929:248) is helpful in understanding the distribution of Cupeño territory with clan ownership marked on the various areas (Fig. 2). Evidence shows that the Cupeño language is closer to Cahuilla than to Luiseño (Bright and Hill 1967; Kroeber 1925).

The Cupeño, throughout their territory, were privy to a great variety of plant and animal foods. Most important were the oaks. Acorns were harvested in October and stored for future use in large woven basketry granaries. Manzanita, sage, chia, buckwheat, wild rose, and elderberry were also collected in Lost Valley. There were also a variety of medicinal plants and animal food sources available in the Cupeño territory (Pigniolo
1998:16). Fibers, and items made from fibers (e.g., nets, baskets, rope), do not preserve well in the archaeological record except under certain conditions of dryness or bog like conditions, thus few of these objects survive. The Cupeño territory also had important riparian habitat, which supplied materials for bows, arrows, baskets, and sandals (APEC 1981; Barrows 1900; Bleitz and Porcasi; Hill and Nolasquez; Strong 1929).

Figure 2. Sketch map of the Cupeño territory showing the lands owned by different clans. te = temewhatnitcem (Northerners) (from Strong 1929:248).

CHAPTER SUMMARY

This thesis evolved from involvement in two field seasons of excavations in Lost Valley. It is of the utmost importance for project reports to be completed and published so that the data and the analyses are added to the archaeological record for posterity.

The study area encompasses the Cupeño territory, and Lost Valley was a part of the temewhatnitcem clan’s seasonally occupied subsistence territory, an area rich in acorns, seeds, small rodents, lagomorphs, and deer. The focus of this thesis is to model possible trade and travel routes between camps, villages, waterholes, or any other area where there was occasion to stop and deposit artifactual remains. The natural history of the area and the
topographic conditions seem to be major factors in the choices that were made as to which routes were taken by the peoples living at the headwaters of the San Luis Rey watershed so long ago. The next chapter provides a review of literature pertinent to the subjects of GIS in archaeology, least-cost path analysis, and how least-cost path has been used in archaeology.
CHAPTER 3

LITERATURE REVIEW

CLASSIC STUDIES GIS IN ARCHAEOLOGY

Two important literature reviews allowed me to form a reading list that related the use of GIS to the study of archaeology. Two authors, Kenneth Kvamme (1999) and David Ebert (2004), deserve credit for informing my initial search for a project. Classic themes in GIS and archaeology were identified in Kvamme’s 1999 publication, and volumes of work and individual manuscripts were chosen from his massive references cited as being of most importance to the foundation of my study (Aldenderfer and Maschner 1996; Allen et al. 1990; Lock and Stančič 1995; Maschner 1996). Each of these works is described below with the intent of showing how emphases changed over time and how each makes a contribution to my project.

A landmark volume describing use of GIS in relation to archaeology was found in Kathleen Allen, Stanton Green, and Ezra Zubrow (1990). The chapters from this volume have been cited repeatedly in many subsequent studies. Some of them have stood the test of time. For example, Kathleen Allen (1990), modeled historic trade networks using GIS, while Jeffrey Altschul (1990), argued for the importance of outliers in predictive modeling rather than use of the model for predicting site location. Landscape theory and GIS formed the foundation of the chapter by Carole Crumley and William Marquart (1990). Robert Warren (1990) wrote a chapter on predictive modeling that became standard method for many projects. Finally, Ezra Zubrow (1990), considered the way archaeological theory was redefined through the use of GIS in archaeological research. Some chapters are dated because hardware and software have changed so rapidly over the last 17 years as can be seen in Scott Madry’s (1990) chapter on computer hardware requirements.

Counting the number of themes represented in this volume, by titles, the predictive model is by far the most prevalent, with six titles having some reference to predictive modeling, or site location modeling. Modeling (in other contexts), regional archaeology, and landscape archaeology followed in number and importance behind predictive modeling and
were mentioned in three titles each. A comparison of themes from *Interpreting Space* to those of the next classic volume by Gary Lock and Zoran Stančić (1995) is presented below and is interesting how the two volumes differ in focus. However, one should note that the 1996 viewpoint was on European use of GIS whereas the 1990 volume was written from an American perspective.

In *Archaeology and Geographical Information Systems: A European Perspective* (Lock and Stančić 1995), the focus of the presentations moved to landscape archaeology with four titles referring to the word landscape in some capacity. The second most important areas were resource management, settlement, and archaeological theory, with reference to two titles each. Predictive modeling was mentioned in only one title, and was called prehistoric location preference. This volume had its focus on European archaeology, and the reader is made aware of differences between American and European focus and also funding. Two books came out the following year (Aldenderfer and Maschner 1996; Maschner 1996) that provide a better view of the trends in the mid-1990s.

Mark Aldenderfer and Herbert Maschner’s (1996) *Anthropology, Space and Geographic Information Systems* edited volume is focused on case studies in anthropology using GIS, six of which were archaeological. Of these six case studies, the titles belied a breakdown of more focus on cognition or cognitive theory in archaeology and settlement, and secondarily on landscape theory. Maschner (1996) in *New Methods, Old Problems* showed a trend towards expanding themes in archaeology. This book is better described using its section titles, as the themes were spread thin with only location modeling, regional archaeology, and landscape archaeology mentioned more than once each. *New Methods* is divided into four sections: 1) Exploratory Data Analysis and Visualization, 2) Cost Surfaces; Viewsheds, or Line-of-Site Analyses; and Site Catchments, 3) Site Location and Environmental Modeling, and 4) New Directions for GIS in Archaeology (Maschner 1996:v-vi).

The review of literature by Ebert (2004) verifies Kvamme’s classic themes, with one additional “new” work (Wescott and Brandon 2000). This volume differed from the others as it contains “Predictive Modeling Toolkit” as part of its title. Of the nine chapters (one being the Introduction), five titles contain the phrase predictive modeling, one contains the term settlement pattern, and one contains the term archaeological theory. Table 1 shows how the
themes are distributed through these five volumes. It is interesting to note that predictive modeling, so at the core of research studies in 1990, loses ground to landscape between 1990 and 2000, only to become a main focus of attention again in 2000. European archaeology shows much more interest in landscape archaeology, and the European volume is the only volume to use the theme of resource management in its titles.

Table 1. Distribution of Classic Themes in GIS and Archaeology

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**RECENT GIS STUDIES IN ARCHAEOLOGY**

Beyond the five classics discussed above, there are some recent volumes describing, using, and analyzing archaeological data incorporating GIS methodology. These include David Wheatley and Mark Gillings (2002), a foundational text for GIS in archaeology; Gary Lock (2003), on computing and archaeology; James Conolly and Mark Lake (2006), a generalized text on GIS and archaeology; and Thomas Evans and Patrick Daly (2006), an edited volume covering a range of topics and research studies important to GIS and archaeology. All of these volumes are European in origin. I will move through each of the volumes chronologically.

A very important book by Wheatley and Gillings (2002), *Spatial Technology and Archaeology*, defines all facets of GIS as it relates to work in archaeology. Wheatley and Gillings wrote this book as a reference source to archaeologists who wish to incorporate GIS into their studies. Archaeologists need more training to get more out of the vast potential of GIS, since the discipline is concerned with spatial information. Early theory in archaeology was based on culture history. Artifacts and features found in a certain space could be plotted
on a map, and inspection of the map by a cultural historian would reveal what well-defined
group of people created the patterns. Space was thought of as a neutral backdrop to culture.
Culture History, or the Classificatory Historical approach, is summarized in this statement:

…processes of diffusion created discrete ‘culture zones’ which corresponded to
culturally homogeneous complexes which were clearly and unambiguously
bounded in space…identified through the establishment of cross-classified trait
lists based upon aspects of material culture, then visualized through the careful
plotting of the distribution of these traits upon maps (Wheatley and Gillings
2002:5).

In other words, Culture Historians collected and documented artifacts, which were
classified, then compared to other classified lists of artifacts to find out which ethnic group
left them behind. There has been a change in thinking about space today as being culturally
defined and constantly negotiated, no longer thought of as a neutral backdrop for human
activity, but one that it is “socially rendered” (Wheatley and Gillings 2002).

Wheatley and Gillings also discuss the theoretical change in archaeology from a focus
on diffusionism, to that of the environment in relation to settlement in the U.S. Julian
Steward led this change in approach, identified as cultural ecology, in the 1920s and 1930s
(Trigger 1989:279), which was later taken up by Gordon Willey as settlement archaeology
(Viru Valley late 1940s) (Trigger 1989:282). Mapping on a regional scale, in the form of
distribution maps, was employed in these studies to visualize change in adaptations “of social
and settlement patterns within an environmental context” (Wheatley and Gillings 2002:5).
The concern was for “recording and analyzing the spatial dimensions of archaeological
material…one of the main instruments of archaeological research and exposition” (Wheatley
and Gillings 2002:6).

In the 1960s there was a decided move away from description through mapping to
identify unambiguous culture groups, to the identification of patterning in the archaeological
record leading to explanation. The New Archaeology demanded scientific proof of noted
observed patterns, in measurements and statistics, and explanation of those patterns. Change
was caused by external factors and these could be seen as traces in the archaeological record
that could be measured (Wheatley and Gillings 2002). Even though the whole book is
important for understanding and using GIS in archaeology, three chapters stand out that were
of particular interest to my research. These were the chapters titled “Digital Elevation
The chapter, “Sites, Territories, and Distance,” explores the spatial property of distance or proximity, and the relationship of distance between objects. “Proximity and distance are...at the core of many important archaeological questions” (Wheatley and Gillings 2002:147). Why is an archaeological object in one place, and not in another? We are looking for explanation. GIS has prompted renewed interest in spatial archaeology and quantitative techniques.

Spatial archaeology uses buffer zones, usually of distance from a point, line, or area. The authors note that cultural factors could be integrated into a buffer analysis (also called a proximity analysis). Vector GIS produce distance buffers and corridors. “The generation of distance buffers or corridors can be regarded as a form of spatial allocation” (Wheatley and Gillings 2002:149).

Voronoi Tessellation is another method of spatial allocation. Tessellation divides up the space surrounding sites into territories. Voronoi Tessellation is also called Thiessen Polygons. A graph is created from a set of points; in this case, the points represent archaeological sites. Another tessellation method is Delaunay Triangulation, which is “the creation of a graph in which the points are used to form the corners of a set of triangles” (Wheatley and Gillings 2002:150).

Distance is a geometric property that can be used in simple analogies and comparisons. More complex analyses require the addition of real factors, such as obstacles to travel, differential cost of movement over varying surfaces, or perception of landscape by the traveler. Instead of distance, the time it takes to travel a certain route can be estimated by the use of cost surfaces. Cost surfaces “can be regarded as modifications to the continuous proximity product that take account not only of proximity but also of the character of the terrain over which that proximity is measured...like distance, these are still simply mathematical models whose archaeological meaning is not fixed: it is up to us to use these as building blocks to create methodologies that have some archaeological meaning” (Wheatley and Gillings 2002:151). The authors provided many avenues of thought about my own least-cost path analysis of travel routes through Lost Valley. The year after the Wheatley and
Gillings book became available for purchase, Gary Lock published a book on computer use in archaeology that included the use of GIS as part of the methodology covered.

*Using Computers in Archaeology: Towards Virtual Pasts* (Lock 2003) was written to be used as a textbook and so explanations of, for instance, the difference between GIS and Computer Aided Design (CAD), are concise and complete. Lock covers such topics as prospection (looking for sites through use of remote sensing equipment), use of computers during excavation, landscape theory, preservation of digital files in Cultural Resource Management (CRM), presentation of work (as in museums, interactive media, online or electronic publication, and in the classroom), and future possibilities that include virtual worlds. Another book that is written in much same vein is that by Conolly and Lake (2006).

*Geographic Information Systems in Archaeology* (Conolly and Lake 2006) is presented as a handbook for those involved in academia or CRM as students or professionals in archaeology. Similar in outline to Wheatley and Gilling’s book (2002), Conolly and Lake write in a much simpler style. And there are additional sections and chapters that show the expanding network of ideas pertaining to the science of GIS in archaeology that include a section on geodatabases, a section on landscape archaeology, a chapter on theory that applies to GIS and archaeology, a chapter on exploratory data analysis, and most relevant to this study, a chapter on routes, networks, cost paths, and hydrology. The same year (2006) another book became available that brought together different authors into an edited volume.

Evans and Daly (2006) are included here because of the fine chapter by Ezra Zubrow on the historical development of digital archaeology (Zubrow 2006). Zubrow provides the context for his chapter through archaeological theory rather than case studies, comparing the development of archaeological theory to the development in technologies affecting archaeological thought. His sequence of historical development of archaeological theory moves from observation (coupled with “calculating machines”), to cultural history (coupled with early mainframe computers), to processual archaeology (coupled with the first, smaller sized computers, but using punch cards), to post-processual archaeology (coupled with the advancement of smaller yet more powerful PCs and the move away from punch card technology), to cognitive archaeology (coupled with more modern PCs and supercomputing workstations) (Zubrow 2006:17, Table 1.1).
SITE PREDICTION, PROCEDURE, AND LANDSCAPE THEORY

According to Ebert (2004), there are three main ways that GIS are used in archaeology: 1) site location prediction, 2) “procedure-related studies,” and 3) landscape theory (Ebert 2004:320). My own review of the literature found this organization to be true and so wish to use it in organizing a review of research papers focused on these topics. I have limited the review to those papers concerning site prediction and landscape theory. Studies that are based on procedure are common and centered on how to do some of the tasks related to GIS use in archaeological studies.

Site Location Prediction

By far the most prevalent research using GIS in archaeology, especially in the U.S., are site prediction location studies. Examples abound in the literature. There are many ways to produce a predictive model. Many of the studies report on the methods of producing their predictive model (e.g., Brandt, Groenewouldt, and Kvanne 1992; Dalla Bona 2000; Duncan and Beckman 2000; Hasenstab and Resnick 1990; Kuna and Adelsbergerová 1995;), while others report on case studies using predictive modeling in a specific area (Carmichael 1990; Dalla Bona and Larcombe 1996; Warren 1990b; Warren and Asch 2000; Wescott and Kulper 2000). Other aspects reported on for predictive modeling are the history and evolution of the methods that have been developed (e.g., Kvanne 1995; van Leusen 1996).

One San Diego State University graduate student in anthropology used predictive modeling as the core of his thesis (Tsunoda 2006). Koji Tsunoda’s thesis is a good example of using GIS with previously recorded archaeological site data. As part of the project Tsunoda interned for California State Parks and worked with the records necessary for his thesis. He was able to show environmental connections between site locations that were previously recorded and archived. Tsunoda anticipated that the information could be used to predict where sites may be located in areas that had not been previously surveyed, or to resurvey areas that may have missed site locations in earlier surveys if the environmental variables were met in the location analysis. This is the beauty of the predictive model. The information on the environment comes from previously recorded sites. There is no doubt that environmental factors play a part in the decision making process that humans use in deciding
where to locate for a day, a week, or a year. Slope, aspect, distance to water source, and elevation were the environmental factors that were considered relevant to Tsunoda’s study.

In 1995, Edward J. Pasahow, also an SDSU graduate student in anthropology with a focus in archaeology, employed early GIS to do an analysis of the prehistoric settlement systems for all of San Diego County. Pasahow had access to SCIC (South Coastal Information Center) that had in its database over 14,000 records of prehistoric sites. Pasahow used the site locations to plot sites by site attribute (such as site type, presences of features, rock art presence, quarry, ceramics present, and etc.) and to show the relationship of the distributions of sites in San Diego County.

Pasahow’s work led me to think about conducting a regional analysis in the much smaller area of Lost Valley. The valley itself proved too small for an analysis of the size needed for this type of study, and so I needed to expand it to a contiguous series of DEMs that are easily accessible for the project. My project took an alternate route to a least-cost path analysis. Pasahow’s thesis informs a predictive model for site location.

Similarly the following authors created predictive models for use in archaeological survey. In 1997, William Hayden used GIS and site locations in the San Joaquin Hills to look at spatial patterning of Late Prehistoric Period sites. He also performed statistical tests in order to show predictive values through artifact counts found in CRM reports. He was able to illustrate the relationship between territorial boundaries and modeled Theissen polygons.

A study of prehistoric site distribution in the Lower Cuyahoga River Valley, Ohio, by Andrew Bauer, Kathleen Nicoll, Lisa Park, and Timothy Matney (2004), used data available from archives to plot 79 archaeological sites into a GIS application. They then added available soil shapefiles as layers for their study area map. The original 79 archaeological sites had been recorded and placed into categories according to time of occupation and archived in the State of Ohio Historical Preservation Office, an agency whose work it is to document and store all materials related to Ohio history and prehistory. The Bauer team (2004) found that the later periods of occupation (Historic, Woodland period, and Late Prehistoric sites) clustered at certain geological locations over a broad range of location types, while early sites (Paleoindian, and Archaic) clustered around fewer geological location types, mainly Pleistocene terraces and areas between ancient, river-born sediments.
A master’s thesis by Nicole Pletka (2005) contains a predictive model that also uses least-cost path. The area of focus was the Newport Coast in Orange County, California. Pletka used available archival data as the basis for regional spatial analysis of sites that have been recorded either as surface sites or as excavated sites. Site location data and corresponding dates were obtained from either the South Central Coastal Information Center (SCCIC) or CRM reports. The study focused on Late Period Gabrielino settlement pattern.

Pletka’s analysis does not include any information about the artifacts recorded from any of the sites. Her method of analysis was to generate hypotheses from archaeological theory and then test her hypotheses with information derived from GIS analysis of the data. Pletka describes the different subsistence strategies used during the Early Holocene, Middle Holocene, and Late Holocene time periods, and the two theoretical paradigms she has framed her research questions around. The first is evolutionary ecology with an optimal foraging model as the main benchmark. The second is cultural ecology with Binford’s (1980) forager-collector continuum as the basis of the argument. She is able to show clustering of the paths, created using Nearest Neighbor analysis, as belonging to different settlement types.

Finally, Robert Legg and David Taylor describe a research project centered on predictive modeling of a particular archaeological feature, the placement of Irish Early Medieval Ringforts (2006). The ringfort is found throughout Ireland. The height of construction occurred during a window in time from about A.D. 600 to A.D. 900. Ringforts have some superstition involved with them, as well as being practical for herd animals to be kept. Thus, the presences of ringforts on the landscape of Ireland have, it is assumed, been largely left as is. They are thought to be agricultural farmsteads that needed protection from thieves and animals at the time. The authors of the study wanted to create a predictive model on where ringforts might be located on lands where there has been no survey, or where the ringforts may have been destroyed and have left no visible evidence. GIS were used to map areas by level of probability using a standard logistic regression equation for the multiple independent variables. However, the model that was produced had limited value in predicting the location of forts in areas outside the study area.
Landscape Theory

A relatively new theoretical position in archaeology is that of landscape theory. One of the early and well-cited volumes on landscape archaeology was edited by Wendy Ashmore and A. Bernard Knapp (1999). In the introductory chapter, “Archaeological Landscapes: Constructed, Conceptualized, and Idealized,” Knapp and Ashmore (1999) concentrate on explanation and some of the terms used in landscape archaeology. Their position in writing this paper is as an introduction to a volume of papers collected on the topic of landscape archaeology. They state that the terms and concepts are not theirs, nor were individual authors given any guidelines on the use of terms in the constructions of the papers. Four themes connecting the submissions are landscape as memory, landscape as identity, landscape as social order, and landscape as transformation.

Landscape as memory – Knapp and Ashmore begin with a simple explanation of landscape in this quote: “Landscape is often regarded as the materialization of memory, fixing social and individual histories in space” (1999:13). They go on to say that the “…most frequently cited embodiment of memory in land is the intricately conceptualized landscape array of Aboriginal Australians” (1999:13). National and ethnic identity is embedded in the memory of the landscape. Many old sites contain memories of the way things were at such physical locations as cathedrals, and cemeteries.

Landscape as identity – Landscape as memory and landscape as identity are linked. People use and reuse certain places in the landscape. They identify with these places just as I return to the same seat in a class. I associate this place in the classroom with the security of a position within the class, and with the ability to return again and again to a specific location. Knapp and Ashmore use the landscape as identity to mean a place to which people return again and again for ritual, ceremonial, or social uses. Activities bind people together and as such become part of their social identity. At these special places the people will leave their mark, such as rock markings, offerings, shrines, monuments, or temples. Identifying with a location in the concept of landscape of identity is well explained in this statement: “At any particular moment in time, certain places become vested with identity be it supernatural, social, or self-identity” (Knapp and Ashmore 1999:15).

Landscape as social order – Landscape “offers a key to interpreting society…the land itself, as socially constituted, plays a fundamental role in the ordering of cultural relations”
(Knapp and Ashmore 1999:16). Similarly, “Social roles, relations and identities, too, are mapped on the land…” (Knapp and Ashmore 1999:16), referring to the placement of houses and whether you live on Park Place or Mediterranean Avenue. Your living space will dictate which schools your children will attend, and what stores you will frequent. Your living space announces individual economic status. In other words the landscape plays a role in social ordering.

Landscape as transformation – Landscapes change over time and according to the uses and alterations to which they have been put, are thus transformed. “The transformations of landscapes is most often linked interpretively with cyclical time…” (Knapp and Ashmore 1999:18), such as the cycles of crops sown and harvested, or the movement of hunter-gatherers in the quest for available food sources, or the site of an annual pilgrimage to a certain monument of natural or man-made origin and the decay and reconstruction that evolves around that memorial site.

The three aspects of cultural landscape defined by Knapp and Ashmore (1999:21) are cultural landscapes, conceptualized landscapes, and ideational landscapes. These labels are used in the identification process of different landscapes in order to preserve important or unique landscapes of either natural formation or those culturally derived.

Constructed landscapes occur when something is altered or added to the landscape as the result of human interaction with it. Human non-sedentary groups (mobile hunter-gatherers or nomadic peoples) leave trails, views, campsites, and other clues about their activities. Sedentary groups (horticulturalists or agrarians) alter the landscape more obtrusively through the development of permanent gardens, houses, villages (often near natural landmarks), burial mounds, temples, dumps, and slag heaps.

Conceptualized landscapes are given meaning by how the people use specific areas of land for social or ritual practices. These may be artistic uses as in cave or rock art, religious uses, as in use of particular areas for vision quests, or awe inspiring uses, as in power spots with great meaning. An example of sacredness associated with place is Mount Shasta, a mountain that dominates the landscape of Northern California (you can see it for miles - even hundreds of miles in some places). Another example of a conceptualized landscape is the Buddhist cave temples (Knapp and Ashmore 1999:11).
Ideational landscapes can also have sacred or symbolic meaning. An ideational landscape is a mental construct, a perceived or conceptualized landscape that is “embedded within ways of living and being” (Knapp and Ashmore 1999:13). This straightforward and highly organized introduction by Knapp and Ashmore is a good starting point for comprehending the meaning and uses of landscape archaeology. Again and again they return to the idea of the uniquely human and “social nature of landscape” (Knapp and Ashmore 1999:7).

Tim Ingold puts forth a different point of view on landscape archaeology in his presentation, “The Temporality of the Landscape” (Ingold 1993). In this article, Ingold defines and clarifies four principle sections in presenting his argument. They are the following: landscape, temporality, temporality of landscape, and the analysis of an actual 1565 landscape painting by Pieter Brugel, “The Harvester” (Ingold 1993:165).

According to Ingold: “…the landscape is the world as it is known to those who dwell therein, who inhabit its places and journey along the paths connecting them” (Ingold 1993:156). Landscape is what you see when you go outside and look around. As you walk from one place to the next, landscape changes as you move through it.

Temporality has to do with time as it relates to a sequence of time or a point in time. Ingold says temporality is not chronology and not history. Temporality is intrinsic in the patterns of activity associated with the construction and maintenance of a living space (dwelling), which Ingold (1993:153) has named the taskscape. Taskscape has to do with what people are doing, what work they engage in. Ingold refers to the qualitatively and heterogeneous (what and how rather than how many, and of diffuse blends) of taskscape as opposed to being quantitative and homogenous (countable numbers of similar undertakings).

Ingold discusses the temporality of landscape, and the taskscape and its relationship to landscape saying the distinction between them is blurred. The landscape is a living process, a work in progress. “…[T]he activities that comprise the taskscape are unending, the landscape is never complete…” (Ingold 1993:162). The taskscape is the sounds of activity; the landscape is what you see. The landscape retains the palimpsests of past occupation and habitation just as a landscape painting might.
Using the painting by Bruegel to illustrate his approach to the analysis of landscape, Ingold (1999) explains how the still antiquated landscape painting captures the essence of lives lived at this point in time. The moment captured was one instance in the nature/culture cycle of land use and dwelling, so this same scene no doubt repeated year after year in a similar way. There is another way to depict landscape, one that possibly more clearly captures the nuances of landscape over a large area and from a different point of view. This is by viewing the landscape from above.

The use of GIS and mapping techniques, and geophysical surveying allows a landscape perspective from a plan view. In an *American Antiquity* article, Kenneth L. Kvamme (2003) explains how GIS and archeo-geophysics can be used to coordinate a view of landscape via digital methods. Using the archeo-geophysical methods of non-invasive ground penetrating radar, resistivity and conductivity, and magnetometry, one can obtain a picture of an ancient landscape with many of its features of use and non-use that lie below the surface.

The technologies of archaeo-geophysics tend to be used over large areas to glimpse a totality of hidden landscape features. These geophysical methods are used to better determine where archaeological digs should be placed so that standard units of excavation may be more fruitful. Use of these archaeo-geophysical tools would preclude the need for shovel test pits (STPs) that are expensive and time consuming for the results that they provide. According to Kvamme’s article, only one percent of STPs yield some sort of artifactual content. STPs are used to determine the best area for layout of project units, where the yield may be the most beneficial to the area under study.

Archaeo-geophysical methods are used extensively in European archaeology, but have not caught on in the United States. Old methods die hard. The equipment necessary to use archeo-geophysical methods for pre-exavation research come at a dear price, in the range of 10 to 20 thousand dollars or much more for one piece of equipment, depending on which avenue is taken. The cost of equipment and the cost and time needed for necessary training in new hardware and new software programs may be the reason why these methods are being adopted more slowly the U.S. Using a technological approach to landscape archaeology would boost both qualitative and quantitative analysis.
As is evidenced by the three examples of the application and approach of landscape archaeology just discussed, there are very different ways of applying and interpreting landscape archaeology. Knapp and Ashmore (1999) presented an organized and thorough overview of landscape archaeology with some new terms. Ingold (1993) philosophized over music and paintings and how resonance, cycles, and rhythms of daily, weekly, yearly activity relate to landscape and taskscape temporally. Kvamme (2003) approached landscape analysis through quantification using new technological developments in GIS and remote sensing. Landscape archaeology contains a diverse set of ideas and approaches, all of which are relevant to study, survey, and analyze in archaeology.

One of the goals of this investigation was to include the use of GIS as a foundation of the project. A second goal was to use previously collected archaeological data and incorporate these into a GIS analysis. One of the problems in the discipline of archaeology is that analyses and reports on excavations lag behind collection and curation of artifacts, even though it is considered unethical to fail to publish a record or report once an excavation is complete (see the Society for American Archaeology website for the eight principles of Archaeological Ethics: http://www.saa.org/aboutSAA/committees/ethics/principles.html). One way of approaching the problem of compliance to ethical principles in archaeology is to provide avenues of analysis that use new technologies for the vast stores of data collected over the years. Even for those data collections that have been published, new questions can be asked, and old assumptions challenged through the use of new methods such as GIS. Linking disciplinary tools is another avenue worthy of exploration.

GIS Least-Cost Path Analyses in Archaeology

One of the earliest studies involving least-cost path and network analysis using GIS in archaeology is that of Kathleen Allen (1990). In her study of trade networks in the northeastern United States, Allen showed how GIS could be used to model trade networks following the watersheds or waterways. Waterways, used as transportation networks, played a part in the distribution of goods between tribes in the Great Lakes area of New York State.

Allen used the NETWORK module of Arc/Info to create a model of trade networks using the New York State hydrology layer as the path of least resistance for connections between known prehistoric sites and known historic trading post locations. In the state of
New York, the prehistoric inhabitants were those of the Five Nations Iroquois. In this early design of GIS used in archaeology, Allen marked out the steps taken to create her model of change in the major trade routes between incoming Euro-American traders and the aboriginal inhabitants, using present New York State as the area boundary. With a background in the prehistory and history of the area, Allen was able to assign time periods for different configurations in trade relations. The models show that the Iroquois first had more control over trade through the region, but gradually, as Euro-American colonists advanced into Iroquois territory, Euro-Americans gained control over trade. Hydrology models follow least-cost paths directionally down slope, as this is the path that water would follow naturally.

Ten years later, Marcos Llobera (2000) takes ideas from some very obtuse philosophers (i.e., Foucault and Bordieu) and makes them understandable. Using a creative approach to the blending of archaeology and GIS, Llobera is a master at the mathematics of cost paths, which is the focus of his writing. Digital Elevation Models (DEM) form the foundational data layers in this study of foot trails in rural areas. Llobera’s study compares modeled paths to those that are present to this day in an area where monumental architectural features are present. He wishes to formulate ideas of how these features function to alter paths that would follow the direction of least resistance. He goes in to some depth about the impact of features on those who use a route near the feature. Well-worn trails are created in a predictable manner, one that can be predicted through the use of mathematical formulae.

Llobera’s model of movement has to do with the study of ancient landscapes. He adds to previous models that take into account specific landscape features and the creation of pathways that guide the traveler through the landscape in a way predicted to inspire awe. Llobera’s focus is on movement through the landscape. Enhanced by the addition of GIS, Llobera creates what he calls a “new GIS routine” (Llobera 2000:65).

The new routine can be described with the goal of exploring “dynamics of movement” in natural landscapes (Llobera 2000:66). Starting with the topography or shape of the landscape, he finds the energy cost of moving through that landscape, taking into consideration the effects of landscape features (a quite extensive step in the routine) (Llobera 2000: 71-74). Then, Llobera combines previous ideas with DEM information, models the movement process, states his assumptions, and presents his results. Presently, ArcView 9.2 will perform a lot of these functions automatically with the correct input.
In the next example of GIS and least-cost path in archaeology, author Trevor Harris (2002) suggests that the most advanced use of GIS in archaeology is simulation of sites in three and four-dimensions. The earliest use in archaeology was to map data and to keep it organized. The next advancement was “spatial analysis and modeling” (Harris 2002:131). Harris covers a range of topics, which include archaeological mapping, 2.5-D display, viewshed analysis, cost surface analysis, 3-D multidimensional modeling, archaeological site prediction, virtual GIS, and virtual worlds. But the main discussion of interest to my study is that of a GIS project that he and Gary Lock completed on Iron Age hillforts. They used cost surface or friction surface to calculate time and effort needed to reach Iron Age hillforts from surrounding habitations, the methods of which have much in common with the modeling of Cupeño travel networks.

One of the most influential papers to my research was posted online in 2003, by the research team of Whitley and Hicks (2003), who showed how an archaeological research project could adapt the use of GIS to predict the location of ancient travel routes between archaeological site locations. The goal of the project was to forge new avenues for thinking about the archaeological record, and to expand discussion of research areas previously limited by available technology. GIS are one such technology that provides a potential avenue for expansion in this area. Digital elevation models (DEMs) were “fused” together, and then the slope, hillshade, and runoff models were derived from the DEMs. A friction surface was created, as well as the point files for the beginning and ending of paths across the friction surface. Of note, their study area was a large rectangular area that crossed three counties and converged a total of 16 USGS Quad maps that represent the basis for the DEMs.

This study is of interest because first, it is exploratory, second, they use DEM derivatives and available data from a project done for archaeological site prediction (so they have a layer of sites with attributes that include the estimated time of occupation), and third (even though it does not say exactly how they do it), they are experimenting with least-cost path from edge to edge of their study area over multiple iterations that move the start and end points at intervals. These cost paths are combined and cleaned up, especially at the edge, where “edge effect” causes the line of least-cost to travel along the study boundary (when it really should continue outside the boundary).
My final example of the use of least cost paths in archaeological study is based on a thesis by Nicole Pletka (2005) (described previously), that uses least-cost path analysis to show clustering of archaeological sites in the Newport Coast area of southern Orange County, California. Pletka used distance to the coast as one of the main attributes for her research that described the movements of prehistoric and protohistoric peoples across the landscape, and how the known sites clustered into three regionally distinct settlement patterns (Pletka 2005).

Pletka used available data as the basis for regional spatial analysis of sites that have been recorded either as surface sites or as excavated sites. All of the sites associated with the study have an associated date from radiocarbon testing that was done under contract, as all of the area is now under development for homes. Her analysis does not include any information about the artifacts recorded from any of the sites. The method of analysis was to generate hypotheses from archaeological theory and then test the hypotheses with information derived from GIS analysis of the data.

Data on site location, dates of occupation, and survey boundaries were entered into a GIS. These data were from site reports filed at South Central Coast Information Center (SCCIC) at California State University, Fullerton and include the following: a report by Macko (1998); a report by Mason and Peterson (1994); and a report on Crystal Cove State Park (Barter 1991). Archaeological sites were digitized using a digital USGS topo quad as the base map. Modifications of boundaries were made where necessary. Pletka posed a series of six hypotheses. One of Pletka’s hypotheses is Hypothesis 1, which states that the sites are randomly placed or clustered. Using nearest neighbor analyses, Pletka found the single closest neighbor to each of the sites, and then ran the statistics for the nearest neighbor. A line was formed on the GIS map between nearest neighbors. The results of this analysis included a map with lines between the sites, which were closest together. This test showed that the sites were clustered in three distinct zones. Hypothesis testing was also conducted for distance from the coast; random or clustered site distribution; placement of intermediate zone sites on least-cost paths; and the distribution of sites with regards to soil type, which Pletka used as a proxy for vegetation type. Pletka’s thesis was inspiring and informative in possible methods that could be used in testing the results of GIS routines.
LEAST-COST PATH IN OTHER DISCIPLINES

The use of GIS have important implications for other disciplines as well. I will summarize those that are pertinent to this thesis. Important work is being conducted in the area of wildlife habitat. The work of Gallo et al. (n.d.) is a good example of inroads into construction of mountain lion breeding corridors to ensure the presence of mates and therefore future populations of mountain lions in California. This particular work was conducted in the Santa Barbara area. Another example of use of least cost path is in a study by Helbing et al. (1997). Working in urban areas, this team found that people walking across wide expanses of undeveloped land would soon create regular trails across the area that could be predicted in advance. In the work of Ganskopp et al. (2000), the probable paths of livestock were modeled in GIS to show that cattle do follow the path of least resistance. The paths that they would form over a range could be predicted.

In Brumm et al. (2002), GIS are utilized for transportation planning in the construction of a road. Finally, Stahl (2005) used GIS to find the best route to send out autonomous ground vehicles. In order for the robotic vehicles to arrive at their destinations without mishap, the path they would follow is figured ahead of their travel. These five examples of least-cost path outside of archaeology show the utility of the program and the multiple ways it can be used in analyzing least-cost paths.

THEORETICAL FOUNDATION

The foundation of this thesis is based on the theoretical framework used by authors of works using GIS for least cost path or for other avenues of inquiry in archaeology. There were as many different theoretical models as there were papers. This section describes the cogent theoretical bases used and argues for the appropriateness of the theoretical framework chosen for this study.

Landscape Archaeology

I looked for explanations of landscape archaeology that were conducted after Knapp and Ashmore (1999) and Ingold (1984) published their work. I was especially interested in how landscape theory is incorporated into newer studies utilizing GIS functionality in archaeological research. In the following section I briefly describe several studies that contained three primary ingredients: landscape theory, GIS, and archaeology.
According to Crumley and Marquardt (1990:73): “Landscape is the spatial manifestation of the relations between humans and their environment.” Landscape can include unoccupied space that is used for religious purposes, resources extraction, rivers, mountains, and so on. Furthermore, two structures determine landscape, sociohistorical structures and physical structures (Crumley and Marquardt 1990:74). Sociohistorical structures include those structures, which are political, legal, and economic, while physical structures include those outside of human control such as climate, soil type, and topography. Within these structures the landscape is produced through human interpretation as in how the world appears to the beholder in the way of aesthetics, sacredness, significance, provider, and protector.

Crumley and Marquardt’s original research focus was on changes to administrative boundaries. In their research they wanted to locate the changes in regional boundaries over time. In defining a region, they choose a comprehensible, identifiable unit that could be selected and compared to other units of a comparable size. Scale is an important comparable between regions. “To find an appropriate scale of analysis, one must search for (1) a measure of the connectivity (at different scales) of the area under consideration with contiguous areas and (2) areas that seem to exhibit a high degree of overlap of a variety of boundaries. Viewed this way, a region never has the same meaning, nor does it occupy the same boundaries throughout its history” (Crumley and Marquardt 1990:75-76). Crumley and Marquardt (1990:78) believe that successful modeling of archaeological regions will depend on the addition of cognitive and historical features. They chose GIS as the tool to help them achieve the goals of the research in combining landscape as a concept in the understanding of regional development (Crumley and Marquardt 1990).

Ten years later, an important book on bridging theory in archaeology helps to define the use and connection of the landscape perspective in archaeology. Schiffer’s 2002 *Social Theory in Archaeology* presents ideas related to the necessity of bridging seemingly opposed theoretical paradigms. As the first chapter of an edited volume, Schiffer starts by describing the practice of redlining in archaeological theory, as there is at present too much literature to master. In a comparison of theoretical camps, Schiffer says that Binfordians can easily redline postprocessual or behavioral theoretical literature, thus paring down their reading load. In the same way Dunnell, from the evolutionary archaeological perspective, can redline
behavioral and processual literature. Since Schiffer is a behavioral, processual archaeologist, he suggests that postprocessual theory should be ignored (Schiffer 2000:4).

The other way to exclude through redlining is on the basis of complexity of the society under study usually divided into three levels: mobile hunter-gatherers (bands), intermediate tribes and chiefdoms, and complex societies (Schiffer 2000:4). Studies of complex societies easily set aside those theoretical works pertaining to intermediate level, and band level societies and so on. Schiffer says redlining on the basis of theoretical school, or level of complexity “is no different than traditional redlining in archaeology based on areal specializations” (Schiffer 2002:4). However, he says that this type of redlining is justified by reading Kuhn’s *Structure of Scientific Revolutions*, which puts forth that competitive theories are too incompatible (in their assumptions) to be combined. Researchers with opposing paradigms cannot comprehend each other’s ideas, so no discourse can take place.

However, Schiffer believes that it is time to stop the separation, and begin integration of these theoretical camps. He thinks that division by camp impedes theory building in archaeology and says there is another way (Schiffer 2000:5). Bridge building is defined as “the construction of any conceptual integument that can connect previously disparate theoretical formulations or relate, theoretically, formerly discrete phenomena” (Schiffer 2000:5-6). Rather than redlining, a better practice would be to become educated in the main literature from all sides and use a blend of theories that best supports the data that you are interested in exploring.

One of the chapters in the Schiffer (2000) volume is by María Nieves Zedeño (2000), who manages public lands for cultural resources. Part of her research has been focused on land tenure policies that affect aboriginal populations. Ideas of land ownership and administrative policy are explored.

Zedeño, looking to explore human-nature relations, does so within a framework of landscape theory. She bridges the management of cultural resources on public lands with a landscape approach (Zedeño 2000:97). She says that in the development of programs dealing with the need for safe havens for immigrants to the United States, policies were made and altered to contend with whatever was required for a repopulation by colonizing Euro-Americans to take place, decidedly not in the best interest of the aboriginal inhabitants. “I am
concerned with understanding how people build social environments through interactions with nature” (Zedeño 2000:97).

Built environments have been frequently studied as far as architecture and monumental building are concerned. The lifeways of hunter-gatherers do not usually leave such remains, so a different approach is necessary to deal with their idiosyncrasies. In contrast to the study of monumental architectural remains, hunter-gatherers “built their social environment around the extraction and appropriation of localized natural resources—plants, animals, minerals, and landforms” (Zedeño 2000:98).

In order to accomplish her landscape study, Zedeño examined the history of land tenure and land tenure policies and the language definitions required for such understanding. Cultural differences in the concepts of bounded space, property ownership, land tenure, and differences between hunter-gatherer and agrarian needs are explored. American political history led to the “notion of space bound tenures” (Zedeño 2000:99). Current legislation, Zedeño reminds us, is the reason we have our archaeological jobs in some cases. The legislation halts some of the procedures of traditional archaeology, but creates new avenues for approaches, which now include a landscape approach. Zedeño sees the link of current research studies between “eclectic approaches and postmodern approaches to human-nature relations” (Zedeño 2000:102), and also between the landscape approach and Native American land tenure systems. The landscape approach, says Zedeño, “provides a frame of reference for understanding human-nature relations at various scales” (Zedeño 2000:102).

One of the ideas that Zedeño wishes to explore is that of landscape theory in archaeology and the way in which single landmarks (localized places or resources that are transformed through use into a places of importance to the culture—I think of site here) are linked “into an integrated network or landscape” (Zedeño 2000: 98, emphasis in original), which is a perfect parallel to what my study is seeking to accomplish. My network would be the trails linking the landmarks or sites that have been recorded. My network model may show areas where sites should be found but have not been recorded yet, in kind of a predictive model of nodes along a network.

From the foundations of these theoretical pieces on landscape archaeology, some with a connection to GIS in archaeology, I lay the framework for my study of the network of trails
through Lost Valley, and the possible connections that may be seen in the modeling of such networks.

GIS: Tool or Science?

Geographic Information Systems have a brief history going back to its original use in the 1960s as a tool for plotting Canada’s land usage by the Canadian government (Longley et al. 2005:16). In the several decades since, GIS have expanded their capabilities to include census data encoding in 1967 (USA). In 1969, map overlay processes were added to GIS arsenals. The development of microcomputers in 1981 allowed the expansion GIS capabilities. Then, the addition of Global Positioning Systems in 1985 furthered the development of GIS using GPS coordinates from the field. Internet based GIS (including MapQuest in 1996) allowed further growth of the GIS industry, which now claims a huge global market. Huge volumes of data available for access in the early to mid 2000s by government and private business entities have furthered the ability for people to learn to use the software without the huge expense of data collection (Longley et al. 2005:19-21).

A debate about whether GIS are science or tool was inadvertently begun through a listserv discussion (GIS-L) in 1993. A tangential discussion about peer reviewed literature led to a point of “GIS as a science” which led to counter point of “GIS as tool”, and the debate was begun. The authors of GIS: Tool or Science? (Wright et al. 1997) collected the transcripts of the discussion through listserv to try to answer the question. They coded the transcripts and divided answers into groupings. It seems that there was a split between those who viewed GIS as a tool, and those that related it with science. This broke down into discussions about the definition of science. According to Wright and colleagues (1997:352-354) the research on the listserv discussion revealed three divisions of use that GIS are put to. These positions are fuzzy and represent a continuum from GIS as tool, to GIS as toolmaking, to the “science of GIS.” From an archaeological perspective, GIS are a suite of tools that can be used to enhance scientific understanding depending on how it is used. The use, and therefore what it is, depends on the user.

CHAPTER SUMMARY

Some say that the history of GIS in archaeology is long; some say it has been utilized only a short period of time. In the review of literature I have included those works that are
relevant to my area of study, which is modeling a network of least-cost path trails that will locate Lost Valley in relation to surrounding known sites. One possible result could be the prediction of the location of undiscovered sites. The literature review begins in 1990 with a major publication (Allen et al. 1990) and progresses from there to include those foundational works that are cited again and again in research papers contributing to the growing volume of literature containing methods of GIS in archaeology. I then researched literature containing least-cost path studies, continuing to literature explaining and using the theoretical foundation of landscape archaeology (or theory) that has gained notoriety in the past ten or more years. This body of literature is the foundation on which my thinking has evolved over the two plus years that I have been cogitating on Lost Valley and the modeling of a possible network of trails that could show relationships with areas within and outside of Cupeño territory. In the next chapter, I review the methodology used in this research project.
CHAPTER 4

METHODS

This chapter is intended to explain the methods used in this research project. The chapter covers the scope of project, the definition of the primary data layer (DEM) and how it is downloaded and prepared for use in a GIS, the description of other data layers required for the project, and the execution of a least-cost path analysis illustrated through a series of steps.

SCOPE OF THE PROJECT

The area of study is Lost Valley, in the north central portion of San Diego County, in southern California. The scope of study involves the use of Geographic Information Systems (GIS) in the construction of a least-cost path analysis or most effective travel route between late period occupation site-locations. Using Lost Valley as the central location, I derived layers of data in the GIS from digital elevation models (DEMs) for different blocks of United States Geological Survey (USGS) 7.5’ quadrangle maps. I began with a test using one DEM (Fig. 3). This DEM is for Hot Springs Mountain, which includes Lost Valley as well as the area near Warner Springs. With the results of the pilot test, a new project was planned, which I call “San Luis Rey Watershed”. This second project incorporated a larger area that covered the San Luis Rey watershed with a total of 27 DEMs (Fig. 4). Varying start and end points were used for least-cost path analysis through the watershed. For the third project, a different block of DEMs was chosen according to the results of the previous analysis. However, the results for Project 3 (the least-cost path analyses) were missing network connections through Lost Valley.

A smaller area of coverage, using a fourth block of DEMs had to be applied which had more potential to show a relationship of Lost Valley to the surrounding area. Finally, the least-cost path analyses were combined with data that included information on site locations from SCIC (the last three project locations are shown in Fig. 5).
Figure 3. Test of the model using the Hot Springs Mountain DEM, start path in Warner Springs area, end path at Lost Valley (screenshot from ArcView 9.2).

Figure 4. Location of the San Luis Rey watershed within San Diego County.
Figure 5. Changes in the boundary of the project area.

This final least-cost path analysis was conducted using two adjacent DEMs: Hot Springs Mountain and Warner Springs. Figure 6 shows the locations of all project DEMs in relationship to the County of San Diego and how the DEMs align with watershed boundaries. Additionally, one path was picked out of the tangle of intertwining generated least-cost paths for further investigation (Fig. 7). This path (shown in orange in Figure 7) was isolated and saved as a jpg file. When there was a change in direction, the coordinates of the start and end and all points in between, were recorded using the identify tool in ArcView 9.2. The
coordinates were then imported into Google Earth, where I was able to mark those coordinates, and import the jpg of the path of interest. Using Google Earth’s manipulation capabilities, I was able to get the line image to line up with the coordinates of the start, end, and change in direction locations that I had marked in Google Earth. I now had a path in Google Earth that could be followed through virtual space to see how the path traversed the local geography.

Figure 6. USGS DEM titles and placement of those used in projects.

**DATA: THE DIGITAL ELEVATION MODEL**

A DEM is a simulated representation of the surface of the earth created by digitization of contour lines from USGS 7.5’ quadrangle maps and the interpolation of the interstices of the contour, so that the end result is a continuous representation of elevation for that area in raster format (Conolly and Lake 2006:4-5). A raster format is composed of a grid of tiny squares. Each square has a value assigned to it, which is a representation of elevation or z-value of the square.
A useful comparison of the DEM(s) used in each project (1-5) can be found in Table 2.

The United States Geological Survey (USGS) website, at http://www.usgs.gov, directs requests for Digital Elevation Models to the GeoComm International Corporation website at http://data.geocomm.com/dem/. DEM downloads are available free of charge at this website for all of San Diego County (and all counties across the U.S., Alaska and Hawaii) in 7.5 minute (1:24,000 scale) tiled data. The DEMs are packaged in Spatial Data Transfer Standard (SDTS) form, which requires a series of steps to unpack for use in ArcView. From the website http://data.geocomm.com/dem/, one can choose state, county, and DEM. Let us use Hot Springs Mountain DEM in San Diego County, California as an example. An account is necessary to log in and retrieve the data file. You will not be asked for your account information until you try to download a file. Enter your login information. Scroll to the file you want to download (again) and click on the green arrow button (that is
Table 2. DEMs Used for Projects

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</table>

Key: Project 1 = Pilot Project; Project 2 = San Luis Rey Watershed; Project 3 = 16 DEMs; Project 4 = 12 DEMs; Project 5 = SCIC Data.

Choose either the 10-meter or 30-meter resolution DEM file by right clicking on the file name. Save it to a folder at the root of your C drive which is named the same name as the DEM you are downloading (in my case, HotSpringsMountain is the name of my folder). Do not use spaces in any folder names or file names when working with DEM files.
After your file has downloaded, open the folder and minimize it. Go back to the download page and save the accompanying text file. The text file has information about the DEM file that you may need, such as the name of the quad, the resolution, the units of measure (feet or meters), the datum, and so on. Open the folder and click on your downloaded DEM file to extract the file from zipped format in WinZip or another zip program (I use ZipGenius, a free online download). Everything is a lot easier to keep track of if you download the extracted files to a folder with the same name as the file number (create the new folder inside the folder with the zip file in it).

Now go to ArcCatalog and find your unzipped file in the menu. From the Conversion Tools menu, choose STDS Raster to Grid. In the pop up menu, find your downloaded file folder and click on it. A four-digit number should appear in the “Select one Prefix” text box. Select that four-digit number; it will be placed in the menu in “Input Prefix.” Name your “Output Grid” in the folder where you would like it to be created; leave the “Record No” at the default name. Click OK. The ArcView software executes the transformation for you. This creates a readable DEM raster with eleven accompanying files. In ArcCatalog, the file is black and white and looks like a negative. The black and white flat image must be given color and depth in ArcMap. Figure 8 shows an example of the Hot Springs Mountain DEM after transformation from SDTS to a grid readable in ArcView.

Figure 8. Example of a DEM after transformation from SDTS format to a grid readable in ArcView on left. Right, after adding color and manipulating visual for hillshade to give depth.
If there was more than one DEM used in my project, they were mosaicked in ArcCatalog into a solid block. All of the transformed DEMs were prepared through geoprocessing for hillshade, slope, and aspect using the Spatial Analysis Extension for ArcView 9.2.

Following the work of Wheatley and Gillings (2002) who use GIS in archaeological analysis, the instructions of Mitchell (1999:142-144) on geographic patterning in the data and cost layers, and the ideas of Pletka (2005) in least-cost path analysis as applied to a problem in the archaeology of the Santa Barbara coast, least-cost path analyses were completed in several steps. The work of Whitley and Hicks (2002) was extremely influential in the latter rounds of least-cost path analysis.

OTHER DATA LAYERS

Shapefiles for the beginning and endings of paths were created and differed in number depending on the size of the DEM blocks or the nature of the terrain in the case of the San Luis Rey watershed (Fig. 4). Shapefiles for streams or other hydrologic features, county boundary, and watershed boundaries, were downloaded from www.sandag.com (San Diego Association of Governments), and those for roads were downloaded from www.sangis.com (San Diego Geographic Information Source).

Once the necessary files were collected, the analysis environment was configured in ArcView 9.2 by creating a geodatabase for each collection of files and images used for this project and directing the analysis environment to these databases.

LEAST-COST PATH ANALYSES

Each least-cost path was created between a pair of points. Within each pair of points, there was one point for starting and one point for ending the path. The number of pairs of start and end point pairs represents the number of least-cost paths desired for each project.

Raster format is necessary for the algorithm for least-cost path analysis to function on the data layers. An algorithm is “a procedure that provides a solution to a problem and consists of a set of unambiguous rules which specify a finite sequence of operations” (Longley et al. 2005:342); the ArcView 9.2 software provides the algorithm. The algorithm allows the creation of the least-cost path by determining which of the eight directions (from
each grid square in the raster file for the DEM) is going to require the least amount of effort in which to move (hence the least-cost path).

The DEM is first processed to produce the several iterations of data layers that are required for a least-cost path analysis. The required layers include the following:

1. A derived slope in percent rise and reclassified to equal intervals.
2. A derived total cost layer from the reclassified slope layer.
3. A derived cost distance and cost direction for each pair of points using the start point shapefile and total cost layer.
4. A derived least-cost path for each pair of start and end point shapefiles over the cost distance layer combined with the cost direction layer.

The framework for this study was based on the availability of site locations, maps, ethnographies, and a GIS program (ArcView 9.2). Part of the theoretical framework is the possibility that people follow the path of least resistance to get from point a to point b. Do people follow the least-cost path? The DEM was the primary source of data. I also collected data for site locations for the area of coverage for two DEMs from South Coastal Information Center (SCIC). Information on trade and trails in the literature was read for comparison to the derived least-cost paths. The data used for site locations in the Cahuilla area was based on Bean, Vane, and Young (1991) for further comparison (Figure 9). People traveling through the country may be following the natural topography of the land. The least-cost paths follow the natural topography. If we use the topography as a starting point, the watershed boundary will be the highest point between two regions. Low points will dictate the direction and amount of water flow. If people did follow the watershed, low points would be in the area of most likely water flow. In many places trails follow along the edges of rivers and streams, then jump over high spots to follow the watercourse of the next canyon. Across open expanses of flat ground, there is less pressure to follow a single path. Paths will spread out to cover a swath of area. There are descriptions of footpaths being deep across the desert as in this description of the Mojave trade route by Malcolm Farmer: “the route of this old trail is not difficult to trace; in fact some of our modern highways cross it, and in some places follow its foot worn course” (1935:155). This also points out the evolution of frequently used paths being altered and upgraded for more and more modern travel.
CHAPTER CONCLUSION

This study has been iterative and thus methods and results from one phase (or project) led to the methods and results for a subsequent phase/project. This has led to problems in the separation of methods and results. In the interest of organizational quality, in the next chapter I concentrate on the results of the final project only. The first four iterations (projects) have been placed in the Appendix, where the reader can peruse them as interest demands. They include the following titles: Pilot Project, San Luis Rey Watershed, Large Block Around Cupeño Territory, and Reducing the Boundary for Cupeño and Adjacent Territory.

Figure 9. An alternate 12-DEM block, showing least-cost paths compared to probable site areas.
CHAPTER 5

RESULTS AND DISCUSSION

This chapter presents the results and discussion of the methods outlined in the previous chapter. Chapter sections include first the original research questions that were posed in the introduction to this thesis, the project in the context of landscape theory, and the results of the virtual tour. The resulting virtual tour was created from the information derived from one of the paths in the network. That one path was chosen over all of the others because it had (1) overlapping instances of portions of the path where two or more paths traversed the same space, (2) stretches of sufficient length to be of interest, and (3) a segment which crossed through Lost Valley, over the watershed boundary, and into the Anza-Borrego desert. The tour is illustrated in small images with captions and, for certain images, additional narrative.

**ORIGINAL RESEARCH QUESTIONS**

1. How is Lost Valley linearly connected to areas to the west and east, within portions of the San Luis Rey and Anza Borrego watersheds?

2. Is Lost Valley situated on a travel network from the Borrego Springs area, which is within the Hot Springs Mountain and Borrego Palm Canyon DEMs, following a least-cost path to sites west of Lost Valley?

3. How does the natural topography of the watershed function in defining travel or trade networks?

4. Is there a relationship between the modeled paths and the archaeological sites that have been documented and recorded?

**HOW IS LOST VALLEY CONNECTED?**

The first two questions can be combined. How is Lost Valley connected linearly to the areas west and east, within portions of the San Luis Rey watershed, and the Anza-Borrego watershed? And, is Lost Valley situated on a travel network from the Borrego Springs area that continues on to the west of Lost Valley? Visual inspection of Figure 10 provides a tentative answer. The multiple renderings of least-cost path analyses provided a network of paths that traversed the Cupeño territory and fanned out in every direction. Lost Valley is passed through by more than one least-cost path, but there are not an abundant
number of crossings. The least-cost path analyses produce a virtual path from Kupa to Lost Valley without using either location as the start or the end of a path. Many more LCPs cross through the lower elevation and flatter area of the San Jose del Valle, mainly in north-south directions. Logically, the network of trails fans out in wide and flat areas to create a wide swath of paths.

Footpaths (rather than cross country perambulating) are still the preferred conveyance, as it is better to walk where one can see the ground, especially in areas with snakes, not to mention less laborious traveling. An explanation of how a foot trail evolves begins as many feet, hooves, and paws flatten the vegetation, causing the ground to become compacted by constant use. Seeds that sprout are trampled down, and eventually the soil becomes too compacted for new seeds to sprout. Only at the edges of the path are plants able to make their way. The ground becomes scarred by generations of pedestrian travelers. This explanation is supported by the research on urban foot traffic presented in *Nature* by Helbing and colleagues in 1997 (see Chapter 3). Ancient trails are still used by modern day hikers traveling from Lost Valley to the Anza Borrego Desert.
CONSIDERATION OF THE NATURAL TOPOGRAPHY

In many instances, least-cost paths follow the drainages. For the path chosen for the virtual tour, the least-cost path did not follow the drainage except to parallel the San Luis Rey River at the west end of the path for a distance, then to meet briefly with Agua Caliente Creek in Lost Valley (Figs. 11 and 12). The path does not follow the drainages as it does in the least cost path from Lost Valley to Kupa (see Fig. 3). Because of the topography, Lost Valley is semi-difficult to reach from either east or west. There seems to be no north to south entry or exit of the valley according to the least-cost path analyses. To go north or south of Lost Valley requires greater effort than to move to the east or west first, then to the north or south.

![Map of San Luis Rey Watershed with least-cost paths and site locations](image)

Figure 11. Using sample data from SCIC for approximate site locations.

RELATIONSHIP BETWEEN LEAST-COST PATHS AND SITE LOCATIONS

There is a visual correlation between the generated least-cost paths and the site locations (Figs. 11, and 12). There is also a visual relationship between the site locations and waterways. There is distinct clustering of sites around the watercourses; in fact, all seem to be within a certain distance of the watercourses. Distance to water may be visualized by using the buffer function in ArcView 9.2. Buffer zones of differing widths can be set up for
different features. In this case, we would be testing to see if sites fell within a certain distance of the watercourses (drainages). It is also possible to create concentric buffers, but for the purposes of this thesis, neither of these tests were conducted.

Figure 12. Areas of probable sites shown with the path chosen for the virtual tour.

GIS AND LANDSCAPE THEORY

According to Knapp and Ashmore (1999), trail networks are a part of the constructed landscape. Human non-sedentary groups (mobile hunter-gatherers or nomadic peoples) leave trails, views, campsites, and other clues to their activities. Just to the east of Lost Valley there is a mountain that all least-cost paths skirt. This mountain is called Hot Springs Mountain. Knapp and Ashmore (1999) also describe conceptual landscapes consisting of special places of ritual, sacred, or social significance. Also, Marcos Llobera (2001) talks about the power of locations on the landscape that are prominent and that command a view over the surrounding area. He suggests that one study how these relate to certain structures in the landscape. Hot Springs Mountain, rimming Lost Valley, would fall under the category of conceptual landscape as a mountain with a commanding view over the valleys below.
In plan view, the landscape in the project area reminds us of the landscape perspective from Kenneth Kvamme (2003) who looked for hidden features of the landscape through GIS analysis with archaeo-geophysical methods of data collection. By using GIS to predict least-cost paths, we are also finding possible connections that may be found on close inspection.

If landscape is something to be experienced, that is embedded in the human psyche, then some way to provide that experience is in order. To provide an experience of landscape from a “fly through” perspective, in order to get some feeling for the commanding views at some points along the chosen path, and possibly the difficulty or ease that the modeled path might take on, the virtual tour was a possible way of presenting my findings and it is to the virtual tour that we now turn.

**VIRTUAL TOUR**

A virtual tour was created using ArcView 9.2, PhotoShop CS, and Google Earth. The results of the tour are presented below. The virtual tour is an idea that I came up with when using Google Earth to find points of junction from my least-cost path analysis in order to inspect the aerial images up close to see what was manifest at these junctions. I thought it would be interesting and extraordinary to take one of the least-cost paths and attempt to follow it to see if a correlation could be seen with actual paths on the ground. A true test would be to take a GPS unit and follow trails on the ground, and then compare these to the least-cost paths generated by the software. The GPS idea was considered, but had to be rejected in the interest of time. It is not known if access is allowed across the many privately owned properties that now comprise the San Jose del Valle and the surrounding area. Permission must first be granted to be allowed into the Lost Valley Boy Scout camp. The trails into Anza-Borrego are California State Park lands and are open to foot travel. Taking the GPS readings for the trail(s) from Lost Valley into Anza-Borrego would be an excellent future project.

The tour begins at a point southwest of *Kupa* in the San Jose del Valle and travels north, then northeast, then east to the boundary of the San Luis Rey watershed (Figs. 13 to 25).
Figure 13. Least-cost path for comparison to an aerial view of the landscape.

The LCP used for the virtual tour is in bright pink. The choice was arbitrary, except that the northeast start point crossed the watershed boundary. Along the path, I took the coordinates produced in ArcGIS using the Info tool.

Figure 14. Isolated LCP saved as a jpg file.

I loaded the jpg into PhotoShop so that I could make it into an image file with a transparent background. I marked the coordinates in Google Earth. The line color was changed to bright orange.
Figure 15. LCP imported into Google Earth.

The line file was adjusted to the marked coordinates with the end points and junctions aligned with the marked coordinates in Google Earth.

Figure 16. Plan view of the southern end of the line file.

Figure 17. A closer view of the southern end of the line file showing the terrain.
Figure 18. Landscape view from the southern end of the line file looking north at a near 90 degree angle.

The fairly flat meadow, part of San Jose del Valle, comes into view.

Figure 19. View of the LCP at the first junction looking north.

Figure 20. First junction pivot. Turning the corner at the first junction to head northeast.
Figure 21. Landscape view from first junction of the LCP facing northeast with Lost Valley on the horizon.

In this image the Google Earth camera is tilted to a near horizontal angle. Looking northeast at the junction towards Lost Valley.

Figure 22. Plan view of the watershed boundary past Lost Valley.

This is where the LCP crosses the highlands between the San Luis Rey watershed and the Anza-Borrego watershed.
Figure 23. View to the east from the crossing of the watershed boundary out to the Anza-Borrego desert. The Salton Sea can be seen on the horizon.

Figure 24. View towards the west from the watershed boundary. A 180 degree turn to the west, looking back at Lost Valley.

Figure 25. A day of instruction at field school in summer of 2003.
Larry L. Leach at the white board. Interested, and motivated students looking on. Giant oaks, serene shade, soft breeze blowing though pines. When you visit, you understand why people traveled to Lost Valley. A serene sanctuary is found.

The virtual tour was intended to give visual perspective to the landscape. On the tour, the most apparent shortcoming was that a moving tour would provide the best experience. The ability for a person to move through a virtual landscape and to be totally immersed in the images could provide an experience of our California landscape to people on the other side of the globe. Short of that, the thumbnail images are most revealing when the horizon is in the image. The 3-D effect is manifest in those images with the horizon. These 3-D images give the best experience, as if one were standing on the spot and looking out. Three-D images can inspire awe, just as the natural landscape can (in special places) for the backwoods hiker and probably did for the ancient traveler as well. Prominences and depressions, besides guiding the path of the traveler, also provide the ability to find Llobera’s (2001) eminences from which to look out over the landscape.

**CHAPTER SUMMARY**

This chapter has summarized the results of experimental GIS methods applied to archaeological data that were presented in Chapter 4. The watersheds form natural corridors and least-cost path analyses show this correlation. The LCPs form the basis for possible trade and travel between the Cupeño and the linguistically related neighbors, the Luiseño and Cahuilla, to the west and east respectively, and to the Ipai (Kumeyaay) to the south. The rough topography of interior southern California creates a challenge for travelers now as well as in the past. Finally, the results presented in this chapter provided sufficient information to allow for a virtual, on-the-ground tour by importing a path to follow into Google Earth. The next (final) chapter brings this investigation to a close and contains the conclusions and recommendations for future research and study.
CHAPTER 6

CONCLUSION

This chapter brings this thesis to a close and discusses future possible research endeavors. The results of the least-cost paths through portions northern San Diego County reveal many possibilities in the use of GIS and archaeology. I began with a fuzzy idea of what I would like to accomplish in the way of a research project. The beginning was a modest trial of one least-cost path through the terrain on one DEM. From there the project expanded to as many as 33 DEMs and ultimately shrank to two DEMs. What became evident is that the project could be expanded infinitely. For a modest list of local possibilities I have come up with the following problems for the future:

**FUTURE QUESTIONS:**

1. What archeological evidence supports the existence of trade networks or subsistence networks to Lost Valley from the west and/or east?
2. Do existing footpaths match those modeled in the least-cost path analysis?
3. How do the results of the least-cost path analysis coincide with the evidence of footpaths in protohistory and history? Are these the same as the Late Period pathways used by the Cupeño?

**FURTHER INQUIRIES:**

Additionally, I have pondered some of the following ideas for avenues of future research. First, the excavated material from Lost Valley, can be compared to excavation or surface collected material from sites located along the network of least-cost paths. Possible travel networks equal possible social networks.

Second, San Gorgonio pass was used to travel from the Banning area to the Colton area. The San Gorgonio pass is another location that can be found on a map and checked through inspection of aerial photographs in seeking information on the locations of trails that lead in and out of the surrounding canyons (Barrows 1900:25-26).

Third, a true test of the reliability of the modeled LCPs would be to take a Global Positioning System (GPS) and follow the trails on the ground, then compare the readings to
the least-cost paths generated by the software. The trails into Anza-Borrego are California State Parks lands and are open to foot travel. Taking the GPS readings for the trail(s) from Lost Valley into Anza-Borrego would be an excellent future project.

Fourth, an inspection of the LCP at the watershed crossing (see Fig. 22) using a buffer of 100 yards on either side to see where the trail(s) cross the watershed boundary would be another important study. If the inspection is fruitful, the same test could be made for other watershed crossings. The watershed boundaries near Lost Valley are in an area of minimal impact through human use or development, so these LCP crossings are the best places to ferret out the original trails through the mountains and into the desert.

**LAST COMMENTS AND OBSERVATIONS**

In her demonstration of trade networks in the northeastern United States, Kathleen Allen (1990) showed how GIS could be used to model trade networks following the watersheds or waterways. Waterways, used as transportation networks, played a part in the distribution of goods between tribes in the Great Lakes area of New York State. I have shown that the drainage systems in southern California were a perfect system for travel. The LCP network seems for the most part to follow the natural topography through which the main passages are the drainage systems in the irregular and rugged terrain of California.

Reflecting on the urban trail study by Helbing et al. (1997), trail development over urban green spaces are predictable. Humans tend to walk through bare ground areas in ways that can be forecasted and arrangements are commonly made when planning walkways and thoroughfares. The ideas from Helbing and colleagues (1997) help one to realize that we are predictable creatures of habit following previously made footpaths rather than continually forging new ones. It is far more comfortable and more secure to follow a known path that has been used successfully in the past. Using footpaths that are well worn gives the traveler a certainty that you will arrive at the desired destination. There is more certainty that a trail will follow a path of least resistance, which will make the going easier. Trails leave a remnant of lived experience.

Here in California we do not have the remnants of indigenous monumental architecture. Many landscape studies rely on the monumental architecture of past peoples as their focus of study. Zedeño (2000:98) reminds us that in contrast to the study of
monumental architectural remains, hunter-gatherers “built their social environment around the extraction and appropriation of localized natural resources—plants, animals, minerals, and landforms.” The LCPs generated through my study could reveal the pathways that follow these natural resources. Plant and animal resources concentrate around areas of water, including drainages, ephemeral or not.

Of equal importance to my study, the idea explored by Zedeño that single landmarks are linked “into an integrated network or landscape” (2000: 98, emphasis in original). This thought leads me to put forth the idea that my network model may show areas where sites should be found but have not yet been recorded, like a predictive model of nodes along a network.

Lastly, in scrutinizing the maps with probable site areas shown (Figs. 11 and 12), there is a lack of site probability on the LCP from Kupa to Lost Valley. Why would this be so? One reason may be because of a lack of systematic archaeological surveys in the area because of private land ownership. Another reason could be because it may not be easily passable because of steepness, thick vegetation, or other natural impediments to travel. Alternately, if the trail is steep, then it may be suitable for travel, but not for habitations that would leave archaeological evidence. There are many questions that remain unanswered.

It is hoped that this research can serve as a foundation for researchers from geography and archaeology that are looking to combine disciplinary methods in their studies. Archaeological field school and course work in GIS formed the basis for pursuing this experiment in methods in a cross-disciplinary work. Cross-disciplinary research has its difficulties, such as lack of cross-disciplinary mentors and specialists. The rewards far outweigh the disappointments. The drawbacks are but mere challenges for the ambitious.
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APPENDIX

FIRST FOUR ITERATIONS OF THE PROJECT
FIRST FOUR ITERATIONS OF THE PROJECT

This Appendix includes the information, background, methods and results for the first four iterations of this thesis project. The project began as a modest idea. I wanted to try something I had learned in a GIS course given at Mesa College: a least-cost path analysis using one DEM block. I decided to use the DEM that included the area of Lost Valley, where I had worked through two summers of field school, and two semesters of laboratory work on the artifacts from that excavation. This became the Pilot Project and connected my graduate studies at SDSU with my course work in GIS at Mesa College. From this project I had the thrill of seeing the powerful GIS program in action and wanted to continue using it in research on my thesis. My thesis would most certainly be focused on the Lost Valley area. But how to incorporate GIS with the findings from an archaeological field school became the challenge. I begin with the story of the pilot project.

PILOT PROJECT

A small-scale test to model a least-cost path was completed, the results of which gave me a fairly good idea of what could be expected in a larger project. One DEM for Hot Springs Mountain was used for the model. The GIS showed the path of least resistance between two points chosen non-randomly on the landscape: these two points were the locations of Cupa, a proto-historic village of the Cupeño, near Warner Springs for the beginning of the path, and CA-SDI-2506, our excavation site in Lost Valley, for the end of the path (Fig. 26, please note that I have offset the least-cost path to show the stream network beneath). The initial test of least resistance was for slope and distance only. The results of other studies that have been done, such as Pletka’s (2006), mirrored my expectations where the aim of the project was to show contact nodes using the spatial capabilities of ArcGIS software between several known site locations on the Santa Barbara coast. I wanted to make sure that least-cost path would give a relevant result and thus conducted this pilot study.

The pilot was limited to the construction of a least cost path or most effective travel route between two occupation site locations dating from the Late Period. The end point for the pilot study was Lost Valley site CA-SDI-2506, in the north-central portion of San Diego
County. Ethnographic (Piniolo et al. 1998:21; Strong 1929), and archaeological (Fleming 1999; Kline 2008) evidence indicates that Lost Valley was occupied during the Late Period. The start point was near the modern town of Warner Springs, which was the site of a Late Period village of the Cupeño Indian tribe, Kupa (or Cupa) until about 1902 (Bean and Smith 1978:589; Hill and Nolasquez 1973:vii; Strong 1929:183).

Figure 26. Pilot screenshot of ArcGIS 9.2 and least-cost path analysis (dark red line) from Cupa (green circle) to Lost Valley and site CA-SDI-2506 (red circle).
Results

A least-cost path was created in ArcView 9.2 (Fig. 26), showing a probable travel path from Cupa, in the lower San Jose Valley, to the higher elevation site at Lost Valley (at approximately 5,000 feet). Water runoff follows the path of least resistance as in the location of the waterways on this map. However, steeper slopes that would hinder the movement of water the least, would not be chosen by a foot traveling human as the effort required to surmount or descend the steeper terrain tends to cause more difficulty than taking an alternate, longer route. The algorithm engaged in ArcView GIS least-cost path analysis has a maximum slope that it recognizes as passable. If the slope is greater than this angle, the least-cost path cannot proceed through the area of too steep of a slope. Even with this exception, the least-cost path does seem to primarily follow the drainages.

SAN LUIS REY WATERSHED

With further readings and study, I decided to use Lost Valley as a place on the landscape and attempt to learn how Lost Valley might fit into a network of least-cost paths. Questions from previous study and research (Kidder and Leach 1981) asked 1) if Lost Valley was occupied year-round, and 2) what influence topography had on travel. I thought that these two questions could be addressed through least-cost path analysis. If Lost Valley were located where multiple least-cost paths came together, I could infer that it was possible that the area was used on a year-round basis. Lost Valley is at approximately 5,000 feet, but is sheltered by surrounding mountains and has a good water supply (see Chapter 2).

The second project involved the mosaicking of 27 DEMs, all of which were necessary to cover the San Luis Rey watershed. The San Luis Rey watershed was chosen because of its proximity to Cupeño territory, which is at the head of the San Luis Rey watershed (the bulbous portion on the east side of the watershed) (Fig. 27). The twenty-seven DEMs for this portion of the project were downloaded individually, extracted with the free zip tool, ZipGenius 6, and then individually converted with the Conversion Tool: SDTS Raster to Grid. After conversion, the DEMs were mosaicked into one large rectangular block. The same process was applied to the block in preparation for creating the least-cost paths as had been applied to the single DEM for the pilot project. Start and end point shape files were created with the Editor Tool, then the distance and direction
surfaces were derived from the derived slope layer from the mosaicked DEMs. This method does not always work, and some adjustments in the map mosaic process were necessary until the block of DEMs lined up properly and did not cause the path to halt at a gap. The gap meant no data to the computer program, and was therefore not passable. Finally, it was necessary to break the 27 DEMs into blocks of twelve, and create the start and end points and then the least cost path analysis on each of the blocks. The blocks of 12 shared the same DEMs at adjacent edges. Because of this overlap, I was able to assemble the paths together to cover the whole area.

Figure 27. The location of the San Luis Rey watershed within San Diego County.

One example of a least-cost path from a possible habitation location along the San Luis Rey River to Lost Valley is shown in Figure 28. When choosing the start and end points for least-cost path analysis within the San Luis Rey watershed, I used Lost Valley as an end point, and then other locations along the San Luis Rey River and its tributaries that had the
environmental conditions for good locations of possible village sites in Luiseño territory. The San Luis Rey watershed, with the exception of the head of the watershed (which was Cupeño territory), was completely within Luiseño territory.

Figure 28. ArcView 9.2 map of San Luis Rey Watershed with elevation shown in relief, waterways (blue lines) within the watershed shown as well as roads (red lines). The least-cost path analysis (neon green line) was made from a point near the coast along the San Luis Rey River to CA-SDI-2506 in Lost Valley.

Results

A problem with the results of the least-cost path analysis using the San Luis Rey watershed as the boundary of the study area is that the least-cost paths produced tended to follow the San Luis Rey River if start and end points were any where near the river, and that in order for any of the least-cost paths to cross into Lost Valley, an end point of the path had to be located at Lost Valley. There was no way to know if the path would make its way through Lost Valley if Lost Valley were not the destination. How was I to determine how Lost Valley was positioned in relation to the surrounding settlement system if I had to use Lost Valley as the end of the path (or the start)? I needed some way to model least-cost paths where the paths would cross through Lost Valley between points that were outside of the area of Lost Valley.
With the San Luis Rey watershed least-cost paths as inspiration, I decided that I needed to use a different set of criteria for the start and end of paths used for the least-cost path analyses. I determined to use a block of DEMs in the same way that was used by Whitley and Hicks (2003). The block of DEMs that was chosen were those that included and surrounded the head of the San Luis Rey watershed, that of the territory of the protohistoric Cupeño, and adjacent territory.

**LARGE BLOCK AROUND CUPEÑO TERRITORY**

The head of the San Luis Rey watershed became the next area of focus in an attempt to narrow down the area where I could concentrate my efforts. A block of 16 DEMs that created a buffer around the head of the San Luis Rey watershed was mosaicked together (Fig. 29).

**Methods**

For this block, the method of marking the start and end paths changed as I incorporated the methods of Whitley and Hicks (2003) into the least-cost path analysis. Whitley and Hicks’ work in the eastern United States (see Chapter 3) utilized a block of DEMs for least-cost path analysis, creating the start and end points for multiple least-cost paths at the boundary of the mosaicked DEMs and running the analysis from north to south and from east to west across the mosaic.

**Results**

The results of the new technique with start and end points around the edge of the mosaicked DEM block was more promising than the previously used placement of the points at Lost Valley, then at other possible locations of sites. By changing the start and end points to random (but spaced) locations along the edge of the mosaicked DEM, I was able to see a reasonable model of where paths would possibly be located if sojourners traveled across an expanse of ground from point A to point B. The only problem with this approach is that it did not lead to any paths making their way through or even near Lost Valley, the focus of the project. This was a dilemma that was remedied by bringing in the west and south boundaries
Figure 29. The head of the San Luis Rey watershed and adjacent area.
of the study area so that it would be probable that a least-cost path would traverse Lost Valley. There was no point in going any further with the project if none of the least-cost paths entered and exited or came close to Lost Valley. The results of this project were the creation of the smaller bounded portion of the San Luis Rey watershed, and subsequent least-cost path analyses using the same technique of equally spacing start and end points around the perimeter of the new boundary and running the least-cost path analysis from north to south, and from west to east.

**Bringing in the Boundary for Cupeño and Adjacent Territory**

A new smaller block for the boundary of the study area was created using a new polygon shapefile, and a new set of start and end points spaced evenly on the sides of the rectangular area. A new set of least-cost paths were run from east to west, then from north to south as in the previous larger block (Figs. 30 and 31).

**Results**

This smaller block and the least-cost paths that were created across it were the most promising in the way of answers that I had been able to produce. At least three of the paths that were produced crossed through Lost Valley. Additionally, the paths crossed the watershed boundary at two locations upon leaving Lost Valley. These were two locations that could be located on aerial maps and inspected for possible trails. Also of interest, other watershed boundary crossings at the head of the San Luis Rey watershed were marked by least-cost paths that did not traverse Lost Valley, but are nevertheless in the vicinity of Lost Valley and therefore of interest to this study.

It is the previous four projects that formed the foundation of my thesis. I provide this appendix to show the evolution of my thinking for the choices that were made at each interval. Least-cost paths were collected from these initial projects and merged together to form the network of paths used in the results of this thesis.
Figure 30. Smaller block around the head of the San Luis Rey watershed.
Figure 31. Close-up of smaller block in Figure 30.
APPENDIX REFERENCES

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ABSTRACT OF THE THESIS

Regional Network Analysis Situating Lost Valley in the Inter-Site Landscape
by
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The purpose of this study is to analyze possible contact pathways through Lost Valley, San Diego County, California, using the methods of least-cost path analysis for both real and modeled travel corridors through the San Luis Rey Watershed. I conducted this study using ArcView 9.2 GIS (geographic information systems), digital elevation models, and aerial photography, in order to show the most likely corridors of travel and trade using least-cost path modeling, and to compare the modeled paths to real trail networks, i.e., those that show up in the aerial photographs and/or those written about in the literature. This study shows how prehistoric and protohistoric peoples traveled through the Lost Valley area and how contact networks were likely established and maintained. The modeled travel corridors are compared to the ethnographic and historic knowledge of the Cupeño who seasonally occupied Lost Valley.