TRAIL ACCESS TO MOUNT UMUNHUM:

Geographic Information System Application of Trail User Preferences, Environmental Impacts, and Land Use Obstacles in the Preliminary Route Development of a Trail Connecting the Woods Trail and the Summit of Mount Umunhum in the Sierra Azul Open Space Preserve

Sean R. Mullin

May 2014

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A Planning Report

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By

Sean R. Mullin

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CONTENTS

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LIST OF TABLES

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LIST OF FIGURES

Note: Cover image by author.

CHAPTER 1 Introduction

Figure 1.1. Various landscapes from Midpen Preserves.
Sources: Top- David Baron via Wikimedia Commons, http://commons.wikimedia.org/wiki/File:Monte_Bello_Open_Space_Preserve.jpg; Second- Überraschungsbilder via Wikimedia Commons, http://commons.wikimedia.org/wiki/File:Russian_Ridge-Wildflowers.jpg; Bottom 3- Author.

Open space and wilderness provide an escape; a respite from the urban and suburban lives we lead. Many residents around the San Francisco Bay Area are lucky enough to have undeveloped lands adjacent to them. The Peninsula and South Bay regions of the San Francisco Bay Area benefit from the forethought of residents who witnessed the population boom and urban expansion of the 1960s and 1970s and worked to establish the Midpeninsula Regional Open Space District (Midpen). Since its creation Midpen has acquired and preserved over 62,000 acres in 26 distinct open space preserves.[1] These lands are preserved in perpetuity and allow residents to retreat into tranquil meadows, towering redwoods, rugged chaparral, and rolling grasslands punctuated by majestic oaks (figure 1.1). The network of trails within these preserves provide the much-needed opportunity to convene with nature and escape the hustle and bustle of urban life. Expansion of this existing trail network would increase the access to these preserves and create more opportunity for area residents to experience the protected lands.

The primary objective of this report is to use a GIS model to identify a preliminary trail route connecting the Woods Trail and the summit of Mount Umunhum in the Sierra Azul Open Space Preserve. This task takes into account the following criteria:

- The physical impacts to the land of trail construction and use;
- The preferences of the different trail users welcome in the Sierra Azul Open Space Preserve (hikers, cyclists, and equestrians); and,
- The land use issues that create obstacles in the trail's development.

1. Midpeninsula Regional Open Space District, "About Us," Midpeninsula Regional Open Space District, http://www.openspace.org/about_us/ (accessed August 31, 2013).

A secondary objective of this report is to develop a GIS model that is flexible and approachable, which identifies preliminary route options based on found relevant data. This tool will be useful to planners exploring preliminary trail routing options in a variety of landscapes, from open space to urban areas. Trail routing is project specific, as every trail is unique to its surroundings. Trail development and use result in unavoidable impacts to the surrounding environment.[2] Part of the trail planning process involves analyzing multiple datasets to determine the optimal route for a proposed trail while minimizing impacts.[3] GIS route modeling is a method that utilizes existing data to identifying potential trail routes. This technology could be a cost-effective method for open space planners and managers to quickly perform preliminary route identification.

Given the ever-increasing budget constraints faced by public agencies, these methods can streamline the planning process and reduce cost. Additionally, GIS models can incorporate large amounts of readily available free datasets, which help reduce costs and allow for preliminary evaluation with limited resources.[4] The development of trail planning tools, such as an approachable GIS model, would benefit agencies like the Midpeninsula Regional Open Space District, as well as other trail planners and open space managers.

1.1. ADDING VALUE TO LOCAL AND REGIONAL TRAIL NETWORKS

The proposed trail would expand the existing trail networks and access to open space in the Bay Area and the Midpeninsula Regional Open Space District. Plan Bay Area, prepared by One Bay Area, forecasts that the nine-county region can expect an additional 2.1 million people by 2040.[5] As populations and densities continue to increase in the San Francisco Bay Area, there will be more pressure put on parks and regional open space preserves that allow recreation.

2. David N. Cole and Peter B. Landres, "Threats to Wilderness Ecosystems: Impacts and Research Needs," Ecological Applications 6, no. 1: (February 1996): 168-184; New Zealand Department of Conservation, *Off-road Mountain Biking: A Profile of Participants and Their Recreational Setting and Experience Preferences*, by Gordon R. Cessford, Science and Research Series No. 93 (September 1995); Nathaniel D. Olive and Jeffrey L. Marion, "The Influence of Use-related, Environmental, and Managerial Factors on Soil Loss from Recreational Trails," *Journal of Environmental Management* 90, no. 3: (March 2009): 1483-1493; Catherine Marina Pickering, Wendy Hill, David Newsome, and Yu-Fai Leung, "Comparing Hiking, Mountain Biking and Horse Riding Impacts on Vegetation and Soils in Australia and the United States of America," *Journal of Environmental Management* 91, no. 3 (January–February 2010): 551-562; Mathew C. Symmonds, William E. Hammitt, and Virgil L. Quisenberry, "Managing Recreational Trail Environments for Mountain Bike User Preferences," *Environmental Management* 25, no.5 (May 2000): 549-564; Jeremy F. Wimpey and Jeffrey L. Marion, "The Influence of Use, Environmental and Managerial Factors on the Width of Recreational Trails." *Journal of Environmental Management* 91, no.10 (October 2010): 2028-2037.

3. Tennessee Department of Environment and Conservation, Recreation Educational Services Division, Greenways and Trails Program, "Pathways to Trail Building," ed. Bob Richards (March 2007), http://atfiles.org/files/pdf/TNpathways.pdf (accessed August 4, 2013).

4. Aleksandra M. Tomczyk, "A GIS Assessment and Modelling of Environmental Sensitivity of Recreational Trails: The Case of Gorce National Park, Poland," *Applied Geography* 31, no. 1 (January 2011): 339-351.

5. Association of Bay Area Governments and Metropolitan Transportation Commission, *Plan Bay Area: Regional Transportation Plan and Sustainable Communities Strategy for the San Francisco Bay Area 2013-2040* (July 18, 2013): 32.

Trails located in the region's open space preserves allow users to convene with nature and escape the urban environment. Described by Thompson as "a fundamental human need," access to nature is an essential component of living in an urbanized environment.[6] As the population increases, the existing trails in the region will likely experience an increase in use and become more crowded. As trails become more crowded, the public will put more pressure on open space managers and planners to develop new trails that provide the essential access to nature.

The proposed trail would connect the summit of Mount Umunhum with the Woods Trail, a section of the Bay Area Ridge Trail (figure 1.2). This would contribute to the Ridge Trail Council's goal of creating a "continuous 550+ mile trail…along the ridgelines overlooking the San Francisco Bay."[7] As shown in figure 1.3, the Woods Trail is already part of the Ridge Trail that connects to Almaden Quicksilver County Park, this upper elevation deviation connecting with the summit of Mount Umunhum would align with the mission of the Bay Area Ridge Trail Council by extending the trail along a ridgeline providing views to the San Francisco Bay.

Figure 1.2. A sign at a trail junction.
A sign at a trail junction shows distances to other trails. The circular blue symbols indicate the direction of the Bay Area Ridge Tail.
Source: Author.

Lastly, the proposed trail would provide a more direct connection to Mount Umunhum from the existing trail network in the Sierra Azul Open Space Preserve. The trail would provide an alternate route to what is currently proposed by Midpen when the summit of Mount Umunhum opens to the public in 2017. Under the current plan only one trail route would allow access to the summit, approaching from the east. This route fails to provide direct summit access from existing trails to the north. The northern connection is significant because it is a direct connection to the majority of the trail system in the Sierra Azul Open Space Preserve. In order to connect from the north without the proposed trail, a trail user would have to navigate a circuitous route, which would eventually connect to the planned trail near the Barlow Road trail. The upper portion of the Woods Trail, adjacent to Mount El Sombroso roughly 1.5 miles north of Mount Umunhum, provides a more direct solution. The existing trail network from Mount El Sombroso is an approximately 6.4 mile journey with significant elevation loss and gain. The proposed trail from the north could reduce this journey to just over 2 miles (route dependent) and minimize the elevation loss and gain.

6. Catharine Ward Thompson, "Urban Open Space in the 21st Century," *Landscape and Urban Planning* 60, no. 2 (July 30, 2002): 59-72.

7. Bay Area Ridge Trail, "About Us," Bay Area Ridge Trail Council, http://www.ridgetrail.org/index.php/about-us (accessed September 1, 2013).

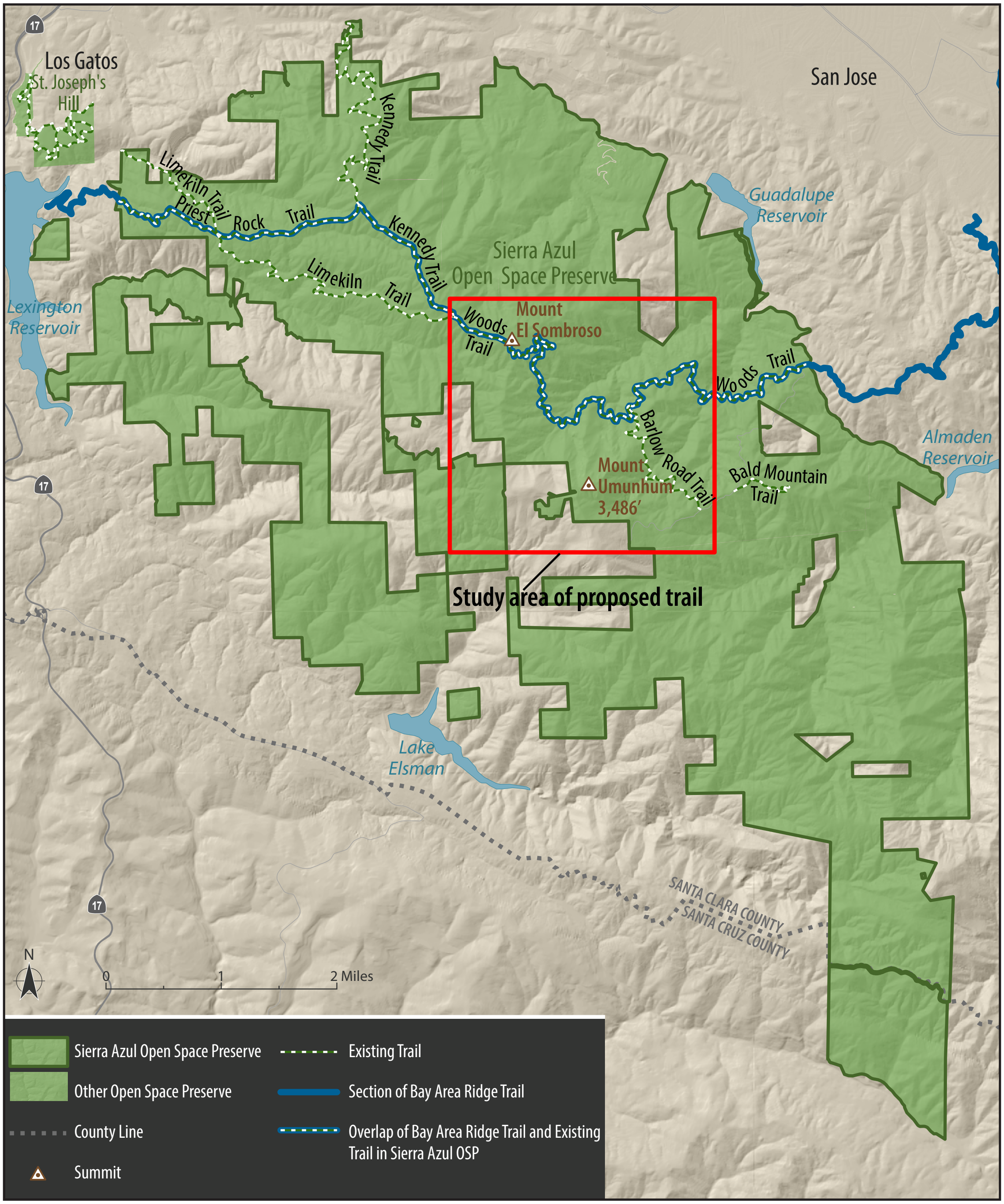

Figure 1.3. Bay Area Ridge Trail and Sierra Azul Trails.
Sections of the Bay Area Ridge Trail use some of the existing trails in the Sierra Azul Open Space Preserve.
Source: Map by author created using data from the Midpeninsula Regional Open Space Preserve, Bay Area Ridge Trail Council, United States Department of Agriculture, ESRI.

1.2. PROPOSED TRAIL'S ALIGNMENT WITH MIDPEN'S GOALS

The development of the proposed trail is within the purview of the stated purpose of the Midpeninsula Regional Open Space District:

> The Midpeninsula Regional Open Space District's purpose is to purchase, permanently protect, and restore lands forming a regional open space greenbelt, preserve unspoiled wilderness, wildlife habitat, watershed, viewshed, and fragile ecosystems, and provide opportunities for low-intensity recreation and environmental education.[8]

Much of the lands surrounding Mount Umunhum and the area of the proposed trail are already owned by Midpen, but not all of these lands are publicly accessible. Midpen has implemented a plan that will open the summit of Mount Umunhum to the public, planning to provide access along one route (Mount Umunhum Road and a trail adjacent to the road). An early phase of the Mount Umunhum Environmental Restoration and Public Access Plan included a connection to the summit from the Woods Trail, but it was later removed from the scope of the project because it was too speculative.[9]

The first steps in developing this trail would be examining the land use and ownership issues involved with creating the trail connection, and exploring preliminary trail routing options. This research is in line with the stated purpose of Midpen in that it will prioritize lands for acquisition and preservation. Additionally, the research will provide preliminary routing options, allowing for public access and low-intensity recreation, also in line with Midpen's mission.

Direct benefits to Midpen would include the identification of a potential trail route and the land ownership issues involved with the proposed trail. This research and modeling could possibly save Midpen time and money that would be involved with this stage of the trail planning process.

1.3. REPORT STRUCTURE

Chapter 2 discusses background information on Mount Umunhum and a discussion of the Midpeninsula Regional Open Space District is given to provide a context for the area in which this trail is proposed. Two brief literature reviews follow in order to identify the physical impacts of trail construction and use (Chapter 3), and the trail characteristics hikers, cyclists, and equestrians prefer (Chapter 4). The literature reviews also incorporate information gathered from two interviews with trail professionals. This information is then evaluated and incorporated into the GIS workflow.

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8. Midpeninsula Regional Open Space District, "About Us," Midpeninsula Regional Open Space District, http://www.openspace.org/about_us/ (accessed August 31, 2013).

9. Midpeninsula Regional Open Space District, *Draft Environmental Impact Report for the Mount Umunhum Environmental Restoration and Public Access Project*, SCH# 2010122037 (December 2011): 1-5.

Chapter 5 examines the GIS model and includes details on resampling and incorporating data into a suitability surface upon which a least-cost path function is applied to determine optimal routes between two points. Chapter 6 discusses the results of the model runs and analyzes these results against the impact and preferences criteria identified in Chapters 3 and 4. Finally, an optimal route is identified based on the data incorporated into the GIS model. The final section, Chapter 7, includes recommendations and a discussion of steps that would follow the process discussed in this report.

CHAPTER

2 Mount Umunhum and Midpen – A Vibrant History

Figure 2.1. View of Mount Umunhum from the north.
Source: Author.

It is important to understand the history of the land upon which a trail is to be developed because it can provide useful insight on the unique concerns and conditions specific to a study area. This chapter discusses the history of the Midpeninsula Regional Open Space District (Midpen) and its acquisition of Mount Umunhum, the destination of the proposed trail. The evolution of the summit of Mount Umunhum can be traced throughout its history from the Native American presence, to its role in the Cold War, and finally its ownership by Midpen and their future plans for the summit.

2.1. MIDPENINSULA REGIONAL OPEN SPACE DISTRICT

The Midpeninsula Regional Open Space District, shown fully in figure 2.2, was created in response to the explosive population growth in the Bay Area during the 1950s and 1960s. Suburban sprawl increased the size of cities in San Mateo and Santa Clara Counties during the 20th century, consuming large amounts of open space and agricultural lands. The occurring land consumption rate alarmed open space advocates in San Mateo and Santa Clara Counties. Their concern was centered on protecting the irreplaceable lands along the Peninsula, which encompass everything from rugged redwood and chaparral mountains as well as baylands, and all open space categories in between. Their concern and effort brought Measure R to the voter ballot in 1972. The passage

Figure 2.2. Extent of the Midpeninsula Regional Open Space District.
Source: Map by author created using data from the Midpeninsula Regional Open Space Preserve, United States Department of Agriculture, ESRI.

of this measure created a special district, shown in figure 2.3, which used a parcel tax to partially fund the Midpeninsula Regional Open Space District. Today, additional funding for Midpen comes from grants and donations. Measure R established Midpen in northwestern Santa Clara County, and voters expanded it in 1976 to include portions of San Mateo County. Subsequent expansions have included small portions of Santa Cruz County in 1992, and an expansion to the Pacific Ocean in San Mateo County in 2004. Currently, Midpen lands total in excess of 62,000 acres in 26 open space preserves, 24 of which are accessible to the public.[10]

10. Midpeninsula Regional Open Space District, "About Us," Midpeninsula Regional Open Space District, http://www.openspace.org/about_us/ (accessed August 31, 2013).

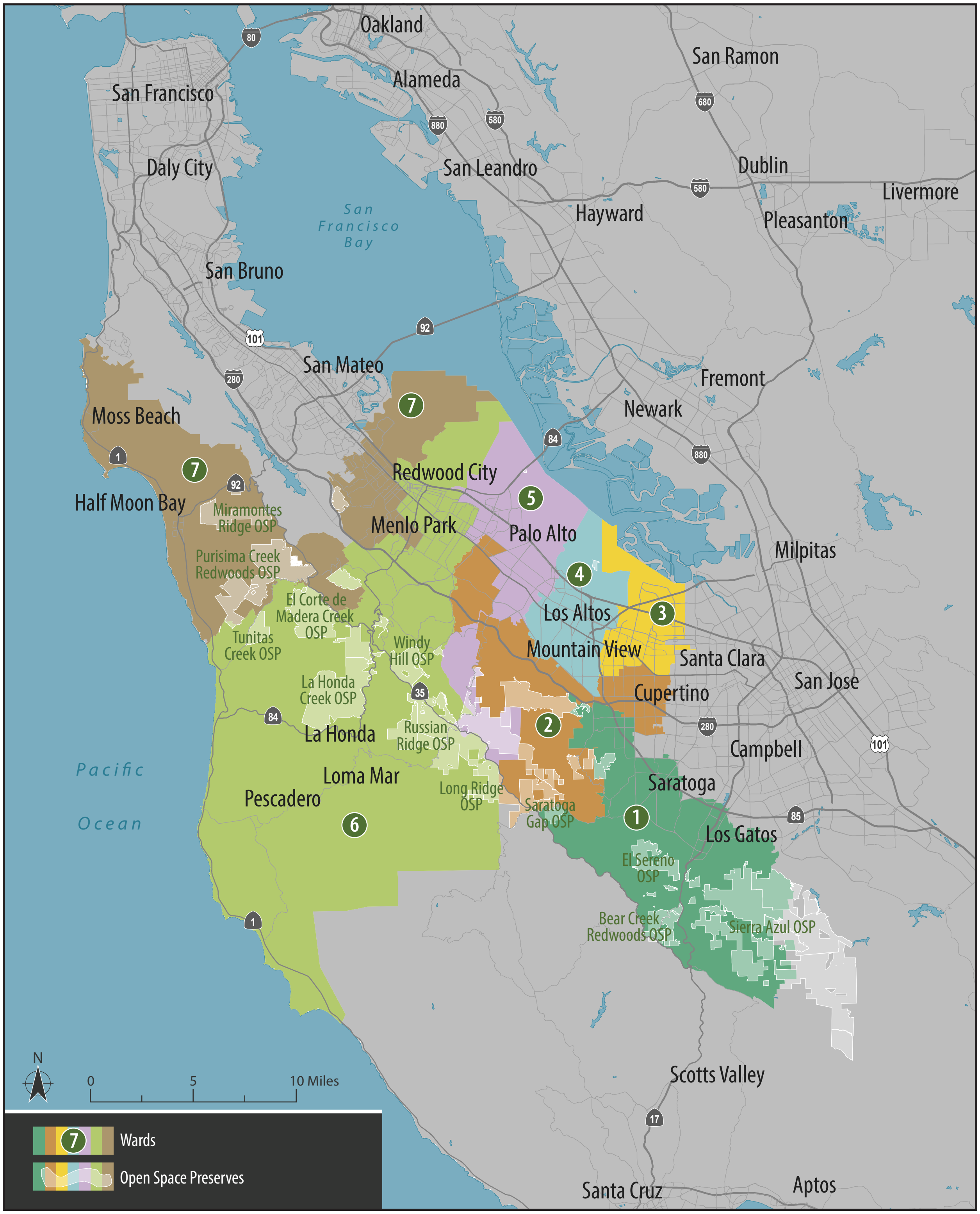

Figure 2.3. Midpen tax assessment district.
Special tax assessment district formed to share in funding the Midpeninsula Regional Open Space District. This map also shows Midpen's seven geographic wards. Each ward is represented by an elected official that serves on Midpen's Board of Directors.
Source: Map by author created using data from the Midpeninsula Regional Open Space District and ESRI.

2.2. SIERRA AZUL OPEN SPACE PRESERVE

The Sierra Azul Open Space Preserve, shown in figure 2.5, is located near south San José, adjacent to the Almaden community and the town of Los Gatos. At 18,446 acres, it is the largest preserve in Midpen and includes 24.4 miles of trails available year round free of charge for hiking, biking, horseback riding, and dog walking.[11] The trail studied in this report would provide a connection between an existing trail and Mount Umunhum within the Sierra Azul. The study area includes lands already owned by Midpen and some adjacent parcels that are currently privately owned.

2.3. MOUNT UMUNHUM

Mount Umunhum is located in the Santa Cruz Mountains in southwestern Santa Clara County. South of San José and southeast of Los Gatos, Mount Umunhum rises to 3,486 feet, and overlooks the South Bay to the east and the Pacific Ocean to the west. Its unique name stems from an Ohlone word meaning "resting place of the hummingbird."[12] Its location gained strategic significance during the escalation of the Korean Conflict and Cold War in the 1950's. The 682nd Radar Squadron was assigned to Mount Umunhum on July 24, 1957 to serve the Almaden Air Force Station; part of the San Francisco Air Defense Sector.[13]

Figure 2.4. Operational radar on the summit of Mount Umunhum, circa 1960s.
Source: United States Air Force 682nd Radar Squadron Veterans Association, http://www.almadenafs.org/ (accessed February 26, 2014).

The summit area was the site of various long-range radar installations. Two example of these radar installations can be seen in figure 2.4; these scanned the Pacific Ocean for incoming threats. The system provided an early warning network, designed to scramble interceptors from various Air Force bases upon any perceived threat. Due to its remote location, the base contained not only radar and radar support buildings, but also housing and recreation facilities for the Airmen and their families.[14] A total of 84 buildings were constructed at the base including a chapel, barbershop, commissary, half-court gym, weight room, bowling alley, and swimming pool.[15]

11. Midpeninsula Regional Open Space District, "Sierra Azul Open Space Preserve," Midpeninsula Regional Open Space District, http://www.openspace.org/preserves/pr_sierra_azul.asp (accessed August 31, 2013).

12. Midpeninsula Regional Open Space District, *Draft Environmental Impact Report for the Mount Umunhum Environmental Restoration and Public Access Project*, SCH# 2010122037 (December 2011): 4.2-7.

13. U.S. Army Corps of Engineers, *Site Survey Summary Sheet for DERP-FUDS Site No. J09CA099900 Almaden Air Force Station* (n.d.).

14. Radomes, Inc., The Air Defense Radar Veterans' Association. *682nd Radar Squadron, Almaden AFS, California Welcome Brochure* (n.d.).

15. Midpeninsula Regional Open Space District, *Draft Environmental Impact Report for the Mount Umunhum Environmental Restoration and Public Access Project*, SCH# 2010122037 (December 2011): 4.2-12.

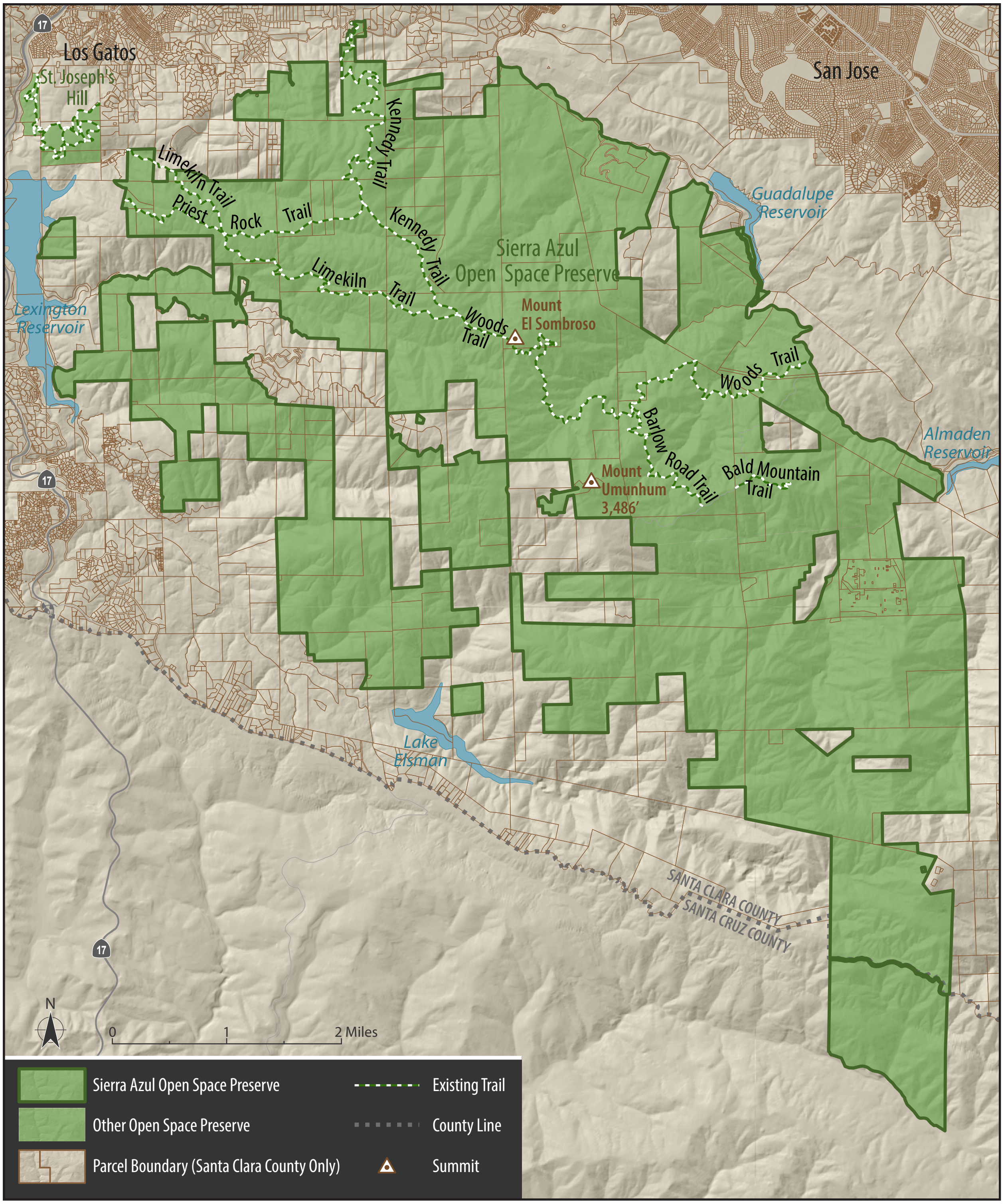

Figure 2.5. The trails and significant summits of the Sierra Azul Open Space Preserve.
Source: Map by author created using data from the Midpeninsula Regional Open Space Preserve, United States Department of Agriculture, and ESRI.

The Almaden Air Force Station was officially closed on June 30, 1980, as surveillance duties shifted to satellite technologies.[16] As the site was decommissioned, surplus items were removed and repurposed, leaving the permanent structures and infrastructure to degrade with time. Since the site was constructed in the early 1950's to the 1960's, many of the materials used for construction have now been discovered to be hazardous to humans, and pose an environmental risk. In short, the legacy of the Almaden Air Force Station is a toxic one.

The Midpeninsula Regional Open Space District purchased the land from the federal government in April 1986 for $260,000. Midpen spent over 20 years pressuring the Federal Government to provide the resources needed to clean up the site and make it safe for visitors. It was not until 2010 that federal government provided funds and clean up could begin. Midpen began remediation and demolition work in 2012, completing demolition of all structures except for the iconic radar tower in early 2014. Work to open the summit to the public by spring 2017 is now underway.[17]

2.4. MOUNT UMUNHUM ENVIRONMENTAL RESTORATION AND PUBLIC ACCESS PLAN

The stated purpose of the Midpeninsula Regional Open Space District is:

> To purchase, permanently protect, and restore lands forming a regional open space greenbelt, preserve unspoiled wilderness, wildlife habitat, watershed, viewshed, and fragile ecosystems, and provide opportunities for low-intensity recreation and environmental education.[18]

It has been a complicated process to achieve this purpose at the Mount Umunhum site, mainly due to the fight with the federal government over cleanup responsibilities. When Midpen acquired the Almaden Air Force Station site, Midpen's long-term vision was to restore the site and open the summit for public access. However, determining who was responsible for the site clean up became a barrier to achieving this goal. During the purchase Midpen understood that the federal government had agreed to responsibility for the cleanup. However, once Midpen pursued federal funding, their request became lost in the thick bureaucracy of the Department of Defense. For over 20 years the site remained closed, and the Army Corps of Engineers conducted only limited cleanup. In 2009, Congress appropriated $3.2 million to clean up and decontaminate the site. With funding secured, Midpen began the planning and construction process, which involved cleaning up the site in preparation to restore it and open it to the public. Construction involved removal of all hazardous materials and the demolition of most structures on site. In early 2014 the cleanup and demolition work was complete except for one standing structure: the 80-foot concrete radar tower.

16. Midpeninsula Regional Open Space District, *Draft Environmental Impact Report for the Mount Umunhum Environmental Restoration and Public Access Project*, SCH# 2010122037 (December 2011): 4.2-12.

17. Midpeninsula Regional Open Space District, "Mount Umunhum Summit Project," Midpeninsula Regional Open Space District, http://www.openspace.org/plans_projects/mt_umunhum.asp (accessed February 25, 2014).

18. Midpeninsula Regional Open Space District, "About Us," Midpeninsula Regional Open Space District, http://www.openspace.org/about_us/ (accessed February 24, 2014).

Midpen has completed the planning process for the future public access to the site. The planning process yielded several scenarios that dictate site design and the course of action needed to reintroduce visitors to the summit. The most significant difference between these scenarios is how they address the concrete radar tower.[19]

Midpen proposed five scenarios for the future of the radar tower, ranging from complete removal to preservation of the structure. On October 17, 2012, Midpen's board selected a scenario titled "Interim Action A: Near-term repair and securing of structure while seeking external partnerships."[20] This scenario preserves the radar tower for five years, allots $414,000 toward the long-term preservation costs, and provides an opportunity for proponents of the tower to develop partnerships and to secure the remaining funding needed to pay for the sealing and continued maintenance of the tower.[21] The scenario plans for work to take place on the tower that will secure the site to a point where visitors can safely stand at the tower's base while visiting the summit. It also offers Midpen an opportunity to pursue the preservation of the tower and open the site to the public while avoiding the financial burdens of direct building preservation. The money saved can be used to continue Midpen's mission: acquiring and preserving open space lands.

19. Midpeninsula Regional Open Space District, *Draft Environmental Impact Report for the Mount Umunhum Environmental Restoration and Public Access Project*, SCH# 2010122037 (December 2011): 4.2-12.

20. Midpeninsula Regional Open Space District, "Board Keeps Tower While Agreeing to Give Supporters Five Years to Develop Partnerships, Resources to Maintain It" (2012 Press Release) (Midpeninsula Regional Open Space District, October 19, 2012), http://www.openspace.org/CGI-BIN/press_releases/121019_Oct17MtgRecap.pdf (accessed February 24, 2014).

21. Ibid.

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CHAPTER 3 General Impacts Resulting from Trail Construction and Use

Identifying the types of impacts resulting from trail construction and use is an important step in trail development. Once these impacts are understood, it is possible to avoid them or mitigate their severity with proper routing, design, and construction techniques. A review of seventeen studies revealed that the most significant impacts of trail construction and trail use fall into the following categories:

- Trampling (vegetation loss, vegetation redistribution, removal of organic litter)
- Erosion (soil loss, rutting, exposed roots)
- Trail divergence (widening, formation of parallel trails, extension)

The literature agrees that in general, building and using trails impacts the land. Trail building alters the physical landscape and trail use continues altering the landscape over time. The majority of the literature indicates that the primary impacts fall within the above categories. This chapter discusses the impacts from trail construction and use in the context of a literature review. The information is then used to provide recommendations that will help minimize disturbance to the land resulting from trail construction and use.

3.1. TRAMPLING

Trampling is identified as an impact of trail use in eleven of the seventeen studies reviewed. Within these eleven studies, trampling is discussed within two different contexts: trampling of undisturbed vegetation resulting from the formation of an unplanned trail, and trampling along and adjacent to established trails. While trampling could be considered a form of erosion in that it removes natural material from a surface, it differs in that trampling specifically deals with the crushing of live vegetation and the removal of organic litter (dead vegetation). Trampling is separated from the discussion of erosion with the acknowledgement that trampling could be considered a step in the erosional process.

Trampling of undisturbed vegetation occurs when unplanned trails are formed, without consideration for routing, design, and impact control.[22] This happens when trail users decide to create their own path across a landscape without planning or studying the area. Four of the eleven studies reviewed discuss trampling in this context. Cole and Landres, Mcdonald et al., New Zealand, and Thurston and Reader each recognize that trampling damages and removes vegetation during the formation

22. New Zealand Department of Conservation, *Off-road Impacts of Mountain Bikes: A Review and Discussion*, by Gordon R. Cessford, Science and Research Series No. 92 (August 1995).

of unplanned trails.[23] Unplanned trails are of particular concern because they do not benefit from proper design (route, design, slope). As a result, the impacts to the land are magnified.

Eight of the eleven studies reviewed discuss the impact trampling has on established trails. Discussion of trampling varies slightly among these studies, but their findings are similar. For example, Cole (1991), and Marion and Wimpey find that trampling is a process that leads to the widening of a trail.[24] This occurs when a user deviates from the intended trail path. Often, the cause for a trail user to diverge from a trail's path is to avoid an obstacle such as mud, rocks, or roots. The result of trampling is the removal of vegetation along the sides of trails, resulting in a wider track. A wider track results in more dirt exposure, which in turn increases erosion along established trails as discussed by Marion and Leung, New Zealand Department of Conservation, and Wilson and Seney. These studies recognize that trampling can remove the organic litter along established trails, which exposes the underlying soil to increased erosion.[25] Pickering et al. and Olive and Marion discuss trampling in a more generalized context, simply identifying trampling as an impact of trail use.[26] These eight studies discuss slightly divergent impacts of trampling along an established trail route, but the overall conclusion is that trampling is a direct result of trail use.

After reviewing these eleven studies, it can be concluded that trampling in either context leads to erosion. With unplanned trails, vegetation is removed, exposing soil and increasing the threat of erosion. With planned trails, trampling results in the removal of organic litter that exposes soil, thus increasing potential erosion. Trampling along planned trails also results in soil compaction, which reduces the soil's ability to absorb water, increasing runoff, and increasing erosion to areas adjacent to the trail.[27]

23. David N. Cole and Peter B. Landres, "Threats to Wilderness Ecosystems: Impacts and Research Needs," *Ecological Applications* 6, no. 1 (1996): 168-184; Robert I. Mcdonald, Richard T. T. Forman, Peter Kareiva, Rachel Neugarten, Dan Salzer, and Jon Fisher, "Urban Effects, Distance, and Protected Areas in an Urbanizing World," *Landscape and Urban Planning* 93, no. 1 (2009): 63-75; New Zealand Department of Conservation, *Off-road Impacts of Mountain Bikes: A Review and Discussion*, by Gordon R. Cessford, Science and Research Series No. 92 (August 1995); John P. Wilson and Joseph P. Seney, "Erosional Impacts of Hikers, Horses, Motorcycles, and Off-road Bicycles on Mountain Trails in Montana," *Mountain Research and Development* 14, no. 1 (1994): 77-88.

24. David N. Cole, *Changes on Trails in the Selway-Bitterroot Wilderness, Montana*, 1978-89, Research Paper INT-450, United States Department of Agriculture, Forest Service. Intermountain Research Station (1991): 4; Jeff Marion and Jeremy Wimpey, "Environmental Impacts of Mountain Biking: Science Review and Best Practices," in *Managing Mountain Biking: IMBA's Guide to Providing Great Riding*, ed. Pete Webber (Boulder, CO: International Mountain Bike Association, 2007): 95.

25. Jeffery L. Marion and Yu-Fai Leung, "Trail Resource Impacts and An Examination of Alternative Assessment Techniques," *Journal of Park and Recreation Administration* 19, no. 3 (2001): 20: New Zealand Department of Conservation, *Off-road Impacts of Mountain Bikes: A Review and Discussion*, by Gordon R. Cessford, Science and Research Series No. 92 (August 1995); John P. Wilson and Joseph P. Seney, "Erosional Impacts of Hikers, Horses, Motorcycles, and Off-road Bicycles on Mountain Trails in Montana," *Mountain Research and Development* 14, no. 1 (1994): 78.

26. Catherine Marina Pickering, Wendy Hill, David Newsome, and Yu-Fai Leung, "Comparing Hiking, Mountain Biking and Horse Riding Impacts on Vegetation and Soils in Australia and the United States of America," *Journal of Environmental Management* 91, no. 3 (2010): 552; Nathaniel D. Olive and Jeffrey L. Marion, "The Influence of Use-related, Environmental, and Managerial Factors on Soil Loss from Recreational Trails," *Journal of Environmental Management* 90, no. 3 (2009): 1484-5.

27. Jeffery L. Marion and Yu-Fai Leung, "Trail Resource Impacts and An Examination of Alternative Assessment Techniques," *Journal of Park and Recreation Administration* 19, no. 3 (2001): 20; John P. Wilson and Joseph P. Seney, "Erosional Impacts of Hikers, Horses, Motorcycles, and Off-road Bicycles on Mountain Trails in Montana," *Mountain Research and Development* 14, no. 1 (1994): 78.

3.2. EROSION

Fourteen studies specially identify erosion as a common or significant impact of trail use.[28] Olive and Marion, Pickering, and Wilson and Seney found that there is some variability in the level of erosion caused by trail users. Researchers found that use type (hiking, mountain biking, equestrian) and the amount of use are the variables that most affect the level of erosion a trail experiences.[29] Of the uses allowed in the Sierra Azul Open Space Preserve, these authors identify equestrians as causing the most erosional impact on a trail.[30] In studies that examine the impact trail conditions have on a user's experience, both Lynn and Brown and Moore et al. found that erosion had a significant negative impact on the user experience. IMBA, Marion and Wimpey, Cole (1985), Goeft and Adler found that trail erosion could be mitigated through proper siting and design.[31] A trail route that closely parallels topography, reduces steep slopes and minimizes high velocity water drainage following storms. This type of drainage exacerbates water's erosional impact along a trail.[32] Trail design can help reduce the impact of water eriosion by allowing for drainage opportunities and minimizing standing water along a trail route.

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28. Luke Chiu and Lorne Kriwoken, "Managing Recreational Mountain Biking in Wellington Park, Tasmania, Australia," *Annals of Leisure Research* 6, no. 4 (2003): 339-361; David N. Cole, "Management of Ecological Impacts in Wilderness Areas in the United States," in *The Ecological Impacts of Outdoor Recreation on Mountain Areas in Europe and North America*, edited by N. G. Bayfield and G. C. Barrow, 138-154, Wye, England: Recreation Ecology Research Group, 1985; David N. Cole, *Changes on Trails in the Selway-Bitterroot Wilderness, Montana*, 1978-89, Research Paper INT-450, United States Department of Agriculture, Forest Service. Intermountain Research Station (1991); Ute Goeft and Jackie Alder, "Sustainable Mountain Biking: A Case Study from the Southwest of Western Australia," *Journal of Sustainable Tourism* 9, no. 3 (2001): 193-211; International Mountain Bicycling Association, *Trail Solutions: IMBA's Guide to Building Sweet Singletrack* (Boulder, Colorado: International Mountain Bicycling Association, 2007); Natasha A. Lynn and Robert D. Brown, "Effects of Recreational Use Impacts On Hiking Experiences in Natural Areas," *Landscape and Urban Planning* 64, nos. 1–2 (2003): 77-87; Jeff Marion and Jeremy Wimpey, "Environmental Impacts of Mountain Biking: Science Review and Best Practices," in *Managing Mountain Biking: IMBA's Guide to Providing Great Riding*, ed. Pete Webber (Boulder, CO: International Mountain Bike Association, 2007), 94-111; Jeffery L. Marion and Yu-Fai Leung, "Trail Resource Impacts and An Examination of Alternative Assessment Techniques," *Journal of Park and Recreation Administration* 19, no. 3 (2001): 17-37; Roger L. Moore, Yu-Fai Leung, Craig Matisoff, Catherine Dorwart, and Alan Parker, "Understanding Users' Perceptions of Trail Resource Impacts and How They Affect Experiences: An Integrated Approach," *Landscape and Urban Planning* 107, no. 4 (2012): 343-350; New Zealand Department of Conservation, *Off-road Impacts of Mountain Bikes: A Review and Discussion*, by Gordon R. Cessford, Science and Research Series No. 92 (August 1995); Nathaniel D. Olive and Jeffrey L. Marion, "The Influence of Use-related, Environmental, and Managerial Factors on Soil Loss from Recreational Trails," *Journal of Environmental Management* 90, no. 3 (2009): 1483-1493; Catherine Marina Pickering, Wendy Hill, David Newsome, and Yu-Fai Leung, "Comparing Hiking, Mountain Biking and Horse Riding Impacts on Vegetation and Soils in Australia and the United States of America," *Journal of Environmental Management* 91, no. 3 (2010): 551-562; Eden Thurston and Richard J. Reader, "Impacts of Experimentally Applied Mountain Biking and Hiking on Vegetation and Soil of a Deciduous Forest," *Environmental Management* 27, no.3 (2001): 397-409; John P. Wilson and Joseph P. Seney, "Erosional Impacts of Hikers, Horses, Motorcycles, and Off-road Bicycles on Mountain Trails in Montana," *Mountain Research and Development* 14, no. 1 (1994): 77-88.

29. Nathaniel D. Olive and Jeffrey L. Marion, "The Influence of Use-related, Environmental, and Managerial Factors on Soil Loss from Recreational Trails," *Journal of Environmental Management* 90, no. 3 (2009): 1483-1493; Catherine Marina Pickering, Wendy Hill, David Newsome, and Yu-Fai Leung, "Comparing Hiking, Mountain Biking and Horse Riding Impacts on Vegetation and Soils in Australia and the United States of America," *Journal of Environmental Management* 91, no. 3 (2010): 551-562; John P. Wilson and Joseph P. Seney, "Erosional Impacts of Hikers, Horses, Motorcycles, and Off-road Bicycles on Mountain Trails in Montana," *Mountain Research and Development* 14, no. 1 (1994): 77-88.

30. Ibid.

31. International Mountain Bicycling Association, *Trail Solutions: IMBA's Guide to Building Sweet Singletrack* (Boulder, Colorado: International Mountain Bicycling Association, 2007); Jeff Marion and Jeremy Wimpey, "Environmental Impacts of Mountain Biking: Science Review and Best Practices," in *Managing Mountain Biking: IMBA's Guide to Providing Great Riding*, ed. Pete Webber (Boulder, CO: International Mountain Bike Association, 2007), 94-111; David N. Cole, "Management of Ecological Impacts in Wilderness Areas in the United States," in *The Ecological Impacts of Outdoor Recreation on Mountain Areas in Europe and North America*, edited by N. G. Bayfield and G. C. Barrow, 138-154, Wye, England: Recreation Ecology Research Group, 1985; Ute Goeft and Jackie Alder, "Sustainable Mountain Biking: A Case Study from the Southwest of Western Australia," *Journal of Sustainable Tourism* 9, no. 3 (2001): 193-211.

Erosion is a significant and concerning impact of trail development. Figure 3.1 is an example of a steep trail sited perpendicular to contour lines, rather than parallel. In this example, the steep slopes allowed storm waters to cause erosional damage to the trail surface. These findings reinforce the significance that the early stages of trail development can have on a trail's impact on the land. The literature supports the importance of choosing the trail's route carefully and incorporating trail-building techniques that help minimize erosion.

Figure 3.1. Erosion along the Priest Rock Trail in the Sierra Azul OSP.
Source: Author.

The most significant methods for minimizing trail erosion are proper siting and design. Considering different types of data during the route selection process can help determine a route that minimizes conditions that exacerbate erosion, such as steep slopes. Essentially, the preliminary trail routing process is the foundation for trail building. If a trail is inappropriately sited, say on a very steep slope, no amount of trail-building techniques will mitigate erosion. Once the preliminary route is established, field studies can then finalize its path, and planners can implement effective construction techniques that will minimize impacts.

3.3. TRAIL DIVERGENCE

Trail divergence occurs at varying degrees of severity and happens when trail users deviate from a defined trail or blaze a new path completely off a defined trail. One example of trail divergence is extension. This happens when users create shortcuts, such as short-cutting switchbacks. A switchback is a reversal in a trail's direction, with a relatively tight turn, used on steep terrain.[33]

32. Jeff Marion and Jeremy Wimpey, "Environmental Impacts of Mountain Biking: Science Review and Best Practices," in *Managing Mountain Biking: IMBA's Guide to Providing Great Riding*, ed. Pete Webber (Boulder, CO: International Mountain Bike Association, 2007), 94-111; Luke Chiu and Lorne Kriwoken, "Managing Recreational Mountain Biking in Wellington Park, Tasmania, Australia," *Annals of Leisure Research* 6, no. 4 (2003): 339-361.

33. United States Department of Agriculture, Forest Service, Technology and Development Program, *Trail Construction and Maintenance Notebook*, Woody Hesselbarth, Brian Vachowski, and Mary Ann Davies. No. 0723-2806-MTDC (2007), http://www.fs.fed.us/t-d/pubs/htmlpubs/htm07232806/page12.htm (accessed April 3, 2014).

Figure 3.2. A shortcut switchback.
This is common without proper barriers installed.
Source: Author.

Short-cutting a switchback occurs when trail users cut through the intended turn as shown in figure 3.2. Trail widening is another example of trail divergence, which occurs when users move just off the defined path of the trail. The result over time is a widening of the trail's path through trampling and erosional forces.

One common reason, cited in the literature, for user deviation from the defined path is the presence of mud on a trail. Figure 3.3 shows an example of the widening of a trail as a result of users avoiding a muddy section. Eight of the seventeen studies reviewed discuss muddiness. Two of these studies identify muddiness as a common impact, but do not discuss it at any length.[34] Marion and Wimpey, and New Zealand Department of Conservation conclude that muddiness is an obstacle that, when present on a trail, can lead to trail divergence when users avoid the muddy section.[35] Cole (1985), Cole (1991), and Marion and Wimpey not only identify muddiness as an impact of trail use, but offer mitigation strategies for addressing the problem through design and trail alterations.[36]

Figure 3.3. Trail divergence.
User avoidance of muddy conditions lead to trail divergence and a wider track.
Source: Oliver Dixon via Wikimedia Commons.

34. Jeffery L. Marion and Yu-Fai Leung, "Trail Resource Impacts and An Examination of Alternative Assessment Techniques," *Journal of Park and Recreation Administration* 19, no. 3 (2001): 17-37; Nathaniel D. Olive and Jeffrey L. Marion, "The Influence of Use-related, Environmental, and Managerial Factors on Soil Loss from Recreational Trails," *Journal of Environmental Management* 90, no. 3 (2009): 1483-1493.

35. Jeff Marion and Jeremy Wimpey, "Environmental Impacts of Mountain Biking: Science Review and Best Practices," in *Managing Mountain Biking: IMBA's Guide to Providing Great Riding*, ed. Pete Webber (Boulder, CO: International Mountain Bike Association, 2007), 100; New Zealand Department of Conservation, *Off-road Impacts of Mountain Bikes: A Review and Discussion*, by Gordon R. Cessford, Science and Research Series No. 92 (August 1995).

Marion and Leung find that trail widening is influenced by both user behavior and the amount of use that a trail experiences.[37] Pickering et al. also found that trail widening is a common result of trail use. In a study examining the relative impacts caused by hiking, equestrian, and mountain bike users, researchers found that all uses cause trail widening. Less controlled styles of mountain bike use (racing, downhill) and equestrian use had the greatest influence on the level of trail widening.[38] Lastly, Cole's 1991 study of trails in the Selway-Bitterroot Wilderness in Montana found that trail widening occurs as a result of trampling, as discussed above.[39]

Regardless of the study method (literature review, short-term or long-term transect field study) the articles reviewed conclude that trail divergence is a result of trail use. Trail divergence comes in various forms and the extent of the impact varies with the type of use and the behavior of the user. Proper trail design can deter some trail divergence, but not all.

There is a relationship between the methods for minimizing the impacts of trail divergence and trampling. The goal is to keep users on the designated path and eliminate any tendencies to stray from the trail. Designing a trail that suits the preferences of trail users will help keep the user focused on the designated path. These preferences are discussed in Chapter 4. Next, it is critical to design a trail that avoids obstacles that lead to a user straying from the trail. This is achieved through proper routing away from immoveable rocks or tree roots and through construction techniques that maximize drainage so mud does not become a problem. Finally, it may be necessary to install barriers to stop users from straying off course. Logs, boulders, or brush piles can be strategically placed to block users from creating their own trail, therefore minimizing impacts to the landscape.

36. David N. Cole, "Management of Ecological Impacts in Wilderness Areas in the United States," in *The Ecological Impacts of Outdoor Recreation on Mountain Areas in Europe and North America*, edited by N. G. Bayfield and G. C. Barrow, 138-154, Wye, England: Recreation Ecology Research Group, 1985: 4; Jeff Marion and Jeremy Wimpey, "Environmental Impacts of Mountain Biking: Science Review and Best Practices," in *Managing Mountain Biking: IMBA's Guide to Providing Great Riding*, ed. Pete Webber (Boulder, CO: International Mountain Bike Association, 2007): 101.

37. Jeffery L. Marion and Yu-Fai Leung, "Trail Resource Impacts and An Examination of Alternative Assessment Techniques," *Journal of Park and Recreation Administration* 19, no. 3 (2001): 20.

38. Catherine Marina Pickering, Wendy Hill, David Newsome, and Yu-Fai Leung, "Comparing Hiking, Mountain Biking and Horse Riding Impacts on Vegetation and Soils in Australia and the United States of America," *Journal of Environmental Management* 91, no. 3 (2010): 555.

39. David N. Cole, *Changes on Trails in the Selway-Bitterroot Wilderness*, Montana, 1978-89, Research Paper INT-450, United States Department of Agriculture, Forest Service. Intermountain Research Station (1991): 4.

3.4. CONCLUSIONS AND MITIGATION STRATEGIES

The impacts identified in the studies reviewed are applicable across all landscapes. These studies identify general impacts of trail use in a variety of settings and all reach similar conclusions. Any trail development in the Sierra Azul Open Space Preserve should consider these impacts and work to minimize their affects on the landscape.

The proposed trail would be located in the Sierra Azul Open Space Preserve. This preserve allows activities that fall into three principal use categories: hiking, mountain biking, and horseback riding. Beyond the common impacts of trail construction and use, the reviewed literature also offers some conclusions on the relative impacts caused by specific users. While a rank ordered list of the three use types allowed in the Sierra Azul is not available based on the literature, two general conclusions can be made:

- Ten of the seventeen studies found that the difference in the level of impact caused by mountain bikes is not significantly different than hikers;[40] and,
- Six of the seventeen studies conclude that horses cause significantly more impact than other uses.[41]

During trail design and construction it is important to consider the severity of impacts from each use. It may be necessary to study the distribution of each use category in the study area to determine the relative use patterns on a new trail. Based on estimated use patterns, specialized construction techniques can be implemented to protect the new trail and adjacent lands from the impacts of a particular use.

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40. Deborah J. Chavez, Patricia L. Winter, and John M. Baas, "Recreational Mountain Biking: A Management Perspective," *Journal of Park and Recreation Administration* 11, no. 3 (1993): 29-36; Luke Chiu and Lorne Kriwoken, "Managing Recreational Mountain Biking in Wellington Park, Tasmania, Australia," *Annals of Leisure Research* 6, no. 4 (2003): 339-361; Ute Goeft and Jackie Alder, "Sustainable Mountain Biking: A Case Study from the Southwest of Western Australia," *Journal of Sustainable* Tourism 9, no. 3 (2001): 193-211; International Mountain Bicycling Association, *Trail Solutions: IMBA's Guide to Building Sweet Singletrack* (Boulder, Colorado: International Mountain Bicycling Association, 2007); Jeff Marion and Jeremy Wimpey, "Environmental Impacts of Mountain Biking: Science Review and Best Practices," in *Managing Mountain Biking: IMBA's Guide to Providing Great Riding*, ed. Pete Webber (Boulder, CO: International Mountain Bike Association, 2007): 94-111; New Zealand Department of Conservation, *Off-road Impacts of Mountain Bikes: A Review and Discussion*, by Gordon R. Cessford, Science and Research Series No. 92 (August 1995); Nathaniel D. Olive and Jeffrey L. Marion, "The Influence of Use-related, Environmental, and Managerial Factors on Soil Loss from Recreational Trails," *Journal of Environmental Management* 90, no. 3 (2009): 1483-1493; Catherine Marina Pickering, Wendy Hill, David Newsome, and Yu-Fai Leung, "Comparing Hiking, Mountain Biking and Horse Riding Impacts on Vegetation and Soils in Australia and the United States of America," *Journal of Environmental Management* 91, no. 3 (2010): 551-562; Eden Thurston and Richard J. Reader, "Impacts of Experimentally Applied Mountain Biking and Hiking on Vegetation and Soil of a Deciduous Forest," *Environmental Management* 27, no.3 (2001): 397-409; John P. Wilson and Joseph P. Seney, "Erosional Impacts of Hikers, Horses, Motorcycles, and Off-road Bicycles on Mountain Trails in Montana," *Mountain Research and Development* 14, no. 1 (1994): 77-88.

41. Jeff Marion and Jeremy Wimpey, "Environmental Impacts of Mountain Biking: Science Review and Best Practices," in *Managing Mountain Biking: IMBA's Guide to Providing Great Riding*, ed. Pete Webber (Boulder, CO: International Mountain Bike Association, 2007): 94-111; Jeffery L. Marion and Yu-Fai Leung, "Trail Resource Impacts and An Examination of Alternative Assessment Techniques," *Journal of Park and Recreation Administration* 19, no. 3 (2001): 17-37; Catherine Marina Pickering, Wendy Hill, David Newsome, and Yu-Fai Leung, "Comparing Hiking, Mountain Biking and Horse Riding Impacts on Vegetation and Soils in Australia and the United States of America," *Journal of Environmental Management* 91, no. 3 (2010): 551-562; New Zealand Department of Conservation, *Off-road Impacts of Mountain Bikes: A Review and Discussion*, by Gordon R. Cessford, Science and Research Series No. 92 (August 1995); Nathaniel D. Olive and Jeffrey L. Marion, "The Influence of Use-related, Environmental, and Managerial Factors on Soil Loss from Recreational Trails," *Journal of Environmental Management* 90, no. 3 (2009): 1483-1493; John P. Wilson and Joseph P. Seney, "Erosional Impacts of Hikers, Horses, Motorcycles, and Off-road Bicycles on Mountain Trails in Montana," *Mountain Research and Development* 14, no. 1 (1994): 77-88.

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CHAPTER 4 Physical Characteristics Preferred by Different Types of Trail Users

The Sierra Azul Open Space Preserve allows three uses on its trail system: hiking, bicycling, and horseback riding.[42] In order to develop a trail that is engaging to its users, it is important to identify the characteristics each use prefers. By incorporating information from several sources, the following discussion develops a set of criteria applicable to the GIS model and develops a set of recommendations for the trail's construction. The sources include:

- A review of literature pertaining to trail user preferences;
- An interview with Bryant Conant, an experienced trail user and builder, advocate, and cartographer;
- An interview with Dong Nguyen, Deputy Town Engineer, Town of Woodside, CA; and,
- Field studies of the existing trails in the Sierra Azul OSP.

4.1. FIELD STUDIES

Data describing the existing trails in the Sierra Azul Open Space preserve was collected during a series of field studies. The author traveled the length of each trail on a mountain bike, and used a Garmin Edge 305 GPS cycling computer to collect data describing trail position, altitude, slope, and distance. During the study, field notes were collected describing trail widths, conditions, and any damage to trail surfaces. Images of the existing trails and terrain were gathered from the Sierra Azul, Long Ridge, and El Corte de Madera Creek Open Space Preserves for use throughout the report.

Figure 4.1. Field studies.
Top: Author at the start point of the proposed trail with Mount Umunhum in the background.
Bottom: Author's shadow during a data collection field study.
Source: Author.

42. Midpeninsula Regional Open Space District, "Open Space Preserves," Midpeninsula Regional Open Space District, http://www.openspace.org/preserves/default.asp (accessed January 31, 2014).

4.2. TRAIL LENGTH AND ELEVATION GAIN

The potential length and elevation gain of the proposed trail would likely not be a significant limitation in its design regardless of its other characteristics. This trail would not be usable independently of other trails given that the study area is located in a central section of the preserve with no possibility for a trailhead located along a roadway. To access the trail a user would have to climb a combination of trails from the east or west. The shortest distance to reach the proposed start point using the existing trail network is approximately 5.6 miles from the west and 4.7 miles from the east; each route involving over 2,000 feet of elevation gain. The straight-line distance between the start and end points of the proposed trail is approximately 1.25 miles with an elevation gain of 582 vertical feet. Even if the actual trail route were double this distance, it would still be an approachable distance to the majority of users that have already made it to one of the two access points. It is reasonable to assume that the trail user who is willing to make the journey to the trailhead would not likely find the potential trail's distance or elevation gain a significant obstacle.

4.3. AVERAGE SLOPE

Average slope, sometimes called *overall trail grade*, is the "slope of a trail from one end to the other."[43] The measure of average slope uses the simplistic rise-over-run calculation, or elevation gained between start and finish points divided by total distance traveled. This calculation does not capture the total ascent of a trail with undulations or that of a long flat trail punctuated by one steep climb, as shown in figure 4.2. Given that the trails in the Sierra Azul Open Space Preserve all have positive altitude gains between their trailhead and terminus, average slope is a suitable measure for comparing the steepness of a trail.

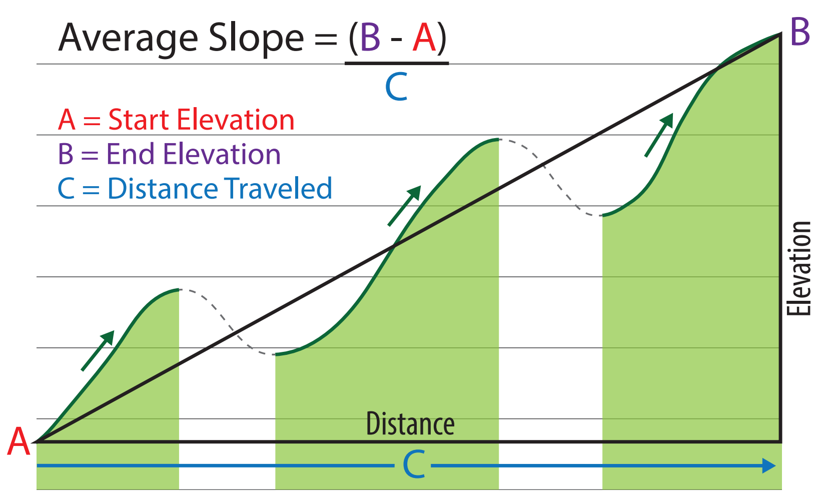

Figure 4.2. Representation of average slope.
Source: Author.

43. International Mountain Bicycling Association, *Trail Solutions: IMBA's Guide to Building Sweet Singletrack* (Boulder, Colorado: International Mountain Bicycling Association, 2007): 64.

4.4. PHYSICAL CHARACTERISTICS BY USE TYPE

4.4.1. Hiking

The literature reviewed offered little in the way of preferences or recommendations for hiking trails. Bryan Conant, an avid hiker and trails advocate in the Santa Barbara County area, suggested that the lack of literature might be because hikers generally cause the least damage to trails and therefore are subject to fewer studies.[44] The focus of existing literature tends to center around mountain biking, equestrian, or multi-use trails. General trail construction manuals and handbooks provide guidance on trail design from a multi-use standpoint. Given that hiking is a component of multi-use trails, it is reasonable to incorporate these recommendations into this study along with information gathered in the field and through interviews.

Slope

A challenge involved with trail building in mountainous terrain is keeping slopes reasonable enough that a user will enjoy them. If the trail includes long sections of overly steep terrain, people will either dislike their experience on the trail, or avoid using the trail altogether . In the context of a multi-use trail, the United State Department of Agriculture's (USDA) *Trail Construction and Maintenance Notebook* recommends limiting maximum slopes to 10% or less.[45] However, Birkby[46] assigns a limit of 15% and IMBA a limit of 15% to 20%[47] for multi-use trails. During the discussion of hiking trails with Bryan Conant, he did not identify a maximum slope value. However, Mr. Conant indicated that from his standpoint, a consistent slope is preferable to one that undulates wildly, even if this results in a longer overall distance.[48] Table 4.1 summarizes these findings.

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44. Bryan Conant, phone interview by author, San José, CA, February 28, 2014.

45. United States Department of Agriculture, Forest Service, Technology and Development Program, *Trail Construction and Maintenance Notebook*, Woody Hesselbarth, Brian Vachowski, and Mary Ann Davies. No. 0723-2806-MTDC (2007), http://www.fs.fed.us/t-d/pubs/htmlpubs/htm07232806/index.htm (accessed February 22, 2014).

46. Robert C. Birkby, *Lightly on the Land: The SCA Trail-building and Maintenance Manual* (Seattle: The Mountaineers, 2001): 97.

47. International Mountain Bicycling Association, *Trail Solutions: IMBA's Guide to Building Sweet Singletrack* (Boulder, Colorado: International Mountain Bicycling Association, 2007): 75.

48. Bryan Conant, phone interview by author, San José, CA, February 28, 2014.

Table 4.1. Slope preferences

Study	Use	Maximum Average Slope	Maximum Slope
Bondurant and Thompson 2007	Mountain Bike	10% – 12.5%	Not given
Birkby 2001	Multi-Use	10%	15%
International Mountain Bike Association 2007	Multi-Use	10%	15% – 20%
Tennessee Department of Environment and Conservation	Multi-Use	5% – 10%	Not given
United States Department of Agriculture 2007	Multi-Use		10%
United States Department of Agriculture 2007	Equestrian	5% –12%	15% – 20%

Sources: Julia Bondurant and Laura Thompson, *Trail Planning for California Communities* (Point Arena, California: Solano Press Books, 2009); Robert C. Birkby, *Lightly on the Land: The SCA Trail-building and Maintenance Manual* (Seattle: The Mountaineers, 2001), 97; International Mountain Bicycling Association, *Trail Solutions: IMBA's Guide to Building Sweet Singletrack* (Boulder, Colorado: International Mountain Bicycling Association, 2007), 75; Tennessee Department of Environment and Conservation, Recreation Educational Services Division, Greenways and Trails Program, *Pathways to Trail Building*, edited by Bob Richards (2007); United States Department of Agriculture, Forest Service, Technology and Development Program, *Trail Construction and Maintenance Notebook*, Woody Hesselbarth, Brian Vachowski, and Mary Ann Davies. No. 0723-2806-MTDC (2007), http://www.fs.fed.us/t-d/pubs/htmlpubs/htm07232806/index.htm (accessed February 22, 2014); United States Department of Agriculture, Forest Service, Technology and Development Program, *Equestrian Design Guidebook for Trails, Trailheads and Campgrounds*, Jan Hancock, Kim Jones, Vander Hoek, Sunni Bradshaw, James D. Coffman, and Jeffery Engelmann, No. 0723-2816-MTDC (2007): Chapter 4.

Width

Two studies discuss trail width recommendations for hiking trails. Both Birkby and Bondurant and Thompson found that 2 to 3 feet on either side of the trail centerline is ample width for hikers (4 to 6 feet total width).[49] Similarly, Wimpey and Marion concluded that widths of 2 to 6.75 feet provide the width necessary for hiking. Mr. Conant indicated that the U. S. Forest Service guidelines for backcountry trails require ample room for two horses to pass each other, approximately 8 feet. However, Conant indicated that this rule is not always reflected on the trails and that the path is often more narrow.[50] A summary of these preferences can be found in table 4.2.

49. Robert C. Birkby, *Lightly on the Land: The SCA Trail-building and Maintenance Manual* (Seattle: The Mountaineers, 2001): 147; Julia Bondurant and Laura Thompson. Trail Planning for California Communities (Point Arena, California: Solano Press Books, 2009): 154.

50. Bryan Conant, phone interview by author, San José, CA, February 28, 2014.

Table 4.2. Width preferences

Birkby	Hike	4 – 6 feet
Wimpey and Marion	Hike	2 – 6.75 feet
Bondurant and Thompson	Multi-use	4 – 6 feet
Conant	Multi-use	8 feet

Sources: Robert C. Birkby, *Lightly on the Land: The SCA Trail-building and Maintenance Manual* (Seattle: The Mountaineers, 2001), 147; Jeremy F. Wimpey, Jeffrey L. Marion, "The Influence of Use, Environmental and Managerial Factors on the Width of Recreational Trails," Journal of Environmental Management 91, no. 10 (2010): 2028-2037; Julia Bondurant and Laura Thompson, *Trail Planning for California Communities* (Point Arena, California: Solano Press Books, 2009), 154; Bryan Conant, phone interview by author, San José, CA, February 28, 2014.

Obstacles

Like equestrians, the mechanics of walking make hikers susceptible to tripping hazards. On the other hand, mountain bikers benefit from the nature of a rolling wheel to overcome many obstacles. While hikers may have more control than equestrians, minimizing this hazard is important. Removal of tripping hazards such as tree roots, exposed rocks, and ruts should be instituted during trail construction. Conant indicated that he has come across varying schools of thought with regard to obstacles present on trails. In general, removal of tripping hazards and a trail surface with a clear view (free from overgrowth) is preferred.[51]

4.4.2. Bicycling

Slope

Three of the seven studies did not quantify either variable but described the preferences. Goeft and Alder indicated that mountain bikers prefer trails that include steep slopes, downhill sections, and short uphill sections.[52] Morey, Buchanan, and Waldman described mountain bikers as preferring trails that are either short and steep or long and flat with a general preference for rolling terrain.[53] Lastly, Symmonds, Hammitt, and Quisenberry's 2000 study of mountain biker preferences indicate that riders prefer a mix of steep and flat terrain. [54] A significant limitation of these three studies is that they are limited to mountain bike use and fail to speak on multi-use trails, such as the trail proposed in this report.

51. Bryan Conant, phone interview by author, San José, CA, February 28, 2014.

52. Ute Goeft and Jackie Alder, "Sustainable Mountain Biking: A Case Study from the Southwest of Western Australia," *Journal of Sustainable Tourism* 9, no. 3 (2001): 193-211.

53. Edward R. Morey, Terry Buchanan, and Donald M. Waldman, "Estimating the Benefits and Costs to Mountain Bikers of Changes in Trail Characteristics, Access Fees, and Site Closures: Choice Experiments and Benefits Transfer," *Journal of Environmental Management* 64, no. 4 (2002): 411-422.

54. Mathew C. Symmonds, William E. Hammitt, and Virgil L. Quisenberry, "Managing Recreational Trail Environments for Mountain Bike User Preferences," *Environmental Management* 25, no.5 (2000): 549-564.

Bondurant and Thompson 2007 determined that mountain bikers prefer average slopes between 10% and 12.5%;[55] while IMBA recommends 10%.[56] Field studies evaluating the existing trails in the Sierra Azul, summarized in table 4.3, reveal an average slope range of 4.3% to 9.1%. Therefore, considering these sources, an average slope range of 4.3% to 12.5% should be used as an evaluation criterion applied to the GIS model. This is a worthwhile goal that is highly dependent on the selected route. Given the variability of terrain where wildland trails are located, it can be expected that short sections would have slopes greater than the preferred maximum average slope of 12.5%. In fact, IMBA suggests that a maximum slope for a given section of 15% to 20% is sustainable, although dependent on local conditions.[57] Anecdotally, it is not uncommon for trails in the Sierra Azul to include sections in excess of 20% slopes.

Table 4.3. Average slopes for existing trails in the Sierra Azul OSP

Trail	Elevation Gain (feet)	Distance (miles)	Average Slope (%)*
Barlow Road	663	1.88	6.7
Kennedy	2,048	5.37	7.2
Limekiln	2,177	4.93	8.4
Priest Rock	1,869	3.88	9.1
Woods	1,444	6.34	4.3

* Average slope calculated by dividing elevation gained by distance.
Source: Field studies by author.

Width

Three studies on the trail preferences of mountain bike riders found that riders generally prefer narrow trails, but these preferences are dependent on experience.[58] Chiu and Kriwoken's study expands on this general preference by dividing mountain bikers into two categories: beginner/novice and expert. Their study found that beginners tend to prefer wider trails while experts prefer more narrow trails.[59] This intuitive notion suggests that as a rider gains skill, they prefer the challenge of narrower trails. Additionally, IMBA's Trail Difficulty Rating System includes a trail width range of 6 inches to 6 feet, depending on the level of difficulty.[60] IMBA's suggested trail widths reflect the preferences of mountain bikers skilled from beginner to expert. Additionally,

55. Julia Bondurant and Laura Thompson. *Trail Planning for California Communities* (Point Arena, California: Solano Press Books, 2009): 178.

56. International Mountain Bicycling Association, *Trail Solutions: IMBA's Guide to Building Sweet Singletrack* (Boulder, Colorado: International Mountain Bicycling Association, 2007): 64.

57. Ibid.

58. New Zealand Department of Conservation, *Off-road Impacts of Mountain Bikes: A Review and Discussion*, by Gordon R. Cessford, Science and Research Series No. 92 (August 1995); Mathew C. Symmonds, William E. Hammitt, and Virgil L. Quisenberry, "Managing Recreational Trail Environments for Mountain Bike User Preferences," Environmental Management 25, no.5 (2000): 549-564;

59. Luke Chiu and Lorne Kriwoken, "Managing Recreational Mountain Biking in Wellington Park, Tasmania, Australia," *Annals of Leisure Research* 6, no. 4 (2003): 339-361.

60. International Mountain Bicycling Association, *Trail Solutions: IMBA's Guide to Building Sweet Singletrack* (Boulder, Colorado: International Mountain Bicycling Association, 2007): 75.

Bondurant and Thompson indicate a preferred width of 4 to 6 feet.[61] Based on these studies, an average mountain biker prefers a trail width of 6 inches to 6 feet, dependent on their skill level. Given the somewhat remote location of the proposed trail, a narrow trail may be appropriate for mountain biking. However, in the interest of safety and appealing to a broader audience, the trail width should reflect all user preferences.

With the exception of the lower portion of the Limekiln trail, the majority of the trails in the Sierra Azul are fire roads, with widths in excess of 12 feet. In the interest of providing more variety in the preserve, it is recommended that the proposed trail be built to the narrowest preference of the three use types. Offering a variety of widths along the trail from the minimum preferred to wider sections would create an interesting route and allow for safe passing of other users.

Obstacles

Technical trail obstacles such as roots, rocks, drop offs, and gullies add variety and challenge to a trail for bicyclists. Three studies that discuss trail preferences of mountain bikers indicated a preference for such features.[62] Such features could be a nuisance or hazardous to other users and would need to be carefully considered during a trail's construction. Additionally, these types of features can be a result of erosion or could accelerate erosional processes as users deviate from the intended trail surface in an attempt to avoid the obstacle. Rather than including obstacles that please mountain bikers but pose a risk to other users, planners can incorporate design features in the trail's route that please all users. Two options are grade changes and gently meandering paths, which create an interesting flow for mountain bikers that presents no risk to other users.

61. Julia Bondurant and Laura Thompson. *Trail Planning for California Communities* (Point Arena, California: Solano Press Books, 2009): 154.

62. Ute Goeft and Jackie Alder, "Sustainable Mountain Biking: A Case Study from the Southwest of Western Australia," *Journal of Sustainable Tourism* 9, no. 3 (2001): 193-211; International Mountain Bicycling Association, *Trail Solutions: IMBA's Guide to Building Sweet Singletrack* (Boulder, Colorado: International Mountain Bicycling Association, 2007); Mathew C. Symmonds, William E. Hammitt, and Virgil L. Quisenberry, "Managing Recreational Trail Environments for Mountain Bike User Preferences," *Environmental Management* 25, no.5 (2000): 549-564.

4.4.3. Equestrian

Slope

Over short distances on appropriate surfaces, equestrians can navigate maximum sustained slopes of 15% to 20%. The maximum average slope recommended by the USDA is in the range of 5% to 12% dependent on the trails surface. In general, harder trail surfaces decrease traction for equestrians. If a hard surface is desired, the maximum average slope should decrease to the lower end of the range. While a softer surface may increase traction and therefore potential average slope, it is important to consider the erosion implications that accompany a soft trail surface on steeper slopes.[63]

Width

A horse's natural stride requires only a 1.5 to 2 foot trail width, however the addition of a rider and pack gear increase required widths. The USDA recommends trail widths of 4 to 8 feet when designing a multi-use trail that will accommodate equestrians.[64] Birkby recommends a trail width of at least 8 feet for equestrian users.[65]

Obstacles

Trail obstacles such as tree roots, ruts, rocks, and curbs, pose a tripping hazard to horses. While other trail users may find these obstacles interesting and challenging, they are dangerous for horses and should be removed. Smooth, consistent surfaces are recommended where possible.[66]

63. United States Department of Agriculture, Forest Service, Technology and Development Program, *Equestrian Design Guidebook for Trails, Trailheads and Campgrounds*, Jan Hancock, Kim Jones, Vander Hoek, Sunni Bradshaw, James D. Coffman, and Jeffery Engelmann, No. 0723-2816-MTDC (2007): Chapter 4.

64. Ibid.

65. Robert C. Birkby, *Lightly on the Land: The SCA Trail-building and Maintenance Manual* (Seattle: The Mountaineers, 2001): 147.

66. United States Department of Agriculture, Forest Service, Technology and Development Program, *Trail Construction and Maintenance Notebook*, Woody Hesselbarth, Brian Vachowski, and Mary Ann Davies. No. 0723-2806-MTDC (2007), http://www.fs.fed.us/t-d/pubs/htmlpubs/htm07232806/index.htm (accessed February 22, 2014): Chapter 4.

4.4.4. Other Trail Features

During the interview with Bryan Conant, he discussed several other trail features that are worth mentioning. Mr. Conant indicated that a trail's construction technique itself can be a feature that can enhance the experience of the trail user. Some examples of these features are crib walls (shown in figure 4.3), intricate rock work, shaded resting spots, views, and even tunnels.[67] Mr. Conant's insights reveal that, while a trail provides people with an opportunity to convene with nature, get exercise, and take in a nice view, a trail's construction technique itself can be an asset that contributes to the enjoyment of the user and should be considered carefully when developing a trail.

Figure 4.3. Crib wall.
Crib walls are retaining structures used in trail construction to create level trails across sloping terrain.
Source: United States Department of Agriculture, Forest Service, Technology and Development Program, Trail Construction and Maintenance Notebook, Woody Hesselbarth, Brian Vachowski, and Mary Ann Davies. No. 0723-2806-MTDC (2007), http://www.fs.fed.us/t-d/pubs/htmlpubs/htm07232806/page12.htm (accessed April 3, 2014).

4.4.5. Additional Considerations

The equestrian community requires some unique consideration when developing a trail intended for their use. While hikers and mountain bikers are in charge of their personal navigation on a trail, equestrians rely on a unique partnership between man and animal. Dong Nguyen is the Deputy Town Engineer for the Town of Woodside, California. Woodside is an equestrian community approximately 30 miles south of San Francisco with an extensive equestrian trail network throughout the 11 square mile town. During an interview with Mr. Nguyen about the trail preferences of equestrians, he made reference to several manuals and books prescribing dimensions for equestrian trails, many of which are referenced in this report. He indicated that the literature provides basic guidelines that outline the needs of the equestrian trail user, but more value comes from the input of the equestrian community itself.[68] This is a significant point applicable to all potential trail users. Collaboration with all stakeholders during the planning process will ensure a more effective planning process yielding a better outcome.

67. Bryan Conant, phone interview by author, San José, CA, February 28, 2014.

68. Dong Nguyen, interview by author, Woodside, CA, February 19, 2014.

4.4.6. Conclusion

Based on literature, field studies, and interviews with trail experts, one can identify the preferred trail characteristics applicable to the proposed trail. Given the variability in such preferences as slope and width, an aggregate value has been determined that incorporates the most constraining user preferences. Table 4.4 summarizes the findings of trail user preferences and how they are best applied to the trail development process presented in this report.

Table 4.4. Application of trail characteristics and user preferences.

Trail Characteristic	Preference	Application (GIS or Trail Building)
Length	Not a factor	Not a factor
Elevation Gain	Not a factor	Not a factor
Obstacles	Free from obstacles	Trail building
Average Slope		
Hiking	5% to 10%	GIS
Mountain Biking	4.3% to 12.5%	
Equestrian	5% to 12%	
Aggregate	*5% to 12.5%*	
Maximum Slope		
Hiking	10% to 20%	GIS
Mountain Biking	15% to 20%	
Equestrian	15% to 20%	
Aggregate	*10% to 20%*	
Width		
Hiking	2 to 6.75 feet	Trail building
Mountain Biking	0.5 to 10 feet	
Equestrian	8 feet	
Aggregate	*6 to 8 feet*	

The interviews with Bryan Conant and Dong Nguyen, along with the literature reviewed, provided insight into the preferences of different trail users. Trail width and slope are primary physical characteristics that could influence the amount of use a trail receives. Build a trail too steep or too narrow, and specific users may not feel comfortable or safe using the trail. Given the effort and expense of trail development, it is best to identify the preferences of intended trail users, and incorporate those preferences into the developmental process. This will help ensure that a wide range of users will enjoy the resulting trail. The limitations identified in this chapter will allow for the incorporation of limitations in the GIS model and contribute to the recommendations for trail construction.

CHAPTER 5 Data Preparation and GIS Workflow

This chapter discusses the development of the GIS model for preliminary route determination used to identify possible routes for the proposed trail. The discussion includes the GIS model, data needs and limitations, data processing, and application of the final datasets to the GIS model.

5.1. GIS MODEL: SELECTING A POTENTIAL ROUTE

The secondary objective of this report is to develop a model that utilizes readily available data to determine a preliminary route of a trail between two points. The literature reviewed presents several different types of models and methods for determining routing across a given landscape. These examples vary from simplistic approaches[69] to complex methodologies involving robust statistical analyses.[70]

While, currently there are methods that utilize GIS and the existing tools within ESRI's ArcGIS for route selection, most methods tend to involve complex functions and means for resampling the data. The workflow studied in this report aims at developing a simple and flexible workflow. In order to determine the trails route one must evaluate either the existing data or easily derived data that describes the study area in which the trail will be located. The flexibility of the GIS model allows users to analyze almost any combination of user-selected data. The user determines what data is relevant to their study and then decides the criteria upon which the model bases its route selection; allowing the model to be adaptable to many different applications.

5.2. MODEL DEVELOPMENT

Nine studies in the reviewed literature were used to develop the key components and foundations that would guide the development of the GIS model discussed in this report. Creating a workflow that is approachable and flexible, and also incorporates accessible data was the goal of the model's framework. The next section discusses the guiding principals of the GIS model's development.

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69. Stephanie A. Snyder, Jay H. Whitmore, Ingrid E. Schneider, and Dennis R. Becker, "Ecological Criteria, Participant Preferences and Location Models: A GIS Approach Toward ATV Trail Planning," *Applied Geography* 28, no. 4 (2008)

70. Min-Yuan Cheng and Guey-Lin Chang, "Automating Utility Route Design and Planning Through GIS," *Automation in Construction* 10, no. 4 (2001): 507-516; Chyi-Rong Chiou, Wei-Lun Tsai, and Yu-Fai Leung, "A GIS-dynamic Segmentation Approach to Planning Travel Routes on Forest Trail Networks in Central Taiwan," *Landscape and Urban Planning* 97, no. 4 (2010): 221-228; 248-258; Aleksandra M. Tomczyk, "A GIS Assessment and Modelling of Environmental Sensitivity of Recreational Trails: The Case of Gorce National Park, Poland," *Applied Geography* 31, no. 1 (2011): 339-351; Aleksandra M. Tomczyk and Marek Ewertowski, "Planning of Recreational Trails in Protected Areas: Application of Regression Tree Analysis and Geographic Information Systems," *Applied Geography* 40 (June 2013): 129-139; Wei-Ning Xiang, "A GIS Based Method for Trail Alignment Planning," *Landscape and Urban Planning* 35, no. 1 (1996): 11-23.

5.2.1. Simplicity

A goal of this report is to produce a GIS model that is approachable with only moderate experience with a GIS. For this reason, any knowledge or use of coding languages is excluded from the workflow. All the procedures and methods are generally included in various versions of ESRI's ArcGIS with Spatial Analyst extension. The model itself is comprised of a set of steps and procedures that yield a trail route based on the data included by the user.

5.2.2. Data Accuracy

The accuracy of the data used for route selection is important. Inaccurate data will produce poor results. Due to their inaccuracies, these poor results generate conclusions and actions that are generally a waste of time, effort, and funding. It is vital to choose data sources carefully and make efforts to acquire the data from their primary sources. For example, if the model needs elevation data, it is best to source the data directly from its creator. The elevation dataset used in this model was created by and sourced from the U. S. Department of Agriculture. Relying on a generic Internet search and acquiring the data from a third-party may yield poor results because there is no way to ensure that the data is in its original form. When aiming for the best result, it is important to remember that the output is only as good as the input.

5.2.3. Age of Data

Another attribute to consider when selecting data is its creation date. The importance of the data's age is dependent on the type of data being considered. For example, if the data describes something that is in a constant state of change, it is vital to source data created recently. For data describing a more constant attribute, the age of the data is not as crucial; although more recent data may exist in a more detailed resolution. The majority of the data used in this report describes the physical characteristics of the study area. Since characteristics such as slope and elevation do not change very often, the data's age is not paramount to the results. When considering the dataset that describes property ownership however, it is important to source the most recent data available.

5.2.4. Expected Limitations

The GIS model developed for this report would be used as a preliminary tool early in the trail's planning process. It is important to remember that the route identified by the model should be used only to guide the on-the-ground routing of the trail. Due to the limitations in spatial resolution, the area of real land represented by a pixel, the GIS model must operate within a generalized realm. This model used elevation data at 3-meter resolution, where each pixel represents a 3-meter square of land. Following a preliminary route selection, further research and field studies would lead to adjustments of the route based on more granular information.

5.3. ARCGIS WORKFLOW AND TOOLS

Figure 5.1 is a summary of the steps in the GIS workflow. What follows is an overview discussion of the workflow for the trail selection model. A more detailed description of these steps can be found in Appendix B.

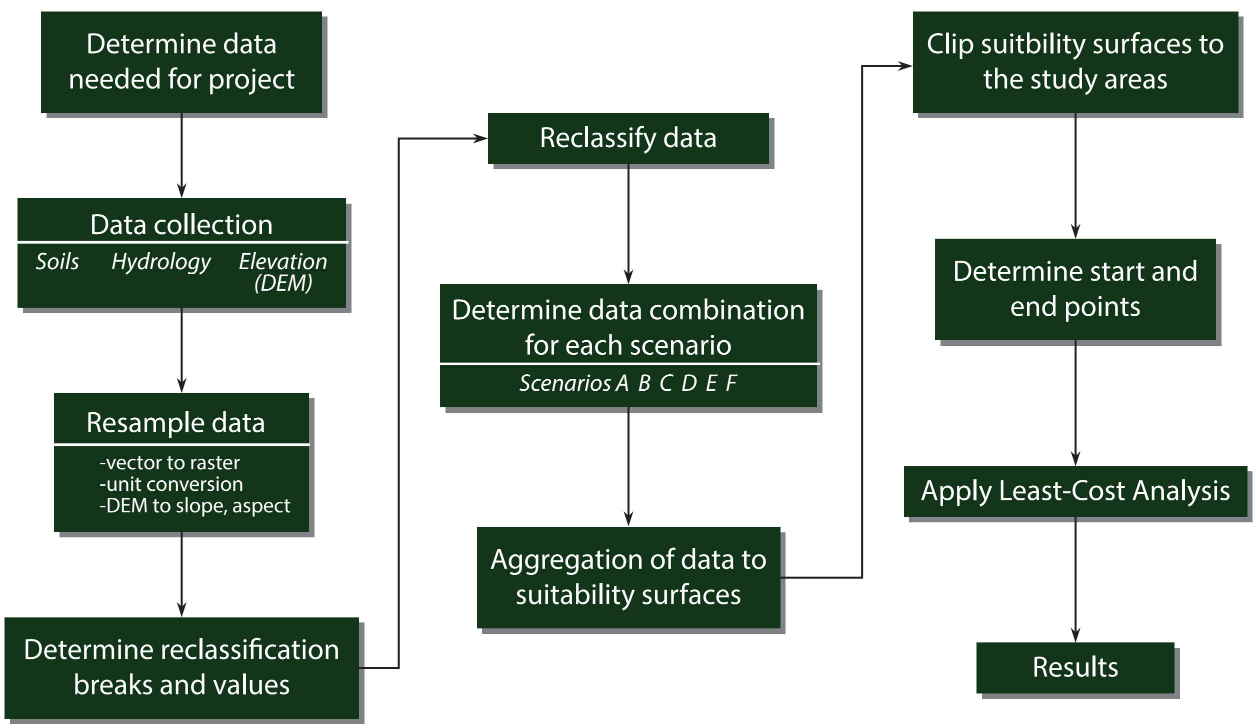


Figure 5.1. GIS Workflow.
Source: Author.

Foundations of the GIS Model for Preliminary Route Planning

This report reviewed nine studies on automated GIS route selection; six of which used a similar workflow to the one used in this report. The development of a grid, where each cell's value represents its suitability for routing a trail, is the foundation of these six studies and the GIS model used in this report. This grid is created by combining several layers of reclassified and weighted data that describes the physical characteristics of the study area. The resulting grid is called a suitability surface. The values contained in the suitability surface represent how suitable each cell of the grid is for trail building. Cell values on the suitability surface represent resistance to trail building. The lower a cell's value, the more suitable it is for a trail. With a defined start and endpoint, the GIS then determines the optimal path across the suitability surface by choosing a path with the least cumulative value, or that of least resistance.[71] ArcGIS, the software used for this report, terms this the Cost Path Function. The authors of these six studies refer to this function as least-cost,[72] route of least impedance,[73] network analysis,[74] and connectivity analysis.[75]

5.4. DATA PREPARATION AND INTEGRATION

One strength of this type of GIS model is its flexibility. It allows the user to customize the workflow based on the data deemed relevant to the question being studied. Datasets can be easily integrated into the model and combined for analysis. The user determines relevancy of each dataset and can decide whether weighting is appropriate to exert more influence on the analysis. In this case, the data describing the physical characteristics of the study area along with property ownership information were found to be the most relevant in determining a preliminary path through the study area.

71. Min-Yuan Cheng and Guey-Lin Chang, "Automating Utility Route Design and Planning Through GIS," *Automation in Construction* 10, no. 4 (2001): 507-516; Chyi-Rong Chiou, Wei-Lun Tsai, and Yu-Fai Leung, "A GIS-dynamic Segmentation Approach to Planning Travel Routes on Forest Trail Networks in Central Taiwan," *Landscape and Urban Planning* 97, no. 4 (2010): 221-228; Stephanie A. Snyder, Jay H. Whitmore, Ingrid E. Schneider, and Dennis R. Becker, "Ecological Criteria, Participant Preferences and Location Models: A GIS Approach Toward ATV Trail Planning," *Applied Geography* 28, no. 4 (2008): 248-258; Aleksandra M. Tomczyk, "A GIS Assessment and Modelling of Environmental Sensitivity of Recreational Trails: The Case of Gorce National Park, Poland," *Applied Geography* 31, no. 1 (2011): 339-351; Aleksandra M. Tomczyk and Marek Ewertowski, "Planning of Recreational Trails in Protected Areas: Application of Regression Tree Analysis and Geographic Information Systems," *Applied Geography* 40 (June 2013): 129-139; Wei-Ning Xiang, "A GIS Based Method for Trail Alignment Planning," *Landscape and Urban Planning* 35, no. 1 (1996): 11-23.

72. Stephanie A. Snyder, Jay H. Whitmore, Ingrid E. Schneider, and Dennis R. Becker, "Ecological Criteria, Participant Preferences and Location Models: A GIS Approach Toward ATV Trail Planning," *Applied Geography* 28, no. 4 (2008): 248-258; Aleksandra M. Tomczyk and Marek Ewertowski, "Planning of Recreational Trails in Protected Areas: Application of Regression Tree Analysis and Geographic Information Systems," *Applied Geography* 40 (June 2013): 129-139.

73. Min-Yuan Cheng and Guey-Lin Chang, "Automating Utility Route Design and Planning Through GIS," *Automation in Construction* 10, no. 4 (2001): 507-516; Chyi-Rong Chiou, Wei-Lun Tsai, and Yu-Fai Leung, "A GIS-dynamic Segmentation Approach to Planning Travel Routes on Forest Trail Networks in Central Taiwan," *Landscape and Urban Planning* 97, no. 4 (2010): 221-228.

74. Chyi-Rong Chiou, Wei-Lun Tsai, and Yu-Fai Leung, "A GIS-dynamic Segmentation Approach to Planning Travel Routes on Forest Trail Networks in Central Taiwan," *Landscape and Urban Planning* 97, no. 4 (2010): 221-228.

75. Wei-Ning Xiang, "A GIS Based Method for Trail Alignment Planning," *Landscape and Urban Planning* 35, no. 1 (1996): 11-23.

5.5. DATA RELEVANT TO THE PROPOSED TRAIL

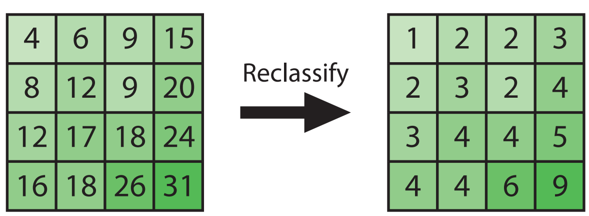
Determining the route of a new trail involves striking a balance between user preferences and minimizing trail use impacts. While many of the user preferences and impact reduction techniques are incorporated during trail construction, preliminary route planning is essential in selecting a route that provides a suitable landscape for a successful trail. For this report, the factors deemed relevant to both user preference and minimizing impacts are slope, aspect, soil type, hydrology, and property ownership.

5.5.1. Slope

A slope layer, which describes the percent slope of each pixel within the area of interest, was created from the digital elevation model using the Slope tool in ArcGIS. The layer was then reclassified based on the preferences of trail users and in order to minimize the impacts of trail use. As discussed in previous chapters, lower slopes are less susceptible to erosion and preferred by trail users. The slope data was reclassified using breaks based on the average slope preferences discussed in Chapter 4 and summarized in table 5.1. The author established the breaks in consideration of the maximum slopes experienced during several field studies of the existing trails in the Sierra Azul Open Space Preserve. It is not uncommon for short sections of trail to exceed 20% and therefore, the upper-limit break was set at 30%. Figure 5.2 describes the reclassification process and shows the breaks used for the slope data.

Table 5.1. Slope preferences by use

Use	Maximum Average Slope
Mountain bike	10% – 12.5%
Multi-use	5% – 10%
Equestrian	5% – 12%



Slope %	Reclassify Value
1-5	1
5-10	2
10-15	3
15-20	4
20-25	5
25-30	6
30+	9

Figure 5.2. Reclassifying slope data.
Source: Author.

5.5.2. Aspect

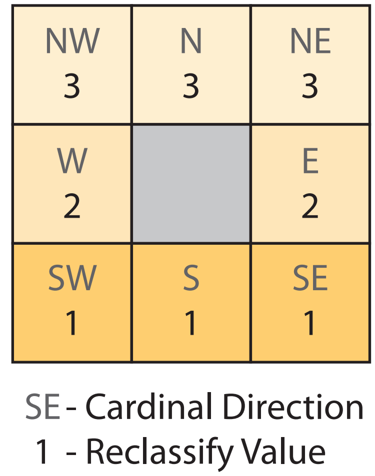


Figure 5.3. Reclassifying aspect data based on cardinal direction. *Source*: Author.

Aspect is another variable that is commonly calculated from a digital elevation model using the Aspect function in ArcGIS. Several of the reviewed studies incorporated aspect into their models.[76] Aspect describes the slope direction of an area of land and is useful in determining an area's potential solar access. Solar access is the amount of time a point receives direct sunlight in a day. This variable is useful in determining the areas that are likely to remain wet for longer periods of time after a storm; increasing the likelihood of erosion. The amount of solar access a trail receives is also important when considering the comfort of the trail users. Depending on the climate, if a trail is exposed to direct sunlight during the hottest portions of the summer, it may be uncomfortable or dangerous to trail users. Given that the proposed trail is located in the temperate climate of the Bay Area, this layer was reclassified with a preference for maximum solar access, which is experienced on southern slopes. South facing slopes were given preference as shown in figure 5.3.

5.5.3. Soil and Drainage Characteristics

How efficiently water drains from a trail's surface following a storm is a primary component of erosion. Trail construction techniques help to minimize erosion by providing proper drainage. The type of soils upon which a trail is constructed is another component of how efficiently a trail handles storm water. Soils vary in their ability to absorb water depending on their composition. Sandy soils absorb water quickly, while soils with high clay content resist absorption; leaving water an opportunity to pool or runoff. High volumes of runoff on sloping terrain can cause erosion along a trail, which damages the surface. Therefore, when designing a trail it is important to understand the drainage characteristics of the soils in the area.

76. Aleksandra M. Tomczyk, "A GIS Assessment and Modelling of Environmental Sensitivity of Recreational Trails: The Case of Gorce National Park, Poland," *Applied Geography* 31, no. 1 (2011): 339-351; Aleksandra M. Tomczyk and Marek Ewertowski, "Planning of Recreational Trails in Protected Areas: Application of Regression Tree Analysis and Geographic Information Systems," *Applied Geography* 40 (June 2013): 129-139; Wei-Ning Xiang, "A GIS Based Method for Trail Alignment Planning," *Landscape and Urban Planning* 35, no. 1 (1996): 11-23.

Four studies identified soil type as an important characteristic to consider when developing a model for trail route determination.[77] Snyder et al.'s 2008 study focusing on GIS trail routing, discussed soil type as an important attribute to consider when routing a trail; however, their case study found little variation in soil type across their study area and it was removed from their model.[78] Sadek, Kaysi, and Bedran's 2000 study on highway routing and layout, included soil type in their model as well. Presumably, their study retained the soils layer because there was enough variability in the soil type across their study area. Soils were rated in terms of their drainage and grading quantities in their GIS model.[79]

Soils data from the USDA's Natural Resources Conservation Service revealed 10 different soil types within the study area of this report. After examining the characteristics of each soil type, it was concluded that there was very little variation among the soils' drainage and permeability characteristics.[80] All the soils in the area drain well, with moderate to rapid permeability. Because the characteristics of the 10 soil types in the study area of the proposed trail are so similar, including this data in the GIS model would not significantly affect the suitability surfaces; all of the cell values of the soils data would be the same across the study area. Like Snyder et al.'s study, the soils data was not included in the development of the suitability surfaces for this report. Appendix C provides a summary of the soil types identified in the study area.

Despite the lack of variation across the study area, soils data should not be omitted from consideration when planning a trail route. Even if little variation is found among the soil types in a study area, an examination of the soils will provide valuable information regarding the drainage and permeability characteristics of the area. The potential impact soil type can have on erosion is significant and should be included in this type of study.

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77. Nathaniel D. Olive and Jeffrey L. Marion, "The Influence of Use-related, Environmental, and Managerial Factors on Soil Loss from Recreational Trails," *Journal of Environmental Management* 90, no. 3 (2009): 1483-1493; Salah Sadek, Isam Kaysi, and Mounia Bedran, "Geotechnical and Environmental Considerations in Highway Layouts: An Integrated GIS Assessment Approach," *International Journal of Applied Earth Observation and Geoinformation* 2, nos. 3–4 (2000): 190-198; Aleksandra M. Tomczyk and Marek Ewertowski, "Planning of Recreational Trails in Protected Areas: Application of Regression Tree Analysis and Geographic Information Systems," *Applied Geography* 40 (June 2013): 129-139.

78. Stephanie A. Snyder, Jay H. Whitmore, Ingrid E. Schneider, and Dennis R. Becker, "Ecological Criteria, Participant Preferences and Location Models: A GIS Approach Toward ATV Trail Planning," *Applied Geography* 28, no. 4 (2008): 248-258.

79. Salah Sadek, Isam Kaysi, and Mounia Bedran, "Geotechnical and Environmental Considerations in Highway Layouts: An Integrated GIS Assessment Approach," *International Journal of Applied Earth Observation and Geoinformation* 2, nos. 3–4 (2000): 190-198.

80. United States Department of Agriculture, Natural Resources Conservation Service, "Official Soil Series Descriptions (OSDs)," *United States Department of Agriculture*, http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/home/?cid=nrcs142p2_053587 (accessed January 19, 2014).

5.5.4. Hydrology

Figure 5.4. A creek near the Woods Trail.
Creeks and other water features are particularly sensitive habitats and can have positive impacts on a trail user's experience.
Source: Author.

When building a trail within stream corridors, it is important to consider that any alteration to the land can have detrimental effects on the wildlife that are dependent on the fragile habitat. It is also important to consider the positive impact a creek can have on a trail user's experience. Striking a balance between minimizing impacts to creek habitats and providing an interesting trail experience by routing a trail near or across a creek is a challenge of trail route planning. Several creeks, like the one shown in figure 5.4, run through the area of this study, providing the opportunity to route the trail across or near creeks. As a default, the GIS model was setup to minimize impacts to delicate creek corridors from trail building and use. Once a preliminary trail route is selected, it is at the discretion of the trail planner to deviate from this route to include creeks in the trail's path. If including a creek along the trail is chosen, or cannot be avoided, it is important to employ construction techniques that minimize impacts from trail construction and use.

Hydrology data was sourced from the County of Santa Clara and examined to determine the potential impacts the trail could have on the surrounding creek corridors. During preliminary route planning, areas within 50 feet of a stream were identified and reclassified with a high value, as

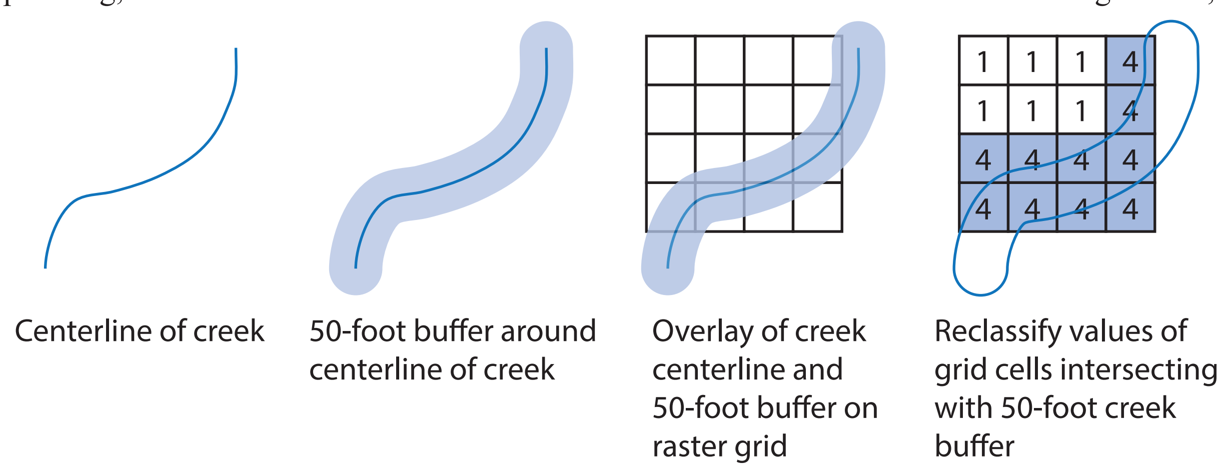


Figure 5.5. Reclassifying hydrology data.
Source: Author.

demonstrated in figure 5.5. The high value of the creek buffer decreases the likelihood that the trail would be routed through these cells. The GIS model was run with and without the creek buffers to evaluate whether it was feasible to route the proposed trail without crossing any creeks. If creek crossing cannot be avoided, it is then important to construct any crossings in such a way that minimizes any potential impacts.

5.5.5. Property Ownership

In an early phase of the Mount Umunhum Environmental Restoration and Public Access Project, the Notice of Preparation of an Environmental Impact Report included a direct connection between the summit of Umunhum and the Woods Trail, in the scope of the project.[81] When the Draft Environmental Impact Report was released, this trail was eliminated from the scope of the project. It was considered to be too speculative because some of the lands the trail would traverse are owned by private land owners.[82] Figure 5.6 shows the study area and includes the privately

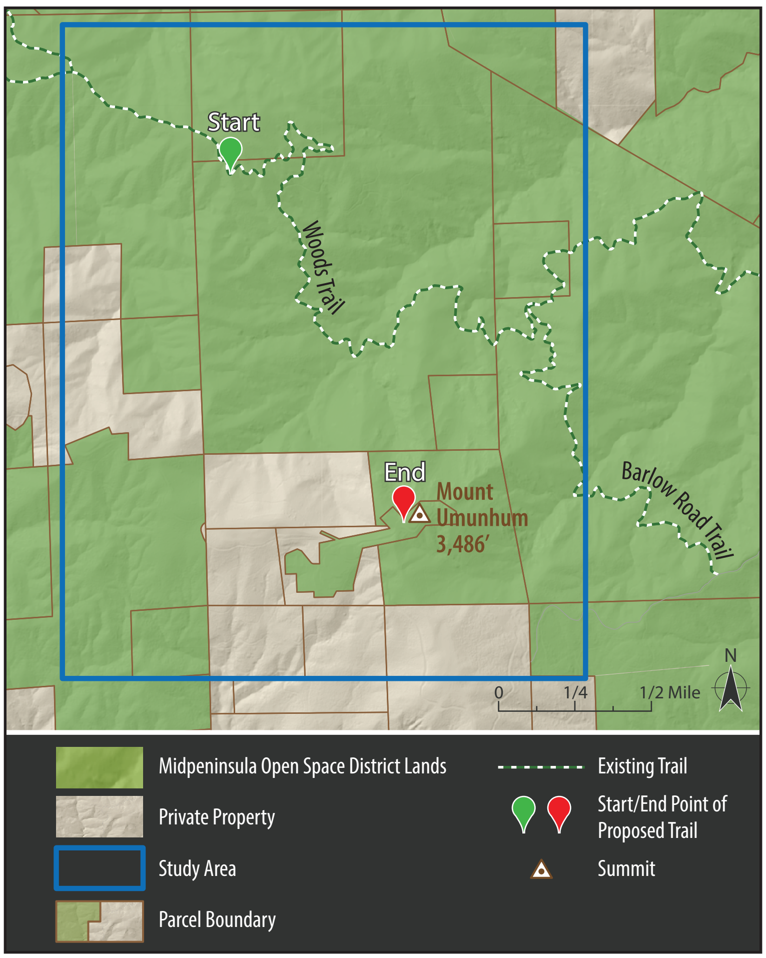


Figure 5.6. Land ownership within the study area.
Source: Map by author created using data from the Midpeninsula Regional Open Space District, Santa Clara County Assessors Office, USDA, ESRI.

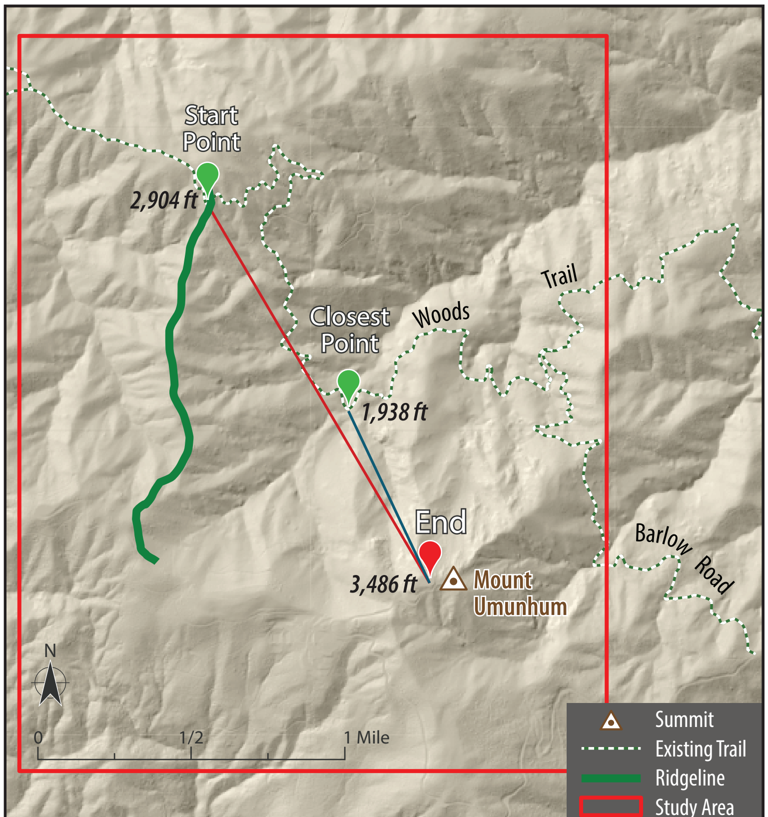
81. Midpeninsula Regional Open Space District, *Notice of Preparation, Mount Umunhum Proposed Environmental Restoration and Public Access Plan*, Santa Clara County, California (2010): 8.

82. Midpeninsula Regional Open Space District, *Draft Environmental Impact Report for the Mount Umunhum Environmental Restoration and Public Access Project*, SCH# 2010122037 (December 2011): 1-5.

owned parcels as well as those owned by Midpen. A direct connection between the start and end points appears possible across lands owned by Midpen, however a route through these lands may not be the most appropriate in the context of meeting user preferences and minimizing impacts. In order to examine differences, GIS modeling scenarios include one scenario in which the trail routing area is limited to lands that Midpen already owns, and one scenario in which trail routing is allowed on all lands within the study area.

5.5.6. Selection of the Start and End Points

The selected start point for the proposed trail is located at a point where a north-south ridgeline intersects the Woods Trail, as shown in figure 5.7. Several factors were considered in the selection of this start point. First, the start point needed to be at an elevation where trail length and elevation gain were reasonable. As shown in figure 5.7, there is a point at which the Woods Trail is closer to the end point, but the elevation gain would be severe over a short distance; and if a suitable path were possible it would likely require the installation of many costly switchbacks. Second, topographic information, hillshade maps, and aerial imagery provided information on the location of ridgelines, gullies, and existing trails, which helped in choosing a preliminary start point. Lastly, field study and local knowledge bolstered research in determining an appropriate start point. The endpoint selected for the proposed trail corresponds to the summit area of Mount Umunhum. This meets the District's goal of opening the summit of Mount Umunhum to the public.



	Distance	Elevation at Start	Elevation Gain from Start to Summit	Slope
Start Point	6,744 ft	2,904 ft	582 ft	8.6%
Closest Point to Summit	2,965 ft	1,938 ft	1,584 ft	53.4%

Figure 5.7. Comparison of proposed start and nearest points.
Comparison of start point of this study and a point along the existing Woods Trail nearest to the end point of the study.
Source: Map by author created using data from the Midpeninsula Regional Open Space District, United States Department of Agriculture.

Figure 5.8. View to Mount Umunhum from the start point used in the GIS model.
Source: Author.

5.6. PREPARING THE SUITABILITY SURFACES

Once each of the datasets have been reclassified, they are then combined to form the suitability surface. A suitability surface is the result of aggregating reclassified layers of data, such as those discussed above, into a single surface. The resulting layer represents a surface where the value of each pixel describes the resistance it would apply to a route during cost-path analysis. The lower the value on the surface, the lower the resistance. Figure 5.9 describes the process of generating a suitability surface.

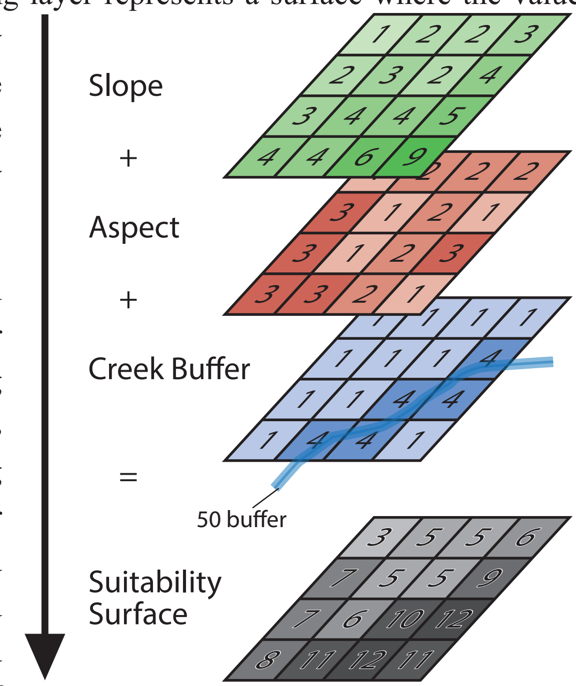


Figure 5.9. Preparing the suitability surface. The reclassified layers are combined into one grid with each cell's value representing the suitability for trail building.
Source: Author.

It is at this time that weighting of any datasets can be applied. Weighting is applied by using the Raster Calculator to multiply a dataset using a weighting factor. The resulting dataset would carry higher values and would thus exert more resistance to trail routing when incorporated into the suitability surface. For this study, equal weighting of the datasets was used for two reasons. First, this equal weighting was used in order to produce a baseline set of results that could then be evaluated for any viable routing. Second, if weighting were incorporated, the number of possible scenarios would increase due to the large number of possible weighting combinations that could be explored. It would be necessary to compare each set of weighted scenarios against the equally weighted baseline scenarios. This discussion would detract from the primary and secondary goals of this report by devolving into an examination of the merits of different weighting scenarios. However, weighting input variables should not be dismissed because it is a very useful tool for prioritizing one variable over another. Should this project move forward, weighting can be incorporated according to recommendations made by professionals more familiar with the study area. The results of this report may spur future research that involves more detailed study and weighting of datasets.

5.7. GEOGRAPHIC CONSTRAINTS

In an early phase of Midpen's planning efforts to open the summit of Mount Umunhum to the public, planners included a trail connection similar to the connection proposed in this report. With the release of the Draft Environmental Impact Report, this trail connection was removed from the scope of the project due to complications with private land ownership.[83] For this study two different study area boundaries were selected for the model runs. The first, shown in blue in figure 5.10, was chosen to explore what the route would look like if constrained to lands currently owned by Midpen. This provides an opportunity to explore the feasibility of a trail that would not require additional land acquisitions. The second study area, shown outlined in red (including the blue area within the red outline) in figure 5.10, allowed for routing over a wider area with no limitations on property ownership. A discussion of these model runs follows.

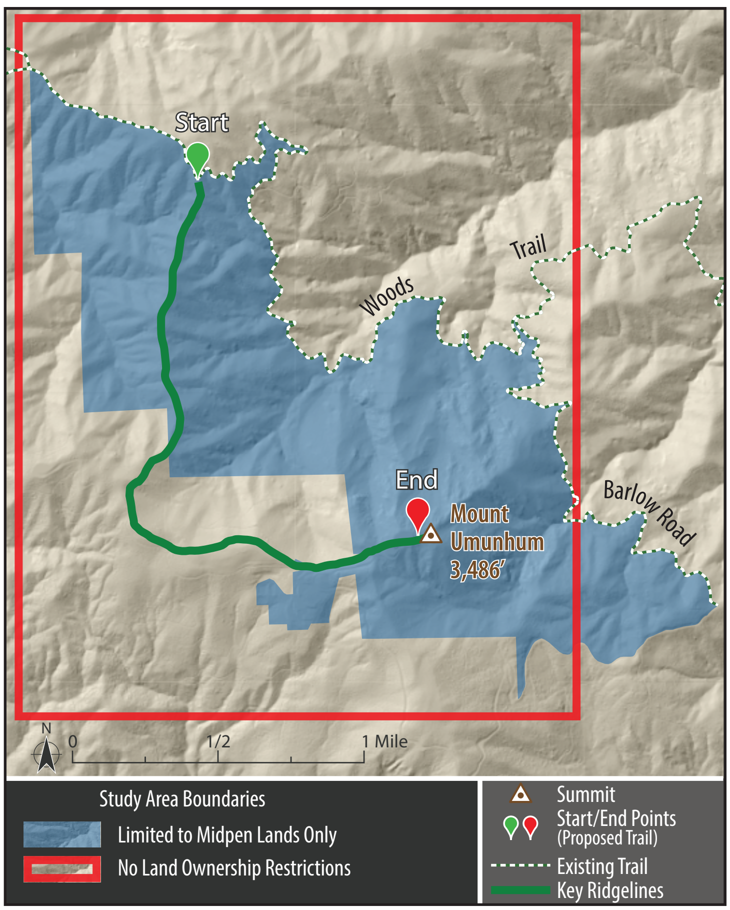


Figure 5.10. Geographic constraints applied to the cost-path analysis.
Source: Map by author created using data from the Midpeninsula Regional Open Space District, United States Department of Agriculture, and ESRI.

83. Midpeninsula Regional Open Space District, *Draft Environmental Impact Report for the Mount Umunhum Environmental Restoration and Public Access Project*, SCH# 2010122037 (December 2011): 1-5.

5.8. ROUTE SELECTION SCENARIOS AND MODEL OUTPUTS

Three scenarios were selected for the model runs after the data was prepared and reclassified. Each scenario used a unique combination of data layers to create each suitability surface. Slope was determined to be the primary dataset because of its direct impact on the usability of a trail. This report excluded scenarios that explored aspect or creeks in isolation because a trail determined on this data alone could include slopes that are not feasible for use. Therefore, slope was used as the base of all scenarios.

Aspect was considered as a secondary variable given its influence on solar access and user comfort. As discussed above, aspect has some influence on erosion and trail usability based on the amount of sunlight a trail section can expect to receive. Aspect was added to slope for the second data grouping to explore the affects of that combination of variables on trail routing.

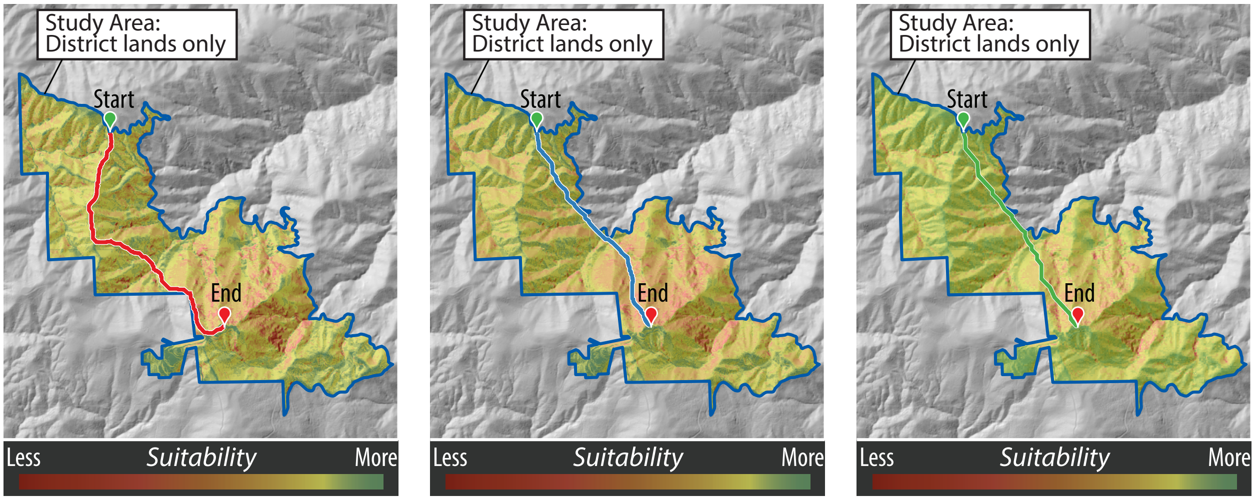
Additionally, creeks were added to slope and aspect in order to determine if it was possible to avoid the riparian corridors in preliminary routing. A number of creeks drain through the study area. Based on a preliminary review of the landscape and creeks, it was determined to be difficult to avoid these features. The final data grouping explores the feasibility of trying to avoid creeks while considering the slope and aspect datasets. If unavoidable, special construction and trail routing techniques are needed to minimize the impact to these sensitive areas.

Lastly, two different study areas were created based on the geographic constraints discussed above. This resulted in a total of six separate model runs. Table 5.2 shows the composition of the six separate model runs, which allow for analysis on the affects of the different data combinations and geographic constraints.

The Cost-Path Analysis was applied to the various suitability surfaces resulting in six different routes between the start and end points. Figure 5.11 shows each suitability surface and the corresponding route determined by the GIS.

Table 5.2. Route selection scenarios

Scenarios	Suitability Surface Composition
District Lands Only	
A	Slope
B	Slope & Aspect
C	Slope, Aspect, & Creeks
All Lands	
D	Slope
E	Slope & Aspect
F	Slope, Aspect, & Creeks



A. Slope

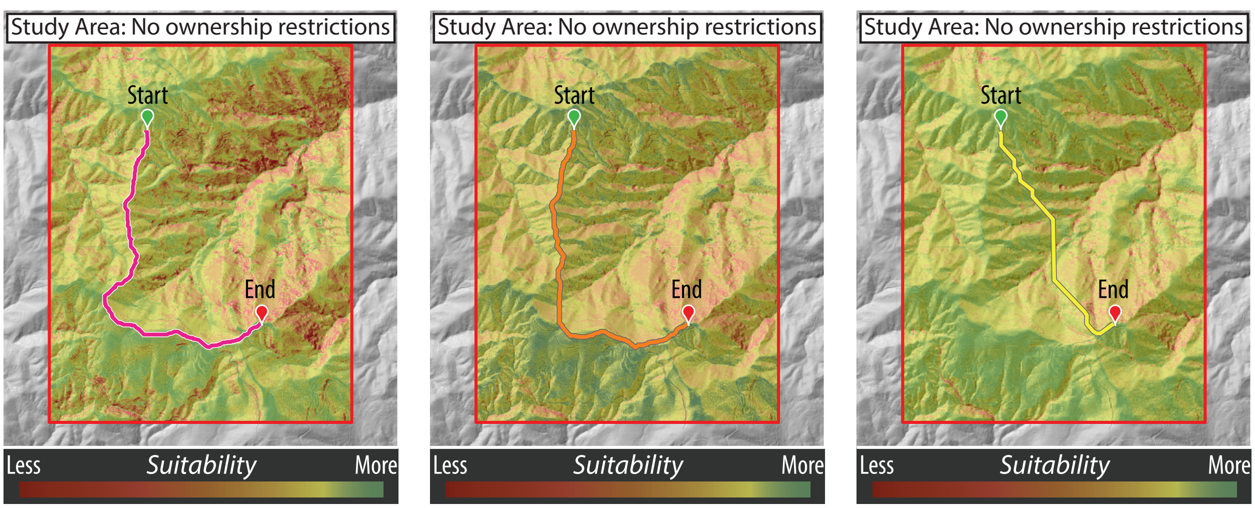
In this scenario, the route was selected on the basis of minimizing slope along the path. The suitability surface included only the slope data and was constrained to the land owned by Midpen.

B. Slope & Aspect

The suitability surface in Scenario B included both slope and aspect, which was constrained to the land owned by Midpen.

C. Slope, Aspect, & Creeks

Scenario C's suitability surface included slope, aspect, and the creek buffers, and was constrained to lands owned by Midpen.



D. Slope

Scenario D was selected on the basis of slope alone, and was not limited to Midpen lands.

E. Slope & Aspect

The suitability surface in Scenario E included both slope and aspect and was not constrained to Midpen lands.

F. Slope, Aspect, & Creeks

Scenario F incorporated slope, aspect, and creek buffers without being limited to Midpen lands.

Figure 5.11. Results of route selection process.
Source: Map by author created using data from the United States Department of Agriculture.

CHAPTER 6 Results and Analysis

This chapter examines the GIS model results of the various scenarios, evaluating them against user preferences and potential physical impacts to the land. An optimal route is then selected and the next steps of trail development are briefed.

6.1. RESULTS OF GIS MODEL RUNS

As discussed in the previous chapter, six different suitability surfaces were used to determine the optimal path for the proposed trail between the start and end points. The model selected the path that offered the least resistance through each surface. The resulting path serves as a preliminary trail route for each dataset. Figure 6.1 shows the results of the six model runs. Clearly, each suitability surface produced a unique result based on the unique combination of data and study area. It is

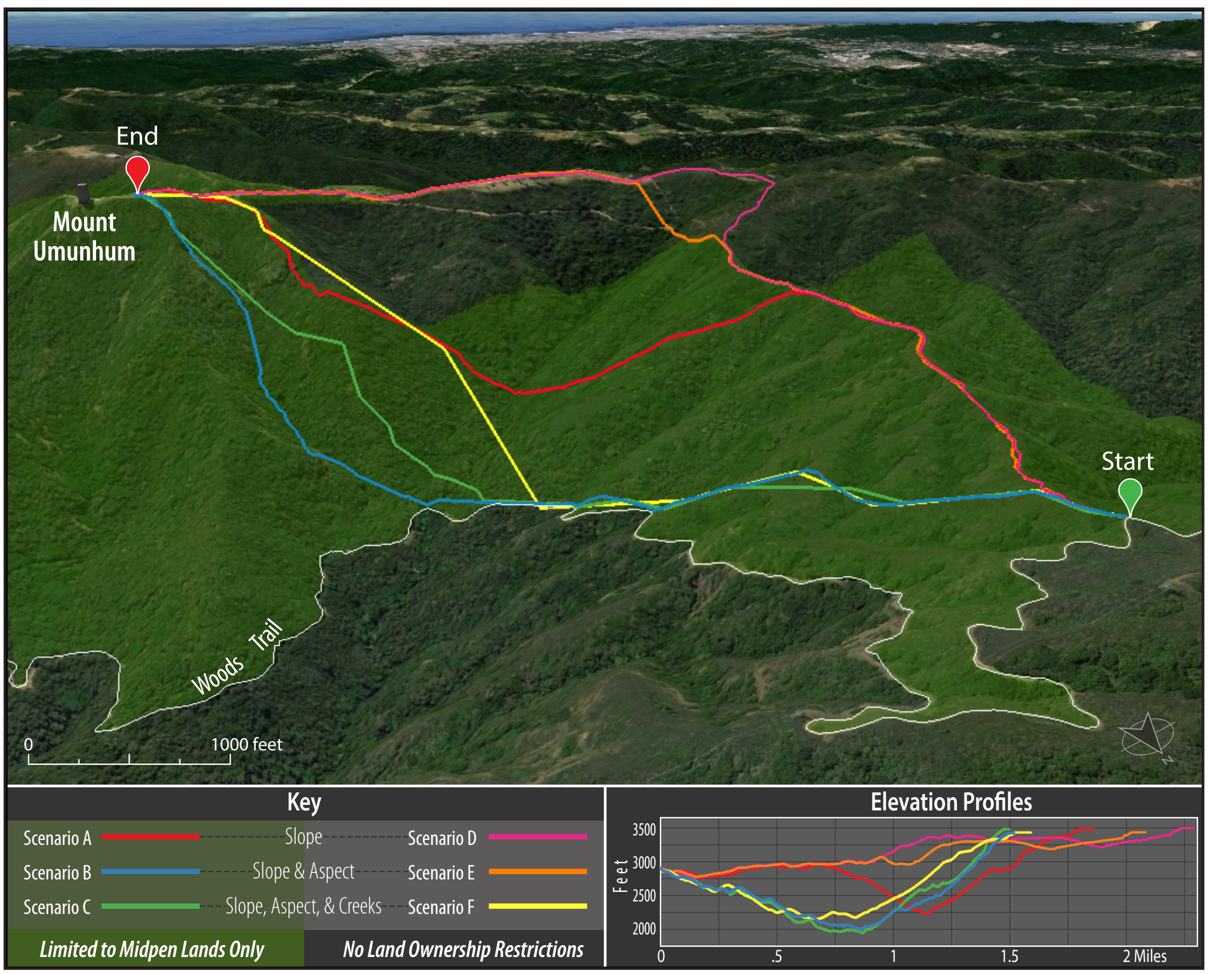


Figure 6.1. Results of the six scenarios.
Source: Map by author created using Google Earth with data from the Midpeninsula Regional Open Space District.

beneficial to explore multiple model runs because the runs provide not only more options to the trail developer, but also an opportunity to understand the affects of the different datasets on the route selection.

The following discussion of the results of the model runs is organized by trail feasibility in pairs of scenarios. Two runs, Scenarios D and E, produced trail routes that are the most feasible; while the others produced routes that included difficult obstacles and barriers such as steep slopes, excessive elevation loss/gain, and a confusing trail network. On the whole, the most promising results were from the scenarios with the fewest data inputs and largest study area. The inclusion of the creeks buffer in the suitability surface (scenarios C and F) produced the least feasible routes, with steep slopes and large elevation changes in relatively short distances.

6.1.1. Scenarios D and E – Most Feasible Routes

The most promising routes produced from the different model runs were from Scenarios D and E, shown in figure 6.2. These routes were selected without restriction of property ownership. The resulting routes traverse ridgelines and minimize large elevation gains and losses. The selected routes for these two scenarios are very similar, with Scenario E briefly deviating from the route of Scenario D to cross an upper section of drainage. Scenario E's suitability surface included aspect data reclassified with a preference for maximizing south-facing slopes. This deviation is likely the result of the inclusion of aspect. As a consequence, Scenario E increases total elevation loss and gain. However, the change in elevation is not severe enough to eliminate the route from consideration.

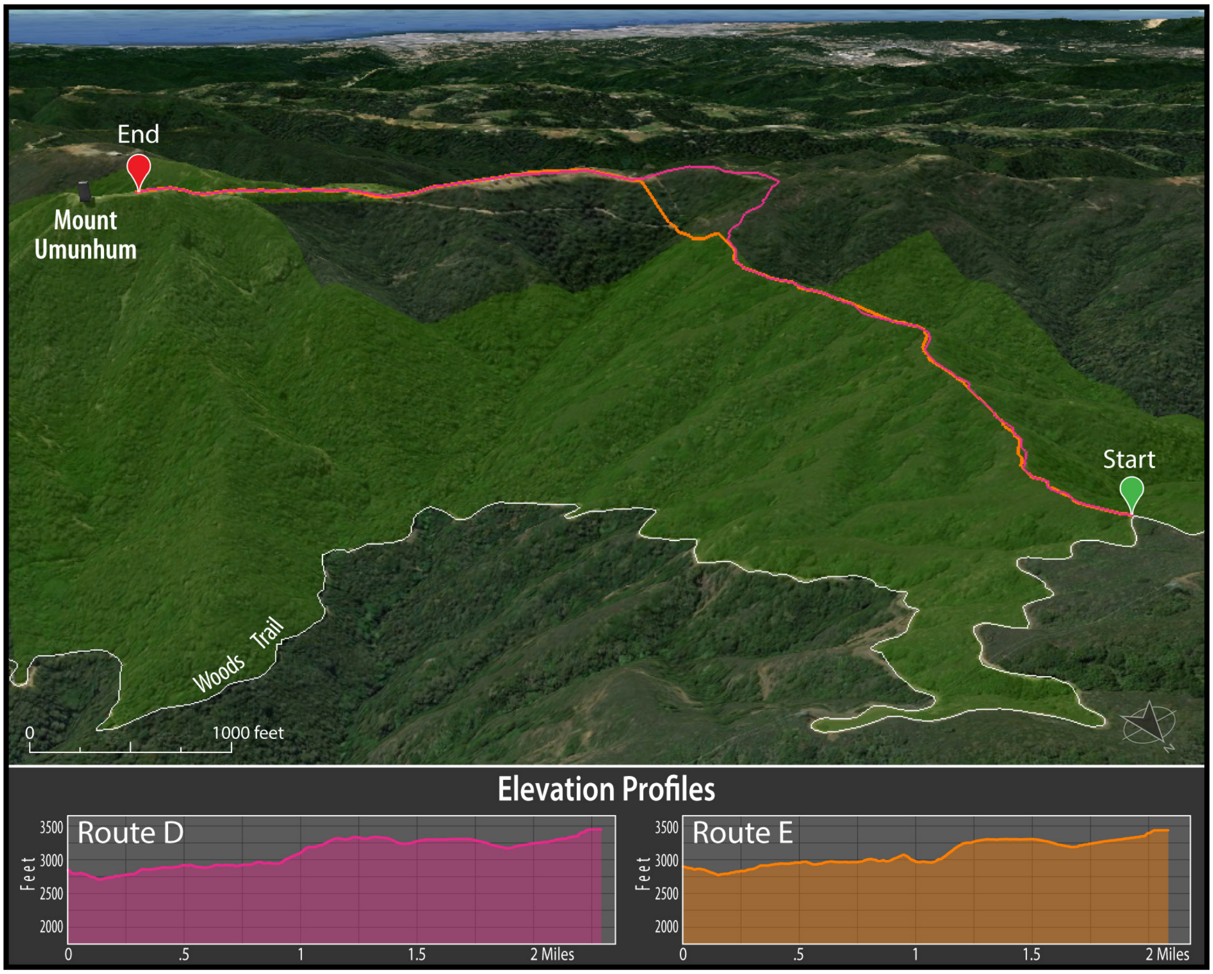


Figure 6.2. Preliminary routes for Scenarios D and E.
Source: Map by author created using Google Earth with data from the Midpeninsula Regional Open Space District.

6.1.2. Scenarios A and B – Less Feasible Routes

Scenarios A and B were limited to lands already owned by Midpen, shown in green in figure 6.3. As a result of this limitation the routes are very different from those in Scenarios D and E. The selected routes travel down into a valley and experience steep descents and climbs. The route of Scenario A, which was based on slope preferences, starts by traversing the same ridgeline that Scenarios D and E utilize, which helps to minimize elevation loss. However, when the route reaches the edge of the District owned land, it is forced down a valley where elevation loss and gain are punctuated and the feasibility of the route is diminished. Scenario B, which considered both slope and aspect in its route selection, descends into a valley almost immediately. In fact, the route descends far enough to intersect with the existing Woods Trail. Elevation losses and gains are quite severe in this scenario, which would make for a difficult journey for trail users and major construction challenges for trail builders. The steep slopes would exacerbate erosion that would negatively affect the surrounding areas. Additionally, Scenario B intersects with the existing Woods Trail in the routes midsection. This is not preferable for two reasons: first, it makes for a confusing trail network and second, it is contrary to the goal of establishing an upper elevation connection between the Woods trail and Mount Umunhum. Based on these conclusion, Scenarios A and B are not recommended routes.

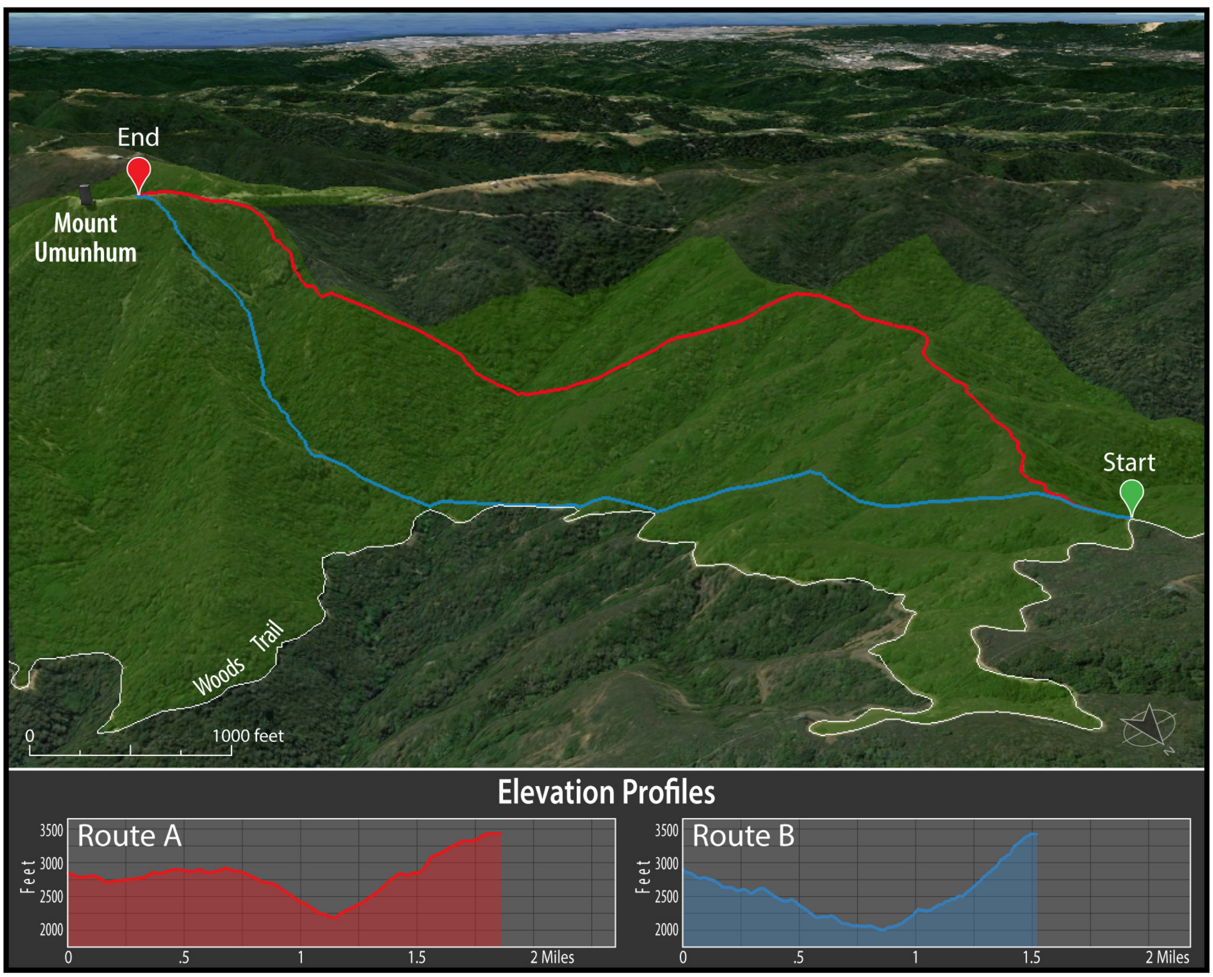


Figure 6.3. Preliminary routes for Scenarios A and B.
Source: Map by author created using Google Earth with data from the Midpeninsula Regional Open Space District.

6.1.3. Scenarios C and F – Least Feasible Routes

Scenarios C and F, shown in figure 6.4, are based on the two suitability surfaces that, in addition to slope and aspect, incorporate hydrology data. The results are similar to Scenario B, with the routes immediately descending into a valley to a point where they intersect with the existing Woods Trail. As discussed above, this is not an optimal situation as the routes include large elevation losses and gains and the intersection with the Woods Trail creates a confusing trail network. The hydrology data drives the routes of Scenarios C and F along paths that would not be enjoyable for trail users as they include excessive slopes and needless elevation loss and gain. The overly steep trails also increase potential for erosion that would be detrimental to the ecosystem and be an expensive maintenance burden to Midpen. Considering these results, these scenarios are not recommended.

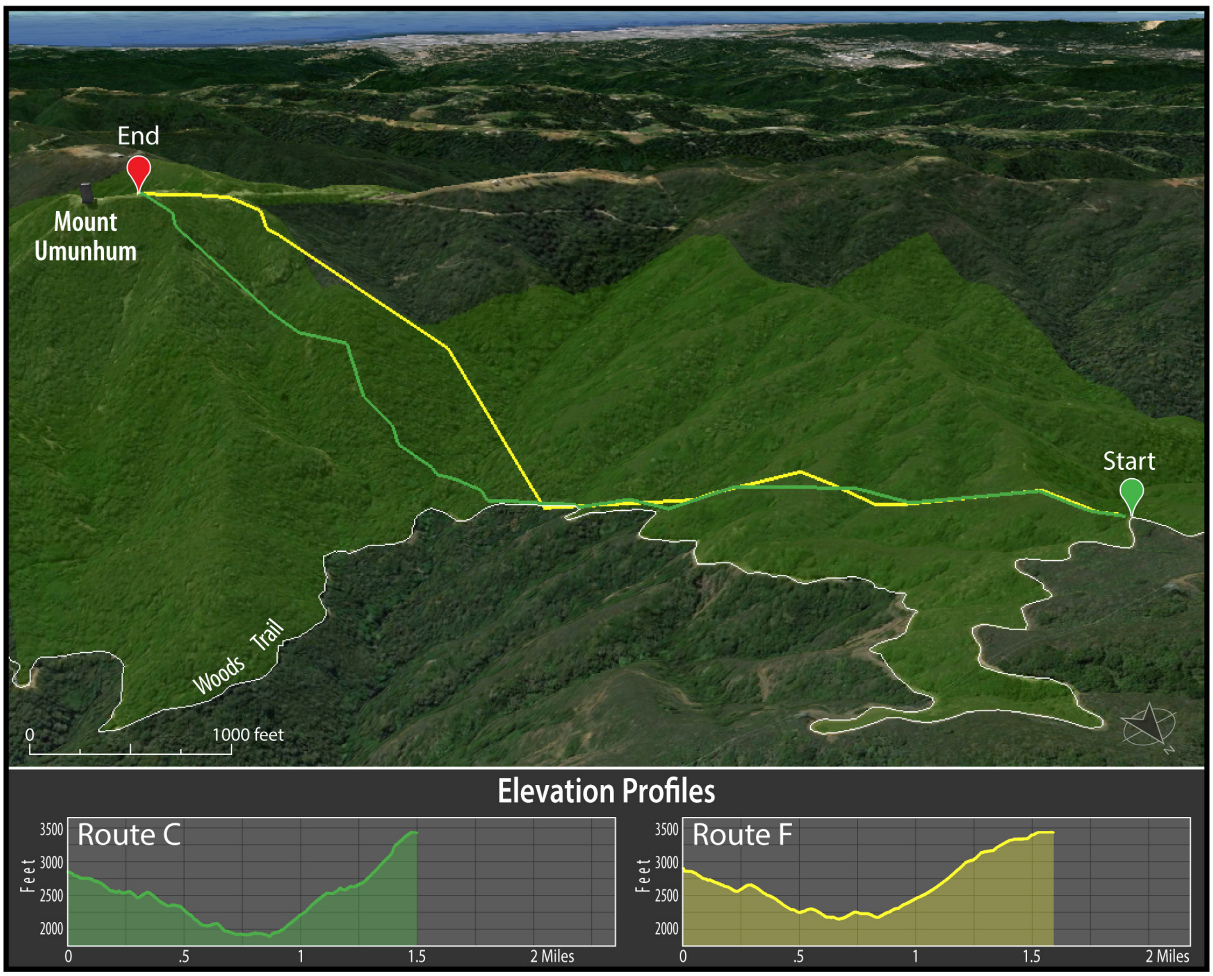


Figure 6.4. Preliminary routes for Scenarios C and F.
Source: Map by author created using Google Earth with data from the Midpeninsula Regional Open Space District.

6.2. ANALYSIS AND OPTIMAL ROUTE SELECTION

6.2.1. Selection of the Optimal Route

The six model runs produced a variety of results, which suggests that each dataset uniquely influences how the GIS model selects the route. From the results, two routes are feasible and four should be excluded. Based on multiple factors, Scenarios B, C, and F should be excluded from consideration. First, the routes developed from the suitability surfaces incorporate large elevation losses and gains that would make for a needlessly strenuous trail. Second, the literature indicates that trail users prefer maximum average slopes in the neighborhood of 12.5%. As shown in table 6.1, Scenarios B, C, and F far exceed this preference. Third, because of the steep slope the potential for erosion would increase. Erosion would expose rocks and roots, create ruts, and lead to muddy conditions. The trail surface would be difficult to maintain and would likely prove unsatisfactory to trail users. Forth, each of these routes intersects with the Woods Trail, which creates a confusing trail network and does not achieve the goal of creating an upper elevation trail connection between the Woods Trail and Mount Umunhum. Lastly, if any of these routes were pursued, the construction involved would be quite expensive. Given the steep slopes, it is likely that a number of swithbacks, retaining walls, and erosion mitigation infrastructures would be needed in order to create a suitable trail over the terrain. These construction techniques are expensive to install and increase maintenance costs; a situation that is discouraged when there are more suitable alternatives.

Table 6.1. Average slopes for each scenario

Scenario	Elevation Gain (feet)	Distance (miles)	Average Slope (%)*
A	1,657	1.88	16.7
B	1,795	1.55	21.9
C	1,744	1.50	22.0
D	1,182	2.29	9.8
E	1,147	2.11	10.3
F	1,646	1.61	19.4

* Average slope calculated by dividing Elevation Gain by Distance

Scenario A, which was limited to land owned by Midpen, produced a route that begins by following the ridgeline adjacent to the starting point. As the route nears the edge of Midpen's land, it changes direction down into a steep valley, making its way to Mount Umunhum up a very steep slope. These rather extreme slopes eliminate this scenario from consideration due to their implications on erosion and trail user preferences.

The suitability surfaces that produced the best results were Scenarios D and E. These routes are the longest of the six scenarios (figure 6.1) and have the least elevation gain. As a result, their average slopes are the lowest at 9.8% and 10.3% respectively. While these average slopes are slightly higher than those of the existing trails in the Sierra Azul Open Space Preserve, they are in line with what users of the preserve have come to expect, and would be consistent with existing trails. Additionally, given the moderate average slopes, erosion would be easier to control and expensive trail-building techniques may not be necessary.

Both of these routes exploit a ridgeline leading from the start point that would provide spectacular views to the east and west, a feature that would increase the experience for trail users. The ridgeline also helps minimize elevation loss and gains, keeping slopes more consistent. Aerial imagery of this ridgeline, shown in figure 6.5, suggests that there may have been a trail or firebreak along this ridge at some point. If this is the case, it may be possible to utilize existing grading and clearing, which would make trail development easier and less expensive.

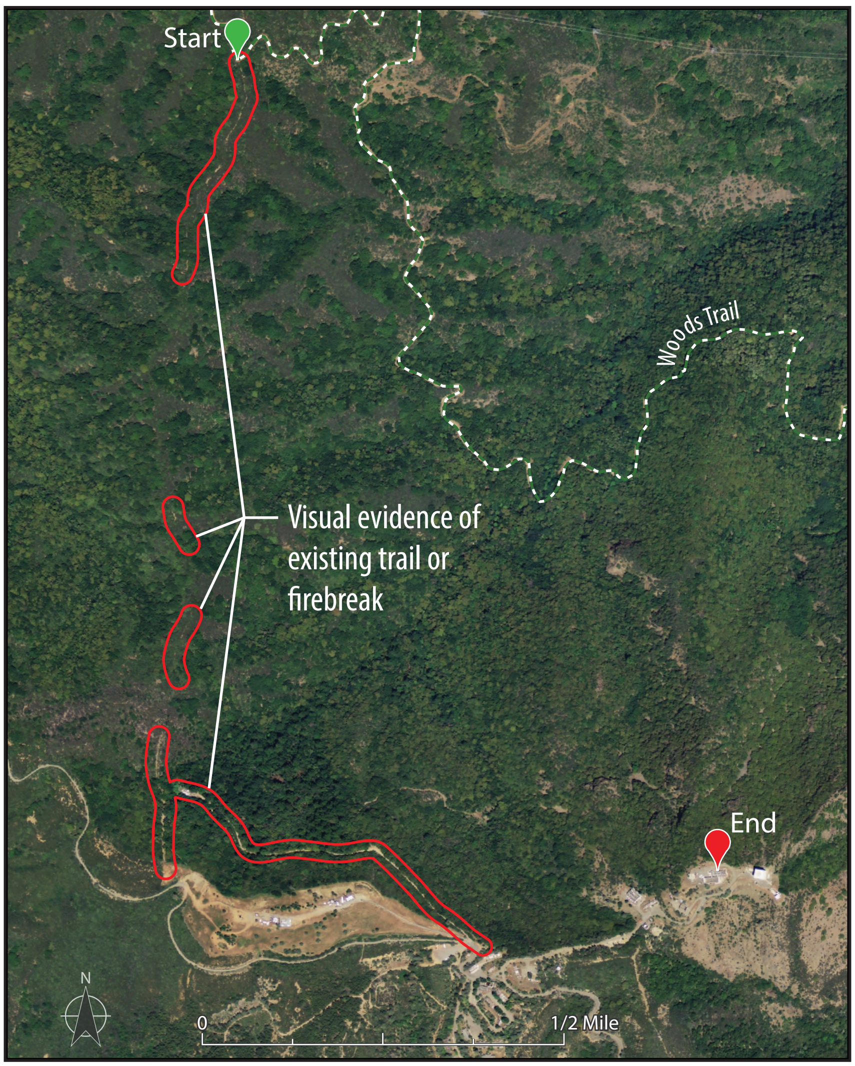


Figure 6.5. Aerial image showing possible abandoned trail features.
Source: Map by author created using data from the Midpeninsula Regional Open Space District, and USDA.

6.2.2. Property Ownership and Acquisition Priorities

Based on the results, Scenarios D and E produce the most suitable routes for development. However, as shown in figure 6.6, their paths run on land that is not owned by Midpen, which complicates development. The inclusion of privately owned lands in the study area produced the most suitable results. This suggests that, in the context of Scenarios D and E, Midpen should prioritize the acquisition of the four parcels where the trail is routed, in order to build the optimal trail.

Of all the potential obstacles involved in developing a trail across undeveloped land, private property may pose the most significant challenge to a successful project. Unlike other barriers, which present multiple avenues towards solution, a private landowner may simply be unwilling to come to an agreement granting access across their land. In this case, alternate trail routes need to be considered. If alternate routes are not possible, the project may have to be abandoned altogether. Determining landownership and negotiating an access agreement could prove to be the most time consuming and complicated portion of the development process.[84]

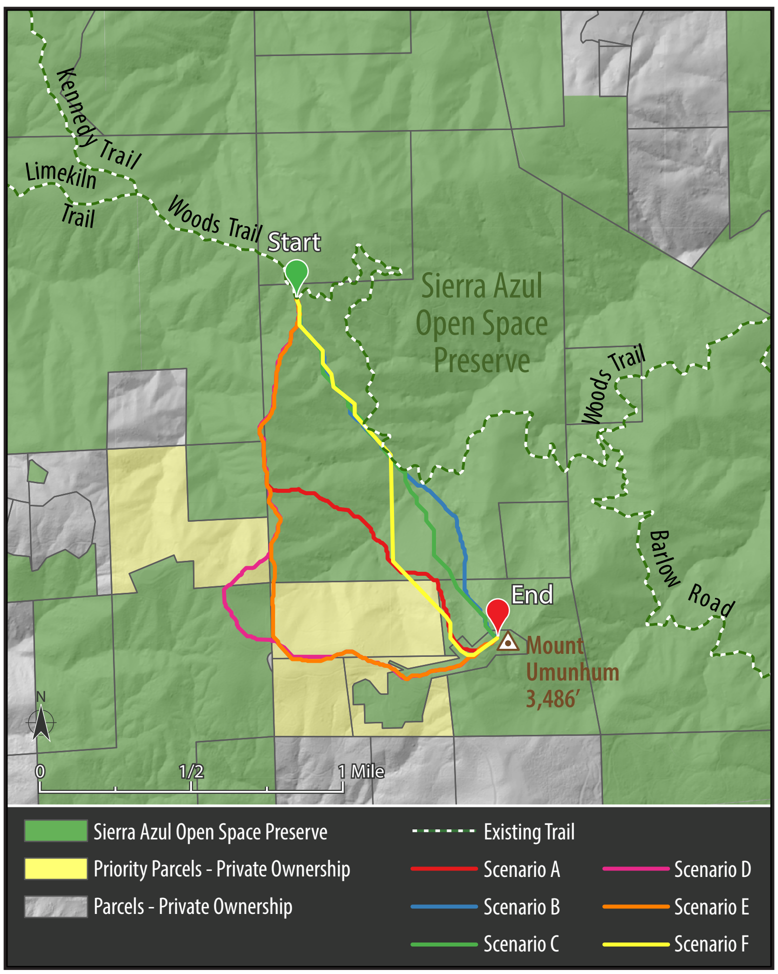


Figure 6.6. Parcels prioritized for acquisition.
Source: Map by author created using data from the Midpeninsula Regional Open Space District, Santa Clara County Assessors Office, USDA, and ESRI.

84. International Mountain Bicycling Association, *Trail Solutions: IMBA's Guide to Building Sweet Singletrack* (Boulder, Colorado: International Mountain Bicycling Association, 2007): 18.

However, private land in the path of a planned trail does not necessarily mean that a project is doomed before it begins. Landowners may be willing to collaborate with trail developers, provided their interests and concerns are addressed in a professional manner. The International Mountain Bike Association (IMBA) offers a basic framework for approaching landowners. IMBA's recommendations stress the importance of clearly communicating the intentions of the trail development, identifying who will benefit from the trail, and identifying and addressing the concerns of the landowner.[85]

As an alternative, Midpen could build an out-and-back trail, shown in figure 6.7, that utilizes portions of the routing of Scenarios A, D, and E. While this may not be the optimal choice in the context of trail connectivity, it would still provide an opportunity to develop a portion of the trail, and a destination trail users could enjoy. Furthermore, there are other examples of this type of trail in other Midpen preserves, so pursuing this option in the Sierra Azul would not set a negative precedent.

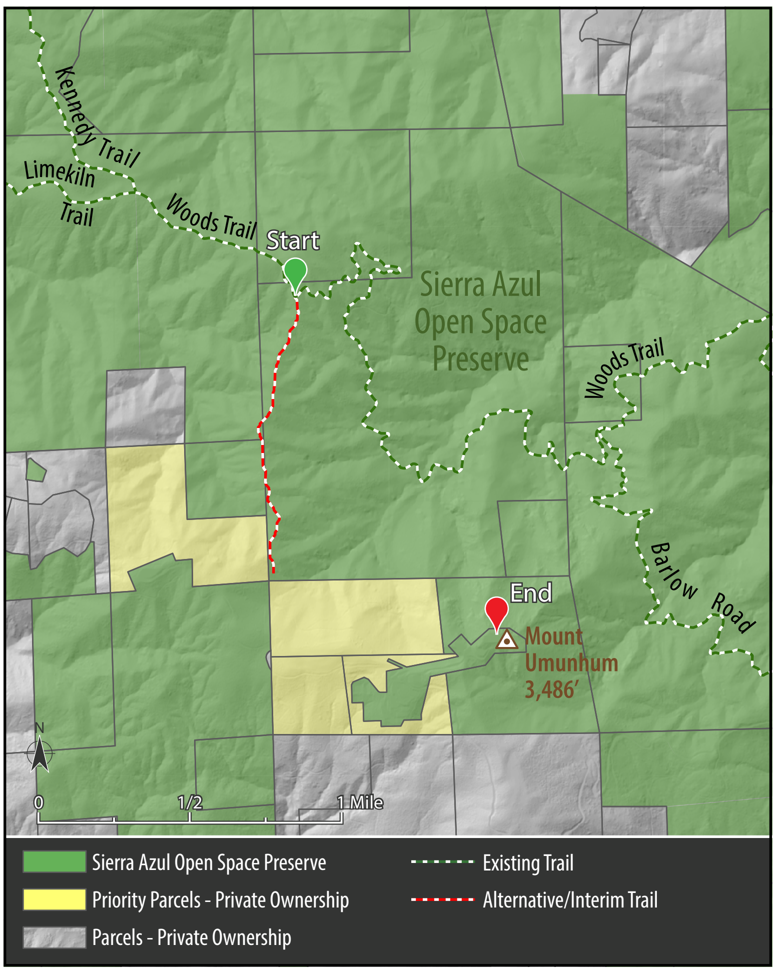


Figure 6.7. Alternative/Interim trail option.
This trail would allow the expansion of the trail network while efforts to acquire the prioritized privately-owned parcels are underway.
Source: Map by author created using data from the Midpeninsula Regional Open Space District, Santa Clara County Assessors Office, and USDA.

85. International Mountain Bicycling Association, *Trail Solutions: IMBA's Guide to Building Sweet Singletrack* (Boulder, Colorado: International Mountain Bicycling Association, 2007): 25.

Scenario A, D, and E utilize the ridgeline (figure 6.5) adjacent to the starting point, exploiting its relatively consistent slope and ample sun exposure. The alternative/interim trail could be built along this ridge, to the edge of Midpen's land. The terminus could include views to east and west, giving users a destination to explore and enjoy. While this portion of the trail is developed, Midpen could explore the acquisition of the four needed parcels, or work to gain access permission from the current landowners. This is an alternative worth exploring because land acquisition/access rights can be a time consuming endeavor. In the meantime, this would provide some access and opportunity to build two-thirds of the proposed trail. Once the landownership issues are resolved, Midpen could complete the trail connection to Mount Umunhum.

CHAPTER 7

Conclusion and Recommendations

7.1. SUMMARY OF RESEARCH FINDINGS

7.1.1. The Trail's Alignment with Midpen's Purpose

The Midpeninsula Regional Open Space District provides the pubic with the opportunity to convene with nature in 24 of its 26 open space preserves. Midpen was formed in response to explosive growth in the Bay Area with the purpose of permanently protecting open space land and providing for low-intensity recreational opportunities. Midpen's open space preserves stretch over 62,000 acres and contain trail networks open to hikers, cyclists, equestrians, and dog walkers.[86] Expansion of the existing trail network allows for increased access to the preserved lands. The trail studied in this report is within the scope of Midpen's purpose, as it would provide access to preserved lands through an upper elevation connection between the Woods Trail and Mount Umunhum in the Sierra Azul Open Space Preserve.

7.1.2. Impacts of Trail Development and Use

By its very nature, development and use of trails through a natural landscape impact the physical environment. Minimizing these impacts begins with identifying the impacts caused by trail development. The literature reviewed identified trampling, erosion, and trail divergence as common physical impacts to land resulting from trail development and use. Trail building activities and/or trampling also remove vegetation, which exposes soil to erosion. Erosion is exacerbated along poorly drained trails and particularly steep trails. These impacts can be minimized with proper routing, trail design, and construction techniques. The literature also argued that the impacts from different types of trail users are not equal. In general, horses cause more impacts to trails than other users, while impacts from hikers and mountain bikers are not significantly different, however specific types of mountain biking (downhill, racing) can increase impacts. Developing a sustainable trail that minimizes impacts to the landscape starts with proper trail routing across suitable landscapes and carries through to appropriate trail construction techniques.

86. Midpeninsula Regional Open Space District, "About Us," Midpeninsula Regional Open Space District, http://www.openspace.org/about_us/ (accessed August 31, 2013).

7.1.3. Trail User Preferences

The conditions preferred by hikers, cyclists, and equestrians were identified through interviews conducted with knowledgeable trail professionals and a literature review. These preferences guided the limitations incorporated into the GIS model used to select optimal routes. Summarized in table 7.1, these preferences should also be incorporated during the design phase of trail development. During this time, review and input of stakeholders regarding the project should be solicited and woven into the trail's design.

Table 7.1. Aggregate trail preferences for all user categories

Trail Characteristic	Preference
Average Slope	
Hiking	5% to 10%
Mountain Biking	4.3% to 12.5%
Equestrian	5% to 12%
Aggregate	*5% to 12.5%*
Maximum Slope	
Hiking	10% to 20%
Mountain Biking	15% to 20%
Equestrian	15% to 20%
Aggregate	*10% to 20%*
Width	
Hiking	2 to 6.75 feet
Mountain Biking	0.5 to 10 feet
Equestrian	8 feet
Aggregate	*6 to 8 feet*
Obstacles	Free from obstacles

7.2. SUMMARY OF GIS MODEL RESULTS

Once the physical impacts of trail development were understood and the trail user preferences were identified, they were evaluated to determine how they could be incorporated into a GIS model. Data was collected, resampled, and aggregated into several grid-based datasets called suitability surfaces. The cell values of the suitability surfaces represented how suitable each cell of the grid is for trail building. These suitability surfaces were integrated into a flexible GIS model, to which a cost path analysis was applied to each surface, producing preliminary routes for six different scenarios.

The resulting GIS model achieved the goals for which it was developed. The GIS model's flexibility allows the user to integrate the specific data deemed relevant for individual projects. The workflow is approachable to novice GIS users, which opens up the use of the tool to a wider breadth of trail developers. The model automates the preliminary route selection process based on data describing the landscape. It produced results that were responsive to the data incorporated into the suitability surfaces: identifying two optimal routes and one alternative for preliminary routing of the proposed trail. This effective tool could save an organization like the Midpeninsula Regional Open Space District time and money in the trail development process. The next steps in the process would involve further vetting of the preliminary routes, exploring the weighting of the datasets, and drafting more detailed plans.

7.3. RECOMMENDATIONS AND NEXT STEPS OF TRAIL CREATION

7.3.1. Further Planning

The next steps in the trail planning process should focus on the development of a more detailed plan for the trail. A primary trail route should be selected from the two optimal routes identified by the GIS model. This route would then be refined in response to Midpen's local knowledge of the area and any additional data not incorporated into this report. Based on the refined route, a series of control points would be identified, guiding the route of the trail on the ground. Control points are specific features, such as views, existing trail infrastructure, or sensitive habitats that influence whether a trail is routed through the proposed location or altered to avoid certain control points.[87] After conducting fieldwork and receiving stakeholder input, the trail's route would be finalized and a construction plan would be drafted that details the schedule, cost, equipment, and labor needed to complete the project.

87. International Mountain Bicycling Association, *Trail Solutions: IMBA's Guide to Building Sweet Singletrack* (Boulder, Colorado: International Mountain Bicycling Association, 2007): 94.

7.3.2. Property Ownership

The two optimal routes identified in the GIS model cross four parcels not currently owned by Midpen. If development of the trail is to continue, Midpen should prioritize the acquisition of these four parcels. Resolving theses ownership issues should begin immediately and run concurrently with the other processes. Whether the solution involves seeking ownership or access easements across the private property, the process will be complicated, time consuming, and likely costly (no matter what). It is best that the process be initiated as early as possible so as not to stand in the way of the remaining tasks.

In the meantime, Midpen could construct a portion of the trail on land they already own. This trail could be developed and put into use while the land ownership issues are resolved, at which time the trail could be connected to the summit of Mount Umunhum.

7.3.3. Construction Techniques

The details of the actual trail construction process are worthy of their own report; many studies and books have been written on the subject. It is important to incorporate construction techniques that minimize site disturbance, create sustainable trails, and incorporate user preferences. It is recommended that any trail developer fully research the proper techniques and consult with experienced trail builders in order to produce a sustainable trail with features that satisfy all potential users. Planners should incorporate techniques that govern speed and help shed water, because these make for a safer trail that will stand up to weather and use. Long-term maintenance should also be considered, and should include budget and labor needs.

7.3.4. Explore Funding Options

The planning process, private property acquisition, and construction carry significant costs associated with the trail development process. There are a variety of solutions for direct cost barriers, so these should be slightly easier to overcome than private property ownership. Both the International Mountain Bike Association and National Trails Training Partnership websites offer an exhaustive list of grants for which the proposed trail may qualify.[88] It is very time consuming to find the funding resources applicable to an individual project, apply for the funding, and recieve the funding awards. Therefore, persistence, patience, and creativity are valuable when researching grants, requesting funding, and conducting fundraising.

88. International Mountain Bicycling Association, "Grants and Funding," International Mountain Bicycling Association, http://www.imba.com/resources/grants (accessed December 3, 2013); "National Trails Training Partnership, "Resources and Library: Finding & Resources," http://www.americantrails.org/resources/funding/index.html (accessed December 3, 2013).

7.4. FINAL THOUGHTS

7.4.1. Collaborative Planning

The planning process for this trail should utilize the collaborative planning process and solicit input from all stakeholders. This point cannot be stressed enough. The collaborative process will help ensure that the users' concerns are heard and, to the extent possible, their specific desires and needs are addressed. The collaborative process also helps build excitement for a project. A trail planner could capitalize on this momentum and reach out for volunteers to help in the construction process. This is beneficial on two fronts. First, it can help reduce construction costs; an important consideration in a climate where funding may be scarce. Second, it allows for the trail user community to be intimately involved with the creation of something they will use. There is also potential for partnerships to go beyond the planning and building process and extend into maintenance and patrol efforts that help to keep trail systems in good condition and safe. In short, involving stakeholders in the planning process benefits both Midpen and the stakeholders, and would likely result in a better trail.

7.4.2. Moving Forward

As the Midpeninsula Regional Open Space District continues work to provide access to Mount Umunhum, they should reconsider this proposed trail and initiate the planning process for its development. The development of this trail would create an alternate access route to Mount Umunhum; one that allows for a continuous dirt path from the Los Gatos area to the summit of the iconic mountain. The trail expands the network of the Sierra Azul Open Space Preserve and creates an opportunity to combine trails for a variety of loops. It is hoped that Midpeninsula Regional Open Space District considers this trail for development in the near future.

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APPENDIX A Data Sources

The following sources provided the primary datasets incorporated into the GIS workflow. Subsequent datasets were produced in the GIS environment as derivatives of these primary sources.

Digital Elevation Model

United States Department of Agriculture, Natural Resources Conservation Service –

GeoSpatial Data Gateway

http://datagateway.nrcs.usda.gov/.

Derivatives produced from dataset:

- Hillshade
- Slope
- Aspect

Aerial Imagery

United States Department of Agriculture, Farm Service Agency, National Agriculture Imagery Program (NAIP).

Source incorporated into GIS environment with the following ArcGIS Server link:

http://gis.apfo.usda.gov/arcgis/services

Hydrology

Santa Clara Valley Water District.

http://www.valleywater.org/Services/SCVWDGISData.aspx

Soils

Study Area Coverage

United States Department of Agriculture, Natural Resources Conservation Service - GeoSpatial Data Gateway

http://datagateway.nrcs.usda.gov/

Soils Index

Data from National Cooperative Soil Survey

http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/home/?cid=nrcs142p2_053587

Parcels

A County of Santa Clara Public Records Request Response Form for GIS data was submitted to the Santa Clara County Office of the Assessor. A request was made for all parcel and street data at the county level. A CD containing the data was received by mail approximately 15 days after the request was submitted.

Request Form:

http://www.sccgov.org/sites/gis/GISData/Documents/Public-Record-Request-Response_form1a.pdf

Trails and Preserve Boundaries

Midpeninsula Regional Open Space District, GIS Data.

http://www.openspace.org/gmap/download_data.asp

APPENDIX

B GIS Workflow

All descriptions/definitions and screenshots were taken from ArcGIS 10.2.1.

Resample Data

Vector to Raster

Vector data consists of points, lines, and polygons defined by x and y coordinates and the connectivity between the points. The cost path workflow requires that the suitability surfaces be in raster format, grids containing cells with individual values. Some of the data downloaded for this report was in vector format and required conversion to raster format. The Feature to Raster tool in the Conversion toolset was applied to layers such as hydrology and soils.

Unit Conversion

The units describing altitude in the digital elevation model were originally in meters. Converting meters to feet was required to maintain consistency between linear units (miles) and vertical units (feet). The conversion process is incorporated into the various functions used to create the slope and hillshade layers. By adjusting the Z Factor in each of these to a constant that converts meters to feet (0.0348), the output layers (slope and hillshade) would utilize feet for the vertical measure. Z Factor is described below.

Z Factor

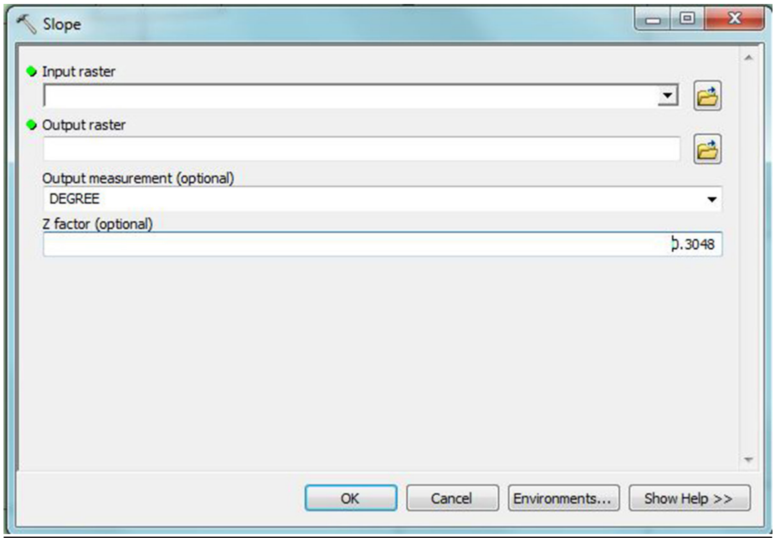
Number of ground x,y units in one surface z unit. The z-factor adjusts the units of measure for the z units when they are different from the x,y units of the input surface. The z-values of the input surface are multiplied by the z-factor when calculating the final output surface. If the x,y units and z units are in the same units of measure, the z-factor is 1. This is the default. If the x,y units and z units are in different units of measure, the z-factor must be set to the appropriate factor, or the results will be incorrect. For example, if your z units are feet and your x,y units are meters, you would use a z-factor of 0.3048 to convert your z units from feet to meters (1 foot = 0.3048 meter).

Convert to Integer

The cost path workflow requires that input values of the suitability surface consist of whole integers. The INT (Spatial Analyst) tool was used to convert each cell value of a raster to an integer by truncation.

Slope (Spatial Analyst)

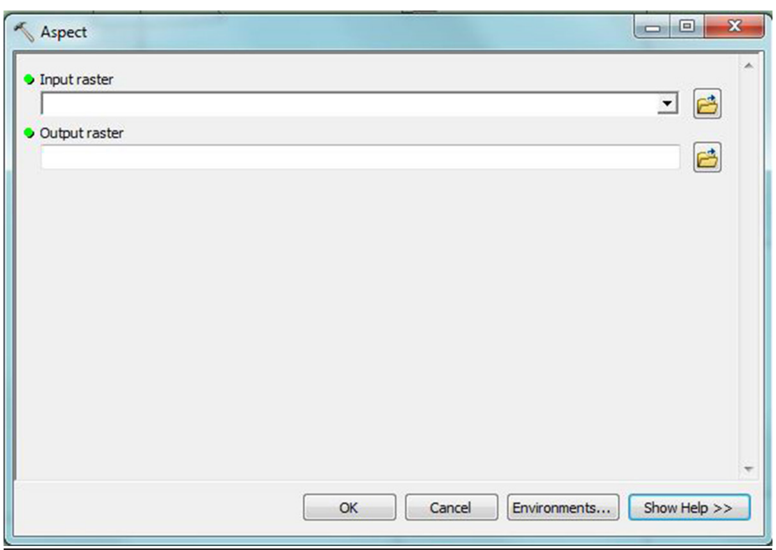
Using the digital elevation model as source data, the Slope tool identifies the slope (gradient, or rate of maximum change in z-value) from each cell of a raster surface.



Input Raster:	Digital Elevation Model
Output Raster:	Slope Surface
Output measurement:	Percent
Z Factor:	0.3048

Aspect (Spatial Analyst)

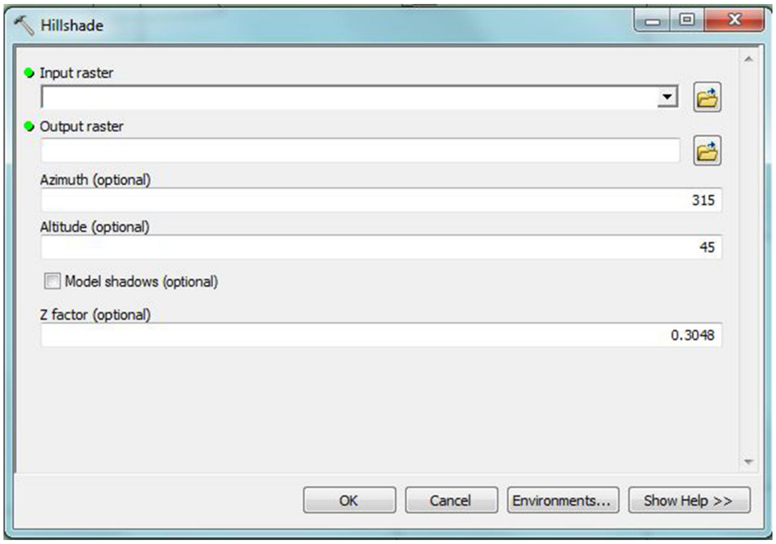
Using the digital elevation model as source data, the Aspect tool derives aspect from a raster surface. The aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors. Aspect can be thought of as the slope direction. The values of the output raster will be the compass direction of the aspect.



Input Raster:	Digital Elevation Model
Output Raster:	Aspect Surface

Hillshade (Spatial Analyst)

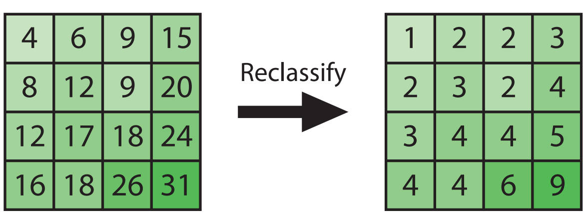
Using the digital elevation model as source data, the Hillshade tool creates a shaded relief from a surface raster by considering the illumination source angle and shadows.



Input Raster:	Digital Elevation Model
Output Raster:	Hillshade surface
Azimuth & Altitude:	Not used
Z Factor:	0.3048

<u>Determine Reclassification Breaks and Values</u>

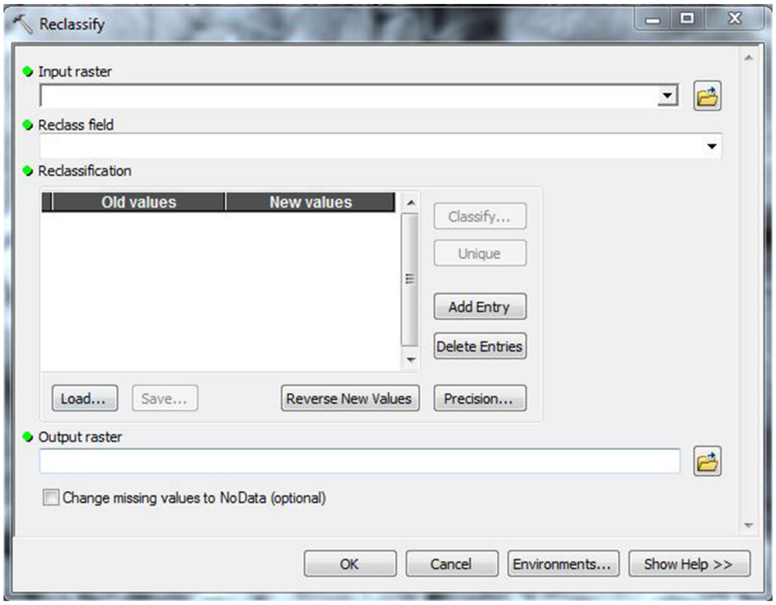
Based on the research and interview process, breaks in the data were determined for reclassification (described in Chapter 6). The process involves reassigning a value to a grid cell based on how the original value relates to the breaks determined. As showin in the figure below, based on the breaks determined for slope, a slope of 18% would be reassigned a value of 4. This process was applied to the slope, aspect, and hydrology datasets.



Slope %	Reclassify Value
1-5	1
5-10	2
10-15	3
15-20	4
20-25	5
25-30	6
30+	9

Reclassify (Spatial Analyst)

The Reclassify tool reclassifies (or changes) the values in a raster.

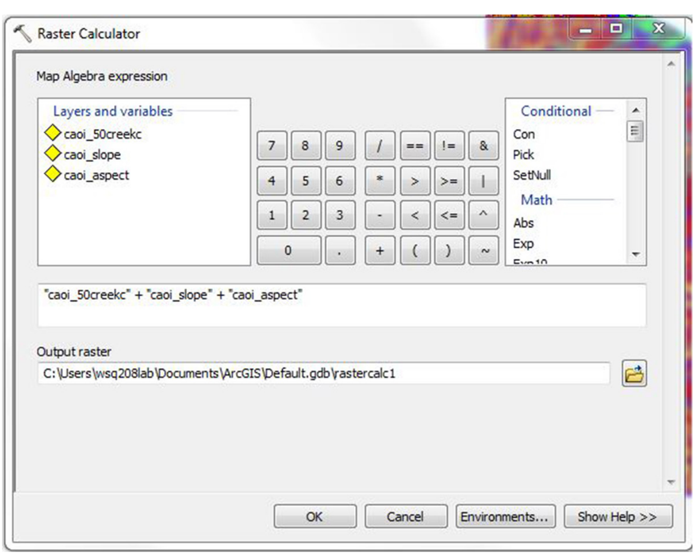


Input raster:	Original raster surface to be reclassified
Reclass field:	Field in the attribute table to which the reclassification is to be applied
Reclassification:	Old values is the range of data to be reclassified to New values
Output raster:	Reclassified surface

Aggregation of Data to Suitability Surfaces

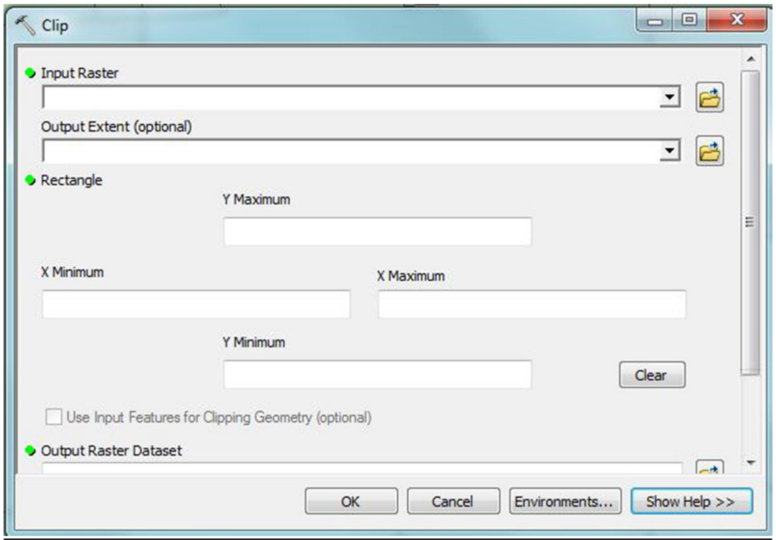
Raster Calculator (Spatial Analyst)

Each scenario combined a different set of surfaces into a single suitability surface using the Raster Calculator tool. As the name implies, the Raster Calculator builds and executes a single Map Algebra expression using in a calculator-like interface.



Clip (Data Management)

Once the suitability surfaces were assembled via the process above, their extents were clipped to their respective areas of interest. Using the Clip tool, which operates similar to a cookie cutter, a spatial subset of a raster was created that was limited to the each study area.



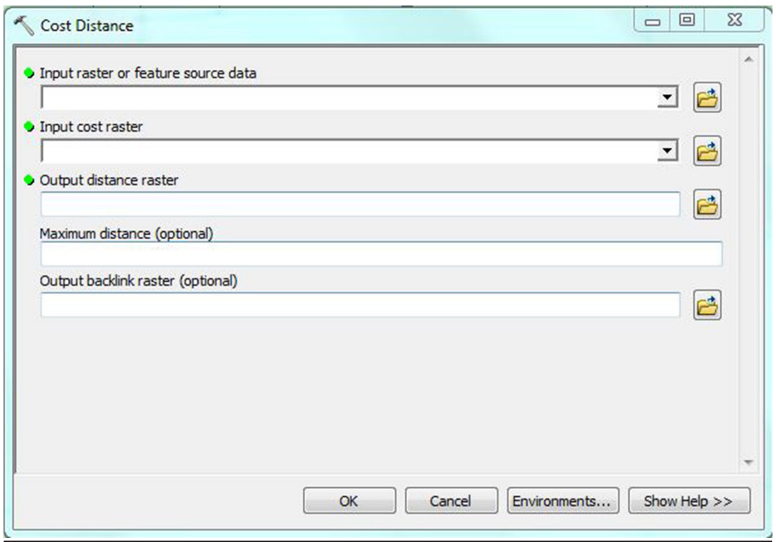
Input Raster:	Suitability surface
Output Extent:	Study area polygon
Output Raster Dataset:	Clipped suitability surface

Least Cost Analysis

The least cost analysis consist of 3 steps that ultimately determine the optimal route between two points based on the least resistive path across a suitability surface.

Cost Distance (Spatial Analyst)

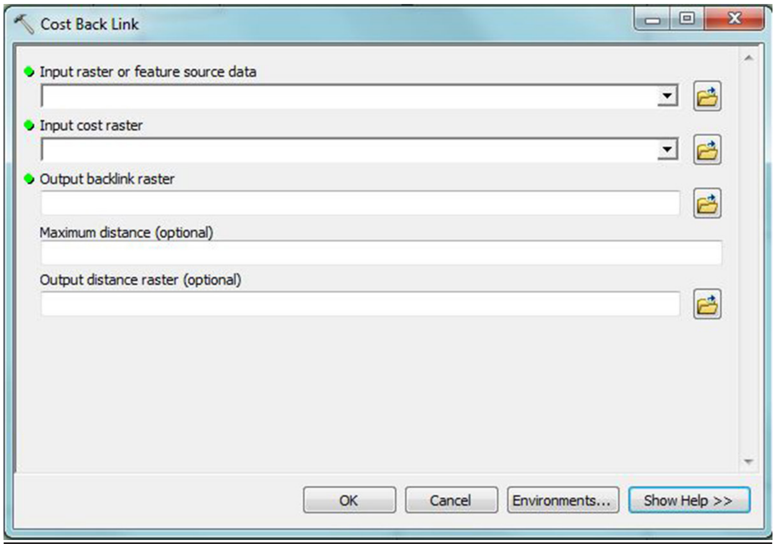
Calculates the least accumulative cost distance for each cell to the nearest source over a cost surface



Input raster or feature source data:	Start point
Input cost raster:	Suitability surface
Output distance raster:	Cost distance surface
Maximum distance:	Not used
Output backlink raster:	Not used (will create backlink surface described in next step)

Cost Backlink (Spatial Analyst)

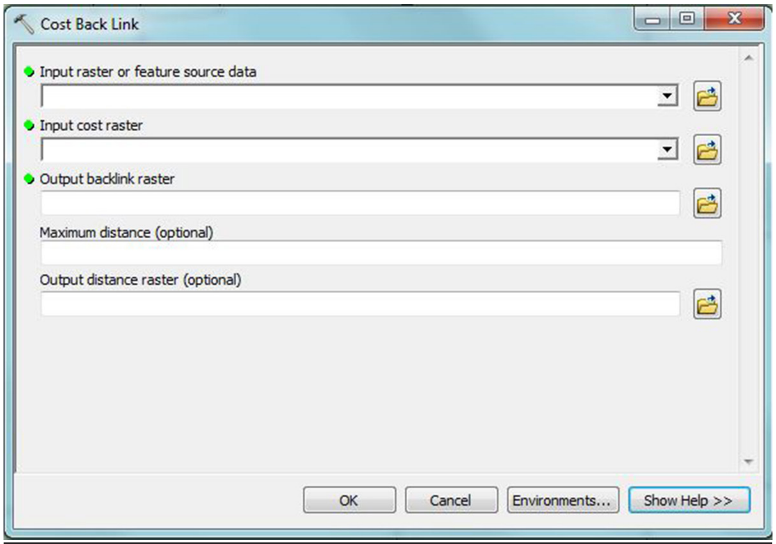
Defines the neighbor that is the next cell on the least accumulative cost path to the nearest source.



Input raster or feature source data:	Start point
Input cost raster:	Suitability surface
Output backlink raster:	Backlink surface
Maximum distance:	Not used
Output backlink raster:	Not used

Cost Path (Spatial Analyst)

Calculates the least-cost path from a source to a destination.



Input raster or feature destination data:	End point
Destination field:	Not used
Input cost distance raster:	Cost distance surface
Input backlink raster:	Backlink surface
Output raster:	Cost path – optimal path between start/end points
Path Type:	EACH_CELL

APPENDIX C

Soils Data Evaluation

Data describing the soils present in the study area was obtained from the United States Department of Agriculture, Natural Resources Conservation Service, accessed through the GeoSpatial Data Gateway.[89] The data was downloaded at the county level for Santa Clara County and brought into a GIS environment for analysis as shown in figure C.1. The following list of soil types was obtained by intersecting the study area with the soils layer. Descriptions of each soil type were obtained from the National Cooperative Soil Survey, which are included below.[90] Analysis of these descriptions revealed that the soils in the study area posses similar characteristics, as follows:

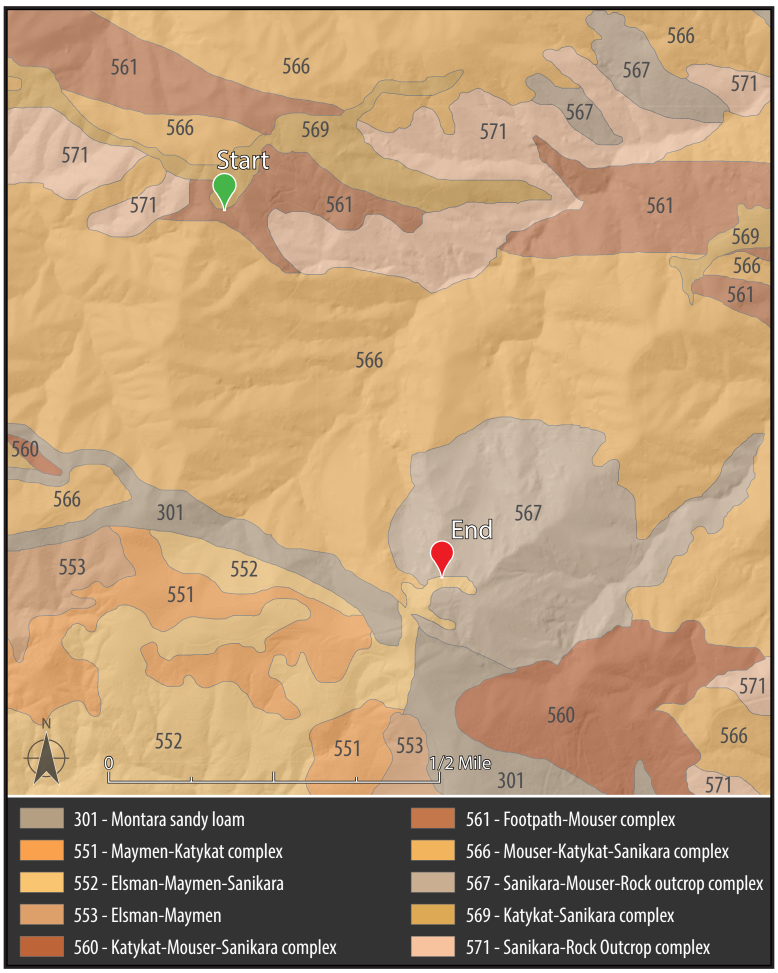


Figure C.1. Soil coverage in the study area.
Source: Map by author created using data from the National Cooperative Soil Survey, and USDA.

89. United States Department of Agriculture, Natural Resources Conservation Service, "GeoSpatial Data Gateway," United States Department of Agriculture, http://datagateway.nrcs.usda.gov/ (accessed January 25, 2014).

90. United States Department of Agriculture, Natural Resources Conservation Service, "Soils," United States Department of Agriculture, http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/home/?cid=nrcs142p2_053587 (accessed January 25, 2014).

Use and Vegetation Summary:

These soils are used for watershed, recreation, and wildlife habitat. Vegetation is California live oak, bay laurel, buckeye, poison oak and annual grasses.

Drainage And Permeability Summary:

Well drained.

<u>Soil Type Descriptions:</u>

MONTARA SERIES

The Montara series consists of shallow well-drained soils that formed in material weathered from serpentinitic rocks. Montara soils are on uplands and ridge tops and have slopes of 5 to 75 percent. The mean annual precipitation is about 28 inches and the mean annual air temperature is about 60 degrees

TYPE LOCATION: Santa Clara County, California; Edenvale Hills near Morgan Hill; 1/2 mile north of Pigeon Point on a private farm road to the O'Connel Ranch, T. 8 S., R. 3 E.

RANGE IN CHARACTERISTICS: Depth to hard bedrock is 10 to 20 inches. Mean annual soil temperature is 59 degrees to 64 degrees F. and the soil temperature usually is not below 47 degrees F. at any time. Soil below a depth of about 4 inches is dry in all parts from May or June to November and is moist in all parts from December to April. Rock fragments are mostly pieces of serpentine rock and they make up 1 to 35 percent of the volume. In most pedons, fragments are less than 15 percent. Sand-size particles are mostly pieces of serpentine rock. The soils are neutral to moderately alkaline, but do not contain free lime. The calcium magnesium ratio is 1:1 or less.

DRAINAGE AND PERMEABILITY: Well drained; medium and high runoff; moderately slow permeability. Seep areas adjacent to rock outcrops may persist for several months after the end of the rainy season.

KATYKAT SERIES

The Katykat series consists of very deep, well drained soils that formed in residuum weathered from sandstone and mudstone. The Katykat soils are on foothills and mountain slopes, and summits. Slopes range from 8 to 75 percent. The mean annual precipitation is about 50 inches and the mean annual air temperature is about 57 degrees F.

TYPE LOCATION: Santa Clara County, California, Sierra Azul Open Space, off of Priest Rock Trail, 230 m east of intersection with Limekiln Trail, U.S.G.S Quad: Santa Teresa Hills, California, Zone 10, 4116092mN, 602795mE, NAD83.

RANGE IN CHARACTERISTICS: Depth to a paralithic contact is greater than 150 centimeters. The mean annual soil temperature is about 56 to 60 degrees F. The soil moisture control section is dry in all parts from about June 1 to October 15 (about 135 days). The particle size control section is 20 to 70 centimeters and averages 18 to 35 percent clay, 0 to 35 percent rock fragments, mostly paragravel and gravel. Organic matter ranges from 7.50 to 0.25 percent to a depth of 150 centimeters.

DRAINAGE AND PERMEABILITY: Well drained, moderately permeable medium to very rapid runoff.

MAYMEN SERIES

The Maymen series consists of shallow, somewhat excessively drained soils that formed in residuum weathered from shale, schist, greenstone, sandstone and conglomerate. Maymen soils are on mountains. Slopes range from 5 to 100 percent. The mean annual precipitation is about 42 inches, and the mean annual temperature is about 54 degrees F.

TYPE LOCATION: Santa Clara County, California, Page Mill Road at Gate 4 of Foothill Park, through gate up hill to west, south on small trail about 100 feet then south into brush., In an unsectionized area of Township 7S, Range 3W, Northing 4133542, Easting 572451, Zone 10, NAD83 - U.S.G.S Quad: Mindego Hill, California.

DRAINAGE AND PERMEABILITY: Somewhat excessively drained; high to very high runoff; moderate to moderately rapid permeability.

MOUSER SERIES

The Mouser series consists of deep and very deep, well drained soils that formed in residuum weathered from sandstone, mudstone and greenstone. The Mouser soils are on summits and side slopes of mountains and hills. Slopes range from 8 to 75 percent. The mean annual precipitation is about 50 inches and the mean annual air temperature is about 57 degrees F.

TYPE LOCATION: Santa Clara County, California, Monte Bello Open Space, Black Mountain north of towers, past WP03 gate on Black Mountain Trail east about 200 feet near large buckeye, 50 feet north of trail., Section 13, Township 7s, Range 3w, Northing 4130699, Easting 575501, UTM Zone 10, NAD83 - U.S.G.S Quad: Mindego Hill, California.

DRAINAGE AND PERMEABILITY: Well drained, moderately slow permeability, medium runoff.

SANIKARA SERIES

The Sanikara series consists of very shallow and shallow to lithic contact, well drained soils that formed in residuum weathered from sandstone and greenstone. The Sanikara soils are on hills, mountain slopes and summits. Slopes range from 8 to 100 percent. The mean annual precipitation is about 50 inches and the mean annual air temperature is about 57 degrees F.

TYPE LOCATION: Santa Clara County, California, New Almaden Quicksilver County Park, Hacienda entrance, Hacienda Road, just up from road on grassy south slope., 4116092mN, 602795mE, UTM Zone 10, NAD83. U.S.G.S Quad: Santa Teresa Hills, California.

DRAINAGE AND PERMEABILITY: Well drained, moderately rapid permeability, medium to very rapid runoff.

FOOTPATH SERIES

The Footpath series consists of moderately deep to a paralithic contact, well drained soils that formed in residuum weathered from greenstone. The Footpath soils are on hills, mountain slopes and summits. Slopes range from 8 to 75 percent. The mean annual precipitation is about 1270 millimeters and the mean annual air temperature is about 14 degrees C.

TYPE LOCATION: Santa Clara County, California, New Almaden Quicksilver County Park, on Randol Trail, in an un-sectionalized area of Range 1E, Township 8S, UTM Zone 10, UTM Northing 4116092, Easting 602795, NAD83, U.S.G.S Quad: Santa Teresa Hills, California.

DRAINAGE AND PERMEABILITY: Well drained, moderately slow permeability.

National Cooperative Soil Survey

USE AND VEGETATION: These soils are used for watershed, recreation, and wildlife habitat. Vegetation is California live oak, bay laurel, buckeye, poison oak and annual grasses.

ELSMAN SERIES

The Elsman series consists of very deep, well drained soils that formed in colluvium over residuum from sandstone and shale. The Elsman soils are on mountain slopes. Slopes range from 8 to 75 percent. The mean annual precipitation is about 50 inches, and the mean annual temperature is about 57 degrees F.

TYPE LOCATION: Santa Clara County, California, Uvas Canyon County Park, Alec Canyon trail, about 200 meters north of Old Logging Camp. In section 7, Range 2E, Township 10S, 4104171 mN, 0607601 mE, Zone 10, NAD83, U.S.G.S Quad: Loma Prieta, California

DRAINAGE AND PERMEABILITY: Well drained, medium runoff, and moderate permeability.

USE AND VEGETATION: These soils are used for watershed, recreation, and wildlife habitat. Vegetation is California live oak, California bay laurel, Madrone, poison oak and Douglas fir.

Bibliography

Association of Bay Area Governments and Metropolitan Transportation Commission. *Plan Bay Area: Regional Transportation Plan and Sustainable Communities Strategy for the San Francisco Bay Area 2013-2040*. July 18, 2013.

Bay Area Ridge Trail Council. “About Us.” Bay Area Ridge Trail Council. http://www.ridgetrail.org/index.php/about-us (accessed September 1, 2013).

Birkby, Robert C. *Lightly on the Land: The SCA Trail-building and Maintenance Manual.* Seattle: The Mountaineers, 2001.

Bondurant, Julia, and Laura Thompson. *Trail Planning for California Communities*. Point Arena, California: Solano Press Books, 2009.

Bonneville Shoreline Trail. “Northern Bonneville Shoreline Trail Master Plan – Chapter 3: Trail Design and Construction Standards.” http://atfiles.org/files/pdf/designbonneville.pdf (accessed December 8, 2013).

California Department of Finance. “Historical Census Populations of Counties and Incorporated Cities in California, 1850–2010.” http://www.dof.ca.gov/research/demographic/state_census_data_center/historical_census_1850-2010/ (accessed November 2, 2012).

Chavez, Deborah J., Patricia L. Winter, and John M. Baas. “Recreational Mountain Biking: A Management Perspective.” *Journal of Park and Recreation Administration* 11, no. 3 (1993): 29-36.

Cheng, Min-Yuan, and Guey-Lin Chang. “Automating Utility Route Design and Planning Through GIS.” *Automation in Construction* 10, no. 4 (2001): 507-516.

Chiou, Chyi-Rong, Wei-Lun Tsai, and Yu-Fai Leung. “A GIS-dynamic Segmentation Approach to Planning Travel Routes on Forest Trail Networks in Central Taiwan.” *Landscape and Urban Planning* 97, no. 4 (2010): 221-228.

Chiu, Luke, and Lorne Kriwoken. “Managing Recreational Mountain Biking in Wellington Park, Tasmania, Australia.” *Annals of Leisure Research* 6, no. 4 (2003): 339-361.

Cole, David N. *Changes on Trails in the Selway-Bitterroot Wilderness, Montana, 1978-89*. Research Paper INT-450, United States Department of Agriculture, Forest Service. Intermountain Research Station (1991), http://www.fs.fed.us/rm/pubs_int/int_rp450.pdf (accessed August 6, 2013).

——. “Management of Ecological Impacts in Wilderness Areas in the United States.” In *The Ecological Impacts of Outdoor Recreation on Mountain Areas in Europe and North America*, edited by N. G. Bayfield and G. C. Barrow, 138-154. Wye, England: Recreation Ecology Research Group, 1985.

Cole, David N., and Peter B. Landres. “Threats to Wilderness Ecosystems: Impacts and Research Needs.” *Ecological Applications* 6, no. 1 (1996): 168-184.

Goeft, Ute, and Jackie Alder. “Sustainable Mountain Biking: A Case Study from the Southwest of Western Australia.” *Journal of Sustainable Tourism* 9, no. 3 (2001): 193-211.

International Mountain Bicycling Association. “Grants and Funding.” International Mountain Bicycling Association. http://www.imba.com/resources/grants (accessed December 3, 2013).

——. *Trail Solutions: IMBA’s Guide to Building Sweet Singletrack*. Boulder, Colorado: International Mountain Bicycling Association, 2007.

Lynn, Natasha A., and Robert D. Brown. “Effects of Recreational Use Impacts on Hiking Experiences in Natural Areas.” *Landscape and Urban Planning* 64, nos. 1–2 (2003): 77-87.

Marion, Jeff, and Jeremy Wimpey. “Environmental Impacts of Mountain Biking: Science Review and Best Practices.” In *Managing Mountain Biking: IMBA’s Guide to Providing Great Riding*, edited by Pete Webber, 94-111. Boulder, CO: International Mountain Bike Association, 2007.

Marion, Jeffery L., and Yu-Fai Leung. “Trail Resource Impacts and An Examination of Alternative Assessment Techniques.” *Journal of Park and Recreation Administration* 19, no. 3 (2001): 17-37.

Mcdonald, Robert I., Richard T. T. Forman, Peter Kareiva, Rachel Neugarten, Dan Salzer, and Jon Fisher. “Urban Effects, Distance, and Protected Areas in an Urbanizing World.” *Landscape and Urban Planning* 93, no. 1 (2009): 63-75.

Midpeninsula Regional Open Space District. “About Us.” Midpeninsula Regional Open Space District. http://www.openspace.org/about_us/ (accessed August 31, 2013).

——. “Board Keeps Tower While Agreeing to Give Supporters Five Years to Develop Partnerships, Resources to Maintain It” (2012 Press Release) (Midpeninsula Regional Open Space District, October 19, 2012). http://www.openspace.org/CGI-BIN/press_releases/121019_Oct17MtgRecap.pdf (accessed February 24, 2014).

——. *Draft Environmental Impact Report for the Mount Umunhum Environmental Restoration and Public Access Project.* SCH# 2010122037. December 2011.

——. "Mount Umunhum Summit Project." Midpeninsula Regional Open Space District. http://www.openspace.org/plans_projects/mt_umunhum.asp (accessed February 25, 2014).

——. *Notice of Preparation, Mount Umunhum Proposed Environmental Restoration and Public Access Plan*, Santa Clara County, California (2010): 8

——. "Open Space Preserves." Midpeninsula Regional Open Space District. http://www.openspace.org/preserves/default.asp (accessed January 31, 2014).

——. "Overview." Midpeninsula Regional Open Space District. http://www.openspace.org/about_us/default.asp (accessed November 22, 2013).

——. "Sierra Azul Open Space Preserve." Midpeninsula Regional Open Space District. http://www.openspace.org/preserves/pr_sierra_azul.asp (accessed August 31, 2013).

Moore, Roger L., Yu-Fai Leung, Craig Matisoff, Catherine Dorwart, and Alan Parker. "Understanding Users' Perceptions of Trail Resource Impacts and How They Affect Experiences: An Integrated Approach." *Landscape and Urban Planning* 107, no. 4 (2012): 343-350.

Morey, Edward R., Terry Buchanan, and Donald M. Waldman. "Estimating the Benefits and Costs to Mountain Bikers of Changes in Trail Characteristics, Access Fees, and Site Closures: Choice Experiments and Benefits Transfer." *Journal of Environmental Management* 64, no. 4 (2002): 411-422.

National Trails Training Partnership. "Resources and Library: Finding & Resources." http://www.americantrails.org/resources/funding/index.html (accessed December 3, 2013).

New Zealand Department of Conservation. *Off-road Impacts of Mountain Bikes: A Review and Discussion,* by Gordon R. Cessford. Science and Research Series No. 92 (August 1995). http://www.doc.govt.nz/documents/science-and-technical/sr92.pdf (accessed March 30, 2014).

——. *Off-road Mountain Biking: A Profile of Participants and Their Recreational Setting and Experience Preferences,* by Gordon R. Cessford. Science and Research Series No. 93 (September 1995). http://csl.doc.govt.nz/documents/science-and-technical/sr93.pdf (accessed March 30, 2014).

Olive, Nathaniel D., and Jeffrey L. Marion. "The Influence of Use-related, Environmental, and Managerial Factors on Soil Loss from Recreational Trails." *Journal of Environmental Management* 90, no. 3 (2009): 1483-1493.

Pickering, Catherine Marina, Wendy Hill, David Newsome, and Yu-Fai Leung. “Comparing Hiking, Mountain Biking and Horse Riding Impacts on Vegetation and Soils in Australia and the United States of America.” *Journal of Environmental Management* 91, no. 3 (2010): 551-562.

Radomes, Inc., The Air Defense Radar Veterans’ Association. *682nd Radar Squadron, Almaden AFS, California Welcome Brochure* (n.d.).

Sadek, Salah, Isam Kaysi, and Mounia Bedran. “Geotechnical and Environmental Considerations in Highway Layouts: An Integrated GIS Assessment Approach.” *International Journal of Applied Earth Observation and Geoinformation* 2, nos. 3–4 (2000): 190-198.

Snyder, Stephanie A., Jay H. Whitmore, Ingrid E. Schneider, and Dennis R. Becker. “Ecological Criteria, Participant Preferences and Location Models: A GIS Approach Toward ATV Trail Planning.” *Applied Geography* 28, no. 4 (2008): 248-258.

Symmonds, Mathew C., William E. Hammitt, and Virgil L. Quisenberry. “Managing Recreational Trail Environments for Mountain Bike User Preferences.” *Environmental Management* 25, no.5 (2000): 549-564.

Tennessee Department of Environment and Conservation, Recreation Educational Services Division, Greenways and Trails Program. *Pathways to Trail Building.* Edited by Bob Richards, 2007, http://atfiles.org/files/pdf/TNpathways.pdf (accessed August 4, 2013).

Thompson, Catharine Ward. “Urban Open Space in the 21st Century.” *Landscape and Urban Planning* 60, no. 2 (July 30, 2002): 59-72.

Thurston, Eden, and Richard J. Reader. “Impacts of Experimentally Applied Mountain Biking and Hiking on Vegetation and Soil of a Deciduous Forest.” *Environmental Management* 27, no.3 (2001): 397-409.

Tomczyk, Aleksandra M. “A GIS Assessment and Modelling of Environmental Sensitivity of Recreational Trails: The Case of Gorce National Park, Poland.” *Applied Geography* 31, no. 1 (2011): 339-351.

Tomczyk, Aleksandra M., and Marek Ewertowski. “Planning of Recreational Trails in Protected Areas: Application of Regression Tree Analysis and Geographic Information Systems.” *Applied Geography* 40 (2013): 129-139.

United States Army Corps of Engineers. *Site Survey Summary Sheet for DERP-FUDS Site No. J09CA099900 Almaden Air Force Station.* n.d..

United States Department of Agriculture, United States Forest Service, Technology and Development Program. *Equestrian Design Guidebook for Trails, Trailheads and Campgrounds*. Jan Hancock, Kim Jones, Vander Hoek, Sunni Bradshaw, James D. Coffman, and Jeffery Engelmann. No. 0723-2816-MTDC (2007). http://www.fhwa.dot.gov/environment/recreational_trails/publications/fs_publications/07232816/ (accessed November 11, 2013).

——. *Trail Construction and Maintenance Notebook.* Woody Hesselbarth, Brian Vachowski, and Mary Ann Davies. No. 0723-2806-MTDC (2007). http://www.fs.fed.us/t-d/pubs/htmlpubs/htm07232806/index.htm (accessed February 22, 2014).

United States Department of Agriculture, United States Forest Service, Trails Unlimited Enterprise Unit. "Trails Unlimited – Services." United States Forest Service, Trails Unlimited Enterprise Unit. http://www.fs.fed.us/trailsunlimited/services/construction.shtml (accessed December 8, 2013).

United States Department of Agriculture, Natural Resources Conservation Service. "Official Soil Series Descriptions (OSDs)." United States Department of Agriculture. http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/home/?cid=nrcs142p2_053587 (accessed January 19, 2014).

United States Department of Transportation, Federal Highway Administration, Recreational Trails Program. "Recreational Trails Program." Recreational Trails Program. http://www.fhwa.dot.gov/environment/recreational_trails/funding/fueluse_est_2012.cfm (accessed December 1, 2013).

——. "Recreational Trails Program (RTP) Factors for Revised Apportionments for FY 2009 to 2012." Recreational Trails Program. http://www.fhwa.dot.gov/environment/recreational_trails/funding/fueluse_est_2012.cfm (accessed December 1, 2013).

Wilson, John P., and Joseph P. Seney. "Erosional Impacts of Hikers, Horses, Motorcycles, and Off-road Bicycles on Mountain Trails in Montana." *Mountain Research and Development* 14, no. 1 (1994): 77-88.

Wimpey, Jeremy F., and Jeffrey L. Marion. "The Influence of Use, Environmental and Managerial Factors on the Width of Recreational Trails." *Journal of Environmental Management* 91, no. 10 (2010): 2028-2037.

Xiang, Wei-Ning. "A GIS Based Method for Trail Alignment Planning." *Landscape and Urban Planning* 35, no. 1 (1996): 11-23.