Lab Report

Title: Using a Weighted Overlay Analysis to Determine Optimal Paths for Summitting
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Author: Eric Gibson
Date: December 19, 2023

Project Repository: https://github.com/gibso632/Final-Project

Abstract

Summiting is a popular activity for hikers, backpackers, and other outdoor enthusiasts. This study uses 10-meter spatial resolution digital elevation models and land cover raster datasets to determine optimal paths for summiteers using an ArcGIS Pro Notebook. Eleven western United States state high points were chosen to create these optimal routes due to their remoteness and degree of difficulty. These paths were created via a proportional weighting of slope angle and a determination of weighting for land cover based on general hiking preferences. Additionally, weighting was performed based on preference of slope over land cover and vice versa. Water features were also considered, including ponds, lakes (both of which were included within the land cover raster dataset), streams, and rivers (created via flow accumulation values). The paths provided helpful instruction for summiting peaks present within this study, however future analyses will be needed with more accurate and additional data from users for more precise and specified outputs.

Problem Statement

Table 1. Deliverables and needs for completion of study.

#	Requirement	Defined As	(Spatial) Data	Attribute Data	Dataset	Preparation
1	Cost Surface	Raster dataset created via weighted overlay analysis of slope and land cover	10-meter spatial resolution raster dataset	Cell values based on multiplication of land cover and slope datasets	Raster calculated to determine optimal routing	Product of using the raster calculator to multiply land cover and slope rasters
2	Optimal Paths	Vector lines created by finding the next lowest value in the cost surface	Vector polyline from the defined starting point to the summit representing the next lowest on the cost surface	Name of summit, length of polyline (miles)	Vector polyline data	Use Optimal Path as Line tool in arcpy with the input raster as the cost surface
3	Streams	Raster dataset created from a 7.5-meter buffer around a streams	10-meter spatial resolution raster dataset representing stream polylines created via the	Weighted value of 10 to limit the number of stream crossings	Raster dataset where stream lines = 10 and all other areas = 1 for multiplication	Reclassify flow accumulation raster to 1 when flow accumulation value is greater than 5000, 0 for

		polyline feature class	Flow Accumulation tool		and conditional statement purposes	all other areas -> create polyline -> buffer -> Polygon to Raster
4	Rivers	Raster dataset created from a 15-meter buffer around a rivers polyline feature class	10-meter spatial resolution raster dataset representing stream polylines created via the Flow Accumulation tool	Weighted value of 50 to severely limit the number of river crossings	Raster dataset where river lines = 50 and all other areas = 1 for multiplication and conditional statement purposes	Reclassify flow accumulation raster to 1 when flow accumulation value is greater than 500000, 0 for all other areas -> create polyline -> buffer -> Polygon to Raster

Input Data

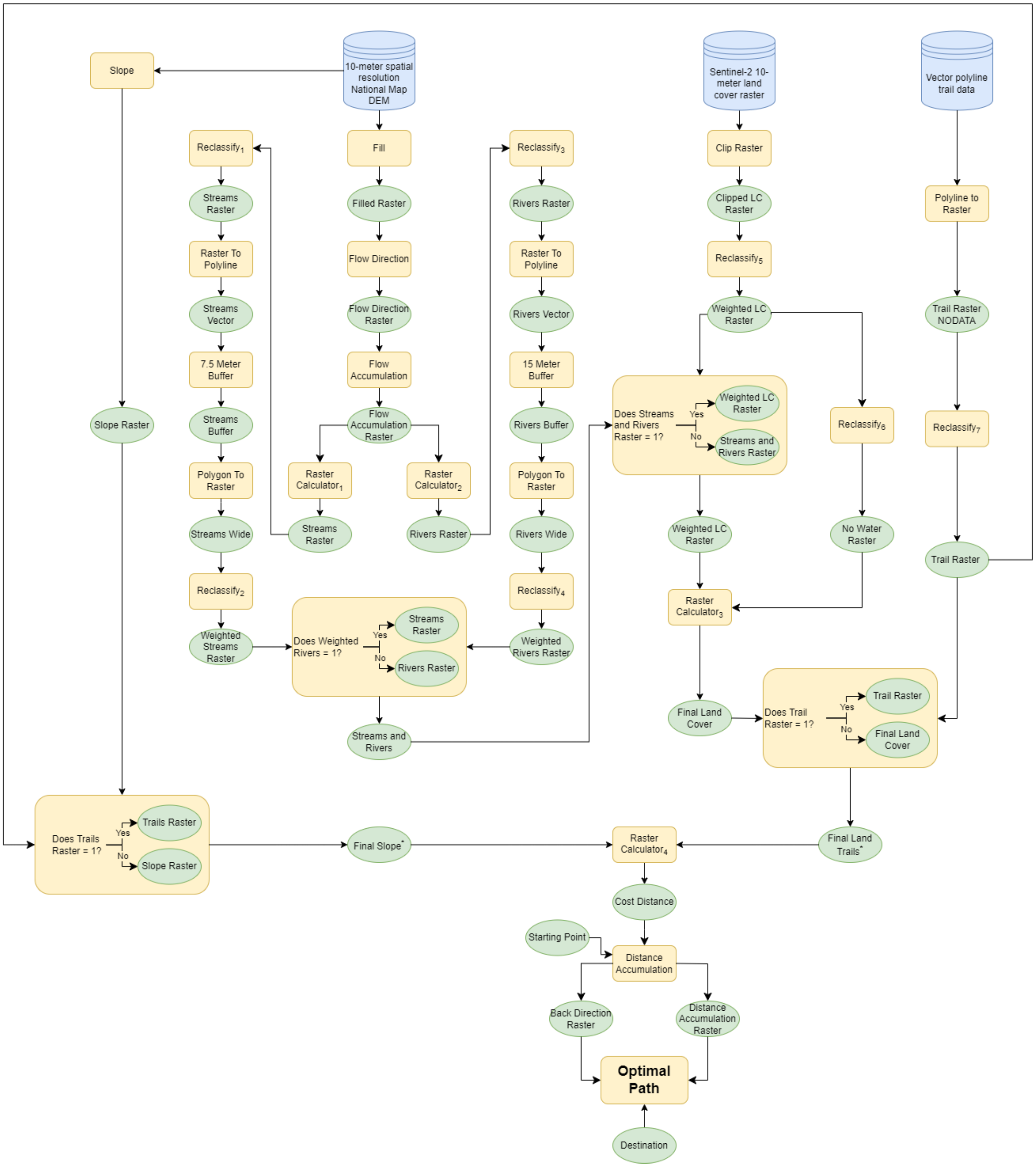
Table 2. Input data to use for study

#	Title	Purpose in Analysis	Link to Source
1	Digital Elevation Model	Creating the slope raster dataset for multiplying with the land cover to create the final cost surface; creating the streams and rivers raster dataset to merge with the land cover dataset.	USGS 10-Meter Spatial Resolution DEM
2	Land Cover Dataset	Provides differing weights based on water features, barren land, snow/ice, farmland, etc.; streams and rivers raster to be merged with dataset; multiplied with slope raster to create the final cost surface	Sentinel-2 10-Meter Spatial Resolution
3	Trail Data	Convert vector data to raster and provide a low weight so the optimal routes follow the trails if present in the area	Data primarily from the USGS here along with other sources depending on availability within National Forests

Methods

The code for performing the study was primarily done within ArcGIS Notebooks utilizing the Python scripting language and the Arcpy library. **Figure 1** provides a detailed flow chart which describes the analyses performed to output an optimal route for summiting mountains utilizing the data listed above. Each subscript within the "Reclassify" and "Raster Calculator" functions relate to **Tables 3 and 4**, which depict the exact calculations those functions performed. Any functions illustrated as a "yes" or "no" question within the flow chart utilized the "Con" tool through Arcpy to provide a conditional statement where if the cells in the raster were equal to the number asked, those cells would still equal their original value. If they were not equal, the cells would then match the values of the cells within the other raster in the conditional statement.

Figure 1. Data flow diagram.



In addition to creating a cost surface by multiplying both the Final Land Trails and Final Slope together, additional cost surfaces were created for different preferences of individuals. For example, an experienced climber may prefer routes with a steeper slope over routes crossing an ice field. By decreasing the weight of the Final Slope raster comparatively to the Final Land Trails raster, then adding each raster together, a cost surface can be created where the output optimal path will elect a route which traverses steep slopes over harsh land cover types. Cost surfaces will also be created with a comparative decrease in weight value for land cover types for individuals preferring harsh land cover types over steeper slope angles.

Table 3. Equations used within the "Reclassify" functions.

$Reclassify_1$	If cell = 0, then convert to "NODATA"
$Reclassify_2$	If cell = 0, then convert to 1; If cell = 1, then convert to 10
$Reclassify_3$	If cell = 0, then convert to "NODATA"
$Reclassify_4$	If cell = 0, then convert to 1; If cell = 1, then convert to 50
$Reclassify_5$	If cell = 1, then convert to "NODATA"; If cell = 2, then convert to 3; If cell = 4 OR 5, then convert to 4; Keep cells with a value of 9; All other values convert to 2
$Reclassify_6$	All values reclassified to 1
$Reclassify_7$	If cell = "NODATA", then convert to 0; If cell has a value, then convert to 1

Table 4. Equations used within the "Raster Calculator" functions.

Raster $Calculator_1$	If cell > 5000, convert to 1
Raster $Calculator_2$	If cell > 500000, convert to 1
Raster $Calculator_3$	LC with Streams Raster * No Water Raster
Raster $Calculator_4$	Final Slope * Final Land Trails

*Rasters multiplied by 0.1 to 0.9 in 0.1 increments, then added to their inverse (0.1*0.9; 0.2*0.8; 0.3*0.7) and so on in addition to being multiplied together.

Results

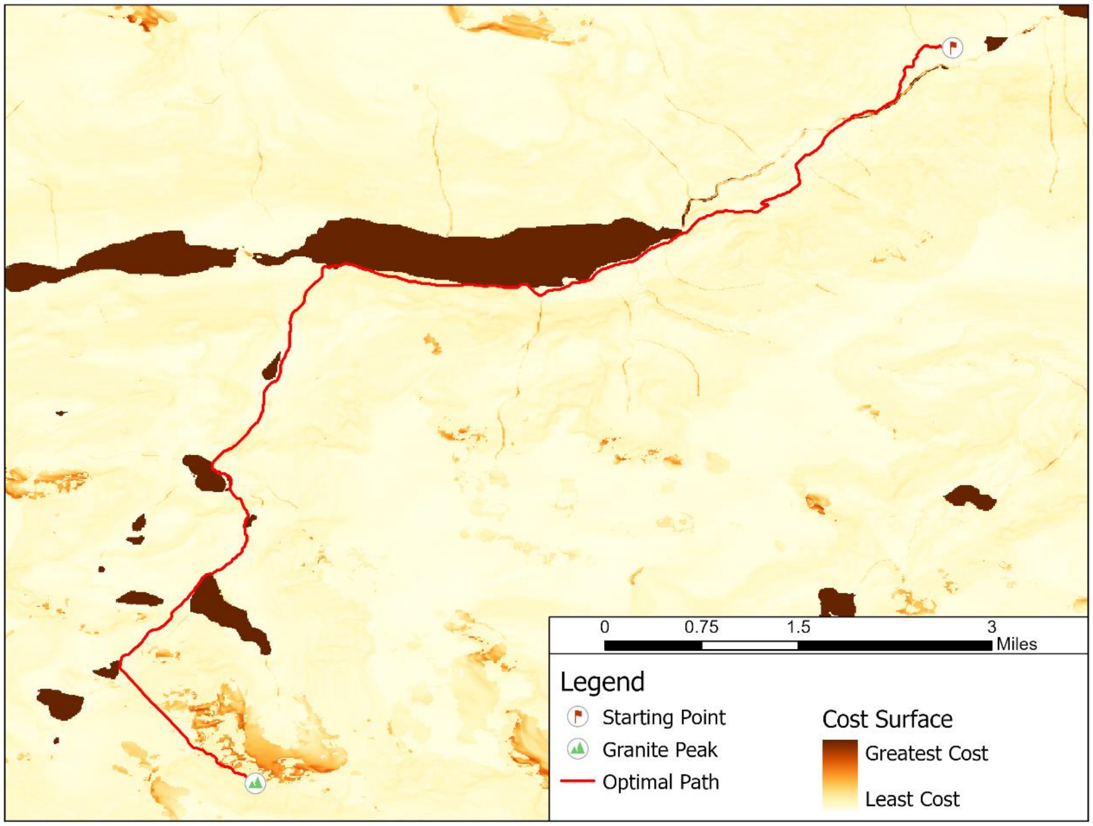
The results below provide the cost surfaces and the original optimal paths for five separate United States state highpoints with two highpoints also showing the cost surfaces and optimal paths for various preferences of slope and land cover. These two highpoints are Granite Peak and Mount Hood. Four of the five chosen high points lack a trail route to the peak to illustrate routes utilizing slope and land cover only to provide a path. These routes include Granite Peak, Gannett Peak, Mount Hood, and Mount Rainier. It is also important to include routes which directly follow a trail to the peak to ensure the optimal route uses the designated trails as well. The optimal path following a trail directly to the peak is Mount Elbert. Routes utilizing the individual preferences will only be ones which are at least partially off-trail, as they will likely be the only routes affected by the weight changes in slope and land cover.

All cost surfaces depicted in the results below utilize the Yellow-Orange-Brown continuous symbology within ArcGIS Pro with the lighter-colored areas depicting a lower cost and, therefore, less difficulties for traversing and the darker-colored areas depicting a higher cost, meaning the extreme slope and/or an unfavorable land cover type may make it difficult to traverse. The optimal paths created via differing weight multipliers are displayed using a Global ArcScene to clearly visualize changes in path routes, land cover types, and slope angles. Click the link below to access the main optimal routes in a 2 and 3-dimensional visualization in an ArcGIS Experience Builder web application:

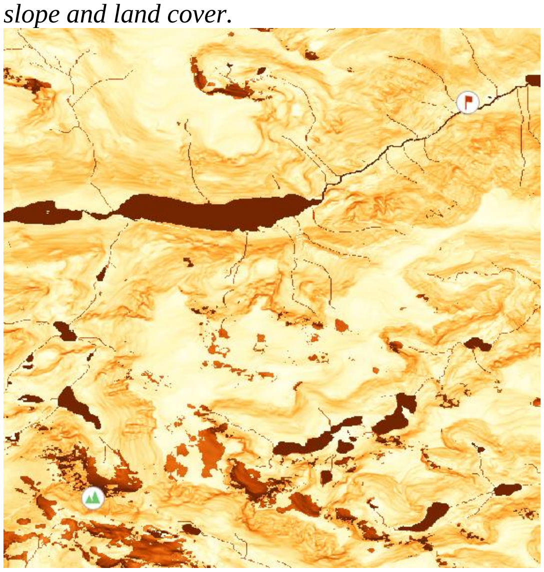
Click here to access the web application

Granite Peak

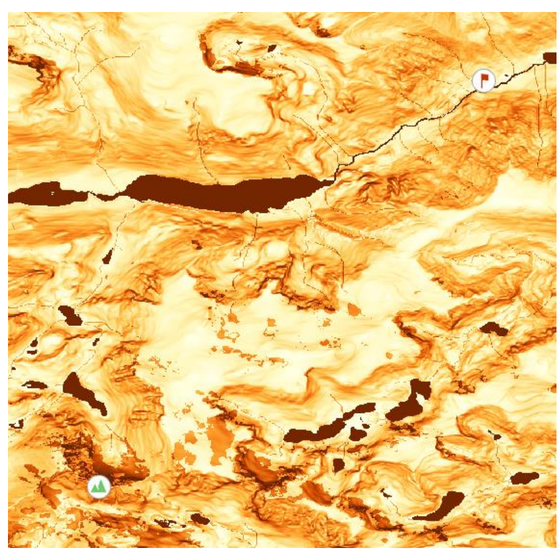
Figure 2. Granite Peak main optimal route with cost surface.



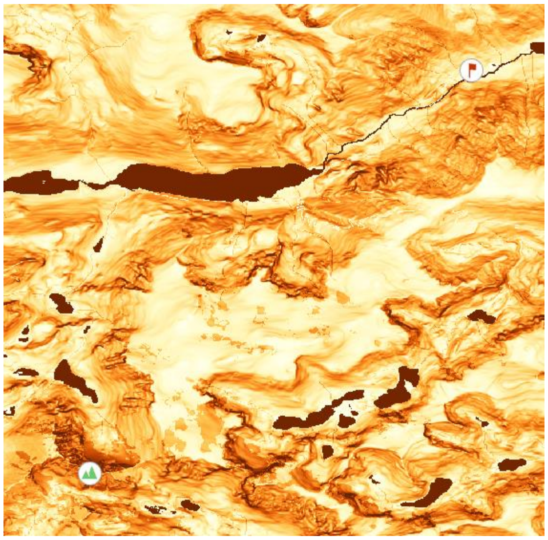
Figures 4-12. Cost surfaces of individual preferences for the Granite Peak route based on differences in weights of slope and land cover.



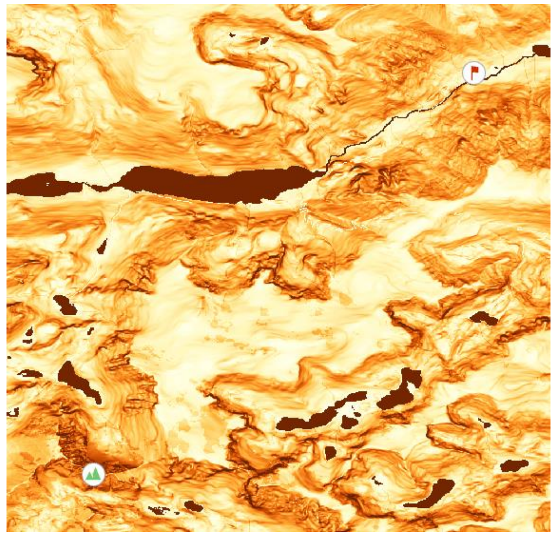
Slope weight: 0.1 | Land cover weight: 0.9



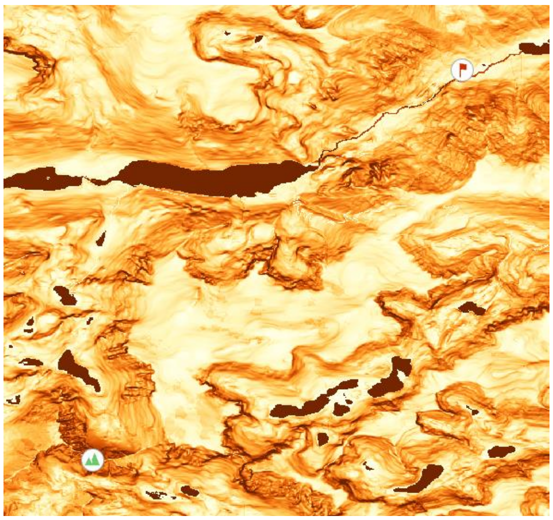
Slope weight: 0.2 | Land cover weight: 0.8



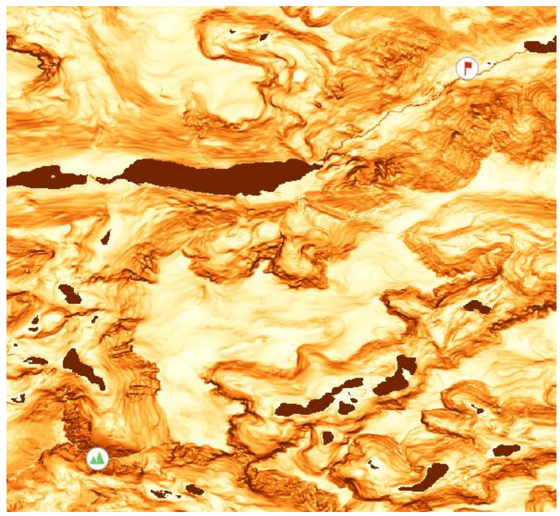
Slope weight: 0.3 | Land cover weight: 0.7



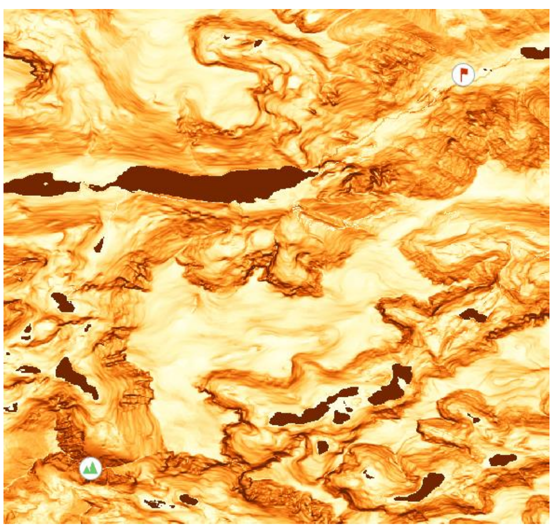
Slope weight: 0.4 | Land cover weight: 0.6



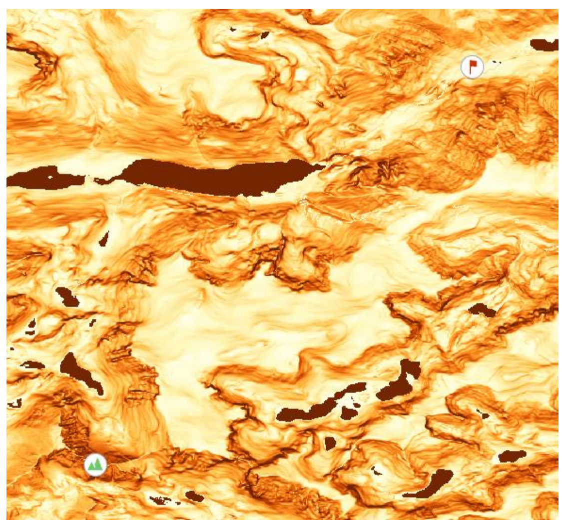
Slope weight: 0.5 | Land cover weight: 0.5



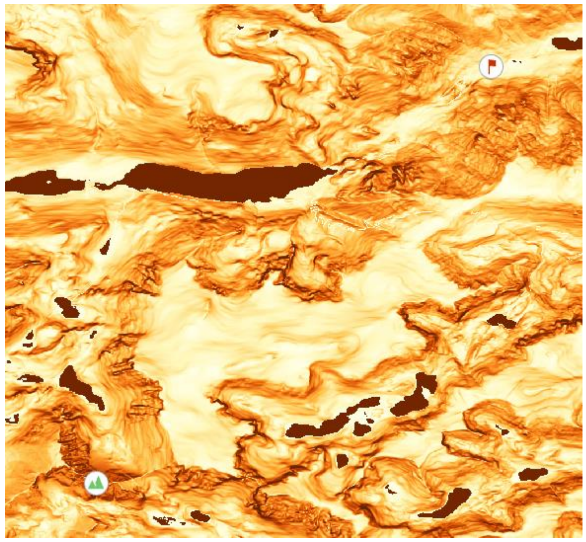
Slope weight: 0.6 | Land cover weight: 0.4



Slope weight: 0.7 | Land cover weight: 0.3

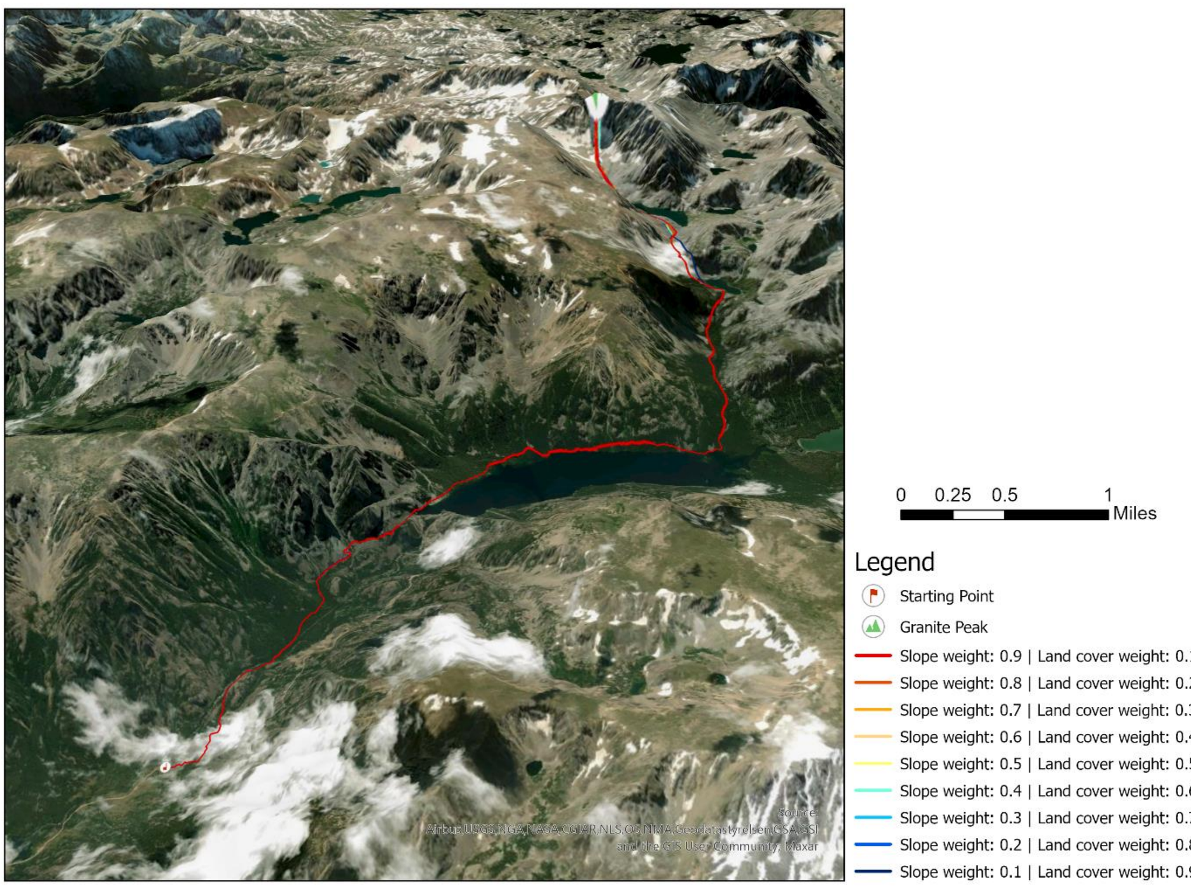


Slope weight: 0.8 | Land cover weight: 0.2



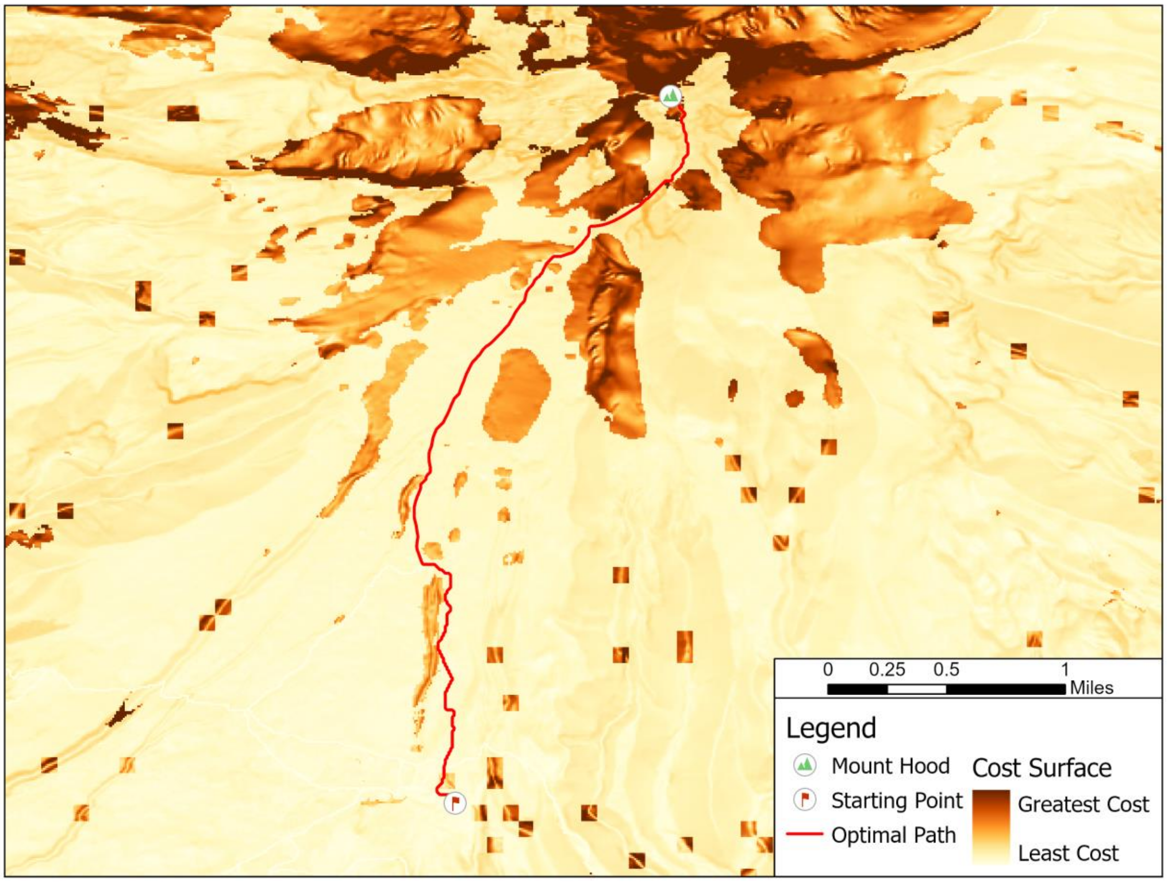
Slope weight: 0.9 | Land cover weight: 0.1

Figure 13. Granite Peak optimal paths created from the various weighted preferences.

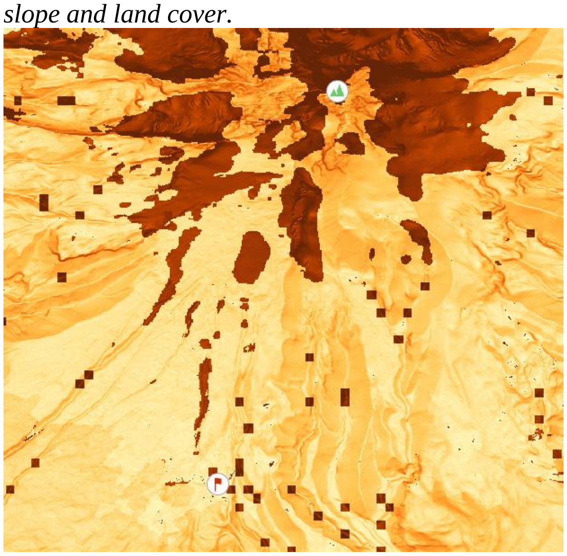


Mount Hood

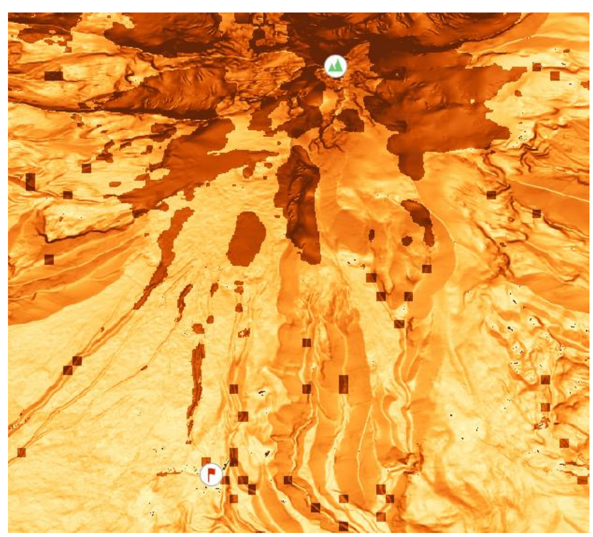
Figure 14. Mount Hood main optimal route with cost surface.



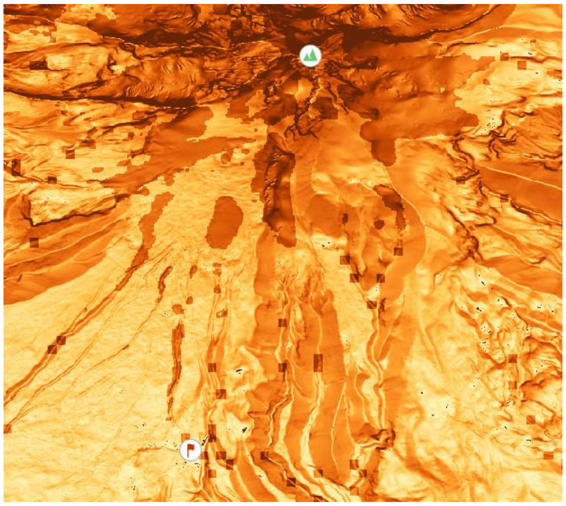
Figures 15-23. Cost surfaces of individual preferences for the Mount Hood route based on differences in weights of slope and land cover.

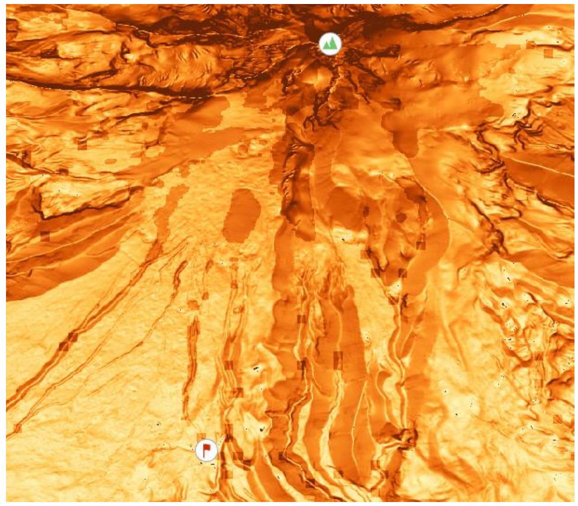


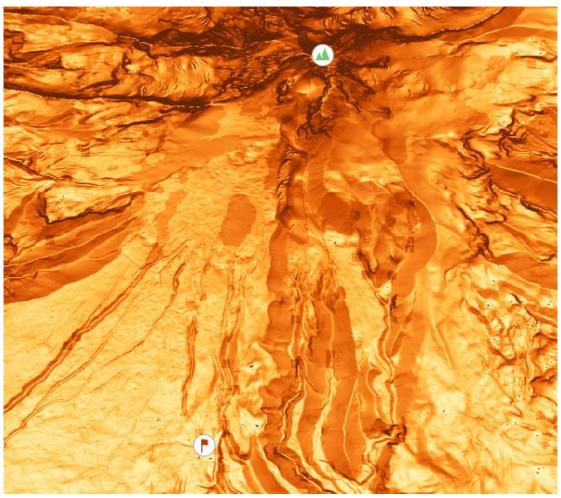
Slope weight: 0.1 | Land cover weight: 0.9

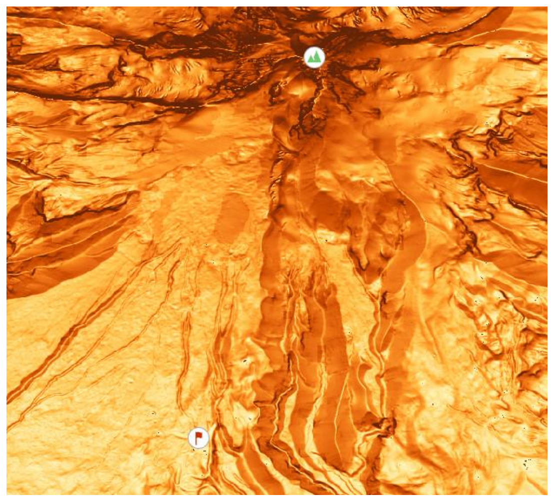


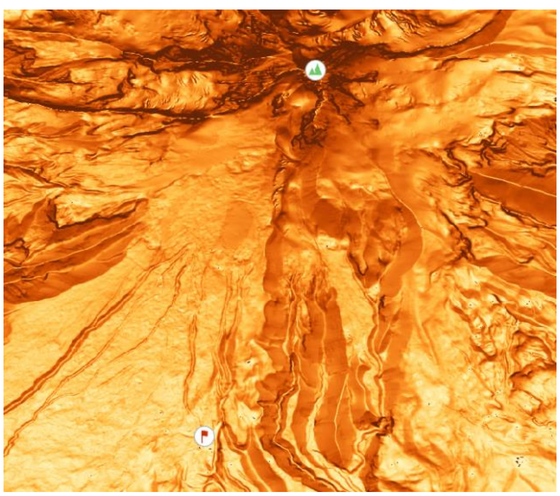
Slope weight: 0.2 | Land cover weight: 0.8

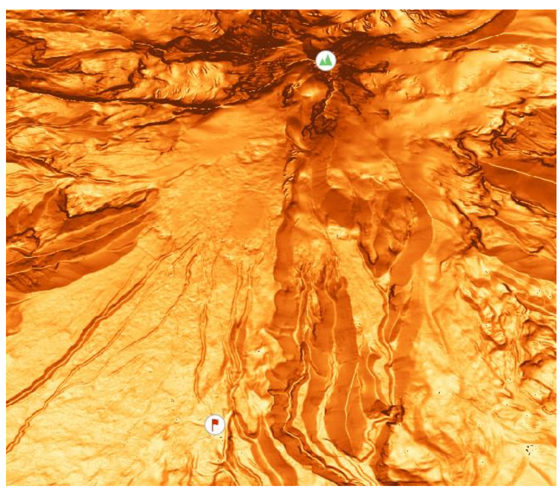

Slope weight: 0.3 | Land cover weight: 0.7

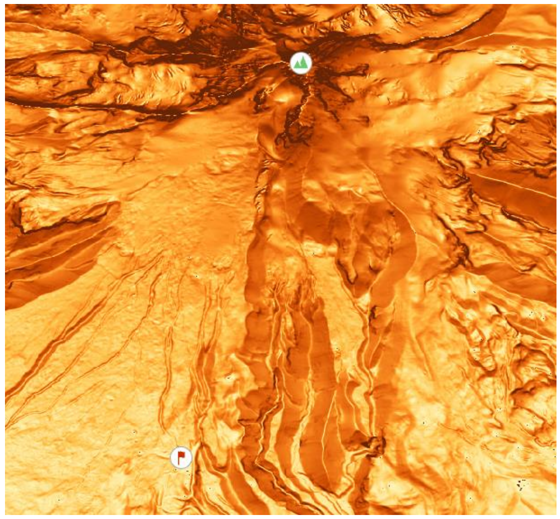

Slope weight: 0.4 | Land cover weight: 0.6


Slope weight: 0.5 | Land cover weight: 0.5


Slope weight: 0.6 | Land cover weight: 0.4

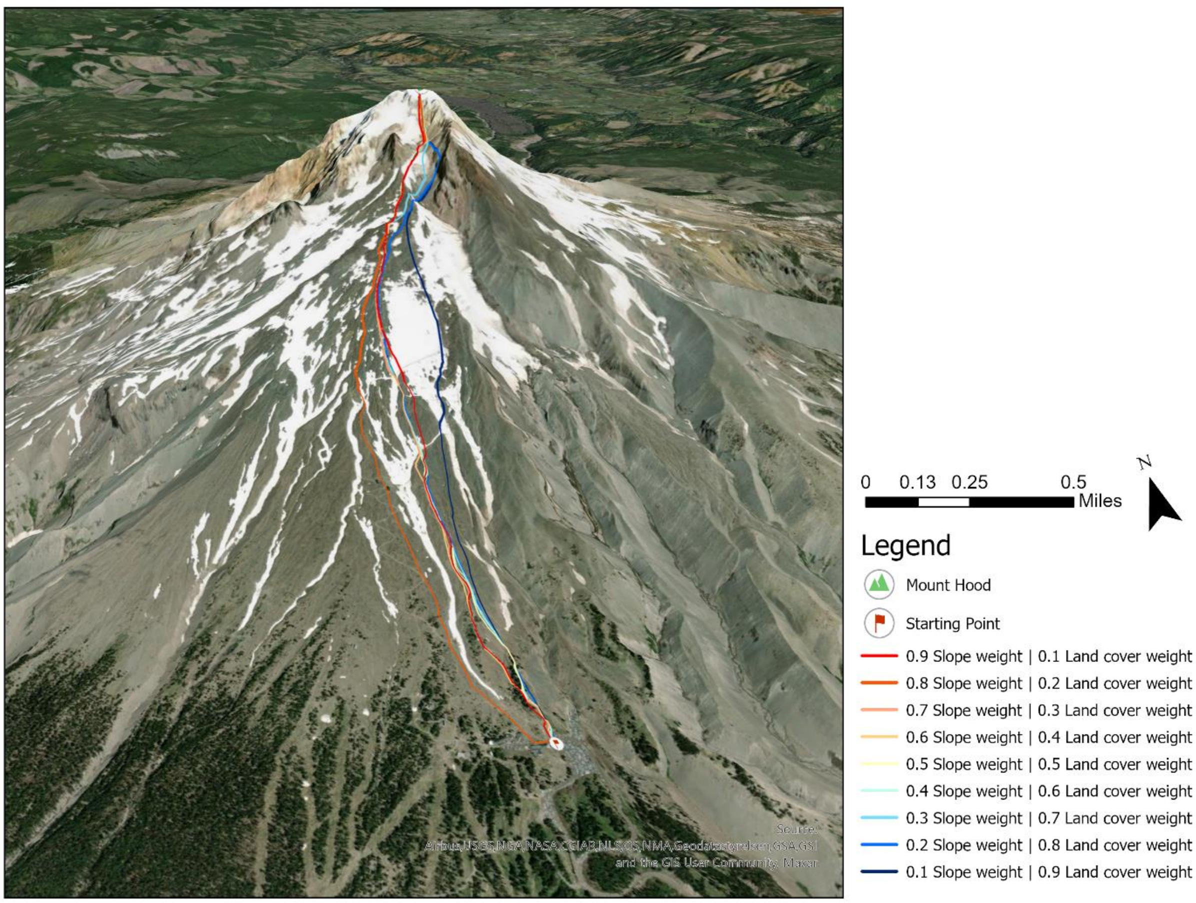

Slope weight: 0.7 | Land cover weight: 0.3


Slope weight: 0.8 | Land cover weight: 0.2



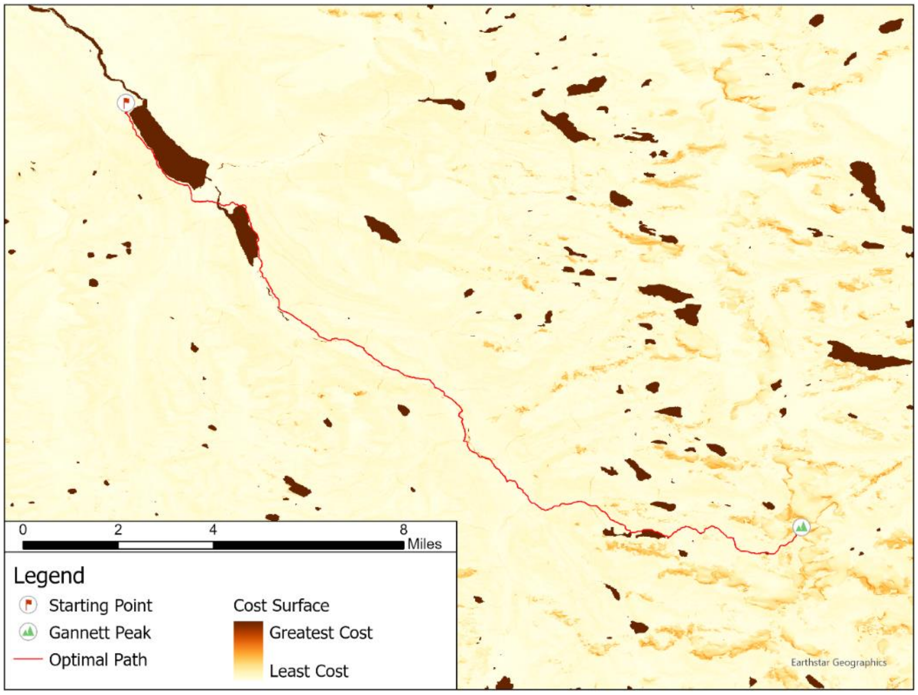
Slope weight: 0.9 | Land cover weight: 0.1

Figure 24. Mount Hood optimal paths created from the various weighted preferences in a 3D ArcScene.



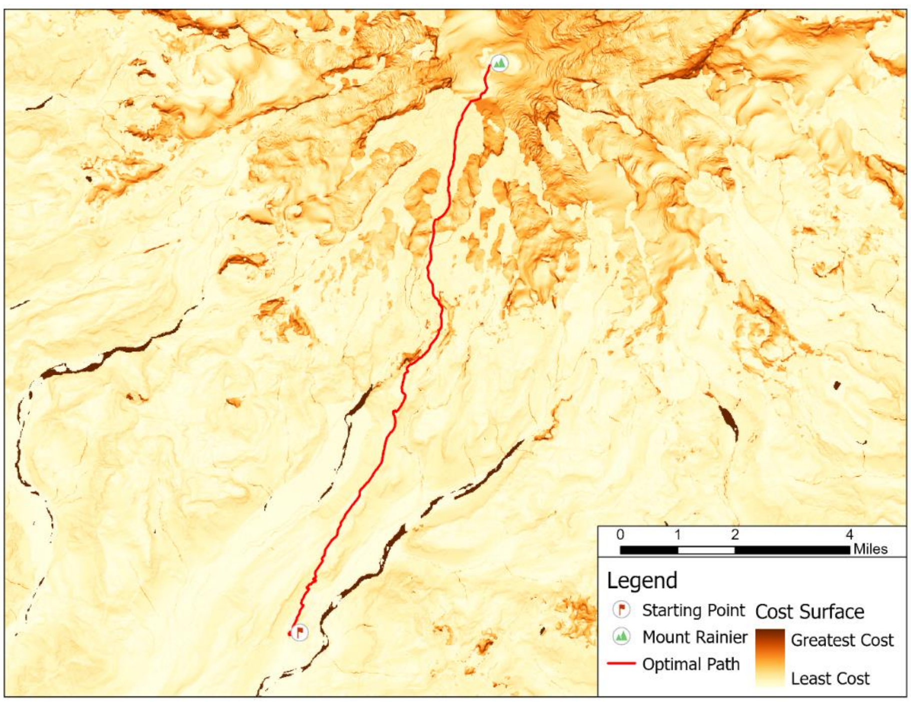
Gannett Peak

Figure 25. Gannett Peak main optimal route with cost surface.



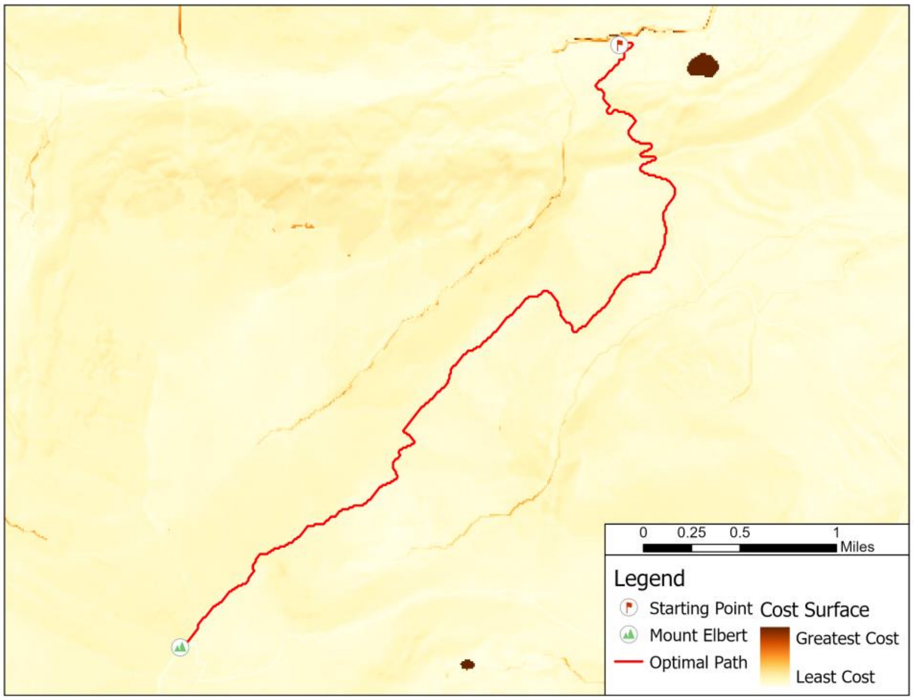
Mount Rainier

Figure 26. Mount Rainier main optimal route with cost surface.



Mount Elbert

Figure 27. Mount Rainier main optimal route with cost surface.



Results Verification

For result verification, a comparison was performed between the main created optimal path within this study and data gathered from various sources illustrating routes previous high-pointers have made. This data was mainly collected from AllTrails.com, a social site which displays various trail routes users have taken all over the world. The Gannett Peak route within AllTrails began at a different location, so a polyline feature depicting GPS data from a trekker through FastestKnownTime.com was used to compare (these routes will be considered verification paths/routes). Firstly, a simple visualization of both paths were used for comparison and can be examined using **Figures 29 – 31** below. Aside from points at which the routes followed trails, there are some noticeable differences between the created optimal route and the routes taken by trekkers. This is especially the case for the Granite Peak routes which actually separate at a fork in the trail where the optimal route continues west and the AllTrails route takes a trail towards the south. This is likely because the optimal route tends to prefer the *shortest* route over the least cost area, not necessarily the easiest route itself, which could be longer.

For a more detailed, quantitative verification, a script was made using an ArcGIS Pro Notebook which created a distance accumulation raster around the optimal path, added points to the AllTrails and GPS routes, and connected the values of the raster cell to each point. The points were positioned at each five percent interval along the route, creating a total of 19 points, which is illustrated once again in **Figures 29 – 31**. Once these values were matched with each point, a spreadsheet was created using the attribute table and presented as a graph shown in **Figure 32**.

This graph provides a more measurable description of how the various paths not just relate to the AllTrails and GPS verification paths, but also how each created optimal path compares to each other. Lower distance accumulation values dictate the optimal route was close to the verification path, while larger distance accumulation values dictate the optimal route was further from the verification path. A value of zero indicates the optimal route intersects the verification path at this point.

Figure 28. Results verification flow chart.

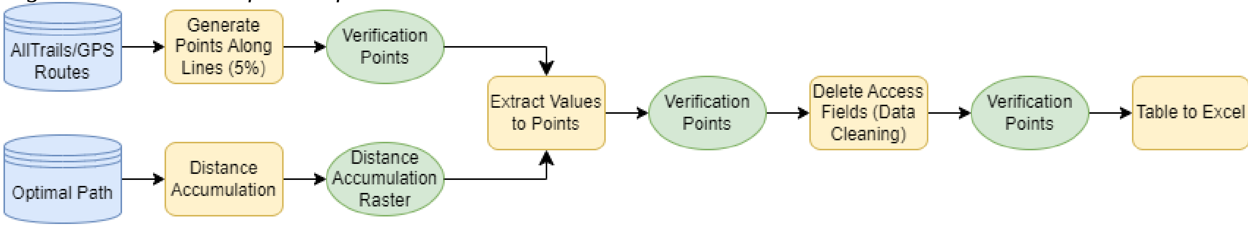


Figure 29. Created Mount Hood optimal path with AllTrails route and points for verification.

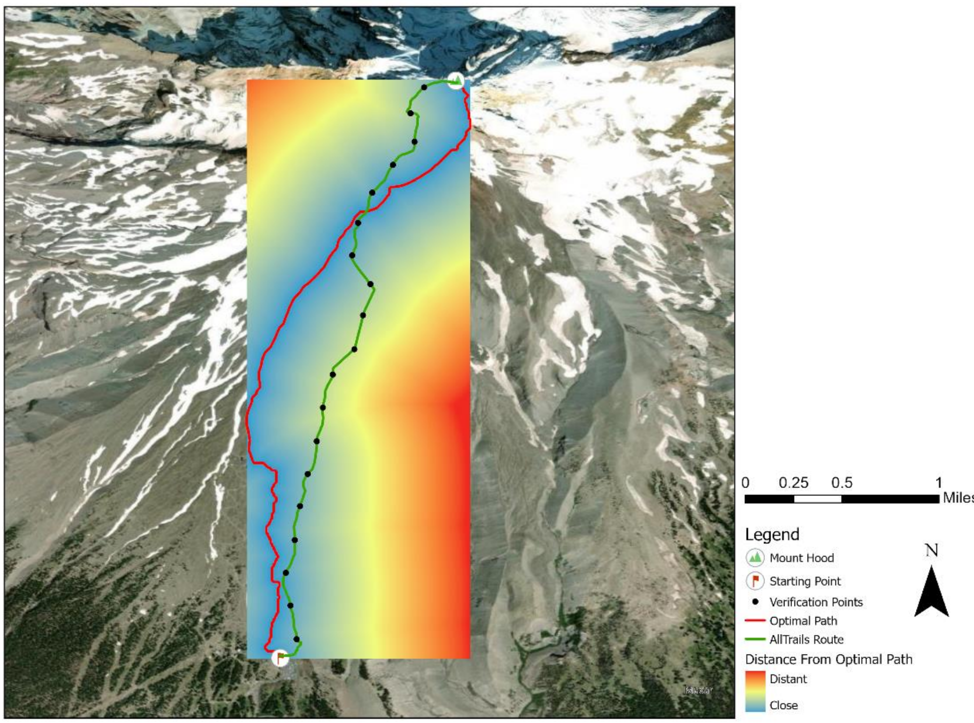


Figure 30. Created Granite Peak optimal path with AllTrails route and points for verification.

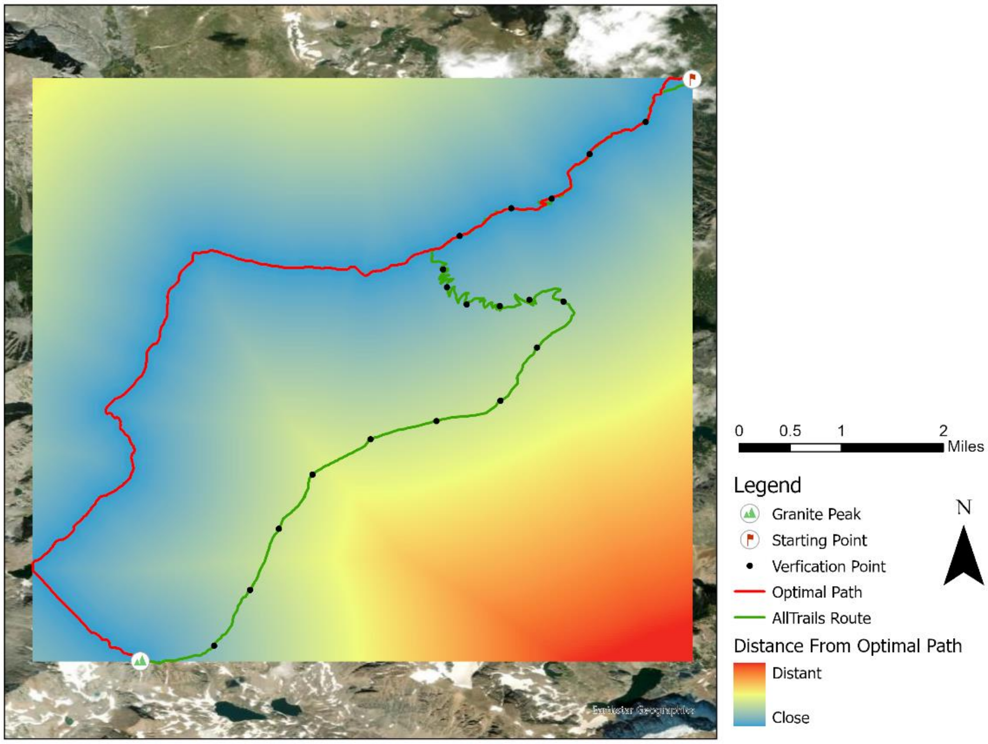


Figure 31. Created Gannett Peak optimal path with GPS route and points for verification.

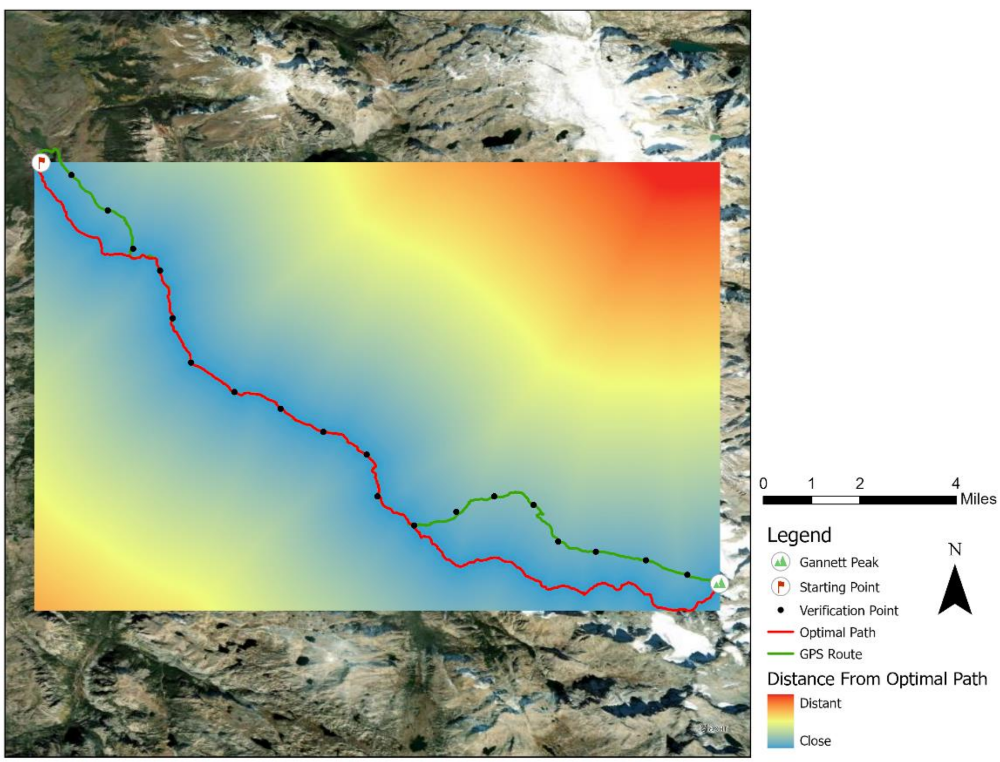


Figure 32. Distance accumulation values of each point at 5% increments along verification paths

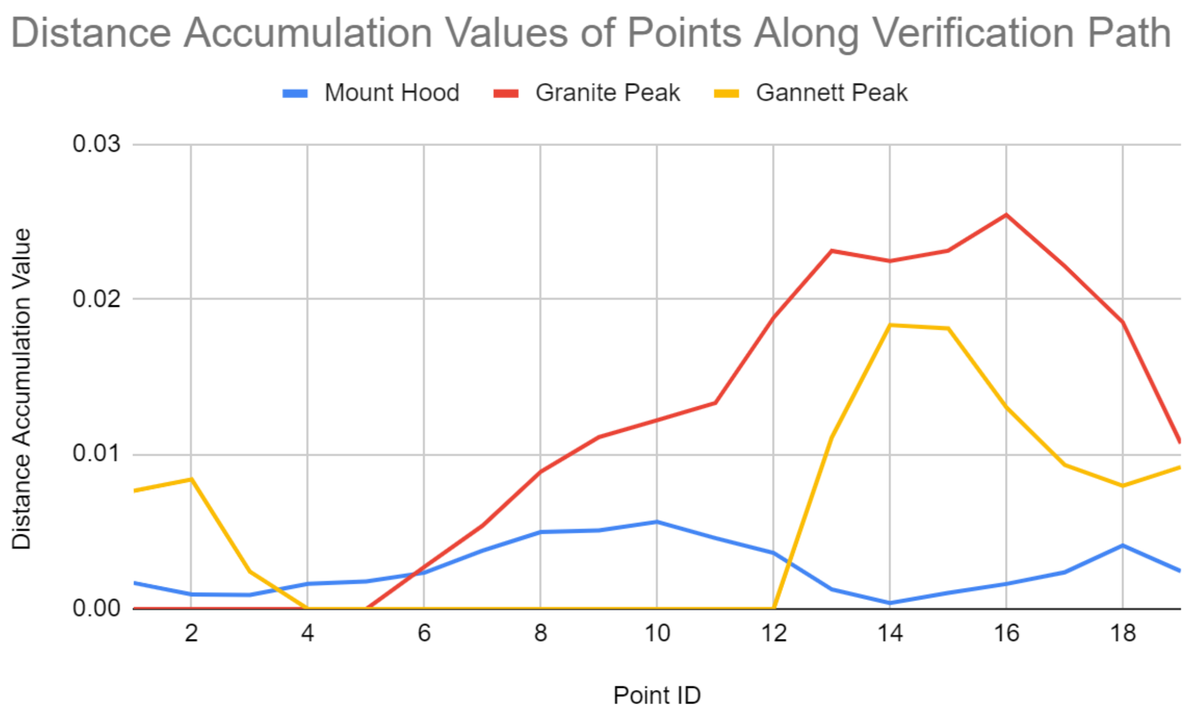


Table 5. Number and percentage of points intersecting, near, and distant from created optimal path.

Name of highpoint	Intersecting (DA value = 0)	Near (DA value between 0.0 and 0.01)	Intermediate (DA value between 0.01 and 0.02)	Distant (DA value > 0.02)
Mount Hood	0 (0.0%)	19 (100.0%)	0 (0.0%)	0 (0.0%)
Granite Peak	5 (26.3%)	3 (15.8%)	6 (31.6%)	5 (26.3%)
Gannett Peak	9 (47.4%)	6 (31.6%)	4 (21.0%)	0 (0.0%)
Total	14 (24.6%)	28 (49.1%)	10 (17.5%)	5 (8.8%)

Verifying the routes created by manipulating the weight multipliers of the slope and land cover rasters was simply performed through visualization. When viewing **Figure 24**, there is a clear variation between the paths which prefer slope over land cover and vice versa. While all share the same general area, the differing weight multipliers altered the paths and provide a clear route for individuals with specific preferences. **Figure 13**, however, depicts paths which have not been changed enough for clear individual preferences. Additionally, both paths tend to take routes which contain nearly vertical slopes, likely due to the routes favoring shorter paths to the destinations. It is clear the calculations for creating these paths will need to be changed and built-upon for future references.

Discussion and Conclusion

This study was performed to create a more efficient way of determining optimal routes for individuals looking to adventure outdoors. Although many of these paths have been created within the field using GPS inputs, this project provides a way of determining various routes to traverse if one decides to high-point a region, reach a destination in a reasonable amount of time, or simply enjoy nature through utilizing various computations, providing a more scientific look at creating hiking routes. This provides a more detailed description of why certain areas are preferred for trekkers, allowing, especially novices, a view into which routes to take for hiking or backpacking endeavors. This study also caters a little to individual preferences on traversing land cover or slope depending on experience, needs, and wants.

Overall, it does seem the relative accuracy of the final optimal paths depends a lot on the specific location and high point within the analysis. For example, distance of the route is a large factor, as, the longer the route is, the greater the chance of inaccuracies regarding the route taking the path of least cost. The main routes tend to choose paths which traverse a short, but incredibly steep, area since, although having a greater slope angle, it is still such a small distance. These routes choosing steeper paths are more understandable for the ones created via low slope weight multipliers, but not as the main optimal paths. This leads to issues regarding the Granite Peak and Gannett Peak routes specifically since these are longer routes, so there are simply more points of steeper terrain than the Mount Hood and Mount Rainier paths.

While this study does provide relatively accurate and reliable routes, it is worth noting these paths are not completely accurate and do need more implementation of specific obstacles and user inputs. Despite utilizing fairly accurate 10-meter spatial resolution slope and land cover rasters, these datasets cannot pinpoint specific obstacles to avoid or provide completely discreet locations, borders, or paths to take. This is simply the nature of raster data itself and it is clear mathematical analyses can only be so crucial when constructing something relatively opinionated. This is why this project and the code utilized to perform these functions will likely be expanded in the future to not only be open source, but also allow users to add any specific obstacles in the region or provide specific weights for different slope angles and land cover types. This analysis should have as many inputs as possible for users to adjust to their specific wants and needs since these routes are created specifically for recreation.

References

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"Gannett Peak (WY)." *Fastest Known Time*, 14 Aug. 2020, fastestknowntime.com/route/gannett-peak-wy#:~:text=and%20tough%20climbing.-,Most%20often%2C%20Gannett%20is%20approached%20from%20the%20south%20via%20the,summit%20day%20for%20most%20parties.

Self-score

Category	Description	Points Possible	Score
Structural Elements	All elements of a lab report are included **(2 points each)**: Title, Notice: Dr. Bryan Runck, Author, Project Repository, Date, Abstract, Problem Statement, Input Data w/ tables, Methods w/ Data, Flow Diagrams, Results, Results Verification, Discussion and Conclusion, References in common format, Self-score	28	**28**
Clarity of Content	Each element above is executed at a professional level so that someone can understand the goal, data, methods, results, and their validity and implications in a 5 minute reading at a cursory-level, and in a 30 minute meeting at a deep level **(12 points)**. There is a clear connection from data to results to discussion and conclusion **(12 points)**.	24	**20**
Reproducibility	Results are completely reproducible by someone with basic GIS training. There is no ambiguity in data flow or rationale for data operations. Every step is documented and justified.	28	**20**
Verification	Results are correct in that they have been verified in comparison to some standard. The standard is clearly stated **(10 points)**, the method of comparison is clearly stated **(5 points)**, and the result of verification is clearly stated **(5 points)**.	20	**18**
		100	**86**