Terrain Analysis and Route Planning using ArcGIS and Spatial Analyst

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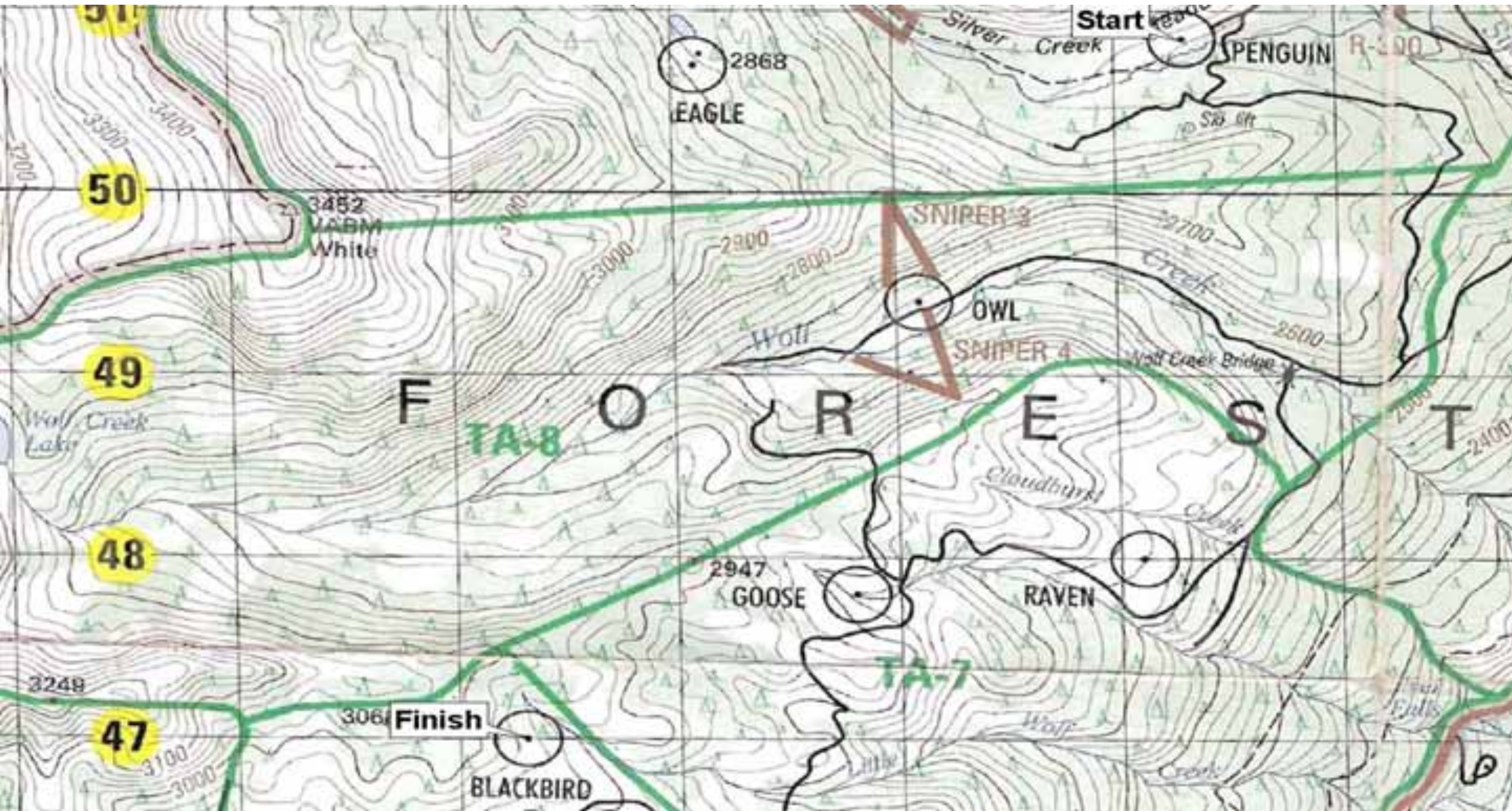
Project started as a way to minimize foot and ankle injuries in the training area.

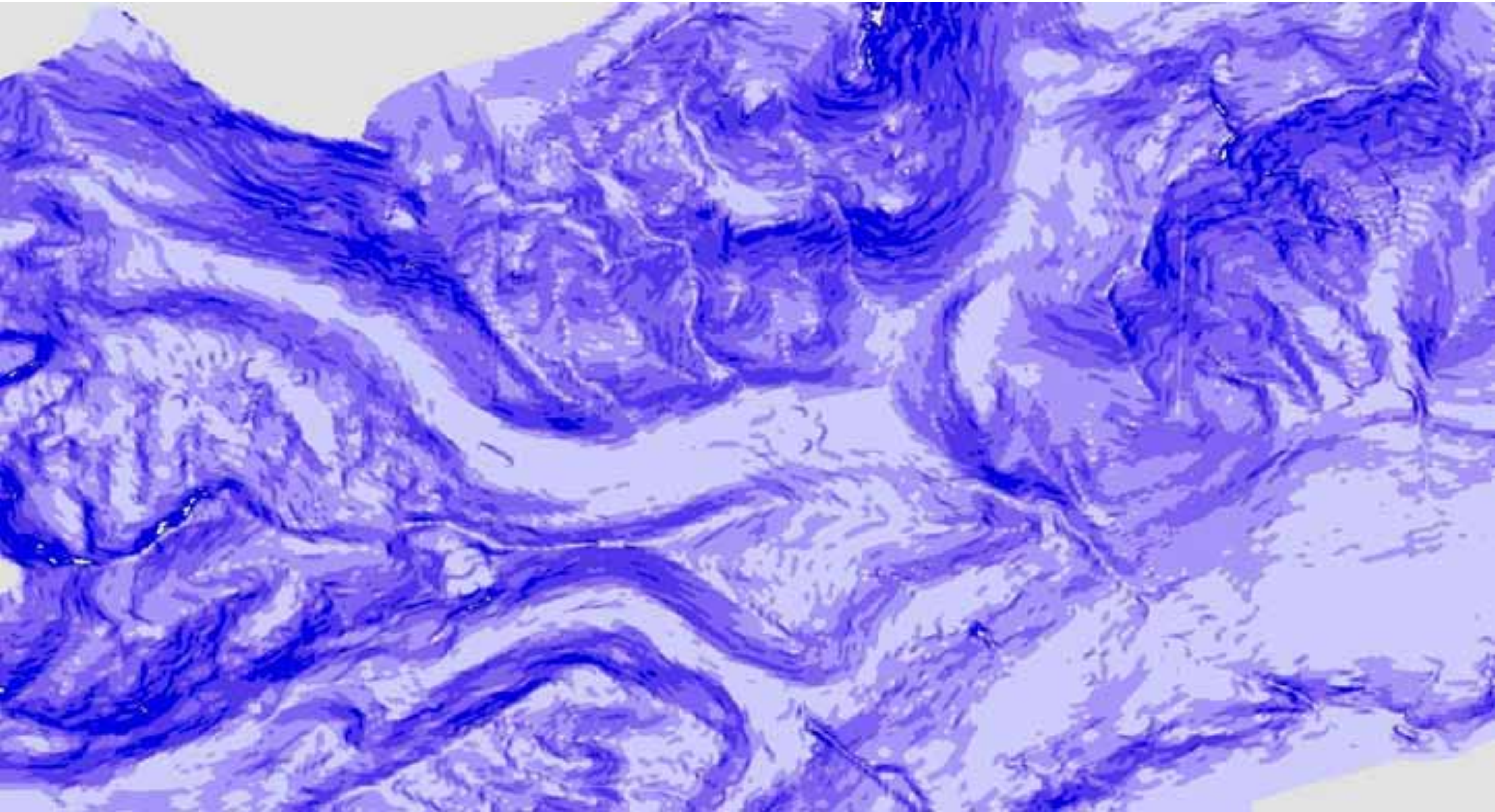
Injuries were occurring because of a combination of steep terrain, poor surface conditions and fatigue.

Route planning for foot traffic on a tactical scale requires knowledge of conditions of the area being traversed.

Field maps generally have enough information to determine slope, vegetative cover and some idea of visibility but give no indication of surface conditions or obstacles that can significantly impede foot traffic.



Slope analysis can be combined with soils data, surface geology and vegetation type to provide a more detailed picture of terrain and provide for better route planning.



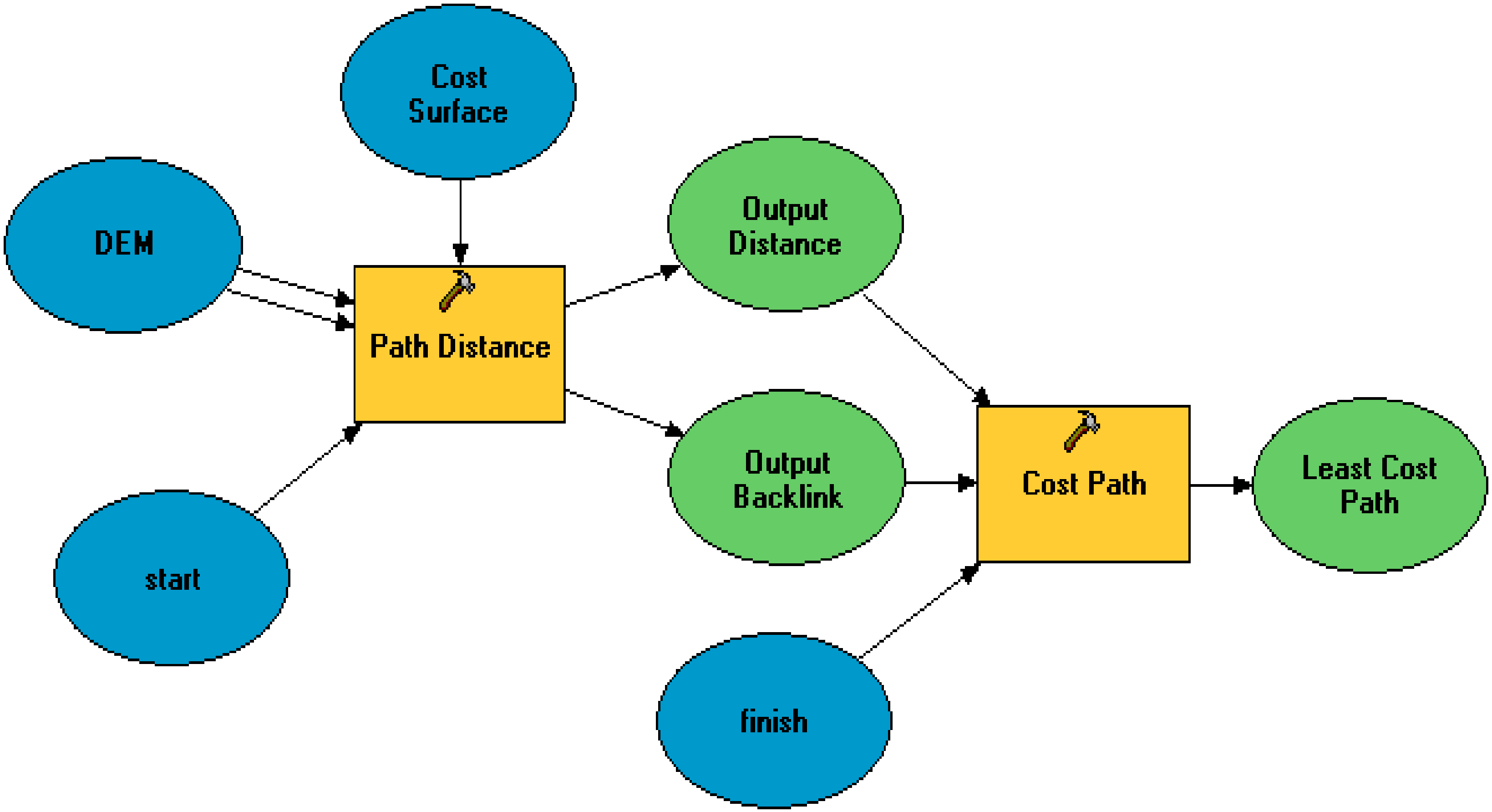
- Approach was to use a least cost path model to find the safest path using our criteria.

- **Least-cost path**: The path between two points which has the lowest travel cost, where cost is a function of time, distance, or other impedance factors.

Least Cost Path Model

Using the Path Distance tool from the Spatial Analyst's Distance Tools to generate a frictional surface (cost distance surface) and a backlink raster for input into the Cost Path tool. The Cost Distance Tool can also be used to generate the cost surface and backlink raster, but the Path Distance Tool accounts for variations in surface distance due to slope and allows for greater flexibility in dealing with vertical factors in slope analysis.

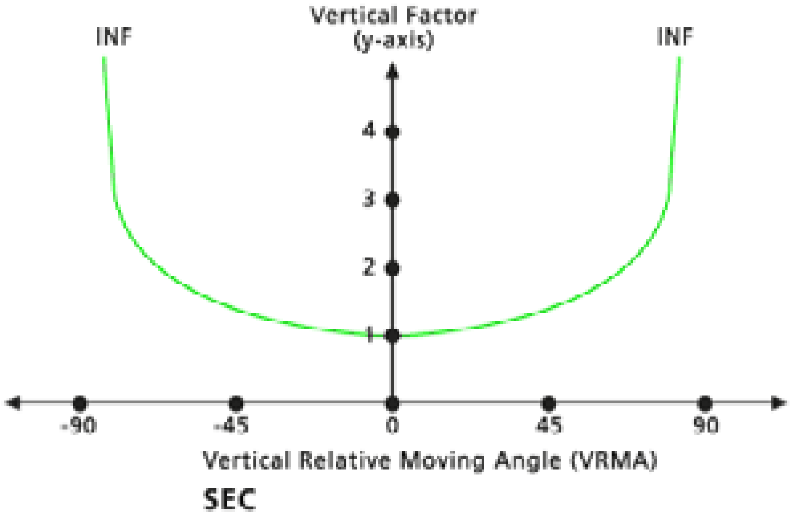
The Path Distance tool was used to to generate a frictional surface (cost distance surface) and a backlink raster for input into the Cost Path tool.



The **Path Distance tool** calculates, for each cell, the least accumulative cost distance to the nearest source, while accounting for surface distance and horizontal and vertical cost factors.

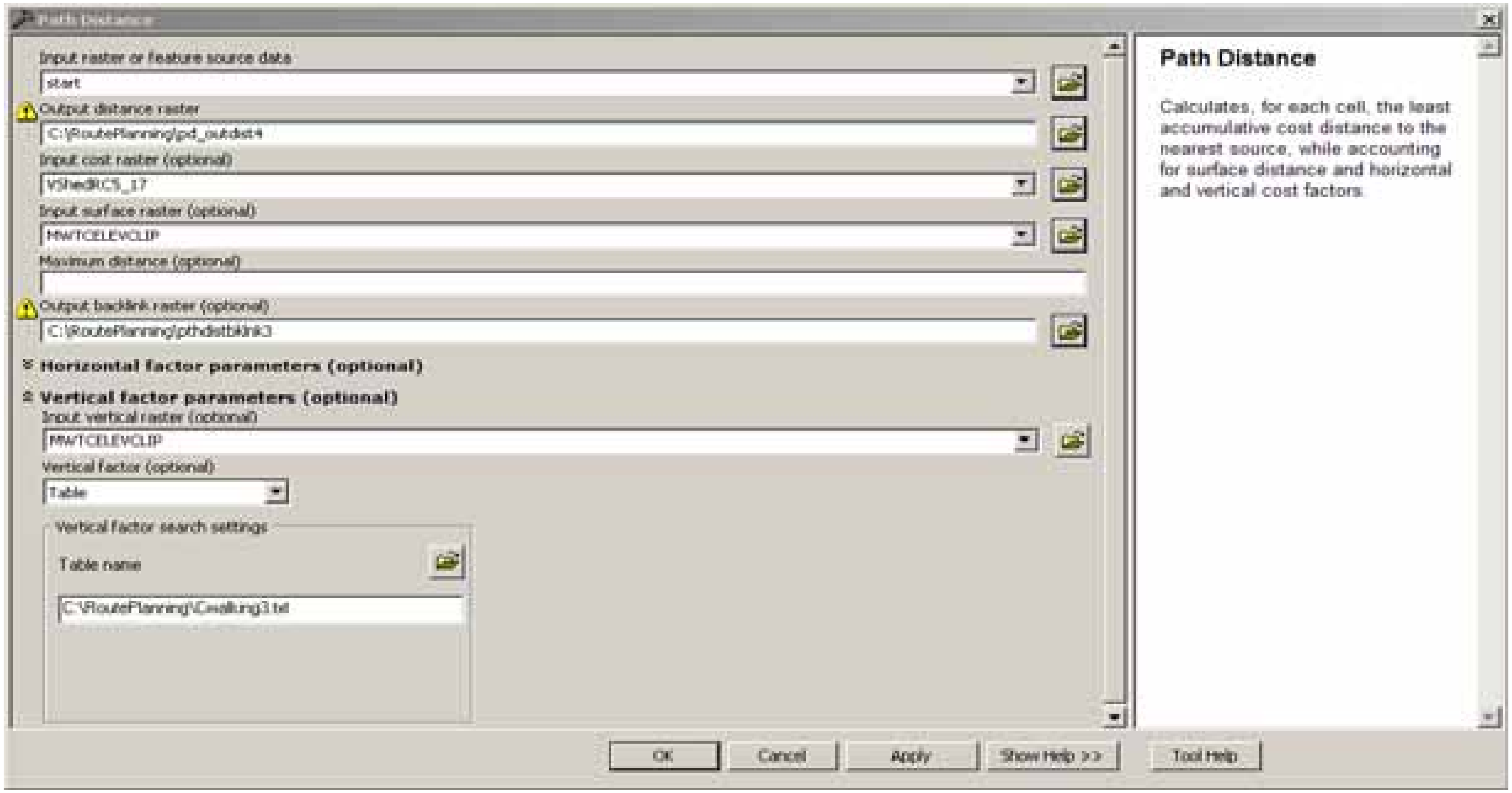
The **Cost Path tool** produces an output raster that records the least-cost path or paths from selected locations to the closest source cell defined within the accumulative cost surface, in terms of cost distance.

- First built model using **Cost Distance** tool to generate friction surface based on slope.

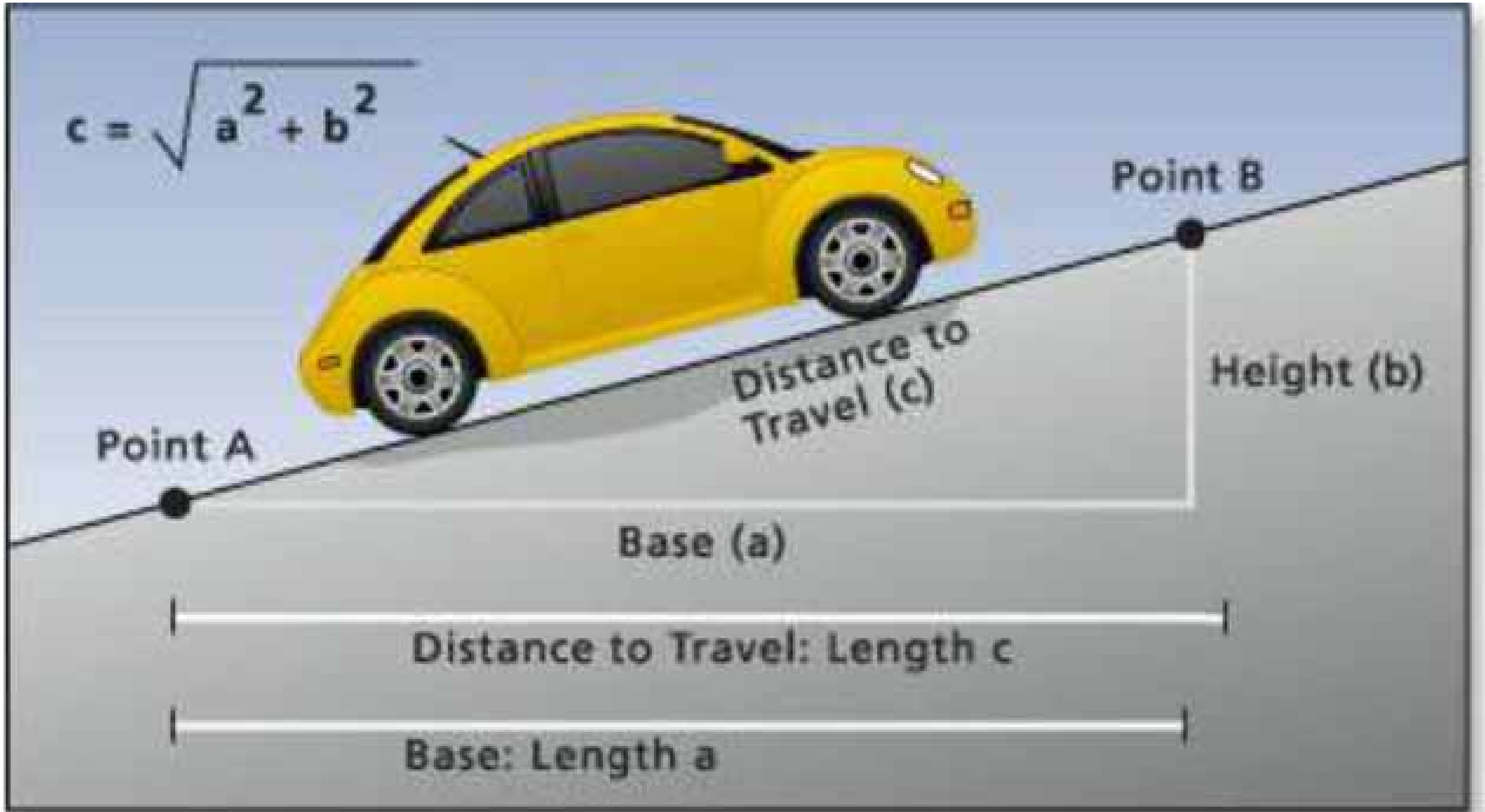


- Using the **Cost Distance** tool, the frictional surface generated considers going downhill to be just as difficult as going uphill.

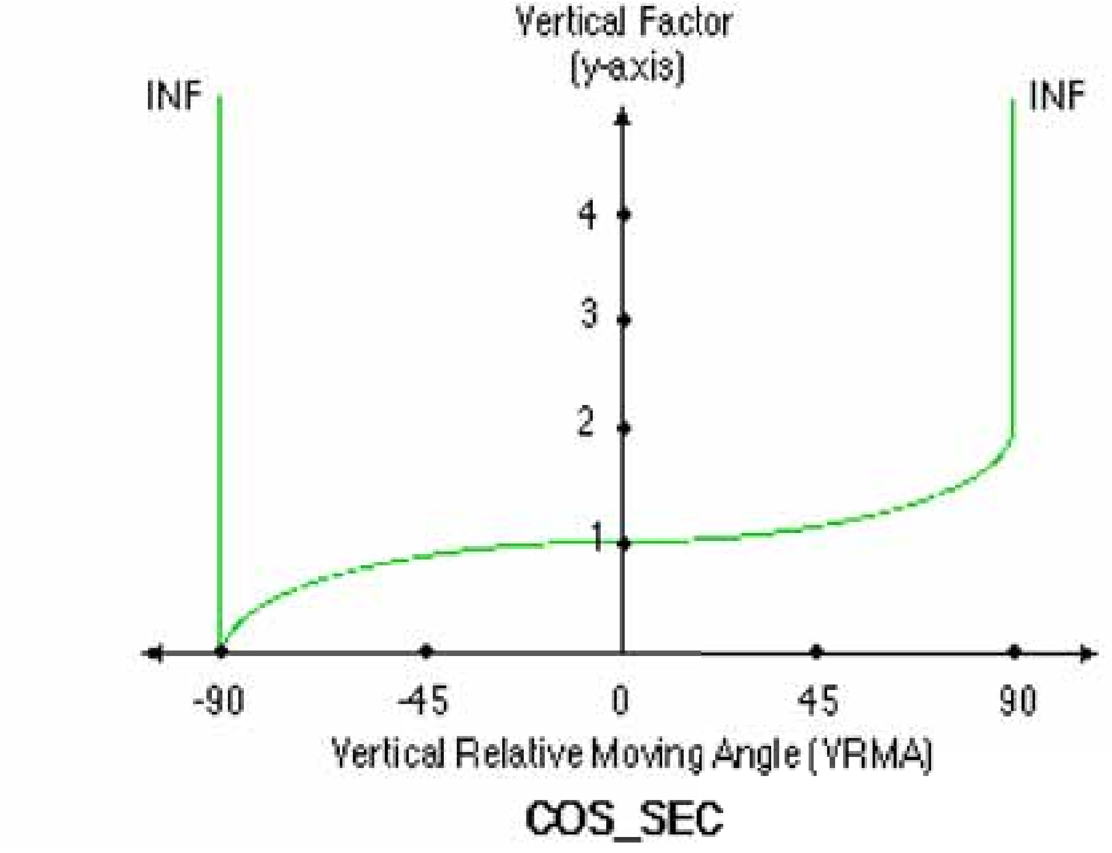
Path Distance tool provides analysis of surface distance of sloping surfaces and for slope analysis based on direction of travel (vertical factor analysis).



Surface Distance
vs
Planimetric Distance



- **Vertical factor analysis** in the Path Distance Tool allows for cost surface analysis of slope based on a variety of curves or allows the use of user data for slope/effort analysis.



- I used a data from a study titled *“The Energy Cost of Walking and Running at Extreme Uphill and Downhill Slopes”.*

- Study shows that (obviously) walking or running uphill takes more energy than walking or running on flat surfaces. But the study also shows that the effort required to travel downhill increases as slope increases beyond a certain point.

Table from: *Energy Cost of Walking and Running at Extreme Uphill and Downhill Slopes*

Table 2. *Minimum cost of walking and cost of running at the indicated slopes on the treadmill*

Slope	Cw	Cr	Slope	Cw	Cr	Slope	Cw	Cr
−0.45	$n=10$ 3.46 ± 0.95	$n=9$ 3.92 ± 0.81	0	$n=10$ 1.64 ± 0.50	$n=30$ 3.40 ± 0.24	0.45	$n=10$ 17.33 ± 1.11	$n=6$ 18.93 ± 1.74
−0.40	$n=10$ 3.23 ± 0.59	$n=13$ 3.49 ± 0.47				0.40	$n=10$ 14.75 ± 0.61	$n=6$ 16.83 ± 0.88
−0.35	$n=10$ 2.65 ± 0.68	$n=18$ 2.81 ± 0.54				0.35	$n=10$ 12.72 ± 0.76	$n=12$ 14.43 ± 1.08
−0.30	$n=10$ 2.18 ± 0.67	$n=24$ 2.43 ± 0.50				0.30	$n=10$ 11.29 ± 1.14	$n=24$ 12.52 ± 0.62
−0.20	$n=10$ 1.30 ± 0.48	$n=24$ 1.73 ± 0.36				0.20	$n=10$ 8.07 ± 0.57	$n=30$ 8.92 ± 0.84
−0.10	$n=10$ 0.81 ± 0.37	$n=24$ 1.93 ± 0.45				0.10	$n=10$ 4.68 ± 0.34	$n=30$ 5.77 ± 0.60

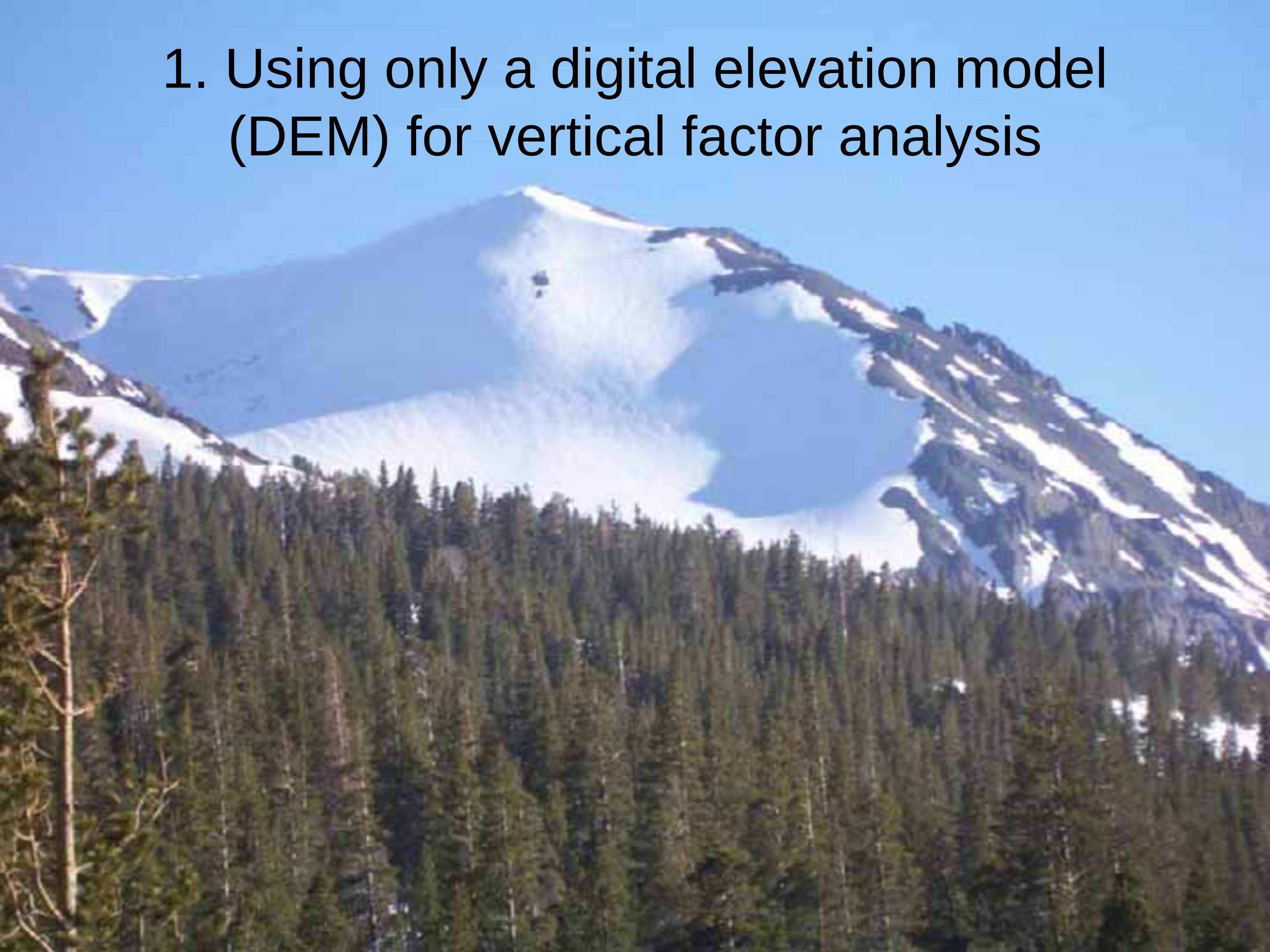
Values are means ± SD. Cw, cost of walking; Cr, cost of running.

- The vertical factor analysis (VFA) travel cost is based on values derived from this table.

- When weighting other layers for analysis through reclassification, the final cost raster to be used in Path Distance Tool must be weighted properly, considering vertical factor analysis, (VFA) or risks either overwhelming the VFA data, or being insignificant to the analysis.

- 4 Different Scenarios
  1. Using only a digital elevation model (DEM) for vertical factor analysis.
  2. Using linear features (roads and streams) combined with vertical factor analysis.
  3. Using polygon features (surface fragments and vegetation) combined with vertical factor analysis.
  4. Using viewshed analysis combined with vertical factor analysis.

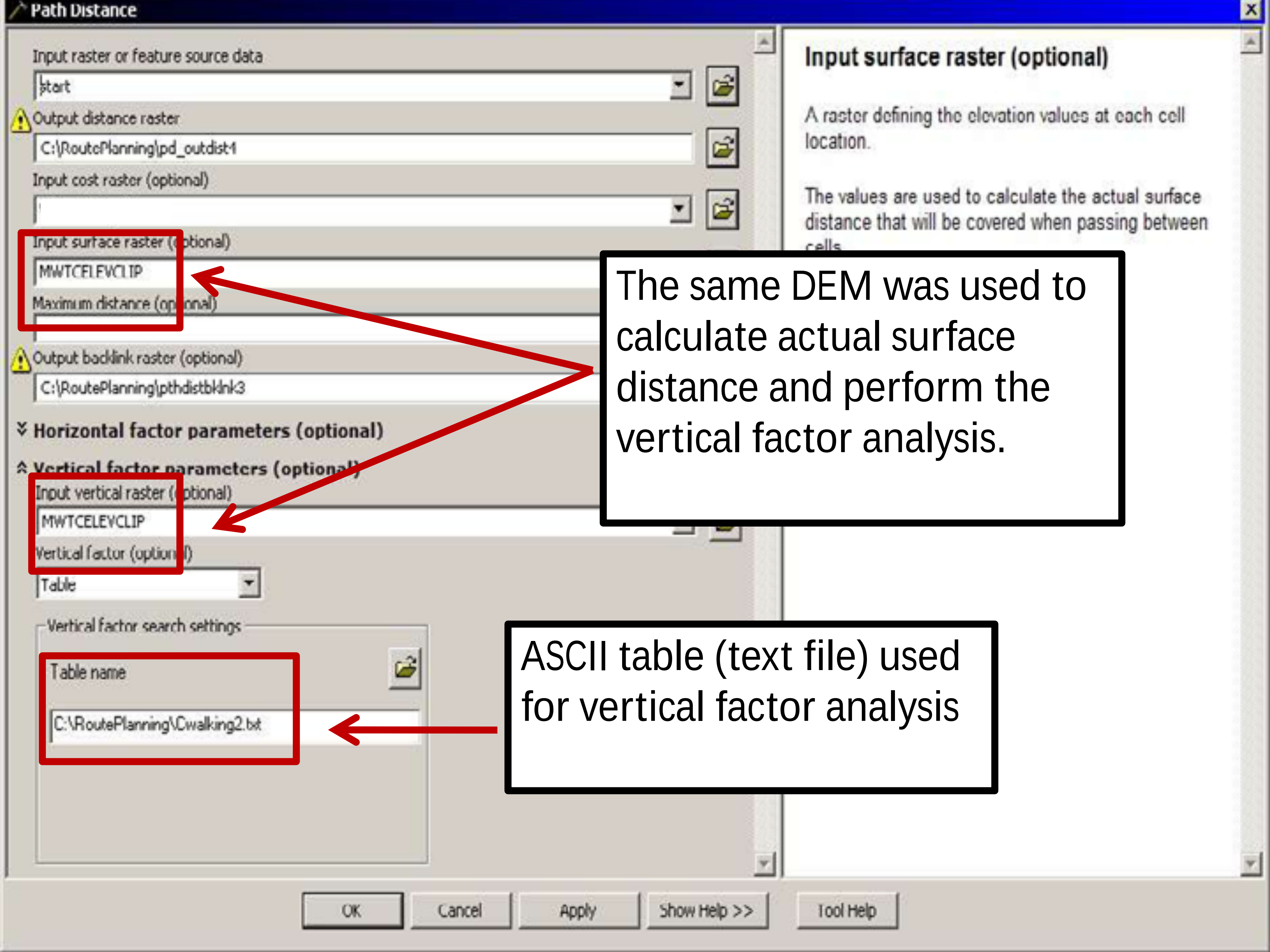
1. Using only a digital elevation model (DEM) for vertical factor analysis



Data Preparation

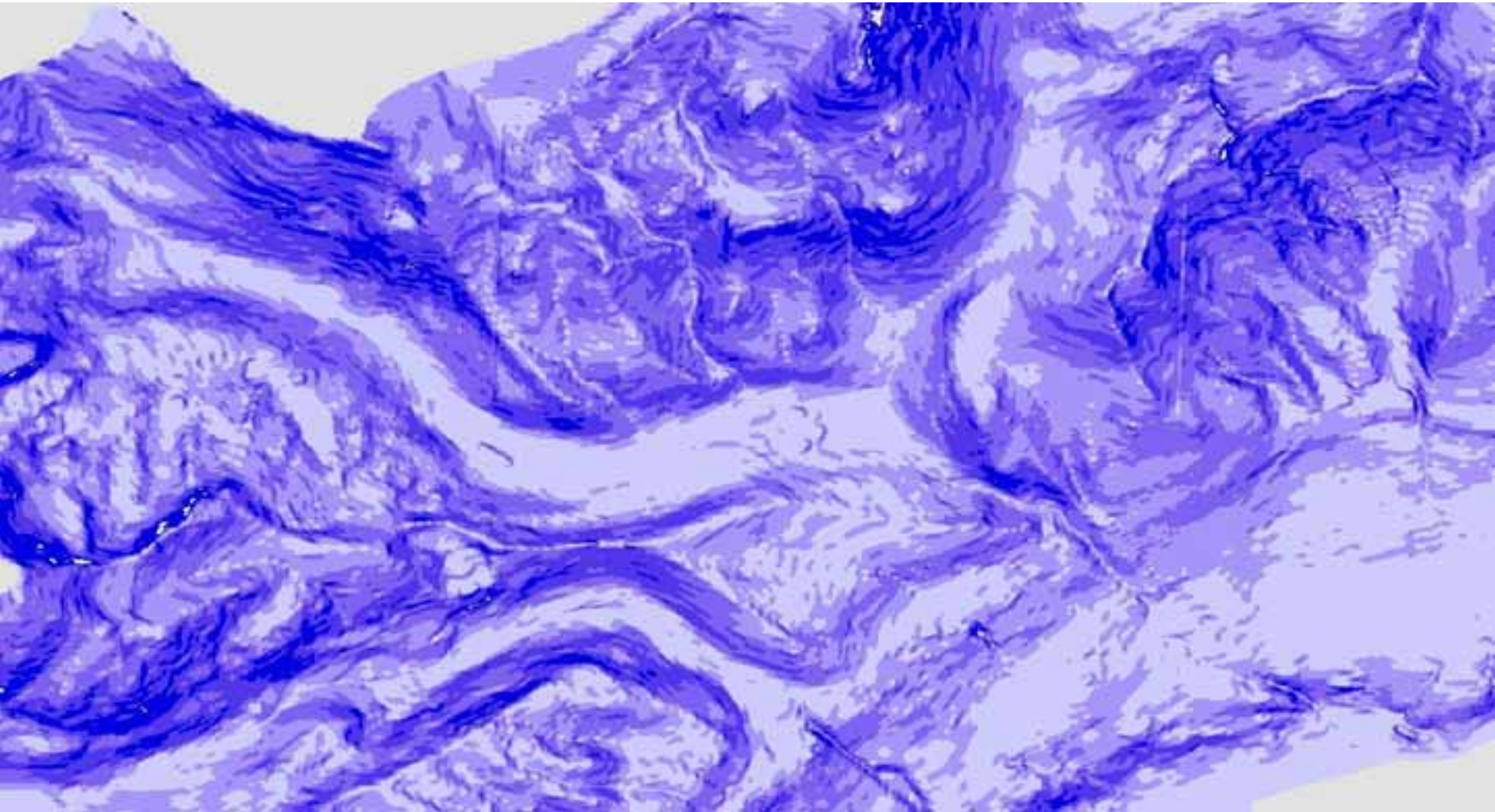
- I used a 30 meter resolution DEM from the USGS, I reprojected to UTM meters and clipped it to the study area.

- Using Spatial Analyst, I calculated a slope raster based on the DEM of the study area.

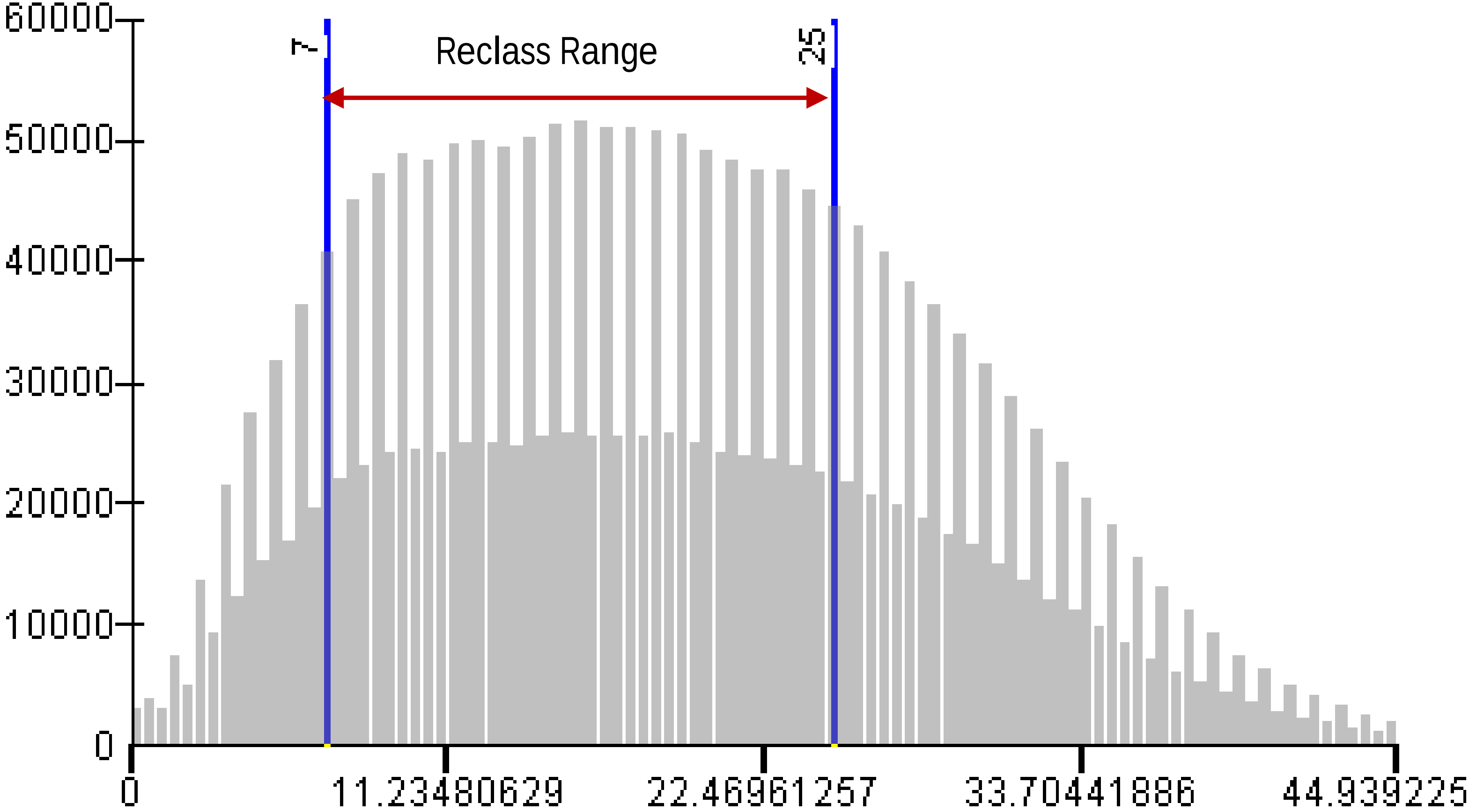


Path Distance
Input raster or feature source data
start
Output distance raster
C:\RoutePlanning\pd_outdist1
Input cost raster (optional)
Input surface raster (optional)
MWTCELEVCLIP
Maximum distance (optional)
Output backlink raster (optional)
C:\RoutePlanning\pthdistbklnk3
Horizontal factor parameters (optional)
Vertical factor parameters (optional)
Input vertical raster (optional)
MWTCELEVCLIP
Vertical factor (optional)
Table
Vertical factor search settings
Table name
C:\RoutePlanning\Cwalking2.txt
OK
Cancel
Apply
Show Help >>
Tool Help
Input surface raster (optional)
A raster defining the elevation values at each cell location.
The values are used to calculate the actual surface distance that will be covered when passing between cells.
The same DEM was used to calculate actual surface distance and perform the vertical factor analysis.
ASCII table (text file) used for vertical factor analysis

- The slope raster calculated from the DEM wasn't actually used in the model, but it was used to help calibrate the model.



Classification of slope raster, the peak of the data values lies between about 7 and 25 degrees.



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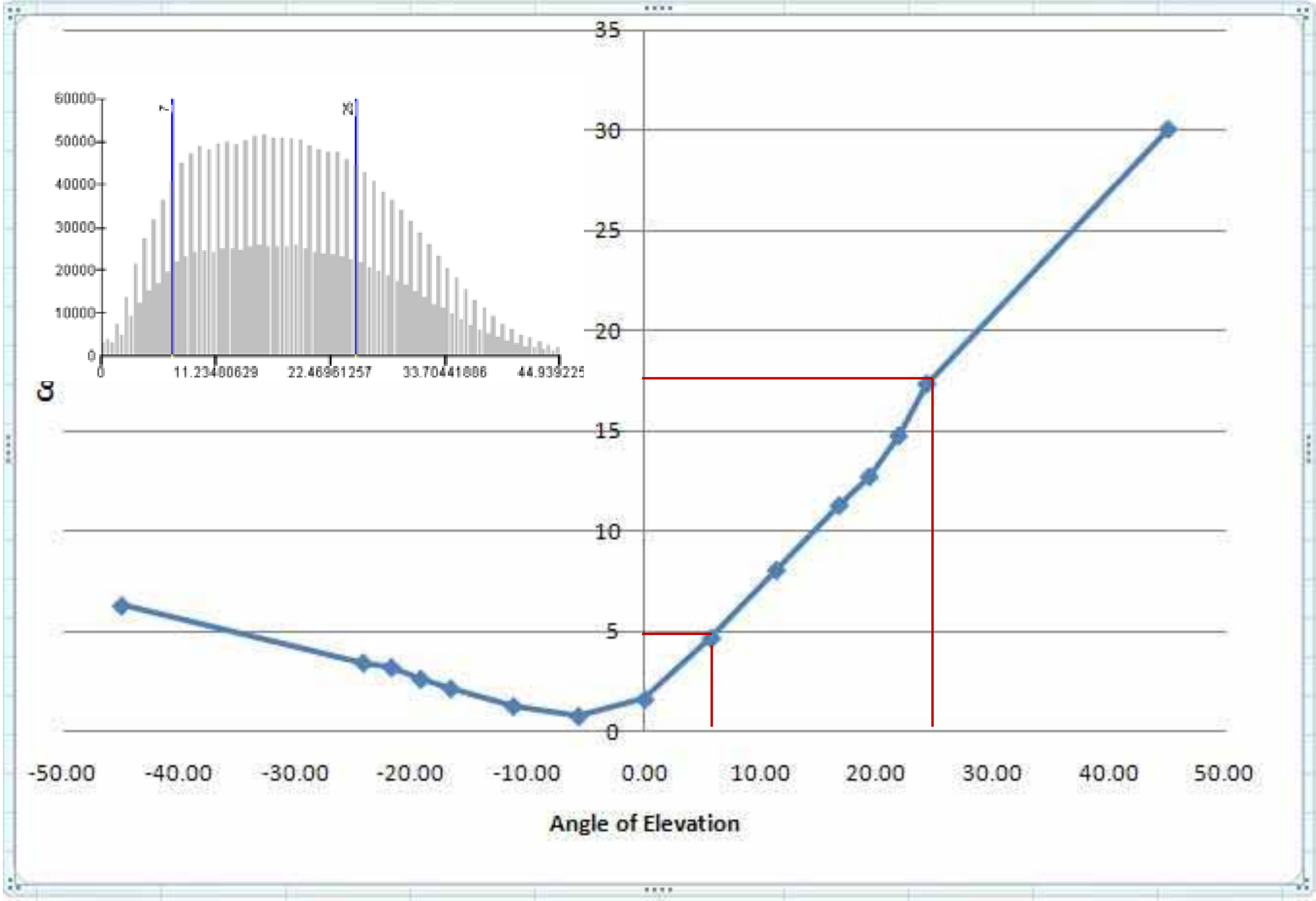
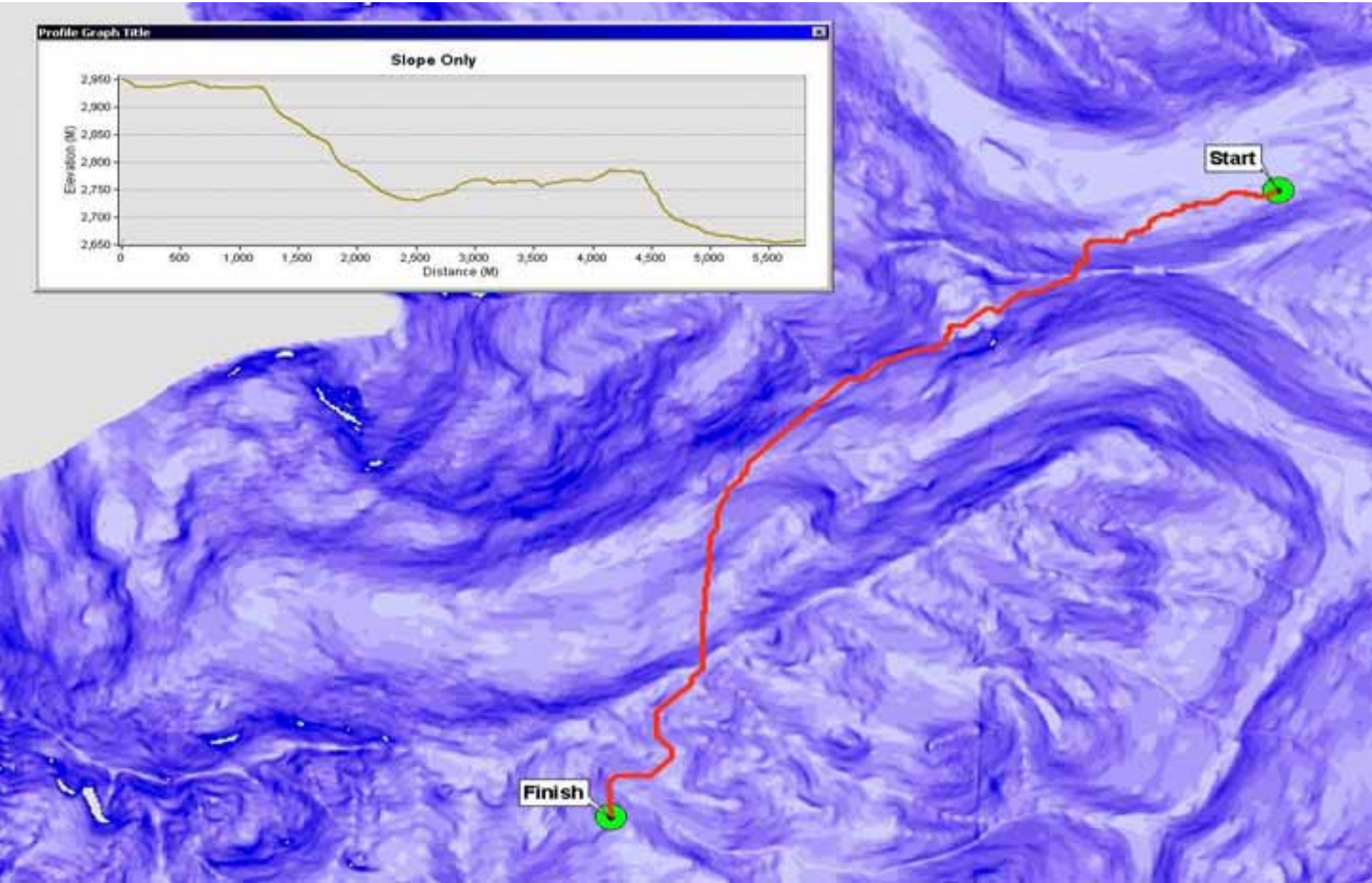


The start and finish points were simple point shapefiles.

Results of Vertical factor Analysis



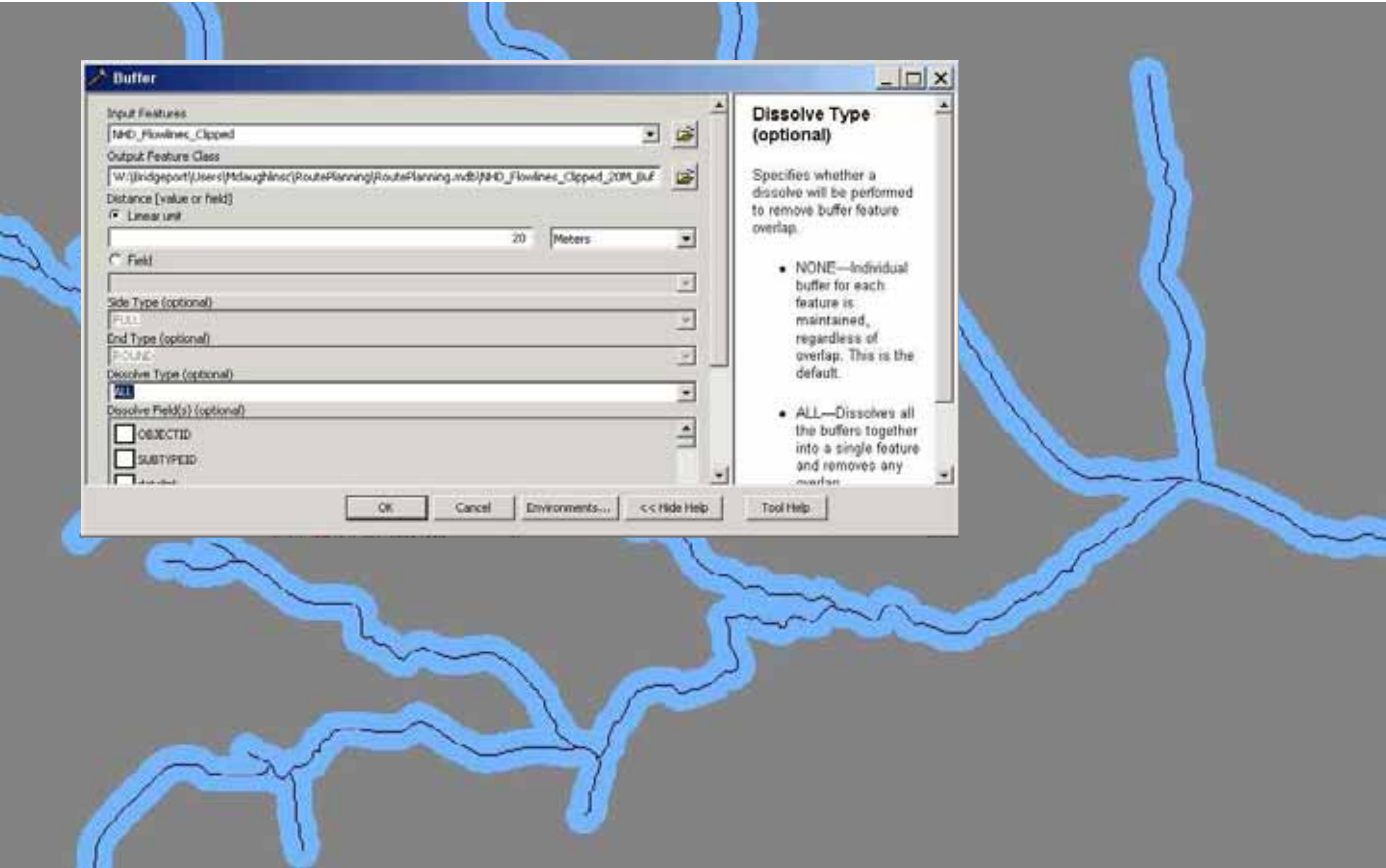
2. Using linear features combined with vertical factor analysis

Data Preparation

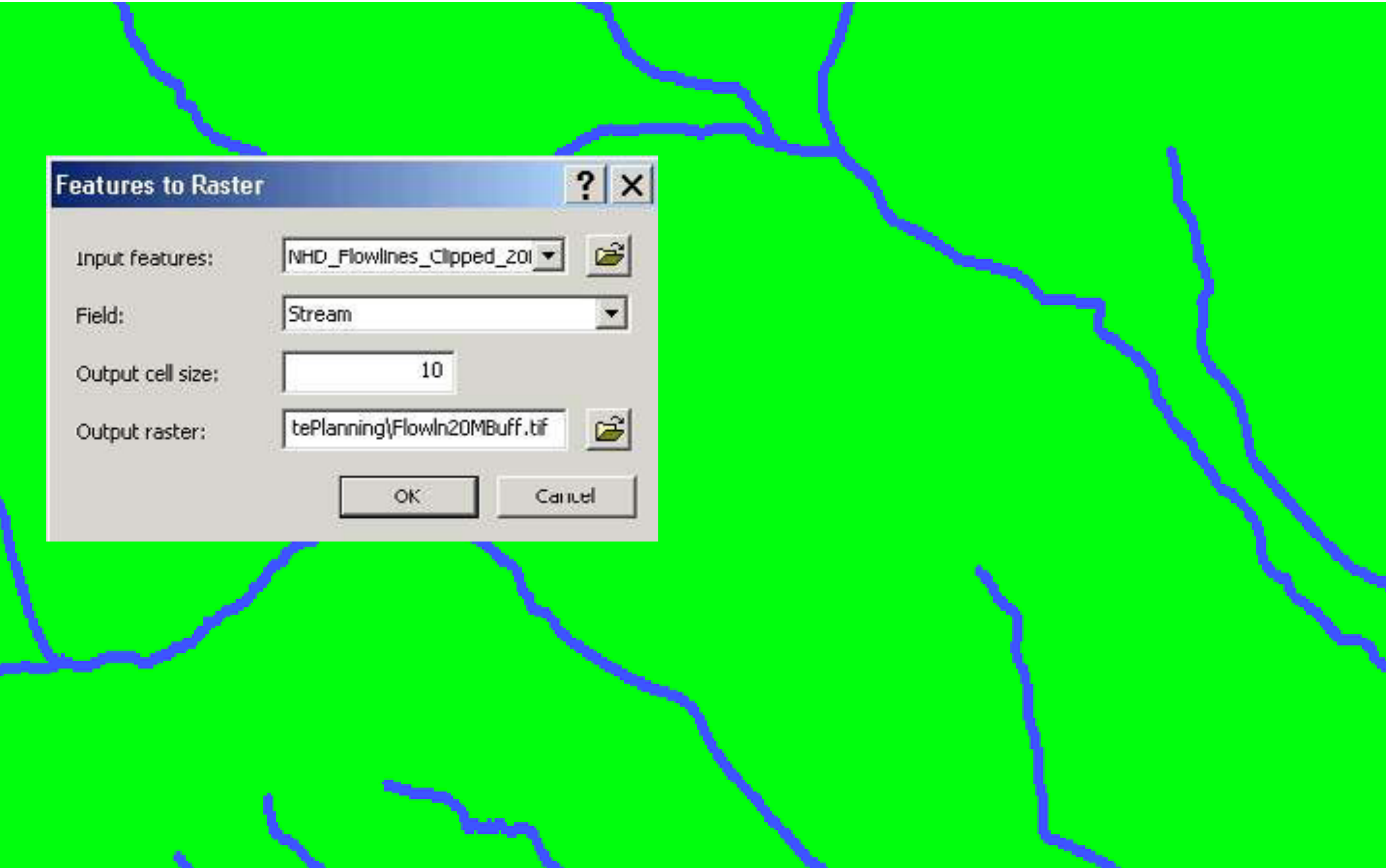
- Used the DEM from first analysis for surface distance and vertical factor analysis.
- 2 separate polyline feature classes (streams and roads) were clipped to the study area.

And…

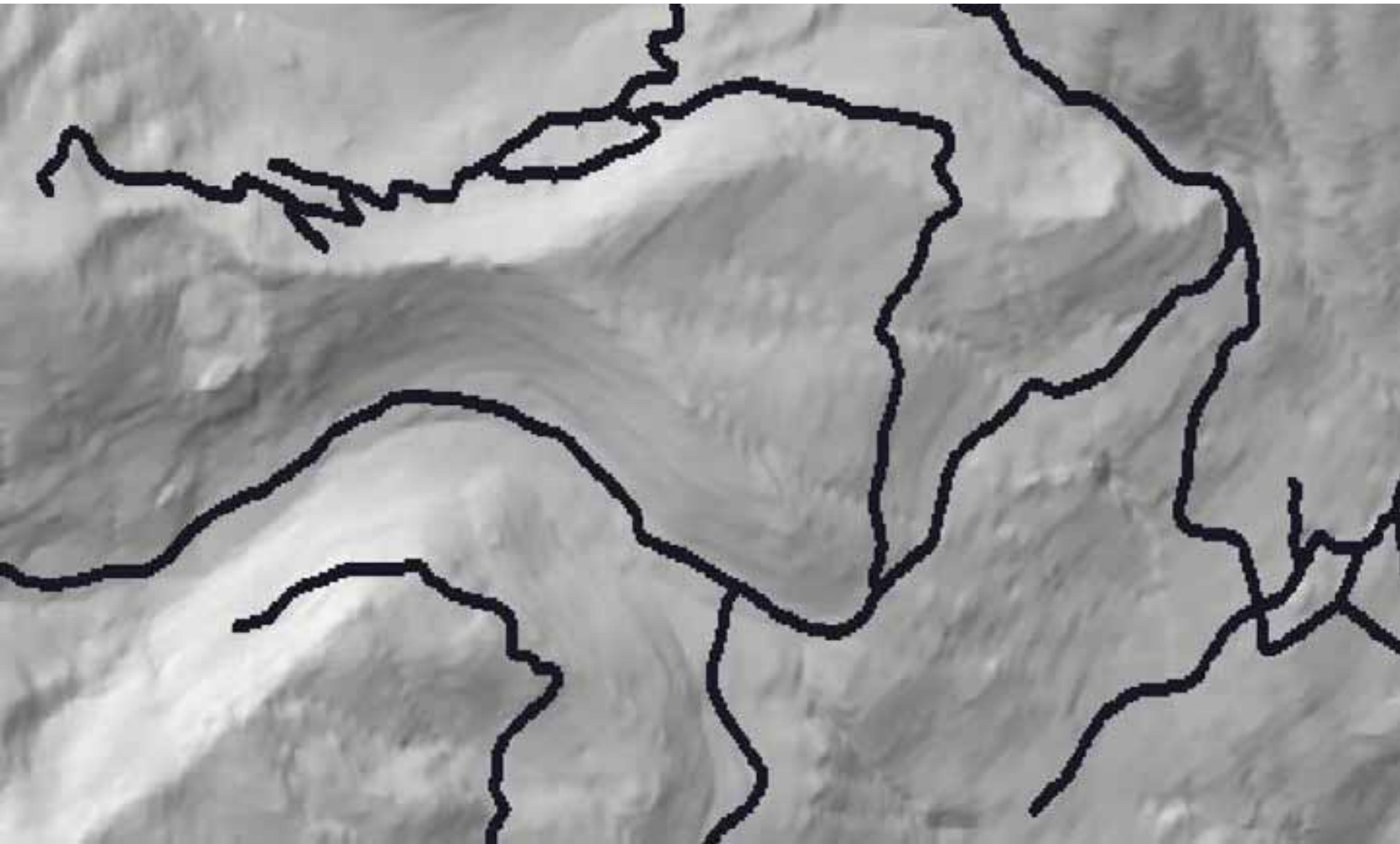
Buffered with a 20 meter buffer



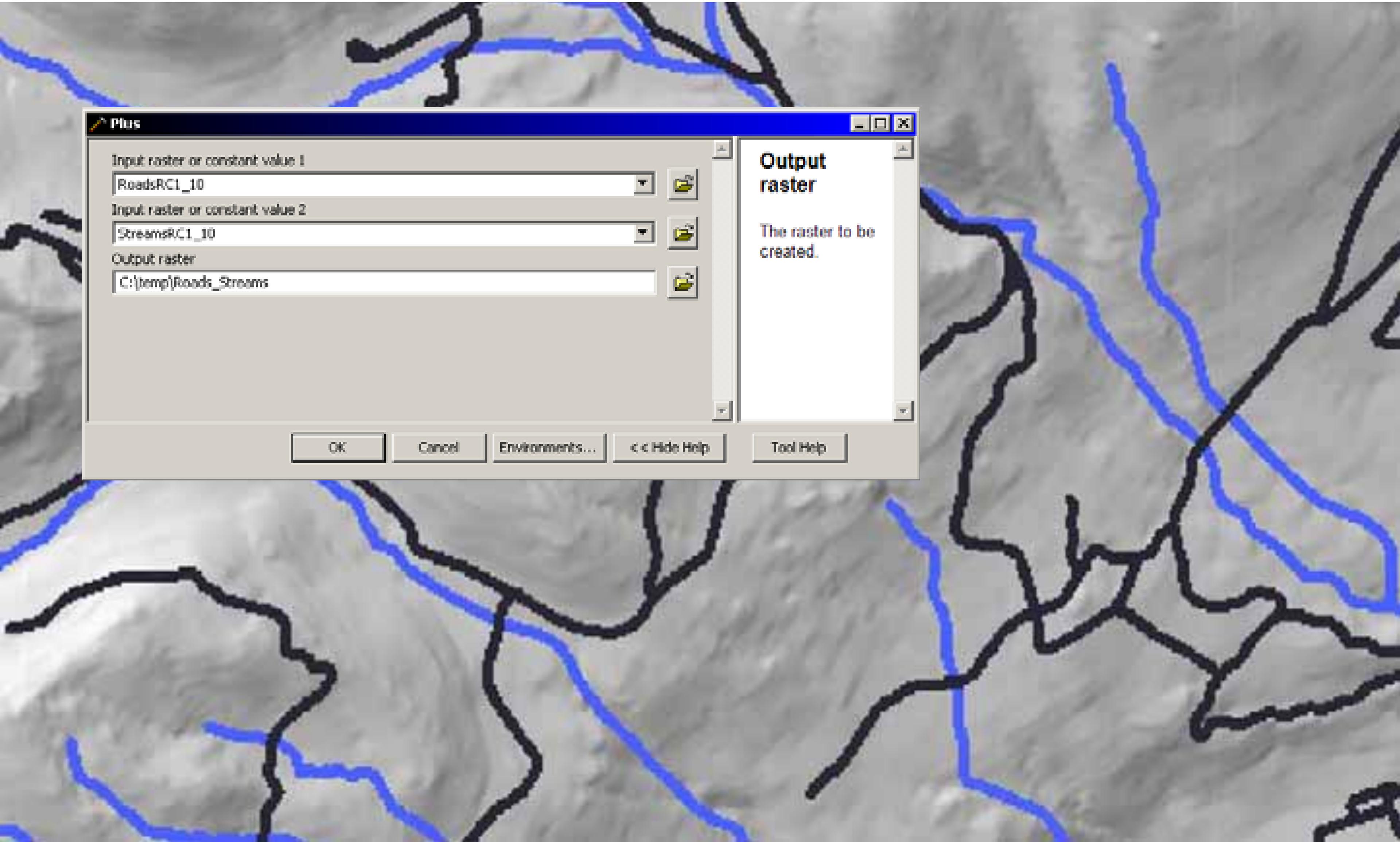
Converted to 10 meter raster



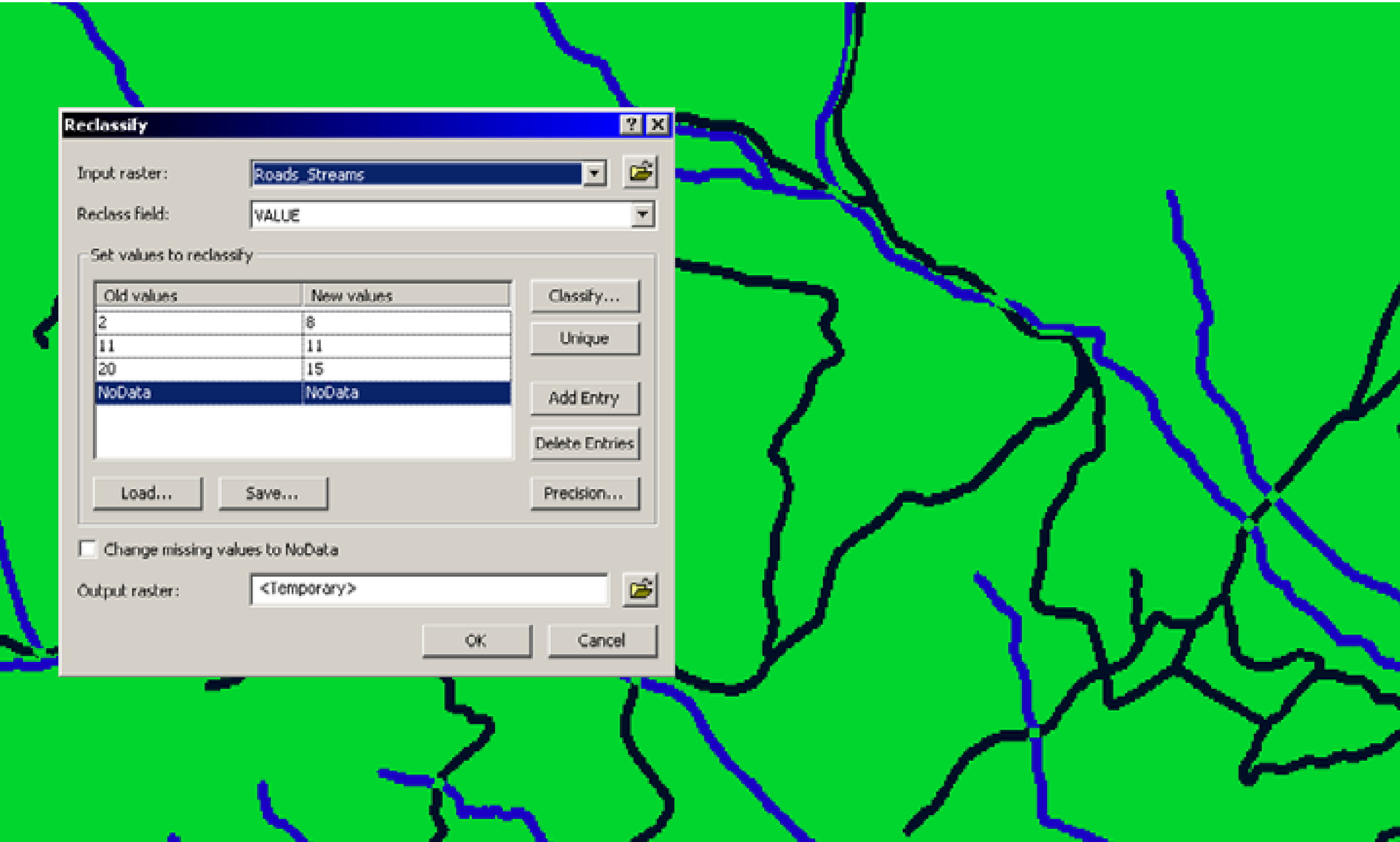
The roads layer was prepared using the same procedure



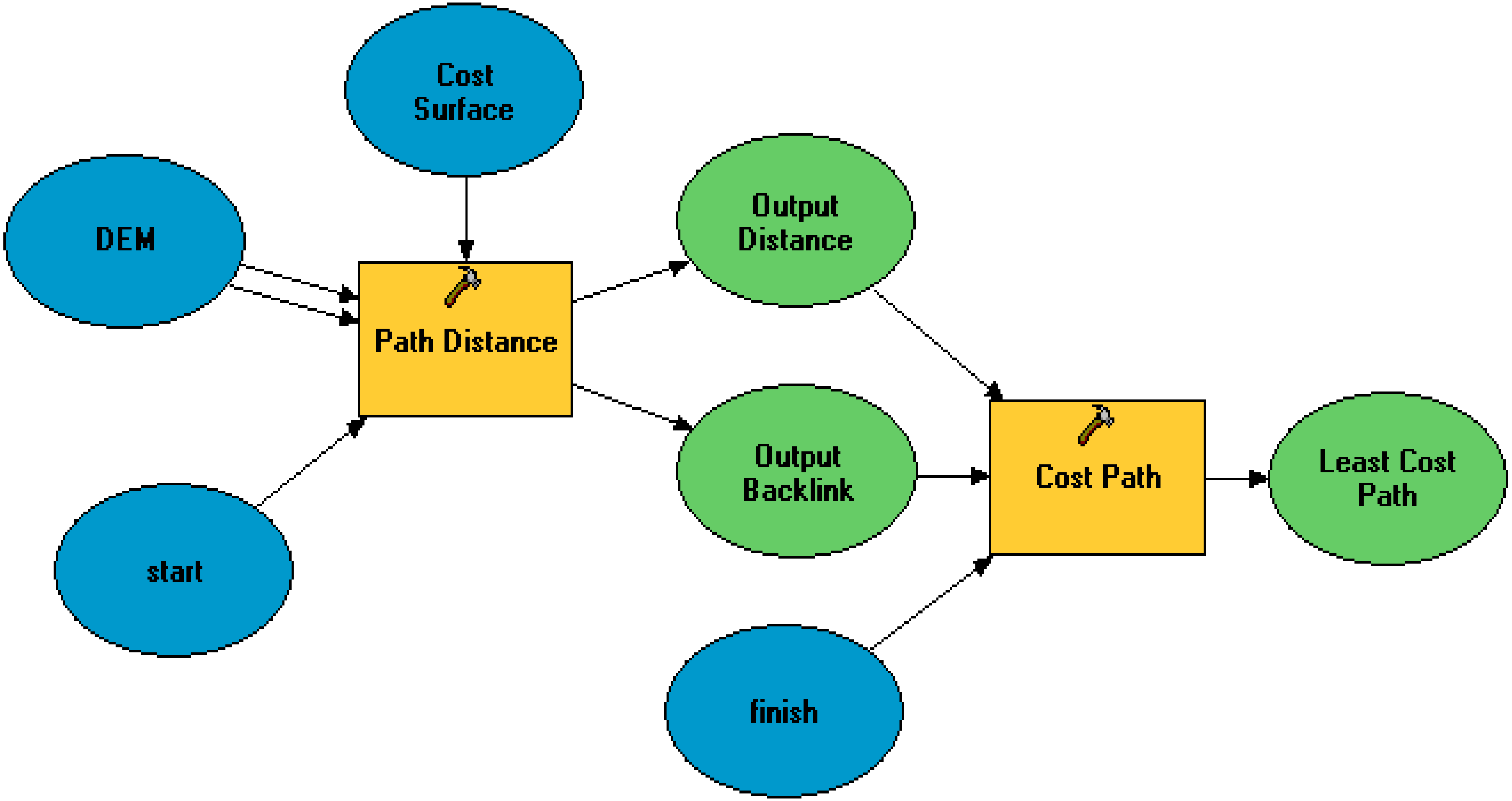
Streams and Roads combined with Plus tool from the Raster Math tool set



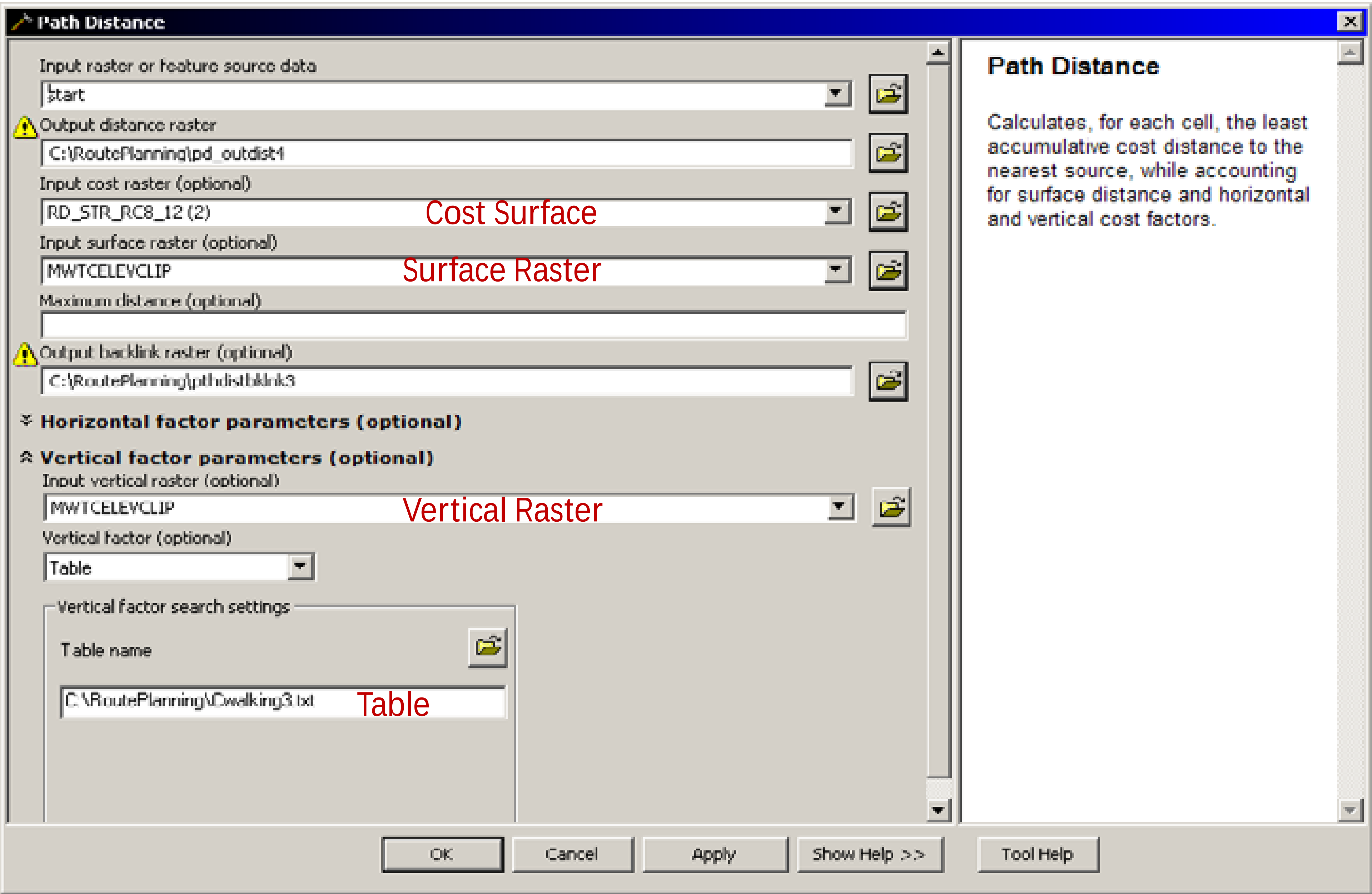
The combined roads and streams reclassified to fit in 5 – 17 reclass range



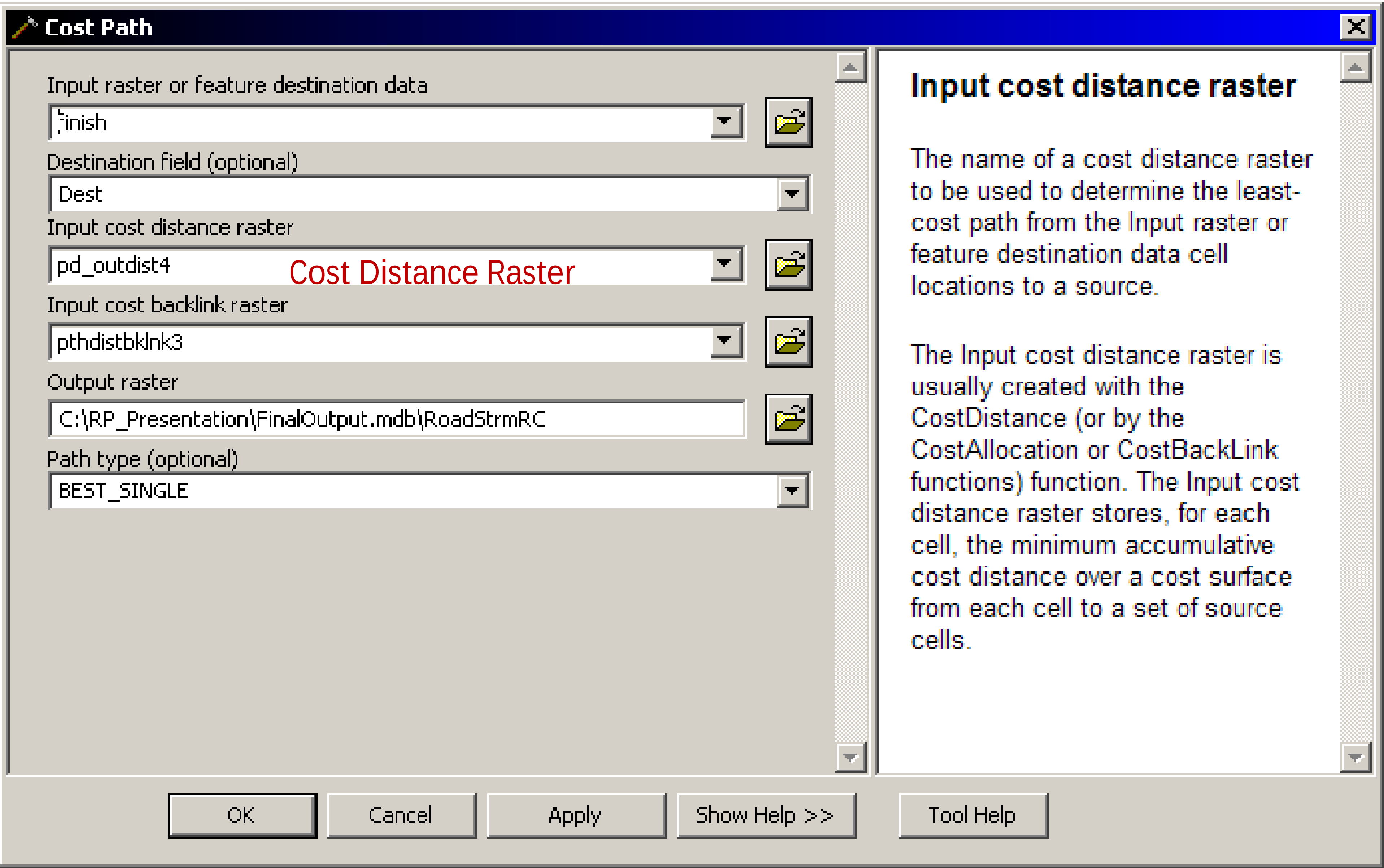
Path Distance – Cost Path Model



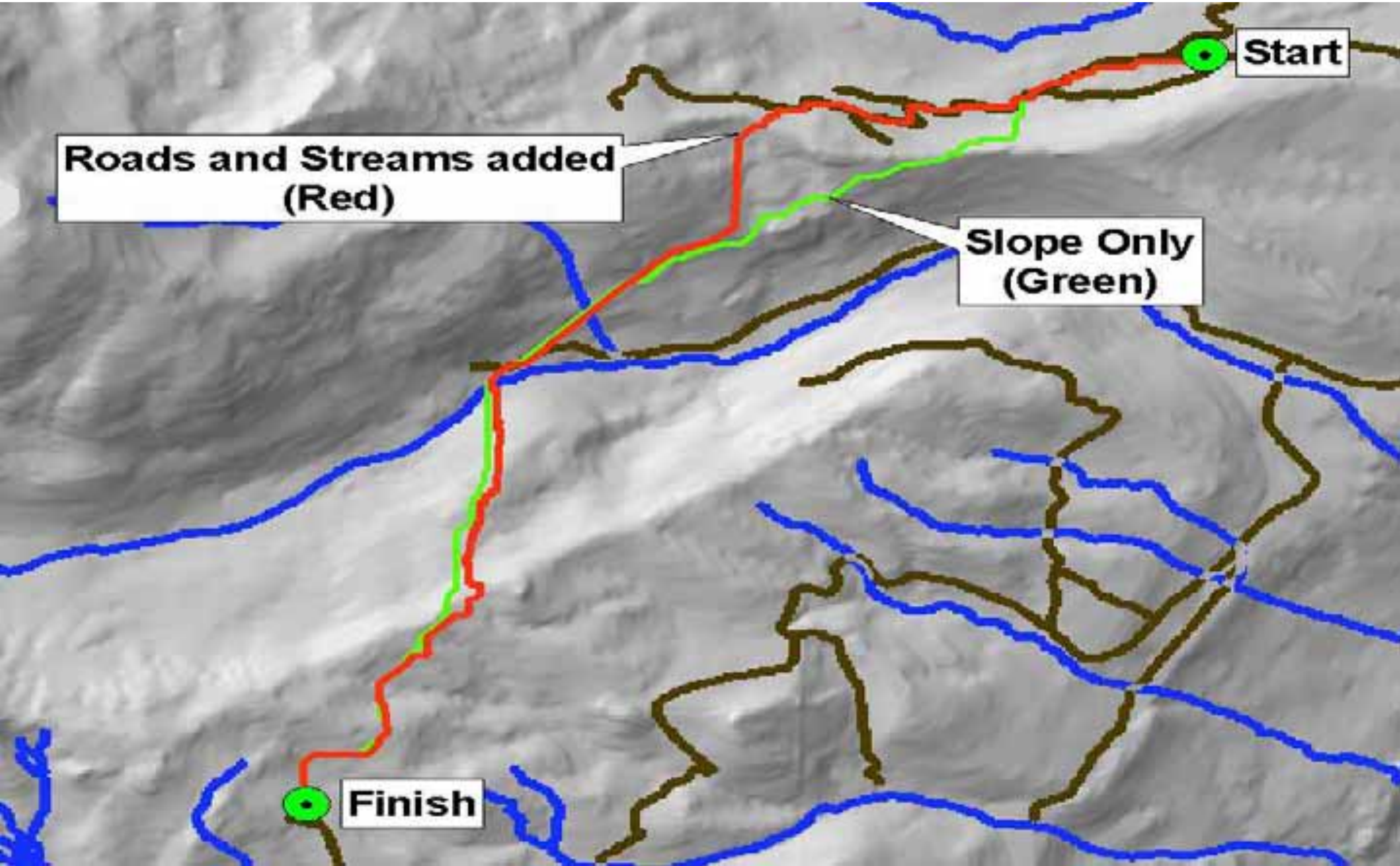
Path Distance Tool



Cost Path Tool



Comparison of slope only vs adding slope and stream cost surface



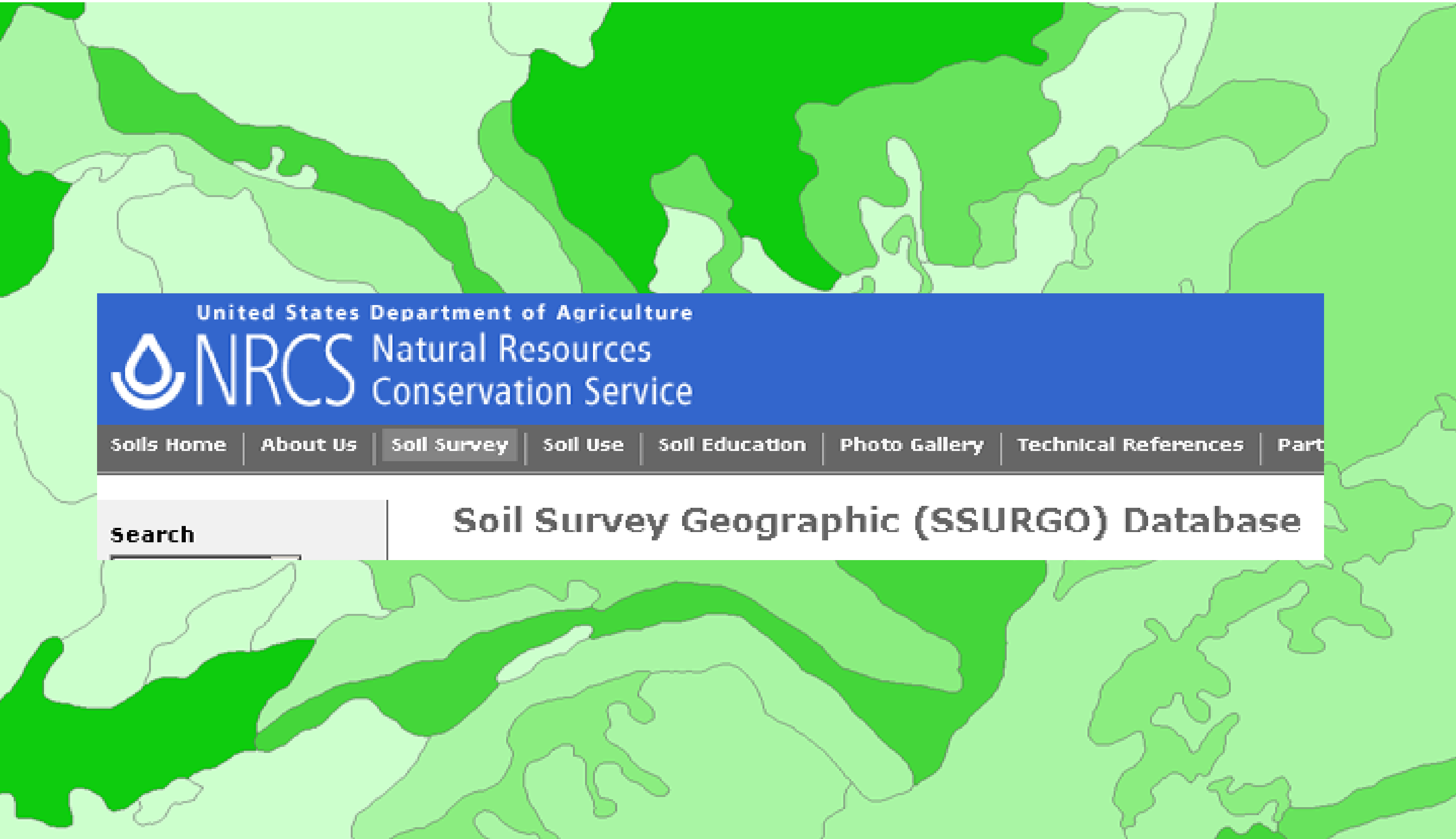
Steeper path mitigated by following road for a portion of the path

3. Using polygon features (surface fragments and vegetation) combined with vertical factor analysis.

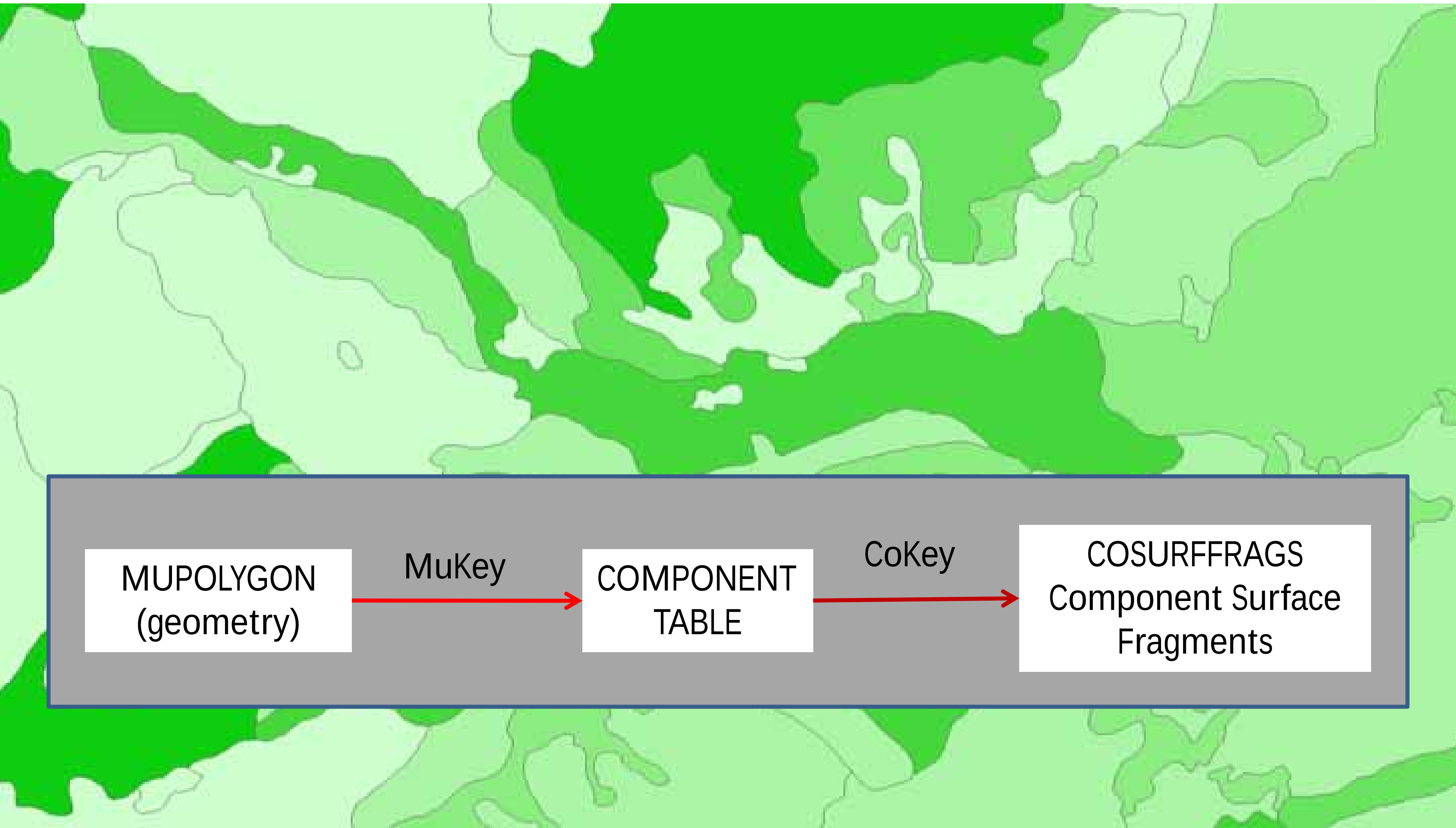
Data Preparation

- Used the DEM from first analysis for surface distance and vertical factor analysis.
- Vegetation and surface texture data derived from the Natural Resources Conservation Service's Soil Survey Geographic Database.

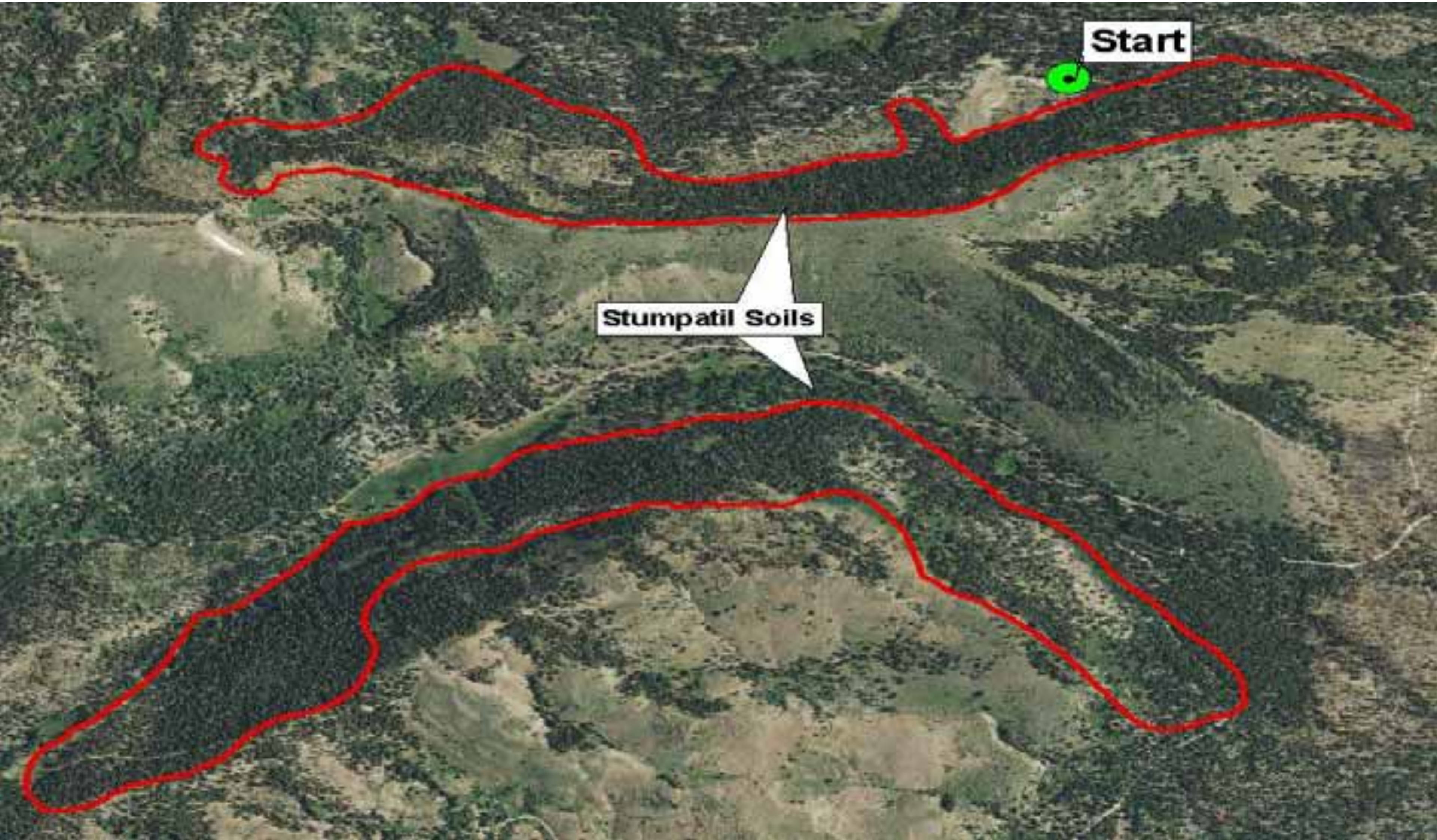
The Natural Resources Conservation Service's Soil Survey Geographic Database



Surface fragments shapefile derived by joining Map Unit polygons to the component table and then to the Component Surface Fragments table.



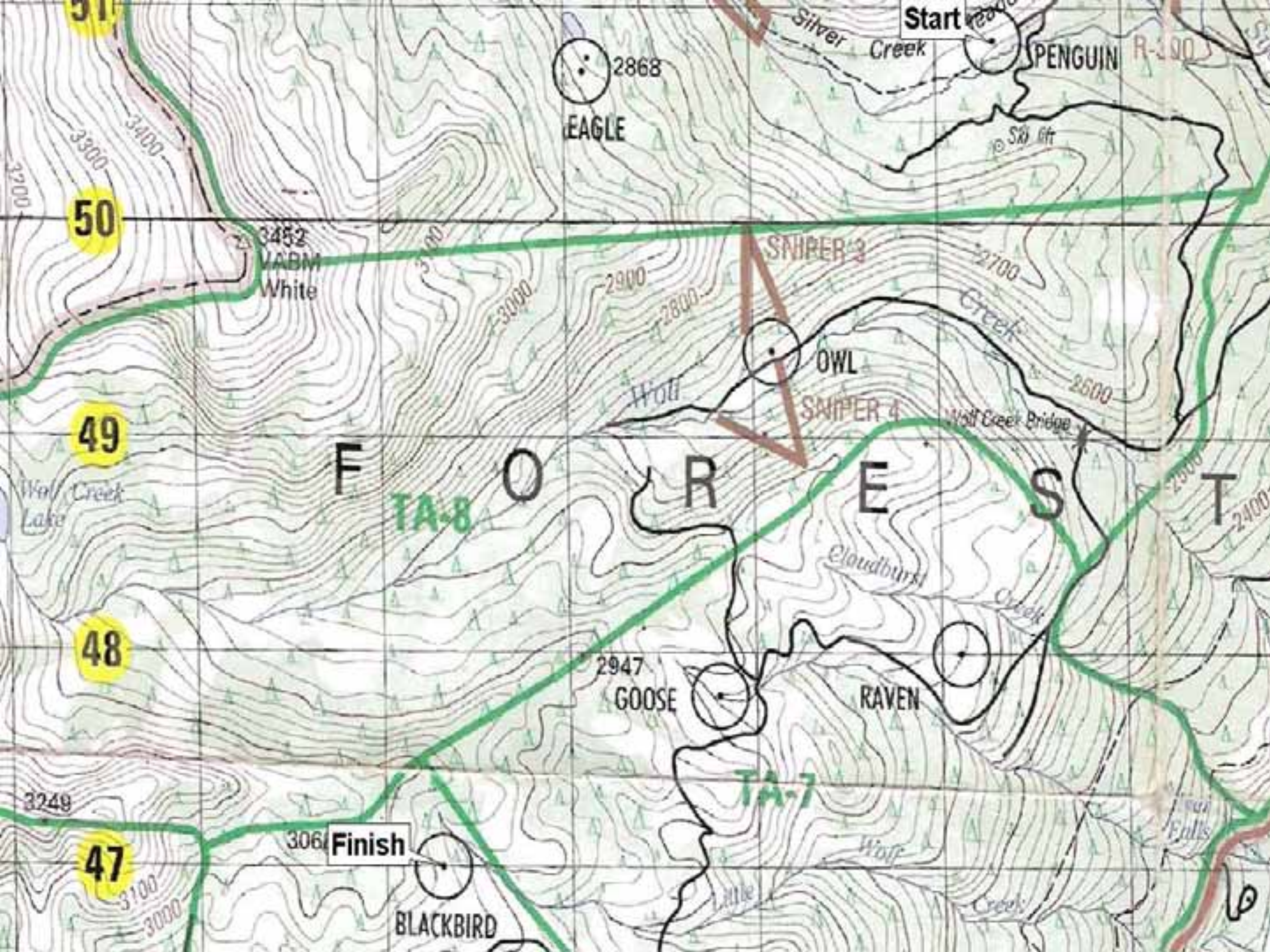
Using air photo analysis and conversations with locals, I determined that the areas marked as having Stumpatil soils were heavily vegetated and could impede foot traffic .



STUMPATIL SERIES

The Stumpatil series consists of very deep, well drained soils that formed in till derived from mixed rocks. Stumpatil soils are on moraines. Slopes are 8 to 50 percent. The mean annual precipitation is about 45 inches and the mean annual temperature is about 38 degrees F.

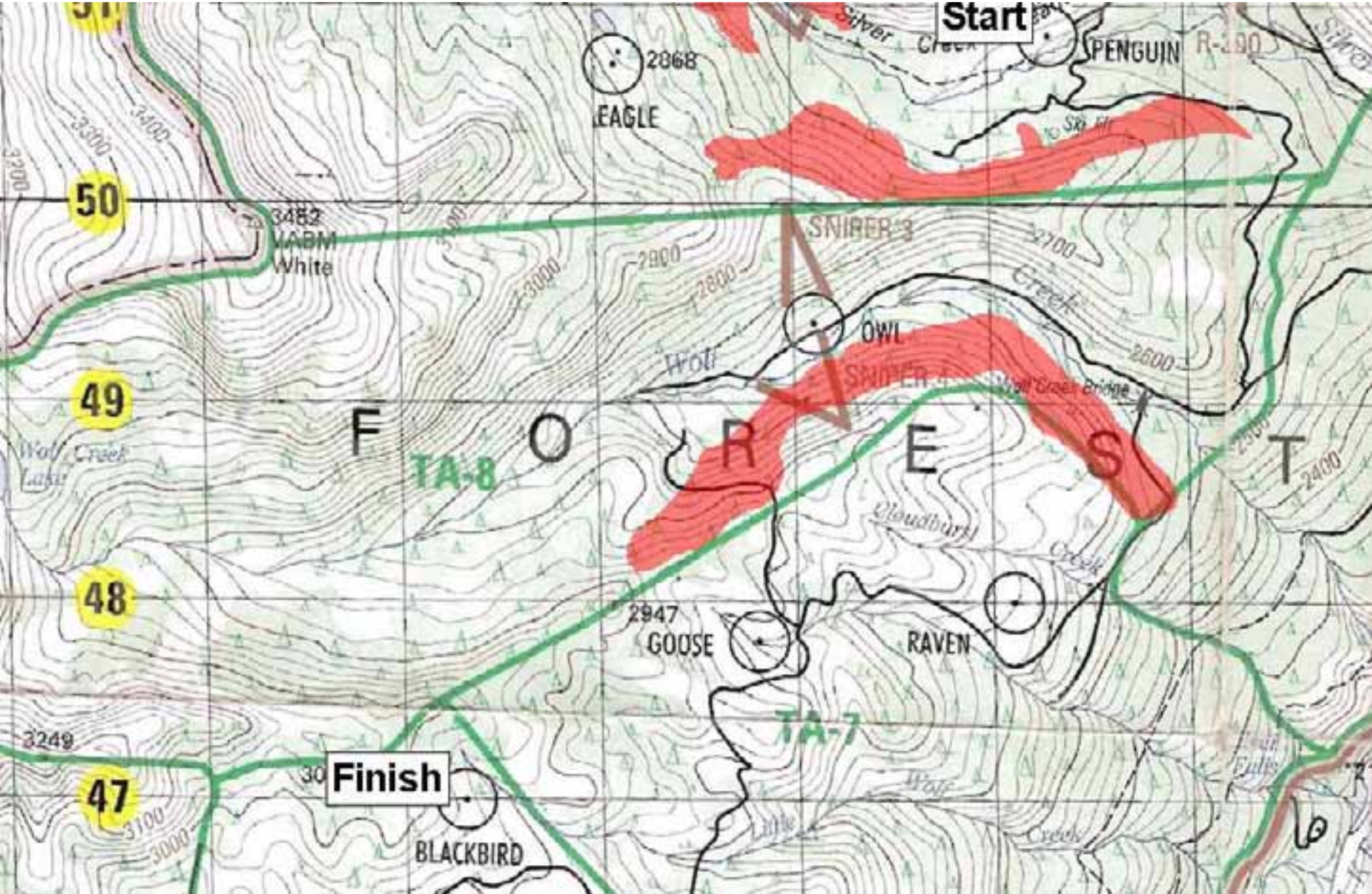
- **USE AND VEGETATION:** Stumpatil soils are used for forest land, recreation, watershed, and wildlife habitat. The native vegetation is mainly a forest canopy of California red fir, lodgepole pine, and western white pine with an understory of needlegrass, mountain brome, bluegrass, and various forbs.



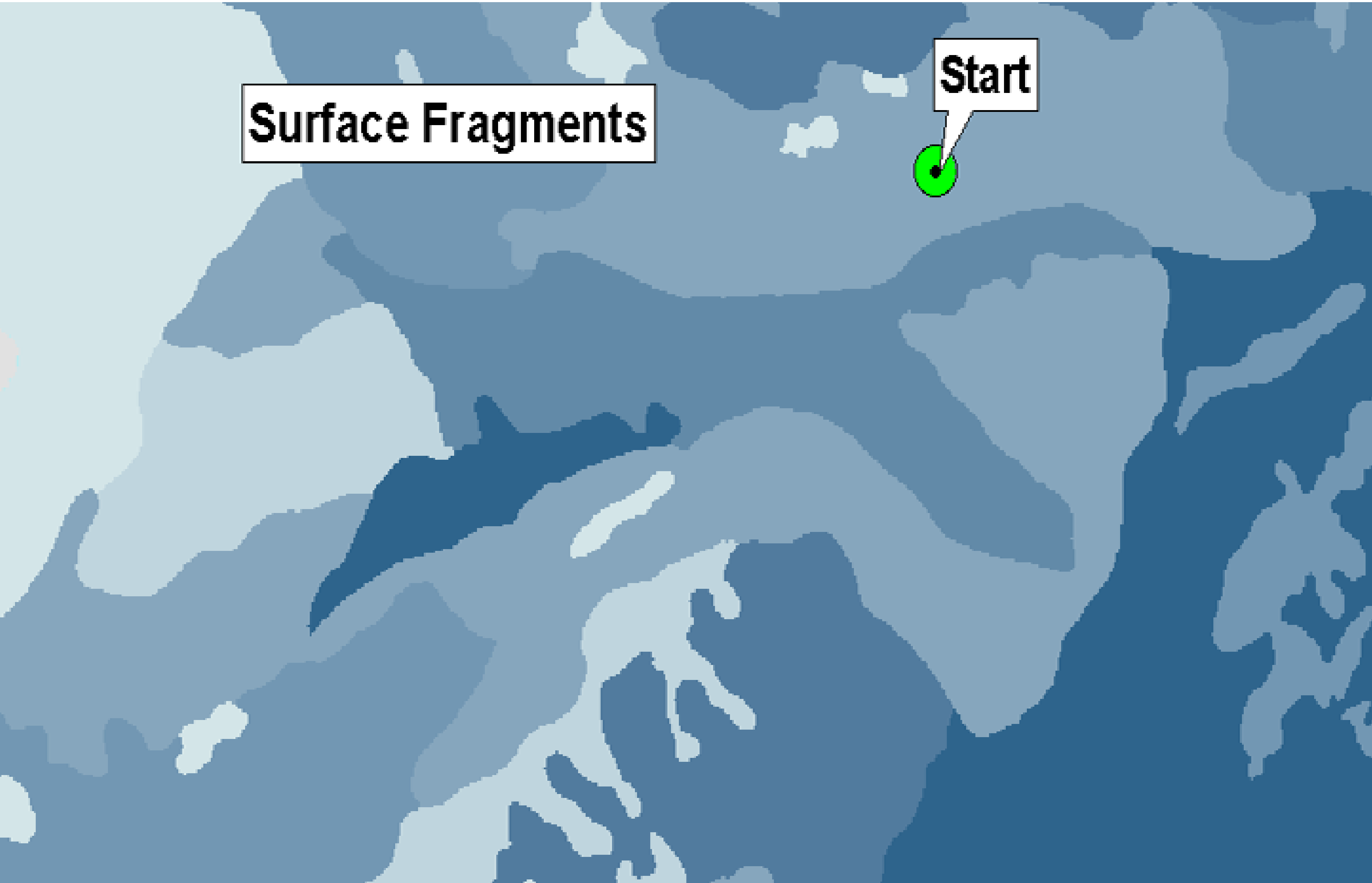
Start
Silver
Creek
PENGUIN
2868
EAGLE
Ski lift
3400
3300
3200
50
3452
VABM
White
SNIPER 3
2900
3000
2800
2700
Creek
OWL
Wolf
SNIPER 4
2600
Wolf Creek Bridge
49
F O R E S T
Wolf Creek
Lake
TA-8
2400
Cloudburst
Creek
48
2947
GOOSE
RAVEN
TA-7
3249
Finish
47
BLACKBIRD
3100
3000
Wolf
Little
Creek
Falls


Start
Stumpatil Soils

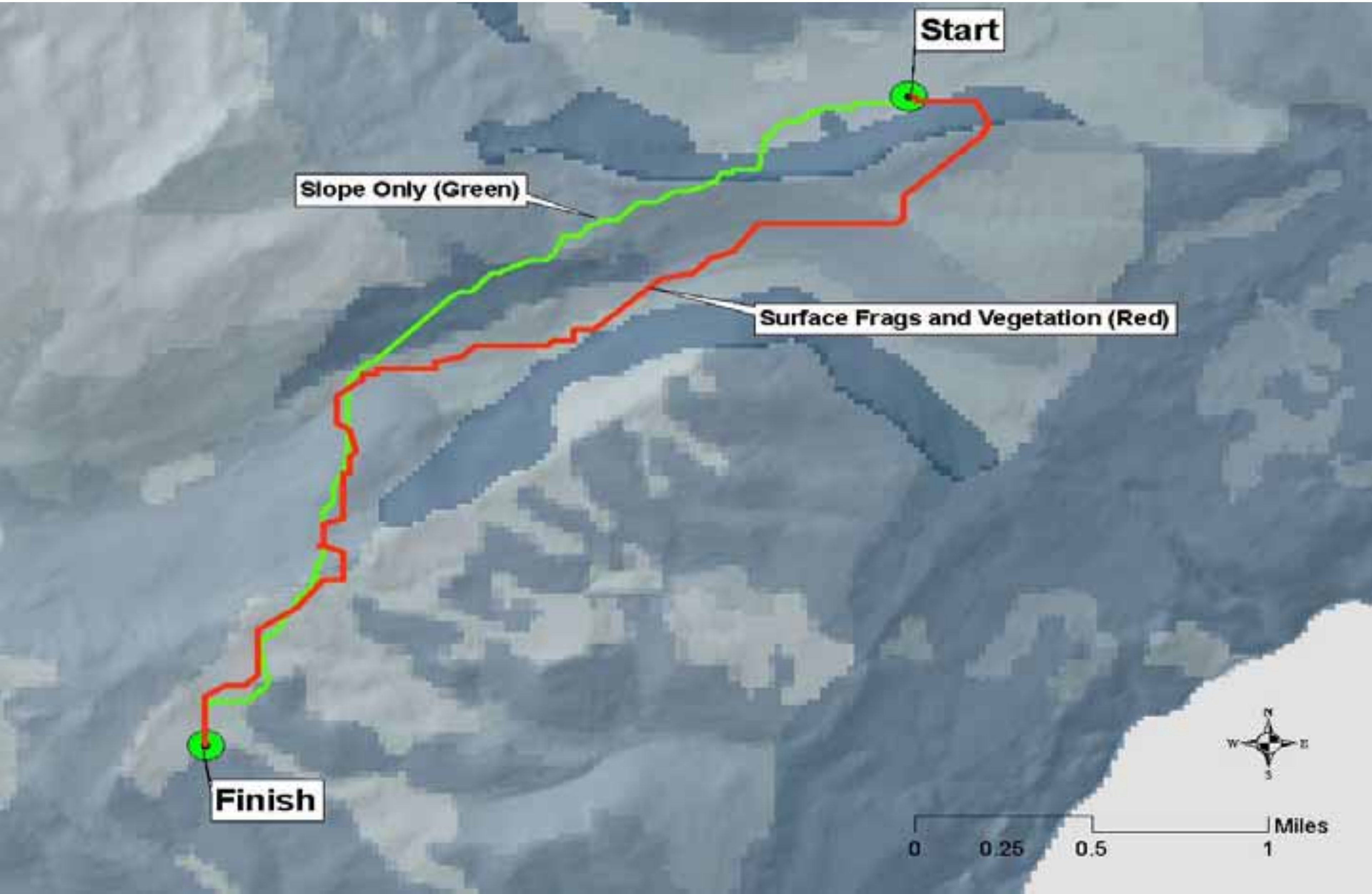
Stumpatil Soils



Surface Fragments



Soils and Surface Fragments

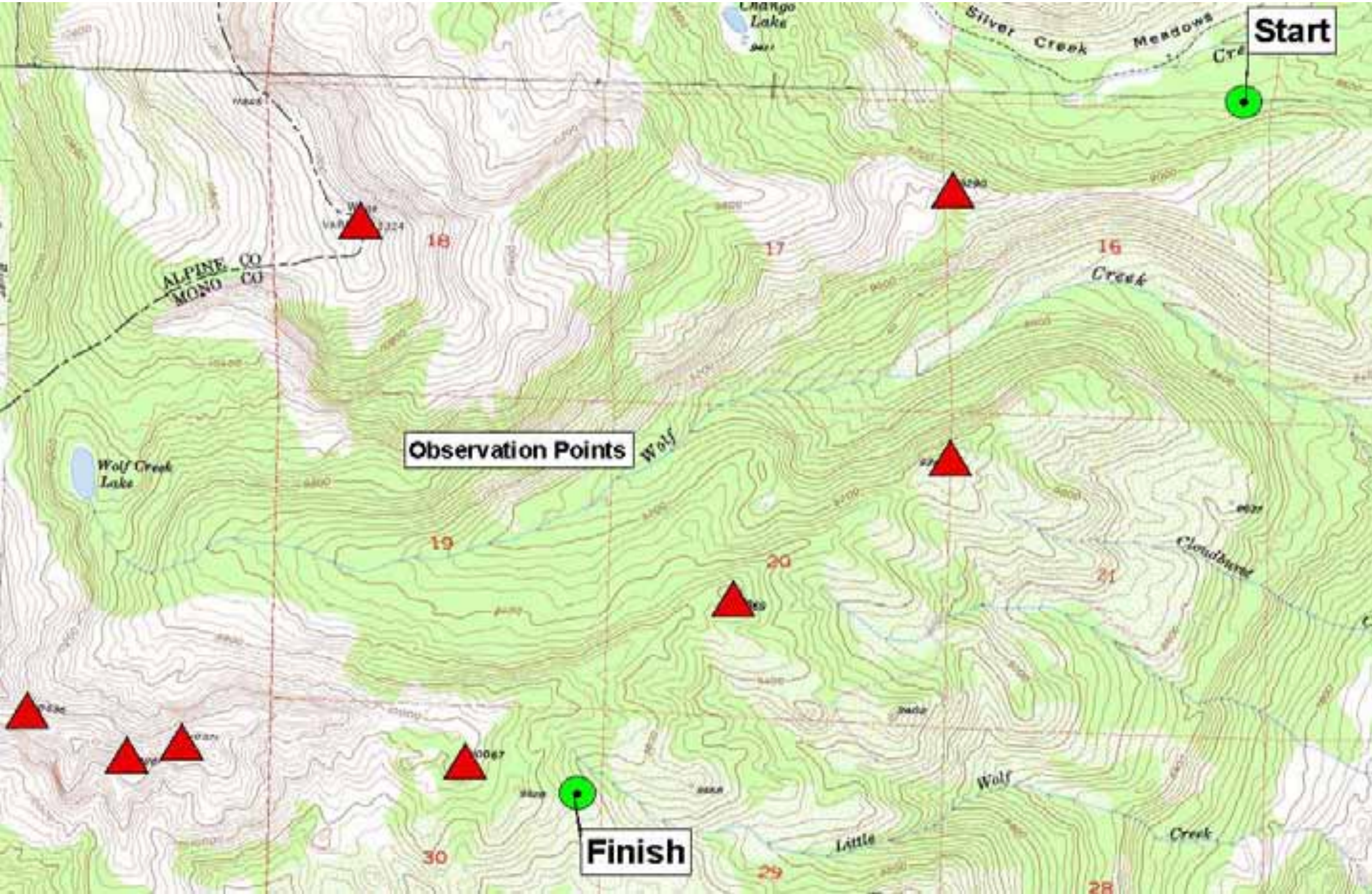


4. Using viewshed analysis combined with vertical factor analysis

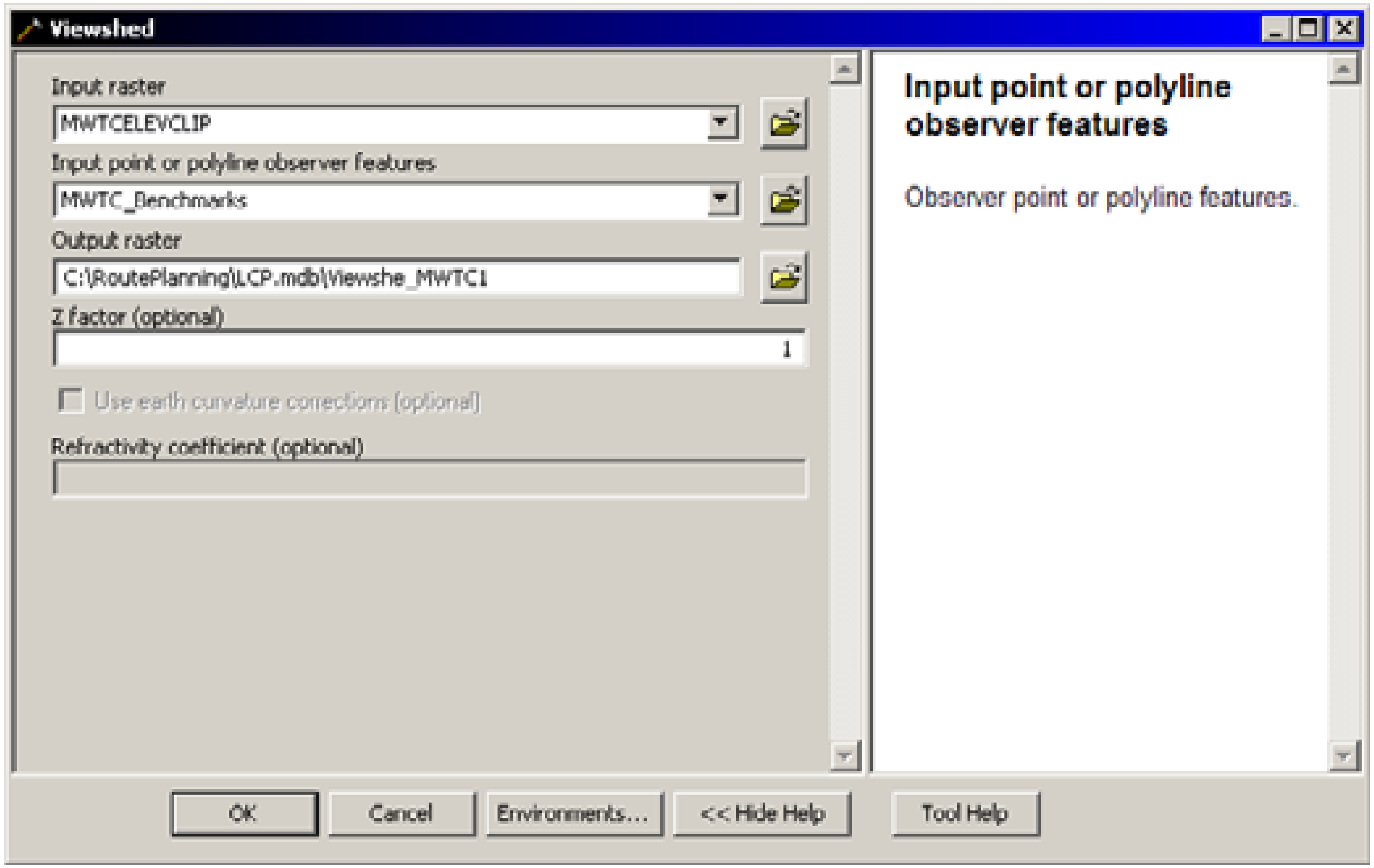
Data Preparation

- Used the DEM from first analysis for surface distance and vertical factor analysis.
- Observation points were digitized off of the Pickel Meadow 7.5 minute quad.
- Viewshed raster of the study area created using Spatial Analyst's viewshed tool.

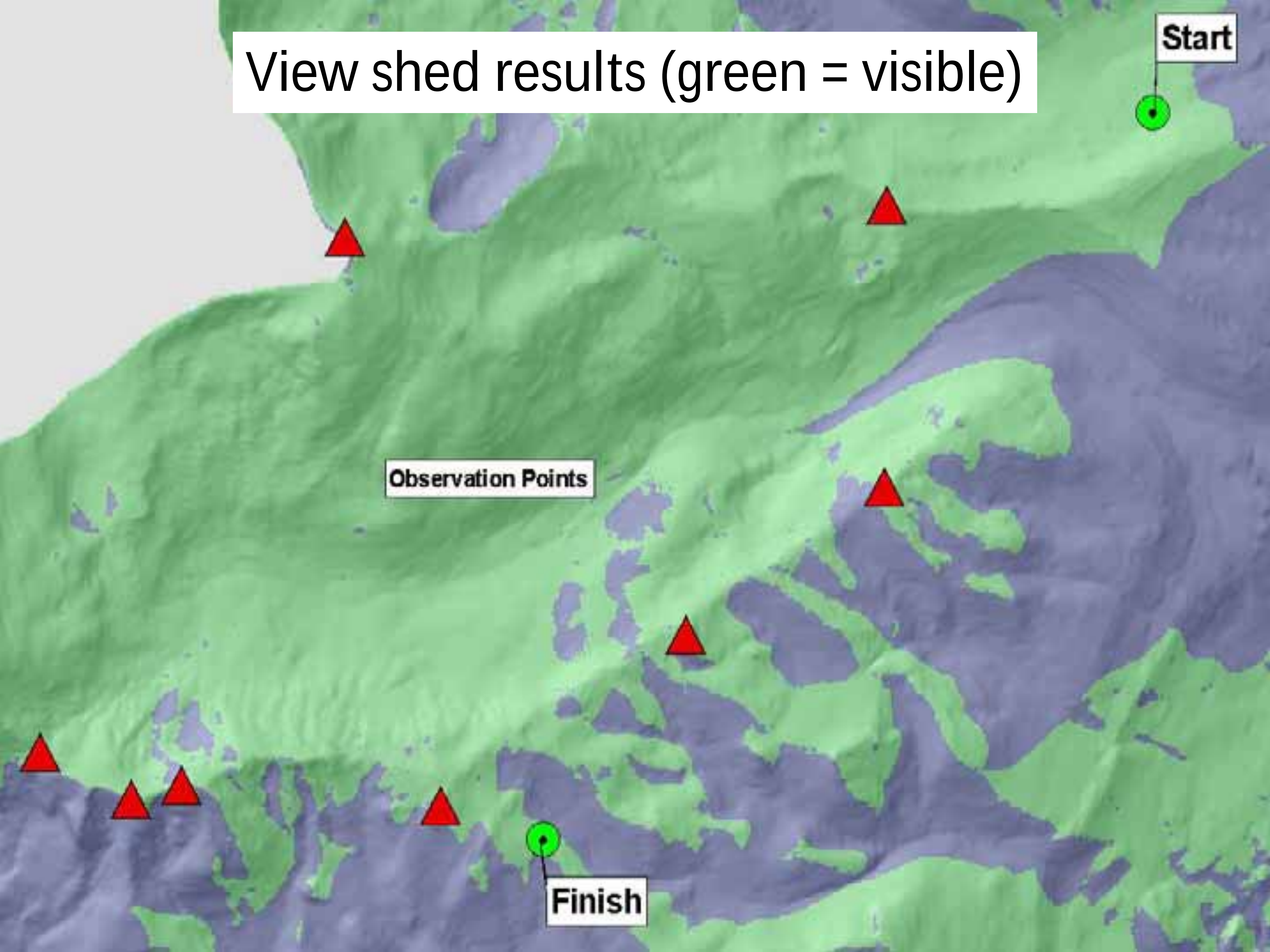
Observation Point Selection



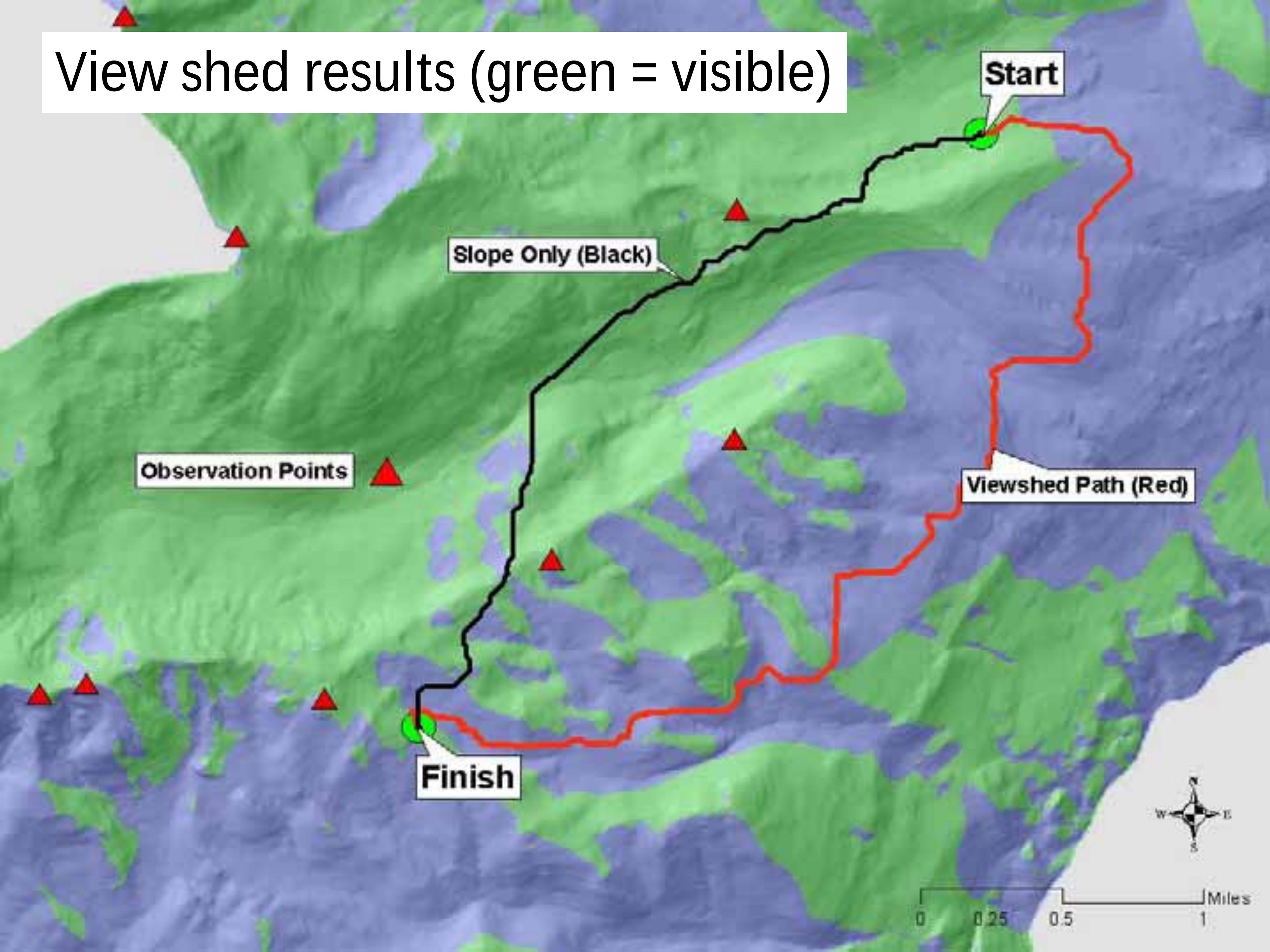
Used Viewshed tool from the 3D Analyst toolbox.



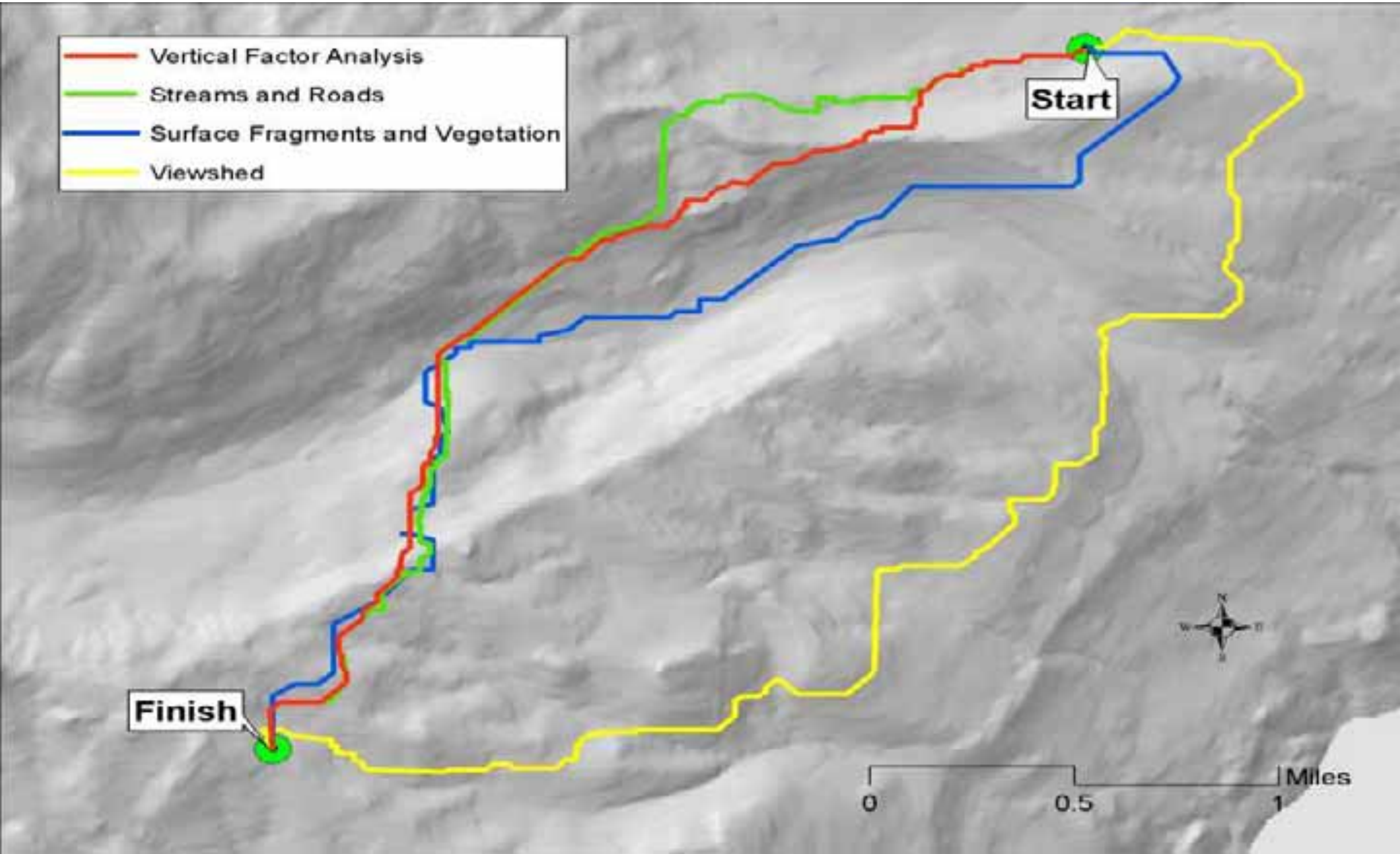
View shed results (green = visible)



View shed results (green = visible)



COMBINED RESULTS



Journal of Applied Physiology 2002 Sep;93(3):1039-46.

Energy cost of walking and running at extreme uphill and downhill slopes.

Minetti AE, Moia C, Roi GS, Susta D, Ferretti G.

Centre for Biophysical and Clinical Research into Human Movement, Department of Exercise and Sport Science, Manchester Metropolitan University, Alsager, Cheshire ST7 2HL, United Kingdom.

Abstract
The costs of walking (Cw) and running (Cr) were measured on 10 runners on a treadmill inclined between -0.45 to +0.45 at different speeds. The minimum Cw was 1.64 +/- 0.50 J. kg(-1). m(-1) at a 1.0 +/- 0.3 m/s speed on the level. It increased on positive slopes, attained 17.33 +/- 1.11 J. kg(-1). m(-1) at +0.45, and was reduced to 0.81 +/- 0.37 J. kg(-1). m(-1) at -0.10. At steeper slopes, it increased to reach 3.46 +/- 0.95 J. kg(-1). m(-1) at -0.45. Cr was 3.40 +/- 0.24 J. kg(-1). m(-1) on the level, independent of speed. It increased on positive slopes, attained 18.93 +/- 1.74 J. kg(-1). m(-1) at +0.45, and was reduced to 1.73 +/- 0.36 J. kg(-1). m(-1) at -0.20. At steeper slopes, it increased to reach 3.92 +/- 0.81 J. kg(-1). m(-1) at -0.45. The mechanical efficiencies of walking and running above +0.15 and below -0.15 attained those of concentric and eccentric muscular contraction, respectively. The optimum gradients for mountain paths approximated 0.20-0.30 for both gaits. Downhill, Cr was some 40% lower than reported in the literature for sedentary subjects. The estimated maximum running speeds on positive gradients corresponded to those adopted in uphill races; on negative gradients they were well above those attained in downhill competitions.