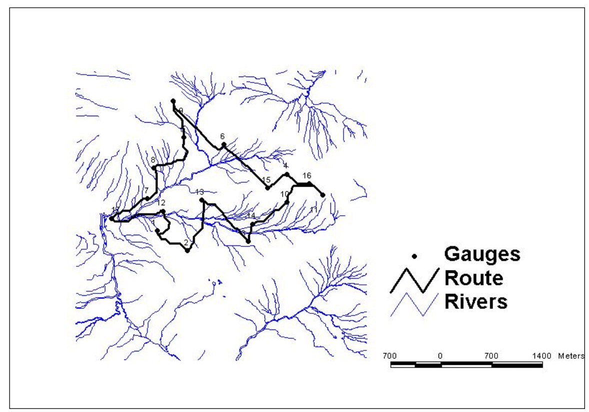
Cost Surface Analysis



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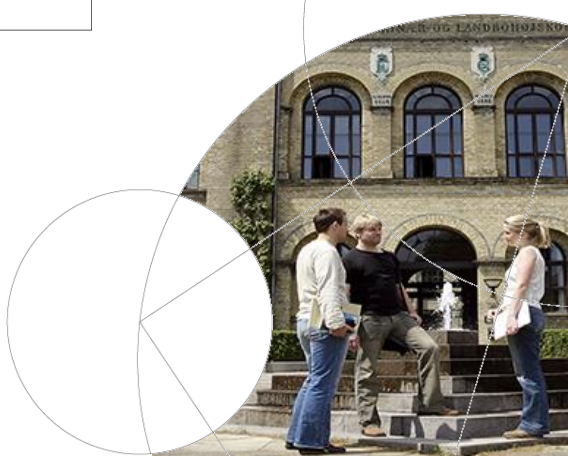
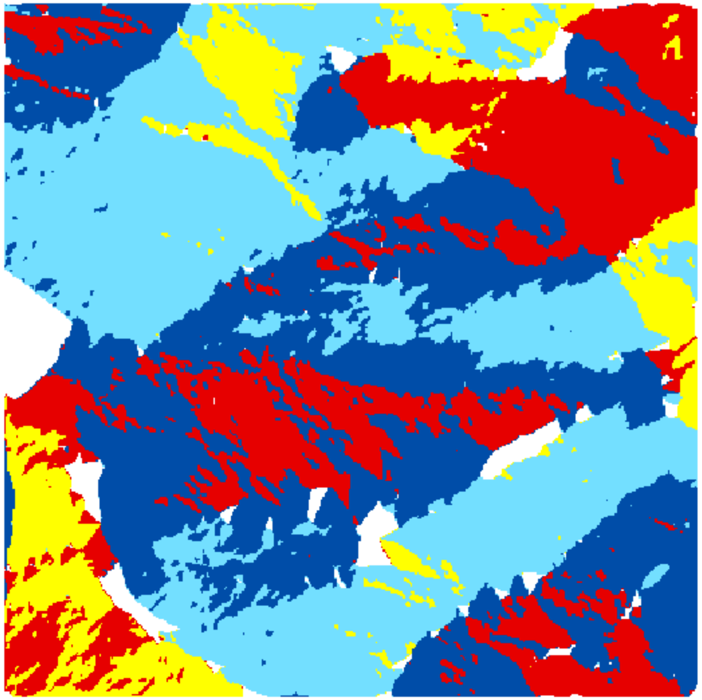


Background

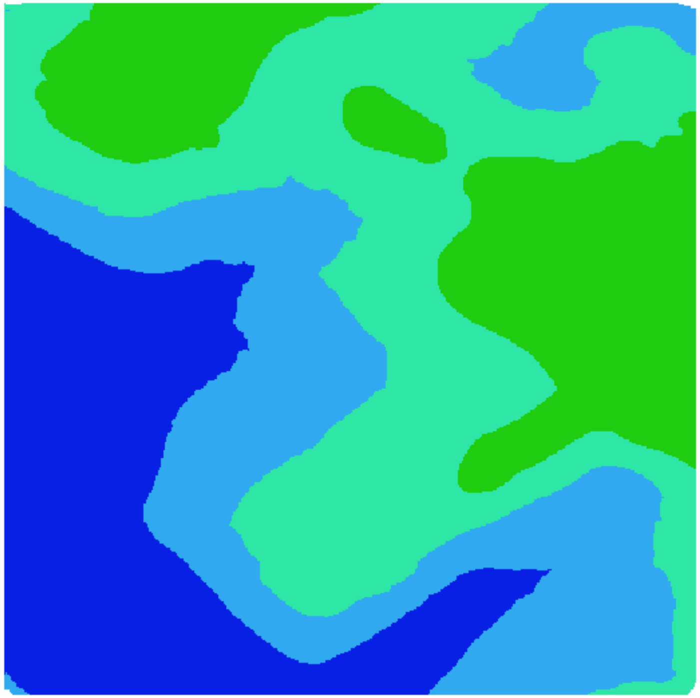
In 1988 a watershed was studied on the Island of Vagar, The Faeroe Islands in order to monitor the orographic effects of the terrain during a cyclone event. The hypothesis was that the local amounts of precipitation were a function of the terrain's elevation and aspect.

On beforehand it was investigated where to place 16 rain gauges representing the the landscape's elevation and aspects. The area investigated was approximately 6 km^2.

Aspects (surface exposures) and elevation zones



North
East
South
West



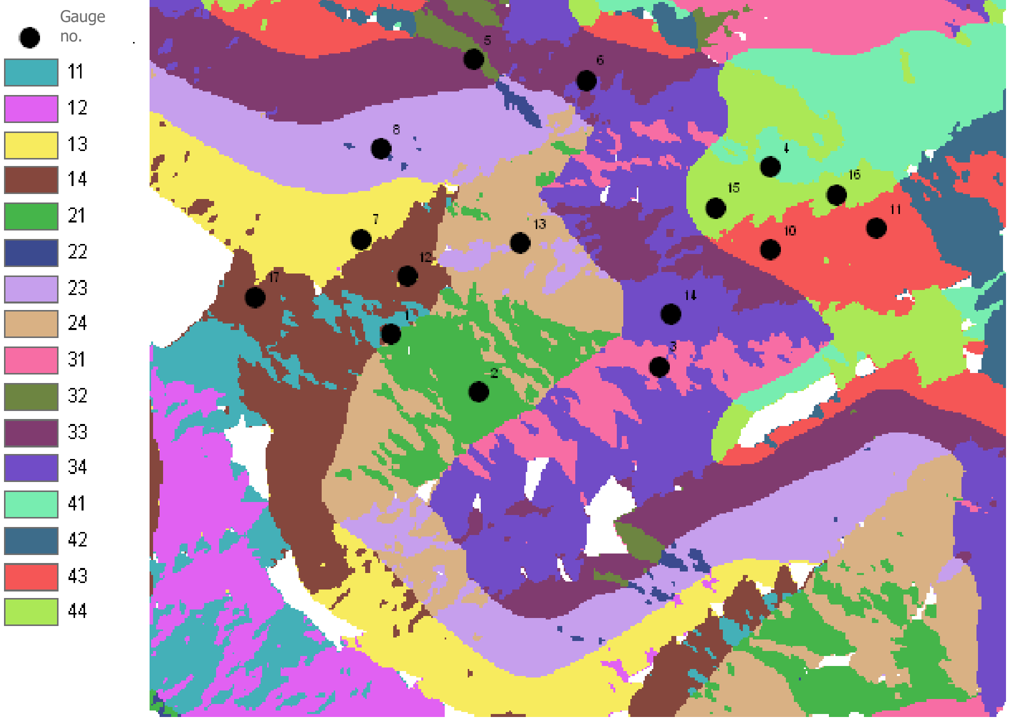
94 - 200
201 - 300
301 - 400
401 - 550

Overlay of aspects and elevations

4 aspect zones:
1 = North
2 = East
3 = South
4 = West

4 elevation zones:
10 = 94-200 m
20 = 201-300 m
30 = 301-400 m
40 = 401-550 m

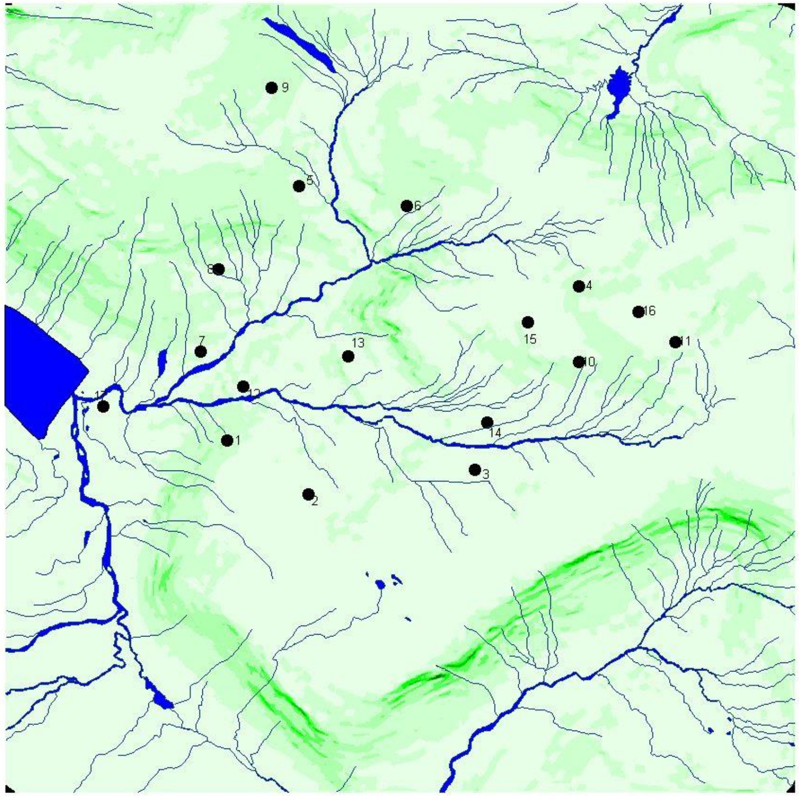
Local sum:
11 = 94-200 m and North
12 = 94-200 m and East
…
…
44 = 401-500 m and West



The problem

The 16 rain gauges must be inspected daily.

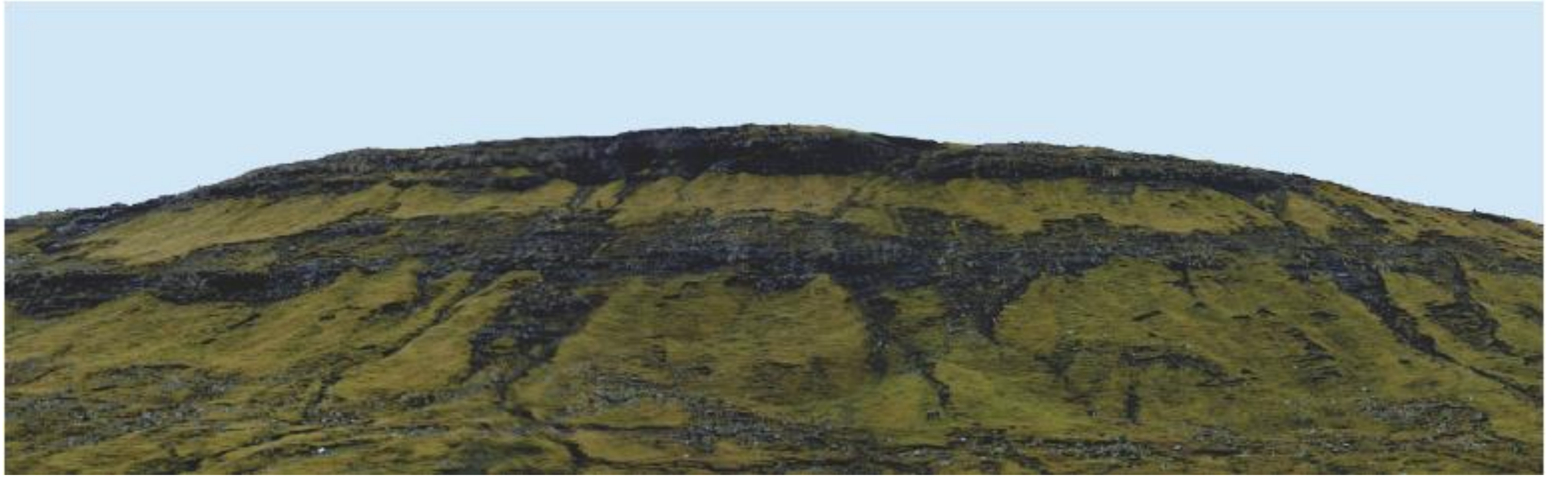
Which way is the fastest to visit them all in this mountaneous terrain dominated by steep slopes and several minor rivers?



Solutions

a) In the field: trial & error (approx. a 6 hours walk)

b) A GIS based analysis by calculating the least cost paths in between all the individual rain gauges. Next, the least cost path is identified from a shortest route optimization on the web of paths visiting all rain gauges only once.

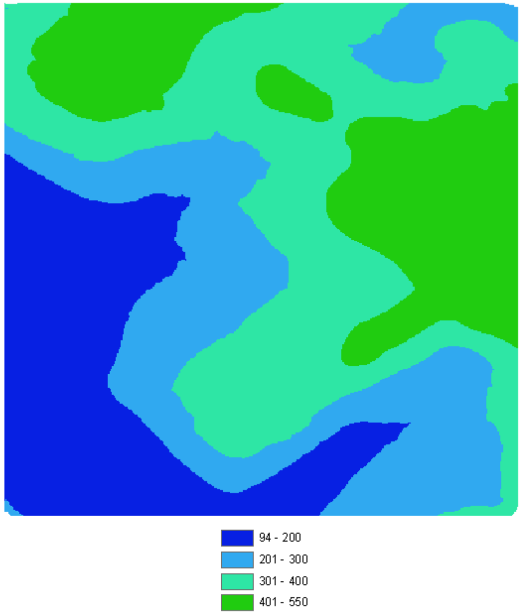


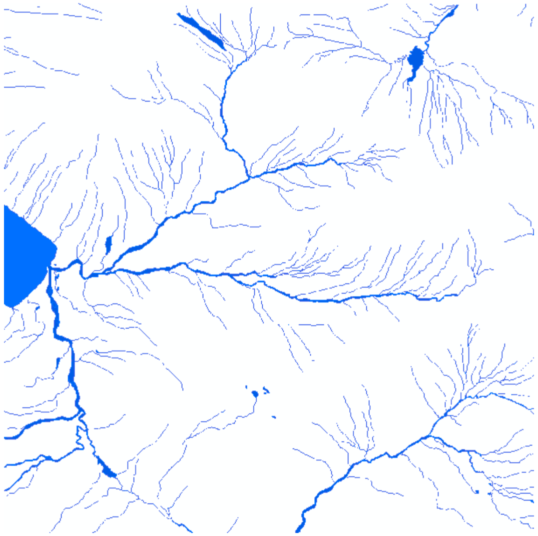
The GIS-based solution

Input-data:

A digital elevation model (DEM)

Digitized layers of minor rivers and lakes





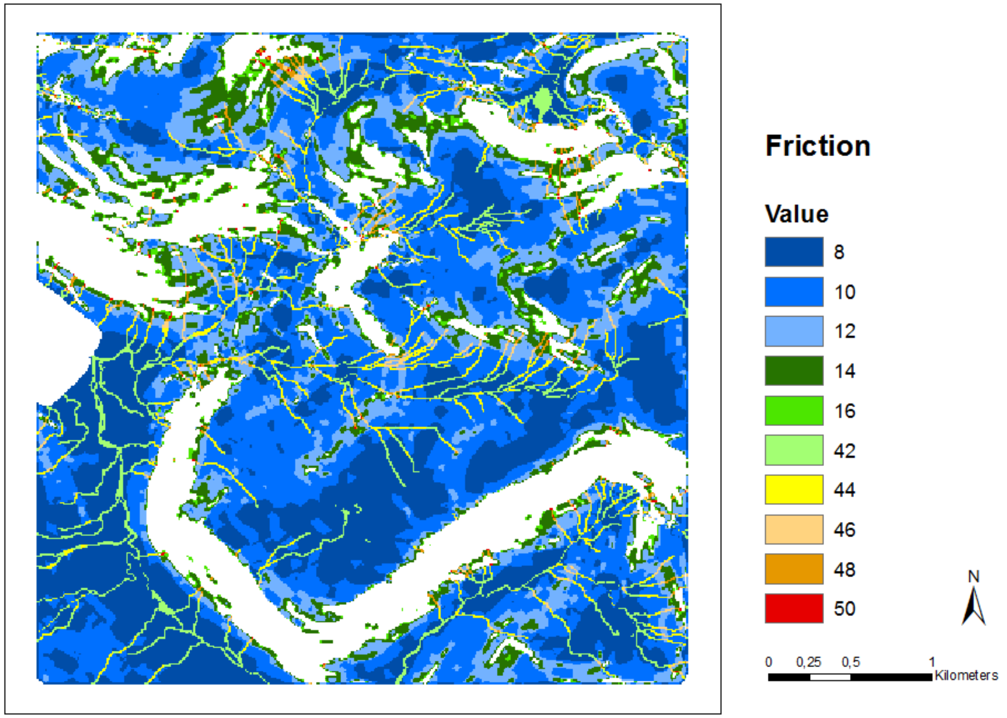
The GIS-based solution

Derived data:

A raster layer with **friction values** expressing the total cost of passing the terrain cells.

The friction's unit of measurement is **seconds** and is a local sum of two layers:

- Time to pass **slope** cells
- Time to pass **river** cells



The Friction layer

Slopes in % are derived from a DTM with a cell size of 10 metres uning the Slope tool.

Next, field experiments revealed how long it takes to pass a 10 meter wide cell as a function of slope. So, the slope layer is reclassified according to the slope classes.

Slope in %	Time in seconds
0-12	8
12-20	10
20-25	12
25-29	14
29-30	16
>30	NODATA

The Friction layer

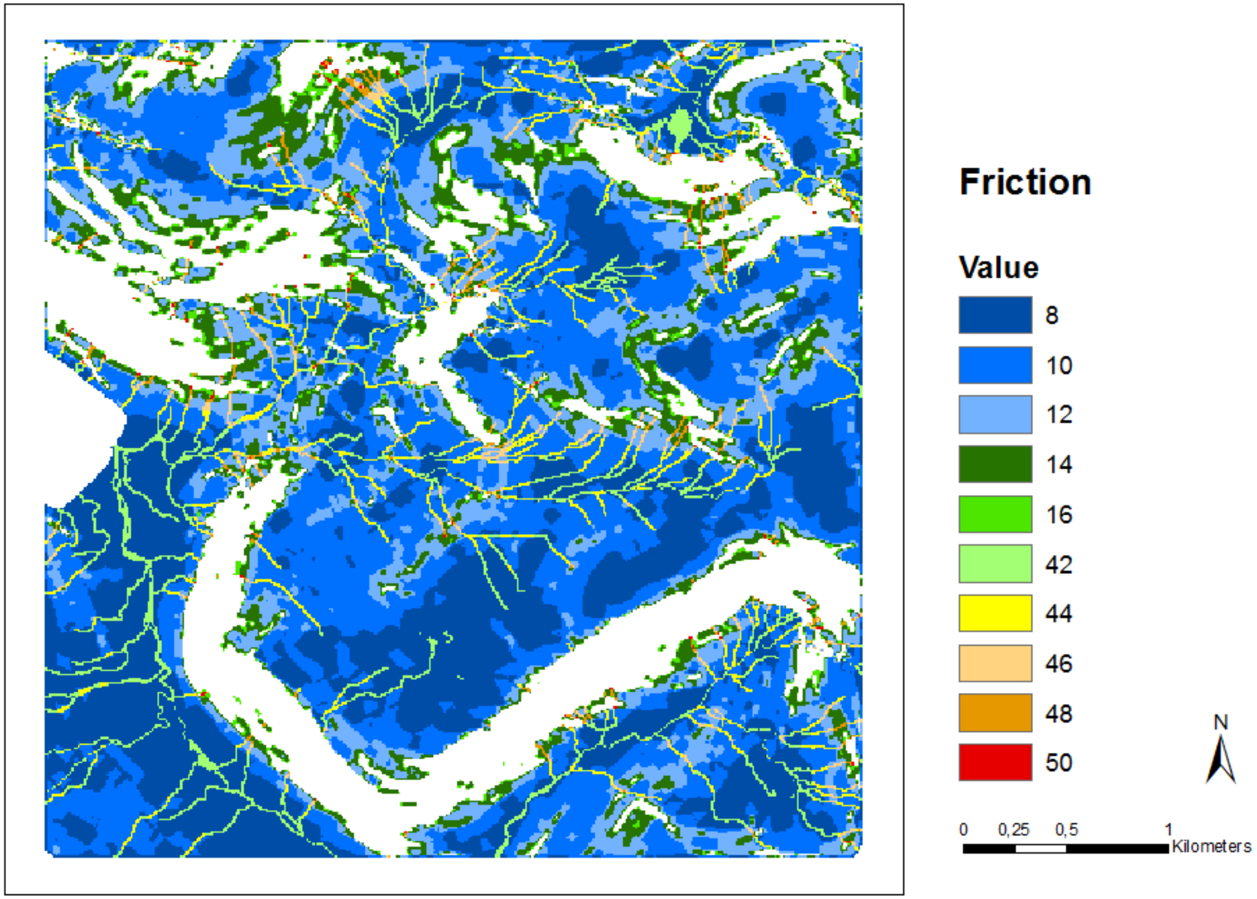
Impassable locations (cells with slopes > 30% and lakes) are assigned the NoData value.

The Friction layer

The cost of passing minor rivers:

Estimated time to pass a 10 meter wide river cell, 25 cm deep with slippery boulders and a steady river flow: 34 seconds.

Cost Distance based on Friction



Distance accumulation method

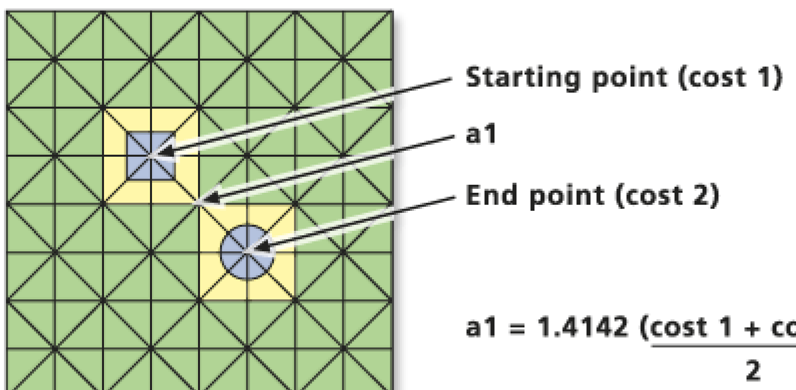
	1	1			
		1			
2					

SOURCE_RASTER

1	3	4	4	3	2
4	6	2	3	7	6
5	8	7	5	6	6
1	4	5		5	1
4	7	5		2	6
1	2	2	1	3	4

COST_RASTER

Value = NODATA



$$a1 = 1.4142 \frac{(\text{cost } 1 + \text{cost } 2)}{2}$$

Horizontal and vertical node calculations

2.0	0	0	4.0		
4.5	4.0	0	2.5		
	7.1	4.5	4.9		
2.5	5.7				
0	1.5				

INPUT_RASTER

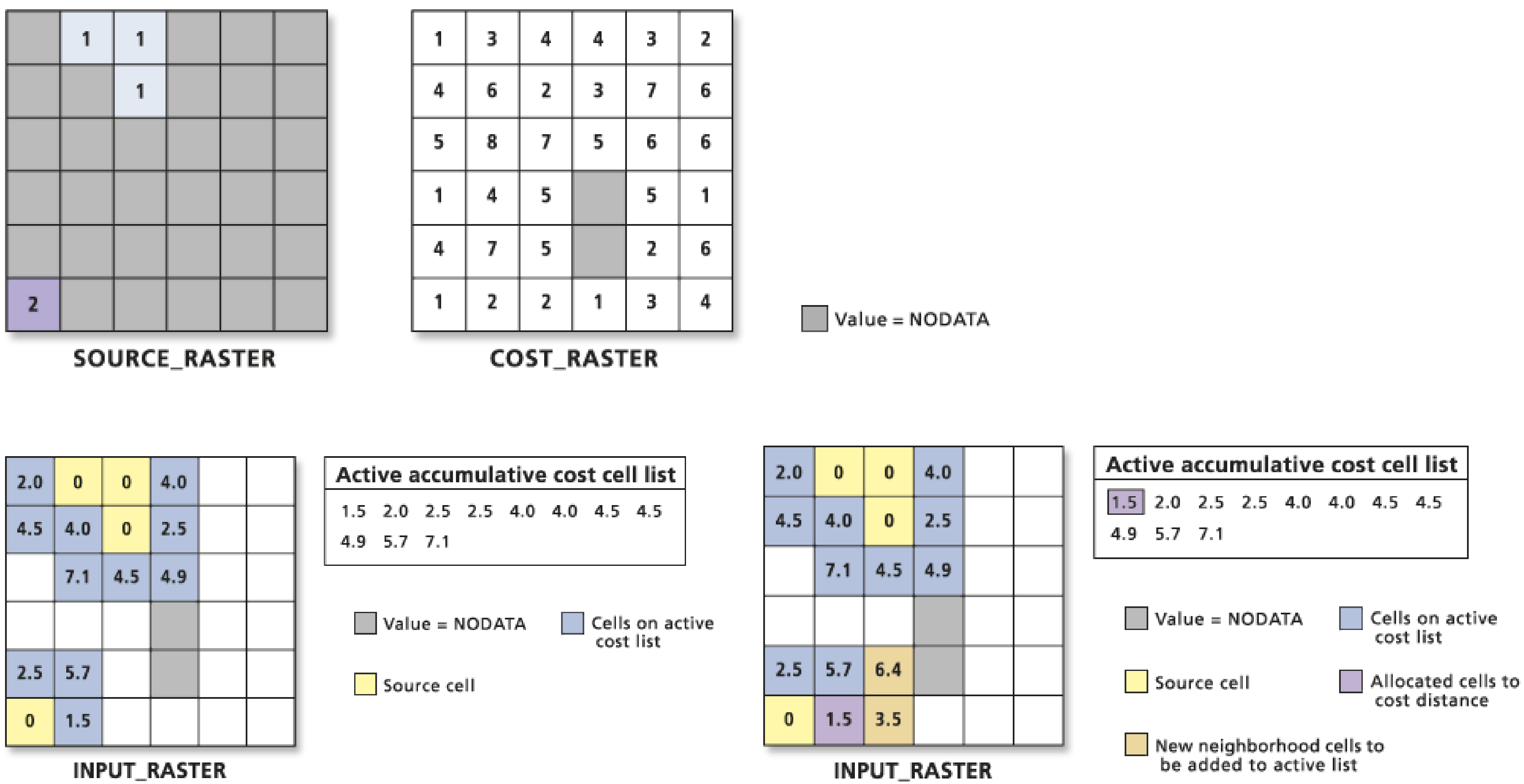
Active accumulative cost cell list

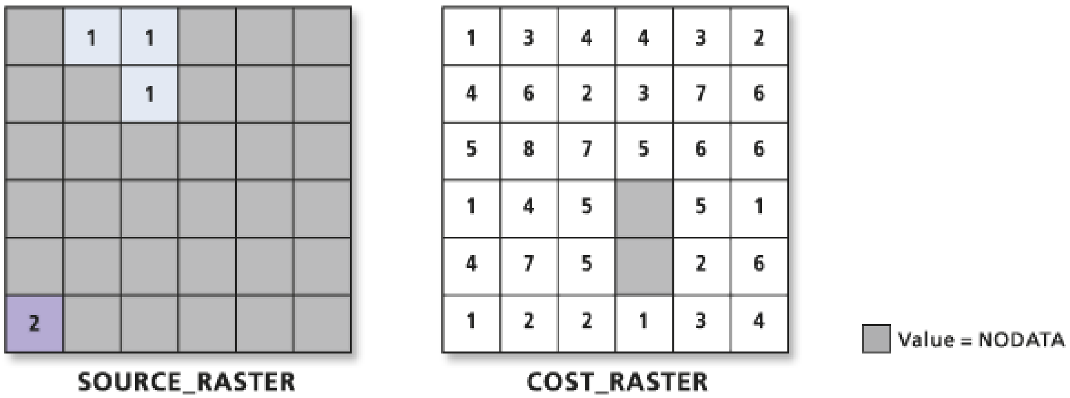
1.5 2.0 2.5 2.5 4.0 4.0 4.5 4.5
4.9 5.7 7.1

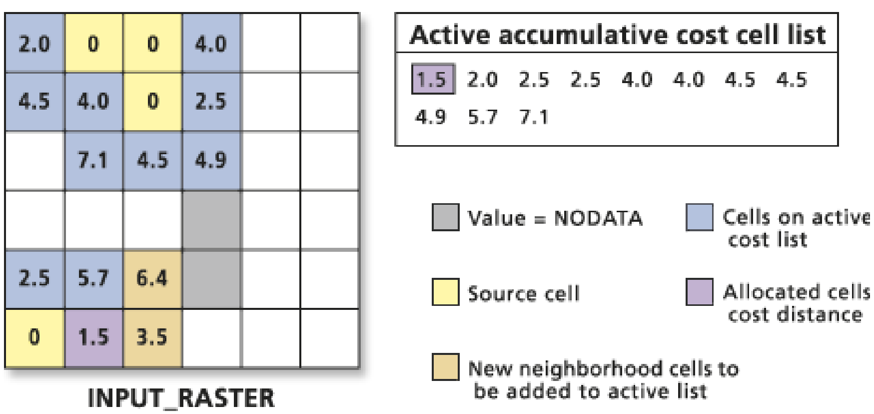
Value = NODATA

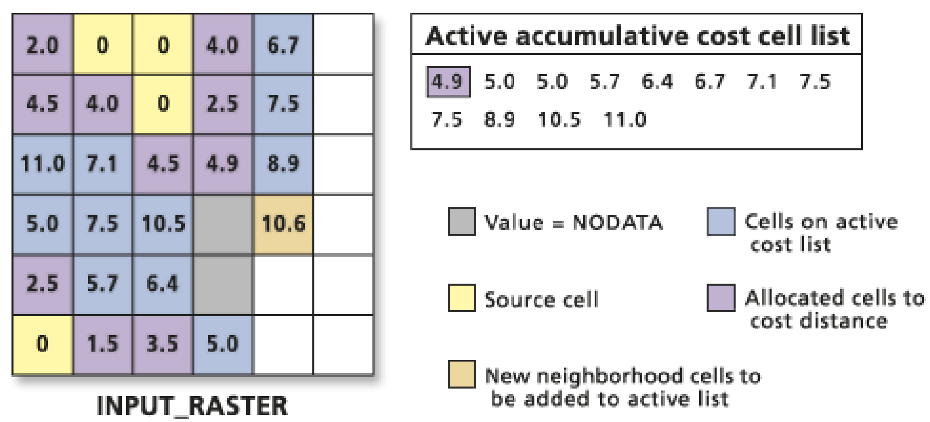
Cells on active cost list

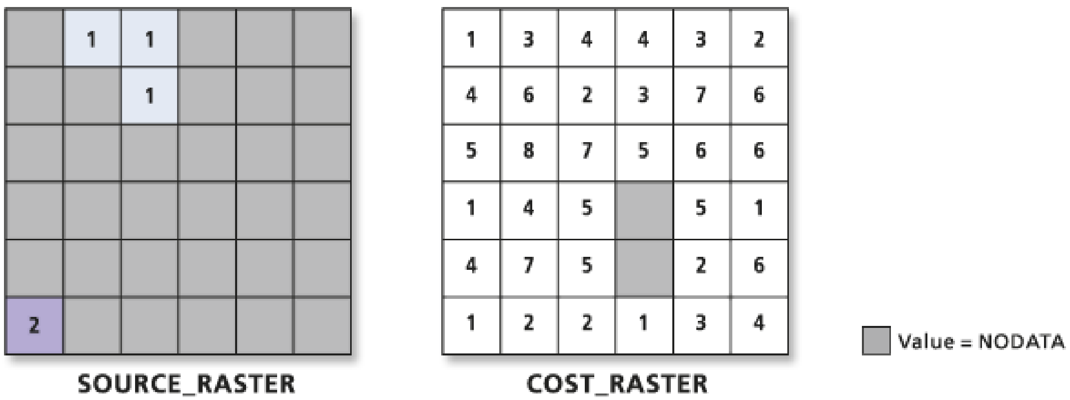
Source cell

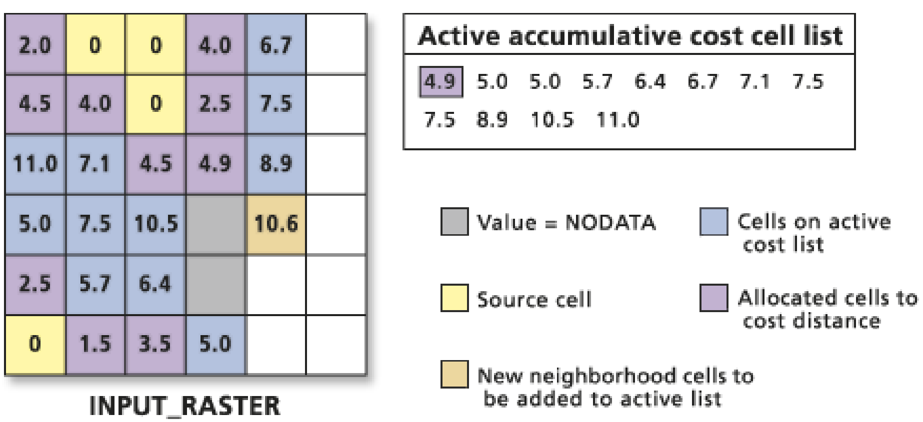

1 1
1
2
SOURCE_RASTER
1 3 4 4 3 2
4 6 2 3 7 6
5 8 7 5 6 6
1 4 5 5 1
4 7 5 2 6
1 2 2 1 3 4
COST_RASTER
Value = NODATA
2.0 0 0 4.0
4.5 4.0 0 2.5
7.1 4.5 4.9
2.5 5.7
0 1.5
INPUT_RASTER
Active accumulative cost cell list
1.5 2.0 2.5 2.5 4.0 4.0 4.5 4.5
4.9 5.7 7.1
Value = NODATA
Cells on active cost list
Source cell
2.0 0 0 4.0
4.5 4.0 0 2.5
7.1 4.5 4.9
2.5 5.7 6.4
0 1.5 3.5
INPUT_RASTER
Active accumulative cost cell list
1.5 2.0 2.5 2.5 4.0 4.0 4.5 4.5
4.9 5.7 7.1
Value = NODATA
Cells on active cost list
Source cell
Allocated cells to cost distance
New neighborhood cells to be added to active list

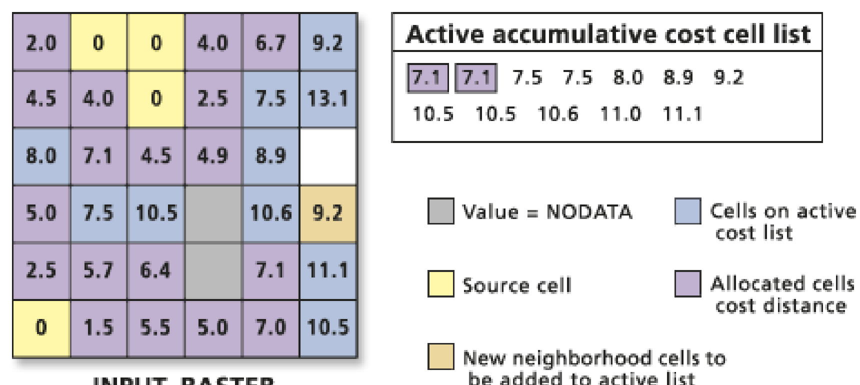

1 1
1
2
SOURCE_RASTER
1 3 4 4 3 2
4 6 2 3 7 6
5 8 7 5 6 6
1 4 5 5 1
4 7 5 2 6
1 2 2 1 3 4
COST_RASTER
Value = NODATA


2.0 0 0 4.0
4.5 4.0 0 2.5
7.1 4.5 4.9
2.5 5.7 6.4
0 1.5 3.5
INPUT_RASTER
Active accumulative cost cell list
1.5 2.0 2.5 2.5 4.0 4.0 4.5 4.5
4.9 5.7 7.1
Value = NODATA
Cells on active cost list
Source cell
Allocated cells cost distance
New neighborhood cells to be added to active list


2.0 0 0 4.0 6.7
4.5 4.0 0 2.5 7.5
11.0 7.1 4.5 4.9 8.9
5.0 7.5 10.5 10.6
2.5 5.7 6.4
0 1.5 3.5 5.0
INPUT_RASTER
Active accumulative cost cell list
4.9 5.0 5.0 5.7 6.4 6.7 7.1 7.5
7.5 8.9 10.5 11.0
Value = NODATA
Cells on active cost list
Source cell
Allocated cells to cost distance
New neighborhood cells to be added to active list


1 1
1
2
SOURCE_RASTER
1 3 4 4 3 2
4 6 2 3 7 6
5 8 7 5 6 6
1 4 5 5 1
4 7 5 2 6
1 2 2 1 3 4
COST_RASTER
Value = NODATA


2.0 0 0 4.0 6.7
4.5 4.0 0 2.5 7.5
11.0 7.1 4.5 4.9 8.9
5.0 7.5 10.5 10.6
2.5 5.7 6.4
0 1.5 3.5 5.0
INPUT_RASTER
Active accumulative cost cell list
4.9 5.0 5.0 5.7 6.4 6.7 7.1 7.5
7.5 8.9 10.5 11.0
Value = NODATA
Cells on active cost list
Source cell
Allocated cells to cost distance
New neighborhood cells to be added to active list


2.0 0 0 4.0 6.7 9.2
4.5 4.0 0 2.5 7.5 13.1
8.0 7.1 4.5 4.9 8.9
5.0 7.5 10.5 10.6 9.2
2.5 5.7 6.4 7.1 11.1
0 1.5 5.5 5.0 7.0 10.5
INPUT_RASTER
Active accumulative cost cell list
7.1 7.1 7.5 7.5 8.0 8.9 9.2
10.5 10.5 10.6 11.0 11.1
Value = NODATA
Cells on active cost list
Source cell
Allocated cells to cost distance
New neighborhood cells to be added to active list

	1	1			
		1			
2					

SOURCE_RASTER

1	3	4	4	3	2
4	6	2	3	7	6
5	8	7	5	6	6
1	4	5		5	1
4	7	5		2	6
1	2	2	1	3	4

COST_RASTER

Value = NODATA

2.0	0	0	4.0	6.7	9.2
4.5	4.0	0	2.5	7.5	13.1
8.0	7.1	4.5	4.9	8.9	
5.0	7.5	10.5		10.6	9.2
2.5	5.7	6.4		7.1	11.1
0	1.5	5.5	5.0	7.0	10.5

INPUT_RASTER

Active accumulative cost cell list

7.1 7.1 7.5 7.5 8.0 8.9 9.2
10.5 10.5 10.6 11.0 11.1

Value = NODATA
Cells on active cost list
Source cell
Allocated cells to cost distance
New neighborhood cells to be added to active list

2.0	0	0	4.0	6.7	9.2
4.5	4.0	0	2.5	7.5	13.1
8.0	7.1	4.5	4.9	8.9	14.5
5.0	7.5	10.5		10.6	9.2
2.5	5.7	6.4		7.1	11.1
0	1.5	3.5	5.0	7.0	10.5

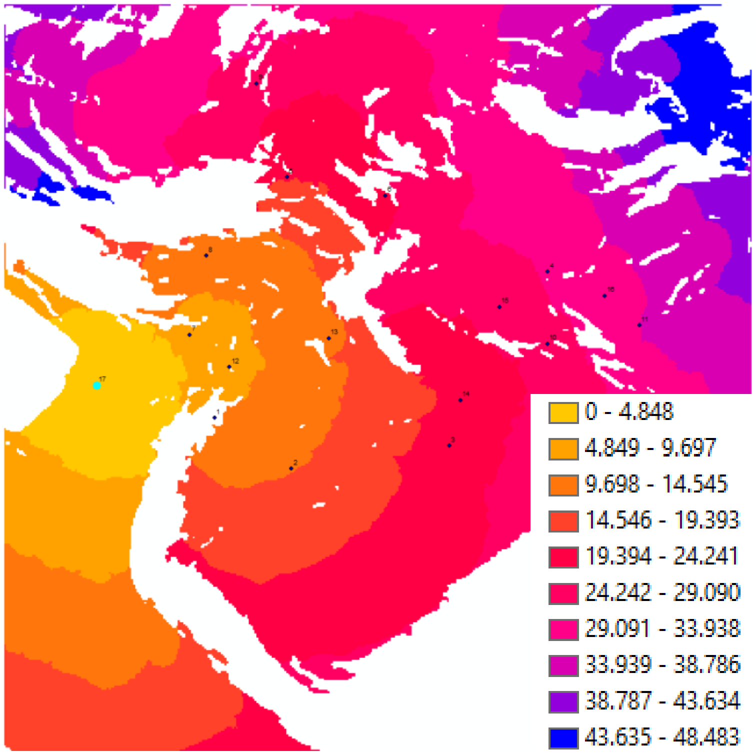
INPUT_RASTER

Active accumulative cost cell list

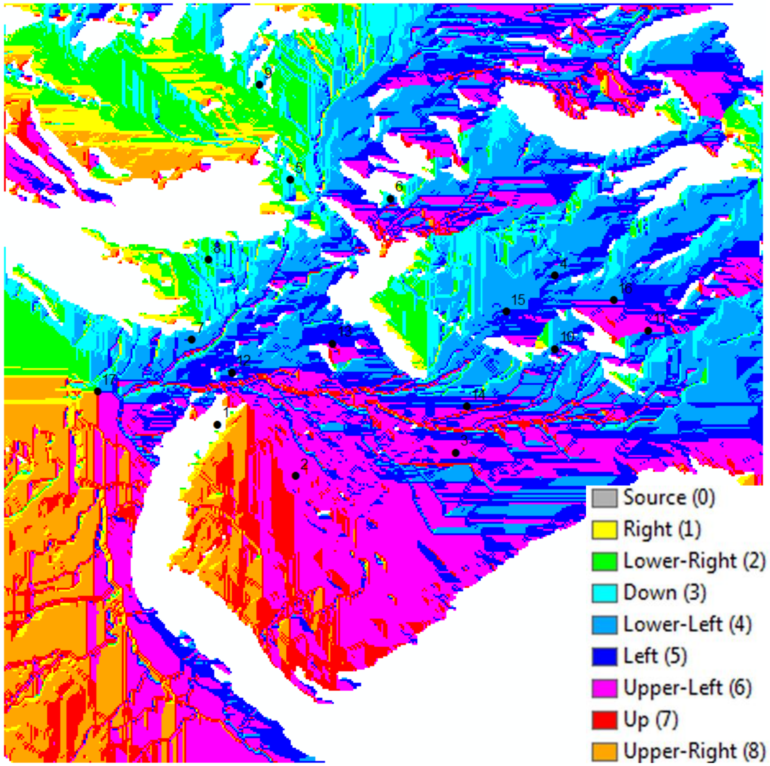
7.5 7.5 8.0 8.9 9.2 9.2
10.5 10.5 10.6 11.0 11.1

Value = NODATA
Cells on active cost list
Source cell
Allocated cells to cost distance
New neighborhood cells to be added to active list

Distance Accumulation and Back Link rasters

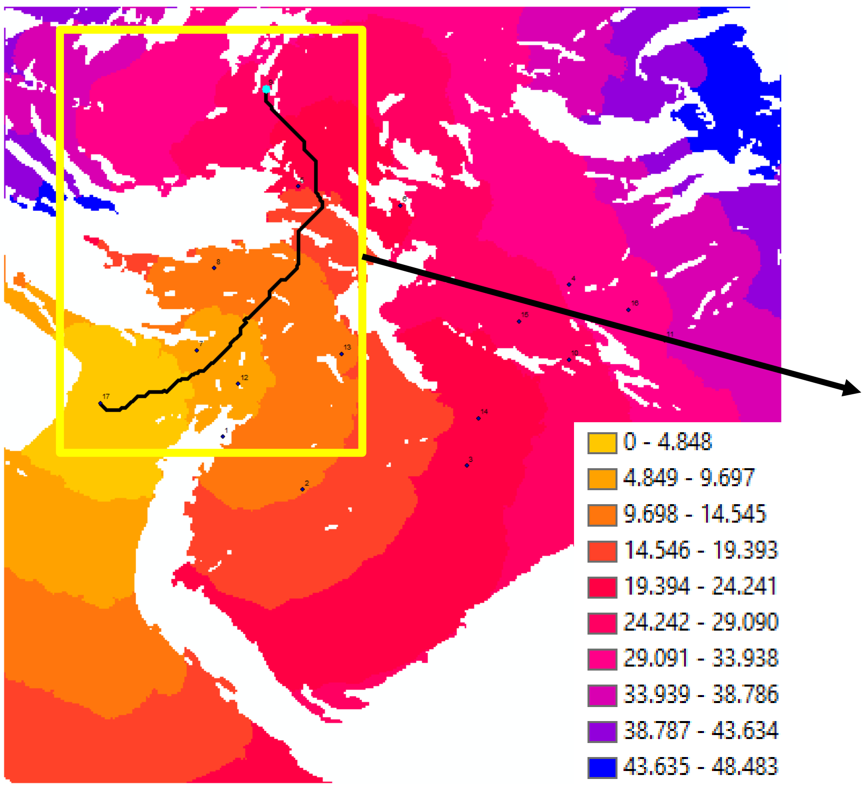


Cost Distance raster

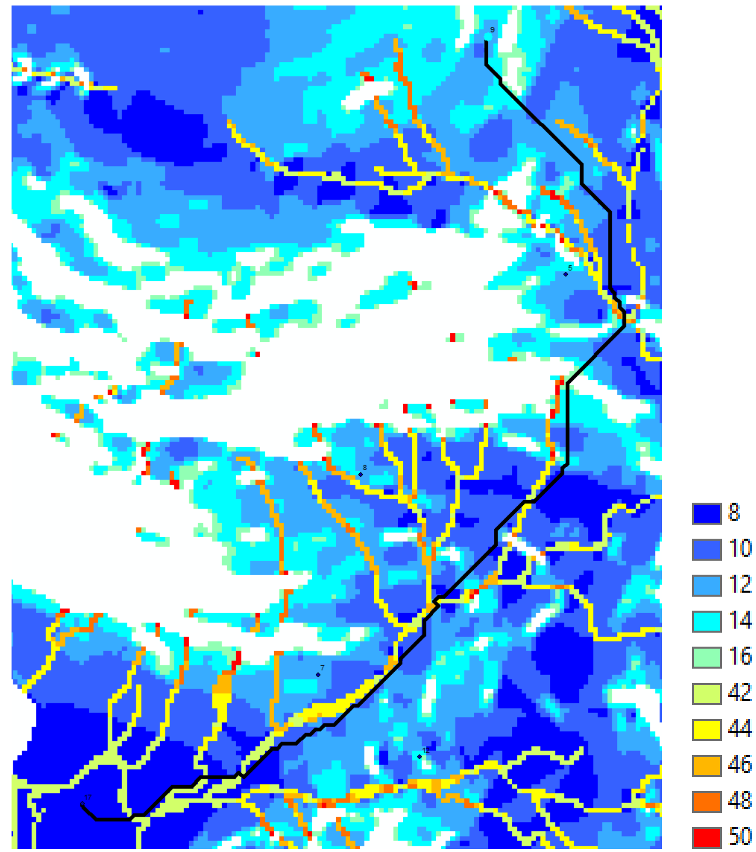


BackLink raster

Optimal path from station no. 9 back to the source

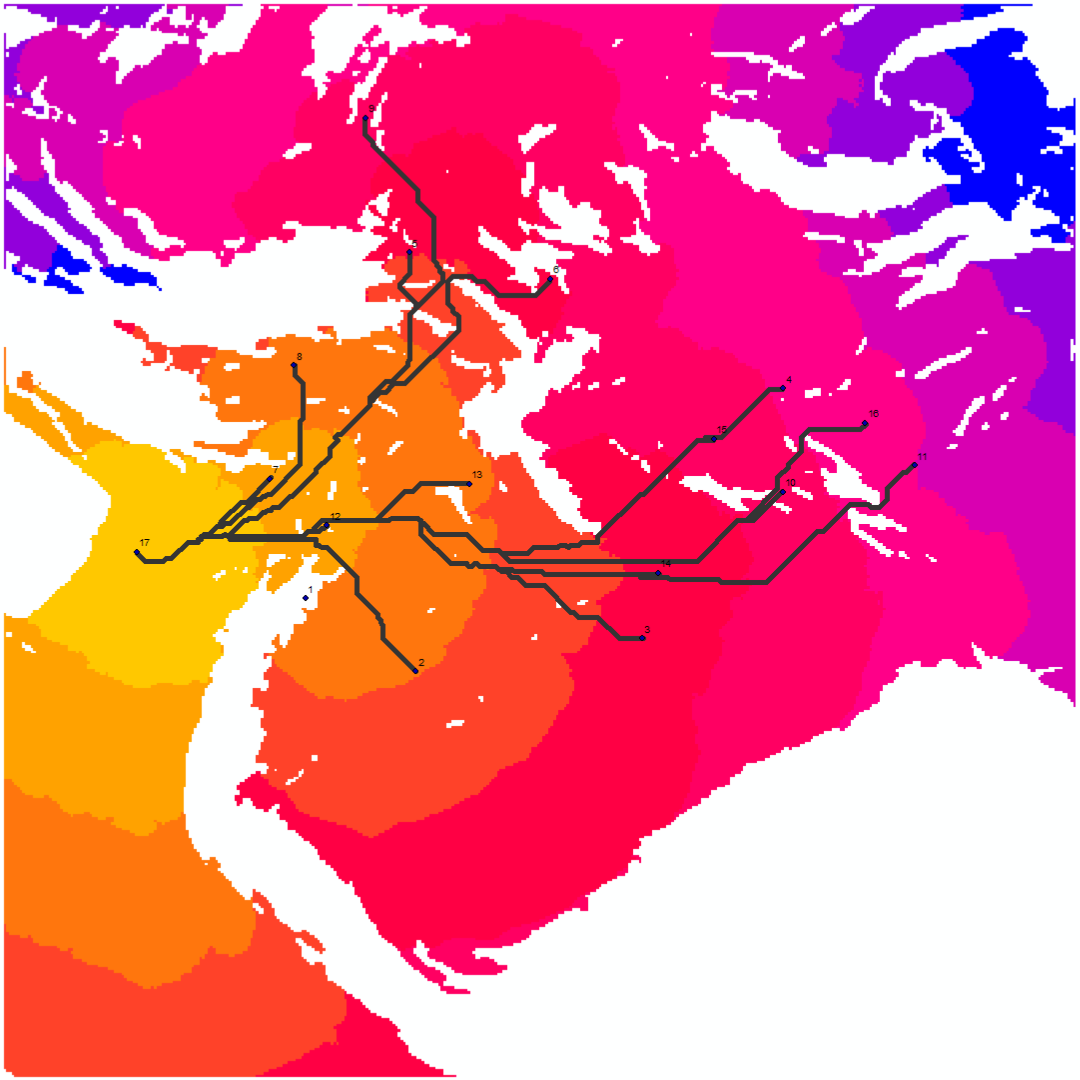


Cost Distance raster



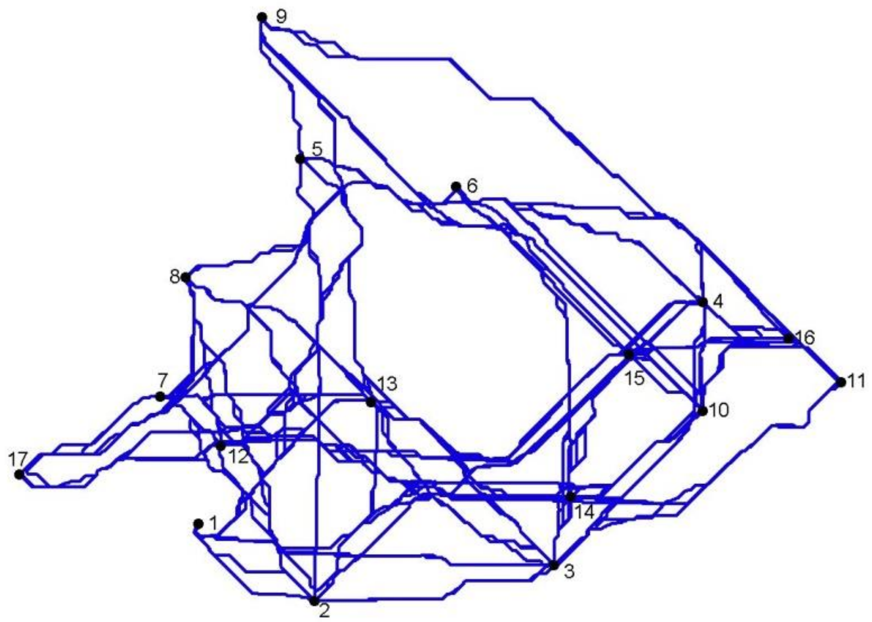
Friction raster

Optimal paths from all rain gauges and back to the source



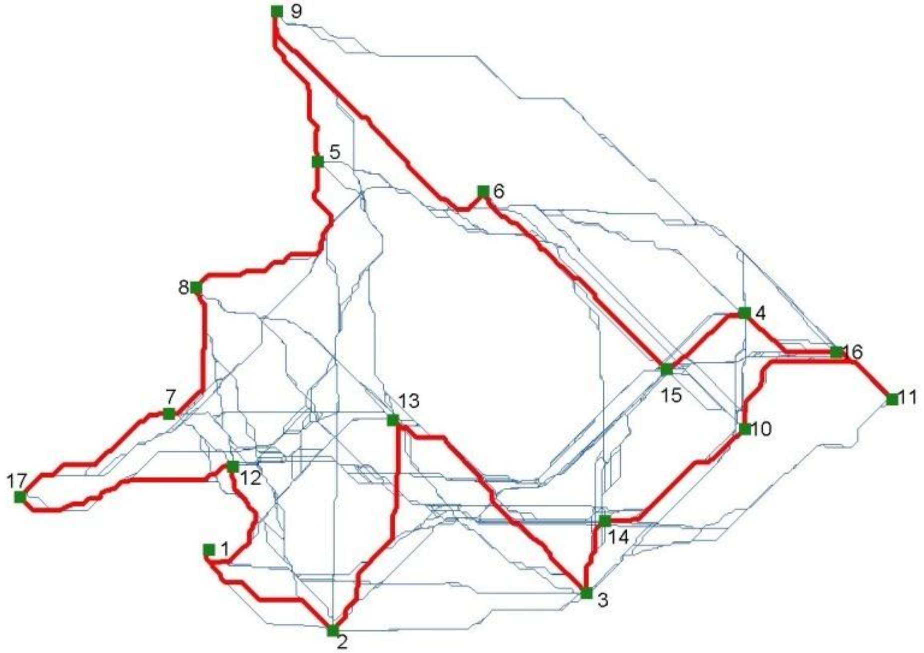
The method ahead

- 16 distance accumulation surfaces are derived using each rain gauge as individual sources.
- Next, optimal paths are derived from all rain gauges and back to the source.

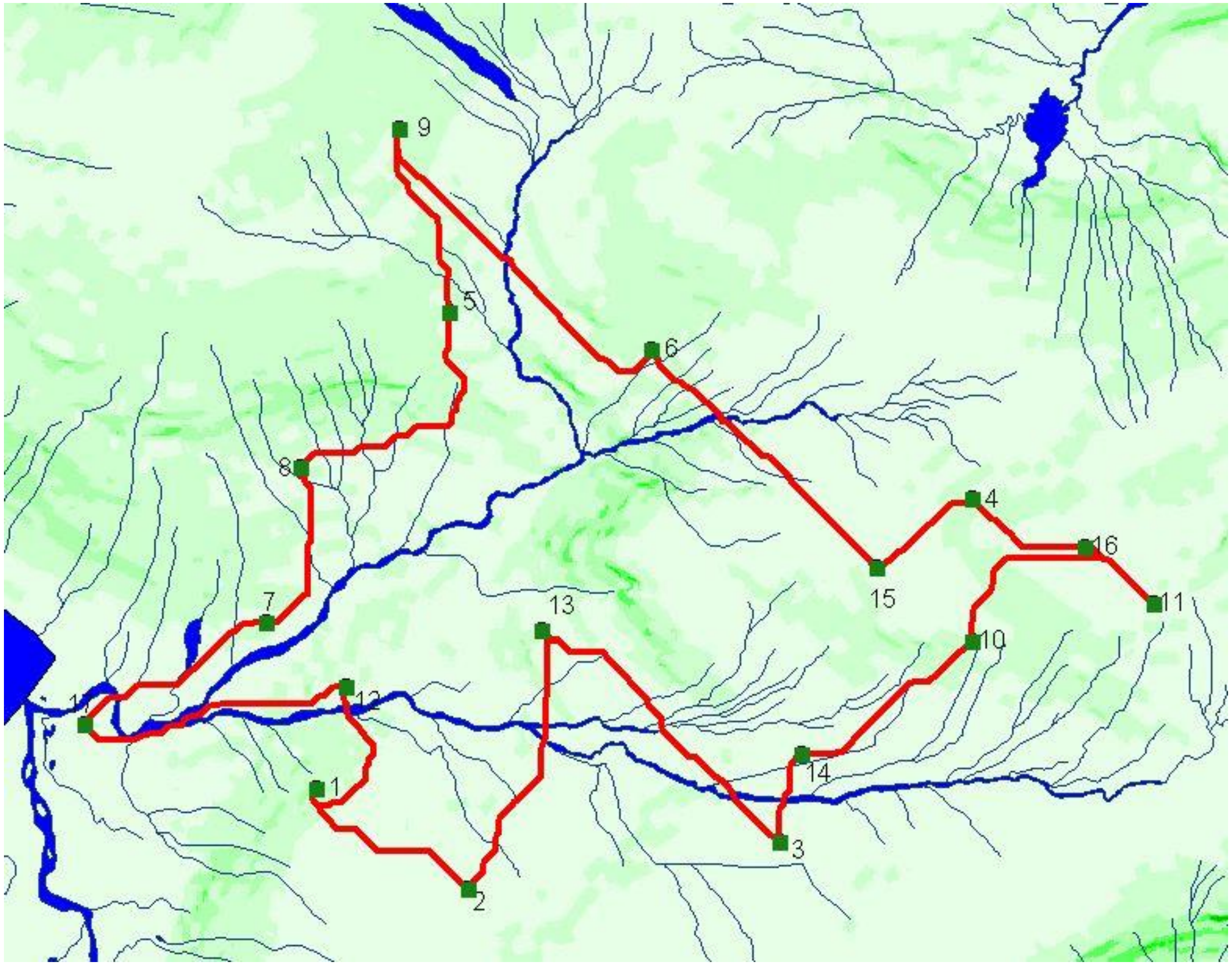


The method ahead

- The web of paths is converted to a road network.
- A shortest path analysis (based on the travelling salesman's principle) is carried out to identify the shortest route from the base camp (station no. 17) visting all rain gauges once and returning

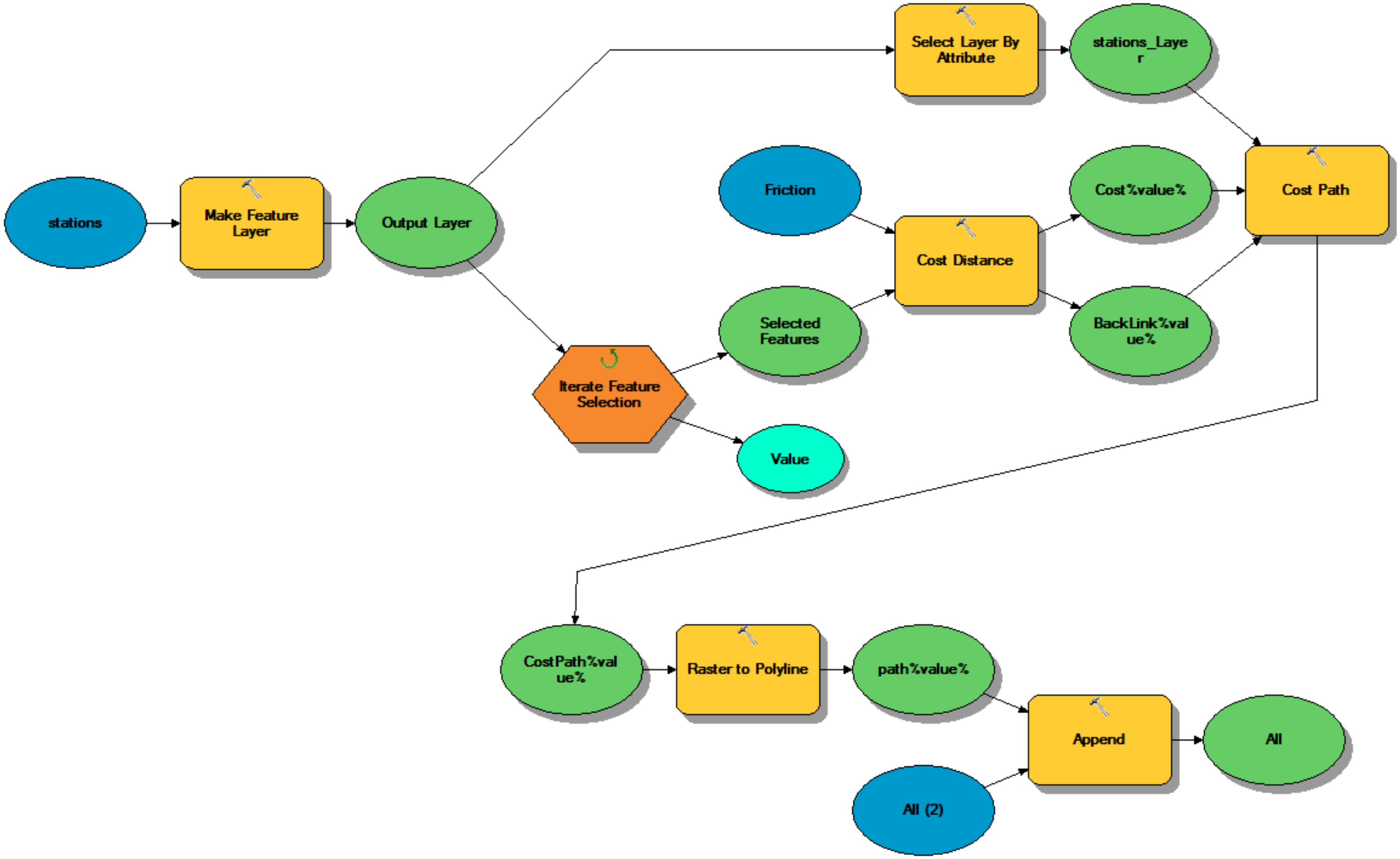


The shortest route



Total length:10562 m
Approximately 4 hours

A model to create a web of shortest paths



Discussion of the result / method problems

- The shortest route is based on two friction parameters, only: Time to pass slopes and minor rivers. More parameters may be added like the local terrain roughness (many/few boulders, grass cover, swampy).
- The friction values are sensitive to the individual – some are better wanderers than others.
- Actually, it's possible to pass slopes up to 40%. However, it takes more time to walk downhill (35 secs. per cell) than uphill (20 secs) but you can't tell a raster GIS that a cell may be entered from different directions with varying friction values.
- Some rivers are deeper than 25 cm which can't be mapped.