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Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis

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Outline

Developed a software tool [written FORTRAN language] to

- Extract topographic structures.
- Delineate drainage network
- Overland the flow path.
- Delineate watersheds.

Test the computer generated watersheds to manually delineated one [Result: Both are very close and spatially identical.

Data used: DEM (Digital Elevation Model)

DEM (Digital Elevation Model)

Gives information about morphology of the land surface

Previous work

- Slope
- Aspect
- Shaded relief

•Points of inflection

Developed a tool to extract

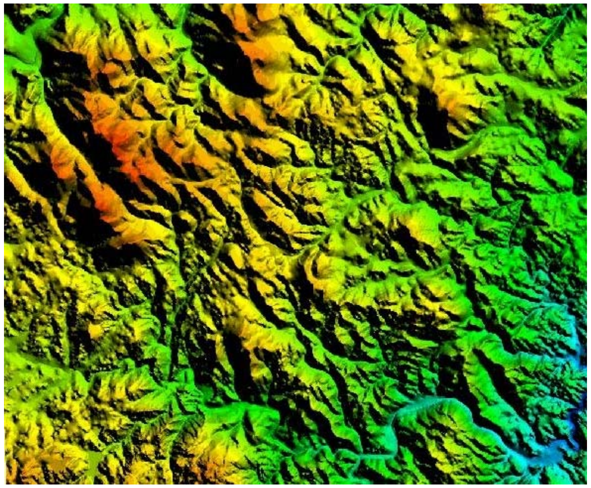
•Topographic depressions
•Flow directions

Initial Phase

- DEM with depression filled data set.
  - Flow direction data set.
  - Flow accumulation data set.

Final Phase

Original DEM + Data from Initial Phase = drainage network, overland flow paths, and watershed delineation.



Filling Depressions in DEM

Depressionless DEM

TABLE 1. FILLING DEPRESSIONS IN A DEM

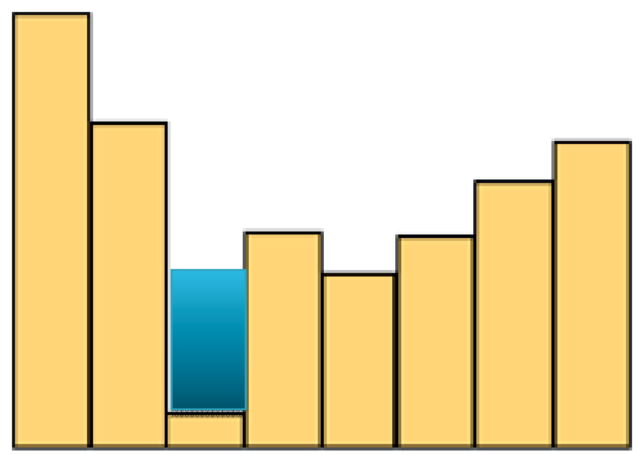
Step	Procedure
1	Fill single-cell depressions by raising each cell's elevation to the elevation of its lowest elevation neighbor if that neighbor is higher in elevation than the cell. This is a simple case and filling them reduces the number of depressions that must be dealt with.
2	Compute flow directions (Table 3)
3	For every spatially connected group of cells that has undefined flow directions because it would have required an uphill flow, find the group's uniquely labeled watershed from the flow directions.
4	Build a table of pour point elevations between all pairs of watersheds that share a boundary (Table 6).
5	For each watershed, mark the pour point that is lowest in elevation as that watershed's "lowest pour point." If there are duplicate lowest pour points, select one arbitrarily.
6	For each watershed, follow the path of lowest pour points until either the data set edge is reached (go to step 7) or the path loops back on itself (go to step 6a).
	6a. Fix paths that loop back on themselves by aggregating the watersheds which comprised the loop, deleting pour points between group members from the table, recomputing "lowest pour point" for the new aggregated watershed, and resume following the path of lowest pour points.
7	In each watershed's path of lowest pour points, find the one that is highest in elevation. This is the threshold value for the watershed. Raise all cells in the watershed that are less than the threshold value to the threshold value.

Filling Depressions in DEM

(a) original DEM

Sample Line	1	2	3	4	5	6	7	8	9	10	11	12
1	778	765	750	740	747	759	765	766	769	776	786	795
2	770	758	745	737	741	751	753	761	777	789	802	814
3	777	763	747	736	735	743	750	767	787	806	820	832
4	786	767	750	737	733	739	752	769	785	797	808	822
5	794	773	756	741	733	733	744	759	772	779	789	806
6	799	782	763	750	737	733	733	745	757	767	782	801
7	802	788	771	761	751	736	733	738	751	764	779	798
8	799	790	780	772	762	746	733	737	754	770	784	794
9	811	799	787	771	757	741	728	730	745	765	779	783
10	823	807	790	774	762	748	733	725	733	750	764	763
11	830	814	801	787	776	761	743	728	725	737	748	751
12	822	818	811	801	791	776	757	739	726	725	735	751

DEM contain depressions that hinder flow routing



Profile view of a sink

Flow Direction

Where will water flow ?

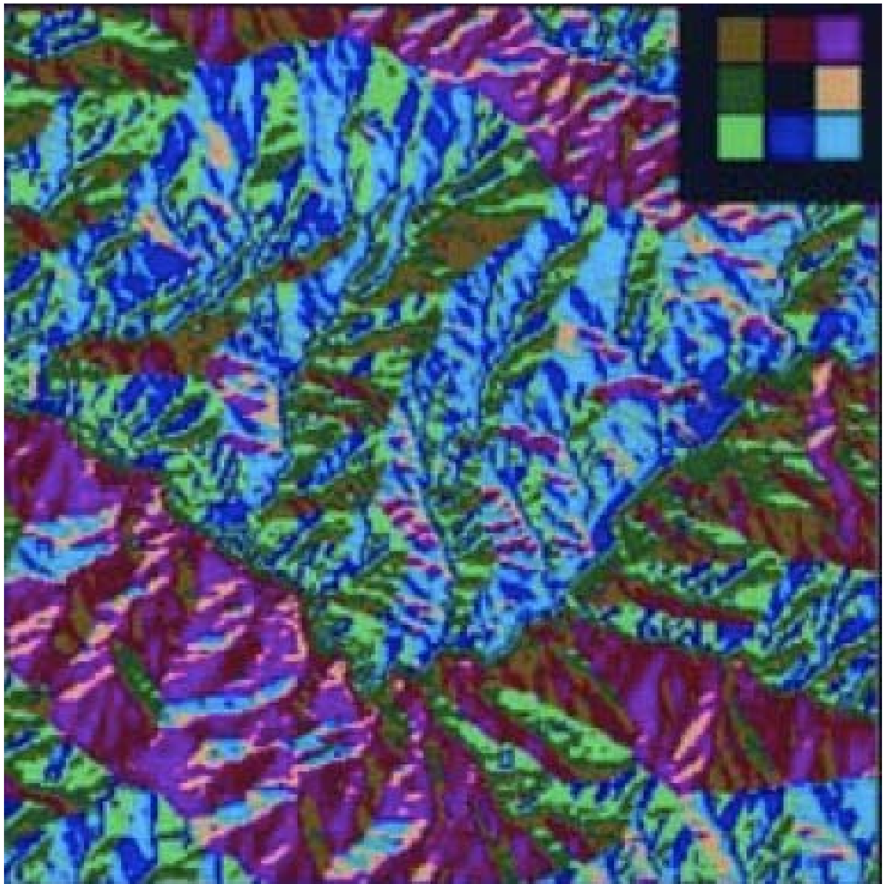


TABLE 3. COMPUTING FLOW DIRECTIONS FOR A DEM

Step	Procedure
1	For all cells adjacent to the data set edge or the study area amsk, assign the flow direction to flow to the edge or the mask. This action is taken under the assumption that the study area is interior to the data set.
2	For each cell not assigned a flow direction in step 1, compute the distance-weighted drop in elevation to each of the cell's eight neighbors.
3	Examine the drop value to determine the neighbor(s) with the largest drop and perform one of the following: 3a. If the largest drop is less than zero, assign a negative flow direction to indicate undefined. This situation does not occur for a depressionless DEM 3b. If the largest drop is greater than or equal to zero and occurs at only one neighbor, assign the flow direction to that neighbor. 3c. If the largest drop is equal to zero and occurs at more than one neighbor, assign the flow direction logically according to a table loop-up. 3d. If the largest drop is equal to zero and occurs at more than one neighbor, encode the locations of those neighbors by summing their neighbor location codes. Neighbor location codes are 64 128 1 32 x 2 16 8 4 for any cell x. If all neighbor elevations were equal to the center cell, the center would receive a value of 255. Examples of steps 3a through 3d are given in Table 4, conditions 1 through 4.
4	For each cell not already encoded as negative, 0, 1, 2, 4, 8, 16, 32, 64, or 128, examine the neighbor cells with the largest drop. If a neighbor is encountered that as a flow direction of 1, 2, 4, 8, 16, 32, 64, or 128, and the neighbor does not flow to the center cell, assign the center cell a flow direction which flows to this neighbor.
5	Repeat step 4 until no more cells can be assigned a flow direction.
6	Make the flow direction value negative for cells that are not equal to 1, 2, 4, 8, 16, 32, 64, or 128. This situation will not occur for a depressionless DEM.

Flow Direction

	Elevation Values			Weighted Drops			Flow Direction
Condition 1	100	102	100	-7.0	-12.0	-7.0	4
	99	90	92	-9.0		-2.0	
	98	94	92	-5.6	- 4.0	-1.4	
Condition 2	92	91	90	-1.4	- 1.0	0.0	2
	92	90	89	-2.0		1.0	
	94	93	90	-2.8	- 3.0	0.0	
Condition 3	90	91	90	0.0	- 1.0	0.0	2
	89	90	89	1.0		1.0	
	90	93	90	0.0	- 3.0	0.0	
Condition 4	92	91	90	-1.4	- 1.0	0.0	Temporarily encoded as 1 + 2 + 4 = 7, and then resolved iteratively
	93	90	90	-3.0		0.0	
	94	93	90	-2.8	- 3.0	0.0	

Condition 1 (Single cell depression)
All 8 neighboring cells have higher elevation than center cell. Flow direction is Undefined

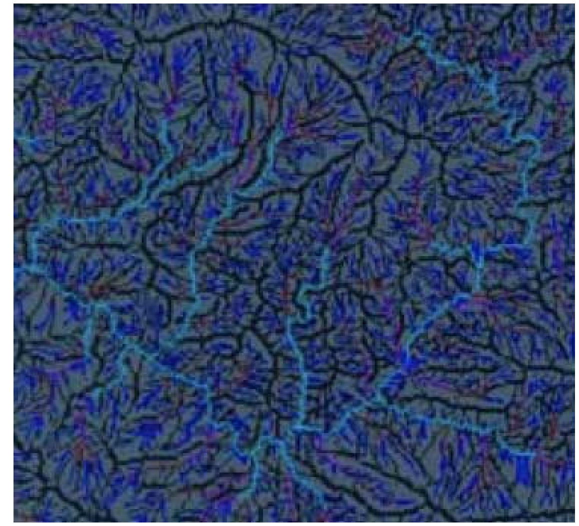
Condition 2 (One neighbor is best)
The distance weighted drop from the center cell is higher for one cell in the neighborhood over all of the other seven cells. Flow direction is assigned to the cell.

Distance weighted drop = central value-neighbor value/distance from central cell, $\sqrt{2}$ for corner cell, 1-non corner cell

Condition 3 (More than one neighbor is a possible choice)
When two or more cells are equal in having the greatest distance weighted drop. Flow direction is assigned logically using table look-up operation.

Condition 4 (Cells is a part of flat areas)
When all cells are equal or greater in elevation compared to the center cell. Time consuming to calculate flow direction (lots of iterations)

Flow Accumulation



Each cell is assigned a value equal to the number of cells that drain to it.

Number of DEM points whose flow paths eventually pass through that point

(d) flow accumulation values

Sample Line	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	0	0	0	0	0	2	1	0	0
2	0	0	1	2	0	0	3	2	1	1	0	0
3	0	0	1	2	10	4	2	1	0	0	0	0
4	0	0	1	2	21	3	0	0	0	0	0	0
5	0	0	1	5	35	3	1	1	0	2	0	0
6	0	0	2	2	6	44	4	1	3	2	0	0
7	0	0	1	2	1	3	62	11	6	2	0	0
8	0	0	1	0	0	0	64	1	0	0	0	0
9	0	0	0	1	7	10	76	4	1	0	0	0
10	0	0	2	4	1	1	3	90	1	1	0	0
11	0	0	0	0	0	0	0	1	95	1	0	0
12	0	0	0	0	0	0	0	0	97	0	0	0

Cell value 0= No other cell to flow (pattern of ridges)

Application

- DEM with depression filled data set.
- Flow Direction data set.
- Flow Accumulation data set.

•Specific Watersheds Delineation
•Automatic Delineation of Sub-Watersheds
•Watershed linkages
•Drainage Networks

Specific Watersheds Delineation

- Flow Direction data set.
- Starter data set.

Starter data set

- A single cells or groups of cells
- Inserted at the outflow points
- Unique positive value

Automatic delineation of Sub-watersheds


(d) automatic watershed starting

Sub watersheds are part of larger watershed

Delta value = Flow accumulation value of the cell– flow accumulation value of cell it flows to

TABLE 5. SUB-WATERSHED STARTING BY AREA THRESHOLD

Step	Procedure
1	Define an area threshold to constrain the minimum area of sub-watersheds.
2	Compute a delta value for every cell by subtracting the flow accumulation value of the cell it flows to from its own flow accumulation value.
3	For each cell where both the flow accumulation value and the delta value are greater than the area threshold, assign the cell a unique positive value in the starter data set.
4	Assign all remaining cells a value of –1.
5	Report how many watersheds were started.

Watershed Linkage

Two or more watersheds link at pour point, the point of lowest elevation on the common boundary between the two watersheds

TABLE 6. DETERMINING POUR POINTS BETWEEN WATERSHEDS

Step	Procedure
1	Compare each cell in a watershed data set to its eight neighbors. When a cell and its neighbor have different watershed labels, proceed to steps 2 through 5.
2	Compare the elevation values of the cell and its neighbor. The larger of the two elevation values is the elevation of the possible pour point they represent, and the line and sample of the cell with the larger elevation is the pour point location.
3	If this pair of watershed labels is not yet in the table of pour points, make a new table entry by recording the pair of watershed labels and the location and elevation of the pour point.
4	If this pair of watershed labels is already in the pour point table, compare the elevation in the table to the elevation for the possible pour point being examined. If the new elevation is lower, replace the old pour point lines, sample, and elevation with the new ones.
5	Repeat the procedure for all cells.

Drainage Networks & Overland Paths

Drainage Networks

Flow accumulation data can be used to produce drainage network data sets When cells with values greater than a threshold value are selected.

The density of the network increases as the threshold value decreases.

Raster lines can be changed into vector lines.

Overland Paths

Flow direction data set can be used to produce the path or paths by following the cell-to-cell linkage until the data set edge is reached.

Evaluation of the software toolbox

Tested with several hydrological studies

Compare the watersheds derived from DEM using toolbox and watersheds manually delineated from topographic maps

Compare the line plots produced from vectorized watersheds to the manually delineated watershed.

Agreement between two are very close and they spatially identical.

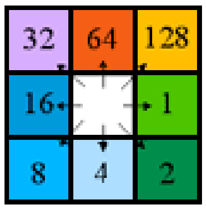
Information extracted from DEM by using this algorithm is directly related with resolution of DEM.

78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

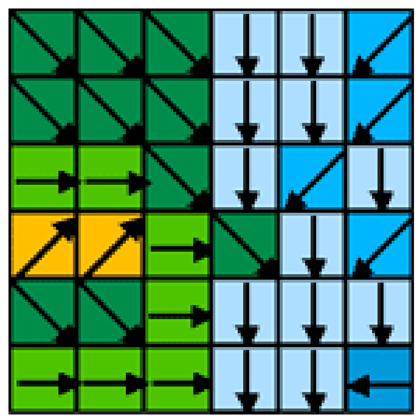
Elevation

2	2	2	4	4	8
2	2	2	4	4	8
1	1	2	4	8	4
128	128	1	2	4	8
2	2	1	4	4	4
1	1	1	1	4	16

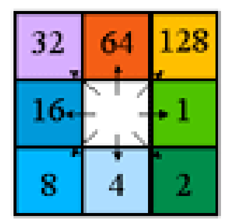
Flow Direction



Direction Coding



0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	2



Direction Coding