RS & GIS in Water Resources Management

Lecture –V

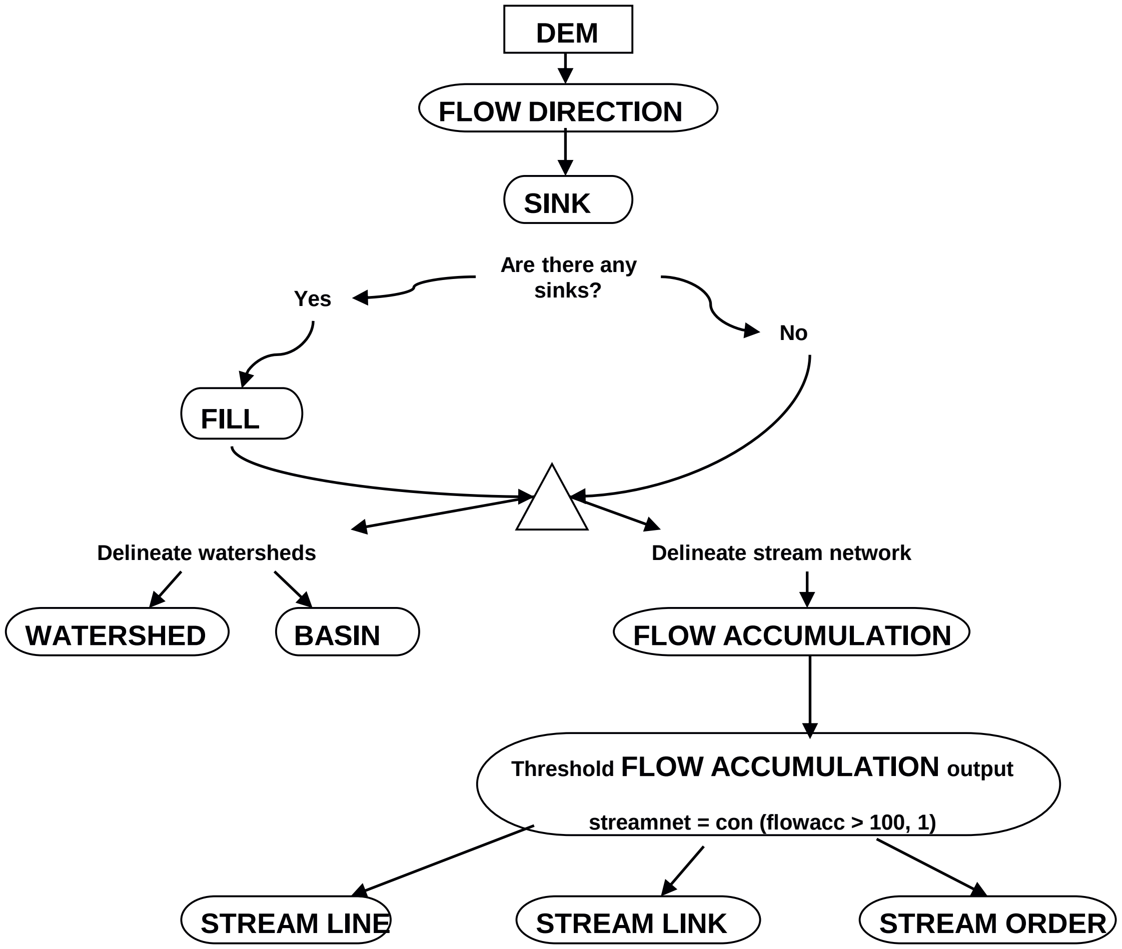
Extraction of Topographic Structure from DEM for GIS Analysis

Course Code: CE 710

Instructor In-charge: RAAJ Ramsankaran

Please note that portions of the material in this lecture comes from ArcGIS help files, David Maidment Lecture notes and other open source lecture notes.

Creating a hydrologically correct DEM and Watershed Delineation



FILLING DEPRESSIONS IN A DEM

An approach suggested by Jenson and Domingue, 1988, PE & RS

Steps Involved:

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.

2. Compute flow directions.

3. For every spatially connected group of cells that has undefined flow direction, find the group's uniquely labeled watershed from the flow directions.

4. Build a table of pour point elevations between all pairs of watershed labels.

Contd.,

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, re-computing "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.

Original DEM

Cell Index	1	2	3	4	5	6	7	8	9	10
1	7	7	6	7	7	7	7	5	7	7
2	9	9	8	9	9	9	9	7	9	9
3	11	11	10	11	11	11	11	9	11	11
4	12	12	8	12	12	12	12	10	12	12
5	13	12	7	12	13	13	13	11	13	13
6	14	7	6	11	14	14	14	12	14	14
7	15	7	7	8	9	15	15	13	15	15
8	15	8	8	8	7	16	16	14	16	16
9	15	11	11	11	11	17	17	6	17	17
10	15	15	15	15	15	18	18	15	18	18

Step 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. :

single-cell depressions

Cell Index	1	2	3	4	5	6	7	8	9	10
1	7	7	6	7	7	7	7	5	7	7
2	9	9	8	9	9	9	9	7	9	9
3	11	11	10	11	11	11	11	9	11	11
4	12	12	8	12	12	12	12	10	12	12
5	13	12	7	12	13	13	13	11	13	13
6	14	7	7	11	14	14	14	12	14	14
7	15	7	7	8	9	15	15	13	15	15
8	15	8	8	8	8	16	16	14	16	16
9	15	11	11	11	11	17	17	14	17	17
10	15	15	15	15	15	18	18	15	18	18

Fill single depression with lowest elevation neighbor

Step 2: Compute flow directions

2a. For all cells adjacent to the data set edge or the study area mask, assign the flow direction to flow to the edge or the mask. Assuming that the study area is interior to the data set.

Neighbor location Flow direction codes are:

64	**128**	**1**
32	**X**	**2**
16	**8**	**4**

Cell Index	1	2	3	4	5	6	7	8	9	10
1	32	128	128	128	128	128	128	128	128	2
2	32									2
3	32									2
4	32									2
5	32									2
6	32									2
7	32									2
8	32									2
9	32									2
10	32	8	8	8	8	8	8	8	8	2

2b. For each cell not assigned a flow direction in step 2a., compute the distance-weighted drop in elevation to each of the cell's eight neighbors.

Weighted drops are calculated by subtracting the neighbor's value from the center cell's value and dividing by the appropriate distance, √2 for corner cells or one for non-corner cells.

Illustrative example

Elevation Values				Weighted Drop		
9	8	9		0.707	2	0.707
11	10	11		-1		-1
12	8	12		-1.414	2	-1.41

2c. Examine the drop value to determine the neighbor(s) with the largest drop and perform one of the following:

	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	

If the largest drop is less than zero, assign a negative flow direction to indicate undefined.

If the largest drop is greater than or equal to zero and occurs at only one neighbor, assign the flow direction to that neighbor.

If the largest drop is greater than zero and occurs at more than one neighbor, assign the flow direction logically according to a look-up table.

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. The center cell is a part of a Flat area

Example for the center cell (3,5):

Elevation Values				Weighted Drop		
12	8	12		-3.53	-1	-3.53
12	7	12		-5		-5
7	7	11		0	0	-2.82

Satisfies Condition 4: largest drop is equal to zero and occurs at more than one neighbor

Flow direction code

64	**128**	**1**
32	**X**	**2**
16	**8**	**4**

Flow Direction = 8+16 = 24

Flow Direction from step 2c.

Cell Index	1	2	3	4	5	6	7	8	9	10
1	32	128	128	128	128	128	128	128	128	2
2	32	1	128	64	128	128	1	128	64	2
3	32	1	128	64	128	128	1	128	64	2
4	32	2	8	32	128	128	1	128	64	2
5	32	2	24	32	16	128	1	128	64	2
6	32	15	184	32	8	16	1	128	64	2
7	32	131	224	32	8	32	1	4	8	2
8	32	128	128	64	96	32	4	2	16	2
9	32	128	128	128	128	64	2	128	32	2
10	32	8	8	8	8	8	8	8	8	2

2d. For each cell not already encoded as negative, 1, 2, 4, 8, 16, 32, 64, or 128, examine the neighbor cells with the largest drop. If the largest drop neighbor is encountered which has 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.

Cell Index	1	2	3	4	5	6	7	8	9	10
1	32	128	128	128	128	128	128	128	128	2
2	32	1	128	64	128	128	1	128	64	2
3	32	1	128	64	128	128	1	128	64	2
4	32	2	8	32	128	128	1	128	64	2
5	32	2	24	32	16	128	1	128	64	2
6	32	15	184	32	8	16	1	128	64	2
7	32	131	224	32	8	32	1	4	8	2
8	32	128	128	64	32	32	4	2	16	2
9	32	128	128	128	128	64	2	128	32	2
10	32	8	8	8	8	8	8	8	8	2

Yellow cells are not encoded as negative, 1, 2, 4, 8, 16, 32, 64, or 128

For all these center cells, all the largest drop neighbor cell flow to the center cell

Only for this center cell, neighbor does not flow to the center cell, therefore the flow direction is revised

Repeat this step until no more cells can be assigned a flow direction.

Flow direction code

64	**128**	**1**
32	**X**	**2**
16	**8**	**4**

2e. 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.

Cell Index	1	2	3	4	5	6	7	8	9	10
1	32	128	128	128	128	128	128	128	128	2
2	32	1	128	64	128	128	1	128	64	2
3	32	1	128	64	128	128	1	128	64	2
4	32	2	8	32	128	128	1	128	64	2
5	32	2	-24	32	16	128	1	128	64	2
6	32	-15	-184	32	8	16	1	128	64	2
7	32	-131	-224	32	8	32	1	4	8	2
8	32	128	128	64	32	32	4	2	16	2
9	32	128	128	128	128	64	2	128	32	2
10	32	8	8	8	8	8	8	8	8	2

Step 3: For every spatially connected group of cells that has undefined flow directions uniquely label the cells.

Watershed labels

Cell Index	1	2	3	4	5	6	7	8	9	10
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	1	0	0	0	0	0	0	0
6	0	1	1	0	0	0	0	0	0	0
7	0	1	1	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0

Cells with undefined flow directions is uniquely labeled as 1

Step 4: Build a table of pour point elevations between all pairs of watersheds that share a boundary.

4a. 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 4b-e.

Searching for different watershed labels

Found

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

4b. 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.

Cell Index	1	2	3	4	5	6	7	8	9	10
1	7	7	6	7	7	7	7	5	7	7
2	9	9	8	9	9	9	9	7	9	9
3	11	11	10	11	11	11	11	9	11	11
4	12	12	8	12	12	12	12	10	12	12
5	13	12	7	12	13	13	13	11	13	13
6	14	7	7	11	14	14	14	12	14	14
7	15	7	7	8	9	15	15	13	15	15
8	15	8	8	8	8	16	16	14	16	16
9	15	11	11	11	11	17	17	14	17	17
10	15	15	15	15	15	18	18	15	18	18

Build a table of pour point elevations

Pair	Elevation	Location	
		X	Y
0-1	12	2	4

larger of the two elevation values (i.e. 12 and 7) represents the pour point (i.e. 12)

Further Search for different watershed labels

Cell Index	1	2	3	4	5	6	7	8	9	10
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	1	0	0	0	0	0	0	0
6	0	1	1	0	0	0	0	0	0	0
7	0	1	1	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0

Found

Table of pour point elevations

Pair	Elevation	Location	
		X	Y
0-1	12	2	4

If this pair of watershed labels (i.e 0-1))is already in the pour point table, go to step 4.c

Step: 4c. 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 location, and elevation with the new ones.

Cell Index	1	2	3	4	5	6	7	8	9	10
1	7	7	6	7	7	7	7	5	7	7
2	9	9	8	9	9	9	9	7	9	9
3	11	11	10	11	11	11	11	9	11	11
4	12	12	8	12	12	12	12	10	12	12
5	13	12	7	12	13	13	13	11	13	13
6	14	7	7	11	14	14	14	12	14	14
7	15	7	7	8	9	15	15	13	15	15
8	15	8	8	8	8	16	16	14	16	16
9	15	11	11	11	11	17	17	14	17	17
10	15	15	15	15	15	18	18	15	18	18

Larger of the two elevation values (i.e. 8 and 7) represents the new pour point (i.e. 8)

Table of pour point elevations

Pair	Elevation	Location	
		X	Y
0-1	12	2	4

Compare the elevation in the table of pour point (i.e. 12) to the elevation for the possible pour point being examined (i.e. 8). the new elevation (i.e. 8) is lower, replace the old pour point location, and elevation with the new ones.

Updated table of pour point elevations

Pair	Elevation	Location	
		X	Y
0-1	8	3	4

Continue the process for complete dataset

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.

Final Table of pour point elevations

Pair	Elevation	Location	
		X	Y
0-1	8	3	4

Pour Point

Cell Index	1	2	3	4	5	6	7	8	9	10
1	7	7	6	7	7	7	7	5	7	7
2	9	9	8	9	9	9	9	7	9	9
3	11	11	10	11	11	11	11	9	11	11
4	12	12	8	12	12	12	12	10	12	12
5	13	12	7	12	13	13	13	11	13	13
6	14	7	7	11	14	14	14	12	14	14
7	15	7	7	8	9	15	15	13	15	15
8	15	8	8	8	8	16	16	14	16	16
9	15	11	11	11	11	17	17	14	17	17
10	15	15	15	15	15	18	18	15	18	18

Step 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, re-computing "lowest pour point" for the new aggregated watershed, and resume following the path of lowest pour points.

Step. 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.

Follow Step 7

7	7	6	7	7	7	7	5	7	7
9	9	8	9	9	9	9	7	9	9
11	11	10	11	11	11	11	9	11	11
12	12	8	12	12	12	12	10	12	12
13	12	8	12	13	13	13	11	13	13
14	8	8	11	14	14	14	12	14	14
15	8	8	8	9	15	15	13	15	15
15	8	8	8	8	16	16	14	16	16
15	11	11	11	11	17	17	14	17	17
15	15	15	15	15	18	18	15	18	18

Follow Step 6 a

Repeat the process until pits are filled

7	7	6	7	7	7	7	5	7	7
9	9	8	9	9	9	9	7	9	9
11	11	10	11	11	11	11	9	11	11
12	12	8	12	12	12	12	10	12	12
13	12	8	12	13	13	13	11	13	13
14	8	8	11	14	14	14	12	14	14
15	8	8	8	9	15	15	13	15	15
15	8	8	8	8	16	16	14	16	16
15	11	11	11	11	17	17	14	17	17
15	15	15	15	15	18	18	15	18	18

Next iteration output

7	7	6	7	7	7	7	5	7	7
9	9	8	9	9	9	9	7	9	9
11	11	10	11	11	11	11	9	11	11
12	12	9	12	12	12	12	10	12	12
13	12	9	12	13	13	13	11	13	13
14	9	9	11	14	14	14	12	14	14
15	9	9	9	9	15	15	13	15	15
15	9	9	9	9	16	16	14	16	16
15	11	11	11	11	17	17	14	17	17
15	15	15	15	15	18	18	15	18	18

Final output

7	7	6	7	7	7	7	5	7	7
9	9	8	9	9	9	9	7	9	9
11	11	10	11	11	11	11	9	11	11
12	12	10	12	12	12	12	10	12	12
13	12	10	12	13	13	13	11	13	13
14	10	10	11	14	14	14	12	14	14
15	10	10	10	10	15	15	13	15	15
15	10	10	10	10	16	16	14	16	16
15	11	11	11	11	17	17	14	17	17
15	15	15	15	15	18	18	15	18	18

Thank You All