Comparison of Flow Routing Algorithms Used in Geographic Information Systems

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Outline

- Background
- Hypotheses
- Study Area
- Fuzzy Classification
- Results
- Conclusions

Hydrologic Units

National Watershed Network

2-digit= 1st level = 22 regions

4-digit= 2nd level = 222 subregions

6-digit= 3rd level = 789 accounting

8-digit= 4th level = 2223 cataloging

new!

10-digit= 5th level = ~22,000 watersheds

12-digit= 6th level = ~160,000 subwatersheds

Slide Courtesy of Bob Pierce

Hydrologic Cycle

Goal is to follow a drop of water from where it falls on the land, to the stream, and all the way to the ocean

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Specific Catchment Area

- Specific catchment area = number of upslope cells x cell area / cell width (in a square-grid DEM)

78	75	80
77	74	76
70	72	65

Elevation

10	20	
	30	
		40

Specific Catchment Area

Single vs. Multiple Flow Directions

Single Flow Direction Grid — A numerical representation of flow direction field in which each cell takes on one of eight values depending on which of its eight neighboring cells is in direction of steepest descent

Multiple Flow Direction Grid — A numerical representation of flow direction field in which flow is partitioned between one or more of the eight neighboring cells such that proportions add up to one

Slide Courtesy of David Tarboton

Flow Directions

103.8	101.5	102.1
101.7	100.0	98.4
100.4	97.2	96.4

FD8 – 45° increments

Some other flow routing algorithms calculate flow directions in 1° increments

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Flow Routing Algorithms

- D8 (O'Callaghan and Mark 1981)
- Rho8 (Fairfield and Leymarie 1991)
- FD8 (Quinn et al. 1991)
- DEMON (Lea 1992, Costa-Cabral and Burges 1994)
- D∞ (Tarboton 1997)

Null Hypotheses

- The performance of five popular flow routing algorithms in computing specific catchment area does not change as flow descends from higher to lower elevations
- The performance of the five flow routing algorithms does not vary across different landscape classes produced with fuzzy k-means algorithm of Burrough and McDonnell (1998)

Study Area Metrics

- Point Dume, CA 1:24K USGS map quadrangle
- 1.3 million grid points with 10 m spacing
- Elevations range from 0 m (sea level) to 859.7 m
- Much of region is parkland or some other type of protected open space
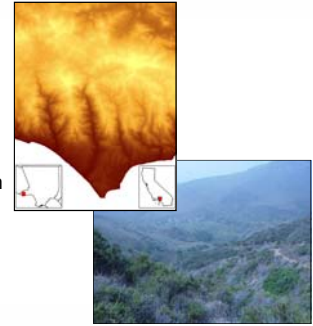

Fuzzy Classification

- Used PCRaster to calculate 8 topographic attributes
  - Elevation
  - Slope
  - Profile Curvature
  - Plan Curvature
  - Distance to Ridgelines
  - Solar Insolation
  - Topographic Wetness Index
  - Sediment Transport Capacity Index
- Used FUZNLM fuzzy k-means classifier to identify 6 landform classes
  - Assigns membership values to grid cells
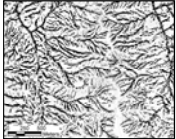 - Assigns classes based on largest membership values

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Fuzzy Classification
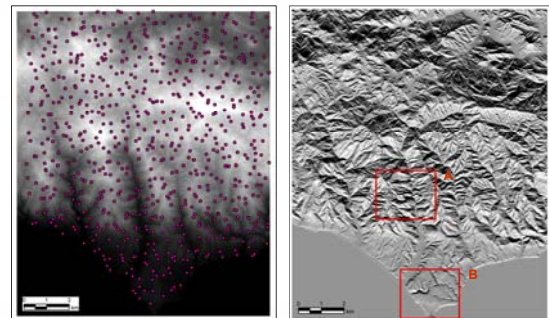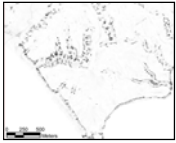
Hilltops / Ridgelines

- High elevations
- Ridgelines are nearby
- Low topographic wetness index
- High solar radiation

INSET A

INSET B
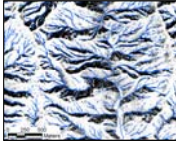
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North-facing Slopes

- High elevations
- Very steep slopes
- Low solar insolation
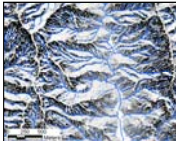
INSET A
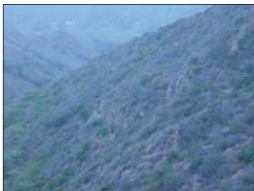

INSET B

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South-facing Slopes

- High elevations
- Very steep slopes
- High solar insolation
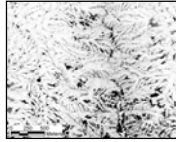
INSET A

INSET B

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Footslopes / Lower Valley Slopes

- Low elevations
- Moderately steep slopes
- Ridgelines are far away
- High topographic wetness index

INSET A

INSET B

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Stream Channels

- Long distances to ridgelines
- High topographic wetness index
- High sediment transport capacity index

INSET A

INSET B

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Coastal Plain / Gentle Slopes

- Low elevations
- Gentle slopes
- High topographic wetness index

INSET A

INSET B

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Crisp Landscape Classes

INSET A   INSET B

Coastal plains / gentle slopes
Moderately steep lower valley slopes
Stream channels
Steep north-facing slopes
Steep south-facing slopes
Hilltops / ridgelines
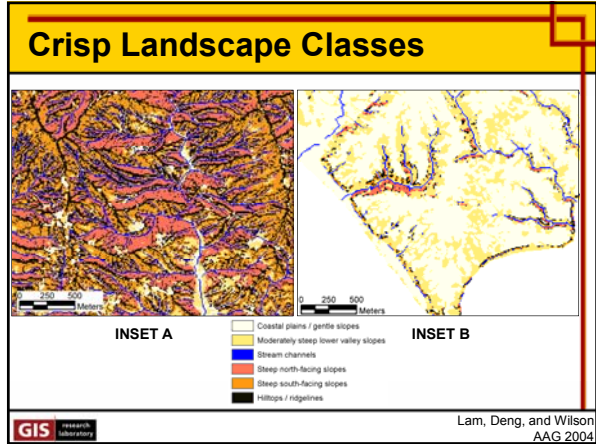
Hypothesis #1

	Number of cells	Minimum	Maximum	Mean SCA (m^2m^{-1})	Standard Deviation (m^2m^{-1})
D8	1,263,296	7.07	2237670.25	3715.27	60584.28
Rho8	1,263,296	7.07	2236030.25	3714.18	60469.64
D∞	1,263,296	10.00	2236762.00	3934.18	61469.07
FD8	1,263,296	2.56	2341777.00	4355.83	69911.69
DEMON	1,263,296	7.07	2214353.00	3428.91	55657.18

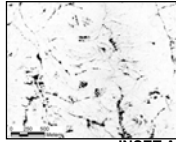|	SCA (m^2m^{-1})						
	≤ 10.0	10.1 – 20	20.1 - 40	40.1 - 70	70.1 - 100	100.1 – 1000	> 1000
D8	12.8	18.5	26.9	16.3	7.2	13.3	5.1
Rho8	13.4	21.6	25.0	14.3	6.7	14.0	5.1
D∞	7.6	12.9	29.9	20.1	7.9	16.0	5.7
FD8	4.5	12.1	24.5	20.7	10.0	23.2	5.2
DEMON	2.7	12.2	29.3	23.6	9.6	17.6	5.0

Source Cells (SCA ≤ 10 m^2 m^{-1})

D8   Rho8   D∞

FD8   DEMON

Stream Cells (SCA ≥ 5,300 m^2m^{-1})

USGS DLG   D8   Rho8

D∞   FD8   DEMON
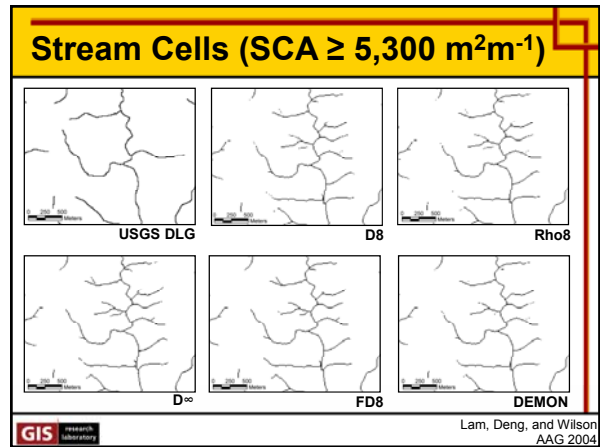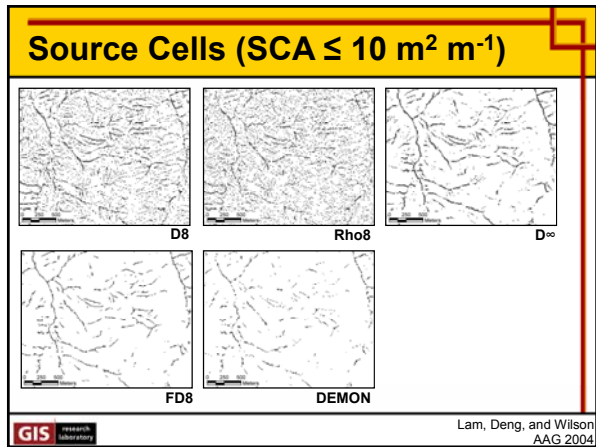
Hypothesis #2

- Chose every 1000th cell and calculated differences between pairs of cell values

- Used matched paired t-test to test whether differences were significantly different than 0

- Compared t-test results by landscape class and flow routing algorithm

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Matched Pairs T-test

Used critical t-test values of ±1.96 (5%) and ±2.58 (1% level of significance)

Class 6 – Ridgelines

	D8	Rho8	D∞	FD8	DEMON
D8	--				
Rho8	-3.55	--			
D∞	-10.97	1.38	--		
FD8	-5.94	-3.67	-3.44	--	
DEMON	-10.93	-5.22	-6.81	1.16	--

Class 4 - North-facing slopes

	D8	Rho8	D∞	FD8	DEMON
D8	--	--	--	--	--
Rho8	-1.04	--	--	--	--
D∞	-2.20	-1.42	--	--	--
FD8	4.00	-3.33	-1.98	--	--
DEMON	-3.78	-1.09	0.76	3.08	--

Matched Pairs T-test

Class 5 – South-facing slopes

	D8	Rho8	D∞	FD8	DEMON
D8	--	--	--	--	--
Rho8	-0.94	--	--	--	--
D∞	-2.24	0.40	--	--	--
FD8	-5.12	-0.45	-2.37	--	--
DEMON	-3.46	0.50	0.71	3.91	--

High elevation summary

	D8	Rho8	D∞	FD8	DEMON
D8	-				
Rho8	1	-			
D∞	3	0	-		
FD8	3	2	3	-	
DEMON	3	1	1	2	-

Matched Pairs T-test

Class 2 – Moderately steep lower valley slopes

	D8	Rho8	D∞	FD8	DEMON
D8	--	--	--	--	--
Rho8	1.78	--	--	--	--
D∞	0.85	-1.96	--	--	--
FD8	-0.38	-2.26	-1.16	--	--
DEMON	-0.55	-2.16	-1.19	0.16	--

Class 3 - Stream channels

	D8	Rho8	D∞	FD8	DEMON
D8	--				
Rho8	1.02	--			
D∞	-0.94	-1.15	--		
FD8	-1.82	-1.44	0.82	--	
DEMON	2.40	0.08	1.17	2.71	--

Matched Pairs T-test

Class 1 - Coastal plain / gentle slopes

	D8	Rho8	D∞	FD8	DEMON
D8	--	--	--	--	--
Rho8	-1.61	--	--	--	--
D∞	0.98	0.99	--	--	--
FD8	-1.13	-1.05	-1.00	--	--
DEMON	-0.19	1.01	-0.98	1.01	--

Low elevation summary

	D8	Rho8	D∞	FD8	DEMON
D8	-				
Rho8	0	-			
D∞	0	0	-		
FD8	0	1	0	-	
DEMON	1	1	0	1	-

T-test Summary

- Number of landscape classes for which null hypotheses was rejected

	D8	Rho8	D∞	FD8	DEMON
D8	-				
Rho8	1	-			
D∞	3	0	-		
FD8	3	3	3	-	
DEMON	4	2	1	3	-

Distribution of Source Cells

Landscape Class	Number of Cells	Number of Cells with SCA ≤ 10 m^2m^{-1}				
		D8	Rho8	D∞	FD8	DEMON
Hilltops / ridgelines	256,012	114,186	79,789	64,966	39,215	23,583
Steep south-facing slopes	323,989	1,686	25,568	481	107	91
Steep north-facing slopes	231,180	5,630	18,584	331	72	86
Moderately steep lower valley slopes	169,173	37	8,245	175	15	9
Coastal plains / gentle slopes	177,787	39,893	36,526	28,995	16,709	9,960
Stream channels	103,888	35	459	94	62	27
Total Area	1,262,029	161,467	169,171	95,042	56,180	33,756

Distribution of Stream Cells

Landscape Class	Number of Cells	Number of Cells with SCA ≥ 5,300 m^2m^{-1}				
		D8	Rho8	D∞	FD8	DEMON
Hilltops / ridgelines	256,012	0	13	15	0	1
Steep south-facing slopes	323,989	8	158	133	11	5
Steep north-facing slopes	231,180	5	137	159	6	6
Moderately steep lower valley slopes	169,173	949	1,439	1,669	1,013	810
Coastal plains / gentle slopes	177,787	801	1,221	1,494	884	793
Stream channels	103,888	26,866	25,744	27,853	27,896	25,678
Total Area	1,262,029	28,685	28,766	31,340	29,885	27,316

Conclusions

- Flow routing results vary systematically from top to bottom of catchments

- Previous studies have demonstrated that different groups of algorithms perform in similar ways
  - D8 and Rho8
  - D∞ and DEMON
  - FD8

- This outcome is partially repudiated by my results – Rho8 and D∞ are most similar and FD8 is most unique

- D8 and Rho8 have many undesirable properties and should be avoided as often as possible

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Lam, Deng, and Wilson
AAG 2004