Refining an Automated Model for Basic Landform Classification

An ArcGIS and Python Approach

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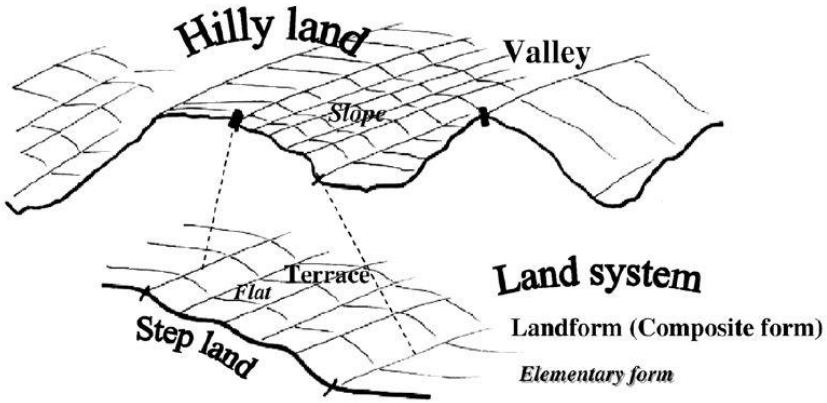
What are Landforms?

- Landforms are categories of structure that can be derived from observable differences in the three-dimensional geometry of the Earth's surface
- Landforms are familiar: plains, mountains, hills, plateaus, etc.
- Despite this familiarity, mapping landforms objectively has been an elusive goal for geomorphologists



Minar 2008

The Challenges of Landform Mapping

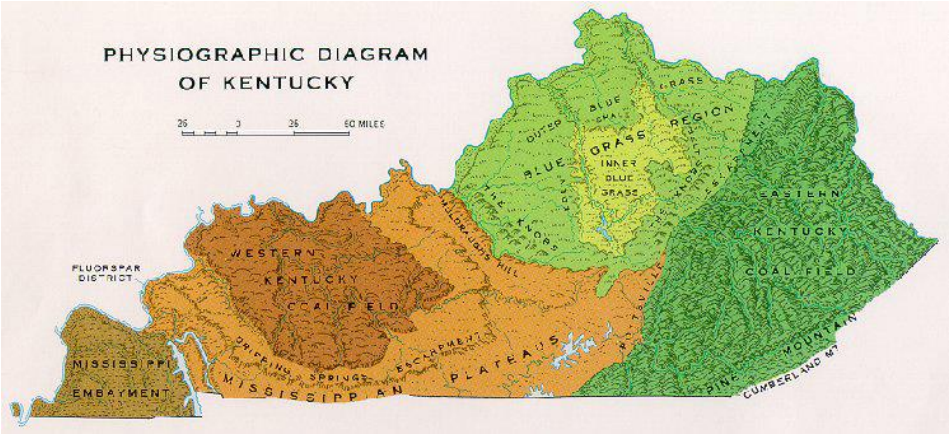
- Removing subjectivity from the process
- Identifying proper break points using geomorphological theory
- Staggering variety of the Earth's surface
- Landforms as objects: *fiat* or *bona fide*?
- Automating complex processes for practical use by land planning and environmental professionals
- Lack of an objective standard against which to validate landform maps or classification systems

Why Classify Landforms?

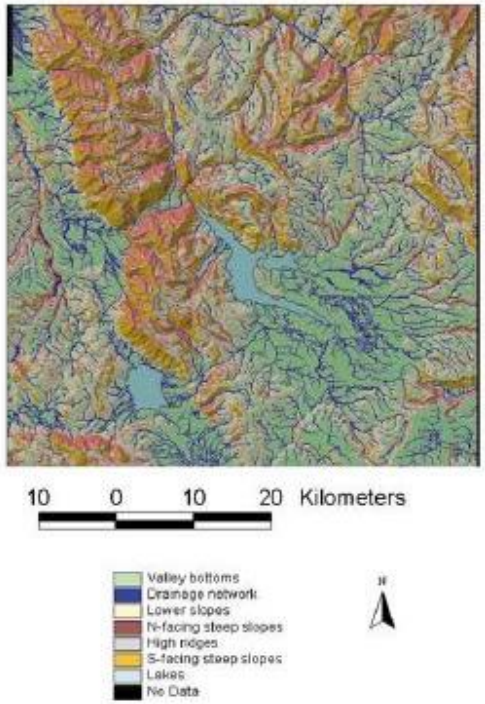
The Uses for Landform Classification

- Land use planning (Zawawi 2014)
- Landslide susceptibility mapping (Dikau 1990, Pike 1998)
- Precision agriculture (Klingseisen 2007)
- Soil condition modeling (Schmidt 2004)
- Forest management (MacMillan 2004, Zawawi 2014)
- Broad framework for mapping ecological units and habitats (MacMillan 2004)
- Generalized constant spatial variable against which to perform spatially based analyses in disciplines such as anthropology, archaeology, geology, geomorphology, biology, ecology, and other natural sciences

The History of Geomorphometrical Mapping



US Forest Service 2015



Burrough 2000

“The Atlantic Coastal Plain is a well marked province, but the hilly topography of it’s landward margin is superficially more like that of the adjacent Piedmont than like the featureless flats near the coast. It is, however very much more nearly related to the latter, into which it grades without crossing any significant line of division.” (Fenneman 1914)

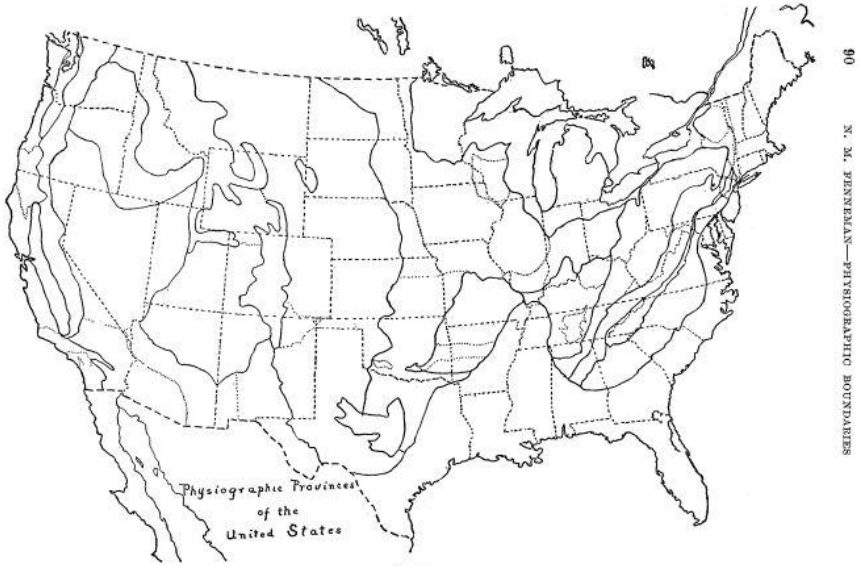
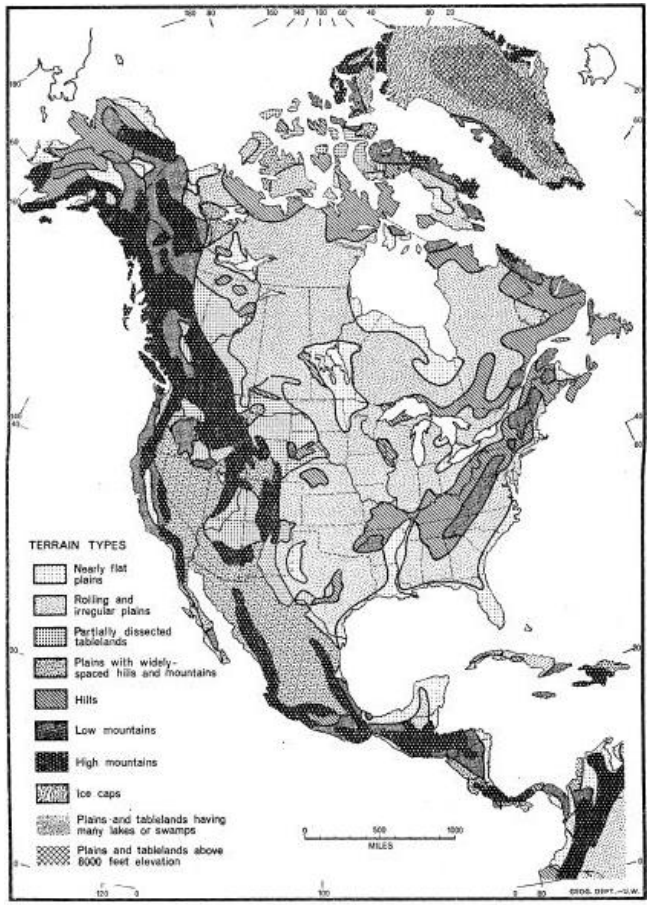


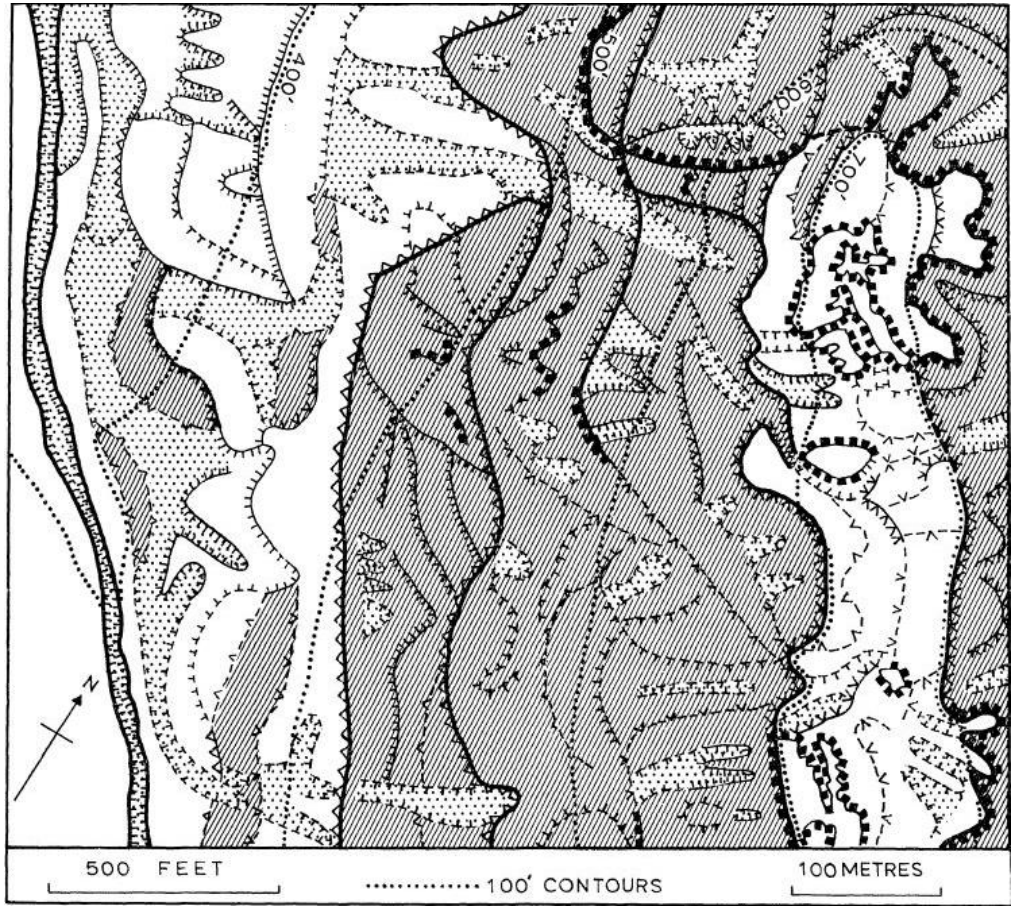
Fig. 1.

Fenneman 1914

Lines of Division – Break Points and Mathematics



Hammond 1954



Savigear 1965

Hammond's Moving Window

SCHEME OF CLASSIFICATION

SLOPE (Capital letter)

A More than 80% of area gently sloping

B 50-80% of area gently sloping

C 20-50% of area gently sloping

D Less than 20% of area gently sloping

LOCAL RELIEF (Numeral)

1 0-30 m (0-100 feet)

2 30-91 m (100-300 feet)

3 91-152 m (300-500 feet)

4 152-305 m (500-1000 feet)

5 305-915 m (1000-3000 feet)

6 More than 915 m (3000 feet)

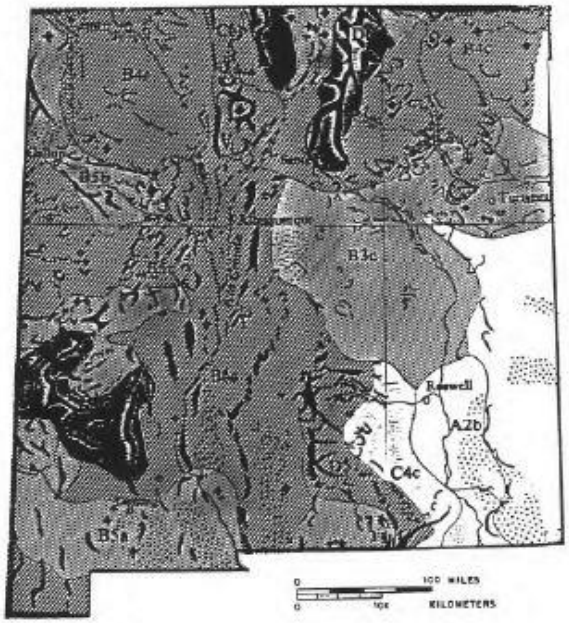
PROFILE TYPE (Lower case letter)

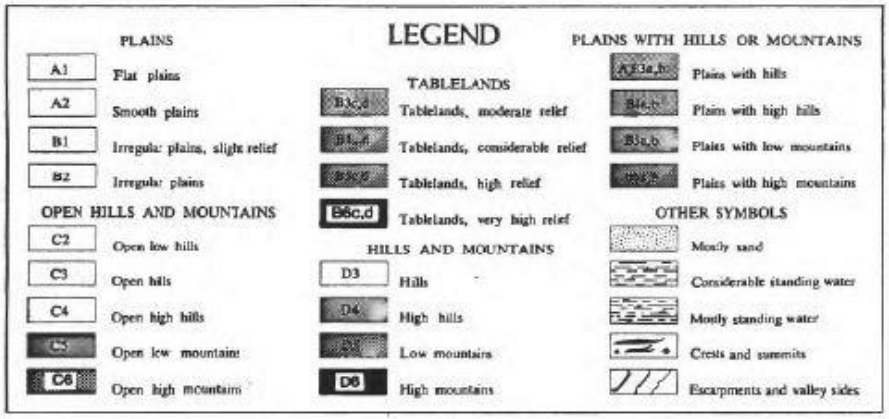
a More than 75% of gentle slope is in lowland

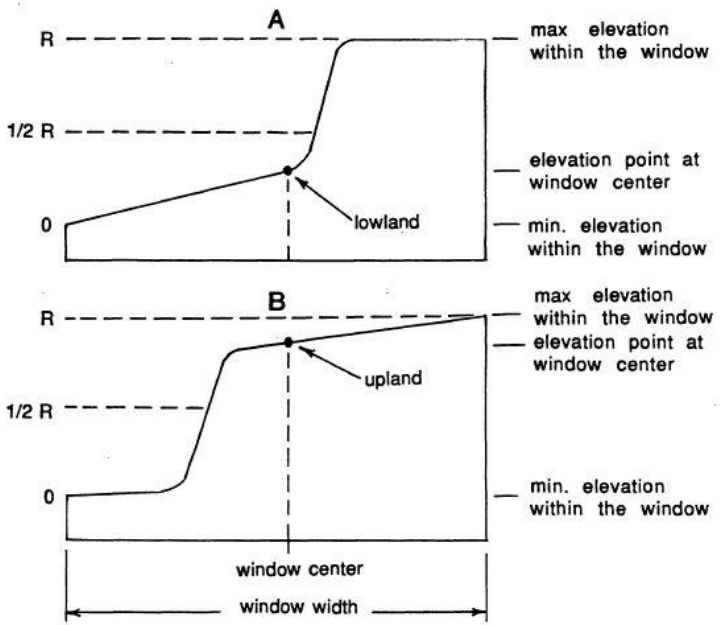
b 50-75% of gentle slope is in lowland

c 50-75% of gentle slope is on upland

d More than 75% of gentle slope is on upland





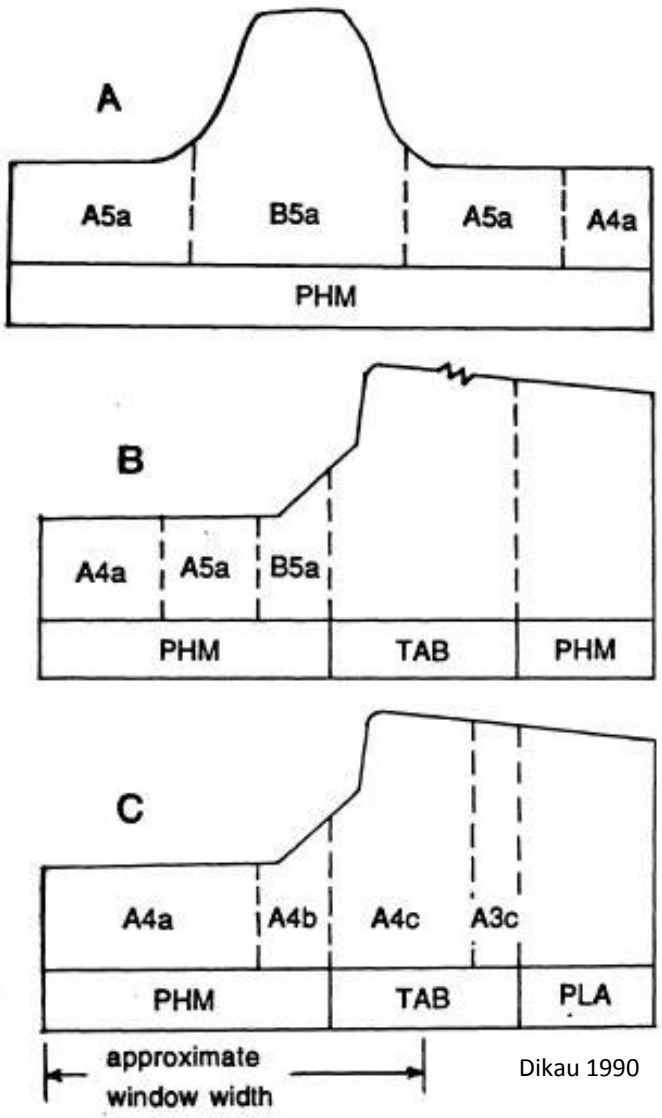


upland: max. elevation - elevation < 1/2 R

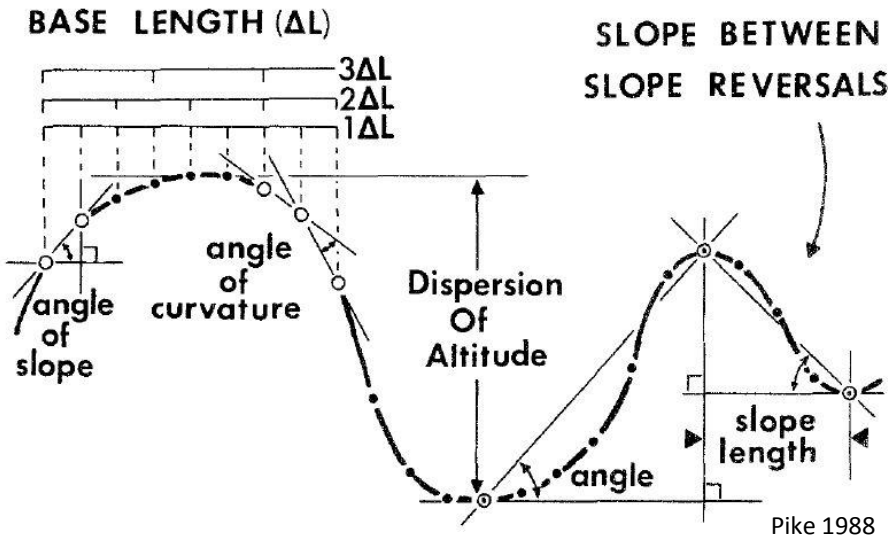
lowland: max. elevation - elevation > 1/2 R

when max. elevation = maximum elevation within the moving window
elevation = elevation at moving window center
R = local relief within the moving window

Extracting Metrics from DEMs



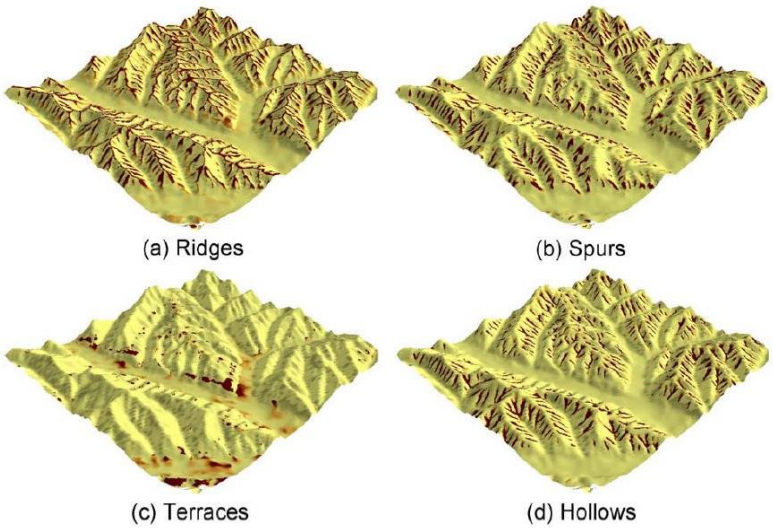
Dikau 1990

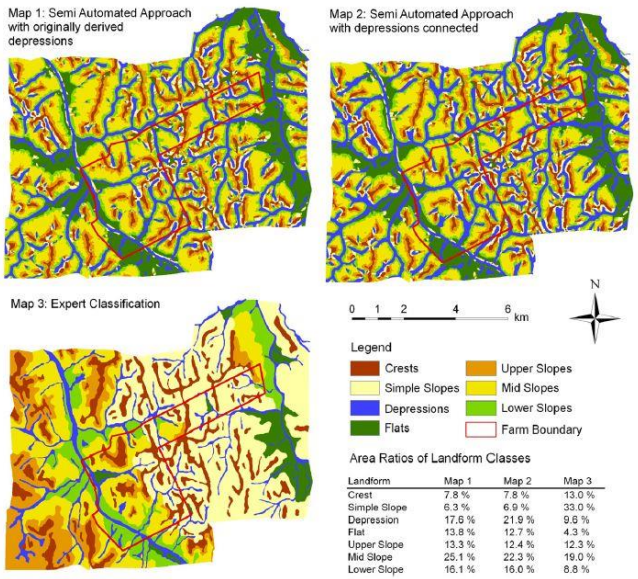


Pike 1988

Profile curvature is one of the most important geometrical properties of terrain derived from early digital elevation model (DEM) data used by Pike (above) and Dikau (left) to identify breakpoints for landform classification and in the case of their studies, locate areas susceptible to landslides.

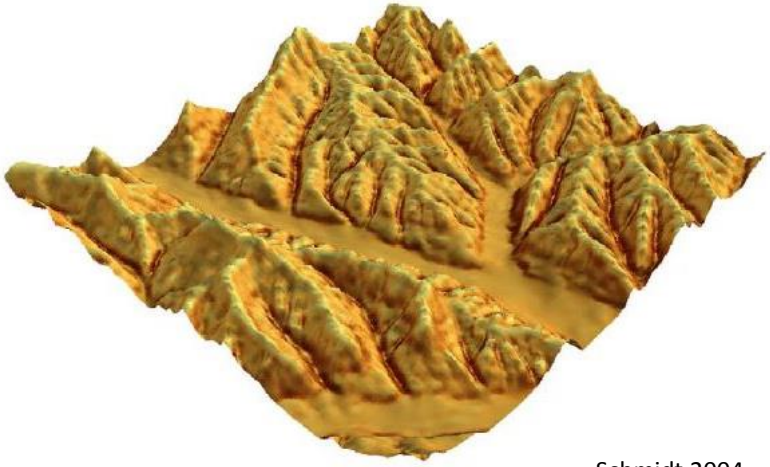
Automating Landform Extraction



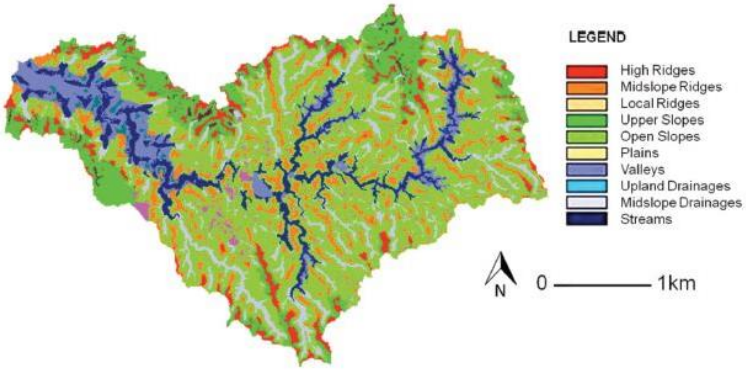


Landform	Map 1	Map 2	Map 3
Crest	7.8 %	7.8 %	13.0 %
Simple Slope	6.3 %	6.9 %	33.0 %
Depression	17.6 %	21.9 %	9.6 %
Flat	13.8 %	12.7 %	4.3 %
Upper Slope	13.3 %	12.4 %	12.3 %
Mid Slope	25.1 %	22.3 %	19.0 %
Lower Slope	16.1 %	16.0 %	8.8 %

Klingseisen 2007



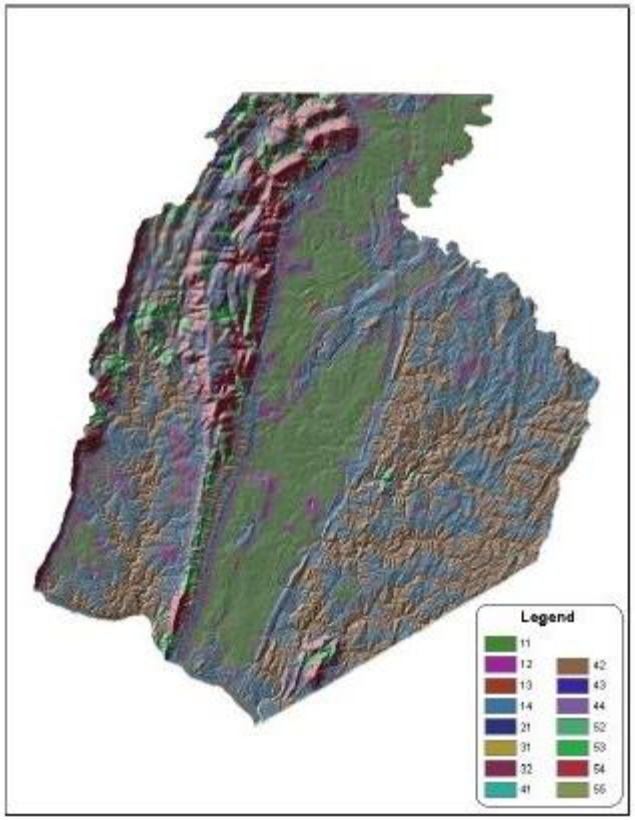
Schmidt 2004



Zawawi 2014

Landform Classification Modeling and ArcGIS

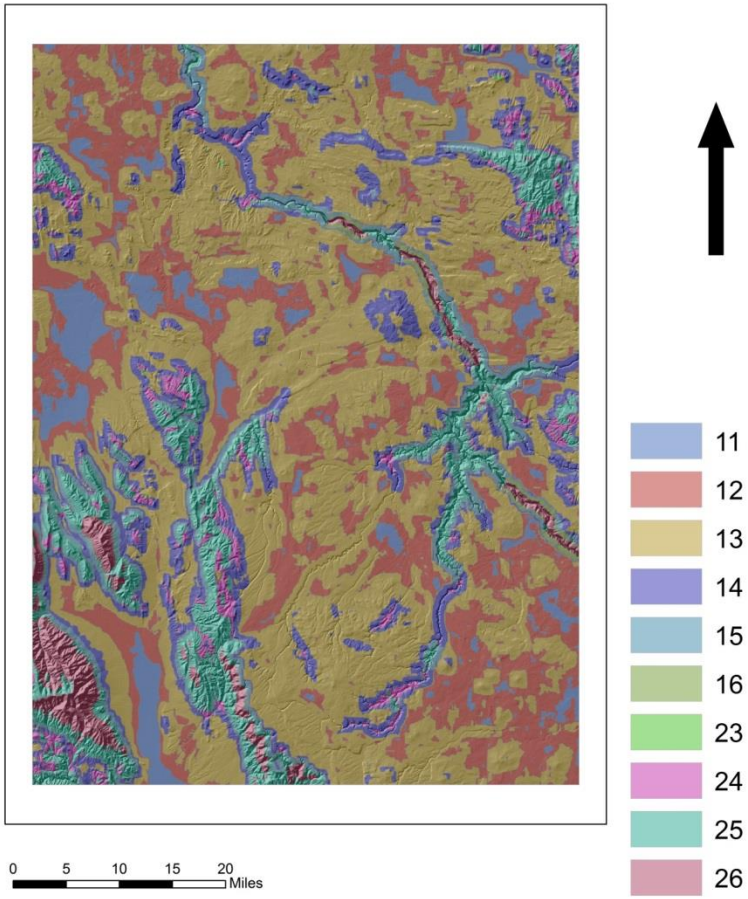
11 Flat or nearly flat plains
12 Smooth plains with some local relief
13 Irregular plains with low relief
14 Irregular plains with moderate relief
21 Tablelands with moderate relief
31 Plains with hills
32 Plains with high hills
41 Open very low hills
42 Open low hills
43 Open moderate hills
44 Open high hills
52 Low hills
53 Moderate Hills
54 High hills
56 High mountains



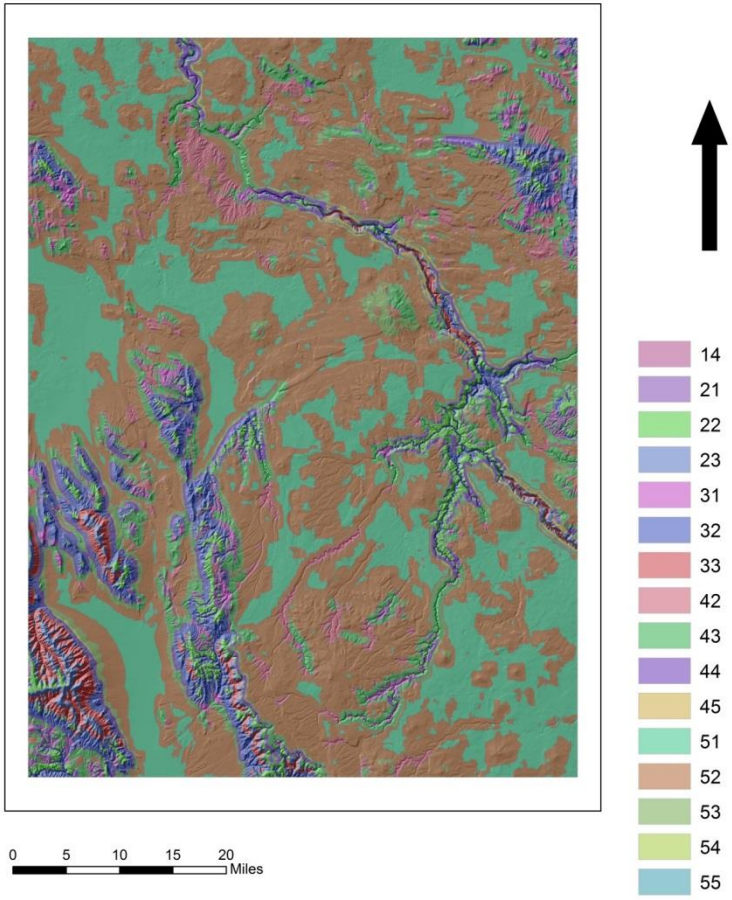
Morgan 2005

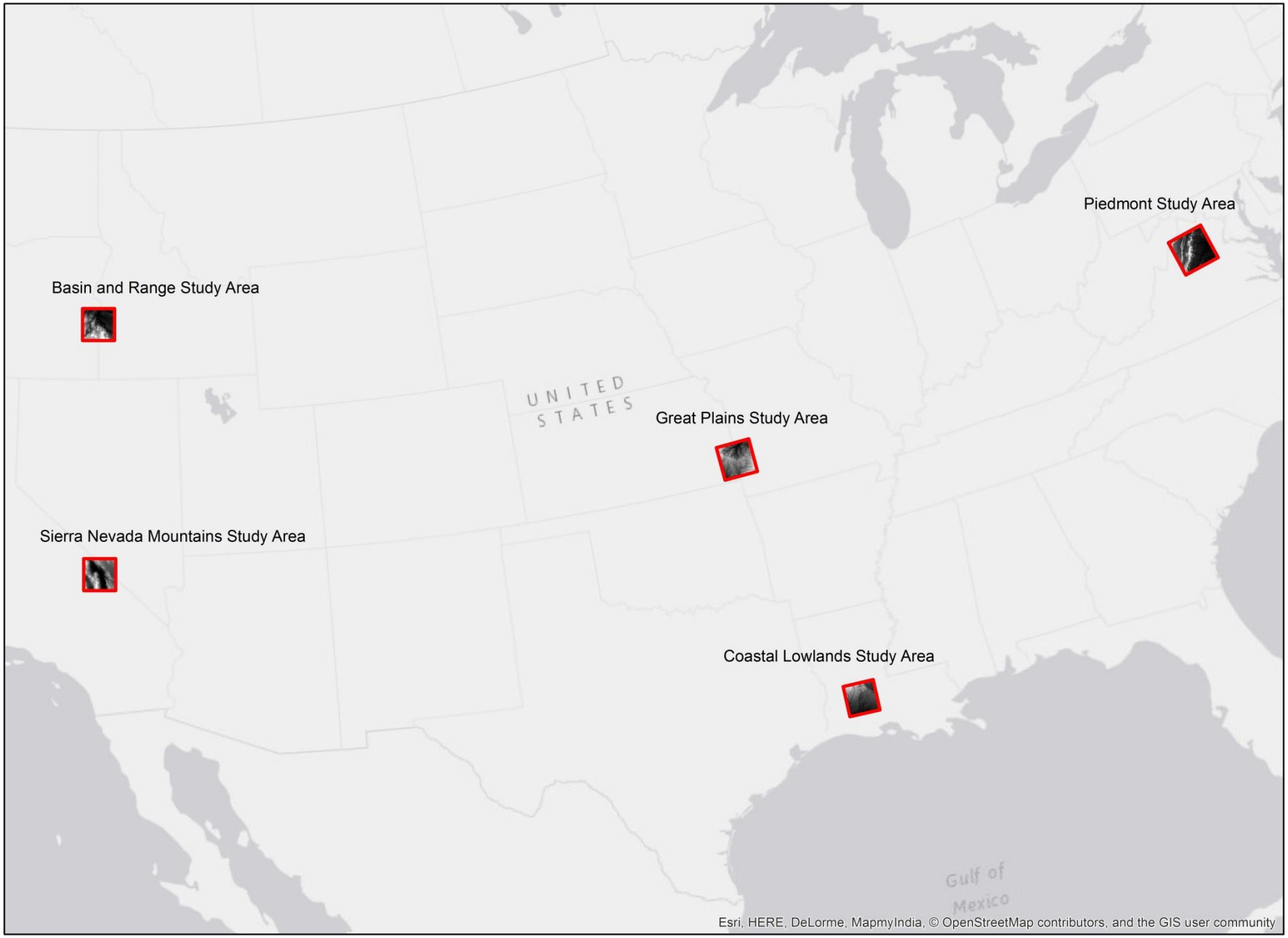
Testing the Models

Missouri Resource Assessment Partnership
(MORAP) Landforms



Hammond Landforms,
50x50 pixel rectangular "moving window"

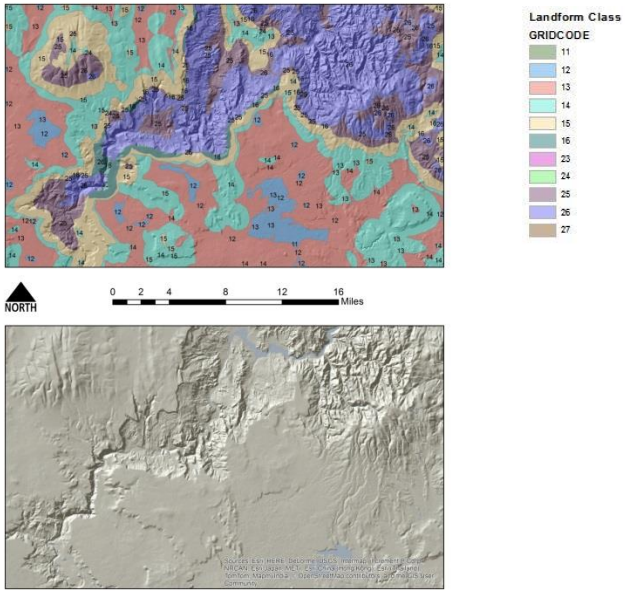


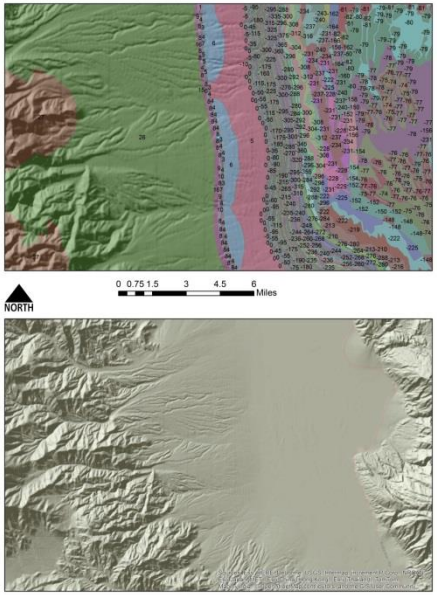

Piedmont Study Area
Basin and Range Study Area
UNITED STATES
Great Plains Study Area
Sierra Nevada Mountains Study Area
Coastal Lowlands Study Area
Gulf of Mexico
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Major Errors

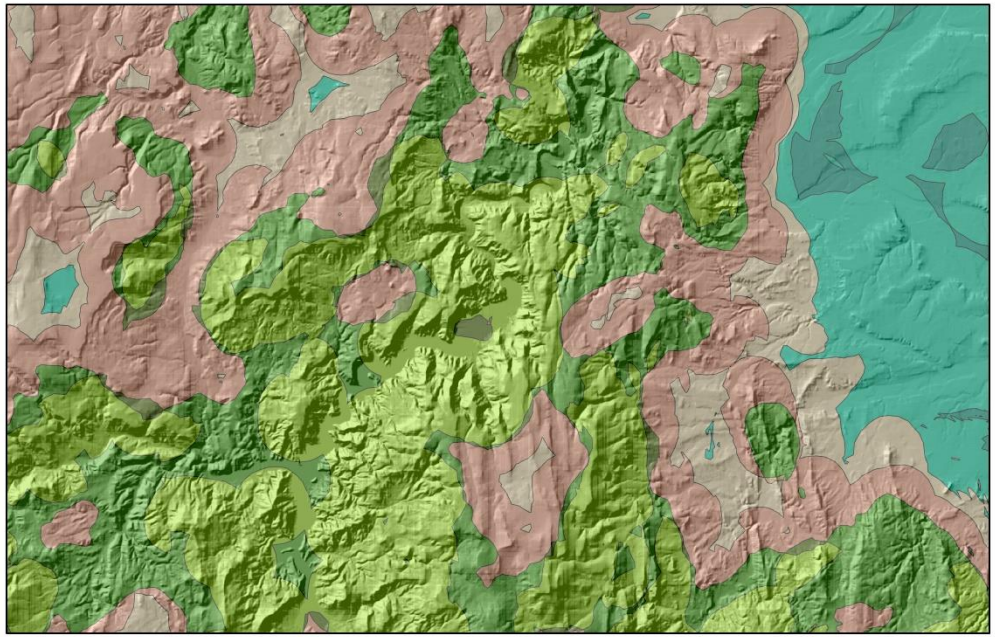
-Model conflates concave and convex areas of extreme relief, coding both as “Mountains”

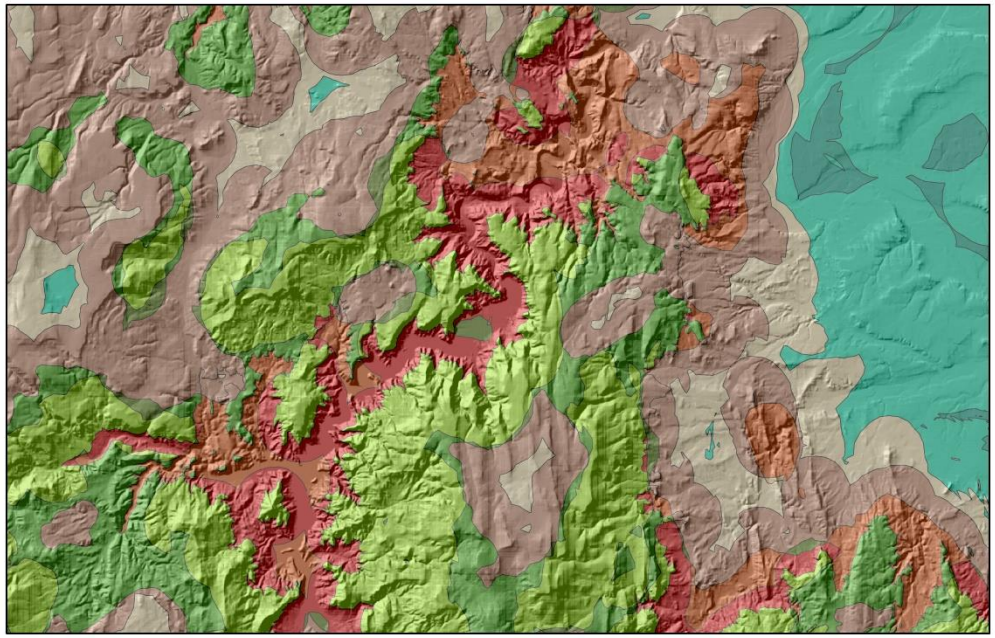
-Model fails to correctly process DEMs containing cells with negative integer values (below sea level areas)





Peaks and Canyons

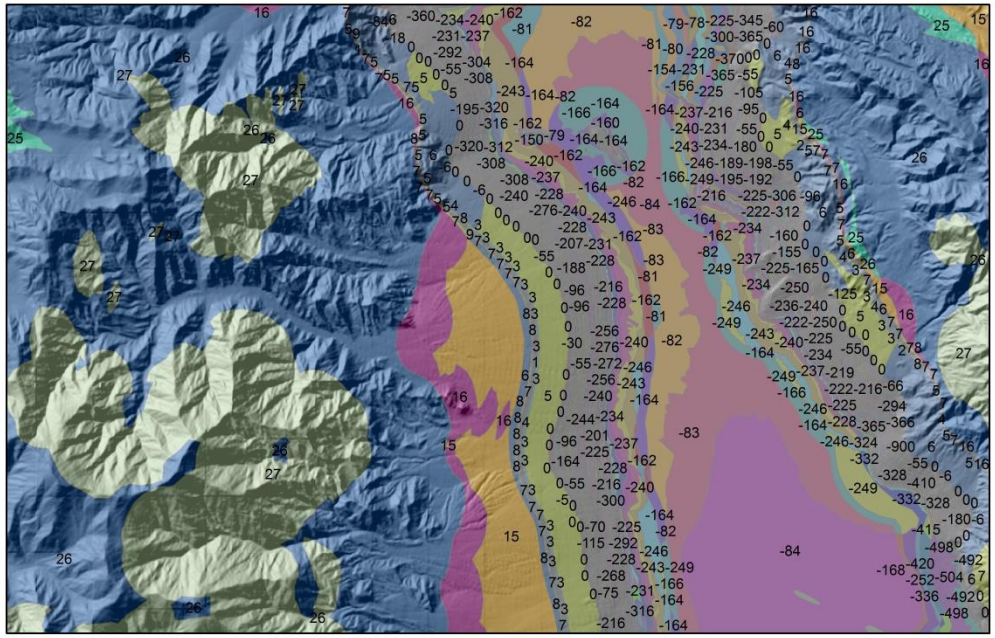


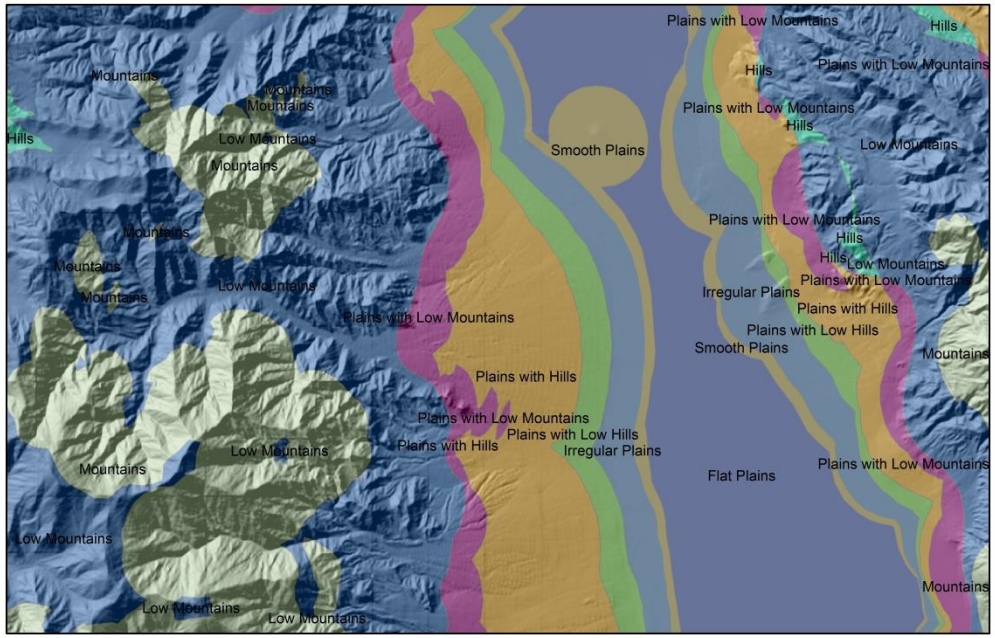


Landform Class

- Canyon
- Arroyo
- Breaks
- Smooth Plains
- Irregular Plains
- Plains with Low Hills
- Low Hills
- Flat Plains
- Plains with Hills
- Plains with Low Mountains
- Hills
- Low Mountains

Negative Integer Cells

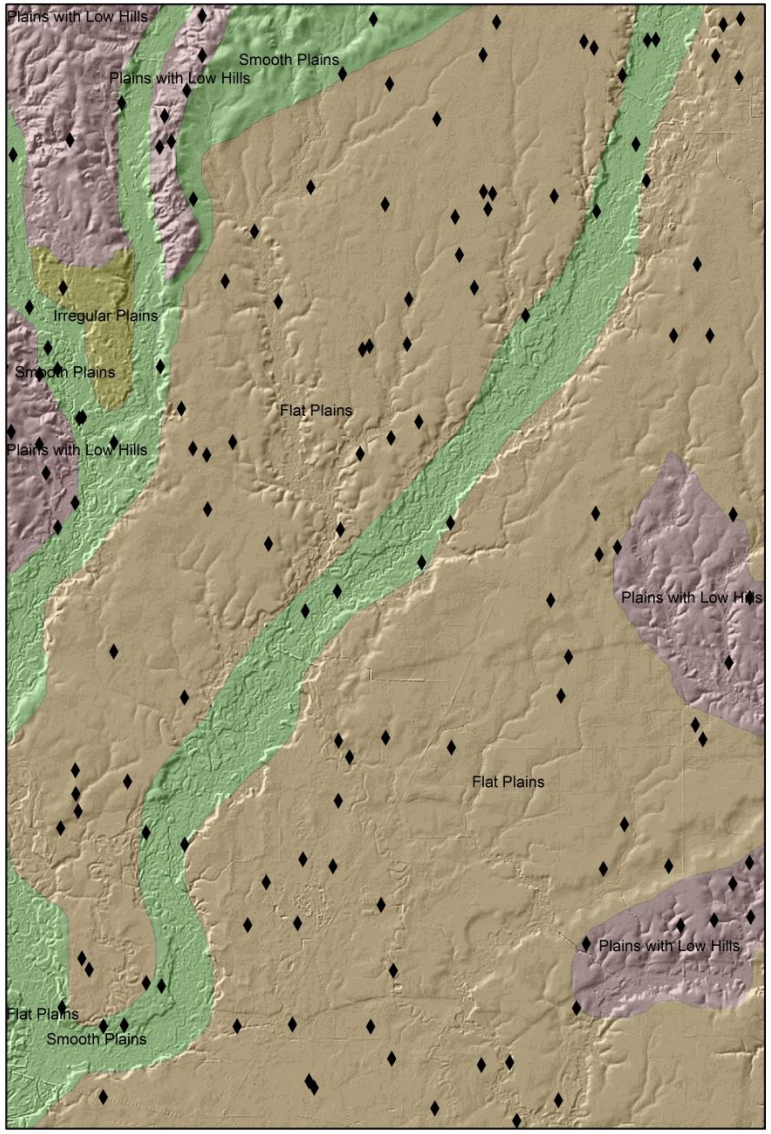




Landform Class

- Flat Plains
- Smooth Plains
- Irregular Plains
- Plains with Low Hills
- Plains with Hills
- Plains with Low Mountains
- Plains with Mountains
- Hills
- Low Hills
- Low Mountains
- Mountains

Model Verification



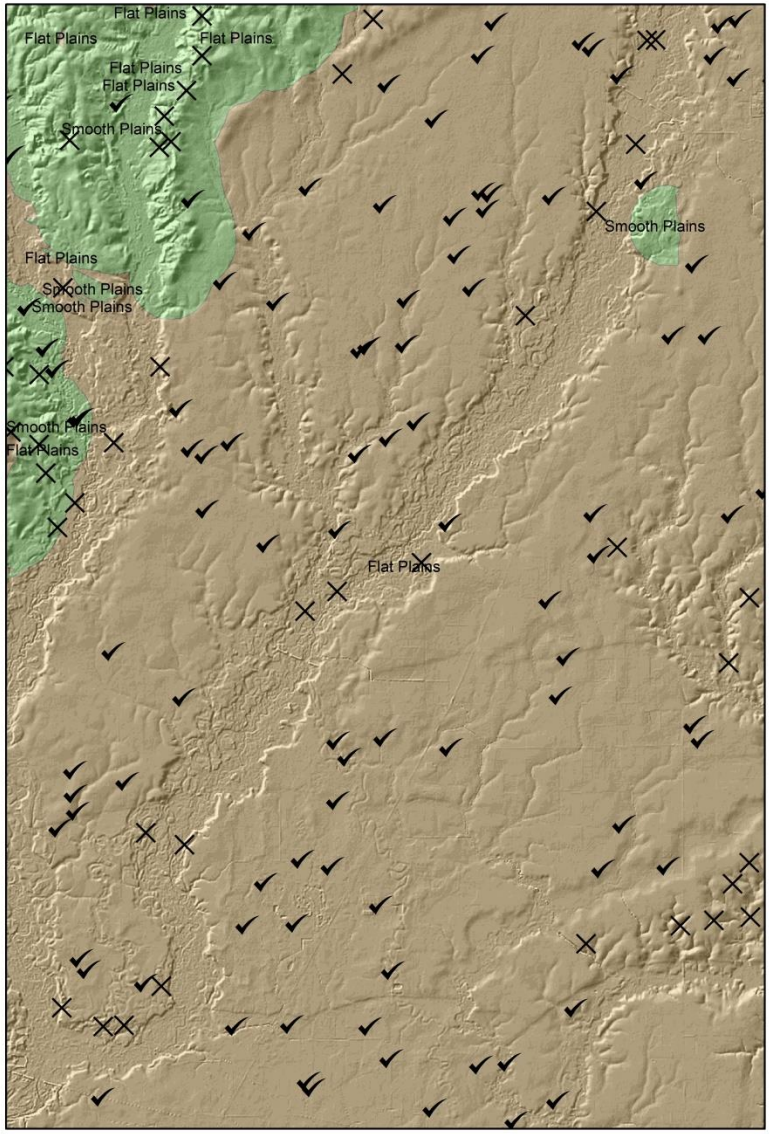


Photo Interpretation Methods

- Photographic interpretation was guided by the landform classes defined in Morgan (2005) and Dikau (1991)
- The 3D capabilities of Google Earth was be used to confirm mapping decisions, along with the following ancillary data:
  - National Agricultural Imagery Program (NAIP) aerial photography
  - USGS state geologic maps
  - USGS topographic maps
  - Soil Survey Geographic Database (SSURGO) data
  - National Hydrologic Dataset (NHD) data

ERROR MATRIX RESULTS

	Arroyo	Breaks	Canyon	Flat Plains	Hills	Irregular Plains	Low Hills	Low Mountains	Mountains	Plains With Hills	Plains With Low Hills	Plains With Low Mountains	Plains With Mountains	Rough Plains	Rugged Plains	Smooth Plains	TOTAL
Arroyo	0	4	3	0	1	0	10	0	0	8	2	2	0	0	2	2	34
Breaks	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	3
Canyon	0	3	5	0	1	0	10	0	0	0	1	0	0	0	2	0	22
Flat Plains	0	0	0	784	0	30	0	0	0	3	73	0	0	0	0	120	1010
Hills	0	3	1	0	45	1	62	9	0	37	13	17	1	6	18	1	214
Irregular Plains	8	0	0	90	0	420	2	0	0	53	303	12	1	75	24	161	1149
Low Hills	0	0	0	0	0	0	1	0	0	6	2	0	1	0	2	1	13
Low Mountains	0	18	0	3	180	19	82	282	95	28	13	14	4	11	21	2	772
Mountains	0	0	0	0	0	1	0	24	45	0	0	0	0	0	0	0	70
Plains With Hills	1	5	2	27	18	78	28	1	0	69	42	13	3	42	17	21	367
Plains With Low Hills	5	1	0	41	0	74	23	0	0	55	56	37	8	58	27	25	410
Plains With Low Mountains	0	3	1	8	3	20	3	3	0	4	2	1	0	7	3	10	68
Plains With Mountains	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Rough Plains	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rugged Plains	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Smooth Plains	2	0	0	131	0	352	0	0	0	40	61	0	0	7	0	269	862
TOTAL	16	37	12	1084	249	996	221	319	140	303	570	96	19	206	116	612	

Total Observations: 5,000
Total Observations in Agreement: 1,977
Percentage Correct: 39%

Klingseisen et al. , in their 2007 paper "Geomorphometric Landscape Analysis Using a Semi-Automated GIS Approach" in the journal *Environmental Modeling & Software,* used a similar approach to test the "accuracy" of their landform mapping software application "LANDFORM 2" against a heads-up expert classification of the landforms in their study area and achieved a percentage correct of 43%.

RESULTS CONTINUED

STUDY AREA	PHYSIOGRAPHIC REGION	PERCENT AGREEMENT	HEADS UP POLYGON COUNT	AUTOMATED POLYGON COUNT	HEADS UP LANDFORM CLASSES REPRESENTED	AUTOMATED LANDFORM CLASSES REPRESENTED
VIRGINIA	PIEDMONT	18%	153	1218	11	10
CALIFORNIA	SIERRA NEVADA MOUNTAINS	28%	163	1126	13	11
KANSAS	GREAT PLAINS	51%	33	882	3	3
LOUISIANA	COASTAL LOWLANDS	73%	34	158	5	3
OREGON	BASIN AND RANGE	8%	157	2951	12	12

CONCLUSIONS

- A standard, widely distributed data set of classified landforms accepted by the discipline of geomorphology would be a more ideal control group against which to verify the output of LFMapper than my heads-up classification.
- While not perfect and not as advanced as some current methods, LFMapper presents something that did not exist before: an easily distributed, mathematically rigorous, research based application for ArcGIS that classifies landforms with minimal input from the user.

Further Work

- Supervised Classification (Veronesi & Hurni 2014)
- Pattern Recognition Classification (Jasiewicz & Stepinksi 2012)
- Fuzzy Sets & Systems (Burrough, Van Gaans & MacMillan 2000), (MacMillan, Pettapiece, Nolan, & Goddard 2000), (Schmidt & Hewitt 2004)
- Verify LFMapper against other current automated landform classification methods

LFMapper Access

“LFMapper” toolbox file and python source code are available at lfmapper.blogspot.com. Please feel free to visit the site, download and use the tool, and download and improve the source code. The bibliography and write-up for this project are also hosted there.

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