DEVELOPING LANDFORM MAPS USING ESRI'S *ModelBuilder*

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OVERVIEW AND OBJECTIVES

Edward H. Hammond (1954, 1964a, 1964b) developed a macro landform classification procedure that has been used for mapping landforms around the world. Hammond's classification is quantitative in nature with explicit definitions that can easily be applied by other researchers. Hammond's procedure combines three important parameters—slope, relief, and profile type—to identify different landform, or terrain types. According to Hammond:

Landform (terrain type) = Slope + Relief + Profile

These landforms (terrain types) were subsequently grouped by Hammond into broader landform categories, such as nearly flat plains, rolling and irregular plains, plains with widely-spaced hills or mountains, partially dissected tablelands, hills, low mountains, and high mountains.

Recently, Dikau (1989 and 1991) and True, et al. (n.d.) attempted to apply Hammond's procedure using geographic information systems. These authors also modified Hammond's three important parameters, and established their own groupings of broader landform categories. With this in mind, the objectives of this model are as follows:

- Implement Hammond's model using the U.S. Geological Survey's 7.5 minute, 30-meter resolution National Elevation Dataset with ESRI's *ModelBuilder*;

- Generate both Dikau's and True, et al.'s versions of Hammond's landform maps;

Completing these objectives required considerable testing of various neighborhood search radii for creation of various focal statistics used to create the slope, relief, and profile parameters. The model, per se, reflects this work in terms of the final radii used for all focal statistics calculations (i.e., 20 pixels). In addition to neighborhood radii search testing, we also spent a considerable amount of time checking all of the derived maps in this model to assure the accuracy of the model logic.

In addition to our interest in landscape research, our purpose for developing this model is to provide an automated means for mapping landforms using NED data using ESRI's *ModelBuilder*. Landform maps are useful for modeling erosion, characterizing watersheds, mapping "land units" for land management purposes, and for developing climate models (i.e., topoclimatology).

THE MODEL

Initial (Pre-Model) Task

- Reproject 7.5-Minute U.S. Geological Survey 30-meter resolution National Elevation Dataset (**NED**) data (1-arc second) to Maryland State Plane 83 meters (or whatever coordinate system is desired by the model user). Information regarding NED can be found at http://ned.usgs.gov/. NED data are available from a online seamless data distribution system or via CD.

Initial Model Tasks

- Create a map (**Map1**) with all *non-zero elevation cells* = 1 (reclassify **NED** so that all cells =1)

- Run the sum (focal statistics) of **Map1** within a 20 pixel radius circular window (**Map2**). The purpose of this step is to determine the number of cells within the 20 pixel radius circular window surrounding each pixel for use in later percentage calculations. The number of cells within the 20 pixel circular window surrounding each pixel is not constant due to the calculation of focal statistics along the border of **NED** data (or the clipped border of an irregular study area).

- Create a floating point version of **Map2** (**Map3**) via the MapAlgebra FLOAT operation. This map will be used later in the model for calculation of percentages within the 20 pixel radius circular window. Note that ArcGIS produces integer values in calculations involving integer maps. If one of the maps is floating point, ArcGIS will output floating point results from arithmetic calculations.

Slope Sub-Model

- Calculate *slope* from **NED** (**Map4**).

- Reclassify *slope* (**Map4**) to the following categories:

0	Areas of greater than 8% slope
1	Areas of less than 8% slope

This is the *slope categories map* (**Map5**).

- Run the sum (focal statistics) of the *slope categories map* (**Map5**) within a 1.5 kilometer circular window (**Map6**).
- Calculate the *percent of near level land* by dividing **Map6** by **Map3** (**Map7**).
- Reclassify the *percent of near level land* (**Map7)** to the following categories:

400	0.00 - 0.2%
300	0.20 - 0.50%
200	0.50 - 0.80%
100	0.80 - 1.0%

This is *Hammond's slope parameter map* (**Map8**).

Relief Sub-Model

- Determine the maximum **NED** value within a 20 pixel circular window (**Map9**).
- Determine the minimum **NED** value within a 20 pixel circular window (**Map10**).
- Calculate the relief by subtracting the minimum **NED** value (**Map10**) from the maximum NED value (**Map9**) to create a *relief map* (**Map11**).
- Reclassify the relief map (**Map11**) into the following categories:

10	0 - 30 meters
20	30 – 90 meters
30	90 – 150 meters
40	150 – 300 meters
50	300 – 900 meters
60	900 – 99999 meters

This is *Hammond's relief parameter map* (**Map12).**

Profile Sub-Model

- Calculate one-half of the maximum relief in the 20 pixel circular window by dividing the *difference map* (**Map11**) by 2 to create a *local relief difference map* (**Map13**).

- Calculate the *average local relief* by adding the minimum NED value (**Map10**) to the *local relief difference map* (**Map13**) to create a *profile value map* (**Map 14**).

- Calculate the difference between the original **NED** value and the *profile value map* by subtracting **NED** from **Map14** to determine an *upland/lowland map* (**Map15**). Note: pixel values of less than 0 in **Map15** represent upland areas; pixel values greater than 0 in **Map15** represent lowland areas.

- Reclassify the *upland/lowland map* (**Map15**) into the following categories:

1	>0 (lowland)
2	<0 (upland)

  This is the *profile type map* (**Map16**).

- Reclassify the *profile type map* (**Map16**) into the following categories:

1	1 (lowland)
0	2 (upland)

  This is the *lowlands map* (**Map17**).

- Identify gentle slopes (i.e., slopes less than 8%) in lowlands by multiplying **Map5** by **Map17** to create a *gentle slopes in lowlands map* **(Map18).**

- Determine the sum (focal statistics) of the *gentle slopes in lowlands map* (**Map18**) map within a 20 pixel circular window (**Map19**).

- Create a floating point version of **Map6 (Map20)** via the MapAlgebra FLOAT operation. Note: as indicated above, this map was created for the percentage calculation in the following step. **Map6** (and its floating point equivalent (**Map20**) represent the sum of the gentle slopes (i.e., slopes less than 8%) within a 20 pixel circular window.

- Calculate the percentage of *gentle slopes in lowlands* by dividing **Map19** by **Map20** (**Map21**).

- Mask any uplands pixels from the *gentle slopes in lowlands map* (**Map21**) by multiplying the *lowlands map* (**Map17**) by the *gentle slopes in lowlands map* (**Map21**) to create as masked gentle slopes in lowlands map (**Map 22**). Note: this step is needed to isolate gentle slopes in lowlands because all pixels in **Map21** include a percentage calculation. Without this step, the next step produces incorrect results.

- Reclassify the percentage of *gentle slopes in lowlands* (**Map22)** to the following categories:

0	0.00 %
2	0.50 - 0.75%
1	0.75 - 1.00%

  This is the gentle slopes in lowlands parameter map (**Map23)**.

- Reclassify the profile type map (**Map16**) into the following categories:

0	1 (lowland)
1	2 (upland)

  This is the *uplands map* (**Map24**)

- Identify gentle slopes (i.e., slopes less than 8%) in uplands by multiplying **Map5** by **Map24** to create a *gentle slopes in uplands map* **(Map25).**

- Determine the sum (focal statistics) of the *gentle slopes in uplands map* (**Map25**) map within a 20 pixel circular window (**Map26**).

- Calculate the percentage of *gentle slopes in uplands* by dividing **Map26** by **Map20** (**Map27**).

- Mask any uplands pixels from the *gentle slopes in uplands map* (**Map27**) by multiplying the *uplands map* (**Map24**) by the *gentle slopes in uplands map* (**Map27**) to create as masked gentle slopes in uplands map (**Map 28**). Note: this step is needed to isolate gentle slopes in uplands because all pixels in **Map27** include a percentage calculation. Without this step, the next step produces incorrect results.

- Reclassify the percentage of *gentle slopes in uplands* **Map28** to the following categories:

0	0.00 %
3	0.50 - 0.75%
4	0.75 - 1.00%

  This is the *gentle slopes in uplands parameter* map (**Map29**).

- Calculate Hammond's *profile parameter map* by adding the *gentle slopes in lowlands map* **Map23** to the *gentle slopes in uplands map* **Map29** (**Map30**).

- Reclassify Hammond's *profile parameter map* (**Map30**) to the following categories:

1	0

This is an *adjusted profile parameter map* (**Map31**). Note: this step is necessary to remove several isolated cells with the value of 0 in **Map23** and **Map29**. The reclassification procedures that create these maps, for some reason, leave cells with isolated values of 0. We have spent a great deal of time trying to diagnose the way ArcGIS is calculating the percentages and reclassifying the percentages in the model. We anticipate removing this step in a future iteration of the model.

Landform Classification Sub-Model

- Calculate the Hammond *terrain type code* by adding *Hammond's slope parameter map* (**Map8**) to *Hammond's relief parameter map* (**Map12)** to create a *temporary landform code map* (**Map32**).

- Calculate the Hammond *terrain type code* by adding the *temporary landform code map* (**Map32**) to *Hammond's adjusted profile parameter map* (**Map31**) to create the final *Hammond's terrain type code map* (**Map33**). Given the coding sequence used to prepare the *slope parameter map* (**Map8**), the *relief parameter map* (**Map12**), and the *adjusted profile parameter map* (**Map31**), the codes on the terrain type code map can potential range from 111 to 464. In other words, the *slope parameter map* codes (100, 200, 300, 400), plus the *relief parameter map* codes (10, 20, 30, 40, 50, 60), plus the *adjusted profile parameter map* codes (1, 2, 3, 4).

- Reclassify the final *Hammond's terrain types code map* (**Map33**) into the following categories:

11	411-414
12	421-424
13	311-312
14	321-324
21	433-434, 333-334
22	443-444, 343-344
23	453-454, 353-354
24	463-464, 363-364
31	431-432, 331-332
32	441-442, 341-342
33	451-452, 351-352
34	461-462, 361-362
41	211-214
42	221-224
43	231-234
44	241-244
45	251-254

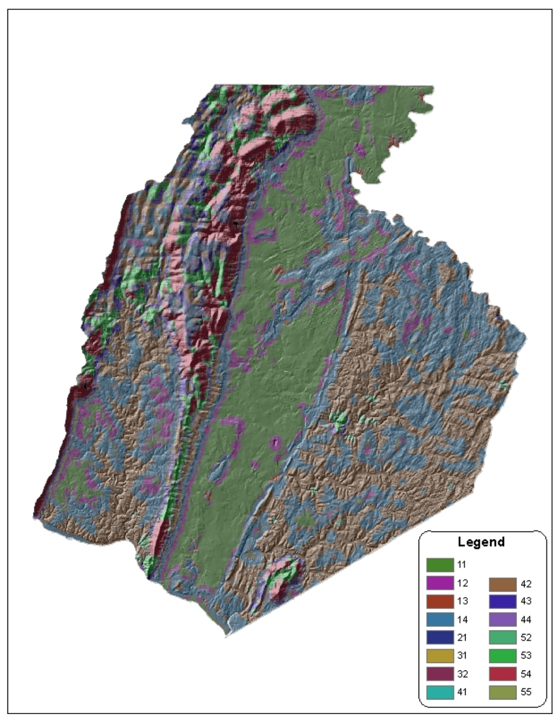
46	261-264
51	111-114
52	121-124
53	131-134
54	141-144
55	151-154
56	161-164

This is the *Dikau landform code map* (**Map34**)

- Smooth the *Dikau landform code map* (**Map34**) using a majority filter operation with 8 neighbors (**Map35**). Note: the purpose of this step is to remove any "salt-and-pepper" pixels within landform units on the map.

  Mask the *Dikau landform code map* (**Map35**) using the *non-zero elevation cells map* (**Map1**). Note: by multiplying the two maps **Map1** serves as a binary mask and clips any codes beyond the study area (i.e., codes created due to the focal statistics operations) for **Map34**. The output from this step is the *final Dikau landform code map* (**Map36**). The meaning for the codes on this map is as follows:

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
22	Tablelands with considerable relief
23	Tablelands with high relief
24	Tablelands with very high relief
31	Plains with hills
32	Plains with high hills
33	Plains with low mountains
34	Plains with high mountains
41	Open very low hills
42	Open low hills
43	Open moderate hills
44	Open high hills
45	Open low mountains
46	Open high mountains
51	Very low hills
52	Low hills
53	Moderate Hills
54	High hills
55	Low mountains
56	High mountains



- Convert the *final Dikau landform code map* (**Map36**) from raster to vector (polygon) format (**Map37.shp**).

In addition to *Dikau landform code map*, we also developed another version of Hammond's landform map using a procedure suggested by the Missouri Resource Assessment Partnership (MORAP) (http://www.cerc.cr.usgs.gov/morap/projects.asp?project_id=17). MORAP is an interagency partnership of the University of Missouri. A sample of the map created by MORAP can be found on the ESRI Web site at http://www.esri.com/mapmuseum/mapbook_gallery/volume18/cartography1.html. The following are the steps used to create this very generalized version of Hammond's landform map:

- Reclassify the relief map (**Map11**) into the following categories:

1	0 - 15 meters
2	15-30 meters
3	30 – 90 meters
4	90 – 150 meters
5	150 – 300 meters
6	300 – 900 meters
7	900 – 99999 meters

  This is the *MORAP relief parameter map* (**Map38).**

- Reclassify the percent of *near level land* (**Map7)** to the following categories:

10	0.50 - 1.00%
20	0.00 - 0.50%

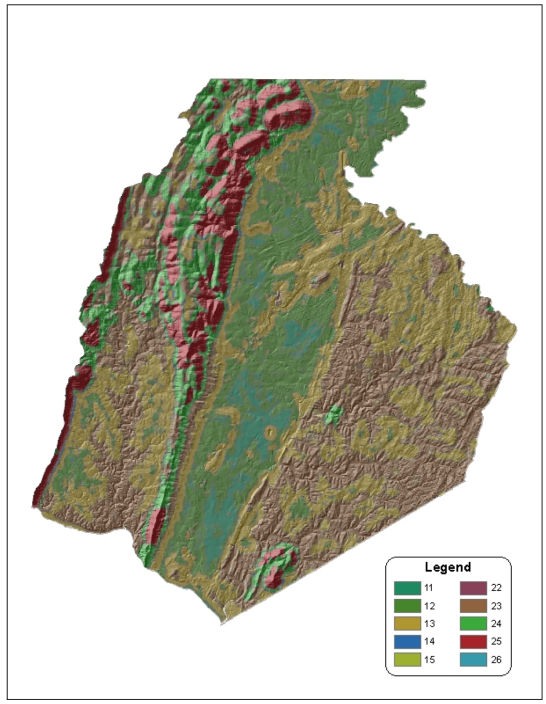
  This is the *MORAP slope parameter* map (**Map39**).

- Calculate the *MORAP landform category* by adding *MORAP slope parameter map* (**Map39**) to the *MORAP relief parameter map* (**Map38)** to create the *MORAP landform map* (**Map40**).

- Smooth the *MORAP landform map* (**Map40**) using a majority filter operation with 8 neighbors (**Map41**). Note: the purpose of this step is to remove any "salt-and-pepper" pixels within landform units on the map.

- Mask the *MORAP landform map* (**Map41**) using the *non-zero elevation cells map* (**Map1**). Note: by multiplying the two maps **Map1** serves as a binary mask and clips any codes beyond the study area (i.e., codes created due to the focal statistics operations) for **Map41**. The output from this step is the *final MORAP landform map* (**Map42**). The meaning for the codes on this map is as follows:

11	Flat plains
12	Smooth plains
13	Irregular plains
14	Plains with low hills
15	Plains with hills
16	Plains with low mountains
17	Plains with mountains
21	Rough plains
22	Rugged plains
23	Breaks
24	Low hills
25	Hills
26	Low mountains
27	Mountains



- Convert the *final MORAP landform map* (**Map42**) from raster to vector (polygon) format (**Map43.shp**).

- We also included an additional step in the model to generate an analytical hillshade for subsequent (non-model) mapping purposes (**Hillshade**). This procedure uses the defaults on options for this tool. The two maps shown in this document represent the *final Dikau landform code map* in vector format (**Map37.shp**) overlayed on the **Hillshade** map, and the *final MORAP landform map* in vector format (**Map43.shp**) overlayed on the **Hillshade** map.

SCRIPTS/ALGORITHMS USED

None.

DATA USED

Only one dataset is needed for use with this model, the 7.5-Minute U.S. Geological Survey 30-meter resolution National Elevation Dataset (**NED**) data (1-arc second) to Maryland State Plane 83 meters (or whatever coordinate system is desired by the model user). Information regarding NED can be found at http://ned.usgs.gov/. NED datasets are available for download from a online seamless data distribution system, or are available on CD from the Earth Resources Observations Systems (EROS) Data Center, Sioux Falls, South Dakota.

SUGGESTIONS FOR USING THE MODEL

The following are several suggestions with regard to running our landform model:

- We have run this model successfully using 30-meter resolution NED data for a single U.S. Geological Survey 7.5 minute quadrangle, for a single county, and for an entire state (Maryland). <u>This model can be replicated nationwide given the availability of the 30-meter NED data</u>. No attempt was made to test the model using either 10-meter resolution NED data, or smaller-scale DEM data, such as the U.S. Geological Survey's 3-arc second DEM data.

- We selected a search radius of 20 pixels for the focal statistics operations used in this model. This radius was based on suggestions in the literature, as well as considerable trial-and-error model testing. Furthermore, we used a circular "neighborhood" for the focal statistics operations. This number corresponds to recommendations by Hammond, MORAP, and others. The user can change this radius in order to see the effect of neighborhood size on landform classification. However, the user should keep in mind that increasing the size of the pixel search radius will correspondingly increase the time required to process the model.

- Depending on the geographic area being mapped, as well as the local topography within the geographic area, not all Hammond, Dikau, or True, et al. (i.e., Missouri Resource Assessment Partnership, or MORAP) codes may be reflected in the final maps. Keep in mind that both landform classifications are designed for worldwide use. The geographic area you are mapping may have a limited range of topographic features due to limited elevation, slope, relief, or profile.

- The model can be readily modified to incorporate changes to the slope, relief, and profile parameters, or to the grouping of the landform codes.

- The model includes documentation of all of the steps described above.

FUTURE

Our work on this model is part of a continuing effort to characterize the landscape of the Mid-Atlantic region. We consider the model we submitted for the Best Practices in Science Modeling competition to be the first version of an ongoing landform modeling effort. We intend to continue our work to refine our model to better characterize landforms and incorporate the work of other researchers. Also, we will be developing a landform map of Maryland using the model that we will submit for the Map Gallery for the ESRI International User Conference in July.

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