Topic 8

Characterizing Terrain Features

8.1 Identifying Micro-Terrain Features

The past several columns investigated surface modeling and analysis. The data surfaces derived in these instances weren't the familiar terrain surfaces you walk the dog, bike and hike on. None-the-less they form surfaces that contain all of the recognizable gullies, hummocks, peaks and depressions we see on most hillsides. The "wrinkled-carpet" look in the real world is directly transferable to the cognitive realm of the data world.

However, at least for the moment, let's return to terra firma to investigate how micro-terrain features can be characterized. As you look at a landscape you easily see the changes in terrain with some areas bumped up (termed convex) and others pushed down (termed concave). But how can a computer "see" the same thing? Since its world is digital, how can the lay of the landscape be transferred into a set of drab numbers?

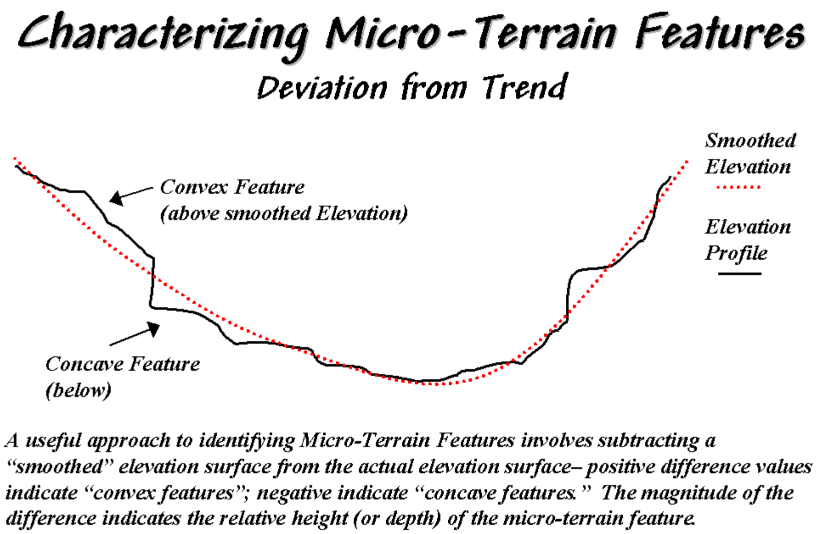


Figure 8-1. Identifying Convex and Concave features by deviation from the trend of the terrain.

One of the most frequently used procedures involves comparing the trend of the surface to the actual elevation values. Figure 8-1 shows a terrain profile extending across a small gully. The dotted line identifies a smoothed curve fitted to the data, similar to a draftsman's alignment of a French curve. It "splits-the-difference" in the succession of elevation values—half above and half below. Locations above the trend line identify convex features while locations below identify the concave ones. The further above or below determines how pronounced the feature is.

In a GIS, simple smoothing of the actual elevation values derives the trend of the surface. The left side of fig. 8-2 shows the actual and smoothed surfaces for a project area. The flat portion at the extreme left is an area of open water. The terrain rises sharply from 500 feet to 2500 feet at the top of the hill. Notice the small "saddle" (elevation dips down then up) occurring between the two hilltops. Also note the small depression in the relatively flat area in the foreground (SW) portion.

In generating the smoothed surface, elevation values were averaged for a 4-by-4 window moved throughout the area. Note the subtle differences between the surfaces—the tendency to pull-down the hilltops and push-up the gullies.

While you see (imagine?) these differences in the surfaces, the computer quantifies them by subtracting. The difference surface on the right contains values from -84 (prominent concave feature) to +94 (prominent convex feature). The big bump on the difference surface corresponds to the smaller hilltop on elevation surface. Its actual elevation is 2016 while the smoothed elevation is 1922 resulting in 2016 - 1922 = +94 difference. In micro-terrain terms, these areas are likely drier than their surroundings as water flows away.

The other arrows on the surface indicate other interesting locations. The "pockmark" in the foreground is a small depression (764 - 796 = -32 difference) that is likely wetter as water flows into it. The "deep cut" at the opposite end of the difference surface (539 - 623 = -84) suggests a prominent concavity. However representing the water body as fixed elevation isn't a true account of terra firma configuration and misrepresents the true micro-terrain pattern.

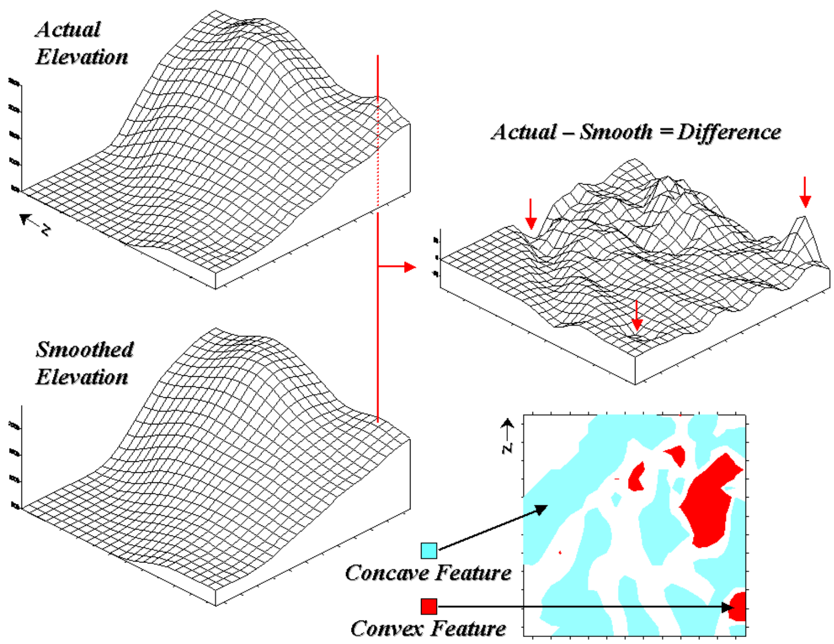


Figure 8-2. Example of a micro-terrain deviation surface.

In fact the entire concave feature in the upper left portion of 2-D representation of the difference surface is suspect due to its treatment of the water body as a constant elevation value. While a fixed value for water on a topographic map works in traditional mapping contexts it's insufficient in most analytical applications. Advanced GIS systems treat open water as "null" elevations (unknown) and "mirror" terrain conditions along these artificial edges to better represent the configuration of solid ground.

The 2-D map of differences identifies areas that are concave (dark red), convex (light blue) and transition (white portion having only -20 to +20 feet difference between actual and smoothed elevation values). If it were a map of a farmer's field, the groupings would likely match a lot of the farmer's recollection of crop production—more water in the concave areas, less in the convex areas.

A Colorado dryland wheat farmer knows that some of the best yields are in the lowlands while the uplands tend to "burn-out." A farmer in Louisiana, on the other hand, likely see things reversed with good yields on the uplands while the lowlands often "flood-out." In either case, it might make sense to change the seeding rate, hybrid type, and/or fertilization levels within areas of differing micro-terrain conditions.

The idea of variable rate response to spatial conditions has been around for thousands of years as indigenous peoples adjusted the spacing of holes they poked in the ground to drop in a seed and a piece of fish. While the mechanical and green revolutions enable farmers to cultivate much larger areas they do so in part by applying broad generalizations of micro-terrain and other spatial variables over large areas. The ability to continuously adjust management actions to unique spatial conditions on expansive tracks of land foretells the next revolution.

Investigate the effects of micro-terrain conditions go well beyond the farm. For example, the Universal Soil Loss Equation uses "average" conditions, such as stream channel length and slope, dominant soil types and existing land use classes, to predict water runoff and sediment transport from entire watersheds. These non-spatial models are routinely used to determine the feasibility of spatial activities, such as logging, mining, road building and housing development. While the procedures might be applicable to typical conditions, they less accurately track unusual conditions clumped throughout an area and provide no spatial guidance within the boundaries of the modeled area.

GIS-based micro-terrain analysis can help us be more like a "modern ancient farmer"— responding to site-specific conditions over large expanses of the landscape. Calculation of a difference surface simply scratches the surface of micro-terrain analysis. In the next few columns we'll look other procedures that let us think like a raindrop while mapping the micro-terrain.

8.2 Characterizing Local Terrain Conditions

Last month's column described a technique for characterizing micro-terrain features involving the difference between the actual elevation values and those on a smoothed elevation surface (trend). Positive values on the difference map indicate areas that "bump-up" while negative values indicate areas that "dip-down" from the general trend in the data.

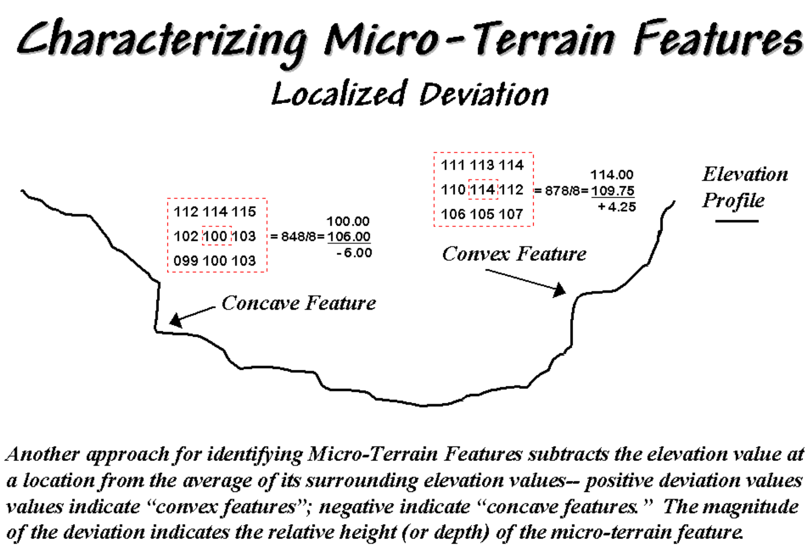


Figure 8-3. Localized deviation uses a spatial filter to compare a location to its surroundings.

A related technique to identify the bumps and dips of the terrain involves moving a "roving window" (termed a spatial filter) throughout an elevation surface. The profile of a gully can have micro-features that dip below its surroundings (termed concave) as shown on the right side of figure 8-3.

The localized deviation within a roving window is calculated by subtracting the average of the surrounding elevations from the center location's elevation. As depicted in the example calculations for the concave feature, the average elevation of the surroundings is 106 that computes to a -6.00 deviation when subtracted from the center's value of 100. The negative sign denotes a concavity while the magnitude of 6 indicates it's fairly significant dip (a 6/100= .06). The protrusion above its surroundings (termed a convex feature) shown on the right of the figure has a localized deviation of +4.25 indicating a somewhat pronounced bump (4.25/114= .04).

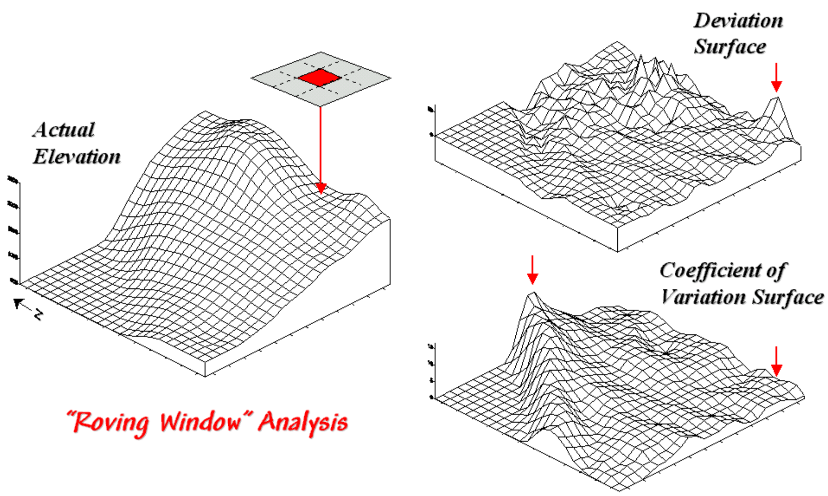


Figure 8-4. Applying Deviation and Coefficient of Variation filters to an elevation surface.

The result of moving a deviation filter throughout an elevation surface is shown in the top right inset in figure 8-4. Its effect is nearly identical to the trend analysis described last month-- comparison of each location's actual elevation to the typical elevation (trend) in its vicinity. Interpretation of a Deviation Surface is the same as that for the difference surface discussed last month—protrusions (large positive values) locate drier convex areas; depressions (large negative values) locate wetter concave areas.

The implication of the "Localized Deviation" approach goes far beyond simply an alternative procedure for calculating terrain irregularities. The use of "roving windows" provides a host of new metrics and map surfaces for assessing micro-terrain characteristics. For example, consider the Coefficient of Variation (Coffvar) Surface shown in the bottom-right portion of figure 31-4. In this instance, the standard deviation of the window is compared to its average elevation—small "coffvar" values indicate areas with minimal differences in elevation; large values indicate areas with lots of different elevations. The large ridge in the coffvar surface in the figure occurs along the shoreline of a lake. Note that the ridge is largest for the steeply-rising terrain with big changes in elevation. The other bumps of surface variability noted in the figure indicate areas of less terrain variation.

While a statistical summary of elevation values is useful as a general indicator of surface variation or "roughness," it doesn't consider the pattern of the differences. A checkerboard pattern of alternating higher and lower values (very rough) cannot be distinguished from one in which all of the higher values are in one portion of the window and lower values in another.

There are several roving window operations that track the spatial arrangement of the elevation values as well as aggregate statistics. A frequently used one is terrain slope that calculates the "slant" of a surface. In mathematical terms, slope equals the difference in elevation (termed the "rise") divided by the horizontal distance (termed the "run").

As shown in figure 8-5, there are eight surrounding elevation values in a 3x3 roving window. An individual slope from the center cell can be calculated for each one. For example, the percent slope to the north (top of the window) is ((2332 - 2262) / 328) * 100 = 21.3%. The numerator computes the rise while the denominator of 328 feet is the distance between the centers of the two cells. The calculations for the northeast slope is ((2420 - 2262) / 464) * 100 = 34.1%, where the run is increased to account for the diagonal distance (328 * 1.414 = 464).

The eight slope values can be used to identify the Maximum, the Minimum and the Average slope as reported in the figure. Note that the large difference between the maximum and minimum slope (53 - 7 = 46) suggests that the overall slope is fairly variable. Also note that the sign of the slope value indicates the direction of surface flow—positive slopes indicate flows into the center cell while negative ones indicate flows out. While the flow into the center cell depends on the uphill conditions (we'll worry about that in a subsequent column), the flow away from the cell will take the steepest downhill slope (southwest flow in the example… you do the math).

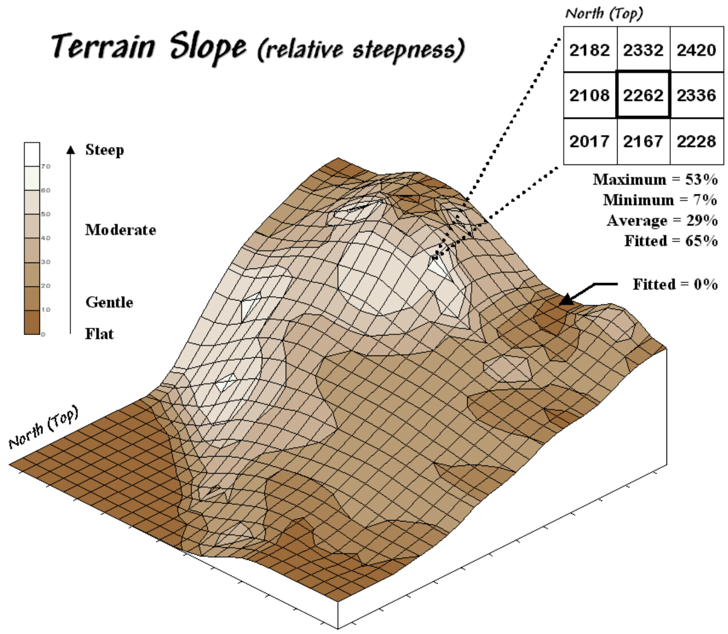


Figure 8-5. Calculation of slope considers the arrangement and magnitude of elevation differences within a roving window.

In practice, the Average slope can be misleading. It is supposed to indicate the overall slope within the window but fails to account for the spatial arrangement of the slope values. An alternative technique fits a “plane” to the nine individual elevation values. The procedure determines the best fitting plane by minimizing the deviations from the plane to the elevation values. In the example, the Fitted slope is 65%… more than the maximum individual slope.

At first this might seem a bit fishy—overall slope more than the maximum slope—but believe me, determination of fitted slope is a different kettle of fish than simply scrutinizing the individual slopes. Next time we'll look a bit deeper into this fitted slope thing and its applications in micro-terrain analysis.

8.3 Assessing Terrain Slope and Roughness

The past few columns discussed several techniques for generating maps that identify the bumps (convex features), the dips (concave features) and the tilt (slope) of a terrain surface. Although the procedures have a wealth of practical applications, the hidden agenda of the discussions was to get you to think of geographic space in a less traditional way—as an organized set of numbers (numerical data), instead of points, lines and areas represented by various colors and patterns (graphic map features).

A terrain surface is organized as a rectangular "analysis grid" with each cell containing an elevation value. Grid-based processing involves retrieving values from one or more of these "input data layers" and performing a mathematical or statistical operation on the subset of data to produce a new set numbers. While computer mapping or spatial database management often operates with the numbers defining a map, these types of processing simply repackage the existing information. A spatial query to "identify all the locations above 8000' elevation in El Dorado County" is a good example of a repackaging interrogation.

Map analysis operations, on the other hand, create entirely new spatial information. For example, a map of terrain slope can be derived from an elevation surface and then used to expand the geo-query to "identify all the locations above 8000' elevation in El Dorado County (existing data) that exceed 30% slope (derived data)." While the discussion in this series of columns focuses on applications in terrain analysis, the subliminal message is much broader—map analysis procedures derive new spatial information from existing information.

Now back to business. Last month's column described several approaches for calculating terrain slope from an elevation surface. Each of the approaches used a "3x3 roving window" to retrieve a subset of data, yet applied a different analysis function (maximum, minimum, average or "fitted" summary of the data).

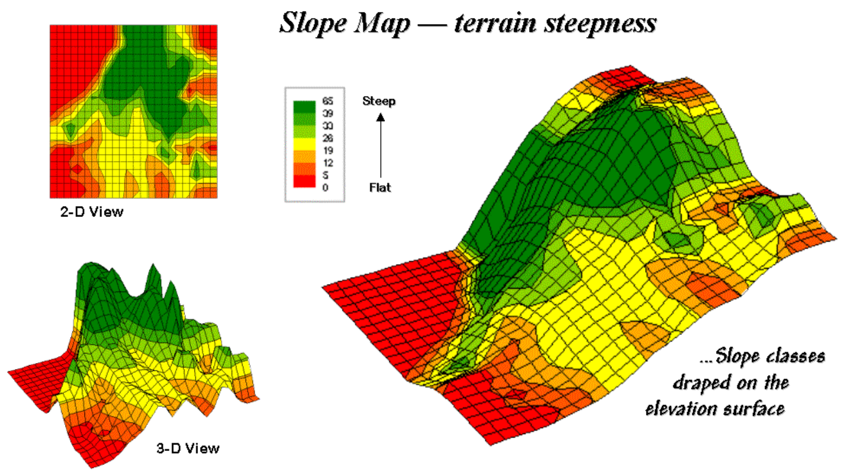


Figure 8-6. 2-D, 3-D and draped displays of terrain slope.

Figure 8-6 shows the slope map derived by "fitting a plane" to the nine elevation values surrounding each map location. The inset in the upper left corner of the figure shows a 2-D display of the slope map. Note that steeper locations primarily occur in the upper central portion of the area, while gentle slopes are concentrated along the left side.

The inset on the right shows the elevation data as a wire-frame plot with the slope map draped over the surface. Note the alignment of the slope classes with the surface configuration—flat slopes where it looks flat; steep slopes where it looks steep. So far, so good.

The 3-D view of slope in the lower left, however, looks a bit strange. The big bumps on this surface identify steep areas with large slope values. The ups-and-downs (undulations) are particularly interesting. If the area was perfectly flat, the slope value would be zero everywhere and the 3-D view would be flat as well. But what do you think the 3-D view would look like if the surface formed a steeply sloping plane?

Are you sure? The slope values at each location would be the same, say 65% slope, therefore the 3-D view would be a flat plane "floating" at a height of 65. That suggests a useful principle—as a slope map progresses from a constant plane (single value everywhere) to more ups-and-downs (bunches of different values), an increase in terrain roughness is indicated.

Figure 8-7 outlines this concept by diagramming the profiles of three different terrain cross-sections. An elevation surface's 2nd derivative (slope of a slope map) quantifies the amount of ups-and-downs of the terrain. For the straight line on the left, the "rate of change in elevation per unit distance" is constant with the same difference in elevation everywhere along the line—slope = 65% everywhere. The resultant slope map would have the value 65 stored at each grid cell, therefore the "rate of change in slope" is zero everywhere along the line (no change in slope)—slope2 = 0% everywhere.

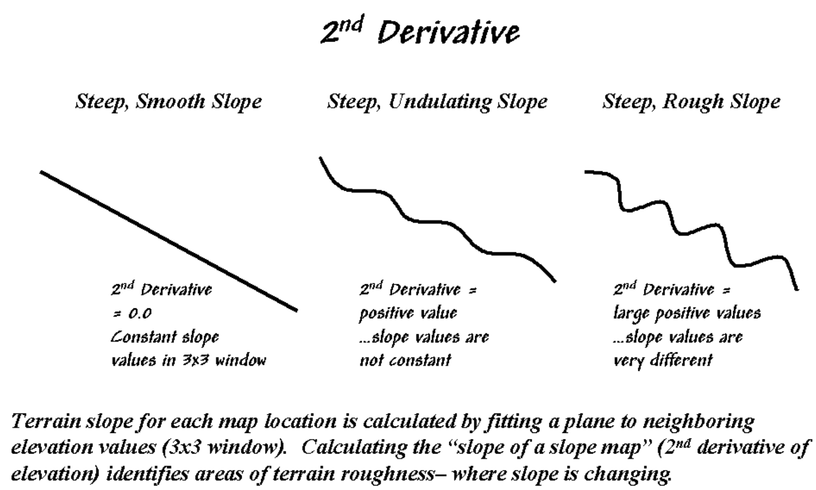


Figure 8-7. Assessing terrain roughness through the 2nd derivative of an elevation surface.

A slope2 value of zero is interpreted as a perfectly smooth condition, which in this case happens to be steep. The other profiles on the right have varying slopes along the line, therefore the "rate of change in slope" will produce increasing larger slope2 values as the differences in slope become increasingly larger.

So who cares? Water drops for one, as steep smooth areas are ideal for downhill racing, while "steep 'n rough terrain" encourages more infiltration, with "gentle yet rough terrain" the most.

Figure 8-8 shows a roughness map based on the 2nd derivative for the same terrain as depicted in Figure 8-6. Note the relationships between the two figures. The areas with the most "ups-and-downs" on the slope map in figure 8-6 correspond to the areas of highest values on the roughness map in figure 8-8.

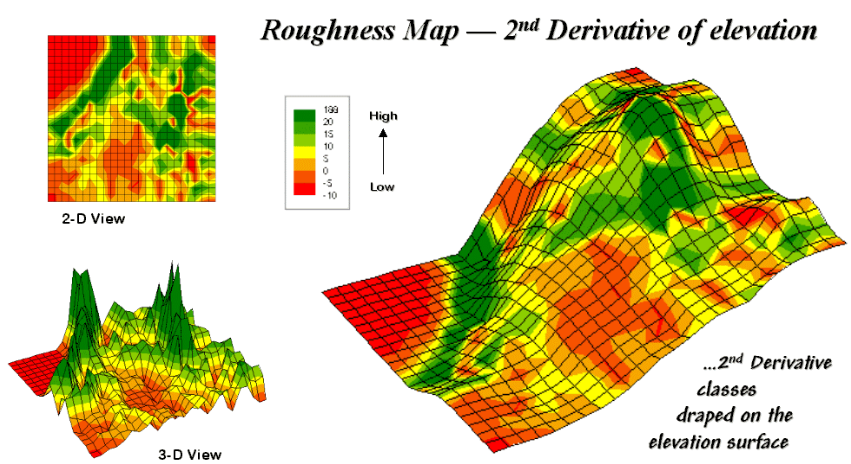


Figure 8-8. 2-D, 3-D and draped displays of terrain roughness.

Now focus your attention on the large steep area in the upper central portion of the map. Note the roughness differences for the same area as indicated in figure 8-8 …the favorite raindrop racing areas are the smooth portions of the steep terrain.

Whew! That's a lot of map-ematical explanation for a couple of pretty simple concepts—steepness and roughness. Next month we'll continue the trek on steep part of the map analysis learning curve by considering "confluence patterns" in micro terrain analysis.

8.4 Calculating Realistic Areas

The earth is flat …or so most GIS maps contend. I am not referring to concern about the curvature of the earth but to the undulations of local terrain. Once projection adjustments are made, a flattened world is assumed—*planimetric* representation. But what happened to the up-and-down wrinkles of the real world? What about actual surface areas and lengths of map features that are clinging to sides of slopes?

Common sense suggests that if you walk up and down in steep terrain you will walk a lot farther than the planimetric length of your path. While we have known this fact for thousands of years, surface area and length calculations were practically impossible to apply to paper maps. However, map-ematical processing in a GIS easily handles the calculations.

In a vector-based system, area calculations use plane geometry equations. In a grid-based system, ***planimetric area*** is calculated by multiplying the number of cells defining a map feature times the area of an individual cell. For example, if a forest cover type occupies 500 cells with a spatial resolution of 1 hectare each, then the total planimetric area for the cover type is 500 cells * 1ha/cell = 500ha.

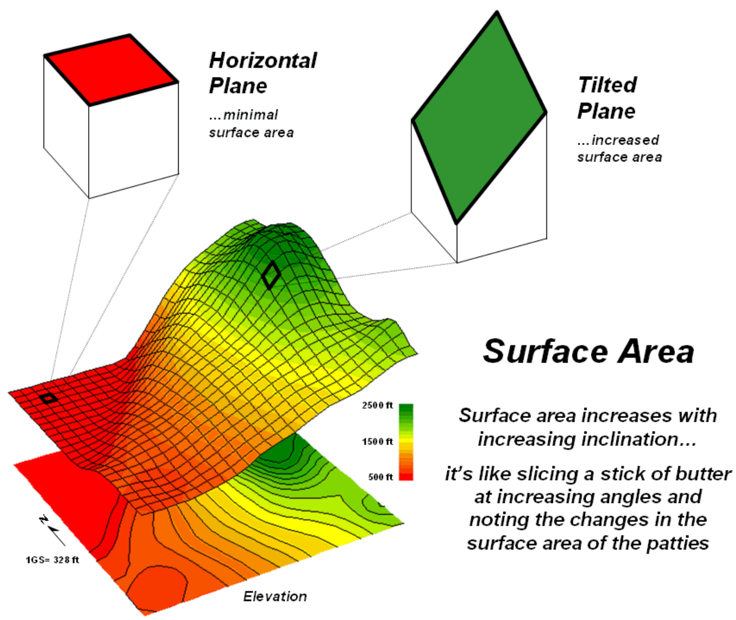


Figure 8-11. Surface area increases with increasing terrain slope.

However, the actual surface area of each grid cell is dependent on its inclination (slope). ***Surface area*** increases as a grid cell is tilted from a horizontal reference plane (planimetric) to its three-dimensional position in a digital elevation surface (see figure 8-11).

Surface area can be calculated by dividing the planimetric area by the cosine of the slope angle. For example, a grid location with a 20 percent slope has a surface area of 1.019803903 hectares based on solving the following sequence of equations:

Tan_Slope_Angle = 20 %_ slope / 100 = .20 slope_ratio
Slope_Angle = arctan (.20 slope_ratio) = 11.30993247 degrees
Surface_Area_Factor = cos (11.30993247 degrees) = .980580676
Surface_Area = 1 ha / .980580676 = 1.019803903 ha

The listing in figure 8-12 identifies the surface area calculations for a 1-hectare gridding resolution under several terrain slope conditions. Note that the column ***Surface_Area_Factor*** is independent of the gridding resolution. Deriving the surface area for a cell on a 5-hectare resolution map, simply changes the last step in the 20% slope example (above) to *5 ha / .9806 = 5.0989 ha Surface_Area*.

%Slope	Tan_Slope_Angle	Slope_Angle	Surface_Area_Factor	Surface_Area (1ha)
0	0.00	00.0000	1.0000	1.0000 ha
20	0.20	11.3099	0.9806	1.0198 ha
40	0.40	21.8014	0.9285	1.0770 ha
80	0.80	38.6598	0.7809	1.2806 ha
100	1.00	45.0000	0.7071	1.4142 ha
150	1.50	56.3099	0.5547	1.8028 ha
200	2.00	63.4349	0.4472	2.2361 ha
300	3.00	71.5650	0.3163	3.1623 ha
infinity	infinity	90.0000	0.0000	infinity

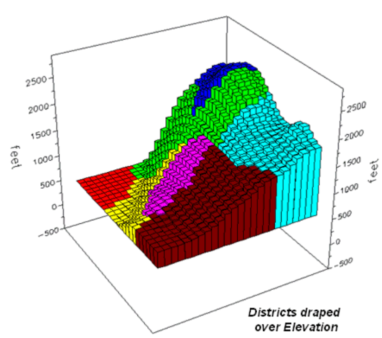
Figure 8-12. Surface areas for selected terrain slopes.

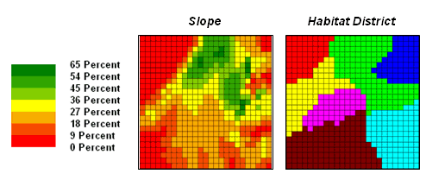
For an empirical test of the surface area conversion procedure, I have students cut a stick of butter at two angles— one at 0 degrees (perpendicular) and the other at 45 degrees. They then stamp an imprint of each patty on a piece of graph paper and count the number of grid spaces covered by the grease spots to determine their areas. Comparing the results to the calculations in the table above confirms that the 45-degree patty is about 1.414 larger. What do you think the area difference would be for a 60-degree patty?

In a grid-based GIS things are a bit less messy. A slope map is derived from an elevation surface then used to map-ematically solve the set of equations for each grid cell. In the MapCalc system, the set of commands calculating surface area for each habitat districts in a project area is…

Step 1) **SLOPE** ELEVATION FOR SLOPE_MAP
Step 2) **CALCULATE** (COS ((ARCTAN (SLOPE_MAP / 100)))) FOR SURFACE_AREA_FACTOR_MAP
Step 3) **CALCULATE** 1.0 / SURFACE_AREA_FACTOR_MAP FOR SURFACE_AREA_MAP
Step 4) **COMPOSITE** HABITAT_DISTRICT_MAP TOTAL WITH SURFACE_AREA_MAP
FOR HABITAT_SURFACE_AREA_MAP

The command macro is scaled to a 1-hectare gridding resolution project area by assigning the value 1.0 (ha) in the third step. If a standard DEM (Digital Elevation Model with 30m resolution) surface is used, the GRID_RES would be set to .09 hectare (30m * 30m= $900m^{2;}$ $900m^2/10{,}000m^2$= .09ha). If the gridding resolution is available in the metadata with the data base, this factor can be automatically set. A similar procedure can be developed for ArcGIS Spatial Analyst or other grid-based map analysis software.





	District	# Cells	Planimetric Area(ha)	Surface Area (ha)	% Difference
	1	58	58.0	58.0	0.00
	2	135	135.0	148.0	9.62
	3	59	59.0	61.9	4.91
	4	76	76.0	78.4	3.16
	5	56	56.0	57.9	3.39
	6	102	102.0	105.0	2.94
	7	139	139.0	141.0	1.44

Figure 8-13. Planimetric vs. surface area differences for habitat districts.

A region-wide, or zonal overlay procedure (Composite), is used to sum the surface areas for the cells defining any map feature—habitat districts in this case. Figure 8-13 shows the planimetric and surface area results for the districts considering the terrain surface. Note that District 2 (light green) aligns with most of the steep slopes on the elevation surface. As a result, the surface area is considerably greater (9.62%) than its simple planimetric area.

Surface length of a line also is affected by terrain. In this instance, azimuth as well as slope of the tilted plane needs to be considered as it relates to the direction of the line. If the grid cell is flat or the line is perpendicular to the slope of a tilted plane, there is no correction to the planimetric length of a line—from orthogonal (1.0 grid space to diagonal (1.414 grid space) length. If the line is parallel to the slope (same direction as the azimuth of the cell) the full cosine correction to its planimetric projection takes hold. The geometric calculations are a bit more complex and reserved for online discussion (see Author's Note).

So who cares about surface area and length? Suppose you needed to determine the amount of pesticide needed for weed spraying along an up-down power-line route or estimating the amount of seeds for reforestation or are attempting to calculate surface infiltration in rough terrain. Keep in mind that "simple area/length calculations can significantly under-estimate real world conditions." Just ask a pooped hiker that walked five planimetric-miles in the Colorado Rockies.

8.5 Identifying Valley Bottoms

The previous sections have focused on localized terrain characteristics, such as slope and roughness. With the exception of surface flow the procedures use a small window that is moved about an elevation surface to summarize the map values. However analyses for broader terrain features, such as identifying valley bottoms, use entirely different approaches.

The upper-left inset in figure 8-14 identifies a portion of a 30m digital elevation model (DEM). The "floor" of the composite plot is a 50-meter contour map of the terrain co-registered with an exaggerated 3D lattice display of the elevation values. Note the steep gradients in the southwestern portion of the area.

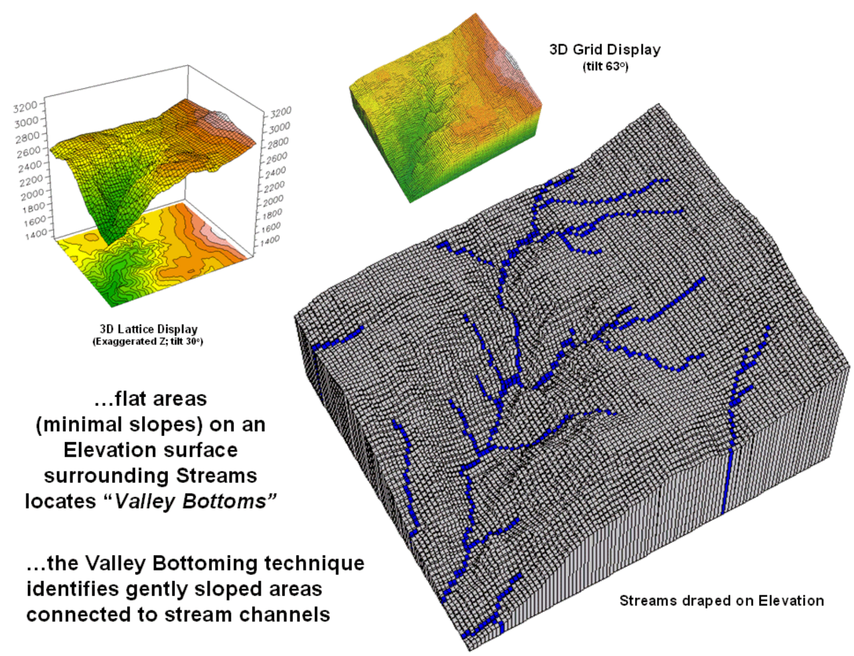


Figure 8-14. Gentle slopes surrounding streams are visually apparent on a 3D plot of elevation.

The enlarged 3D grid display on the right graphically overlays the stream channels onto the terrain surface. Note that the headwaters occur on fairly gentle slopes then flow into the steep canyon. While your eye can locate areas of gentle slope surrounding streams in the plot, an automated technique is needed to delineate and characterize the valley bottoms for millions of acres. In addition, a precise rule set is needed to avoid inconsistencies among subjective visual interpretations.

Like your eye, the computer needs to 1) locate areas with gentle slopes that are 2) connected to the stream channels. Figure 8-15 shows the slope calculation results for the project area. The small 3D grid plot at the top identifies terrain steepness from 0 to 105% slope. Gently sloped areas of 0-6% are shown in green tones with steeper slopes shown in red tones. The gently sloped areas are the ones of interest for deriving valley bottoms, and as your eye detected, the computer locates them primarily along the rim of the canyon. But these areas only meet half of the valley bottom definition—which of the flat areas are connected to stream channels?

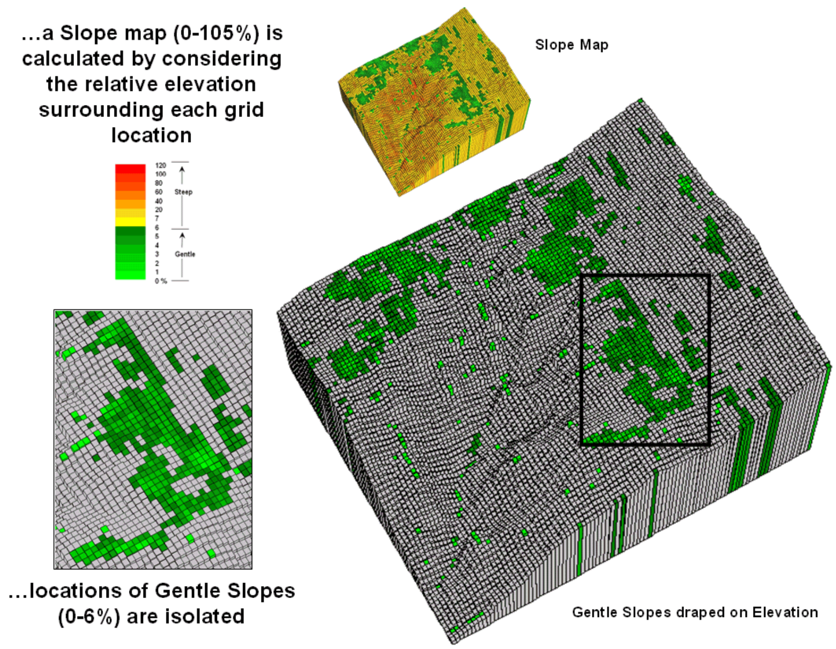


Figure 8-15. Slope values for the terrain surface are calculated and gently sloped areas identified.

Figure 8-16 identifies the procedure for linking the two criteria. First the flat areas are isolated for a binary map of 0-6% slope=1 and greater slopes=0. Then an effective distance operation is used to measure distance away from streams considering just the areas of gentle slopes. The enlarged inset shows the result with connected valley bottom as far away as 900 meters.

While the prototype bottoming technique appears to work, several factors need to be considered before applying it to millions of areas. First is the question whether the 30 meter DEM data supports the slope calculations. In figure 2 the horizontal stripping in the slope values suggests that the elevation data contains some inconsistencies. In addition what type of slope calculation (average, fitted, maximum, etc) ought to be used? And is the assumption of 0-6% for defining valley bottoms valid? Should it be more or less? Does the definition change for different regions?

Another concern involves the guiding surface used in determining effective proximity—distance measurement uphill/downhill only or across slopes? Do intervening soil and vegetation conditions need to be considered in establishing connectivity? A final consideration is designing a field methodology for empirically evaluating model results. Is there a strong correlation with riparian vegetation and/or soil maps?

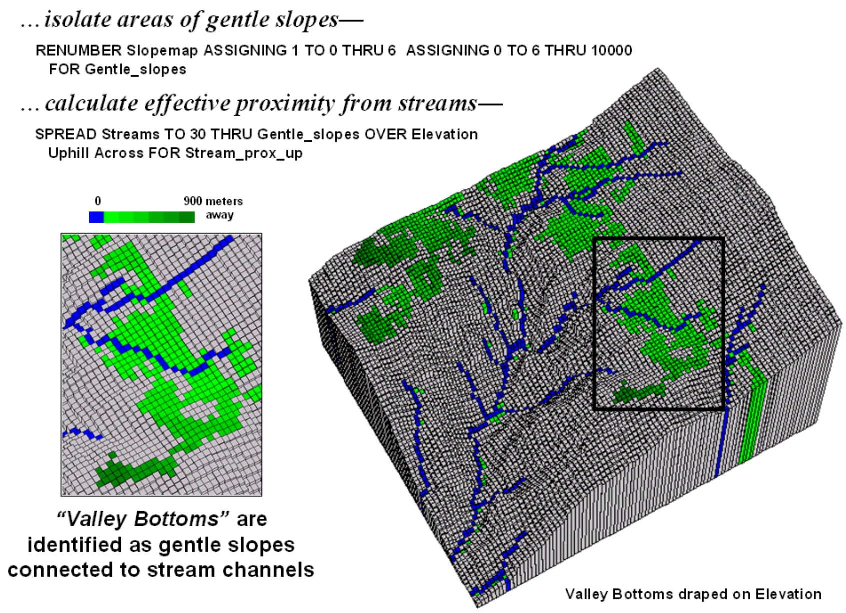


Figure 8-16. Valley bottoms are identified as flat areas connected to streams.

That's the fun of scholarly pursuit. Take a simple idea and grind it to dust in the research crucible—only the best ideas and solutions survive. But keep in mind that the major ingredient is a continuous flow of bright and energetic minds.

8.6 More on Slope's Slippery Slope

If you are a skier it's likely that you have a good feel for terrain slope. If it's a steep double-diamond run, the timid will zigzag across the slope while the boomers will follow the fall-line straight down the hill.

This suggests that there are myriad slopes—uphill, across and downhill; N, E, S and West; 0-360 azimuth—at any location. So how can a slope map report just one slope value at each location? Which slope is it? How is it calculated? How might it be used?

Digital Elevation Model (DEM) data is readily available at several spatial resolutions. Figure 8-17 shows a portion of a standard elevation map with a cell size of 30 meters (98.43 feet). While your eye easily detects locations of steep and gentle slopes in the 3D display, the computer doesn't have the advantage of a visual representation. All it "sees" is an organized set of elevation values—10,000 numbers organized as 100 columns by 100 rows in this case.

The enlarged portion of figure 8-17 illustrates the relative positioning of nine elevation values and their corresponding grid storage locations. Your eye detects slope as relative vertical alignment of the cells. However, the computer calculates slope as the relative differences in elevation values.

The simplest approach to calculating slope focuses on the eight surrounding elevations of the grid cell in the center of a 3-by-3 window. In the example elevation values (center inset), the individual percent slope for *d*-*e* is change in elevation (vertical *rise*) divided by change in position (horizontal *run*) equals [((8071 ft – 8136 ft) / 98.43 ft) * 100] = -66%. For diagonal positions, such as *a*-*e*, the calculation changes to [((8071 ft – 8136 ft) / 139.02 ft) * 100] = -47% using an adjusted horizontal run of SQRT(98.43**2 + 98.43**2) = 139.02 ft.

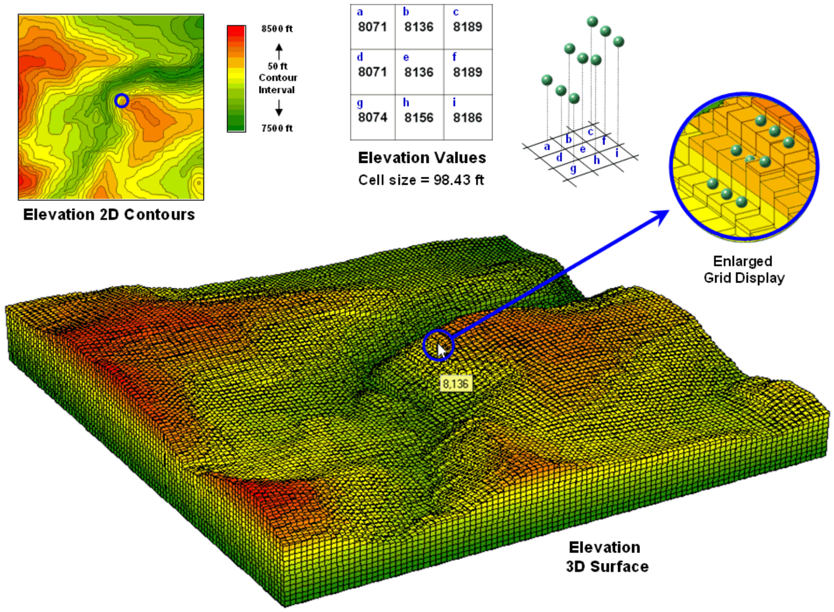


Figure 8-17. A terrain surface is stored as a grid of elevation values.

Applying the calculations to all of the neighboring slopes results in eight individual slope values yields (clockwise from *a-e*) 47, 0, 38, 54, 36, 20, 45 and 66 percent slope. The ***minimum*** slope of 0% would be the choice the timid skier while the boomer would go for the ***maximum*** slope of 66% provided they stuck to one of the eight directions. The simplest calculation for an overall slope is an arithmetic ***average*** slope of 38% based on the eight individual slopes.

Most GIS systems, however, offer more sophisticated solutions for characterizing the overall slope for a grid location. One approach summarizes the relative changes in rise to run for x and y-directions in the 3x3 window (***generalized***). Another fits a plane to the nine elevation values (***fitted***) then computes the slope of the plane.

Figure 8-18 shows several slope maps derived from the elevation data shown in figure 8-1 and organized by increasing overall slope estimates. The techniques show somewhat similar spatial patterns with the steepest slopes in the northeast quadrant. Their derived values, however, vary widely. For example, the *average* slope estimates range from .4 to 53.9% whereas the *maximum* slope estimates are from 3.3 to 120%. Slope values for a selected grid location in the central portion are identified on each map and vary from 0 to 59.4%.

So what's the take-home on slope calculations? Different algorithms produce different results and a conscientious GIS user should be aware of the differences. A corollary is that you should be hesitant to download a derived map of slope without knowing its heritage. The chance of edge-matching slope maps from a variety of systems is unlikely. Even more insidious is the questionable accuracy of utilizing a map-ematical equation calibrated using one slope technique then evaluated using another.

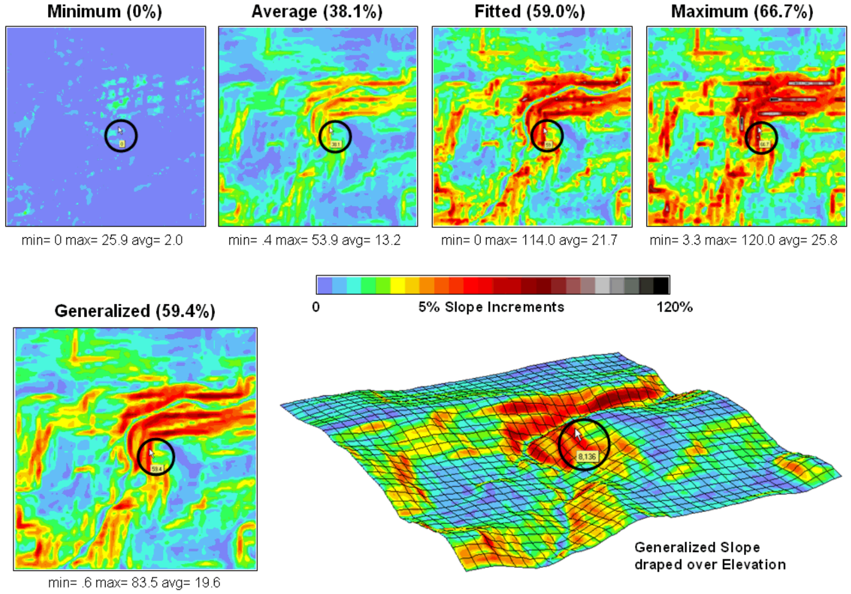


Figure 8-18. Visual comparison of different slope maps.

The equations and example calculations for the advanced techniques are beyond the scope of this column but are available online (see author's note). The bottom line is that grid-based slope calculators use a roving window to collect neighboring elevations and relate changes in the values to their relative positions. The result is a slope value assigned to each grid cell.

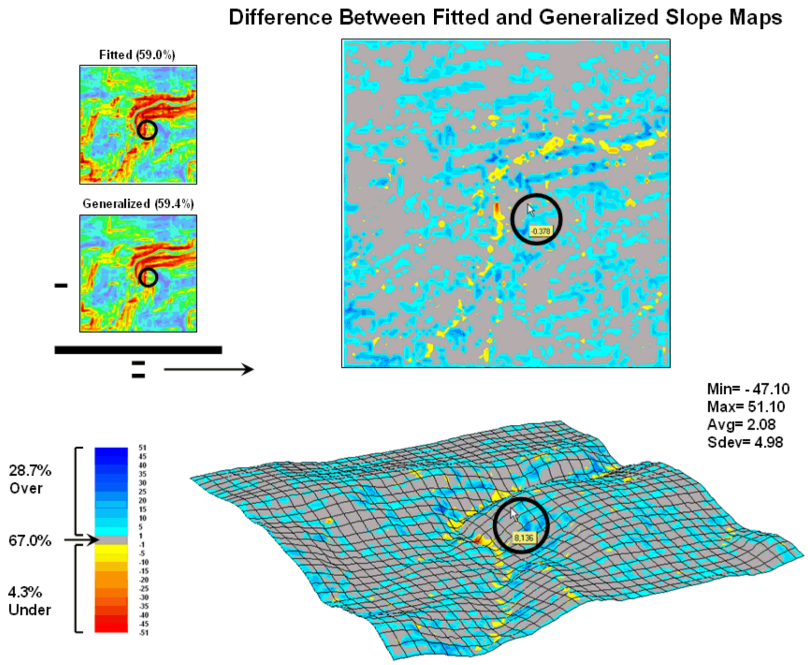


Figure 8-19. Comparison of Fitted versus Generalized slope maps.

The two advanced techniques result in very similar slope estimates. Figure 8-19 compares the two slope maps by simply subtracting them. Note that the slope estimates for about two-thirds of the project area is within one percent agreement (grey). Disagreement between the two maps is predominantly where the *fitted* technique estimates a steeper slope than the *generalized* technique (blue-tones). The locations where *generalized* slopes exceed the *fitted* slopes (red-tones) are primarily isolated along the river valley.

Author's Note: An Excel worksheet investigating Maximum, Minimum, and Average slope calculations is available online at the "Column Supplements" page at http://www.innovativegis.com/basis.

Author's Note: The figures presented in this series on "Characterizing Micro-Terrain Features" plus several other illustrative ones are available online as a set of annotated PowerPoint slides at the "Column Supplements" page at http://www.innovativegis.com/basis.

Author's Note: For background theory and equations for calculating surface area and length… see ***www.innovativegis.com/basis****, select "Column Supplements," Beyond Mapping, December 2002.*

Author's Note: For background theory and equations for calculating surface slope… see ***www.innovativegis.com/basis****, select "Column Supplements," Beyond Mapping, January 2003.*

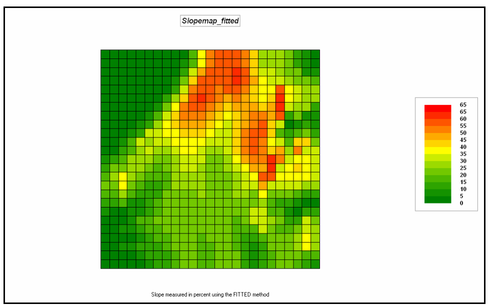
8.7 Exercises

Access *MapCalc* using the *Tutor25.rgs* by selecting **Start** à **Programs** à **MapCalc Learner** à **MapCalc Learner** à **Open existing map set** à **NR_MapCalc Data** à **Tutor25.rgs**. The following set of exercises utilizes this database.

8.7.1 Deriving Slope

Derive a map of "fitted" slope from the Elevation surface…

Neighbors à **Slope**
SLOPE Elevation Fitted FOR Slopemap_fitted



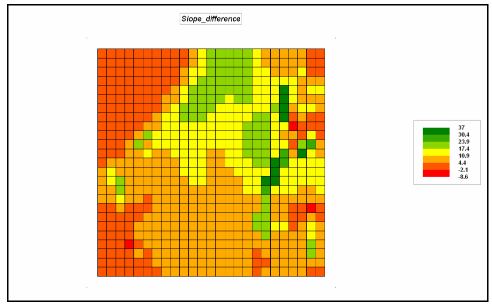
Displayed as User Defined Ranges, # Ranges = 14, Green 0 to 5, Yellow 35 to 40 and Red 65 to 70

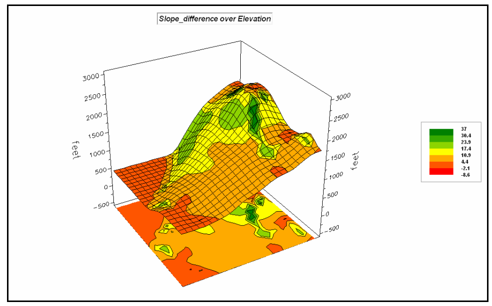
…and one using the "average" calculation mode.

Calculate the difference in slope estimates between the two techniques.

Overlay à **Calculate**
CALCULATE (Slopemap_fitted - Slopemap_average) FOR Slope_difference

Drape the result over a 3D Lattice plot of the Elevation surface b y using the Binoculars button to view the Elevation map and then selecting from the Main menu **Map** à **Overlay** à **Slope_difference**.



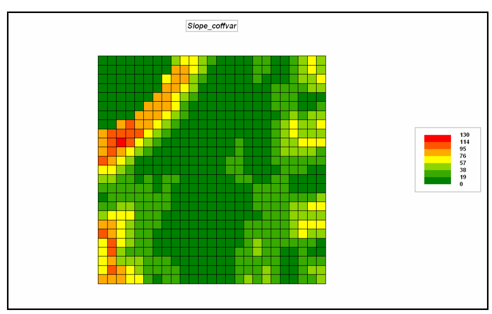


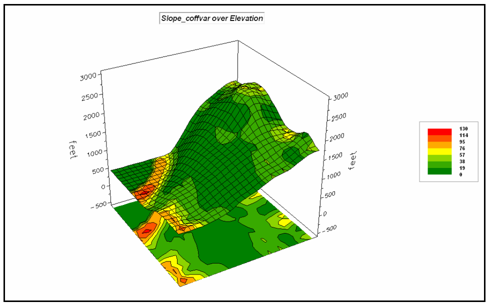
Can you explain the large differences between the two slope maps? …the negative vales on the difference map?

8.7.2 Establishing Terrain Roughness

Derive a map of roughness by entering the following command. Drape the result on a 3D Lattice plot of the Elevation surface.

Neighbors à **Scan**
SCAN Slopemap_fitted CoffVar IGNORE 0.0 WITHIN 1 CIRCLE FOR Slope_coffvar

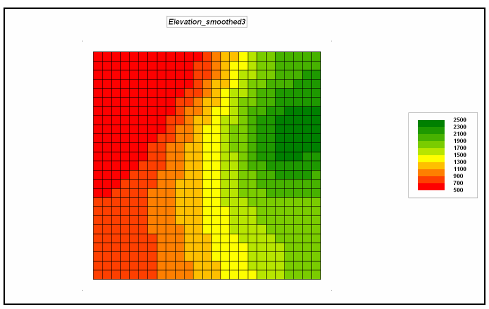




8.7.3 Identifying Convex/Concave Features

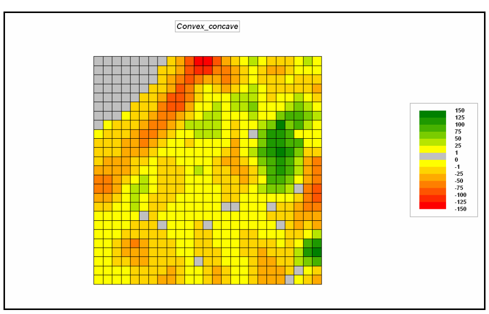
Create a "smoothed" map of Elevation by entering the following command.

Neighbors à Scan
SCAN Elevation Average IGNORE 0.0 WITHIN 3 CIRCLE FOR Elevation_smoothed3



Calculate the difference between the actual Elevation surface and the smoothed one.

Overlay à Calculate
CALCULATE (Elevation – Elevation_smoothed3) FOR Convex_concave



Displayed as User Defined Ranges, # Ranges = 14,and color sets as -150 to -125 = red, -1 to 0 = yellow, 0 to 1 = light grey, 1 to 25 = yellow and 125 to 150 = green

Range Display

Min [>=]	Max [<]	Count	acres	% Gridded Area	Color	Lock
125	150	3	7.409	0.48		On
100	125	10	24.698	1.6		Off
75	100	15	37.046	2.4		Off
50	75	14	34.577	2.24		Off
25	50	40	98.791	6.4		Off
1	25	184	454.437	29.44		On
0	1	53	130.898	8.48		On
-1	0	13	32.107	2.08		On
-25	-1	175	432.209	28.0		Off
-50	-25	76	187.702	12.16		Off
-75	-50	27	66.684	4.32		Off
-100	-75	11	27.167	1.76		Off
-125	-100	2	4.94	0.32		Off
-150	-125	2	4.94	0.32		On

Drape the result over a 3D Lattice plot of the Elevation surface