

## Topic 7

# Analyzing Spatial Context

### 7.1 Spatial Analysis Operations

Grid-based map analysis involves two broad categories of operations—*Spatial Statistics* and *Spatial Analysis*.

Table 4-1 outlines some of the specific techniques within each category.

**Spatial Statistics** tools, like the ones presented in the previous discussions on comparing maps, interpolation, data grouping and predictive models, respond to “numerical” relationships in mapped data.

**Spatial Analysis** tools, on the other hand, investigate “contextual” relationships, such as slope/aspect, buffers, effective proximity, optimal path, visual exposure and shape analysis\*. Rather than statistical investigation of mapped data relationships, these techniques examine geographic patterns, vicinity characteristics and connectivity among features.

From this perspective, four classes of spatial analysis techniques can be identified that—*reclassify* map categories, *overlay* two or more

maps, measure *distance* and connectivity, and characterize cartographic *neighborhoods*.

**Table 4-1. Grid-based Map Analysis Operations**

<p><b>Spatial Statistics</b> tools investigate statistical patterns and relationships among maps, such as—</p> <ul style="list-style-type: none"> <li>✓Descriptive Statistics</li> <li>✓Normality Tests</li> <li>✓Point Density Maps</li> <li>✓Geographic Trend Analysis</li> <li>✓Spatial Interpolation</li> <li>✓Spatial Autocorrelation</li> <li>✓Scatter Plots</li> <li>✓Variograms</li> <li>✓Residual Analysis</li> <li>✓Error Mapping</li> <li>✓Coincidence Statistics</li> <li>✓Change Surfaces</li> <li>✓Comparison Tests</li> <li>✓Spatial Correlation and Dependency</li> <li>✓Multivariate Regression</li> <li>✓Clustering</li> <li>✓Map Similarity</li> </ul>
<p><b>Spatial Analysis</b> tools derive new maps based on spatial context, patterns, surface configuration, proximity, connectivity and flows, such as—</p> <ul style="list-style-type: none"> <li>✓Geographic Search</li> <li>✓Weighted Proximity Analysis</li> <li>✓Slope and Aspect</li> <li>✓Visual Exposure</li> <li>✓Optimal Path</li> <li>✓Local, Regional and Map-Wide Overlay</li> <li>✓Nearby Neighbor Summary</li> <li>✓Edge, Shape and Pattern Characterization</li> <li>✓Narrowness</li> <li>✓Logical, Ranking, Rating and Mathematical Combination</li> <li>✓Confluence Surfaces</li> <li>✓Propensity Analysis</li> <li>✓Travel-Time Surfaces</li> <li>✓Competition Analysis</li> </ul>

**Reclassification** operations, in the broadest sense, merely repackage existing information on a single map. **Overlay** operations, on the other hand, involve two or more maps and result in the delineation of new information.

**Distance** operations generate entirely new information by characterizing the relative positioning of

map features. **Neighborhood** operations summarize the conditions occurring in the general vicinity of a location.

While precision agriculture often involves spatial statistics in its applications, most other GIS

applications focus on spatial analysis operations, particularly the “geo-query” capability to retrieve locations of map features stored in a database.

For example, a forester might want to identify forest parcels of Douglas fir on Cohasset soil within a county.

Or a real estate agent might query the residential listing for houses within a specified distant of a school and costing less than \$300,000.

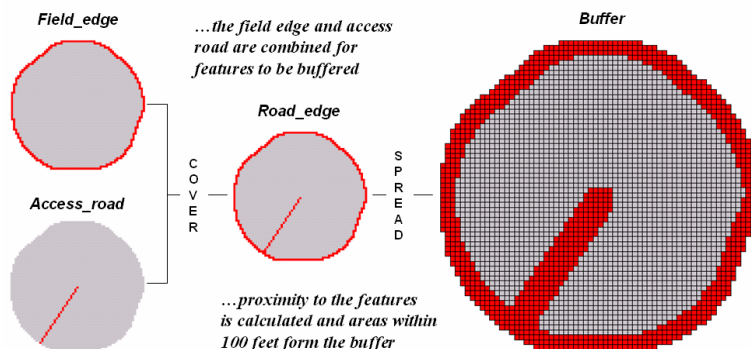


Figure 7-1. A distance tool can be used to buffer special features in the field.

### 7.2 Applying Spatial Analysis Tools

While geo-query has minimal application in precision agriculture, some of the other spatial analysis operations hold great potential. For example, proximity relationships within a field can be analyzed (see figure 7-1).

Most fields exhibit considerable differences at their edges and along access roads. These features can be identified and a buffer created around them.

This technique is often used to eliminate “outlier responses” as described in Topic 6 discussion about stratifying maps for developing better prediction models.

An overlay operation can be used to summarize the yield data within a region, such as the buffer. For example the command “COMPOSITE Buffer WITH 2000\_Yield\_Volume Average FOR Buffer\_avgYield” calculates the average yield within the buffered and non-buffered (interior) areas. As shown in figure 7-2 the Buffer map serves as a template that identifies the spatial subset of yield locations for cookie-cutter summary. Note the dramatic differences in the descriptive statistics for the Buffer and interior regions of the field.

In addition to familiar concepts like proximity and region-wide summary, spatial analysis offers entirely new capabilities. For example we all know that water, if given its head, will take the steepest downhill path over a terrain surface. The command “DRAIN Entire OVER Elevation

FOR Flowmap” utilizes this common sense physics to generate a map of water flow concentrations.

In effect, the procedure places a drop of water at a location on the elevation map and allows it to pick its path down the surface in a series of steepest downhill steps. As each grid cell is traversed it gets the value of one added to it. As the paths from other locations are considered, the areas sharing common paths get increasing larger values (one + one + one, etc.).

Figure 7-3 shows a 3-D grid map of the elevation surface and its resulting flow confluence. The enlarged inset the upper-left shows the paths taken by a couple of drops into a slight depression. The paths are based on the assumption that water will follow a route that chooses the steepest downhill step at each point (grid cell “step”) along the terrain surface.

The inset in the lower-right of the figure shows the considerable inflow into the depression as a high peak in the 3D display. The high value indicates that a lot of uphill locations (128) are connected to this feature.

Now turn your attention to upper-right portion of the figure that shows the Flowmap draped over the terrain surface. The gray tone on ridges of the surface indicate locations where only one rain drop occurs—all flow is away. The green and yellow tones identify areas with increasing number of paths, or

confluence of water. The red areas identify locations of pooling with large amounts of water collecting—

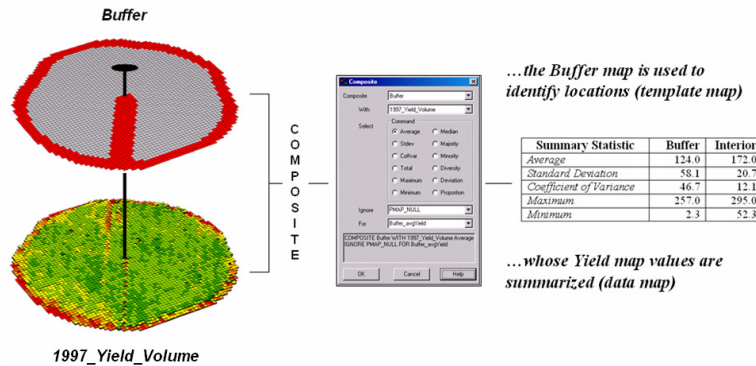


Figure 7-2. A region-wide summary generates statistics of just the buffered areas

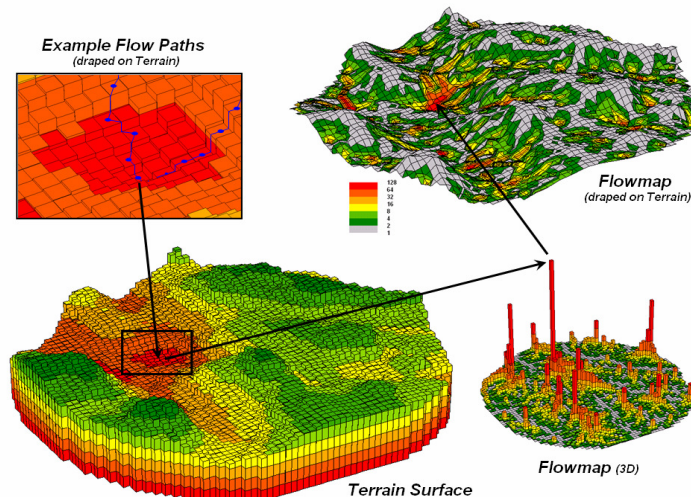


Figure 7-3. Map of surface flow confluence.

depressions in the terrain surface.

### 7.3 GIS Modeling

The *Flowmap* identifies surface water confluence throughout the field with larger numbers indicating locations with lots of uphill contributors—gully washers. However, surface flow is just one factor for determining where applied chemicals and materials are likely to concentrate, as well as fine soil particles and organic residue.

The procedure can be extended for a simple “erosion potential” model by considering terrain slope, a neighborhood spatial analysis operation 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 7-4, there are eight surrounding elevation values in a 3x3 roving window. Individual slope lines through the center cell are computed to identify the *Maximum*, *Minimum* and *Average* slope values as reported in the figure. Note that the large difference between the maximum and minimum slope (0.08 to 4.16%) suggests that the overall slope is fairly variable.

An alternative technique is calculated by “fitting

a plane” to the elevation values by minimizing the deviations from the plane to the nine individual values. In the example, the *Fitted* slope is 5.00% and is a good indicator of the overall slope for the location.

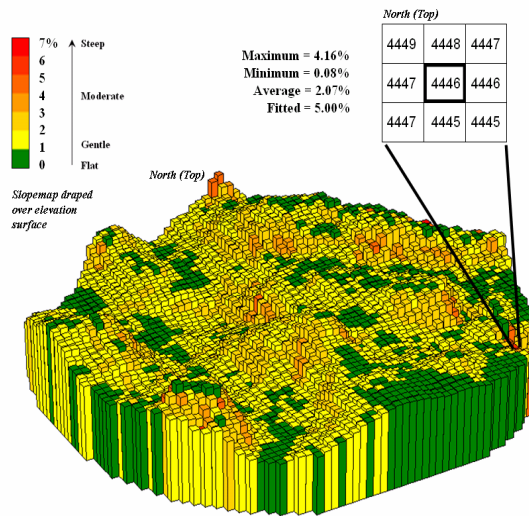


Figure 7-4. Calculation of slope considers the arrangement of elevation differences.

The *Slopedmap* and *Flowmap* can be used to develop a simple erosion potential model. While the flow of the processing shown in figure 7-5 might appear unfamiliar, the underlying assumptions are quite straightforward. The *Slopedmap* characterizes the relative “energy” of water flow at a location, while the confluence values on the *Flowmap* identify the “volume” of flow. It’s common sense that as energy and volume increases, so does erosion potential.

The first step in the model classifies slope into three relative steepness classes—1= Gentle, 2= Moderate and 3= Steep for the *S\_class* map. The next step does the same thing for relative flow classes—1= Light, 2= Moderate and 3= Heavy for the *F\_class* map.

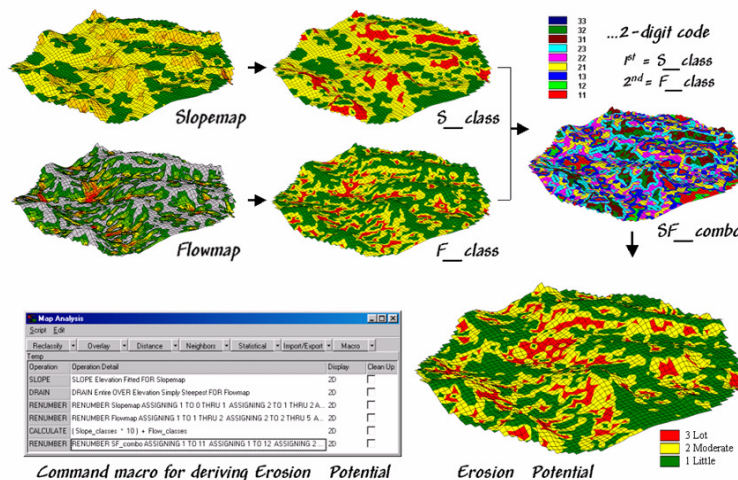


Figure 7-5. Areas of Gentle, Moderate, and Steep slopes (*S\_class*) are combined with areas of Light, Moderate and Heavy flows (*F\_class*) into a single map (*SF\_combo*) that is reclassified to identify areas of Little, Moderate, Lot erosion (*Erosion\_Potential*).

multiplied by 10 then added to the *F\_class* map to create a two digit code where the first digit identifies the slope class and the second digit the flow class.



For example, on the *SF\_combo* map, the category "33 Steep: Heavy Flow" (dark blue) identifies areas that are relatively steep (*S\_class*=3) and have a lot of uphill locations contributing water (*F\_class*=3). Loosened dirtballs under these circumstances are easily washed downhill. However, category "12 Gentle; Moderate Flow" (light green) identifies locations with much less erosion potential. In fact, deposition (the opposite of erosion) occurs in areas of gentle slope, such as category "11 Gentle; Light Flow" (dark red).

The final step interprets the slope/flow combinations into *Erosion\_Potential* classes of Little, Moderate and Lot. Note that the red areas indicating a lot of potential erosion align with the sides of sloping terrain, whereas the green areas indicating little erosion potential are at the flat tops and bottoms of the terrain surface. Of particular concern are red areas near the edge of the field where materials are easily washed off the field and could enter streams.

Before you challenge the scientific merit of the simplified model, note the basic elements of the GIS modeling approach—*flowchart* and *command macro*. The flowchart is used to summarize the model's logic and processing steps. Each map represents a step in the model's logic and each arrow represents an analysis operation. The sentences in the macro perform the model steps that derive the intermediate and final maps.

The macro enables entering, editing, executing, storing and retrieving individual operations that comprise the application. The flowchart provides an effective means for communicating the processing steps to individuals with minimal GIS experience. The explicit linkage between the macro and the flowchart provides a common foothold for communication between the two perspectives—logical and mechanical— of a GIS application. It also provides a whole new paradigm for ag research and technology transfer.

\* See [www.innovativegis.com/basis/MapAnalysis/](http://www.innovativegis.com/basis/MapAnalysis/), an online book entitled *Map Analysis*, for a series of Topics on spatial analysis compiled from the GeoWorld column, Beyond Mapping by this author from 1996 through the present. Also, the books *Beyond Mapping* (1993) and *Spatial Reasoning* (1995) present additional spatial analysis techniques (John Wiley and Sons publisher).

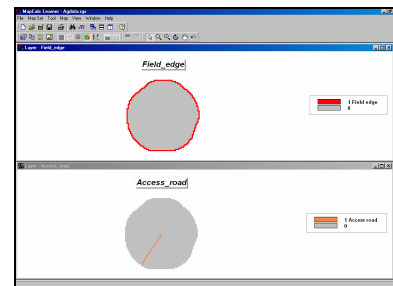
## 7.5 Exercises

Access MapCalc using the *Agdata.rgs* data set by selecting **Start→ Programs→ MapCalc Learner→ MapCalc Learner→ Open existing map set→ PA\_AgData.rgs**. The following set of exercises utilizes this database.

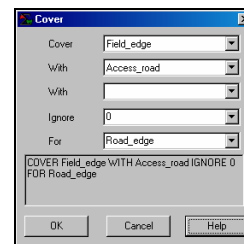
### 7.5.1 Delineating Field Edges



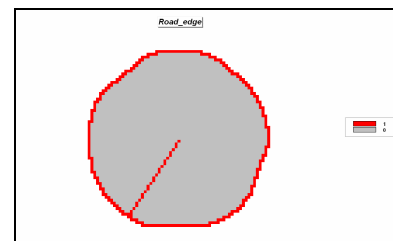
Use the *View* tool to generate top-and-bottom displays of the **Field\_edge** and **Access\_road** maps as shown below.



Select **Map Analysis→ Overlay→ Cover** and complete the following command to combine the two maps.



COVER Field\_edge WITH Access\_road IGNORE 0 FOR Road\_edge

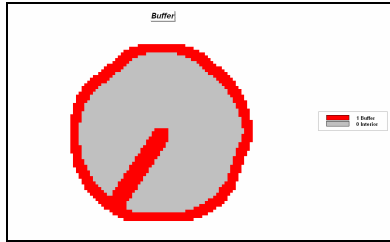


Complete the following commands to generate a 150-foot buffer (3 cells) around the field edge and access road.

**Map Analysis→ Distance→ Spread**

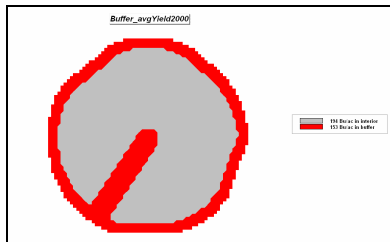
*SPREAD Road\_edge NULLVALUE PMAP\_NULL TO 3 Simply FOR Road\_edge\_proximity*

**Map Analysis→ Reclassify→ Renumber**  
*RENUMBER Road\_edge\_proximity ASSIGNING 1 TO 0 THRU 2.999 ASSIGNING 0 TO 3 FOR Buffer*



Calculate the average yield within the buffer using the **Buffer** layer as the “template map” for summarizing the values on the **2000\_Yield\_Volume** “data map.”

**Map Analysis→ Overlay→ Composite**  
*RENUMBER Road\_edge\_proximity ASSIGNING 1 TO 0 THRU 2.999 ASSIGNING 0 TO 3 FOR Buffer*



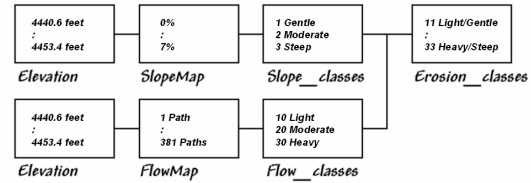
Repeat the processing using the **Composite** command to determine the standard deviation, coefficient of variation, maximum and minimum yield statistics for the buffer and interior areas.

How do these statistics compare to the ones presented in the discussion for the 1997\_Yield\_Volume in the body of this topic? Although the absolute values are different, is there a consistent relationship between the buffer and interior yield levels? Be sure to consider both the typical (average) and the variation (standard deviation) in the two sets of statistics.

## 7.5.2 Deriving Erosion Potential

Become familiar with the following simple model for estimating soil erosion potential...

Logical flowchart—

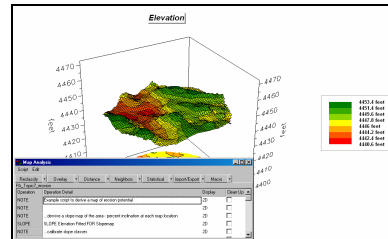


Command sequence (Script)—

Map Analysis			
Script Edit			
Precedence	Overlay	Distance	Neighbors
PA_Topic7_erosion			
Operation	Operation Detail	Display	Clean Up
NOTE	Example script to derive a map of erosion potential	2D	<input type="checkbox"/>
NOTE	...derive a slope map of the area- percent inclination at each map location	2D	<input type="checkbox"/>
SLOPE	SLOPE Elevation Fitted FOR SlopeMap	2D	<input type="checkbox"/>
NOTE	...derive a map of surface flow- number of uphill locations passing surface flow through each map locations	2D	<input type="checkbox"/>
DRAIN	DRAIN Entire OVER Elevation Simply Steepest FOR Flowmap	2D	<input type="checkbox"/>
NOTE	...calibrate slope classes	2D	<input type="checkbox"/>
RENUMBER	RENUMBER SlopeMap ASSIGNING 1 TO 0 THRU 1 ASSIGNING 2 TO 1 THRU 2 ASSIGNING 3 TO 2 THRU 2	2D	<input type="checkbox"/>
NOTE	...calibrate flow classes	2D	<input type="checkbox"/>
RENUMBER	RENUMBER Flowmap ASSIGNING 1 TO 1 THRU 2 ASSIGNING 2 TO 2 THRU 5 ASSIGNING 3 TO 5 THRU 5	2D	<input type="checkbox"/>
NOTE	...combine slope and flow classes into a 2-digit number- first digit indicates slope class (1= gentle, 2= moderate, 3= heavy)	2D	<input type="checkbox"/>
CALCULATE	(Slope_classes * 10) + Flow_classes	2D	<input type="checkbox"/>
NOTE	...calibrate the combined slope/flow map for erosion potential (surface material movement)- 1= little movement, 2= moderate, 3= heavy	2D	<input type="checkbox"/>
RENUMBER	RENUMBER SE_combo ASSIGNING 1 TO 11 ASSIGNING 1 TO 12 ASSIGNING 2 TO 13 ASSIGNING 3 TO 14	2D	<input type="checkbox"/>
NOTE	...end of command macro	2D	<input type="checkbox"/>



Press the **Map Analysis** button to pop-up the **Map Analysis** dialog box. Select **Script→ Open** then navigate to and select **PA\_Topic7\_Erosion.scr** file.



Resize and position the script window to the lower-left portion of the display window as shown.

Execute the script a line at a time by double-clicking on a command line, interpreting the dialog box information then submitting the command by pressing **OK**.

The first portion of the erosion model...

NOTE	...derive a slope map of the area- percent inclination at each map location
SLOPE	SLOPE Elevation Fitted FOR SlopeMap
NOTE	...calibrate slope classes
RENUMBER	RENUMBER SlopeMap ASSIGNING 1 TO 0 THRU 1 ASSIGNING 2 TO 1 THRU 2 ASSIGNING 3 TO 2 THRU 2
NOTE	...derive a map of surface flow- number of uphill locations passing surface flow through each map locations

...creates a map of terrain steepness (SlopeMap) then “calibrates” the steepness into three classes (1= Gentle, 2= Moderate, 3= Steep).

The next portion of the model...

NOTE	...derive a map of surface flow- number of uphill locations passing surface flow through each map locations
DRAIN	DRAIN Entire OVER Elevation Simply Steepest FOR Flowmap
NOTE	...calibrate flow classes
RENUMBER	RENUMBER Flowmap ASSIGNING 1 TO 1 THRU 2 ASSIGNING 2 TO 2 THRU 5 ASSIGNING 3 TO 5 THRU 5
NOTE	...combine slope and flow classes into a 2-digit number- first digit indicates slope class (1= gentle, 2= moderate, 3= heavy)

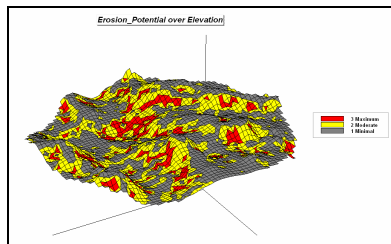
...creates a map of water confluence (Flowmap)  
then “calibrates” water flow into three classes  
(10= Light, 20= Moderate, 30= Heavy)

The final portion of the model...

NOTE ...combine slope and flow classes into a 2-digit number-- first digit indicates slope class (1= gentle, 2= moderate, ...  
CALCULATE (Slope\_classes \* 10) + Flow\_classes  
NOTE ...calibrate the combined slope/flow map for erosion potential (surface material movement)- 1= little movement, 2= ...  
RENUMBER RENUMBER SF\_combo ASSIGNING 1 TO 11 ASSIGNING 1 TO 12 ASSIGNING 2 TO 13 ASSIGNING 1 TO ...

...first combines the steepness and flow maps into a single erosion potential map to identify each map location by a two-digit code where the first number (tens digit) indicates the flow class and the second number (ones digit) indicates the steepness class. For example, 11= Light/Gentle (low erosion potential) and 33= Heavy/Steep (high erosion potential).

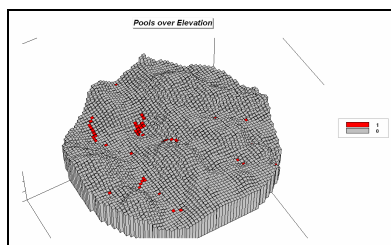
The erosion potential map then is interpreted into three classes (1= minimal, 2= moderate and 3= maximum) of relative erosion susceptibility.



Do the results align with common sense? Are the areas of maximum erosion susceptibility where you expected? Minimal susceptibility area where you expected?

Use the Renumber command to isolate the areas with high flows (>50 paths) and display the result draped on a 3-D Grid Display of the Elevation surface as shown below.

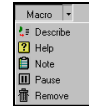
RENUMBER Flowmap ASSIGNING 0 TO 1 THRU 50  
ASSIGNING 1 TO 50 THRU 500 FOR Pools



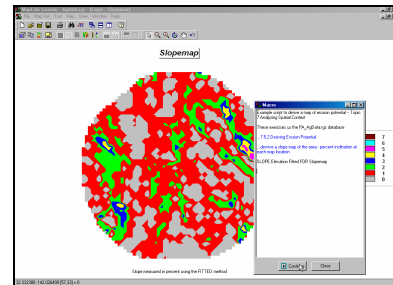
Use the Rotate display tool to view the plot from various perspectives. Do the

results align with common sense? Are the areas of the “pools” where you expected (low areas/depressions)? How might you use this information in understanding surface flows of applied materials? Or understanding organic material build-up?

Whenever you use the Map Analysis tools the commands are automatically saved in the sequence you entered them. Selecting **Script**→**Save As** and specifying a file name will save your work session.

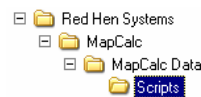


The **Macro** button provides editing capabilities including embedded notes and pauses.



Map Analysis→Script→Open→PA\_Topic7\_erosion.scr  
Script→Run Script...press Continue to advance

To execute a stored script, select **Map Analysis**→**Script**→**Open** and specify the file name of the script. Selecting **Script**→**Run Script** will automatically execute the command list. When a **Pause** is encountered you can interact with any of the display tools, such as the **Data Type** or **Shading Manager**. Press the **Continue** button to advance the script until the next pause.



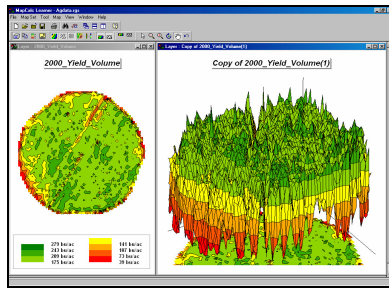
There are several scripts demonstrating general GIS modeling applications with the MapCalc evaluation materials. As time and interest permits you might review some of the applications in other fields, such as natural resources and geo-business.

### 7.5.3 Localized Yield Variability



Use the **View** tool to generate a copy of the **2000\_Yield\_Volume** map by selecting it and pressing the **Cone View** button.

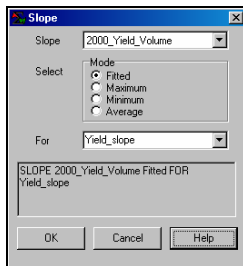
Create side-by-side 2-D and 3-D grid displays of the yield data as shown below.



Note that the yield surface has peaks and valleys similar to a terrain surface. The *Slope* command used in the previous exercise actually computes the 1<sup>st</sup> derivative of a surface—change in elevation per unit of space (grid cell). The slope value at any location indicates how rapidly the surface is changing at that location.

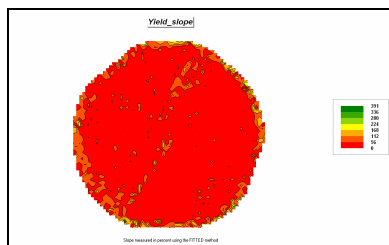
But what if you calculated the slope of an elevation surface? How would you interpret the change in yield per unit of space? What would a large slope value indicate?

Enter the following command to calculate a slope map of the **2000\_Yield\_Volume** data.



*SLOPE 2000\_Yield\_Volume*

*Fitted FOR Yield\_slope*



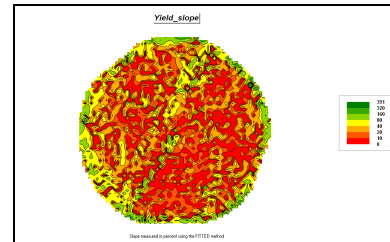
Range Display	Min	Max	Count	Area	% Gridded Area	Color	Lock
0-56	0	56	2635	151	80	Red	On
56-112	56	112	472	27.1	14	Orange	On
112-168	112	168	126	7.23	3.8	Yellow	On
168-224	168	224	39	2.24	1.2	Light Green	On
224-280	224	280	12	0.689	0.36	Green	On
280-336	280	336	4	0.23	0.12	Dark Green	On
336-392	336	392	1	0.0574	0.03	Very Dark Green	On

Right-click on the display and select the *Shading Manager*. Note that 80% of the map has slope values between 0 and 56 (red).

Range Display	Min	Max	Count	Area	% Gridded Area	Color	Lock
0-10	0	10	2635	151	80	Red	On
10-20	10	20	472	27.1	14	Orange	On
20-40	20	40	126	7.23	3.8	Yellow	On
40-80	40	80	39	2.24	1.2	Light Green	On
80-160	80	160	12	0.689	0.36	Green	On
160-320	160	320	4	0.23	0.12	Dark Green	On
320-640	320	640	1	0.0574	0.03	Very Dark Green	On

Create a more

useful display by selecting **User Defined Ranges** and entering 10, 20, 40, 80, 160, 320 in the **Min[<+]** column of the table. Press **OK** to display the map with the new progressive set of ranges.



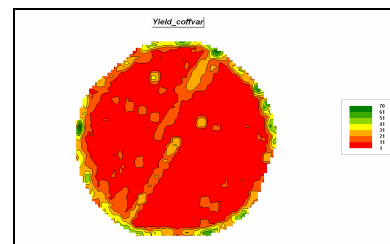
Note that the areas of rapidly changing yield values (large slopes shown in green tones) are predominantly along the field edges and the access road. The northeast portion of the field, however, also exhibits rapidly fluctuating yield.

Another map analysis operation for characterizing localized variation is *Scan*. This neighborhood command summarizes map values within a specified reach/vicinity of a location. For example, enter...

#### Map Analysis → Neighbors → Scan

*SCAN 2000\_Yield\_Volume CoffVar IGNORE 0.0 WITHIN 1 CIRCLE FOR Yield\_coffvar*

...to generate a map of the coefficient of variation ( $stdev/mean*100$ ) of the yield values within a 1-cell (50-feet) radius.



Higher values on this map locate areas with wildly fluctuating yield values. Note the similarity between the *Yield\_slope* and *Yield\_coffvar* maps. Both show the northeast portion of the field as having high localized variation in the data that is easily explained—expect high variation along field edge and access road, but not in the field interior.

Can you suggest how you might investigate if you suspect soil type differences? Hint: the *Composite* command might be useful.

You can exit the program by selecting **File → Exit** or by clicking on the “X” in the upper-right corner of the MapCalc program window. If you want to save your work, specify a new file name, such as *AgData\_Topic7\_exercises.rgs*. Each exercise set assumes you will start with the basic *AgData.rgs* data set and this database will become cluttered with exercise maps if you save your results to it each time.