Topic 1

Overview

1.1 Introduction

Geographic Information Systems (GIS) technology can be used to visualize and analyze spatial patterns and relationships within and among mapped data. Population dynamics, best management practices, sustainable forestry, and optimal harvesting plans are some examples of applications designed to improve decision making and ensure sound natural resources decisions.

While many of these application-specific procedures evolved independently, they share a common set of basic tools, techniques, approaches and concepts. In the early stage of development in the 1980s, efforts were narrowly-focused and incrementally evolved as the pieces of application puzzles fell into place. GIS innovators comprised a small group of natural resources researchers using complex hardware and software environments with access to very little pre-packed digital data.

In just a couple of decades, the situation has dramatically changed with modern computers on every desk having ready access to comprehensive data bases of digital maps—the technological conditions are in place. What remains, however, is an equivalent advance in the human-ware component generating a paradigm shift from non-spatial data analysis to spatial reasoning and problem solving. Understanding the new set of tools and how to apply them is complicated by the fact that most potential users have minimal exposure to quantitative analysis of spatial information.

Recognizing that "*maps are numbers first, pictures later*" is critical to the new mindset. Digital maps are radically different from their paper map counterparts. In a GIS map colorful patterns and symbols are replaced by organized sets of numbers that explicitly describe "where" as well as "what." Similarly, procedures for analyzing digital mapped data often are significantly different from manual map processing and traditional statistical analysis. This book is designed to help readers appreciate the similarities and differences between the approaches, understand basic map analysis procedures and identify important opportunities and limitations in their use.

1.2 Mapping versus Analysis

Vector-based desktop mapping is rapidly becoming a commonplace part of modern natural resources management. The close link between these systems and traditional database management programs has fueled the adoption. In many ways, "*a database is just picture waiting to happen.*" The direct link between attributes described in a database record and their spatial characterization is conceptually easy. Geo-query by clicking on a map to pop-up the attribute record or searching a database then plotting the selected records are extremely useful extensions of contemporary procedures. Increasing data availability and Internet access coupled with decreasing desktop mapping system costs and complexity make adoption of *spatial database* technology a practical reality.

Maps in their traditional form of point, lines and polygons identifying discrete spatial objects align with manual mapping concepts and experiences learned as early as girl and boy scouts. Grid-based maps, on the other hand, represent a different paradigm of geographic space that opens entirely new ways to address complex issues. Whereas traditional vector maps emphasize "*precise placement* of physical features," grid maps seek to "*statistically characterize* continuous geographic space in both real and cognitive terms." The tools for mapping of database attributes are extended to analysis of spatial relationships. This book focuses on the basic concepts, considerations and procedures in grid-based data handling and analysis operations as they apply to natural resources applications. Two broad capabilities are discussed—*spatial statistics* and *map analysis*.

In turn, *spatial statistics* can be grouped into two camps—surface modeling and spatial data mining. *Surface modeling* involves the translation of discrete point data into a continuous surface that represents the geographic distribution of the data. Traditional non-spatial statistics involves an analogous process when a numerical distribution (e.g., standard normal curve) is used to generalize the central tendency of a data set. The derived average and standard deviation reflects the typical response and provides a measure of how typical it is. This characterization seeks to explain data variation in terms of the numerical distribution of measurements without any reference to the data's geographic distribution and patterns.

In fact, an underlying assumption in most traditional statistical analyses is that the data is randomly distributed in space. If the data exhibits a geographic pattern (spatial autocorrelation) many of the non-spatial analysis techniques are less valid. Spatial statistics, on the other hand, utilizes geographic patterns in the data to further explain the variation in a set of sample data.

There are numerous techniques for characterizing the spatial distribution inherent in a data set but they can be characterized by three basic approaches:
- *Point Density* mapping that aggregates the number of points within a specified distance (number per acre),
- *Spatial Interpolation* that weight-averages measurements within a localized area (e.g., kriging), and
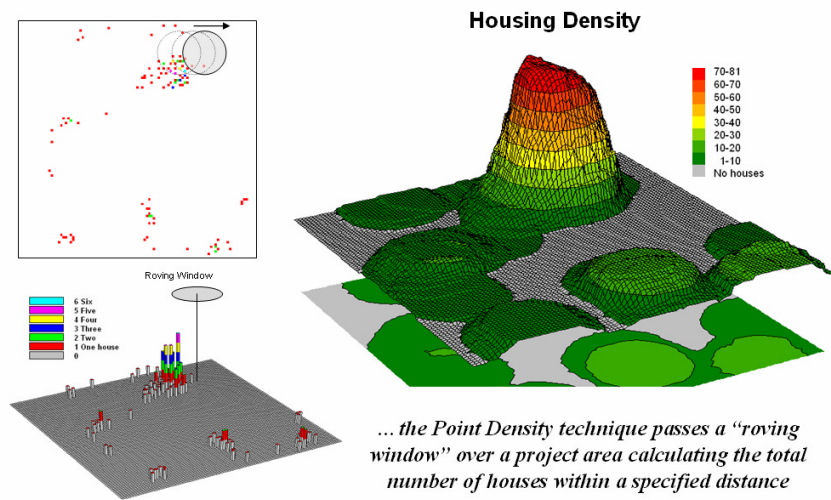- *Map Generalization* that fits a functional form to the entire data set (e.g., polynomial surface fitting).

Figure 1-1. Calculating the total number of houses within a specified distance of each map location generates a housing density surface.

For example, consider figure 1-1 showing a point density map derived from a map identifying housing locations. The project area is divided into an analysis frame of 30-foot grid cells (100c x 100r = 10,000 cells). The number of houses for each grid space is identified in left portion of the figure (colored dots in the 2D map and "spikes" in the 3D map).

A neighborhood summary operation is used to pass a "roving window" over the project area calculating the total number of houses within a quarter-mile of each map location. The result is a continuous map surface indicating the relative density of houses—peaks where there is a lot of nearby houses and valleys where there are few or none. In essence, the map surface quantifies what your eye sees in the spiked map—some areas with lots of house and others with very few.

While surface modeling is used to derive continuous surfaces, *spatial data mining* seeks to uncover numerical relationships within and among mapped data. Some of the techniques include coincidence

summary, proximal alignment, statistical tests, percent difference, surface configuration, level-slicing, and clustering that is used in comparing maps and assessing similarities in data patterns.

Another group of spatial data mining techniques focuses on developing predictive models. For example, one of the earliest uses of predictive modeling was in extending a test market project for a phone company (figure 1-2). Customers' address were used to "geo-code" map coordinates for sales of a new product enabling distinctly different rings to be assigned to a single phone line—one for the kids and one for the parents. Like pushpins on a map, the pattern of sales throughout the test market area emerged with some areas doing very well, while other areas sales were few and far between.

The demographic data for the city was analyzed to calculate a prediction equation between product sales and census block data. The prediction equation derived from the test market sales was applied to another city by evaluating exiting demographics to "solve the equation" for a predicted sales map. In turn the predicted map was combined with a wire-exchange map to identify switching facilities that required upgrading before release of the product in the new city.
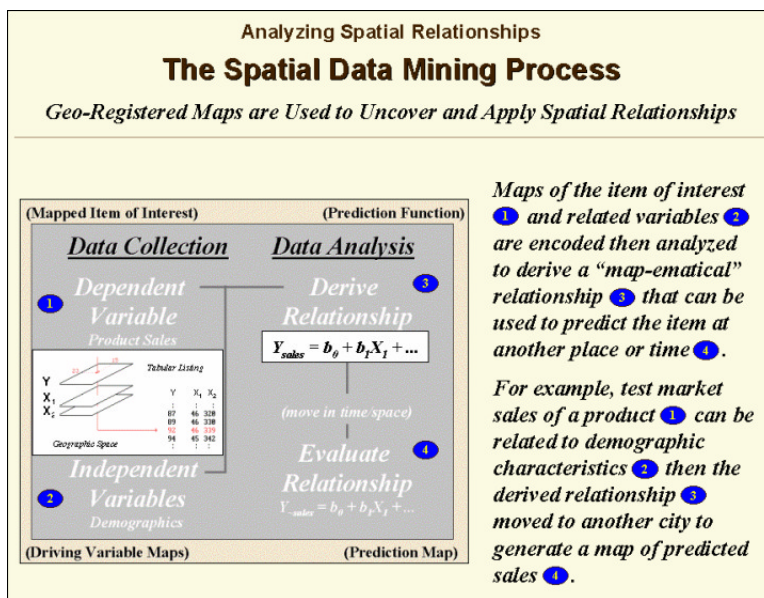
Figure 1-2. Spatial Data Mining techniques can be used to derive predictive models of the relationships among mapped data.

While predictive modeling is a major part of geo-business, crime mapping and precision agriculture applications, it is not frequently used in natural resources. Spatial statistics presents a wealth of opportunities for translating techniques into natural resources contexts. The existing wealth of current natural resources applications has had an entirely different focus emphasizing map analysis.

Whereas spatial data mining responds to "numerical" relationships in mapped data, ***map analysis*** investigates the "contextual" relationships. Tools such as slope/aspect, buffers, effective proximity, optimal path, visual exposure and shape analysis, fall into this class of spatial operators. Rather than statistical analysis of mapped data, these techniques examine geographic patterns, vicinity characteristics and connectivity among features.

1.3 Suitability Modeling

One of the most frequently used map analysis techniques is *Suitability Modeling*. These applications seek to map the relative appropriateness of map locations for particular uses. For example, a map of the best locations for a campground might be modeled by preferences for being on gentle slopes, near roads, near water, good views of water and a southerly aspect.

These spatial criteria can be organized into a flowchart of processing (see figure 1-3) where boxes identify maps and lines identify map analysis operations. Note that the rows of the flowchart identify decision criteria with boxes representing maps and lines representing map analysis operations. For example, the top row evaluates the preference to locate the campground on gentle slopes. The first step calcualtes a slope map from the base map of elevation by entering the command—

   SLOPE Elevation Fitted FOR Slopemap

The derived slope values are then reclassified to identify locations of acceptable slopes by assigning 1 to slopes from 0 to 20 percent—

   RENUMBER Slopemap ASSIGNING 1 TO 0 THRU 20 ASSIGNING 0 TO 20 THRU 1000
      FOR OK_slope

—and assigning 0 to unacceptably steep slopes that are greater than 20 percent.

In a similar manner, the other criteria are evaluated and represented by maps with a value of 1 assigned to acceptable areas (white) and 0 assigned to unacceptable areas (dark grey). The individual preference maps are combined by entering the command—

   CALCULATE OK_slope * OK_road * OK_water * OK_view * OK_aspect FOR Campground_suitability
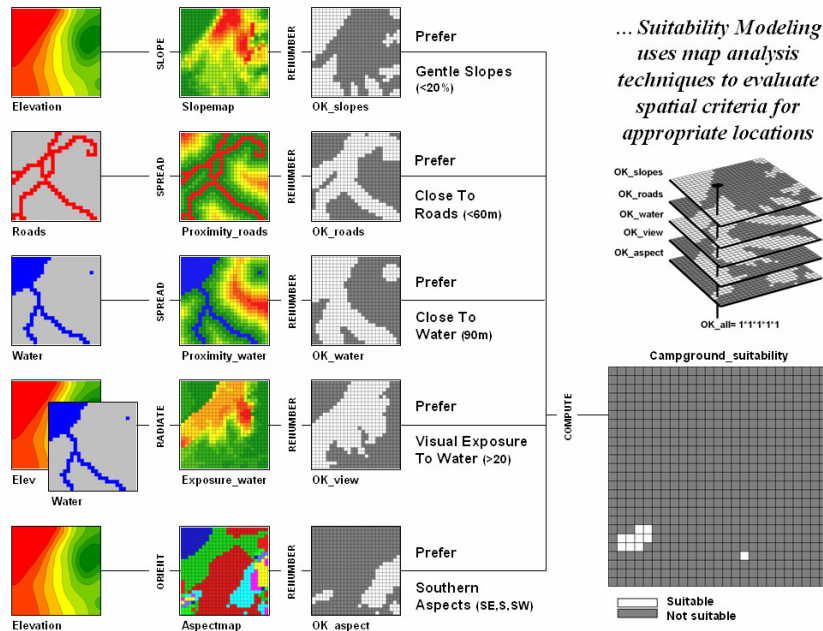
Figure 1-3. Map Analysis techniques can be used to identify suitable places for a management activity.

The process is analogous to manually overlaying maps on a light-table popularized by Ian McHarg in his 1960s book "Design with Nature." The process involves drafting a series of maps reflecting decision criteria on transparent sheets by interpreting and tracing information from existing paper maps. For example, steep areas where contour lines are close together on an underlying topographic map are covered with an opaque color (unacceptable) while gentle sloped areas are left clear (acceptable). In a similar fashion transparent overlays are drafted for each of the other criteria. The stack of maps is viewed on a light-table and areas that remain clear identify locations where the activity is acceptable.

The map analysis procedure depicted in figure 1-3 simply substitutes values of 1 and 0 for clear and opaque colors. The multiplication of the digital preference maps is analogous to stacking the map overlays on a light-table. A location that computes to 1 (1*1*1*1*1= 1) corresponds to McHarg's clear areas indicating acceptable. Any numeric pattern with the value 0 will result in a product of 0 indicating an unacceptable area.

While some map analysis techniques are rooted in manual map processing, most are departures from traditional procedures. For example, the calculation of slope is much more exacting than ocular estimates of contour line spacing. And the calculation of visual exposure to water presents a completely new and useful concept in natural resources planning.

Other procedures, such as optimal path routing, landscape fragmentation indices and variable-width buffers, offer a valuable new toolbox of analytical capabilities. This book is designed to introduce readers to the new tools and gain insight into there effective use.

1.4 The Case Studies

The case studies in this book begin with a series of techniques used to visualize and summarize mapped data and ends with several techniques that develop maps that can be used to guide management decisions. The focus is on methodology (the map analysis "toolkit") and not on the scientific results or generalizations about the complex biological, physical and social factors driving natural resource decisions in a particular area. These intricate relationships are left to readers to scrutinize, interpret and put into context within their own natural resources environment.

The objective of the series of exercises is to demonstrate the analysis procedures on a consistent set of data. The intent is to build a progression of case studies that illustrates the wealth of emerging analytical capabilities that are available.

One might argue that "the technical cart is in front of the scientific horse." In many instances that appears true. We can collect data and view the numbers as maps or summary statistics, but struggle to make sense of it all. In part, the disconnection isn't technology versus science but the predicament of "the chicken or the egg" coming first.

We have a radically different set of analysis tools than those available just a decade ago. Concurrently, we have a growing amount of geo-registered data, such as demographics, housing prices, zoning and product sales. The computer industry is turning out software and machines that are more powerful, yet costing less and less and easier to use. Agriculture equipment companies are developing instruments and implements that respond to "on the go" movements throughout a field. In short, the pieces are coming together.

The next decade in natural resources will focus on making sense of the site-specific relationships we measure. The technology is here (an analytical toolbox) to bridge the gap between maps and decisions. Its widespread application will be determined by how effectively map analysis techniques are applied.

Table 1-1 lists the topics that will be covered in the case study series. Many of the topics are discussed in the "Beyond Mapping" columns appearing in *GeoWorld* (Adams Business Media, 1996 to the present) and are compiled online at—

http://www.innovativegis.com/basis/MapAnalysis/

This book is organized into thirteen topics and two appendices that lead reader from an understanding of the fundamental nature of mapped data through a series of basic procedures used in deriving, analyzing and applying spatial information. A case study approach is used with each topic area describing the application of a set of related analysis techniques. The discussion is followed by a series of hands-on exercises providing practical experience in applying the techniques. The exercises include step-by-step instructions that are thoroughly annotated.

A consistent data set is used to demonstrate several of the emerging data analysis capabilities. Hopefully, the examples will stimulate innovative thinking and new techniques as much as it outlines how existing map analysis procedures can be applied. All of the processing is done within a standard personal computer environment using software provided on the companion CD.

Table 1-1. Book Topics
Overview
Maps as Data
Reclassifying and Overlaying Maps
Mapping Visual Exposure
Creating Variable-Width Buffers
Applying Effective Distance and Connectivity
Identifying Optimal Routes
Characterizing Terrain Features
Analyzing Landscape Patterns
GIS Modeling Procedures
Surface Modeling
Spatial Data Mining
Predictive Modeling

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1.5 Exercises

The companion CD contains the MapCalc Learner software used in the hands-on exercises. The following exercises provide instructions for installing the software and introduce some of software's basic capabilities. To begin, insert the companion CD into your computer and the main menu will automatically appear.

If this main menu doesn't appear select "Start"à "Run"à "Startup.bat" from the Windows Task Bar.

1.5.1 Examples of Analysis Capabilities
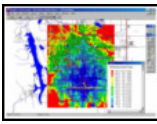
 From the main menu select **Example Applications** à **Short Video Demos** à **MapCalc Basics** à and choose **Open** to launch a short video on basic use of the software including interactive 2D/3D plotting, display types, display navigation, accessing maps for display and graphical overlay.
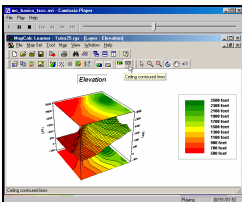

"MapCalc Basics" instructional video

You can replay the video by clicking the "right arrow" button (*Play*) in the upper left portion of the window. Close the video by clicking the "X" button in the upper right portion of the window.

From the "Short Video Demos" menu, select **Calculating Slope and Surface Flow** à **Open** to launch another short video demonstrating use of some basic map analysis operations. The application describes calculating slope and flow maps using an elevation surface.
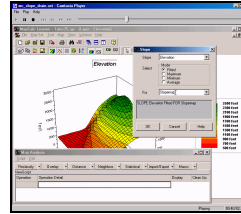
"Calculating Slope and Surface Flow" instructional video

From the Video Demo menu, press the *Back* button in the top-left portion of your browser window to return to the *Applying MapCalc* menu (see below).
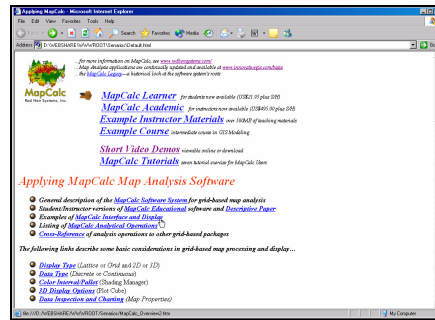

Main Menu for annotated example applications

There are numerous annotated examples of MapCalc operation and applications. For example, the *Mapping Wildfire Response* scenario determines the on- and off-road response-time based on varying terrain and land cover conditions.
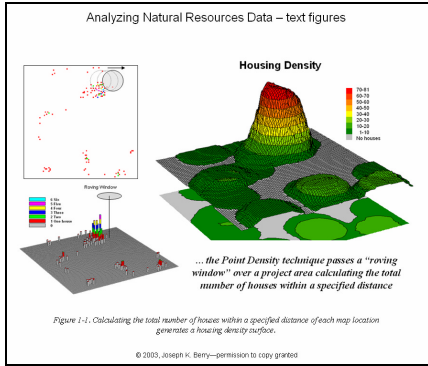
As time and interest permits, click on other links of interest to activate additional examples. Examples using the *Tutor25.rgs, Island.rgs* and *BigHorn.rgs* databases demonstrate numerous natural resources applications.

1.5.2 Viewing Full Color Figures
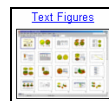
 Select the **Text Figures** link to access a full color PowerPoint slide set of all of the workbook figures. Choose **Open** to view the figures provided PowerPoint is installed on your

system. Choose **Save** to save the slide set to your hard drive.

Figure 1-1. Calculating the total number of houses within a specified distance of each map location generates a housing density surface.

Color display of maps is critical to visual analysis. You are encouraged to refer to the corresponding full color slides as you read the various topics in this book.

Permission to copy and use the slides in presentations and papers is granted. Reference slides as "Figure *x-xx* from course materials supporting GEOG 3110 Introduction to GIS Modeling, J.K. Berry, University of Denver, 2004."

1.5.3 Installing Companion Software

Re-access the main menu and close all other open programs.

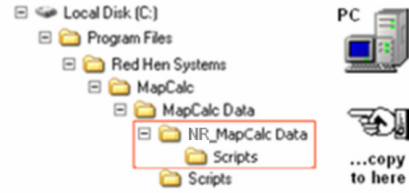*__Step 1__: install programs*

In turn, install the three companion software programs by clicking on their respective links. Click on the **Open** button then follow the on-screen instructions using the default specifications (recommended).

__Step 2__: copy special data

Install the data and support materials for *MapCalc* by copying the **\NR_MapCalc Data** folder on the CD to the—
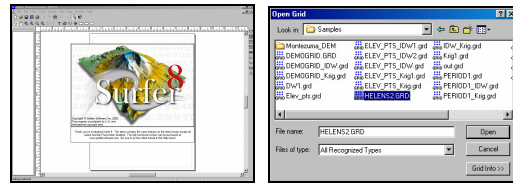

...\MapCalc Data folder where the *MapCalc* program was installed.

__Step 3__: test installation

Once the programs and data are successfully installed, test the systems as described below.

·   To test the **Surfer** installation, click on **Start**à **Programs**à **Golden Software Surfer 8**à **Surfer 8**.

From Surfer's main menu, select **Map**à **Surface** and specify **…\Samples\Helens2.grd** as the grid layer to open. Press the **Open** button to plot the data.
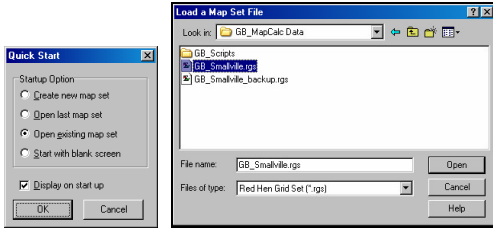
If Surfer has been properly installed a three-dimensional plot of Mt. St. Helens will appear (see below).
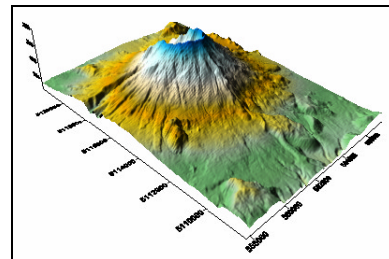
You can exit the program by selecting **File** à **Exit** or by clicking on the "**X**" in the upper-right corner of the Surfer program window. Do not save the plot file.
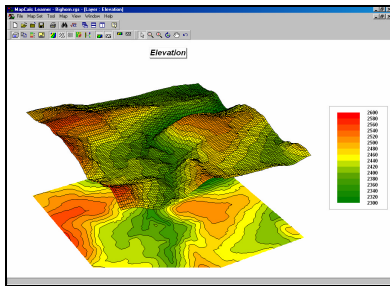
·   To test the **MapCalc** installation, click on **Start**à **Programs**à **MapCalc Learner**à **MapCalc Learner**.

Crtl/Shift/P à à

Select **Open existing map set** and browse to the …**NR_MapCalc Data** folder containing the workbook data and support materials. Specify **Bighorn.rgs** to access one of the data bases used in this case studies.

If MapCalc has been properly installed a three-dimensional plot of elevation will appear (see below).

You can exit the program by selecting **File** à **Exit** or by clicking on the "**X**" in the upper-right corner of the MapCalc program window. Do not save any of your changes to the baseline *Bighorn.rgs* database.

- To test the **SnagIt** installation, click on **Start**à **Programs**à **SnagIt 6**à **SnagIt 6**.

  If this banner page appears, SnagIt has been successfully installed. Simultaneously press the keys **Crtl/Shift/P** to activate the SnagIt screen capture utility. Highlight or drag a portion of the screen then click the right button to capture and press the "**Finish**" button to save.
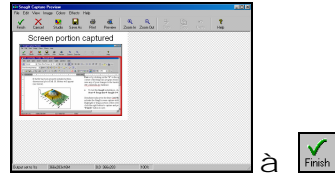
You can exit the program by selecting **File** à **Exit** or by clicking on the "**X**" in the upper-right corner of the SnagIt program window.

<u>Note</u>: Microsoft Windows has a basic screen capture capability. Pressing the Print Screen button on the key board places a graphic of the entire current display on the "clipboard" that can be pasted into other programs.

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