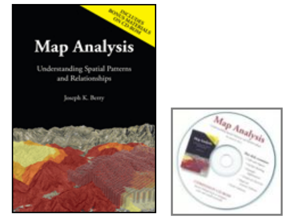
Beyond Mapping III

Topic 4 – Calculating Effective Distance



Map Analysis **book/CD**

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Extending GIS Procedures with Variable-Width Buffers

(GeoWorld, November 2000)

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GIS technology has made great inroads over the past decade. It has been propelled from an emerging expertise delivered by a cadre of specialists to mass-marketed applications that are accessed by end-users in a wide array of disciplines. However in many instances, these applications are more extensions of computer graphics and database technology than they are extensions of geographic principles and spatial reasoning.

In part, the graphical and inventory aspects of traditional maps have dominated the digital translation of spatial information. Users can enter an address and instantly view a map of that location and print a set of driving instructions. One can publish a couple of hundred scanned topographic sheets on a CD that can be panned and zoomed at several scales. Images and even streaming video can be linked to their precise locations on a map and accessed over the web simply by clicking on an embedded symbol.

The digital expression of familiar mapping procedures represented the first wave in recasting GIS technology. The extension of these procedures to new techniques and methods of spatial analysis forms a second wave. While the early focus was on automation of a solution to a "compelling need," the second wave requires communicating entirely new ways of doing things. Survival in the next round of the GIS evolution will focus more on innovation and education than on technique translation and automation.

A good example of infusing extended GIS procedures is in generating buffers. Everyone relates to the concept of "within <fill in the distance>" of a shopping center, missile target, stream, neighborhood, or critical habitat area. The concept invokes a circle or concentric ring about a map feature and has a rich heritage in manual map processing. In fact, a simple buffer represents a "compelling need" induced by environmental statute for many land planners and managers. For the rest of us, it represents a potential opportunity to change how we perceive spatial processing.

Most folks immediately recognize the shortcomings of a simple buffer. Common sense tells us that while delineating a single "as-the-crow-flies" distance under all possible intervening conditions might meet the letter of the law, it often violates reality. The concept of variable-width buffers that match reality has been with us for years—what is missing is a traditional mindset and experience with a tool. What is needed for second wave applications is education that fosters understanding and confidence in the extended procedures.

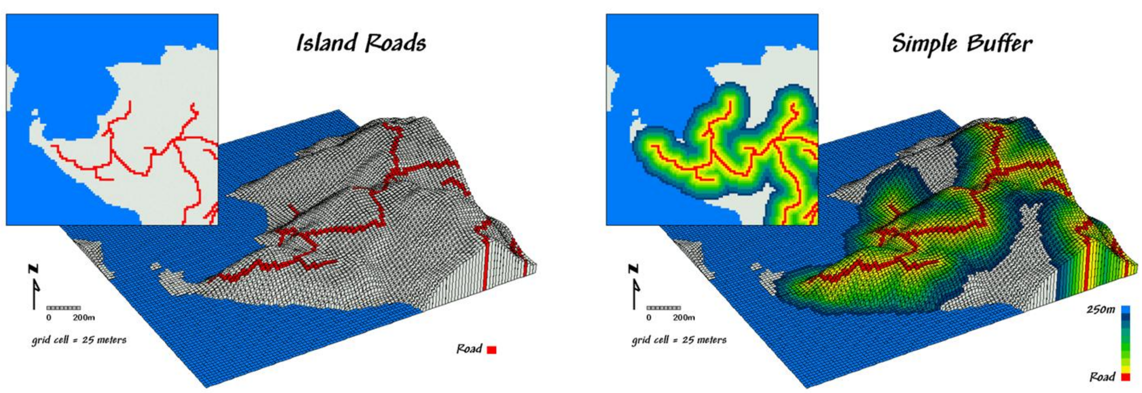

Figure 1. A Simple Proximity Buffer identifies the distance to roads throughout the buffered area. Note that the buffer extends into the ocean—an inappropriate "reach" for terrestrial applications.

Consider the road network and its 250-meter ***Simple Proximity Buffer*** as depicted in figure 1. In most desktop mapping systems a "Buffer Tool" is used to automatically inscribe a line at a given distance from a complex feature. The dark blue edge of the buffer in the figure identifies this maximum reach. However, the color progression indicates the relative proximity within the buffer—from yellow (close) to dark blue (far). While most folks have little experience with a simple proximity buffer, they immediately relate to the concept and value of the added information.

Also they immediately see some of its limitations. Notice how the consistent reach causes the buffer to extend into unintended areas—the ocean in this case. The "geographic slop" is more than graphically troublesome; it can skew statistics and misrepresent spatial relationships for terrestrial applications.

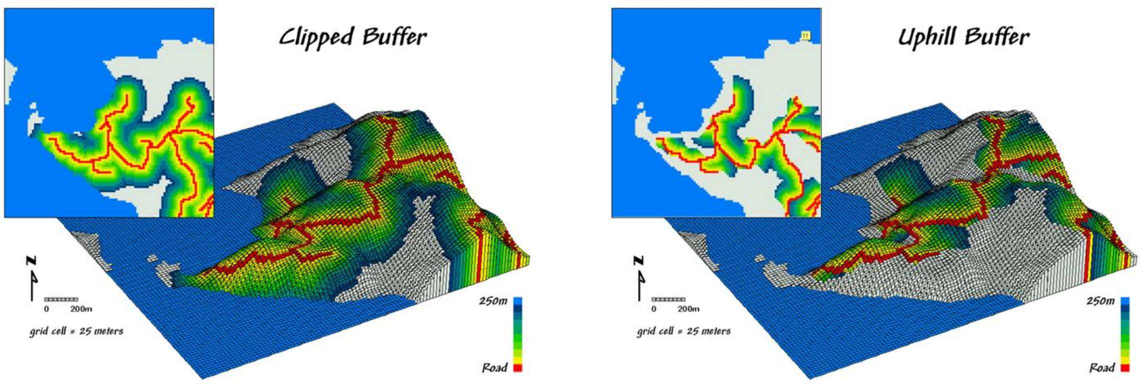

Figure 2. The figure on the left clips the simple buffer to represent only land areas. The figure on the right uses the elevation surface to identify only areas that are uphill from the roads.

The left side of figure 2 shows a ***Clipped Buffer***, the first conceptual step toward variable-width buffers. Some GIS systems calculate a simple buffer then simply mask the unwanted areas. Other systems introduce a masking map during processing that prohibits calculations within unwanted areas. The latter approach is by far the best as it paves the way for considering other geographic factors that affect the generation of realistic buffers.

For example, consider the ***Uphill Buffer*** maps on the right side of figure 2. In this instance the measurement of proximity for the buffered area was forced to extend only "uphill" from the roads as defined on a guiding surface (a short conceptual step from a masking map). The results when draped over the elevation surface confirm that only uphill locations are identified. By simply specifying "downhill" only those locations that are below the roads (and not within in the ocean mask) would be identified.

The division of a simple buffer into its uphill and downhill components can be important. A road engineer sees different land slippage considerations in the two areas. An environmental scientist concentrates on the downhill portion for flows of oil and other chemicals from the road. In fact in most applications consideration of the characteristics and conditions within a buffer are at least as important as the outline of its extent.

The ability to establish proximity-based buffers that react to geographic conditions isn't part of our paper map legacy. However, the concept is ingrained in practical experience. As subsequent columns in this mini-series will show, the ability to identify up/downwind buffers, noise attenuation buffers, customer travel-time buffers and other effective proximity buffers that respond to geographic conditions are no longer beyond our reach. The tools are at hand (and actually have been for quite some time). What waits is a second wave of innovative applications that take advantage of the new tools and instill their commonplace acceptance.

Create Effective Distance Buffers to Improve Map Accuracy

(GeoWorld, January 2001)

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One of the most fundamental operations in GIS is the "buffer." It enables one to view the immediate neighborhood surrounding a map feature and with a bit more processing identify and summarize the neighboring conditions. In most applications, the "reach" of the buffer is specified and a concentric line at the given distance is drawn about an indicated point, line or area feature. In traditional buffering all of the locations within the buffer are thought to be the same—merely "within the buffered area."

Figure 1, on the other hand, shows some of the extensions to traditional buffering that were discussed in the past couple of columns. Inset *a)* characterizes the relative proximity of all locations within a road buffer of 250 meters. Inset *b)* clips the road buffer for infeasible areas, such as open water. A buffer identifying just the uphill areas from the road is shown in inset *c)*. Insets *d)* and *e)* characterize the locations within 250 meters that can be seen from the road network (*Viewshed*) and their relative amount of visual exposure (*Expose*).

Inset *f)* shows the proximity to the road for areas within the viewshed buffer. This information can be useful in determining visual impact—locations that are seen a lot and are near roads equate to high visual impact. Similarly, noise dissipation can be coarsely modeled as inversely related to line-of-sight distance—it's fairly quiet at locations that are relatively near the road but on the other side of a ridge (outside the line-of-sight buffer).

The previous discussions should have you rethinking the utility of scribing lines that are "everywhere-the-same" in characterizing the influences about a map feature. In the real world, spatial context is rarely as simple as implied by the lines of a traditional buffer.

For example, consider hiking in mountainous terrain. In gentle terrain you move along at a brisk pace. But as the terrain becomes steeper, progress slows until eventually there are slopes that repels most hikers (no pun intended). It is common sense that steep intervening conditions can make locations "effectively" farther away. Conversely, gentle intervening slopes make locations much more accessible.

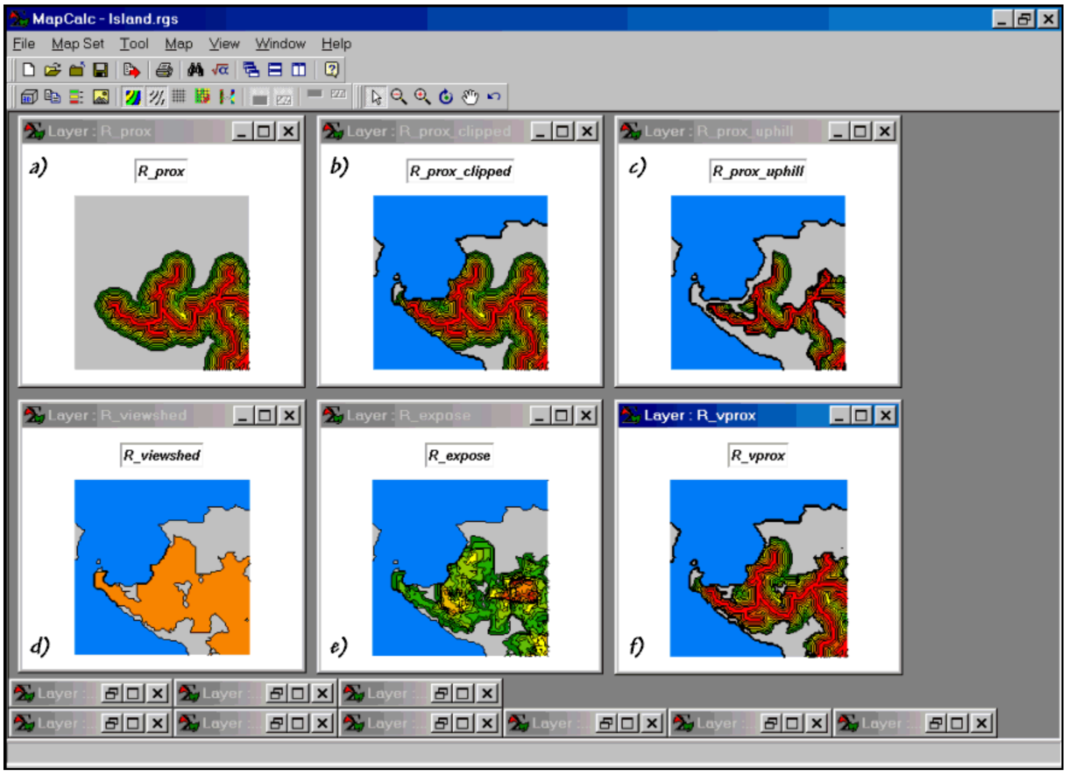

Figure 1. Examples of Variable-Width and Line-of-Sight Buffers.

The effect of slope on defining a buffer's reach is developed in Figure 2. The top left inset is a map of the slope conditions from 0 to 100 percent. The *Hiking_Friction* map calibrates the slopes in terms of the relative ease of foot-travel— 0-5% Easy, 5-10% Moderate, 10-20% Hard, 20-40% Difficult, and >40% a no-go situation.

It is important to note that the value 1 is assigned to the easiest conditions to cross and all other slope conditions are assigned a value indicating increased difficulty— 2= twice as hard, 5= five times as hard, 10= ten times as hard and –2 for inaccessible no-go areas.

Calibration of these values relate to the relative "cost" of traversing a grid cell and in this instance it was assumed to take 15 seconds to cross the easiest 25 meter cell. A moderate cell, on the other hand, is twice as difficult and takes 30 seconds to cross; a hard cell takes 75 seconds (1.25 minutes); and a difficult cell takes 250 seconds (4.17 minutes). An effective-distance operation is used that extends and contacts the width of the buffer considering the intervening conditions as calibrated on the friction map (*Hiking_Buffer* inset in figure 2).

In this instance, an effective buffer reach of 50 cells was used. If the road were surrounded completely by gentle slopes, the buffer would extend a consistent 50 cells from all locations and have the appearance of a traditional buffer. However, as steeper areas are encountered the geographic reach is shortened. In fact the portion of the road in the lower right of the map is surrounded by "no-go" conditions and the buffer is truncated at the edge of the road.

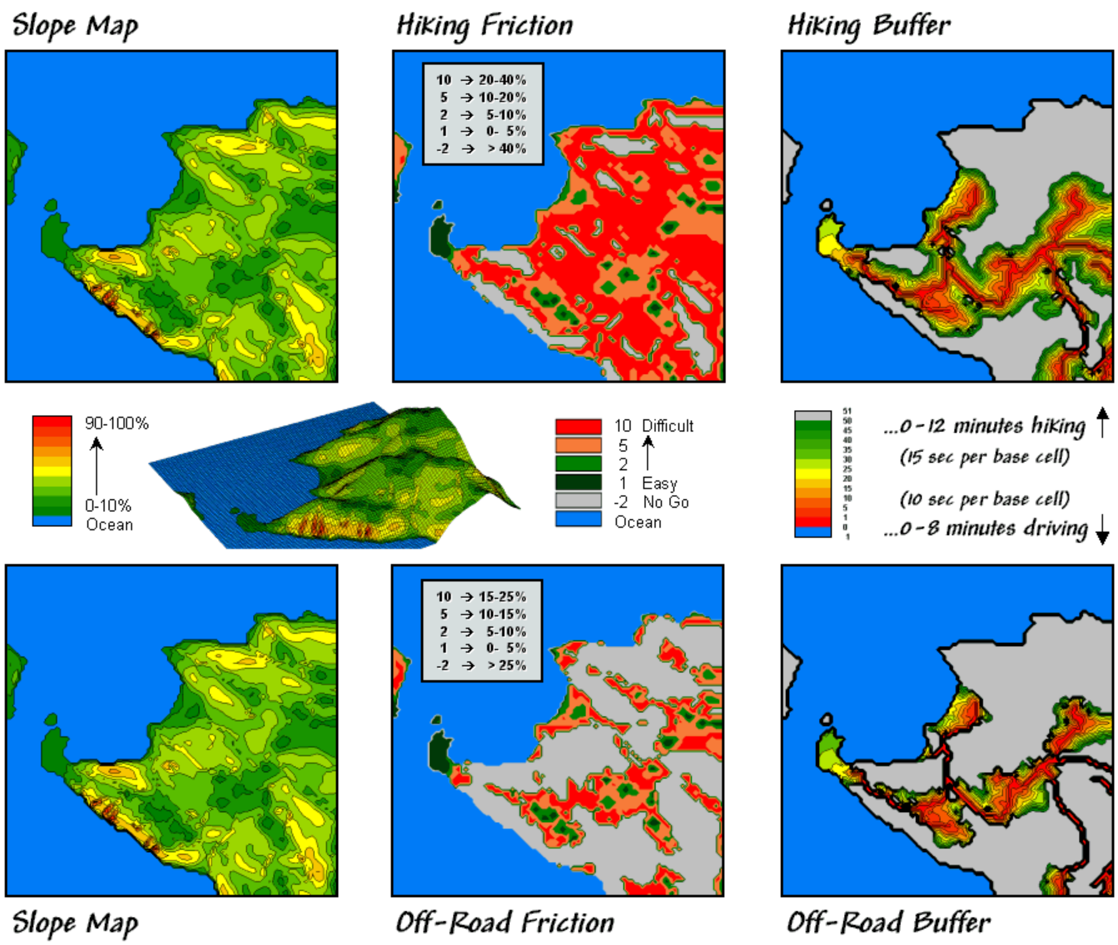

Figure 2. Development of Effective-Distance Buffers for Hiking and off-road travel.

The lower set of maps in figure 2 repeats the analysis to create an effective-distance buffer assuming vehicular off-road travel. The slope map was calibrated for off-road travel assuming an 10 second base friction for the gentle slopes (0-5%); 20 seconds for 5-10%; 50 seconds for 10-15%; 100 seconds (1.7 minutes) for 15-25%; and >25% a no-go situation. Note the extensive area of inaccessible regions identified in the *Off-Road_Friction* map giving the buffer a spindly look.

Now compare the hiking and off-road buffers based on effective-distance. A significantly larger portion of the *Off-Road_Buffer* is classified as inaccessible. An effective reach of 50 cells is used in both cases, but the calibration generates a 0 to 12 minute buffer for hiking and a 0 to 8 minute buffer for an off-road vehicle. In both instances, the effective buffers are radically different from that of a traditional fixed-width buffer and provide considerable more information about relative movement within the buffered area.

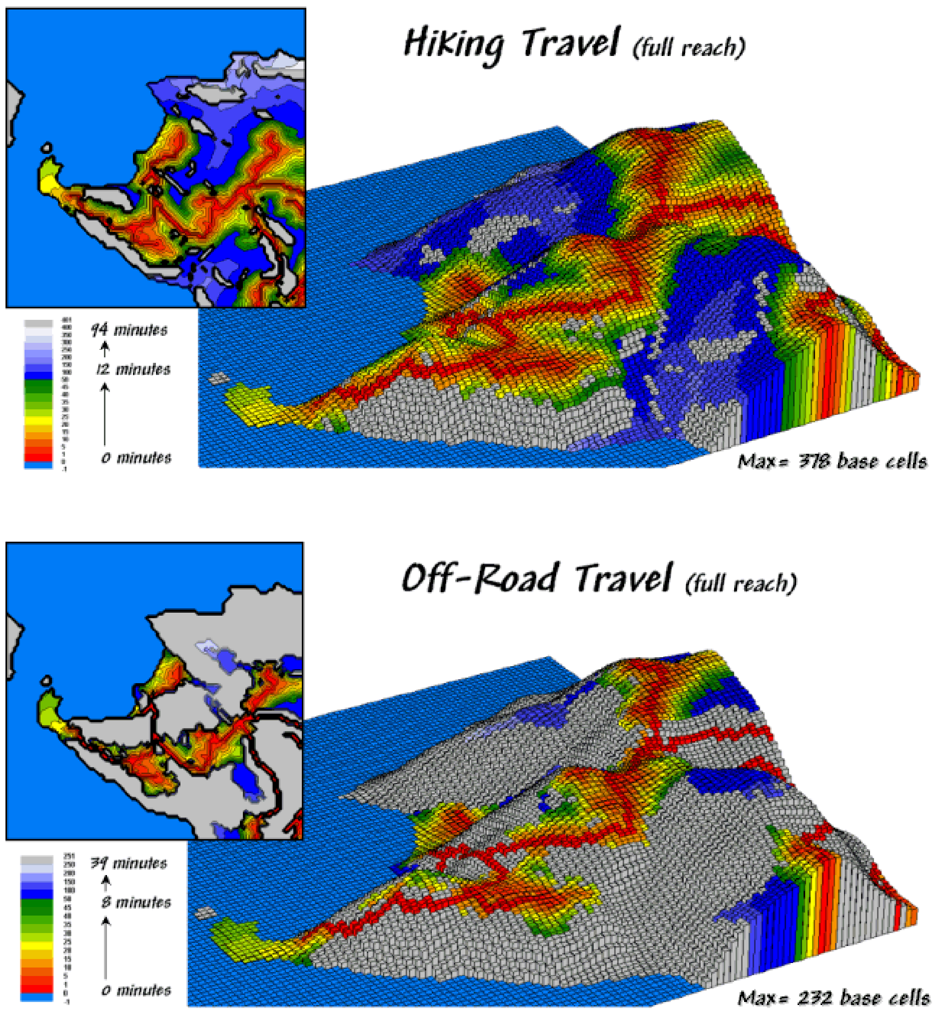

Figure 3. Comprehensive Travel-Time Maps for Hiking and Off-Road Movement.

Figure 3 literally extends the processing a bit farther by increasing the reach to encompass all accessible areas by hiking or off-road travel. The blue tones on each map identify incrementally larger reaches beyond the buffers shown in figure 2. Note that the areas reached by off-road travel are significantly less than those reached by hiking.

Also note the extended reach shown for the area in the lower right portion of project. The off-road travel map extends along a relatively gentle ridge but stops abruptly as the slopes exceed 25%. The hiking travel map, on the other hand, extends along the ridge and clear to the ocean. The gray tones indicate areas that are beyond reach (inaccessible) and can occur as pockets. The farthest location for a hiker is 94 minutes (378 effective cells) and for a off-road vehicle, is 39 minutes (232 effective cells).

One's first encounter with variable-width buffers might seem a bit uncomfortable since we can't create them with a ruler, but the concept aligns with common sense. A traditional buffer makes the broad assumption that the reach is everywhere the same. The different types of variable-width buffers reject this assumption and attempt to characterize the intervening conditions and their affects on the buffer's reach.

Of course the accuracy of the new buffers depends on the exactness of the ancillary data and the algorithms underlying the enabling map analysis operations. However, in most applications the inherent inaccuracy of the underlying assumption of traditional buffers far outweighs these concerns—a simple buffer is most often simply wrong.

Measuring Distance Is Neither Here nor There

(GeoWorld, April 2005)

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Measuring distance is one of the most basic map analysis techniques. Historically, ***distance*** is defined as *the shortest straight-line between two points*. While this three-part definition is both easily conceptualized and implemented with a ruler, it is frequently insufficient for decision-making. A straight-line route might indicate the distance "as the crow flies," but offer little information for the walking crow or other flightless creature. It is equally important to most travelers to have the measurement of distance expressed in more relevant terms, such as time or cost.

The limitation of a map analysis approach is not so much in the concept of distance measurement, but in its implementation. Any measurement system requires two components— a standard *unit* and a *procedure* for measurement. Using a ruler, the "unit" is the smallest hatching along its edge and the "procedure" is the line implied by aligning the straightedge. In effect, the ruler represents just one row of a grid implied to cover the entire map. You just position the grid such that it aligns with the two points you want measured and count the squares (top portion of figure 1). To measure another distance you merely realign the implied grid and count again.

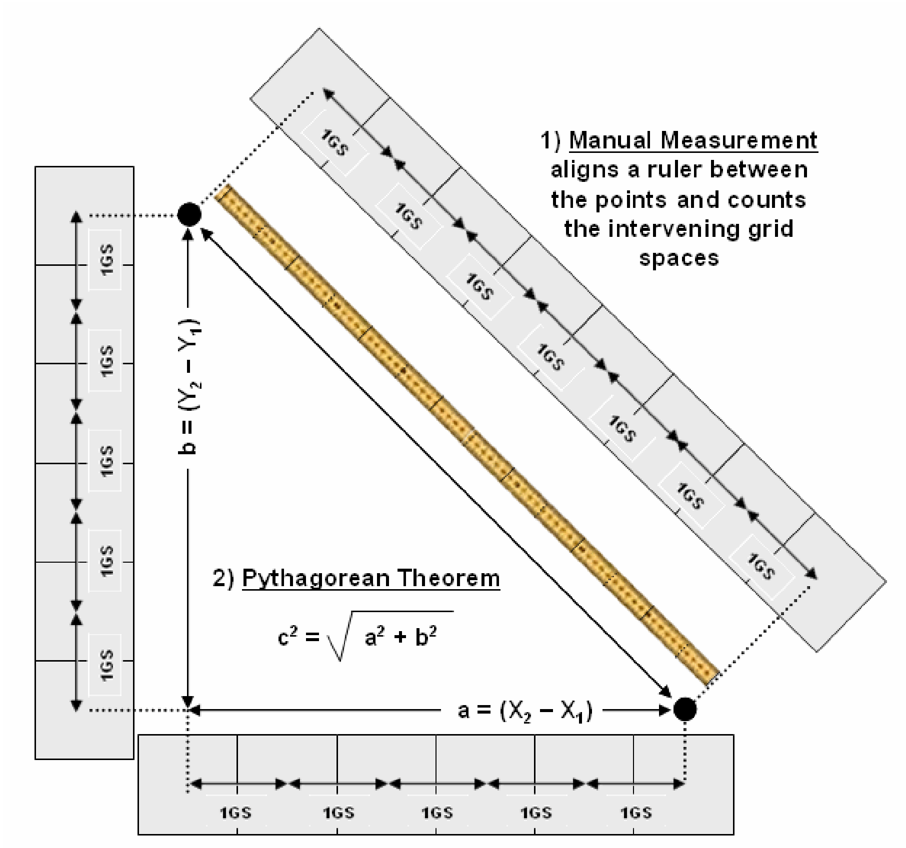

Figure 1. Both Manual Measurement and the Pythagorean Theorem use grid spaces as the fundamental units for determining the distance between two points.

In a GIS (and grade school geometry) the grid is a fixed reference and distance is calculated as the hypotenuse of a right triangle formed by the grid's rows and columns (bottom portion of figure 1). Yet, this mathematical procedure is often too limited in both its computer implementation and information content.

Proximity establishes the distance to all locations surrounding a point— *the set of* <u>*shortest straight-lines*</u> *among* <u>*groups of points*</u>. Rather than sequentially computing the distance between pairs of locations, concentric equidistance zones are established around a location or set of locations (figure 2). This procedure is similar to the wave pattern generated when a rock is thrown into a still pond. Each ring indicates one “unit farther away”— increasing distance as the wave moves away. Another way to conceptualize the process is nailing one end of a ruler at a point and spinning it around. The result is a series of “data zones” emanating from a location and aligning with the ruler’s tic marks.

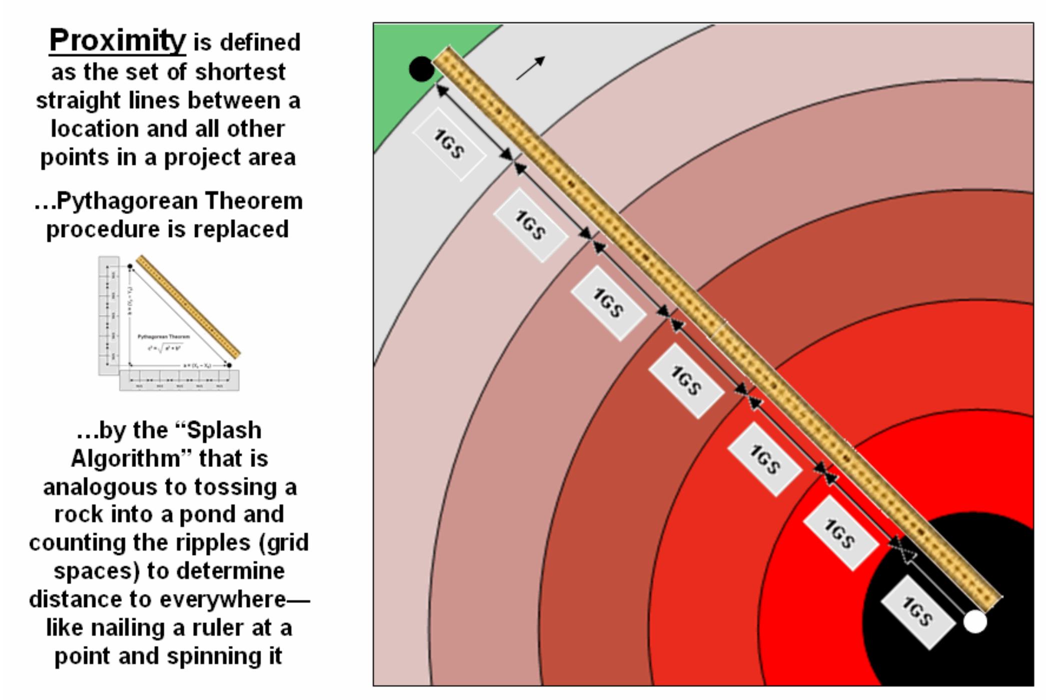

Figure 2. Proximity identifies the set of shortest straight-lines among groups of points (distance zones).

However, nothing says proximity must be measured from a single point. A more complex proximity map would be generated if, for example, all locations with houses (set of points) are simultaneously considered target locations (right side of figure 3).

In effect, the procedure is like throwing a handful of rocks into pond. Each set of concentric rings grows until the wave fronts meet; then they stop. The result is a map indicating the shortest straight-line distance to the nearest target location (house) for each non-target location. In the figure, the red tones indicate locations that are close to a house, while the green tones identify areas that are far from a house.

In a similar fashion, a proximity map to roads is generated by establishing data zones emanating from the road network—sort of like tossing a wire frame into a pond to generate a concentric pattern of ripples (middle portion of figure 3). The same result is generated for a set of areal features, such as sensitive habitat parcels (right side of figure 3).

It is important to note that proximity is not the same as a buffer. A buffer is a discrete spatial object that identifies areas that are within a specified distance of map feature; all locations within a buffer are considered the same. Proximity is a continuous surface that identifies the distance to a map feature(s) for every location in a project area. It forms a gradient of distances away composed of many map values; not a single spatial object with one characteristic distance away.

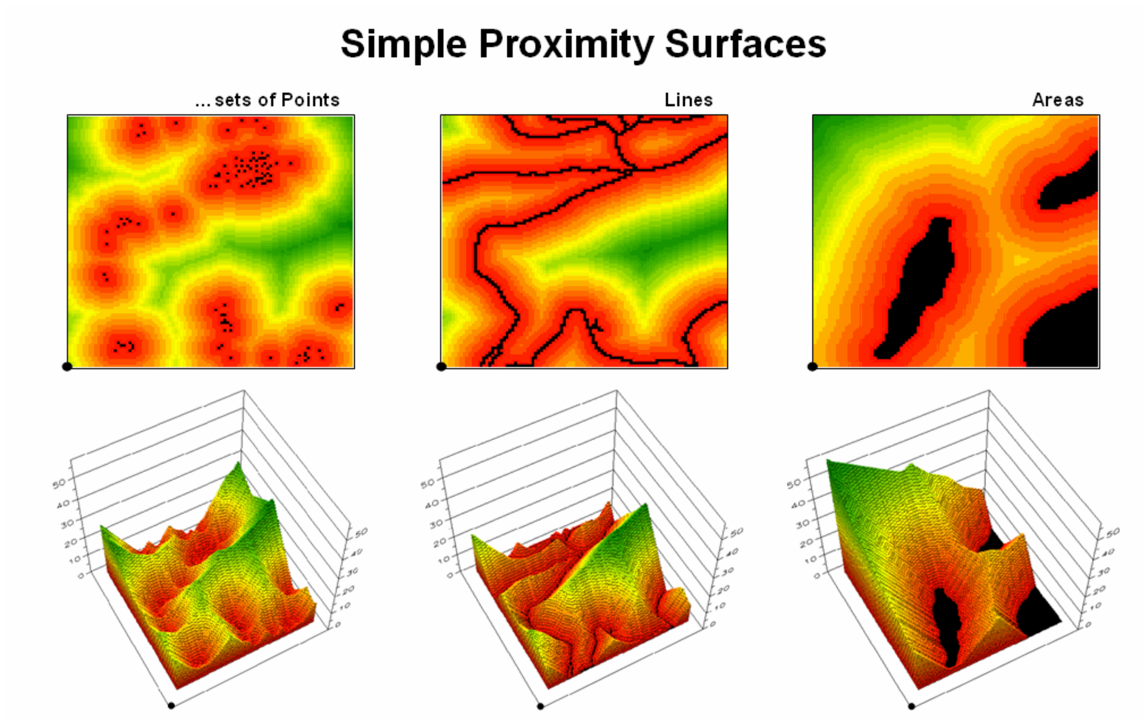

Figure 3. Proximity surfaces can be generated for groups of points, lines or polygons identifying the shortest distance from all location to the closest occurrence.

The 3D plots of the proximity surfaces in figure 3 show detailed gradient data and are termed *accumulated surfaces*. They contain increasing distance values from the target point, line or area locations displayed as colors from red (close) to green (far).

The starting features are the lowest locations (black= 0) with hillsides of increasing distance and forming ridges that are equidistant from starting locations. Next month will focus on how proximity is calculated—conceptually easy but way too much bookkeeping for even the most ardent accountant.

Extend Simple Proximity to Effective Movement

(GeoWorld, June 2005)

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Last section's discussion suggested that in many applications, the shortest route between two locations might not always be a straight-line. And even if it is straight, its geographic length may not always reflect a traditional measure of distance. Rather, distance in these applications is best defined in terms of "movement" expressed as travel-time, cost or energy that is consumed at rates that vary over time and space. Distance modifying effects involve weights and/or barriers— concepts that imply the relative ease of movement through geographic space might not always constant.

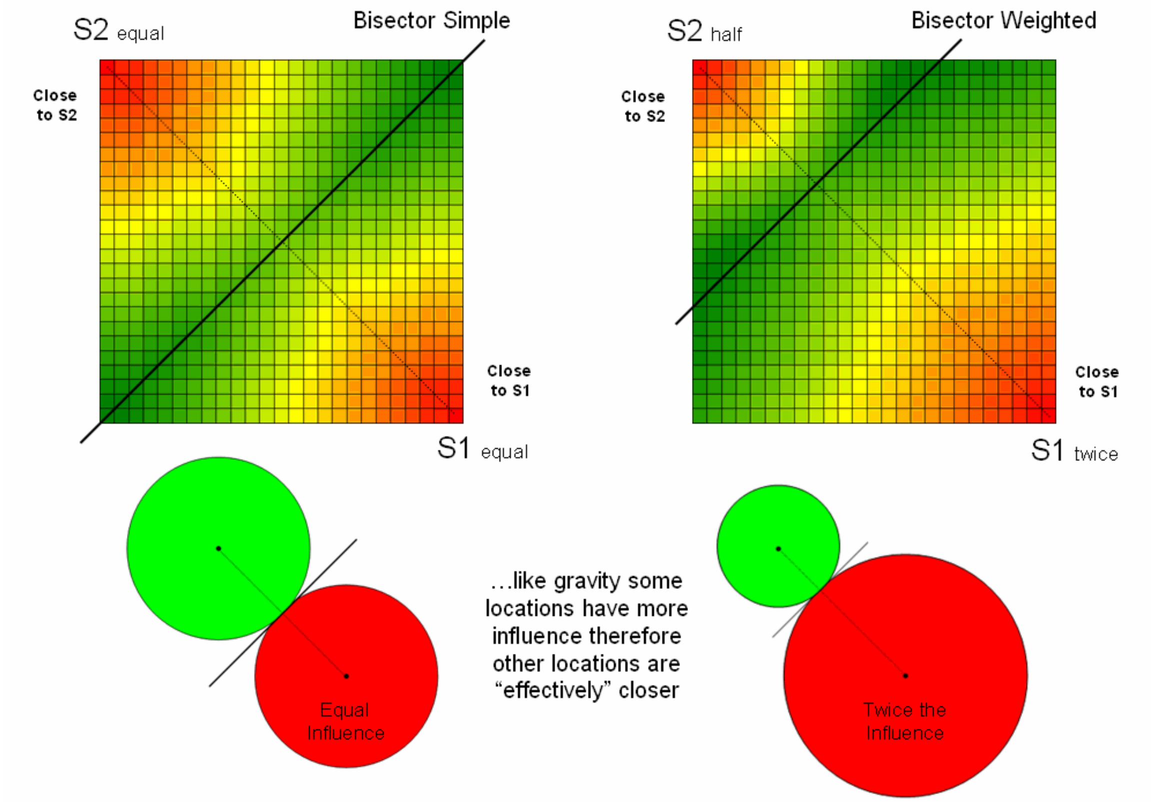

Figure 1. Weighting factors based on the characteristics of movement can affect relative distance, such as in Gravity Modeling where some starting locations exert more influence.

Figure 1 illustrates one of the effects of distance being affected by a *movement characteristic*. The left-side of the figure shows the simple proximity map generated when both starting locations are considered to have the same characteristics or influence. Note that the midpoint (dark green) aligns with the perpendicular bisector of the line connecting the two points and confirms a plane geometry principle you learned in junior high school.

The right-side of the figure, on the other hand, depicts effective proximity where the two starting locations have different characteristics. For example, one store might be considered more popular and a "bigger draw" than another (Gravity Modeling). Or in old geometry terms, the person starting at S1 hikes twice as fast as the individual starting at S2— the weighted bisector identifies where they would meet. Other examples of weights include attrition where movement changes with time (e.g., hiker fatigue) and change in mode (drive a vehicle as far as possible then hike into the off-road areas).

In addition to weights that reflect movement characteristics, effective proximity responds to intervening conditions or barriers. There are two types of barriers that are identified by their effects— absolute and relative. *Absolute barriers* are those completely restricting movement and therefore imply an infinite distance between the points they separate. A river might be regarded as an absolute barrier to a non-swimmer. To a swimmer or a boater, however, the same river might be regarded as a *relative barrier* identifying areas that are passable, but only at a cost which can be equated to an increase in geographical distance. For example, it might take five times longer to row a hundred meters than to walk that same distance.

In the conceptual framework of tossing a rock into a pond, the waves can crash and dissipate against a jetty extending into the pond (absolute barrier; no movement through the grid spaces). Or they can proceed, but at a reduced wavelength through an oil slick (relative barrier; higher cost of movement through the grid spaces). The waves move both around the jetty and through the oil slick with the ones reaching each location first identifying *the set of <u>shortest</u>, but <u>not necessarily straight-lines</u> among <u>groups of points</u>*.

The shortest routes respecting these barriers are often twisted paths around and through the barriers. The GIS database enables the user to locate and calibrate the barriers; the wave-like analytic procedure enabling the computer to keep track of the complex interactions of the waves and the barriers.

For example, figure 2 shows the effective proximity surfaces for the same set of starter locations discussed in the first section in this topic. The point features in the left inset respond to treating flowing water as an absolute barrier to movement. Note that the distance to the nearest house is very large in the center-right portion of the project area (green) although there is a large cluster of houses just to the north. Since the water feature can't be crossed, the closest houses are a long distance to the south.

Terrain steepness is used in the middle inset to illustrate the effects of a relative barrier. Increasing slope is coded into a friction map of increasing impedance values that make movement through steep grid cells effectively farther away than movement through gently sloped locations. Both absolute and relative barriers are applied in determining effective proximity sensitive areas in the right inset.

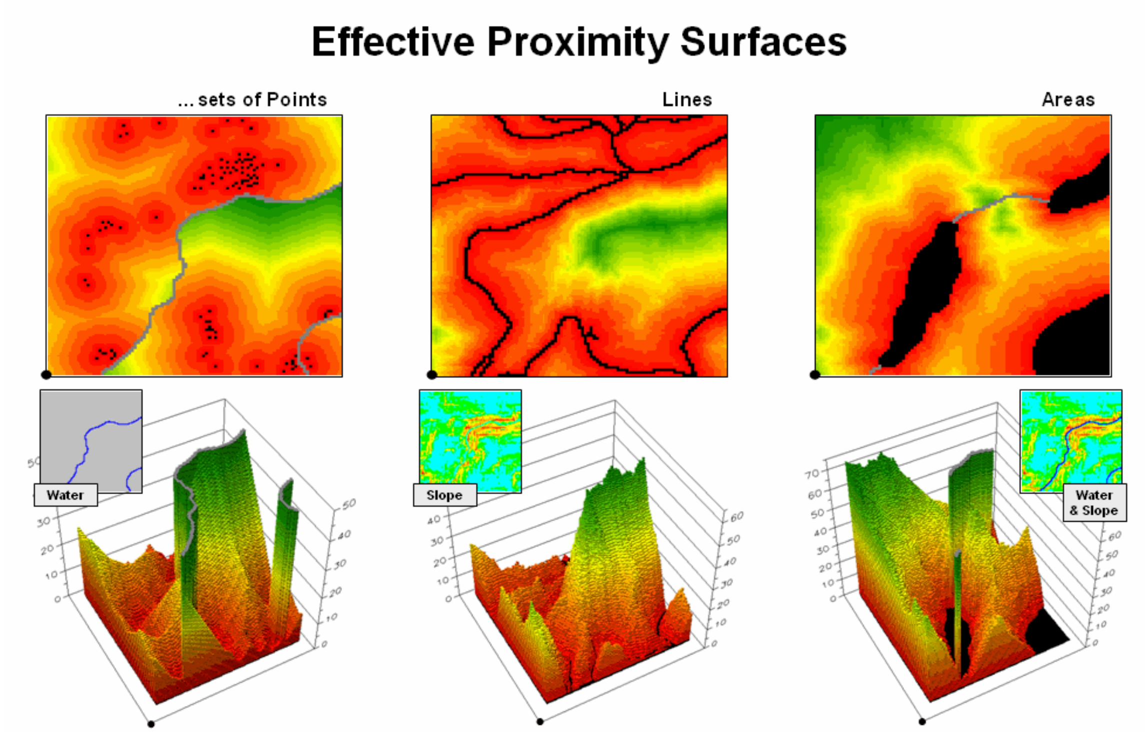

Figure 2. Effective Proximity surfaces consider the characteristics and conditions of movement throughout a project area.

The dramatic differences between the concept of distance "as the crow flies" (simple proximity) and "as the crow walks" (effective proximity) is a bit unfamiliar and counter-intuitive. However, in most practical applications, the comfortable assumption that all movement occurs in straight lines totally disregards reality. When traveling by trains, planes, automobiles, and feet there are plenty of bends, twists, accelerations and decelerations due to characteristics (weights) and conditions (barriers) of the movement.

Figure 3 illustrates how the splash algorithm propagates distance waves to generate an effective proximity surface. The Friction Map locates the absolute (blue/water) and relative (light blue= gentle/easy through red= steep/hard) barriers. As the distance wave encounters the barriers their effects on movement are incorporated and distort the symmetric pattern of simple proximity waves. The result identifies the "shortest, but not necessarily straight" distance connecting the starting location with all other locations in a project area.

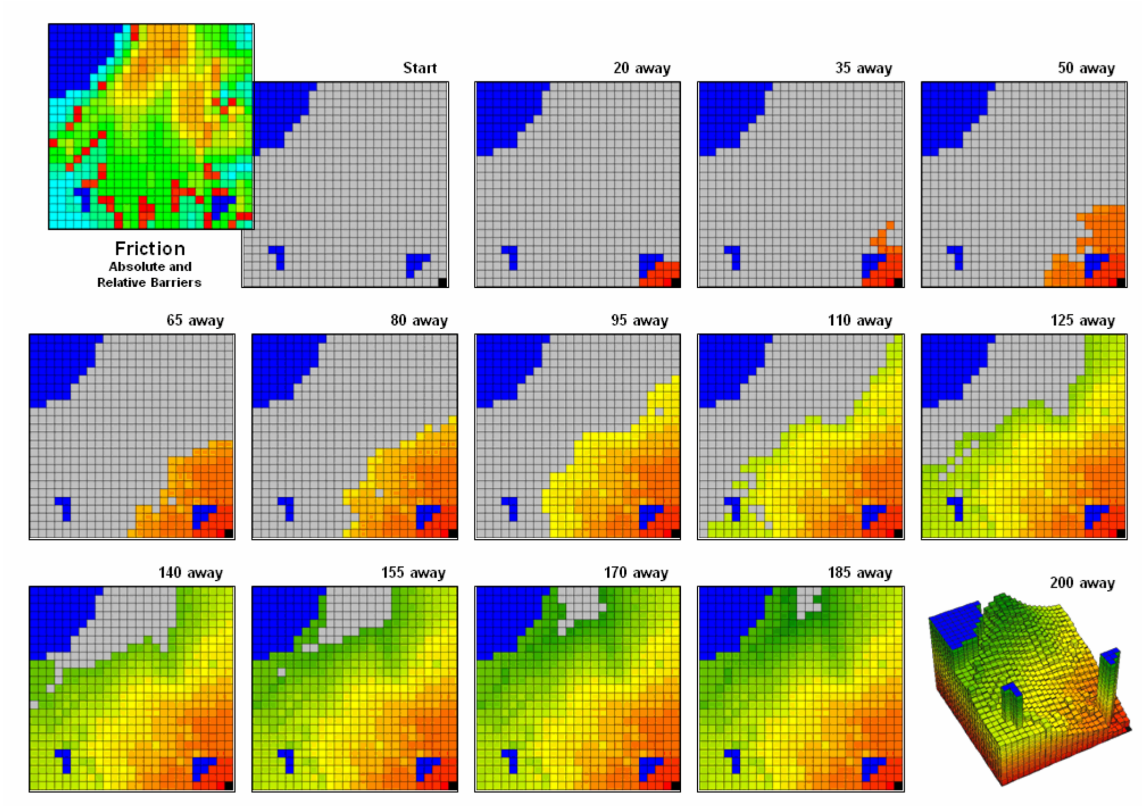

Figure 3. Effective Distance waves are distorted as they encounter absolute and relative barriers, advancing faster under easy conditions and slower in difficult areas.

Note that the absolute barrier locations (blue) are set to infinitely far away and appear as pillars in the 3-D display of the final proximity surface. As with simple proximity, the effective distance values form a bowl-like surface with the starting location at the lowest point (zero away from itself) and then ever-increasing distances away (upward slope).

With effective proximity, however, the bowl is not symmetrical and is warped with bumps and ridges that reflect intervening conditions— the greater the impedance the greater the upward slope of the bowl. In addition, there can never be a depression as that would indicate a location that is closer to the starting location than everywhere around it. Such a situation would violate the ever-increasing concentric rings theory and is impossible except on Star Trek where Spock and the Captain de-materialize then reappear somewhere else without physically passing through the intervening locations.

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*Further Online Reading: (Chronological listing posted at **www.innovativegis.com/basis/BeyondMappingSeries/**)*

(Calculating Simple and Effective Proximity)

Use Cells and Rings to Calculate Simple Proximity — *describes how simple proximity is calculated (May 2005)*

Calculate and Compare to Find Effective Proximity — *describes how effective proximity is calculated (July 2005)*

Taking Distance to the Edge — *discusses advance distance operations (August 2005)*

(Deriving and Analyzing Travel-Time)

Use Travel-Time Buffers to Map Effective Proximity — *discusses procedures for establishing travel-time buffers responding to street type (February 2001)*

Integrate Travel-Time into Mapping Packages — *describes procedures for transferring travel-time data to other maps (March 2001)*

Derive and Use Hiking-Time Maps for Off-Road Travel — *discusses procedures for establishing hiking-time buffers responding to off-road travel (April 2001)*

Consider Slope and Scenic Beauty in Deriving Hiking Maps — *describes a general procedure for weighting friction maps to reflect different objectives (May 2001)*

Accumulation Surfaces Connect Bus Riders and Stops — *discusses an accumulation surface analysis procedure for linking riders with bus stops (October 2002)*

(Use of Travel-Time in Geo-Business)

Use Travel Time to Identify Competition Zones — *discusses the procedure for deriving relative travel-time advantage maps (March 2002)*

Maps and Curves Can Spatially Characterize Customer Loyalty — *describes a technique for characterizing customer sensitivity to travel-time (April 2002)*

Use Travel Time to Connect with Customers — *describes techniques for optimal path and catchment analysis (June 2002)*

GIS Analyzes In-Store Movement and Sales Patterns — *describes a procedure using accumulation surface analysis to infer shopper movement from cash register data (February 1998)*

Further Analyzing In-Store Movement and Sales Patterns — *discusses how map analysis is used to investigate the relationship between shopper movement and sales (March 1998)*

Continued Analysis of In-Store Movement and Sales Patterns — *describes the use of temporal analysis and coincidence mapping to enhance shopping patterns (April 1998)*

(Micro-Terrain Considerations and Techniques)

Confluence Maps Further Characterize Micro-terrain Features — *describes the use of optimal path density analysis for mapping surface flows (April 2000)*

Modeling Erosion and Sediment Loading — *illustrates a GIS model for assessing erosion potential and sediment loading (May 2000)*

Identify Valley Bottoms in Mountainous Terrain — *illustrates a technique for identifying flat areas connected to streams (November 2002)*

(Surface Flow Considerations and Techniques)

Traditional Approaches Can't Characterize Overland Flow — *describes the basic considerations in overland flow (November 2003)*

Constructing Realistic Downhill Flows Proves Difficult — *discusses procedures for characterizing path, sheet, horizontal and fill flows (December 2003)*

Use Available Tools to Calculate Flow Time and Quantity — *discusses procedures for tracking flow time and quantity (January 2004)*

Migration Modeling Determines Spill Effect — *describes procedures for assessing overland and channel flow impacts (February 2004)*

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