

Map Analysis: *Understanding Spatial Patterns and Relationships*

by [Joseph K. Berry](#)

Topic 5 – Calculating Visual Exposure

18 Line-of-Sight Buffers Add Intelligence to Maps (GW, December 2000)

19 Identify and Use Visual Exposure to Create Viewshed Maps (GW, June 2001)

20 Visual Exposure Is in the Eye of the Beholder (GW, July 2001)

21 Use Exposure Maps and Fat Buttons to Assess Visual Impact (GW, August 2001)

Further Reading

Hands-on Experience

18 Line-of-Sight Buffers Add Intelligence to Maps

As noted in Topic 4, ***simple buffers*** are often just that—too simple for real world applications. The assumption that there are uniform conditions throughout a fixed distance from a map feature rarely squares with reality. A consistent 100, 200 or 300-meter buffer around roads often includes inappropriate results within a buffer, such as ocean areas. Or they can include areas that are inconsistent with an assumption, such as a concern for just the uphill locations from roads.

Variable-width buffers, on the other hand, respond to both intervening conditions and the type of connectivity. They expand and contract to reflect spatial reality around map features by clipping inappropriate and inconsistent areas.

Tracking the variations within a buffer is just as important. Instead of simply being within or outside a buffered area, each location can be identified as to its proximity to the buffered feature. For example, all of the uphill locations within 250 meters (variable-width buffer) can be assigned their proximity to a road—a continuum of information throughout the buffer instead of simply an “in or out” characterization.

Another type of variable-width buffer involves line-of-sight connectivity. In this application a *viewer location* “looks” over an elevation surface up to a specified distance and identifies all of the areas it can see.

Figure 5-1 shows a 250-meter ***line-of-sight buffer*** surrounding the road network. Note that variations in the terrain cause the buffer to truncate areas that are not seen, yet are still within the 250-meter reach.

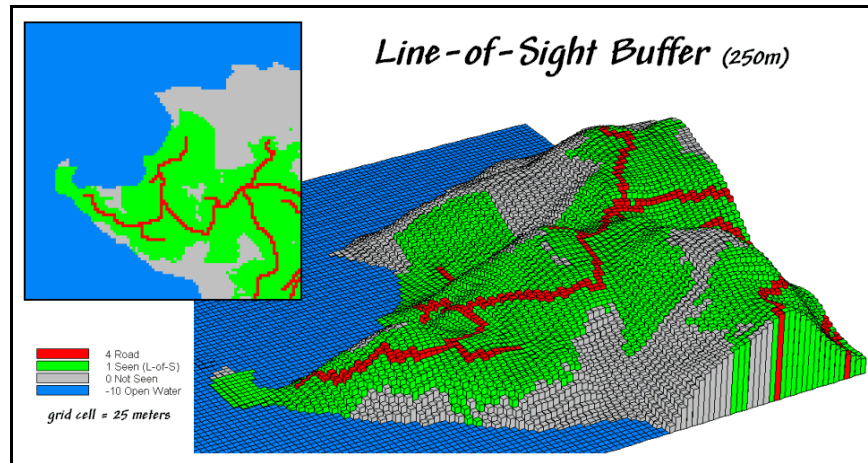


Figure 5-1. The “viewshed” of the road network forms a variable-width, line-of-sight buffer.

The conceptual basis for calculating line-of-sight connectivity is quite simple. The position of a viewer location (one of the road cells in this example) determines its height from an elevation map of the area. The cell’s height is compared to the elevations of its eight surrounding cells to establish a set of *rise-to-run* ratios—change in elevation per horizontal distance. The rise/run ratios for the next ring of cells are computed. If a new location’s ratio is greater, it is marked as seen and its ratio becomes the one to beat for subsequent locations in that direction. The process is repeated for successive rings up to the buffer limit. Then the next viewer cell is considered until the entire road network has been evaluated.

In practice, the line-of-sight procedure is a bit more complex as additional factors, such as vegetation height, often are included in determining the *viewshed* defining the buffered area. Also, the process can be extended to keep track of the number of times each buffer location is seen (e.g., number of road cells connected to it). The result is a measure of *visual exposure* for each buffer location. Instead of simply delineating the buffer limits, information about the relative exposure throughout the buffer is noted.

Figure 5-2 contains a map of the visual exposure within the 250-meter viewshed. Note the four areas of relatively high exposure to roads (warmer tones). While these areas might be ideal for visually aesthetic activities, the areas of minimal exposure (cool tones) or those entirely outside the buffer (gray) are more suitable for “ugly things.” For example, a national park might use a visual exposure buffer to assist forest planning for foreground management zones. A telecom company might use the information to help locate cell-towers.

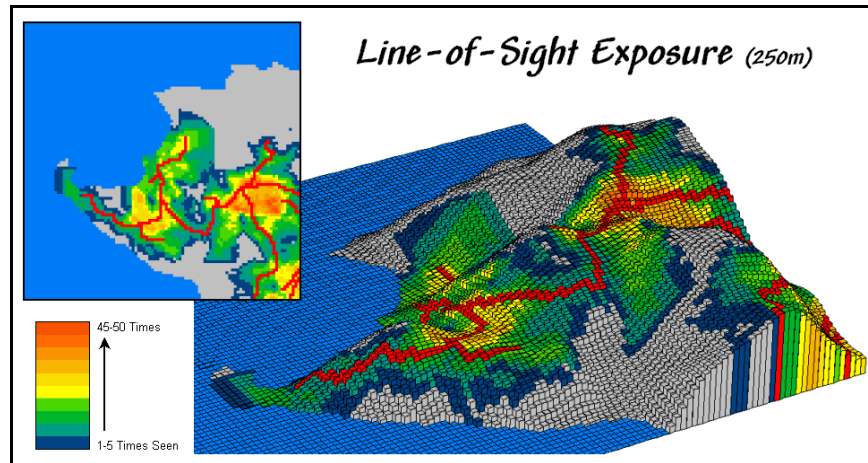


Figure 5-2. A “visual exposure” map identifies the number of times each map location is visually connected to an extended map feature.

Or a developer might focus on candidate areas for “Soothing Acres Estates” that have minimal visual exposure and road noise. Spatial modeling of noise dissipation can be a complex undertaking, but line-of-sight connectivity is a fundamental element. While sound waves bend more than light waves, they also tend to be blocked by intervening terrain. A road on the other side of a ridge is neither seen nor heard—provided there is a big pile of dirt separating the source and receptor.

Also, sound waves fade dramatically as a function of distance ($1/d^2$). Figure 5-3 incorporates this dissipation for a line-of-sight **noise buffer**. The cells adjacent to the road are the loudest (yellow—1.00 times the noise level). Those at the limit of the 250-meter reach are a whole lot quieter (blue—0.010 times the noise level). Noise levels at cells that have intervening terrain or are beyond the buffer-reach (gray) are considered inaudible.

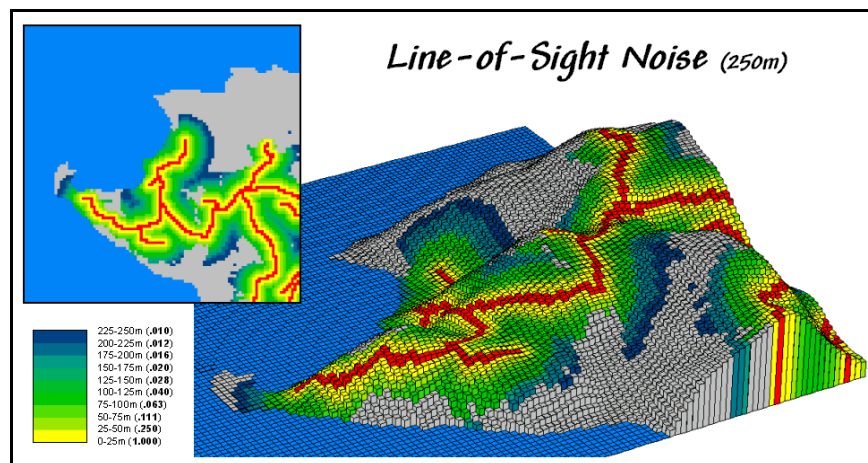


Figure 5-3. A “noise buffer” considers distance as well as line-of-sight connectivity.

Admittedly, the assumptions in modeling noise dissipation in this example are simplified, but they do reflect reality better than a simple buffer that totally ignores the very real

effects of distance and surrounding terrain. There are several possibilities for improving the accuracy of the noise levels within the buffer, such as treating neighboring vegetation types differently. However, these extensions involve consideration of “relative barriers” in characterizing variable-width buffers.

19 Identify and Use Visual Exposure to Create Viewshed Maps

The past discussion touched on the concept of *effective proximity* in deriving variable width buffers and travel-time movement. The procedures relax the assumption that distance is only measured as “the shortest straight line between two points.” Real world movement is rarely straight as it responds to a complex set of absolute and relative barriers. While the concept of effective proximity makes common sense, its practical expression had to wait for GIS technology.

Similarly, the measurement of *visual connectivity* is relatively new to map analysis but has always been part of a holistic perspective of a landscape. We might not be able to manually draw visual exposure surfaces yet the idea of noting how often locations are seen from other areas is an important ingredient in realistic planning. Within a GIS, detailed maps of visual connectivity have become a reality and are nearing commonplace use.

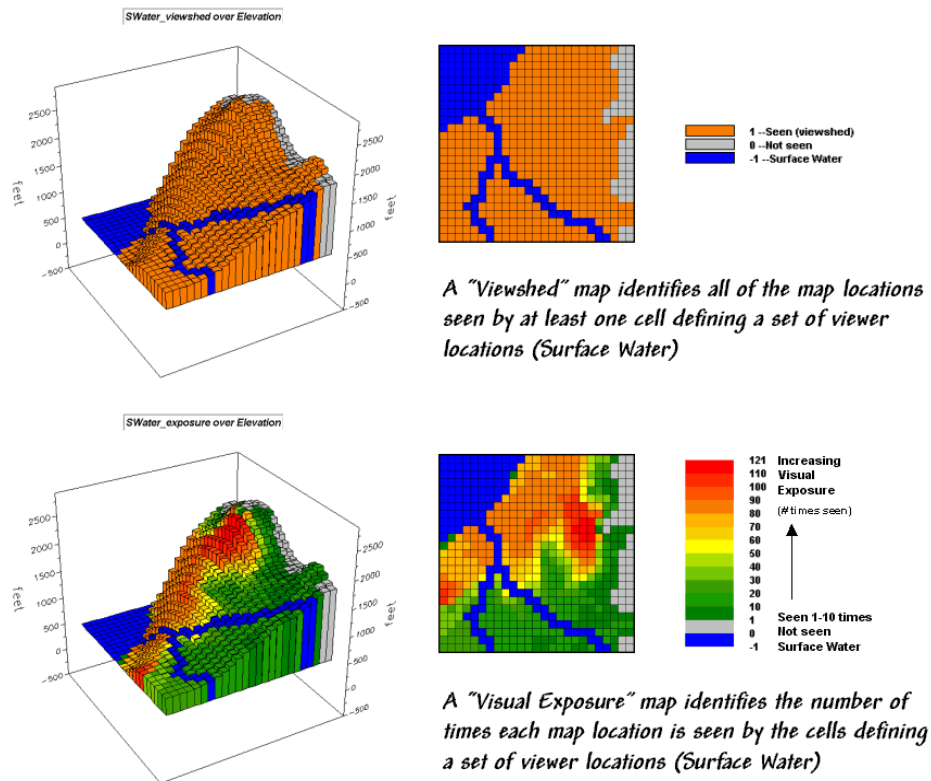


Figure 5-4. Viewshed of all surface water locations.

For example, the **viewshed** map shown in top portion of figure 5-4 identifies all the map locations that are seen (tan) by at least one cell of surface water (dark blue). The light gray locations along the right side of the map locate areas that are not visually connected to water—bum places for hikers wanting a good view of surface water while enjoying the scenery.

The bottom portion of the figure takes visual connectivity a step further by calculating the number of times each map location is seen by the “viewer” cells. In the example there are 127 water cells and one location near the top of the mountain sees 121 of them... very high **visual exposure** to water. In effect, the exposure surface “paints” the viewshed by the relative amount of exposure—green not much and red a whole lot.

So how does the computer determine visual connectivity? The procedure actually is quite simple (for a tireless computer) and is similar to the calculation of effective proximity. A series of “distance waves” radiate out from a water cell like the ripples from a rock tossed into a pond (see figure 5-5). As the wave propagates, the distance from the viewer cell (termed the *run*) and the difference in elevation (termed the *rise*) are calculated for the cells forming the concentric ring of a wave. If the *rise/run* ratio is greater than any of the ratios for the previous rings along a line from the viewer cell, that location is marked as seen. If it is smaller, the location is marked as not seen.

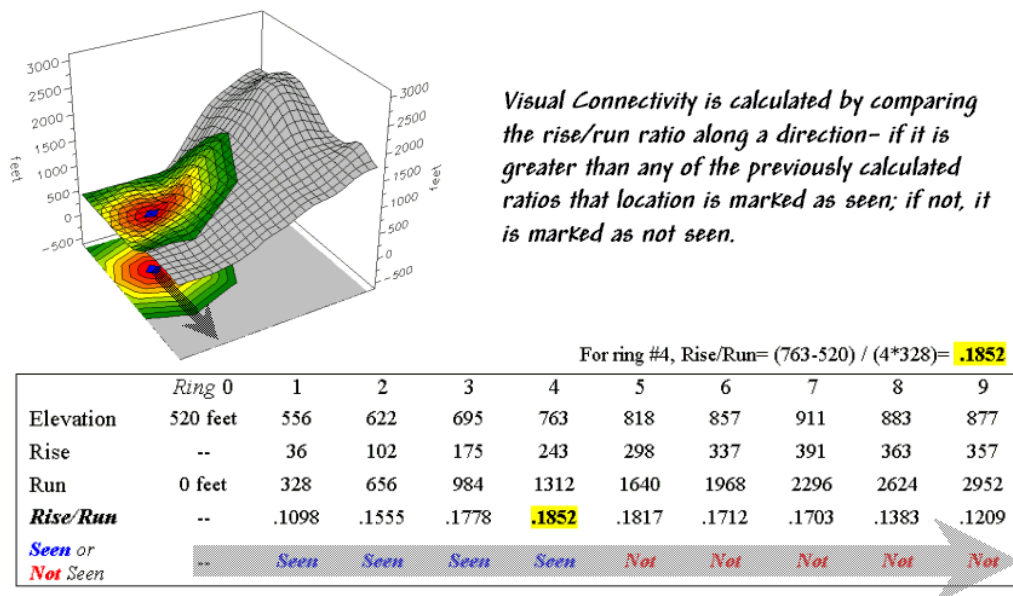


Figure 5-5. Example calculations for determining visual connectivity.

In the example shown in figure 5-5, the rise/run ratios to the south (arrow in the figure) are successively larger for rings 1 through 4 (marked as *seen*) but not for rings 5 through 9 (marked as *not seen*). The computer does calculations for all directions from the viewer cell and marks the seen locations with a value of one. The process is repeated for all of the viewer cells defining surface water locations—127 times, once for each water cell. Locations marked with a one at least once identify the viewshed. Visual exposure, on the other hand, simply sums the markers for the number of times each location is seen.

Now let's complicate matters a bit. Suppose there is a dense forest with 75-foot trees that grow like "Chia Pet" hairs out of the elevation surface. The forest canopy height is analogous to raising the elevation surface an equal amount. But unless you're a bird, your eyeball stays on the ground and the trees act like screens blocking your view.

The 3-D plot in figure 5-6 shows the effect of introducing a 75-foot forest canopy onto the elevation surface. Note the sharp walls around the water cells, particularly in the lower right corner. The view on the ground from these areas is effectively blocked. The computer "knows" this because the first ring's rise/run ratio is very large (big rise for a small run) and is nearly impossible to beat in subsequent rings.

The consequence of the forest screens is shown in the maps on the right. The top one doesn't consider trees, while the bottom one does. Note the big increase in the "not seen" area (gray) along the stream in the lower right where the trees serve as an effective visual barrier. If your motive is to hide something ugly in these areas from a hiking trail along the stream, the adjacent tree canopy is extremely important.

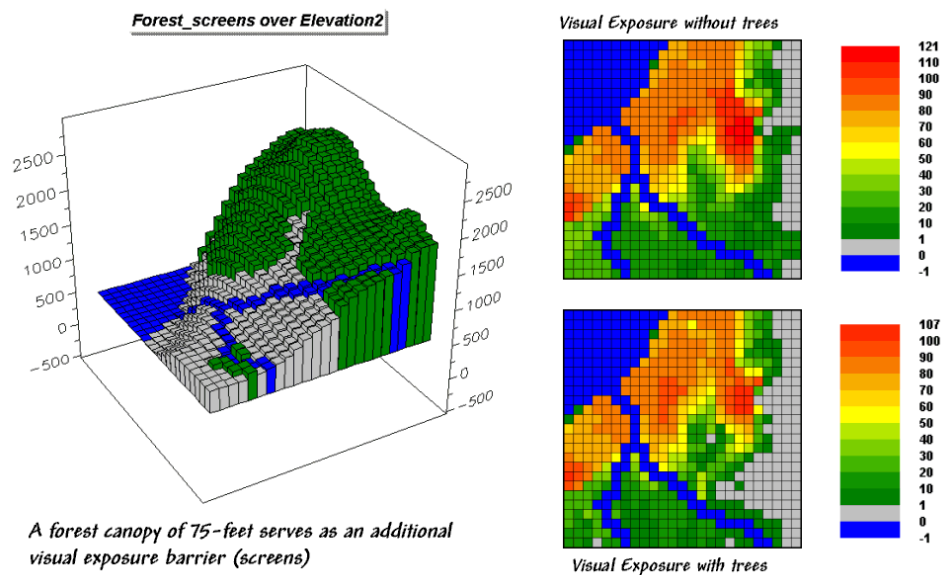


Figure 5-6. Introducing visual screens that block line-of-sight connections.

The ability to calculate visual connectivity has many applications. Resource managers can determine the visual impact of a proposed activity on a scenic highway. County planners can assess what is seen, and who in turn can see, a potential development. Telecommunication engineers can try different tower locations to "see" which residences and roadways are within the different service areas.

Within a GIS, users can easily simulate “what if” by changing the locations of the viewer cells and screens then comparing the visual exposure maps generated under the different scenarios—sort of like a visual impact spreadsheet. Like most things in GIS, however, “you ain’t seen nothing yet”... more on visual connectivity and its uses next month.

20 Visual Exposure Is in the Eye of the Beholder

The previous section introduced some basic calculations and considerations in deriving visual exposure. An important notion was that “viewer” locations can be a point, group of points, lines or areas—any set of grid cells. In the example described last month, all of the stream and lake cells were evaluated to identify locations seen by at least one water cell (termed a *viewshed*) or the number of water cells seeing each map location (termed *visual exposure*).

In effect, the water features are similar to the composite eye of a fly with each grid cell serving as an individual lens. The resulting map simply reports the line-of-sight connections from each lens (grid cell) to all of the other locations in a project area.

Figure 5-7 shows a similar analysis for a road network. The cells defining the roads are shown in the map on the left with a draped display on the elevation surface as the inset. The computer “goes” to one of the road cells, “looks” everywhere over the terrain and “marks” each map location that can be seen with a value of one. The process is repeated for all of the other road cells resulting in the map on the right—a viewshed map with seen (tan), not seen (gray).

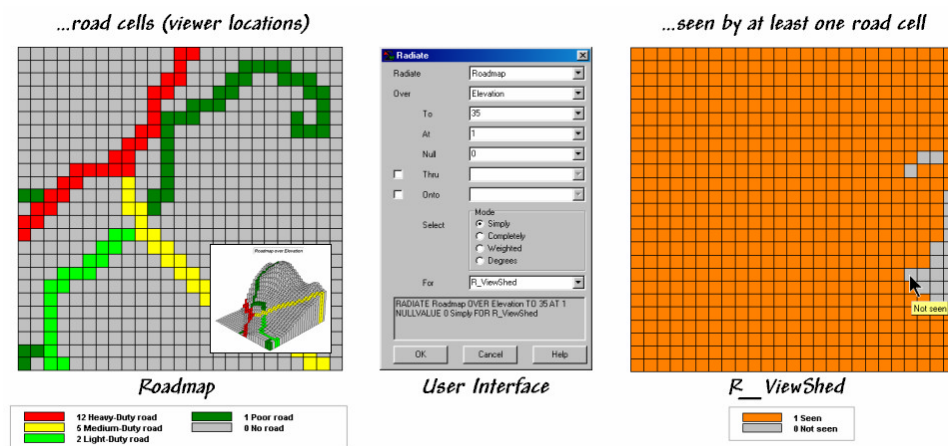


Figure 5-7. Identifying the “viewshed” of the road network.

The interface in the middle of figure 5-7 shows how a user coerces the computer to generate a viewshed map. In the example, the command *Radiate* is specified and the *Roadmap* is selected to identify the viewer cells. The *Elevation* map is selected as the terrain surface whose ridges and valleys determine visual connectivity from each lens of the elongated eyeball. The *To 35* parameter tells the computer to look up to 35 cells away in all directions—effectively everywhere on the 25x25 cell project area. The *At 1* specification indicates that the eyeball is 1-foot over the elevation surface and the *Null 0*

sets zero as the background (not a viewer cell). The *Thru* and *Onto* specifications will be discussed a little later.

As the newer generations of GIS software take hold, more and more systems are replacing their command line interfaces with dialog boxes similar to the one in the example. Clicking on the *Simply* radio button instructs the computer to create a new map specified as *R_ViewShed*—the map displayed on the right in figure 5-7.

Locations on the *R_ViewShed* map that didn't receive any connectivity marks (value 0) are not seen from any road cell. Figure 5-8 shows results using different calculation modes and the resulting maps.

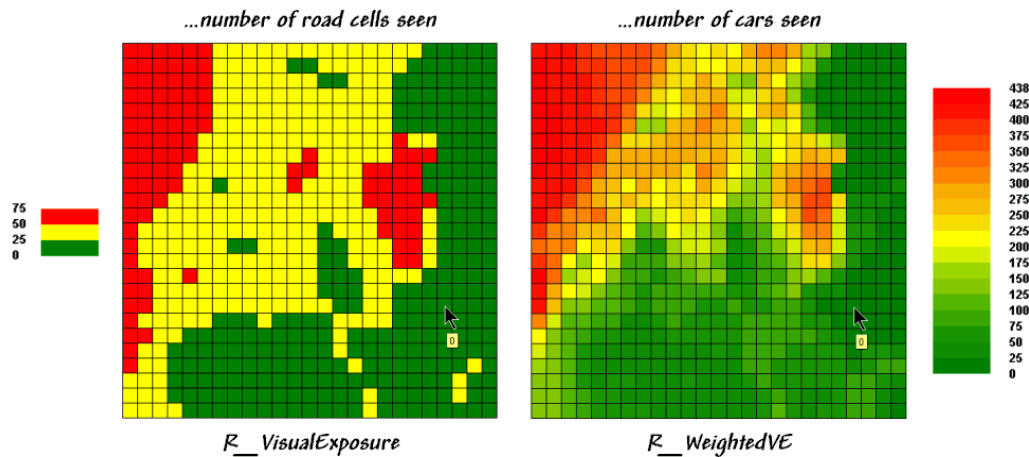


Figure 5-8. Calculating simple and weighted visual exposure.

The values on the *R_VisualExposure* map were generated by clicking *Completely* to calculate the number of roads cells that “see” each location in the project area—from 0 (not seen) to 75 times seen. Generally speaking, you put ugly things where the numbers are low and pretty things where the numbers are high.

But just the sum of road cells that are visually connected doesn't always tell the whole story. Note the values defining the different types of roads on the *Roadmap* in figure 5-7—1 Poor road, 2 Light-duty, 5 Medium-duty, and 12 Heavy-duty. The values were craftily assigned as “relative weights” indicating the average number of cars within a 15-minute time period. It's common sense that a road with more cars should have more influence in determining visual exposure than one with just a few cars.

The calculation mode was switched to *Weighted* to generate the *R_WeightedVE* map displayed on the right side of figure 5-8. In this instance, the *Roadmap* values are summed for each map location instead of just counting how many road cells are visually connected. The resultant values indicate the relative visual exposure based on the traffic densities—viewer cells with a lot of cars having greater influence.

Now turn your attention to the *Thru* and *Onto* specifications in the example interface. The *Thru* hot-field allows the user to specify a map identifying the height of visual barriers within the area. In the last section's discussions it was used to place the 50-foot tree canopy for forested areas—the “Chia Pet” hairs on top of the elevation surface that blocks visual connections. The *Thru* map contains height values for all “screen” locations and effectively adds the blocking heights to the elevation values at each location—0 indicates no screen and 50 indicates a 50-foot visual barrier on top of the terrain.

The *Onto* hot-field is conceptually similar but has an important difference. It addresses tall objects, such as smoke-stacks or towers, which might be visible but not wide enough to block views. In this instance, the computer adds the “target” height when visual connectivity is being considered for a cell containing a structure but the added height isn't considered for locations beyond. The effect is that the feature pops-up to see if it is seen but doesn't hang around to block the view beyond it.

Figure 5-9 depicts yet another way of dealing with extended features. Assume you want to assess the difference in visual impact of two proposed power line routes shown in the 3-D inset in the figure. In this instance, *Powerline1* is first selected as the viewer map (instead of *Roadmap*) and the *At* parameter is set to 50. The command is repeated for *Powerline2*.

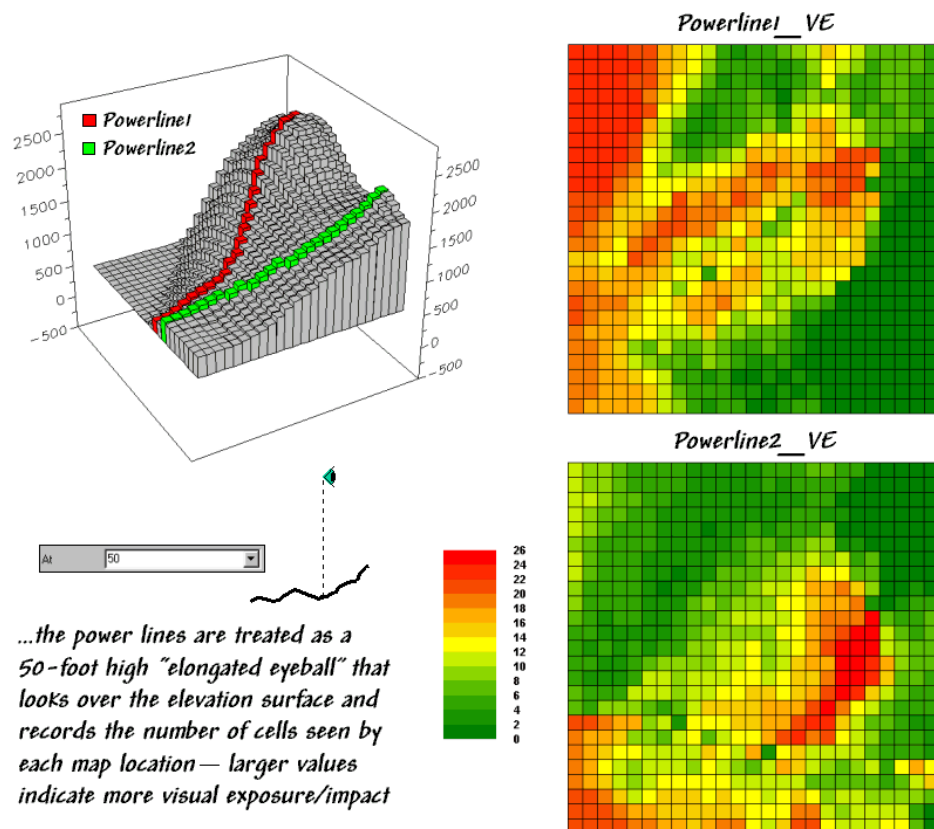


Figure 5-9. Determining the visual exposure/impact of alternative power line routes.

These entries identify the power line cells and their height above the ground. The *Powerline1_VE* map shows the number of times each map location is seen by the elongated *Powerline1* eyeball. And by “line-of-sight,” if the power line can see you, you can see the power line. The differences in the patterns between *Powerline1_Ve* and *Powerline2_VE* maps characterize the disparity in visual impact for the two routes. What if your house was in a red area on one and a green area on another? Which route would you favor? ...not in my visual backyard.

21 Use Exposure Maps and Fat Buttons to Assess Visual Impact

The previous section described several considerations in deriving visual exposure maps. Approaches ranged from a simple *viewshed* (locations seen) and *visual exposure* (number of times seen) to *weighted visual exposure* (relative importance of visual connections). Extended settings discussed included *distance*, *viewer height*, *visual barrier height* and special *object height*. This section investigates how models using visual exposure can be used in decision-making.

Figure 5-10 rekindles the important points before tackling visual impact modeling. The maps on the left identify input information for calculating visual exposure. The *PowerLine1* map serves as an elongated eyeball, the *TreeHeight* map identifies areas with a 75-foot forest canopy that on the *Elevation* surface.

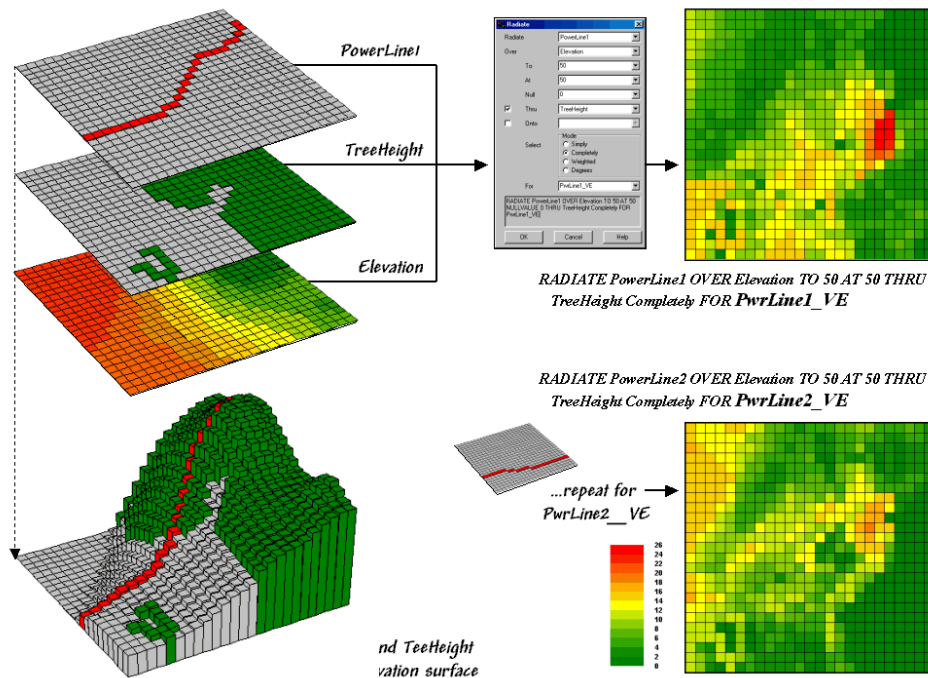


Figure 5-10. Calculating visual exposure for two proposed power lines.

The 3-D inset is a composite display of all three input maps. The user interface shown in the middle is used to specify viewer height (*At 50*) that raises the power line 50-feet above the surface. A large distance value (*To 50*) is entered to force the calculations for all locations in the study area. Finally, the visual exposure mode is indicated (*Completely*) and a name assigned to the derived map (*PwrLine1_VE*).

The top-left map shows the result with red tones indicating higher visual exposure. The lower-left map shows visual exposure for a second proposed power line that runs a bit more to the south. It was calculated by simply changing the viewer map to *PowerLine2* and the output map to *PwrLine2_VE*. Compare the patterns of visual exposure in the two resultant maps. Where do they have similar exposure levels? Where do they differ? Which one affects the local residents more?

This final question requires a bit more processing to nail down—locating the residential areas, “masking” their visual exposure and comparing the results. Figure 5-11 outlines a simple impact model for determining the exposure difference between the two proposed routes. The visual exposure maps on the left are the same as those in figure 1 and serve as the starting point for the impact model.

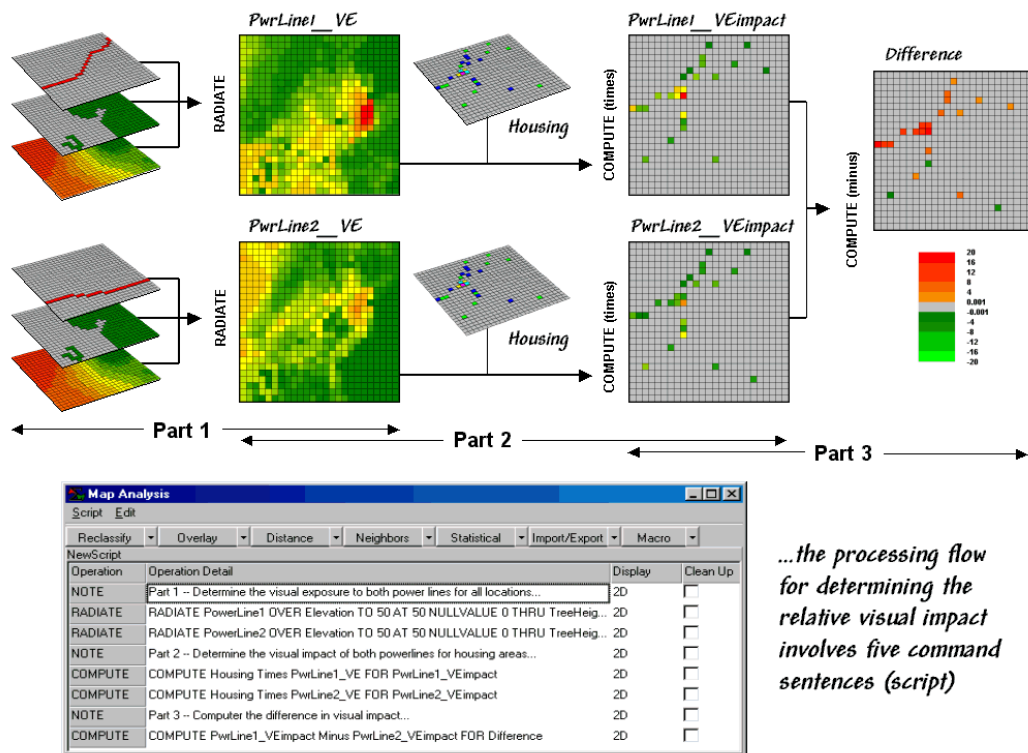


Figure 5-11. Determining visual impact on local residents.

The *Housing* map identifies grid cells that contain at least one house. The values in the housing cells indicate how many residences occur in each cell—1 to 5 houses in this case; a 0 value indicates that no houses are present. This map is multiplied by the visual exposure maps to calculate the visual impact for both proposed routes

(*PwrLine1_VEimpact* and *PwrLine2_VEimpact*). Note that the visual exposure for areas without a house results in zero impact—0 times any exposure level is 0. Locations with one house report the calculated exposure level—1 times any exposure level is the same exposure level. Locations with more than one house serve as a multiplier of exposure impact—2 times any exposure level is twice the impact.

The final step involves comparing the two visual impact maps by simply subtracting them. The red tones on the *Difference* map identify residential locations that are impacted more by the *PowerLine1* route—the higher the value, the greater the difference in impact.

The dark red locations identify residents that are significantly more affected by route 1—expect a lot of concern about the route. On the other hand, there are only three locations that are slightly more affected by route 2 (dark green; fairly low values).

The information in the lower portion of figure 5-11 is critical in understanding GIS modeling. The conceptualization of a spatial problem, such as visual impact on residents, must be translated into a sequence of map analysis operations. In this instance, there are three parts— 1) visual exposure, 2) visual impact and 3) comparison. Each of the sentences in the script shown at the bottom of the figure is entered via a command dialog box similar to the one in figure 1. The script can be saved, edited and re-run at a later time or on another project area.

The ability to save and re-run a map analysis sequence sets the stage for the current revolution in GIS technology. Figure 5-12 shows another simple impact model that determines the visible portion of a power line route and its distance from any location.

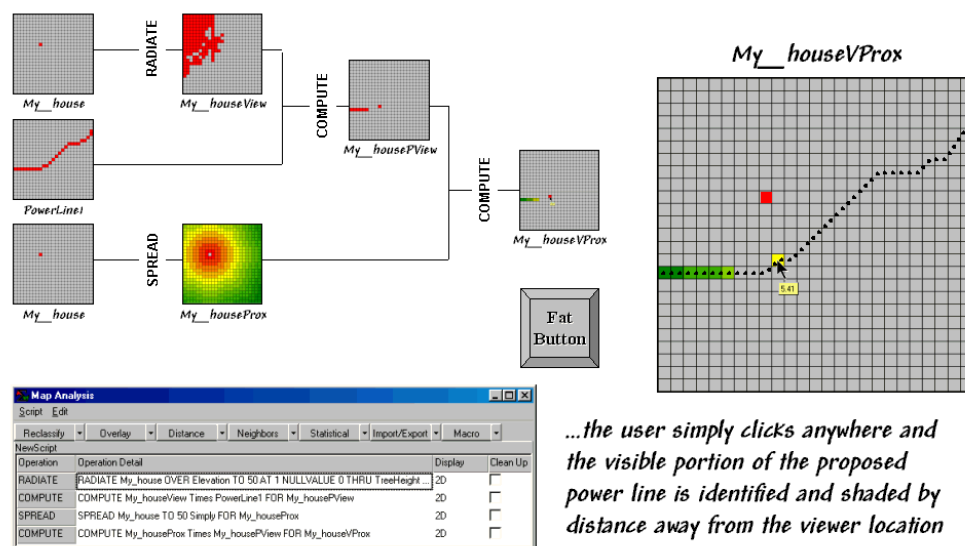


Figure 5-12. Determining visible portions of a proposed power line.

The flowchart shows the logical structure of the analysis and the intermediate maps generated—

- ü Calculate the viewshed from the selected point
- ü Mask the portion of the route within the viewshed
- ü Calculate proximity from the selected point
- ü Mask the proximity for just the proportion of the route

The script identifies the four sentences that solve the spatial problem. The revolution is represented by the “Fat Button” in the figure.

Within a GIS, the *fat button* calls a command script that dutifully executes the stored commands. In this example, the user would push the fat button and the program would direct them to “click anywhere on the base map.” Once the location is set, the *My_house* map is defined and the script is run for that location. The next thing the user would see is the final map indicating the visible portion of the route and how far away it is. Click on another location and its result is displayed.

The ability to pop-up special input interfaces and launch command scripts moves the paradigm of a “GIS Toolbox” to one of “Application-specific” solutions. With the advent of COM-object modules the entire application can be moved outside of the GIS. The bottom line is to expect a lot of map analysis applications taking hold in places you never dreamed. Heck, they could be links within an impact statement that encourages a reader to “click anywhere on the base map” to see what you would see—an interactive viewshed.

Further Reading (hyperlinks on companion CD)

Extended Visual Exposure Techniques

Exposure Surface Analysis for Assessing Relative Visual Vulnerability and

Aesthetics (Basis Posting) — paper for GeoTech Conference, GeoWorld-Adams Business Media, Vancouver, BC, Canada, March 16-19, 2003.

http://www.innovativegis.com/basis/present/GIS03_Visual/GIS03_Visual.htm

Use Maps to Assess Visual Vulnerability (GW Feb 2003) — BM column discussing a procedure for identifying visually vulnerable areas.

<http://www.geoplace.com/gw/2003/0302/0302bmp.asp>

Try Vulnerability Maps to Visualize Aesthetics (GW Mar 2003) — BM column describing a procedure for deriving an “aesthetics map” based on visual exposure to pretty and ugly places.

<http://www.geoplace.com/gw/2003/0303/0303bmp.asp>

Visual Exposure Application Examples

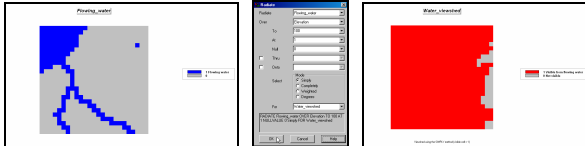
Determining Visual Exposure: *A land planner needs to determine areas that are highly visible from the road network for consideration in a new development plan for the county. (uses MapCalc Learner Tutor25 dbase)*

http://www.innovativegis.com/basis/Senarios/Visibility_scenario.htm

Modeling Visual Exposure from Roads and Houses: A natural resource manager needs a map that identifies the relative visual exposure of forested lands in the county. This information is important in deciding where visually sensitive activities should and shouldn't be located. (uses MapCalc Learner Tutor25 dbase)

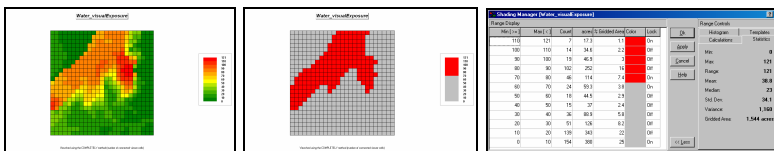
http://www.innovativegis.com/basis/Senarios/VisModel_scenario.htm

Hands-on Experience (exercises on companion CD)



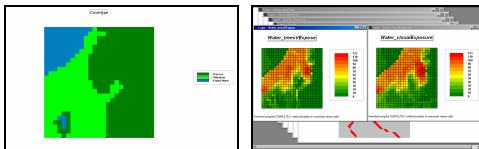
Exercise 5.1 Calculating Viewsheds —

in this exercise you will first create a map of all the water locations (viewer map) in the Tutor25 database and then generate a simple viewshed map that indicates the visual connectivity to water— all locations are identified as either 0= not seen or 1= seen from at least one water location.



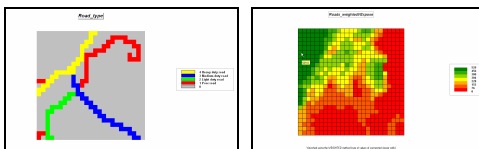
Exercise 5.2 Calculating

Visual Exposure — this exercise demonstrates generating a visual exposure map to water indicating the number water locations visually connected to each grid location in a project area— 0= not seen with increasing values indicating higher visual exposure to water.



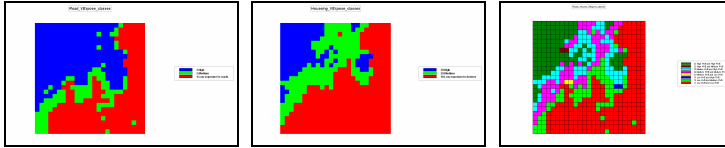
Exercise 5.3 Accounting for Screens — this

exercise extends the previous exercise to create another visual exposure map to water that accounts for a screening forest canopy of 75 feet and then compares the result to the “non-screened” solution to determine the differences in the two approaches.



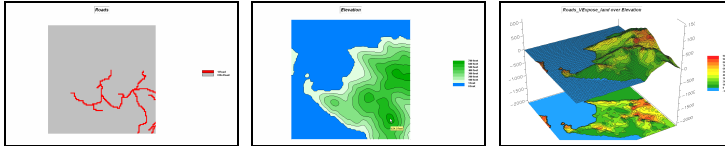
Exercise 5.4 Calculating Weighted Visual

Exposure — this exercise first calibrates Roads in terms of traffic flow and then creates a weighted visual exposure map accounting for the relative amount of traffic on different road types— 0= not seen from any road location with increasing values indicating higher weighted visual exposure to traffic flows.



[Exercise 5.5](#) Modeling Visual

Exposure Impacts — *this exercise creates and classifies visual exposure maps for relative connectivity to roads and houses (Low, Medium, High) and then combines the two classified maps into a single map that characterizes the joint visual exposure for each map location using a 2-digit code— a location with a value of 11 indicates 1= Low housing exposure and 1= Low roads exposure; a value of 12= Low/Medium, ... to a value of 33= High/High.*



[Exercise 5.6](#) Extending

Visual Analysis to Other Areas — *this exercise creates a visual exposure map to roads and graphically overlays it on the Elevation surface for the Island database.*
