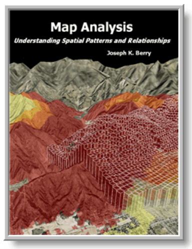
Beyond Mapping III

Topic 29: Spatial Modeling in Natural Resources



***Map Analysis* book with companion CD-ROM for hands-on exercises and further reading**

Harvesting an Understanding of GIS Modeling — *describes a prototype model for assessing off-road access to forest areas*
Extending Forest Harvesting's Reach — *discusses a multiplicative weighting method for model extension*
A Twelve-step Program for Recovery from Flaky Forest Formulations — *describes a spatial model for identifying Landings and Timbersheds*
E911 for the Backcountry — *describes development of an on- and off-road travel-time surface for emergency response*
Optimal Path Density isn't all that Conceptually Dense — *discusses the use of Optimal Path Density to identify corridors of common access*
Extending Emergency Response Beyond the Lines — *discusses basic model processing and modifications for additional considerations*
Comparing Emergency Response Alternatives — *describes comparison procedures and route evaluation techniques*
Bringing Travel and Terrain Directions into Line — *describes comparison procedures and route evaluation techniques*
Assessing Wildfire Response (Part 1): *Oneth by Land, Twoeth by Air* — *discusses a spatial model for determining effective helicopter landing zones*
Assessing Wildfire Response (Part 2): *Jumping Right into It* — *describes map analysis procedures for determining initial response time for alternative attack modes*
Mixing It up in GIS Modeling's Kitchen — *an overview of map analysis and GIS modeling considerations*
Putting GIS Modeling Concepts in Their Place — *develops a typology of GIS modeling types and characteristics*
A Suitable Framework for GIS Modeling — *describes a framework for suitability modeling based on a flowchart of model logic*
GIS's Supporting Role in the Future of Natural Resources — *discusses the influence of human dimensions in natural resources and GIS technology's role*

Note: The processing and figures discussed in this topic were derived using MapCalc™ software. See www.innovativegis.com to download a free MapCalc Learner version with tutorial materials for classroom and self-learning map analysis concepts and procedures.

<Click here> right-click to download a printer-friendly version of this topic (.pdf).

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Harvesting an Understanding of GIS Modeling

(GeoWorld, April 2010)

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Vast regions of the Rocky Mountains are under attack by mountain pine beetles and a blanket of brown is covering many of the hillsides. Dead and dying trees stretch to the horizon. In five years there will be just sticks poking up and within twenty years the forest floor will look like a game of "pick-up sticks" with a new forest poking through.

It's an ecological cycle, but it is both aggravated by and aggravating to many of us who live and play in the shadows of the mountains. Is there something we can do to contain the spread and hasten the regenerative cycle? One suggestion is to remove the dead wood to speed forest health and convert it to useful products to boot.

This appears attractive but just knowing there are giga-tons of beetle-gnawed biomass awaiting "wood utilization" solutions isn't a fully actionable answer. What products are viable? Where and how much harvesting is appropriate?

These two basic questions captured the attention of combined graduate project teams at the University of Denver. A "capstone MBA" team focused on the business case while a "GIS modeling" team focused on the geographic considerations. Their joint experience in identifying, describing and evaluating potential solutions provided an opportunity to get their heads around a complex issue requiring integration of spatial and non-spatial analysis, both at a macro state-wide level and a micro local level. The experience also provides a springboard for a short Beyond Mapping series on GIS modeling (scar tissue and all).

Our outside collaborators (a non-profit organization and a large energy company) narrowed the investigation to biomass for augmentation of base-load electric energy generation—first lesson, *always heed the client's interests*. This assumption narrows the macro considerations as haul distances from a plant are critical. Considering mountainous travel, buffering to a simple geographic distance is insufficient and travel-time zones were recommended—second lesson, *clients love the on-road travel-time concept*.

The concept of modeling off-road access, on the other hand, is a bit harder to appreciate. It was decided that a micro level "proof-of-concept prototype model" for assessing forest access would be developed. Figure 1 depicts the map variables and basic approach taken for a hypothetical demonstration area—third lesson, *never use real data for a prototype model if you want clients to concentrate on model logic*.

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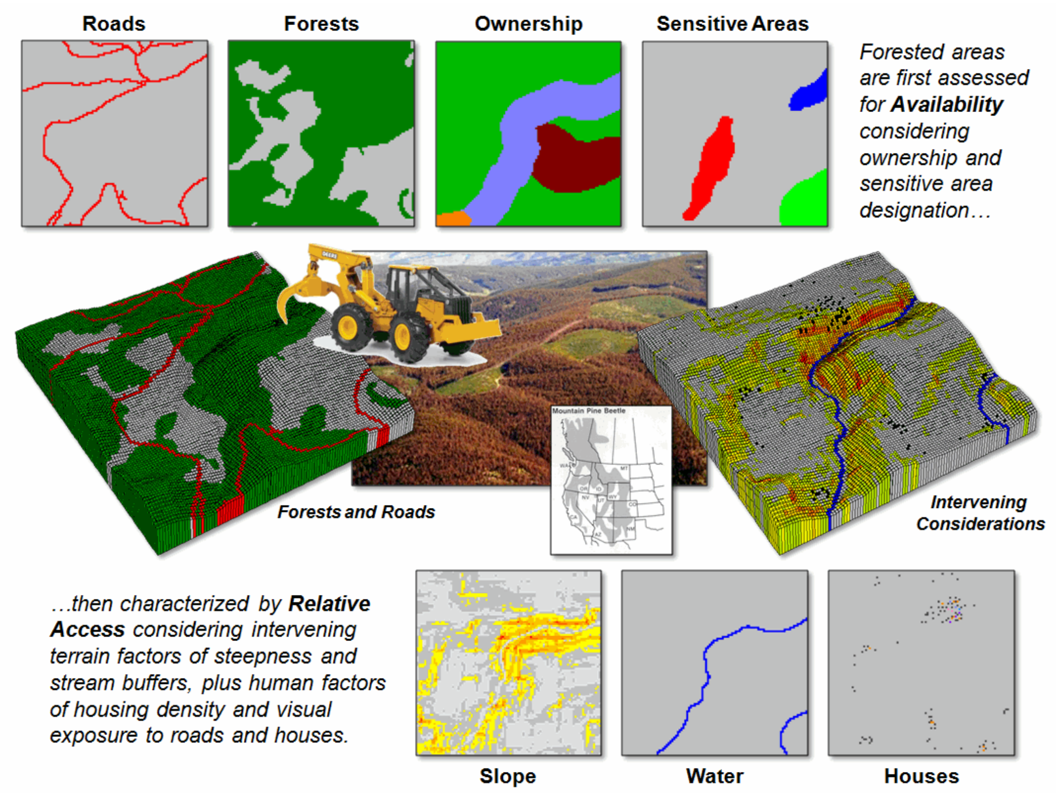


Forested areas are first assessed for ***Availability*** *considering ownership and sensitive area designation…*

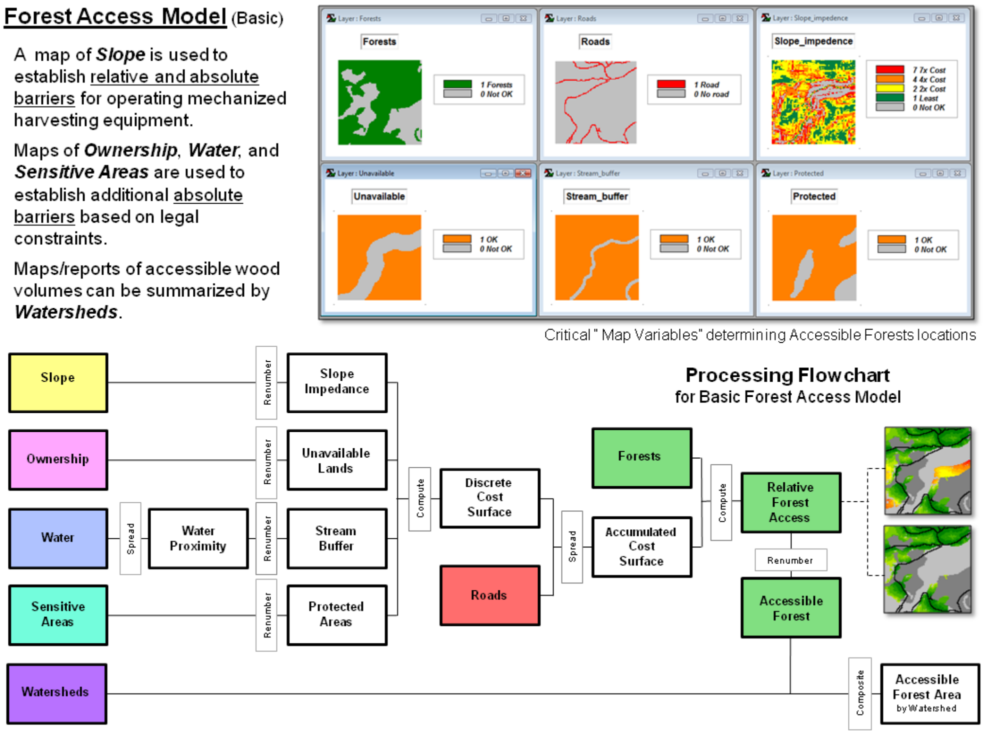
…then characterized by ***Relative Access*** *considering intervening terrain factors of steepness and stream buffers, plus human factors of housing density and visual exposure to roads and houses.*

Figure 1. Relative harvesting access is determined by availability of forest lands as modified by intervening conditions.

The first phase of the basic model determines ***Availability*** of lands for harvesting activity. Legal concerns, such as ownership, stream buffers and sensitive areas must be identified and unavailable lands removed from further consideration. In addition, physical conditions can become "absolute barriers," such as steep slopes beyond the operating range of equipment. A second phase characterizes the relative ***Access*** of available lands by considering intervening conditions as "relative barriers," such as increasing slope in operable areas increases costs of harvesting.

It is important not to "over-drive" the purpose of a Prototype Model as a mechanism for demonstrating a viable approach and stimulating discussion—fourth lesson, *"keep it simple stupid (KISS)" to lock a client's focus on model approach and logic*. Anticipated refinements should be reserved for a "Further Considerations" section in the presentation describing the prototype model.

If model refinement accompanies prototype development, there isn't a need for a prototype. But that is the bane of a "waterfall approach" to GIS modeling. You can easily drown by jumping off the edge at the onset; whereas calmly walking into the pool with your client engages and involves them, as well as bounds a manageable first cut of the approach and logic … baby steps with a client, not a top-down GIS'er solution out of the box. Fifth lesson—*there is a sweet spot* *along a client's perception of a model from a Black box of confusion to Pandora's box of terror.*



Forest Access Model (Basic)

A map of ***Slope*** is used to establish relative and absolute barriers for operating mechanized harvesting equipment.

Maps of ***Ownership***, ***Water***, and ***Sensitive Areas*** are used to establish additional absolute barriers based on legal constraints.

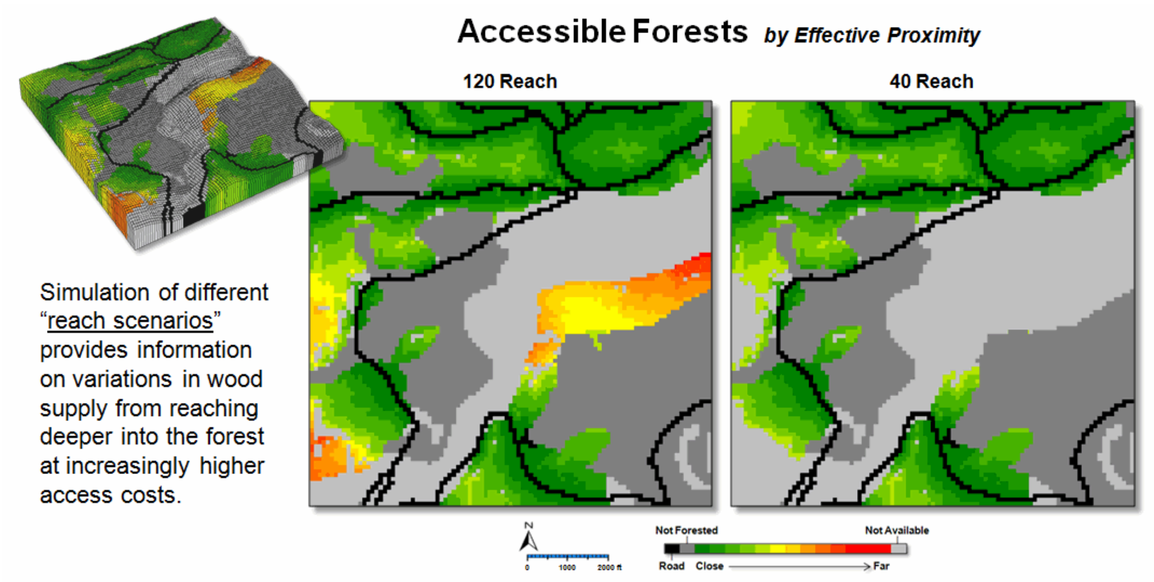
Maps/reports of accessible wood volumes can be summarized by ***Watersheds***.

Critical " Map Variables" determining Accessible Forests locations

Figure 2. Flowchart of the basic model involves four base maps and ten processing commands.

Figure 2 contains a flowchart of model logic for the basic Availability/Access prototype model. Only four base maps and ten commands are involved in a demonstrative first cut. A Slope map is used to derive slope impedance where ranges of steepness are assigned 1 (most preferred)= 0-10%, 2= 10-20%, 4= 20-30% 7 (seven times less preferred)= 30-40% and 0 (unavailable)= >40%. The other maps of Ownership, Water and Sensitive Areas are used to derive binary maps where 1= available and 0= unavailable lands. The final step calculates the acreage of accessible forests within each watershed.

The four calibrated maps are multiplied for a Discrete Cost Surface that contains a zero for unavailable lands (any 0 in the map stack sends that location to 0) and the relative "friction values" based on terrain steepness are preserved for available areas (1 * 1* 1 * friction value retains that value). In turn, this map is used to generate the relative access map using a "Least Cost" approach that will be discussed in next month's column that "lifts the hood" on technical considerations (see Author's note).



Simulation of different "reach scenarios" provides information on variations in wood supply from reaching deeper into the forest at increasingly higher access costs.

Figure 3. Different effective "reaches" into the accessible forested areas can be generated to simulate varying budget sensitivities.

Figure 3 provides an early peek at some of the output generated by the basic Forest Access model. The left inset shows the relative access values for all of the available forested areas with warmer tones indicating a long harvesting reach into the woods; light grey, unavailable and dark grey, non-forested. A user can conjure up different "reach" scenarios defining accessible forests as a means to understand the spatial relationships from grabbing just the "low hanging economic fruit (…err, I mean wood)" that is easily accessed (right inset), to increasingly aggressive plunges deeper into the woods at increasingly higher access costs.

Also, consideration of human concerns, such as housing density and visual exposure, might affect a practical assessment of the access reach. Finally, locating suitable staging areas (termed "Landings") for wood collection and the delineation of the forest areas they serve (termed "Timbersheds") provide even more fodder for next couple of columns.

Author's Note: *For a discussion on "Calculating Effective Distance and Connectivity" see the online book, **Beyond Mapping III**, Topic 25, posted at www.innovativegis.com/basis/MapAnalysis/.*

Extending Forest Harvesting's Reach

(GeoWorld, May 2010)

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The previous section described a basic spatial model for determining relative harvesting availability and accessibility of beetle-killed forests for harvesting. The prototype model was developed by "capstone MBA" and "GIS modeling" graduate teams at the University of Denver.

A non-profit organization and a large energy company served as outside collaborators and narrowed the focus to the extraction of biomass for base-load electrical energy generation.

State-wide analysis involving on-road travel was proposed for assessing hauling distances of wood chips to power plants where the resource would be further refined and mixed with coal. Adjusting for mountainous travel along the road network, some beetle-kill areas simply are too far from a plant for consideration.

Local level analysis involving off-road harvesting is considerably more complex. In summary, this processing determines the relative accessibility from the landings into the forest considering a variety of terrain, ownership and environmental considerations. Adjusting for off-road access, some beetle-kill areas are unavailable or effectively too far from roads for harvesting.

The Basic Access Model outlined in the top portion of figure 1 demonstrates the types of factors that can be considered in assessing off-road access. The processing first identifies *absolute barriers* to harvesting based on ownership, environmentally sensitive areas, water buffers and terrain that is too steep for equipment to operate. These factors are represented as binary map layers with 1= available and 0= unavailable for harvesting activity.

Relative barriers to forest access are rated from 1= most preferred to 9= least preferred. In the prototype model, slopes within the harvesting equipment operating range are used to demonstrate relative barriers with increasingly steeper slopes becoming less and less desirable. Multiplying the stack of map layers identifying absolute and relative barriers results in an overall preference surface for harvesting with values from 0 (no-go), to 1 (best) through 9 (worst). The final step uses grid-based *effective distance* techniques to determine the relative accessibility of available forested areas from roads (see author's note).

As an extension to the basic model, human concerns for minimizing visual exposure and housing density are outlined in the lower portion of figure 1. The procedure first derives a visual exposure density surface identifying the number of times each location is seen from houses and roads and then calibrates the exposure from .5 (low exposure) through 1.0 (high exposure). Similarly, a housing density surface identifying the number of houses within a half mile radius was calibrated from .5 (low density) to 1.0 (high density). The two adjusted maps are averaged for an overall weighting factor for each map location.

When the multiplicative weight is applied to the preference map stack, it improves (lowers) preference ratings in areas with low visual exposure and housing density, while retaining the basic ratings in areas of high visual exposure and housing density. The effect on the model is to favor reaching farther into available forested areas in locations that are less contentious.

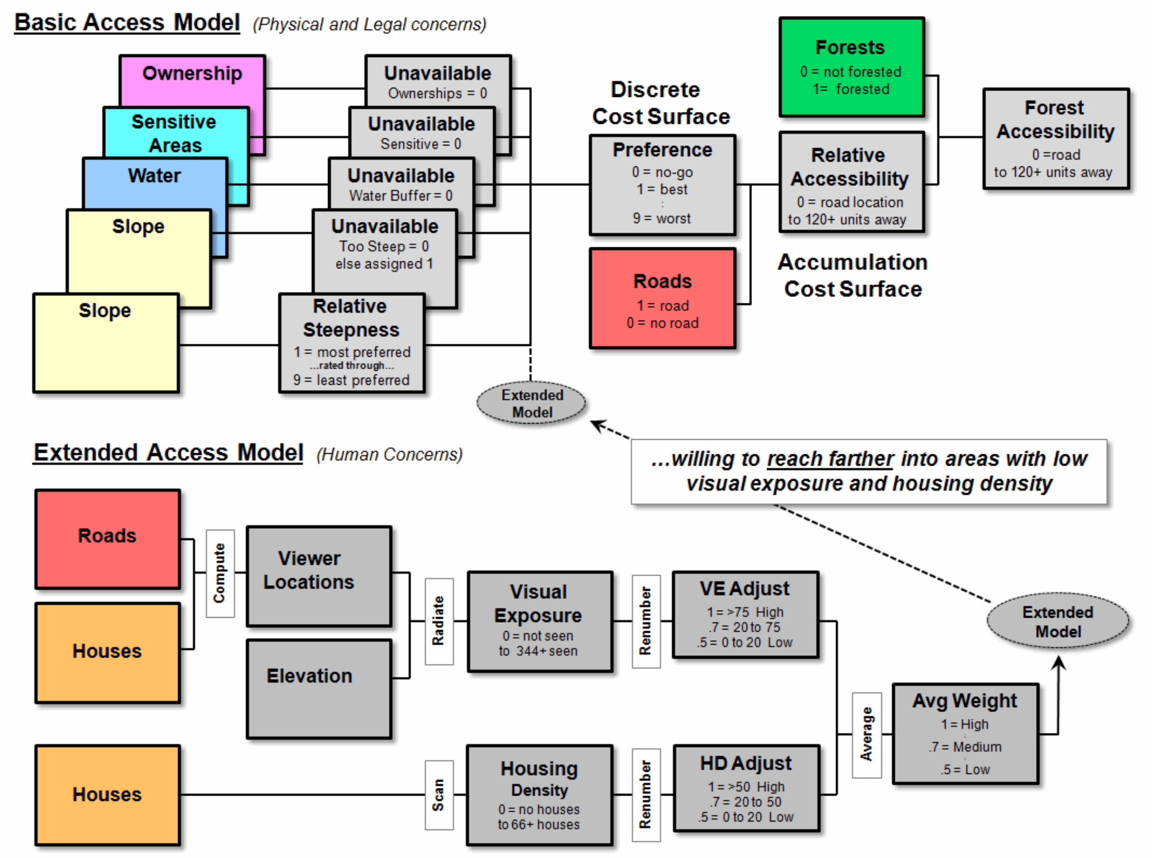


Figure 1. The Extended Access Model develops a multiplicative weighting factor based on housing density and visual exposure of potential harvesting areas.

Figure 2 compares the results with the left side of the figure tracking the results of Basic Model and the right side tracking the results of the Extended Model that favors harvesting in areas of low human impact. The effective distance to the farthest available forest location is reduced by a third from 116 to 76. The 3D plots on the bottom of the figure (insets c and d) depict the results as bowl-shaped accumulation surfaces with the lowest value of 0 “cells away” from the road in the lower center portion of the project area. Note the considerable easing (lower values; flattening of the surface) of the relative proximity at the circled remote location.

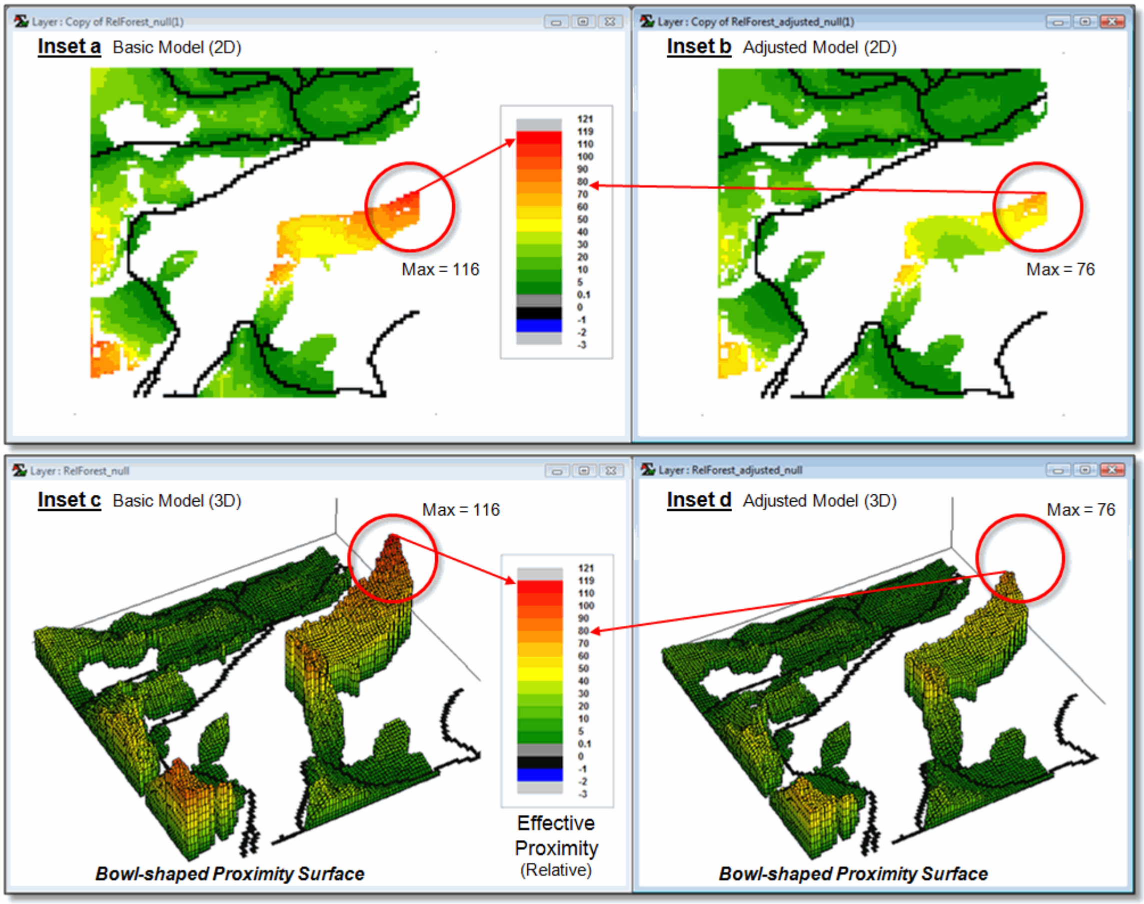
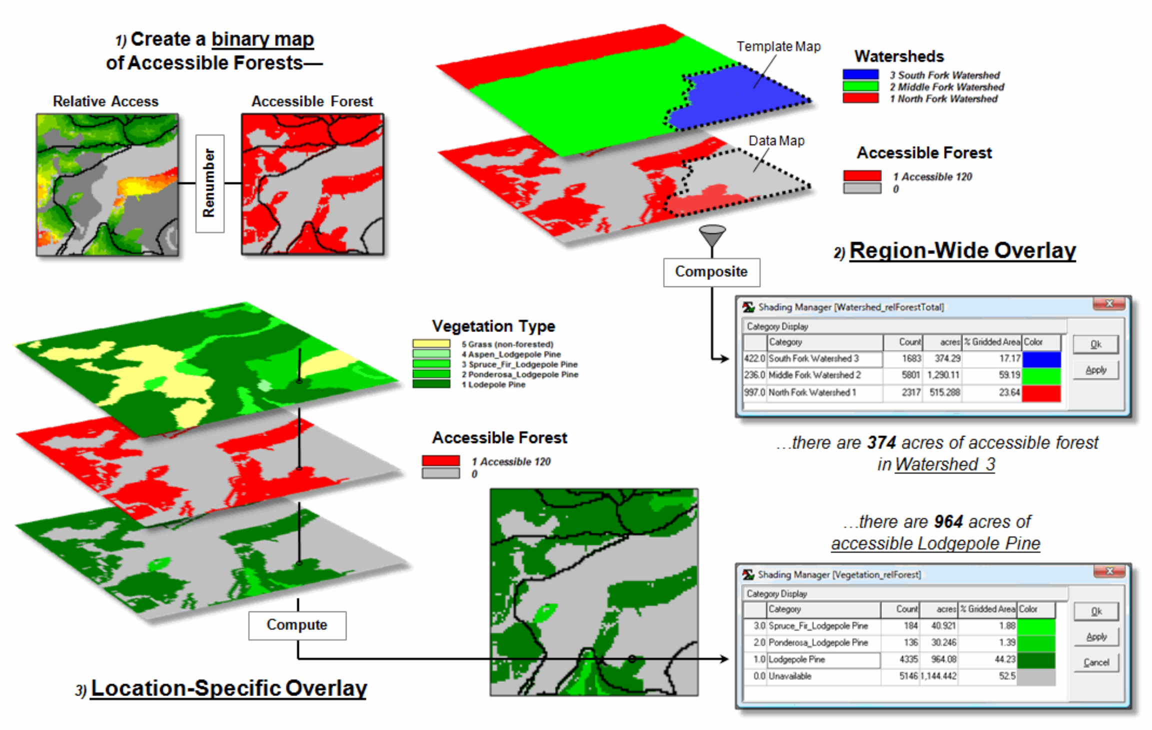


Figure 2. Comparison of Basic and Extended model results.

Figure 3 illustrates a couple of techniques for summarizing related map information using a binary map of accessible forest areas. A region-wide (zonal) overlay operation can be used to "count" the total number of acres of accessible forest in each of the three watersheds (e.g., 374 aces of accessible forest in Watershed 3). Also, by simply multiplying the binary map times the vegetation map identifies the vegetation type and area for all of the accessible forest locations (e.g., 964 acres of accessible Lodgepole pine).

The ability to repackage all beetle-kill areas into those meeting harvesting availability and access requirements is critical. Just knowing that there are giga-tons of biomass out there isn't sufficient until they are mapped within a comprehensive decision-making context. The next section explores procedures for determining the best set of staging areas, termed "landings," and the characterization of the potential wood chip supply within each of their corresponding "timbersheds."



Shading Manager [Watershed_relForestTotal]

Category Display

	Category	Count	acres	% Gridded Area	Color
422.0	South Fork Watershed 3	1683	374.29	17.17	🟦
236.0	Middle Fork Watershed 2	5801	1,290.11	59.19	🟩
997.0	North Fork Watershed 1	2317	515.288	23.64	🟥

*…there are **374** acres of accessible forest in Watershed 3*

*…there are **964** acres of accessible Lodgepole Pine*

Shading Manager [Vegetation_relForest]

Category Display

	Category	Count	acres	% Gridded Area	Color
3.0	Spruce_Fir_Lodgepole Pine	184	40.921	1.88	🟩
2.0	Ponderosa_Lodgepole Pine	136	30.246	1.39	🟩
1.0	Lodgepole Pine	4335	964.08	44.23	🟩
0.0	Unavailable	5146	1,144.442	52.5	⬜

Figure 3. D. Summarizing accessible forest areas by watersheds and vegetation type.

Author's Note: *For a discussion on "Calculating Effective Distance and Connectivity" see the online book, Beyond Mapping III, Topic 25, posted at* www.innovativegis.com/basis/MapAnalysis/.

A Twelve-step Program for Recovery from Flaky Forest Formulations

(GeoWorld, June 2010)

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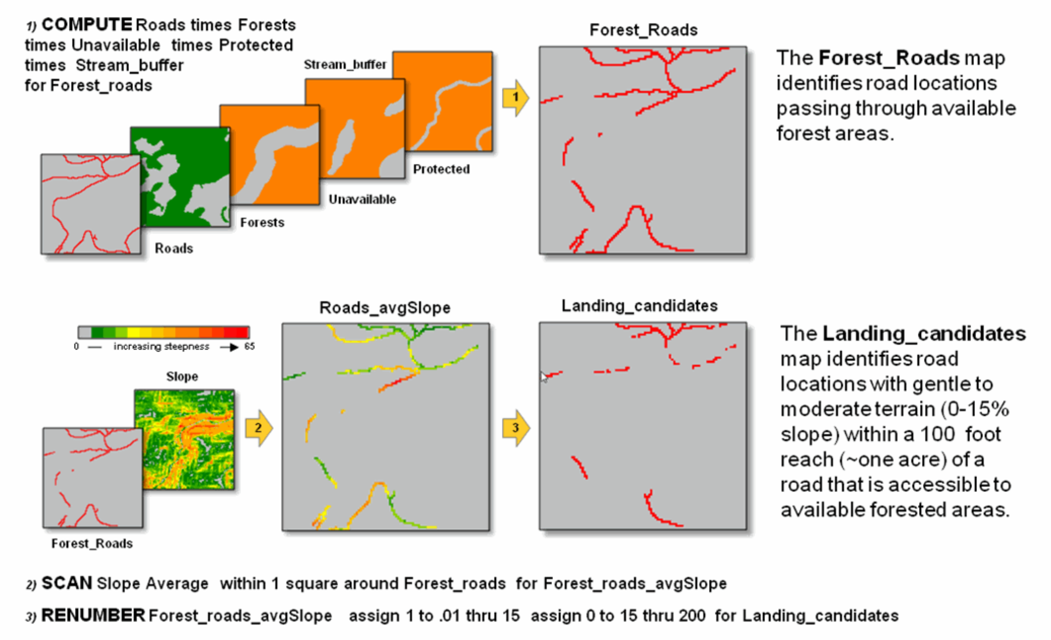
The last two sections described a basic spatial model for determining forest availability and access considering physical and legal factors that, in turn, was extended to include human concerns of housing density and visual exposure to harvesting activity. This column builds on those procedures for a further formulated model that 1) identifies the best set of staging areas for wood collection, termed "*Landings*" and 2) delineates the harvest areas optimally connected to each landing, termed "*Timbersheds.*"

The model involves logical sequencing of twelve standard map analysis steps that are described using MapCalc commands that are easily translated into other grid-based software systems (see author's note). The top portion of figure 1 uses the five "binary maps" created in the basic model to generate a map of potential landing areas. The maps are calibrated as 1 = available and

0 = not available for harvesting, and when multiplied together (*1. Compute*) results in 1 being assigned to all roads locations passing through available forest areas— 1*1*1*1*1= 1; if a zero appears in any map layers it results in a 0 value (not a road in an available forest area).



1) **COMPUTE** Roads times Forests times Unavailable times Protected times Stream_buffer for Forest_roads

The **Forest_Roads** map identifies road locations passing through available forest areas.

The **Landing_candidates** map identifies road locations with gentle to moderate terrain (0-15% slope) within a 100 foot reach (~one acre) of a road that is accessible to available forested areas.

2) **SCAN** Slope Average within 1 square around Forest_roads for Forest_roads_avgSlope

3) **RENUMBER** Forest_roads_avgSlope assign 1 to .01 thru 15 assign 0 to 15 thru 200 for Landing_candidates

Figure 1. Identifying candidate Landing Sites that are along forested roads in gently sloped areas (steps 1-3).

The lower portion of figure 1 depicts using a neighborhood/focal summary operation (*2. Scan*) to calculate the average slope within a 100-foot reach of the each forested road cell. The third step (*3. Renumber*) eliminates potential landing areas that that are in areas with fairly steep surrounding terrain (> 15% average slope). The result is removal of over two thirds of the total number of road locations.

Figure 2 shows processing steps 4 through 9 used to locate the best landing sites. In step 4, the Discrete Cost map indicating the relative ease of equipment operation created in the basic model is masked (*4. Compute*) to constrain harvesting activity to just the forested areas. The Accumulated Proximity from roads is calculated (*5. Spread*) resulting in an effective distance value for each forest location that respects the intervening terrain conditions from forested roads.

The optimal path from each forest location to its nearest road location is determined and the set of paths are counted for each map location (*6. Drain*) resulting in an Optimal Path Density surface. The insets in the upper-right portion of figure 2 shows 2D and 3D displays of this less-than-intuitive surface. Note the yellow and red tones where many forest locations are optimally accessed—with one road location in the southern portion of the project area servicing 785 forested locations. The long red path leading to this location is analogous to a primary road

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where more and more collector streets join the overall best route.

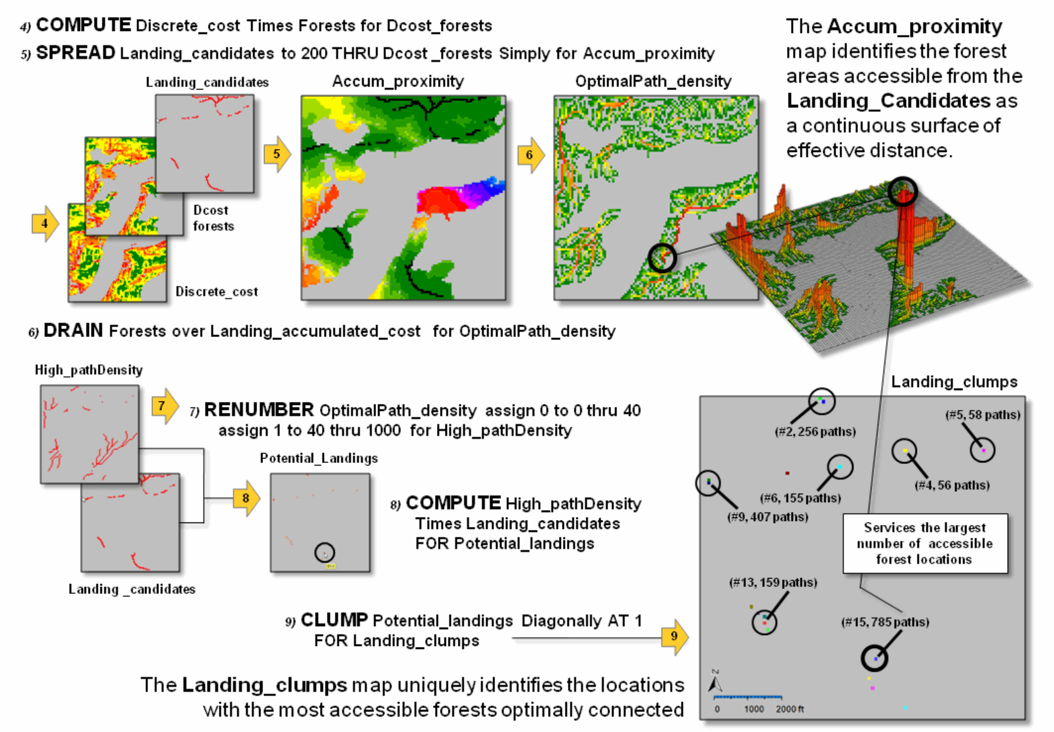
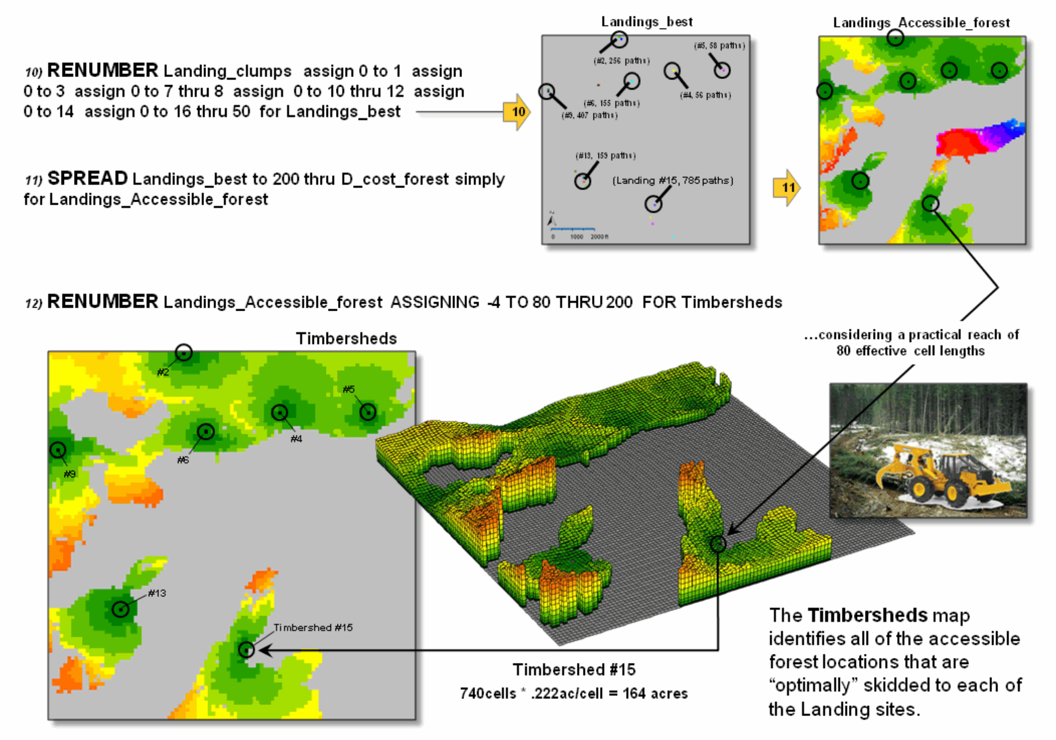


Figure 2. Locating the best Landing Sites based on optimal path density (steps 4-9).

The summary statistics, along with expert judgment is used to identify an appropriate final set of landing sites that is suitably dispersed throughout the project area (*10. Renumber*) as depicted in the upper portion of figure 3. These final locations for *Landings* are used to derive new effective distance values for each forest location considering intervening terrain conditions (*11. Spread*) in a manner similar to step 5. Finally, expert judgment is used to limit the reach in each of the Timbersheds to a manageable distance (*12. Renumber*).

The lower portion of figure 2 shows the steps for isolating the best landing sites. The highest levels of optimal path density are isolated (*7. Renumber*) and then masked to identify the forested road locations with the highest optimal path density (*8. Compute*). In turn these locations are assigned a unique ID value (*9. Clump*) and summary statistics on each of the “best” potential landing sites are generated.



10) **RENUMBER** Landing_clumps assign 0 to 1 assign 0 to 3 assign 0 to 7 thru 8 assign 0 to 10 thru 12 assign 0 to 14 assign 0 to 16 thru 50 for Landings_best

11) **SPREAD** Landings_best to 200 thru D_cost_forest simply for Landings_Accessible_forest

12) **RENUMBER** Landings_Accessible_forest ASSIGNING -4 TO 80 THRU 200 FOR Timbersheds

…considering a practical reach of 80 effective cell lengths

Timbershed #15
740cells * .222ac/cell = 164 acres

The **Timbersheds** map identifies all of the accessible forest locations that are “optimally” skidded to each of the Landing sites.

Figure 3. Identifying and characterizing the Timbersheds of the best Landing Sites (steps 10-12).

To put the spatial analysis into a decision context, a “thumbnail” estimate of the wood chip resource for Timbershed #15 is 164ac * 40T/ac = 6560 tons. At $15 to $30 per ton this converts to 6560T * $22.50 = $147,600. From another perspective, assuming 6000 to 8000 btu per pound of woodchips the energy stored in the biomass translates to 6560T * 2000lb/T * 7000btu/lb = 91,840,000,000 btu. At 3412 btu per kilowatt hour this converts to 91,840,000,000btu / 3412btu/kWh = nearly 27 million kilowatt hours …whew!

Any way you look at it there is a lot of energy locked up in the giga-tons of beetle-gnawed biomass blanketing the Rockies. GIS modeling of its availability and access is but one of several critical steps needed in determining the economic, environmental and social viability of a “wood utilization” solution.

Author’s Note: *See http://www.innovativegis.com/basis/MapCalc/MCcross_ref.htm for cross-reference of MapCalc commands to other software systems. An animated PowerPoint slide set of this 3-part Beyond Mapping series on “Assessing and Characterizing Relative Forest Access” and materials for a “hands-on” exercise are posted at www.innovativegis.com/basis/MapAnalysis/Topic29/ForestAccess.htm.*

E911 for the Backcountry

(GeoWorld, July 2010)

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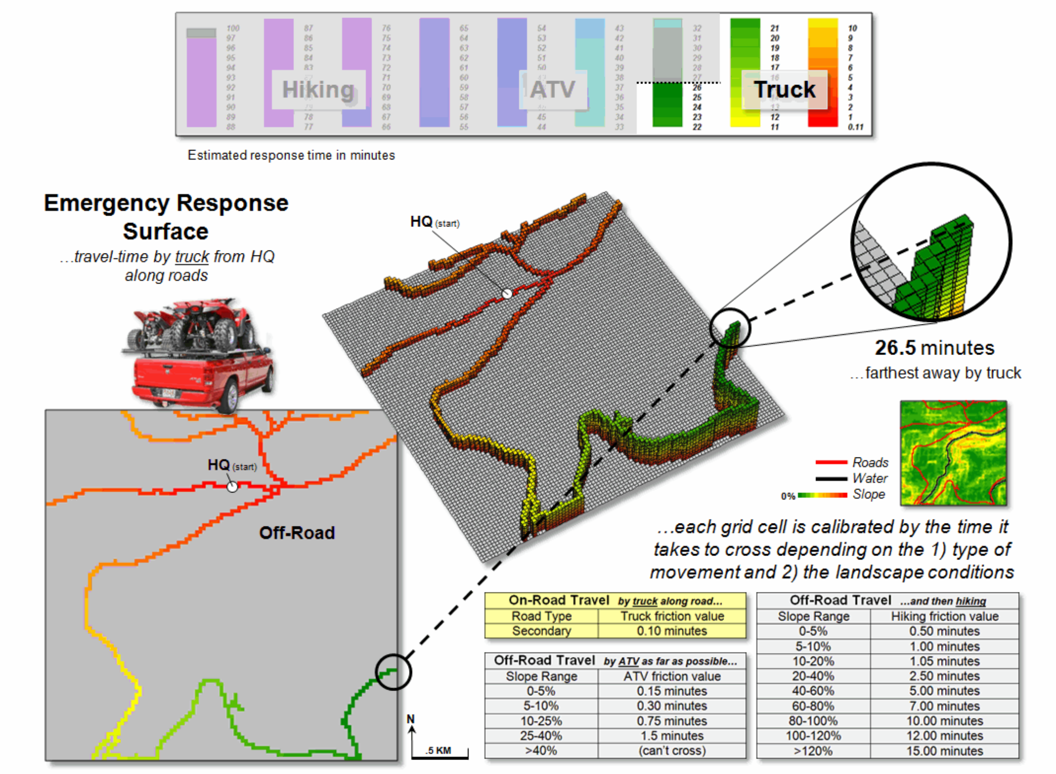
One of the most important applications of geotechnology has been Enhanced 911 (E911) location technology that enables emergency services to receive the geographic position of a mobile phone. The geographic position is automatically geo-coded to a street address and routing software is used to identify an optimal path for emergency response. But what happens if the call that "I've fallen and can't get up" comes from a backcountry location miles from a road? The closest road location "as the crow flies" is rarely the quickest route in mountainous terrain.

A continuous space solution is a bit more complex than traditional network analysis as the relative and absolute barriers for emergency response are scattered about the landscape. In addition, the intervening conditions affect modes of travel differently. For example, an emergency response vehicle can move rapidly along the backcountry roads, and then all terrain vehicles (ATV) can be employed off the roads. But ATVs cannot operate under extremely steep and rugged conditions where hiking becomes necessary.



…each grid cell is calibrated by the time it takes to cross depending on the 1) type of movement and 2) the landscape conditions

On-Road Travel *by truck along road…*	
Road Type	Truck friction value
Secondary	0.10 minutes

Off-Road Travel *by ATV as far as possible…*	
Slope Range	ATV friction value
0-5%	0.15 minutes
5-10%	0.30 minutes
10-25%	0.75 minutes
25-40%	1.5 minutes
>40%	(can't cross)

Off-Road Travel *…and then hiking*	
Slope Range	Hiking friction value
0-5%	0.50 minutes
5-10%	1.00 minutes
10-20%	1.05 minutes
20-40%	2.50 minutes
40-60%	5.00 minutes
60-80%	7.00 minutes
80-100%	10.00 minutes
100-120%	12.00 minutes
>120%	15.00 minutes

Figure 1. On-road emergency response travel-time.

The left side of figure 1 illustrates the on-road portion of a travel-time (TT) surface from headquarters along secondary backcountry roads. The grid-based solution uses friction values for each grid cell in a manner analogous to road segment vectors in network analysis. The difference being that each grid cell is calibrated for the time it takes to cross it (0.10 minute in this simplified example).

The result is an estimate of the travel-time to reach any road location. Note that the on-road surface forms a rollercoaster shape with the lowest point at the headquarters (TT = 0 minutes away) and progressively increases to the farthest away location (TT = 26.5 minutes). If there are two or more headquarters, there would be multiple "bottoms" and the surface would form ridges at the equidistance locations in terms of travel-time—each road location assigned a value indicating time to reach it from the closest headquarters.

The lower-right portion of figure 1 shows the calibrations for on-road travel by truck and off-road travel by ATV and hiking as a function of terrain steepness and recognition of rivers as absolute barriers to surface travel. The programming trick at this point is to use the accumulated on-road travel-time for each road location as the starting TT for continued movement off-road. For example, the off-road locations around the farthest away road location starts "counting" at 26.5, thereby carrying forward the on-road travel time to get to off-road locations. As the algorithm proceeds it notes the on- and off-road travel-time to each ATV accessible location and retains the minimum time (shortest TT).

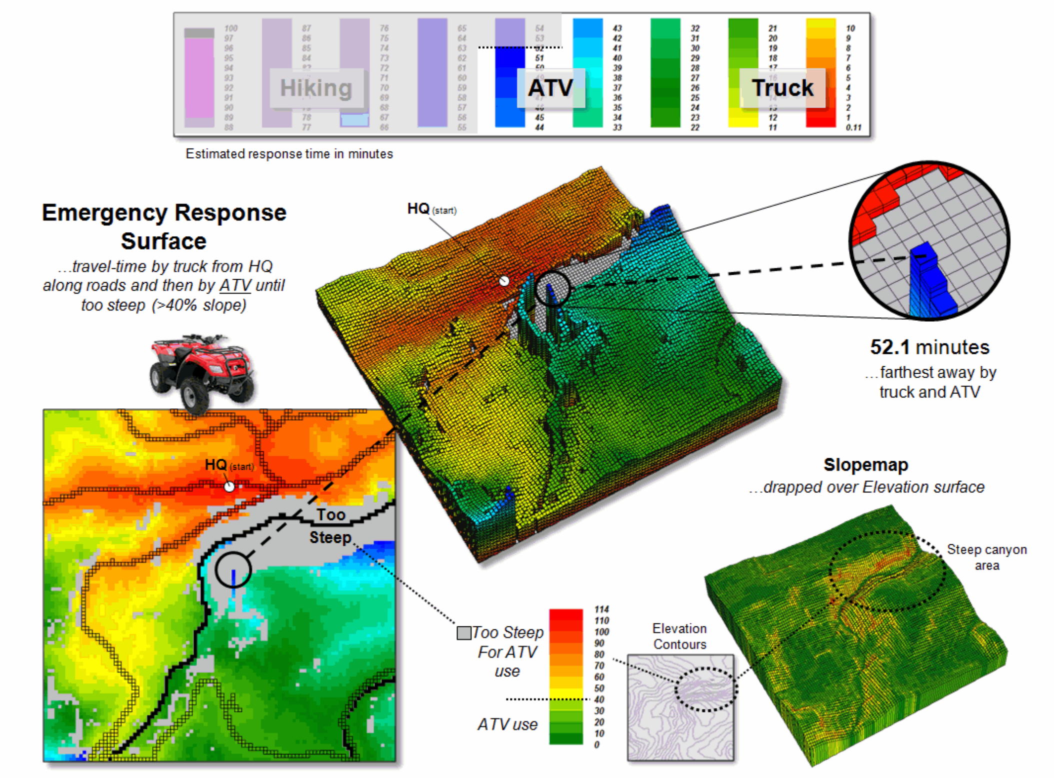


Figure 2. On-road plus off-road travel-time using ATV under operable terrain conditions.

Figure 2 identifies the shortest combined on- and off-road travel-times. Note that the emergency response solution forms a bowl-like surface with the headquarters as the lowest point and the

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road proximities forming “valleys” of quick access. The sides of the valleys indicate ATV off-road travel with steeper rises for areas of steeper terrain slopes (slower movement; higher TT accumulation). The farthest away location accessible by truck and then ATV is 52.1 minutes.

The grey areas in the figure indicate locations that are too steep for ATV travel, particularly apparent in the steep canyon area (lower left insert with warmer tones of Slope draped over the Elevation surface). The sharp “escarpment-like” feature in the center of the response surface is caused by the absolute barrier effect of the river—shorter/easier easier access from roads west of the river.

Figure 3 completes the emergency response surface by accounting for hiking time from where the wave front of the accumulated travel-time by truck and ATV stopped. Note the very steep rise in the surface (blue tones) resulting from the slow movement in the rugged and steep slopes of the canyon area. The farthest away location accessible by truck, then ATV and hiking is estimated at 96.0 minutes.

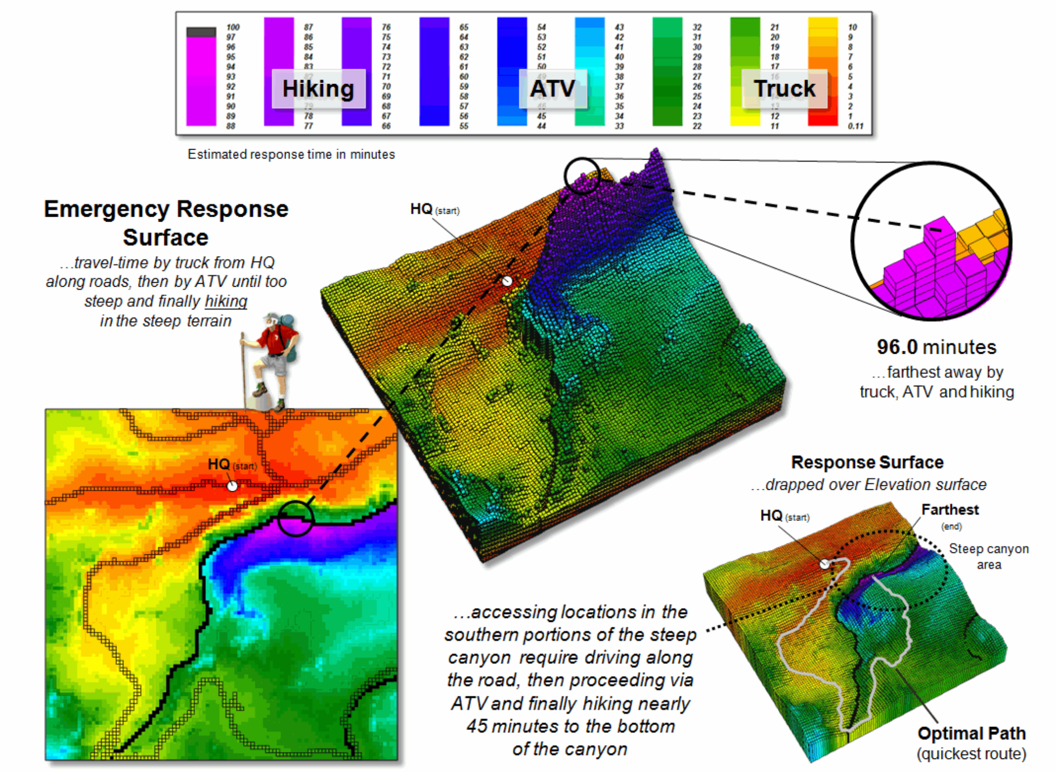

Figure 3. On-road plus off-road travel-time by ATV and then hiking under extreme terrain conditions.

The lower-left insert shows the emergency response values draped over the Elevation surface. Note that the least accessible areas occur on the southern side of the steep canyon. The optimal (quickest) path from headquarters to the farthest location is indicated—that is within the assumptions and calibration of the model.

Later in this topic we will investigate some alternative scenarios, such as constructing a suspension bridge at the head of the canyon and identifying helicopter landing areas that could be used. However the next two sections investigate travel/terrain interaction and optimal path density to identify access corridors.

The bottom line of all this discussion is that GIS modeling can extend emergency response planning "beyond the lines" of a fixed road network—an important spatial reasoning point for GIS'ers and non-GIS'ing resource managers alike.

Author's Note: *See www.innovativegis.com/basis/MapAnalysis/Topic29/EmergencyResponse.htm for an animated slide set illustrating the incremental propagation of the travel-time wave front considering on- and off-road travel and materials for a "hands-on" exercise in deriving continuous space emergency response surfaces.*

Optimal Path Density is not all that Dense (Conceptually)

(GeoWorld, January 2013)

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The previous section addressed "Backcountry 911" that considers both on- and off-road travel for emergency response. Recall that the approach uses a stepped-accumulation cost surface to estimate travel-time by truck, then all-terrain vehicle (ATV) and finally hiking into areas too steep for ATVs.

The result is a map surface (formally termed an ***Accumulation Surface***) that identifies the minimum travel-time to reach all accessible locations within a project area. It is created by employing the "splash algorithm" to simulate movement in an analogous manner to the concentric wave pattern propagating out from a pebble tossed into a still pond. If the conditions are the same, the effect is directly comparable to the uniform set of ripples.

However as the wavefront encounters varying barriers to movement, the concentric rings are distorted as they bend and wiggle around the barriers to locate the shortest effective path. The conditions at each grid location are evaluated to determine whether movement is totally restricted (absolute barriers) or, if not, the relative difficulty of the movement (relative barrier). The end result is a map surface identifying the "shortest but not necessarily straight line" distance from the starting location to all other locations in a project area.

The emergency response surface shown in figure 1 identifies the minimum travel-time via a combination of truck, ATV and hiking from headquarters (HQ) to all other locations. Travel-time increases with each wavefront step as a function of the relative difficulty of movement that ultimately creates a warped bowl-like surface with the starting location at the bottom (HQ= 0.0

minutes away). The blue tones identify locations of very slow hiking conditions that result in the "mountain" of increasing travel-time to the farthest away location (Emergency Location #1= 96.0 minutes away).

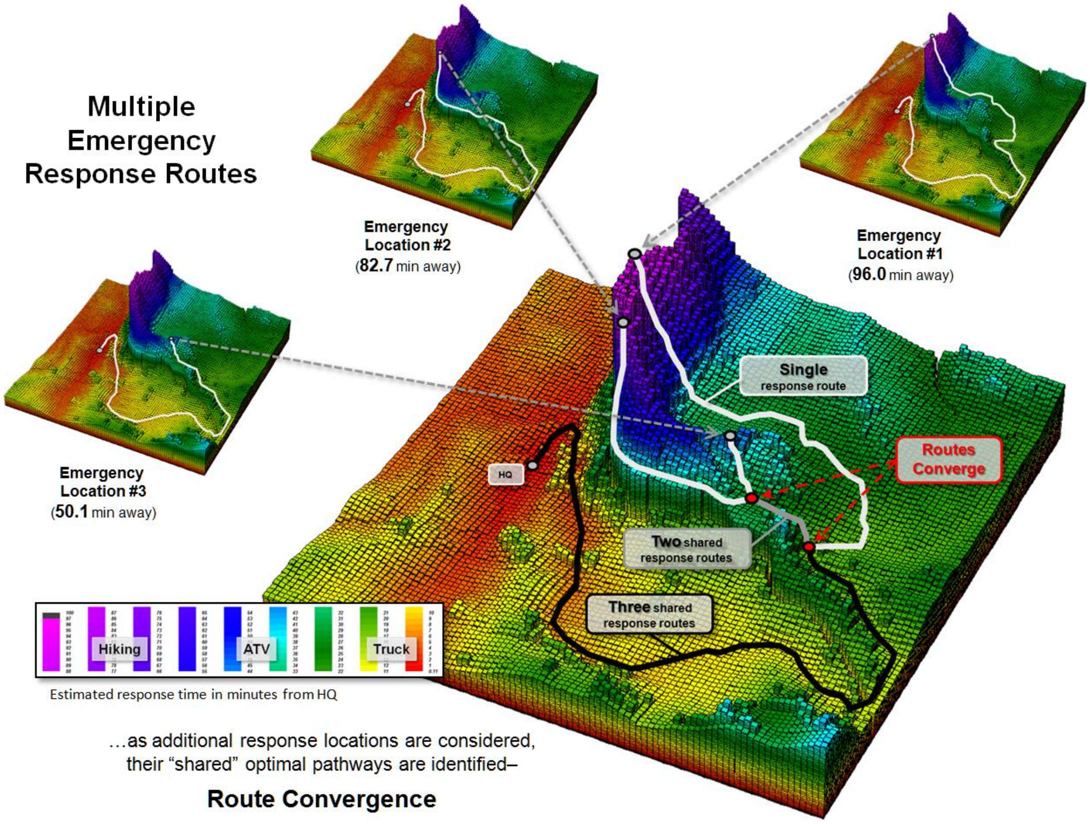

Figure 1. Multiple optimal paths tend to converge to take advantage of "common access" routes over the travel-time surface.

The quickest route is rarely a straight line a crow might fly, but bends and turns depending on the intervening conditions and how they affect travel. The ***Optimal Path*** (minimum accumulated travel-time route) from any location is identified as "*the steepest downhill path over the accumulated travel-time surface*." This pathway retraces the route that the wavefront took as it moved away from the starting location while minimizing travel-time at each step.

The small plots in the outer portion of Figure 1 identify the individual optimal paths from three emergency locations. The larger center plot combines the three routes to identify their convergence to shared pathways— grey= two paths and black= all three paths.

The left side of figure 2 simulates responding to all accessible locations in the project area. The result is an "***Optimal Path Density***" surface that "*counts the number of optimal paths passing through each map location.*" This surface identifies major confluence areas analogous to water running off a landscape and channeling into gullies of easiest flow. The light-colored areas represent travel-time “ridges” that contain no or very few optimal paths. The emergency response “gullies” shown as darker tones represent off-road response corridors that service large portions of the backcountry.

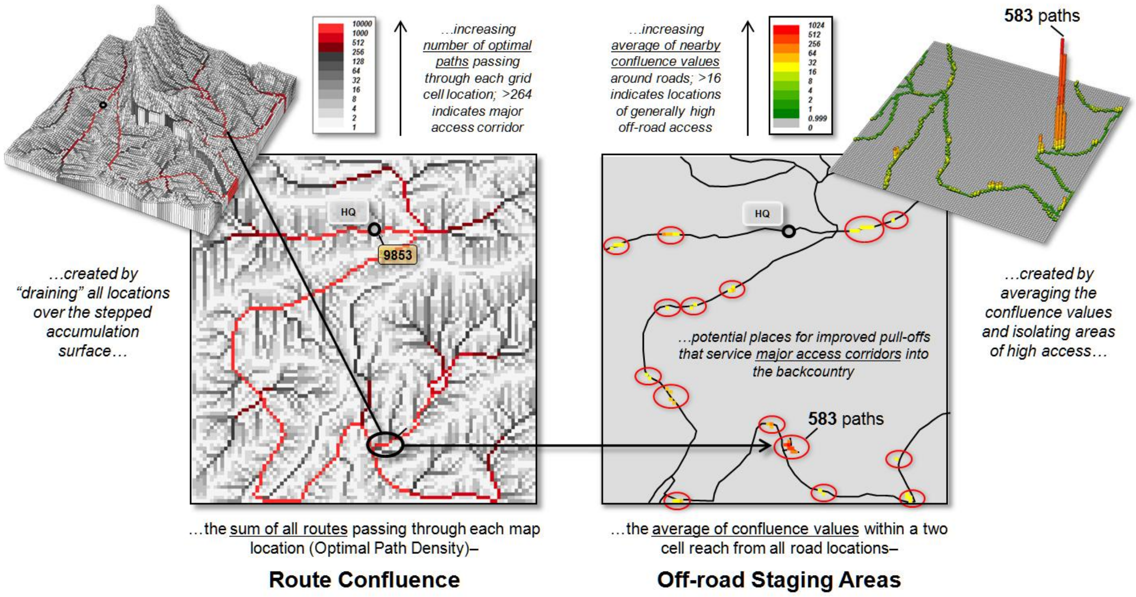

Figure 2. The sum of all optimal paths passing through a location indicates its relative rating as a “corridor of common access” for emergency response.

These “*corridors of common access*” are depicted as increasingly darker tones that switch to red for locations servicing more than 256 potential emergency response locations. Note that 9,853 locations of the 10,000 locations in the project area “drain” into the headquarters location (the difference is the non-accessible flowing water locations).

This is powerful strategic planning information, as well as tactical response routing for individual emergencies (backcountry 911 routing). For example, knowing where the major access corridors intersect the road network can be used to identify candidate locations for staging areas. The right side of figure 2 identifies fifteen areas with high off-road access that exceeds an average of sixteen optimal routes within a 1-cell reach from the road. These “jumping off” points to the major response corridors might be upgraded to include signage for volunteer staging areas and improved roadside grading for emergency vehicle parking.

In many ways, GIS technology is “more different, than it is similar” to traditional mapping and geo-query. It moves mapping beyond descriptions of the precise placement of physical features to prescriptions of new possibilities and perspectives of our geographic surroundings— an Optimal Path Density surface is but one of many innovative procedures in the new map analysis toolbox.

Author’s Note: *a free-use poster and short papers on Backcountry Emergency Response are posted at* *www.innovativegis.com/basis/Papers/Other/BackcountryER_poster/*.

Extending Emergency Response Beyond the Lines

(GeoWorld, August 2010)

(return to top of Topic)

The previous section described a basic GIS model for backcountry emergency response considering both on- and off-road travel. The process used grid-based map analysis techniques that consider the spatial arrangement of absolute barriers (not passable) and relative barriers (passable with varying ease) that impede emergency response throughout continuous geographic space.

While the processing approach is conceptually similar to Network Analysis, movement is not constrained to a linear network of roads represented as a series of irregular line segments but can consider travel throughout geographic space represented as a set of uniform grid cells. The model assumes that the response team first travels by truck along existing roads, then off-loads their all-terrain vehicles (ATV) for travel away from the roads until open water or steep slopes are encountered. From there the team must proceed on foot. The result of the model is a travel-time map surface with an estimated minimum response time assigned to each map location in a project area.

Last section's discussion described the key conceptual considerations and results of the three stages of backcountry emergency response model—truck, ATV and hiking movement. The most notable points were that movement proceeds as ever increasing waves emanating from a staring location that are guided by absolute/relative barriers and results in a continuous travel-time map (bowl-like 3D surface).

Figure 1 outlines the processing as a flowchart. Boxes represent map layers and lines represent analysis tools (MapCalc commands are indicated). The flowchart is organized with columns characterizing "analysis levels" proceeding from Base maps (existing data), to Derived maps, to Interpreted maps, to Modeled map solutions. The progression reflects a gradient of abstraction from "fact-based" (physical) characterization of the landscape involving Base and Derived maps, through increasingly more "judgment-based" (conceptual) characterizations involving Interpreted and Modeled maps expressing spatial relationships within the context of a problem.

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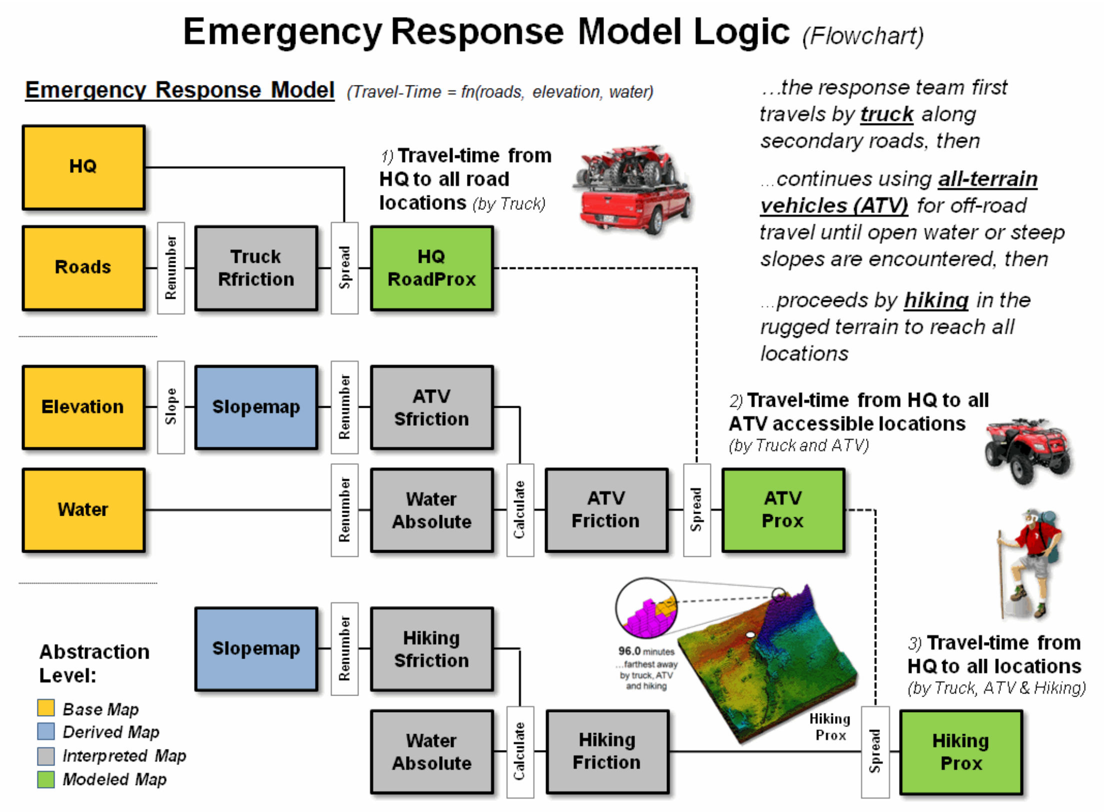

Figure 1. Flowchart of map analysis processing to establish emergency response time to any location within a project area.

The row groupings represent "criteria considerations" used in solving a spatial problem. In this case, the processing first considers truck travel along the roads then extends the movement off-road by ATV travel and finally hiking into the areas that are inaccessible by ATV. The off-road movement is guided by open water (absolute barrier for both ATV and hiking) and terrain steepness (relative barrier for both ATV and hiking and absolute barrier for ATV in very steep slopes).

Figure 2 identifies modifications to the model considering construction of new ATV and hiking trails and a helipad. The left side of the figure updates the ATV and hiking "friction" maps with lower travel-time values for the trails over the unimproved off-road travel impedances. The hiking trail includes a foot bridge at the head of the canyon that crosses the river. The revised friction values (ATV trail = 0.15 minutes; hiking trail = 0.5 minutes) directly replace the old values using a single command and the model is re-executed.

In the case of the new helipad (right side of the figure) the hiking submodel is used but with a new starting location that assumes an 18 minute scramble/flight time to reach the location.

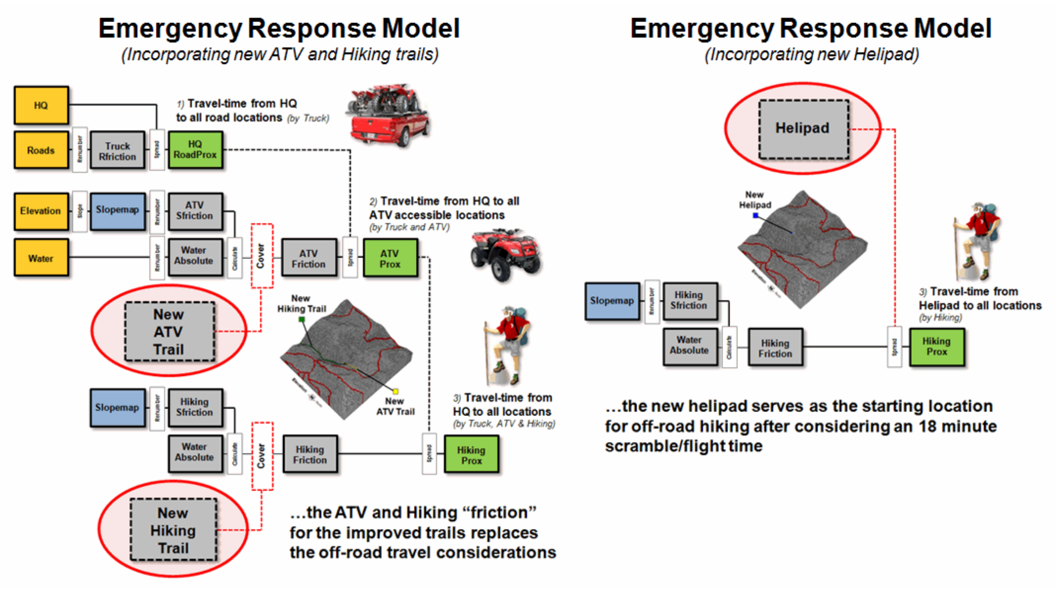

Figure 2. Extended response models for new trails (left) and helipad (right).

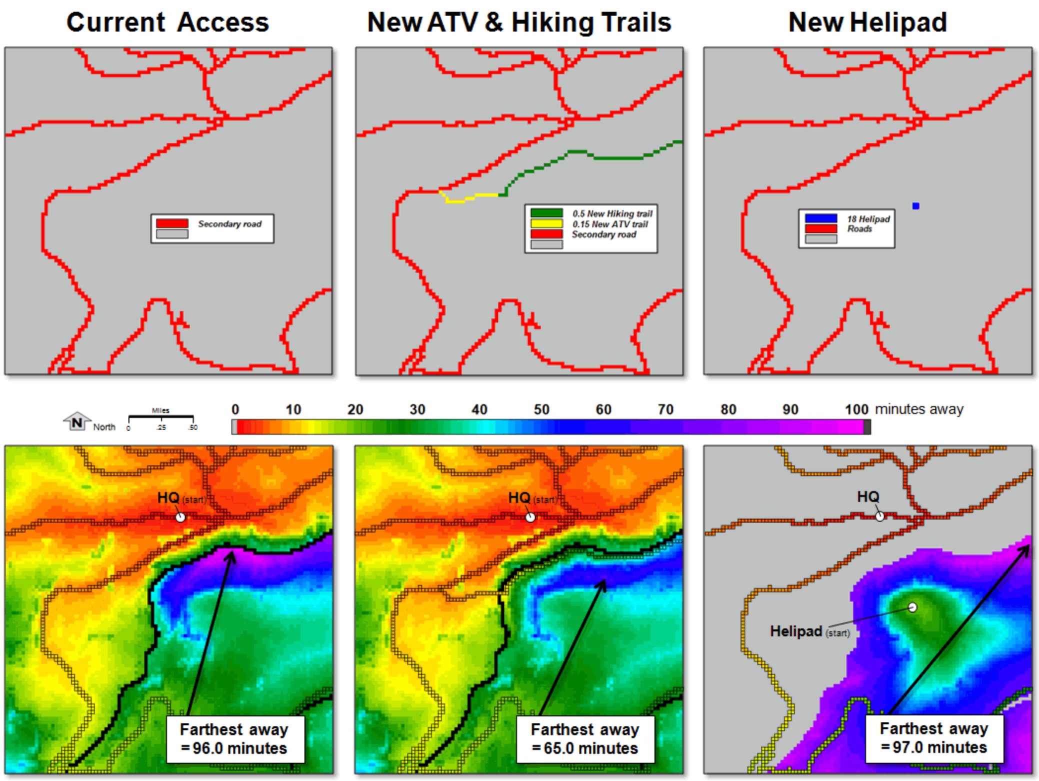

Figure 3. Emergency response surfaces for the current situation, additional trails and helipad.

The bottom portion of figure 3 shows the three emergency response surfaces. Visual inspection

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shows considerable differences in the estimated response time for the area east of the river.

Current access requires truck travel across the bridge over the river in the extreme SW portion of the project area. Construction of the new trails provides quick ATV access to the foot bridge then easy hiking on the improved trail along the eastern edge of the river for faster response times on the east side of the canyon (light blue). Construction of the new helipad greatly improves response time for the upper portions of the east side of the canyon.

The next section's discussion will focus on quantifying the changes in response time and developing routing solutions that indicate the type of travel (truck, ATV, hiking, helicopter) for segments along the optimal path to any location.

Comparing Emergency Response Alternatives

(GeoWorld, September 2010)

(***return to top of Topic***)

The last couple of sections described a simplified backcountry emergency response model considering both on- and off-road travel and then extended the discussion by simulating two alternative planning scenarios—the introduction of a new ATV/Hiking trail and a Helipad. The conceptual framework, procedures and considerations in developing the alternative scenarios were the focus. This section's focus is on comparison procedures and route evaluation techniques.

The left side of figure 1 depicts the minimum expected travel-time from headquarters to all locations within a project area under current conditions. The river in the center (black) acts as an absolute barrier that forces all travel to the southeastern portion across a bridge in the extreme southwest. This makes the farthest away location more than an hour and a half from the headquarters, although it is less than half a mile away "as the crow flies."

The inset in the center of the figure locates a proposed new ATV/Hiking trail. The first segment of from the road to the river enables ATV travel. A light suspension bridge crosses the river to provide hiking access to an improved trail along the southern side of the canyon.

While the trail is justified primarily for increasing recreation potential within the canyon, it has considerable impact on emergency response in the canyon. Note the introduction of the green and light blue tones along the river that indicate response times of about half an hour as compared to more than an hour and a half (purple) currently required.

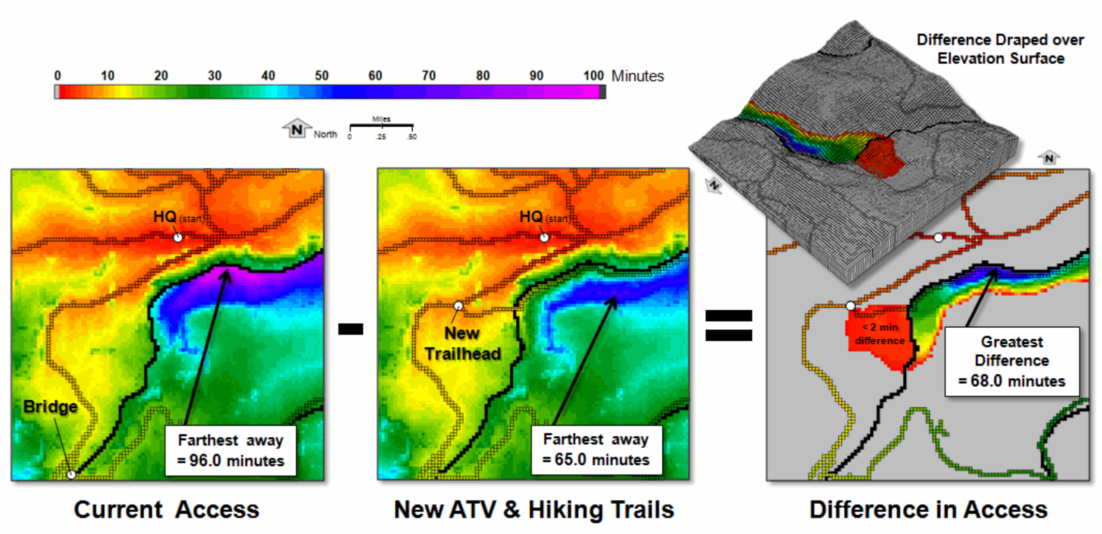

Figure 1. Subtracting two travel-time surfaces determines the relative advantage at every location in a project area.

The right side of figure 1 shows the difference in travel-time under current conditions and the proposed new trail. This is accomplished by simply subtracting the two maps—where 0 = unchanged response times (light grey), values = difference in the response times (red through blue tones). The red area between the road and the suspension bridge notes that ATV access is slightly improved (less than 2 minutes difference) with the introduction of the new trail. The greens and blues show considerable improvement in response time with a maximum difference of 68.0 minutes.

Draping the result over the elevation surface shows that the south side of the canyon bottom is best serviced via the new trail. The more important, non-intuitive information is the dividing line of best access approach (red line) halfway up the southern side of the canyon. Locations nearer the top of the canyon are best accessed via the current truck/ATV/Hiking utilizing the southern bridge.

Figure 2 extends the analysis to characterize the optimal path for the most remote location under current conditions. The first segment (red) routes the truck along the road for approximately 19 minutes to an old logging landing. The ATV's are unloaded and precede off-road (cyan) toward the northeast for an additional 15 minutes (19 + 15= 34 minutes total). Note the route's "bend" to the east to avoid the sharply increased travel-time in the rugged terrain along the west canyon rim as depicted in the travel-time surface.

Once the southern side of the canyon becomes too steep for the ATVs, the rescue team hikes the final segment of 62 minutes (violet) for an estimated total elapsed time of 96 minutes (19 + 15 + 62 = 96). A digitized routing file can be uploaded to a handheld GPS unit to assist off-road navigation and real-time coordinates can be sent back to headquarters for monitoring the team's progress—much like commonplace network navigation/tracking systems in cars and trucks, except on- and off-road movement is considered.

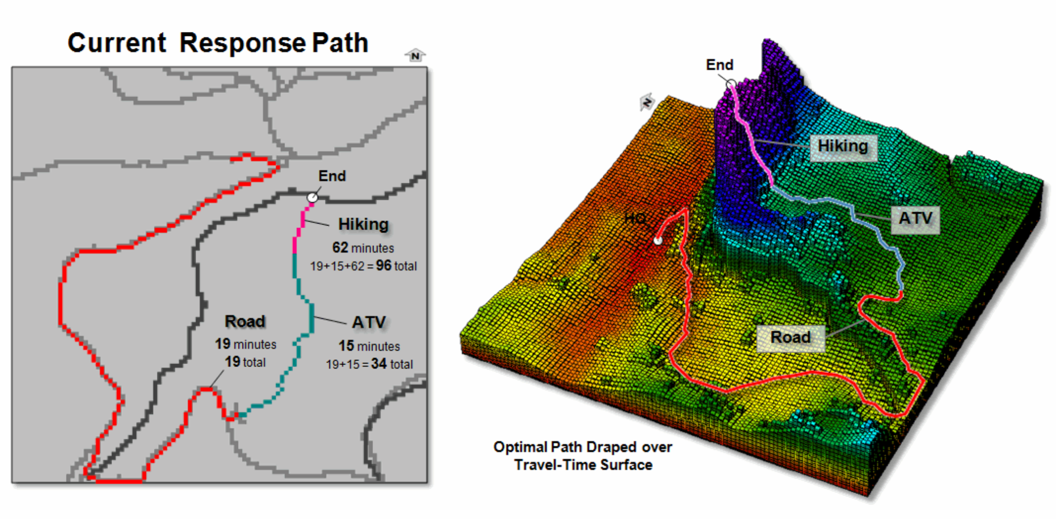

Figure 2. The optimal path is identified as the steepest downhill route over a travel-time surface. (see Author's Note)

The backbone of the backcountry emergency response model is the derivation of the travel-time surface (right side of figure 2). It is "calculated once and used many" as any location can be entered and the steepest downhill path over the surface identifies the best response route from headquarters—including Truck, ATV and Hiking segments with their estimated lapsed times and progressive coordinates.

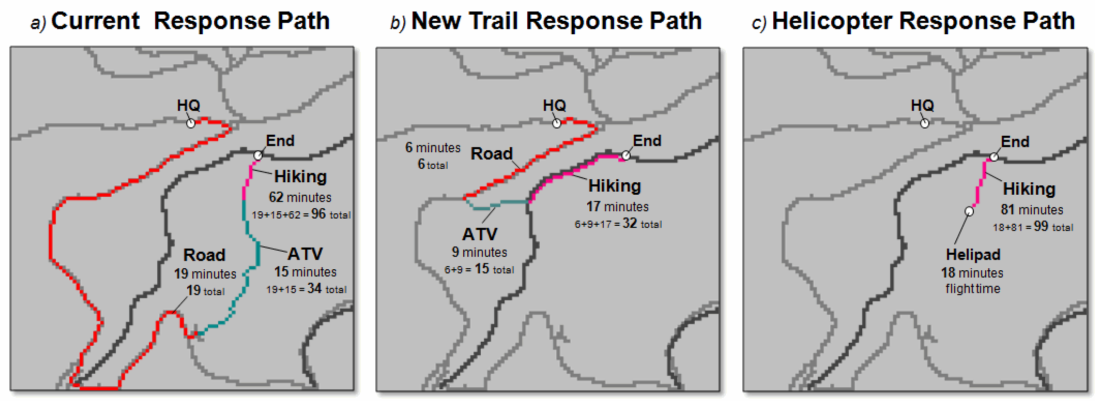

Figure 3. Comparison of emergency response routes to a remote location under alternative scenarios.

In addition, alternate scenarios can be modeled for different conditions, such as seasons, or proposed projects. For example, figure 3 shows three response routes to the same remote location—considering a) current conditions, b) new trail and c) new helipad. In this case, the response is much quicker for the new trail route versus either the current or helipad alternatives.

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It is important to note that the validity of any spatial model is dependent on the quality of the underlying data layers and the robustness of the model—garbage in (as well as garbled throughput) is garbage out. In this case, the model only considers one absolute barrier to movement (water) and one relative barrier (slope) making it far too simplistic for operational use. While it is useful for introducing the concept, but considerable interaction between domain experts and GIS specialists is needed to advance the idea into a full-fledged application …any takers out there?

Author's Note: *See www.innovativegis.com/basis/MapAnalysis/Topic14/Topic14.htm#Hiking_time for a more detailed discussion on deriving off-road travel-time surfaces and establishing optimal paths.*

Bringing Travel and Terrain Directions into Line

(GeoWorld, December 2012)

(**return to top of Topic**)

The three previous sections addressed "Backcountry 911" that considers both on- and off-road travel for emergency response. As identified in the left portion of figure 1, the analysis involves the development of a "stepped accumulation surface" that first considers on-road travel by assigning the minimum travel-time from headquarters to all of the road locations. As shown in the figure, the farthest away location considering truck travel is 26.5 minutes occurring in the southeast corner of the project area.

The next step considers disembarking anywhere along the road network and moving off-road by ATV. However, the ability to simulate different modes of travel is not available in most grid-based map analysis toolsets. The algorithm requires the off-road movement to "remember" the travel-time at each road location and then start accumulating additional travel-time as the new movement twists, turns, and stops with respect to the relative and absolute barriers calibrated for ATV off-road travel (see Author's Note 2).

The middle-left inset in figure 1 shows the accumulated travel-time for both on-road truck and off-road ATV travel where the intervening terrain conditions act like "speed limits" (relative barriers). Also, ATV travel is completely restricted by open water and very steep slopes (absolute barriers). The result of the processing assigns the minimum total travel-time to all accessible locations comprising about 85% of the project area. The farthest away location assuming combined truck and ATV travel is 52.1 minutes occurring in the central portion of the project area.

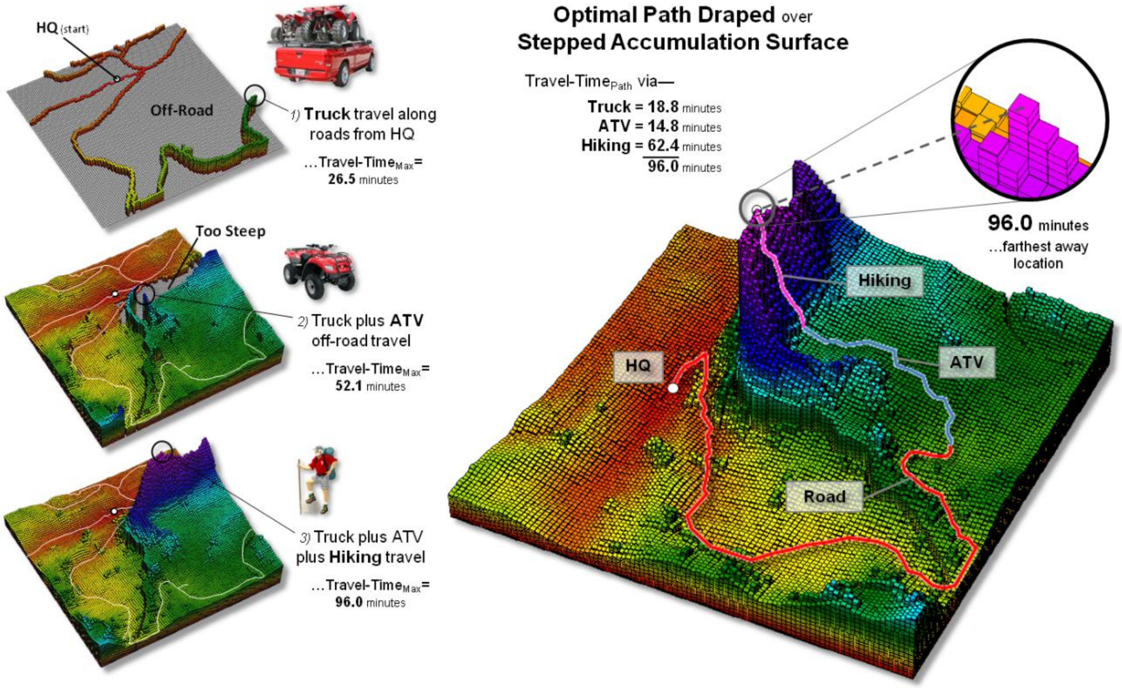


Figure 1. A backcountry emergency response surface identifies the travel-time of the "best path" to all locations considering a combination of truck, ATV and hiking travel.

The remaining 15% is too steep for ATV travel and necessitates hiking into these locations. In a similar manner, the algorithm picks up the accumulated truck/ATV travel-time values and moves into the steep areas respecting the hiking difficulty under the adverse terrain conditions. Note the large increases in travel-time in these hard to reach areas. The farthest away location assuming combined truck, ATV and hiking is 96.0 minutes, also occurring in the central portion of the project area.

A traditional accumulation surface (one single step) identifies the minimum travel-time from a starting location to all other locations considering "constant" definitions of the relative and absolute barriers affecting movement. It has two very unique characteristics— 1) it forms a bowl-like shape with the starting point (or points) having the lowest value of zero = 0 units away from the start, and 2) continuously increasing travel-time values reflecting the relative ease of movement that warps the bowl with areas of relatively rapid increases in travel-time associated with areas of high relative barrier "costs."

A stepped accumulation surface (top-center portion of figure 2) shares these characteristics but is far more complex as it reflects the cumulative effects of different modes of travel and the impact of their changing relative and absolute barriers on movement. Note the dramatic "ridge" running NE-SW through the center of the project area, as well as the other morphological ups and downs in total combined travel-time.

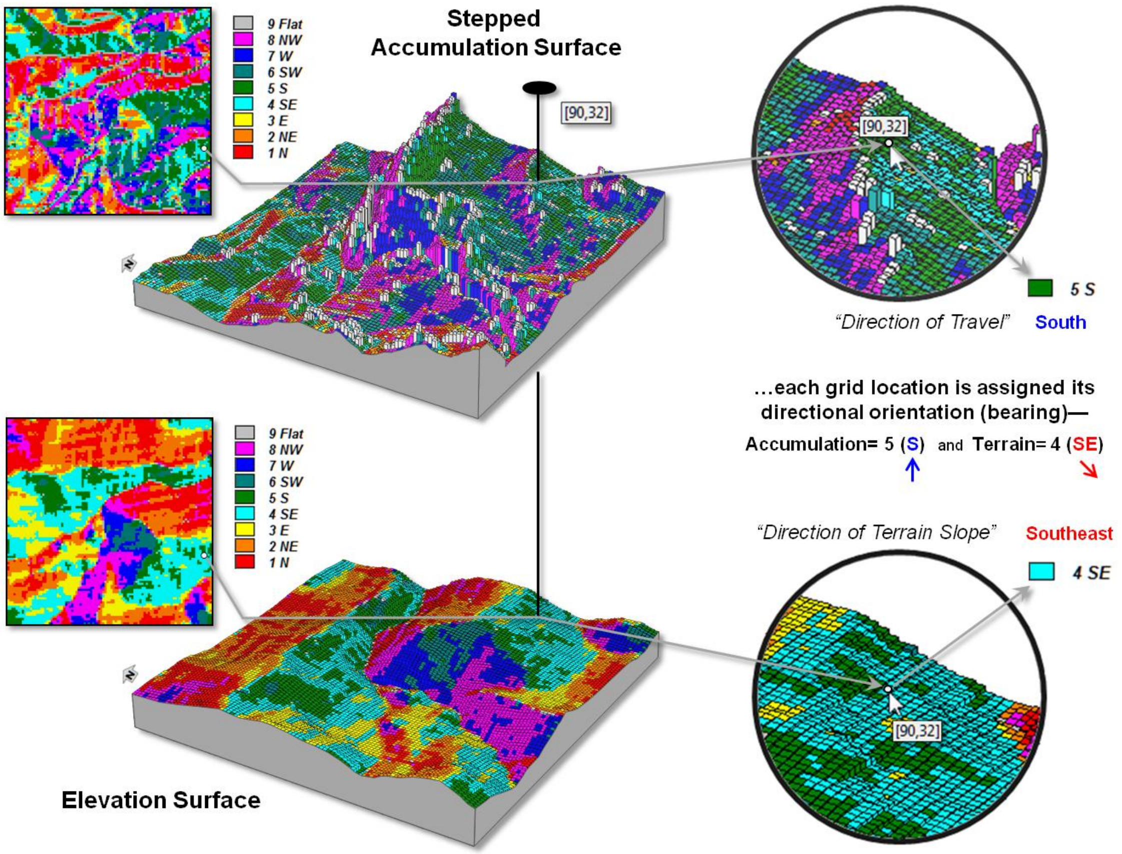


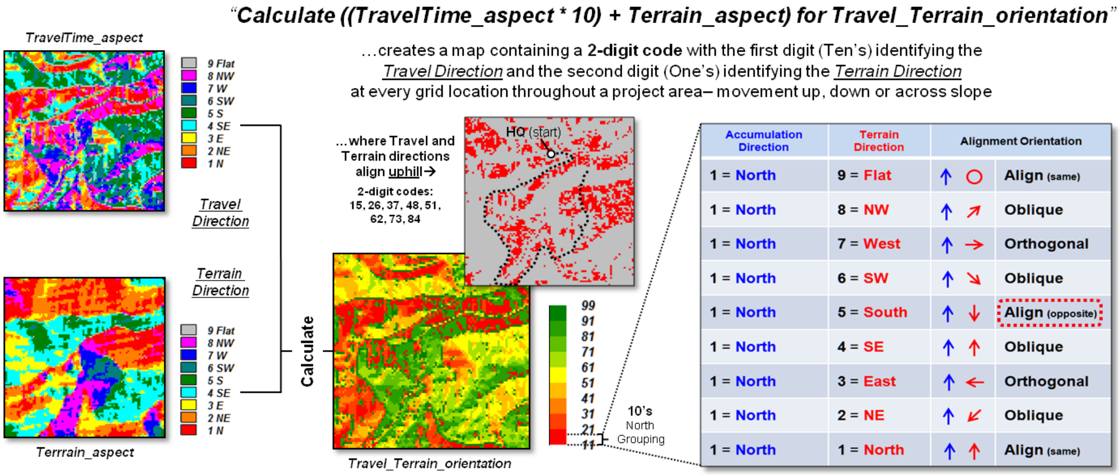
Figure 2. Maps of travel and terrain direction are characterized by the aspect (bearings) of their respective surfaces.

In a sense, this wrinkling is analogous to a terrain surface, but the surface's configuration is the result of the relative ease of on- and off-road travel in cognitive space— not erosion, fracture, slippage and subsidence of dirt in real world space.

However like a terrain surface, an "aspect map" of the accumulation surface captures its orientation information identifying the direction of the "best path" movement through every grid location. The enlarged portion in the top-right of the figure shows that the travel direction through location 90, 32 in the analysis frame is from the south (octant 5). The lower portion of the figure identifies the terrain direction at the same location is oriented toward the southeast (octant 4). Hence we know that the movement through the location is across slope at an oblique uphill angle.

Figure 3 depicts a simple technique for combining the travel and terrain direction information. A 2-digit code is generated by multiplying "Travel Direction" map by 10 and adding it to the "Terrain Direction" map. For example, a "11" (one-one, not eleven) indicates that movement is toward the north on a north-facing slope, indicating an aligned downhill movement. A "15" indicates a northerly movement up a south-facing slope.

The center inset in the figure isolates all locations that have "aligned uphill movement" (opposing alignment) in any of the cardinal directions indicated by 2-digit codes of 15, 26, 37, 48, 51, 62, 73, and 84. Locations having "aligned downhill movement" are identified by codes of 11, 22, 33, 44, 55, 66, 77, and 88. All other combinations indicate either oblique or orthogonal cross-slope movements, or locations occurring on flat terrain without a dominant aspect.


"Calculate ((TravelTime_aspect * 10) + Terrain_aspect) for Travel_Terrain_orientation"

…creates a map containing a **2-digit code** with the first digit (Ten's) identifying the *Travel Direction* and the second digit (One's) identifying the *Terrain Direction* at every grid location throughout a project area– movement up, down or across slope

…where Travel and Terrain directions align uphill→

2-digit codes: 15, 26, 37, 48, 51, 62, 73, 84

Accumulation Direction	Terrain Direction	Alignment Orientation	
1 = North	9 = Flat	↑ ○	Align (same)
1 = North	8 = NW	↑ ↗	Oblique
1 = North	7 = West	↑ →	Orthogonal
1 = North	6 = SW	↑ ↘	Oblique
1 = North	5 = South	↑ ↓	Align (opposite)
1 = North	4 = SE	↑ ↑	Oblique
1 = North	3 = East	↑ ←	Orthogonal
1 = North	2 = NE	↑ ↙	Oblique
1 = North	1 = North	↑ ↑	Align (same)

Figure 3. A 2-digit code is used to identify all combinations of travel and terrain directions.

I realize the thought of "an aspect map of an abstract surface," such as a stepped accumulation surface might seem a bit uncomfortable and well beyond traditional mapping; however it can provide very "real" and tremendously useful information. Characterizing directional movement is not only needed in backcountry emergency response but crucial in effective timber harvest planning, wildfire propagation modeling, pipeline routing and a myriad of other practical applications— such out-of-the-box spatial reasoning approaches are what are driving geotechnology to a whole new plane.

Author's Note*: for a detailed discussion of "stepped accumulation surfaces," see Topic 25, calculating Effective Distance and Connectivity in the online book Beyond Mapping III posted at www.innovativegis.com/basis/MapAnalysis/.*

Assessing Wildfire Response (Part 1):

Oneth by Land, Twoeth by Air

(GeoWorld, August 2011)

(*return to top of Topic*)

Wildfire initial attack generally takes three forms: *helicopter landing*, *helicopter rappelling* or *ground attack*. Terrain and land cover conditions are used to determine accessible areas and the relative initial attack travel-times for the three response modes. This and next month's column describes GIS modeling considerations and procedures for assessing and comparing alternative response travel-times.

The discussion is based on a recent U.S. Forest Service project undertaken by Fire Program Solutions (see Author's Notes). I was privileged to serve as a consultant for the project that modeled the relative response times for all of the Forest Service lands from the Rocky Mountains to the Pacific Ocean—at a 30m grid resolution, that's a lot of little squares. Fortunately for me, all I needed to do was work on the prototype model, leaving the heavy-lifting and "practical adjustments" to the extremely competent GIS specialist, wildfire professionals and USFS helitack experts on the team. The objectives of the project were to model the response times for different initial attack modes and provide summary maps, tables and recommendations for strategic planning and management of wildfire response assets.

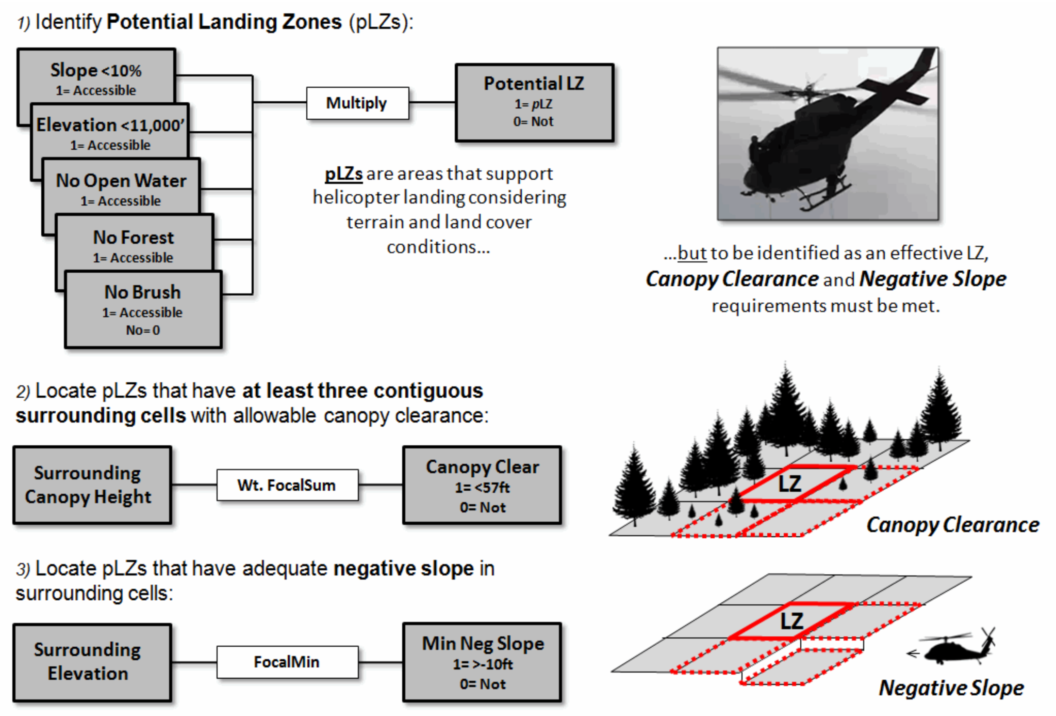


Figure 1. Generalized outline of a grid-based model for identifying Potential Landing Zones (pLZs) that are further evaluated for helicopter approach/departure considerations of Canopy Clearance and Negative Slope.

The most challenging sub-model involved identifying helicopter landing zones (see figure 1). A simple binary suitability model is used to identify Potential Landing Zones (pLZs) by assigning a map value of 1 to all accessible terrain (gentle slopes and sub-alpine elevations) and land cover conditions (no open water, forest or tall brush); with 0 assigned to inaccessible areas. Multiplying the binary set of maps derives a binary map of pLZs with 1 identifying locations meeting all of the conditions (1*1*1*1*1= 1); 0 indicates locations with at least one constraint.

Interior locations of large contiguous pLZs groupings make ideal landing zones. However, edge locations or small isolated pLZs clusters must be further evaluated for clear helicopter approach/departure flight paths. At least three contiguous cells surrounding a pLZ must have forest canopy of less than 57 feet to insure adequate *Canopy Clearance*. In addition, it is desirable to have a *Negative Slope* differential of at least 10 feet to aid landing and takeoff.

Two steps are required for evaluating canopy clearance (see figure 2). A reclassify operation is used to calculate a binary map with canopy heights of 57 feet or less assigned a value of 1; 0 for taller canopies. A neighborhood operation (*FocalSum* in ArcGIS) is used to calculate the number of clear canopy cells in the immediate vicinity of each pLZ cell (3x3 roving window). If all cells are clear, a value of 9 will be assigned, indicating an interior location in a grouping of pLZ cells.

For derived values less than 9, an edge location or isolated pLZ is indicated. If there are more than four surrounding cells with adequate clearance, there has to be at least three that are contiguous and the pLZ is assigned a map value of 1 to indicate that there is a clear approach/departure; 0 for locations with a sum of less than 4.

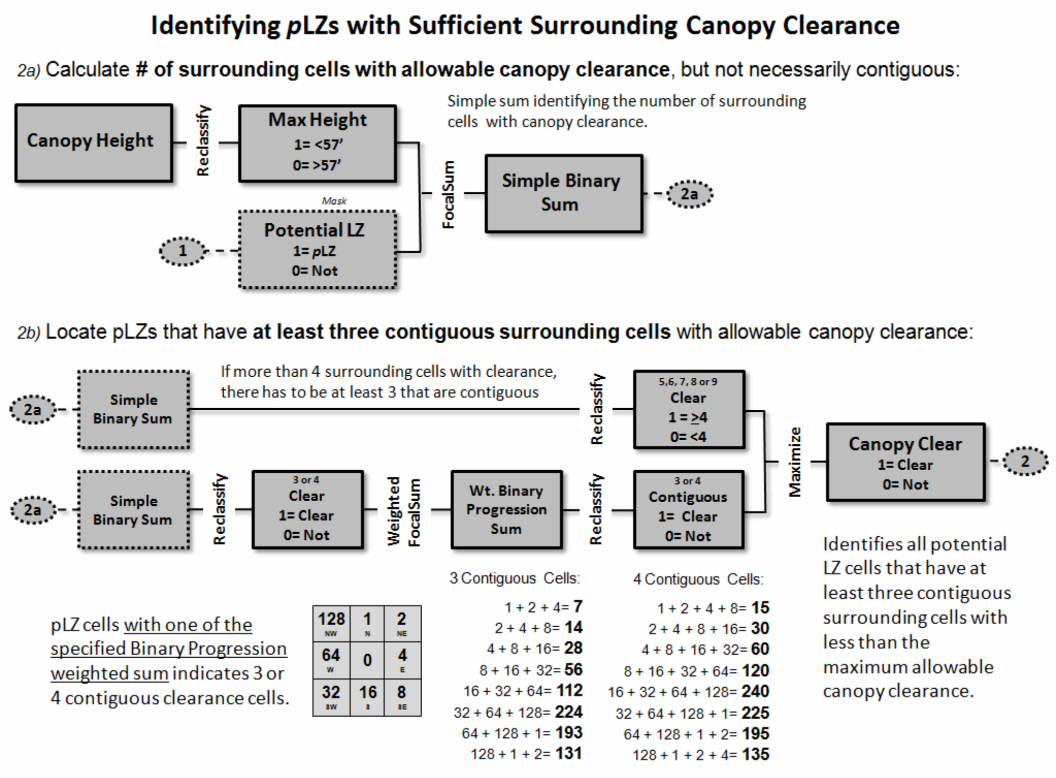


Figure 2. Procedure for identifying pLZs with sufficient surrounding canopy clearance.

Derived values indicating 3 or 4 clear surrounding cells must be further evaluated to determine if the cells are contiguous. First, locations with a simple binary sum of 3 or 4 are assigned 1; else= 0. A binary progression weighted window—1,2,4,8,16,32,64,128—is used to generate a weighted focal sum of the neighboring cells. The weighted sum results in a unique value for all possible configurations of the clear surrounding cells (see the lower portion of figure 2). For example, the only configuration that results in a sum of 7 is the binary progression weights of 1+2+4 indicating contiguous cells N,NE,E.

The weighted binary progression sums indicating contiguous cells are then reclassified to 1; 0=else. Finally, the minimum value for the "greater than 4 Clear" and "3 or 4 Clear" maps is taken resulting in 1 for locations having sufficient contiguous canopy clearance cells; else=0.

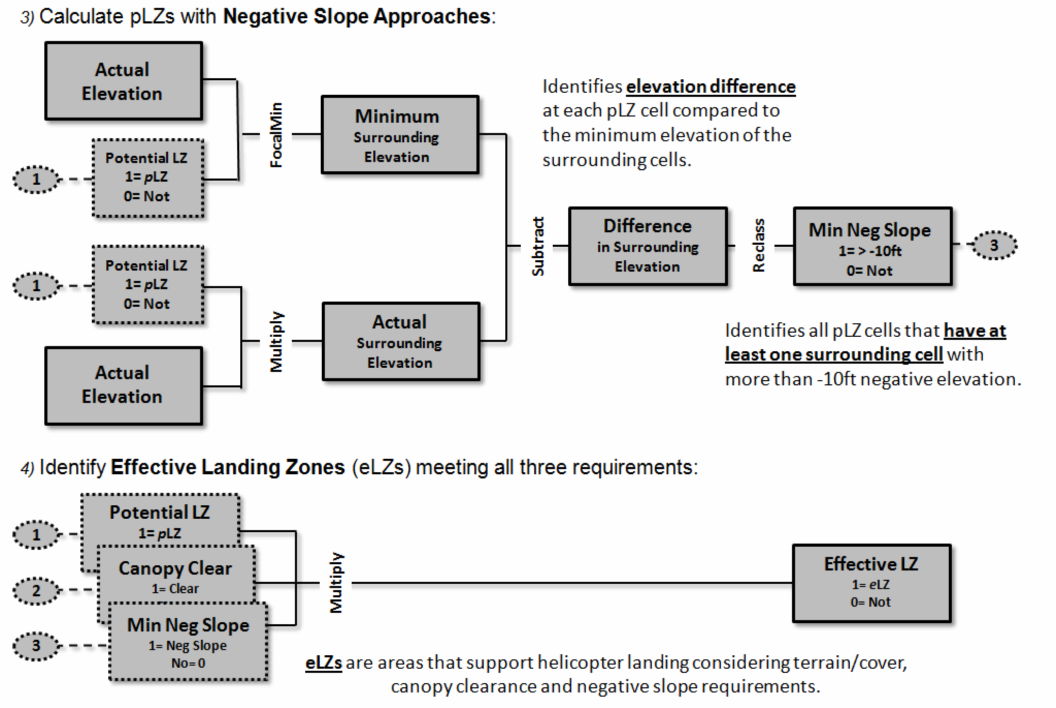


Figure 3. Procedures for identifying pLZs with sufficient negative slope (top) and combining all three considerations (bottom).

The top portion of figure 3 outlines the procedure for evaluating sufficient negative slope by determining the difference between the minimum surrounding elevation and each pLZ elevation. If the difference is greater than 10 feet, a map value of 1 is assigned; else= 0.

The final step multiplies the binary maps of Potential LZ, Canopy Clearance and Minimum Negative Slope. The result is a map of the Effective LZs as 1*1*1= 1 for locations meeting all three criteria.

In the operational model, the negative slope requirement was dropped as the client felt it was of

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marginal importance. Next month's column will describe the analysis approaches for identifying ground response areas, helicopter rappelling zones and the translation of all three response modes into travel-time estimates for comparison.

Author's Notes: *For more information on Fire Program Solutions and their wildfire projects contact Don Carlton, DCARLTON1@aol.com*.

Assessing Wildfire Response (Part 2): Jumping Right into It

(GeoWorld, September 2011)

(*return to top of Topic*)

The previous section noted that wildland fire initial attack generally takes three forms: *helicopter landing*, *helicopter rappelling* or *ground attack* as determined by terrain and land cover conditions (also "*smoke-jumping*" but that's a whole other story). The earlier discussion described a spatial model developed by Fire Program Solutions (see Author's Notes) for identifying helicopter landing zones. The following discussion extends the analysis to modeling and comparing the response times for the three different initial attack modes for all locations within a project area.

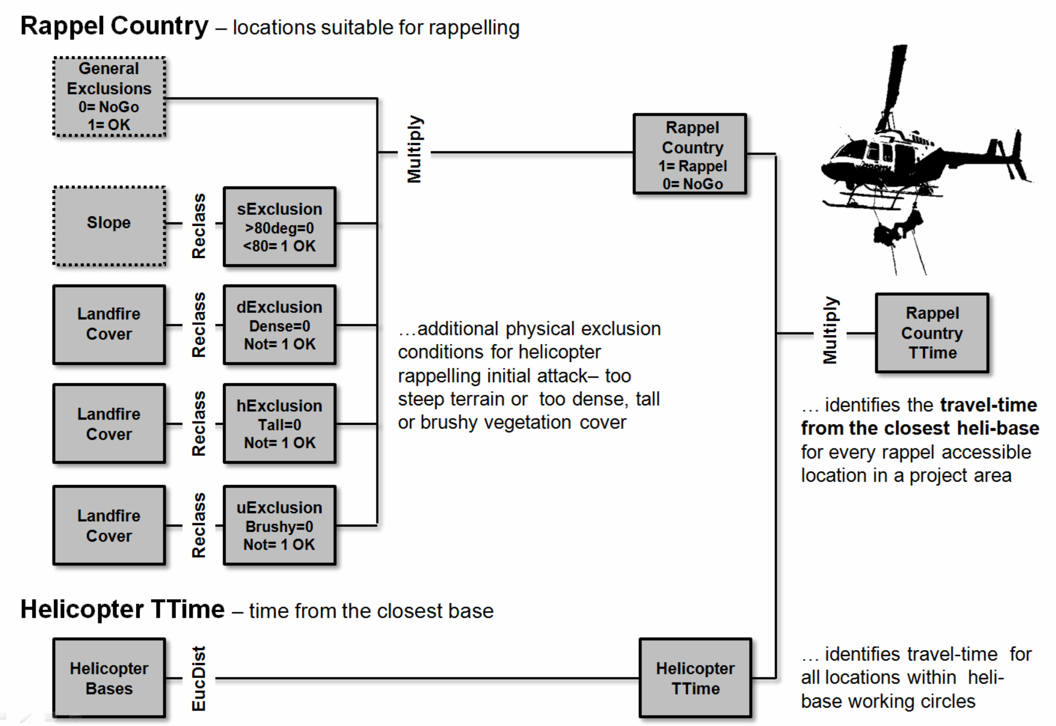

Figure 1. Major steps and considerations in modeling wildfire Helicopter Rappel Attack travel-time.

Figure 1 identifies the major steps in determining "Rappel Country" …there are some among us so heroic (crazy?) that they rappel out of a helicopter just to get to a wildfire before the crowd. Rappel country is defined as the areas where rappelling is the most effective initial attack mode based on project assumptions. In addition to general exclusions (e.g., open water, 10,000 foot altitude ceiling), rappelling must consider four other highly variable physical exclusions—extremely steep terrain (>80 degrees), very dense and/or tall forest canopies and dense tall brush. The simple binary model in the upper portion of figure 1 is used to identify locations suitable for rappelling (1= OK; 0= NoGo) where the fearless can jump from a hovering helicopter and slide down a rope between the trees up to a couple of hundred feet to the ground.

The lower portion of the figure uses a simple distance calculation to identify the travel-time within a 75 mile working circle about a helibase assuming a defined airspeed, round trip fuel capacity and other defining factors. By combining the binary map of rappel country and the helicopter travel-time surface, an estimated travel-time from the closest helibase to every Helicopter Rappelling Accessible location in a project area is determined.

In a similar "binary multiplication" manner, the helicopter travel-time to each Effective Landing Zone can be calculated. However, the landing crew must hike to a wildland fire outside the landing zone. This secondary travel is modeled in a manner similar to that used for the off-road movement of the ground response model described below. The helicopter flight time to a landing zone and the ground hiking time to the fire are combined for an overall travel-time from the closest helibase to every Helicopter Landing Accessible location in a project area.

Figure 2 outlines the major steps in modeling the combined on- and off-road response time for a ground attack crew. On-road travel is determined by the typical speed for different road types. The calculations for deriving the travel-time to cross a 30m grid cell are shown in the rows of the table for five classes of roads from major highways (R1) to backwoods roads (R5). Note that the slowest travel taking .1398 minute to traverse a backwoods road cell is over eight times slower than the fastest (only .0172 min/cell).

Off-road travel is based on typical hiking rates under increasingly steep terrain with the steepest class (2.2369 min/cell) being 130 times slower than travel on a highway. In addition, some locations form absolute barriers to ground movement (e.g., very steep slopes, open water).

The three types of impedance are combined such that the minimum friction/cost value is assigned to each location. A null value is assigned to locations with absolute barriers. This composited friction (termed a *Discrete Cost Surface*) is used to calculate the effective distance for every location to the closest dispatch station. The procedure moves out from each station in *time step waves* (like a stone tossed into a pond) that considers the relative impedance as it propagates to generate an *Accumulated Cost Surface* (TTime in minutes) identifying the minimum travel-time from the closest initial dispatch location to every location in a project area (see Author's Notes).

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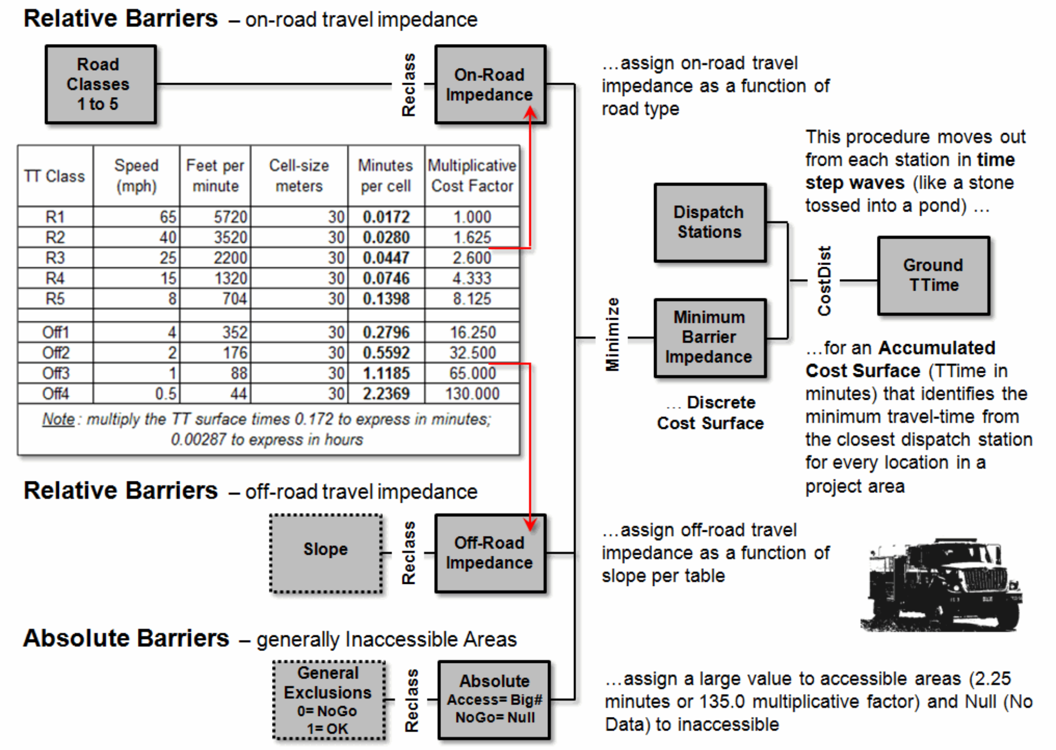

TT Class	Speed (mph)	Feet per minute	Cell-size meters	Minutes per cell	Multiplicative Cost Factor
R1	65	5720	30	**0.0172**	1.000
R2	40	3520	30	**0.0280**	1.625
R3	25	2200	30	**0.0447**	2.600
R4	15	1320	30	**0.0746**	4.333
R5	8	704	30	**0.1398**	8.125
Off1	4	352	30	**0.2796**	16.250
Off2	2	176	30	**0.5592**	32.500
Off3	1	88	30	**1.1185**	65.000
Off4	0.5	44	30	**2.2369**	130.000

Note: multiply the TT surface times 0.172 to express in minutes; 0.00287 to express in hours

…assign on-road travel impedance as a function of road type

This procedure moves out from each station in **time step waves** (like a stone tossed into a pond) …

…for an **Accumulated Cost Surface** (TTime in minutes) that identifies the minimum travel-time from the closest dispatch station for every location in a project area

…assign off-road travel impedance as a function of slope per table

…assign a large value to accessible areas (2.25 minutes or 135.0 multiplicative factor) and Null (No Data) to inaccessible

Figure 2. Major steps and considerations in modeling wildfire Ground Attack travel-time.

The three separate travel-time surfaces can be compared to identify the attack mode with the minimum response time (see figure 3) and the differential times for alternative attack modes. In operational situations, this information could be accessed for a fire's location and used in dispatch and tactical planning.

In the "Rappel Country" project the information is used for strategic planning of the arrangement of helibase locations with rappel initial attack capabilities. Tabular summaries for travel-time from existing helibases by terrain and land cover conditions were generated. In addition, rearrangement of helibase location and capabilities could be simulated and evaluated.

From a GIS perspective the project represents a noteworthy endeavor involving advanced grid-based map analysis procedures over a large geographic expanse from the Rocky Mountains to the Pacific Ocean that was completed in less than four months by a small team of domain experts and GIS specialists. The prototype analysis originally developed was interactively refined, modified and enhanced by the team and then applied over the expansive area.

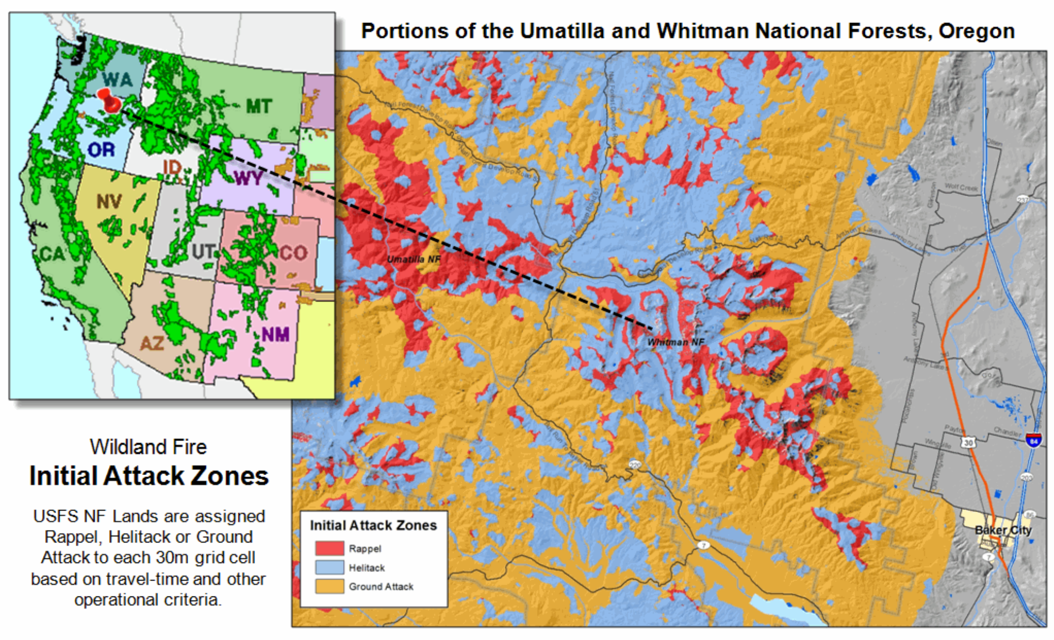

Figure 3. An example of a map of the "best" initial attack mode for a fairly large area draped over a Google 3D image.

As with most projects, database development and model specification/parameterization formed the largest hurdles—the grid-based map analysis component proved to be a "piece-of-cake" compared to nailing down the requirements and slogging around in millions upon millions of geo-registered 30m cells …whew!

Author's Notes: *For more information on Fire Program Solutions, LLC and their wildfire projects contact Don Carlton, DCARLTON1@aol.com; for an in-depth discussion of travel-time calculation, see the online book Beyond Modeling III, Topic 25, Calculating Effective Distance, posted at www.innovativegis.com/Basis/MapAnalysis/Default.htm.*

Mixing It up in GIS Modeling's Kitchen

(GeoWorld, May 2013)

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The modern "geotechnology recipe" is one part data, one part analysis and a dash of colorful rendering. That's a far cry from the historical mapping recipe of basically all data with a generous ladling of cartography. Today's maps are less renderings of "precise placement of physical features for navigation and record-keeping" (meat and potatoes) than they are interactive "interpretations of spatial relationships for understanding and decision-making" (haute cuisine).

Figure 1 carries this cheesy cooking analogy a few steps further. The left portion relates our modern food chain to levels of mapped data organization from mouthfuls of map values to data warehouses. The center and right side of the figure ties these data (ingredients) to the GIS modeling process (preparation and cooking) and display (garnishing and presentation).

A map stack of geo-registered map layers is analogous to a pantry that contains the necessary ingredients (map layers) for preparing a meal (application). The meal can range from Pop-Tart à la mode to the classic French coq au vin or Spain's paella with their increasing complexity and varied ingredients, but a recipe all the same.

GIS Modeling is sort of like that but serves as food for quantitative thought about the spatial relationships and patterns around us. To extend the cooking analogy, the rephrasing of an old saying seems appropriate— "Bits and bytes may break my bones, but inaccurate modeling will surely poison me." This suggests that while bad data can certainly be a problem, ham-fisted processing of perfect data can spoil an application just as easily.

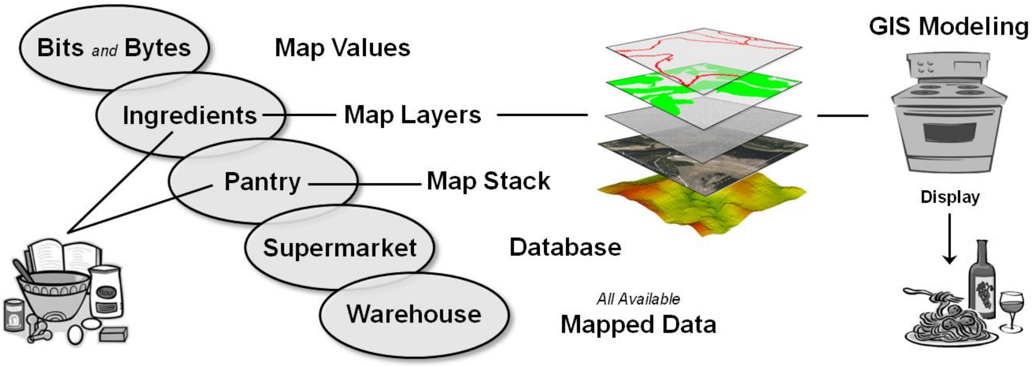


Figure 1. The levels of mapped data organization are analogous to our modern food chain.

For example, a protective "simple distance buffer" of a fixed distance is routinely applied around spawning streams that ignores the relative erodibility of intervening terrain/soil/vegetation conditions which can rain-down dirt balls that choke the fish in highly erodible palaces and starve-out timber harvesting in places of low erodibility**.** In this case, the simple buffer is a meager "rice-cake-like" solution that propagates at megahertz speed across the mapping landscape helping neither the fish nor the logger. A more elaborate recipe involving a "variable-width buffer" is needed, but it is rarely employed.

GIS tends to focus a great deal on spatial data structure, formats, characteristics, query and visualization, but less on the analytical processing that "cooks" the data (meant in the most positive way). So what are the fundamental considerations in GIS models and modeling? How does it relate to traditional modeling?

At the highest conceptual level, GIS modeling has two important characteristics—processing structure and elemental approaches. The center portion of figure 2 depicts the underlying

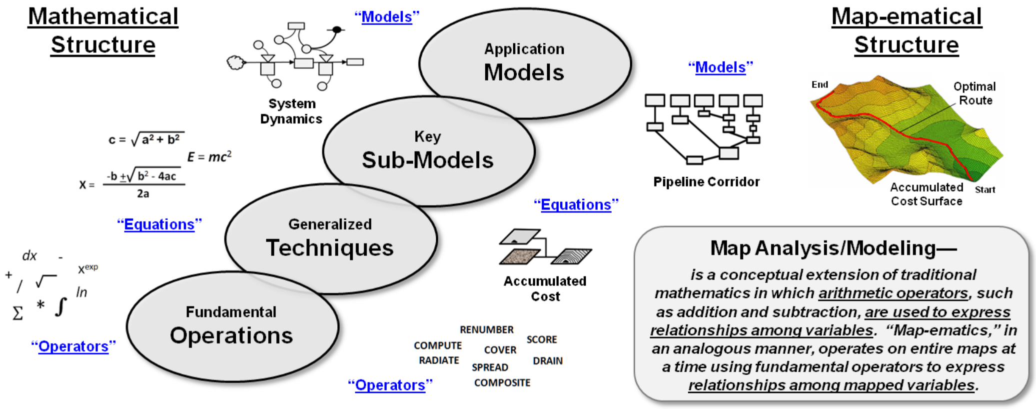
Processing Structure for all quantitative data analysis as a progression from fundamental *operations* to generalized *techniques* to key *sub-models* and finally to full application *models*.

This traditional mathematical structure uses sequential processing of basic math/stat operations to perform a wide variety of complex analyses. By controlling the order in which the operations are executed on variables, and using common storage of intermediate results, a robust and universal mathematical processing structure is developed.

The "map-ematical" structure is similar to traditional algebra in which primitive operations, such as addition, subtraction, and exponentiation, are logically sequenced for specified variables to form equations and models. However in map algebra 1) the variables represent entire maps consisting of geo-registered sets of map values, and 2) the set of traditional math/stat operations are extended to simultaneously evaluate the spatial and numeric distributions of mapped data.

Each processing step is accomplished by requiring—

- retrieval of one or more map layers from the map stack,
- manipulation of that mapped data by an appropriate math/stat operation,
- creation of an intermediate map layer whose map values are derived as a result of that manipulation, and
- storage of that new map layer back into the map stack for subsequent processing.



Map Analysis/Modeling—
is a conceptual extension of traditional mathematics in which arithmetic operators, such as addition and subtraction, are used to express relationships among variables. "Map-ematics," in an analogous manner, operates on entire maps at a time using fundamental operators to express relationships among mapped variables.

Figure 2. The "map-ematical structure" processes entire map layers at a time using fundamental operators to express relationships among mapped variables in a manner analogous to our traditional mathematical structure.

The cyclical nature of the retrieval-manipulation-creation-storage processing structure is analogous to the evaluation of "nested parentheticals" in traditional algebra. The logical sequencing of map analysis operations on a set of map layers forms a spatial model of specified application. As with traditional algebra, fundamental techniques involving several primitive operations can be identified that are applicable to numerous situations.

The use of these primitive map analysis operations in a generalized modeling context accommodates a variety of analyses in a common, flexible and intuitive manner. Also it provides a framework for understanding the principles of map analysis that stimulates the development of new techniques, procedures and applications (see author's note 1).

The ***Elemental Approaches*** utilized in map analysis and GIS modeling also are rooted in traditional mathematics and take on two dimensions— *Atomistic/Analysis* versus *Holistic/Synthesis*.

The *Atomistic/Analysis* approach to GIS modeling can be thought of as "separating a whole into constituent elements" to investigate and discover spatial relationships within a system (figure 3). This "Reductionist's approach" is favored by western science which breaks down complex problems into simpler pieces which can then be analyzed individually.

The *Holistic/Synthesis* approach, in contrast, can be thought of as "combining constituent elements into a whole" in a manner that emphasizes the organic or functional relationships between the parts and the whole. This "Interactionist's approach" is often associated with eastern philosophy of seeing the world as an integrated whole rather than a dissociated collection of parts.

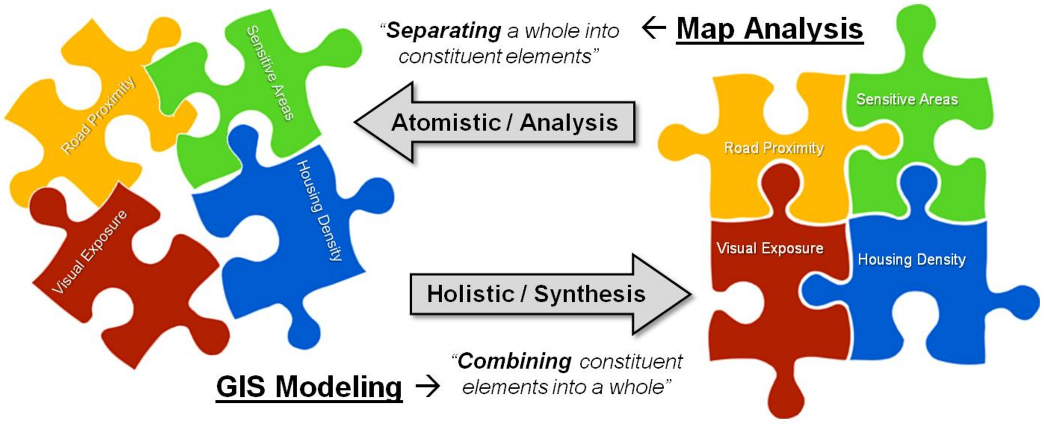


Figure 3. The two Elemental Approaches utilized in map analysis and GIS Modeling.

So what does all this have to do with map analysis and GIS modeling? It is uniquely positioned to change how quantitative analysis is applied to complex real-world problems. First, it can be used account for the spatial distribution as well as the numerical distribution inherent in most data sets. Secondly, it can be used in the atomistic analysis of spatial systems to uncover relationships among perceived driving to variables of a system. Thirdly, it can be used in holistic synthesis to model changes in systems as the driving variables are altered or generate entirely new solutions.

In a sense, map analysis and modeling are like chemistry. A great deal of science is used to break down compounds into their elements and study the interactions—atomistic/analysis. Conversely, a great deal of innovation is used to assemble the elements into new compounds—holistic/synthesis. The combined results are repackaged into entirely new things from food additives to cancer cures.

Map analysis and GIS modeling operate in an analogous manner. They use many of the same map-ematical operations to first analyze and then to synthesize map variables into spatial solutions from navigating to a new restaurant to locating a pipeline corridor that considers a variety of stakeholder perspectives. While dictionaries define analysis and synthesis as opposites, it is important to note that in geotechnology, analysis without synthesis is almost worthless …and that the converse is just as true.

***Author's Notes**: 1) see the discussion of the SpatialSTEM approach in Topic 30, "A Math/Stat Framework for Map Analysis" posted at www.innovativegis.com/basis/MapAnalysis/Topic30/Topic30.htm. 2) For more on GIS models and modeling, see the GeoWorld series of Beyond Mapping columns (January, February and December 1995) in the online book Beyond Mapping II, Topic 5, "A Framework for GIS Modeling" posted at www.innovativegis.com/basis/BeyondMapping_II/Topic5/BM_II_T5.htm.*

Putting GIS Modeling Concepts in Their Place

(GeoWorld, October 2010)

(**return to top of Topic**)

The vast majority of GIS applications focus on spatial inventories that keep track of things, characteristics and conditions on the landscape— mapping and geo-query of *Where* is *What*. Map analysis and GIS modeling applications, on the other hand, focus on spatial relationships within and among map layers— *Why*, *So What* and *What If*.

Natural resource fields have a rich heritage in GIS modeling that tackles a wide range of management needs from habitat mapping to land use suitability to wildfire risk assessment to infrastructure routing to economic valuation to policy formulation. But before jumping into a discussion of GIS analysis and modeling in natural resources it seems prudent to establish basic concepts and terminology usually reserved for an introductory lecture in a basic GIS modeling course.

Several years ago I devoted a couple of Beyond Mapping columns to discussing the various types and characteristics of GIS models (see Author's note). Figure 1 outlines this typology with a bit of reorganization and a few new twists and extensions gained in the ensuing 15 years. The dotted connections in the figure indicate that the terms are not binary but form transitional gradients, with most GIS models involving a mixture of the concepts.

Simply stated any model is a representation of reality in either material form (*tangible representations*) or symbolic form (*abstract representations*). The two general types of models include structural and relational. *Structural models* focus on the composition and construction of tangible things and come in two basic forms— *action* involving dynamic movement-based models, such as a model train along its track and *object* involving static entity-based models forming a visual representation of an item, such as an architect's blueprint of a building. CAD and traditional GIS inventory-oriented applications fall under the "object" model type.

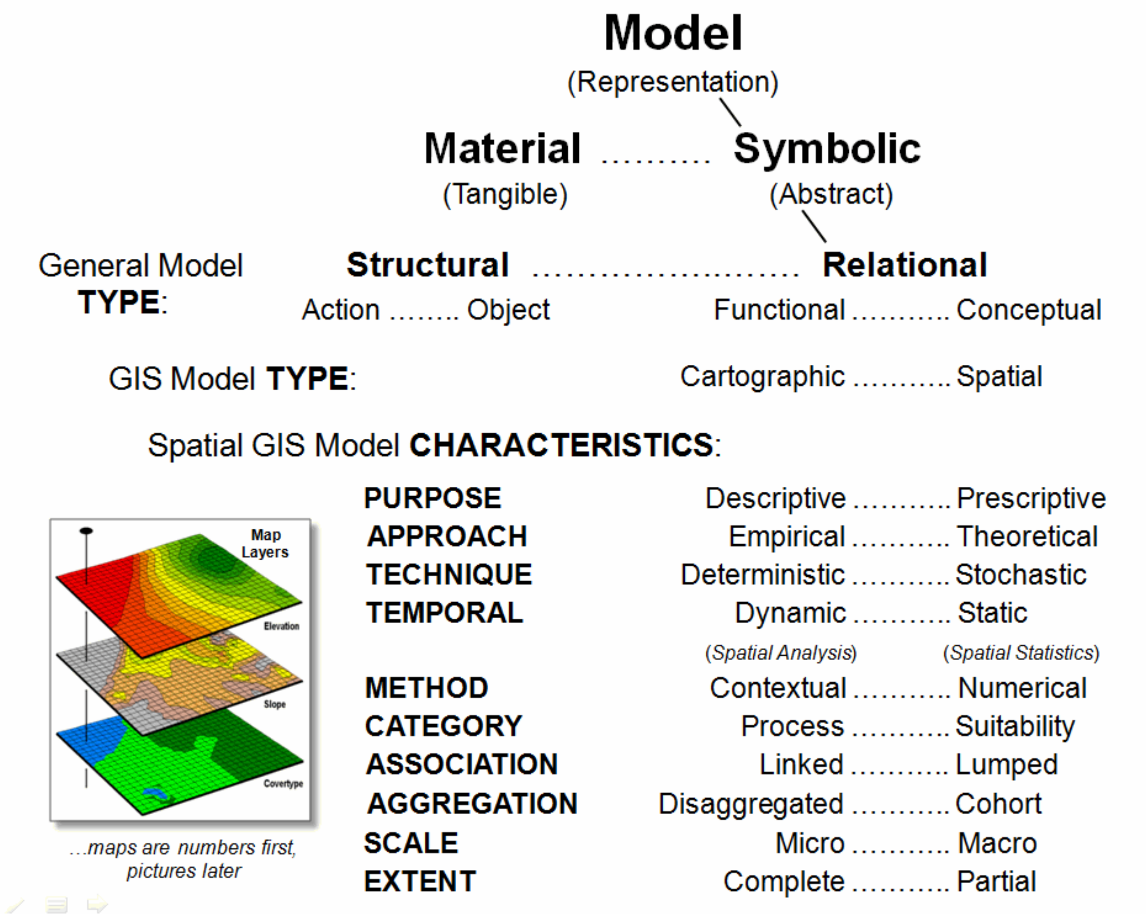
Relational models, on the other hand, focus on the interdependence and relationships among factors. They come in two types— *functional* models based on input/output that track relationships among variables, such as storm runoff prediction and *conceptual* models based on perceptions that incorporate fact interpretation and value weights, such as suitable wildlife habitat derived by interpreting a stack of maps describing a landscape.

Fundamentally there are two types of GIS models—cartographic and spatial. *Cartographic models* automate manual techniques that use traditional drafting aids and transparent overlays (i.e., McHarg overlay), such as identifying locations of productive soils and gentle slopes using binary logic expressed as a geo-query. *Spatial models* express mathematical and statistical relationships among mapped variables, such as deriving a surface heat map based on ambient temperature and solar irradiance involving traditional multivariate concepts of variables, parameters and relationships.

All GIS models fall under the general "symbolic --> relational" model types, and because digital maps are "numbers first, pictures later," map analysis and GIS modeling are usually classified as mathematical (or maybe that should be "map-ematical"). The somewhat subtle distinction between cartographic and spatial models reflects the robustness of the map values and the richness of the mathematical operations applied.

The general characteristics that GIS models share with non-spatial models include purpose, approach, technique and temporal considerations. *Purpose* identifies a model's intent/utility and often involves a *descriptive* characterization of the direct interactions of a system to gain insight into its processes, such as a wildlife population dynamics map generated by simulation of life/death processes. Or the purpose could be *prescriptive* to assess a system's response to management actions/interpretations, such as changes in a proposed power line route under different stakeholder's calibrations and weights of input map layers.

A model's *Approach* can be empirical or theoretical. An *empirical* model is based on the reduction (analysis) of field-collected measurements, such as a map of soil loss for each watershed for a region generated by spatially evaluating the empirically derived Universal Soil Loss equation. A *theoretical* model, on the other hand, is based on the linkage (synthesis) of proven or postulated relationships among variables, such as a map of spotted owl habitat based on accepted theories of owl preferences.



Model
(Representation)

Material .... **Symbolic**
(Tangible) (Abstract)

General Model **TYPE**: **Structural** .... **Relational**
Action .... Object Functional .... Conceptual

GIS Model **TYPE**: Cartographic .... Spatial

Spatial GIS Model **CHARACTERISTICS**:

PURPOSE	Descriptive	Prescriptive
APPROACH	Empirical	Theoretical
TECHNIQUE	Deterministic	Stochastic
TEMPORAL	Dynamic	Static
	(Spatial Analysis)	*(Spatial Statistics)*
METHOD	Contextual	Numerical
CATEGORY	Process	Suitability
ASSOCIATION	Linked	Lumped
AGGREGATION	Disaggregated	Cohort
SCALE	Micro	Macro
EXTENT	Complete	Partial

...maps are numbers first, pictures later

Figure 1. Types and characteristics of GIS models.

Modeling *Technique* can be deterministic or stochastic. A *deterministic* model uses defined relationships that always results in a single repeatable solution, such as a wildlife population map based on one model execution using a single “best” estimate to characterize each variable. A *stochastic* model uses repeated simulation of a probabilistic relationship resulting in a range of possible solutions, such as a wildlife population map based on the average of a series of model executions.

The *Temporal* characteristic refers to how time is treated in a model— dynamic or static. A *dynamic* model treats time as variable and model variables change as a function of time, such as a map of wildfire spread from an ignition point considering the effect of the time of day on weather conditions and fuel loading dryness. A *static* model treats time as a constant and model variables do not vary over time, such as a map of timber values based on the current forest inventory and relative access to roads.

The modeling *Method*, however, is what most distinguishes GIS models from non-spatial models by referring to the spatial character of the processing— contextual or numerical. *Contextual*

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methods use spatial analysis to characterize "contextual relationships" within and among mapped data layers, such as effective distance, optimal paths, visual connectivity and micro-terrain analysis. *Numerical* methods use spatial statistics to uncover "numerical relationships" within and among mapped data layers, such as generating a prediction map of wildfire ignition based regression analysis of historical fire occurrence and vegetation, terrain and human activity map layers.

Spatial Analysis (contextual spatial relationships) and *Spatial Statistics* (numerical spatial relationships) form the "toolboxes" that are uniquely GIS and are fueling the evolution from descriptive mapping and "geo-query" searches of existing databases to investigative and prescriptive map analysis/modeling that address a variety of complex spatial problems— a movement in user perspective from "recordkeeping" to "solutions."

The *Category* characteristic of GIS models is closely related to the concept of "Relational" in general modeling but speaks specifically to the type of spatial relationships and interdependences among map layers. A *process*-oriented model involves movement, flows and cycles in the landscape, such as timber harvesting access considering on- and off-road movement of hauling and harvesting equipment. A *suitability*-oriented model characterizes geographic locations in terms of their relative appropriateness for an intended use.

Model association, aggregation, scale and extent refer to the geographic nature of how map layers are defined and related. *Association* refers to how locations relate to each other and can be classified as *lumped* when the state/condition of each individual location is independent of other map locations (i.e., point-by-point processing). A *linked* association, on the other hand, occurs when the state/condition of each individual location is dependent on other map locations (i.e., vicinity, neighborhood or regional processing).

Aggregation describes the grouping of map locations for processing and is termed *disaggregated* when a model is executed for each individual spatial object (usually a grid cell), such as in deriving a map of predicted biomass based on spatially evaluating a regression equation in which each input map layer identifies an independent "variable," each location a "case," and each map value a "measurement" as defined in traditional statistics and mathematical modeling.

Alternatively, *cohort* aggregation utilizes groups of spatial objects having similar characteristics, such as deriving a timber growth map for each management parcel based on a look-up table of growth for each possible combination of map layers. The model is executed once for each combination and the solution is applied to all map locations having the same "cohort" combination.

GIS modeling characteristics of *Scale* and *Extent* retain their traditional meanings. A *micro* scale model contains high resolution (level of detail) of space, time and/or variable considerations governing system response, such as a 1:1,000 map of a farm with crops specified for each field and revised each year. A *macro* scale model contains low resolution inputs, such as a 1:1,000,000 map of land use with a single category for agriculture revised every 10 years.

A GIS model's *Extent* is termed *complete* if it includes the entire set of space, time and/or variable considerations governing system response, such as a map set of an entire watershed or river basin. A *partial* extent includes subsets of input data that do not completely cover an area of interest, such as a standard topographic sheet with its artificial boundary capturing limited portions of several adjoining watersheds.

For those readers who are still awake, you have endured an introductory academic slap and now possess all of the rights, privileges and responsibilities of an introductory GIS modeling expert who is fully licensed to bore your peers and laypersons alike with such arcane babble. Next month's discussion will apply and extend these concepts to model logic, degrees of abstraction, levels of analysis and processing levels using an example model for assessing campground suitability.

Author's Note: *If you have old GW magazines lying about, see "What's in a Model?" and "Dodge the GIS Modeling Babble Ground" in the January and February 1995 issues of GIS World (the earlier less inclusive magazine name for GeoWorld) or visit www.innovativegis.com, Beyond Mapping III, Chronological Listing, and scroll down to the Beyond Mapping II online compilation of Beyond Mapping columns from October 1993 to August 1996 that is in back-burner preparation.*

A Suitable Framework for GIS Modeling

(GeoWorld, November 2010)

(**return to top of Topic**)

Suitability Modeling is one of the simplest and most frequently used GIS modeling approaches. These models consider the relative "goodness" of each map location for a particular use based on a set of criteria. For example, figure 1 outlines five *Criteria* considerations for locating a campground: favor gentle terrain, being near roads and water, with good views of water and oriented toward the west.

In the flowchart of the model's logic, each consideration is identified as a separate "row." In essence every map location is graded in light of its characteristics or conditions in a manner that is analogous to a professor evaluating a set of exams during a semester. Each spatial consideration (viz. exam) is independently graded (viz. student answers) with respect to a consistent scale (viz. an A to an F grade).

Figure 2 identifies *Analysis Levels* as "columns" used to evaluate each of the criteria and then combines them into an overall assessment of campground suitability. *Base Maps* represent the physical characteristics used in the evaluations— maps of Elevation, Roads, and Water in this case. But these "facts" on the landscape are not in a form that can be used to evaluate campground suitability.

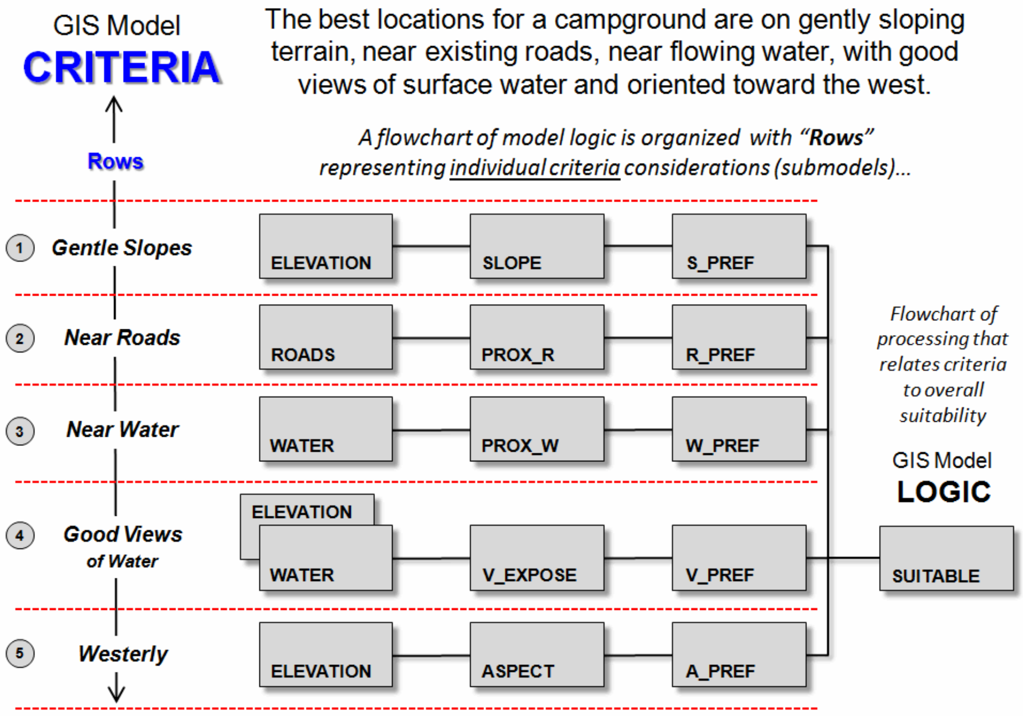

Figure 1. Campground Suitability model logic with rows indicating criteria.

Derived Maps translate physical descriptions into suitability contexts. For example, it is not Elevation per se that affects campground suitability, but the rate and direction of the change in elevation expressed as Slope and Aspect that characterize terrain configuration. Similarly, it is not the presence of roads and water but the relative closeness to these features that affects the degree of suitability (Prox_R and Prox_W).

Interpreted Maps identify increasing abstraction from Facts on the landscape to Judgments within the context of suitability. At this level, derived maps are interpreted/graded into a relative suitability score, usually on a scale from 1 (least suitable/worst) to 9 (most suitable/best). Using the exam grading analogy, a map location could be terrible in terms of terms of proximity to roads and water (viz. a couple of F's on two of the exams) while quite suitable in terms of terrain steepness and aspect (viz. A's on two other exams).

Like a student's semester grade, the overall suitability, or *Combined Map*, for a campground is a combination of the individual criteria scores. This is usually accomplished by calculating the simple or weighted-average of the individual scores. The result is a single value indicating the overall "relative goodness" for each map location that in aggregate forms a continuous spatial distribution of campground suitability for a given project area.

However, some of the locations might be constrained by legal or practical concerns that preclude building a campground, such as very close to water or on very steep terrain. A *Constraint Map*

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eliminates these locations by forcing their overall score to “0” (unsuitable).

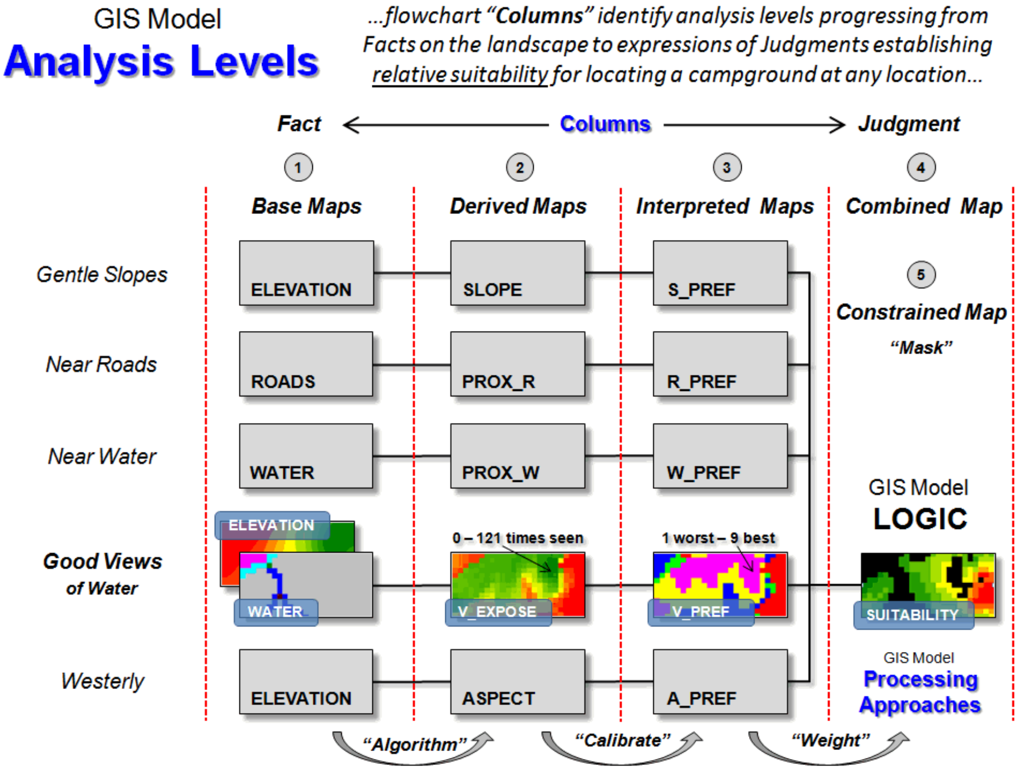


Figure 2. Flowchart columns represent analysis levels transforming facts into judgment.

The logical progression from physical Facts to suitability Judgments involves four basic *Processing Approaches*— Algorithm, Calibrate, Weight, and Mask. For example, consider the goal of “good views of water.” The derived map of visual exposure to water (V_Expose) uses an *Algorithm* that counts the number of times each location is visually connected to water locations—

```
RADIATE Water OVER Elevation TO 100 AT 1 Completely FOR V_Expose
```

…that in this example, results in values from 0 to 121 times seen. In turn, the visual exposure map is *Calibrated* to a relative suitability scale of 1 (worst) to 9 (best)—

```
RENUMBER V_Expose ASSIGNING 9 TO 80 THRU 121  ASSIGNING 8 TO 30 THRU 80  ASSIGNING
5 TO 10 THRU 30  ASSIGNING 3 TO 6 THRU 10  ASSIGNING 1 TO 0 THRU 6  FOR V_Pref
```

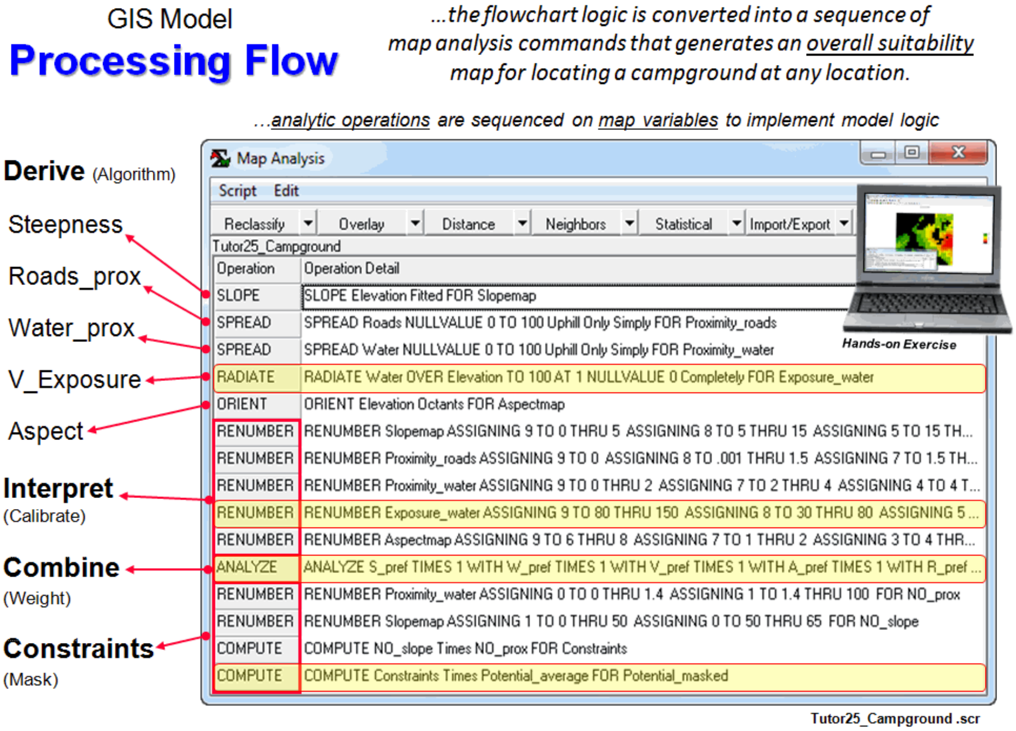
The interpreted visual exposure map and the other interpreted maps are *Weighted* by using a simple arithmetic average—

```
ANALYZE S_PREF TIMES 1 WITH W_PREF TIMES 1 WITH V_Pref TIMES 1 WITH A_PREF TIMES 1
WITH R_PREF TIMES 1 Mean FOR Suitable
```

Finally, a binary constraint map (too steep and/or too close to water = 0; else= 1) is used to *Mask* unsuitable areas—

```
COMPUTE Suitable Times Constraints FOR Suitable_masked
```

Figure 3 depicts the *Processing Flow* as a series of map analysis operations/commands. You are encouraged to follow the flow by delving into more detail and even complete a hands-on exercise in suitability modeling (see author's note)— it ought to be a lot of fun, right?



Operation	Operation Detail
SLOPE	SLOPE Elevation Fitted FOR Slopemap
SPREAD	SPREAD Roads NULLVALUE 0 TO 100 Uphill Only Simply FOR Proximity_roads
SPREAD	SPREAD Water NULLVALUE 0 TO 100 Uphill Only Simply FOR Proximity_water
RADIATE	RADIATE Water OVER Elevation TO 100 AT 1 NULLVALUE 0 Completely FOR Exposure_water
ORIENT	ORIENT Elevation Octants FOR Aspectmap
RENUMBER	RENUMBER Slopemap ASSIGNING 9 TO 0 THRU 5 ASSIGNING 8 TO 5 THRU 15 ASSIGNING 5 TO 15 TH...
RENUMBER	RENUMBER Proximity_roads ASSIGNING 9 TO 0 ASSIGNING 8 TO .001 THRU 1.5 ASSIGNING 7 TO 1.5 TH...
RENUMBER	RENUMBER Proximity_water ASSIGNING 9 TO 0 THRU 2 ASSIGNING 7 TO 2 THRU 4 ASSIGNING 4 TO 4 T...
RENUMBER	RENUMBER Exposure_water ASSIGNING 9 TO 80 THRU 150 ASSIGNING 8 TO 30 THRU 80 ASSIGNING 5 ...
RENUMBER	RENUMBER Aspectmap ASSIGNING 9 TO 6 THRU 8 ASSIGNING 7 TO 1 THRU 2 ASSIGNING 3 TO 4 THR...
ANALYZE	ANALYZE S_pref TIMES 1 WITH W_pref TIMES 1 WITH V_pref TIMES 1 WITH A_pref TIMES 1 WITH R_pref ...
RENUMBER	RENUMBER Proximity_water ASSIGNING 0 TO 0 THRU 1.4 ASSIGNING 1 TO 1.4 THRU 100 FOR NO_prox
RENUMBER	RENUMBER Slopemap ASSIGNING 1 TO 0 THRU 50 ASSIGNING 0 TO 50 THRU 65 FOR NO_slope
COMPUTE	COMPUTE NO_slope Times NO_prox FOR Constraints
COMPUTE	COMPUTE Constraints Times Potential_average FOR Potential_masked

Figure 3. Processing flow that implements the Campground Suitability model.

Author's Note: *An annotated step-by-step description of the Campground Suitability model and hands-on exercise materials are posed at www.innovativegis.com/basis/Senarios/Campground.htm. Additional discussion of types and approaches to suitability modeling is posted at www.innovativegis.com/basis/MapAnalysis/Topic23/Topic23.htm.*

GIS's Supporting Role in the Future of Natural Resources

(GeoWorld, December 2010)

(***return to top of Topic***)

My completely charming wife recently made a thought-provoking presentation entitled "Human Dimensions: From Backstage to Front and Center" for a seminar series on Decades of Change in

Ecological Research at Colorado State University. In the talk she made reference that in 1970s individual disciplinary scientists controlled the podium of discussion, and social science, its issues and human dimensions, were primarily back stage in natural resource research, planning and management (left side of figure 1).

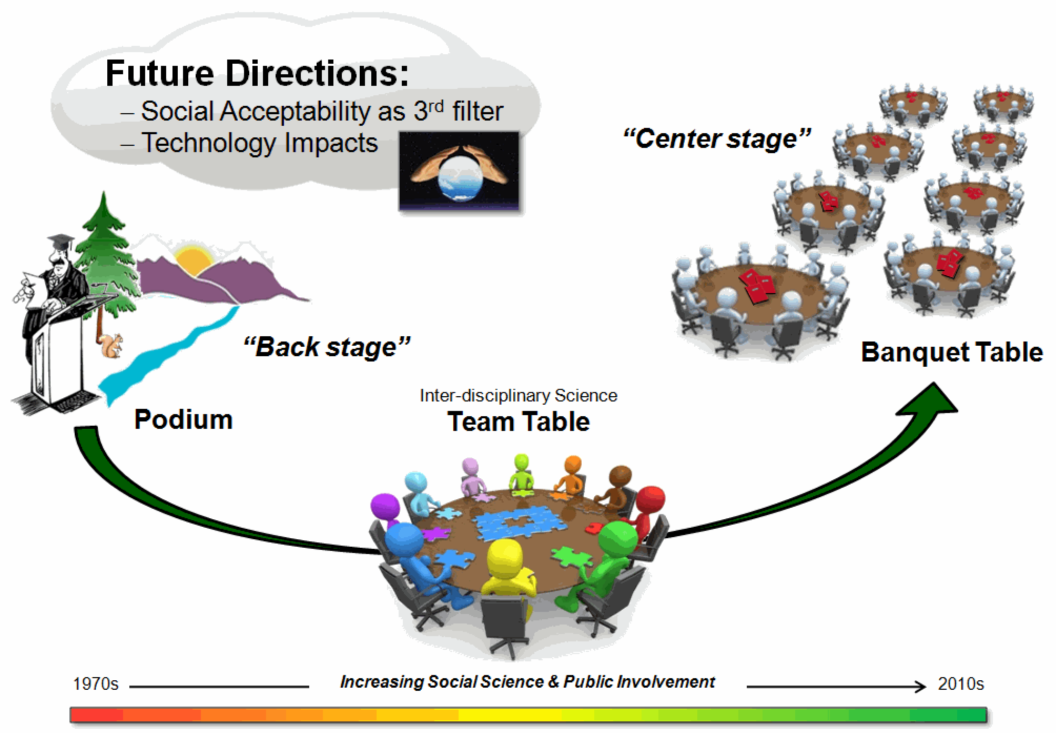


Figure 1. Social science and human dimensions in natural resources have moved from back stage to front and center.

In the 1980s, the podium became a "team table" with a diversity of disciplines collaboratively engaged in science-based discussion for assessing management options. The discussion around the table was expanded to include social science's theories and understandings of human values, attitudes and behaviors.

During the 1990s, the team table expanded further to a room full of "banquet tables" containing a broad diversity of interests promoting direct and active engagement of scientists, managers, stakeholders and representative publics in the conversation. The interaction was space/time bound to scheduled meetings, representative input, organized discussion and manual flip chart documentation.

What dramatically changed over the years is the role of human dimensions in addressing natural resource issues from its early "back stage" position to a "front and center" involvement and increasingly active voice. Today and into the future, *Social Acceptability* has fully joined *Ecosystem Sustainability* and *Economic Viability* as a critical third filter needed for successful decision-making (figure 2). Like a three-legged stool, removal of any of the legs results in an unstable condition and the likelihood of failed decisions.

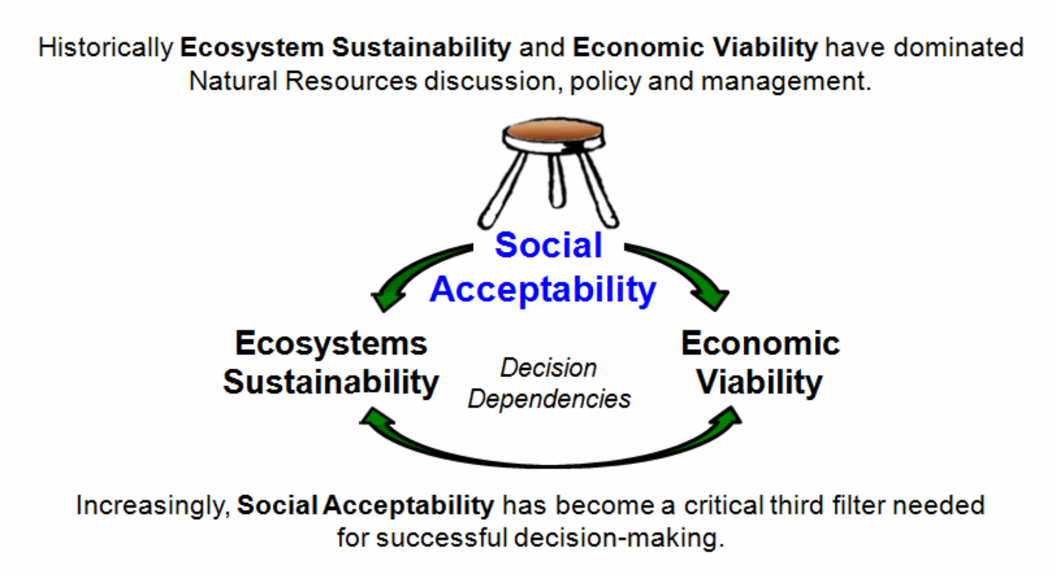


Figure 2. Social acceptability of plans and policy has become an important third filter in natural resources management.

Joining social acceptability as a significant factor impacting the future of natural resources is the changing capabilities and roles of technology— with geotechnology poised to play a key supporting role. Spatially-enabled *Social Networking* concepts, such as “community collaborative mapping,” “participatory GIS,” “user generated content” and the “spatial tweet” will be the shared futures of social science, natural resources and geotechnology.

To a large extent, GIS technology had a fairly slow start in natural resources as practical application got mired in the forest mensuration and mapping units within most NR organizations— data first, utility later. While innovative research projects demonstrated new ways of doing business with spatial data, the data-centric perspective of the specialists (mapping and geo-query) dominated the analysis-centric needs of the managers, policy and decision makers (spatial reasoning and modeling).

But with the growing voice of human dimensions in natural resources there appears to be a plot twist in the works. Maps are being viewed less and less as static wall hangings depicting “*where is what*” and more as dynamic spatial expressions of “*why, so what and what if…*” within the context of alternative management and policy options.

That brings us to one of the hottest new things in computing… “crowdsourcing.” In case some of you (most?) might not be aware of this new field, a thumbnail sketch with a bit of discussion seems in order (figure 3). *Crowdsourcing* is a term that mashes the words "crowd" and "outsourcing" to describe *the act of taking tasks traditionally performed by a team of in-house or outsourced specialists, and outsourcing the tasks to the community through an 'open call' to a large group of people (the crowd) asking for their input (Wikipedia).*

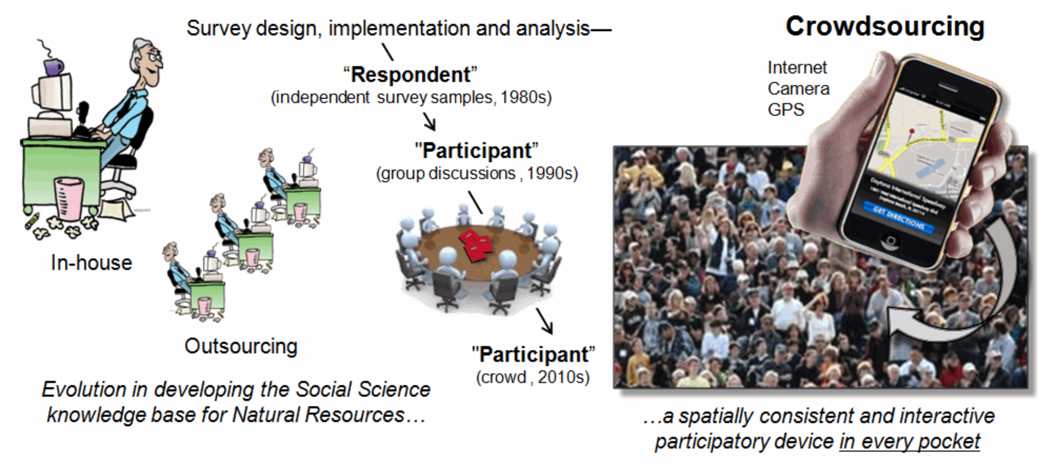


Figure 3. Crowdsourcing solicits mass collaboration via the Internet in formulating socially acceptable policy and plans.

For example, the public may be invited to carry out a design task (also known as "community-based design" and "distributed participatory design"), or help capture, systematize or analyze large amounts of data (citizen science) by *leveraging mass collaboration enabled by the Internet*.

Many cities now provide a smart phone "app" for citizens to take a picture of a pothole and send the geo-tagged photo to the streets department. In a similar manner, park users could report hiking trail locations in need of repair, rate their of trail experience or even send pictures of areas they believe are unusually beautiful or ugly. Crowdsourcing simply provides a modern mechanism for completing a survey in digital form while in route or when they get back to the parking lot and civilized connectivity.

However for natural resource professionals and GIS'ers, crowdsourcing can go well beyond data collection by extending the "social science tools" for consensus building and conflict resolution used in calibrating and weighting spatial models. For example, a model for routing an electric transmission line that considers engineering, environmental and development factors can be executed under a variety of scenarios reflecting different influences of the criteria map layers as interpreted by different stakeholder groups (see Author's Note). The result is infusion of the collective interpretation and judgment required for effective cognitive mapping—participatory input.

Currently, the calibrating and weighting a spatial model usually involves a small set of representatives sitting around a table and hashing out a presumed collective opinion of a larger group's understanding, interpretations and relative weightings. Crowdsourcing suggests one can hang a routing or other spatial model out on a website, invite folks to participate, have some

GUI's that let them interactively set the model's calibrations and weights, and then execute their scenario. They could repeat as often as they like, and once satisfied with a solution they would submit the model parameters. Sort of a virtual public hearing but with more refined interaction and less stale doughnuts and lukewarm coffee left on the tables.

To complete the playhouse metaphor, mapping and geo-query will set the stage, while spatial reasoning and modeling plays out the production with the active participation of an extended audience of scientists, managers, stakeholders and publics—sort of a natural resources experimental theater in the round. This ought to be fun with human dimensions front and center in the limelight and geotechnology handling the stage management.

Author's Note: *For a discussion of procedures in participatory GIS see the online book,* ***Beyond Mapping III****, Topic 19, "A Recipe for Calibrating and Weighting GIS Model Criteria" posted at www.innovativegis.com/basis/MapAnalysis/*.

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