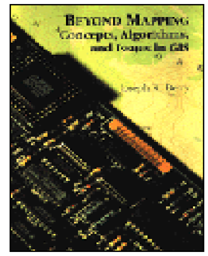
Beyond Mapping I

Topic 10 – Cartographic and Spatial Modeling



***Beyond Mapping* book**

GIS Mirrors Perceptions of Decision Criteria — *describes a flowcharting procedure that expresses GIS model logic in a clear and concise form*

Effective Standards Required to Go Beyond Mapping — *identifies and describes four levels of GIS standards (data Exchange, Geographic, Algorithmic and Interpretational)*

Maps Speak Louder than Words — *describes analysis procedures that translate decision-maker concerns into maps*

Is Conflict Resolution an Oxymoron? — *discusses how weights are used combining individual map layers of concern to derive an overall map of suitability that reflects group consensus*

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GIS Mirrors Perceptions of Decision Criteria

(GIS World, February 1993)

…whether you like it or not

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As GIS takes us beyond mapping to application modeling, our attention is increasingly focused on the considerations embedded in the derivation of the "final" map. The map itself is valuable, but the thinking behind its creation provides the real insights for decision-making. From this perspective, the model becomes even more useful than the graphic output. Yeah, sure.

No, it's true. Consider the simple model outlined in Figure 1. It identifies the suitable areas for a campground considering basic engineering and aesthetic factors. Like any other model it is *a generalized statement, or abstraction, of the important considerations in a real-world situation*. It is representative of one of the most common GIS applications— a suitability model. There are other types, but for now, let's take a closer look at this one.

First, note that the model is depicted as a flowchart with boxes indicating maps, and lines indicating GIS processing. It is read from left to right. For example, the top line tells us that a map of elevation (ELEV) is used to derive a map of relative steepness (SLOPE), which in turn, is interpreted for slopes that are better for a campground (S-PREF).

Next, note that the flowchart has been subdivided into compartments by dotted horizontal and vertical lines. The horizontal lines identify separate sub-models expressing suitability criteria— gently sloped, near roads, near water, with good views of water and a westerly aspect. But more on these details latter. For now concentrate on the overall structure of the model. The vertical lines indicate increasing levels of abstraction. The left-most PRIMARY MAPS section identifies the base maps needed for this application. In most instances, they are physical features described through field surveys— elevation, roads and water. They are our inventory of the landscape that we accept as "fact."

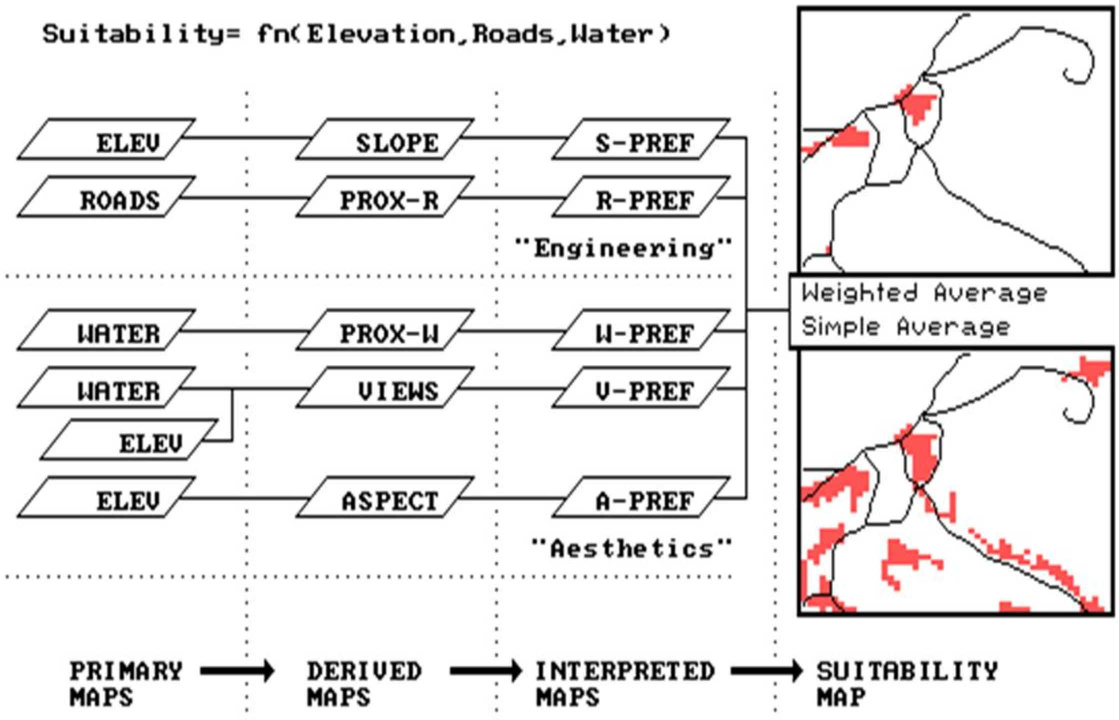

Figure 1. Campground Suitability Model. The "best" areas are gently sloped, near roads, near water, with good views of water and a westerly aspect.

The next group is termed DERIVED MAPS. Like primary maps, they are "facts." It is just that they are difficult to collect and encode, so we use the computer to derive them. For example, slope can be measured with a clinometer, but it is impractical to collect this information for the 2,500 quarter-hectare locations (grid cells) in the project area. Similarly, the distance to roads can be measured by a survey crew "pulling tape." But it is just too difficult. Note that these first two levels of model abstraction are concrete descriptions of the landscape. We could check the accuracy of our primary and derived maps simply by taking them into the field and measuring. They exist. They're tangible. We're comfortable.

The next two levels, however, are an entirely different matter. It is at this juncture that we move from "fact" to "judgment" …from the *description* of the landscape to the *prescription* of a proposed land use. The INTERPRETED MAPS are the result of grading landscape factors in terms of an intended use. This involves assigning a relative "goodness value" to each map condition. For example, gentle slopes are preferred locations for campgrounds. However, if you were assessing suitability for a ski area, the steeper slopes might be better. It is imperative that a common goodness scale is used for all of the interpreted maps. It's like a professor's grading of several exams throughout the term. Each test (analogous to a primary or derived map) is graded. As you would expect, some students (analogous to map locations) score well on an exam, while others flunk.

The final SUITABILITY MAP is a composite of the set of interpreted maps. Like the professor at the end of the term, you simply average the test scores for each student's semester grade. There, that's it. Everyone (analogous to each map location) is given an overall ranking. In the figure, the lower map inset identifies the best overall scores. However, you might want to do some spatial spreadsheet "what-if-*ing*." What if views (V-PREF map) are ten times more important than the other preferences? The upper map inset shows that the good locations, in this scenario, are severely cut back to just a few areas. But what if steepness was more important? Or proximity to water? Where are best locations now? Are there any consistently good locations?

Whoa! Too abstract. It's time to look at the specifics of the model. The horizontal compartments chart the processing of the individual criteria. The "engineering" concerns for avoiding steep slopes and large distances from existing roads is common sense. It costs a lot more to construct a campground under these conditions. Hidden behind the flowchart is the actual code (termed a "macro") which achieves the objectives. Expressed in MapCalc command sentences, they are:

```
SLOPE ELEVATION FOR SLOPEMAP
RENUMBER SLOPEMAP FOR S-PREF ASSIGN 9 TO 0 THRU 5 ASSIGN 8
  TO 6 THRU 15 ASSIGN 5 TO 16 THRU 25 ASSIGN 3 TO 26 THRU 40
  ASSIGN 1 TO 41 THRU 100
SPREAD ROADS TO 100 FOR PROX-R
RENUMBER PROX-R FOR R-PREF ASSIGN 9 TO 0 ASSIGN 8 TO
  1 ASSIGN 7 TO 2 THRU 3 ASSIGN 4 TO 4 THRU 6 ASSIGN
  1 TO 7 THRU 100
```

The "slope" and "spread" commands create the derived maps indicating steepness and proximity to roads. These in turn are "renumbered" (i.e., calibrated) with 9 being the best through 1 being the worst. For example, the value 9 is assigned to the gentlest slopes of 0-5% and the closest distances of 0 cells away (100m grid spacing).

The "aesthetics" considerations of being near water, having good views of water and oriented toward the west are expressed in the following sentences.

```
SPREAD WATER TO 100 FOR PROX-W
RENUMBER PROX-W FOR W-PREF ASSIGN 9 TO 0 THRU 2 ASSIGN 7 TO
  3 THRU 4 ASSIGN 4 TO 5 THRU 6 ASSIGN 1 TO 7 THRU 100
RADIATE WATER OVER ELEVATION COMPLETELY TO 10 FOR VIEWS
RENUMBER VIEWS FOR V-PREF ASSIGN 9 TO 30 THRU 100 ASSIGN 8
  TO 20 THRU 29 ASSIGN 6 TO 15 THRU 19 ASSIGN 4 TO 5 THRU
  14 ASSIGN 1 TO 0 THRU 4
```

ORIENT ELEVATION FOR ASPECTMAP
RENUMBER ASPECTMAP FOR A-PREF ASSIGN 9 TO 6 THRU 8
ASSIGN 7 TO 1 THRU 2 ASSIGN 3 TO 4 THRU 5 ASSIGN 1 TO 3

The "spread," "radiate" and "orient" commands generate the derived maps. "Renumber" calibrates each map using the same grading scheme. For example, 9 is assigned to the closest distances to water of 0-2 cells away, the most visually exposed to water of 30-100 connections and the westerly octants of 6-8. Such power, you're in command. Like the professor, your interpretations control the fate of thousands of entities (analogous to map locations).

The easy part is the next step. Just enter:

AVERAGE S-PREF TIMES 1 WITH R-PREF TIMES 1 WITH W-PREF TIMES
1 WITH V-PREF TIMES 1 WITH A-PREF TIMES 1 FOR RANKING

for an overall ranking. Locations with an average of 7 or better are displayed with the road network for reference in the lower inset. These locations are the contenders for the campground.

But we might want to do some additional thinking. You know, try a few things. Note that the "times 1" in the averaging command indicates the weighting factor for each map. Edit the sentence to "V-PREF TIMES 10" and resubmit to make good views more important. The result is the map on top, with a much narrower set of choices.

Actually, there are three types of modifications you can make— weighting, calibration and structural. Each involves editing the "macro," then resubmitting. Weighting modifications affect the compositing of interpreted maps into the overall suitability map, as described above. Calibration modifications affect the assignment of the individual "goodness ratings." For example, you might assign 9 (best) to a broader range of slopes, say 0-10%. I wonder if that changes things much.

Weighting and calibration modifications are easy and straight forward—edit a parameter, then resubmit and see the effect. Structural changes are something else. They involve changing the logical structuring of the flowchart. For example, it might occur to you that forested areas are better than open terrain. To handle this, you need to add a new sequence of maps to the "aesthetics" compartment beginning with a cover type map. Now you are GIS*ing*— conceptualizing the important considerations as maps, and expressing their relationships as GIS commands. Actually that's map-ematical modeling— a piece of cake.

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Author's Note: As with all Beyond Mapping columns, allow me to apologize in advance for the "poetic license" invoked in this terse treatment of a complex subject. Readers with the MapCalc Tutorial disk should review TU-DEVEL.CMD which executes a similar suitability model. A related discussion on modeling appears in a paper by Berry and Berry, "Assessing Spatial Impacts of Land use Plans," in the Journal of Environmental Management, 27:1-9, 1988.

Effective Standards Required to Go Beyond Mapping

(GIS World, March 1993)

…the problem is that there are so many different ones

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The previous section outlined the basic concepts in GIS modeling. Behind each complex map there is a sequence of commands (termed a macro) which reflects the "rational thinking" of the application model. The processing often is summarized into a flowchart for easier communication. Once structured, the model can be repeatedly executed in a manner similar to running "what if" scenarios in spreadsheet analysis. That must be it— GIS is merely a spatial spreadsheet.

Yep, you're right... in part. Actually, spreadsheet analysis is just one piece of a larger field called mathematical modeling. Now that maps are numbers (which we process with map-ematics) it becomes apparent that GIS comes with all the rights, privileges and responsibilities of other mathematics. First and foremost, is a requirement to cloud common sense with litany of terminology. At the risk of heated debate, let me suggest that are three broad types of models in GIS— the data model, the relational model, and the application model. Data and relational models describe how spatial information is developed and stored within the GIS. An example of a data model is the use of Kriging to spatially interpolate a set of point measurements into a continuous surface, or mapped variable. With remotely sensed data, it is the classification procedure and the spectral signatures. Once a "map variable" is defined, the relational model assigns "spatial topology" and "attribute characteristics" within the context of the GIS system.

Whew, did you survive that opaque statement? Do you know what it means? Several of the earlier Beyond Mapping articles discussed some the important considerations in these models (GW September, 1989 through April, 1990). In short, the data and relational models describe the "what and where" of spatial information. An application model, on the other hand, addresses the "so what" aspects of mapped data. It investigates the intra- and inter-relationships of maps. The application model is used to gain conceptual clarity and better understanding of a system or issue.

In the broadest of definitions, there are two types of application models— cartographic and spatial. The distinction between the two lies along a continuum extending from conceptual to system modeling. The degree of mathematical rigor is a good litmus test of the two types. For example, I recently had a graduate GIS class nearly split between civil engineers and natural resource managers. The term projects of the resource managers tended toward cartographic models expressing their understanding of a issue, such as spotted owl habitat. These conceptual models were heavy on insight, but relatively light on mathematics and empirical study. The engineers' models, on the other hand, generally involved the spatial evaluation of existing equations, such as Horton overland flow of surface water. One student even had a model with a single equation that exceeded four lines of code (e.g., (ln(map1 ** map2)...). The differences in approach and GIS requirements between the cartographic and spatial modelers were readily apparent.

These differences, along with those raised in data and relational models, places new demands on map standards. Like the fabled Kracken, in Greek mythology, standards will rise from a sea of confusion and inundate our feeble structures of paper map standards. The assault is on four fronts— exchange, geographic, algorithm and modeling. *Data Exchange standards*, the easiest to address, merely involve establishing data formats for the importing and exporting of maps among different GIS systems. In the U.S., the recently released Spatial Data Transfer Standards (SDTS) has effectively made exchange standards a non-issue. But what of the other three areas of concern?

Geographic standards for manually prepared maps have been evolving for hundreds of years. Historically, they have been concerned with the spatial precision used in locating the boundaries of map features. Concepts, such as map scale and projection, are well-developed and standardized. For the most part, these standards are easily translated into the digital world of GIS. But there are some hidden pitfalls GIS's characterization of mapped data.

A major problem lies in the assignment of numbers (thematic values) to represent the various characteristics and conditions of a map variable. For example, a map of soils might contain numbers which merely reflect the color pallet used to plot the standard colors associated with each soil class. These numbers are likely sufficient for most mapping and data base management applications, but modeling is more demanding. Numbers from 0 to 100 might be used to identify the clay content of each soil class. For runoff modeling, a saturation index might be a more useful expression of soil distribution than simply soil class number. On a vegetation map, numbers incorporating the range of age and stocking, as well as species, might be required. A sophisticated spatial timber supply model will require a statistical description of the variance in all of these data.

That's the problem— the simple translation of map symbols and colors into numbers may not be sufficient for many of the application models. Review of geographic standards for the "corporate data base" needs to be extended to include the informational content, as well as locational precision. In the U.S., the standards for various base maps are under review in the "national map-down" which is coordinated by the Geological Survey. Chances are the soil and vegetation maps resulting from this review will be radically different from the current paper product expressions. GIS modeling demands will be at the core of these changes.

Algorithmic standards, involving the processing capabilities within a GIS, must also be addressed. At the computational level various algorithms need to be benchmarked, and users given guidelines for their appropriate use. For example, the differences among maximum, average and fitted slope algorithms should be established and users advised which is most appropriate for particular applications. Spatial interpolation, distance measurement, visual analysis and fragmentation indices are other examples of algorithms awaiting review.

At another level, the processing structure of GIS can be made more standard. In the early years of data base management, the various products had little to do with one another. The advent of the Standard Query Language (SQL) greatly added to the utility of these systems. In a similar vein, a "GSL" (GIS Standard Language) would stimulate the development and exchange of application models. Without it (or at least a basic set of functionality) our modeling efforts are atomized. It's like each car company deciding where to put the clutch, brake and gas pedals— both dumb and dangerous.

A coordinated assault on algorithm standards is not, as of yet, in place. However, several factors in the natural maturation of GIS are contributing its refinement. Within academia, the growing number of courses and texts in GIS are contributing to definition of a common and comprehensive processing structure. As GIS vendors look over their shoulders at the competition, they tend to incorporate the "good ideas" of others. Finally, as an increasing number of large procurements hit the street, their specifications provide a defacto definition of processing capabilities. This same maturation progression was evident in data base management— GIS is just its younger sibling.

Let's see, exchange standards have been addressed, geographic standards are being addressed, and algorithm standards are gleam in the eyes of a venturesome few. But what about standards in the models themselves? Such concerns, referred to as *Interpretational standards*, have received minimal attention. To date, emphasis has been on producing products, not the verification of the results or logic behind a final map. As more and more "modeled" maps surface, there is an increasing opportunity to scrutinize modeling results. If an area is classified as excellent elk habitat, or ancient forest, but those on the ground know different, the product will eventually be deemed sub-standard.

Two procedures might accelerate this process. First, empirical verification results could be included with a final map, like the geographic descriptors of scale and projection. If "ground truth" shows that ancient forest was incorrectly identified a third of the time, the user of the product should be so advised. If empirical verification isn't possible, error propagation modeling can be used to estimate the reliability of the final map (see Beyond Mapping, November, 1991 through February, 1992). Keep in mind that, by definition, modeling is an abstraction of reality (an "educated" guess).

Another useful tool in establishing interpretation standards is the map "pedigree." This is a new addition to a map's legend brought on by GIS modeling. In its simplest form, the pedigree is merely a listing of the macro (commands) used to create the final map. More elegant renderings contain a flowchart of processing as well. These succinct descriptions of model logic provides and entry point for evaluating the model and suggesting changes. As GIS modeling matures, a map without its pedigree will be as unacceptable as dog show contestant without its AKC papers.

In the past, maps were principally accepted on face-value. A neatly drafted map indicated the cartographer's concern for accuracy. If it looked good, it was probably good. But GIS modeling has changed the playing field, as well as the rules. Without effective standards that address this new environment, GIS will have difficulty going beyond mapping.

Maps Speak Louder than Words

(GIS World, April 1993)

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By their nature, all land use plans contain (or imply) a map. The issue is just that— "what should go where." As noted in the last couple of articles, there is a lot of thinking that goes into a final map recommendation. One can't simply arm a survey crew with a "land use-ometer" to measure the potential throughout a project area. The logic behind the land use model and its interpretation by different groups are the basic elements leading to an effective land use map "solution." The map itself is merely one rendering of the thought process.

The potential of "interactive" GIS modeling extends far beyond its technical implementation. It promises to radically alter the decision-making environment itself. A "case study" might help in making this claim. The study uses three separate spatial models for allocating alternative land uses of conservation, research and residential development. In the study, GIS modeling is used in consensus building and conflict resolution to derive the "best" combination of competing uses of the landscape.

The study takes place in consulting heaven— the western tip of Caribbean island of St. Thomas. Base maps of roads, shoreline, elevation, and current flow formed the basis of the application. Separate suitability models were developed for three alternative land uses— conservation, research and development. The final model addressed the best allocation of land, by simultaneously considering all three potential landscape uses. The departure from "traditional" analysis is that the GISs were used in "real-time" to respond to the questions and concerns of decision-makers. In doing so, the modeling contributed to consensus building and conflict resolution, as well as graphic portrayal of the final plan. But first, let's quickly consider the three alternative models (see Author's Note for a more detailed reference).

A map of accessibility to existing roads and the coastline formed the basis of the Conservation Areas Model. In determining access, the slope of the intervening terrain is considered. The 'slope-weighted' proximity from the roads and from the coastline was calculated. In these calculations, areas that appear geographically near a road may actually be much less accessible. For example, the coastline may be a 'stone's throw away' from the road, but if it's at the foot of a cliff it may be effectively inaccessible for recreation.

The two maps of weighted proximity from both the roads and the coast were combined into an overall map of accessibility. The final step of the analysis involved interpreting relative access into conservation uses (see figure 1). Recreation was identified for those areas near both roads and the coast. Intermediate access areas were designated for limited use. Areas effectively far from roads were designated as preservation areas.

The characterization of the Research Areas Model first used the elevation map to identify individual watersheds. The set of all watersheds was narrowed to just three based on scientists' requirements that they be relatively large and wholly contained areas (Figure 2). A sub-model used the prevailing current to identify coastal areas influenced by each of the three terrestrial research areas.

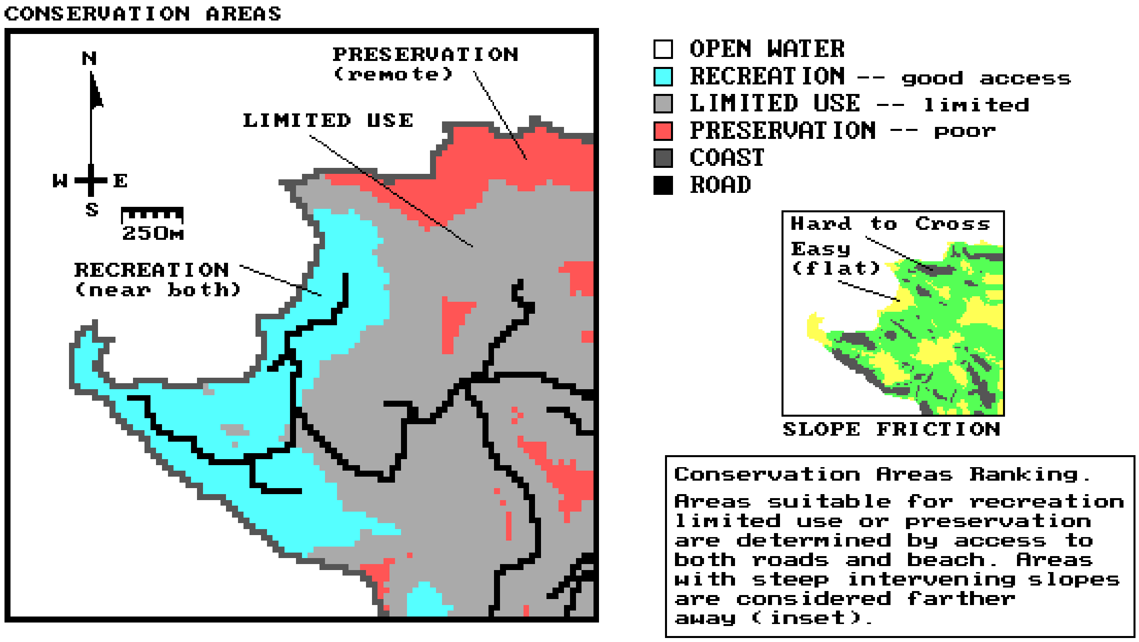

Figure 1. *Conservation Areas Map.*

The Development Areas Model determined the 'best' locations for residential development. The model structure used is nearly identical to that of "campground" suitability model described two issues ago—mega-bucks estates simply replaces tent city. Engineering, aesthetic, and legal factors were considered. As before, the engineering and aesthetic considerations were treated independently, as relative rankings (analogous to, midterm test scores). An overall ranking (analogous to, term grade) was assigned as the weighted average of the five "preference" factors. The legal constraints, on the other hand, were treated as "critical" factors. For example, an area within the 100 meter set-back was considered unacceptable, regardless of its aesthetic or engineering rankings.

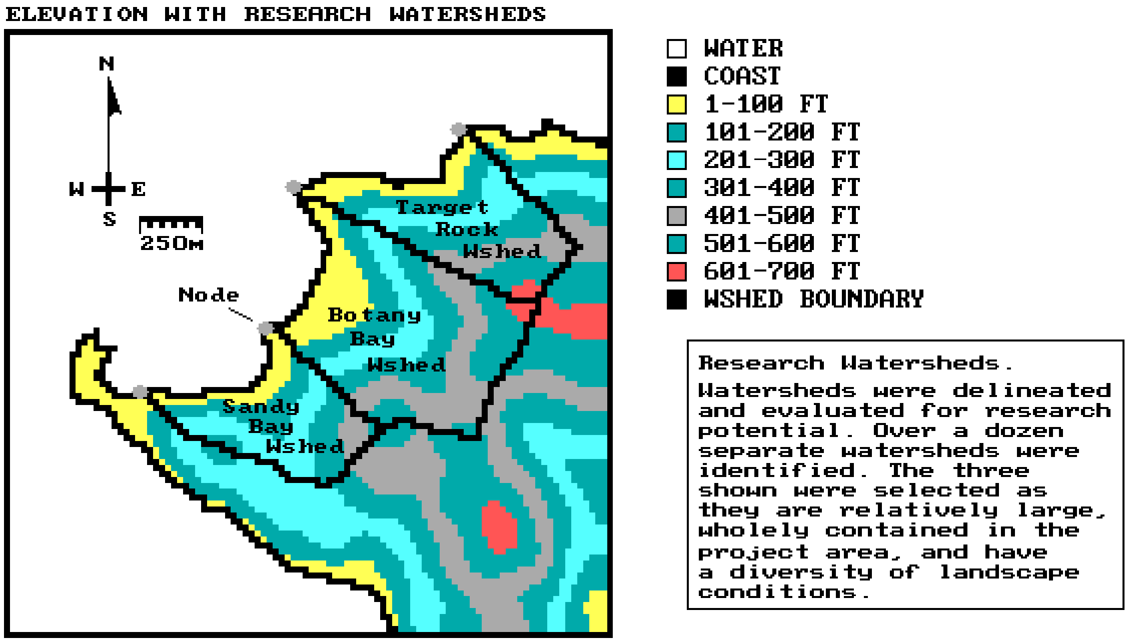

Figure 2. Research Areas Map.

Figure 3 shows a composite map containing the simple arithmetic average of the five separate preference maps used to determine development suitability. The constrained locations mask these results and are shown as light grey (values within constrained areas are assigned the preference value of 0). Note that approximately half of the land area is ranked as 'Acceptable' or better (darker tones). In averaging the five preference maps, all criteria were considered equally important at this step.

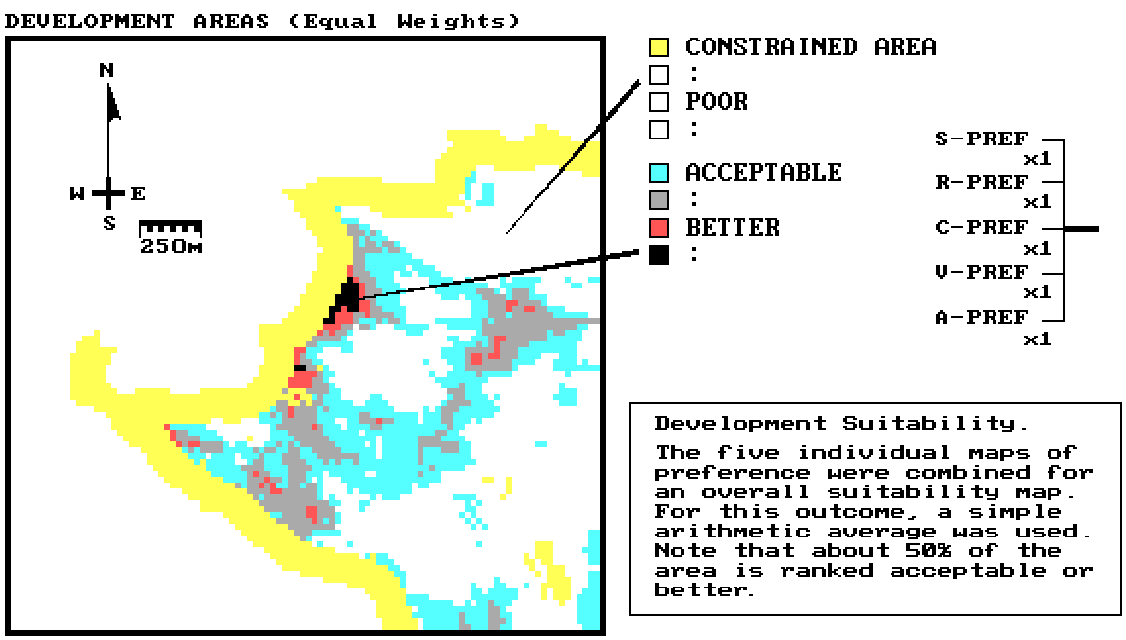

Figure 3. *Development Areas Map (Unweighted).*

The analysis was extended to generate a series of weighted suitability maps. Several sets of weights were tried. The group finally decided on:

- ✓ *view preference times 10 (Most Important)*
- ✓ *coast proximity times 8*
- ✓ *road proximity times 3*
- ✓ *aspect preference times 2*
- ✓ *slope preference times 1 (Least Important)*

The resulting map of the weighted averaging is presented in Figure 4. Note that a smaller portion of the land is ranked as 'Acceptable' or better. Also note the spatial distribution of these prime areas are localized to three distinct clusters.

The group of decision-makers was involved in construction of all three of the individual models—conservation, research and development. While looking over the shoulder of the GIS specialist, they saw their concerns translated into map images. They discussed whether their assumptions made sense. Debate surrounded the "weights and calibrations" of the models. They saw the sensitivity of each model to changes in its parameters. In short, they became involved and understood the map analysis taking place. That's a far cry from viewing a "solution" map for the first time at a public hearing. Or, hearing the continued reference by the experts to the three volume report each time there is a question. Heck, you didn't have the time (nor expertise) to read the report in the first place. Damned if you will read it after tonight's vote.

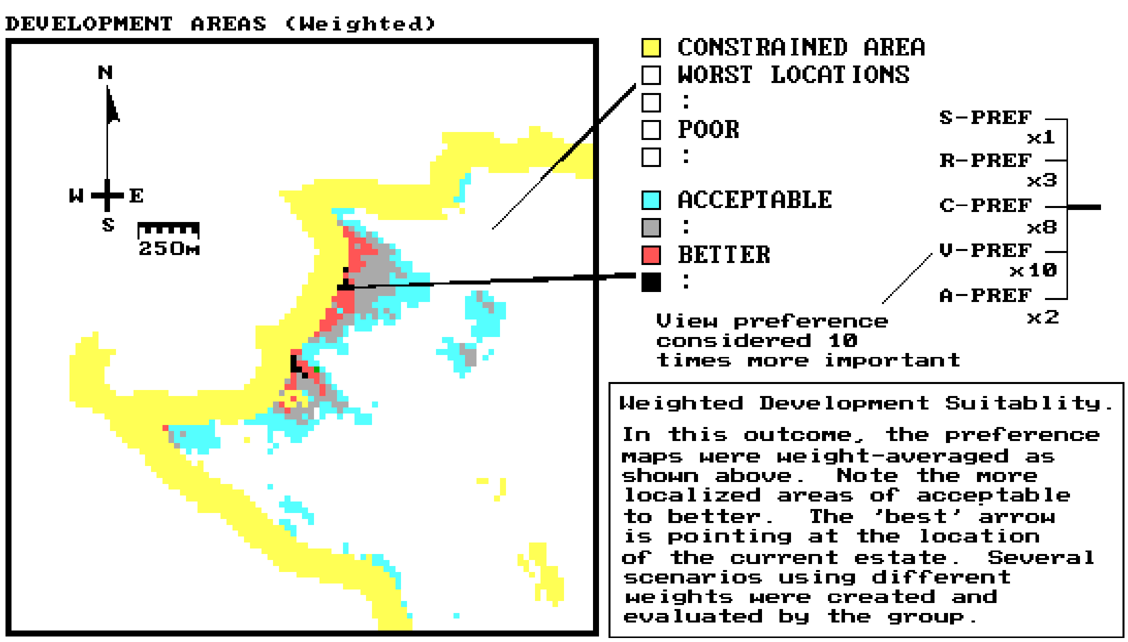

Figure 4. *Development Areas Map (Weighted).*

That's the new twist GIS modeling brings. It enables decision-makers to be just that— decision-makers.

Not choice-choosers constrained to a few pre-defined alternatives. The involvement of decision-makers in the analysis process contributes to *consensus building*. As you see your concerns, and those of others, incorporated into the analysis, you get a better feeling about the issue. In this case, the group reached consensus on the three independent land use renderings. That sets the stage for the final show-down—*conflict resolution*. See you next issue.

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Author's Note*: As with all Beyond Mapping articles, allow me to apologize in advance for the "poetic license" invoked in this terse treatment of a complex subject. Readers with the MapCalc Tutorial disk should review the "digital" slide show BB-BK.BAT which contains a slide set of the application described. A more detailed discussion on the application is in "GIS Resolves Land Use Conflicts: A Case Study," 1993 GIS International Source Book, available from the GIS World Bookshelf.*

Is Conflict Resolution an Oxymoron?

(GIS World, May 1993)

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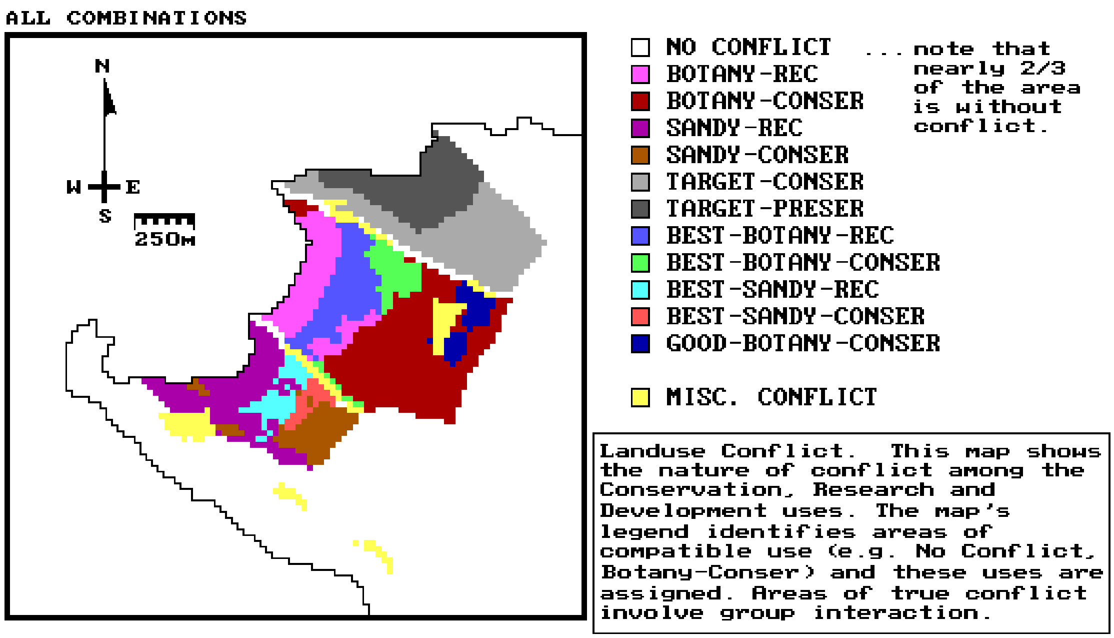
The previous section might have left you hanging. The three analyses determined the best use of the project area considering conservation, research and development criteria in a unilateral manner. However, what about areas common to two or more of the maps? These are the areas of conflict are where the decision-makers must "either fish or cut bait." Three basic approaches in resolving conflicts are at your disposal— hierarchical dominance, compatible use and tradeoff. *Hierarchical dominance* assumes certain land uses are more important and, therefore, supersede all other potential uses. *Compatible use*, on the other hand, identifies harmonious uses and assigns several uses to a single location. *Tradeoff* recognizes the hardcore conflicting uses on a parcel-by-parcel basis and attempts resolve that land use takes precedence. Effective land use decisions involve elements of all three of these approaches.

From a map processing perspective, the hierarchical approach is easily expressed in a quantitative manner and results in a deterministic solution. Once the political system has identified a superseding use it is relatively easy to map these areas and assign a value indicating the desire to protect them from other uses. Multiple use also is technically simple from a map analysis context, though often difficult from a policy context. When compatible uses are identified, a unique value identifying both uses is simply assigned to all areas with the joint condition.

Conflict arises when the uses are incompatible. In these instances, quantitative solutions to the allocation of land use are difficult, if not impossible, to implement. The complex interaction of the frequency and juxta-positioning of several competing uses is still most effectively dealt with by human intervention. GIS technology assists decision-making by deriving a map which indicates the set of alternative uses vying for each location. Once in this graphic form, decision-makers can assess the patterns of conflicting uses and determine land use allocations. GIS can also assist by comparing different allocation scenarios and identifying areas of difference.

In the "consulting heaven" study, the Hierarchical Dominance approach was tried, but it was a total failure. At the onset, the group was uncomfortable with identifying one land use as always better than another. However, just for fun, identifying development as least favored, recreation next, and the researchers' favorite watershed taking final precedence demonstrated the approach. The resulting map was rejected as it contained very little area for development, and what areas were available, were scattered into disjointed parcels— infeasible conditions. Even if you could clarify conflict in 'policy space,' it is frequently muddled in the complex reality of geographic space.

The alternative approaches of compatible use and tradeoff both depend on generating a map indicating all of the competing land uses for each location in a project area— a comprehensive *conflicts map*. Figure 1 is such a map considering the Conservation Areas, Research Areas and Development Areas maps. Note that most of the area is without conflict (lightest tone). In the absence of the spatial guidance in a conflicts map, there is a tendency to assume every square inch is in conflict. In the presence of a conflicts map, however, attention is quickly focused on the unique patterns of actual conflict.



<u>Figure 1.</u> Conflicts Map.

First, the areas of actual conflict were reviewed for compatibility. For example, it was suggested that research areas could support limited use hiking trails, and both activities were assigned to those locations. However, most of the conflicts were real and had to be resolved "the hard way." Figure 2 presents the group's 'best' allocation of land use. Dialogue and group dynamics dominated the tradeoff process. As in all discussions, individual personalities, persuasiveness, rational arguments and facts affected the collective opinion. The initial break-through was the agreement that the top and bottom research areas should remain intact. In part, this made sense as these areas had significantly less conflict than the central watershed.

It was decided that all development should be contained within the central watershed. Structures would be constrained to the approximately twenty contiguous hectares identified as best for development, which was consistent with the island's policy to encourage 'cluster' development. The legally 'constrained' area between the development cluster and the coast would be for the exclusive use of the residents. The adjoining research areas would provide additional buffering and open space, thereby enhancing the value of the development. In fact, it was pointed out that this arrangement provided a third research setting to investigate development, with the two research watersheds serving as control.

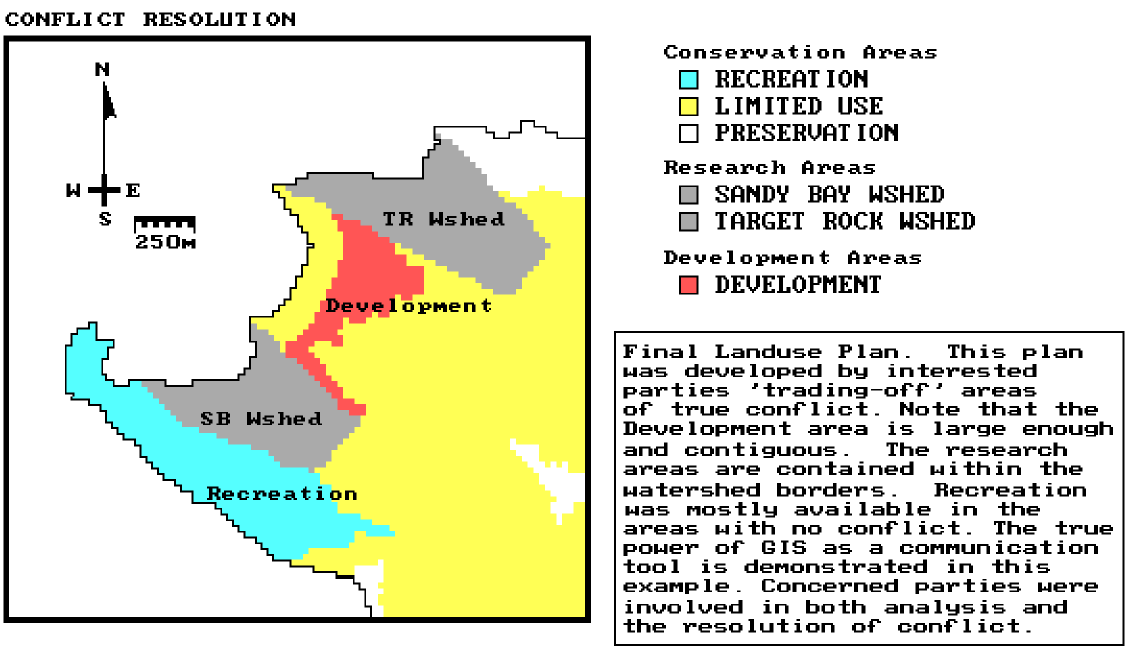


Figure 2. Final Map of Land Use Recommendations.

Recreation use then received the group's attention. This step was easy as a large part of the best recreation area was in the southern portion with minimal conflict with the other uses. Finally, the remaining small 'salt and pepper' parcels were absorbed by their surrounding 'limited or preservation use' areas. In all, the group's final map is a fairly rational land use allocation result and one that is readily explained and justified. Although the decision group represented several diverse opinions, this final map achieved consensus. In addition, each person felt as though they actively participated and, by using the interactive process, better understood both the area's spatial complexity and the perspectives of others.

This last step of tradeoffs in the analysis may seem anticlimactic. After a great deal of 'smoke and dust raising' about computer processing, the final assignment of land uses involved a large amount of subjective judgment. This point, however, highlights the capabilities and limitations of GIS technology. Geographic Information Systems provide significant advances in how we manage and analyze mapped data. It rapidly and tirelessly allows us to assemble detailed spatial information. It also allows us to incorporate much more sophisticated and realistic interpretations of the landscape. It doesn't, however, provide an artificial intelligence for land use decision-making. GIS technology greatly enhances our decision-making capabilities, but does not replace them. It is both a toolbox of advanced analysis capabilities and a sandbox to express our creativity and concerns.

Author's Note: *The application reported demonstrates the important concepts GIS modeling— the material is presented for demonstration purposes only. Readers with the MapCalc Tutorial disk should review the "digital" slide show BB-BK.BAT which contains a slide set of the application described. A more detailed discussion on the* *application is in "GIS Resolves Land Use Conflicts: A Case Study," 1993 GIS International Source Book, available from the GIS World Bookshelf.*

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