# GIS IN ISLAND RESOURCE PLANNING: A CASE STUDY IN MAP ANALYSIS

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*This chapter demonstrates the important concepts and practical considerations in map analysis using GIS. The case study presents three separate spatial models for allocating conservation, research and development land uses in planning island resources. A fourth model addresses conflict resolution in determining the best combination among the competing uses.*

## INTRODUCTION

Historically, maps have been used for navigation through unfamiliar terrain and seas. Within this context, the preparation of maps accurately locating physical features is the primary focus of attention. More recently, however, analysis of mapped data for decision making has become an important part of resource planning. During the 1960s, manual analytical procedures for overlaying maps were popularized. These techniques mark an important turning point in the use of maps – from one emphasizing physical description of geographical space to another spatially prescribing appropriate management actions. This movement from *descriptive* to *prescriptive* mapping has set the stage for revolutionary concepts of map structure, content and use. GIS provide the means for effecting such a transition. In one sense, this aspect of GIS is similar to conventional map processing involving map sheets and drafting aids such as pens, rub-on shading, rulers, planimeters, dot grids and acetate sheets for light-table overlays. In another sense, these systems provide a vast array of analytical capabilities enabling managers to address complex issues in entirely new ways.

GIS have several roles in spatial information processing. First, GIS can be viewed as a tool for 'computer mapping', emphasizing the creation and updating of traditional map products. From this perspective, the term GIS is purely descriptive – graphical output of information provided by the user. GIS then became viewed as a technology for 'spatial database management', providing a linkage between descriptive attributes and geographical locations. From this perspective, GIS are still purely descriptive, providing graphical summaries of the results from spatial data queries.

More recently, the roles of GIS as map production tools and as a database technology have evolved to include the capabilities for interpretation – as well as presentation – of mapped data. Within this context, the interrelationships among mapped data become the focus of attention. In such work, entirely new spatial information is created as users derive and interpret landscape factors for specific management activities. The application described in this chapter is one example of this revolution in map analysis, as applied to the planning of island resources. The history and theory of map analysis is covered extensively by Tomlin 1991 (in this volume).

## MAPS AS DATA

Spatial analysis often involves large volumes of data. These data are characterized by maps describing both the 'where' (the locational attribute) and the 'what' (the thematic attribute). Map scale and projection determine the form of coordinates locating landscape features in geographical space. The features indicate the theme of the map, such as a soil map or a road map. Traditionally, this information is identified by lines and shadings carefully drawn on paper sheets. In a GIS, this information is computerized and stored as numbers. It is this digital nature of maps that fuels the revolution in map analysis.

Manual cartographic techniques allow simple manipulation of maps, but are limited for the most part to qualitative, rather than numerical processing. Such procedures are severely handicapped and often do not provide the numerical input demanded by modern decision-making models. Traditional quantitative approaches, on the other hand, enable numerical analysis of the data but the sheer magnitude of mapped data becomes prohibitive for practical processing. Most often, decisions are made based on the 'average' slope or 'dominant' soil type occurring over large geographical areas. These simplifying values are easily manipulated with a calculator but gloss over the actual spatial complexity of a landscape. For example (see Berry 1987a), a study area may have a gentle average slope most often containing very stable soil. Under these typical conditions, traditional analysis using the spatially aggregated averages would be free to allocate a land use generating high surface water runoff. However, scattered throughout the area may be pockets of very steep slopes with highly erodible soils. In these instances, the results could be environmentally devastating – a condition missed by assuming that the averages pertain everywhere.

The ability of GIS technology to retain detailed geographical information in characterizing space, termed locational specificity, is a major advantage over traditional numerical analysis, especially when allied to analytical procedures. For example (see Berry and Berry 1988), a set of maps indicating a town's suitability for residential development considering soil types, slopes, wetlands, farmland preservation, proximity to existing residential areas, schools, parks and numerous other factors could be drawn in various colours on to clear plastic sheets and overlaid on a light-table or office window. The resulting composite colours and subtle hues could be interpreted as a measure of overall suitability for development for all locations within the town (locational specificity). However, the manual approach does not allow for different weights being assigned to the various factors (a very realistic decision-making condition requiring thematic specificity), such as considering soil type as being twice as important as proximity to existing development and four times as important as the farmland classification. Even more frustrating is that the composites most often result in an undifferentiated deep magenta almost everywhere when more than just a few maps are used!

## SPATIAL MODELLING

GIS systems store information as numbers, rather than colours, shadings, lines or discrete symbols. When overlaying a set of maps the values can be summed, averaged, weight-averaged, minimized, or any of a host of other appropriate statistical or mathematical operations. The result is a new number assigned to each location which is a numerical summary or mathematical function of the conditions occurring at that location on the 'input' maps. Such procedures greatly extend traditional map processing capabilities and provide a sort of 'map-ematics' (see Berry 1987b, 1987c).

As an example (see Berry 1987d), the spatial relationship between roads and timber resources can be rigorously modelled. Traditional timber supply analysis generalizes resource accessibility into a few broad groupings, such as the proportion of trees near roads, set back, and distant. The timber supply is calculated from values describing the typical timber composition within each broad accessibility zone. A serious limitation in this approach is that all trees are assumed to be transported straight to the nearest road. This concept of distance as the 'shortest straight line between two points' is the result of our traditional tool, the ruler – not reality. A straight line may indicate the distance 'as the crow flies' but offers little information about the complex pattern of spatial barriers in the real world: such a straight line from a stand of trees to the road might cross a pond or steep slopes (very realistic obstacles that must be circumvented by the harvesting machinery), effectively making the distance much greater. In fact, the actual route may be so much further that the trees are economically inaccessible.

Advanced GIS procedures can consider obstacles in computing effective distance and express this distance in decision-making terms, such as dollars or gallons of fuel, instead of static geographical units of metres or miles. The result is a more useful map of effective distance, indicating harvesting cost at each location throughout a study area as a function of landscape characteristics and harvesting equipment capabilities. Such timber access information can be combined with a map of forest cover for a new map indicating the forest type and harvesting cost combinations throughout a study area – the principal input to traditional supply models, yet now spatially specific *and* realistic.

It is the combined factors of digital format, spatial and thematic specificity and advanced analytical procedures which form the foundation of computer-assisted map analysis. The case study presented in this chapter demonstrates these points. Three separate spatial models allocating different land uses are presented. A fourth model addresses conflict resolution in determining the best combination among the competing uses.

## DATABASE DEVELOPMENT

Since the 1970s, an ever-increasing quantity of mapped data are being collected and processed in digital format. Early use of GIS technology required users to become experts in the emerging field and develop their own systems and databases. Their efforts also required large mainframe computers costing hundreds of thousands of dollars, environmentally controlled buildings and a staff of computer technicians. These conditions made GIS non-viable for most potential users. More recently, GIS systems have become available for personal computers with a total investment of less than US $5000, with the familiar office desktop as the computing environment.

As a means of demonstrating GIS technology in resource planning, a demonstration database and example analyses are presented. The Professional Map Analysis Package (pMAP) by Spatial Information Systems (SIS 1986) and its optional modules were used for all data encoding, processing and map output. The total cost of the complete package is under US $1500. Processing and map displays were done with an IBM PC-AT 'clone' computer and a standard dot matrix printer. All of the accompanying figures were photographed from a standard EGA colour monitor. An inexpensive digitizer was used for encoding maps. The total cost of this general-purpose hardware in 1990 was about US$3000. The database was prepared in one man-week. The analyses were completed in three days. The finished report took nearly two weeks to prepare, with final map graphics for slides and figures requiring the greatest time (Berry *et al.* 1989).

The western portion of St Thomas, US Virgin Islands, comprises the demonstration site. A nested database centred on Botany Bay and consisting of three windows held at different resolutions was developed (Plate 55.1). Five primary data planes were digitized from two adjacent USGS topographic map sheets: island boundaries, elevation, roads, geographical points and cultural features. Ocean depth was digitized from a combination of US-NOAA and locally-produced navigational charts. A data plane indicating neighbourhood districts was obtained from a tourist map published by the local Merchants' Association. The digitized data were then converted to the three windows and stored as separate databases. These encoded data were used to derive maps of slope, aspect, proximity to road, proximity to coast, watersheds, 'coastalsheds' and visual exposure to coastline; these were used in the demonstration analyses determining the best locations for recreation, research and residential development.

## MAP ANALYSIS

Four analyses were performed using the high resolution (25 × 25 m analysis grid) Botany Bay vicinity database. The first investigates the best areas for conservation uses including recreation, limited use and preservation. The rankings are based on relative accessibility to both existing roads and the coastline. The second model identifies the best areas for ecological research by characterizing watershed conditions and the 'coastalsheds' they influence. The third analysis determines the best locations for residential development considering several engineering and aesthetic factors. The final model addresses the best allocation of land, simultaneously considering all three landscape uses.

The analyses presented are hypothetical and do not represent actual plans under consideration. Field-verified data and considerable advice from local individuals would be required to transform these demonstrations into actual land use recommendations.

## Defining Conservation Areas

A map of accessibility to existing roads and the coastline forms the basis of the conservation areas model. In determining access, the slope of the intervening terrain was considered. The following assumptions were used in characterizing off-road movement:

- 0 to 20 per cent slope, easiest to cross.
- 21 to 40 per cent slope, twice as difficult to cross as the easiest.
- 41 per cent slope or more, three times as difficult to cross as the easiest.

In implementing these criteria, a map of slope was first generated from the encoded map of elevation, then interpreted for relative ease of movement using the criteria described above. The 'weighted' distances first from the roads, then from the coastline, to all other locations in the study area were calculated. In these calculations, areas that appear geographically near a road may actually be much less accessible. Similarly, the coastline may be a 'stone's throw away', but if it is 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 (Plate 55.2). Recreation was identified for those areas near both roads and the coast. Intermediate access areas were designated for limited use. Areas effectively 0.5 km or more away from both were designated as preservation areas. In determining accessibility, weighted distance is calculated in which areas with steep intervening slopes (lower right inset) are considered further away than their simple geographical distance would imply.

The ability of the GIS to calculate weighted distance provides a much more realistic interpretation of accessibility than do traditional methods involving rulers. However, the access map generated in this analysis is limited by data availability. In addition to slope, land cover type and density could be considered in characterizing the intervening terrain. If these data were available, they could be easily incorporated in the 'friction' map, with areas of steep, dense cover being the most difficult to cross. Similarly, if trails are known, they should be digitized and used to update the relative ease of movement implied by the slope, cover type and density maps. Another extension to the model would use aerial photos to identify beaches or other unique attractions along the coastline. These special areas can be incorporated in the distance calculations so they have more influence – things are effectively more accessible if they are more attractive. An intrepid recreationalist will travel much further, even over rough terrain and dense cover, for a unique experience.

## Defining Ecological Research Areas

The characterization of the Botany Bay area for ecological research involved several sub-models. The first used the elevation map to identify individual watersheds. 'Nodes' defining the bays are identified where ridges meet the shore. The steepest uphill path from each node identifies the lateral ridge forming the sides between watersheds. The upper boundaries are more difficult to determine. In this process, each map location identifies its steepest downhill path over the elevation map – like water running down the surface after a storm. The result is a map that contains the number of 'paths' passing through each location. Those areas with only one path identify upper ridges with water running off, but no uphill neighbours. The approach works well in areas of considerable relief or highly resolved elevation data. Flat areas or inconsistent elevation values yield unreliable results. For the Botany Bay study area, the procedure identified about 80 per cent of the boundaries. Interactive human intervention was necessary to fill in the boundaries through the areas in which the computer failed.

Once all of the watersheds were identified, three major ones were isolated as best for research (Plate 55.3). These included the Target Rock, Botany Bay and Sandy Bay watersheds, selected because of the scientists' requirements that they be relatively large, wholly contained areas, with a diversity of landscape conditions. The second sub-model develops a summary table of watershed characteristics such as ownership, accessibility and terrain conditions, useful in planning ecological experiments and control areas. This process treats each watershed as a 'cookie-cutter' placed over another map and stores the data summarized, for example, as the average of all elevation values occurring within the Target Rock watershed. In general, the Target Rock watershed was found to be intermediate in size, divided between two administrative districts, the most remote watershed with intermediate elevations forming relatively steep, rough, northerly sloping terrain. The Botany Bay watershed is much larger, almost entirely within one district, relatively accessible and has terrain similar to Target Rock but is oriented to the west. The Sandy Bay watershed is much smaller, is wholly contained in one district and is easily accessible, with a similar westerly oriented terrain but much lower in elevation.

The final sub-model identifies and then summarizes the 'coastalshed' influenced by each of the three watersheds. The delineation of the coastal areas influenced by the landscape required the simulation of the prevailing southerly current. This process can be visualized as creating a three-dimensional surface forming a plane tilted from south to north over the ocean portion of the study area (right portion of Plate 55.4). The steepness of the plane corresponds to the rate of flow – the steeper it is, the faster the current. In this case, current flow was assumed to be the same throughout the area. However, detailed oceanographic charts show a similar map as blue arrows whose orientation and length indicate direction and rate of current flow. Such information, if available, could be used to refine the plane used in this analysis. The coastal portions of each of the watersheds formed the starting locations for delineating the corresponding coastalsheds. Like water flowing down a roof, areas down-current are identified by moving downhill along the tilted plane. It was assumed that thorough mixing among the watersheds' inputs would occur within 0.5 km, thereby defining the extent of the down-current movement.

Plate 55.4 shows the three coastalsheds corresponding to the three research watersheds. There are several limitations in the procedure used in delineating these coastalsheds. Most notable is the lack of detailed information on current flow and depth, tides and thermal incline. Indeed, the interaction among these variables is complex and not fully understood in a modelling context. Although the coastalsheds delineated appear to be reasonable approximations, an empirical study involving dye and buoy releases would be necessary for detailed research on the land–water interface.

## Defining Areas for Development

To determine the 'best' locations for development, several maps describing aesthetic, engineering and environmental factors were considered. These included:

- Engineering
  gentle slopes
  close to roads
- Aesthetics
  close to coast
  good view of coast
  westerly aspect
- Environmental constraints
  100 m set-back from coast
  no slopes over 50 per cent

The engineering and aesthetic considerations were treated as gradients. This approach interprets the data as relative rankings, or preferences, for development. For example, an area viewing twice as long a section of shoreline as another location is ranked twice as desirable. The environmental constraints, on the other hand, were treated as critical factors. For example, an area within the 100 m set-back is considered unacceptable, regardless of its aesthetic or engineering rankings.

Figure 55.1 is a flowchart of the Development Areas Model. The 'boxes' represent maps and the 'lines' represent processing operations. The schematic maps on the left identify encoded data, termed Primary maps. These data are transformed into Derived maps which are physical and could be measured, but are more easily calculated. The Interpreted maps are an abstraction of the physical ones indicating the relative preference of conditions for an intended use – residential development in this case. The final level of abstraction is the Prescriptive map, created by combining the individual preference expressions into a single map. This general approach of moving from encoded data through increasing levels of abstraction is common to all prescriptive models. The user conceptualizes the important relationships involved in a spatial decision, then uses GIS analytical tools to express them.

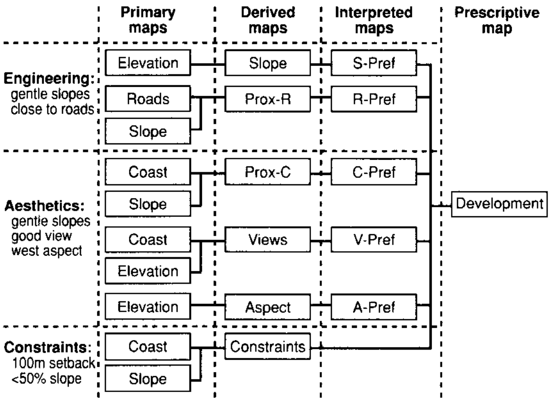


**Fig. 55.1** Flowchart of the Development Areas Model.

To incorporate the engineering considerations, a slope map was created from the encoded map of elevation. The slope map was interpreted on a scale of 0 (terrible) to 10 (best), as

10 – Best (0–5 per cent slope)
8 – (6–15 per cent slope)
6 – (16–25 per cent slope)
3 – (26–40 per cent slope)
1 – Worst (>40 per cent slope)

These criteria recognize the increased site preparation and building costs on steeper slopes. A related concern characterizes the preference for proximity to existing roads, in recognition of the increased cost of driveway construction as a function of distance. In the same manner as used in the Conservation Model, distance was weighted by intervening slopes. The map of effective proximity to roads was interpreted on the same '0 to 10 goodness scale' as:

10 – Best (0–50 effective units away)
8 – (51–100 effective units away)
6 – (101–200 effective units away)
3 – (201–400 effective units away)
1 – Worst (>400 effective units away)

The aesthetics consideration for siting development used in this model favoured being near the coast and having a good view. A slope-weighted proximity to coast map was created, then interpreted as:

10 – Best (0–100 effective units away)
9 – (101–150 effective units away)
8 – (151–200 effective units away)
6 – (201–300 effective units away)
4 – (301–400 effective units away)
3 – (401–600 effective units away)
1 – Worst (>600 effective units away)

To determine the visual aesthetics, the 'viewshed' of the shoreline was generated by computing the lines of sight in all directions over the elevation map from all of the shoreline locations. This procedure is analogous to standing on the shore and noting all the locations you can see, then moving down the beach 25 m and again noting the visual connections. When all shore locations have been considered, a 'visual exposure' map is formed, with each inland location assigned a value equal to the number of times it was seen. The locations with high visual exposure values are interpreted as having the best views. In this analysis, vegetative cover was not considered as an additional visual barrier on top of the elevation, but could have been if a map indicating canopy height were available. The composite visual exposure map was interpreted for view preference as:

10 – Best (>90 connections)
8 – (80–90 connections)
6 – (60–79 connections)
4 – (11–59 connections)
1 – Worst (0–10 connections)

The last consideration indicates the preference for westerly facing slopes. Such orientation allows a greater chance to view the setting sun. Easterly orientations were ranked as next best as they provide inspiring sunrises for energetic individuals. An aspect map was created from the encoded map of elevation, then interpreted as:

10 – Best (West)
9 – (Southwest)
8 – (Northwest; flat)
7 – (East; Southeast)
5 – (North; Northeast; South)

To determine environmental constraints to development, simple proximity to coast and steepness were considered. Maps of distance to coast and slope were interpreted as:

0 – Unsuitable (<100 metres from coast)
0 – Unsuitable (>50 per cent slope)

Plate 55.5(a) shows a composite containing the simple arithmetic average of the five separate preference maps. Environmentally constrained locations masked these results (values within constrained areas being forced to 0) and are light grey. Note that approximately half of the land area is ranked as 'Acceptable' or better (warmer tones). In averaging the five preference maps, all criteria were considered equally important.

The analysis was extended to generate a weighted suitability map preferentially favouring certain criteria as:

- 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 composite is presented in Plate 55.5(b). Note that a much smaller portion of the land is ranked as 'Acceptable' or better. Also note the spatial distribution of these prime areas is localized to three distinct clusters.

Three important aspects of cartographic modelling are illustrated in the Development Areas Model: dynamic simulation, concise expression and flexibility. By changing parameters of the model (preference values for slope, proximity, visual exposure, and orientation), a user can simulate numerous alternatives and gain insight into the sensitivity of the planned activity to the actual spatial patterns of the various factors. It is important to note that the decision maker is interactively interrogating the model as new maps are progressively generated. This approach contrasts sharply with manual techniques requiring tedious preparation of a separate set of overlays for each enquiry. Most often in such a manual approach, the patience of both the draftsperson and the decision maker ebbs after just a couple of iterations and a choice of one of the alternatives is made. The ease in simulating numerous scenarios using GIS encourages the decision maker to become an active ingredient in the analysis process and to develop a set of potential alternatives.

The quantitative nature of GIS technology also provides an effective framework for concise expression of complex spatial relationships. The flowchart of processing shown in Fig. 55.1 is an example. In a manner similar to a simple equation, this process uses a series of map operations successively to derive intermediate maps and ultimately leads to a final map of development suitability. Thus the flowchart establishes a succinct format for communicating the logic, assumptions and relationships embodied in the analysis.

Finally, the GIS approach encourages decision makers to change the model as new conditions or insights are developed. For example, the effect of a proposed road could be incorporated. The proposed route would be digitized and added to the existing road map. The model would be re-run and a new suitability map generated. The new suitability map could be compared to the previous one without the proposed road simply by subtracting the two maps. Differences equal to zero identify areas that did not change their suitability ranking. Non-zero differences indicate both the type of change (positive for increased suitability rating) and the magnitude of change (larger values indicate more change). Other factors, such as remoteness from existing or proposed utility lines, could be similarly incorporated.

In the pMAP system, the flowchart shown in Fig. 55.1 is implemented by entering a series of sentences. Changes may be made simply by editing the 'narrative' of a command file with a word processor and re-running the analysis. The 'preference weighting' sub-model takes less than two minutes to run on an inexpensive IBM PC-AT compatible computer. Running the model requires no more technical skills than those used in running database management and spreadsheet packages now commonplace in most offices. A decision maker could simulate several preference scenarios and compare the results in less than 30 minutes. Within this context, individual map products are no longer the focus; rather it is how maps change under various scenarios which provide information. In this approach, a decision maker becomes an active participant in the analysis rather than a 'choice chooser' among a few alternatives provided by the analyst.

## A CONFLICT RESOLUTION MODEL

The previous three analyses determined the best use of the Botany Bay area considering conservation, research or development criteria in a unilateral or independent manner. However, most land use decisions require resolution of competing uses. Three basic approaches in resolving conflicts include 'hierarchical dominance', 'multiple use' and 'trade-off'. Hierarchical dominance assumes certain land uses are more important and, therefore, supersede all other potential uses. Multiple use, on the other hand, identifies compatible uses and assigns several uses to a single location. Trade-off recognizes conflicting uses at individual locations and attempts to develop the best mix of uses by choosing one over the others on a parcel-by-parcel basis. Effective land use decisions involve elements of each 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 suitable value indicating the desire to protect them from other uses. Multiple use also is technically simple from a map analysis context, although often difficult from a policy context. Once compatible uses are identified, a unique value is simply assigned to all areas with this joint condition.

Conflict arises when the uses are not entirely compatible or, as with many uses, completely incompatible. In these instances, quantitative solutions to the allocation of land use are difficult, if not impossible, to implement. So far, optimization models, such as linear or goal planning, have not been successfully extended to geographical space. The complex interaction of the frequency and juxtapositioning of several competing uses is still most effectively dealt with by human intervention. GIS technology assists in decision making under these conditions by deriving a 'conflict' map which indicates the set of alternative uses for each location. Once in this visual form, the decision maker 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.

Hierarchical consideration of all three uses for the Botany Bay vicinity was performed. A map identifying just the 'recreation' areas was isolated from the Conservation Areas map. Similarly, a map of just the 'best' development areas was isolated from the Development Areas map; and a map isolating the 'Botany Bay watershed' was derived from the Research Areas map. Plate 55.6 shows the result of a hierarchical combination of these data. For this composite, development was least favoured, recreation next with the Botany Bay watershed taking final precedence. This process is similar to overlaying a set of maps delineated on transparencies. The information on each successive map layer obscures information on the preceding maps, while transparent areas allow information to show through. Note that the resultant map in Plate 55.6 contains very little area for development that is not fragmented into disjointed parcels, that is, non-feasible conditions. The hierarchical approach often results in such non-feasible solutions. What is clarified in 'policy space' is frequently muddled in the complex reality of geographical space.

An alternative approach is to create a map indicating all of the potential land uses for each location in a project area – a comprehensive 'conflicts' map. Plate 55.7(a) is such a map considering the Conservation Areas, Research Areas and Development Areas maps. Note that most of the Botany Bay area does not have competing uses (dark green). In most applications, this counter-intuitive condition exists. However, vested interest parties and decision makers alike assume conflict is everywhere. In the absence of the spatial guidance in a conflicts map, proponents attempt to convince others that their opinion is universally best. In the presence of a conflicts map, attention is quickly focused on the unique patterns and possible trade-offs and affording enlightened compromise.

Plate 55.7(b) presents one interpretation of the information on the Botany Bay conflict map (Plate

55.7(a)). This 'best' allocation involved several individuals' subjective trade-offs among areas of conflict, with research receiving the greatest consideration. Dialogue and group dynamics were involved in this process. As in all discussions, individual personalities, persuasiveness, rational arguments and facts resulted in the collective opinion. It was agreed that the Target Rock and Sandy Bay watersheds should remain intact. These watersheds have less conflict with other uses than does the Botany Bay watershed. They also have significant differences in their characteristics which would be useful in designing research experiments.

The remaining good development areas were set aside, ensuring that all development was contained within the Botany Bay watershed. In fact, this constraint would provide a third research setting to investigate development, with the other two watersheds serving as control. Structures would be constrained to the approximately 20 contiguous hectares identified as best for development, consistent with the island's policy to encourage 'cluster' development. The 'limited use' area between the development cluster and the coast would be for the exclusive use of the residents. The Sandy Bay and Target Rock research areas would provide additional buffering and open space. Conservation uses then received the group's attention. This step was easy as the large area extending from little St Thomas Point along the southern coast was identified for recreation with minimal conflict. Finally, the remaining small 'salt and pepper' parcels were absorbed by their surrounding 'limited or preservation use' areas. In all, this provides 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 he or she had actively participated and, by using the interactive process, better understood both the area's spatial complexity and the perspectives of others. The result then is acceptable but not necessarily so in all such studies!

This last step 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 interpretation. This point, however, highlights GIS capabilities and limitations. GIS provide significant advances in data management and analysis and rapidly and tirelessly allow detailed spatial information to be assembled. They also allow much more sophisticated and realistic interpretations of the landscape to be incorporated, such as visual exposure and weighted distance. They do not, however, provide artificial intelligence for land use decision making. GIS greatly enhance decision-making capabilities but do not replace them.

## CONCLUSIONS

The preceding discussion and demonstrations have established the important concepts in map analysis using GIS. Fundamental to this is the digital map – storing information as numbers, rather than as colours, shadings, lines or discrete symbols. This format enables maps to be rapidly updated and searched for a variety of spatial relationships. Within this context, the computer can be used to automate the manual cartographic process. From another perspective, the digital map may be treated as quantitative data and analysed in a manner analogous to traditional mathematics and statistics. Models can be constructed by logically sequencing basic map analysis operations on spatial data to solve specific application 'equations'. However, the unknowns of these equations are represented as entire maps, defined by thousands of numbers. This 'map-ematics' forms a conceptual framework for spatial modelling, easily adapted to a wide variety of applications in a familiar and intuitive manner.

Yet GIS is more than a cold, calculating science. It enables decision makers to propose scenario after scenario and to assess the spatial impacts of each one, as demonstrated in the two Development Areas maps. It also provides new analytical procedures that make analyses more realistic, as demonstrated in the Conservation Areas map's effective distance and the Development Areas map of visual exposure. The step-by-step process forms a concise expression of the assumptions and relationships used in the analysis, as demonstrated in the Development Areas flowchart. Most important of all, it provides a medium for consensus building that stimulates constructive discussion, as demonstrated in the interpretation of the Conflicts map. The fact that all of the demonstrations were completed on a personal computer confirms that GIS are coming within both the fiscal and technical reach of most resource professionals.

Readers might conclude that GIS application to island planning is an exacting science, or that the approach is nothing more than a handle-cranking exercise which can be carried out without much thought. It could also be suggested that it is entirely whimsical and unscrupulous planners may simply substitute 'weighting factors' that ensure their desired result. All three of these conclusions are partly right and partly wrong. The old adage of 'garbage in, garbage out' is particularly appropriate in GIS modelling. Inadequate topographic maps, for instance, will generate nonsense slope values, especially if the sampling is coarse. The mathematical solution to 1 per cent change in slope, unless the data are both accurate and highly resolved, can provide a false impression of exactness.

Another pitfall of planning models, whether GIS based or not, is that they are almost canonized. Implementation becomes merely a task of specifying the inputs and waiting for the 'black box' to transform them into a decision. The complexity and uniqueness of each decision situation becomes subordinate to standardization and ease of implementation. At the other extreme, no standards exist and each model is a subjective interpretation. In these instances, GIS are vulnerable to misuse as merely a means to 'prove' a point. The models are designed and calibrated to support a particular position – analogous to the adage 'statistics don't lie, statisticians do'.

These potential pitfalls are overcome only by informed end-users. In the application presented here, a group of interested individuals were involved from model development through to implementation. This integrative decision-making approach brings together a variety of disciplines to address a specific project. Under this open approach, the focus of deliberation becomes the analysis process and each participant is involved in the development of all aspects of the model. Manual map analysis, on the other hand, is so tedious that it is left to the technician; the decision makers enter the process after a few alternatives have been identified. They attempt to assess quickly both the analysis process and the relative merits of each alternative. They then become 'choice choosers' by selecting one of the limited set of alternatives assembled in the manual analysis.

Management of land has always required spatial information as its cornerstone. However, purely descriptive maps of the landscape are not enough. They must be translated into prescriptive maps expressing the interrelationships among mapped data in terms of the decision at hand. GIS technology provides the means to integrate these mapped data fully into resource and land use decision making.

## NOTE

This chapter is based on an application sponsored by MacArthur Foundation under the direction of the Tropical Resources Institute, Yale University. The report demonstrates the important concepts in the development and analysis of a spatial database for the Botany Bay vicinity, St Thomas, US Virgin Islands. Its objective is to familiarize readers with the practical considerations and potential capabilities of computer-assisted map analysis in resource planning and management. The encoded and derived maps presented have not been field checked for accuracy. The maps should not be used in actual planning activities without extensive field verification. All of the analyses presented are academic and do not represent actual plans under consideration – the material is presented for demonstration purposes only.

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