# Development of a decision support mapping utility for water resources planning

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## Abstract

The optimum utilisation of water resources is essential for our continued economic development and for the preservation of our limited resource base. At present the process of resource planning is expensive and mathematically complex. This is inappropriate for assessment and comparison of multiple scenarios. The use of microcomputers and simple graphical manipulation and display techniques can assist in rapid screening of proposed plans and will result in easier interpretation of output by the decision-makers. A versatile, yet cost-efficient mapping utility has been developed as part of a decision support system to assist the decision-maker in reaching the most beneficial solution. The utility is designed for implementation on a standard IBM-compatible hardware configuration. A brief overview of the system, its capabilities and the potential applications are presented.

## Introduction

Water is a non-renewable, natural resource of limited quantity, without which man cannot survive. There is no area of our daily lives in which water does not play an important, if not a vital, role. It is therefore essential that the decision-maker(s) in charge of water resource planning be assisted wherever possible by modern, scientific techniques, in order to reach a solution which will maximise benefits for the community.

Lee and Moore (1975) pointed out the problem facing the modern-day decision-maker:

> "It appears that in reality the decision-maker is one who attempts to achieve a set of multiple objectives to the fullest possible extent in an environment of conflicting interests, incomplete information, limited resources, and limited ability to analyse the complex environment."

The importance of water to man has resulted in the extensive development of water resource planning techniques over the past 3 or 4 decades and the use of mathematical methods is well documented (Stephenson, 1970; Martin, 1983; Baxter, 1985; Bulkley et al., 1985; Gollehon et al., 1985; Allen and Bridgeman, 1986).

It has been found that the implementation of these mathematical models in practical planning situations is extremely limited. It is our experience that the following are the main reasons for the limited use of these techniques.

- **Mathematical restrictions and complexity of application**
  The mathematical constraints imposed by many of these techniques lead to assumptions making the final model a poor reflection of the real study region. The complexity of the analysis procedure often results in only the creators of the method being able to use it.

- **Format of output and results**
  The data input and display of results are often inapplicable to the audience at which they are aimed. Interpretation will often not be possible or, more dangerously, will lead to incorrect conclusions being drawn from misinterpreted results.

- **Multidisciplinary input and conflict**
  The use of a multidisciplinary team is essential for correct water resource planning. This can, however, lead to communication problems and conflict.

- **Costs of planning**
  The mathematically complex techniques employed at present require the services of high level professional personnel for long periods of time. Often the model can then only be used for a short time before it is outdated and requires further professional man-hours to be updated. These resources are costly and are often not available. It is also common that the decisions must be made within a restricted timetable which cannot accommodate the usual long development period.

It is necessary that the decision-making professions be provided with a methodology which is able to present water resource planning in an easy-to-understand format and can be implemented in the shortest possible time. Part of this ongoing philosophy is the development of graphical systems for the manipulation, display and simple analysis of data and results.

Many commercial geographic information systems (GIS) exist, such as REGIS (Intergraph), ARC/INFO (Computer Vision) and SICAD (Siemens). These systems are able to manipulate, analyse and display spatial data, yet there is a dearth of systems that can easily be incorporated into 'user designed' analytical structures and are also cost-effective for small organisations.

Present CAD/GIS systems are either not versatile enough, when used for specific mapping tasks, or are cost-prohibitive. The latter constraint becomes more apparent when considering small research organisations or developing regions. In this paper we describe a simple and cost-effective tool that can be used as an effective method in spatial data manipulation and display. This has been termed a mapping utility or tool.

The mapping of distinct features (e.g. roads, rivers, and other cartographic items) has, prior to automation, been annotated on maps using manual techniques. Development of automated mapping procedures originated through the direct translation of the manual methods. The present trend, however, is towards original systems which will produce the required output directly. In order to extend the abilities of these mapping systems, programmers have added data-base systems capable of storing vast amounts of geographical information, hence the concept of a geographic information system or GIS was born.

The incorporation of the utility as part of a decision support

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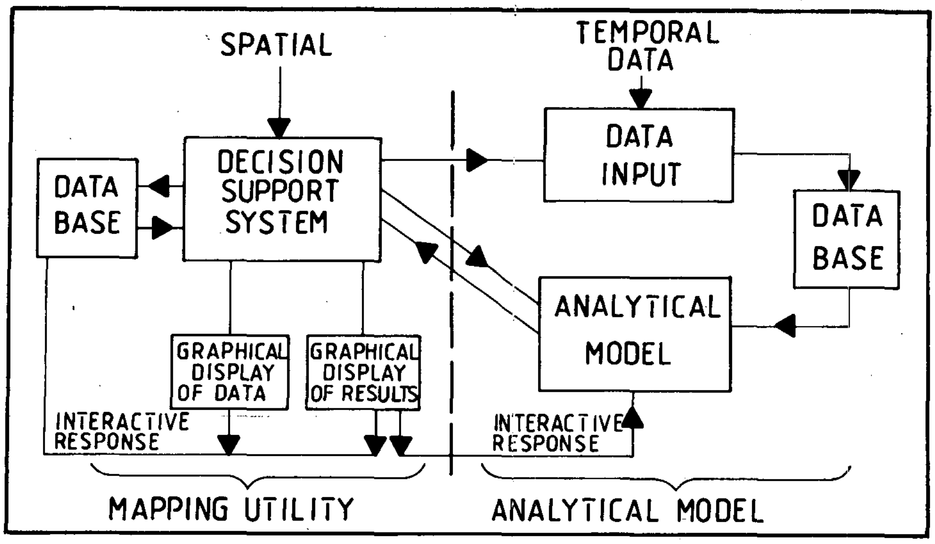


*Figure 1*
*Schematic of mapping utility as decision support system*

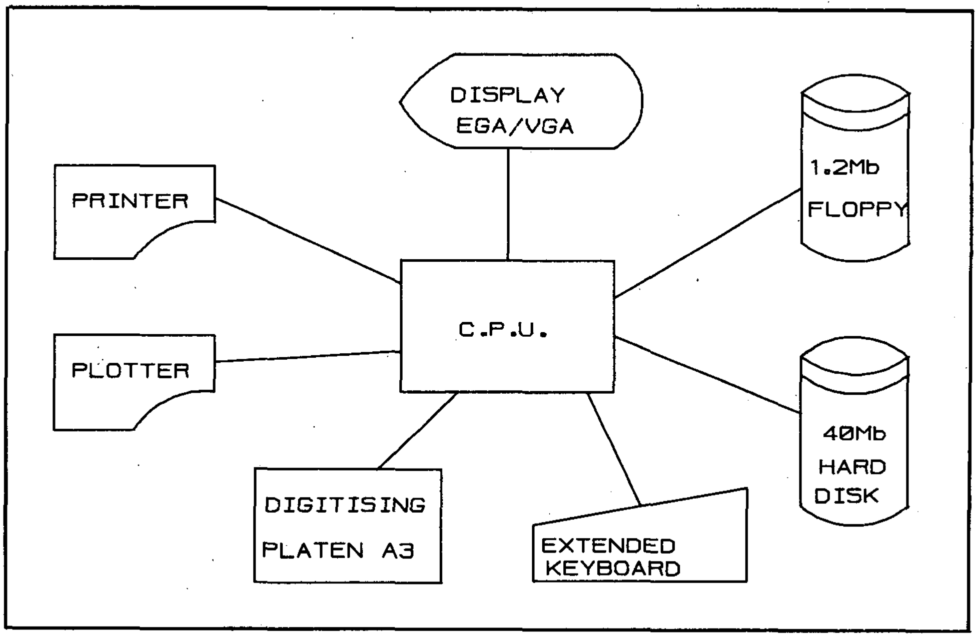


*Figure 2*
*Minimum hardware configuration*

system to aid the decision making process is shown in Fig. 1.

The mapping utility is not as complex as the commercial GIS, yet if required it is able to carry out many of the functions commonly required of a GIS. More importantly it can be customised to the specific needs of the planner. Once customised the utility can be integrated with the developed application software. The utility may also be customised as a stand-alone system with its own internal core driver. Data can therefore be manipulated either within the graphics system or externally before being displayed.

## Hardware requirements

In the past the majority of the large, powerful computer-aided design (CAD) and geographic information systems (GIS), were confined to mainframe or minicomputer systems. This was largely due to the speed and memory requirements of these packages. With the vast improvements made over the last 5 years in microprocessor technology, it has recently become feasible to run these packages on standard microcomputers (although integrated

GIS systems still require a super-microcomputer to execute effectively).

With the current pace of technology, the definition of a conventional or 'common' configuration is very difficult; however, a minimum configuration can be suggested. Figure 2 illustrates the minimum configuration required for the graphics utility (excluding specific requirements for individual applications).

The system is designed to run on the IBM or compatible microcomputer using the Intel 80 x 86 processor family using the MS-DOS operating system.

Advantages in speed are gained with the inclusion of a maths coprocessor. The cost of the coprocessor is however significant in non-highly industrialised countries, therefore the mapper system has been designed to run with or without the addition of the maths coprocessor.

The enhanced graphics adaptor (EGA) graphics card was initially chosen as this is considered to be the basic level at which graphics can be effectively manipulated and provides an affordable entry level resolution for the small company or research institute. It has the advantage of being upwardly portable to the video graphics array (VGA) standard which increases the screen resolution.

Due to the high amount of data transfer and the large storage of data which is inherent in any CAD/mapping system, we recommend that a hard disk system of 20 MB or larger be used. The addition of a file caching system to increase speed of the hard disk I/O is also recommended.

In order to obtain a hard copy of the map displayed on the screen at any time, provision has been made for both a printer and a plotter driver. The standards chosen for these options were the Epson graphics printer (ESC/P command set, dot-matrix) and the HPGL plotter format, which have become universally accepted standards.

## Methods

It is important to consider the nature of the data as this will affect both the method of data capture and the storage of coordinates. Beran (1982) suggested that geophysical data could be classified into various categories. In this paper we consider 3 classes of data:

- Continuously varying data which are usually expressed as isolines (e.g. altitude and rainfall).
- Continuous feature information (e.g. river channnels, roads and railways).
- Constant value information which is expressed on maps as a patchwork (e.g. forests, vegetation cover and soil types).

The scale of the map originally digitised will have a pronounced effect on the level of sensitivity of localised anomalies. This is apparent when maps of different scales are digitised into the same filing system. The digitised information is, of course, only as good as the source maps. Brown and Fuller (1985) found that source maps compiled by different countries, had different levels of detail especially with reference to river channels. They used two different map scales to overcome local features and thus produced two different map data bases.

The mapper utility described in this paper has the ability to establish separate data bases for each of 5 default scales. These scales were chosen to cover the full spectrum of possibilities and for ease of map availaility.

Each scale has a unique size which is the most convenient for digitising on an A3 digitiser. Table 1 shows the scales used and the corresponding size of the map area in degrees, which can comfortably be placed on a standard A3 digitising platen.

These unique sizes lead directly to the reference methodology for the mapping system. Each digitised segment is referenced by the latitude and longitude of the bottom left-hand corner. Any area can then be called up by giving latitude and longitude of the bottom left and top right corners of the required square. Similarly, for specific basins these values are stored in the basin reference file. Figure 3 illustrates the ability to combine any number of these map segments on the screen.

Once a series of segments are loaded and displayed on the screen, a facility exists whereby 'zooming out' will result in further segments being added to the screen. The increase in area is directly related to the scale being used and moves by one segment increment in a north and east direction.

### Vectors

The vector data storage format was chosen as the primary method of data storage, as it is both time and space efficient. In order to represent a line between any two points on a two-dimensional system, the minimum requirement is an X and Y coordinate at both ends, that is four points. To facilitate data retrieval and regeneration of the vector, the number of vertices are also recorded.

When the operator has reached the end of the vector he wishes to store, he selects either the 'open' or 'close' option from the data entry menu. The 'open' option accepts the vector as is, whereas the 'close' option will include the start coordinates as the new end point and complete the vector to form a closed traverse. At this point, regardless of the option chosen, the number of points, followed by the X and Y coordinates at each point, are written to the layer file.

Layer files are created in order to allow the user control over the display of any combination of data on the screen at any one time. There is no limit to the number of layers allowed as all the data are accessed from disk and are not stored in memory. A number of layers of different names can be defined for each basin/map data base at set-up time; the default is 10. Each layer has a default colour on entry which can also be changed for each project. It is possible to use any colour for a vector if the default colour is found to be unacceptable for that layer.

The ability to 'flood-fill' a defined area has been included. A standard vector as described above, with the 'close' option chosen, is utilised as the boundary of the area to be filled. A fill colour is chosen and a point within the relevant closed vector is specified. The 'flood-fill' command is an intrinsic function in the programming language. From a specified point it will fill the area within the closed vector in the desired fill colour.

A further feature is a labelling system which allows the specification and positioning of a label at any point on the map.

All of the above information can be stored on a single layer file or separated according to the operator's final display or analysis re-

**TABLE 1**
**AVAILABLE SCALES AND MAP SEGMENT INCREMENT**

| File code | Scale | Area | Increment |
|---|---|---|---|
| A | 1:1 000 000 | 2° x 2° | 2° |
| B | 1: 500 000 | 1° x 1° | 1° |
| C | 1: 250 000 | 0,5° x 0,5° | 0,5° |
| D | 1: 50 000 | 0,1° x 0,1° | 0,1° |
| - | 1: 10 000 | 0,02° x 0,02° | 0,02° |

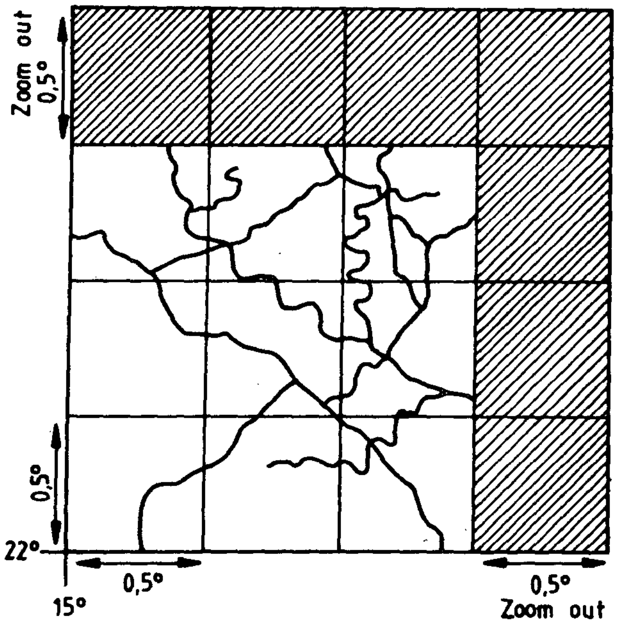


*Figure 3*
*Map segment layout for a scale of 1:250 000*

quirements. The facility to erase any of the above features is included.

In order to provide a more detailed picture of the area being studied a window system has been included. If the screen map resolution is not acceptable to the operator he may request a window. The screen is then quartered and the operator may choose the quarter in which he would like to work. The program will then window in (zoom in) on this quarter, allowing it to fill the screen. The program will redraw the entire map, vector by vector. The user, however, only sees the information displayed in the window. This method is slow during regeneration but allows the system to store the data without having to determine the change points at all the window boundaries. Windowing in this manner can be carried out on two consecutive levels. This allows for the screen display to be scaled up 8 times (magnification).

**Raster**

With microcomputer systems, information on each dot (or pixel) can be stored directly in the video memory. This ability allows dot or patchwork information to be captured and displayed. Four pieces of information are required for each dot, namely: the active layer to which the raster data are to be assigned; the colour; and the X and Y coordinates of the pixel. The raster data are stored in the same file designation as the vector data. Whilst more than one colour may be defined for a layer, it is recommended that a different layer be used for each colour. The trade-off for this ability to address every dot on the screen is the amount of storage required. To overcome storing large areas of non-vector information, a special vector method is employed which has been described above (see discussion on flood-fill).

The raster type data are entered by the system in a slightly different way to that of vectors. Firstly an area on the screen is selected by the user using a movable window. The selected area is then zoomed in. Each pixel within the zoomed area is represented on the screen by blocks of the appropriate colour (this will only apply to the layers that are active on the screen at the time of the zoom). The user can then select a new layer, a different colour and indicate the 'pixels' to be 'turned on'. The pixel information for the current layer can only be stored by explicitly indicating the relevant soft key.

With this method each pixel may be defined on more than one layer, although only one colour will appear on the screen at any one time. This is an important aspect in the development of a system applicable to a wide range of applications.

## Applications

### General

The planning and analysis of water resource systems have in the past been carried out on an *ad hoc* basis, each project being evaluated as a stand-alone system. No facility existed whereby the planner could obtain a clear overview of all facets of the problem at hand. Due to the increased awareness of the limits of our natural resources in relation to the growth of the population, it has become essential that a more comprehensive methodology be developed to assist the planning professions.

The first step in the process of studying a particular region is the capturing of the physical map. This follows the standard procedure for any digitising process with the required detail being captured on layers defined by the operator.

An illustration of typical layers which can be used for general water resource analysis problems is given below:

- Catchment boundaries
- Roads
- Railway lines
- Settlements and their names
- Dams and lakes
- Main rivers
- Tributaries
  - Underground lakes (if available)
  - Underground streams (if available)
  - Dykes and aquifers (if available)
- Contours
- Overlay grids (1/4 or 1/2 degree intervals)

The ability to specify which of the information items and/or layers should be displayed at any one time is possible using the map utili-

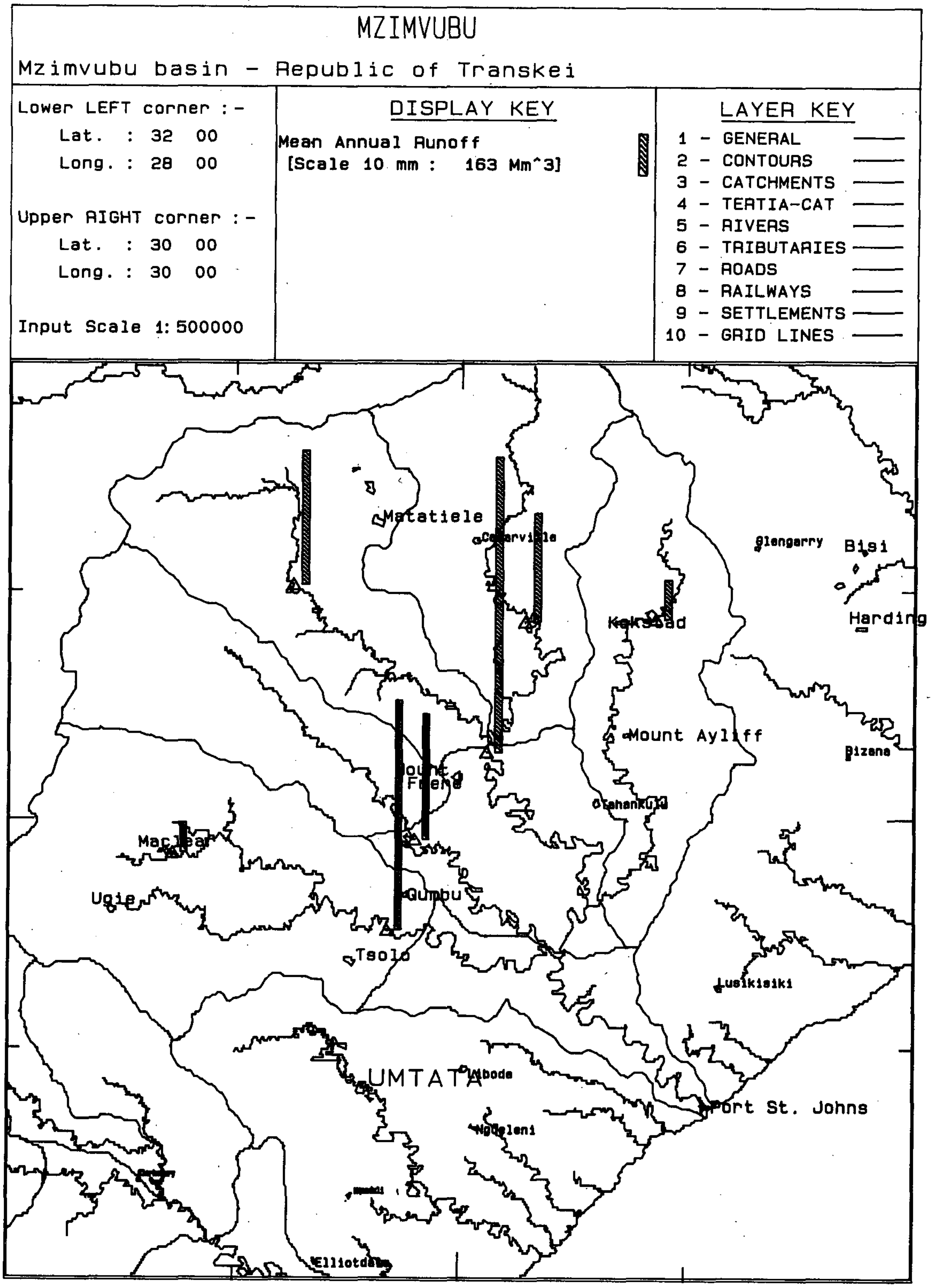


*Figure 4*
*Example of mapping utility plotter output for the Mzimvubu Basin, Republic of Transkei*

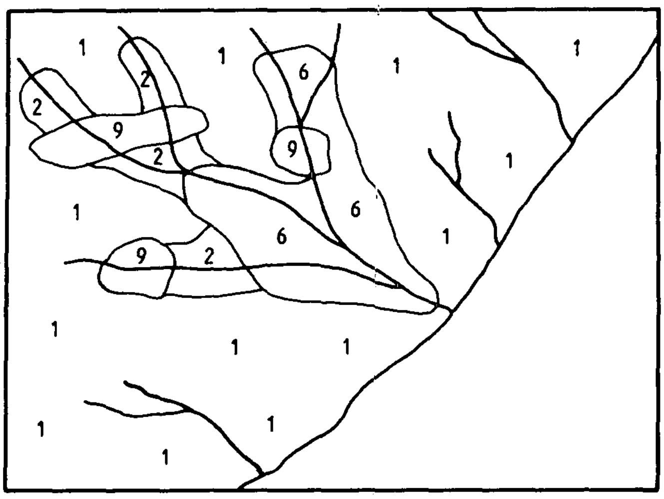


*Figure 5*
*Illustration of overlay for geological site conditions*

ty described. It is feasible therefore to display the population densities and overlay the available water supply data. This immediately indicates the areas requiring increased investment in water supply orientated projects. The analysis section is totally interactive. It is therefore possible to erase the population densities and superimpose the ground water potential, in order to assess the possibility of using the aquifers as a potential water supply source to satisfy any shortfalls.

### Resource displays

The Mzimvubu River drainage basin, situated in the Republic of Transkei, was used to demonstrate resource mapping with the graphics utility. The map was digitised in at a scale of 1:500 000. Figure 4 shows bar graphs at the bottom of each subcatchment superimposed on the basic map of the Mbashe Basin. Note that not all the layers are 'switched' on for the benefit of clarity on a monochrome printout. The graphs represent various categories of river flow, for example average monthly and cumulative monthly. On the screen each bar is represented in a different colour for each location. The data can also be used as input to more complex analysis procedures.

### Screening of plans/optimum location

A core driver is included within the program specifically designed for the analysis of water resource plans and optimum location of new projects. This methodology can be adopted to serve a variety of similar tasks not directly related to water resources planning.

The methodology is initiated through a special menu option. For the region selected the relevant layers are displayed on the screen to assist the operator in the development of his overlays. The overlays are a spatial representation of the decision-maker's preferences or physical constraints on the project. A typical example of a physical overlay would be the geologically favourable areas for dam construction or government-imposed land zoning. Overlays which would simulate the decision-maker's preferences would include intangibles such as ecological effects, recreation and flood alleviation. A scale from 1 to 10 is provided in order that the operator can grade the effects of the imposed measure, over the mapped area, according to the decision-maker's preferences or the physical constraints. A typical overlay for geological conditions in determination of a reservoir site is shown in Fig. 5.

The operator may define as many overlays as are required by the specific project. A six-character identifying string is assigned to each of the overlays. Suitability analysis (Berich, 1985) can now be carried out using a procedure called indexing. Indexing requires that a weight is given to each of the overlays to be combined for the suitability analysis. This weight is assigned by the decision-maker and can be varied to perform a simplified sensitivity analysis. The procedure analyses selected overlays (raster files), using the weighting in the following form:

$$I = C_1V_1 + C_2V_2 + C_3V_3 + \ldots\ldots\ldots C_nV_n \qquad (1)$$

where:

I = index value
Cx = weighting coefficient
Vx = variable codes in separate overlay files (raster)

The index value obtained now can be displayed as an overlay on the physical map previously digitised. An illustration of the combination and indexing of two overlays is shown in Fig. 6.

The decision-maker is provided with a simple picture of the suitability of an area for the proposed development either by the display of only non-conflicting or coincidental areas. The data can be used to generate acceptability contours which will facilitate interpretation. The facility exists to specify the overlays to be used in each analysis, the effects due to the neglect or incorporation of various factors can therefore be investigated. This allows decision-makers to investigate a variety of factors in the screening process. The process is rapid and can therefore be used for immediate sensitivity analysis to establish which of the factors require more detailed analysis. The process rapidly screens out unsuitable options at a minimum cost. The incorporation of intangible effects is an added benefit of the process.

### Others — e.g. stream lengths, area of catchment

With the development of hydrological simulation models becoming more physically-based (i.e. the parameters to the model can be

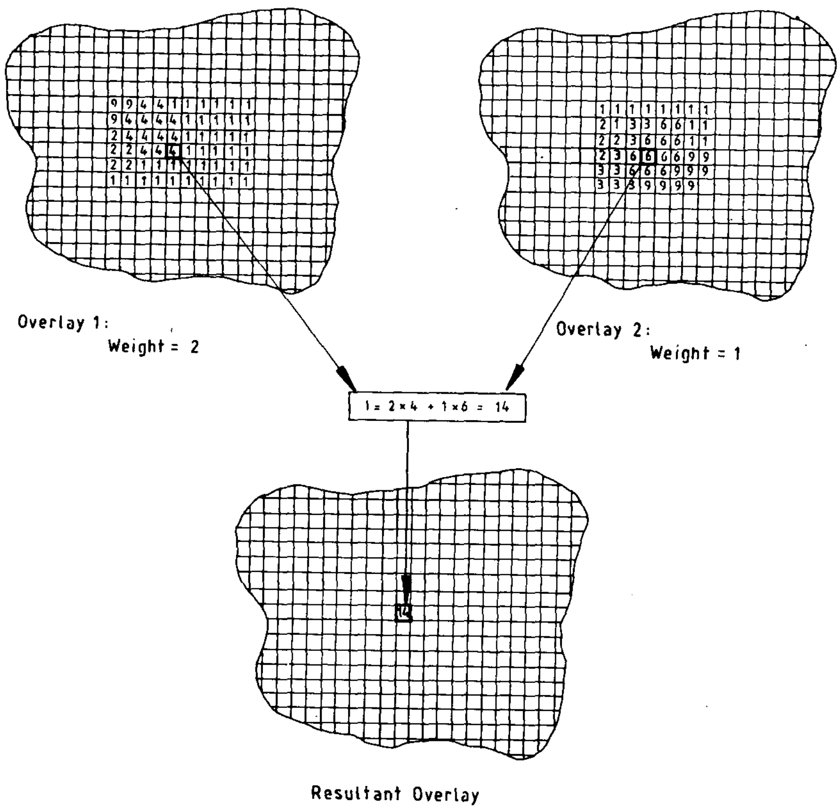


*Figure 6*
*Indexing methodology for combination of two overlays*

determined by physical measurement), certain parameters may be determined from maps. Items such as slope, the length of streams, and the area of catchments are perhaps the most obvious.

Models such as TOPMODEL (Beven and Kirkby, 1979) and unit hydrograph analysis involve the entry of numerous topographic data values that can be derived from a map. The graphics subsystem can be used to enter the relevant map's information and an application can then be added comprising the simulation model and a series of routines to interpret the map information. The graphics utility will therefore act as an intelligent front end for the capture of data for simulation programs.

## Discussion

The package has been designed to provide a practical planning tool for use by decision-makers in developing regions, posessing limited technical manpower and skills. The system is user-friendly and requires a negligible training period when compared to conventional CAD/GIS systems.

It is the intention of the authors that the graphics utility developed in this paper can be incorporated into a variety of applications packages. The tool provides the operator with the ability to interpret data rapidly which would otherwise require a detailed analysis of tabular data. The utility is compiled in a stand-alone format and Fig. 1 gives an indication of a typical integration configuration with an independent analysis package.

A variety of applications have been identified. The descriptions of its use in a resource mapping and the optimum location selection process, illustrates some of the benefits of a graphical system. Display of data and results allows for simple interpretation by decision-makers and reduces the possibility of misinterpretation. Graphical output further allows the planners to visualise the spatial distribution of the resource and the spatial effects of decisions. The indexing and overlay methods allow for rapid screening of unsuitable project proposals and can be used for sensitivity analysis of the identified factors. The availability of accurate and up-to-date maps allows any user to access and input spatially variable data into his model.

The mapping utility has further been used in association with a mass balance analysis program developed by one of the authors. The utility is used to input and analyse spatially variable data such as rainfall, evaporation, infiltration, etc. Integration was found to be simple and the customisation was minimal. Results of the analysis were used in the comparison of the effects of urbanisation on the water balance of small catchments (Lambourne and Sutherland, in preparation).

The graphics utility developed satisfies the major requirements of a utility of this nature, namely versatility, ease of use, compatibility and low cost. The utility will, no doubt, be found to be lacking in certain areas by specific users. It was never the intention to develop a tool which would satisfy all needs and it is not considered to be a replacement for any of the commercially available CAD or GIS packages. We hope merely to have provided the engineer, planner or any other decision-maker, with the means to capture, analyse and display spatially variable data quickly and simply, using the hardware configuration which is already at his disposal.

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