

Selecting a GIS for a National Water Management Authority*

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ABSTRACT: Owing to the complex, inter-disciplinary nature of geographical information systems (GIS), and to the wide variety of commercial GIS software available, considerable effort is needed to select software and hardware which most nearly matches an agency's requirements.

- Current procedures for manipulating data must be evaluated in terms of equivalent or enhanced GIS methods;
- It must be determined which fundamental GIS concepts are necessary to support the level of user requirements;
- A suitable pilot study may need to be implemented;
- The size of the initial configuration, and its potential growth path, must be determined; and
- Different groups within the agency must be satisfied with the choice: top management, technical personnel, and users.

This paper discusses the selection of a GIS for a national water management authority, from a pilot study through the formulation of technical specifications and benchmarking, to the procedure for final evaluation.

INTRODUCTION

HAVING DECIDED TO USE geographical information systems (GIS) technology, an agency must then select software packages, and possibly hardware as well. However, GIS is a complex, continually developing, inter-disciplinary technology. There are many different GIS offerings on the market, with widely diverging capabilities. User experience of GIS ranges from solid success to frustrated failure. Thus, the choice of GIS software is not straightforward. Yet the implications of the choice are far-reaching. The work procedures which will have to be followed, the analytical capabilities available or able to be built into the system, the forms of output possible, will all be determined largely by the choice.

The Department of Water Affairs (DWA) in South Africa was faced with this choice early in 1987. Obviously, the application requirements of an agency must determine in part the selection criteria for a GIS. In the case of the DWA, its brief is to manage the scarce water resources, of which the availability from year to year is highly variable, in a developing country having both first and third world sectors. That this is a formidable and demanding task is best illustrated by quoting from a recent publication of the DWA (Department of Water Affairs, 1986):

"The average annual rainfall of about 497 mm for South Africa as a whole is well below the world average of 860 mm. A comparatively narrow region along the eastern and southern coastlines is moderately well-watered, but the greater part of the interior and the western portion of the country are arid or semi-arid. Sixty-five percent of the country receives less than 500 mm of rain annually, which is usually regarded as the minimum for successful dryland farming. Twenty-one per cent of the country receives less than 200 mm... .

"Over most of the country the average annual potential evaporation, which ranges from about 1100 mm to more than 3000 mm, is well in excess of the annual rainfall. This affects surface runoff from rainfall significantly and causes high evaporation losses from water stored in dams.

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"In some areas the highly variable river flow can have periods of up to 10 consecutive years of less than average flow. This must be allowed for in both the planning and the operation of water supply systems... .

"Water availability is distributed poorly in relation to regions of economic growth and the cost of providing water in South Africa will rise in the future owing to the greater distances that water will have to be transported to areas of increasing demand."

Water resource management in this context requires skilled engineers and hydrologists to analyze and manipulate spatially-referenced data from a wide variety of sources. With the increasing sophistication of automated and electronic data collection methods, the ever-increasing amounts of data can often overwhelm manual methods or even current computer-aided procedures. In contrast, there are often too few data where they are needed, making interpretation more difficult. In this case, sensitivity analysis is appropriate but is arduous using current methods.

In all, a more automated approach was indicated (Conley, 1988). This is set out clearly in the following extract (Department of Water Affairs, 1986):

"Since the DWA has to respond to and possibly influence changes in demand that depend on many imponderables related to the development of a country with a growing competitive enterprise economy in a changing sociopolitical climate, the execution of a master development plan, which would have inherent rigidity, is inappropriate. Instead the DWA is refining a flexible, dynamic national water management strategy, which embodies the concept of the best utilization of the water that is actually available and which seeks to achieve optimal resource allocation. Management decisions will be supported by modern data processing facilities that permit the rapid evaluation of alternatives in consultation with users... .

"To provide technical professionals, planners, policy-makers, decision-makers and the public with data to evaluate the possibilities and limitations with respect to water resources, it is the policy of the DWA to rely on the support that rapid technological developments in the field of data processing can provide. The DWA is accordingly expanding a comprehensive, modern data system for the convenient storage, retrieval, manipulation, analysis, effective presentation and dissemination of alphanumeric and graphical information."

THE PROCEDURE FOLLOWED

When the decision to select a GIS was taken, GIS was hardly known in South Africa, and tended to be confused with Computer-Aided Drafting (CAD) or "intelligent graphics."

The literature of which we were aware was reviewed, and a survey was made of GIS-type technology already being used in the country. The few known sites which were visited were running primarily cartographic applications, for example, for urban management. Local vendors of CAD/mapping/GIS software were also visited.

At this stage a small core group in the DWA, although still relatively new to GIS technology, was convinced that GIS offered the best solution to the requirements for data manipulation and analysis, while top-level management were still cautious. A significant exercise which convinced them of the potential worth of GIS, and which contributed substantially to our GIS education, was the undertaking of pilot studies. These provided the opportunity for potential users of GIS in the DWA to experiment with GIS applications and to gain practical experience of their benefits and limitations. Various GIS operations and concepts were tested, including spatially and alphanumerically keyed queries, symbology, interpolation between isolines, and linking alphanumeric data in a database to the graphics.

A study tour of the United Kingdom and Europe had been undertaken late in 1986. Included were visits to user sites and vendors, and the Auto Carto London conference. The impression gained was that there was a diversity of GIS systems on the market having widely varying capabilities in general and in specific areas. It became clear that, when selecting a GIS, it was critical for us to pay attention to the sound fundamental design of the system so that it could be adapted to meet user requirements; the uninitiated could easily be misled by impressive graphics into opting for a system which lacked the analytical ability essential for our applications.

Being a public agency, the DWA could not simply purchase the GIS it believed most closely matched its requirements. It had to issue an open tender, evaluate the offers according to predetermined criteria, and perform benchmark tests if necessary. Finally, a contract would be awarded to the tenderer offering the lowest priced system which met the specification.

The tender issued by the DWA was the first in South Africa calling for full GIS capabilities. It was decided to appoint consultants to assist in writing the technical specification, and to assist in evaluating the tender responses and designing benchmark tests. The consultants had to have expertise in the field and be commercially unbiased. The Centre for Advanced Computing and Decision Support (CACDS) of the CSIR (formerly the Council for Scientific and Industrial Research) was chosen to perform this function.

FACTORS INFLUENCING THE CHOICE

THE AGENCY

Large, long-established, socially-responsible organizations must necessarily exercise caution in implementing a new technology as an act of faith. Top-level management has to be convinced of the anticipated value for money, which may not be easy. Managers have to become familiar with the technical aspects to appreciate how shorter-term expenditure could effect longer-term savings. The engineering and scientific users must also be satisfied, along with the technical GIS personnel who will implement and maintain the system. Some will tend to side with others against the introduction of GIS technology. Differing or competing perspectives, personalities, and interest groups increase the difficulty of selecting and promoting a GIS, particularly where the principles and concepts are not well or uniformly understood. To gain support, much can be achieved by well-

presented and relevant demonstrations of GIS applications and problem-solving abilities.

GIS REQUIREMENTS

In some cases the function of an agency may almost completely define its GIS requirements, for example, an agency responsible for maintaining the cadastre. In other cases the GIS requirements may be quite ill-defined and open-ended, for example, a GIS research group. Differing perspectives as to the nature of the requirements may also exist. Relatively easily identified are requirements which are based on current non-GIS methods and procedures. On the other hand, a vendor may have a different view of a potential user's requirements, biased by the strengths and weaknesses of his own product. A third view (the GIS view?) would be founded on a thorough understanding of the agency's responsibilities and data, with an equally good understanding of the capabilities and potential of GIS technology.

A substantial part of the DWA's GIS requirements are defined by its function of managing water resources. But the necessity of planning the management of these resources as the demand for water increases over the next decades, driven by industrial development and the pressure of population growth, along with changing geo-political structures, implies that a GIS for the DWA must be able to cope, and cope well, with changing requirements in the future. This touches on the fact that at present it is generally not possible to buy a turn-key GIS off the shelf. What can be bought is a set of GIS tools which may be used to fashion a GIS according to the user's requirements.

GIS AND RELATED TECHNOLOGIES

Considerable confusion can exist concerning the similarities and distinctions between GIS and related technologies, such as CAD and computer-aided cartography. As our knowledge of GIS increased, it became clear that there are critical differences. For example, a CAD-based GIS could have severe limitations in storing the topological relationships between spatial data explicitly.

FINANCES AND PERSONNEL

GIS for sophisticated and large-scale applications is not cheap, although the cost of entry-level systems is dropping all the time. The initial cost of hardware and software ranges from a few thousand to hundreds of thousands of dollars, with the cost of the software often predominating, and this may represent only one-fifth of the total expenditure needed to make the GIS fully operational. The present state-of-the-art commercial systems usually require extensive software development to tailor them to meet requirements.

An important factor to consider is the cost of expanding the system. In terms of hardware, this is determined largely by the cost of graphics workstations, and the cost of upgrading the central host computer should this prove necessary. Software expansion costs depend on the pricing formula for each package, i.e., whether they are priced per workstation or per host.

Skilled personnel are essential to the successful implementation of a GIS. This has not only financial implications; such personnel may not be available or difficult to retain, especially in a developing country. It may be necessary to retrain existing staff in the new technology.

In South Africa the demand for scarce water is increasing rapidly and volumes of data are expanding. In order that the continued development of the country be maintained, it is critical that problems concerning the supply of water and the management of water resources on a catchment basis continue to be solved in the future. Thus, in spite of the high cost and skilled staffing required, we consider GIS to be an appropriate technology for a developing country.

INTER-DISCIPLINARY REQUIREMENTS

GIS is an integrating technology. It intersects many different disciplines and professions. In our context these include civil engineering, land surveying, remote sensing, hydrology, geohydrology, chemistry, and CAD. The data the GIS must store and manipulate are similarly diverse, including topographic, cadastral, alphanumeric, time-series, and grid-based data. For these reasons, a GIS must meet widely varied and sometimes opposing requirements. On the one hand, an engineer choosing the site and design of a dam can analyze data and run models of rainfall/runoff relationships satisfactorily, using schematic diagrams only. On the other hand, a land surveyor may want to enter and extract coordinate data to 12 significant digits. At the end of the day, results must be composed into a digestible form for presentation to decision-makers or the public.

While the need to address the requirements of several disciplines places a high premium on the flexibility and versatility of a GIS, it also suggests a second approach: instead of using a single package attempting to be all things to all disciplines, rather use several highly-developed specialized packages, integrated around a GIS in a way that is transparent to the naïve user. The DWA opted for the latter approach.

THE SCALE OF THE APPLICATION

The DWA's responsibilities extend over a vast geographic area (1.3 million km²), and planning horizons stretch over decades. While estimates of the volume of data required to be stored on the GIS are difficult to make they are on the order of gigabytes. These factors impose their own requirements. The ability of the database to handle large volumes of data with acceptable access times is crucial. It must be possible to extract conveniently a set of data, corresponding to a study area, from the central database, manipulate it, update it, and post it back. Customized procedures and standardized user interfaces for accessing the GIS are important, so that professionals and specialists may use it as a tool without becoming GIS experts.

In a large, long-term system, software and hardware obsolescence must be addressed. Software which has already been ported to several makes of computer will more probably outlive ageing hardware.

CONTENTS OF THE SPECIFICATION

At an early stage it was realized that the specification for the GIS was critically important. As the contract for the GIS would be awarded to the lowest tenderer meeting the specification, it was essential to clarify our real requirements in writing. In particular, it was vital to screen out any essentially CAD- or mapping-based system with a limited ability to model and analyze geo-referenced data. It was also envisaged that certain of our requirements could be met by the vendors modifying or adding to their products.

A comprehensive specification (Department of Water Affairs, 1987) was written over a period of several months. Various existing specifications for cartographic and CAD systems were used initially as source documents, and specialists in the DWA who would use the GIS were consulted, such as surveyors and those concerned with remote sensing. A draft of the specification was sent to all potential vendors for comment, to reduce the chance of the tender being biased and to identify omissions.

Aware of the wide range of GIS-type software under development, but not knowing what would be offered, we graded our requirements according to the scheme: Essential, Highly Desirable, Desirable, and Optional. In this way we allowed for the possibility of having to compromise should no tenderer meet all our higher requirements.

In writing the document, we were faced with the problem of translating high-level user requirements into GIS specifications.

There were two courses open to us. In the one, we could have attempted to list the requirements of each possible application in detail. This held the two-fold disadvantage of possibly overlooking some requirement, and of not catering for unknown future requirements. Instead, we took an alternative generic approach using a conceptual model of geographic entities. The model reduced all geographic phenomena to "features," a feature being a uniquely identifiable entity on the surface of the earth. It consisted of a set of spatial attributes (the coordinates describing the position of the feature on the surface of the Earth), a set of non-spatial attributes (typically alphanumeric data associated with the feature), and a classification. The three primitive feature types are point, line, and area. A compound feature has two or more features as its components.

By assuming that all GIS applications would access data by means of the feature model, the specification became simple and more elegant. In addition, this catered for the "conceptual growth path" of the GIS. In a planning environment where future scenarios have to be analyzed, we need to ensure that the GIS would be able to handle concepts and models of which we were not yet aware. Provided that the feature model encompasses these future requirements, the GIS should be able to do so.

The GIS is seen as a base for running scientific models, some of which reside on other systems. It has to make data available to such models, and store the results for further analysis and presentation.

Some essential aspects of the specification are described below.

DATABASE

A GIS must be founded on a robust database designed to store and access spatial and non-spatial data efficiently in a manner which, at least to the naïve user, appears integrated. Redundancy should be controlled, consistency is essential, and there should be no practical limits to the size of the database. The ability to model geographic features is essential, and, in particular, there should be no limitation on the geographic extent of a feature. The database should appear to be seamless, irrespective of any spatial or other partitions used to increase efficiency or for any other reason.

TOPOLOGY

The explicit storage of topological relationships between spatial attributes of different features, such as exclusion and intersection, is essential.

QUERIES ON THE DATABASE

Queries based on spatial, topological, and alphanumeric keys are required.

ANALYSIS

Polygon overlaying and vertical integration is a fundamental analytical tool which must be supported.

PROJECTIONS

As South Africa extends across 13° of latitude and 18° of longitude, the ability to display spatial data in the various projections in common use in the region (Gauss Conformal, Lambert Conformal, and Alber's Equal Area) is essential.

SECURITY

It was envisaged that the GIS would consist of a central database accessed simultaneously by many users having read-access rights. The database should also allow read-access to data currently extracted with write-access. Different users would have custody of different classes of feature, i.e., write-access rights. There

would also be some sensitive data to which only selected users would have read-access.

USER INTERFACE

The ability to customize the interface, create menus, commands, etc., is essential.

MACRO LANGUAGE

A high-level macro language is essential. It was envisaged that this would be the chief means by which many of the requirements specified would be achieved.

VENDOR SUPPORT

This was seen as another important area. We would require expert consulting services for setting up the GIS, and also a positive response by the vendor to our changing requirements.

RASTER DATA

Although our primary need was for a vector-based GIS, it was recognized that certain studies would be performed more conveniently using a raster structure. The ability to import raster data, for example classified satellite images, is essential.

OPEN SYSTEM

The DWA has several in-house FORTRAN programs which lend themselves to adaptation for use in a GIS environment. Thus, it is essential that the means be available for in-house or third-party software to be integrated with the GIS. This implies an open and modular design, and ideally the availability of a library of relocatable subroutines for accessing the GIS data structures and subsystems directly.

DTMs

Facilities are necessary for using digital terrain models, integrated with the GIS.

EXTERNAL DATABASES

It is necessary to be able to integrate geo-referenced data, held in other corporate databases on other computers, with the GIS. This requirement includes updating to and from these external databases.

HARDWARE

A wide range of requirements indicated that a single type of computer would not suffice. The large central database would have to be served by a powerful host minicomputer. A stand-alone graphics workstation would be most suited to running applications which needed extensive processing and graphics capabilities, and would also be appropriate at remote sites where communication speeds with the host would be relatively slow. A PC would meet the requirement of a portable system for use at different sites, and would also allow the DWA to provide GIS facilities to its engineering consultants at an affordable cost.

The system has to support the wide-area network being used by other government agencies, and also interface with existing hardware.

Although the primary function of the DWA is not to provide high-quality graphics output such as maps, it was deemed appropriate to buy high-quality color graphics output devices for use in presenting results to management and to the public.

EVALUATION

The specification consisted of two parts: the specification proper, and several answer schedules where detailed questions were asked concerning the functionality of the offered system, to which the tenderers had to respond (Department of Water Affairs, 1987).

The evaluation procedures to be followed were laid down in broad outline, although interpreting some of the conditions in the GIS context was not straightforward. The fundamental concepts on which the tendered systems were based differ widely and were not easily matched with the GIS concepts we specified. Often, when comparing systems, a quantitative comparison was not possible and a qualitative comparison had to suffice.

In order to compare the prices of the different systems offered, the configurations had to be modified to make them functionally comparable. For example, if vendor A offered a facility at a certain cost, and vendor B did not have such a facility, the cost of the facility had to be subtracted from the total cost of vendor A's system for purposes of comparison.

In order to facilitate evaluation, the responses of the tenderers were entered into a spread-sheet program for analysis.

BENCHMARK

While the specification was seen as crucial to ensure that a suitable GIS was selected, it was recognized that a written description of the requirements, as well as a written response by the tenderers, had severe limitations in a complex and imperfectly understood field such as GIS. Thus, a series of benchmark tests were drawn up and issued to those tenderers who appeared on paper to meet our requirements most nearly.

The benchmark was designed to test the essential and critical requirements in the specification, using topographic, DTM, and image-processed data, as well as to gain an indication of the reliability and accuracy of certain operations, and of the system's ability to handle large amounts of data. Even supplying data to the tenderers for the benchmark was not a trivial task. The data had to incorporate all the GIS concepts which we considered important, such as the feature model and topological relationships between the spatial attributes of features. Existing data exchange formats were not sophisticated enough to preserve all of these concepts. At the time, a proposed National Standard for the Exchange of Digital Geo-referenced Information had been published in South Africa (Clarke *et al.*, 1987) and it was decided to supply the data using a subset of this format. On the whole, this format served our requirements adequately and presented little difficulty to the tenderers who read the data (Greenwood, 1988).

CONCLUSION

Selecting a GIS proved to be a more exacting task than was initially envisaged. We underestimated the time required for writing the specification and for evaluating the offers received. As this was the first tender for a full GIS in South Africa, and also due to our inexperience, we went into more detail than would be necessary were we to repeat the exercise.

Hardware and GIS software were acquired at the end of the selection process. The effectiveness of the process will be revealed as the system is implemented, as the data are captured and integrated, and as more and more users exploit the system.

Conclusions and recommendations we can make are as follows:

- Developing expertise in GIS before entering the market is a wise approach and worth the time and effort.
- The pilot studies were most valuable in educating us in GIS concepts and in refining our requirements. They also helped convince top-level management of the benefits of GIS.
- By spending time investigating GIS technology and involving potential users, the GIS was accepted as a potential solution to a felt need, and not viewed as an unwanted imposition.
- The specification should concentrate on generic concepts rather than on fine details. Commercial GIS software is a set of tools, so the specification should ensure that the tools are adequate to fashion the GIS according to the user's requirements.
- The tender document should be drawn up to facilitate evaluation;

for example, the specification and answer schedules should be physically integrated.

- The benchmark should concentrate on critical requirements which can be used to distinguish between the leading tenderers.
- Ensure that all tenderers understand the concepts and terminology used in the specification and benchmark, and how they should be interpreted in terms of their own terminology.

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REFERENCES

- Clarke, D. G., A. K. Cooper, E. C. Liebenberg, and M. H. Van Rooyen, 1987. *A National Standard for the Exchange of Digital Geo-referenced Information*, NRIMS CSIR Special Report SWISK 45, 201 p.
- Conley, A., and J. J. Olivier, 1988. GIS in the Management of Scarce Public Resources, *Computer Graphics '88*, pp. B2-36-B2-37, General Computer Consulting.
- Department of Water Affairs, 1986. *Management of the Water Resources of the Republic of South Africa*.
- , 1987. *Tender Documentation for Geographic Information System* Volume I: Specification, 122 p.; Volume II: Schedules, 118 p.
- Greenwood, P. H., 1988. Using the Proposed National Exchange Standard for GIS Data, *Computer Graphics '88*, pp. B1-21-B1-29, General Computer Consulting.

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Sabbatical Leave Teaching/Research Opportunity

The Natural Resources Program of the Asian Institute of Technology has teaching/research positions opening in May and September 1990, and January, May, and September 1991. AIT, located 42 km. north of Bangkok, operates on trimesters, providing advanced education in civil engineering, natural resources development, information technology, human settlements planning, and management technology. Students represent countries across Asia and the Pacific region. Room, board, recreational, and health care facilities for short-term faculty are provided on campus.

The program's Remote Sensing Laboratory include a digital analysis facility with two workstations for the IBM 3083 mainframe using DIMAPS software, two workstations for a microVax II mini using Pericolor/ geode software, and two NEC APC IV workstations for ERDAS (version 7.3 software). All systems have image processing/GIS capability. Outputs are to screen ink-jet plotters, Versatek printers, and other hard copy devices, as well as to an Optronics Colorwrite. The digital analysis facility includes a visual analysis facility and a photographic processing facility. These facilities are available to short-term faculty.

The faculty member will be expected to devote between 3-5 contact hours per week to teaching duties and advising trainees on their term projects. Instructional areas of interest include: remote sensing, GIS, RS/GIS applications, environmental impact assessment, regional planning, and resource economics.

An honorarium of US \$3,000 will be provided to help defray costs. Interested persons should submit a C.V., the research they wish to pursue, and their period of availability. For further information, contact:

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