DEVELOPMENT OF A 3D GEO-REFERENCED GROUNDWATER MODEL FOR SALINITY MANAGEMENT

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ABSTRACT

This paper presents the findings thus far from a research project designed to create a three-dimensional virtual geographical environment that will enable the visual and digital analysis of ground water and surface water. The study area is the irrigation region around Deniliquin, New South Wales, Australia.

The study involves the identification of key physical characteristics of the landscape and water flow above and below the surface. The three-dimensional groundwater model is based on the integration of hydrological modelling software, GIS software and geographical visualization techniques.

The model is being used to create a realistic three-dimensional visualisation of the land where the impact of changes in the land cover characteristics can be shown to influence the movement and quality of the groundwater system. Both visual and digital analyses are possible in this model.

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Abstract and symbolically presented maps or environment models in either digital or analogue forms require a reasonable level of interpretation and background knowledge. A demand for a better medium of communication conveying the meaning of the representations into a format more readily understood by laypeople has been increased (Pietsch 2000). Interactive three dimensional (3D) modelling and visualisation techniques have been seen as effective ways to communicate with users in many fields such as environmental geology, disaster mitigation, urban and regional planning and urban geological applications (Masumoto, Raghavan *et al*. 2002). In recent years, data acquisition technologies for 3D urban environments have improved considerably. (Coors 2003). It appears that the current development in environmental modelling and modelling tools facilitates a combination of factors arising from both computer science and software engineering. Easy access to digital data and advanced spatial technologies such as geographic information systems (GIS), remote sensing, and global positioning system (GPS) accelerate a development of better ways of natural resource management.

The development of GIS over the last two decades has shown clearly not only that there are more spatially explicit ways of looking at environment management, but also that management decision-making based on the analysis and models of spatial data can lead to cost effective benefits. GIS is the flexible set of software tools that provide a comprehensive measure of integration in the context of spatially focussed environmental management in a single package (Argent 2003). The integration of GIS and visualisation modelling has the potential to become a richer communication medium. Linking the simulation interface to the attributes databases through an existing GIS provides a powerful method for search and retrieval of information tied to 3-dimensional form (Liggett and Jepson 1995).

Soil salinity develops as a consequence of the hydrology of the landscape shifting towards a new equilibrium based on increased groundwater recharge (Murray-Darling Basin Commission 2002). It is identified that areas of high groundwater level and the areas of irrigated land are susceptible to soil salinity (Fraser and Joseph 1998). Groundwater rising and soil salinity which are inter-related causes and effects are one of the major environment problems to be managed in Australia. About 2.5 million hectares of land are now affected as a consequence of increases in saline groundwater discharge over the past four decades, and at least a fourfold increase in affected land is predicted over the next three to four decades (Coram, Houlder *et al*. 2000).

To understand salinity across the Australia landscape and through time, it is necessary to understand how groundwater systems respond to changing recharge, and how the excess water that results from increased recharge is distributed. Lack of knowledge on these systems has limited the ability to manage soil salinity (National Land and Water Resources Audit 2002). For appropriate management of soil salinity, the extent of the groundwater flow systems contributing to salinity, and the processes that control groundwater discharge need to be understood using the most effective means of communication.

Statement of the problem

Groundwater modelling is hindered by the lack of adequate information about the groundwater flow systems and the need for an interactive and efficient system for data preparation and results analysis. Such a lack of information usually necessitates the use of tedious iterative methodology within a sensitivity analysis scheme. The groundwater modelling approach integrates the outputs from different programs for data preparation and analysis such as a particular spread sheet program, GIS etcetera (Froukh 2002). It is not possible to identify the individual features in every single catchment at a national scale, but it is possible to identify groundwater flow systems, with distinct geological and topographical features (Coram, *et al.* 2000).

There is a strong need for 3D GIS to manage 3D geometry and topology, integrate 3D geometry and semantic information, analyse both spatial and topological relationships and visualise the data in a suitable form. Operating GIS in 3D space and multidimensional time frames has become a practical complement to advanced simulation technologies (Antenucci 1993). For example, the flow of water is a truly 3D phenomenon and all attempts to approximate that motion in a space of lesser dimensions are just that – approximations (Vozenilek 1999).

GIS and 3D visualisation have been separate technologies, but to be effective in a design environment they need to be more closely integrated. An obvious way to couple GIS and 3D visualisation is to generate designs in a GIS and to output design files for viewing in CAD systems. In many cases interaction with the design will switch between a 2D map representation and a 3D scenic representation. Context switching should be easy and intuitive. Related representations in 2D maps and 3D scenes can be linked through a view-controller paradigm to synchronise user interaction with the database model (Pullar and Tidey 2001). This attempt at coupling systems has been commonly used. However this is not acceptable when one considers human computer interaction and the need for highly interactive exploration and analysis of a 3D model.

The groundwater flow systems define two levels of information that are critical to management. The first is the extent and responsiveness of the system to changes in recharge levels. The flow system extent can be delineated as regional, intermediate or local scales. This type of delineation can be used to provide information about the extent of the management activity to control dryland salinity, and the responsiveness of the system to the management activity. The second level of information is the type of hydrogeological and topographical features that influence the style of dryland salinity in a particular area. In order to identify spatial and temporal trends in the soil salinity, it is important to understand characteristics that enable managers to adopt hydrogeologically appropriate strategies (Coram, *et al.* 2000).

To gain the data of depth to groundwater, it is usual to employ interpolation techniques of point data from each observation well. But interpolation dose not consider any hydrogeologic parameters. If there are not enough data, the interpolated depth to water distribution results can lead to inaccurate assessment. Numerical modelling of groundwater flow can supply these insufficient data, if it is calibrated properly. A groundwater modelling program is inconvenient for the management of spatial data and it is hard to modify the input data (Lee 1999).

Research Aim

The primary aim for this research is to develop a 3-dimensional geo-referenced groundwater model for salinity management which integrates a groundwater modelling system and GIS. The system should allow the synthesis of land cover, topographic, geologic, hydrologic, and climate information gathered from numerous sources. To understand the correlation between land use changes and subsurface hydrologic conditions comprehensively, the system should include functionality to geographically reference the groundwater with its vertical values. It is not the intention of this research to build a completely operational 3D geo-referenced groundwater model for incorporating salinity management immediately, rather it is to investigate the feasibility of combining the existing GIS data, imaging system with 3D groundwater modelling to give a better understanding of groundwater mobilisation influencing salinity. In this research project, the outcomes from an interactive 3D geo-referenced groundwater model representing hydrogeological characteristics of areas susceptible to soil salinity can give land managers a better understanding in a sophisticated medium of communication which would lead to efficient land use planning and the effective management of natural resources. Figure 1-1 is one of the analogue 3D diagrams from which a computer 3D geo-referenced groundwater model can be developed.

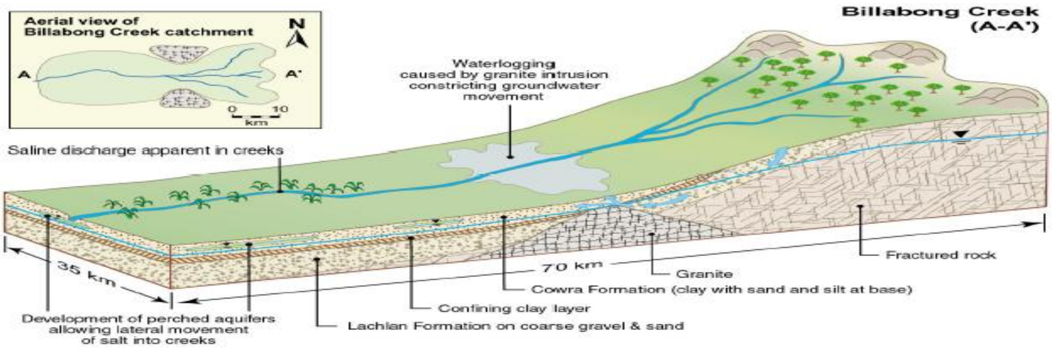

Figure 1-1 A diagram of Billabong Creek for groundwater investigation
(National Land and Water Resources Audit 2001)

Objectives

Three objectives are set that lead to the fulfilment of the aim. They are as follows;

- To find correlations between parameters of a groundwater mobilisation and land use changes based on the types of groundwater flow systems.
- To develop 3D representation tools implemented in a GIS for mapping the movements of groundwater in relation with soil salinity. The production of interactive cross sections of hydrogeological maps should be integrated in the interactive 3D GIS.
- To determine the feasibility of placing the functionality of an existing GIS and imaging system into the one geospatial modelling environment that will enable the user to undertake interactive 3D modelling and spatial and temporal analysis of existing digital geographical data.

Key research questions

The research objectives can be achieved by addressing the research questions below.

- What are the key characteristics in controlling groundwater mobilisation and salinity problems?
- What parameters should be used to determine the correlation between a groundwater mobilisation and land use changes?
- What kinds of functionality have to be available in a 3D GIS with application to groundwater modelling?
- What kinds of database and map representation techniques are needed for the visual analysis of geographical features and the spatial analysis of the data in 3D geo-referenced space?
- How can the data and functions of a groundwater model be represented as spatial and thematic characteristics in 3D geo-referenced space?
- How can groundwater simulation of the temporal hydrogeological processes be represented in 3D geo-referenced space?

Research Methodology

In order to achieve the research objectives, the research is divided into four stages. Figure 1.2 illustrates the research structure.

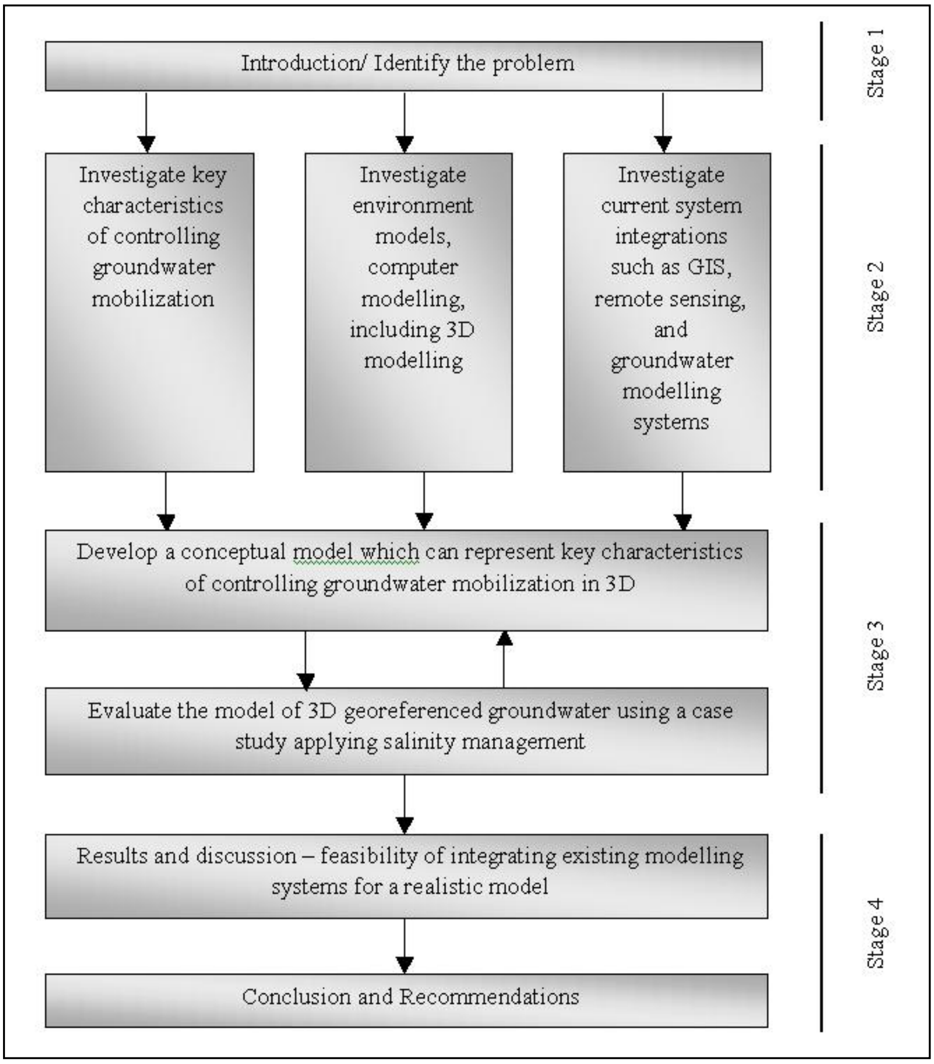

Figure 1-2 Research structure

The first stage introduces background information and identifies the problem to be addressed. The second stage reviews the literatures on salinity, groundwater, environment modelling, and systems integration which can lead to the development of a geo-referenced 3D groundwater model. The third stage will develop a conceptual model representing characteristics of controlling groundwater mobilisation in three-dimensional spaces. Sufficient discussion about how each characteristic can be represented in an integrated 3D environment will be followed. For evaluation of it, the model will be applied to the salinity management of an irrigation area in Murray Darling Basin as a case study. The forth stage is the presentation of results of the analysis and discussions for further development.

Review of Literature on key characteristics controlling groundwater mobilisation

It is important to identify the key characteristics controlling groundwater movement which will broadly fall under the following categories atmospheric water, landuse, landform, drainage density, aquifer, and subsurface factors. A literature review on salinity, groundwater movement, groundwater recharge and discharge was undertaken.

Review of Literature on Environment Modelling and Systems Integration

A model is a numerical approximation of real world processes which we use to evaluate the likely response or behaviour of a real system (Hoxley 1997). This research will focus on current computer environment modelling approaches to manage natural resource and disasters. It is crucial to comprehend the effects of proposed changes before they are implemented. A common way to do this is to view modifications through computer simulation and to assess their impact. Environment models can be used to test management options economically.

Advances in computer technology have provided the opportunity to present geoscience information in new and innovative ways. A multi-disciplinary approach to 3D visualisation encompassing cartography, GIS, remote sensing, graphic design, programming, and video editing to the post-processing of these visualizations brings new ways of natural resource management (Hay 2003). The current approaches in systems integration for natural resource management have been researched. Geographic information systems (GIS), groundwater modelling systems, and remote sensing have been analysed and the coupling of GIS, groundwater modelling systems and 3D visualisation has been investigated.

Development of a Conceptual Model

With the development of GIS, the water and salt balance algorithms can now consider the intersection of individual land parcel attributes with salinity data. This approach assumes that water is finite in quantity within a rive basin and hydrologic components are accountable. These components include precipitation, river inflow and outflow, evaporation, transpiration, groundwater inflow and outflow, deep percolation, surface runoff and changes in storage. The GIS calculates the areas of all polygons with homogeneous characteristics for various management alternatives (Houser and Bishop 1993). By changing the management classification or crops on individual land parcels, or all areas with specific attributes, the system quickly evaluates alternate scenarios of groundwater movement and the salinity problem. The concept of three-dimensional geo-referenced groundwater for salinity management, which integrates groundwater modelling system and GIS, is being developed with the considerations mentioned above. It is the focus of this research to develop the geo-referenced groundwater conceptual model in 3D space considering representations of key characteristics controlling groundwater movements.

It is not the intention of this research to build a completely operational a 3D geo-referenced groundwater model for incorporating salinity management immediately, rather it is to investigate the feasibility for combining the existing GIS data, imaging system with 3D groundwater modelling to give a better understanding of groundwater mobilisation causing salinity.

Evaluate the Model - A Case Study

The groundwater modelling integrates the outputs from different programs for data preparation and analysis which include the groundwater database, GIS, and groundwater modelling system. The system allows the synthesis of geologic, hydrologic, and climate information gathered from numerous sources. The selection of a study area where the integrated model will be applied for a case study is part of the Murray-Goulburn Irrigation District, where a shallow water table threatens about 385,000 hectares of productive land. Data preparation and interpretation techniques such data conversion techniques, interpolation techniques are will be used as the model employs datasets to build an empirical groundwater model.

Discussion and conclusions

The initial task associated with this research was to identify the key characteristics of the natural environment that related to the theme of the study. Once these were identified it was important to discover the relationships within and between each of the key characteristics so that spatial and temporal changes, along with important processes, could be linked to available spatial data types.

Current spatial data are quite simple in structure and content when compared to the aspect of the natural environment that they represent. It was important to identify the limitations of the data and also the limitations of the algorithms used to process the data. This part of the study is important so that new conceptual approaches based on current theory can be developed which in the future may be incorporated into the spatial modelling.

With the increasing sophistication of visualization techniques it is timely to contribute to the research into effective ways of incorporating the strengths of different modelling paradigms into a new integrated system. This new system will begin as a conceptual model and this conceptual model will be subjected to peer evaluation. Specific aspects of the model will be tested and demonstrated using existing software. Spatial data, from the geographical area selected for the case study, will be used to test and demonstrate the concepts.

The information society in which we live tends to provide individuals with more information than they can digest. If sophisticated geographical visualizations of spatial relationships and processes relating to the study of soil salinity, can be used in place of more cumbersome methods of dissemination then this will aid in the advance towards more effective decision making in the future.

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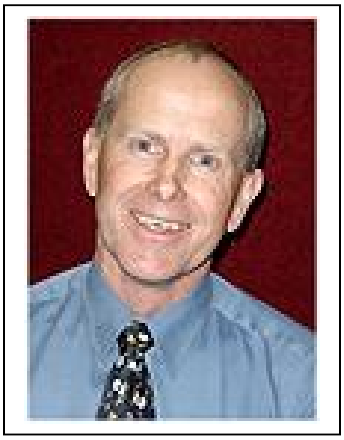
David Fraser – Biographical – 2005



David is a Senior Lecturer at the RMIT University, Melbourne Australia. He is a member of the School of Mathematical and Geospatial Sciences management committee and is the Director of Research Programs (Geospatial) in the School. He is also co-vice-chair of the Commission on Education and Training, International Cartographic Association.

David Fraser has a Bachelor of Applied Science in Cartography and a Master of Environmental Science. His PhD research related to the development of a spatial database capability model for rural GIS applications. He has managed projects for members of the rural community dealing with groundwater recharge mapping, soil salinity mapping and monitoring, large map scale GIS for catchment management, surface water mapping and the determination of the impact of grazing in the Mallee using satellite imagery,

David has written many papers relating to the applications of the mapping sciences to agriculture. He has been invited to present his research at meetings of professional organisations and on radio. He has also presented his research findings in Thailand, China, Great Britain, Malaysia, Spain, Scotland, Russia, South Africa, Vietnam and Canada. David, along with a colleague, set up the Centre for Remote Sensing and GIS at the RMIT University in 1992.

David is currently working on the development of a spatial model using satellite imagery and GIS data for groundwater and soil salinity measurement, monitoring and mapping. He is also part of as project team undertaking water management at the Mekong Delta, Ho Chi Minh City, Hue and Hanoi, Vietnam.

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