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Visualisation of data layers, the key to increasing integrity of geological based groundwater models

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Abstract: Mapping of groundwater aquifers has historically followed the path of 2D geological maps and interpreted cross sections derived from available geological borehole data. Isopachs or aquifer thicknesses are then derived from data layers. The addition of geophysical interpretation, through methods such as gravity and electro-magnetic surveys provide some confidence of continuity between boreholes. The advent of GIS and modern computer modelling has stretched the data further into the three dimensional digital world with the use of high-end numerical modelling and high-tech visualisation tools.

Input data may be assessed for quality and integrity. However, rarely are the digital data layers assessed by visual inspection. With a visual inspection the influence of individual data points on data layers is more easily accounted for, enabling a more rigorous assessment of the quality and or suitability of input data. Visual inspection aids in the identification of geological structures that often have significant impacts on groundwater dynamics, where such structures are often not identifiable from 2 dimensional borehole data. Visual inspection also allows a range of experts to view the aquifers in a multi- dimensional state and apply additional knowledge to the development of the models.

While many models may be based upon all available data, we argue that without visual assessment they are not based upon all available interpretation and assessment tools. We propose that models of complicated geological systems undergo several stages of visual assessment, including for example:

1. Integration of raw data sets and preliminary 3 dimensional model development,
2. Visualisation of layers, identification of spurious data and any geological features and discussion of where or what additional data sets are required (e.g., geophysics etc).

The aim of the research is to develop a methodology to provide proper representation of the subsurface geology to enable the development of a better understanding of aquifers and the water resource contained within. By making use of the increased speed and capacity of 3D visualisation software and hardware, more reliable conceptual models for groundwater sustainability investigations and better communication tools to explain the results to stakeholders can be produced.

Keywords: *Groundwater, 3D visualisation, 3D modelling, data visualisation*

1. BACKGROUND

Groundwater exists within the pore spaces and fractures within the sediments and rocks that make up the landscape. Using this water resource entails taking a portion of this water out where the geology is favourable and the water quality is suitable. Sustainable management of groundwater is helped greatly by knowing the location and size of the favourable geology (aquifers), their landscape setting and connection with recharge areas.

Traditional hydrogeological investigation and mapping has relied on geological interpretation and groundwater bore data to build an understanding of an area. The results are usually paper maps, cross sections and aquifer parameters that may then also be used to build numerical models of the groundwater system of interest.

Over the past two decades, the oil and minerals industries have been developing computer based 3D data management and visualisation systems (akin to GIS) to manage and interpret their geological data. Hydrogeologists in the US, Canada and Europe have started exploring how to utilise these methods for groundwater needs (Berg & Thorleifson, 2001; .Berg & Thorleifson, 2007).

This paper describes some of the early findings from a study (Gill, 2009) now underway that is exploring the potential of these new 3D technologies for Australian conditions, using three Victorian case study areas. Specifically, this paper provides a description of how the available data has been assimilated using GoCAD (geological object computer aided design software) and how the ability to visualize the geological data gives us much greater confidence in our interpretations of the geology of the study areas. Visualisation will also allowed us to identify deficiencies in the data and open up the possibilities of integrating other data sets, such as geophysics data, in a more structured and rigorous way.

The underlying need for this work is to improve groundwater resource management outcomes. If the 3D data sets and visualisation tools can lead to more accurate spatial and interpreted understanding of the various aquifer systems that contain and confine the water resource, then two key user groups should benefit. Firstly, groundwater resource users will be able to see images of the aquifers that they rely on. These images can be made available in a number of formats with suitable contextual information (such as rivers, lakes, roads or other surface features).

The second key user group will be the water authorities who need to manage the resource use. The same visualisations developed for the groundwater users can be attributed with relevant hydrogeological data (such as groundwater salinity, water ages, hydraulic conductivity, pressure level data) to gain deeper insights into the potential and limitations of the groundwater. The visualisations also provide more robust conceptual models of the system prior to developing numerical models to simulate behaviour and responses of the groundwater system to future scenarios.

2. DATA

2.1. Types – sources – preparation

There is much geological and hydrogeological information available for most parts of the State of Victoria. From the late gold Rush era in the 1880's, extensive drilling work was undertaken to follow the gold bearing alluvial deposits under the basalt and younger alluvial sediments to delineate what were called 'deep leads'. This original data (Hunter, 1909) was interpreted to provide images of the sub-surface in the form of cross sections of gold bearing alluvial deposits (Figure 1).

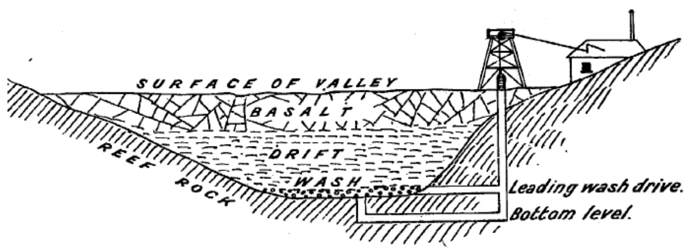

Figure 1. A cross section of a typical deep lead alluvial gold mining layout (from Hunter, 1909).

For a study area of approximately 2500 km^2 to the north of Ballarat around the towns of Creswick, Clunes and Carisbrook, some 2400 bore sites were found. Early drilling data was combined with drilling records from mining and groundwater exploration data up to the present day in order to develop the fundamental geological data set for the study area. The lithology of the region was interpreted from the drilling data and other sources following the method below:

1. Lithological information from bores that had descriptive logs of sufficient quality was captured in a format suitable for input to the 3D geological visualisation software.
2. Inferred bores at the edges of mapped bedrock outcrops were added. These points were given a zero depth and an elevation so as to force overlying layers to zero at these points.
3. Additional points along streams with known elevations were added to enforce the surface lithology at these points to conform to the known DEM. (Previously generated surface layers for the upper volcanics occasionally had heights greater than the recorded DEM elevations, especially along drainage lines).
4. After viewing a number of bore logs, patterns in the six main lithology types were identified and defined as the major units. These major units form the basis of the geological objects that are then visualized.

2.2. Data issues

Gathering geological data for the study areas is a major undertaking. While the geology of all areas in the state is known and mapped, the scale and reliability is highly variable and the detail in the depth direction is only exhibited in a limited number of published cross sections. Such cross sections are an essential tool used by geologists to make sense of sub-surface geological relationships. In the study areas being investigated, cross sections have been the only tool available up until now to exhibit the interpretations of drilling data, and given the distribution of high reliability drilling data, cross sections are often unable to resolve sufficient detail in areas of interest. Similarly 2D sediment distribution maps (Figure 2) show just part of the story where modelling and data gaps suggested isolated packages of thicker sediments.

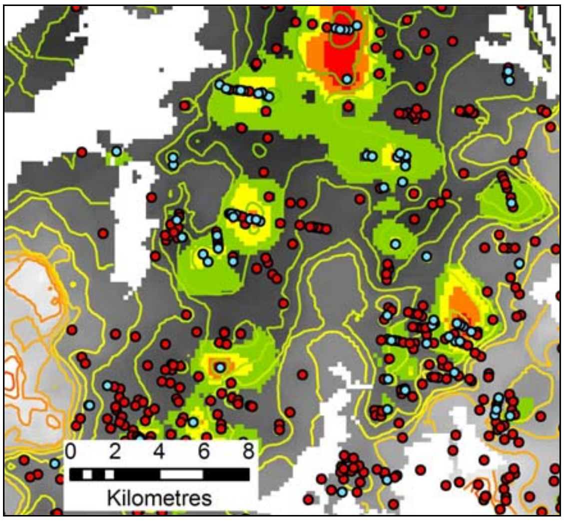

Figure 2. Discontinuous deep lead sediments in 'isolated' thicker patches (colour range), with bedrock contours and bores that intersected deep lead sediments (blue) or not (red).

Apart from the reliability of data quality, having no single repository of bore data poses significant issues in data collation. Since the first European gold explorers (1870's) began exploring for gold rich alluvium, bores have been sunk across the landscape. Early government records captured some of this information and then instigated their own programs to develop the goldfields. Initially recorded in paper publications, these records were collated into microfiche records and then into a digital format during the last two decades by the Geological Survey of Victoria. Company reporting on exploration activities also includes drilling details which have been variably captured and stored. Various other authorities collate bore data relevant to their needs, but each has developed databases to their own designs and requirements. This includes the water management authorities (statewide observation bore network and the water data warehouse), catchment management authorities, government research departments (salinity monitoring bores) and possibly even consultancies and Landcare groups. More recently as some of the various groups recognized that others have data that could be useful, some efforts to combine portions of the databases have occurred. Database structures vary in format (e.g., Microsoft Office Access databases, spreadsheets and custom built systems), currency (single snapshot of bore records through to updates as new bores were constructed) and even what was recorded (some only record bore location, depth and whether water was intersected with others having full geological logs, water quality & yields etc). There has also been the assumption that all bores were retrieved from old paper records and company reports. Investigations undertaken during this project have shown that many still lay hidden away in paper and microfiched reports and are yet to be fully utilised.

In addition to the disparate databases described above, the variation in the style of bore log causes delays with log descriptions varying from simple to detailed interpretations (e.g., 'hard rock' to 'fine to medium grained clay-rich sand and minor gravel'). Missing bore logs are also a problem, particularly in areas where a single bore could provide the only subsurface description. Other issues of concern encountered in all databases include several bores with the identical location coordinates, no location coordinates or incorrect coordinates, and descriptions of overlapping intervals.

Other data sets critical to the development of the model include surface geological polygon layers, interpreted groundwater flow system mapping, any 'old' understandings of deep leads and geophysical datasets such as raster images of gravity and magnetic surveys. Each needs to be georeferenced to make easy transition into appropriate software such as GoCAD and ArcGIS.

3. GEOLOGICAL OBJECTIVE

Geological interpretation is a 3 dimensional spatial plus time (4D) mode of thinking that has to deal with these disparate pieces of information that need to be assembled into a complete picture according to a set of geological rules. The geological integrity of the interpretations is critical to how reliable subsequent assessments will be. For example, the mining industry needs to make decisions on where to invest exploration effort, or define the economics of a mine or oil reserve on the basis of the understanding of the sub-surface relationships and extents of target features. Specific to this project is the desire to improve groundwater interpretation by building more accurate interpretations of the geological structures that host and convey sub-surface water resources.

Groundwater interpretations rely on aquifers being defined in a logical way according to the geological rules. Groundwater itself depends on the pore spaces in the geological formations and the flow of water depends on the connectivity of those pore spaces and understanding the elevations and relationships between rock units and the aquifer. Knowing how much is there depends on understanding the physical dimensions and holding capacity of the aquifer formations. Groundwater resource users need to know where the resource is located and managers of the resource need to know where the users are and how much they are using. Defining sustainable use of the resource depends upon judgements that are made about the likely recharge mechanisms and where in the landscape it happens. Regulatory mechanisms to manage water shortage often include options for users to trade water, so being able to see where trade is suitable or not often depends upon the aquifer configuration involved.

Another geological objective is to generate sound conceptual understanding of the subsurface in order to support numerical groundwater models. Numerical models are used to simulate water movement and changes in levels according to fundamental hydrogeological principles. Groundwater modelling packages such as MODFLOW (groundwater flow model, McDonald and Harbaugh, 1988) are used for this purpose. Fundamental to such modelling, is an accurate delineation of the major hydrogeological units, hence any method that improves understanding of the fundamental geology will lead to improved hydrogeological numerical models (Artimo et al., 2003).

A key objective of geological mapping in the pre-digital age was the bringing together of all available data and interpretations to generate a legacy product (geological maps) that could be used by others. By building conformable and extendable data sets for use in visualisation software frameworks, we are no longer limited to having finished products (maps) that take enormous effort to update. Instead, geological products can be readily updated and utilised with other geo-referenced data, with significantly improved spatial accuracy.

4. CONSTRUCTING THE MODEL

All data from bore logs, geological maps, cross sections and geophysical data sets are used to understand and interpret the subsurface geology, particularly the major hydrogeological unit relationships and their extent. Having collated and checked the quality, format and integrity of the data layers, they are processed through the ArcGIS analysis tools (Environmental Systems Research Institute GIS software products) to form a raster for each interpreted unit. The results are initially interrogated for completeness and alignment to geological interpretations. At this point vertical distance between rasters can indicate a unit thickness for example. The rasters are then exported to ASCII format ready for importing into GoCAD (Figure 3). Here the ASCII data can be processed into a surface which can be viewed, rotated and modified using the various tools available.

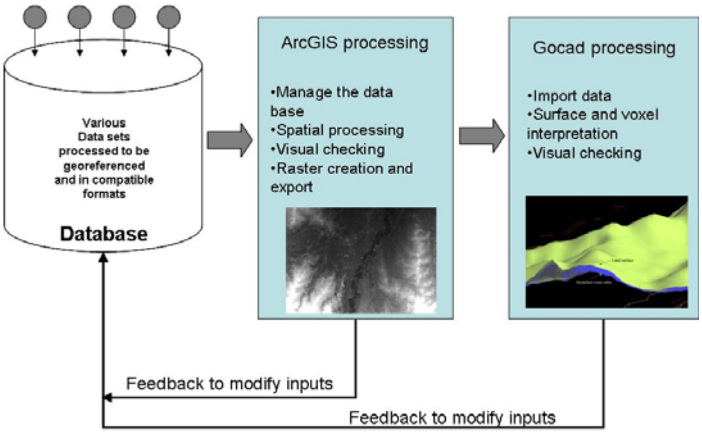

Figure 3. Conceptual Flow diagram of data collation, manipulation and modelling followed by visualisation.

5. USING VISUALISATION TO IMPROVE THE MODEL

5.1. Early findings

Apart from the above mentioned shortcomings in databases and data quality, a few other aspects were noted during the study. Data density is not even, due to the types of investigations and needs of the past drilling programs. As seen in Figure 4, the density of bores across the study area highlights the concentration of bores along roadsides and clusters in areas of particular need with bores being tens to a few hundred metres apart in some places while in other areas there may not be a single bore for several hundred metres to kilometres.

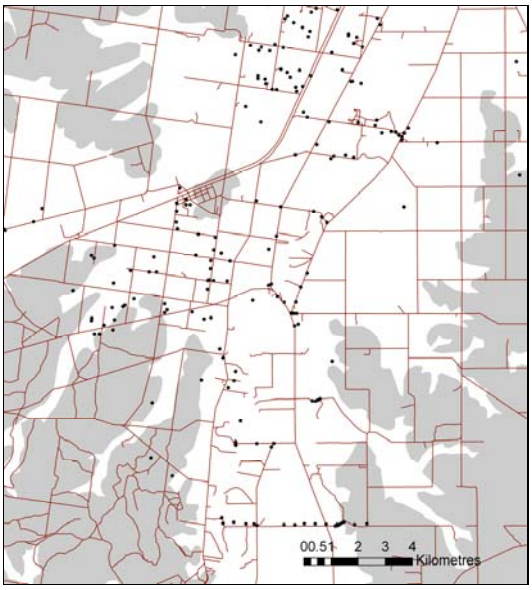

Figure 4. Bore density in the Campaspe catchment study area. Black dots – bores used in study, grey – outcropping bedrock, white – alluvial cover sequence, lines- road network.

The confidence in a modelled surface is also dependant on and limited by the strength and functionality of modelling tools available. ArcGIS raster/surface creation methods were employed using standard inverse distance weighted modelling. The modelling shows broader valley profiles than the anticipated narrower and steeper valleys.

5.2. Visualisation steps

Visualisation of the initial data points and subsequent surfaces in GoCAD identified ill-fitting data.

Having gathered as much point and line data that could be found for the study areas into a suitable format readable by GoCAD, the visualisation process enabled numerous incongruities in the data to be easily identified by the project geologists. Figure 5 demonstrates a simple example of adjacent bores with recorded bedrock intersections at quite different elevations. A re-look at the bore log of the 'shorter' hole found that it had been misinterpreted as having reached bedrock. Drilling had in fact stopped in a sedimentary clay unit higher in the sequence. Numerous other 'sinks' were noted in the modelled surface and ongoing review of the data sets will identify the causes.

Historical accounts (Hunter, 1909; Canavan 1988) noted during the early mining era that the deep lead deposits in the upper Loddon Valley were not continuous down the valley and in places where the sediment was expected the mine workings ran up against older bedrock. When viewed in plan the discontinuous nature of the deep lead sediments was noted in the modelled data (Figure 2). This enabled interpretations of features that supported basin formation. With the ability to visualize interpreted fault lines (Holdgate et al., 2006) and the modelled deep lead surfaces obliquely using 3D software, explanations for these continuity problems can be more readily developed. Based upon evidence in outcropping bedrock on either side of the valley, mapped fault lines with height displacements that are supported by the drilling data can be superimposed upon the visualisation quite easily. By visualising the relationship of cross cutting faults (identified by Holdgate et al., 2006) a geological explanation of the distribution of deep lead sediments (Figure 6), emerged. The discontinuous nature of the lead had been identified previously (Hunter, 1909), but an explanation had not become fully apparent until the entire aquifer system was visualised. This finding has implications on how the resource will be managed in the future. This is further supported by data such as hydrogeochemical data (Hagerty, 2008) that can be readily integrated into the visualisation to build confidence that the interpretation is sound.

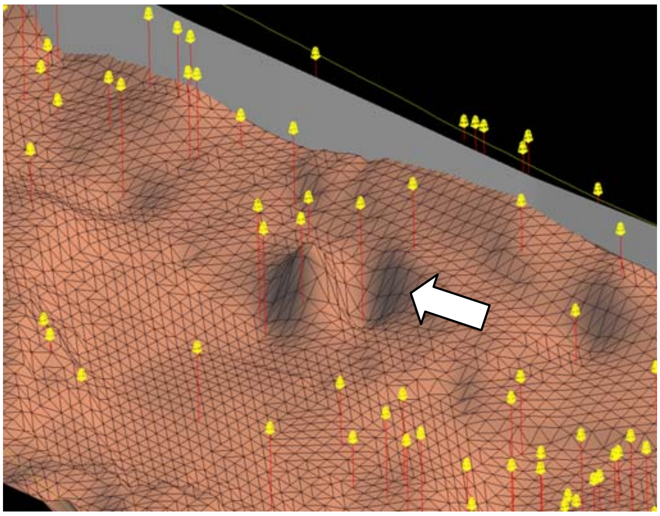

Figure 5. Modelled surface in the Campaspe catchment showing bedrock 'topography' where adjacent data points (bores-yellow derrick with red bore trace) gave a spurious result (arrow).

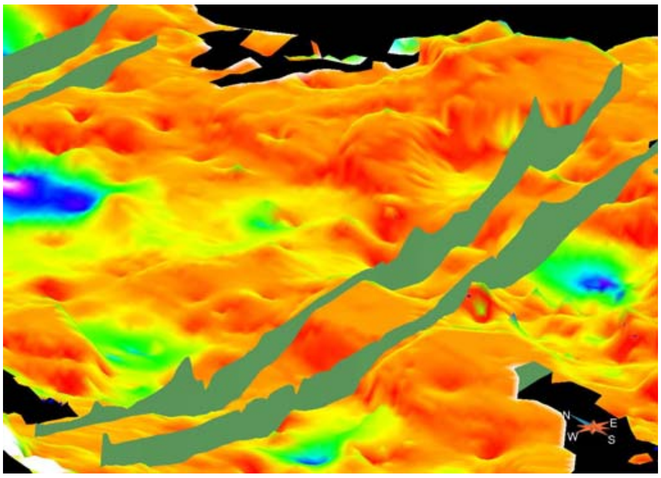

Figure 6. An image of the Ballarat north study area showing faults (green) cutting across the deep lead sediments that are coloured to indicate increasing thickness (green – blue – purple – white).

6. CONCLUSIONS AND RECOMMENDATIONS

Employing visual checking techniques to modelled surfaces and features is a worth while procedure in all processing of digital data. Such qualitative and quantitative analysis utilises the power of the human eye to evaluate the integrity of the data, modelling and subsequent interpretations. Multiple inputs bring the risk of errors and misinterpretations, where acceptance of a model could lead to further problems such as environmental damage, investment loss or loss of confidence in scientific investigation. Applying simple visual checks to make sure that a feature 'looks right' or fits a known and accepted geological interpretation is an easy task and something most investigators would be confident in.

Moving to 3D digital data storage, interpretation and mapping does generate a new set of issues that must be addressed. Some of these include:

- Visualisation products are interpretation products that have involved various degrees of original data correction or manipulation, often based upon expert opinion. Reconciling amended and original data and recording decision making beneath final products needs to be recorded somehow.
- Due to base data density variation and quality, means of conveying reliability of the visualisations needs to be developed. One approach might be to indicate bore locations and quality codes along with a grid that indicates what other data has been available, for example geophysics interpretations or mapped bedrock outcrop.
- Government corporate mapping layers and databases in public ownership need to be maintained with high integrity into perpetuity. Whereas a paper map can be date stamped and becomes final once printed, different expectations arise with digital products. Maintaining integrity is a need facing all geodata managers, and so building in compliance with a widely endorsed system such as GEOSciML (an XML

application schema used to transfer geoscience data via networks, see http://www.seegrid.csiro.au) is essential.

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REFERENCES

Artimo, A., Makinen, J., Berg, R.C., Abert C.C. and Salonen, V-P. (2003), Three-dimensional modelling and visualisation of the Virttaankangas aquifer, southwestern Finland. *Hydrogeology Journal*, 11, 378-386.

Berg, R.C. and Thorleifson, L.H. (2001), Introduction –Developing large diverse datasets and constructing three dimensional geologic and groundwater models. Geological models for groundwater flow modelling. (http://www.isgs.uiuc.edu/reserach/3Dworkshop/2001/workshops.html).

Berg, R.C., Russell H.A.J. and Thorleifson, L.H. (2007), Introduction –Three dimensional geologic mapping for groundwater applications. Geological models for groundwater flow modelling. (http://www.isgs.uiuc.edu/reserach/3Dworkshop/2001/workshops.html).

Canavan, F. (1988), Deep lead gold deposits of Victoria, Bulletin 62, Geological Survey of Victoria,

Gill, B.C. (2009), Raising National Water Standards Project #208 – Improving knowledge and understanding of groundwater resources using 3D visualisation and quantification tools. A state and federally funded research project (unpublished report to Steering committee).

Hagerty, S.K. (2008), Groundwater – surface water interactions in the Tullaroop catchment, Central Victoria. A thesis submitted in partial fulfilment of the requirements for a Bachelor of Environmental Science (Honours), Latrobe University.

Holdgate, G.R., Wallace, M.W., Gallagher, S.J., Witten, R.B., Stats, B. and Wagstaff, B.E. (2006), Cenozoic fault control on ‘deep lead’ palaeoriver system, Central Highlands, Victoria. *Australian Journal of Earth Sciences*, 53, 445-468.

Hunter, S. (1909), The deep leads of Victoria. Memoirs of the Geological Survey of Victoria No. 7. Department of Mines, Victoria.

McDonald, M.G. and Harbaugh, A.W. (1988), A modular three dimensional finite difference groundwater flow model, Techniques of Water-Resources Investigations, Book 6. U.S. Geological Survey.