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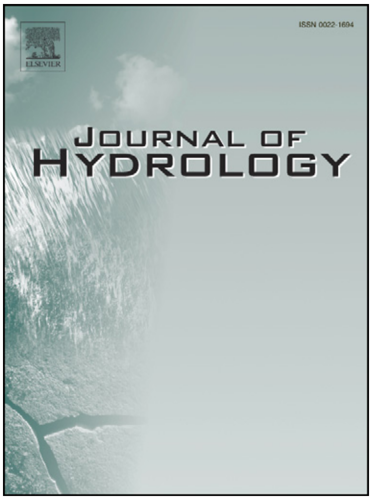

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Article 9: How scientific knowledge informs community understanding of groundwater

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Abstract

Robust information is integral to any good decision-making process. Information needs to be seen as credible by the community and defensible by scientists and independent reviewers. To achieve the water planning outcomes of the National Water Initiative, we need a common understanding of the issues, informed and supported by both research-based scientific expertise and local experiential knowledge of the resource system and risks of changes to the consumptive pool, to return overdrawn water systems to environmentally sustainable levels of extraction. In addition, recognition of regional differences, Indigenous needs, and impacts of land-use and climate change are required. We focus on how participatory approaches of interpretation and communication of scientific knowledge about groundwater hydrology can assist communities' understanding and acceptance of the need for better management.

Keywords: Groundwater planning; Visual tools; Science communication

1.0 Introduction

Inadequate hydrogeological information and limited longitudinal data about the inter-relationship of flow, recharge, and extraction in relation to many Australian groundwater systems have implications for making soundly based water planning decisions. The National Water Initiative (NWI) (COAG, 2004) expects that water allocation decisions will rely on the best available knowledge. This is to include Indigenous knowledge as well as the knowledge generated by scientists working within a Western knowledge paradigm and other stakeholders.

The NWI requires jurisdictions to address a number of issues associated with groundwater, many of which demand improvements in the knowledge-base about:

- groundwater-surface water connectivity;
- sustainable extraction rates and regimes; and
- the relationship between groundwater and important groundwater-dependent ecosystems (NWC, 2008).

Concomitant with awareness of resource limits is a greater appreciation that research and careful management are required to overcome uncertainties and difficulties in resource assessment and estimation of sustainable rates of utilisation. There appears to be widespread agreement amongst Australian water resource agencies that groundwater is 'neither understood nor managed as well as sustainability aspirations demand (NWC, 2008).

Scientists argue that the influence of groundwater on ecosystems in Australia is poorly understood: a 1998 report on groundwater ecosystem dependence concluded that there was then virtually no literature specific to this very important topic (Hatton and Evans, 1998). At that time, most of the environmental water allocation literature in Australia ignored groundwater components of the water balance. By 2003 this knowledge gap had still not been sufficiently addressed, such that scientists observed that, with a few notable exceptions, the groundwater requirements of terrestrial, riparian, wetlands and stygian ecosystems remained poorly understood (Murray et al., 2003). Only within the past decade or so has scientific attention been paid to the relationship of ecosystems and groundwater. Progress has been slow (NWC 2009) and the 2011 Biennial Review of the NWI indicated that “quantifying surface and groundwater connectivity and aligning their management is unfinished business in most jurisdictions” (NWC, 2011, p10). A recently upgraded toolbox for assessing ecological requirements of groundwater dependent ecosystems, with useful examples, is an indication of more recent efforts towards improving and consolidating knowledge (Richardson et al 2011).

Thus, given the scale of depletion of groundwater systems, not only in Australia but also globally, sharing information among resource managers and users is essential to involvement of all stakeholders in achieving sustainable management. Our Water Planning Tools (WPT) project introduced two tools which would improve understanding of groundwater systems among stakeholders.

2.0 Methods for improving knowledge

While the data situation is improving across the country because of nationwide commitments, the resourcing of data collection and analysis has been a low priority in the past, and limited metering of extraction, particularly of groundwater, has contributed to a lack of historical and current data (Hamstead et al., 2008). Local communities often complain about the modelling ‘black box’ based on scant or potentially unreliable data. Such lack of data challenges scientists and modellers to give best advice to decision-makers and where relevant, justification to the community of the need for a change from ‘business as usual’. A characteristic of this resource dilemma is that groundwater extraction is not publicly visible, nor are the impacts obviously related.

Recent reviews of water planning have identified challenges to water planning as 1) ensuring that all relevant knowledge is understood and considered effectively by key stakeholders in an open, inclusive and transparent decision-making process; 2) integrating local and Indigenous knowledge into ‘expert’ forms of assessment; and 3) integrating risk assessment into water planning, particularly of climate change in circumstances of uncertainty and scepticism (Bates et al., 2010; Hamstead et al., 2008; Mackenzie, 2008; Tan et al., 2010). Participatory methods that involve the community in exploring and sharing knowledge must be part of the way forward.

2.1 Transparent consideration of knowledge

A fundamental barrier to effective resource planning and management is the failure of researchers to adequately exchange knowledge and understanding with local communities (Boreux et al., 2009). Theoretical models of science communication can be used as an explanatory and evaluative framework for our work. The traditional "deficit model" involves linear transmission of knowledge and assumes a gap must be filled. However, simply applied, it does not acknowledge that people learn best when the information has personal meaning. The more advanced "contextual model" recognises that individuals process information according to social schemas shaped by personal and cultural context and so information needs to be directed to the audience. However a further two models better address the importance of local knowledge, participation and the political context: the "lay expertise" and the "public engagement" models. The former highlights the interactive nature of scientific process and values the knowledge of non-scientists. The latter engages the public in policy issues involving scientific and technical knowledge (Brossard and Lewenstein, 2010). In practice, though, projects tend to use mixed approaches of blended models to suit different contexts (ibid).

Our project to improve understanding of groundwater used aspects of the last three models. We tailored our methods to the audience having first interacted with them to determine their needs (contextual). We sought their data and their understanding of the resource and incorporated it where possible in groundwater visualisation models (lay expertise). We also engaged two of the three cases in policy discussions about resource management (public engagement). Not only were public engagement and stakeholder participation over-riding values in our approach, but methods of assessing public engagement from the socio-political literature can contribute to the lexicon of science communication.

Scientists need to be prepared to provide knowledge in a usable form to effectively engage with community (Ewing et al., 2000). One way of doing this is through a participatory approach to investigations which encourages communication between scientists, resource users and managers, and decision makers. While science provides a systematic and rigorous method of analysis and is largely seen as objective, impartial, and prestigious, partnering with local communities who have a stake in the research ensures the relevance of acquired information in meeting their needs and interests (Lovejoy, 2009). Local people are often the best placed to take action on local issues: they can complement, extend, refine, or initiate conventional science. A collaborative approach to information gathering enables 'citizen directed scientific questions to be asked, answered, and acted on by those who are affected by and who affect natural resources in local places' (Carr, 2004, p 847).

Advocates of participatory approaches (Fernandez-Gimenez et al., 2008; Kainer et al., 2009; Pahl-Wostl, 2006; Shackleton et al., 2009) claim that community involvement in problem identification, research, modelling, and monitoring provide major benefits. It can lead to: shared understanding among diverse participants (social learning); greater trust among parties and credibility in the findings; better consideration of science in planning, and greater adoption in practice.

Two techniques of participatory knowledge-building are relevant to our WPT research relating to groundwater systems: joint fact-finding and visualisation.

An easy way to undermine credibility in science is through inconsistencies and disputes between scientists, or presenting 'blue ribbon' science understood only by other scientists. Joint fact-finding can be used to address information gaps and scientific uncertainty and translate information in a form that is more credible. In a joint fact-finding process, participants pool their information and have a face-to-face dialogue between independent technical experts agreed on by the parties, decision-makers and other stakeholders, usually with neutral facilitation. This falls within the "lay expertise" model of science understanding. The emphasis is on translating technical information into a form that is accessible to all parties using graphics and a clear explanation. (Ehrmann and Stinson, 1999; McCreary et al., 2001).

Joint fact-finding can be time consuming, difficult to coordinate, and deadlines often make it impossible to undertake the ideal process. To compensate for these challenges, participants need to be informed about deadlines and make decisions about how much information is enough. Experts may need to be coached on how to present complex information clearly. Less-knowledgeable parties may need additional training or assistance. However if properly structured and adapted to meet the needs of each situation, collaborative fact-finding can contribute to more cohesive relationships among parties and a better understanding of differing views, contributing to the foundation for a broad consensus.

Approaches to improve the effectiveness of agricultural extension confirm the value of joint fact-finding and co-learning. Agricultural extension has historically employed a traditional transfer-of-technology extension model, using a “teaching” or “information transfer” approach which appeared to operate almost independently of its recipient's needs (Allen et al., 1998). In recent years, the new vision of successful extension describes a system within which land managers, research, extension, education and other interests interact, craft new knowledge and advance the development of their understanding within a co-learning experience. This forces an appreciation of the nature and quality of the relationships and interactions amongst the players and the combined knowledge sets they bring to the situation.

The second technique, visualisation, can assist in presenting information clearly and unambiguously. It can tailor information to the audience (contextual model). Use of visual images has been found to rapidly increase people's environmental awareness and has the potential to affect behaviour. Participatory, visual methods such as GIS models, have been employed in various climate change studies to facilitate capacity building and address the meaning of global climate change issues at a local level. Shaw et al. (2009) suggest that when visualisations are combined with the 'co-production of knowledge' at a meaningful scale, enhanced understanding and a willingness to act at a local level occurs more readily. While meaningful dialogue can occur through both verbal and written communication, images have great potential to be used more extensively to stimulate public engagement. Swaab et al. (2002) found that groups with visualization support reached consensus more easily. The elicitation of values and emotive qualities appear to be factors in the impact of visualisation techniques (Baldwin and Chandler, 2010; Sheppard, 2005, p 647).

Visualisation tools can be used in conjunction with joint fact-finding to enhance understanding of complex problems. McCown (2002), for example, found the relationship between the system developer and its eventual users was paramount in the adoption rates of purpose-built decision support tools for land managers. Effective new decision support systems transcend mere involvement when they embody mutual understanding based on shared recognition of, and respect for, others' ways of viewing the world. This opens up opportunities for co-creating information systems that utilise the comparative advantages of both practical and scientific knowledge. Intervention emphasis thus shifts from prescribing action to facilitating learning in actions (ibid: 180).

We found visualisation methods particularly well suited to the groundwater management context as it enables users to “see the unseen”. Joint fact-finding and visualisation tools were used, to understand the impacts from water scarcity, climate change and a sustained mining boom on groundwater resources. Thus to set our work in a science communication frame, a hybrid of the contextual, lay expertise and public engagement models has informed our approach.

2.2 Interpretation of Western research-based knowledge to be relevant to Indigenous people

Integrating local (including Indigenous) knowledge into decision-making is more effective when driven by local people with a local agenda (Roughley, 2007). ‘For cooperative research to work, research has to matter: not simply to those who bring new ideas into a community, but to the people within that community...’ (Davidson-Hunt, 2007, p 303). Like most cases of engagement, people need to see that their input makes a difference. Indeed, influencing the form of negotiation and incorporation of public values into decisions are criteria for evaluating engagement (Murdock et al 2005). This is a challenge, though, when trying to incorporate Indigenous values into a statutory process such as water planning and where the desires of Indigenous community may well conflict with existing use regimes.

Natural resource management approaches are most appropriate when they build on the existing capacities and allow on-going group learning and adaptation. Engagement needs to be tailored to the purpose of consultation and needs of the particular group (Baldwin and Twyford 2007). Engaging Indigenous people through practical activities ‘on country’ leads to more successful outcomes as community members can also fulfil cultural responsibilities and transfer knowledge across generations (Hill et al., 2012; Roughley, 2007). Smith et al. (2005)

suggest that incorporating local and experiential knowledge in a model development process not only provides a learning mechanism for communities, but also ensures models are culturally appropriate.

As an unseen and poorly understood resource, groundwater powerfully affects the health of Australia’s major ecosystems, and in many regions sustains Indigenous lifeways. In the 1998 and 2003 national reviews of groundwater (Hatton and Evans, 1998; Murray et al., 2003), the knowledge base and the significance of groundwater dependent ecosystems to Indigenous people, particularly in the Australian desert, was briefly noted, although Indigenous people were not then considered by those authors as a potential source of hydrological or ecological knowledge. This is in spite of the fact that Aboriginal occupation of the Australian continent and movement of Aboriginal groups depended on knowledge of water distribution and use of technology to harvest water and aquatic resources for tens of thousands of years (Bandler, 1995; Keen, 2003; Thorpe, 1928). Knowledge of environmental conditions, ecological features and processes, social conventions, as well as rich complex cultural landscapes were constructed around spiritually powerful water bodies, such as rock-holes and billabongs, created by ancestral beings.

Tailoring visual techniques for understanding the groundwater system to the purpose and needs of the local community, was made possible because of thorough stakeholder analyses undertaken to ensure relevance of the WPT project to the community, thus facilitating "contextual" communication (Hoverman et al., 2012; Jackson et al., 2012; Tan et al.,2012).

3.0 The Water Planning Tools Project

Our research commenced with stakeholder analyses to establish the range of interests, level of understanding, experience in and capacity for participation in planning. This was a critical step to inform the types of tools and the manner in which they were developed. For example, in the Howard East rural residential area of the Northern Territory (NT), there was significant stakeholder scepticism about the state of groundwater based on preliminary information provided by government water agencies; while in the Central Condamine Alluvium (CCA) region, an area of intensive irrigation for cotton in Queensland, stakeholders were called to accept a large reduction in allocation during the process for amending the Water Resource Plan. This recommendation would mean a high personal cost for landholders and would be based on data and numerical models that were unclear to lay persons. As a result, a Groundwater Visualisation *Tool* was important to build community confidence in technical information in both Howard East and the Condamine. This approach utilised a computer software program developed by hydrogeologists and software engineers. The Groundwater Visualisation *System*[1] was used to integrate available groundwater data and demonstrate the geological structure and boundaries of the aquifer, enable interrogation such as cross sections, and display local and regional drawdown effects of bore abstraction over time and season, as well as key relationships including between abstraction and recharge (James et al, 2009; Hawke et al, 2009). The visualisation model was developed using data from government sources which was then interpreted and enhanced using local knowledge and information. Our evaluations showed that the organised participatory process to develop the model in the Howard East area was effective in improving understanding and building trust of stakeholders in scientific information. In the Condamine time pressures did not allow for participatory development of the Groundwater Visualisation System. However because stakeholders in the region had both capacity and experience in water planning, the approach

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[1] GVS refers to the Groundwater Visualisation System software that is developed by QUT; GVT refers to the approach used by the Water Planning Tools team to use this as an interactive tool with the community.

was warmly welcomed by the community reference panel set up as part of the planning process, as ‘best practice’ communication of groundwater information to the public. In both examples, the visualisation models and the accompanying animation “got the message across” from the local agency of the need for management and contributed to the necessary dialogue about future use.

3.1 Howard East and the Groundwater Visualisation Tool

3.1.1 Outcome of stakeholder analysis, which illustrated need for GVT

As a precursor to regional water allocation planning in the Howard East Aquifer, between August and November 2008, thirty-five stakeholder representatives and community members were interviewed to discuss potential issues of concern (Nolan, 2009). Interviewees included representatives of Traditional Owners, industry (primary, secondary, and tertiary), urban residents, peri-urban residents, community and environmental groups, government (local, territory and federal) and research and education agencies. The researcher worked closely with representatives of the Northern Territory agency with responsibility for water planning, Natural Resources, Environment, The Arts and Sport and PowerWater Corporation, a government-owned corporation and the sole supplier and distributor of power, water and sanitation services in the region.

The outcomes of the interviews, reported on in Jackson et al. (2012), demonstrated a widespread lack of understanding of groundwater systems and related pressures, the perception of an endless water supply due to the monsoon, and a lack of confidence in the science underpinning decision making due to poor quality information on current usage, recharge rates, quantity available for use, and the value of the resource. This led to low confidence in the government’s groundwater models underpinning resource decisions.

Furthermore, quite a few community members were openly belligerent to government personnel and mistrusted data made available.

3.1.2 The GVS and its use

In the main Howard East Aquifer, the complex and locally fractured (occasionally cavernous) nature of the geological strata layer referred to as the *dolomite* means that bore yields are highly variable over a given area (from 0-60 litres per second), giving rise to a number of myths about the origins and amount of groundwater available for consumption. Working with hydrogeologists, the project team provided a participatory approach to develop a 3D visualisation tool that was cost effective, easy to use and able to be installed on household and public computers from a CD.

The Groundwater Visualisation System software uses a combination of in-house and open source software to create a 3D hydrogeological framework to represent an area’s aquifers (Cox et al., 2009). Additional features can be built into it to add new functionality and allow users to slice the ground in a given area, rotate the result and view a cross section illustrating what is happening underground. Thus, users can interrogate the model, by slicing sites near monitoring bores and even animate the standing water levels in the bore (if that monitoring data is available). Thus it can present a visual record of changes in groundwater levels and demonstrate the relationship between rainfall and recharge over seasons and longer time periods (see figures in Jackson et al., 2012). The software is *not* intended, however, to be a predictive groundwater dynamics model, but rather a useful tool for agency staff to show regional and local drawdown effects and trends.

In order to build credibility and community's trust in the groundwater educational tool, a participatory approach to information gathering and dissemination was used (Hawke et al., 2009). The Groundwater Visualisation System was created by independent experts at Queensland University of Technology who integrated information from horticulturists (how, when, and which bores were used and depth), PowerWater (history and reason for production bores before residential development), drillers (drill sites, logs, and knowledge of where to drill), and Natural Resources, Environment, The Arts and Sport (monitoring data). A bore survey, semi-structured interviews with local experts, and participatory mapping exercises were undertaken with bore drillers and the community at different stages of the tool's development (see Figure 1). This co-production of knowledge through public participation fed into the model at specific times. The integration of knowledge by the independent expert, thereby led to better data interpretation and greater likelihood of the tool being used (see Jackson et al., 2012 for staging of the process).

Figure 1 here Caption as follows

Figure 1: *From Top left*: Meeting held between modellers and NTHA representative; *Top Right*: Second Public Forum held in September 2009; *Bottom Left*: First Public Forum held April 2009; *Bottom right*: Meetings held with key stakeholder groups to gain input into model when 70% complete.

3.1.3 Participant Evaluation of Groundwater Visualisation Tool

The process and outcomes of the Groundwater Visualisation Tool were evaluated by (a) a brief questionnaire administered at two points in time during the tool's development process and (b) a focus group led by the project team at the completion its development (Nolan et al., 2009).

Questionnaire respondents reported that the participatory aspects such as surveys, mapping exercises, regular updates, and meetings, had increased trust in the science underlying the Tool and, consequently in Natural Resources, Environment, The Arts and Sport's hydrological models. Responding to stakeholders' questions and giving them a range of options of how to get involved improved the uptake, understanding, and educational value of the final tool.

Focus group discussions revealed that a high value was placed on the visualisation characteristics - 'a picture tells a thousand words'. This visualisation enabled community members to see their bore in the context of others, the subsurface geology and the cumulative impact of many bores. It was also seen as a highly valuable tool by drillers and horticulturalists for planning of future drillholes.

3.2 Central Condamine Alluvium and the Groundwater Visualisation Tool

3.2.1 Outcome of stakeholder analysis, which illustrated need for the Tool

An initial component of the Condamine stakeholder analysis consisted of a response to a survey by twenty-three leaders in community, irrigation, agribusiness, finance, community, and pastoral sectors (George et al., 2010). The survey had two primary objectives:

1. to assess the needs of industry, agricultural and natural resource managers and others, with regard to knowledge and skills relevant to water planning;
2. to collate opinions with respect to the content, process, and format of tools to be developed and communicated in water allocation planning.

All groups indicated that the main issue was declining bore performance and/or over-allocation of water from the aquifer. The main concern from all groups except the environment sector was maintaining reliability of their water supply now and into the future. The stakeholder analysis found conflict both within and across stakeholder groups over water planning issues and the need for a better understanding of groundwater performance and use on a sub-catchment level. Stakeholders suggested that this could be addressed through a 'time and space' 3D animation of the aquifer that reflects changes due to rainfall, streamflows and other forms of aquifer recharge, and groundwater extraction. A 3D animation would also be useful in communicating and discussing information about the groundwater and its sustainability with each of the stakeholder groups. The Queensland Department of Environment and Resource Management wanted to make the point that the impact of 40 years of groundwater abstraction, including through a drought, had produced substantial groundwater level drawdown.

3.2.2 The Groundwater Visualisation System and its use

The Groundwater Visualisation System software enabled a simple display of the time/space variations in groundwater hydrology. As with other GIS applications, layers and information contained in the tool are able to be 'switched off' individually to allow communication of such information. The user is able to manipulate the model image as they rotate, zoom, cut cross-sections, and drag through the model (Figures 2, 3, and 4). During development it was suggested by the Department of Environment and Resource Management that the portrayal of geological data from the drill hole logs be simplified by identifying only the water bearing layers (i.e. "sands and gravels"). This step was implemented and helped to illustrate the effect of extraction on water levels, conceptualise sustainable use of the aquifer, and thus contribute to planning and decision making.

Specific aspects of the aquifer that the Department of Environment and Resource Management wanted to be represented to the community were:

a. locations of observation bores, and their relation to surface topography, roads, streams, and landuse features;
b. location and growth in the number of all production bores drilled;
c. clarity about the value and purpose of observation bores, and how to display system behaviour;
d. depth of (observation) bores, and screened zones (i.e. what depth the groundwater is from);
e. observation bore groundwater level trends over time (e.g. from 1970) and their relationship to rainfall;
f. observation bore groundwater level trends in space and location of greatest drawdown;
g. observation bore salinity trends over time and space, and in relation to water-bearing zones;
h. some indication of depth to bedrock, based on existing knowledge, even if incomplete; and
i. water-bearing zones (i.e. production zones) to be represented by depths of screens .

Figure 2 here Caption as follows

Figure 2: Screen capture of the main scene from the GVS Condamine alluvial aquifers

Figure 3 here Caption as follows

Figure 3: Slice Tool visible in the Scene Viewer window, Condamine alluvial system with cross section showing the water table

Figure 4 here Caption as follows

Figure 4: Screenshot of user interface for the Condamine GVS model (source: James et al 2012)

The Tool was demonstrated to the Community Reference Panel in May 2010. This was an opportunity to get preliminary feedback on anything that might need changing and its usefulness. After the 30 minute presentation by the Queensland University of Technology team, the Panel members and the Department of Environment and Resource Management staff were asked a number of questions to determine their satisfaction with, and interest in using it as a tool for communication. This feedback was the final step before distributing the Tool to the community and handing the product over to the Department of Environment and Resource Management to be used as part of community consultation upon the release of the draft amendment to the Water Resource Plan in the second half of the year.

3.2.3 Participant Evaluation of Groundwater Visualisation Tool

All Community Reference Panel members found that it was easy to understand the meaning of all the layers in the Groundwater Visualisation Tool and most were confident they could use it if it were accompanied by an instruction manual. The benefits of the use of such a tool were reported as:

> *‘being able to see what was under the ground and spatial relationships between individual bores, aquifers, water quality, water levels and basement features’;*

‘gives a good picture of how the aquifer has changed to date. A very interesting database’;

‘useful awareness raising tool. Seems fairly simple to operate and reasonably comprehensive’; and

‘aid community discussion. To allow individual analysis of data at home’.

They indicated that the ‘visual 3D presentation of the alluvium and bedrock makes understanding of how the system operates easier for non technical people’, and it helps ‘less involved stakeholders better understand the system and therefore appreciate the management decisions and contribute to any discussion’. Some Community Reference Panel members suggested that the Tool would be useful in reducing uninformed discussion, which could help reduce conflict, as everyone would be speaking from the same knowledge base. While most felt it was best to keep it simple at this stage, some indicated that more information about lateral flows, Walloon Coal measures related to coal seam gas, and a data layer of groundwater dependent ecosystems would be useful improvements.

The Groundwater Visualisation Tool was later demonstrated to students from Dalby State High School, to provide a copy of the tool to the students and staff at the school as a resource and generate further feedback on the tool (Tan et al., 2012). The students, like the Community Reference Panel members, thought it was a useful means for presenting technical information about the aquifer to a wider audience. All of the students who particpated indicated that they found it easy to understand and felt confident in being able to use the tool with the associated users’ guide. The students thought it was important not just for farmers but the wider community to be able to understand the impacts of water extraction on the groundwater alluvium.

3.3 Tiwi Islands and the 3D Physical Groundwater Model

In the Tiwi Islands Northern Territory, Indigenous communities were consulted in order to begin water management planning in advance of competition for groundwater or scarcity. As a result, a different means of initiating a planning dialogue was adopted (Hoverman et al., 2012). An interactive or operating 3D Physical Groundwater Model was used to demonstrate relationships between groundwater, rainfall, aquifer recharge, production bores, billabong, and spring flow. It was constructed as a plexiglass box with a tank for water that circulated through a cross-section of soil using electricity which also charges a battery so it could be used in remote areas (Figure 5). Evaluations showed that this tool was appropriate both in the context and the purpose for which it was used.

Figure 5 here Caption as follows

Figure 5: Operating the 3D Physical Groundwater Model (source: Northern Territory Natural Resources, Environment, The Arts and Sport)

Because the model was interactive and dynamic, it held the interest and attention of participants; as it was not reliant on written information or complex technologies, it proved to be a good catalyst for provoking discussion. During the demonstration the aquifer recharge and discharge cycle was repeated several times, and with each cycle awareness of new features grew.

Although the objective for using the groundwater model had been to improve understanding of the water cycle, in fact the model stimulated discussions about the actual water dynamics in Tiwi landscapes as participants drew comparisons with local water features. In some cases these conversations ventured into discussions of the impacts of changing rainfall patterns from climate change or the potential effects of development on existing water resources.

Both workshop participants and the Tiwi Land Rangers, in separate evaluation exercises, judged the 3D groundwater model to be the ‘best’ tool for engaging participants to share information about groundwater issues, its uses and values.

4.0 Discussion

The Water Planning Tools project demonstrated innovative methods for building knowledge in the science behind management to enable the community to participate more fairly in future decision processes.

Progress towards achieving both process and outcome goals can be used to assess public participation in environmental decision-making. *Process* relies on fairness of procedures and structures that empower all relevant stakeholders to be involved and competent with adequate knowledge to be able to influence the form and function of the negotiation and participate meaningfully in both technical and nontechnical negotiations. *Outcome* goals involve trust and incorporation of public values in decisions (Webler 1995, Chess and Purcell 1999 and Beierle 1999 cited in Murdock et al 2005, p224).

The use of visual and physical tools to illustrate groundwater hydrology provided a mechanism to improve community understanding of the need for management of this valuable resource. Up until this point, the hydrological models used by government to explain groundwater characteristics were neither engaging nor convincing. In Howard East, the participatory approach to building the Groundwater Visualisation Tool, which involved joint fact-finding, was important in building trust and confidence in the data and the tool, even though not all data were useable for the model. It prepared the local community for participation in the water planning process. In the Condamine, the Groundwater Visualisation Tool usefully demonstrated the relationship between extraction, groundwater levels, rainfall and recharge. It provided information for certain parts of the system that had not been well understood. In the Tiwi Islands, the 3D model engaged residents in understanding groundwater and its vulnerability to impacts of climate change and future development. This was essential background in preparation for the Tiwi Islands Water Resource Strategy.

These outcomes would not have been possible without certain key ingredients:

1. A stakeholder analysis in each case study and time spent building rapport was essential to design appropriate tools tailored for the purpose of engagement and needs of the community. This contributed to participation process goals of fairness and competence.
2. Input from participants with local knowledge, combined with joint fact-finding and interaction with the scientists, added credibility to the science. This contributed to participation outcome goals of trust and incorporation of public values. In Howard East, the groundwater hydrogeologists spent substantial time engaging with the community, presenting the hydrogeology, incorporating local data into the model, and then demonstrating how to use it. Testing initial data in the Condamine first with government officers then querying of it by locals, improved understanding of aquifer behaviour. Likewise local knowledge was used to determine which aspects of groundwater needed to be explained in the Tiwi Islands.

3. Good collaboration between independent experts and the State government agency on data access and presentation was essential. Success depends on a fair stakeholder process that promotes competence as well as a willingness on the part of the agency to respect and be open to community participation and influence (Murdock et al 2005).
4. Finally, the project reinforced the benefits of visualisation techniques for understanding the system, promoting discussion, and, in Howard East in particular, for reducing conflict between community and government.

While the tools were beneficial for the reasons mentioned, comparison of the case studies illustrated the challenges in building appropriate tools, as well as the constraints, in ensuring that knowledge informs decision-making.

The different physical characteristics and available data of the two case studies had implications for resourcing the Groundwater Visualisation System development. The Howard East geological data, although readily made available from Natural Resources, Environment, The Arts and Sport, required substantial interpretation within the model to interpolate between bores. Additional data from drillers and water users was found to be helpful to increase community confidence. This required a substantial amount of expert hydrogeologist time. While data provided by Department of Environment and Resource Management for the Central Condamine Alluvium was fairly well organised, data reliability was affected by a complicated aquifer system with uncontrolled bore drilling resulting in leaks between aquifers. Approximately 100 of the most reliable data sets, based on time series and geological description, were from Department of Environment and Resource Management's observation bore monitoring network.

In Howard East, once the community was engaged with the information in 2008, it would have been opportune to progress with the water planning process for that area. However the Northern Territory government and Natural Resources, Environment, The Arts and Sport delayed commencement of the Howard East Aquifer Water Allocation Plan, with a Water Advisory Committee finally being appointed in late 2010. While the community has greater capacity because of this project, the momentum created by the engagement was lost.

In the Condamine, we sought to match historical groundwater bore data with sites of importance to Indigenous people to illustrate the relationship between extraction and condition of groundwater dependent ecosystems (such as Lake Broadwater). However the lack of groundwater data points and data errors made it impossible to show such a relationship with Indigenous sites. Of significance, the inability to access data related to impacts on the water resource by coal seam gas development remained an unresolved issue.

In addition, the Community Reference Panel's support for a 40% cutback in water allocations could not be attributed solely to the Central Condamine Alluvium Groundwater Visualisation Tool . Major factors were also acceptance of independent scientific evidence provided by the Commonwealth Scientific and Industrial Research Organisation which recommended a specific sustainable yield of the aquifer, as well as a mature understanding of issues by stakeholders from more than thirty years of social learning.

Finally, the initial vision for developing a visualisation tool for Central Condamine Alluvium groundwater was that it would be interactive and predictive. That is, it could be manipulated by the user to explore the outcomes of future rainfall-extraction scenarios. For the budget and in the time frame, such an interactive tool could not be built.

While participants in the Tiwi Islands study found benefits in the physical groundwater model, the Water Planning Tools team did not rate this tool highly against the project criteria of *process, technical quality, stakeholder outcomes* and *planning outcomes.* The team's reasons were that it provided only limited information which could inform planning outcomes and was not based on an actual situation. Undoubtedly, and consistent with the contextual model of science communication, applying the model to a local water planning issue with direct relevance to the stakeholders would increase its contribution.

45.0 Conclusion

In an age of climate, resource, and ecological uncertainties, planning issues are not resolved merely by providing additional data. A key factor in our project was an open, transparent and inclusive process which involved collaboration among experts, community and government. The neutrality of the Water Planning Tools researchers in facilitating the contribution of use and other information by community members, combined with the independent experts acknowledging and integrating the data into the Groundwater Visualisation System, resulted in this joint fact finding exercise being crucial to community participants' acceptance of the science and its credibility, particularly in Howard East.

Visualisation methods are particularly well suited to illuminating the mystery and complexity of groundwater. Used with the community in 'co-production of knowledge', visual portrayal of information at a meaningful scale to users stimulated discussion and understanding of the need for improved management in both Howard East and the Central Condamine Alliance.

The physical groundwater model used in the Tiwi Islands confirmed that engagement must be tailored to the purpose of consultation and needs of the particular group (Baldwin and Twyford 2007). The practical demonstrations 'on Country' meant that the Indigenous people were more able to easily engage with the tool. Future application of this tool could usefully be based on co-redevelopment of the tool to illustrate implications of a particular situation and location of concern, based on local knowledge. In terms of science communication, this work involved a hybrid of styles, dominated by the public engagement approach.

This work has wider significance across a range of natural resource management issues in terms of the benefits of using collaborative, participatory and visual methods to assist understanding. Nevertheless, a particular challenge remains. With uncertainty surrounding climate change, a tool which is continually updated and allows community members to interrogate a system and its response to a variety of climatic and usage conditions in a predictive fashion would assist in strategy development, and community and agency preparedness and risk management. Such tools could help address the threats to Australian groundwater security from a variable climate and the pressures of sustained use by agriculture and mining.

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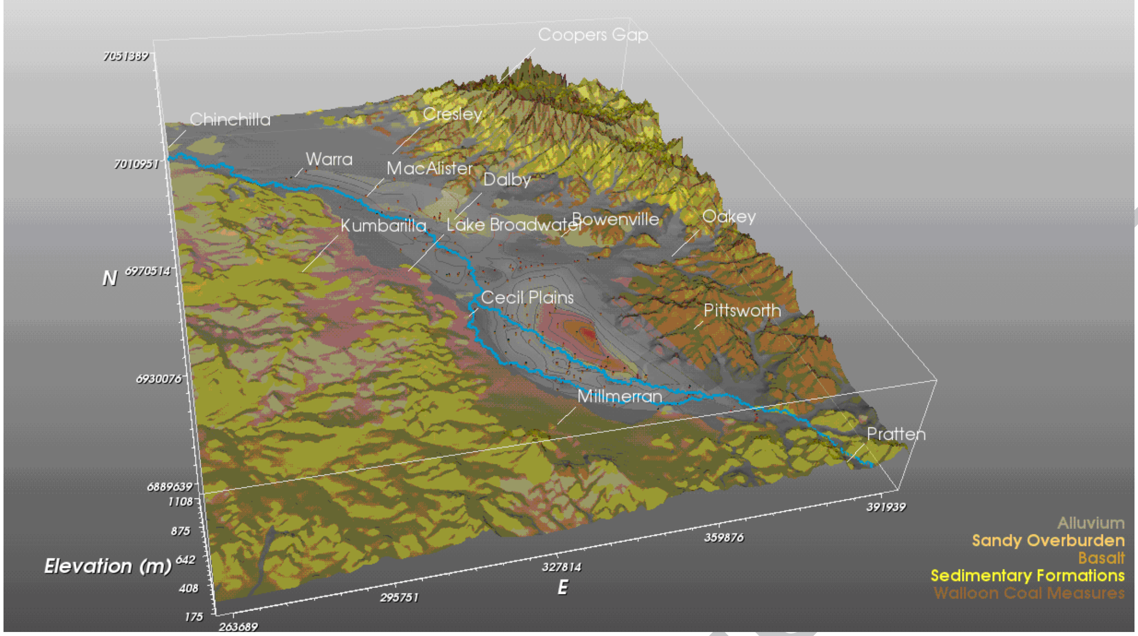
830 
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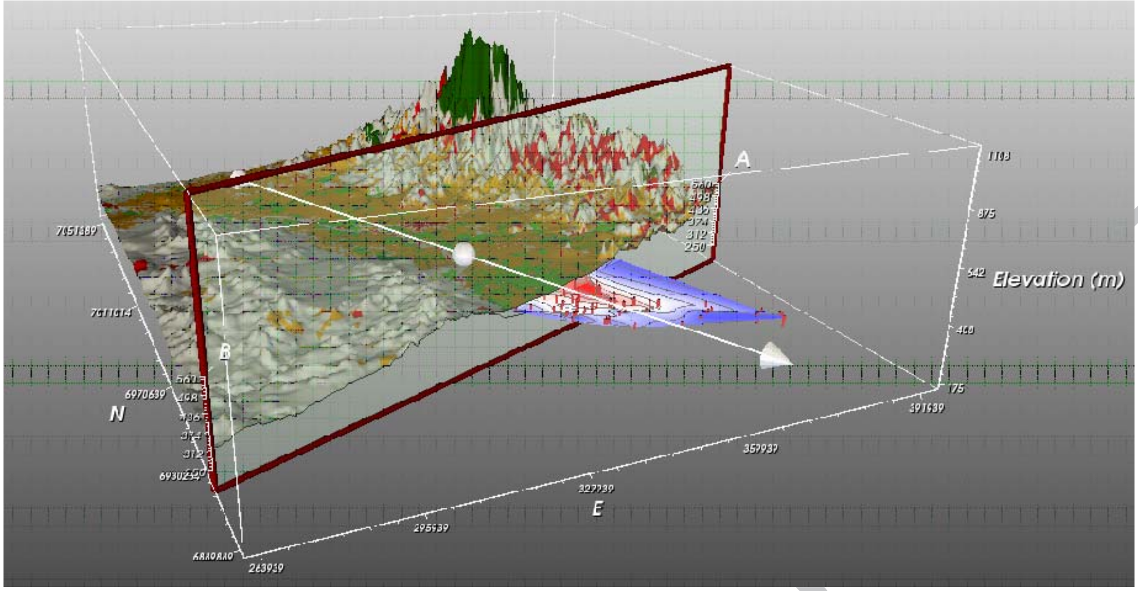
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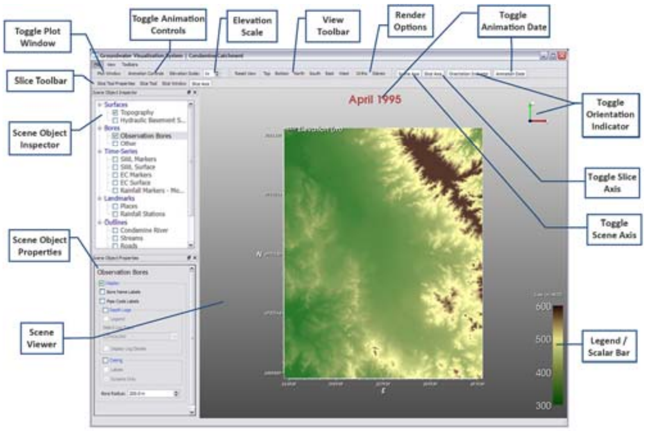
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Figure 1

Figure 5

Highlights

- Participatory inclusive methods were used in co-production of knowledge
- Visual models enhanced understanding of complex groundwater systems
- Expert, community and government collaboration contributed to acceptance of science
- Tools must reflect the purpose of engagement and needs of the community