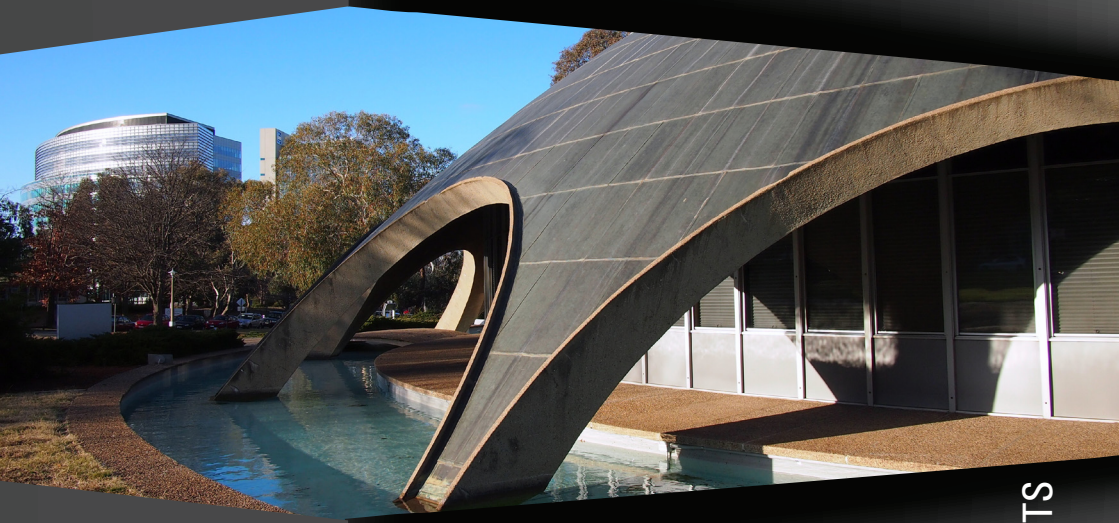
NATIONAL CENTRE FOR GROUNDWATER RESEARCH AND TRAINING

THE SHINE DOME

3-5 NOVEMBER 2015

AUSTRALIAN GROUNDWATER CONFERENCE



ABSTRACTS

DAY 1 Abstracts
Tuesday 3 November 2015

Morning Plenary

Community confidence demands groundwater information

Graham Hawke
Bureau of Meteorology

Groundwater provides more than 30% of Australia's total consumptive water and is increasingly used to supplement traditional surface water sources. Groundwater is the major source of water in many regions such as Perth, now providing around 60% of water supply. The shared nature of groundwater resources, increasing demand from growing populations, expanding irrigation, industry and mining, changing climate and rainfall, all contribute to the challenge of sound management. The Millennium Drought was a catalyst for increased groundwater use to supplement irrigation and urban needs. In some places, community confidence in management was challenged by perceptions of excessive, inequitable access to groundwater and third party impacts. The delayed response of groundwater to climate perturbations can provide a valuable buffer compared to surface water, but also mask adverse impacts on Groundwater Dependent Ecosystems. Because groundwater is a hidden and complex resource to communicate, public confidence in its management can suffer. Negative perceptions can be counterbalanced by providing clear information – at local, regional and national scales – with different techniques and levels of insights. The Bureau of Meteorology collects, standardises, stores and analyses groundwater information with the cooperation of water agencies around Australia. The creation of a nationally consistent and accessible repository of groundwater information from over 800,000 bores supports the understanding and managing of groundwater, evidenced with the Bioregional Assessments Coal Seam Gas and large coal mines. The Bureau's integrated suite of groundwater information products, for use by professionals and the public, can help build confidence in the management of this vital resource. Case studies will demonstrate the potential use of national, integrated groundwater information, including the new Australian Groundwater insight product. The Bureau can derive deeper insights from enhanced techniques to reveal changing climate and hydrogeological responses. Continued collaboration with groundwater managers and the university sector is needed to ensure enduring improvements in groundwater information.

Afternoon Plenary

What social and psychological factors predict acceptance of water management approaches and how can acceptance be increased?

Dr Kelly Fielding, Associate Professor Anne Roiko, Dr Angela Dean, Tracy Schultz
The University of Queensland, CRC for Water Sensitive Cities

The transition to more sustainable water management practices and policies requires an understanding of the social and psychological dimensions that can act as barriers or facilitators of policy and practice uptake. In this talk I explore key drivers of people's acceptance of water management policy/practice, that is, the knowledge, values and identities that influence their decisions. An understanding of these factors is critical as it can help to identify why people may resist some policies and recommended practices and how we might develop more effective communication to appeal to pre-existing values and identities. I present data from survey and experimental studies with members of the general community who were recruited to be representative of the population of interest. The studies seek to: 1) benchmark Australian water literacy, 2) understand the factors that influence water management policy acceptance (e.g., acceptance of alternative water sources), and 3) develop and test the effectiveness of communication that seeks to increase positive responses to policies and practices. The survey data reveals that there is relatively low water literacy in Australia, although state and urban versus rural differences are evident. The survey data also suggests key factors influencing water management policy acceptance include age, water literacy, environmental identity, trust in science and government, and comfort with technology. Experimental studies reveal that strategies that address key concerns about water management policies (e.g., safety, trust) lead to increases in acceptance of alternative water sources. These findings highlight that agencies seeking to change policy and practice need to understand the knowledge, values, and identities of the individuals and groups involved. Insights into these factors may help communication efforts to be tailored more effectively.

Morning Keynotes

Status of managed aquifer recharge in Australia and issues perceived by proponents and regulators in each state

Peter Dillon, Craig Simmons, Karen Lang
National Centre for Groundwater Research and Training

This will provide a systematic synthesis of findings of the informal meetings following the NCGRT Distinguished Lecturer Tour where an open invitation has been given to discuss “local MAR progress, plans and implementation issues". Uptake of MAR has been quite non uniform in Australia with the dominant states SA, WA and Vic. Why is this technology not being adopted elsewhere when there are many examples now of successful application? In WA and Vic the guidelines and entitlement policy frameworks exist. In other states the governance arrangements are not as clear and it is not known why this is the case. This miniature activity is intended to reveal drivers and impediments to innovation, good practice and good governance. Discussions and interviews are to follow the NCGRT Lectures in June and July and information from a range of stakeholders will help with an assessment of the key drivers and issues. Where necessary quantitative data will be recorded using post meeting survey techniques. The discussions and interviews will inform interpretation. Where there are common traits across States, these will be summarised. This will be determined when the lecture program has run its course. It is intended that results will inform, without finger-pointing, future policy development, research and information dissemination that will allow benefits of MAR to be fully achieved in Australia.

Implementation of the MDB Basin Plan for the management of groundwater resources in the Murray Darling Basin: Future issues and challenges

Peter Hyde, Dr Tariq Rana, Ms Chrissie McKnight
Murray Darling Basin Authority

The Basin states are now preparing new water resource plans (WRPs) to implement the Basin Plan's sustainable limits on surface and groundwater diversions, and to meet the requirements of the water quality and salinity management plan and environmental watering plan. The state WRPs must meet the Basin Plan requirements and be accredited by the Commonwealth Water Minister. Water resource plans for 36 Water Resource Plan Areas (16 groundwater, 14 surface and six with both) across the Basin need to be in place by 2019. The implementation timetable provides an opportunity to examine some of the future challenges to effectively and efficiently implement the Basin Plan. Defining the tasks required to address Basin Plan obligations and prioritising these tasks are the main challenges to the successful implementation of the Basin Plan. These tasks include:

- Actions required to meet Basin Plan obligations;
- Timing of those actions;
- Setting minimum standards required to fulfil obligations;
- Setting processes for developing, reviewing and amending planning guidelines; and
- Consultation.

To further support the Basin Plan outcomes, the MDBA is committed to working with the Basin States to ensure that the Plan's implementation obligations are given effect in ways that implementation costs are kept to a minimum. There is also a strong need for the MDBA and Basin States to adopt strategic approaches to integrating social, economic and environmental knowledge in implementing the Basin Plan, and on the science needed to meet future challenges. In order to achieve any lasting reform, one of the main challenges is to genuinely involve those affected by the reform. MDBA is making a concerted effort to understand the views of communities across the Basin, and to involve them in the implementation of the Basin Plan.

“National overview of the office of Water Science”

Peter Baker
Office of Water Science

The Office of Water Science is leading the Australian Government’s efforts to improve understanding of the water-related impacts of coal seam gas and large coal mining development by:

- providing secretariat and technical support to the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) which advises Australian government regulators on the water-related impacts of coal seam gas and large coal mining development proposals
- managing the Australian Government’s programme of targeted bioregional assessments to assess the potential impacts of coal seam gas and large coal mining developments on water resources and water-related assets
- managing the Australian Government’s research programme to identify and address critical gaps in scientific understanding of the water-related impacts of coal seam gas and large coal mining developments.

To perform this role a National Partnership Agreement on Coal Seam Gas and Large Coal Mining Development (the NPA) was established. The NPA was entered into between the Commonwealth of Australia and Queensland, New South Wales, Victoria and South Australian governments to strengthen the regulation of coal seam gas and large coal mining development by ensuring that future decisions are informed by substantially improved science and independent expert advice.

These actions are ensuring that the best available science is available to inform regulatory decision-making on coal seam gas and large coal mining developments that are likely to have a significant impact on water resources.

The Australian Groundwater Explorer

Eloise Nation, Zahid Ahmad, John Sharples, Elisabetta Carrara
Bureau of Meteorology

Under the Commonwealth Water Act (2007) the Bureau of Meteorology is tasked with a range of functions which require it to collect, hold, manage, interpret and disseminate Australia's water information including groundwater. One of the main objectives of the Bureau in the last few years has been to develop a consistent representation of groundwater across Australia and to have standardised groundwater data easily accessible and downloadable to all. This has resulted in the Bureau's Groundwater Information Suite - to be launched at this conference - which for the first time ever brings together groundwater data for the whole of Australia in a nationally consistent manner. The Australian Groundwater Explorer is the core of this suite of products and comprises of the National Groundwater Information System, the National Aquifer Framework and time series of groundwater levels and salinity. The Australian Groundwater Explorer was developed in collaboration with State and Territory water agencies, whose datasets are available through the Explorer, and was co-funded by the National Water Commission. The Groundwater Explorer is a considerable achievement. It is the first system to make Australian bore data readily available at a national scale and puts local, State and Territory groundwater information into an Australia-wide context. In addition, this tool makes a large body of data broadly accessible without the need for specialised software. The Explorer has recently been improved following a user requirements review. In 2014, in its first release, the Explorer contained groundwater level data for a pilot area covering south-eastern Australia. Since then data from all the States and Territories has been added to the Explorer. It now contains more than 55,000 bores with water level data. The Explorer is also updated annually with the latest bore and bore log data from the National Groundwater Information System. This presentation will demonstrate some use cases for the Explorer, as well as discuss the limitations and challenges the Bureau faced in collating and standardising this data.

Putting numbers to myths: a review of the impacts of unconventional gas on water resources

Dr Margaret Shanafield[1], Professor Peter G. Cook[2], Professor Craig Simmons[1]
1. National Centre for Groundwater Research and Training
2. CSIRO

The Australian resources industry stands poised to increase production of unconventional gas resources dramatically in the near future, consistent with world trends. Public response has been (understandably) weary, alarmed by the potential consequences of gas production activities within their communities. In lieu of receiving unbiased, considered information on what risks exist and what their relative severity is, a blanket fear of "fracking" has grown within the areas where exploration or gas production is commencing. In response, this project aims to estimate the likelihood of adverse impacts from unconventional gas production activities on water resources. This includes potential shallow groundwater contamination, surface water contamination, subsidence, depletion of shallow aquifers, and induced seismicity. Specifically, we aim to quantify the probabilities of the likelihood of incident occurrence based on available literature globally, with an emphasis on what is relevant to the Australian experience. Where possible, simple metrics, based on underlying physics of groundwater flow and transport, will be developed to predict impacts under a range of input conditions within hydrogeologic scenarios. Knowledge gaps will also be identified, with the goal of informing better regulation into the future. The outcome is designed to support the public and regulators in decision-making based on all available evidence and first-principles science.

Afternoon Keynotes

Thinking beyond the aquifer: a synthesis of integrated groundwater management and its challenges

Anthony Jakeman[1], Olivier Barreteau[2], Randall J Hunt[3], Jean-Daniel Rinaudo[4], Andrew Ross[5]
1. Australian National University
2. IRSTEA France
3. USGS USA
4. BRGM France
5. UNESCO

Managing groundwater systems is a grand challenge problem. How do we manage this crucial resource in an acceptable way, one that considers the sustainability of the resource for future generations and the socioeconomic and environmental impacts? In many cases this means restoring aquifers of concern to some sustainable equilibrium over a negotiated period of time, and seeking opportunities for better managing groundwater conjunctively with surface water and other resource use. However, there are many, often- interrelated, dimensions to managing groundwater effectively. It is important that the science and social science foundation be well supported, to work on, and with, the policy framework, and to ensure that the wider community, and stakeholders in areas of concern, support and participate in making the challenging decisions. Generally, an integrated approach will mean "thinking beyond the aquifer", a view which considers the wider context of surface water links, catchment management and cross-sectoral issues with energy, climate, agriculture and the environment. This presentation will distil the essence of a book in press on Integrated Groundwater Management. The book involving 28 chapters from some 80 authors documents for the first time the dimensions and requirements of sound integrated groundwater management (IGM). The primary focus is on groundwater management within its system, but includes other linkages beyond the aquifer as required. It attempts to articulate to researchers, practitioners and water resource managers the concepts and tools required for defensible IGM, to document how IGM can be applied to achieve more sustainable socioeconomic and environmental outcomes, and to articulate some of the issues ahead that will challenge IGM. The book is divided into five sections: integration overview and problem settings; governance; socioeconomics; biophysical aspects; and modelling and decision support.

Groundwater and Planning: Sustainable Allocation, Monitoring and Community Engagement

Cameron Holley
Connected Waters Initiative Research Centre
NCGRT
Faculty of Law, UNSW Australia

The management of scarce groundwater resources involves numerous complex challenges, not least developing appropriate allocation limits for extraction and establishing efficient and equitable allocation between competing uses at various interacting scales. Practitioners, lawmakers and scholars continue to struggle with designing water governance approaches that adequately address these challenges. However, in recent decades, one of the more credible approaches to emerge is collaborative groundwater allocation planning (CGP). While there is a growing literature examining CGP, there is a lack of empirical fieldwork to connect governance theory with grounded practice to identify what works, when and how. In response, this paper draws on a comparative and empirical examination of two CGP cases in South Australia and Western Australia, deliberately chosen to represent a diversity of geographic areas, aquifers and legislative requirements. Approximately 15 interviews (e.g. government, farmers, scientist and other non-government interests) were completed in each case. Questions explored three underexamined CGP issues: sustainable allocation, monitoring/adaption and community engagement. Both cases of CGP evidenced success and weakness. (i) Sustainable allocation: is more likely to be achieved where there is a local/regional water crisis, community buy-in, scope for conjunctive use and/or legal power (or its threat) to reduce water allocations. (ii) Monitoring/adaptation: more difficult to achieve on large scales, often underfunded and can be undermined by a lack of compulsory metering and economic drivers/ownership. (iii) Engagement: more likely to be successful where there is a crisis, science is integrated early with community experience, small scales/populations and sustained funding. Comparing different CGP cases, the paper identifies guiding principles on issue including the nature and scale of funding, use of information and legal process and powers to guide practitioners and scholars to choose appropriate CGP approaches in different settings and deliver effective and legitimate groundwater outcomes.

Morning Shine Dome Sessions – Murray-Darling Basin Authority Plan

Approaches to Achieve Sustainable Use and Management of Groundwater Resources in the Murray Darling Basin - Using Rules and Resource Condition Limits

Tariq Rana, Peter Hyde
Murray-Darling Basin Authority

The Murray-Darling Basin plan is the first time a limit on all groundwater use across the Basin has been set using a consistent approach. Sustainable diversion limits (SDLs), which are the maximum amount of water that can be taken for consumptive use, have been applied to all groundwater systems across the Murray– Darling Basin. The SDLs are designed to ensure groundwater take is sustainable for each groundwater system as a whole. Under the Basin Plan, groundwater systems should not experience: declining groundwater levels, significant structural damage, increased salinity, reduced contributions to stream flows or reduced flows to ecosystems and environmental assets that depend on groundwater, all of which are consequences of over-extraction. Groundwater resources vary in terms of: aquifer depth, salinity, connections to streams, the dependence of environmental assets, aquifer yield and the intensity of extraction. The sustainable use of groundwater, for some systems will only be achieved, if SDLs are supported by management rules that accounts for the local or site specific impacts of groundwater take. The MDBA has identified rules for groundwater use and resource condition limits (RCLs), which are to protect users and assets from local impacts. Typically RCLs are water levels or salinities at key monitoring sites (such as sites in stressed parts of the aquifer near significant environmental assets). These rules and RCLs are available for jurisdictions to use in water resource plans to manage the site specific impacts of groundwater take, and to provide a suggested framework on how an assessment of the need for rules can be undertaken. Guidance on selecting rules to address identifies needs in different circumstances and how RCLs may be developed has also been prepared for different hydrogeological settings.

Research and knowledge needs for improving groundwater management in the MDB

Tariq Rana, Peter Hyde
Murray-Darling Basin Authority

The Basin Plan is the first time that a limit on groundwater use has been established across the Basin. This is in contrast to surface water, where a cap has been in place since the mid-90s. The Basin Plan also represents the first time a consistent management arrangement will be applied across all of the Basin's groundwater resources. Groundwater use within the MDB ranges between 10 and 25% of total consumptive use. In areas such as the Murrumbidgee, Lachlan and Namoi groundwater played a significant part in ensuring that local economies survived the Millennium drought. Further research in groundwater is critical to ensure greater productive use from groundwater while protecting environmental assets and functions such as stream base flow that are reliant on groundwater. The most pressing science questions for improving he groundwater management plans in the MDB are:

- How do we improve our understanding of groundwater/surface water connectivity and then apply that understanding in the planning and trade contexts?
- How do we improve and apply updated and innovative recharge estimation techniques?
- How do we apply greater scientific and socio-economic rigour to improve groundwater management?
- How do we improve and apply updated and innovative tools to effectively manage groundwater dependent ecosystems; and
- How we can achieve the long term salinity outcomes?

In order to address these questions, the MDBA has recently entered into a 3 year, Strategic Groundwater Research Partnership with the NCGRT. It is expected that under this partnership, the MDBA and the NCGRT will collaboratively work with agencies and with state government to prioritise and fund research and investigations to develop innovative and practical management actions for a successful implementation of the groundwater management plans.

Data and Information needs for the Murray Darling Basin Plan monitoring, evaluation and reporting requirements

Peter Hyde, Christine McNight
Murray-Darling Basin Authority

In Data from groundwater monitoring networks is essential to informing groundwater planning and management decisions. Current groundwater monitoring regimes within the Murray-Darling Basin are subject to on-going stresses; with cost and resource constraints in the states, maintenance and monitoring frequencies are becoming venerable and may be compromised.
Existing groundwater monitoring networks have in general been designed for monitoring state water resources or as an element of discrete research programs. The Plan for the Murray-Darling Basin sets out the requirements for state prepared water resource plans and associated groundwater monitoring and evaluation requirements. As such there may be a gap between existing monitoring and data collection and data requirements to inform the monitoring and evaluation of the groundwater elements of the Basin Plan. Without appropriate monitoring networks and data collection the value of the investment made in the Murray-Darling Basin by the Australian Government could be compromised.

The MDBA is working with the Basin states to:

- measure the progress towards achieving Basin Plan groundwater outcomes;
- evaluate the capacity of groundwater monitoring and data collection to inform these outcomes; and
- informing future state and Basin plans.

Creating a demand for groundwater to develop a healthy trading market

Brendan Cossens, Simon Cowan
Goulburn-Murray Water Rural Water Corporation

In Victoria, the groundwater trading market is considered immature largely because there is not a strong demand for groundwater.Caps on entitlement have been established for higher yielding aquifers with desirable water quality to ensure resources are managed sustainably. However, groundwater usage is typically less than 50% of entitlement in Victoria. Low usage may be attributed to licence holders retaining entitlement in case of reduced surface water availability, uncertainty about trading rules, difficulty in finding someone to trade with, or waiting for the next generation to return to the farm. Capping entitlement without appropriately considering how usage might increase means groundwater is underutilised; which in turn affects regional development. The challenge is to create a demand for groundwater via a healthy trading market, which then allows entitlement to be transferred to its highest value use. Options that may assist with creating a demand for groundwater include understanding licence holder drivers for use; widespread introduction of carryover; reform to separate a licence to take from a licence to use and operate (i.e. unbundling); allowing trade of entitlement across and between larger areas; allowing trade which considers the level of usage proportional to caps; increasing the ease of accessing entitlement; and tools which provide increased confidence and certainty to licence holders. Changes to existing Victorian licensing legislation would be needed to separate the take and use components and to permit trade to conditionally exceed entitlement caps. Additional thinking about Murray-Darling Basin Plan trading rule elements such as hydraulic connectivity between two locations, timing, reliability and volume is needed to help eliminate unnecessary market barriers. Allowing groundwater to be traded to its highest value use requires a need to stimulate demand and remove unnecessary barriers to a healthy trading market. This will require supportive legislation informed by bold thinking, practical resource management and underpinned by sound science.

Complexities in applying trade principles to groundwater trade in the MDB

Edwina Carter, Dermot McKane, Victor Smiles,
Murray-Darling Basin Authority

Policy settings for water trade present a challenging set of issues to manage. Meeting both the objectives of the Basin Plan water trading rules and overall water management objectives requires a number of complex issues to be considered, especially in relation to groundwater trade. Section 22 of the Water Act 2007 (Cwth) requires that:

- the Basin Plan contain water trading rules, and
- the rules contribute to achieving the Basin water markets and trading principles set out in Schedule 3 of the Act.

Sections 12.24 – 12.26 of the Basin Plan prohibit the trade of a groundwater water access right between two locations unless certain conditions can be met. These conditions have presented a number of complex policy implementation issues for the MDBA. The presentation will explore:

- Basin Plan water trading rule conditions that must be met in order for the trade of a groundwater water access right to another location,
- complexities of applying trade principles and objectives to groundwater trade using examples, and lessons learned.

Groundwater trading - Slow to start, or just too hard? Research findings from Victoria

Bruce Gill[1, 2], Xiang Cheng[1]
1. Economic Development Victoria
2. La Trobe University

This presentation will describe the findings from some research looking into opportunities to increase agricultural utilisation of groundwater. With most of the main groundwater management areas in Victoria now fully allocated, opportunities for new users to obtain an allocation or existing licensees to increase their allocation can only occur through trade. Analysis of usage data reveals that even during the peak of the last drought (2008/9 season) usage by existing license holders rarely exceeded 50% of the annual permissible consumptive volume (analogous to sustainable yield). Moreover, between 50 to 70% of individual license holders use less than 5% of their allocation each year, yet unlike surface water, groundwater trading remains negligible. Social research has been conducted to gain qualitative data from irrigation farmers, licensed bore owners, water brokers and agency staff about their experience and views on trading groundwater. Qualitative analytical software was used to draw out themes from the social survey data which were then considered in the context of the state groundwater resource management rules and current agricultural circumstances. The results show there is a complex mix of social, economic, institutional and technical reasons why much of the un-used groundwater available to agriculture remains in the ground. Barriers to trade include perceptions among sleeper license holders that by trading their un-used allocation, they risk having their allocation reduced at license renewal, or that selling their water will lead to increased overall usage and put future availability at risk. Water brokers highlight low numbers of trades at low margins, unrealistic selling prices and administrative difficulties. Irrigators who have successfully traded identify that there are few participants in trading, technical appraisals are expensive and administrative requirements and fees are burdensome, especially when compared to surface water trading. Opportunities to improve trade are as yet ill-defined, but are unlikely to be simple or easily implemented. None-the-less, findings from this study will assist in the development of policy responses or actions that reduce impediments to groundwater trading.

New Water from Old Rocks: The case for conjunctive water management and use of unallocated groundwater from the crystalline rock formation aquifers of the south eastern Murray Darling Basin.

Kimberley Patrick
WoyWoy Global - New Water for a Thirsty World

In this seminar, our objective is to socialise a new conceptual hydrogeological model for the south eastern Murray Darling Basin highlands. This conceptual model describes a deep-seated, regionally-extensive and highly interconnected renewable groundwater resource within the crystalline rock formations of the Murray Darling Basin. These water resources are occurring within structures that are the result of expansion related brittle rock failure associated with large igneous rock forming events. The project combines interpretation of remotely sensed images, major ion chemistry of groundwater and perennial springs, and field measurements of rock outcrop geometric forms. To support this model, we present original analysis of the fractal geometric controls on hydrologically significant phenomenon in the greater Canberra region. We also explain from our analysis how these water resources are mostly unaccounted for in existing Water Sharing Plans and they are in effect, from an accounting perspective, new sources of water. We outline an integrated vision for how these water resources could be conjunctively managed to increase availability and reliability of high security water for irrigators and for environmental flows in the Murray Darling Basin. To unlock the economic, social and environmental benefits of developing these unallocated groundwater resources will require investment in new groundwater surveys, advanced engineering trials, and development of predictive numerical groundwater models. The development of the essential science and technology for sustainable management of these water resources needs to occur in parallel with the enactment of government policies that will encourage private sector investment into exploration, assessment and trading of water from these deeper groundwater sources into regulated surface waterways of the Murray Darling Basin. If this approach works in Australia, then it may also have the potential to be applied in a number of other economically water scarce locations worldwide.

Benefiting in-stream salinity: the Upper Darling Salt Interception Scheme, Glen Villa, NSW

Faye Williamson
NSW Office of Water

The Upper Darling Salt Interception Scheme (the Scheme) is located 30 km downstream of Bourke, NSW, along the Darling River at Glen Villa. The presence of saline springs entering the Darling River at this location has been known for some time with early explorers noting the non-potable water in the area (Mount, 1995). The Scheme's interception of saline groundwater at Glen Villa is expected to improve water quality downstream of the site at the Menindee Lakes and contribute to reducing the average electrical conductivity (EC) of the Murray River in South Australia. Five production bores have been installed in the semi-confined Quaternary alluvial aquifer to lower groundwater pressures and mitigate the rate at which saline groundwater enters the Darling River. To improve conceptual understanding, a period of aquifer testing was undertaken in 2013. The Scheme has now been operating continuously since November 2014. A partly telemetered network of 35 observation bores, five production bores and four surface water gauging stations is used to monitor the relationship between groundwater levels, river stage and EC, and to evaluate the performance of the scheme. The salinity within the alluvial groundwater system ranges from fresh (1000 µS/cm) to saline (50,000 µS/cm) depending on both vertical and horizontal distance from the Darling River. To analyse the hydraulic gradient between the fresher shallow aquifer and the deep saline aquifer, the differing densities were corrected using the Post et al (2007) theoretical framework. The data obtained to date shows that the Scheme's operation results in a reduction of in-stream salinity at Glen Villa however, further work will be required to quantify the impact of the Scheme on the average EC in the Murray River in South Australia.

Can irrigators adapt their water use to meet the requirements of the Murray Darling Basin Plan? A case study for the Namoi catchment, NSW

Jenifer Ticehurst, Professor Allan Curtis
Australian National University

Climate change and water reform has meant that irrigators in the Murray Darling Basin (MDB) are under increasing pressure to improve their water use efficiency to remain profitable. The Namoi catchment has a particularly long history of high groundwater dependence, particularly for cotton crops, and producers have received large cuts to their entitlements. Further anticipated cuts in the draft MDB Plan instigated public concern about its socio-economic impact. We surveyed groundwater irrigators in the Namoi catchment about their intention to adopt various management practices, including modifying flood irrigation practices, changing from flood to spray irrigation, and deepening water storage dams, all of which would improve their irrigation Water Use Efficiency (WUE). The response options varied from "Not interested at this time to "Definitely intend to do this". We calculated how much water could be saved on each property based upon the irrigators' intention to change practice, their estimated future irrigated area of different crops, their dam capacity, and a literature review on potential water savings from change in practice. We used the ranges in values to predict water savings for the catchment under two scenarios: (1) a conservative estimate of adoption across the catchment, and (2) a maximum possible savings. The results showed that up to 100.9GL/yr could be saved from irrigators who showed some intention to change their irrigation practices, with a more conservative estimate being about 20GL/yr. Both values exceed the required cuts to the irrigation entitlements in the current MDB Plan of 10GL/yr (of surface water) for the Namoi catchment. This indicates that currently accepted techniques for improving WUE have the capacity to meet, and even exceed, the required water entitlement cuts specified in the MDB Plan. Therefore the Namoi irrigators have anability, and an intention, to adapt to the MDB Plan.

Morning ANU Theatre 1 Sessions - State of the Art Modelling & Data Management

Groundwater Hydrochemistry Portal – a spatial database for Australian groundwater hydrochemistry and isotopes data

Baskaran Sundaram[1], Andrew Feitz[1], Joseph Bell[1], Matti Peljo[1], Eloise Nation[2], Luke Wallace[1]

1. Geoscience Australia, Canberra ACT, Australia
2. Bureau of Meteorology, Melbourne, Victoria, Australia

Groundwater is increasingly being relied upon for drinking water, as well as for agricultural and industrial use in Australia. Access to both groundwater availability and quality data is essential to support informed decision- making about our vital groundwater resources. While national datasets of groundwater levels, pressure and groundwater entitlements have been collated and made available by the Bureau of Meteorology, access to nationally consistent groundwater chemistry data is limited. Groundwater chemistry including isotopic data is essential to better understand groundwater origins, ages and dynamics, processes such as recharge and inter-aquifer connectivity and for informing conceptual and numerical groundwater models. The objective of this project is to develop a nationally consistent data discovery tool and web-based mapping portal to visualise, analyse and download groundwater chemistry and environmental isotope data. A new spatially-enabled groundwater hydrochemistry database including a bulk data loading function has been developed based on hydrochemistry data from projects completed in Geoscience Australia. The database includes information on physical chemical parameters (EC, pH, redox potential, dissolved oxygen), major and minor ions, trace elements, nutrients, pesticides, isotopes and organic chemicals. Upon loading the data to the database, all hydrochemistry data are assessed for reliability using Quality Assurance/Quality Control procedures and all datasets were standardised. Further development will include a data access portal, open geospatial consortium (OGC) web services and various 'views' on the data to suit specialised uses. The newly developed groundwater hydrochemistry portal will be linked to the Bureau's Australian Groundwater Explorer. The Explorer provides the location of more than 820,000 bores around the country and a national picture of groundwater levels with more than 55,000 bores with water level data. Linking the Groundwater Hydrochemistry Portal with the Explorer will ensure that nationally consistent data is available online to support the science and decision making concerning Australia's groundwater resources.

Improving groundwater numerical modelling efficiency through use of geospatial information systems tools and processes.

Kimberley Saflian, Sebastian Focke, Robert Suansri, Stuart Brown
Parsons Brinckerhoff

Environmental impact assessments require numerical modelling to simulate potential impacts to groundwater systems and connected surface water systems. The finite difference code MODFLOW and associated programs have become industry standard for groundwater modelling. Typically MODFLOW input files are prepared using a commercial graphical user interface (GUI). However these interfaces have their limitations with respect to spatial data and in many cases data must be pre-processed before being imported to the model. In this paper we present a workflow for efficient preparation of spatial and temporal data related to mining using ArcMap. Numerical models seek to simulate processes such as: Response to groundwater abstraction from dewatering and pit inflows for mining, modelling potential yields and aquifer responses for water supply. The modeller needs to be able to; Import a complex mining schedule into the numerical model input files via the GUI and represent a mining footprint that changes in time. This needs to be represented within the layered 3D model geology framework and using specific model boundary types (e.g. MODFLOW Drain). The challenge is to make this process efficient and repeatable, to be able to deal with schedule changes at late notice. The improved workflow consisted of: populating the numerical model geodatabase interactively using GIS rather than manually using excel. Spatial files of proposed mining activity with attributes of each mine area including mine year and proposed depths were able to be added using a join to give the geodatabase spatial location. A Digital Elevation model (DEM) was created using the best available elevation data and constrained to creek lines using the “topo to raster” tool. Groundwater modelling can have improved outcomes by utilising the available ArcMap tools, by achieving better data accuracy with advanced pre-processing or by reducing pre-processing allowing for more time to be allocated to running modelling scenarios.

Use of integrated hydrological databases as a tool to manage regional scale data sets and support operational, environmental and regulatory outcomes

Tim Lawton
BHP Billiton Iron Ore

To integrate a temporal hydrogeological database with existing drillhole data systems to capture technical data that supports analysis and reporting from local to regional scale. Establish a robust, assured dataset for water management at operation and catchment scale. Support internal reporting and external reporting to regulator and market. An SQL temporal database was designed and populated with a full set of historical data spanning 40 years across BHP Billiton's Pilbara operations. The database was integrated with existing drillhole data systems allowing integration of borehole information into analysis. Licence and reporting conditions were added to establish the basis of automated and dashboard reports. Integration of telemetry and automated validation added to improve accuracy and speed of access. Silverlight frontend, Excel interface and visibility in spatial data systems facilitated intuitive data management, interrogation and rapid identification of data changes in key areas. Implementation of an integrated database has allowed rapid access to all aspects of our hydrological dataset including bore details, groundwater, surface water and weather. Integration of these elements provided the basis of understanding for key mine-scale and catchment-scale hydrological processes. The ability to access high quality, standardised data quickly for internal and external use has reduced overhead and provided the basis for dashboard reporting and integration with analytical packages. Integrating time series water data into exiting business data systems enables rapid analysis and assessment to support operational and environmental outcomes. Use of a custom database and interface provides flexibility, adapting to changing requirements. Data confidence provides a sound basis for engaging with external entities for approvals, regulatory and sustainability reporting.

VlexDB - the description of a modern and secure online geoscience data management system

Ian Hunt
Sci Sys Pty

The focus for the VlexDB data management system was to move away from loosely formatted spreadsheets on several computers and hard-coded databases to a customizable single database hosted on an encrypted and secure online platform. This new data management system comes with a secure website based log-in and online management tools. VlexDB was designed to capture, manage and report geoscience data such as hydrogeology and environmental data. This enables capturing and managing a broad range of data such as hydrogeological exploration data or site baseline data for environmental impact assessments. VlexDB is a flexible and customizable application to suit the user's data needs and not hard-coded to a specific attribute structure. The main internal structure ensures that the database is robust and the user can add tables and attributes to the database as needed. The application can be scaled as the project grows and expands. The application uses strict user access rights with different levels of access ranging from 'administrator' privileges to 'normal users' and 'reporting only' users to maintain a high level of control. The system employs data capturing tools such as Lookup lists that can be created to ensure that data capturing is concise and clear. The system also includes a 'Standards' reporting tool to measure compliance to pre-set criteria for regulatory or internal compliance standards. The application also contains several existing reports and diagrams that can be exported for further use. The system keeps a detailed log of actions and changes made to the database by the individual users. The system allows an administrator to report the user logs and see the exact date and time when changes were made to the database by individual users. This system should make it much more productive to manage hydrogeological and environmental data between different sites and offices.

The 3D Water Atlas: enhanced scientific analysis for groundwater understanding and governance.

Alexandra Wolhuter, Sue Vink, Friska Pambudi, Jane Hunter
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Groundwater systems are an important economic resource in Australia, with multiple, often competing uses. The geological setting, range of usage and variety of data sources makes it difficult to retrieve and synthesise all of the data required to understand groundwater systems, establish good governance instruments and support the sustainable management of groundwater resources. The need for a tool that integrates a wide range of heterogeneous data sources into a single platform for visualising and analysing groundwater data became evident with the rapid expansion of the CSG industry in Queensland. The 3D Water Atlas was created as a platform we hope will fulfil this need. The Water Atlas is a 3D groundwater quality atlas of the Surat Basin that combines groundwater data from Queensland's Groundwater Database, baseline water quality data and CSG well water quality data collected by CSG companies into a common data model. The groundwater data, along with a geological stratigraphic model and other spatial datasets such as the Digital Cadastre Database can then be displayed, explored and analysed in 3D via a Web browser.

To facilitate the end users' ability to interpret Water Atlas data, a range of analytical services are also available. For example, data can be filtered so that only bores that source water from a certain formation are displayed. Automated QA/QC processes filter and flag any questionable data. Users can also explore trends in water quality or water levels from selected aquifers by viewing Piper and Stiff diagrams, pie charts, time series graphs and cross-sections. These tools can assist with a broader understanding of natural system variability as well as help companies, independent scientists and policy makers to understand and identify potential threats to groundwater resources, improve decision making in coal seam water treatment and determine where to focus attention for improved risk management and governance.

Using scenario analysis to investigate uncertainty in water resource trade-offs

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In water resource management, scenarios have been used as an important tool to account for uncertainties in climatic, socio-economic and political domains, including their effects on future availability, demand and management strategies of surface water and groundwater. There are however opportunities to improve how such scenarios are used and hence obtain more meaningful insights from them. For instance, integrated models in particular are characterised by multiple outputs and a wide range of uncertain inputs, parameters and model assumptions. A crucial issue is therefore in specifically understanding the importance of these various sources of uncertainty on the trade-off between objectives. We examine this issue in an integrated model which estimates flow and groundwater levels, farm profits and ecological impacts of various drivers such as climate change and water policy. The integrated model contains a hydrological model (which includes streamflow and groundwater), surface water and groundwater extraction rules, a farm decision model and an ecology model. The scenarios used consider uncertainty in climate, crop price, adoption rate of irrigation techniques and annual water allocations (including surface water and groundwater). The trade-off matrix contains annual farm profits, flood suitability index for the maintenance and survival of river red gum, groundwater suitability index for the maintenance and survival of river red gum, annual average groundwater depth and annual minimum groundwater depth. A parameter/model component is considered important when different plausible scenarios generate substantially different trade-offs between model outputs, i.e. it is not certain what trade-offs are expected between objectives. This study demonstrates the importance of exploring component uncertainty in integrated modelling for water resource management. When the model uncertainty is too high to produce meaningful result for trade-offs, then either the uncertainty should be reduced through targeted research (as identified through the analysis), and/or an adaptive management framework should be considered.

Interactive MODeling (iMOD) to Facilitate Stakeholder Engagement in Model Building with Fast and Flexible Sub-Domain Modeling Techniques

Weibe Borren, Peter Vermeulen, Perry de Louw, Dimmie Hendriks, Alex Minett, Bennie Minnema
Deltares

Stakeholders (e.g. water companies, water boards) and decision makers (e.g. municipalities, provincial and national governments) are increasingly participating in jointly developing numerical groundwater models that cover land areas of common interest. The reason for this is twofold: (1) minimize the undesired high costs of repeatedly developing individual - partly overlapping - models, and (2) facilitate stakeholder engagement participation in the model building process. To facilitate this Deltares has developed iMOD (interactive MODeling), an open-source and free-of-charge groundwater modelling environment based on the concepts of MODLOW. iMOD is an easy to use Graphical User Interface and an accelerated version of MODFLOW with fast, flexible and consistent sub-domain modelling techniques. iMOD provides the necessary functionalities to manage very large groundwater models, including interactive generation of sub-models with a user-defined (higher or lower) resolution, consistent with the underlying set of model data. Fast visualisation tools (maps, cross sections, 3-D views, timeseries display, water balances etc.) facilitate stakeholder participation during the process of model building. A major difference with other modelling packages is the generic geo-referenced data structure that may contain files with unequal resolutions and can be used to generate sub-models at different resolutions applying up- and down-scaling concepts. This is done internally without creating sub-sets of the original model data. For modellers and stakeholders, this offers high performance, flexibility and transparency. iMOD will be demonstrated with groundwater modelling cases from the Netherlands (high resolution large- scale modelling) and Canada (regulatory process using iMOD coupled to Delft-FEWS). iMOD is widely used in the Netherlands in models for several consortia of stakeholders on national, regional and local scale. The operational system in Canada shows that iMOD models and the special features of iMOD can be used by regulators without the need of being a modelling expert.

A new and innovative approach to the estimation of stock and domestic groundwater use in the Surat Cumulative Management Area, Queensland

Dhananjay Singh
Office of Groundwater Impact Assessment

In the Great Artesian Basin (GAB), the take of groundwater for stock and domestic (S&D) purposes is predominantly unmetered. For a variety of reasons, this situation is unlikely to change. However, given this take represents > 70% of total GAB water use in the Queensland, improving the methodology for estimating S&D use is critically important to achieving sustainable groundwater management outcomes. The Office of Groundwater Impact Assessment (OGIA) is responsible for assessing the cumulative groundwater impacts from coal seam gas activities in the Surat Cumulative Management Area (CMA). Accounting for S&D use (20,000 bores) is a key input into the regional groundwater model development work which underpins this cumulative impact assessment. To improve estimates, OGIA has developed a methodology which integrates readily available state-wide datasets to ensure consistency and repeatability of the method. Broadly, the methodology involves:

- Determining property types (rural, peri-urban and urban) and livestock carrying capacity to estimate average stock water requirements for each property.
- Determining the presence, volume and seasonal availability of additional non-groundwater supplies for each property.
- Calculation of S&D groundwater demand for average, dry and wet years to incorporate seasonality and lower and upper bound estimates of water use.
- Distribution of estimated water use to property bores, with validation against bore yields.

Results suggest that there are spatial trends in S&D water use in the Surat CMA which reflect agro-climatic conditions. For example, water use increases from non-GAB alluvial aquifers in the east, to GAB aquifers in the west (approx. 1.0ML/bore to 4.5ML/bore in dry years). This methodology has advanced and reduced the error margins for estimating S&D use. The approach integrates the latest remote sensing datasets and landscape understanding. A significant benefit of the approach is the potential applicability of the method across the GAB and other groundwater resources.

Estimating unmetered groundwater abstraction in Queensland's coal seam gas basins

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Centre for Water in the Minerals Industry, Sustainable Minerals Institute

Groundwater abstraction, primarily for stock and domestic usage, occurs via thousands of mostly unmetered bores in Queensland's Surat basin, with hundreds more in the Bowen basin. The consequent uncertainty in the amount and spatial distribution of abstraction may have significant effects in understanding regional groundwater system response, and hence in assessing potential impacts of coal seam gas operations. This study aims to couple advanced spatiotemporal statistical methods and analytical methods to better estimate unmetered abstraction and better quantify the uncertainty associated with such estimates. While metering data are sparse, there are increasing numbers of spatiotemporal datasets (e.g. climate, stocking rates, groundwater quality etc.) which may be predictive of abstraction volumes. These can be used as covariates to construct spatial multivariate regression models to estimate abstraction at unmetered locations. However, the metering data are characterised by complicated statistical features, such as zero- valued observations, non-Gaussianity, and non-stationarity. This severely limits the use of many classical estimation techniques, such as kriging. We make use of modern Bayesian spatiotemporal modelling techniques, which allow for these features and quantification of model uncertainty in a robust way. Methods for basin-wide prediction are still being developed; we present an example application for a well- metered subset of the model domain in the Condamine Alluvium. Our model predicts both probability and magnitude of abstraction from bores in space and time, using Gaussian Markov random spatial field approximations. Initial results show reasonable agreement with previous estimates, but additionally offer rigorous quantification of uncertainty in the estimate, which has been lacking to date. These techniques allow groundwater abstraction to be estimated in a manner well suited for sensitivity analysis of numerical groundwater models. Work is ongoing to extend these models by incorporating other estimates of abstraction (e.g. baseline assessment data and other 'analytical' estimates) with metered data to produce basin-wide estimates.

Morning ANU Theatre 2 Sessions – Groundwater Energy & Resources (CSG)

Assessment of Hydrogeological Connectivity between the Condamine Alluvium and the Underlying Walloon Coal Measures for Predicting Cumulative Coal Seam Gas Impacts in Queensland

Sanjeev Pandey[1], Stephen Denner[2], Josh Monchrieff[1], Dhananjay Singh[3], Mark Gallagher[3], Simon Gossmann[2], Chris Dickinson[1], Randall Cox[3]
1. Klohn Crippen Berger, Brisbane, QLD
2. Arrow Energy Pty Ltd, Brisbane, QLD
3. Office of Groundwater Impact Assessment (OGIA), Brisbane, QLD

The groundwater resources of the Condamine River Alluvial Aquifer (CA) in Queensland have been extensively developed over the past 60 years primarily for irrigation purpose. Current and proposed coal seam gas development in the Surat Basin extends to underneath the western edge of the CA footprint and involves depressurisation of the Walloon Coal Measures (WCM) which forms the basement for the alluvium. This could potentially impact on CA depending upon the connectivity between the alluvium and the underlying Walloon Coal Measures. An initial assessment of impact was undertaken in 2012 by the Queensland Office of Groundwater Impact Assessment (OGIA) in the Surat Underground Water Impact Report (UWIR). OGIA has since then been leading an extensive study supported by Arrow Energy through drilling and test pumping. The study comprises of multiple lines of investigations to improve current understanding of the connectivity in terms of geological, hydrogeological and hydrochemical characteristics of the interface between the CA and the WCM. Studies described in this paper include geological modelling, drilling and test pumping to assess the distribution, and hydraulic conductivity of, the CA and WCM interface; a multivariate hydrochemistry analysis to assess potential intermixing of water between the two; and collection of water level data for drawing relative piezometric surface maps to assess and quantify cross formational flow. Detailed test pumping at two representative sites also provided quantitative assessments of vertical hydraulic conductivity across the two formations. These assessments collectively suggest that there has been limited cross formational flow and mixing of groundwater between the CA and WCM, despite the presence of large vertical hydraulic gradients in a number of areas of high groundwater extraction. Outcomes from the work will be incorporated into a revised version of the Surat CMA regional groundwater flow model to update impact predictions in 2012 UWIR.

Influence of Mechanical Loading and Unloading in Interpreting Vertical Connectivity Between Two Aquifers – An Example from Condamine Alluvium and Walloon Coal Measures Connectivity Study

Josh Moncrieff[1], St.John Herbert[2], Stephen Denner[2], Keith Phillipson[3], Sanjeev Pandey[1]
1. Klohn Crippen Berger
2. Arrow Energy
3. Queensland Office of Groundwater Impact Assessment

The groundwater resources of the Condamine River Alluvial Aquifer (CA) in Queensland have been extensively developed over the past 60 years, primarily for irrigation water supply. Current and proposed coal seam gas development in the Surat Basin extends beneath the western edge of the CA footprint and involves depressurisation of the Walloon Coal Measures (WCM), which form the basement for the alluvium. This could potentially impact CA groundwater resources, depending on the hydraulic connectivity between the alluvium and the underlying WCM. An initial impact assessment was undertaken in 2012 by the Queensland Office of Groundwater Impact Assessment (OGIA) in the Surat Underground Water Impact Report (UWIR). OGIA has since then been leading an extensive study, supported by Arrow Energy through drilling and test pumping. This study comprises multiple lines of investigation to improve understanding of connectivity in terms of geological, hydrogeological and hydrochemical characteristics of the interface between the CA and the WCM. As part of this study, two detailed pumping tests were carried out in the CA footprint to assess the hydraulic connection between the CA and WCM, involving pumping from the CA while monitoring the response at monitoring bores in both formations. During one of the pumping tests, groundwater levels in the confined WCM were observed to vary by up to a metre, but there appeared to be little or no correlation between these fluctuations and the more substantial groundwater level changes observed in the overlying CA. A detailed assessment of these data indicates that mechanical loading and unloading effects related to changes in surface water storage and groundwater storage in the overlying CA is likely to have caused much of the observed fluctuations in the WCM. Mechanical loading effects are not routinely considered in most groundwater investigations, but these results indicate that for a confined aquifer like the WCM, exclusion of these effects could lead to an overestimation of vertical hydraulic conductivity.

Permeability Variations Associated with Geological Structures in the Walloon Coal Measures, Surat Basin, Queensland

Gerhard Schoning, Daan Herckenrath, Keith Phillipson
Office of Groundwater Impact Assessment

The Office of Groundwater Impact Assessment (OGIA) is currently developing a revised regional groundwater flow model to assess the cumulative impacts of Coal Seam Gas (CSG) activities in southern Queensland. Significant efforts have been put into the parameterization of this revised model and coal permeability plays a major role within this parameterization workflow. Coal permeability is generally assumed to be strongly depth-dependent. However, this depth dependency can also vary significantly spatially due to weathering, depositional environment and the presence of structures. Based on drill-stem test (DST) observations, spatial trends have been observed in permeability-depth relationships in the Surat Cumulative Management Area (CMA).

Approximately 2,750 DST measurements from the Walloon Coals have been used to determine a permeability-depth relationship based on the best-fit to all the available DST data. As expected, a single permeability-depth relationship does not yield a desirable fit to all the data, which means that in some cases the depth relationship underestimates coal permeability by up to two orders of magnitude and overestimates permeability by up to four orders of magnitude. The variance from the best fit was calculated as permeability residuals, and these were plotted spatially to identify zones of intrinsic permeability differences. This method identified both high and low permeability zones where a generalized permeability-depth relationship was not sufficient to explain the observed spatial variability. Some of these spatial trends correlate well with the presence of faults and other structures in the Surat Basin and their orientation with respect to present day principal horizontal stress directions. Faults and associated fractures which are oriented normal to the maximum horizontal stress direction appear to be correlated well with areas of relatively low coal permeability. Conversely faults orientations which are aligned with the maximum horizontal stress directions correlate well with areas of relatively high coal permeability.

Stochastic Lithofacie Permeability Modelling Using Borehole Geophysics, DST, Core and Pumping Test Data

Daan Herckenrath, Gerhard Schöning, Luca Traverso, Keith Phillipson, John Doherty
Office of Groundwater Impact Assessment, Queensland Government

The Office of Groundwater Impact Assessment in Queensland is currently developing a revised regional groundwater model to assess the cumulative impacts of Coal Seam Gas (CSG) activities in southern Queensland on regional aquifer systems. As part of a parameterisation workflow for this model, many detailed groundwater flow models (referred to as “numerical permeameters”) have been built to estimate the stochastic properties of formation-scale permeabilities for various stratigraphic units in the Surat Basin. These stochastic properties are subsequently used for parameterisation of the regional model. As input for these numerical permeameters, stochastic realisations of lithology are populated with stochastic realisations of depth- dependent permeability relationships that are constrained by various types and scales of borehole data. A statistical framework is presented that estimates the stochastic properties of these depth-dependent permeability relationships pertaining to various lithology classes found within each stratigraphic unit. These include the estimation of coal permeability relationships for different structural regions within the Surat Basin. Input parameters of these stochastic models include the statistical moments of parameters describing the depth-dependent permeability relationships. Petrophysical logs, drill-stem test (DST) data and literature values are used to estimate the prior distribution of the input parameters pertaining to each identified lithology class (including coal) for each stratigraphic unit. Combining the stochastic permeability models with lithology information available from down-hole geophysical logs for around 3,500 bores, stochastic permeability samples can be generated at locations and scales that correspond to the available measurements, with account taken of uncertainties of the exact depth at which these measurements were gathered. The parameters of each facie-specific stochastic permeability model are then estimated to yield a match between the statistical moments of the simulated permeability samples and those pertaining to the three types of available borehole data. The estimated permeability models are then used as input for numeric permeameter calculations.

Quantifying the impact of leaky wells using AEM in the Condamine Catchment

Mark Hocking, Dr Craig Beverly, Associate Professor Bryce Kelly
Hocking et al.

The Condamine Catchment is within the Surat Basin, and has seen much exploration for gas resources, particularly since 2000. Abandoned exploration wells leak gas and may discharge poor quality water from the Walloon Coal Measures (WCM) into the overlying fresh groundwater within the Condamine River Alluvial (CRA). Thus there are concerns about the impact of improperly decommissioned exploration wells. To quantify the potential impact of a leaky abandoned well on groundwater resources, consideration of both point and broad scale processes is required. Traditional attempts to simulate groundwater processes generally utilise Finite Difference (FD) or Finite Element (FE) modelling. The development of the Analytical Element Method (AEM) provides an alternative modelling paradigm. The general difference between FD/FE and AEM models, are:

1. FD/FE models require explicit discretisation of the domain, whereas AEM models do not;
2. In AEM models an aquifer has infinite extent, while FD/FE models require defined boundaries;
3. In FD/FE models a point (well) or line (stream) feature influence is averaged over the node/cell, whereas in AEM models they are not averaged;
4. FD/FE models are more suitable for modelling heterogeneous settings than AEM models;
5. AEM models are more suitable for modelling the near well zone than FE/FD models.

A steady state AEM model was calibrated against known groundwater level and river-based flow using PEST. A hypothetical leaky well was incorporated into the model to provide a direct link between the WCM and CRA. Calibration constrained Latin Hyper-cube sampling was undertaken to assess predictive uncertainty. Results found a fully open 96 millimetre diameter hole (HQ core) allowed on average 120 m3/day of flux to the CRA from the WCM. A log relationship between hole diameter and transfer flux is apparent, where a 50 and 250 millimetre diameter hole equates to 112 and 131 m3/day of flux, respectively.

Australian Government funded research in groundwater hydrology in the context of CSG extraction.

Scott Lawson
Office of Water Science

The Office of Water Science (OWS) is leading the Australian Government's efforts to improve understanding and management of the water-related impacts of coal seam gas and large coal mining development. This occurs in a number of ways, including:

- support to the IESC which advises Australian government regulators on the water-related impacts of coal seam gas and large coal mining development proposals
- managing a research programme to identify and address critical gaps in scientific understanding of the water-related impacts of coal seam gas and large coal mining developments.

The OWS has identified a range of matters associated with assessment of impacts to water resources and associated ecosystems that have high levels of uncertainty, and/or are commonly not adequately evaluated or explained. The OWS has subsequently implemented research on these to ensure that the best available science is available to inform regulatory decision-making on coal seam gas and large coal mining developments.

From a groundwater hydrology perspective, there are significant uncertainties associated with aquifer connectivity, particularly regarding aquitard properties, and the influence of faults and bores as leakage pathways.

Research is currently being undertaken on:

- understanding of vertical hydraulic conductivity in aquitards to examine the risk of depressurisation at a range of scales;
- methods and processes for assessing fault properties and their influence on propagating depressurisation to linked aquifers and surface environments;
- conceptualisation, representation and parameterisation of aquitards and faults in regional groundwater models, including upscaling of properties, to improve quantification of predictive uncertainty in regional groundwater flow and pressure simulation, and
- bore and well induced inter-aquifer groundwater connectivity to determine the consequence of inter-aquifer connectivity caused by the degradation or substandard construction of bore holes and wells.

Isotopes: the keys to understanding connectivity above coal seam gas operations

Richard Cresswell[1], Glenn Toogood[2], Kumar Narayan[3]
1. Jacobs
2. Santos Energy NSW
3. A.N Consulting, Brisbane

Santos Energy NSW have installed a network of monitoring bores across the Narrabri region targeting multiple formations and designed for both pressure and chemistry sampling to aid in understanding hydrogeological processes and provide baseline data for future potential coal seam gas (CSG) development beneath Petroleum Exploration Licence (PEL) 238. These augment the existing network of State and private bores and allow collection of a full suite of analysed parameters, including major and minor ions, hydrocarbons, metals and isotopes. The characterisation, patterns and trends seen in the chemical and isotopic data demonstrate an isolated coal measures sequence and identify critical parameters that may be used as indicators of any unwanted inter-formational connectivity. CSG extraction will target coal seams of the Gunnedah Basin, which locally underlie the sediments of the Coonamble Embayment, a splay off the Surat Basin of the Great Artesian Basin (GAB). Within the GAB sequence, the Pilliga Sandstone is used for groundwater supply and displays chemistry and isotopic characteristics similar to other aquifer formations elsewhere in the GAB (such as the Cadna-Owie – Hooray aquifers of the Surat and Eromanga Basins). The underlying Gunnedah Basin sediments exhibit a similar chemical evolution, accentuated due to higher salinity, carbon availability and very low sulphate levels. Critically, hydraulic separation is maintained by a thick (up to 400m) aquitard/aquiclude sequence, acting as an effective aquiclude in this region. Radio-isotopes provide distinctive signatures, but stable isotopes of water and carbon provide the greatest distinction between groundwaters and appear to be strongly influenced by the biogeochemical process operating along different flow-paths and provide a means to distinguish the deeper groundwaters from those in the GAB.
We conclude, from chemistry and isotope data that there is no groundwater interaction between the deep (Gunnedah Basin) and shallow (GAB) groundwaters beneath PEL238.

A heuristic for assessing the effects of leaky bores and faults on the propagation of CSG-related depressurization

Chris Turnadge[1], Luk Peeters[1], Dirk Mallants[1], Rebecca Doble[1], James McCallum[2], Alistair Usher[3],
1. CSIRO Land and Water
2. Flinders University
3. Office of Water Science

Depressurisation of coal seams for coal seam gas (CSG) production can propagate through aquitards and result in drawdown in overlying aquifers. Because geological faults and leaky bores can generate preferential flow pathways, they can compromise the regional-scale sealing capacity of aquitards. However, the representation of leaky bores and faults in regional scale numerical groundwater flow models is challenging. The goal of this research is to derive a heuristic, i.e. a rule of thumb, which can be used as a first pass screening of the consequences and relevance of both faults and leaky bores in regional groundwater flow systems. By combining the representative elementary volume concept and by defining equivalent hydraulic conductivity using a linear sum, a simple closed-form equation can be derived that expresses the regional-scale equivalent vertical hydraulic conductivity (Kv) of an aquitard as a function of three key factors. These are (1) the aquitard Kv, (2) the spatial density of leaky bores or conducting geological faults, and (3) the Kv of these preferential pathways (i.e. bores or faults). Analysis of the derived equation indicates that the equivalent Kv starts to deviate noticeably from its background value without preferential flow paths as soon as the proportion of the aquitard area with an enhanced Kv approaches the ratio of aquitard equivalent Kv to bore/fault Kv. While the derivation of this heuristic is straightforward, its validity is examined through comparison with a complex regional scale groundwater model that incorporates a stochastically-generated fault network and leaky bores. The derived heuristic provides a sound basis for a first order assessment of the effects of leaky bores and geologic faults on regional scale groundwater flow and may be used as a screening tool.

Multi-tracer approach to investigate groundwater recharge and aquifer connectivity in the Clarence-Moreton and eastern Surat basins in southeast Queensland

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1. CSIRO Land and Water Flagship
2. Geoscience Australia, Symonston, ACT)
3. Australian Nuclear Science and Technology Organisation, Lucas Heights, NSW
4. Connected Waters Initiative, School of Biological, Earth and Environmental Sciences, UNSW

The Walloon Coal Measures (WCM) in the Clarence-Moreton and the Surat basins in QLD and northern NSW contain up to approximately 600 m of mudstone, siltstone, sandstone and coal. Wide-spread exploration for coal seam gas (CSG) within both basins has led to concerns that the depressurisation associated with the resource development may impact on water resources in adjacent aquifers. In order to predict potential impacts, a detailed understanding of sedimentary basins hydrodynamics that integrates geology, hydrochemistry and environmental tracers is important. In this study, we show how different hydrochemical parameters and isotopic tracers (i.e. major ion chemistry, dissolved gas concentrations, δ2H and δ13C of CH4, δ13C-DIC, δ18O, δ2H, 87Sr/86Sr, 3H, 14C and 36Cl) can help to improve the knowledge on groundwater recharge and flow patterns within the coal-bearing strata and their connectivity with over- or underlying formations.
Dissolved methane concentrations in groundwaters of the WCM in the Clarence-Moreton Basin range from below the reporting limit (10 µg/L) to approximately 50 mg/L, and samples collected from nested bore sites show that there is also a high degree of vertical variability within the aquifer. Other parameters such as 3H, δ13C & 14C in DIC collected along assumed flow paths are also highly variable, which indicates local groundwater flow cells rather than regional flow. In contrast, 87Sr/86Sr isotope ratios of WCM groundwaters are very uniform and distinct from groundwaters contained in other sedimentary bedrock units. This suggests that 87Sr/86Sr ratios may be a suitable tracer to study hydraulic connectivity of the Walloon Coal Measures with over- or underlying aquifers, although more studies on the systematic are required. Overall, the complexity of recharge processes, aquifer connectivity and within-formation variability confirms that a multi-tracer approach is required to understand aquifer connectivity in these sedimentary basins.

Afternoon Shine Dome Sessions – Groundwater Management/Science-Policy

Border Rivers Groundwater Model – an inter-state initiative for Groundwater Management without Borders

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1. NSW Office of Water
2. DNRM Queensland
3. DSITI Queensland

The Border Rivers alluvial aquifers upstream of Keetah Bridge are shared by both New South Wales and Queensland, thus requiring a common resource management strategy. To achieve this, both states have initiated a collaborative project developing a numerical groundwater model for the Border Rivers alluvium aquifer. The model will provide predictive information to resource managers of both states to jointly inform the management framework for the cross border alluvial system. This model uses the latest and most sophisticated groundwater modelling platform from the USGS, MODFLOW-USG, whose unstructured grid capability is most suited to the long and narrow nature of the alluvium. Hydrogeologists and groundwater modellers from both states have jointly developed a conceptual model, characterising the Border Rivers alluvium as a narrow, incised alluvial system that comprises a highly connected upper aquifer, an intermediate clay layer forming an aquiclude/aquitard, and a lower aquifer that ranges from semi-confined in the upstream areas to confined in the downstream end. The alluvium is underlain by the Great Artesian Basin (GAB) and Texas Beds. The surface isopachs of each model layer were hand contoured to achieve the best control for layer determinations. Over 20 years usage data for both the groundwater and surface-water is available. An open-source visualisation package (Paraview) has been employed to envision the conceptualised model in 3D, and will be presented as the key interactive and animated highlight of this model development. The outcomes of this model will provide a platform for both states to align their Water Resource Planning processes to jointly manage the cross border groundwater system in its entirety. This inter-state collaborative approach is a benchmark of co-operation between different agencies working together towards a common natural resource management goal and has national and international significance.

Reports from the front line: Compliance and enforcement of non-urban water extractions in NSW

Darren Sinclair
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Compliance and enforcement (C&E) represents the pointy end of national water policy. Without effective C&E, many other policy approaches may be rendered impotent. And yet there has been very little comprehensive investigation of C&E among water users. This project reports on how water users have responded to regulation, including their (i) motivations for complying with legal obligations; (ii) views and experiences with the NSW Office of Water's C&E policies and practices; (iii) sources of information and its perceived usefulness; and (iv) knowledge of water regulations and resources. Draws on a quantitative survey of approximately 4,000 NSW water licence holders, and supplementary face-to-face interviews (50 landholders/stakeholders). Three catchments/regions were studied, namely: (i) Central West (CW); (ii) Murray and Murrumbidgee (MM); and (iii) Richmond, North Coast (NC). These regions were deliberately chosen to represent a diversity of: (i) water sources (rivers and groundwater); (ii) locations (inland and coastal); and (iii) authorisations (e.g. licences, approvals and stock and domestic). (i) Motivations – most support the need for regulation. Fairness, social reputation, peer reputation and morals rank highly as motivators, unlike penalties. Economic advantage is seen as the main reason for illegal extraction. (ii) Experiences – few have experience with compliance officers, but of those that have, most have a negative view. Most support tougher enforcement. (iii) Communication/education – most claim they do not get enough information, and want more, and prefer traditional media and trust neighbours/family/peers. (iv) Knowledge/resources – most have little knowledge of broad policy and regulation, but good knowledge of what impacts them. There is room to tailor communication and education strategies around C&E, including leveraging peers and third parties; enhance the inspectoral presence; emphasise procedural fairness; increase awareness of enforcement actions/penalties; and provide guidance on how best to comply and the benefits of compliance.

Simulating flood behaviour in the Lower Murrumbidgee River, Australia using an integrated surface water-groundwater model

Michael Butts, Birgitte von Christiersen, **Craig Mackay**, Diego Molina Machés, Terry van Kalken, Douglas Graham
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The aim of this paper is to investigate the importance of both surface and subsurface processes on flood plain inundation in both wetlands and riparian floodplains. Flooding can result in significant social, economic and environmental damages, however regular flooding is important to the health and functioning of river wetland ecosystems. Integrated catchment management must therefore address the risks posed by floods while protecting freshwater ecosystems. The dynamics and extent of flooding are controlled by a number of factors such as the magnitude of the event, vegetation and land use distribution, the floodplain topography, channel and river bank geometry. However, processes like the exchange between surface and groundwater and losses via infiltration and evapotranspiration may also be important particularly for riparian wetlands. In this paper, we present an integrated modelling tool capable of simulating flooding in both urban areas and riparian wetlands. The model captures the hydraulic processes in the river, the dynamic surface water-ground water interactions, and the infiltration and evaporation effects on flooding. One of the most important challenges in simulating flood behaviour for catchment management is the need to verify the reliability of these models. Traditional observation data are limited to flows or water levels within the river channels and few observations are found in the floodplain areas of interest. Satellite imagery and aerial photography of flood extent are used here to assess the simulated flooding behaviour in the Lower Murrumbidgee River, between Carrathool and Maude Weir. Our investigations show that while evapotranspiration and infiltration are important in the wetland, spilling in the upstream area affects both the local flooding and the wetland dynamics downstream which in turn is strongly controlled by local channel and river bank geometry.

Groundwater interference assessment: a tool to improve confidence and certainty in groundwater investment decisions

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Investment in using groundwater for large scale development is fraught with risk and uncertainty for the developer, as it can be difficult to achieve the desired yield and quality and be confident in satisfying licensing requirements. A Groundwater Interference Assessment Tool is being developed to provide developers with greater confidence to invest, and to improve efficiency and consistency in the licensing process. The tool will support investigations to access groundwater, identification of resource management considerations; and assessment of the potential impacts of extraction on existing groundwater users and the environment. The first stage of building the tool has focussed on the hydrogeological logic and risk assessment components. This included: characterising the hydrogeological setting, identifying surrounding water assets, determining an analytical assessment approach and developing a risk assessment framework. The hydrogeological setting draws upon existing state-wide databases such as the Victorian Aquifer Framework to develop a simple conceptualisation of the groundwater system to enable extraction impacts to be considered. Existing state-wide datasets are also employed to identify water assets including bores, groundwater- dependent ecosystems and streams. Analytical solutions, which are readily parameterised from available data sets, are then applied to the appropriate hydrogeological conceptualisation to determine groundwater extraction impacts. The risk assessment considers the consequences of threat based on management acceptability criteria and water asset susceptibility to impact; and also the likelihood of exceeding the acceptability criteria based on a probabilistic analysis. A Microsoft Excel spreadsheet prepared to trial the hydrogeological logic and risk assessment concluded that the responses were intuitively correct and, when applied to previous licence assessments, resulted in the right outcomes. The application of the tool will increase consistency and transparency in the assessment of groundwater licence applications and improve certainty for decision-makers. Further development of state-wide datasets, moving to a spatial platform on the internet, and automatic population of data inputs will further improve the licence assessment process and provide developers with greater confidence to invest in groundwater.

A Groundwater Hub for Southern Victoria

Terry Flynn
Southern Rural Water

Our brief was to design and develop an effective website that converted the content from Southern Rural Water's hard copy groundwater atlases into impressive website information. Our business needs were to:

- Support and demonstrate sustainable water resource management
- Maximise the economic productivity of groundwater
- Enhance customer control and convenience

Three website journeys were identified:

- Customer Journey (farmer user segment) – User needs simple information and online engagement tools that enable access to groundwater, understanding the status of groundwater resources or obtaining advice about access to water.
- Consultant Journey (Industry, Government Agency segments) – User needs access to both information and data on the groundwater resources and referral to other internal or external resources.
- Shopper Journey (Media, Government Agency, Student and Activist segments) – User needs access to information on the groundwater resources. This user has little or no direct interaction with our staff.
- In Southern Victoria, groundwater contributes about $275M to the economy every year
- Its nature, management and value is poorly understood
- Compared with other states Victoria has strong regulation around groundwater access and use
- Aquifers can store vast quantities of groundwater for millions of years.
- Only a fraction of the groundwater in storage is allocated for use
- Groundwater users only take about 30% of licence entitlement

The outcomes from our project have been:

- providing a greater reach for the atlas content, particularly for groundwater customers;
- linking the groundwater atlas to existing functions and information on the existing SRW website;
- providing customers and stakeholders with effective self-help services;
- reducing the cost of maintaining up-to-date information; and,
- increasing the user experience with interactive applications and access to 3rd party resources

The website will become operational in June 2015.

A POTABLE GROUNDWATER SOURCE FOR PORT HEDLAND, WESTERN AUSTRALIA

Mal McGivern
Water Corporation

The Water Corporation of Western Australia completed a hydrogeological investigation to assess the potential to bring into operation the Bulgarene borefield (BB), within the greater Degrey groundwater catchment area, which is located 60km east of the town of Port Hedland. The (BB) is potentially the last significant sustainable water source in reasonable proximity to both the town of Port Hedland, and existing water supply infrastructure. The investigation examined the potential for the (BB) to provide an additional 2GL of water per year from the four existing, currently unequipped production bores to supply the town of Port Hedland. The (BB) is situated between the Degrey and Ridley Rivers, which have substantial ecological and indigenous heritage values within the region. Further complexities also exist as the (BB) is also located within a working pastoral lease, adjacent to an operating iron ore mine and within close proximity to the coast. An extended aquifer test has never been completed on this borefield previously. This investigation drilled and logged 4 monitoring bores in the shallow aquifer as well as the deeper target aquifer. These new bores, as well as existing bores and water holes were monitored, while the aquifer was under significant stress (80 l/sec) during two separate pumping tests. The collected data then helped redefine the conceptual model, including the extent of drawdown within the borefield. Bore logs as well as water level data were collected and analysed and then incorporated into a numerical model with the results compared to previous work undertaken on the borefield. Results from the project indicated 2GL with the possibility for an additional 2GL could potentially be abstracted without adversely affecting culturally sensitive permanent water holes or other users within the area.

A multi-disciplinary approach to characterising groundwater flow systems in the Cleve Hills: Eyre Peninsula, South Australia

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The geologically diverse Cleve Hills in the eastern Eyre Peninsula of South Australia is rich in natural resources including agriculture land, native vegetation and mineral deposits. However, non-prescribed groundwater resources are poorly understood, but a critical factor to an economy dependant on agricultural and mining. Furthermore, as a large area (~3000 km2) without recent development, groundwater infrastructure is dilapidated and hydrogeological and piezometric head data is sparse. The South Australian Government acknowledged a need to develop an understanding of these water resources, while assisting future industrial development and maintaining sustainable water supplies for communities and the environment. In response, the Goyder Institute established the Goyder Facilitating Long-term Outback Water Solutions (GFLOWS-2) project to conduct a regional groundwater investigation. GFLOWS-2 investigated the scale of groundwater flow systems, their vertical connectivity and the sources of salinity. Given the paucity of existing data, a multi-disciplinary approach was employed. This included: collating data from government and industry, collecting new piezometric head and environmental tracer data and the re- interpretation of airborne geophysical datasets. Interpretation of surface geology, subsurface lithology and geophysics indicate that the Cleve Hills and adjacent valleys have diverse hydrogeological settings including, unconfined fractured rock and sedimentary aquifers respectively. Variations in piezometric head influenced by undulating topography and shallow depths to impermeable bedrock along hydrogeological transects indicate predominantly localised flow systems. Similarly, environmental tracer concentrations in groundwater suggest timescales for these flow systems is a few hundred years at most. Strontium and stable isotopic compositions suggest groundwater salinity is caused by the concentration of vadose zone soil water by evapotranspiration. These findings are important for assessing the potential of groundwater resources, as well as the likely socioeconomic and environmental impacts under future development scenarios. Furthermore, the project provides specific recommendations for future groundwater monitoring and the basis for investigation of valley system aquifers.

Adaptive Management of the Groundwater Resources on Eyre Peninsula

Simone Stewart, Steve Barnett
Department of Environment, Water and Natural Resources

Surface water resources in South Australia are scarce, therefore groundwater resources are heavily relied upon to supply water for all purposes. The Eyre Peninsula region of South Australia is characterised by thin karstic limestone aquifers which are the principal source of water for town water supply, irrigation, stock and domestic purposes. Groundwater sourced from within the Southern Basins and Musgrave Prescribed Wells Areas contributes around 85% of Eyre Peninsula's total reticulated water demand (not including Whyalla). Due to the heavy reliance on groundwater, a Water Allocation Plan (WAP) provides the framework for sustainable management of the prescribed groundwater resources by considering the competing environmental, social and economic demands for groundwater. Recharge and groundwater storage is known to vary strongly in response to changes in climatic conditions and therefore an effective adaptive management process is essential for sustainable management. The first WAP implemented in 2001 introduced annual allocations based on a ten year moving average of calculated recharge. This methodology worked well until the 2006 drought highlighted that this approach did not take into account declines in storage volumes caused by natural discharge. The current revision of the WAP has allowed the introduction of a new adaptive management approach. Arc Hydro Groundwater was used to create a 3-D hydrostratigraphic model to define the aquifer geometry and the saturated extent of the aquifer in order to calculate the volume of groundwater in storage. The model can then be updated with the most-recent monitoring data to calculate changes in storage volumes which can then be used to determine annual allocations. The magnitude of the changes to the allocation depends on the assessed level of storage relative to resource condition triggers. This approach will ensure that the levels of allocation will reflect the condition of the groundwater resource to a much greater extent.

Groundwater resource capacity investigations for the Barossa region, South Australia

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Department for Environment Water and Natural Resources

Traditional water balance approaches have been the primary mechanism for assessing the sustainability of groundwater resource management practices in Australia. However the uncertainty of each component of the water balance is not commonly scrutinised in detail nor is it quantified, leaving a relatively low confidence in the adequacy of this approach. This additional step of quantifying uncertainty is a central feature of technical work being undertaken to support the revision of a water allocation plan for a significant viticultural region in South Australia. This approach has been adopted in order to strengthen the conceptual hydrogeological model of the multi-aquifer system and investigate the potential relationships and balance between groundwater extraction and groundwater – surface water exchange, water dependent ecosystems, natural & artificial recharge processes and groundwater flow paths using simple field and desktop based methods. The range of water balance components are then incorporated into the development of a numerical groundwater model, thereby imposing constraints on the problem of model non-uniqueness. Additional constraints on model non- uniqueness are applied based on the analysis of environmental tracer data which has clarified the balance between multiple recharge sources of the primary aquifers in the system. Further use of the model as a tool for predictive scenarios, development of conjunctive use management frameworks, informing on the timing of impact and changes to regional flow paths are highly relevant under the threat of salinity encroachment and the likely reduced recharge and water availability as a result of climate change. This more robust approach is necessary to identify potential groundwater condition limits of salinity, impact on water dependent ecosystems and water availability which will guide the development of a flexible water policy framework that provides the optimal benefit to all users of the resource.

Using groundwater modelling for water resource management: Berry Springs, Northern Territory

Mardi Miles
NT Department of Land Resource Management

The growth of Darwin has resulted in increased development of the surrounding rural areas. This has led to an increase in groundwater demand for stock and domestic purposes as well as horticulture. Berry Springs is a rural community located 47 km South of Darwin, and relies on groundwater for water supplies. The area is underlain by a dolostone aquifer, in which high yielding bores may be constructed. The area hosts intensive agriculture, with a large number of rural living blocks. To cater for the increase in demand for rural living, the area will likely undergo further subdivision. Unsustainable extraction from the Berry Springs dolostone aquifer will lead to reduced dry season flows and ecological degradation and even salt water ingress where tidally influenced rivers overlie the aquifer if the resource is not effectively managed. A groundwater model was developed by the NT Department of Land Resource Management and calibrated against long term climate data, surface water gaugings and groundwater level monitoring data. The change in groundwater discharge at the spring sites under the current water use scenario was compared to modelled natural discharge to determine the level of impact on the resource. Scenarios of future water use under a water plan to include the increased water use attributed to subdivision for rural living, was then applied to the model to predict potential impact on spring discharge and flow. The model is being used as an adaptive management tool which informs water allocation planning, and also enables the Department to make management decisions regarding water licence applications and provide advice regarding the sustainability of future development. The prediction of discharge following a given wet season allows for annual allocations to be made to ensure dry season flows are maintained and iconic groundwater dependent ecosystems are protected.

How key findings and uncertainty delivered under the Bioregional Assessment (BA) programme may inform consideration of coal resource development in the Gloucester sub region

James Hill
Office of Water Science, Department of the Environment

The BA's will provide a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of potential direct, indirect and cumulative impacts of coal seam gas and coal mining development on water resources including any impacts associated with salt production/salinity. The aim of the BA programme is to strengthen the science underpinning regulatory decisions on potential water related impacts from coal seam gas and large coal mining developments, whilst establishing a robust and transparent evidence base for causal pathways that connect depressurisation and dewatering of coal seams with impacts on water dependent asset across 6 priority bioregions within eastern Australian coal Basins. In addition to delivering an improved scientific understanding the BA's will also highlight uncertainties associated with the data and its subsequent analysis. According to scientific norms it is always possible to develop more precise and better explanations, no matter how thoroughly studied, is fully explained or understood. This paper will focus upon some of the inherent uncertainties associated with the surface water and groundwater modelling approaches in the Gloucester BA subregion and then elaborate on how interim learning's resulting from the uncertainty analysis may used inform the groundwater research, management and policy communities. For example a range of potential data and knowledge gaps were identified whilst developing groundwater and surface water models to quantify potential impacts on water-related assets in the Gloucester subregion. Knowledge of such gaps could be used by proponents as areas of focus within Environmental Impact Statements, and used by regulators to target monitoring conditions and future research required by proponents. The identified gaps could also guide any future state or Commonwealth Government research and data acquisition efforts.

The strengths and benefits of using Modflow-USG for the development of the Central Condamine groundwater flow model

Leon Leach
Department of Science, Information Technology and Innovation

This presentation describes benefits of using the MODFLOW unstructured grid (MFUSG) model in the calibration and scenario testing of the calibration of Central Condamine groundwater flow mode. It also discusses how improvements were mad to the accuracy of the model by the incorporation of all available data from 1960 to 2103 in the calibration. New pre and post processing software were developed. One strength has been the optimising of the model over the full range of stresses (pumping and recharge) with the associated range of groundwater level fluctuation. A further strength of using MFUSG is the reduction in the number of active cell, resulting in less run times whilst improving upon model scenario accuracy. Pre-processing software was developed that facilitated a two fold quadtree refinement on an initial 1500 mm by 1500 m orthogonal grid, without the need for an existing Modflow grid. This refinement in grid size was to account for spatial variability in observation data, stream drainage and recharge, and drawdown surrounding bores. Groundwater level data at varying time periods and frequency of measurements were available for over 250 monitoring bores, from 1955 to 2014. This data set was enhanced by the construction of potentiometric surface maps for each decade. River bed recharge was derived from the surface water Integrated Quantity and Quality model (IQQM) for the Condamine river system. The estimated volume in groundwater storage is 43,000GL. Groundwater take for irrigation purposes commenced in the late 1950s, and by 2013, the estimated cumulative take of groundwater was 1,660 GL of which 1,377GL has been metered. Metered use was adjusted to the day scale. The model was calibrated at the day scale thus eliminating the need for spatial or temporal adjustments. BeoPest64 with regularisation and SVD assist were employed during calibration. The only calibration parameters were hydraulic conductivity and specific yield, at 456 locations, which were optimised to 353,334 observations belong to 499 observation groups. The diagnostic statistics vary spatially with the net model SRMS and SMSR being 2.34 and 2.27 respectively. The new model allows for more acurate and reliable scenario modeling under the water resource planning processes.

Water stable hydrogen and oxygen isotopes in a hydrogeologist toolbox – Hydrocalculator software

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The University of Western Australia

Groundwater recharge in northern Australia is mainly driven by cyclones that are characterised by distinct stable hydrogen and oxygen isotope signatures. These signatures can be used as natural tracers to estimate water budgets but require careful estimation of evaporative losses prior to infiltration. However, determination of evaporation losses and overall estimation of water budgets, particularly in highly dynamic systems, can be challenging due to uncertainties in monitoring of water flow and volume measurements of water bodies. In this study, we developed and tested a new user-friendly software (Isotope Hydrocalculator) based on the revised Craig-Gordon model (C-G), which allows quick and robust estimation of evaporative losses based on simple measurements of water isotope composition [1,2]. We assessed the accuracy of the C-G model and tested the software against results from field pan evaporation experiments in the Hamersley Basin of Western Australia after Cyclones Heidi and Lua (2012). The mean evaporative losses calculated based on changes in the water stable isotope composition were in good agreement with estimates based on water level observations ($R2 = 0.998$ $p<0.001$). Differences were on average 0.2% and always <2.2%. The main constraint and source of the largest uncertainty is the estimation of ambient moisture isotope composition. Using a mean annual air temperature and relative humidity (24°C, 31%), mean evaporate loss prior to recharge in the Hamersley Basin ranged from 13% to 20%. This relatively small loss compared to the potential pan evaporation (~3000 mm/yr) can only occur due to rapid recharge [3].

The use of environmental tracers to determine focused recharge from a saline disposal basin and irrigation channels in the Murray Darling Basin

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La Trobe University

Lake Tutchewop in northern Victoria is a former ephemeral wetland that has been used as a saline disposal basin since 1968, forming part of the management of the Murray River. The use of saline disposal basins can potentially lead to focused recharge of saline groundwater that can impact the surrounding groundwater and nearby land use. It is important to monitor and investigate any impacts in order to determine the future sustainability of these basins. The extent of saline focused recharge from Lake Tutchewop and fresh recharge from nearby unlined irrigation channels was determined using pore water and groundwater stable isotope and major ion chemistry, which were able to separate the influence of lake water, irrigation water and regional groundwater. In the ~45 years since its inception as a saline disposal basin, saline water from Lake Tutchewop has infiltrated into the groundwater only up to 165 metres in most directions from the lake shore, and a maximum of 700 m laterally and 11.5 metres deep due to preferential groundwater flow along a palaeochannel, so it has had limited, if any, impact on surrounding agricultural land use. Fresh water leakage from unlined irrigation channels extends up to 10 m deep beneath major channels, validating the current program to replace these with pipelines. An area of shallow saline groundwater northwest of the lake, identified using Airborne Electromagnetic (AEM) imaging, is not a saline groundwater plume emanating from Lake Tutchewop; instead it reflects the distribution of clay-rich surface sediments, which slow down infiltration and therefore increase the salinity of the underlying groundwater through the impact of evapotranspiration.

Constraining spatial variability in groundwater recharge in an arid environment with carbon 14

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Carbon-14 (14C) is a widely used tracer for investigating groundwater recharge, and can also be used as a calibration target in numerical models (through particle tracking or solute transport approaches). However interpretation of 14C in groundwater is complicated by a number of factors, such as difficulty in determining the initial 14C activity at the time of recharge. Also in arid zones where fluxes are low, diffusive transport of 14C may become significant (and particle tracking approaches to interpreting 14C are not appropriate). In this study, measurements of 14C in unsaturated zone gas were made at five sites in the Ti Tree Basin in central Australia. Additionally, vertical profiles of 14C were obtained from nested piezometers at 12 sites across the basin. Modelling of unsaturated zone 14C transport was performed to understand the controls on unsaturated zone 14C activities. This understanding then fed into a 3D numerical groundwater flow and 14C transport model of the Ti Tree Basin. A relationship between unsaturated zone thickness and 14C activity near the watertable was observed, with generally more depleted 14C activities where unsaturated zones were thicker. This relationship was used to create a boundary condition for 14C input into the 3D model of the Ti Tree Basin. The model was calibrated to both hydraulic head and 14C measurements, and calibration was achieved with the aid of parameter estimation software, where recharge rates were optimised within geographically determined zones (based on existing knowledge of spatial variability in recharge in the basin). The result is a map of spatial variability in groundwater recharge in the Ti Tree Basin. This study demonstrates the importance of understanding solute boundary conditions in transport modelling. It also demonstrates how this may be achieved through data collection, and how such data and modelling may help resolve spatial variability in recharge.

Emulation of recharge and evapotranspiration processes in shallow groundwater environments

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In shallow groundwater environments, depth to water table (DTWT) can have an impact on both recharge and evapotranspiration (ET). Simple representations of recharge and ET in MODFLOW are often not flexible enough to capture the system behaviour. Appropriate representation can be achieved using complex, fully coupled vegetation-surface-vadose zone-groundwater models, but for regional groundwater models and where comprehensive uncertainty analysis is required, the long computational times and relative instability can make this unfeasible. The objective of this research was to test the feasibility of a third option: emulating recharge and ET functions using a more complex soil-vegetation-atmosphere transfer (SVAT) model, and substituting these functions into MODFLOW for more rapid groundwater model runs. The methodology was tested in the south east of South Australia and western Victoria to provide net recharge (recharge minus groundwater ET) estimations for a regional groundwater model. WAVES, a one-dimensional SVAT model, was used to produce net recharge – depth relationships for 635 combinations or landscapes of twelve climate zones, seven soil types and five vegetation types. The relationships were integrated into MODFLOW using a lookup table with depth interpolation, based on the calculated groundwater depth for each cell. The process used a landscape key to correlate the soil, vegetation and climate conditions at each cell with the appropriate net recharge function, and the MODFLOW segmented evapotranspiration (ETS) package was modified to automate this process within the groundwater model. Model outputs compared favourably with satellite estimations of regional net recharge at a regional scale, but further automated calibration is required to improve the spatial patterns of net recharge prediction. The methodology provided robust estimates of recharge and ET, and a means of incorporating remote sensing data into the groundwater model. It is a step toward better constraining groundwater models using recharge and ET fluxes.

Estimation of recharge at different spatial and time scales: Border Rivers

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Recharge is one of the important, but difficult parameter to quantify in groundwater resources management. For the Border Rivers groundwater model, a collaborative project between New South Wales (NSW) and Queensland (QLD), recharge was quantified at different spatial and time scales. At a regional scale, the Gravity Recovery and Climate Experiment (GRACE) satellites was applied to monitor changes in total water storage (TWS) in saturated and unsaturated zones. Monthly GRACE data in conjunction of groundwater levels from the monitoring bores were used to develop a linear relationship. Fifty monitoring bores were drilled along the Dumaresq River from October 1958 to June 1960. Thus, the groundwater monitoring network over a sixty-year period has provided a rare opportunity to better comprehend the groundwater dynamics (recharge discharge processes) of the Dumaresq groundwater system. The surface/aquifer system switches from gaining to losing reaches, depending on the local climatic variability. At a reach scale, localised, transient recharge was calculated using the classical Dupuit- Forchheimer equation, which ranged from ** to ** mm/year. At a point scale, deep drainage was estimated using the HYDRUS-1D model. For the simulation period (1890- 2015), daily precipitation values varied between 0 mm and 171 mm, while actual evapotranspiration, based on Morton's method, varied from 2.2 to 8.8 mm. In the same period, deep drainage for a sandy loam soil profile at depth of 10 m ranged from 0 to 0.03 cm/day (11 mm/year). In addition, the chloride mass-balance provided recharge estimates in the same order of magnitude. It should be noted that, in some reaches of the study area, quantification or assessment of recharge and discharge processes is complex due to the fact that upward fluxes from the Great Artesian Basin (GAB) aquifer systems and downward fluxes induced by stream leakage as a component of transmission losses can simultaneously take place in the shallow aquifer systems. For disentanglement of these complex hydrological processes environmental tracers should be used.

Shallow groundwater recharge and residence time in two separate flood plains along an aridity gradient in South Queensland, Australia

Dioni Cendón, Associate Professor Bryce F.J. KELLY, Dr Josh LARSEN, Stuart HANKIN, Dr Cath HUGHES, Dr Karina MEREDITH, Dr Suzanne HOLLINS, Charlotte IVERACH
ANSTO

Fertile floodplains in headwater Darling-Murray catchments like the Condamine have endured profound physiographic changes over the last ~150 years, including the onset of intensive agriculture and groundwater abstraction since the 1960s. This has placed groundwater within alluvial aquifers under stress, raising allocation concerns and triggering salinity problems in some areas. Approximately 1,000 km west, across a decreasing rainfall gradient (659 mm/yr at Dalby to 198 mm/yr at Ballera), the Cooper Ck floodplain (near Ballera) is still in pristine condition and provides an ideal example of arid zone hydrological processes. This study compares groundwater from two alluvial systems with an emphasis on understanding groundwater recharge processes under various climatic conditions. Groundwater was collected from the Condamine alluvium in 2014 from 30 irrigation and monitoring wells. Groundwater was collected from the Cooper Ck alluvium between 2008 and 2011, from piezometers installed along a transect between major waterholes. All bores were sampled for major, minor/trace elements, water stable isotopes (δ18O and δ2H), δ13C in dissolved inorganic carbon, 3H, 14C and sulfate isotopes (δ34S δ18O) in selected samples for both study areas. The groundwater dataset was complemented with available long term rainfall data. Both locations showed that groundwater had depleted isotopic signatures consistent with recharge associated with large floods. Also in both locations groundwater defined well-correlated evaporation lines (R2>0.95), consistent with mixing with other sources. Groundwater near main channels contained 3H and 14C consistent with modern recharge, however, in the Cooper Ck modern recharge appeared restricted to areas like channel confluences. This study has implications for understanding how to sustainably use groundwater resources and the role of floods in recharging floodplain aquifers. Comparing the two sites provides a snapshot of how the Condamine could respond to increased aridity.

Aquifer recovery during the transition from drought to a wet period: the mechanisms and pathways to recovery

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In semi-arid environments with climate cycles driven by the El Niño-Southern Oscillation (ENSO), groundwater provides a reliable resource for agricultural and portable use. During the drought in early 2000s, abstraction from alluvial aquifers had lowered groundwater levels and thereby affected river at low flow conditions. Recoveries were reported following the wetter climate between 2010 and 2012. This study quantifies the dominating recharge mechanisms, particularly the role of focused recharge during the recovery of depleted aquifers. As a part of a long-term monitoring program funded by the NCRIS Groundwater Infrastructure project, groundwater levels have been recorded at Maules Creek Catchment in the Namoi Valley since 2007. The recent natural climatic transitions from dry to wet have been captured with high spatial and temporal resolution. The climate and hydrology data were analysed to reveal the controlling recharge mechanisms. A general recovery of groundwater levels was observed across the Maules Creek Catchment. Groundwater rise of about 1.5 m was observed Near the Namoi River and 2 to 3.5 m were observed along the mountain front of the Nandewar Range. Along the intermittent section of Maules Creek below the main groundwater abstraction area, water table elevated about 5 m. It appears aquifers along disconnected stream reaches receive substantial recharge even during smaller runoff events. Results also suggested a complete recovery requires at least two consecutive wet years. By contrast, the impact of sporadic floods on groundwater levels near connected reaches (like the Namoi) has been demonstrated to be modest. The results reveal flood recharge is more efficient at ephemeral and intermittent reaches. The mountain front influx is substantial yet needs longer time to reach the alluvial aquifer. Understanding these processes, their distribution and their temporal reoccurrence are essential for using the groundwater resource sustainably as a drought buffer into the future.

Proportioning Groundwater Hydrograph Fluctuations to Rainfall Recharge and Quantifying Recharge Lag- Time Using Impulse Response Function Modelling

Mark Hocking, Associate Professor Bryce Kelly
University of New South Wales

There are numerous methods that can be employed to estimate groundwater recharge rates. The majority of these methods have high uncertainty associated with the estimate and rely on knowledge or estimates of other hydrogeological parameters, such as specific yield. This project presents an underutilised signal analysis method for proportioning rainfall recharge contributions to the fluctuations observable in groundwater hydrographs. The method also quantifies the lag time between rainfall and recharge at the water table. We analysed 255 unconfined bore hydrographs on Vertosol soils of the Condamine River Alluvial Aquifer using predefined impulse response functions in continuous time (PIRFICT) modelling (von Asmuth et al., 2012). From the PIRFICT analysis mean rain-derived groundwater recharge between 1990 and 2012 was estimated to be 4.4 mm/year. The mean response time between rainfall and recharge at the water table was 5.3 years, however the range of estimates is large: 188 days to 48 years. Over the same time period the average groundwater level declined 8.7 cm/year. Comparison of groundwater recharge rates generally agrees with published field estimates and numerical simulation estimates. This study demonstrates that PIRFICT modelling can be used to independently estimate groundwater recharge contributions to groundwater hydrograph fluctuations. Importantly, the method provides a robust statistical estimate of the lag between rainfall and recharge at the water table. To improve the management of groundwater resources the time lag between rainfall and aquifer recharge must be correctly incorporated into regional water balance models used to manage groundwater allocations and assess environmental impacts.

Solute and evaporation gradients formed by episodic river recharge over-time in a dryland aquifer.

K. Meredith, S.E. Hollins, C.E., Hughes, D.I. Cendón, A. Griffiths.
ANSTO

The generally accepted hypothesis that river recharge forms the primary groundwater source in arid zone environments remains difficult to prove due to the remoteness and expense of studying these hydrologically complex systems in detail. Therefore we designed a study that would significantly advance our understanding of how a groundwater system is being recharged in a dryland region of the Darling River catchment, Australia. A range of hydrochemical and isotope tracers (Cl-, δ18O, δ2H, and 3H) measured in all components of the hydrological cycle were used in this multi-year study to understand and quantify groundwater recharge under wet and dry climatic conditions. The evaporation and concentration gradients observed in the unsaturated zone confirmed that small volumetric inputs from periodic rainfall were not the major recharge mechanism. Sampling which incorporated a large river recharge pulse from an overbank flooding event in March 2012 provided conclusive evidence for groundwater originating from high flow episodic river recharge. The use of long-term environmental data such as isotope records to understand how economically important water resources may respond to climate change with increasing temperatures and changing drought/flood regimes will be essential for future sustainability.

Ecohydrological Units – a method to represent ecohydrology at a landscape scale

Daniel Huxtable[1], Jed Youngs[2], Seth Johnson[3]
1. Equinox Environmental
2. BHP Billiton
3. Hydroconcept

BHP Billiton Iron Ore operates five mining hubs across a 400km by 200km extent of the remote Pilbara region in Western Australia. Pit and infrastructure development, mine dewatering and other activities create a regional water footprint. The ecological implications of the water footprint of BHP Billiton and other operators is difficult to assess due to the large scale of the region, data limitations (particularly for ecological response to changed hydrology), and natural hydrological variability. The concept of Ecohydrological Units (EHUs) was developed to support the company's environmental stewardship commitments and for a broad ranging environmental approval (the Strategic Environmental Assessment, or SEA). EHUs provide a landscape-scale conceptualisation of the linkages between water and ecology. In doing so, they help identify areas where regional changes in hydrology may have an ecological outcome. EHUs are landscape elements with broadly consistent and distinctive ecohydrological attributes. They can be distinguished on the basis of dominant water balance processes operating within them. A set of ecohydrological factors were formulated for classifying EHUs in the study area, including: landscape position, land surface type, surface drainage processes, groundwater\surface water connectivity, major vegetation types and wetland habitat types. These factors were used to classify nine EHUs, ranging from upland source areas to transitional flow zones to lowland receiving areas. EHUs were spatially defined in the project area using standard data sets including the Pilbara land system mapping (Van Vreeswyk et al. 2004), a high-resolution digital elevation model, depth to groundwater, vegetation mapping and Landsat data. For the environmental change assessment, the sensitivity of each EHU to change in the surface water or groundwater regime was then classified. This was aligned against the degree of expected hydrological change and via a simple matrix the "ecohydrological change potential" was defined. EHUs were delineated across a broad stretch of the Central Pilbara region using the method and datasets described above. The approach was applied to a major mining proposal, the SEA. The Ecohydrological Units approach has proven effective for appreciating landscape-scale ecohydrological processes and sensitivities in the Pilbara. It has been usefully applied to a wide-ranging mining environmental assessment to provide meaningful ecological context for the predicted water footprint and to help identify areas for future management focus. It is considered that the method could have broader application in the Pilbara and could be adapted for use in other regions.

Application of hydrogeology for the conservation of Cypripedium candidum orchid, Manitoba, Canada.

David Toop
Manitoba Conservation and Water Stewardship

Manitoba is home to 37 species of terrestrial orchids. Cypripedium candidum, the small white lady's slipper orchid is listed as endangered at federal and provincial levels. Known sites appear unrelated and are scattered over a distance of several hundred kilometres. Most Manitoba native orchids show affinity for groundwater dependent ecosystems. This study explored the influence of groundwater on candidum sites. Cypripedium candidum site distribution was examined at map scale in relation to topography, hydrology, vegetation cover and shallow aquifer distribution. Visits were made to ten growing sites to understand landscape scale characteristics. Shallow bored were installed at two sites to explore geology, water levels and water chemistry. Regionally, candidum colonies were found to be preferentially located on the discharge margins of shallow sand aquifers in areas with calcium rich soils. Local site indicators showed high water tables and sand or fractured clay sub soils, high pH and sulphate deficiency. Three hydrodynamic models were identified, which could be applied to all known sites. Candidum preferentially colonised areas of intensified groundwater discharge. In western Manitoba candidum were found in swales near contact springs. In eastern Manitoba, beach ridges running perpendicular to slope served as water retention and release structures. Drainage was retained on the upslope, flowed through the aquifer and was released as concentrated discharge on the downslope side. A similar effect was seen at three sites where roads acted as barriers, forcing flow under the road and up the other side. Cypripedium candidum showed preference for specific hydrological, hydrogeological and hydrochemical situations. Identifying similar settings is key to discovery of previously unidentified colonies of candidum and for habitat conservation. To effectively protect candidum, it is not enough to protect the growing site. The broader hydrogeological setting must also be preserved.

Preliminary Assessment of Groundwater Manipulation as a Management tool for Black Box Vegetation

Andrew Telfer, Alison Charles
Australian Water Environments

Surface watering is intended to improve or maintain the condition of floodplain vegetation communities along the Lower Murray by increasing soil moisture availability, reducing soil and groundwater salinity, triggering seed germination and supporting recruitment. Surface watering has tended to be biased toward red gum communities which occupy lower floodplain terraces and hence black box communities are under-represented in environmental watering strategies. To date the success of surface watering has produced variable results with respect to ecological outcomes. Where environmental watering has been successful, analysis of the mechanisms which drive this change has largely been correlative rather than causative. Whilst it is generally accepted that surface watering is important for seed germination, the long term effectiveness of surface watering in providing benefits to mature trees by reducing soil and groundwater salinity has been largely unexplored and unquantified. Based on the Living Murray trials at Bookpurnong, it seems probable that floodplain management which involves groundwater manipulation provides an opportunity to deliver ecological benefits for mature black box communities. However, there are only limited examples where the role of groundwater in providing a source of low salinity water has been examined with key uncertainties including: how effective is surface watering in emplacing a low salinity lens; and how effective is the low salinity lens in reducing the salinity of the overlying unsaturated zone. The aim of this presentation is to demonstrate that groundwater salinity exerts an influence on environmental watering outcomes. Further, the presentation will aim to identify indicators that can be used to predict ecological outcomes, including for Black Box vegetation, from watering at new or existing sites. These outcomes will be illustrated using historical data from environmental watering on the Lower Murray floodplains in the Mallee CMA area over the last decade, supplemented by targeted data collection, and analysis of trends spatially and temporally.

Afternoon ANU Theatre 2 Sessions – Groundwater Energy and Resource (CSG/Mining)

Hydrology of Coastal Upland Swamps on the Woronora Plateau

Martin Krogh
NSW Office of Environment & Heritage

The Southern Coalfield independent inquiry panel and the NSW Planning Assessment Commission recommended that additional research into the impacts of subsidence on swamps was needed. It was recommend that the research should focus on the resilience of swamps as functioning ecosystems, and the relative importance of mining induced, climatic and other factors which may lead to swamp instability. The Hydrology of Upland Swamps Project was developed to provide the necessary data (evaporation, rainfall, aquifer levels, soil moisture, discharge) to construct a water budget for three upland swamps on the Woronora Plateau, one of which has now been undermined. Impacts to this swamp, part of the EPBC listed Coastal Upland Swamp endangered ecological community, were clearly identified. This contrasted strongly with swamp aquifer levels, soil moisture levels and flow downstream of two reference swamps which were not undermined. The overall effect of longwall mining has been a loss of the consistent perched aquifer within the undermined swamp, a slower saturation of swamp sediments in response to rainfall , increased desiccation of the swamp and reduced delivery of water to the downstream catchment. Using a preliminary water budget model, a shortfall of approximately 0.3 – 0.4 ML/day of flow to the downstream catchment has been calculated for the undermined swamp. These results have major implications for the long term persistence of the swamp community above areas impacted by longwall mining and their delivery of water to the downstream catchment, which in this case forms part of Sydney's drinking water supply.

Assessment and management of longwall mining impacts to groundwater and EPBC listed peat swamps - a Commonwealth perspective.

Mitchell Bouma, Scott Lawson, Rod Dann
Department of the Environment

This paper refers to studies on potential impacts to peat swamps from longwall coal mining, and the use of improved knowledge in developing advice to regulators and supporting regulatory decisions and approval conditions. Two categories of peat swamps are listed as threatened ecological communities under the EPBC Act (1999). They largely occupy Sydney Basin sandstone plateaux, and commonly rely on shallow groundwater levels or discharge. On the advice of the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC), the Office of Water Science (OWS) commissioned and published three reports on peat swamps. Supported by the OWS, the IESC has provided advice to regulators that aims to protect peat swamps from mine subsidence impacts. The reports highlight risks to swamps from subsidence, fracturing, and groundwater drawdown and drainage, and indicate that:

- To date, no strategies—other than changes in mine plan layout—have been proven to effectively mitigate longwall mining impacts to peat swamps.
- Ecological baseline data must be established before mining, and subsidence and hydrological monitoring must be undertaken to warn of ecological risks.
- Remediation of peat swamps following damage by subsidence cannot be relied upon as a management option.

Industry proponents have highlighted resilience of peat swamps to historical mining and proposed adaptive management measures to mitigate impacts. However, IESC advice has identified the potential for irreversible impacts which cannot be adaptively managed. A recent approval from the Commonwealth regulator for mining in the Illawarra region included conditions to limit subsidence, and constrain the extent of mining to minimise impacts to overlying swamps. Improved understanding of peat swamps has enabled development of specific advice to regulators on assessment, monitoring, management and mine layout. There are however, ongoing uncertainties relating to fracturing, hydrological responses and ecological tolerances which require further research.

Field investigations into hydrogeological effects of longwall mining in the Southern Coalfield, NSW, Australia

Stuart Brown, Angus McFarlaine, Chiara Holgate, Andrea Madden, Richard Walsh, Gary Brassington
Parsons Brinckerhoff

Longwall mining commonly results in ground subsidence and associated deformation and fracturing of overlying strata. The development of disturbance zones in the overlying strata causes a number of changes to groundwater systems, including changes in vertical and horizontal permeability and an increase in the overall storage via strata dilation. In recent years a number of semi-empirical formulas have been developed to calculate the vertical extent of connective fracturing above longwall mines. These approaches can yield a wide range of estimates of height of connective fracturing and contribute to uncertainty in predictions of environmental impact from numerical modelling. It is important that model assumptions are underpinned by high quality field data relating to changes in hydraulic parameters as a result of mine subsidence. This paper presents key results from hydrogeological investigations carried out in sandstone overburden directly over a longwall panel at the Dendrobium mine in the Southern Coalfield of NSW. Investigations involved drilling diamond core holes to a depth of 288 m and carrying out permeability testing, down-hole flow testing and cross-hole tracer tests using dye and saline water. The configuration and spacing of the test holes was chosen to enable identification of cross-hole tracer movement in more than one direction and to minimise interference between tests. The study was divided into two parts: four holes were drilled and tested prior to the passage of the longwall, and a further five holes were drilled and tested after the longwall was complete. In addition, groundwater levels and pressures were monitored throughout mining and following the post-mine study. The pre- and post-mining investigations carried out in this study provide important constraints on the extent of mining related disturbance and its effect on groundwater systems with implications for numerical modelling.

Hydrogeological variability across the Sydney-Bowen Basin.

Claire Stephenson, Duncan Irvine, Thomas Walters
Australasian Groundwater and Environmental Consultants

The coal mining industry is a significant contributor to Australia's gross domestic product. Open-cut and underground mining involves interaction with groundwater, either directly or indirectly. Legislation in relation to groundwater management has resulted in a growing need to more accurately quantify the change in groundwater resources due to mining activities. In order to achieve this, hydrogeological parameters need to be better understood. Elongated basins of Permo-Triassic clastic sediments run through Queensland and New South Wales, forming the Sydney-Bowen Basin, which is the main source of Australia's economic black coal reserves. Tectonic deformation and movement of the Sydney-Bowen Basin created sub-basins, such as the Sydney, Gunnedah and Bowen basins. This investigation looks at the hydraulic variability of the various sub-basins. The study involved consolidating extensive field data collected by the authors, and other data within the public domain. The study found key trends based on the spatial distribution of the data, lithology and depth of the stratigraphy. We have utilised these trends to assist with verifying hydrogeological parameters where extensive field testing is either not available or limited. The outcome is the ability to more accurately quantify groundwater resources and predict impacts associated with coal mining and coal seam gas operations and development.

Tertiary basalt aquifers and coal mining – a unique and challenging interaction

Tim Armstrong, James Tomlin, Henry McCarthy
Australasian Groundwater and Environmental Consultants (AGE)

Managing the interaction between coal mining and agricultural industries presents a challenging issue for Australian state and federal governments, particularly where productive groundwater resources are found. An example of this interaction occurs in the Bowen Basin coal fields of central Queensland. Here, productive aquifers of Tertiary aged basalt are irregularly distributed throughout the region and are commonly targeted for livestock water supplies, and to a lesser extent, for mine water supply. The basalt aquifers are also intersected by coal mines as the industry expands throughout the basin. Applying appropriate groundwater protection policy to these basalt systems is a challenge because they are very difficult to adequately conceptualise and accurately model. Similar to basalt systems worldwide, the basalt aquifers of the Bowen Basin have large spatial variability in aquifer parameters, resulting in highly compartmentalised systems. The Queensland government requires proponents of major mining projects to assess the potential environmental impacts arising from mining development, including groundwater assessments. The key objective of the groundwater assessments is to robustly and conservatively predict the zone of groundwater depressurisation around the project at milestone times during and after mining. The results of these assessments guide the project approvals process and the environmental protection conditions that governments apply to the projects. Typical field data often only provides limited "windows" into the structure of the basalt formations and commonly fail to adequately resolve their complex aquifer architecture. As a result, subsequent groundwater models are near impossible to calibrate and the predictive results are indicative only if aquifer connection exists. However despite their limitations, these groundwater models are an indispensable tool in understanding the basalt aquifer systems. This presentation summarises the experience of the authors working on mining projects in the Bowen Basin and highlights the challenges that arise during the course of these basalt aquifer investigations.

Mitigating High Pressure Water Inflows at the Ernest Henry Underground Mine

Anna-Katrin Greve[1], Joe Evert[2]
1. Ernest Henry Mining
2. Mineright, Cloncurry, QLD, Australia

In March 2012 large flows of high pressure (5200 kPa) and high temperature (49 degrees) water were intersected during development in the Ernest Henry Underground Mine. The high flow quickly filled the 1/7 decline and the heat of the water created a hostile work environment. To predict and mitigate the risk of water intersects during future development, the present conceptual model of the local fractured aquifer was reviewed and a dewatering strategy targeting the highest water risk zone was developed. In addition to a targeted dewatering strategy, stand piping and grouting methods have been optimised to allow development through water bearing ground. Combining hydrograph data from 56 Vibrating Wire piezometers with a reviewed structure interpretation allowed identification of a highly compartmentalised aquifer. A total of eight aquifer zones with different degrees of fracture connectivity were identified within the mine. Targeting the zone with the highest hydraulic conductivity for dewatering allowed dropping the piezometric water level in the underground mine by 650 metres, while increasing the overall dewatering volume by only 20%. Dewatering was carried out from the lowest mine level to allow dewatering by passive drainage. Due to the increasing mine depth during mine development, two stages of dewatering have been carried out and a third and final stage is scheduled to commence at the end of 2015. In addition to dewatering, water risks during mine development were mitigated by high pressure grouting. Optimisation of standpiping and grouting methods has allowed a sequential reduction in the cycle time during mine development in water bearing ground. Drilling through valved standpipes has mitigated the risk of uncontrolled water inflows through drill holes. The combination of targeted dewatering and optimised grouting methods allowed safe and efficient mine development through formations with high water pressure and high hydraulic conductivity.

Final voids lakes at open cut coal mines - a perspective on the challenges and opportunities

James Tomlin
Australasian Groundwater and Environmental Consultants

As Australia's mining sector adjusts to slowing demand for minerals, once profitable coal mines are being placed in 'care and maintenance' or closing. At the same time many large coal mines have been approved and are planning to operate over the coming decades, closing sometime in the future. Many of the open cut coal mines will leave an open void at closure, within which a lake will form over time. Governments, communities and mining companies are all trying to understand how the lakes that form in final voids interact with the groundwater regime, and if they represent a future liability or opportunity. This presentation summarises the various options miners are currently proposing for treatment of final voids at coal mines prior to closure, and the multidisciplinary challenges in characterising the long term impacts from these landforms. It also categories the issues raised by communities, governments and miners when considering the challenge of the final void lake. The presentation draws on the authors experience and public domain data from numerous open cut mining projects in the Queensland and New South Wales coal fields to provide a snap shot of the current situation and future trends. The results provide perspective for those charged with decision making around final void lakes at coal mines, and areas of focus for investigators assessing the influence of final void lakes on groundwater regimes.

Comparison of different techniques for simulating post-mining voids in groundwater recovery models

Arash Mohajeri, Dr. Pavel Dvoracek, Andrew Durick
Australasian Groundwater and Environmental Consultants Pty Ltd (AGE)

Open cut mining has become a common practice over the last few decades in Australia, as a method of extracting shallow mineral resources. Since total backfilling is normally unfeasible, for both practical and economic reasons, open pit or mine voids remain after the completion of extraction operations. Issues exist with mine voids for local and regional groundwater systems. Environmentally safe and economically effective designs can be achieved by establishing informed final void management strategies. Numerical modelling is an important part of final void management and can assess both short- and long-term impacts of voids on groundwater systems.
The common approach for simulating the interaction between voids lakes and groundwater systems is to incorporate the mine void into the groundwater solution domain as a high-conductivity zone. This method is referred to as the "High K lake" technique. Previous studies have developed this approach using fully saturated models. Therefore, the "High K lake" technique is most useful for simple problems and a more sophisticated approach is needed for the simulation of complex groundwater systems. In this study, the USGS MODFLOW lake package (LAK3) is compared to the "High K lake" conceptual approach in the simulation of post-mining conditions and groundwater recovery into mine voids. The comparison of both techniques showed that for the same underlying assumptions, the predicted recovery rates, recovery times and the final elevation of void lake water level varied.

HYDROCHEMICAL CLASSIFICATION OF GROUNDWATER IN THE GLOUCESTER BASIN, NSW.

Carolina Sardella[1], Stuart Brown[1], Bob Corbett[2],
1. Parsons Brinckerhoff
2. AMCI Investments Pty Ltd.

Baseline groundwater level and quality monitoring programs provide the primary scientific data to assess potential impacts to groundwater and surface water resources from mining activities.
Gloucester Resources Ltd is proposing to develop and operate an open cut coal mine as part of the Rocky Hill Coal Project (RHCP) in the Gloucester Basin. Baseline monthly groundwater level and quality monitoring has been carried out within the RHCP mine application area since 2011. The Gloucester Basin is a synclinal structure comprising Permian sedimentary and volcanic rocks. The groundwater system comprises four main hydrogeological units that overlie largely impermeable Carboniferous basement rocks: alluvial deposits along major creek lines, shallow (<150m) fractured rock zones, and a thick succession of low permeability coal measures comprising interbedded coal seams and interburden units of very low permeability. Currently there are 15 groundwater monitoring bores installed within RHCP mine application area (five are screened within the alluvium, six within the shallow rock and four within coal seams). Nested monitoring bores were installed at four sites to assess the water quality characteristics and interaction of the different hydrogeological units. In this study we have applied bivariate ratio plots and cluster analysis to identify several hydrochemical groups in the northern Gloucester Basin. Groundwater in the study area falls within a restricted range in terms of hydrochemical facies and major ion chemistry. There are several subtle differences between each hydrochemical group which can be related to a distinct hydrogeological environment or pathway. We found that salinity and Ca/Cl ratios provided the best discriminators. This study is a useful tool for the understanding of groundwater movement and surface water interaction in the Basin under pre-development conditions.

Assessing groundwater impacts due to fracture stimulation and pilot testing programs for coal seam gas exploration: Waukivory Pilot Project in the Gloucester Basin, NSW

Becky Rollins[1], Sean Daykin[1], Stuart Brown[1], James Duggleby[2], John Ross[2]
1. Parsons Brinckerhoff
2. AGL Energy Ltd

Coal Seam Gas (CSG) forms an important component of future domestic gas supply in Australia. Exploration for CSG requires drilling and testing of pilot gas wells to assess the gas resource and likely produced water volumes. In some cases, gas wells are fracture-stimulated; a process of pumping a fluid and sand under pressure into the coal seam to open cleats and fractures at depth, increasing the hydraulic conductivity and enabling the flow of water and gas. Public concern has focussed on a potential connection between target coal seams and shallow groundwater resources, and the perceived risk of water quality impacts. There has been a lack of good quality monitoring information with which to assess these risks, particularly in low permeability Permian Coal Measures. In late 2014 AGL carried out testing of four pilot gas wells at Waukivory within the Stage 1 Gas Field Development Area of the Permian Gloucester Basin, NSW. As part of the pilot testing program, extensive monitoring of groundwater, surface water and gas well produced water was carried out prior to, during and following fracture stimulation and subsequent flow testing. Samples of fracture stimulation fluid were also tested to identify key analytes as indicators of impact to adjacent water resources. No BTEX or chlorine based compounds were used in the fracture stimulation fluid, and none were detected in the fluid samples. This paper presents results from the monitoring program. Interpretation of the results included identification of water level and water quality trends and assessment as to whether apparent trends were naturally occurring or potentially attributed to project activities. The investigation found no clear evidence for enhanced connectivity between target coal seams and shallow groundwater during, and in the three months following fracture stimulation. The results provide important calibration constraints for impact assessment modelling.

Standardised scientific approach to measurement of hydrogeological impacts from underground coal gasification (UCG).

Angela Bush, Dr Chris Cuff, Dr Maree Corkeron, Dr Cecily Rasmussen,
C&R Consulting

Using new technology and best practices such as carbon capture and storage (CCS), underground coal gasification (UCG) has potential to improve recovery of energy from coal. The unique needs of UCG require regulation modification for successful and safe management of its development. The objectives of this study are: to demonstrate the spatial distribution of temperature and fluid pressure trends in and around the UCG chamber throughout operations; and to identify measurable criteria using fluid pressure trends to define a fluid active zone (FAZ). The aim of defining FAZ is to aid both operators and regulators in the assessment of UCG chamber conditions and potential groundwater contamination risks. Density corrected fluid pressure data from vibrating wire piezometers monitoring a UCG site were converted to hydraulic head. Fluid temperature for density correction was estimated from chamber proximity and operational parameters. The temporal and spatial differences in head relative to background levels (determined from regional hydrographs) were contoured, showing the evolution of FAZ through burn progression. The contour maps show FAZ evolution (in terms of head) both temporally and spatially. Drawdown rates are highest in the target coal and closest to the chamber, with much lower rates recorded in the distal overburden (radius 50–450 m). Fluctuations in coal seam head mirroring operational pressure changes confirm the importance of active management to maintain the protective cone of depression. The delineation of FAZ around a UCG chamber is crucial for effective UCG operation and compliance monitoring. With the application of a simple but standardised scientific method, UCG operators can track FAZ evolution. This interpretation of monitoring data: 1. delivers real-time information for operation controls to reduce groundwater contamination risk; and 2. gives an objective and meaningful monitoring tool for compliance. Additionally, inclusion of FAZ definition in initial modelling for site selection purposes enables identification of unacceptable potential impacts.

Assessing the potential impact on water resources from future onshore natural gas development in southern Victoria

Greg Hoxley, Randal Nott, Louise Lennon, Simon Baker, Richard Evans, Nic Unland
Jacobs

Future development of onshore natural gas in Victoria has been identified as having potential to affect water resources. An assessment of the potential impacts on water resources was initiated by Government to refine the approach to exploration and development. A broad scale impact assessment approach was developed for four hazards:

- Aquifer depressurisation
- Groundwater contamination by hydraulic fracturing
- Land subsidence
- Induced seismicity Design and Methodology

Two parallel approaches were developed that when combined gave an overall assessment of potential impacts to inform an approach. This study focussed on the Otway and Gippsland regions of southern Victoria. For aquifer depressurisation a drawdown estimate was calculated for identified prospective areas. This was compared with defined impact thresholds that had been previously defined for other groundwater impacting uses, such as licenced extraction. For the risk of groundwater contamination from hydraulic fracturing, land subsidence and induced seismicity, global experience was assessed against the best available information on Victorian conditions. General risk factors were assessed through literature. Maps of impact classified into low, moderate and high impact have been prepared for two areas in southern Victoria – Gippsland and Otway. The study has combined available data, such as depth to watertable, extent of gas sources and 3D aquifer geometry to assess potential impacts from aquifer depressurisation. The potential impact of onshore gas development on water resources in the Otway region of Victoria has been successfully mapped.

DAY 2 Abstracts
Wednesday 4 November 2015

Morning Plenary

Barriers to flow: advancing aquitard assessments for energy and mineral resource projects

W. Timms
UNSW

Aquitards, low permeability barriers to flow, can limit potential impacts of depressurization or dewatering and migration of contaminants associated with energy and mineral resource projects.
Aquitard research addresses a lack of data and understanding of processes within rock strata above underground mines, and extraction of unconventional gas resources, and also within natural and engineered clayey-earth barriers to flow near open pit mines. An overall framework for aquitard assessments was developed, including various multi-disciplinary site, laboratory and modelling studies in a staged approach commensurate with risk to the project and water resources. Detailed research within this framework will be presented including 1) reliable drill core scale measurements of vertical hydraulic conductivity (K_v), 2) approaches for core-site-basin scale monitoring and modelling of aquitard-aquifer systems, and 3) identifying the potential of discontinuous or continuous preferential flow paths through aquitards. Results to date include: 1) numerous K_v data for various aquitards and conditions (between 10^{-6} and 10^{-12} m/s) and benchmarking of lab methods highlighting appropriate core sampling, test fluids and conditions to prevent bias; a site example verifying lab data with in situ, high frequency pore pressure data; 2) a work flow for core-site-basin with geo-statistical methods to test representative cores (with a specified degree of heterogeneity) followed by fluvial process modelling generating multiple permeability distributions for groundwater flow modelling; and 3) innovative characterisation of a dual porosity, low permeability media by numerical modelling of a new geotechnical centrifuge test (interrupted flow); and an isotope method (vapour equilibration of $\delta^{18}O$, $\delta^{2}H$ on drill core) which assists in identifying slow diffusive versus rapid transport through aquitards. In conclusion, aquitards can effectively disconnect groundwater systems, enabling development of underlying resources. However, innovative techniques for aquitard assessment may be required where the integrity of aquitards under varying stress conditions is a potential risk to projects and water resources.

Afternoon Plenary

Modelling: where it is now, where it should be, and why it may not get there.

John Doherty
Watermark Numerical Computing

The last thirty years have seen the emergence of powerful numerical simulators. These are used on a daily basis to explore the outcomes of proposed groundwater management strategies. It is important to remember however, that the nature of modelling, and of expert knowledge and data that supports modelling, is such that modelling should never be asked to predict what the outcome of a proposed management strategy will be. It can only be asked to predict what the outcome of a proposed management strategy will NOT be. Its ability to do this gives modelling a secure place in decision support – not as a crystal ball, but as an invaluable aid to risk assessment. To achieve its potential in decision support, a simulator must dance with equally complex software that performs essential complementary tasks. These include context-specific parameter upscaling, highly parameterized inversion, processing of calibration datasets to formulate objective functions that afford estimated parameters some protection from model-defect-induced bias, construction of geologically sensible regularisation constraints, calibration-constrained uncertainty analysis, visualization, and much more. Workflows, incorporating all of these actions, must be developed and disseminated so that modellers can be guided through these complex processes. Workflow-based software platforms which accomplish many of these tasks (up to a point) form the core of simulation-based decision-support in the petroleum industry. The groundwater industry is at a stage of maturity where similar (but not by any means identical) software platforms are urgently required. But what is it in the culture of our industry that is preventing this from happening? Is it because we expect our software for free? Is it because overseas government institutions on whom we largely rely for our software have been funded enough to emasculate a vibrant private sector who could provide this industry with the software that it needs, but have not been funded well enough to replace it? Is the real price that our industry pays for free software an ongoing failure to make important decisions with the level of model-based support that it would otherwise possess? Like many issues, there are no simple answers to these questions. Nothing is for certain, except that they are in urgent need of discussion.

Morning Keynotes

Working with the minerals industry in facilitating outback water solutions for remote parts of South Australia – The South Australian Goyder Long-Term Outback Water Solutions (GFLOWS) Projects.

Timothy Munday, Mat Gilfedder, Andrew Taylor, Tania Ibrahimi, Yusen Ley Cooper
CSIRO

Mining and energy development in South Australia's far north is set to have significant consequences for the water resources of the region. These industry sectors generate significant economic value to the State and their support remains a priority for the government. The scale of potential developments from current exploration programs, facilitated in part by the by the SA Government's PACE Program, will inevitably result in an increase in infrastructure requirements, including access to water resources to support mines and minerals processing. However, increased demand for water, and in particular groundwater, is likely to be compromised by the limited information we have about these resources. There is a recognised need to expand this knowledge so that water availability is not a limiting factor to development. The Goyder Institute's Long-Term Outback Water Solutions (G-FLOWS) Project was established to help address this. In a partnership with State agencies, the Project sought to extend our understanding of the hydrogeology of underexplored regions of South Australia with enormous potential for significant mineral resources. Working with the minerals exploration companies the project has employed exploration geophysical data sets, including local scale airborne electromagnetic, regional scale airborne magnetics and contemporary terrain data to better define the physical hydrogeological framework for priority regions including the Musgrave Province and the Northern Eyre Peninsula. The geophysical data reveal a complex basement and sedimentary infill in wrench grabens, and extensive inset palaeovalley system which contains groundwater of variable quality. The existence of these sedimentary aquifers was already known, but the geophysics revealed unrecognised complexities with implications for groundwater resource potential. Regional scale water resource maps have been generated that provide a framework for groundwater resource determination. The approach, when coupled with data on groundwater recharge, provides a basis for understanding aquifer hydrodynamics and upscaling the resource potential, with possible application elsewhere.

Applying hydrocarbon systems analysis to assess aquitard hydraulic performance

Professor Jim Undershultz[1], Peter Pasini[1], Micaela Grigorescu[2],
1. The University of Queensland Centre for Coal Seam Gas
2. Geological Survey of Queensland

In the development of on-shore gas resources there are a number of recognised technical and non-technical risks. Some of these are related to the degree of interaction predicted between gas reservoir development and adjacent water resources. They could take the form of declining pressure in adjacent aquifers or increased hydrocarbon content due to gas production wells not being 100% efficient at capturing liberated hydrocarbons. Our ability to adequately characterise and mitigate these risks depends to a large degree on 1) our ability to understand baseline conditions, 2) forecast the volume of associated water anticipated to be co-produced and 3) our ability to forecast the continuity and performance of aquitards (top, intraformational and fault seal) within the stratigraphic succession of interest. Unfortunately, at the start of resource development this is also when there is the least amount of data to constrain the problem and history shows that we tend to conservatively overestimate the volume of associated water and overestimate the hydraulic continuity of the strata. We use a hydrocarbon systems analysis approach to identify the migration of hydrocarbons and non- hydrocarbon gases through Bowen and Surat basin strata at different geological times. These fingerprint migration pathways that may ultimately relate to aquitard performance at the gas development time-scale. Outcomes from this approach can be explored within a risk assessment framework for resource interaction on a human time-scale that can inform the development of more cost effective measurement, monitoring and verification strategies. We note that both oil shows and ethane appear at various locations across the basin that are above regional seals that separate thermally generated hydrocarbon source rocks. Some might relate to up fault migration and others to across aquitard migration.

Strategies for measuring and interpreting hydraulic heads in coastal aquifers

Vincent Post, Eddie Banks, Maria Pool
Flinders University

Field observations of hydraulic head variations in space and time provide flow directions and magnitudes, and can also be used to estimate the hydraulic properties of aquifers. In coastal aquifers, the measurement and subsequent interpretation of head data is complicated by the variability of the groundwater density. This paper presents the results of a series of head measurements in the coastal aquifers south of Adelaide. The objective was to determine the flow pattern along transects perpendicular to the coast. Complications arise from the range of densities encountered (between 999 and 1047 kg/m3) as well as tidal fluctuations. Results of this study show that the density of the standing water in observation wells is not uniform due to leakage along the joiners of the casing. By measuring the temperature and electrical conductivity as a function of depth, a correction term can be added to the measured head but significant uncertainty is introduced, thus complicating the determination of the flow pattern. Analysis of the tidal head variations reveals that the aquifer is stratified in terms of its permeability. Interpretation of the amplitude damping and lag times provides an order-of-magnitude estimate of the hydraulic diffusivity of the aquifer, but the method consistently shows an increase of transmissivity values with distance inland. This has been observed elsewhere, and appears to be an artefact of the method. The nature of this phenomenon is investigated using numerical models that take into account the heterogeneity of the aquifer and non-linear effects due to fluctuations of the water table.

Effect of flooding on the evolution of groundwater chemistry; North-west Australia

Shawan Dogramaci, Assocate Professor Grzegorz Skrzypek
Rio Tinto Iron Ore

The arid and semiarid regions are usually characterised by not only very low precipitation but also extremely high potential evaporation rates. In order to fully understand the hydrochemical evolution of groundwater, it is critical to determine the major sources of solutes contributing to salinity increase. The Hamersley Basin of northwest Australia, hosting one of the largest iron ore deposits on the planet.. The groundwater of the alluvial and meta-sedimentary fractured rock aquifers of the basin are characterised by wide range of salinity form fresh to brines (>150g/L). The groundwater acquired unique strontium isotope signatures due to interaction with exceptionally old aquifer matrix (2.8Ga). A combination of, δ2H, δ18O and δ87Sr isotope analyses was used to constrain the hydrochemical evolution model and to identify sources of solutes in groundwater [1]. The δ87Sr signature in groundwater in three major aquifer types ranged from 11.8‰ to 40.6‰ and reflected the mineralogy of aquifer matrix. Groundwater in the Fortescue Marsh terminal basin had a rather constant δ87Sr signature of 36.6±1.4‰ irrespective of salinity levels, δ18O and strontium concentration. This groundwater can be considered as mature in a geochemical sense, representing the final stage of water evolution on the basin scale. The Sr isotope mass balance calculation shows the contributions of dissolved ions from three major sources: >92% from precipitation, ~7% from carbonate rocks and <1% from rocks with highly radiogenic signatures (shales and clays). These results confirmed that water salinity is primarily driven by rainfall chemistry in floodwaters rather than water-rock interactions in the catchment. Moreover, ion transport due to horizontal groundwater inflow to the terminal basin is rather negligible compared to the vertical infiltration of direct precipitation and fresh flood water. The cyclic wetting-drying and de-dolomitisation, the only locally significant geochemical processes influencing groundwater hydrochemistry, have no significant influence on δ87Sr values, which are primarily reflecting solute origin [1].

Fate of engineered nanoparticles: Challenges in informing human and ecological health risk assessments

Denis O'Carroll
UNSW

Nanotechnology is met with both excitement and scepticism. On the one hand there are tremendous technological opportunities through the exploitation of the unique properties of nanoparticles. On the other hand, there is concern that nanoparticles will have adverse effects on human and ecological health when they are released to the environment. Unfortunately, the risks of engineered nanoparticles (ENPs) to soil and subsurface environments are as yet unknown, limited, in part, by a lack of basic scientific understanding of their release from commercial products, as well as their ecotoxicity and subsurface transport. This study fills part of this data gap, investigating the subsurface transport of two emerging engineered nanoparticles, nanosilver (nAg) and carbon nanotubes (CNTs), of concern due to their potential negative environmental impacts. This presentation will focus on the impact of porous media grain size on the mobility of these engineered nanoparticles in saturated one-dimensional column experiments and their mobility in the vadose zone. An innovative method, utilizing the synchrotron at Argonne National Laboratory in Chicago, for quantifying in-situ nAg transport will also be discussed. In addition the numerical modeling phase of the study, investigating the mobility of CNTs at the field scale, will be presented. Results suggest that mechanisms in addition to those associated with colloid filtration theory need to be included in the numerical model to simulate observed behavior. Results also suggest that engineered nanoparticles are much more mobile in subsurface systems than currently assumed. Work of this nature is urgently needed by policy makers to make informed decisions related to the beneficial use of nanotechnology.

Groundwater recharge investigation at the NCRIS Fowlers Gap Site in semi-arid western NSW

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2. School of Geography, Earth and Environmental Sciences, University of Birmingham, Edgbaston, Birmingham, UK.

Groundwater recharge investigation in semi-arid environments is frequently difficult due to a lack of suitable (or any) data. This lack of data was recognised in the NCRIS Groundwater Infrastructure Program and significant monitoring resources were installed at the UNSW Arid Zone Research Station at Fowlers Gap, 110 km northeast of Broken Hill. Monitoring at a remote facility, where rain may not fall for months, where temperatures frequently exceed 40 degrees, and dust is common, is particularly difficult! More so because the rain that does fall is often associated with high intensity and rapidly generates run off. To try and overcome some of these problems, a high density telemetered monitoring network has been installed that comprises 18 tipping-bucket rain gauges, a climate station, video monitoring of two creeks, level monitoring in the creeks and 12 groundwater monitoring bores located on the downstream outwash fan. Most of the data is uploaded daily using the Telstra 3G network. Daily checking of data allows equipment failure to be recognised and rectified. In January 2015, an exceptional rainfall event comprising three intense bursts of rainfall over a 36 hour period was successfully captured using the NCRIS network. The storm event produced a 2.5 m flood in Fowlers Gap Creek that caused over-bank flow and travelled many kilometres out over the plain before filling Lake Bancannia. We will present the results from monitoring of this event which greatly exceeded the previously highest rainfall in the 45 years of daily record available at Fowlers Gap. Data available so far (May, 2015) indicates that little groundwater recharge actually occurred, however a more complete set of data will be presented for the first time at the IAH/NCGRT conference.

Making use of new opportunities and technologies for the measurement of environmental tracers

Ian Cartwright
Monash University

The range of environmental tracers available for use today is wide and varied. In many cases the technologies that we use are adapted from other fields and the key insights are in recognising their potential utilisation in examining processes in the hydrosphere. Examples of this include the use of Rn to measure groundwater inflows to streams, where much of the technology has been adapted from the monitoring programs of Rn in air. The atmospheric nuclear test program drove the development of tritium measurements, the IAEA tritium facility was set up in 1958 following recognition that the elevated tritium in the 1950's would be an ideal tracer of hydrosphere residence times. Likewise the technology developed for monitoring of CFC's and SF6 in the atmosphere has allowed these traces to be applied to solving hydrogeological problems.

Perhaps the most exciting current trend is the ability to measure tracers continuously to capture transient events. The improvement in sensor technology means that a range of analytes may be measured continuously and data retrieved in real time. In addition, continuous measurements of stable isotopes (via cavity ring-down spectroscopy) and Rn (via Rn-in-air detectors) are becoming more common. Much of this equipment is lightweight, portable, and has modest power consumption, which makes it ideal for autonomous field deployment. The ability to generate time series of data allows geochemical tracers to be integrated with other continuous datasets (such as rainfall, temperature, heads, or streamflow).

While we have many tools, the toolbox might not be full and the next development may well exist but being used to answer a different question.

Afternoon Keynotes

Determining realistic specific storage input values for groundwater flow models: a case study from the Surat Basin, Queensland.

Richard Evans[1], Lindsey Campbell[2], Patrick McKelvey[2],
1. Jacobs
2. QGC

Specific storage (Ss) values are a key parameter in estimating aquifer response to pumping within confined aquifer systems. Yet limited published specific storage values exist for sedimentary rock aquifers. Recent numerical modelling of QGC's proposed CSG development within the Surat Basin, Queensland, identified that variation in the Ss had the largest influence on predicted impact to the groundwater system. Insufficient historical groundwater monitoring data existed to adequately constrain the Ss values during model calibration, so a broad Ss range (four orders of magnitude) was carried into predictive scenarios. When this broad range of values was simulated, the variations between the predicted impacts were unacceptably large. Evaluation of a more realistic Ss range was then undertaken to reduce the range in values, and thereby improve understanding of potential groundwater impacts. Ss values were derived from three sources – calculation from aquifer pumping test results, reference text values and calculation from geotechnical core test results. Existing reports give typical Ss values within the consolidated formations averaging about 5 x 10-5 m-1. Results using the adopted methods yielded consistent estimates of between 3 x 10-7 m-1 to 1 x 10-5 m-1 with the majority of values occurring within 1 x 10-6 m-1 and 1 x 10-5 m-1. The new values of Ss are considerably smaller than values previously adopted for the basin and hence significantly influence impact predictions. Note that storativity (S) calculated from pumping tests often results in an overestimate of Ss. Ss estimates calculated from reference text values indicate that it may be possible to estimate Ss based on rock type (lithology), providing estimates for porosity were available. Values for porosity across the Surat Basin can be estimated from petrophysical logs. The results of Ss calculated from geotechnical results indicate that the variation in skeletal compressibility with depth may be more important, and thus may exceed the variation due to lithology type.

DOES MODFLOW-USG/ALGOMESH GIVE THE SAME RESULTS AS MODFLOW-SURFACT?

Noel Merrick, Dr Damian Merrick
HydroAlgorithmics Pty Ltd

MODFLOW-USG is a finite volume numerical method released by the USGS in 2013. AlgoMesh is a new automated tool, tailored to MODFLOW-USG, that generates meshes with triangular or Voronoi (polygonal) cells that vary smoothly in size and shape between feature boundaries and open areas of a model. The AlgoMesh graphic user interface provides several advanced tools for fine-tuning the model geometry and resulting grid, including the ability to insert structured sub-grids tailored to mining applications. It directly writes MODFLOW-USG input files and allows import of binary results for subsequent export to other post-processing software. For MODFLOW-USG/AlgoMesh to be adopted with confidence, the veracity of the code and the equivalence of model outputs with more traditional modelling tools require demonstration. To this end, a synthetic model has been designed to allow comparative testing against MODFLOW-SURFACT. The model consists of 11 flat layers with uniform properties except for a corridor of alluvium which hosts a river. At a depth of 450 metres, two longwall panels separated by a narrow pillar are placed in a coal seam. Mining of the coal seam occurs for nine years followed by a 50 year recovery period. As the designs for the structured and unstructured grids kept the number of cells similar, more detail was possible in the AlgoMesh implementation near the river and across the longwall panels. Given transient mining, the first action was to write a new routine for time-variant materials (TVM) to operate similarly to SURFACT's TMP facility. The considered model outputs are mine inflows, groundwater hydrographs and river baseflow. Due to different grid areas, there is a slight difference in rainfall recharge inputs. Despite this, the models agree closely but not exactly. The question remains: Which of the two approaches is the more accurate, given differences in spatial resolution and mathematical solution?

Morning Shine Dome Sessions – Surface Water-Groundwater Interactions/Floodplains & GDE's

Through the eyes of the Boinkas: Characterisation of wetland-groundwater interactions in the South East region of South Australia

Chris Turnadge, Sebastien Lamontagne, Andrew R. Taylor, Stan D. Smith
CSIRO Land and Water

The semi-arid South East region of South Australia features regionally extensive shallow groundwater resources and numerous wetlands. Under a potentially drier future climate, reduced recharge to groundwater may result in reductions in the regional water table. This can result in changes to wetland–groundwater interactions and, consequently, to wetland water level dynamics. However, interactions between wetlands and shallow groundwater in the South East region are generally poorly characterised. The objective of this research was to identify the key features that significantly affect wetland–groundwater interactions in the South East region. This in turn would lead to the improved conceptualisation of South East wetlands. In particular, we focused on deflation basin wetlands that are common across the region. Three South East wetlands were examined in detail: Bool Lagoon, Lake Robe and Deadman's Swamp. For each location, all existing climatic and hydrological data were reviewed while surface water and soil samples were collected for hydrochemical and isotope analyses. In total, six key features that significantly affect wetland–groundwater interactions were identified. Following the Tothian theory of nested groundwater flow systems, landscape position and topography can provide a first indication of whether a wetland is located in a regional recharge, flow-through or discharge zone. This conceptualisation can be further refined by considering the presence of subsurface controls, as well as local scale wetland features such as morphometry, clogging layer presence and the existence of managed surface water augmentation. In addition, for one of the three wetlands studied it was found that it can be described using a concept from the past – that of the Boinka. Consideration of the six key features identified may lead to improved conceptualisation of South East wetlands. This can assist future wetland management through greater understanding of their function as a part of the regional hydrogeological system.

The transit time of water in headwater catchments

Professor Ian Cartwright[1], Dr Uwe Morgenstern[2]
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While headwater streams contribute a significant proportion of the total water to many river systems, the transit times of water in headwater catchments are largely unknown. Here we use high-precision Tritium measurements to understand first-order controls on transit times of water in headwater streams in the upper Ovens catchment (southeast Australia). Samples were collected at varying streamflows from seven headwater tributary sites in steep-sided valleys in basement rocks and three sites on the Ovens River where there are alluvial sediments adjacent to the river. Tritium activities vary from 1.63 to 2.45 TU, which are lower than local rainfall (~3 TU). Tritium activities are highest following higher winter flows and lowest at summer baseflow conditions. The variation of major ion concentrations with discharge implies that different stores of water from within the catchment (e.g. from the soil or regolith) are mobilised during rainfall events rather than there being simple dilution of groundwater by rainfall. Mean transit times calculated using an exponential-piston flow model range between 6 and 29 years and estimates from other flow models are similar. There is a broad correlation between Tritium activities in individual catchments and runoff coefficients which may reflect variations in evapotranspiration and recharge. The Ovens River has similar mean residence times to the headwater streams implying there is no significant input of old water from the alluvial gravels. That the water contributing to the upper catchment streams in the Ovens catchment has a mean residence time over several years implies that these streams are buffered against rainfall variations on timescales of a few years but are likely to respond to longer timescale climate variations. Similarly, changes to landuse that impact evapotranspiration will affect streamflow over these timescales.

Baseflow and Regional Groundwater Model Calibration

Bill Meynink
Mine Water Specialists International Pty Ltd

Stream baseflow, for a catchment in dynamic equilibrium with its climate, is groundwater discharge. When quantified, baseflow is useful in regional groundwater model calibration. The conceptual realism of a simple hillslope baseflow model, that represents surface runoff (quickflow) and baseflow (slowflow) as storage cascades in parallel, is demonstrated using flow and electrical conductivity records from 40+ Australian catchments. This conceptual realism is further demonstrated by applying the model to two landmark studies linking baseflow model parameters, persistence, storage and baseflow index, to geology and regolith: the 500+ catchment study in Great Britain of Boorman, Hollis & Lilly, and the Lacey & Grayson study of 100+ catchments in Australia.

Victorian Alpine Bogs and Groundwater Relationships – A progress report of Technical Studies at Mount Buller

Tim Anderson, Dr Tim Wills, **Grant Jones**
GHD

Mt Buller Alpine Resort has significant constraints on its capacity to store and supply potable water during times of peak demand, which impacts their ability to sustain and grow visitation to the resort. The constraints on the existing water storage limit optimal functioning and future development of the resort. The Mt Buller Mt Stirling Alpine Resort Management Board (RMB) has commenced a series of projects designed to assist the RMB's obligation to provide a secure and reliable future water supply to the Resort. The project centrepiece is a new 100 megalitre (ML) dam to primarily supply the resident and visitor populations with potable water while also maintaining the Resort's amenity and functionality during winter for skiing and snow-play, through snowmaking. As part of the design and planning approvals for the storage project, geotechnical, hydrogeological and ecological investigations were undertaken to determine the potential impacts of the water storage construction and on-going operation on the sensitive environment of Mount Buller. The proposed storage location is within the Mt Buller Resort ski area, north of the final stretch of the unsealed Summit Road over the existing Boggy Creek ski lift alignment and extending north down the hillside to the Summit Nature Walk track. Immediately down-gradient of the proposed storage footprint, on the north-facing slopes an ecological community of Alpine Sphagnum Bogs and Associated Fens has been mapped. The community is listed under the Commonwealth Environment Protection and Biodiversity Conservation (EPBC) Act 1999 and is synonymous with the Victorian Flora and Fauna Guarantee (FFG) Act 1988 listed community, Alpine Bog Community. The hydrogeology of the summit is relatively complex, with basalt capping overlying granitic bedrock materials. A weathering profile in the granite has been interpreted including previously unmapped alluvium and colluvium deposits derived from the granite. A series of historic landslips have also been mapped, which correspond with these sensitive ecological communities. The ecology of Victorian Alpine Bogs and groundwater dependence is poorly understood – the bogs are considered an important mechanism for stabilising soils in Alpine environments, but themselves constitute a significant community. To understand the environmental impacts, a geological model was developed from the geotechnical and hydrogeological investigations with mapping and ground-surveying of the Alpine bogs. A groundwater monitoring program was established both on the storage footprint, but also in down-gradient areas including the margins of the Alpine bog communities. The monitoring network comprised 12 monitoring bores, with automated water level logging undertaken in selected bores. A groundwater level monitoring program was implemented in late 2014, and the results of the monitoring to date, are indicating variable water level behaviour and dynamic responses at the summit. Some monitoring bores are highly reactive to rainfall events, particularly those bores in the sandy, residual granitic soils and landslip surfaces where the bogs thrive. Other bores in the bedrock (and alluvial/colluvial deposits) have shown a consistent dewatering response (over 3 m) during the summer period.

Baseflow Characterisation and Stream Depletion Risks

Chris Nichol, Michael Finger, AliceDrummond, Ian Cartwright,
Groundwater Logic Pty Ltd

The Department of Environment, Land, Water and Planning (DELWP) develops policy and legislation relevant to environmental water management in Victoria, Australia. DELWP has until recently focused on surface water systems to establish environmental watering to protect or improve systems that may be at risk from water use. Understanding of groundwater-dependent ecosystems (GDEs) was, prior to this project, inadequate for consideration in the water allocation framework. DELWP aimed to develop this understanding, with an initial focus on baseflow-dependent waterways. This project developed an efficient and cost effective method for quantifying groundwater-surface water interactions in both regulated and unregulated streams: digital baseflow filtering 'trained' to environmental tracer data (the 'electrical conductivity (EC) mass balance' method). EC was chosen given its prevalence in gauge records, and it is comparatively cheap and practical to expand the existing EC gauging network. The method was applied at the reach-scale using upstream and downstream gauge pairs, and at the catchment scale, using individual gauges. The project also developed a method of assessing ecological and equitability risks of groundwater and surface water usage to these interactions. Baseflow estimates made using an EC mass balance compared well with those estimated using other tracers including radon and major ions on the Mitchell River. Hence EC was considered a suitable baseflow tracer for this study. Using the baseflow analysis in conjunction with existing river management models, an ecological risk assessment framework was applied to assess the impacts of a range of groundwater development scenarios on ecological objectives defined in environmental flow studies (e.g. minimum low flows and fresh (event) flows). Baseflow behaviour is too spatially variable to allow reliable generic digital filter transposition across catchments and reaches. Baseflow estimates can be used in a simple and conservative manner to estimate potential risks of groundwater abstraction on environmental stream flow components.

Identifying the water source of terrestrial vegetation by combining remote sensing and field based measurements - A case study from Barwon Downs.

Stephen Parsons[1], Leighton Randell[1], Jon Fawcett[2], Richard Cresswell[1], Jo Poon[1], Joanna Lee[3]

1. Jacobs
2. CDM Smith
3. Barwon Water

The risks posed to vegetation by groundwater extraction from the Barwon Downs borefield were investigated by a field and remote sensing investigation. The study aimed to determine if and to what extent terrestrial vegetation uses groundwater, and from which a likely risk to terrestrial vegetation can be established. The field study focused on thirteen sites within and outside borefield influence. During late summer 2015, a field-sampling program (soil, vegetation and groundwater) of water potential, stable isotope samples (δ18O and δ2H), soil and water chemistry was conducted to assess the likely water source for vegetation. NDVI analyses for four dates enabled spatial comparison of sites and provided an historical indication of change in vegetation activity. The findings from the field assessment indicate that at the time of sampling the vegetation is likely to be using soil water rather than groundwater. However, in areas of shallow watertable, opportunistic use of groundwater is likely. The study also found the stable isotopic signature was depleted and had little variation throughout the soil profile indicating rapid recharge that occurred mainly during high intensity rainfall events, providing sufficient soil water stores. The NDVI analysis suggests that there is some groundwater use by vegetation during prolonged periods of below average rainfall, where the groundwater is shallow. However, there is no evidence in the NDVI data that groundwater extraction has had a negative impact on vegetation activity/ condition. While groundwater pressures in the pumped aquifer have declined in aquifer outcrop areas, it is apparent that shallow groundwater has been buffered from the regional pressure decline and/or that vegetation has adapted to the decline in groundwater level. This study has shown how 'hard' field data, providing a snap shot of groundwater-vegetation interaction, can be supplemented by remote sensing to provide a fuller temporal picture of tree water use and condition.

Assessing management options for improving floodplain vegetation health with models of unsaturated zone water and salt fluxes

Chris Li, Graham Green,
Department of Environment Water and Natural Resources

The ecological health of the River Murray floodplains has deteriorated substantially over several decades, due to river flow regulation resulting in reduced flooding frequency and elevated groundwater salinity. The South Australian Riverland Floodplain Integrated Infrastructure Program (SARFIIP) is to establish infrastructure that will enable management options including managed surface inundation and manipulating and maintaining the freshwater lenses in the watertable aquifer through groundwater pumping. One of SARFIIP's objectives is to enhance ecological conditions to promote health and resilience of flora and fauna. This requires the establishment and maintenance of root zone salinity conducive to the health of floodplain vegetation. To enable the potential salinity benefit to the root zone to be assessed, modelling was undertaken to examine the variation of vertical water and salt fluxes in the unsaturated zone under the proposed management methods. A suite of unsaturated zone models representative of various floodplain conditions was developed using LEACHM, which is a one-dimensional process-based model of water and solute movement in variably saturated media. Since the floodplain environment is highly heterogeneous, different combinations of soil profiles, vegetation rooting depths and watertable depths were considered. Management scenarios simulated included (i) no actions; (ii) groundwater freshening; (iii) managed surface inundation and (iv) groundwater freshening and inundation combined. The results show that if no actions are undertaken, soil salinity near the surface will keep increasing due to capillary rise and evapotranspiration. Where freshening of saline groundwater occurs, the lower soil profile benefits from slightly reduced salinity but upper soil layers (0 – 2 m) remain saline for the duration of a 100- year simulation. Where managed surface inundation occurs, significant freshening of a previously saline soil profile is achieved, however deep rooted vegetation may draw saline groundwater upwards. Where groundwater freshening and inundation occur in combination, the salinity of the entire soil profile is reduced.

Modelling Salt Dynamics on the River Murray in South Australia – Floodplain Modelling

Virginia Riches, Juliette Woods, Tariq Laattoe, Carl Purczel
Department of Environment, Water and Natural Resources

The River Murray is part of a river-floodplain system that is naturally prone to salinity. Groundwater models of the River Murray region in South Australia have been developed in recent years to inform long term salinity management and reporting obligations, however few have focussed on floodplain groundwater processes. The aim of this work was to simulate floodplain processes in a groundwater model, to improve conceptual understanding and investigate the best modelling methodology. A groundwater process model was developed to enable floodplain processes to be investigated separately. The process model was based on real world data, including hydraulic parameters, stratigraphy and the relationship between groundwater and surface water. The model included the overlying clay layer of the Coonambidgal Formation, which is commonly omitted from groundwater models due to it being limited to the floodplain environment and model convergence issues that tend to occur when it is included. The model was constrained with current understanding of floodplain evapotranspiration, groundwater fluxes into the floodplain and flux to river. The floodplain processes investigated with the model included changes in river level, floodplain inundation and evapotranspiration. Various topographic and hydrogeological situations were simulated. Spatial discretisation, temporal discretisation, parameter sensitivity and process representation were explored. It was found that time discretisation was important for capturing the impact of fluctuating river levels and that changing how evapotranspiration is implemented can result in changes to key interactions between surface water and groundwater. This work highlighted the importance in floodplain modelling of understanding the scale at which processes occur and how they interact. It also resulted in recommendations for floodplain modelling methodology, including appropriate MODFLOW code and associated solvers and packages.

Groundwater model for managing a saline floodplain at Pike, South Australia

Carl Purczel, Virginia Riches, Juliette Woods
Department of Environment, Water and Natural Resources

The South Australian River Murray floodplain is naturally saline, but river regulation, land clearance and irrigation have exacerbated the salinity, leading to ecological degradation in some areas. The South Australian Riverland Floodplains Integrated Infrastructure Program (SARFIIP) aims to improve the health of selected floodplains through saline groundwater management works and the construction of environmental regulators to inundate large floodplain areas. One of the selected floodplains is at Pike, South Australia, south of Renmark. A groundwater model is being constructed of the floodplain with the initial aim of improving conceptual understanding. Prior modelling studies of the region have focused on salt flux to the river, while neglecting the impact to the floodplain. Floodplain processes are generally not well understood and are rarely included in any detail, especially within a regional scale groundwater model, primarily due to the complexity of these processes. This model is an attempt to incorporate the current understanding of the processes operating within a floodplain environment with particular emphasis being placed on recharge and evapotranspiration. This requires simulation at finer spatial and temporal scales than previously attempted for the site. The model simulates both groundwater and solute transport, using MODFLOW and MT3D. Model construction required careful representation of river level change, evapotranspiration, inundation recharge and solute transport. The model is informed by detailed LiDAR topography, remote sensing of actual evapotranspiration, soil surveys, electromagnetic geophysical surveys of various kinds, bore logs, aquifer tests, aquifer monitoring, unsaturated zone modelling, surface water models, and a series of generic groundwater process models. The construction and calibration process is detailed. The model will continue to be updated to incorporate the findings of ongoing fieldwork at Pike Floodplain. The eventual aim is to develop a model which can be used to assess the salinity impact of works and measures on the floodplain.

Sustainable yield concepts in atoll islands

Peter Sinclair[1], Sandra Galvis Rodriguez[1, 2], Amandine Bosserelle[1], Vincent Post[2], Adrian Werner[2],
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2. Flinders University, Adelaide Australia

Historically, the concept of sustainable yield has been developed and applied to relatively large continental groundwater environments with complexities and competing demands requiring sophisticated management approaches. Groundwater resources in atoll islands by contrast are shallow, of limited extent, are developed mostly for domestic needs only, and require management approaches which are suited to the unsophisticated environment in which they are found. Atoll groundwater systems are unique in having a thin freshwater lens 'floating' on a body of brackish water. The freshwater, accessed via shallow wells, is limited only by the quality or salinity of the groundwater that the community is prepared to accept. In the Pacific different communities tolerate different salinities at different times, depending on their need and the availability of alternative freshwater supplies. Groundwater which is routinely consumed and used by one community will be considered too saline by another. Early studies of atoll groundwater resources focused on identifying the safe yield of groundwater, that is, the amount of groundwater available within an extended dry period that does not breach a nominal salinity level. This approach, whilst useful to help guide development, may be considered restrictive in some cases for the longer term management. Therefore, there is a need to develop versatile sustainable yield approaches suitable for application with island communities with different needs. The concept of a sustainable yield range is being investigated with the support of the European Union for two Pacific cases studies, Kiribati and Tuvalu. The range will be based on pre-agreed acceptable salinity levels that government and community are prepared to tolerate under different conditions, for pre-defined periods, with consideration of impacts to the groundwater system. This paper will explore the development of this approach, and present some preliminary findings.

Impact assessment of a freshwater lens on atoll islands using numerical modelling

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Fresh groundwater is a scarce resource on atoll islands and faces short-term threats from increasing demand, extreme weather conditions, pollution, as well as long-term climate change and sea level rise. On the atoll of Tarawa in the Republic of Kiribati, salinisation of the Bonriki island freshwater lens, driven by increased pumping to meet the rising demand caused by population growth, is a key concern. In this study, published literature and analysis of historical records of salinity and water level measurements were used to develop a conceptual model of the Bonriki freshwater lens. A numerical groundwater model of the variable-density groundwater flow system was built using SEAWAT. This model was used to assess the impacts from groundwater abstraction, climate variability, inundation from storm surge overtopping events and sea level rise. The model results highlighted the strong control of rainfall variability on the temporal dynamics of the freshwater lens. The numerical model scenarios further showed that abstraction is one of the most significant parameters influencing the modelled salinity. The longevity of the adverse effects of inundation was found to be strongly dependent on the recharge conditions after the flooding event.

Assessment of water resources in atoll islands

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2. Government of Kiribati

Water is a scarce resource in atoll islands. Limited rainwater harvesting and small fragile freshwater lenses can result in a shortage of freshwater for communities domestic water needs during extended dry periods. Undertaking groundwater resource mapping in outer islands and developing options for improved water supply with communities is one of the objectives of the European Union funded KIRIWATSAN project. Water resources assessments were carried out in thirty six villages across eight atoll islands to identify options for improved water supply and sanitation in keeping with the socio economic and cultural constraints and preferences of the island communities. Groundwater is relied upon for the domestic water supply needs of over 90% of all households. The size of freshwater lenses, identified using electromagnetics, varied from negligible to significant, with the variability in freshwater thickness dependent on sediment composition, island width and rainfall recharge. Survey investigations estimated the available groundwater resources with options for groundwater abstraction and identification of drought-resilient areas.
Existing groundwater wells are in general poorly constructed and susceptible to contamination, with more than 80% of tested wells indicating the presence of E. coli. Improvements in well design and well abstraction techniques such as locally-made hand-pumps or Tamana pumps, coupled with awareness and collaboration with the village community will improve fresh water supply availability, water safety and water security longer term. Collaboration with the village council and the community to customise and institutionalise water management, operation and maintenance systems into the existing village structure and societal setting is essential to the long-term success of improved water supply systems in these isolated and self-sufficient communities.

Electromagnetic Mapping of Freshwater Lens Thickness in Outer Atoll Islands, Bikaati, Kiribati

Amit Singh
Secretariat of the Pacific Community

Amongst other methods EM procedure to assess freshwater lens thickness on low atoll islands is the most preferable one. Based on simple assumptions such as; water table close to the sea-level, the freshwater seawater interface lies with the penetration scope of the EM34 i.e. in the upper 30m, and the geology of the island along the profile is homogenous and ''offshore'' calibration (calibration on mainland at Bonriki water reserve), freshwater lens thickness on an atoll island which do not have monitoring bores can be mapped using electromagnetic method. For Bikaati the maximum freshwater thickness of 4m is aligned towards the lagoon, where unconsolidated sediments are thickest, and islet width maximum. The freshwater lens thins out as the islet width decreases. The thin freshwater lens is vulnerable to contami-nation from the surface source. The thin lens on the islet constitutes no further groundwater development. Further de-tailed study of freshwater lens on Bikaati may involve electrical resistivity imaging, however relatively thin lens reduces the need for such a survey. Many atoll islands successfully meet the criterion for successful application of this method, and extents freshwater lens of these islands can be successfully determined.

Recharge dynamics to a freshwater lens on a tropical island

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Knowledge of the balance between groundwater recharge and discharge is vital to sustainably manage groundwater reserves stored in freshwater lenses on islands. In tropical ecosystems, recharge and discharge are characterised by large seasonal variations whereby very wet periods of heavy monsoonal rain alternate with long periods of little to no rain and high evapotranspiration.
This study applied a range of different hydrogeological and hydrochemical techniques to estimate groundwater recharge to a freshwater lens on a remote tropical island in the Arafura Sea, Northern Territory. The techniques included established approaches such as, the chloride mass balance technique, the water table fluctuation method and borehole temperature profiling. In addition, environmental tracers (chlorofluorocarbons- CFCs, SF6, tritium and carbon-14) were used to determine the apparent groundwater age and estimate recharge. The island's annual rainfall (1090 mm) falls predominantly between the months of November and April. The flat topography and permeable unsaturated zone promotes infiltration. Young groundwater, indicated by the presence of CFCs, SF6 and tritium was observed up to 60 metres below ground surface. Groundwater recharge estimates based on CFC-12 ranged from 25 to 150mm/yr. Chloride concentrations in many of the shallow groundwater wells suggest recharge rates of 10 to 160 mm/yr. Measured water levels show that groundwater recharge to the aquifer during two recent cyclone events can be more than a metre within a 24 hour period. The results of this study showed that the application of different methods can help reduce uncertainty in groundwater recharge estimates because of the different spatial and temporal resolutions at which each method applies. It also raised further questions on the conceptualisation of the groundwater system, and emphasises that using different types of data can often reveal the true complexity of a seemingly-simple groundwater system.

Understanding groundwater dynamics on barrier islands using geochronological data: An example from North Stradbroke Island, South-east Queensland

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Freshwater lenses underneath barrier islands are dynamic systems affected by changing sea levels and groundwater use. They are vulnerable to contamination and over-abstraction. Residence times of fresh groundwater in barrier islands are poorly understood and have mostly been assessed by modelling approaches and estimates without fundamental validation with chronological estimations. Assessing residence time and recharge rates will improve significantly our understanding of hydrological processes of coastal environments that will in turn allow us to make informed decisions on groundwater use and environmental protection. This project focused on groundwater recharge rates and residence times of the fresh water aquifer system of North Stradbroke Island, south-east Queensland, Australia. Groundwater bores, wetlands and submarine groundwater discharge points in the tidal areas (wonky holes) were sampled along a transect across the island and were analysed for major ion chemistry and stable isotopes (δ2H, δ18O, δ13C) in combination with 3H, 14C analysis and 222Rn. Calculated 3H using a 90% exponential-piston flow model and 14C ages range from 12 to >100 years and modern to 3770 years, respectively, indicating a highly heterogeneous aquifer system with mixing from low and high conductive areas. The major ion chemistry in combination with stable and radiogenic isotopes suggests that a significant groundwater component derives from the fractured rock basement and older sedimentary formations underlying the sand dunes of the island. The results help refining the conceptual and numerical groundwater flow model for North Stradbroke Island in this particular case but also demonstrate the possible complexity of barrier island hydrogeology.

Effects of alongshore morphological variations on nearshore groundwater flow and solute transport: field observations and 3D numerical simulations

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The effects of morphological variations on nearshore groundwater flow and solute transport were investigated through field measurements and three-dimensional (3D) variable density groundwater models of a permeable carbonate sand system on the island of Rarotonga. The results show that the bi-directional beach morphology, combined with tides, induced a significant alongshore flow component, and modified greatly local circulating transport of pore water and salt in the intertidal zone. The hydraulic condition and bathymetry of the creek enabled further and more rapid landward intrusion of seawater, which in turn provided additional alongshore hydraulic head and concentration gradients to drive pore water flow and salt transport in the alongshore direction. The creek explained a saltwater plume at an intermediate depth between fresher water. This salt plume would otherwise be considered anomalous if flow and salt transport were modelled only in the 2D vertical section along the measurement transect. The 3D pore water flow in the nearshore zone was also complicated by the landward hydraulic head condition, resulting in pore water drainage across the landward section of the creek while seawater infiltrating the seaward section of the creek. Our results provide new insights into the complexity, intensity and time-scales of mixing among fresh groundwater, recirculating seawater and creek water in three dimensions. The 3D characteristics of nearshore pore water flow and solute transport, not simulated by previous 2D models, have important implications for studies of submarine groundwater discharge and associated chemical input to coastal sea as well as conditions of the beach habitat.

Discrimination between anthropogenic and seawater contamination in the coastal groundwater of Hermitage (Reunion Island) from geochemical investigations

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Salinization remains a major cause of degradation of water quality in the world. This widespread phenomenon is particularly problematic in arid or semi-arid areas where freshwater resources are found in very limited quantities and where the recharge by rainwater is low. The mechanisms behind the salinization of a groundwater system are various and complex owing to the diversity of geographical contexts, geological settings and climate variability. In Reunion Island (Indian Ocean), the main factor involved in the salinization of groundwater bodies is the seawater intrusion. However, various anthropogenic sources also exist, such as domestic waste-water or agricultural return flow. Determining the origin of the salinity is a prerequisite to effectively manage this problem. Combined with hydrogeological investigations, geochemical methods, including the use of major and minor elements molar ratios, have proven particularly suitable for the discrimination of salinity sources. In the coastal aquifers of Hermitage, hydrogeological time-series were recorded and chemical analyses were carried out at quarterly frequency. Hydrogeological time-series analysis revealed that 1) the groundwater mineralization is influenced by tidal fluctuations, 2) the groundwater electrical conductivity raised during the monitoring period, and 3) direct intensive infiltrations triggered peaks of salinity. Chemical analyses carried out during the same period showed a rise in the major anions Cl-, SO42- and NO3-, with an excellent correlation coefficient of 0.98 between electrical conductivity and sulfate concentration. The Na+/Cl- and SO42-/Cl- molar ratios calculated are respectively equal to 1.6 and 0.10. These values indicate clearly an anthropogenic impact associated with a discharge of domestic waste-water. This study underlines the efficiency of geochemical tools in order to discriminate the origin of salinity in these contexts under anthropic pressure.

Hydrochemical assessment of a freshwater resource on Rottnest Island, Western Australia

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This project investigated the groundwater hydrochemical processes within an Island aquifer system on Rottnest Island, located ~18 km west of Perth, WA. A freshwater lens on the Island supplies around 25% of the Island's potable water requirements, however there is limited information regarding the dynamics of the lens and its resilience to ongoing abstraction and reduced recharge. Understanding the hydrochemical processes and residence times of the groundwater is essential for making use of the system sustainable. Groundwater samples were collected quarterly from 12 production bores to obtain seasonal information and from 15 monitoring bores biannually to monitor the mixing zone. Rainfall samples were collected on a weekly basis. The chemical composition of water samples were analysed by ion chromatography and inductively coupled plasma-mass spectrometry, while δ18O and δ2H stable water isotopes (SWIs) were analysed by isotope ratio mass spectrometry. Tritium was analysed by liquid scintillation after being distilled and electrolytically enriched. Hydrochemical analysis shows varied water types and suggests a mixing trend between a fresh and saline end-member. Samples range in composition from fresh Ca-Na-Mg-HCO3-Cl to saline Na-Cl groundwaters with increasing electrical conductivity (EC). The mixing trend is also observed in the SWIs results, with the values becoming more enriched with increasing EC. Fresh water within the lens was found to be 'young' and recharged within the last 10 to 30 years. While the fresh groundwater beneath Rottnest Island was found to be recently recharged and is arguably a sustainable resource, the hydrochemical results highlight the importance of a long-term management strategy to ensure that the mixing zone below the freshwater lens does not increase to a point where the freshwater source is no longer viable. The declining winter rainfall in the Perth region, resulting in reduced recharge to the lens, makes the management of this resource even more essential.

Towards a numerical approach to identify Hydrogeological Landscape Units

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Groundwater salinity remains a major issue due to its impact on agriculture and infrastructure. In Australia, it is recognized that groundwater salinity varies significantly across space and time. In NSW, the state government has developed a landscape classification for management based on hydrogeology, landuse and landscape aspects, mainly derived from GIS overlays and operator experience. In this study, we use historical water quality data, geology and drilling logs to develop a more rigorous numerical approach to landscape classification. A combination of statistical methods (Generalised additive model (GAM) and Semi-variogram analysis) was used to identify the significant spatio-temporal factors that induce the variability of groundwater salinity across the Muttama catchment (1059km2) in the southern part of NSW, Australia. The statistical model explained 88% of the variance in the electrical conductivity levels in the groundwater across the landscape. Geology and lag rainfall were the key factors that explained overall catchment groundwater salinity, thus defining the hydrogeological landscape units. Semi-variogram analysis revealed the remaining residuals did not indicate further spatial organisation. Current work focusses on also predicting groundwater response times. Therefore, the results of this study highlighted framework to numerically develop hydrogeological units based on the geological landscape characteristics.

Reinterpretation of the stratigraphy of Murray-Peel area of the Southern Perth Basin.

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The Murray-Peel area is located south of Mandurah and is one of the fastest growing regional areas of Western Australia. The area has been historically dependent on groundwater and yet despite this, major aquifers in the area have always been relatively poorly understood, with most groundwater users dependent on the unconfined superficial aquifer. However with the unconfined aquifer nearing full allocation there is increasing interest in the potential of the underlying groundwater units, in particular the Leederville aquifer. To investigate the potential of the deeper aquifers and to better understand this resource the Department of Water undertook a major drilling investigation program between late 2012 and 2013. The main target of the investigation was a better knowledge of the Leederville aquifer, including its distribution, water quality, yield and recharge mechanisms. Pre-existing stratigraphic and geophysical information was combined with new lithology and geophysical logging, palynology, water chemistry and isotope data collected from a series of 19 investigation bores drilled as part of the project. As a result of the investigation, the stratigraphy and hydrogeology of the area has been significantly reinterpreted. For example, there is extensive evidence of the presence of both the Cattamarra Coal Measures and Eneabba Formation at significantly shallower depths than was originally anticipated during the investigation design. There is also evidence that structural control of the depths and distribution of these units is more significant than was originally thought. This paper will discuss how this revised stratigraphic interpretation has been developed over the course of the investigation and its implications for groundwater management in the area.

Hydrogeological evidence for covered karst in southwestern Victoria, SE Australia

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The Early-Late Miocene Port Campbell Limestone is a cool-water open marine calcarenite deposited across much of southwestern Victoria, and is mostly overlain by a thin sheet of the marine Pliocene Loxton Sand, deposited as coastal dunes and offshore muds. The limestone is a porous, high-yielding, largely confined aquifer with dual porosity/permeability: 30-50% intergranular porosity and transmissivity of 150-400 m2/day, along with karstic transmissivity of <3000 m2/day due to conduits intersected in ~3% of bores. The high quality groundwater (<1000 mg/l) is extensively used for irrigation and town supplies. The Port Campbell Limestone is not generally regarded as a karst aquifer, and there is little obvious karst geomorphology (e.g. cave systems, sinking streams or springs). A detailed hydrological/hydrogeological study was undertaken on three small catchments on the northern margin of the Port Campbell Limestone. The topography of the southern catchment is characterised by a shallow closed depression that represents a doline developed in the limestone beneath the clay-rich Loxton Sand. The watertable contour map also shows a closed depression attributed to the presence of subsurface conduits within the limestone (responsible for the doline development). The northern catchments, where the limestone is thinner, show subsurface capture of surface drainage, such that there is virtually no surface runoff from one of these catchments due to leakage into a conduit in the underlying limestone. Thus the study areas show the presence of a covered karst that is probably characteristic of the entire aquifer, with the typical karst features of doline development and strong connectivity between surface water and groundwater regimes. Groundwater management plans for the Port Campbell Limestone must take its karstic nature into account; the rapid rate of conduit flow means that changes to recharge and/or contaminant plumes may be much more quickly transmitted through the limestone than if flow were entirely intergranular.

Geochronology of the Condamine Alluvium

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1. Klohn Crippen Berger
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The Condamine Alluvium is an important source of water for a variety of industry between Toowoomba and Chinchilla. Numerous technical studies have been completed on the system over the past four decades; conceptualisation studies, groundwater models and field testing. Despite this effort, the system still presents challenges in understanding, particularly: why is the lowest point of the system not at the 'downstream' end? why is alluvium downstream of Chinchilla so constrained?, why is recharge so limited? and why does geology and chemistry dramatically transition from south to north? This paper presents an interpretation of the evolution of the Condamine Alluvium, with particular emphasis on its relationship with the Main Range Volcanics of the Toowoomba region. A sequenced and logical approach to understanding depositional settings, alluvial source material, evolving landforms and time, has been developed. This has been used to build a history of the system to understand why some areas of alluvium are starkly different to others, and why the alluvium appears atypical of other drainage patterns west of the Great Divide.
Original interpretation comprises deconstruction of regional scale geological systems supported with direct comparison of the unique attributes of the Condamine with other alluvium in the region. Areas of uncertainty are acknowledged and discussed. This geochronological summary is by no means complete and without conjecture. Further work is required to confirm areas of uncertainty, and other postulated geochronological models should be considered. The main value of this work is that it places depositional understanding on the nature and distribution of alluvium, and hence provides technical understanding to better inform the manner in which water resources system might be managed.

Interactive Hydro-stratigraphic 3D PDF Models

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As part of DEWNR's Non-Prescribed Groundwater Assessment project, simplified hydro-stratigraphic 3D models were produced for sedimentary basins in several Natural Resources Management Regions in South Australia. The aim of the 3D models is to improve the understanding of the geometry of the groundwater systems and allow estimation of groundwater storage volumes. The 3D models are viewed using Adobe Reader® and can be downloaded from DEWNR's WaterConnect website (link below). Groundwater data used in the production of the 3D models is sourced from the National Groundwater Information System database. These data are interpolated using algorithms based on the Australian National University Digital Elevation Model program to spatially display simplified hydro-stratigraphic units. Other data inputs used included digital elevation models, hydro-stratigraphic logs, seismic data and surface geology. Groundwater level and salinity data are also incorporated where they are available. ESRI ArcGIS® and AquaveoTM ArcHydro Groundwater applications were used to produce model elements and to export to 3D format. The model was formatted into an Adobe Portable Document Format (PDF) to allow model elements to be controlled via interactive buttons. Users can zoom, rotate, toggle layers on and off, generate cross sections and apply vertical exaggeration. The models provide a readily accessible 'state-of-the-art' 3D model with a small file size. The models are capable of providing estimates of aquifer storage volumes, context for groundwater drilling projects and assist in identifying groundwater resources for future development. The models currently guide the validation and verification of groundwater data (e.g. determining aquifer monitored) and support targeted groundwater investigations. Future uses may include groundwater assessments and management. The models can be upgraded as knowledge of groundwater systems improves and additional information becomes available.

Quantitative assessment of the value added to regional groundwater model predictions by airborne geophysical surveys

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Numerical models of groundwater flow are invaluable for aiding water resource management decisions. The models are often constructed based upon limited and uncertain sub-surface data collected at point locations. Consequently, the simplification of groundwater systems required to construct numerical models of groundwater flow may be poor representations of the true system. Recent research into the effect of model simplification suggests that poor model simplification can lead to model prediction bias and predictive error variance that can increase with model calibration. Inclusion of interpretations from airborne geophysical surveys in construction of geological models promises to improve true system representation, and this study quantitatively examines the effect of including airborne geophysical interpretations in groundwater model construction on model predictions. A synthetic case study is presented where a geological model is constructed to represent the “true” system, and transferred to numerical models for forward modeling of synthetic transient electromagnetic (TEM) data, and hydraulic head data. In a first test case a simplified geological model is constructed based upon sparse point samples of the true geological model, transferred to a numerical model of groundwater flow and calibrated against the synthetic hydraulic head data. In a second test case a simplified geological model is constructed based upon point samples of the true geological model and the interpretations from an inversion of the synthetic TEM data, transferred to a numerical model of groundwater flow and calibrated against the synthetic hydraulic head data. We present a comparison of the groundwater model predictions of the two test cases with respect to the “true” model prediction. Based on the results, we contend that increased use of geophysical surveys in regional groundwater resource assessments improves aquifer understanding, and groundwater model predictions leading to more informed groundwater management.

Regional-scale mapping on a local-scale budget. A case-study from the Murchison region of Western Australia

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The communities, industry and environment of the Murchison region of Western Australia are dependent on groundwater to meet their water requirements. This includes town water supplies, Aboriginal communities, mining, pastoral users and the environment. The Murchison region is known to have significant palaeochannel groundwater resources. However, despite their importance to the region and an increasing recognition as a significant groundwater resource, the distribution and properties of these palaeochannels have historically been poorly understood, with much of the previous groundwater investigation and development concentrating on shallow alluvial or calcrete aquifers. Meeting and balancing the often competing water requirements of the diverse range of users requires water managers to have the best possible understanding. To address this requirement the Western Australia Department of Water and CSIRO designed and undertook a large-scale regional investigation project targeted specifically at understanding the palaeochannel groundwater systems. The project has adopted a very non-traditional airborne electromagnetic (AEM) survey design approach in an attempt to minimise the collection of data that is outside the bounds of the anticipated area of the palaeochannels and therefore not relevant to the project objectives. This approach met the objective of producing an accurate three-dimensional understanding of the palaeochannels over an extremely large project area – approximately 6% of Western Australia – while staying within the constraints of a limited project budget. This paper will discuss in detail the survey design approach that was taken, comparing the anticipated results from the design phase with the outcomes of the survey. It will also discuss the potential for this approach to be more widely adopted in designing future regional AEM surveys that have very specific mapping targets.

Facies prediction for locating groundwater supplies in Timor-Leste using airborne electromagnetic data

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CSIRO

In this work we show the reprocessing and inversion of a frequency-domain helicopter-borne electromagnetic data (FDEM) acquired the Baucau karst in Timor-Leste.
Transforming electromagnetic data to models of conductivity and depth will yield a great deal of different models which will vary according to the processes applied to the data and the algorithms used. In this case we have firstly re-calibrated the original in order to get a better agreement between the measured and predicted data. We then have inverted the recalibrated data using a deterministic few-layer and smooth-layer inversion. And lastly, on the recalibrated data we have also run a trans-dimensional Bayesian McMC algorithm in order have a better understanding of model uncertainty, at each airborne electromagnetic (AEM) survey location. The reprocessing and inversion results from the AEM data, we have used as the stepping stones in the interpretation and understanding of the framework of the regional hydro-geology and the architecture of the Baucau plateau. Conductivity and depth sections, derived from the survey, enabled us the prediction of preferential flow paths within the Baucau limestone. And drove our selection of ten sites where surface nuclear magnetic resonance (SNMR) soundings where acquired, based on prognostics of where the highest yielding free flowing groundwater is most likely to be within this study area.

Combining geophysical datasets for determining groundwater resource potential linked to remote communities in the APY lands, South Australia

Aaron Davis, Andy Parsekian, Denys Grombacher, Kevin Cahill and Brady Flinchum
CSIRO

The Anangu Pitjantjatjara Yankunytjatjara lands of South Australia are dependent on groundwater for almost all of its water needs. However, much of the region is challenged by the paucity of hydrologic and hydrogeological information. In a project that combined the interpretation of regional airborne geophysics with ground-based time-domain electromagnetics (TEM) and surface nuclear magnetic resonance (sNMR), the nature and geometry of an aquifer system supporting the local community in Kaltjiti was refined and the groundwater resource potential of the area confirmed. The structural grain of the region, defined through an analysis of airborne magnetics, is dominated by extensive E-W shearing forming localised wrench grabens, interpreted to contain significant sediment packages and groundwater. To the north of Kaltjiti, we identified a localised wrench graben, with an interpreted sediment infill. Local stock bores tapped this aquifer although its geometry and therefore the available resource remained undetermined. The acquisition of TEM and sNMR soundings across the structure helped define the aquifer sequence and geometry. Their combination provided results that were used to infer the groundwater content, quality and hydraulic properties of the aquifer. The TEM indicated that the graben contained a relatively conductive sediments, while the sNMR results indicated that groundwater was present in the near surface, extending deeper into the graben structure. Previous studies have determined that rapid, episodic recharge is the dominant driver of groundwater recharge in the area. The relative young age of the groundwater sampled in the graben supports this. Although the aquifer hydrodynamics around Kaltjiti is unclear, this study has helped constrain elements of the story and lends support to the use of regional and targeted local geophysical investigations to elaborate the groundwater resource potential that supports industry and community alike in these remote areas. Further use of the methods described here are currently underway in the region.

A Regional Water Balance model for the South East of South Australia: Addressing challenges associated with shallow water table simulation

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A regional-scale groundwater flow model and LEACHM unsaturated zone model have been developed as part of the Goyder South East Regional Water Balance Project. These models, in combination, fill a critical need to quantify the regional water balance for the south east of South Australia, where groundwater is the primary water source. The south east of South Australia presents a number of modelling challenges. In particular, it is characterised by very shallow water tables, meaning that accurate simulation of the relationship between depth to water table and recharge/discharge processes is critical. This is difficult within a regional scale groundwater model with large (i.e., 1 km x 1 km) cell size. The objective of this research was to develop an understanding of the potential for uncertainty when using different modelling approaches for representing recharge/discharge processes within the regional scale water balance model. The approaches differed in the degree to which they incorporated topographic variation and water table dynamics. The analysis highlights the high potential for uncertainty when modelling recharge/discharge processes in shallow water table environments and provides guidance for future modelling activities in these environments.

Optimising regional groundwater monitoring networks: 'Data Worth' and 'Correlation' methods

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Groundwater monitoring networks are costly to maintain and efforts to identify the most cost effective disposition of monitoring networks are the focus of many jurisdictions. One example of this effort is in the Kapiti coast region, New Zealand, where a long term groundwater monitoring network was established with the purpose of assessing long term groundwater trends, and the impact of increasing levels of groundwater abstractions on streams, rivers and wetland areas within the catchment. To ensure the Regional government is spending its monitoring budget most effectively, the current monitoring network is being reviewed. Two analyses were undertaken to both identifying the 'optimal' disposition of this network for a fixed budget (which could include the installation of new wells), and identify any redundancy within the network. The first method was a model based data worth analysis, which assessed the effectiveness of each individual bore within the existing and proposed monitoring network. The worth of data from each monitoring bore was defined by the extent to which the uncertainty of a specific prediction is reduced through acquisition of the monitoring data from that well. The specific predictions related to the purpose of the monitoring network, e.g. the impacts of groundwater abstraction on wetland water levels or stream depletion rates etc. The second method used correlation of groundwater level time series between wells, and where wells were highly correlated, redundancy of effort was identified. The study successfully demonstrated that the substantial financial costs of a regional monitoring network can be optimised (even a priori), by understanding of the value of various monitoring strategies in terms of informing key decisions, to ensure the greatest return on investment.

Going beyond interpolation for the parameter estimation and uncertainty analysis of groundwater models by using copulas for constrained spatial field generation

Sreekanth Janardhanan, Andras Bardossy, Sebastien Hoerning
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Inversion based approaches are popularly used for the parameter estimation of groundwater models. While some approaches assume homogeneity or piecewise constancy of the groundwater model parameters, others incorporate spatial heterogeneity by considering the geostatistical structure of the underlying parameter fields. In the latter approach, the parameter values are often estimated at pre-determined control points or pilot points and are interpolated to the rest of the numerical model grid. Interpolation often results in artificial smoothing of the parameter fields in the groundwater model. In this study we illustrate a methodology based on conditional spatial field generation using Gaussian copulas for the calibration and uncertainty analysis of numerical groundwater models. In this method a conditional hydraulic conductivity field is generated as a weighted sum of unconditional Gaussian random fields generated using spatial copulas. The squared sum of these weights is optimised to meet the linear equality and inequality constraints imposed by point or local measurements, for example hydraulic conductivity measurement obtained from pump-tests. Subsequently, the methodology helps to identify continuous domains of weights for combining unconditional random fields with the advantage of incorporating non-linear constraints. Typical non-linear constraints encountered in the calibration of groundwater models include matching the observed groundwater head distribution in space and time. Using the proposed approach, infinite number of hydraulic conductivity fields which satisfy these non-linear constraints can be generated which helps in the quantification of the uncertainty in the groundwater model. We applied this methodology for the calibration and uncertainty analysis of a synthetic groundwater model and compared it with the Null-space Monte Carlo analysis using pilot point approach. The proposed method was found to be more comprehensive and less subjective in describing the groundwater model prediction uncertainty over the other method.

Gradient-Based Calibration and Uncertainty Analysis using a Simplified Surrogate Model Conjunctively with a Complex Groundwater Model

Wesley Burrows, Dr John Doherty
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Groundwater models are becoming increasingly more complex, both in terms of structural detail incorporated to replicate complex geological environments, and also the algorithms employed to simulate complex hydrogeological processes. Such models may attempt to simulate variable-density flow and transport and/or de-saturation and re-wetting, for example. Inclusion of such complexity is warranted in pursuit of a more accurate simulator of system state, however will inevitably lead to lengthy model runtimes and highly non- linear observation to parameter relationships. Both these outcomes can be prohibitive to the application of the efficient Gauss-Marquardt-Levenberg (GML) method for parameter estimation and uncertainty quantification. A simplified surrogate version of the original model can be effectively integrated into GML estimation, where the former is used for the calculation of observation partial derivatives with respect to parameters that collectively comprise the Jacobian matrix. Theoretically, if the original complex model is maintained for parameter upgrade testing, the meagre consequence of this conjunctive usage, should there be any, will be a loss of parameter resolution. Of course this means that a reduction in potential parameter variability may not be achievable to the extent that it might using the complex model alone, however this may be a small price to pay for the amenity of using GML. Approximation of posterior parameter probability can then be further improved through imposition of calibration-constraints, in accordance with the detailed model's assessment of this, and this task made more computationally efficient with similar conjunctive usage. We demonstrate this approach through the medium of several synthetic test cases where variable-density flow conditions prevail. Simplification strategies such as grid-coarsening and analytical versions of the complex model are integrated into GML estimation and facilitated by functionality implemented in PEST. This approach is ubiquitously applicable to gradient-based estimation methods and has immediate application in modelling exercises plagued by excessive runtimes and numerical convergence difficulties.

Modelling surface water - groundwater interactions for conjunctive water management using eWater Source

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The need for conjunctive management of surface and groundwater resources is well recognised but estimating the impacts of stream-aquifer fluxes on surface water flows and groundwater levels remains a challenging task. Surface water – groundwater interactions tend to be poorly handled in both surface and groundwater models. Surface water models often represent groundwater interactions as a simple loss or gain while groundwater models often represent the river as a simplistic boundary condition. Tools that do explicitly represent surface water – groundwater interactions are rarely implemented within a framework that facilitates conjunctive water resources planning and management. Additionally, such tools tend to be computationally and data intensive and their application can be limited due to data and resource constraints. Motivated by these issues, a new groundwater modelling tool has been developed for the eWater Source modelling platform. Source is designed to simulate all aspects of water resource systems to support integrated planning and management at urban, catchment and river basin scales. The new Groundwater Numerical Model for 1- Dimensional Flow (GN1D) estimates the stream-aquifer flux, including the impacts of processes such as groundwater pumping, injection, evapotranspiration, rainfall and irrigation recharge and flood recharge. The GN1D model is designed to be simple and easy to use, representing the dominant processes while avoiding the data and computational complexities of a full 3D groundwater flow model. It complements and extends other surface water – groundwater interaction tools already available in Source. We examine the performance of the GN1D model using a case study in the Upper Macquarie groundwater management area in New South Wales, Australia, where both surface and groundwater resources are extensively utilised. Strengths and limitations of the approach are explored through comparison with a MODFLOW groundwater model of the region. The results indicate that the GN1D model is able to adequately capture the surface-groundwater exchange flux and highlight the types of processes that the model is suitable to represent.

Comparison of zonation and pilot points approaches in regional groundwater flow models: implications for prediction accuracy and uncertainty quantification

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Despite the availability of tools to develop highly-parameterized groundwater models, using zones of uniform hydraulic properties is common practice. Reasons include that zonation often constrains the inverse problem to be a well-posed inverse problem, reduces implementation complexity and does not demand high computational resources. However, model simplicity can be an issue in regional models because predictions often depend on the heterogeneity of hydraulic properties. Two consequences of this are: (i) oversimplified models can hardly simulate the system with a sufficient level of accuracy, and (ii) uncertainty quantification is unreliable. Previous studies mainly investigated these issues with synthetic cases at the local scale. This study presents a real-world regional case (the Adelaide Plains regional aquifers system) where implications of model parameterisation are analysed. Both zonation and pilot points parameterisations were implemented and compared. The improvement in the fit to measurements was quantified as well as the difference in uncertainty estimates on a number of key predictions. The magnitude of structural error that should be considered to derive a reasonable level of uncertainty estimates when using the zonation approach is also discussed. The results provide a concrete example of the implications of using a low-parameterisation scheme in a regional scale model.

Accurate Modelling of Horizontal Wells and Tunnels through Upscaling of Screen-Scale Flow Processes

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The aim of this paper is to present a modelling methodology for accurately implementing small-scale geometrical features in large-scale numerical groundwater models, with consideration of their actual geometrical properties on the local scale. Examples of small-scale features (and their properties) are vertical and horizontal wells (with screen diameter), tunnels (diameter and shape) and surface water features like drainage lines and small rivers (width and clogging layer). A direct implementation of small-scale features in large-scale models usually results in numerically challenging model setups with large element numbers and/or strong element size contrasts. The presented method overcomes this restriction by applying an upscaling technique to implement these features while maintaining practical computational effort and model simplicity. In this paper, we present how local scale flow processes that govern the amount of water collected by small-scale features can be transferred from a small-scale model to a regional scale model. The local scale flow process is first modelled on a high-resolution model that can provide a very high level of accuracy. The inflow behavior is then reduced to an upscaling parameter, determined through inverse modelling. The upscaling parameter is finally applied to the regional scale model. The paper presents a number of applications where this technique was applied in numerical modelling projects. The presented examples include vertical and horizontal wells, as well as access tunnels, both in a water management and mining context. Using the presented methodology, it was possible to consider the design parameters of small-scale features in large-scale (regional) groundwater models at a high level of accuracy while maintaining practical numerical effort. The presented methodology can be generalized beyond the presented examples, type of discretization and software utilized.

Methods for simulating subsidence-induced deformation above longwalls in groundwater models

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HydroSimulations

Longwall mining results in subsidence and the associated deformation and fracturing within overlying strata can extend upward to the surface or to environmental or other important features, such as alluvial aquifers and local bores. Understanding the extent and degree of deformation is critical to assessing the effects of longwall mining on a hydrogeological system. This paper outlines some methods and considerations for modelling this fracturing and deformation used by the authors on projects in various NSW coalfields. A number of conceptual models and methods are available for estimating both the height to which deformation will occur and the degree and mode of enhancement to aquifer properties (e.g. recent work by Ditton and Merrick, 2014 or Tammetta, 2012 plus more besides). The geometry and enhanced permeability and porosity properties can be used to parameterise a groundwater model. The use of boundary conditions to simulate downward drainage and zero-pressure conditions in the goaf has some appeal, however the timing and location of these is user-specified and effectively forces a solution on the modelled groundwater system. Rather, simulation of enhanced aquifer properties is recommended, as this allows calibration of the permeabilities applied to the model, and allows more realistic simulation of groundwater level recovery after the cessation of active drainage of the adjacent workings. Time-slice models have been used successfully, however the MODFLOW-SURFACT 'TMP' package (HydroGeoLogic) and MODFLOW-USG 'TVM' package (HydroAlgorithmics) conveniently allow simulation of altered aquifer properties within a single model run, covering both goaf areas and the high permeability and porosity roadways and other workings around longwalls. Calculation of the extent of deformation and assignment of permeabilities can be done on varying scales, e.g. mine-wide, area by area, longwall by longwall, or even (model) cell-by-cell. A cell-by-cell approach is advocated where possible as it allows capture of more detail, specifically changes to sensitive parameters, including longwall cutting height and variation in the depth of cover.

Fast GPU-Parallelised Solvers for MODFLOW-USG

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Long model run times and numerical stability issues often arise when developing large, complex MODFLOW models. The unstructured grid version of MODFLOW, MODFLOW-USG, has helped to mitigate some of these issues in many cases, by allowing model cell counts to be reduced while more accurately modelling important features in a model through localised refinement and appropriately-constrained cell orientations. Despite this, there remains significant room for improvement in model run times as modellers push the boundaries of accuracy and scope in unstructured grid models. In this paper, we present an adaptation of the linear solvers in MODFLOW-USG targeting highly-efficient Graphics Processing Units (GPU), as opposed to conventional Central Processing Units (CPUs). Effective parallelisation and optimisation of solver code to run on the thousands of computing cores offered by modern GPU devices permits significant reductions to be made in overall model run times. This work builds on previous developments in Parallel MODFLOW, a practical and portable suite of MODFLOW codes incorporating fast GPU solvers, and presents the results of extending Parallel MODFLOW to permit fast, parallelised execution of large unstructured grid models in MODFLOW-USG. The new solver is applied on a large, real-world mining model and a medium-sized synthetic model, and the resulting speedups are presented.

Performance of Locally Refined Lower Burdekin Unstructured Grid Groundwater Flow Model

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This paper presents the performance of MODFLOW unstructured grid (MFUSG) model of the Lower Burdekin region in terms of efficiency and accuracy. The existing calibrated conventional structured grid regional Lower Burdekin MODFLOW-2000 (MF2K) groundwater flow model is used as the reference. With similar model results, MFUSG model is found to be efficient as compared to the conventional MF2K model. The performance of the regional Lower Burdekin groundwater flow model with the locally refined grid is also presented. With increased resolution within the Horseshoe Lagoon (HL) area, the predictive capability of the unstructured grid model can be enhanced. The calibrated structured 350mX350m gridded three-layer Lower Burdekin MODFLOW-2000 groundwater flow model (LBMF2KGFM) was first converted to unstructured parent MFUSG groundwater flow model (PMFUSGGFM) using a groundwater utility. While reproducing similar results, it was observed that the run time of PMFUSGGFM was almost one third of LBMF2KGFM by ignoring the inactive cells of the original model. This is encouraging since there is enormous time saving in the calibration and uncertainty analysis processes where repetitive model runs are required. Next, a locally refined child MFUSG groundwater flow model (CMFUSGGFM) of the HL area with a grid size of 175mX175m was created from LBMF2KGFM. The two models, PMFUSGGFM and CMFUSGGFM were stitched together using another groundwater utility. The model water balance in the locally refined HL area was then analysed. The result of the parent-child MFUSG groundwater flow model (PCMFUSGGFM) was similar to that of PMFUSGGFM but with increased resolution within the HL area with a runtime comparable to the parent model. With the acquisition of finer data within the HL area, the predictive capability of the PCMFUSGGFM in the HL area can be improved.

Latrobe Valley Coal Mine Groundwater Modelling using MODFLOW Unstructured Grid

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AGL - Loy Yang, EnergyAustralia and GDF-Suez operate open cut brown coal mines in the Latrobe Valley to supply power to their respective electricity generation stations. To maintain stable geotechnical conditions it is necessary to depressurise the major aquifers at each mine. The objective of this study was to configure and calibrate a regional groundwater model of the Gippsland Basin, and simulate future mine operation scenarios to assess the impacts of aquifer depressurisation and associated land subsidence, and to inform mine rehabilitation planning. The regional groundwater model was developed in MODFLOW-USG with fine grid resolution around the current and future mine areas. The 18 layer model is based on the hydrostratigraphy of the Latrobe Valley, incorporating information from detailed mine geological models. A transient historical groundwater model was configured at monthly stress periods (from 1960 to 2014), and includes groundwater extractions, mine development, land subsidence and recharge (configured using PERFECT), along with various other boundary conditions. The model was successfully calibrated against observed groundwater levels and land subsidence. The calibrated model was used to develop predictive models of future mine development and post-mining recovery. The model has successfully been used to assess the predicted aquifer depressurisation against target aquifer pressures and estimate the extent and magnitude of aquifer induced land subsidence. The model has also been used to assess the post-mining recovery requirements, optimise the placement of overburden within the mines to promote floor stability during the void filling phase, and assess the rate of recovery in the regional confined aquifers. The development of the regional MODFLOW-USG model has allowed the mine operators to develop detailed mine scale models to plan and optimise their individual aquifer depressurisation programs and rehabilitation planning while also talking into account the cumulative impacts of other mine operations and groundwater extractors in the region.

Cautionary tales, tribulations and new approaches for geostatistical water table mapping

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The interpolation of sparse groundwater head observations to produce potentiometric maps is a fundamental hydrogeological approach for understanding the direction of groundwater flow and estimating the change in aquifer storage. Traditionally, interpolation was undertaken by manual estimation of head contours and more recently using numerical interpolation approaches, such as kriging. The watertable surface is, however, often a subdued reflection of the topography; with local variability influenced by the rainfall, landuse and geology. These factors are therefore drivers of the observed head and can potentially be used as predictors in the interpolation. Kriging with external drift (KED) is a widely adopted approach to make use of such predictors, and to date it has been used to include the land surface elevation as a predictor of water table surface via a generalised least squares linear relationship. The resulting maps are often significant improvements over ordinary kriging, showing plausible flow directions and gradients, and the maps have been applied for risk assessments in a number of Victorian salinity management plans and water resource assessments. The KED approach does however have a number of fundamental weaknesses. This paper illustrates these weaknesses by application of KED to regions that highlight each weakness – specifically, excessive noise in the head, first and second order non-stationarity of the random field and poor interpolation of radial flow. To overcome these weaknesses, a multivariate colocated cokriging approach that accounts for the contribution of stream networks is detailed and applied. In comparison to KED, the new approach produces lower cross- validation errors and overcomes the weakness of excessive noise and non-stationarity but has limited success in interpolating radial flow. Notwithstanding this limitation, the approach provides a powerful means for deriving significantly more insight from sparse observation networks. This is demonstrated for selected regions of Victoria over the last 30 years.

Can flows through a fracture network clean contaminated aquifers?

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This project aims to establish a general model to predict the contaminant transport dynamics in aquifers featuring fracture networks. Our research focuses on identifying and comprehending the complex coupled mechanisms of diffusion-advection at the fracture scale, and incorporating them into effective macroscopic transport properties. Effective macroscopic transport properties are systematically measured from simulated REVs featuring (i) a network of percolating fractures through which a Darcy flow is established and(ii) a porous matrix in which the flow is negligible and diffusion is the dominant mode of transport. The numerical experiments, based on a Brownian-tracer method, consist of measuring the time required to reduce the concentration of contaminant in the matrix by 80% by injecting “clean water” through the network. A large number of simulations are used to pinpoint and quantify how the “cleaning time” depends on key parameters including (i) the Darcy velocity, (ii) the molecular diffusivity of the contaminant, (iii) the typical fracture aperture and length and (iv) the network density. Using this methodology, we provide an unprecedented comprehensive set of data covering a wide range of these parameters. Further still, we introduce a novel model capable of predicting the “cleaning time” for all the tested systems, which we derived by analysing the fundamental mechanisms of transport and their coupling. Our results establish a general framework for the groundwater research community to apply toward analysing and rationalising the transport properties of a variety of systems. Furthermore, this outcome constitutes a step toward improving the reliability of contaminant transport prediction in aquifers featuring fracture networks.

A Statistical Analysis of Groundwater Geochemistry in Western Sydney, Australia.

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Multivariate analysis (MVA) allows unbiased, quantitative classification of water samples that can assist in identifying water types and processes affecting quality (Cloutier et al., 2008, Menció & Mas-Pla 2008). In this study, water quality data from Western Sydney was analysed using MVA to understand spatial and temporal variations. Currently knowledge of the shallow groundwater system is limited in this region, and this is negatively effecting management of salinity. Groundwater samples were collected from 25 sites throughout Western Sydney on 21 occasions between July 2011 and July 2013. The samples were analysed for major ions, stable isotopes and physicochemical parameters. MVA was undertaken using hierarchical cluster analysis (HCA) and principal component analysis (PCA). HCA of averaged data identified five groundwater types ranging from low (1572µS/cm) to high (26390µS/cm) salinity. PCA confirmed that salinity (42%) was the main factor explaining data variability, with isotopic enrichment (16%) and carbonate weathering (16%) also important. HCA of monthly datasets highlighted that processes including overland flow, surface ponding, upward leakage of underlying saline groundwater and surface water recharge periodically affected some sites. Upwards leakage of underlying saline groundwater is thought to be an important source of salinity in the region, especially in Type 3 waters. During wet periods Type 3 waters were more closely related to fresh waters (Type 1), however in extremely wet conditions Type 3 waters become increasingly similar to high salinity waters (Type 5). This suggests that enhanced upward leakage of highly saline groundwater may occur at these times. MVA has significantly improved our understanding of the shallow groundwater system in Western Sydney. Application of the knowledge gained from this study should result in improved planning and management of water in the region and hence reduce the occurrence of salinity-related issues.

ISOTOPIC & HYDROGEOCHEMICAL STUDY OF RADIONUCLIDE & LANDFILL LEACHATE MIGRATION IN A CONTAMINANT DISPOSAL PRECINCT IN SYDNEY'S SOUTHWEST

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During the 1960s the Australian Atomic Energy Commission disposed of low level radioactive waste in shallow trenches at the Little Forest Legacy Site (LFLS). Radionuclides included small amounts of plutonium, uranium, fission products Cs-137 and Sr-90, and tritium. Adjacent sites were used for disposal of night soil, municipal waste and industrial liquid waste. Contaminant distributions, groundwater levels, environmental isotopes and hydrogeochemistry were measured at LFLS to assess the relative importance of different contaminant transport pathways, sources and mechanisms and support management of the site. Sources include the LFLS waste, fallout from nuclear weapons testing, and adjacent landfills which contain some artificial radioactive substances. Tritium is a conservative tracer of subsurface water movement, and has been used to identify potential contaminant pathways at the LFLS. In addition, variations in Sr-87/Sr-86, δC-13(DIC) and evolution of δS-34 have been used to help identify processes occurring at the site. Within the trenches, the degradation of organic matter results in localised methanogenesis, as suggested by enriched δH-2 and δC-13(DIC) values in adjacent subsurface water. The isotopic signatures enable differentiation of LFLS contaminants from those originating from nearby sources including an adjacent quarry used for municipal waste which contributes leachate (characterised by elevated tritium, enriched δH-2 and δC-13(DIC) as well as a chemical signature) into the underlying groundwater system. The study has shown "bathtubbing" (overflow of waste trenches during rainfall events) to be an important mobilisation mechanism, contributing to tritium movement at the site and localised migration of radionuclides (particularly actinides Pu and Am) from trenches to surface soils. However sub-surface migration of actinides from the LFLS trenches has been retarded by low transmissivity clay-rich soils. The value of hydrogeochemical and isotopic tracers in understanding hydrological and contaminant transport processes is demonstrated by this work and will contribute to future management of the precinct.

The role of groundwater dissolved organic matter on arsenic mobilisation in a shallow alluvial aquifer in the Namoi Valley, NSW, Australia

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The aim of this study is to gain a better understanding of the environmental fate and mobility of arsenic by correlating to DOM reactivity in floodplain aquifers. Water samples were collected from the river, groundwater and hyporheic zone at the Bellevue Farm on the Namoi River upstream of, Narrabri, NSW, Australia. Since arsenic is redox sensitive, and its mobility is reliant upon its redox state, As (III) and As(V) were separated in situ by using an As(V) specific zeolite absorbent. Organic matter fluorescence analysis was also performed using a Horiba Aqualog scanning spectrophotometer to determine the fluorescent organic matter constituents and quality. The water chemistry was depleted in dissolved oxygen and a weak correlation was found between dissolved Fe(II) and dissolved As(III). A set of 44 excitation emission matrix (EEM) measurements of water samples from the surface and alluvial environment were decomposed into three fluorescent components; humic- (C1), fulvic- (C2) and protein-like (C3) substances. High DOM fluorescence intensity (range 315-760) was observed from surface water and shallow (<0.6 m) hyporheic zone pore water samples. In contrast, groundwater DOM fluorescence intensity was mostly low and constant (range 9-76). The fact that groundwater DOM fluorescence is constant while dissolved Fe increases, indicates that DOM from the river alone cannot explain the increase in dissolved groundwater Fe(II). The groundwater chemistry results suggest that degradation of dissolved organic matter from the river is not the only process controlling the release of Fe(II) by reductive iron-oxide dissolution and associated arsenic release. Sedimentary organic matter must also play a significant role in these processes. This study highlights the important to understand the biogeochemistry of surface water groundwater interactions to predict the release and mobility of arsenic in riparian zones in order to assess potential health implications for portable groundwater abstraction.

How Background Fluorescence Analysis (BFA) Revolutionizes Commercial Water and Compounds of Concern Tracing in Australia

Martin H Otz,
Nano Trace Technologies

One of the more difficult tasks at any site is to determine in which direction and how fast ground water and/or compounds of concern (COC) flow through the subsurface. Use of conventional hydrogeologic approaches alone often results in erroneous estimation of ground water flow pathways and their directions, often with grave consequences to the project's scope of work and budget. To the surprise of some hydrogeologists and engineers, the majority of ground water volume typically flows along preferential pathways. This is a concept that is widely recognized in the water tracing community, but unfortunately less well recognized outside of it. At ten Australian project sites with contaminated ground water, we were able to demonstrate the efficacy of a new fluorescence fingerprinting tracing technique. Affected and non-affected ground water samples were collected at each site during a sampling event. Two unpreserved and unfiltered 40 mL clear glass VOA vials were preconditioned with the sample water before the sample was collected. Holding times may be up to two weeks without any measurable changes. This flexibility allows for multi-tiered sample approaches to help evaluate temporal effects. For more than 5 years the background fluorescence (BFA) approach has delineated preferential ground water flow paths at 10 sites in Australia including 6 gas stations, 2 former oil & gas production sites, 1 power plant, 1 oil & gas refinery. BFA has also consequently improved our understanding of COC migration. The results of these studies suggest that implementation of successful and cost-effective remediation is assisted through the use of high resolution site characterization (HRSC) techniques. However, many current HRSC tools can lack the capability to separate natural from anthropogenic background, dissolved versus separate-phase areas, and fail to clearly demonstrate (not compute) contaminant fate and transport. BFA has the potential to help close those data gaps.

Mapping salinity distribution within aquifers at at statewide scale - pitfalls and opportunities. A case study from Victoria.

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Groundwater salinity is the primary water quality parameter used to inform the potential "beneficial uses" of groundwater. Maps of salinity data are often used to target drilling for resource use or in assessing the potential impacts of contamination on beneficial uses. Victoria has released individual salinity maps for each of the aquifers across the state. This provides, in theory, a three dimensional distribution of potential water use across the state. Is this a huge leap forward, or is this an "overstretch" of how data is used? This presentation explores the methodology for salinity mapping, with a critical review of strengths and weaknesses of the approach used. A discussion is provided on the risks and rewards of data in this format, and the potential opportunities it can provide. Overall, the paper concludes the opportunities out way the risks - but as always, there is more to be done.

Managing and communicating groundwater risk associated with excavations in urban areas

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Beca

With the increasing intensification of development in the Auckland urban area has come an increased appreciation of the potential for excavations for new developments to result in groundwater level changes that might cause basement flooding, damaging ground settlement or the migration of contaminants. In Auckland these issues are compounded by the complex geological setting comprising variably fractured Quaternary to recent lava flows, Pleistocene age alluvium and Tertiary age fractured very weak sandstone and siltstone bedrock. The lava flows result from multiple vents and exhibit a wide range of hydraulic properties that vary in profile and laterally, and over short distances. The alluvium is considered to be compressible; but the magnitude of consolidation settlement is over-estimated on almost all projects. The bedrock includes lenses and more significant channel deposits of a well cemented gritstone that has a mass permeability more akin to the basalt lava flows. Compared to academic research projects, private and publicly funded developments are often subject to much shorter investigation and design periods, and investigations are constrained by access in developed areas. In light of this and the complex geological setting, how do geotechnical practitioners develop appropriate conceptual models, select the right parameters and numerical models and communicate realistic estimates of potential groundwater effects? This paper reviews the results of three tunnelling projects (two cut and cover trenches and one driven tunnel) undertaken in urban Auckland, as well as experience from many smaller basement excavations to consider key lessons learnt for future projects. Lessons include the value of appropriately scoped preconstruction monitoring, identification, and rationalisation of the many layers of conservatism, back analysis of reasonable parameters, selection of analytical methods, and finally clear communication of risk to both the regulatory body and public.

Searching for Water on the Kāpiti Coast – The challenges of finding water in an area that is soaking wet

Eric van Nieuwkerk
Beca

Although the Kāpiti Coast is relatively wet with an average rainfall of 1029 mm/year, it has proven to be challenging to locate a reliable source of water for the construction of an expressway that does not interfere with sensitive wetlands, existing domestic water supply users (shallow aquifer) or public groundwater supplies (deep aquifer). The geology and hydrogeology of the The Kāpiti Coast provides a particular challenge for expressway construction. The abundance of existing roads, streams and rivers creates the need for installing numerous bypasses, bridges and culverts. Settlement prone peaty soils are a geotechnical challenge, but also support several wetlands of high ecological and cultural value. Numerous domestic and public water supply wells are present in this relatively populous area and the proximity to the coast makes the aquifers sensitive to saline intrusion. Therefore, adaptation of location, screening depth and design of the water supply wells was required to limit environmental effects while maximising well yield. Geological and groundwater modelling was a key part of the approach to assess environmental effects on a regional and local scale. Verification of groundwater levels and confirmation of ground conditions was achieved through establishing and monitoring over 110 monitoring bores and flow models were calibrated to the groundwater levels, stream gauging and pumping test results. Analytical solutions were also used to support assessment of depletion effects on nearby wetlands and streams. This combination of techniques enabled selection of optimal location, screening depths and design of the water supply wells. In such a complex environment, there are several trade-offs to be made and use of monitoring in combination with regularly updated modelling has been imperative to establishing a reliable source of water, particularly in this naturally wet environment.

GROUNDWATER DEPENDENT ECOSYSTEMS MANAGEMENT IN URBAN SETTINGS

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Melbourne Water is responsible for managing waterways in the Port Phillip and Western Port region. A key aspect of this role is the protection of Groundwater Dependent Ecosystems (GDEs), primarily wetlands and streams with inferred high reliance on groundwater. In managing GDEs it is important to understand the hydrogeology of the catchments, interaction between groundwater and surface water and the hydrology and ecology of waterways and wetlands. These aspects help in the development of surface water and the project aimed to:

- Assist with the delivery of Melbourne Water's Healthy Waterways Strategy, through developing an improved understanding of the groundwater dependent features of waterway ecological assets and ecosystems
- Protect and ultimately improve the health of high value and high risk GDEs in Melbourne Water's region
- Characterise previously identified GDEs through a process that engaged stakeholders and technical specialists
- Identify planning and approvals requirements and logistics in accessing sensitive areas. GHD undertook a review of previously mapped GDEs in Melbourne Water's service area to appraise available spatial datasets relevant to the GDE prioritisation process. A short-list of GDE sites was established through review and interrogation of existing data and undertaking of Multiple Criteria Decision Analysis of prioritised sites and stakeholder engagement. Site Investigations were undertaken to establish long-term surface water and groundwater monitoring networks. These investigations helped characterise the hydrogeological setting and monitoring requirements.

Melbourne Water is now familiar with the technical, logistic and planning approvals requirements relevant to the development of water monitoring networks, and can address other priority GDE sites using the updated 'GDE Catalogue' and the processes undertaken in this project. Melbourne Water has commenced periodic data download and review of collected data, with a view to assessing potential GDE impacts.

A MULTI-METHODOLOGY FOR IMPROVING ADELAIDE'S GROUNDWATER MANAGEMENT

Okke Batelaan1, Eddie Banks1, Jordi Batlle-Aguilar, Etienne Bresciani, Peter Cook, Roger Cranswick, Stan Smith, Chris Turnadge2, Daniel Partington1, Vincent Post1, Maria Pool Ramirez1, Adrian Werner1, Yueqing Xie1, Yuting Yang1

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Groundwater is a strategic and vital resource in South Australia playing a crucial role in sustaining a healthy environment, as well as supporting industries and economic development. In the Adelaide metropolitan region ten different aquifer units have been identified, extending to more than 500 m below sea level. Although salinity within most of these aquifers is variable, water suitable for commercial, irrigation and/or potable use is predominantly found in the deeper Tertiary aquifers. Groundwater currently contributes only 9000 ML/yr of Adelaide's total water consumption of 216,000 ML, while in the Northern Adelaide Plains 17000 ML/yr is used. However, major industries, market gardeners, golf courses, and local councils are highly dependent on this resource. Despite recent rapid expansion in managed aquifer recharge, and the potential for increased extraction of groundwater, particularly for the commercial and irrigation supplies, little is known about the sources and ages of Adelaide's groundwater. The aim of this study is therefore to provide a robust conceptualisation of Adelaide's groundwater system. The study focuses on three important knowledge gaps: 1. Does groundwater flow from the Adelaide Hills into the sedimentary aquifers on the plains? 2. What is the potential for encroachment of seawater if groundwater extraction increases? 3. How isolated are the different aquifers, or does water leak from one to the other? A multi-tool approach has been used to improve the conceptual understanding of groundwater flow processes; including the installation of new groundwater monitoring wells from the hills to the coast, an extensive groundwater sampling campaign of new and existing groundwater wells for chemistry and environmental tracers analysis, and development of a regional scale numerical model rigorously tested under different scenario conditions. The model allowed quantification of otherwise hardly quantifiable quantities such as flow across fault zones and through aquitards. Scenario modelling allowed analysis of the water resources status up to 2100. This includes several development scenarios (current or increased/decreased extraction rate) as well as taking into account outputs from climate change predictions and potential increase of MAR. It is shown that groundwater in the fractured aquifer bedrock in the hills is significantly younger than groundwater in the Adelaide plains area, indicating that the Adelaide groundwater system is, at least, partially recharged by lateral flow from water infiltrated in the hills. However, increasing ages with depth, are indicative of vertical infiltration from rainfall and inter-aquifer leakage. A better understanding of processes controlling these two sources of fresh groundwater, as well as evaluating their relative importance to Adelaide's groundwater budget is thoroughly investigated by using the regional numerical groundwater model. The modelling results show that the regional groundwater system is severely stressed. The main aquifers provide water from storage, which is replenished by water from formations with decreasing storage above and below the main aquifers. The salinity distribution along the coastline is shown not to be simply an equilibrium situation with an intruded seawater wedge extending inland. Tertiary aquifers can still contain old freshwater near the coast, and in deeper layers a hypersaline brine has been identified, which could constitute a previously-overlooked source of salinity. Further studies will have to determine the actual risk of salinization of the aquifers due to different more saline sources. This study is the first comprehensive investigation of the groundwater resources within the Adelaide environment and supports strongly integrated water management of the resource.

Coupled flow and transport model-based chloride mass balance for groundwater recharge estimation for the Adelaide Plains

Etienne Bresciani, Yueqing Xie, Roger Cranswick, Vincent Post, Okke Batelaan
School of the Environment, Flinders University

Chloride is widely used for estimating groundwater recharge using the chloride mass balance method (CMB), especially in semi-arid and arid regions. Cl has spatially variable input into the groundwater due to the spatial variability of chloride deposition and of recharge processes. Hence, for the CMB method groundwater flow paths from the water table to the observation wells must be known in order to obtain correct recharge estimates. In practice, simplistic assumptions are often made on groundwater flow paths, whereas a robust approach requires a coupled flow and transport model. The use of a coupled model also avoids biases induced by surface water leakage, of which the effects on groundwater concentrations cannot be simply estimated otherwise. Finally, modelling allows uncertainties to be quantified using a classical framework. In this talk, the feasibility of model-based CMB is demonstrated for the example of the Adelaide Plains regional groundwater flow system. Recharge estimates and associated uncertainties are derived. Results are also compared to recharge estimates based on the classical (non-model-based) CMB method.

Modelling of a heavily pumped regional groundwater system: Adelaide Pains, South Australia

Daniel Partington, Etienne Bresciani, Okke Batelaan, Vincent Post
National Centre for Groundwater Research and Training, Flinders University

The Adelaide Plains (AP) located around Adelaide, South Australia provides important groundwater resources which are relied upon by a wide array of users. In order to ensure that the aquifers are able to continue to meet allocation demands at a suitable quality, it is necessary to be able to simulate the behaviour of the AP groundwater system under historical and future climates and under different pumping and Managed Aquifer Schemes (MAR). For this purpose a MODFLOW NWT model was developed of the area. The area covering 1700 km2, is subject to substantial pumping (~30 GL/yr) and also has a large number of MAR schemes in operation, under construction and under investigation with potential for stormwater harvesting estimated at 60 GL/yr. Transient models considering periods of pre-development (1900-1950), development to now (1950- 2013) and future scenarios (2013-2100) were considered with the latter undergoing perturbations relating to climate change, increasing/decreasing pumping, and increasing MAR schemes. The first two transient models were used to assess how the system functioned in terms of areas and sources of recharge, internal flow dynamics and how the system responded to continually increasing rates of pumping. Following this, future scenarios were simulated. The modelling showed that the system exhibited complex system dynamics, whereby the assessment of the individual aquifers being most exploited were not indicative of the overall change in the system. It was seen that other aquifers in the system were more stressed by the heavy pumping and experienced significant losses from storage, which put the desirable aquifers at risk of salinization through creating upwelling from very deep saline tertiary aquifers, and also from inducing seawater intrusion through the uppermost layer of the model.

Afternoon ANU Theatre 2 Sessions- Groundwater Energy and Resource (overlap with Groundwater Management/ Science – Policy)

Hydrogeological Regulatory Conditions Setting and Implementation, an effort to move towards best practices

Fabienne d'Hautefeuille
Cardno

Hydrogeological regulatory conditioning on small to major projects are derived under a range of legislation. Regulatory conditions can be issued at both Federal and State levels. Where conditions relate to groundwater, the large majority of the conditions result from the application of environmental protection legislation and water management legislation. Two approaches are generally adopted for the setting of conditions:

1. An envelope approach, which tends to result in the same set of conditions for each project type or activity type; the;
2. A site specific approach with detailed conditions based on perceived risks to defined environmental values.

Similarly, two responses to the conditions seem to be adopted within the Industry receiving the conditions:

1. Strict implementation of the conditions without technical hydrogeological consideration whether the condition is suitable and/or sufficient to address and manage the level of risk to groundwater and associated values.
2. A hydrogeological review of the conditions to assess whether the conditioning is suitable or requires negotiation with the regulators. This can lead to engagement with the regulatory body and possibly changes to the conditions. This paper investigates the mechanisms behind the setting of hydrogeological regulatory conditions and discusses what may trigger different approaches to implement those requirements. The paper raises concerns about the suitability and efficiency of the conditions and whether or not the intent of the legislation has been addressed. This highlights the role of the hydrogeologist in the design, application and implementation of the regulatory condition. This further raises a question of environmental responsibility towards accurate management and protection of groundwater and associated values.

Challenges for water sharing in the context of large-scale and long-term impacts on regional groundwater systems

Anthony Smith, Isabelle Donnie, Rikito A. Gresswell, Lloyd R. Townley, Glenn M. Toogood, Thomas Neame, Kumar A. Narayan
CDM Smith

A key objective of water policy is to achieve equitable sharing of water resources between competing uses – both now and in the future. Predictive groundwater flow modelling currently provides the only means by which potential implications of current water management practices can be forecast and the effectiveness of management options assessed. The NSW Aquifer Interference Policy is an example of recent water policy that requires the impact of water taken from a water source to be predicted prior to approval, including the direct take from the target water source and indirect take from connected groundwater and surface water sources. Recent regional-scale groundwater modelling of the potential impacts of proposed coal seam gas development in the Gunnedah Basin has shown long response times to depressurisation within the basin, and very slow movement of groundwater between connected water sources. Potential transfers of water from shallow unconfined aquifers to deeper aquifers are predicted to occur hundreds of years after coal seam gas development has finished; the rates of transfer are very small but sustained over long periods. Within the context of existing water policy, it is challenging for regulators to decide how a potential indirect interference to an aquifer, many years in the future, should be considered by regulators and other stakeholders. The presentation will include methods for presenting and visualising modelling results to assist in meeting this challenge.

Estimating water exchanges between bedrock and alluvial aquifers – implications for mining projects in NSW

Neil Manewell
Australasian Groundwater and Environmental Consultants Pty Ltd

In New South Wales, the government requires proponents of major mining projects to estimate the volume of water their open cut and underground operations would indirectly take from any adjacent alluvial water sources and/or streams. These projects rarely directly intersect alluvium, rather only take water indirectly through depressurisation of strata adjacent to the alluvium. Importantly, the volume of the indirect take of water from alluvium and streams cannot be directly measured with instruments, only inferred from water level records and predicted using analytical and numerical models. The proponents of mining projects must typically purchase the estimated volume of groundwater as a licence or entitlement, which can require a significant outlay, one sometimes based on an uncertain estimate. We investigated the influence of using different modelling methodologies on the estimate of indirect water take from the alluvium and streams. To do this we created a hypothetical groundwater system with an alluvial aquifer, a stream, bedrock and a hypothetical mining project in the deeper strata, offset from the stream. We then varied the geometry of the alluvial aquifer and layering within the model, and compared the predictions of indirect water take. We used both MODFLOW-USG and MODFLOW-SURFACT to simulate groundwater flow and varied the algorithm representing flow within the unsaturated zone, whilst changing the geometry of the alluvial aquifer. We compare the indirect water take provided by each model variant and investigate the reasons for the differences. The results allow a better understanding of the effect these assumptions have when calculating indirect water take on behalf of mining clients, and the implications of different methodologies.

Application of trigger levels for groundwater resource development

Daniel Barclay
Australasian Groundwater and Environmental Consultants Pty Ltd

The Queensland government issues proponents of mining projects with an Environmental Authority, which sets out requirements for environmental monitoring, including monitoring of groundwater. Commonly the Environmental Authority stipulates a reference site methodology for developing trigger levels for groundwater quality based on ANZECC, 2000. Under this approach, essentially “upstream sites” are compared with “downstream sites” in a groundwater system. The reference site was developed for monitoring of surface waters and ecosystems. Groundwater in Queensland mining areas can be used for stock watering, industrial use and occasionally drinking water where suitable, but commonly groundwaters are brackish or saline and rarely meet the environmental value of aquatic ecosystems. The reference site methodology can be applicable in a groundwater environment with a similar flow regime, with the same bio-geographic/climatic conditions and similar geology, soil type and topography. However, hydrogeology is often complex and groundwater systems vary significantly both spatially and vertically. This complexity often renders the reference site approach unsuitable. We provide an alternative method for developing water quality trigger levels for mining projects that removes the challenges of the reference site methodology and recognises naturally varying groundwater quality. The method utilises a control chart approach and a decision tree to determine appropriate trigger levels. It uses both a visual and robust statistical analysis of the data to evaluate trends and determine the source of impacts. The method provides a reliable and systematic approach for those charged with managing groundwater impacts at mining projects.

Adopting catchment scale outcome based thresholds to manage mining related groundwater impacts, BHP Billiton Iron Ore, Pilbara WA.

Blair Douglas, Jed Youngs, Jon Hanna
BHP Billiton

BHPBIO has implemented a strategic and risk based approach to groundwater resource management. Three catchment scale adaptive management plans which cover an area of approximately 25000 km2 were implemented via a staged and iterative approach from 2010 to 2015 which: 1) characterised hydrological conditions; 2) identified seven key hydrological dependent receptors in the area of influence; 3) set management objectives and thresholds for each key receptor; 4) predicted the range of potential hydrological changes associated with mining and natural conditions and 5) set out practical and tested adaptive management techniques to minimise the area of influence and reduce the long term potential impacts to groundwater resources. Outcome based monitoring and management thresholds adopted for Ethel Gorge stygofauna community reflects the historical variance in groundwater levels and quality established from 40 years of hydrological data. These thresholds informed the use of the Ophthalmia Dam managed aquifer recharge facility which infiltrates surplus water generated from dewatering activities. Coondewanna Flats community thresholds were based on 10 years of observed groundwater level fluctuations. Groundwater injection was trialed over a period of 2 years to evaluate long term management alternative to maintain groundwater levels and prevent potential impacts to vegetation from mine dewatering activities. The early warning triggers and management thresholds at each receptor are precautionary and are based on existing scientific knowledge, which consider the risks of technical and operational uncertainty and the need to interpolate catchment-wide data. These outcomes deliver transparency for the company, provide Regulatory and community confidence and demonstrate a pathway to address broader cumulative impacts.

Empowering Landholders to Monitor Groundwater in Areas Adjacent to Mining or Gas Developments

Ross Carruthers, Mabbie Elson
Department of Natural Resources and Mines

The Department of Natural Resources and Mines (DNRM) in Queensland has recently implemented a new groundwater monitoring program for its intensive and economically important Coal Seam Gas (CSG) industry. There are two sub-projects: CSG Net & CSG Online. CSG Net is a community based monitoring program where landholders in CSG areas are engaged in groups, provided with information on the CSG industry and groundwater systems and encouraged to measure groundwater levels in their private water wells on a monthly basis. At regular intervals landholders forward the data to the department for storage within the department's groundwater database. Outcomes from the landholder monitoring, and monitoring undertaken by DNRM and CSG companies, are shared and discussed at annual workshops. CSG Online involves the installation of continuous monitoring loggers and telemetry on at least 60 strategically located sites with data available to the community 'live and online'. The new initiative is yielding multiple benefits.

- Landholders are empowered to monitor their own water wells in the knowledge that an improved and transparent monitoring framework is in place to protect their interests.
- Government has a more effective and efficient monitoring network and improved accountability and relationships with landholders.
- The new monitoring program uses the current level of operational resources but with an 8 fold greater spatial and 12 fold greater temporal monitoring footprint than the previous network.
- Results are used to independently cross-reference and verify groundwater monitoring results from CSG companies, providing enhanced community confidence in industry data.

The new monitoring program has been highly successful to date. Similar programs are being actively considered for use in other sectors in Queensland where operational activities associated with industries such as mining or shale gas may impact on landholder's access to groundwater resources.

A review of groundwater management arrangements in western Queensland.

Michael Jamieson
Department of Natural Resources and Mines, Queensland

About half the water bores of Western Queensland access aquifers managed under the Great Artesian Basin Water Resource Plan (GAB WRP), and half tap aquifers managed under other legislative arrangements. This paper sets out the findings from a review of licensing arrangements in these non-GABWRP aquifers, intended to help with water resource planning. Trends in bore drilling and abandonment were assessed. The dates that bores are drilled are collected but bore abandonment dates are not, necessitating use of a spreadsheet based model. Most of the aquifers in the area, primarily used by the grazing industry, have had stable water bore numbers for decades. The exceptions are the fractured rock aquifers and areas near significant mining projects, such as the Galilee Basin around Alpha and Jericho, basement aquifers around Mount Isa and Einasleigh, and basalts near Einasleigh and Richmond. In these aquifers water bore numbers have grown noticeably since 2000, probably because of water demands generated directly and indirectly by local mining projects, as well as extended droughts. These fractured rock aquifers are different to the more regional aquifers of western Queensland as they are known to respond relatively quickly to climatic variation such as drought. Declining water levels in these aquifers during the 2000s and more recent drought periods appear to have prompted bore owners to drill new bores. Future growth in demand for groundwater in western Queensland could potentially come from shale gas activities, coal mines in the Galilee Basin, and new mineral mines in the Mount Isa Minerals province and Georgina Basin. New groundwater management rules are being considered for Georgina Basin aquifers near Elizabeth Springs and Boulia, the Sturgeon Basalts near Richmond, and the Winton Mackunda Aquifer, a likely water source for the developing shale gas industry of the Cooper Basin.

Defining the Quantitative Uncertainty in Drawdown Compliance, Groundwater Supply for the Olympic Dam Mine, South Australia

Gabor Bekesi[1], Murray Tyler[2]
1. Cardno
2. BHP Billiton

Wellfield B supplies 30 ML/day of groundwater from the south-western Great Artesian Basin (GAB) to the Olympic Dam mine and to the town of Roxby Downs in South Australia. The south-western GAB is a unique artesian system. Wells are up to 1000m deep, wellhead pressures are up to 100m H2O and groundwater temperatures are up to 90C. The combined effects of high groundwater temperature and antecedent flow in non-dedicated monitoring wells create uncertainties in the calculated drawdown. The regulation is based on the area contained within the 10 m drawdown contour and is limited to 4450 km2 by 2036. This drawdown footprint area was determined from numerical modelling at 95% confidence. As there is practically no recharge locally, drawdown at a constant abstraction is expected to increase logarithmically with time and the drawdown footprint linearly. The objective is to define the uncertainties in the determination of the drawdown footprint to assess if temporal trends in the drawdown footprint are consistent with those predicted from modelling: is the wellfield on track to comply and what deviation from the modelled drawdown footprint may be considered significant. The 10 m drawdown contour is determined from individual drawdowns calculated from wellhead pressure and temperature measurements at between 25 and 35 sites in any year. The methodology developed involves Monte-Carlo modelling. A number of drawdown scenarios were created within a constrained range. These drawdowns were kriged (es required by regulation). The resultant areas were analysed using standard statistical methods. Allowing for uncertainty, determined as ± 230 km2, the drawdown footprint since 2000 is consistent with the predicted trends, with the exception of 2008.

Environmental significance of the groundwater resource in Pilbara

Olga Barron, Irina Emelyanova
CSIRO

In Pilbara climatic conditions, groundwater resources have important environmental functions. As terrestrial groundwater dependent ecosystems (GDEs - vegetation, spring, pool) ultimately mark groundwater discharge zones, their delineation and characterisation allows better understanding of groundwater processes but also facilitating GDEs ecohydrological analysis. The main objectives of the research were to classify and delineate potential and, where possible, actual GDEs at a regional scale, determining their dependency on various water resources (groundwater, surface water, rainfall). GDEs habitats were mapped based on combined consideration of geological, hydrogeological and hydrological settings, available information of mapped vegetation and their typical ecohydrological characteristics as well as remotely sensed (RS) data analysis. The types of groundwater sources which support GDEs vary throughout the Assessment area: from large regional aquifers (such as hosted in the sedimentary basins and dolomites) and localised aquifers (such as paleovalleys or mineralised BIF) to groundwater which doesn't form an aquifer (small alluvial systems or fault zones). The vegetation identified as GDEs were also classified with likelihood of their groundwater dependency: from highly dependent to partly dependent to non-groundwater dependent riparian vegetation. The majority of the individual GDEs remained relatively constant between 1988 and 2011. Where GDEs are highly dependent on groundwater, their characteristics (an extent, greenness and wetness, derived from RS analysis) were not dependent on climate parameters. Sensitivity of GDEs characteristics to climate variability progressively increases when the likelihood of their dependency on groundwater reduces. Groundwater deeper than 10 m below ground does not influence RS detected greenness of vegetation. In contrast with other riparian vegetation, GDEs were insensitive to both seasonal variations in river flow or individual flow events. Significant changes in ecohydrological conditions (e.g. reduction in rainfall intensity or groundwater abstraction) manifest in changes of GDE greenness after the second hydrological cycle following the initial impact.

Development of a spring typology to inform the assessment of risks and to guide management arrangements in the Surat Cumulative Management Area, Queensland.

Jon Fawcett
CDMSmith

The Office of Groundwater Impact Assessment (OGIA) has developed 17 conceptual models and a typology for springs (wetlands) in the Surat Basin, an area of intensive coal seam gas development in Queensland. Since 2013, there has been a significant investment in monitoring and research at wetlands by the CSG companies and OGIA. Data collected has included time series wetland discharge, extent, chemistry, flora, macroinvertebrate assemblages and local hydrogeology. A critical and often overlooked component of wetland risk assessments is identifying the ecological components of an ecosystem that are directly linked to groundwater. These "ecological endpoints" are the backbone for the development of monitoring and mitigation arrangements. Data is analysed in relation to local hydrogeology, hydrochemistry and wetland dynamics with relationships between these elements and ecology determined. Pictorial and text based conceptual models describing the major components of the wetland system at a landscape and wetland scales are developed. Following conceptualisation, a wetland typology is established which informs OGIA's key management requirement which is to understand: how would wetlands respond to a change in the groundwater regime, what are the implications of this change and what are suitable indicators? Four groupings of wetlands were identified for the Surat Basin. The types are based on the following wetland attributes:

- landscape setting;
- geomorphology;
- groundwater flow systems;
- regolith;
- water regime; and
- ecology (macroinvertebrates and flora).

For each wetland type, the wetland water requirements and suitable monitoring indicators are identified. A critical assessment of the implications of a change in the groundwater regime is also developed. The established wetland typology allows for a more structured approach to consider impacts and monitoring requirements for wetlands. Wetlands that respond and function in a similar manner can be evaluated collectively. The approach and framework has broad applicability, particular across other parts of the Great Artesian Basin.

Evaluating predicted impacts to the Lucky Last spring complex through enhanced local scale hydrogeological conceptualization

Steven Flook[1], Dr Jon Fawcett[2]
1. Office of Groundwater Impact Assessment, Department of Natural Resources and Mines
2. CDM Smith

This paper presents work completed over the last three years at Lucky Last, a high value (EPBC listed) spring in the Surat Basin, led by the Office of Groundwater Impact Assessment (OGIA) and undertaken collaboratively with industry. The project is directed at improving confidence in the assessment of the risks to springs associated with coal seam gas (CSG) water extraction in the region. The project highlights the benefits of applying a hypothesis testing and multiple lines of evidence approach to investigate complex natural systems. The springs are located in an area of significant geological complexity, overlying the regionally significant Hutton-Wallumbilla Fault that makes interpreting the source aquifer to this group of springs problematic. A desktop assessment included geological, hydrologic and hydrogeochemical analysis. A key outcome from this phase of the project was the identification of four plausible mechanisms of spring genesis. A work program was designed to test the identified hypotheses which incorporated geological mapping, construction of nested investigation bores, water pressure and hydrochemistry mapping and ground geophysics. The synthesis of the new data provides a revised understanding of the hydrostratigaphy and source aquifer to the spring. Based on the new conceptualisation, the springs are now understood to be less susceptible to pressure reductions in regional aquifers. The outcomes of the project provide a basis for improving confidence in the prediction of future water pressure impacts and in the design of monitoring arrangements at this site.

Preferential pathways, diffuse discharge and recharge to Dalhousie Spring: learnings from a new groundwater model for the Western Eromanga part of the GAB.

Dr Phil Hayes[1], John Mosquera[2], Murray Tyler[3], Gabor Bekesi[4], Alan Puhalovich[2]
1. Golder Associates, Brisbane
2. Golder Associates, Perth
3. BHP Billiton, Adelaide
4. Cardno Lane Piper, Adelaide

Abstraction of groundwater in the southwest Eromanga Basin for agriculture and mining causes depressurisation of the Great Artesian Basin Algebuckina aquifer. A new groundwater flow model of the Eromanga portion of the Great Artesian Basin has been developed to evaluate aquifer depressurisation and the potential for impacts on southwest marginal springs. The model is developed with the MODFLOW-USG code, enabling enhanced resolution in the basin margin, at springs and in well field areas. It was calibrated using PEST with pilot point and regularisation methods to take account of expert knowledge and observations of spring flow, aquifer pressure and drawdown. The model builds on the significant recent studies of the Allocating Water and Maintaining Springs in the Great Artesian Basin reported by Keppel et al. (eds) 2013. Isotopic studies suggest that diffuse upward leakage from GAB aquifers to overlying shallow aquifers is a significant component of the water balance in the Western Eromanga basin. Model calibration with significant diffuse leakage is only possible with vertical hydraulic conductivity values that align with the theory that preferential pathways dominate the effective vertical permeability of confining shale units. The Dalhousie Spring complex in South Australia is the largest concentrated discharge of groundwater in the Eromanga basin. The representation of Dalhousie Spring flow in the model supports the theory that infiltration from ephemeral Fink River flows provides active recharge to the spring complex. The new model advances understanding of the water balance components for the Eromanga Basin, including spring flows, and provides a tool for future management of water resource and impact prediction.

DAY 3 Abstracts
Thursday 5 November 2015

Morning Plenary

Geoscientific contributions to groundwater resources decision making

Dr Chris Pigram
Geoscience Australia

Recent multidisciplinary geoscience investigations by Geoscience: Australia have led to unprecedented insights into new opportunities and constraints to development of groundwater. In studies such as the Broken Hill Managed Aquifer Recharge project, Ord Valley Airborne Electromagnetic Survey and Northern Territory Coastal Plains Airborne Electromagnetic Survey, the challenges of integrating disparate information including regional geophysical data and remotely sensed information with more traditional groundwater data have necessitated innovative interpretations and a growing appreciation of the importance of understanding the structural characteristics of the subsurface in controlling groundwater behaviour. These features can play a fundamental role in influencing groundwater processes, and have a significant influence on the nature of groundwater-surface water interactions, the distribution and health of groundwater dependent vegetation, the characteristics of seawater intrusion, the evolution and morphology of current and ancestral drainage features. Understanding them is critical for identifying future subsurface opportunities and constraints for subsurface supply and storage of water. GA's growing body of work on the architecture of groundwater systems demonstrates the critical value of new information in fundamentally revising existing conceptual understanding of landscape evolution and the characteristics and future behaviour of groundwater resources. These insights are fundamental to wise management of water resources, and to developing appropriate predictive tools for apprehending potential future impacts of on groundwater resources. The challenge is now to develop more efficient techniques for characterising and integrating multiple primary datasets relevant to characterising the nature of the subsurface architecture, and for routinely including measures of geological conceptual uncertainty in predictive modelling of future groundwater scenarios. Only with this level of information and quantitative rigour will decision makers be provided with a realistic indication of the level of confidence that can be placed on modelled scenarios.

What lies beneath: rural landholder interpretation of the risks of aquifer exploitation in Australia

Professor Allan Curtis, Dr Emily Mendham,
The Graham Centre for Agricultural Innovation, Charles Sturt University

Risks associated with the management of groundwater in farming landscapes are at the forefront of public discourse in Australia and North America. There has been little social research examining rural landholder attitudes to groundwater use and management. This is an important gap given the critical role social acceptability plays in resource access decisions, the important role groundwater plays in sustaining livelihoods, and the vital role it plays in maintaining groundwater dependent ecosystems. This paper addresses that gap by exploring how rural landholders interpret risks associated with groundwater use for irrigated agriculture. We do that using a case study from south eastern Australia where farmers' livelihoods are increasingly dependent on groundwater. We draw upon spatially referenced survey data from a random sample of rural landholders in the Wimmera region to investigate the extent and nature of concern about risk associated with pumping groundwater. We also explore the factors influencing risk interpretation, including occupational identity and proximity to the aquifer. Survey results suggest that while there is concern about pumping groundwater for irrigated agriculture in the Wimmera region, there is also considerable confidence that negative outcomes can be avoided. The dimension of risk of most concern to respondents was the possibility that the benefits of pumping groundwater would not be shared equitably. Those reporting lower concern about the risks of groundwater pumping were more likely to own properties located above the aquifer, to exhibit a strong business orientation including prioritising economic values compared to environmental values, and to express attitudes indicating they thought private property rights should be protected. A substantial proportion of survey respondents indicated they were 'Unsure' on all the risk items in the survey. It seems the future social acceptability of groundwater exploitation in the Wimmera region will depend on the extent that those 'Unsure' shift to the 'Agree' or 'Disagree' cohorts.

The Western Water Dashboard: A View of Groundwater Licensing in the Western US

Rebecca Nelson [1, 2], Debra Perrone[2]
1. Melbourne Law School
2. Woods Institute for the Environment, Stanford University

The Western Water Dashboard project is a web-based visualization tool displaying information about groundwater resources and licensing practices in the 17 western US states. It aims to assist policy-makers in the western US and abroad to identify regulatory approaches and tools to control groundwater withdrawal. We analyse how states adopt the following key tools in licensing provisions: criteria for issuing groundwater licences; special groundwater management areas (which typically impose stringent requirements on groundwater licensing relative to groundwater laws that exist elsewhere in the state); requirements to meter and report withdrawals; and penalties for violating licence terms. We developed a template and an associated codebook to record, in a standardised way, how each state reflects these elements. Data were collected using a range of standard legal research techniques (e.g., legal text searches and analysis, reviewing secondary literature, interviews with state agency staff). The project demonstrates in a detailed way how selected western US states vary in adopting these licensing tools, and for each tool, identifies a spectrum of precise formulations of the tools. In addition to producing a menu of regulatory options for each tool, the project uncovers significantly greater use of special groundwater management areas than the literature has acknowledged. These areas represent a pragmatic way in which states can modernise their laws and control the effects of groundwater withdrawal without undertaking wholesale regulatory reform.

Evolution of Water Allocation Plans in South Australia

Steve Barnett
Department of Environment, Water and Natural Resources

All the high value low salinity groundwater resources in South Australia have Water Allocation Plans which set extraction limits and establish rules for the allocation and transfer of water entitlements. The NRM Act wisely requires that each Plan must be reviewed every ten years.
Water Allocation Plans must evolve to take into account numerous factors which include;

- New information and understandings of the groundwater resource
- New demands, new threats and new opportunities
- New management approaches
- Advice from the Crown Solicitor which varies from time to time

In achieving the ultimate goal of sustainable groundwater development, a Water Allocation Plan should not lead to the unintentional denial of access to the resource which would have been sustainable. The revision of the Water Allocation Plans for the Southern Basins and Musgrave PWAs is a perfect case study of how WAP evolution can benefit groundwater users, the environment and the resource itself. The original Water Allocation Plans were released in 2001 and were the product of the knowledge and understanding existing at the time. Since then, unpredictable factors such as drought and mining developments have required new approaches for the WAP revision. The major components of the revised Water Allocation Plan are; 1. Use of the change in groundwater storage to determine changes in annual allocations, rather than a 10 year rolling average of recharge. This approach is more responsive and better reflects the actual condition of the resource. 2. Consideration of all groundwater resources rather than concentrating only on lenses containing drinking quality water below 1000 mg/L. 3. Allowing development of 'new' resources if investigations can demonstrate it can be achieved sustainably. A risk-based approach in determining how much groundwater should be allocated to the environment.

Building a bridge with effective consultation: bringing together science, policy and the community to improve groundwater management

Karina Joy, Simon Cowan
Goulburn-Murray Water

Goulburn-Murray Water (GMW) consults with customers, stakeholders and the community when developing groundwater management plans. Its approach to consultation is driven by current State Government policy and a fundamental commitment to partner with customers. GMW has recognised that listening to and understanding what is important to customer's leads to effective management planning outcomes. GMW has developed a consultative approach to management plan development which focusses on bridging the gap between a sound technical understanding of groundwater resources, policy requirements and customer values and needs. This requires a toolkit of skills beyond just an understanding of hydrogeology and policy. This recognition has seen GMW's consultation tools include facilitated workshops, community meetings, customer surveys and reference groups. GMW's consultative approach is tailored to reflect associated social, environmental and economic risks for each groundwater management plan. In the Central Victorian Mineral Springs Groundwater Management Area (GMA), GMW undertook a multifaceted approach to consultation which included customer surveys, public meetings and the establishment of a groundwater reference group. Community angst about groundwater extraction and resource management in this GMA had occurred prior to plan development. This demonstrated the importance of undertaking effective consultation. The key to successful consultation was providing an accessible overview of our technical understanding of the groundwater system coupled with the use of facilitated meetings. Facilitated workshops enabled GMW to elicit from participants key concerns, values and the management tools they felt would be effective. This type of consultation resulted in the development of a plan that was simple, cost effective, adaptive and most importantly, embraced by the community. Consultation forms a key part of successfully developing groundwater management plans. However, effective consultation needs to be commensurate with risk and should ideally address the needs and concerns of groundwater users and stakeholders. Hydrogeologists and natural resource managers need to be adaptive and draw on a range of tools and techniques to provide effective consultation.

Aboriginal People and Groundwater Planning in NSW

Bradley Moggridge
NSW Office of Water

Australia's First Peoples rely on surface water and groundwater, this has been the case for thousands of generations primarily to ensure their survival in a dry landscape (Australia being the driest inhabited continent on earth). Aboriginal people place protecting and managing water landscapes as a high priority as it is a cultural obligation to do so based on traditional lore and customs. This paper considers the knowledge and opportunities western water science / planning can gain from one of the oldest living cultures on the planet not currently a component of the water planning and management regime. By 2019 the NSW Aboriginal Water Initiative has to walk in two worlds in the preparation of 22 Water Resource Plans under the Murray Darling Basin Plan, which includes 10 groundwater plans. The two worlds include engaging and establishing protocols with many complex and diverse NSW Aboriginal communities from different water landscapes – salt water, the mountains, desert, to floodplains and river country (muddy water) to identify cultural values and water dependencies as well as interpreting those values and dependencies into a language and format that water planners and government can understand and hopefully include into planning instruments. The Aboriginal Water Initiative has over the past 3 years established a considerable bank of data, experiences and lessons on collecting water dependent cultural values primarily in coastal water landscapes and will now target its focus west of the Great Divide into the MDB. The Aboriginal Water Initiative, (the only Aboriginal water unit in Australia) will highlight how water dependent cultural values and uses are identified and protected in modern day water planning and management. The Aboriginal Water Initiative's work is not done there, as there are larger policy questions and opportunities to further influence, such as reforming the legislative instruments to allow better access to water for Aboriginal people and also influencing environmental watering decisions.

Groundwater Insight: Presenting a national picture of groundwater

John Sharples, Elisabetta Carrara, Champika Wethasinghe
Bureau of Meteorology

Groundwater is the sole source of water in many regions of Australia and provides more than 30% of the country's total consumptive water . The Millennium Drought (2000–2009) was a catalyst for unprecedented reforms to Australian water management which were formalised through the National Water Initiative in 2004. As part of this reform the Bureau of Meteorology was given a key role to improve the collection and dissemination of water information, including groundwater, through the *Water Act 2007*. The Bureau has adopted a collaborative approach and worked closely with State and Territory governments and other Commonwealth agencies to develop the groundwater products. This strategic guidance and technical input has resulted in the development of a comprehensive range of groundwater information products to be launched at this conference. Two products part of the Bureau's Groundwater Information Suite are the Australian Groundwater Explorer and the Groundwater Insight. The Explorer is designed to deliver nationally consistent groundwater data at the bore scale. The Groundwater Insight is a complementary product presenting high level summary and contextual data. Where the Explorer is for users who need specific data, the Insight provides high level information for people unfamiliar with groundwater. This includes hydrogeology and aquifer boundaries, groundwater management and a first pass analysis of groundwater levels. The insight will also include some unique data sets not currently available elsewhere. Notably it presents a national Groundwater Management Area data set, including information on Entitlement Limits and current levels of Groundwater Entitlement. There is also a national analysis of 5, 10 and 20 year trends in groundwater level. This presentation will outline the content of the Insight and discuss the methods involved, and challenges faced, in presenting nationally standard groundwater information.

Groundwater and the changing water cycle

Neil McIntyre
University of Queensland

Of all the elements of global and regional water cycles, groundwater arguably has the least understood role. The limited understanding has implications for understanding the global water, nutrient and energy cycles; and the resilience of groundwater resources to regional and global change. We present the case for using Australia's dynamic and intensely observed groundwater basins as new observatories of water cycle change. International progress in understanding the role of groundwater in regional and global scale water cycles is reviewed. For example, the over-abstraction of groundwater in the Ganges Basin, where regional scale impacts on groundwater levels are detectable from satellites, has been shown to feed back to monsoon rainfall patterns. Other examples from Europe and North America illustrate the insights that can be gained by integrating groundwater models into regional water cycle models. In Australia, coal seam gas (CSG) extraction involves the injection of considerable volumes of ancient water to the surface over a time-scale of years; and mining below the water table can also considerable perturb the regional groundwater system. While the direct impacts on groundwater resources are intensively studied, the impacts on the regional water cycles are not. We use the case study of the Surat Basin in Queensland, Australia, to illustrate the almost unique opportunity for regional water cycle research. Australia has a great opportunity to conduct world leading research into the role of groundwater in regional and global water cycling because: The large scale of its basins and diversity of groundwater residence times; the relatively rapid perturbations that have happened during the past century; the accelerating perturbations due to CSG and mining development in some areas; and the $100s million being invested in groundwater data associated with mining and CSG development. A collaborative research initiative is called for.

Afternoon Keynotes
CSIRO – Bioregional Assessments

Bioregional Assessments: Evaluating the impacts of coal mining and coal seam gas extraction on water- dependent assets

David Post
CSIRO

The Australian Government has implemented a programme of research termed 'bioregional assessments' to investigate the potential water-related impacts of coal seam gas and large coal mining developments. This research will provide scientific information for the Independent Expert Scientific Committee (IESC) to use in developing their advice to Commonwealth and state government regulators. These bioregional assessments are now being carried out in six bioregions across Australia, namely the Lake Eyre Basin, Clarence-Moreton, Northern Inland Catchments, Northern Sydney Basin, Sydney Basin and Gippsland Basin bioregions. The Bioregional Assessment Programme is a collaboration between the Department of the Environment, the Bureau of Meteorology, CSIRO and Geoscience Australia. It aims to provide a baseline level of information on the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential direct, indirect and cumulative impacts of coal seam gas and coal mining on water-dependent assets. This presentation will provide an overview of the issues related to the impacts of coal mining and coal seam gas extraction on water-dependent assets across the bioregions being examined as part of the Bioregional Assessment Programme. The methodology used to undertake bioregional assessments will be described, and results of the programme to date will be presented.

Hydrodynamics in the Clarence-Moreton bioregion: why we need integration of 3D geology, hydrochemistry and groundwater flow paths

Matthias Raiber, Dr. Tao Cui, Dr. David Rassam
CSIRO Land & Water Flagship

There is a substantial interest in developing coal seam gas (CSG) reserves contained within coal seams of the Walloon Coal Measures in sub-basins of the Great Artesian Basin and linked basins (e.g. Clarence-Moreton and Surat basins) in Queensland and New South Wales. In order to understand how depressurisation of the coal-bearing strata can potentially affect water resources in shallow aquifers and surface water systems, the Australian Government has commissioned the Bioregional Assessment Programme, a scientific analysis that provides a baseline level of information on the ecology, hydrology, geology and hydrogeology of a bioregion. In this presentation, we describe the development of a 3D geological model of the Clarence-Moreton bioregion (the eastwards draining part of the Clarence-Moreton Basin) which integrates shallow alluvial (<30 m thick), volcanic and deep sedimentary aquifers. We will also show how the integration of 3D geology with pre-existing and publically available hydrochemical and groundwater level data can help to improve the conceptual understanding of basin hydrodynamics. The integrated analysis of spatial patterns of hydrochemistry and flow paths suggests that in some areas within the Clarence-Moreton bioregion in Qld, the Walloon Coal Measures are likely to be recharged through overlying volcanic rocks or volcanic intrusions. Furthermore, the assessment of spatial and temporal groundwater level fluctuations and head gradients between shallow and deep aquifers and surface waters enabled an assessment of how these systems are connected, and how this connection varies both spatially and temporarily. By assessing the variability of groundwater chemistry along flow paths and water level head gradients together with the 3D geological model, we were able to improve the conceptualisation of how aquifers throughout the bioregion are recharged and interact, which will facilitate the development of reliable conceptual and numerical models that describe these connectivity pathways.

Clarence-Moreton groundwater model for bioregional assessment: trade-off between complexity and simplicity

Tao Cui, Dr. Russell Crosbie, Dr. Matthias Raiber, Dr. Luk Peeters, Dr. David Rassam, Dr. Mat Gilfedder, Dr. Sreekanth Janardhanan
CSIRO Land and Water

Groundwater models are often criticised due to a lack of reliable field data and simplifications. On the other hand, uncertainty analysis requires a model with a short execution time in order to adequately explore the model space by running a model hundreds of thousands times. The required short running time poses a limitation on the number of parameters that can be included in a model. Such trade-offs have to be considered during the development of a regional groundwater model for the Clarence-Moreton Basin to assess the potential impact of depressurisation associated with coal seam gas (CSG) activities on water-dependent assets. This work discusses the decision making process of four key trade-offs and their impact on model predictions:

1. Transfer of geological model to groundwater model: a three dimensional geological model with an emphasis on the shallow alluvium system has been constructed. What is the optimal way to convert this to a groundwater model that can satisfy the running time criteria?
2. Parameterisation: pilot points, zones and permeability-depth relationships are mixed to balance between parameter numbers, execution time and heterogeneity representation.
3. Boundary conditions: the potential impact of depressurisation on surface water and its associated ecosystems also need to be investigated for bioregional assessments. The assessment of impacts on surface water requires short stress periods to capture the daily, monthly and seasonally change signal in surface water bodies. The stress period has to be chosen as a trade-off between surface water change signals and groundwater model running time.
4. Calibration database: in the Clarence-Moreton Basin, depressurisation of coal-bearing strata will happen at depths of approximately 400 – 700 m. However, most monitoring data are from shallow bores screened in alluvium and basalts. To what extent will such a calibration help to reduce the predictive uncertainty?

Analytic element models as fast screening tools in coal resource development impact assessments

Luk Peeters[1], Russell S Crosbie[1], Praveen Rachakonda[2], Tao Cui[1], Jim Kellet[3], Simon Knapp[3],
1. CSIRO Land and Water
2. CSIRO Energy
3. Geoscience Australia

Assessing the magnitude and likelihood of impact of coal resource development on groundwater often necessitates the time consuming and resource intensive development of complex groundwater models. In the early stages of impact assessment, preliminary, less complex models can focus research efforts, provide initial impact estimates and guide further model development.

Analytic element (AE) modelling allows transient, multilayer groundwater modelling, but is limited in its representation of spatial variability and aquifer geometry. However, the grid-independent modelling technique allows to quickly and automatically vary key conceptual model choices (type and position of boundary conditions and faults, number and thickness of model layers, hydrogeological properties). This enables the AE modelling to be incorporated in a comprehensive sensitivity and uncertainty analysis. In the Bioregional Assessment Programme, AE modelling is applied in three different bioregions. In the Clarence-Moreton Bioregion it is used to estimate of the spatial extent of coal seam gas (CSG) production impact to guide the development of a complex numerical model; in the Galilee Basin to assess impacts of coal mining on regional springs, while in the Gloucester basin, the impact on the weathered zone from coal mining and CSG is assessed, taking into account uncertainty in aquifer geometry and fault presence. The probabilistic impact estimates allow to distinguish in each region between zones with low and high probability of impact. In addition, the sensitivity analysis allows to identify the relevance of conceptual model issues, such as the relatively low sensitivity of the model results to fault properties in the Gloucester basin. AE models have proven to be invaluable in the early stages of impact assessment to have a sound and justifiable means to limit scope and area of investigation.

Modelling responses to changed surface water and groundwater conditions associated with coal resource development at a regional scale

Holland KL, O'Grady AP, Mitchell P, Macfarlane C, Sparrow A, Hayes K and Barry S
CSIRO

The Bioregional Assessment (BA) Programme is assessing the potential direct, indirect and cumulative impacts of coal resource development on water resources through a scientific analysis of the ecology, hydrology, hydrogeology and geology of a bioregion. Bioregions are expansive, typically covering a diverse combination of complex human and ecological systems, and broad geographic extents. Landscape classification is used to reduce the complexity of describing the impacts of hydrological changes in a bioregion. Landscape classes have similar physical, biological and hydrological characteristics and provide a natural aggregation of hydrological impacts to meaningful water dependent biophysical systems. A significant challenge in BA is to develop robust models of the response to changed hydrological conditions associated with coal resource development for each landscape class. In many cases, the hydrological changes following coal resource development have not been experienced previously. This means that many of the hydrological changes, both in magnitude and sequence, may be novel in these systems so little data will exist to empirically calibrate these relationships using statistical methods. Instead, BA will use receptor impact models (RIMs) developed using expert opinion through a formal elicitation methodology. For example, the conceptual model of river red gum woodlands suggests that leaf area index (LAI) is a good indicator of river red gum vegetation density and condition and that changes in flooding frequency and groundwater depth (hydrological response variables) will be key drivers in any change in river red gum LAI (impact variable). Expert elicitation scenarios will quantify the responses of receptor impact variables for a range of possible hydrological impact variables to assess future potential impacts. This approach will support debate and decision making related to coal resource development, while providing an enduring architecture that will support future assessments if or when the empirical information base, and modelling capability, within that bioregion improves.

Groundwater recharge to coal basins in eastern Australia

Russell Crosbie
CSIRO Land and Water Flagship

The Bioregional Assessment Programme is investigating the potential impacts of coal seam gas and large coal mining developments on water resources and water-related assets. Part of this work is to develop numerical groundwater models which require an input of the groundwater recharge. The groundwater recharge is important in determining the overall water balance of a region and is particularly sensitive to the time after development ceases for the region to return to hydrological equilibrium. Many of these areas have poorly understood recharge mechanisms and little detailed past work to build upon. The chloride mass balance is the most widely used method for estimating recharge in Australia but is under- utilised in this industry. Each state has a database of thousands of measurements of chloride in groundwater that can be used to build an understanding of the recharge in a region. This investigation has grouped recharge estimates by stratigraphic formation in outcrop areas to develop regression equations between average annual rainfall and average annual recharge to enable the recharge estimates to be upscaled to the entire region under investigation. This work suggests that recharge to coal bearing formations is typically less than the formations that surround them. In the Sydney Basin the recharge to the Newcastle or Illawarra Coal Measures can be up to an order of magnitude lower than the Hawkesbury Sandstone or the sand dune systems that are productive aquifers, the coal measures have a recharge rate that is comparable to the Wianamatta Shale that is considered an aquitard. Similarly in the Clarence-Morton Basin, the Walloon Coal Measures recharge can be up to an order magnitude less than the Tertiary Volcanics. This investigation has demonstrated that we can do better than assigning recharge as an arbitrary percentage of rainfall and that this can be quite different between stratigraphic units.

Morning Shine Dome Sessions – Surface Water Groundwater Interactions

Mapping groundwater discharge and water chemistry in a perennial stream in northern New South Wales

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The objective was to improve the understanding of groundwater contributions in maintaining the flow regime, hydrochemical environment and ecological processes in the perennial section of a stream in northern NSW. This is part of a larger project investigating hydrogeochemical and ecological responses in the hyporheic zone of streams which aims to develop ecohydrological models that improve understanding of the ecological impacts of groundwater drawdown from human activities. To identify and map groundwater discharge zones, a 1.5 km section of permanent pools and flowing reaches of Horsearm Creek in the Namoi Catchment fibre-optic cables were deployed. These cables recorded surface water temperature every 20 min over a 3-day period in February. Fifty-seven surface water samples were collected and analysed for radon activity, electrical conductivity (EC), dissolved oxygen (DO), nutrients (NO3-, NH4+ and PO43-), redox-sensitive parameters (Fe2+ and Mn2+), DOC and organic matter fluorescence (FDOM). Stream discharge was gauged at eight cross sections. Surface water temperature anomalies indicated localised inflow of relatively cool groundwater (~20 °C). These zones of suspected groundwater discharge had high radon activities compared to surface water at sites without groundwater discharge. The discharge sites also had a geochemical signature with an EC distinct from upstream surface water, higher dissolved oxygen levels (~5 mg/L), and contained relatively high nitrate (0.5 mg/L) and low DOC (<0.5 mgC/L). Combining these physical and chemical tracers allows groundwater discharge and associated water quality to be mapped and provides a basis for developing a conceptual framework for its eco-hydrological functioning. Depriving streams of their groundwater contribution could increase periods of no-flow and adversely alter water quality, with implications for ecohydrological processes and functioning in the hyporheic zone of streams. Understanding these processes is important for assessing impacts of groundwater drawdown caused by human activities.

Organic matter content and redox chemistry in upwelling and down-welling hyporheic zones of a groundwater fed stream

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This research project was initiated to improve understanding of organic matter content and redox chemistry in upwelling and down-welling hyporheic zones of a groundwater fed stream in northern New South Wales. This is part of a larger project investigating hydrogeochemical and ecological responses in the hyporheic zone of streams which aims to develop ecohydrological models that improve understanding of the water-related ecological impacts of groundwater drawdown from human activities such agriculture and mining.Surface water samples were collected from a 1.5 km section of permanent pools and flowing reaches of Horsearm Creek in the Naomi Catchment (NSW). Samples were analysed for total organic carbon (TOC) and fluorescence, dissolved oxygen (DO), electrical conductivity (EC), pH, major cations, anions, and nutrients. In addition, selected upwelling and downwelling zones were further characterised through the sampling from the saturated sediment layer. Compared with upwelling hyporheic zones, samples collected from down-welling zones were characterised by higher TOC, ammonia and pH, but lower DO. Down-welling zones also had higher As, Fe, P and Mn and low nitrate indicating more reduced conditions compared to the upwelling zones. In the down-welling zones the organic matter was more terrestrially-derived and refractory. In upwelling zones DO was higher at depths 0.6 to 0.8 m compared with 0.3 to 0.4m below the streambed. Perennial hyporheic flow in Horsearm Creek is supported by localised inputs of regional groundwater which is oxygenated and low in TOC. Inputs of oxygenated groundwater influence the redox chemistry and organic matter processing in upwelling hyporheic zones, which in turn influences stream ecology including the habitat for hyporheic fauna. Thus activities causing drawdown in groundwater fed streams may impact redox chemistry, organic matter processing and stream ecology.

On the limits of heat as a tracer to estimate reach-scale river-aquifer exchange flux

Yueqing Xie, Peter Cook, Craig Simmons, Chunmiao Zheng
National Centre for Groundwater Research and Training

For the past few decades, heat has been used to estimate river-aquifer exchange flux at discrete locations by comparison of river and groundwater temperature. In recent years, heat has also been employed to estimate reach-scale river-aquifer exchange flux based only on river temperature. However, there are many more parameters that govern heat exchange and transport in surface water than in groundwater. In this study, we assessed the accuracy of temperature-based estimates of exchange flux in two synthetic rivers and in a field setting in order to identify whether heat can be employed as a reliable tracer. Two synthetic rivers were established on the basis of typical upland and lowland rivers reported in literature, whereas the field setting was the Heihe River in northwest China. In these river systems, we first determined the uncertainty ranges of parameters in the heat balance models. Then we estimated the uncertainty ranges of river-aquifer exchange flux based on the heat balance analysis. For the large 32km-long synthetic river with a flow rate of 63 m3/s (i.e., 5.44 × 106 m3/d), the upper and lower bounds of the river-aquifer exchange flux can be determined when the actual flux is around 100 m2/d. For higher and lower actual fluxes, only minimum and maximum bounds respectively can be determined. For the small 32km-long synthetic river with the flow rate of 0.63 m3/s (i.e., 5.44 × 104 m3/d), only the bounds can be estimated when the actual flux is near 10 m2/d. In the field setting, results show that the river-aquifer exchange flux must be less than 100 m2/d, but a lower bound cannot be determined. The large ranges of estimated river-aquifer exchange flux in both theoretical and field settings indicate the need to reduce parameter errors and combine heat measurements with other isotopic and/or chemical methods.

Validation of novel temperature sensing techniques for identifying groundwater – surface water interaction in Lake Taupo, New Zealand.

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Whakaipo Bay, Lake Taupo, New Zealand, was selected as a case study site for validation of novel temperature sensing techniques for understanding groundwater – surface water (GW-SW) interaction. This work is a component of the GNS Science-led SMART Aquifer Characterisation (SAC) program, which aims to assemble and validate a suite of highly innovative methods to characterise New Zealands groundwater systems at the national and aquifer scale. Techniques employed at Whakaipo bay included Thermal Infra-Red (TIR) imagery and Fibre-Optic Distributed Temperature Sensing (FODTS). Satellite TIR imagery was downloaded from Landsat 8 and airborne TIR images were acquired from a TIR camera mounted to a fixed-wing aircraft. TIR images were processed to surface temperature estimates, and were then used to identify possible GW-SW interaction locations for placement of FODTS equipment. Horizontal FODTS deployments were used to identify locations of GW-SW interaction and vertical FODTS deployments were used to quantify the flux of GW using a simple energy balance model. Satellite TIR images indicated potential for the technique to be used at Whakaipo Bay. Best results were obtained from night-time images although further processing and filtering is required to improve image quality. Airborne TIR images further confirmed areas of cooler GW flow into the bay with higher resolution. Use of FODTS allowed for accurate GW inflow locations and temperatures to be identified, and groundwater fluxes to be calculated. Novel temperature sensing techniques for identification of GW-SW interaction have been validated at Whakaipo Bay, Lake Taupo. TIR and FODTS methods have been used to provide information on the location and volumes of groundwater discharging into surface waters. Additional work is being undertaken to investigate GW-SW interaction in other hydrological settings (e.g. estuaries, rivers, lakes and streams), and to further validate these novel techniques.

Morning ANU Theatre 1 Sessions – Community Engagement & Decision Making

Legal Implications Arising from the Development of an Irrigation District in the West Canning Basin, WA

Madeleine Hartley
Kingfisher Law

The Western Australian State Government and Andrew Forrest have separately announced the potential to establish an irrigation and agricultural district in the West Canning Basin (the Basin) in WA. This presentation scrutinizes the legal implications for developing the Basin in this way. It examines the interaction between the Rights in Water and Irrigation Act 1914 (WA) and the Pilbara Groundwater Allocation Plan (PGAP); Department of Water statewide policies regarding water metering and trade and their applicability to such a district; and the potential impact of water law reforms currently proposed in WA to the establishment of a new water intensive district in the north-west. The methodology is confined to a desktop review of relevant legal frameworks, legal and scientific literature, and government policies including groundwater allocation plans. Their application to the development of the Basin and water law reforms was then analysed, after which hypothetical success and shortcomings were revealed. The Basin is regulated under the non-statutory PGAP. The primary aquifer, the Canning-Wallal, has limited water available for licensing, making the possibility of increased water availability for irrigation and agricultural pursuits particularly enticing. Water law reform in WA will likely see the PGAP transition to a statutory plan, which will account for any new water and allocate it pursuant to seasonal variability. To increase transparency and permit trade, consumptive use should be metered and water priced from the outset. These outcomes must be prioritised in order for the Basin to sustainably support a water intensive district. WA has the opportunity to proactively ponder a legal framework for effective water resources management and efficient use that can be rolled out simultaneously to the development of the district. Important lessons can also be learned from the continuing challenges faced in other parts of the State to help ensure the district's viability.

The groundwater games: modelling cooperation in groundwater basins using agent-based models

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Human interactions with groundwater systems often exhibit complex features that hinder the sustainable management of the resource. This leads to costly and persistent conflicts over groundwater at the catchment scale. One possible way to address these conflicts is by gaining a better understanding of how social and groundwater dynamics coevolve using agent-based models (ABM). Such models allow exploration of 'bottom- up' solutions (i.e., self-organised governance systems), where the behaviour of individual agents (e.g., farmers) results in the emergence of mutual cooperation among groundwater users. There is significant empirical evidence indicating that this kind of 'bottom-up' approach may lead to more enduring and sustainable outcomes, compared to conventional 'top-down' strategies such as centralized control and water right schemes (Ostrom 1990). New modelling tools are needed to study these concepts systematically and efficiently. Our model uses a conceptual framework to study cooperation and the emergence of social norms as initially proposed by Robert Axelrod in 1986, which we adapted to groundwater management. We developed an ABM that integrates social mechanisms and the physics of subsurface flow. The model explicitly represents feedback between groundwater conditions and social dynamics, capturing the spatial structure of these interactions and the potential effects on cooperation levels in an agricultural setting. Using this model, we investigate a series of mechanisms that may trigger norms supporting cooperative strategies, which can be sustained and become stable over time. For example, farmers in a self-monitoring community can be more efficient at achieving the objective of sustainable groundwater use than government-imposed regulation. Our coupled model thus offers a platform for testing new schemes promoting cooperation and improved resource use, which can be used as a basis for policy design. Importantly, we hope to raise awareness of agent-based modelling as a new tool for studying complex human-groundwater systems.

Investigating groundwater in north-western Australia – balancing the needs of management, traditional owners and pastoralists.

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Department of Water, WA

Industrial and agricultural development in the Kimberly region of Australia depends on groundwater, in an area where safe limits to abstraction are largely unknown. These resources occur in areas where traditional owners and their spiritual connection to land and water are essentially dependent on groundwater. Groundwater investigations must navigate the divide between aspirations for development with the preservation of culture and heritage values. We present a multi-disciplinary groundwater investigation, with comprehensive engagement of traditional and pastoral landowners to refine focus areas. Remote sensing, bore installation, soil moisture analysis, qualitative and quantitative vegetation assessments and environmental tracer analysis for rainfall, soils, groundwater, plants and surface water features were applied to define regional flow paths, recharge, yields and interaction between groundwater and surface water ecosystems. The area was divided into several Management Zones, based on location of seawater interface, depth to groundwater, groundwater dependent ecosystems (GDEs) and identification of a sub-regional confining layer. Several GDE types were characterised including springs, baseflow creek systems and coastal dune seeps. The influence of regional groundwater on these shallow groundwater systems was assessed and used to map interaction across a broader area. Recharge, through-flow and environmental water requirements were calculated then used to assign a sustainable yield to each management zone, along with zone-specific considerations for licensing water. This research shows that a regional groundwater investigation with continuous involvement of traditional owners and pastoralists can meet the diverse aspirations of these groups, and the resource management needs of the state. Areas of the aquifer were identified as favourable for groundwater development, while elsewhere use is constrained by either aquifer parameters or environmental water requirements. Reducing uncertainty around limits to abstraction, the State can encourage appropriate development, while protecting environmental, cultural and community interests. Involving traditional owners throughout investigations where possible, built mutual trust and co-ownership of the results, as well as capacity for continued monitoring of groundwater long after the project is finished. Ultimately, while the state manages the resource, this is on behalf of the people in the region.

Intensifying smallholder agriculture in Cambodia through groundwater irrigation: balancing opportunities and risks

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Smallholder rice farmers in Cambodia are starting to experience shifts in seasonality, with changes to timing and quantity of rain in the wet season and a longer dry season. This can reduce the yields of rice crops that are traditionally rain-fed and rely on timely water for success. The results of this are felt at the local level, where food security and livelihoods are diminished, and at the national level since agricultural export is a significant contributor to Cambodia's GDP. Across the last twenty years, groundwater has been increasingly pumped by farmers both to remedy a drought, supplement rainfed irrigation and to allow double-cropping into the dry-season. And groundwater use is likely to continue to grow, particularly in light of further opportunities such as irrigation of higher-value crops with different water timing requirements than those provided by rice- centric surface water canal systems. The flip side of these opportunities is concerns about the sustainability of the resource and the potential for damage in a fast-developing nation where land use changes can reduce both recharge and water quality. To better understand these opportunities and risks for smallholder farmers, conceptual frameworks has been designed to link, and inform the modelling of, key factors influencing groundwater development in Cambodia. Data has been draw from previous studies and discussions with key stakeholders to develop these linkages. The framework attempts to provide an integrated assessment of controllable and uncontrollable social, environmental and economic factors influencing decision-making both in terms of supply (e.g. sustainable extraction limits, cost of pumping) and demand (e.g. climate change effects, irrigation timing and quantities, cropping decisions, conjunctive uses such as domestic supply). Analysis of these linkages can provide new insights into Cambodian smallholder agricultural intensification in a changing climate and what role groundwater can (and should) play.

Afternoon ANU Theatre 2 Sessions – Caves/Groundwater Recharge/Climate

Characterising Groundwater Recharge from Cave Terrestrial Lidar and Drip Water Analysis

Kashif Mahmud, Dr. Gregoire Mariethoz, Professor Andy Baker, Dr. Pauline C. Treble, Ms Monika Markowska and Ms Liz McGuire
UNSW Australia

Limestone aeolianites constitute karstic aquifers covering much of the western and southern Australian coastal fringe. They are a key groundwater resource for a range of industries such as winery and tourism, and provide important ecosystem services such as habitat for stygofauna. Caves offer a natural inception point to observe both the long term groundwater recharge and the preferential movement of water through the unsaturated zone of such limestone. With the availability of automated drip rate logging systems and remote sensing techniques, it is now possible to deploy the combination of these methods for larger scale studies of infiltration processes within a cave. In this study we present the largest spatial and temporal survey of automated cave drip rate monitoring published to date in two large chambers of the Golgotha Cave, South-West Western Australia, with the aim of better understanding infiltration water hydrogeology and the relationship between infiltration, stalactite morphology and groundwater recharge. By applying morphological analysis of ceiling features from Terrestrial Lidar data, coupled with long-term drip time series and climate data, we demonstrate the nature of the relationships between infiltration through fractures in the limestone and groundwater recharge. Similarity between drip rate time series can be interpreted in terms of flow patterns, cave chamber morphology and lithology. Moreover, we develop a new technique to estimate groundwater recharge even in large scale caves, which is important for understanding the water cycle, for contaminant transport and for water management. The drip loggers do not demonstrate a single discharge response to effective precipitation, instead displaying an apparently diverse range of drip rates, with varying statistical properties. This new technique can be applied to other cave sites to identify highly focused areas of groundwater recharge and can help better estimate the total recharge volume.

Cave stalagmites as records of past recharge frequency in semi-arid Australia

Monika Markowska, Andy Baker, Martin S. Andersen, Helen Rutlidge, Catherine, N. Jex, Mark O. Cuthbert, Gabriel C. Rau, Lewis Adler, Peter W. Graham, Gregoire Mariethoz, Christopher E. Marjo, Pauline C. Treble
ANSTO/UNSW

Understanding past variability in groundwater recharge over recent time scales (0 – 10 ka) in Australia is essential for future sustainable groundwater management in a changing climate. Currently, there are limited data about past infiltration rates and their relationship to environmental controls that dominate recharge variability. Speleothem (cave precipitates) records may provide a new approach to understanding past infiltration (i.e. recharge rates), in addition to traditional interpretations of connectivity between climate and the hydrological cycle, in drier parts of Australia. In this study we used Cathedral Cave, (SE Australia) located in a temperate semi-arid climate, as a natural laboratory to investigate cave infiltration rates and the climate-karst-cave interactions driving the isotopic (δ18O) and chemical variability in modern drip water. These findings were then used to interpret the δ18O stalagmite record from two modern speleothems growing during the last ~50 years. Modern drip water results showed that the δ18O composition was enriched by up to 2.77 ‰ relative to annually weighted mean rainfall. Isotopically lighter δ18O occurred during infiltration events, followed by subsequent isotopic enrichment as evaporation in the unsaturated zone fractionated δ18O of stored water. Drip rate monitoring revealed that larger events leading to infiltration were infrequent (0 – 3 a-1) and the 'effectiveness' of these infiltration events was controlled by antecedent moisture conditions in the soil zone. In drier climatic zones, evaporation drives the enrichment of δ18O in the unsaturated zone, allowing periods of infiltration to be identified from the stable isotopic composition of drip waters. Our findings are important for interpreting speleothem records from regions with infrequent recharge and high evaporation rates. Such records are likely to contain evidence of past infiltration events moderated by an evaporation signal, allowing records of paleo-recharge to be reconstructed for drier climate regions of Australia.

What controls the cave drip water temperature? Analysis and implications for paleoclimate reconstruction from speleothems

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Cave drip water temperature influences cave hydrobiochemical processes and also speleothem based paleoclimate signals (e.g. biomarkers, isotopes, etc). Yet very little is known about what controls cave drip water temperature. This experimental investigation reveals the dominant heat transfer mechanisms. Design and Methodology: A shallow cave drip water flow path along a flowstone was instrumented with a number of high resolution temperature sensors and drip loggers. Cave and surface climate parameters: Pressure, Relative Humidity (RH) and Temperature were monitored with high frequency. Three separate land surface irrigation experiments were conducted comprising of multiple applications of water at the surface above the cave. One of the irrigation batched was enriched with deuterium (610% VSMOW) as a conservative tracer. The cave drip water temperature measurements clearly reveal the presence of all common heat transport mechanisms (e.g. conduction, convection, latent heat exchange). In general, the cave drip water has the same temperature as the subsurface conduction profile of the rock at that depth. However, at fast flow rates the warmer/colder signal during summer/winter is being washed down convectively leading to temperature anomalies of up 1.5 °C. Importantly, daily cave venting reduces the cave RH thus leading to evaporative cooling of drip water of up -2.5 °C. Cave drip water temperature is mainly controlled by the subsurface heat conduction profile as well as the cave climate. This, however, depends on the drip rate and length of flow path exposed to the cave air. Paleoclimate reconstruction requires depth-dependent deconvolution of the subsurface conduction signal as well as consideration of past or present cave venting and evaporative cooling.

Impacts of climate change and land use on threatened ecological communities of stygofauna in southwest Western Australia

Stefan Eberhard
Subterranean Ecology Pty Ltd

The objective was to improve understanding of climatic and land use drivers of groundwater decline affecting threatened ecological communities (TECs) of stygofauna in the Margaret River caves, Western Australia. A secondary objective was to trial supplementing recharge by rainfall harvesting to ameliorate groundwater decline and conserve stygofauna habitat. A PhD study in the Margaret River caves characterised the ecological and molecular genetic relationships of the stygofauna communities, karst hydrology, vegetation, rainfall, climate and potential threatening processes. A conceptual ecohydrological model was developed. Radiometric dating and stratigraphic levelling of sediments were used to reconstruct a history of groundwater changes in Jewel Cave spanning the Early Pleistocene to Present. A recharge supplementation trial in Lake Cave involved harvesting rainfall while monitoring groundwater quality to ensure that conditions were maintained for hydrogeochemical processes and stygofauna. Molecular genetic evidence suggested that the stygofauna survived in situ, the low groundwater levels experienced in the Late Pleistocene (ca. 12,000 BP). In the last 10 years groundwater in Jewel Cave has declined below the lowest recorded Pleistocene limit. While the drying climate trend in southwest Western Australia is a major factor, cumulative rainfall departure analysis identified additional stressors contributing to groundwater drawdown, most likely from nearby tree plantations. Recovery Plans prepared for the TECs, which are listed as endangered under the EPBC Act, have failed and almost all known occurrences have disappeared, presumed extinct. The recharge trial in Lake Cave succeeded in maintaining water levels, water quality and habitat for stygofauna. Listing species or ecological communities as threatened under State or Federal legislation does not necessarily guarantee their conservation. While stygofauna evidently possess some degree of adaptive capacity and resilience to groundwater drawdown, there is little quantitative data or understanding of their ecological responses, thresholds and capacity for recovery.

Afternoon Shine Dome Sessions – Managed Aquifer Recharge (MAR)

Australia Pacific LNG Aquifer Injection Trials – Proving Technical Feasibility of Large Scale Managed Aquifer Recharge to the GAB

Andrew Moser
Origin Energy Limited

Australia Pacific LNG is a joint venture between Origin Energy, Conoco Philips and Sinopec to develop a coal seam gas (CSG) to liquified natural gas (LNG) project. Both State and Federal environmental approvals for the project required trials of the injection of treated CSG water back into aquifers of the Great Artesian Basin. The trials were to be undertaken in a rapidly evolving environment, where State-based regulatory frameworks to authorize water injection were in their infancy. Australia Pacific LNG implemented a series of trials at four different locations across its gas fields targeting (where present) three aquifers of the Great Artesian Basin (Gubberamunda Sandstone, Hutton Sandstone and Precipice Sandstone) at each location. Depths ranged from 50m to 1,500m. The purpose of the trials was to assess the technical and economic feasibility of aquifer injection to manage large volumes of treated CSG water and increase aquifer pressures as a potential mitigation measure for the potential impacts of CSG-induced drawdown on landholder groundwater entitlements and Matters of National Environmental Significance. This presentation describes the workflow followed to prove feasibility, focusing on the technical but also identifying regulatory drivers. It describes the different trial designs and their execution to understand the necessary geochemical and hydraulic requirements for operational scheme design. Lessons learned from the six individual trials executed, including clogging and its remediation, metal mobilization management will be described.

The Reedy Creek Aquifer Injection Scheme – Design and Operation

Ryan Morris
Origin Energy Limited

The Reedy Creek aquifer injection scheme underpins gas production from a field of several hundred CSG wells. The scheme has the capacity to manage up to 40ML/day of treated CSG water through a field of 12 injection bores. The scheme was initially designed with 20 bores targeting an aquifer greater than 1,300m below ground. Multiple aquifer schemes were considered in the scheme design but were found to be less attractive. Hydraulic data from the injection trials combined with modified petroleum industry petrophysical techniques, provided improved understanding of the target aquifer with each new bore drilled allowing the initial number of injection bores to be reduced to 12, with five in-field monitoring bores. Pressure and flow data is recorded at one-second intervals by the control system in each of the injection bores and monitoring bores. A simple screening tool has been developed to allow bore performance to be easily checked. Excursion from a pre-defined pressure-flow relationship for each of the injection bores triggers more detailed analysis by a hydrogeologist, with a second trigger to cease injecting through that bore if performance deteriorates further. More detailed analysis is undertaken with an analytical model that is based on the principle of superposition. History matching of a pre-defined start-up sequence and multi-rate testing program allowed aquifer hydraulics and the well losses for each bore to be resolved. The calibrated model allows any changes in well performance to be separated from pressure build-up in the aquifer. It is also used to understand future capacity constraints. Regional monitoring shows the effects of Reedy Creek injection several tens of kilometers from the bore field. The hydraulic response of the aquifer is already providing an understanding of bulk hydraulic characteristics of the aquifer, as well as intra-formational complexity at a resolution not previously possible.

Managed Aquifer Recharge in Canberra - Capturing and Using Urban Drainage

David Ife
URS Australia

The Canberra Integrated Urban Waterways Project (CIUWP) is aimed at reducing the use of potable water by providing an alternative source for irrigation of recreation reserves and parks in the new urban areas. During major storm events, the Sullivans Creek catchment which covers the northern urban area generates more than 200 ML of flow, of which only 65 ML can be stored in the stormwater retention ponds for subsequent reuse because of capacity constraints within the drainage system. This study was initiated by the ACT government as part of the CIUWP to assess the feasibility of using Managed Aquifer Recharge to store excess urban catchment flows from an urban drainage area encompassing the Sullivan Creek catchment in North Canberra. A detailed hydrogeological investigation was carried out in accordance with the Australian Guidelines for Water Recycling: 2C Managed Aquifer Recharge (NHMRC–EPHC–NRMMC, 2009), focussing on the basement Canberra Formation which comprises Silurian calcareous shale, limestone and sandstone. Limestone within the basement was found to comprise highly transmissive zones corresponding to fractures and karst associated with a regional fault system. Trial testing indicated that injection rates exceeding 2,000 m3/day per well were readily achievable with the hydraulic impact zone elongated sub-parallel to the structural lineation and test pumping confirmed that these rates could be recovered from the aquifer. The injection of treated stormwater (TDS 125 mg/L, pH 8.6) into the limestone (TDS 500 mg/L, pH 7.8), resulted in a mixed concentration of 300 mg/L and pH of 7.7. Hydrochemical modelling suggests that, while carbonate minerals are at a concentration where precipitation is possible, it is unlikely that there will be a significant increase or decrease in storage capacity within the aquifer as a result of injection of surface water into groundwater. Testing confirmed that Canberra Formation limestone aquifer has the potential store and recover in excess of 1 GL/year for irrigation of parks and gardens.

Successful Approaches to Managed Aquifer Recharge (MAR) – Goal Setting, Planning, Design and Execution

Michael Goff
Beca Ltd.

The objective of this presentation is to communicate successful approaches to planning and executing a managed aquifer recharge (MAR) project. Success of a Managed Aquifer Recharge (MAR) project depends on establishment of appropriate goals, planning to meet those goals, careful science based design and dedication to the programme of development. Identified goals for a project are essential in developing proper design and benchmarks for measurement of success. Goals can include disposal of unwanted water, storage of water for seasonal or long term recovery, basin replenishment and recharge for water quality benefits. These goals can be combined in many cases. A detailed understanding of the limitations of MAR and the project elements should lead to successful goal setting and project outcome. Planning of a MAR project is more detailed in some ways than traditional surface reservoir solutions. Detailed hydrogeological and geochemical understanding is essential. Stakeholder involvement is increasingly important to successful projects especially involving reuse water. Design considerations include availability of surplus water for recharge with regard to timing and quantity, availability of land and facilities depending on selected approach, need for treatment on recovery if applicable and establishment of monitoring for regulatory compliance and early identification of problems. Execution of the project requires stakeholder buy-in and dedication to the programme. Monitoring must be maintained for regulatory compliance and determination of status with respect to project goals. Technical approaches to MAR are described through the examples of actual projects in place or being developed in USA, UAE and AU. Significant cost and resource benefits of storage in aquifers over traditional surface storage approaches or development of additional resources is discussed with examples drawn from on-going projects.

A multi-scale experimental and modelling program for estimating groundwater recharge in the Surat Basin

Nena Bulovic[1], **Neil McIntyre[1]**, Joshua Larsen[2], Lucy Reading[1,3], Warren Finch[1], Abdollah Jarihani[2] and Sven Arnold[1]

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3. Science and Engineering Faculty, Queensland University of Technology

Groundwater resources in the semi-arid Surat Basin of south-east Queensland support groundwater-dependent ecosystems and are utilised for regional agriculture, industrial and domestic purposes. Large volumes of water have been and continue to be abstracted for irrigation, and are also now being abstracted from coal seams as part of the gas extraction process. Whilst there has been major investment in monitoring and modelling the groundwater response of the Surat to this extraction, there is still a limited amount of knowledge about the groundwater recharge – the recharge processes, their space and time variability, and how to upscale them. The objective of this presentation is to describe a new research effort to address these questions. A 3.5-year multi-scale recharge research program includes monitoring and modelling at plot, field and small catchment scales, and using remote sensed data and comparisons with previously published estimates to regionalise estimates across the Surat basin. Three experimental sites have been identified, which allow maximum research value to be gained from existing government and CSG company monitoring, and represent particular knowledge gaps concerning recharge processes in the Condamine Alluvium, the Gubbermunda Sandstone and Main Range Volcanics. The experiments are at an early stage; however preliminary recharge and deep drainage estimates are spatially and temporally heterogeneous at both regional and local scales, with values varying by orders of magnitude (0-100's mm/year) and influenced by long-term climate, soil and geology. New values are comparable to previous studies utilising other estimation techniques. The large investment in groundwater monitoring and modelling associated with coal seam gas development in the Surat Basin provides a unique opportunity to understand the groundwater system and the recharge processes that drive it. There is a need to focus further research on the importance of storm events, local (e.g. streambed) versus diffuse recharge and the translation of shallow drainage estimates to groundwater recharge.

Analysing adaptation options to increase water use efficiency for Cotton Production in the lower Namoi

Takuya Iwanaga, Dr. Baihua Fu
iCAM

Overallocation of water resources in the Murray-Darling Basin has led to the deterioration of local ecosystems. Recent regulatory reforms have attempted to mitigate environmental damage by significantly reducing the amount of surface and groundwater allocated to agriculture. Further reductions may occur in the future, increasing pressure on irrigators to be more water efficient. Irrigators are exploring adaptation options to increase water use efficiency. Measures include deepening existing farm dams to proportionally reduce evaporative losses, and converting irrigation systems to more efficient types, primarily spray irrigation. It is also possible for irrigators to store water in 'underground dams' using managed aquifer recharge, reducing losses to evaporation which are projected to increase under future climate conditions. Managed aquifer recharge is not without its disadvantages. For example, certain hydrogeological characteristics are required for its application. Financial comparisons are a necessity if an informed decision is to be made regarding which option to implement. Such comparisons typically rely on assumed values and neglect the many uncertainties that exist in any socio-environmental system. The breakeven analysis of Arshad et al. (2014) is used to assess the financial feasibility and impact on water use efficiency of implementing a number of adaptation options. This method identifies a point at which an investment 'breaks even'; where no financial loss or gain is made. These breakeven points signify thresholds at which current or proposed strategies are no longer viable and aid in assessing the uncertainties inherent within each option. Collectively these breakeven points indicate conditions where financial gains or losses may be incurred. Results of analysis show many factors are already at or close to conditions in which planned improvements may not be beneficial. These include an additional 7.58% increase in evaporation rate and lower than expected irrigation efficiency. Such conditions increase the attractiveness of managed aquifer recharge.

Groundwater Replenishment Systems (GRS) for the sustainable management of catchment-scale water quantity and quality challenges (New Zealand)

Bob Bower[1], Dave Thomson[1], Brett Sinclair[1], Clare Houlbrooke[1], Jane West[1], Catherine Cockburn[1], Patrick Durney[2], Dennis Crone[3]

1. Integrated Water Management Systems Group (Golder Associates LTD)
2. Environmental Canterbury
3. Gisborne District Council

Drought cycles, amplified by climate change and coupled with groundwater over-allocation and usage, are leading to water scarcity becoming a critical issue for natural resource management throughout Australasia. Through sheer necessity, these challenges are forcing us to revisit how we fundamentally approach the management of groundwater quality and quantity and, by extension, rivers and stream baseflows. Golder's (LTD) Integrated Water Management Systems (IWMS) group is working with users, environmental interests and regulatory agencies to tackle these large scale issues through community-based collaborative approaches. These approaches are structured around step-wise, risk-based assessments leading to pilot-scale trials. Our objective is to apply the physical and regulatory tools of Managed Aquifer Recharge (MAR) in establishing economically viable, environmentally sustainable, catchment-scale Groundwater Replenishment Systems (GRS). This approach looks to address water management issues at the catchment scale, where substantial changes to the primary water balance drivers are occurring. Changes to irrigation practices, groundwater mining and more prolonged drought cycles lead to net declines in the dynamic storage of groundwater and often degradation of water quality. In this presentation the IWMS group provides an overview of challenges, drivers and opportunities for two case studies in New Zealand. Beneath the Poverty Bay Flats (Gisborne, NZ) decadal declines in groundwater pressures in a confined coastal aquifer have occurred, raising a risk of reductions in groundwater allocations for users and threatening the aquifer with potential saline water intrusion. The Hinds Plains Catchment (Canterbury, NZ) is one of the most productive agricultural areas in NZ, with the past 15 – 20 years seeing a significant increase in the amount of groundwater usage coupled with dramatic degradation of groundwater quality from increases in agricultural nitrogen leaching. A summary of the technical and regulatory tools being developed for these projects will be presented.

UPDATING AUSTRALIA'S APPROACH TO GROUNDWATER QUALITY PROTECTION: GROUNDWATER QUALITY PROTECTION GUIDELINES

Kate Dowsley, Dr Peter Dillon
Jacobs
CSIRO, Glen Osmond, SA, Australia

An extensive revision of the Groundwater Quality Protection Guidelines (the Guidelines) was undertaken to provide for improved management and protection of groundwater quality, consistent across jurisdictions. Since the original guidelines were produced in 1995 there have been significant advances in our understanding of groundwater management. These scientific advances were translated into the policy context to guide better protection of Australia's groundwater resources. A consultative approach was taken to developing the guidelines, with drafts reviewed by over 60 stakeholder groups including jurisdictional water and environment managers, community and industry stakeholders. The National Groundwater Subgroup provided significant inputs and guidance, to ensure relevance across Australia, and to avoid conflicts with current State and Territory legislation. The Guidelines present a practical strategy to maintain or enhance groundwater quality so as to support Environmental Values by:

- Adopting principles of intergenerational equity, polluter pays and precautionary principle
- Recognising the need for ecologically sustainable development
- Establishing a risk-based 12 step process to develop a Groundwater Quality Protection Plan The 12 element process for developing a groundwater protection plan includes:
- Assigning Environmental Values to groundwater through stakeholder consultation
- Setting water quality objectives, which may be numerical guideline limits and/or narrative statements on quality objectives, and
- Developing management strategies that are tailored to individual groundwater protection scenarios. Critically, the guidelines highlight linkages with other water and environment management policies and processes. The changes since the 1995 guidelines are presented.

The revised updated groundwater guidelines that are now available, continue to form part of the National Water Quality Management Strategy, but should be easier to implement through improved definition of environmental values, and link with the Managed Aquifer Recharge Guidelines. They contain an over-arching framework supported by practical tools and strategies, and are therefore an important resource for groundwater managers, land-use planners and environment managers.

Understanding clogging and groundwater quality impacts of recycled water managed aquifer recharge (MAR)

Joanne Vanderzalm, Elise Bekele, Karen Barry, Mike Donn, **Peter Dillon,** Anna Kaksonen, Geoff Puzon, Jason Wylie, Thomas Walsh, Matthew Morgan, Konrad Miotlinksi, Kevin Cahill, Don McFarlane.
CSIRO

Australia has considerable potential for supplementing groundwater resources and increasing the proportion of water that is recycled via managed aquifer recharge (MAR). However, the utilisation of sedimentary deposits for MAR is not without technological challenges; such as clogging that is detrimental to the infiltration process and the impacts of recycled water on the receiving groundwater quality. Two field investigations were undertaken to investigate these challenges: (1) an infiltration gallery located in predominantly medium-grained Aeolian sand deposits typical of the coastal plain of Western Australia at the Floreat Infiltration Gallery site; and (2) soil aquifer treatment (SAT) using recharge basins located within a mixture of fine- and course- gradient riverine deposits in Alice Springs, NT. The infiltration gallery was able to recharge the aquifer using filtered secondary treated wastewater at an average rate of 4 m/d over a 5 month period. Changes occurred spatially in gallery wastewater levels and soil moisture contents surrounding the gallery suggesting that heterogeneous clogging developed locally within the gallery and promoted increased flow of wastewater laterally away from the gallery. Infiltration rates in the five SAT basins, constructed in lower permeability sediments, varied from 0.2 to 1 m/d. Implementation of filtration as an additional pre-treatment step improved the quality of recharge water to the SAT basins and resulted in at least 40% improvement in average infiltration rate. There was no evidence of nitrate removal at either site due to the prevalence of aerobic conditions. The Spearwood Sand was effective in reducing the concentrations of recharged phosphate and dissolved organic carbon during infiltration. Freshening of groundwater on site and down-gradient from the Alice Springs SAT scheme occurred, which is an important consideration when assessing potential uses of this groundwater resource. Stable isotopes indicated the presence of recharge water 1000m down-gradient, not apparent with other less sensitive environmental tracers.

Is Groundwater in the South Pacific Islands Vulnerable to Future Climates?

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Geoscience Australia, Canberra, ACT, Australia

Islands in the South Pacific region rely heavily on groundwater and for many islands it is the only reliable source of freshwater throughout the year. Sea-level rise and changes in rainfall patterns are likely to put water resources—already under pressure from increasing populations and pollution—at further risk, threatening the long-term viability of communities and islands. This study has undertaken a first-pass regional assessment to better understand the vulnerability of fresh groundwater systems to future climates for 15 Pacific Island countries and territories. Applying a groundwater vulnerability framework, relative potential vulnerability of groundwater to future: (i) low-rainfall periods and (ii) mean sea-level rise has been assessed for projected 30-year periods centered on 2050 and 2085. The framework rates the potential impact (sensitivity and exposure) of a climate hazard which is offset by the intrinsic ability of a groundwater system to be managed for future climate impacts. A hydrogeologically-based typology has been developed for the study. The typology identifies five types of islands, each with similar groundwater systems—Low Carbonate, Limestone, Volcanic, Composite and Complex. These island types underpin the assessment of groundwater vulnerability. The assessment has found that there are a large number of islands in the region with groundwater systems that are potentially vulnerable to future low-rainfall periods and projected sea-level rise. The majority of assessed Low Carbonate islands have the highest rating of relative potential vulnerability to low-rainfall periods or mean sea-level rise by mid- and end-of-century. Complex islands (>2,000 km^2) are the least vulnerable to low-rainfall periods or mean sea-level rise. These results have implications for future water management and planning in the Pacific region in that they can assist regional water managers and policy makers to develop and prioritise adaptation options and identify areas where more detailed analysis of groundwater vulnerability could be undertaken.

Have our catchments reached hydrological and salt equilibrium after large scale land clearing?

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2. The University of Melbourne

The replacement of deep-rooted native vegetation with shallow-rooted agricultural crops has resulted in increased recharge causing rising water table. This has led to extensive dryland salinity and stream degradation throughout the Murray-Darling Basin. However, there are a number of challenges in assessing the salinity risk and effectiveness of management options. A key question is how long it will take for the increased recharge after land clearing to be balanced by the increased discharge and how long the increases in stream salinity will continue in different landscapes. This study investigated the timeframe for the establishment of a new hydrological equilibrium and salt balance after land clearing in the Goulburn Broken dryland region using the following approaches:

- a nonlinear transfer function groundwater time-series model to predict future groundwater trends;
- BC2C model to estimate groundwater response time to land clearing; and
- CATNode model to model contributions of water and salt load to stream.

The time-series modelling showed that the majority of bores in the region will have a flat or slightly upward trend in the next 25 years and beyond under long-term average climate conditions. Average groundwater response time estimated by the BC2C model ranges from 5 to 50 years across the 34 sub-catchments in the region. The CATNode modelling indicated that stream flow in the majority of sub-catchments in the region would remain steady until the end of the simulation period in 2100 while salt load and salinity continue to increase although at a gradually reducing rate over the same period. These results suggest that the groundwater flow systems in the region have reached or nearly reached hydrological equilibrium, but the catchment salt balance will take longer to achieve. This study provides important new knowledge for the development of salinity management strategies for the region.

A framework and graphical tools to assess transience in groundwater systems in response to land use and climate

Matthew Currell
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The assessment of transient (as opposed to steady-state) behaviour in groundwater systems in response to land use and climatic change can be challenging. The objective of this research was to provide a framework and set of graphical tools that can be readily used by groundwater managers to assess the likely importance of transient behaviour in a given system in response to particular drivers, such as climatic cycles of varying length. It is widely recognised that aquifers respond on different time scales to hydrological change, and that many hydrological drivers are not stationary. We propose that in order to assess whether transient behaviour is likely to be important, three factors need to be examined together: 1. Aquifer 'response time', which is related to hydraulic parameters; 2. Temporal variation of the dominant hydrological driver(s) – such as climatic systems that influences recharge; 3. The temporal and spatial scale of interest to management (e.g. whole basinversus sub-catchment). Using simple analytical formulations of aquifer response time, represented graphically in 2 dimensions with the period of cyclic hydrological drivers, we provide a new tool that allows simultaneous assessment of these three factors. This facilitates rapid assessment of the likely importance of transient behaviour of a given system, on time-scales of interest to groundwater management. The tool and framework could be widely used to assess whether detailed modelling of transient behaviour is required for a particular management problem, or whether steady state approximations are more appropriate (or adequate). Using the tool to examine how local, intermediate and regional groundwater systems respond to particular climate systems (e.g. ENSO; Glacial-Interglacial Cycles) reveals important information. Most regional aquifers in recharge limited areas are likely still responding to long term climatic shifts such as glacial- interglacial transitions; smaller-scale aquifers are sensitive to transience driven by multi-year climatic change.

A new plan for a changing climate: Developing a flexible and adaptive approach to shallow groundwater management in the Shepparton Irrigation Region, Northern Victoria.

Simon Cowan, Krystle Gillingham, Karina Joy,
Goulburn-Murray Water

In the late 1990s, a groundwater management plan (the Plan) was developed in the Shepparton Irrigation Region (SIR) when watertables were high, and expected to stay high. However, the millennium drought (1997 to 2010) and changes to irrigation practices led to concerns the plan was no longer fit for purpose. The Plan focussed on salinity mitigation and did not contain measures for wet and dry climatic conditions or reflect the opportunistic nature of shallow groundwater in the SIR. Additionally, increasing licence fees saw many users relinquish groundwater licences; reducing the capacity to mitigate salinity. The revocation of the Plan and establishment of an alternative management framework was supported by an assessment of management options and groundwater user behaviours and expectations. Also, a salt and water balance provided a contemporary assessment of hydrogeology and land salinisation in the SIR. Support for a new plan was also aided by a critical examination of groundwater management costs. The assessment found that flexible, adaptable and lower cost management would address issues arising from both high and low watertable conditions. Social research showed strong user support for less intensive management, paying less and accepting individual risk associated with extracting and using shallow groundwater. Consultation also established that management costs were disincentives for users to retain licences. Additionally, the salt and water balance demonstrated watertables principally respond to climate, and management is limited by the fragmented and opportunistic characteristics of shallow aquifers. A new planning approach in the SIR has highlighted the importance of management measures that are practical and cost-effective. Acceptance of this new plan is due in large part to rigorous social research and consultation. Investment in understanding user values, behaviours and cost drivers, as well as understanding barriers to shallow groundwater use, has led to widespread support for the management changes. Further, understanding shallow groundwater behaviour in both wet and dry climatic conditions was fundamental to making the case for low cost, flexible and adaptable management.

Changing land use in an uncertain climate – impacts on surface groundwater flows and water quality in the Goulburn River, Hunter Valley NSW

Julia Imrie, Professor Ian White
Australian National University

The Goulburn is the largest tributary of the Hunter River, a highly connected surface groundwater system and one of the least studied and understood river catchments in NSW - notwithstanding its influence on downstream water quality and the Hunter River Salinity Trading Scheme. Broad indicators show a long term upward trend in annual summer rainfall and changing land use from agriculture to mining. This has implications for surface and groundwater flows, water quality and the viability of groundwater dependent ecosystems requiring targeted research. The study investigates geological sources, drivers and trends in water quality, flows and catchment yield through analysis of available government and industry hydrologic, groundwater and climatic data supplemented and collated with 'snap shot' water sampling. Methodology includes the analysis of hydro-chemical data to characterise aquifer groups and interaction between sources. The research focuses on key sub-catchments and hydrological features to elucidate surface groundwater connectivity, flow paths, key hydro-geological processes and the effects of changing land use. BOM climate records and long term spatial averaging are utilised to determine trends in inter-annual and intra- annual rainfall; climate cycles and decadal drought. Preliminary findings highlight crucial differences in the hydro-geology of tributaries and their contributions to flow and salinity. Geologies that contain significant salt stores juxtapose with dilution inputs from fresher groundwater sources. Cumulative effects of major catchment activities on groundwater sources; activating salts and modifying groundwater flows and quality, are intimately linked to variable rainfall conditions, aquifer recharge and catchment yield. In the upper Goulburn evidence indicates mine groundwater de-watering and discharge is altering stream water chemistry and elevating salinity. This research will assist the future planning and management of the Goulburn and Hunter catchments providing essential information for balancing development with protection of the environment.

Modelling water balances at tropical savanna and pasture sites in northern Australia

Cuan Petheram, Dr Lindsay Hutley, Dr Jason Beringer, Dr Richard Weinnman, Mr Joseph Kemei, Mr Matthew Northwood, Dr Peter Isaac, Dr Guy Bogg
CSIRO

Tropical savannas are increasingly threatened by clearing and landuse change. Although many studies have examined the impacts of vegetation change on water yield in temperate and Mediterranean climates, there have been fewer studies in tropical regions and the results are less conclusive. In the first study of its type in northern Australia, a SVAT (soil-vegetation-atmosphere-transfer) model, WAVES, was used to help develop a process understanding of the impacts of vegetation change on groundwater recharge in the Daly River catchment. Two neighbouring sites, an uncleared tropical savanna (UC) on Red Kandasol Blain soils and an improved pasture (IP) inter-sown with a tropical legume on Red Kandasol Oolloo soils, were instrumented with eddy covariance systems to monitor fluxes including evapotranspiration (ET), wind speed and soil water dynamics over a 6 year period (July 2008 to June 2014). Soil hydraulic properties and chemistry were also measured at each site. These data were used to parameterise the WAVES model and assess modelled water balance components. WAVES reproduced the temporal changes in stand water use well, except on days where water use was low due to low evaporative demand, and during seasonal transitional periods. There was also good agreement between modelled results and a salt tracer analysis. Using WAVES to extend the analysis over an 80-year time period, the majority of non-evaporated water becomes deep drainage (~90%) and overland flow (~70%) at the UC and IP sites respectively. This is thought to be due in part to differences in soil texture and anthropogentic disturbance of the soil at the IP site. A change in the partitioning of excess water into overland flow and deep drainage following clearing may have implications for the Daly River, where in-stream, riparian and near-shore marine ecosystems are highly dependent upon the quantity, quality and timing of dry season flows.

Impact of land use and climate change on surface and groundwater resources in SE Australian upland catchments

Evan Dresel[1], Joshua F. Dean[2], Fahmida Perveen[3] - John A. Webb[3], Edoardo Daly[4], Peter Hekmeijer[1], S. Michael Adelana[1], Samantha P. Glover[3], Matteo Camporese[5]
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2. University of Sterling, UK
3. La Trobe University, Melbourne
4. Monash University, Melbourne
5. University of Padua, Italy

Water balance and flow dynamics were assessed for seven catchments in the Glenelg River basin, southwestern Victoria, Australia. The region is within the high rainfall zone of southeast Australia and is an important area for red meat, wool, plantation forestry, and cropping. Land-use change has potential to alter river flows especially due to varying evapotranspiration. Ephemeral catchments dominated by farm pasture and by Eucalyptus globulus plantations, located in 3 different geologic settings, were studied for about 4 years to associated land-use traits to catchment water balance Groundwater levels for the plantations declined through the study period while levels in the farm sites increased. Surface flow occurred mainly during winter, and was dominated by rapid runoff. Annual rainfall and flow in all catchments declined during the study with no obvious flow difference due to plantation establishment. Annual flow duration was highly variable due to effects other than land use. Surface and near surface water storage exerted a strong influence on rainfall-runoff relationships. Calculated evapotranspiration was 86-115% of the precipitation for all catchments. Evapotranspiration greater than rainfall at the plantations was attributed to direct uptake of groundwater by the trees. The presence of grass buffers along streams enhances groundwater recharge and saturation-dependent overland flow, reducing the potential impacts of plantations. Fully saturated soil profiles near streams, surface water storage, and drainage are believed to have a greater impact on flow duration curves than groundwater discharge.

Give and take: response in shallow groundwater systems to rainfall and extraction pressure on the Condamine Floodplain

Kate Reardon-Smith, Dr. Andy Le Brocque
University of Southern Queensland

Issue: Declining groundwater systems threaten the sustainability of agricultural and eco-hydrological systems. This is likely to be exacerbated under projected climate change. This research investigates the dynamics of alluvial groundwater systems on the Upper Condamine Floodplain, a major irrigated cropping area in the northern Murray-Darling Basin, in order to better understand the relationship between land use, climate and recharge of shallow groundwater systems. The specific objective is to model discharge and recharge rates in groundwater systems in terms of key land use and climatic drivers in this landscape. This study analyses historical trends in the regional groundwater monitoring bore time series data in relation to patterns of irrigation development, land use and climate (rainfall) on the Condamine floodplain. Historical groundwater monitoring data from over 300 bores and streamflow monitoring data is modelled in relation to rainfall data and extraction pressure over time. The results of this research build our understanding of the often complex interconnections between land use/land cover and climatic, hydrological and ecological systems and contribute to adaptive and sustainable resource management.

Unstable fresh groundwater plumes of the western slopes of the Great Dividing Range.

David Allen
Groundwater Imaging Pty Ltd

Groundwater studies and modelling of the fresh groundwater plumes under each river crossing the western plains of the Australian Great Dividing Range have been collated in the effort of the MDBA to determine Sustainable Extraction Limits. This effort has focused principally on estimation of recharge. It gives estimated ages for groundwater within each of these plumes with accuracy upon which groundwater license extraction limits depend. The objective of my paper is to explore historical and predictive implications of these findings and to present appropriate management practices. Collation of plume details along with geophysical survey and geomorphological evidence of the nature and history of the plumes' emplacement was used to postulate and assess various models of their development and projected impact of various management strategies. The estimated ages of water in the plumes range from hundreds to thousands of years. Implied by these ages are imminent limits to the time freshwater can be extracted from bores in the plumes beneath each river. In some cases, even if extraction induces extra recharge, most bores on plume extremities will become saline within hundreds of years at current extraction rates. As pressure from surrounding saline groundwater compensates for extraction, there is real potential that some plumes will be almost completely consumed within 300 years leaving only bores near the recharge sources in operation. Fresh groundwater plumes in the western plains are unstable. Of immediate need are laws that promote increased conjunctive management of shallow groundwater and surface water storages rather than dependence on the deeper plumes. A farmer extracting shallow groundwater will reduce water use by improving deep drainage and thus crop vigor while also preventing pressure that can salinize the valuable fresh groundwater plumes beneath.

Afternoon ANU Theatre 2 Sessions – Inter-aquifer Leakage & Connectivity/Isotopes

Requirements and opportunities for the use of high resolution geothermal profiles to determine vertical groundwater flow in aquifers

Dylan Irvine[1], Prof Ian Cartwright[1], Dr Vincent Post[2], Prof Craig Simmons[3], Dr Eddie Banks[2]
1. Monash University
2. Flinders University
3. National Centre for Groundwater Research and Training

Steady state analytical solutions that use geothermal profiles to estimate vertical groundwater fluxes have been available since the 1960s; however they are still not widely used. With very high resolution temperature sensors (0.0001 °C) available, there is scope to further investigate the use of temperature data in hydrogeology. The objectives of this study were to determine the reliability of vertical flux estimates from 1D analytical solutions based on high resolution synthetic and field geothermal profiles. Synthetic geothermal profiles were generated using homogeneous and heterogeneous aquifer properties using FEFLOW. Fluxes were estimated for different recharge rates, lengths of geothermal profile, temperature resolution and for different ratios of vertical to horizontal flow using the Bredehoeft and Papadopulos (1965) solution. Following the synthetic studies, geothermal profiles from the Willunga Basin in South Australia were assessed. Analyses of synthetic geothermal profiles show that the flux estimates from the Bredehoeft and Papadopulos method from the use of relative to low (0.01°C) resolution temperature improved with high resolution (0.0001°C) temperature, and a wider range of fluxes could be determined. When high resolution temperature data were analysed, it was also possible to assess shorter (e.g. 20 m) sections of the geothermal profile and provide estimates of how flux varied with depth. Geothermal profiles in the Willunga Basin suggest a large range of fluxes from ~70 to >800 mm/yr, and show evidence of fluid exchange between different aquifer units. The use of high resolution temperature data and steady state analytical solutions can provide estimates of vertical groundwater fluxes with methods that do not require expensive and time consuming laboratory analyses. The 1D analytical solution provided reliable estimates of flux in synthetic 2D flow fields with heterogeneous properties, and can be used to investigate fluid exchange between aquifer units.

Important role of porewater stable isotope analysis in investigations of low permeability strata, Sydney Basin

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The need for water in the southern Sydney Basin is subject to competition between industry, the need for water supply and the environment. The area includes Sydney Water Catchment, several closed and operating underground coal mines, coal seam gas industry and private water supply bores. In addition, it is home to swamps and wetlands which form part of the sensitive ecosystems. This project was initiated to provide more understanding into groundwater movement and the role of low permeability rock formations as a barrier to vertical flow in sedimentary basins. A novel porewater stable isotope technique was applied as part of multi-disciplinary investigations of hydrogeology and geomechanical behaviour of rock formations. The rock core samples were collected immediately following drilling, and were carefully preserved. The samples were analysed for stable isotopes using Los Gatos analyser (calibrated with Los Gatos and VSMOW standards) and for Cl content in UNSW Australia analytical laboratory. In addition, pore pressure data from vibrating wire piezometers was used to assess the flow velocity to support the stable isotope data analysis. This research focused on conceptualising groundwater conditions and qualifying vertical and horizontal components of groundwater flow and seepage at the interface of high and low permeability rock strata. The study found that detailed vertical profiling using porewater stable isotopes, supported by other investigative methods, allows differentiation between hydrostratigraphic units and provides their detailed understanding within the southern part of the Basin. Due to overall low salinity within the sedimentary strata, Cl was not found to be a useful tracer. The research findings are important as they show that porewater stable isotope analysis can be a valuable method in the Australian setting where past climate had enough variability in $\delta 18O$ of the recharge water to introduce sufficient contrast. The method also has the advantage of being applied in the areas where it is not possible to have a suitable network of standpipe piezometers. Characterisation of groundwater flow in sedimentary basins using traditional groundwater methods can be greatly improved by the addition of porewater stable isotope analysis.

The vertical permeability of the Leederville Formation and South Perth Shale – New insights from centrifuge testing in Perth, WA.

Doug Anderson
UNSW

More than half of Perth's potable water supply is derived from groundwater with as much as 20% being sourced from the Leederville aquifer, part of the Gnangara groundwater system, which supports groundwater dependent ecosystems and associated ecological, social and cultural value. Management of these resources by the West Australian Department of Water (DOW) is facilitated with several tools including the Perth Regional Aquifer Modelling System (PRAMS); a modelling tool developed within the MODFLOW software framework. In their model calibration report for PRAMS CyMod Systems (2009) draw attention to a lack of direct measurement of vertical leakage and vertical aquifer properties in the Leederville aquifer and its adjacent aquitards. It suggests additional quantification and spatial mapping to improve model calibration for more accurate predictions of impacts of groundwater abstraction. DOW are now undertaking a groundwater management study, the Perth Confined Aquifer Capacity study, to better examine the impacts of continued groundwater use from the Leederville and Yarragadee aquifers. This paper documents the results of recent vertical hydraulic conductivity testing on thirteen drill core samples recovered from the South Perth Shale and the Leederville Formation (comprised of the Pinjar, Wanneroo and Mariginiup members). The core samples were tested at UNSW Australia's Geotechnical Centrifuge Laboratory using established centrifuge techniques that have been adapted by the Water Research Laboratory (WRL). WRL's new test method relies upon a combination of constant and falling head centrifuge measurements at accelerated gravity (up to 500G) to provide reliable estimates of the in-situ core scale vertical and horizontal hydraulic conductivity. The technique can provide accurate data in short-time frames (0.5 to 5.0 days) for regular and irregularly shaped samples with hydraulic conductivities in the range of 0.1 m/d to 3E-07 m/d. This new vertical hydraulic conductivity data-set has only just been made available. The benefits of the data-set for the management and modelling of mining and water resource projects will be discussed.

Argon-39: new possibilities for groundwater dating up to 1000 years from ATTA

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While several methods exist to assess groundwater flow and transport on time scales below a century (3H, CFCs, SF6, 85Kr), a severe practical dating gap exists for centuries up to few millennia. This time scale is very important because it covers the strongest impact of man on groundwater systems, like land clearance or the agricultural revolution. The radioactive isotope argon-39 (39Ar) has a half-life of 269 years and is the ideal, and only, tracer for dating water in the time range of 50–1000 years. However, its routine application was difficult due to its extremely low atmospheric abundance (39Ar/Ar = 8.2 E-16). Over the last 30 years, Low Level Counting (LLC) was the only viable technique for detecting 39Ar with reasonable effort. In the last decade a laser-based atom counting method, Atom Trap Trace Analysis (ATTA), became a promising alternative for dating groundwater [Ritterbusch et al. 2014]. For LLC methods, 1-3 tons of water must be degassed in the field to obtain enough gas for the required 600 ml of argon, whereas the required sample size for ATTA is presently only 10–25 L water. This makes groundwater sampling practical by removing the need for degassing in the field, but it also allows applications in other environmental reservoirs, like dating of glacier ice or ocean water. Besides the new analytic method, various sampling protocols and preparation setups were developed to link the fieldwork with the new detection technique. In this talk, a description of the techniques required for Ar-39 dating of groundwater will be given, starting from sample degassing in the field, followed by the sample purification in the lab and the analysis with LLC or ATTA. The added value of 39Ar to studying hydrological processes will be demonstrated in recent groundwater studies as well as in an outlook to applications in other systems.

Inter-aquifer leakage and groundwater flow inferred from environmental tracers especially noble gases

Stacey Priestley[1], Andrew Love[1], Daniel Wohling[2], Vincent Post[1], Paul Shand[3], Rolf Kipfer[4], Tim Payne

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3. CSIRO
4. EAWAG

Management decisions regarding sustainable yields or resource exploitation require an understanding of the groundwater system (Alley et al., 2002, Cherry and Parker 2004). There can be significant errors in the estimates of groundwater flow in large scale flow systems by not taking into account inter-aquifer leakage rates (Love et al., 1993, Toth 2009). In most groundwater systems, the quantity or location of inter-aquifer leakage is unknown. The increase in coal seam gas (CSG) production has provided further interest in inter- aquifer leakage and contaminant migration. There are very few robust methods available to investigate inter-aquifer leakage on a regional scale. This preliminary study investigated inter-aquifer leakage in arid-zone, regional-scale, sedimentary groundwater systems: the Great Artesian Basin (GAB) and the Arckaringa Basin. Environmental tracers were used in conjunction with more traditional analysis of hydraulic head and geological data to determine groundwater flow paths, areas of groundwater mixing, and to characterise and quantifyinter-aquifer leakage. The suite of environmental tracers and isotopes used includes the isotopes of water, radiocarbon, chloride-36, uranium isotopes and noble gases. The methodology was effective in identifying a lack of inter-aquifer connectivity at most locations and localised inter-aquifer leakage due to secondary permeability in the aquitard. Recharge from surface water features and around basement highs could also be inferred from the data.

New Stable and Radioactive Noble Gas Tracers at CSIRO

Axel Suckow
CSIRO Land & Water Flagship

CSIRO is Australia's leading pioneer of new applications of environmental tracers in groundwater, surface water and aquitard pore water for nearly four decades. This involved adapting dynamically to the needs of our customers – state agencies and industry partners. Our group pioneered in the application of stable isotopes, later of 14C and 36Cl. Their commercial availability made our group shift to the less common, most useful tracers. The most recent step of this continuous adaption moved us into the role of the only laboratory on the southern hemisphere to supply measurements of stable noble gases (He, Ne, Ar, Kr, Xe) and radioactive noble gas isotopes (85Kr, 39Ar, 81Kr) in (ground)water samples. Noble gases are the most versatile tool among the environmental tracers. They allow assessing flow velocities on time scales from years (85Kr), centuries (39Ar), millennia (4He) up to one million years (81Kr) and beyond (4He, 40Ar, 21Ne, 134Xe, 136Xe). Knowing flow velocities is indispensable in managing groundwater as a resource for drinking water, agriculture, industry and mining. Noble gases also allow reconstructing infiltration conditions (temperature, salinity, altitude) and distinguishing infiltration processes, like recharge after flooding a dry riverbed versus constant infiltration from a permanently loosing stream. As such they are indispensable tools in any groundwater assessment, in the study of surface water – groundwater interaction, groundwater – sea water interaction, assessing aquitard permeability, aquifer systems and the calibration of numerical models for groundwater flow and transport. The talk will give details of the new analytical facility at CSIRO Waite campus, demonstrating why it is better adapted to Australian groundwater problems than the few existing overseas laboratories. It will demonstrate how the new tracers fit into multi-tracer studies with other more common tracers (18O/2H, 3H, CFCs, SF6, 14C, 36Cl): these need noble gas information and noble gases are more robust because chemically inert. Application details will be given in talks by other authors of the team within the context of single projects and case studies.

Assessing connectivity between an aquifer and coal seam gas production using water geochemistry and methane isotopes.

Charlotte Iverach, Dioni I. Cendon, Stuart I. Hankin, Dave Lowry, Rebecca E. Fisher, James L. France, Euan G. Nisbet, Andy Baker, Bryce F.J. Kelly
Connected Waters Initiative Research Centre, UNSW Australia

Expanding coal seam gas (CSG) production has created public concern surrounding the impact on groundwater quality and quantity in adjacent or overlying aquifers. To address this potential risk, we need to map pathways of hydraulic connectivity. We show that the combined measurements of methane (CH4) concentration and isotopic composition, dissolved organic carbon (DOC) concentration and tritium (3H) activity can highlight pathways of connectivity between the Walloon Coal Measures (WCM), the target formation for CSG production, and the Condamine Alluvium in the Condamine Catchment, south-east Queensland, Australia. At 17 locations, both groundwater and degassing air samples were collected from irrigation bores. The degassing air samples were collected by pumping gas into 3 L Tedlar bags. This air was analysed for both its methane concentration and isotopic signature using a Picarro 2132-i analyser. The groundwater at each location was analysed for 3H, by counting beta decay events in a liquid scintillation counter, and for [DOC], measured by isotope mass spectrometry. To determine the isotopic signature of the WCM methane ambient air samples were collected adjacent to CSG co-produced water holding ponds. These samples were also analysed using the Picarro 2132-i analyser. We then used isotopic mixing plots to identify the source signature of CH4 in the degassing irrigation bore samples and the ambient air samples adjacent to CSG water storage dams. Within the mixing plots samples graph along clear trend lines, which allows water and gas sources to be assigned. The trends in the mixing plot indicate potential local hydraulic connectivity between the WCM and the overlying Condamine Alluvium. These results demonstrate that a combination of CH4 concentration and isotopic analysis, as well as groundwater geochemical data, can provide an early indication of hydraulic connectivity in areas of CSG and shale gas production.

A Field Based Investigation Of Aquifer Connection Between The Pedirka Basin And The Great Artesian Basin, Northern Territory

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2. Department of Environment, Water and Natural Resources

In 2012, the Australian Government established an Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Developments to provide scientific advice on the potential impacts these activities may have on water resources. Under this initiative, DEWNR was funded to investigate aquifer interconnectivity between the Pedirka Basin (PB) and the overlying Great Artesian Basin (GAB). A dedicated investigation site was developed on Andado Station (Northern Territory) with nested piezometers completed at depths up to 521 m in the Crown Point Formation (PB), Purni Formation (PB), Algebuckina Sandstone (GAB) and the Cadna-Owie Formation (GAB). A multi-well 48-hour aquifer test was undertaken in the Purni Formation to investigate hydraulic connection throughout the profile. Time series groundwater chemistry and environmental tracers (14C, □□2H, □18O 87Sr/86Sr) were collected during the aquifer test and from all nested wells. A conceptual model of the aquifer system was developed and tested using the analytical modelling software MLU (Hemker, 1999a). A drawdown response was observed in both upper and lower GAB aquifers within 200 minutes of commencing the aquifer test. The observed pressure response was best simulated applying a model that conceptualises the Algebuckina Sandstone and upper Purni Formation as a series of layered sandstone aquifers. Notably, interbedded shale layers identified from wire-line logging do not appear to significantly impede vertical connection between the Purni Formation and GAB aquifers. No clear evidence of disconnection was identified from the major ion signature, □2H and □18O or 87Sr/86Sr composition of GAB and PB groundwater samples. The apparent groundwater age, based on 14C concentration indicates that modern recharge is not occurring and that palaeo-recharge to the PB and GAB may have been contemporaneous in this region. Study findings have implications for both the development of coal resources in the PB and the management of groundwater resources in the GAB.

Arckaringa Basin aquifer connectivity - Application of multiple approaches

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1. Department of Environment, Water and Natural Resources
2. Flinders University

The Australian Government through the Department of the Environment funded the South Australian Department of Environment, Water and Natural Resources (DEWNR) to collate and ground-truth baseline groundwater, surface water and ecology information to inform the Bioregional Assessment Programme in the Lake Eyre Basin (LEB). Within the LEB bioregion an investigation of aquifer connectivity in the Arckaringa subregion was undertaken. This project involved coring a hole to ~110 m through the Great Artesian Basin (GAB) and into the Arckaringa Basin (Permian) sequence, to provide an assessment of vertical flow via hydraulic, hydrogeological and hydrochemical analysis. The vertical core profile was used to develop 1D numerical and analytical models to simulate evolution of aquitard porewater chemistry. Point estimates of the aquitard (Stuart Range Formation) hydraulic head were obtained via vibrating wire piezometers. Upscaling of groundwater inter-aquifer connectivity to a regional-scale was undertaken using regional hydraulic head and hydrochemical data, especially noble gases. This provided an improved understanding of inter-connectivity between the Permian sequence and overlying GAB aquifer, and intra-connectivity within the Arckaringa Basin. Multiple investigation techniques revealed a very low degree of connectivity, in the study area, between the Arckaringa Basin and overlying GAB (J-K aquifer). The flow (flux) through the aquitard is very small, in the order of millimetres per 1000 years. This approach combining geochemical and isotopic profiling with insitu hydrodynamics has the benefit of characterising a regional-scale that is of interest for groundwater resource management. A reliable range of estimates for aquitard bulk hydraulic conductivity were obtained, enabling constraint of flux estimates and increasing confidence in the assessment of aquifer connectivity. Finally, aquitard porewater profiles and associated 1D modelling indicate a complex palaeohydrogeology with associated salinity variability. It is thought this is one of few investigations in the southern hemisphere that has undertaken this type of aquitard assessment.

Career Posters

Comparison of modelled and remotely-sensed evapotranspiration on catchment scales

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In most catchments, evapotranspiration (ET) is the largest component of the water budget besides precipitation, yet it is the most difficult to estimate. In recent years, the advent of remotely-sensed data based ET algorithms (R-S ET) and distributed hydrological models with remotely-sensed input data has significantly improved ET estimation over point scale measurements. However information on the inter-comparison of these methods is limited in literature. This study compares the ET estimates from the MOD16 R-S ET dataset and the ET calculations from a SWAT hydrological model. The analyses are performed on monthly timescales for a 6 year period (2000 – 2005). Evapotranspiration over seven sub-basins in the Western Mount Lofty Ranges of South Australia, with varying principal land covers, soil type and meteorological conditions are evaluated in this study. The SWAT model is calibrated by fitting simulated to observed runoff and the MOD16 dataset is compared to the evapotranspiration calculated by the calibrated model.

Both methods showed strong correlations across the catchments, with Pearson's correlation coefficient, root mean square error and mean absolute error ranges of 0.68 – 0.90, 11 – 36 mm/month and 8 – 28 mm/month respectively. The highest correlations were observed in the catchment with croplands as the principal land cover, and the least correlation was for the catchment with the forest land cover. The MODIS datasets predicted significantly higher ET than SWAT in the forested catchments, which is consistent with studies that compared MODIS data to measured ET rates using flux towers.

An 8-step process to understanding water requirements of remnant vegetation in urban areas

Timothy Anderson[1], Phoebe Mack[1], Dr Sjaan Bidwell[1], Bertrand Salmi[2], Alex Moodie[2], Marie Keenan[2]
1. GHD
2. City of Greater Dandenong

The City of Greater Dandenong has a number of nature reserves and open space areas which are being encroached upon by urban development. These nature reserves play a role in supporting biodiversity, but also provide valuable green areas for public enjoyment. The reserves are subject to significant stresses. The Millennium drought, climate change and changes to the surrounding catchments with increasing urbanisation are factors that contribute to the deterioration of these areas. Water stress is perceived to be a factor in the deterioration. Bushland management plans unfortunately do not attempt to tackle the issue, generally focusing on planting and weed control. The City is continually looking at ways to better manage its reserve, with an onus on securing water supplies to these nature reserves since the Millennium drought. Improved management of stormwater is seen as a key solution to addressing water deficiencies, however there are a number of uncertainties that need to be addressed to support management planning – are the ecosystems suffering from water deficiency, what is the groundwater dependence, could stormwater infiltration create water logging issues, how do you measure the benefit? In order to determine the water requirements of the reserve, GHD developed an assessment framework for the project. The framework was applied to understand the ecosystem values, current condition, threats and groundwater dependence. In applying the framework, it was necessary to characterise the ecosystems, the hydrology and hydrogeology of the reserve, and the water requirements of its ecological values. Following development of the framework, it was applied to two nature reserves with the City, the Coomoora Woodland Flora and Fauna Reserve, and National Drive. Each reserve had core ecological values that were identified as requiring protection, e.g. inland snow gums (Eucalyptus pauciflora subsp. niphophila) and river red gums (Eucalyptus camaldulensis). Threats, including those related to the water cycle and groundwater were identified, and a list of possible mitigation measures was also identified, including ecological thinning, stormwater infiltration, and managed aquifer recharge. Advantages of the framework is that it can be applied by the City to any of its existing parks and reserves, but also land proposed to be developed and/or offset reserves. As a result, opportunities to maintain and protect sites' water cycle stress can be identified and management measures implemented where required. Additionally, a better understanding of water regime requirements may also better inform other management decisions, especially weed control. The next phases of the project include implementing soil moisture and groundwater monitoring at the study areas to establish baseline conditions, which could be used to inform when intervention is required, but also assess the efficacy of remedial measures.

SURVIVING THE MILLENNIUM DROUGHT AND BEYOND: SECURING POTABLE SUPPLIES IN VICTORIA'S CENTRAL HIGHLANDS REGION

Tim Anderson, John Frdelja
GHD

South-east Australia was subjected to its most severe drought on record between 1997 and 2010 which had a significant impact on water resources in Victoria's Central Highlands region. After more than a decade of below average rainfall, pronounced effects on the security of supply manifested in numerous towns that were historically reliant upon surface water supplies. This resulted in widespread water restrictions, a deterioration in water quality in some cases, community distress and pressure (social and political) on the responsible water supply authority. This paper presents a summary of the issues that were overcome by establishing multiple groundwater supplies, and some of the post-drought challenges and activities, including forward planning. Central Highlands Water, the authority responsible for providing safe and secure water supply to urban populations in the region embarked upon major groundwater investigations and projects to secure supply for impacted communities. The water supply to Victoria's third largest city, Ballarat, was subject to severe stress, and groundwater investigations were undertaken to supplement supply to the city. Smaller towns and communities at Maryborough, Daylesford, Avoca, Beaufort, Forest Hill, Learmonth, Waubra, and Amphitheatre also required investigations and works. These activities included drilling programs, production bore construction, water quality sampling, pumping test investigations and technical reporting. Drilling targets included volcanic basalt sequences and palaeochannels ('deep leads'). Issues that had to be overcome included:

- Managing water restrictions and community expectations
- Identifying target areas for drilling
- Drilling contractor availability
- Licensing and regulatory approvals (including environmental and cultural heritage)
- Assessing impacts to existing groundwater users and the environment
- Water quality considerations
- Logistics of establishing delivery infrastructure (pipelines and power)
- Developing and implementing monitoring programs

Despite the drought breaking in late 2010, and with another El Nino event predicted this year, continued groundwater investigations and works are required to support future water supply security. Interim licensing and testing for a potential Managed Aquifer Recharge (MAR) scheme at the Ballarat West water supply borefield was recently undertaken. Ongoing extraction and monitoring programs are also being reviewed to confirm that groundwater supplies are sustainable and impacts to existing users and the environment (e.g. waterways and groundwater dependent ecosystems) are as predicted.

A statistical approach to establishing appropriate groundwater level triggers in sensitive wetlands

Theadora Avanidou
Beca Ltd

The Mackays to Peka Peka Expressway will be part of the Wellington Northern Corridor, identified as a road of National Significance for New Zealand. The 18 km long Expressway runs in close proximity to several wetlands of significant ecological and cultural value in which even small changes in surface and groundwater level outside normal seasonal levels may have a deleterious effect on wetland health. Resource consent conditions for Expressway construction require groundwater monitoring and management to avoid, remedy or mitigate changes in groundwater levels and wetlands caused by the construction and operation of the project. Although a rigorous groundwater monitoring programme was established prior to construction commencing, with some 110 piezometers to record natural variations in groundwater levels, there was a limited number of measurements available for the understanding of "normal" wetland levels. The Kāpiti Coast wetlands were formed in different ways and the water level in some will naturally vary more than in others. For this reason a statistical approach was developed for calculating the drawdown and high water trigger levels for the 22 telemetered piezometers located in and around five sensitive wetlands. Using data from telemetered piezometers monitored by the Regional Council for many years that are screened in the same shallow aquifers outside the project area, the "expected" water level was calculated for each project piezometer based on a multiple linear regression analysis for each reading. A variation of the expected value increased by the margin of error of the 80% confidence prediction interval outside the expected water level triggers an alert for the monitoring bore. The monitoring data demonstrate that the statistically calculated triggers take into consideration district-wide changes in groundwater levels and more clearly distinguish natural effects such as weather patterns from those resulting from construction activities than triggers set as a standard difference.

Caves: observatories of Australia's diffuse groundwater recharge history

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Quantifying the timing and extent of diffuse groundwater recharge is crucial for our understanding of groundwater recharge processes. However, diffuse recharge is notably difficult to quantify. Our novel approach is to use caves as natural observatories of the diffuse recharge process, with the aim of improving our understanding of diffuse recharge in the context of climate change and climate variability. Since 2010, funded by the NCRIS Groundwater Infrastructure project, researchers from UNSW and ANSTO have established a long-term, national monitoring program of infiltration into caves using automated loggers. Five karst regions, in semi-arid, temperate, sub-tropical and montane climates from southwest WA to the mid- north coast of NSW, have been instrumented with automatic infiltration loggers. Over 200 loggers (between 10 and 40 per cave) have collected data on the timing and amount of diffuse recharge, from sites of contrasting limestone geology, starting in 2010. We present empirical data on the timing and relative amounts of diffuse recharge from 2010 to present. Caves with a range of depths from 0-40m show decreasing frequency of diffuse recharge events with depth below ground surface. Event-based rainfall intensity is confirmed to be the primary driver of diffuse groundwater recharge at all fractured rock sites, whereas annual rainfall amount is the primary driver at a site with high primary porosity. Inter-annual variability in the frequency and relative amount of recharge is compared to climate forcing variables such as the ENSO and surface temperature. Groundwater recharge is via both direct (river recharge) and diffuse processes. With anthropogenic global warming, increased temperatures will increase evaporation, and will likely change ENSO patterns, both of which will affect diffuse groundwater recharge. Our cave observatory system helps improve our understanding of the diffuse recharge process and provides a baseline monitoring network during a period of climate change.

Gunnedah Coal Basin Groundwater Monitoring

Cate Barrett, Richard Green, Douglas Trudeau,
Department of Primary Industries NSW Office of Water

The NSW Office of Water is responsible for the strategic management of the State's surface water and groundwater resources. NSW is currently experiencing growth in mining and petroleum projects, in particular coal seam gas and large coal mining developments. The NSW Office of Water is increasing the spatial coverage of their bore network through the drilling of new groundwater bores in and around Gunnedah and Narrabri NSW. The objective of the drilling program is to construct monitoring bores into the Gunnedah Basin and the overlying fresh water aquifers that will aid in further understanding the impacts of nearby coal mines and proposed coal seam gas development on groundwater. Four monitoring bores have been completed in the Gunnedah area, three are constructed in the nearest accessible hydrostratigraphic unit in the Triassic or Permian strata overlying the main coal seams, the forth in the Jurassic volcanic's overlying the Gunnedah Basin. Near Narrabri five monitoring bores are at various stages of completion (May 2015). Two holes have been completed in the Permian coal seams. The remaining bores in the Jurassic Sandstone overlying Gunnedah basin. Geophysical logs were run at each site to assist in determining aquifer horizons. The geophysical logs are matched with the geological log of the drill cuttings. Collectively this information is used to confirm geological formations and inform the selection of the optimum bore screen depths. On completion all bores are instrumented to collect real time groundwater water/pressure levels and quality data. All of these sites will utilise mobile network IP communications to transfer data from field devices to the telemetry and data management systems which is available live on the NSW Office of Water web site. Data collected from these sites will be used to better inform groundwater modelling in the area as well as monitoring the impact of mining and coal seam gas development on the groundwater resources in the area.

SNMR soundings in the Baucau region of Timor-Leste for groundwater management

Aaron Davis, Yusen Ley-Cooper
CSIRO

Baucau is the second largest town in Timor-Leste, and it is expected that the population will increase fourfold by 2030. This will cause increased pressure on the water resources for the city and the surrounding area. Situated on the northern side of the Baucau Formation, a weathered limestone shelf that was uplifted a few million years ago, the region gets about 1500 mm rainfall per year which acts as direct recharge for groundwater resources. Groundwater is currently obtained from natural springs in the town centre and pumped back up to the top of the shelf. In neighbouring villages, groundwater is obtained from local springs. Our work, undertaken in consultation with BESIK (Bee, Saneamentu no Ijiene iha Komunidade), follows the reprocessing and inversion of a helicopter-borne airborne electromagnetic (AEM) survey previously flown over the Baucau limestone plateau near Baucau. The inversions indicate the possibility of palaeo-drainage systems in the plateau that could act as preferential flow paths for groundwater discharge to surrounding areas. CSIRO and staff at BESIK selected a series of target locations for further investigation using ground- based TEM and SNMR geophysical techniques. We chose 10 TEM and SNMR sites in an attempt to target the potential drainage pathways located from the bottom elevations of the Baucau Limestone Formation. Two valleys near Baucau were chosen for TEM and SNMR transects, while another drainage path was chosen for investigation near the village of Ostico. Our inversion results showed the presence of groundwater at all locations in excess of 10—15%. The groundwater is expected to occur both in the Baucau Limestone, and the clogging clay layer that exists between the limestone and the underlying Viqueque Formation. Based on these findings, we have recommended exploration drilling at 8 different locations.

Groundwater monitoring bore drilling project: Broke, Merriwa and Gunnedah–Spring Ridge Deep Monitoring Bore Drilling 2013-2014

Richard Green, Cate Barrett, John Williams, Anthony Bowling and Greg Russell
Department of Primary Industries (Office of Water)

NSW is currently experiencing growth in mining activity, in particular coal seam gas and large coal mine projects. As a result, groundwater is being extracted from within the Permo-Triassic Sydney and Gunnedah sedimentary coal basins to accommodate such development. The NSW Office of Water has historically focussed monitoring of groundwater levels on shallow alluvial aquifers in these areas as irrigation typically accounted for the vast majority of extraction. However, it has become important to gather baseline information on groundwater levels and quality in deep formations underlying the shallow alluvial aquifers used for such purposes. The NSW Office of Water has recently increased the spatial coverage of its monitoring bore network through the drilling of nine new deep groundwater bores between August 2013 and July 2014, in the Sydney and Gunnedah Basins. The drilling project was funded under the National Partnership Agreement for Coal Seam Gas and Large Coal Mining Development. The increased monitoring coverage will assist in identifying future impacts arising from coal seam gas and coal mine projects on important groundwater resources. For this project a total of 1,732 m of drilling occurred with individual bore depths ranging from 39 to 307m in depth. Two sites that were artesian and bores had to be sealed to control flow and pressure gauges were fitted to monitor groundwater heads. The nine new bores (and one additional existing monitoring bore) were fitted with telemetry instrumentation to relay monitoring information collected directly to the NSW Office of Water real time data web site—http://www.water.nsw.gov.au/realtime-data/default.aspx. This paper will discuss the establishment of the network and preliminary hydrogeological results. The enhanced monitoring network will assist the NSW government in managing the State's groundwater resources sustainably and also allow the community and industry to access the data via the web.

When is a Groundwater Dependent Ecosystem not a Groundwater Dependent Ecosystem? A critical review of identification methodologies

Chris Hambling, Carly Waterhouse, Thomas Neame
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Hydrogeological processes can create ecological species assemblage and composition that are dependent on the presence of groundwater or groundwater dependent ecosystems (GDEs). Land and water resource use within a catchment has the potential to affect the ecological function and structure of a GDE, and ultimately, affect the features viability by altering surface and subsurface conditions outside of normal physiological tolerances or dispersal capabilities of communities reliant on a specific type of groundwater. In Australia, research has been undertaken into identifying GDEs, most notably the publishing of the Groundwater Dependent Ecosystems Atlas (NWC, SKM, CSIRO, Cogha, BOM, 2012). In practice, for project or regional specific assessments, difficulties in the identification and confirmation of the presence of GDEs can be encountered as a result of spatial, temporal, anthropogenic or natural variations. Methods for identification of GDEs can include remote sensing, appraisal of historical maps, reviews of previous surveys, helicopter surveys, hydrogeological analysis, hydrochemical comparison, and ground truthing. Remote sensing has proved useful in identifying areas which could potentially be groundwater dependent by analyzing the signature of the vegetation present, although to improve reliability this requires on ground information to refine the approach. On ground surveys including speaking directly to land holders about their land has proved to be a highly successful and specific approach, however is time consuming and cannot be applied easily to large areas, and this approach can be limited by commercial or political drivers. It is concluded that a combination of methods, which will be dependent on the scale, aims and objectives of the assessment are required to identify the potential for, and then to confirm the presence or absence of GDEs within any given location.

Characterising ephemeral river recharge in arid Australia

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In 2012, the Australian Government established an Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Developments to provide independent expert scientific advice concerning the impacts such developments may have on water resources. As part of this initiative, the Australian Government funded DEWNR to address a critical knowledge gap concerning surficial recharge mechanisms to the Pedirka Basin (PB) under present-day arid conditions. Ephemeral river recharge (ERR) was hypothesised to occur where the Finke River flows across the outcropping edge of the PB in the remote western Simpson Desert. Ten piezometers were positioned along three transects perpendicular to the Finke River. Hydrochemical, hydraulic and geophysical techniques were used to improve the hydrogeological understanding of the connection between the Finke River and the PB, and to characterise the geological controls on ERR mechanisms. Two hydrostratigraphic units were identified in the study area: Quaternary alluvial sediments associated with the Finke River; and the underlying Crown Point Formation (CPF), which is a glaciofluvial to periglacial unit of the PB. The investigation identified no modern recharge from the Finke River to the CPF via ERR, owing to low permeability of aquifer sediments (K 0.001–0.09 m/d), low driving gradient and limited storage capacity in the CPF. Modern recharge via ERR is restricted to the alluvial aquifer and is associated with smaller flow events in the Finke River. Unexpectedly enriched δ2H and δ18O ratios suggested more frequent smaller flow events contribute greater overall recharge to the aquifer/s than less frequent large flows, owing to limited storage capacity. Recharge estimates derived from Carbon-14 ranged from 3–34 mm/y from the Finke River to the alluvial aquifer, and ≈0.1–3 mm/y from the alluvial aquifer to the CPF. The investigation has resulted in a revision of the conceptual model of surficial recharge to the PB.

How key findings and uncertainty delivered under the Bioregional Assessment (BA) programme may inform consideration of coal resource developments- Hunter sub region

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The BA's will provide a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of potential direct, indirect and cumulative impacts of coal seam gas and coal mining development on water resources including any impacts associated with salt production/salinity. The aim of the BA programme is to strengthen the science underpinning regulatory decisions on potential water related impacts from coal seam gas and large coal mining developments, whilst establishing a robust and transparent evidence base for causal pathways that connect depressurisation and dewatering of coal seams with impacts on water dependent asset across 6 priority bioregions within eastern Australian coal Basins. In addition to delivering an improved scientific understanding the BA's will also highlight uncertainties associated with the data and its subsequent analysis. According to scientific norms it is always possible to develop more precise and better explanations, no matter how thoroughly studied, is fully explained or understood. This paper will focus upon some of the inherent uncertainties associated with the surface water and groundwater modelling approaches in the Hunter BA subregion and then elaborate on how interim learning's resulting from the uncertainty analysis may used inform the groundwater research, management and policy communities. For example a range of potential data and knowledge gaps identified whilst developing groundwater and surface water models to quantify potential impacts on water-related assets in the Hunter subregion. Knowledge of such gaps could be used by proponents as areas of focus within Environmental Impact Statements, and used by regulators to target monitoring conditions and future research required by proponents. The identified gaps could also guide any future state or Commonwealth Government research and data acquisition efforts.

NUDLC Minimum Construction requirements for water Bores in Australia, 3rd Edition

Mick Hoban
National Uniform Drillers Licencing Committee (NUDLC)

The Minimum Construction Requirements for Water Bores in Australia was initiated to provide a consistent standard reference for the water bore drilling industry. The requirements focus on protecting groundwater resources from contamination, deterioration, and uncontrolled flow associated with poorly constructed bores, and on the construction of bores to provide a good water supply. The first edition was published in 1997 and it has been reviewed periodically to keep it current. This third edition is the outcome of an extensive review process. It draws on the combined experience and knowledge of the drilling industry and regulators, and incorporates submissions from both groups. Features of this edition are:

- the separation of the requirements into mandatory requirements and good industry practice (explained in text below)
- the development of principles, which are the critical elements in constructing, maintaining, rehabilitating, and decommissioning bores, and protecting the groundwater resource of Australia
- significant updates of some technical aspects, including casing, sealing, and bore head completion
- that it is written for a wider audience.

Mandatory requirements are enforceable by regulators for the protection of the groundwater resource. Good industry practice draws on the industry's experience and describes methods and techniques which, while not mandatory, are recommended to:

- help satisfy mandatory requirements
- provide efficient and cost effective water bores
- ensure the long term efficiency and operation of the water bore

The purpose of the book is to provide a technical basis for, and a description of, the minimum requirements for constructing water bores in Australia. It provides a bore construction standard that is consistent across Australia. The book is a reference that can be used by hydrogeologists, drillers, clients and regulators.

Participatory groundwater management at village level in India – Empowering communities with science for effective decision making

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Arid Communities and Technologies

There are many reasons behind worsening groundwater situation leading towards scarcity of quality water supply to sustain lives and livelihood in India and other parts of the world. The lack of proper scientific understanding among various stakeholders has been identified as one of the important gaps in sustainable management of groundwater. In this paper, we share experiences from Gujarat and Rajasthan in western India where scientists, NGOs, government agencies and village leaders worked together to explore strategies for sustainable groundwater management. The study involved a total of eleven villages of Gujarat and Rajasthan, India. The main aim of the study was to educate community through an intensive capacity building of rural youth, called 'Bhujal Jaankars (BJs)', a hindi word meaning groundwater informed. The Bjs were trained with relevant theory and practical exercises in their local settings so that they can perform geo- hydrological evaluation of area, monitor groundwater and share their findings and experiences with village communities. The BJs went through a 45-day training program covering mapping, land and water resource analysis, geo-hydrology, and water balance analysis and finally groundwater management strategies. The BJ approach has highlighted some important learning that can be replicated in other parts of the two states and beyond. There are now 35 BJs who regularly monitor groundwater and rainfall in the two study watersheds and provide data to both scientific and rural communities. The study demonstrated that BJs' capacity building has helped to provide scientific basis for village level groundwater dialogue. This is now leading the communities and other stakeholders to improve their decision making regarding groundwater use, recharge strategies and other aspects of sustainable groundwater management. Although the BJ program has been successful and BJs can act as a valuable interface between local communities and decision makers, there exists some challenges such as need for mechanisms and funding sources that will sustain the BJs in longer term, wider acceptance of BJs among scientific communities, involvements of BJs in natural resources management programs of the state and central governments in India.

A hydrogeological characterisation of the Arckaringa Basin, South Australia

Mark Keppel
Department of Environment, Water and Natural Resources

In 2012, the Australian Government established an Independent Expert Scientific Committee (IESC) on Coal Seam Gas (CSG) and Large Coal Mining Developments to provide independent expert scientific advice concerning the impacts such developments may have on water resources. As part of this initiative, the Australian Government commissioned DEWNR to address previously identified knowledge gaps concerning regional scale architecture and conceptualisation of the groundwater systems within the Arckaringa Basin. Basin architecture investigations reveal that the Arckaringa Basin is not only structurally complex, but the majority of this complexity stems from fluvioglacial activity during the Permo-carboniferous, rather than faulting. In addition, the architectural complexity suggests that sub-basinal hydrogeological systems may exist that are isolated from the regional flow system, a feature that may have important ramifications with respect to understanding the impact of groundwater resource development in this region. To help define regional groundwater characteristics, hydrochemistry data were collected in addition to a compilation of historical data. Investigations were largely focussed on the southeast corner of the Arckaringa Basin due to limited existing groundwater infrastructure and historical data. It was possible to distinguish two broad hydrostratigraphic units within the area of this investigation, namely the shallow Great Artesian Basin (GAB) aquifer and the deeper Boorthanna Formation/ crystalline basement units, aided in part by trends observed in isotopic hydrochemistry data. Additionally, despite hydrogeological complexities, isotope hydrochemistry data was used to suggest that groundwater within certain portions of the basin may have once flowed in a different direction to what is observed today using hydraulic head distribution. Possible explanations for such discrepancies include paleoclimatic variations or neotectonics influences on topography and structural geology. Consequently, interpretation of current-day flow of “old” groundwater using hydrochemistry may be limited if considered in isolation of hydraulic head data.

Broken Hill emergency drought water supply - Renmark Group aquifer investigations

Mark Mitchell
NSW Office of Water

The investigation was undertaken to assess the potential of the Renmark Group within the Menindee Trough as an emergency drought water supply source for Broken Hill. The available information on the Renmark Group within the Menindee Trough suggested that a potential suitable aquifer was present at a depth of about 200 to 250 metres. The aquifer is known to be saline and would require reverse osmosis treatment. This influenced the selection of the investigation area to a location in close proximity to the water supply pipeline from the Menindee Lakes to Broken Hill and access to power supply infrastructure to operate the potential water supply scheme. The investigation involved the construction and pump testing of six test production bores to assess the potential of the Renmark Group as an emergency drought water supply during periods when available surface water has been exhausted from the Menindee Lakes System. The investigation drilled 5 test production bores over a length of about 5.2km perpendicular to the general north-east to south-west orientation of the Menindee Trough. These bores identified the presence of a fine to coarse grained quartz sand at a depth of approximately 200 metres below ground surface, ranging in thickness from about 5 to 20 metres in thickness. Pump testing was conducted for a period of four days at each test production bore site. The pumping rates at four of the five sites was on average 21 L/s at the fifth site due to the aquifer characteristics it was tested as a rate of 10.43 L/s. Water quality samples were collected during each pump test to identify the water quality, monitor potential changes and to assist in the design of the required water treatment infrastructure. The investigation has identified that the Renmark Group has the potential subject to further investigations to be a source of an emergency drought water supply for Broken Hill.

Groundwater Management: Anglesea Borefield : Trigger Levels used for Ecological Protection

Jeffrey Morgan
GHD Pty Ltd

Barwon Water (BW) obtained a Bulk Entitlement (BE) from the Victorian Government in 2009 to install and operate the 7000 ML/year (19.2 ML/day) Anglesea Borefield. Groundwater extracted from the borefield augments Geelong's urban water supply. The borefield comprises of seven production bores which extract potable class groundwater from the Lower Eastern View Formation (LEVF) aquifer, at depths of around 300 to 600 m below ground. The LEVF aquifer is overlain by two other aquifer systems, the Upper Eastern View (UEVF) Aquifer and Perched Water Table (PWT) Aquifer in two swamplands. A condition of the BE was a resource assessment review after three years of abstraction and the collection of hydrologic and ecological data. Based on the BE Review undertaken in 2013, one of the highest impact risks identified was the Anglesea Swampland, with potential drawdown, flow impacts and acid generation resulted in high ecological risks being assessed for this area A trigger level was therefore established with the objective of protecting the ecological values of the swamplands. The trigger level however had to be established with limited historical groundwater level data, and therefore limited information in regards to the natural variation in groundwater levels prior to pumping. The trigger levels are now included in the BE and have been set for the two bores in the Anglesea Swampland:

- Bore P19: UEVF Aquifer, and,
- Bore P8: PWT Aquifer.

To take into account the natural climatic variability in groundwater levels, the triggers in the bores in the Anglesea Swampland area vary based on the relationship with shallow groundwater levels in a bore (P17) in the Salt Creek Swamplands (which are not expected to be influenced by pumping over the long term) (refer Figure 1). As the triggers levels have been established with only 3-4 years of data, and there are errors in the regression relationship between P17, and P8 and P19, it was proposed that the trigger has an error allowance based on two standard deviations on the error between the calculated water level and the observed groundwater level. This standard deviation can be adjusted based on the collected data up until Barwon Water re-starts extraction. As pumping is not expected for the next 5 years, this additional data would significantly refine the appropriateness of the trigger. The trigger formulas therefore becomes

— P8 Trigger (mRL) = 0.3131 x P17 (Monthly average mRL) + 9.4666 - 2 SDs of error, and
— P19 Trigger (mRL) = 0.2391 x P17 (Monthly average mRL) +16.8 – 2 SDs of error Where
— mRL = metres reduced level
— 2 SDs of error= two standard deviations calculated from the error between the monthly average recorded groundwater level (mRL) and the monthly average groundwater level (mRL) calculated from the P17 relationship

The trigger mechanism proposed is designed to identify drawdown impacts in the water table aquifer in an ecologically sensitive swampland, associated with groundwater abstraction from a deeper aquifer. The mechanism proposed is designed to account for climatic variations, when there is limited historical data available for comparison, and therefore identify drawdown associated only with the proposed borefield extraction

Design and Operation of the 40ML/day Reedy Creek Aquifer Injection Scheme

Ryan Morris
Origin Energy

The Reedy Creek aquifer injection scheme underpins gas production from a field of several hundred CSG wells. The scheme has the capacity to manage up to 40ML/day of treated CSG water through a field of 12 injection bores. The scheme was initially designed with 20 bores targeting an aquifer greater than 1,300m below ground. Multiple aquifer schemes were considered in the scheme design but were found to be less attractive. Hydraulic data from the injection trials combined with modified petroleum industry petrophysical techniques, provided improved understanding of the target aquifer with each new bore drilled allowing the initial number of injection bores to be reduced to 12, with five in-field monitoring bores. Pressure and flow data is recorded at one-second intervals by the control system in each of the injection bores and monitoring bores. A simple screening tool has been developed to allow plant operators to easily assess bore performance during weekly checks. Excursion from a pre-defined pressure-flow relationship for each of the injection bores triggers more detailed analysis by a hydrogeologist, with a second trigger to cease injecting through that bore if performance deteriorates further. More detailed analysis is undertaken with an analytical model that is based on the principle of superposition. History matching of a pre-defined start-up sequence and multi-rate testing program allowed aquifer hydraulics and the well losses for each bore to be resolved. The calibrated model allows any changes in well performance to be separated from pressure build-up in the aquifer. It is also used to understand future capacity constraints. Regional monitoring shows the effects of Reedy Creek injection several tens of kilometers from the bore field. The hydraulic response of the aquifer is already providing an understanding of bulk hydraulic characteristics of the aquifer, as well as intra-formational complexity at a resolution not previously possible.

Surface-stabilized Nanoscale Iron for the Remediation of Subsurface Contaminants

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Higher reactivity and enhanced electron donating property of nanoscale iron compared to bigger sized particles makes the use of nanoiron particles a promising technology for the remediation of groundwater contaminants. However, limited dispersion stability and transport of nanoscale iron particles lead to ineffective performance on nanoscale iron particles in the subsurface. The primary objective of the research was to investigate the stability, transport, and application of laboratory-synthesized, xanthan gum surface-stabilized nanoscale iron particles in the remediation of residual Non Aqueous Phase Liquids (NAPLs). Nanoscale iron particles were synthesized using borohydride reduction method. Stability of nanoscale iron particles in xanthan gum solutions were tested using batch studies. Series of batch experiments were performed to investigate the reactivity of xanthan gum modified nanoscale iron particles in the degradation of residual NAPL. Trichloroethylene (TCE) was used as a model NAPL. Column studies were performed to study the transport of xanthan gum modified nanoscale iron particles. 0.5 g/L xanthan gum solution was as good as 0.8 g/L and 1 g/L solutions in creating stable suspension of nanoscale iron particles. Degradation of TCE was much faster with excess iron compared to iron-limited conditions. For excess iron condition, 25 % of TCE degraded in the first 25 minutes and slowed thereafter. For iron-limited conditions, reactions were much slower. Only 30 % of TCE degraded in 10 days. Transport study was performed at ambient pH, 0.01 M ionic strength, and a velocity of 0.5 ml/min. Maximum effluent concentration of nanoscale iron particles was 35% of reservoir concentration. Distribution of iron particles was higher in the influent side and decreased towards the effluent side. This research will help determine the scenario for optimal performance of nanoscale iron particles. Dynamic studies implemented in this research project will help identify real subsurface transport conditions better than batch studies.

Great Artesian Basin Hydrogeological atlas – maps and datasets for regional geology, hydrogeology and hydrochemistry

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Geoscience Australia

The Great Artesian Basin (GAB) is the largest groundwater basin in Australia both in area and groundwater volume. Groundwater from the GAB is a vital resource for pastoral, agricultural, and extractive industries as well as for town water supplies. Effective and responsible management of these groundwater resources, often for competing interests, requires sound understanding of how the groundwater system works at a regional scale. A new hydrogeological atlas presents a refinement of recent work undertaken by Geoscience Australia (GA) in Great Artesian Basin Water Resource Assessment (GABWRA) project and the former Carbon Capture and Storage Groundwater Project. Subsequent new information has led to some of the concepts and interpretations being revised or refined for this atlas. Key highlights in this atlas are interpretation of the extent and thickness of the major aquifers and aquitards, regional water table and the basin-wide variation of water chemistry found within the major aquifers. The altas presents a compilation of maps documenting some of the key regional geological, hydrogeological and hydrochemical aspects of the GAB. It provides insights into the current understanding of the regional geometry and physical characteristics of the rocks and water contained within this vast groundwater basin and baseline information against which future changes can be assessed. The atlas and associated datasets combine to form a valuable information resource base to support informed water management decisions within the GAB. Data and knowledge gaps, especially for groundwater chemistry measurements, are clearly evident in the maps. It will assist both water managers and communities to better understand and manage the groundwater resources contained within the GAB.

Recharge estimation across the headwaters of the Condamine Basin using storage-discharge relationships

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Groundwater recharge estimates are required to evaluate sustainable groundwater abstractions and needed to understand regional water balances. This study estimates recharge in the Condamine Basin headwater region dominated by the Main Range Volcanics, which is a major basalt fractured rock. Its acts as a water resource to local graziers, irrigators and towns, and is also considered a recharge zone to the underlying Great Artesian Basin formations. The characteristics of stream flow recession in the absence of rainfall have been used to infer upstream catchment storage properties. One aspect of this storage-discharge relationship that is useful for recharge estimation is when increases between hydrograph recessions occur following a rainfall event because of increased storage. The main assumption in this case is that recharge has increased the storage within flow systems connected to the stream, which is then reflected in the increased recessional flow. Using flow records from 4 catchments (~100 km^2) across the headwaters of the Condamine Basin, we evaluate storage –discharge relationships and estimate recharge due to larger individual rainfall events over the last few decades. Groundwater recharge estimates obtained using the storage-discharge method resulted in values that were of a similar order of magnitude but generally smaller than those obtained from other techniques. This discrepancy may arise because of some inherent assumptions and limitations within the techniques, and some important assumptions in the storage – discharge analysis are explored further, including the impact of evapotranspiration (ET) on the flow recession and user subjectivity in defining events. The general abundance of high quality long-term flow data make storage-discharge relationships a viable and simple recharge estimation technique. However, accurately addressing the assumptions and limitations is important in ensuring these methods are broadly applicable.

Use of remote sensing to determine the impact of landuse on evapotranspiration and groundwater in Western Victoria, SE Australia.

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Shifts in agricultural landuse can disturb the hydrological balance and put stress on water resources which can then directly affect groundwater recharge. The aim of the current study is to investigate the response of evapotranspiration and groundwater availability to rainfed agricultural landuse in two adjacent catchments in western Victoria, SE Australia, one predominantly managed as a tree plantation (*Eucalyptus globulus*) and other as pasture for sheep grazing. The spatial variability of evapotranspiration within the catchments was estimated from Landsat and climate data by partitioning the surface energy balance components using SEBARA (Surface Energy Balance Algorithms for Rainfed Agriculture). The surface energy balance calculations show that the tree plantation, compared to the pasture, has a lower albedo, emissivity, and outgoing longwave radiation due to higher net radiation input, but the *Eucalyptus* trees show a lower surface temperature due to the cooling effect of the evapotranspirative water loss (average 6.6 ^{o}C less), and this results in a lower soil heat flux. The higher available net radiation and lower soil heat flux in the tree plantation translate into higher latent heat flux and evapotranspiration. As a result, the plantation has 15-20% higher evapotranspiration than the pasture. Comparison of the calculated evapotranspiration with estimates from a flux tower in the pasture catchment and sapflow measurements in the tree plantation shows that an estimation accuracy of more than 95% was achieved. The spatial variability in daily evapotranspiration across the plantation catchment is both positively and negatively correlated with groundwater depth and relief. In the higher elevation part of the catchment, where the groundwater is deeper, evapotranspiration is less; this is also true of the lower elevation area with shallow saline groundwater adversely affecting the tree health. In the pasture evapotranspiration is highly correlated with areas of shallow groundwater and low relief. Therefore, detailed mapping of evapotranspiration using remote sensing can provide useful information on recharge, through its relationship to groundwater usage by plants.

Application of Monte Carlo Analysis in a Groundwater Flow Model of Mine Pit Dewatering

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Aquifer heterogeneity has been recognized by the hydrogeological scientific community as one of the most challenging issues in prediction of the flow of water in the subsurface environment. The problem of natural heterogeneity is further accentuated by the small number of field data that are usually collected to characterize a particular site, and the uncertainty related to the initial and boundary conditions. As a result traditional modelling techniques fail to quantify the inherent uncertainty of model predictions which could have significant implications for site owners and regulators. In this work we demonstrate how Monte Carlo simulation techniques can be used to quantify predictive simulation uncertainty. A three dimensional groundwater flow model was developed to provide an understanding of how mining operations will affect groundwater flow in the aquifers underlying an open cut thermal coal mine, in the Bowen Basin of Central Queensland. Sensitivity analysis to pit inflows, and aquifer depressurization at the end of mine life indicated that model predictions are sensitive to the adopted hydraulic parameters (hydraulic conductivity and specific storage) of the near surface alluvium, while model predictions remained relatively stable with respect to changes of rainfall infiltration rate and hydraulic parameters of the remaining units that included fractured Tertiary basalts. Analysis of 150 Monte Carlo simulation results, where model parameters were sampled from pre-defined population distributions, allowed the quantification of model sensitivity through the lower order statistical moments of the model outputs, i.e. pit inflow rates and aquifer depressurization extent. The main advantage of this approach is that it allows site owners to base their business plans on reasonable site water management requirements and regulators to better understand potential environmental effects.

Development of a Water Production Simulation Tool for Coal Seam Gas in Queensland

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Klohn Crippen Berger

Predicting how much water will be produced as a by-product of Coal Seam Gas (CSG) extraction is a significant challenge in managing CSG water. The Queensland DERM commissioned Klohn Crippen Berger to develop a tool capable of forecasting where, when, and how much CSG water will be produced under various industry expansion scenarios in Queensland up to 2060. The aim was to provide a consistent and transparent indication of CSG water production. The 'water production tool' (WPT) can be used to forecast volumes and evaluate the impact of alternative industry expansion scenarios on likely volumes of CSG water. The WPT uses the Theis equation to account for effects of pumping time on well yields in confined aquifers. Multiple pumping wells in close proximity reduce the required pumping rates for coal seam depressurisation. From this, pumping effects are projected spatially to assess interference effects between wells. Two modifications were made to address the dual phase nature of CSG extraction and the impact of shallower extraction of CSG. These factors modify hydrogeological parameters in a consistent manner to more closely match observed water production. Water production is then up-scaled for the region. Two industry-expansion scenarios were undertaken, to both test the WPT and to provide plausible estimates of CSG water production. These provide a comparison of likely water production based on information from the major CSG companies and an alternative based on coal seam variability and infrastructure which is aligned with broader regional development drivers. WPT estimates were compared with other approaches and are in fairly close agreement for earlier years of CSG development. After 2035, the WPT's independent scenario predicts greater volumes of water than other reported state-wide estimates. The WPT has been verified, validated and independently reviewed. Sensitivity analyses were undertaken to identify variables which have the greatest potential to affect CSG water estimates. Intensity of industry expansion and expected operational life of each producing well were found to be the most sensitive.

SAR Alkalinity ratio as a potential indicator of CSG induced methane migration to aquifers in Surat Basin

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To ensure the industry compliance, the CSGCU investigates complaints related to potential impacts of CSG operations on water bores in CSG development areas. Public concern regarding increased gas levels in water bores is a significant contemporary issue in this regard. Methane gas naturally occurs in all geological formations in Surat Basin and has been reported in water bores since 1900s. Currently the CSGCU has to answer these questions (1) Is methane levels in aquifers/water bores increasing (2) If yes, is it related to CSG industry. Conceptually, any methane escaped from coal seams as a result of depressurisation has the potential to migrate along gas phase migration paths, if any, in to the overlying aquifers. Consequently this methane will rise through porous saturated aquifer media. The hydrochemical reaction regime associated with this rising methane will impact existing carbonate equilibrium & subsequently alkalinity & cation ratios. Hence, theoretically Alkalinity relationships can be used as a potential indicator of interaction between groundwater in aquifers and migrating methane from target CSG formations. A block of hydrochemical data was analysed using statistical techniques to examine this concept. This pilot analysis depicted a significant correlation between SAR & Total Alkalinity which can be used as a potential indicator of interaction between groundwater in aquifers and migrating methane from target CSG formations. The poster presents the outcome of the pilot study. The current work including hydrogeological, geochemical & statistical analysis will continue to establish temporal and spatial patterns. Geochemical modelling will be undertaken to analyse methane groundwater interaction under various conditions and threshold methane contamination levels. Establishing limitations of this method and identifying additional indicators will also be components of the continuing work.

Understanding the interaction between surface water and groundwater in New Zealand – a integrated modelling approach

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In New Zealand, large rivers originate in mountains, lose water to the groundwater in upper plains and generally gain water from the groundwater in lower plains, before flowing into the sea. These plains are places where daily human activity takes place and water is the key factor and very vulnerable to climate change. The New Zealand national hydrological model (TopNet), based on TopModel concepts, has been developed for flood prediction and water resources assessment at National and regional scales. It has been applied successfully in most areas across New Zealand except some plains with strong surface water and groundwater interaction due to its over-simplified groundwater process. In this study, a more realistic conceptualisation of surface water groundwater interaction is implemented in the national hydrologic model. This is done by adding additional groundwater processes to current TopNet to simulate groundwater flow and interaction with rivers and to provide the ability to incorporate local information (e.g. flow and groundwater). This integrated model is expected to study the surface water and groundwater processes and assess the impact of agriculture practices and climate change at local and national levels. The integrated surface water-groundwater model was then applied to the Pareora watershed in the Canterbury region of New Zealand where a strong interaction between the river and groundwater has been documented and a large number of flow measurement sites and information along the river main stream is available. Results show: compared to original TopNet, the integrated model improved flow simulation significantly and explains river dynamics quite well. This indicates that the integrated model could be used at local and national scales to improve the simulation of hydrological processes in flat areas where groundwater processes are important, to assess impact of climate change, and etc.

Multi-fidelity uncertainty estimation of groundwater flow models

Michael Asher, John Jakeman
ANU

Groundwater models are typically characterized by a high degree of uncertainty in their inputs, parameters, and calibration data. Quantification of these uncertainties involves running these models many times, which is often computationally infeasible due to the slow run-times of spatially distributed groundwater models. Surrogate models can be used to capture the dominant features of a complex model, at a lower computational cost. A simple example is an identical model with a coarser spatial discretization. While uncertainty estimates provided by the surrogate alone may not reliably reflect the results of the complex model, novel techniques have been developed to combine the simple and complex model in an uncertainty estimation framework. We apply two such methods, the Multilevel Monte Carlo and a multi-fidelity stochastic collocation approach to a finite difference groundwater flow model. A major barrier to the widespread application of these methods to groundwater models is the difficulty in upscaling and downscaling parameters between the different resolutions. There is little consensus in the literature about which techniques are most appropriate for changing the scale of a parameter. Our research aims to assess the performance of multi-fidelity uncertainty analysis despite the known drawbacks of these techniques.

On the influence of grid resolution in regional groundwater models

Etienne Bresciani, Daniel Partington, Vincent Post, Okke Batelaan
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Results of groundwater flow models are often grid-resolution dependent. The influence of grid-resolution on the results suggests a deficient representation of some physical processes, at least on coarse grids. During calibration, some parameters would take a surrogate role to compensate for such deficiencies. Therefore, consequences on model predictions might be relatively insignificant for predictions that are of the same nature as the data comprising the calibration dataset, i.e. for most models heads. However, consequences on other types of predictions remain unknown. In any case, it is unfortunate that the influence of grid resolution seems to preclude the use of parameters calibrated on a coarse grid for simulations on a finer grid. In this study, we will demonstrate a methodology that enables to reduce the influence of grid resolution in regional groundwater models to some extent.

A Model Warehouse: Best Practices for Data Management

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Department of Environment, Water and Natural Resources

Computer modelling has increasingly become an important tool for natural resources assessment, management and planning. It can assist in analysis of the risks to the sustainability of natural resources under current and future development and help in making informed decisions on allocation and management options. Model development requires significant resources, including financial, time, expertise and information. Once developed, effective management and archiving are essential for maintaining the technical integrity of the models. This allows for future reproduction, expansion and improvement while at the same time acting as a repository for data and knowledge of the system. Consolidated knowledge and information can be built on in an effective and efficient manner for future applications. The Department of Environment, Water and Natural Resources (DEWNR) of South Australia initiated the Model Warehouse (MW) project in 2010 for groundwater models and is now expanding it to include surface water and ecology models. The MW involves a systematic approach to the archiving and naming of models, related files and folders, as well as development of operational rules, data management, protocols for model development, rules for using the Department's models and specifications for modelling projects. The MW facilitates a proactive and integrated approach to the sustainable management of the environment, water and natural resources of South Australia. Information on existing and the most up to date models for all of the state's groundwater, surface water and ecology in all areas of importance is made available on the Department's WaterConnect website for public access.

Statistical assessment of chemical and hydraulic trends in groundwater of the Mooki River alluvium

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The Mooki River is situated in the New South Wales headwaters of the Murray-Darling Basin. Groundwater in the alluvium is essential for agriculture, town water and environmental flows. Irrigation extraction has caused widespread groundwater level decline while proposed coal mines are predicted to cause localised drawdown in the alluvial aquifer. Previous studies have considered the relationship between extraction and changes in groundwater level and salinity in a general sense up to 2011. However, in part due to incomplete chemistry records, a comprehensive, integrated assessment of historic groundwater level and chemistry data has to now been lacking. Further, previous studies relied on bimonthly groundwater level records precluding assessment of higher frequency hydraulic response. We aimed to address these analysis gaps by characterising chemical and hydraulic trends dating back to the 1960's and analysing high frequency hydraulic data. We aimed to relate these trends to hydraulic connectivity and anthropogenic and environmental stresses to improve our understanding of system behaviour. Historic groundwater chemistry records were quality-checked and supplemented with additional sampling. Manual water level readings were historically recorded bimonthly in state monitoring bores. We recorded water levels with dataloggers at 15-minute intervals in representative boreholes for comparison. Time series data were analysed using multivariate statistics and interpreted in the context of lithological setting, groundwater extraction and climatic variability. The 15-minute interval data enabled estimation of loading efficiency to distinguish loading response from recharge and an assessment of how monitoring frequency influences interpretation. Our integrated analysis provided insight into catchment processes and showed how long-term groundwater chemistry trends are related to hydraulic changes in the system. We recommend that to adequately characterise system response, lower frequency hydraulic observations should be supplemented with higher frequency data. Our increased system understanding can inform continuing effective groundwater management and enable improved predictions of future stress effects.

Viral and bacterial contamination in a sedimentary aquifer in Uruguay: evaluation of coliforms as regional indicators of viral contamination.

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In many areas of Uruguay groundwater is the only source of water for human consumption and for industrial-agricultural economic activities. Traditionally considered as a safe source, groundwater is commonly used without any treatment. The Uruguayan law requires bacteriological (fecal) analysis for most water uses, but virological analyses are not mentioned in the legislation. In the Salto district, where groundwater is used for human consumption and for agricultural activities, bacterial contamination has been detected in several wells but no viruses analysis have been performed. The Republic University (UDELAR), with the support of the National Agency for Research and Innovation (ANII), is studying the incidence of virus and fecal bacteria in groundwater on an intensive agriculture area of the Salto district. An initial screening campaign of 44 wells was performed in which, besides total and fecal coliforms, rotavirus and adenovirus were detected. A subgroup of the screening wells (15) where selected for bimonthly sampling during a year. In accordance with literature results, single well data analysis shows that coliform and viral contamination can be considered as independent variables. However, when spatial data is integrated, coliform and viral contamination show linear correlation. Single well series analysis show no correlation between biological contamination and pH, conductivity, temperature, precipitation or piezometric level. Integrated sampling campaign data, suggest that biological contamination may be associated to recharge events. The study suggests that bacterial and virus contamination correlation depends on scale. At local scale (well scale) virus and bacterial contamination can be considered as independent variables. At regional scale (aquifer scale) virus and bacteria contamination are linearly correlated. Data also suggest that contamination outbreaks might be related to recharge events. Therefore, for the Salto aquifer, the presence of bacteria contamination could be used as indicator of viral contamination at a regional scale.

Fluorescence Spectroscopy as an Emerging Measurement Technology for Groundwater OM

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Recent production of bench and field fluorometers, which provide rapid assessment of fluorescent dissolved organic material (FDOM), has enabled measurement of groundwater FDOM to become a cheap and effective tool in the hydro-chemical characterisation of a site. Here we will provide an overview of actual and potential applications of the technology. Measurement techniques include field sensors held in a flow cell while sampling to provide real time data, deployment of sensors in a well for long term logging and bench top instruments which provide excitation emission matrices (EEMs) and absorbance data. Data collected includes both relative fluorescence intensity and absorbance at specified wavelengths. The key to application of fluorescence data collected is identification of common fluorescence intensity peaks. This is achieved through development of a parallel factor analysis (PARAFAC) model. Fluorescence spectroscopy was used to develop a PARAFAC model for the aquifer at the UNSW Wellington research station using 480 collected EEMs. Using a combination of the modelled components and absorbance data at 340 nm, key variations in groundwater FDOM type and concentration at the site have been identified. The identified FDOM sources across the site were: aquifer background; landfill leachate; river infiltration and recharge fluxes through the land surface. Fluorescence spectroscopy has significant potential for application as a tool for groundwater characterisation based on variations in FDOM. Current data collection methods include standalone measurements or coupling with established techniques. Our findings suggest application of these methods can significantly enhance site hydro-chemical characterisation from both contaminated land and groundwater resource aspects. Further development and application of fluorescence spectroscopy will promote methods which can be implemented as common practice benefiting government, research and commercial focused investigations.

Natural temperature variations and soil moisture content in the vadose zone

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UNSW Connected Waters Initiative

Soil moisture content and temperature are two of the most important control parameters for many biogeochemical and physical processes in the vadose (unsaturated) zone. As such, estimation of both quantities is crucial for many near-surface groundwater investigations. Recent developments in groundwater heat tracing have demonstrated the utility of passive measurements in studying surface water-groundwater interaction. Novel applications of heat-tracing to the vadose zone provide ample opportunities for further insight. Two approaches are taken to investigate saturation levels in the subsurface using temperature. Firstly, a first- principles analysis of heat transport in unsaturated porous media, combined with an empirical model of porous media thermal conductivity, is used to develop a semi-analytical model that can be used to estimate soil moisture content from passive temperature measurements. Secondly, a fully-coupled finite-element model of a highly-transient estuarine inter-tidal system is constructed and compared with field measurements. The diurnal temperature amplitude and phase parameter space of our semi-analytical model for soil moisture content is analysed to understand the applicability of the model. The model is also tested with finite-element modelled data that combines Richard's equation with the physics of heat transport in porous media. Soil moisture and temperature measurements from a field campaign at Korogoro Creek in Hat Head, NSW are compared with modelled results based on air temperature and surface water level and temperature measurements, as well as thermal and soil moisture retention curves determined from grab samples. The coupled nature of soil moisture and temperature in the vadose zone allows for models that exploit natural temperature variations to estimate soil moisture content. In highly transient systems, a coupled modelling approach allows for the dynamics of the vadose zone to be understood, which in turn can inform studies of biological and geochemical processes.

Modelling Regional CSG Groundwater Impacts - Upscaling a CSG Reservoir Model

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The Office of Groundwater Impact Assessment (OGIA) is currently developing a revised groundwater flow model to assess the cumulative impacts of Coal Seam Gas (CSG) activities on regional aquifer systems in southern Queensland. However, this requires development of new groundwater modelling tools that also account for the specific geology of CSG-reservoirs, connectivity between coal-seams and production wells, and flow of both gas and water within the CSG-reservoir. These tools have to be developed in such a way that traditional requirements of regional scale groundwater modelling can be met. An up-scaling methodology is presented for a CSG development area located in the Surat Basin. A detailed 294-layer reservoir model (ECLIPSE) was used to simulate the flow of both gas and water within this CSG- reservoir, while employing a synthetic development scenario. An 8-layer upscaled groundwater model was simultaneously developed that aims to match the water production and CSG-induced drawdown simulated by the reservoir model. For this purpose an adapted version of MODFLOW-USG was used that 1) employs a modified van Genuchten function to account for coal seam water desaturation processes, 2) employs a dual porosity representation to replicate the effects of coal and interburden on groundwater flow within coal measures, 3) adopts near-well permeability enhancement to account for coal seam – well connectivity and 4) applies a descending drain methodology to simulate CSG water extraction and replicate vertical hydraulic head gradients in gas-filled production wells. Drawdowns simulated by the upscaled MODFLOW-USG model match those produced by the detailed, dual- phase ECLIPSE model well. Most upscaled rock properties can be directly inferred from measured rock properties. Remaining properties were derived from pressures and saturations calculated by the detailed reservoir model. These studies form part of a regional upscaling workflow that OGIA has developed to support regional-scale CSG impact assessment modelling.

Analysis of groundwater salinity trends in South Australia

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Department of Environment, Water and Natural Resources

In South Australia, there are 14 Prescribed Wells Areas (PWAs) and six Prescribed Water Resources Areas (PWRAs) containing significant groundwater resources. Since 2009, the Department of Environment, Water and Natural Resources (DEWNR) has prepared Groundwater Status Reports (GSRs) on an annual basis for these groundwater resources. These reports provide stakeholders and local communities with factual information and an analysis of current groundwater level and salinity monitoring data together with levels of extraction. The reports further determine the status of the groundwater resource for a particular year using a 'traffic light' system. Analysis of trends in salinity data associated with these reports have revealed a correlation between salinity levels and local pumping regimes in some regions. Closer examination of the hydrogeology found that vertical movement of more saline groundwater from above and below was the driver of these salinity changes. Instances of saline water up-coning into the fresher zones within the Quaternary Limestone aquifer under heavy pumping conditions were observed within the Southern Eyre Peninsula region. Meanwhile, downward leakage of overlying brackish water into freshwater aquifers has occurred in the Langhorne and Currency Creek areas of the south-western Murray Basin. This process has also been observed in the Kangaroo Flat area in the north-eastern part of the Northern Adelaide Plains PWA. Fortunately, the rising salinity trends due to vertical movement appear to be reversible when the local pumping regime changes, which would not be the case if the rising salinity was caused by lateral movement of significant volumes of saline groundwater within the aquifer. These observations have assisted in the sustainable management of the groundwater resources through better control of pumping regimes in these regions.

Coupled process modelling and performance of repository components

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In the UK radioactive waste repository concept (NDA Report No. NDA/RWMD/030), radioactive waste glass will be disposed in a composite barrier system. This consists of the vitrified waste form, steel canisters, backfill and natural barriers. This multi-component barrier system is considered essential for the protection of groundwater resources from radionuclide contamination in the near field of a geological repository over a long period of storage. However, the complexities of repositories and the associated uncertainties make it challenging to inspire policy-makers with confidence in this solution. To this end, waste form dissolution data was obtained from single-pass flow-through experiments to provide the source term for GoldSim RT, an extension of the GoldSim simulation framework. The aim is to understand the effect of the dissolution components on the release into the near field. The waste was hypothetically emplaced within a clay host rock conceptualised as a cuboid, and a stable geological setting was assumed. A simulation time of one million years was considered for the model. The dissolution data indicates the presence of $3.4 \times 10^{-5}, 4.8 \times 10^{-7}$ and $1.4 \times 10^{-6}\ mol/L$ as concentrations of ^{135}Cs, ^{90}Sr and ^{235}U, respectively, in the waste form. GoldSim uses probabilistic distributions to capture uncertainties in the input parameters, and propagating through the model to reach output distributions reflecting the relative performance of the barriers and the overall uncertainty in the system. The results showed that ^{99}Tc and ^{129}I are likely to be the radionuclides having the greatest impact on groundwater contamination over long periods of time. The sensitivity analysis results revealed that host rock parameters and waste form dissolution are generally the most important parameters controlling the migration of radionuclides. However, the non-linearity of the concentration results with the input parameters suggests that other factors, which could not be determined from the model, might also be significant.

Analysis of groundwater level trends in South Australia

Mojtaba Karbasi
Department of Environment, Water and Natural Resources

In South Australia, there are 14 Prescribed Wells Areas (PWAs) and six Prescribed Water Resources Areas (PWRAs) containing significant groundwater resources. Since 2009, the Department of Environment, Water and Natural Resources (DEWNR) has prepared Groundwater Status Reports (GSRs) on an annual basis for these groundwater resources. These reports provide stakeholders and local communities with factual information and an analysis of current groundwater level and salinity monitoring data together with levels of extraction. The reports further determine the status of the groundwater resource for a particular year using a 'traffic light' system. Analyses of trends in water level data associated with these reports have revealed a correlation between water levels and rainfall patterns in most regions. Whilst this is not surprising for unconfined aquifers that receive recharge directly from rainfall, the same trends were observed in confined aquifers that are not recharged from rainfall which suggests a different driver for the trends. Examination of extraction trends also found a relationship with rainfall patterns in most areas where irrigation is the dominant groundwater use, with irrigation demand lower in wet years and higher in dry years. Extraction has a strong influence of on pressure levels in confined aquifers and is considered to be the main driver of level trends, with an indirect correlation with rainfall. In areas where no significant extraction occurs, the same trends in both unconfined and confined aquifers are observed. This suggests that for unconfined aquifers, rainfall recharge in general has a stronger influence on water levels than extraction, except in areas of intense pumping. For confined aquifers, the absence of an extraction driver means that hydrostatic loading and possibly inter-aquifer leakage may be contributors to the trends. Recognising the different drivers of water level trends in various aquifers is essential for better management of South Australia's groundwater resources.

Mapping karst features and recharge pathways using resistivity imaging: A case study Wellington Caves, NSW, Australia

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Karst landscapes occupy 10% of the Earth's surface, and worldwide many communities rely on fresh water from karst aquifers. Knowledge of recharge pathways helps manage karst aquifers, however mapping recharge pathways in karst terrains remains a challenge. Modern multi-electrode resistivity imaging cables and improved signal noise reduction algorithms enable higher resolution resistivity images to be collected. In this study, we demonstrate the benefits of electrical resistivity imaging for mapping karst features and recharge pathways through the Garra Limestone, Wellington, NSW, Australia. Borehole lithological logs, groundwater level data, site geological knowledge, and previously mapped sinkholes and conduits were used to control the interpretation of the electrical resistivity images. Two types of anomalies are commonly observable in the resistivity images run over and adjacent to Wellington Caves. In the near-surface unsaturated zone electrically resistive air-filled joints and conduits form distinct anomalies beneath the low resistivity soils that overlie the limestone or fill the upper portion of sinkholes. In the saturated zone, conduits filled with low resistivity clay or water produce clear anomalies when surrounded by high resistivity limestone. The resistivity images highlight the position of previous unknown major conduits, which will be the target of future studies. Resistivity imaging has also delineated the paleochannel surface between the valley filling alluvial sediments and the thinly bedded limestone, and indicates potential pathways of interaction between the alluvial and karst aquifers. At Wellington Caves (a major tourist attraction) the alluvial aquifer to the west of the caves is used to supply groundwater for irrigated agriculture. It is therefore important to understand the interactions between the alluvial and karst aquifers to enable the best management of both sectors.

Groundwater salinity intensifies drought impacts, reducing refuge capacity in forests in the Campaspe catchment

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University of Southern Queensland

Issue: Shallow groundwater aquifers frequently support drought refuges for water-dependent ecosystems. However, where aquifers are affected by over extraction and pollution, their potential as drought refuges may be compromised. This project investigated the response of groundwater connected riverine forests to intense drought conditions equivalent to those predicted under severe climate change for 2030. The study was conducted in an area where shallow groundwater resources are subject to both exploitation and salinisation. We used remotely sensed vegetation productivity (Enhanced Vegetation Index) data from a long term dataset (2000–2011) at 475 riverine forest sites in the Campaspe catchment, Victoria. Generalised additive mixed models and boosted regression trees were used to model the relationship between forest change during drought and environmental covariates including groundwater condition. Up to 44% of the variation in forest change during drought was explained by the models. Greatest decline in forest productivity occurred in areas of high salinity (> 6000 µS/cm) associated with shallow groundwater depths (0 to 5 metres), while least decline during drought was evident in areas of lowest salinity (< 2000 µS/cm) and groundwater depths exceeding 7.5 metres. In landscapes where groundwater quality is not compromised previous studies have shown that shallow groundwater provides an important buffer against drought. This study shows that, where groundwater salinisation has occurred, forests connected to shallow groundwater are instead more vulnerable to drought and the capacity of groundwater connected habitats to function as drought refuges is reduced.

Participatory Groundwater Management: Possible Options for Up / Out Scaling

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Concern over the sustainable management of groundwater has led to a growing interest in issues of local level collective action. This interest has emerged largely as a consequence of the ineffectiveness of the traditional approaches like regulatory and economic measures to manage the resources sustainably. Of late, initiatives of community based groundwater management practices are being tried in number of states in India. Some of these initiatives are observed to be effective in checking degradation of groundwater, providing protective irrigation, enhancing equity; etc. However, these initiatives adopt different management modalities and practices apart from confining to small areas. Besides, the possibilities for scaling up / scaling out and sustaining them in the long run have not been explored in detail. This paper attempts to assess the strengths and weakness of some of the community based groundwater management (CBGM) initiatives in two southern Indian states of Andhra Pradesh and Telangana. The primary objective is to assess the feasibility of up / out scaling these approaches to sustainable groundwater management. The paper assesses the operational modalities and the impact of these practices on access, equity and sustainability of groundwater use at the village and household level using qualitative and quantitative research from eight villages in three districts. It is argued that CBGM has great potential for enhancing sustainability of groundwater management in an equitable manner. The participatory management models need to have a strong scientific basis for ensuring sustainability. Besides, there is need for developing an integrated model drawing from different approaches adopted in different initiatives in order to make it more generic and applicable globally. Such a model should integrate scientific, socioeconomic and policy aspects that suit the local conditions.

Can We Manage Groundwater?

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Effective groundwater management plans are crucial for water resource security and we can't tell whether they work unless they are quantitatively tested. However, the majority of groundwater management plans are not subjected to, or even conducive to, quantitative analysis; and the development of a method to quantitatively assess plan effectiveness is the focus of my research. Through considering groundwater management as a systems control problem, I've developed a novel assessment criterion based on engineering control theory to determine the proportion of Australian groundwater management plans that are conducive to quantitative analysis. Assessment is ongoing and at present one plan can be assessed as written. Many external and management related drivers impact the state of an aquifer and are often misinterpreted as evidence of plan effectiveness but, the state of an aquifer is not an indication of plan effectiveness. To quantify the effectiveness of a management plan in a Victorian water supply protection area, management actions consistent with the region`s plan will be simulated in a numerical groundwater model and the impact each driver isolated. Utilizing additional numerical models of highly complex hydrogeological systems, I will examine how the effectiveness of groundwater management plans depends on the complexity of both the hydrogeological environment and management framework determining when management succeeds and fails. It is anticipated simulation results will yield insights on plan improvements. This research has important implications and could potentially lead to the redesign of groundwater management plans to ensure testability and adoption of routine quantitative analysis of plans. The main purpose of my research to shift our management perspective from Do we have a groundwater management plan? to How do we know our management plans is working?

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