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Executive Summary

An estimated 18 million people live within 50 km of the Australian coast. Groundwater in Australian coastal aquifers is a vital freshwater resource to many of these communities, being used for urban and rural residential supply as well as for industrial and agricultural activities. Water scarcity, increasing population demand and climate change are combining to place growing pressure on Australia's coastal groundwater reserves and security of supply. Excessive groundwater use may result in intrusion of seawater into fresh groundwater reserves which may render them unsuitable for further use. Appropriate coastal groundwater management is therefore imperative to ensure sustainable use and ongoing availability of supply.

In recognition of their importance in sustaining the environment, communities and industry, a number of studies have been conducted across Australia over the last decade to better understand coastal groundwater resources. Several of these were funded through the National Water Commission's Groundwater Action Plan in recent years to address critical groundwater knowledge gaps. To maximise benefits to coastal groundwater resource protection and sustainable use, it is essential to disseminate the findings of these projects to key stakeholders and decision makers.

The National Coastal Groundwater Management Knowledge Transfer Workshop was held in Canberra on 28 and 29 May 2013. It aimed to support recent investment in coastal groundwater management by facilitating an exchange of information across the policy-research-management paradigms. Each day of the workshop focussed on separate themes:

- Day 1, 28 May 2013: Current project activities; key achievements, outputs and lessons learnt.
- Day 2, 29 May 2013: Emerging priorities, challenges and future directions for coastal groundwater management and policy implications.

A range of outputs and lessons learnt from recent projects were identified during the workshop and recorded in Section 2.2 for future reference. Of particular importance are the following knowledge gaps and research priorities identified by workshop participants (Section 2.3).

Key knowledge gaps:

- Comprehensive understanding of the location, geometry and movement of seawater intrusion (SWI), the saltwater-freshwater interface and SWI processes. This knowledge is critical to coastal groundwater management in many areas.
- Appropriate groundwater monitoring strategies and methods. The development of consistent guidelines for monitoring is an efficient way to improve the quality of coastal groundwater monitoring and allow greater comparability between areas.
- Long-term groundwater level, salinity, chemistry and extraction data for most coastal aquifers. Since groundwater extraction is a key driver of SWI, it is imperative that accurate extraction data are recorded although limited information is available in some areas.
- How climate change, climate variability and population demand should be accounted for in groundwater management plans (both water availability and quality).
- The extent of offshore fresh water resources and aquifer systems.

- Hydrogeological conceptual understanding of multi-layered aquifer, fractured rock and karst aquifer systems and how to model them.
- Understanding of submarine groundwater discharge (SGD) location and flux as well as the dynamics of dependent marine ecosystems.
- Understanding of paleo-systems; how they may affect salinity, complicate understanding of modern SWI and affect groundwater flow (e.g. relict saline water in the Darwin peri-urban area, NT and the role of paleochannels in groundwater and solute flow in the Burdekin, Qld).
- The risks and associated costs of not managing SWI appropriately. Publicising risks and costs may encourage appropriate investment in monitoring and research.
- A general lack of expertise regarding coastal groundwater processes and investigation tools in general was commonly noted during the workshop.

Recommendations and priorities for future research

A number of research and capacity building activities are proposed to enhance effective management and protection of coastal groundwater resources:

- Develop national best practice monitoring and management guidelines for coastal aquifers and SWI.
- Further research the movement of seawater into coastal aquifers in response to aquifer development and improve the tools to model seawater movement and assess management strategies. Although several useful tools have been developed, their existence should be more widely advertised and their uptake and application require encouragement.
- Develop and employ a methodology to value coastal groundwater resources in financial, social and ecological terms to inform policy and decision makers on the potential implications of inappropriate management and the importance of ongoing monitoring.
- Assess the risks that climate change and climate variability pose to groundwater availability and quality and consider any socio-economic and/or ecological implications.
- Investigate the extent and location of SWI/SGD offshore in confined aquifers in key locations. As part of this process, the use of geophysical mapping and environmental tracer approaches (e.g. hydrochemistry, isotopes, temperature etc.) for coastal groundwater resource assessment and identification of SWI risk areas should be explored.
- Investigate the geometry and behaviour of freshwater lenses and SWI associated with islands. Although these are typically relatively fragile systems vulnerable to a wide range of possible impacts, they have been poorly studied in Australia compared to mainland systems.
- Develop a toolkit of simple-to-complex methods of assessment that can be linked to the cost, risk and complexity of particular groundwater systems. This may partly focus on making existing methods cheaper (e.g. through smart phone remote sensing). It would include simple tools for undertaking first pass assessments of risk and vulnerability.
- Develop a repository for tools, procedures and modelling methods and guidelines and publicise it to encourage uptake and use.
- Synthesise existing knowledge from relevant disciplines such as geophysics, geochemistry, geology and hydrogeology. Data mining may be useful in this regard (particularly if there is a lack of funds for additional data gathering). The development of linked models allowing calibration with other data (e.g. chemistry and temperature) in multidisciplinary approaches may prove useful.

- Assess the ecological importance of groundwater in coastal areas. For offshore ecosystems, this would include mapping biota and SGD occurrences to understand SGD-dependent ecosystems.

Future directions

These workshop proceedings record recent work and lessons learnt in coastal groundwater management and stakeholders' views on emerging management issues, key knowledge gaps and future research priorities. Workshop participants agreed that a position paper be drafted for consideration through Ministerial Council Process. The position paper will be developed in collaboration with, and submitted to, the National Groundwater Sub Group which has a policy advisory role to the National Water Reform Thematic Oversight Group (Water TOG). It is anticipated that the position paper will be used to inform the National Groundwater Strategic Plan currently in development.

List of abbreviations

AEM	Airborne Electromagnetic
BoM	Bureau of Meteorology
CSG	Coal Seam Gas
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DPIPWE	Department of Primary Industries, Parks, Water and Environment
DSEWPaC	Department Of Sustainability, Environment, Water, Population and Communities (now Department of the Environment)
GA	Geoscience Australia
GDE	Groundwater Dependent Ecosystem
MAR	Managed Aquifer Recharge
NCGRT	National Centre for Groundwater Research and Training
NGIS	National Groundwater Information System
NGSG	National Groundwater Sub Group
NOW	New South Wales Office of Water
NSW	New South Wales
NT	Northern Territory
NWC	National Water Commission
NWI	National Water Initiative
QA/QC	Quality Assurance and Quality Control
SA	South Australia
SCEW	Standing Council on Environment and Water
SGD	Submarine Groundwater Discharge
SWI	Seawater Intrusion
TWWI	Treated Wastewater Injection
Water TOG	Water Reform Thematic Oversight Group
WA	Western Australia

1 Introduction and overview

Fresh groundwater stored in Australia's coastal aquifers is an important resource for urban and rural residents as well as for industry and agriculture. More than 85% of Australians live within 50 km of the coast and, for numerous coastal towns and communities, groundwater is an important water supply. However, in recent decades continuing population growth coupled with significant reductions in rainfall have placed increased pressure on Australia's coastal groundwater reserves.

Various government agencies, research organisations and natural resource management groups have undertaken studies in recent years to improve the understanding of coastal groundwater systems. Several of these were funded through the National Water Commission's Groundwater Action Plan in recent years to address critical groundwater knowledge gaps. To maximise the benefits of this funding to coastal groundwater resource protection and sustainable use, it is essential to disseminate key findings of these projects to relevant stakeholders and decision makers and use them to inform future research priorities.

The 2013 National Coastal Groundwater Management Knowledge Transfer Workshop was held in Canberra on 28 and 29 May 2013. It was organised by Geoscience Australia (GA), the National Centre for Groundwater Research and Training (NCGRT) and CSIRO Water for a Healthy Country. The workshop aimed to support the effectiveness of investment in coastal groundwater management by facilitating an exchange of information across the policy-research-management paradigms.

The workshop provided an opportunity for government and research groups to consider the outputs of various coastal groundwater projects and how these outputs may best support stakeholder interests. The main purposes of the national workshop were to:

- Share results and knowledge from various coastal groundwater projects around Australia.
- Promote project outputs as a source of practical information for water managers.
- Identify key knowledge gaps and discuss priorities for future work in coastal groundwater management.

The workshop was designed to assist national efficiency and capacity by facilitating efficient information exchange between researchers and managers. Workshop attendees represented a spectrum of stakeholders with an interest in coastal groundwater resources and included government, policy, management, scientific, and technical representatives.

The workshop proceedings compiled in this report will form the basis of advice to the Australian Government on priorities for future coastal groundwater management and research.

2 Workshop proceedings

The workshop invitation and program outline the topics covered and are included in Appendix A. While the workshop included presentations from many stakeholder group representatives, the main focus of this report is to summarise a series of group discussions that aimed to identify key outputs of recent projects, lessons learnt and future directions for coastal groundwater management and research. Workshop presentations are only briefly summarised in following sections, which focus on the outcomes of group breakout and discussion sessions. Links to presentations that workshop presenters agreed to make publically available are included in Appendix B for further information.

2.1 Workshop format

Each day of the workshop focussed on separate themes:

- Day 1, 28 May 2013: Current project activities; key achievements, outputs and lessons learnt.
- Day 2, 29 May 2013: Emerging priorities, challenges and future directions for coastal groundwater management and policy implications.

The morning sessions on Day 1 and Day 2 consisted of a series of presentations from workshop attendees. Workshop participants were separated into four discussion groups in the afternoons to discuss the morning presentations and answer specific questions associated with future work requirements in coastal groundwater management. At the end of each day, the four groups presented their findings for further discussion. Group discussion summaries and recommendations are included in the following sections.

2.2 Day 1: Current project activities; key achievements, outputs and lessons learnt

Day 1 focussed on recently completed and ongoing coastal groundwater projects with a view to identifying key outputs and recording lessons learnt to inform future project activities.

2.2.1 Day 1 Session 1: Welcome, introduction and background

Session 1 provided background, introductory and overview information for the workshop and included:

*Welcome (Stuart Minchin, GA).*The welcome address was delivered by Dr Stuart Minchin, Chief of the Environmental Geoscience Division of GA. The purpose of the workshop was briefly outlined and the workshop participants welcomed.

Opening- An update on the National Groundwater Action Plan and the National Water Initiative (Justin Foley on behalf of Kerry Olsson, NWC). Information was provided on the research, assessment and policy legacies of the National Groundwater Action Plan that ended in June 2012. An overview was given of the current NWC's role of monitoring, audit and assessment.

*Overview of workshop program (Jane Coram, GA).*Jane Coram, GA Groundwater Group Leader, discussed the national workshop context and provided a brief overview of the workshop program.

Understanding coastal aquifers – aquifer characterisation, modelling, monitoring and management (Adrian Werner, Flinders University / NCGRT). Technical aspects of coastal groundwater dynamics and seawater intrusion (SWI) were presented to set the scene for subsequent discussions. Several important issues were explored surrounding monitoring and management techniques.

2.2.2 Day 1 Session 2: Recent and ongoing coastal groundwater projects

Session 2 focussed on recent and ongoing coastal groundwater projects undertaken by jurisdictional and Australian government agencies and research organisations. It included the following presentations:

National scale vulnerability assessment of seawater intrusion: a summary (Baskaran Sundaram, GA). The methodology and results of an NWC-funded project focussed on coastal Australia's vulnerability to SWI were presented. The project provided the first national-scale perspective on this increasing threat to coastal groundwater security for current and future conditions. Further information can be found at http://archive.nwc.gov.au/library/waterlines/85.

Synthesis of recent Australian submarine groundwater discharge studies using environmental tracers (Sebastien Lamontagne, CSIRO). The use of radioactive isotopes and daughter products (uranium, thorium, radon and helium) as well as salinity and temperature to identify submarine groundwater discharge (SGD) was explored using three examples. Most of these methods were reported to be suitable to Australian conditions although the use of temperature had limited applicability in many areas due to low contrast between surface water and groundwater.

Geophysical mapping for coastal groundwater resource assessment and understanding seawater intrusion into freshwater aquifers (Ken Lawrie, GA). The usefulness of various geophysical techniques for mapping and assessing SWI and coastal groundwater resources was assessed. A variety of aspects relating to the applicability of geophysical surveys were explored including technical limitations, budget, anticipated geological and hydrogeological conditions, access constraints and scale. The importance of trans-disciplinary approaches to assessment was emphasised by way of a case study where the processing of airborne electromagnetic (AEM) survey data was informed by hydrodynamics, hydrochemistry and geological information from boreholes.

Sustainable management of coastal groundwater resources: a case study from Mid North Coast of New South Wales (Laura Gow, GA). An integrated approach to sustainably managing coastal groundwater use to protect groundwater dependent ecosystems (GDEs) and water supplies from SWI was developed using GDE risk mapping, field and laboratory data, numerical modelling (using various climate and pumping scenarios) and cost-benefit analysis. Indicators and triggers (review and response) were developed for use as early warnings of groundwater system stress and the development of a remote sensing GDE monitoring tool was explored. Further information can be found at http://archive.nwc.gov.au/library/waterlines/79.

NSW Groundwater quality and coastal groundwater dependant ecosystems (John Williams, NSW Office of Water). This presentation focussed on a 2009-2012 project that aimed to improve understanding of the effects on groundwater quality and GDEs in NSW coastal sand and alluvial aquifers from extraction, tidal cycles and climate change. Fieldwork, modelling and remote sensing were used to highlight the relative risk to GDEs under various extraction and climate change scenarios using a risk assessment framework developed as part of the project. Further information can be found

at http://www.water.nsw.gov.au/Water-management/Water-availability/Risk-assessment/Risk-assessment-guidelines-for-groundwater-dependent-ecosystems.

Towards improved understanding and management of the Burdekin coastal plain groundwater system (Keith Bristow, CSIRO). This presentation provided an overview of the complex groundwater management requirements in the Burdekin system. Groundwater levels are rising in the west due to irrigation on lower permeability soils but falling in the east due to extraction for irrigation. Salinity issues are dominated by mixing of river water/fresh groundwater and modern/relict seawater. While some areas have declining salinity levels, others have increasing salinity levels and overall there does not seem to be a net improvement (decrease) in groundwater salinity over time. The issue of nitrate accumulation in groundwater from fertilisers in the Burdekin was also discussed, with the data suggesting nitrate transported by groundwater discharge could be the single biggest unaccounted for source of nitrate entering the Great Barrier Reef lagoon.

Assessment and interception of submarine groundwater discharge as a national coastal-zone water resources asset (Jeffrey Turner, CSIRO). The characteristics of submarine groundwater discharge (SGD) and methods for its detection and measurement were outlined. Since SGD may support marine ecosystems, understanding the consequences of its interception/capture is important. The use of treated wastewater injection to offset SGD interception was explored using an example from Beenyup in Western Australia (WA).

Stakeholders' and Jurisdictions' current activities in coastal aquifer management. A number of presentations were included under this item:

- *North West Coastal Urban Corridor, Western Australia Department of Water (Christie Silva).* This presentation focussed on a scheme of groundwater allocations for the North West Coastal Urban Corridor based on water balances and flow nets. Extraction allocations were made to flow cells of between 25% and 50% of estimated throughflow. Work is still required to set up effective monitoring networks, determine trigger values and define actions in response to trigger breaches.
- *Northern Territory Coastal Aquifers and SWI, Department of Land Resource Management (Des Yin Foo).* A case study of AEM application to mapping salinity in aquifers in the Darwin peri urban area was presented that identified unanticipated threats from saline paleo groundwater bodies. No groundwater management plan exists for this area. Currently, service providers manage groundwater in the NT but since they manage supplies rather than resources, there is potential that systems may become degraded before protection measures are introduced. There is a need for greater management of groundwater systems in the Northern Territory.
- *Activities of the New South Wales Office of Water (John Williams).* The NSW Office of Water (NOW) is currently rolling out its aquifer interference policy. It includes limitations on allowable mining impacts to groundwater, with some mines possibly having an impact to GDEs near the coast. NOW is developing a map of high priority coastal GDEs that may assist with impact management. Modelling guidelines and baseline monitoring requirements are also in development. Groundwater modelling and SWI investigation are being undertaken in the Botany Sands.
- *Tasmanian Department of Primary Industries, Parks, Water and Environment (Miladin Latinovic).* This presentation summarised the current status of coastal groundwater management in Tasmania. Tasmania lacks relevant data and has no SWI policy, in part due to lack of evidence of SWI from past investigations. As SWI has not been identified as a major issue as yet, and given the considerable ongoing task of establishing sustainable groundwater management in Tasmania, SWI is considered a lower priority at this time. However, flooding in

Seven Mile Beach in 2009 caused by rising groundwater levels due to an exceptional rainfall event resulted in groundwater being included in the Tasmanian Vulnerable Coasts project so this could prompt further work on SWI.

- *Preliminary investigation of seawater intrusion into a fresh water coastal aquifer – lower South East – South Australia (Saad Mustafa and Steve Barnett, South Australian Department of Environment, Water and Natural Resources)*. This presentation outlined the results of a detailed project assessing SWI in the Tertiary Limestone Aquifer (TLA) in the Port MacDonnell area and the threat it may pose to important GDEs. The freshwater-saltwater interface was detected at four locations, but it was emphasised that interface detection does not necessarily imply active SWI which was only identified at one location (Eight Mile Creek where salinity is gradually increasing). Further investigation, monitoring and modelling are proposed.
- *Current activities in coastal groundwater management, Queensland (Department of Science, Information Technology, Innovation and the Arts, Leon Leach)*. An NWC-funded project to develop a modelling toolkit to support sustainable management of the Lower Burdekin groundwater system was presented. The project assessed rising water tables, declining groundwater quality, discharge of poor quality groundwater, seawater movement, future impacts of land and water use, and climate variability. It involved a number of methods including remote sensing, fieldwork (drilling and monitoring), geochemical assessment, groundwater discharge studies, mapping, evapotranspiration studies, development of a detailed water balance, modelling and uncertainty analysis.

2.2.3 Day 1 Session 3: Group breakout and discussion session

Workshop participants were divided into four groups for the afternoon breakout session on Day 1 and asked to complete the following tasks:

1. Identify useful tools/methods and key outputs from recent projects with a focus on the morning's presentations.
2. Comment on the usefulness of these products to participants.
3. Highlight important lessons learnt.
4. Provide suggestions on how best to disseminate useful tools/methods and key outputs.

Each group presented their results to the workshop following the breakout session as detailed in Appendix C. Several items were identified as important by more than one group and discussion among the workshop participants highlighted a number of pertinent issues. A summary and collation of the key findings and group discussion points is outlined below.

Identified useful tools/methods/key outputs from recent projects with future applicability:

- Environmental tracers for the identification of SGD and assessing its rate and variability. Some of these methods (e.g. temperature measurements) may provide good cost/benefit ratios when applied at suitable scales in appropriate settings, although they typically allow only qualitative to semi-quantitative assessment. The low cost of temperature measurements makes it of particular interest as a tracer although its applicability may be limited in Australia due to low temperature contrasts and resolution issues in low discharge areas.
- Upscaling methods including remote sensing, environmental tracers and water chemistry (e.g. extrapolating between points of measured SGD) may be particularly useful to inform groundwater management. They serve as a way for science to assist or test decision making but have variable applicability.

- The development of review and response trigger levels to assist with groundwater management and to act as early warning systems. Consideration of the sensitivity of parameters for which trigger levels are set is an important part of this process (e.g. water levels in coastal bores in high permeability formations may not show large variations even as SWI occurs).
- Geophysical mapping techniques such as AEM. These were considered to provide broad spatial coverage, allow integration with a variety of other data and provide an effective means of communication to stakeholders.
- Simple mathematical tools to describe the position and movement of the saltwater-freshwater interface are well suited to data-poor areas, for first-pass assessments, and for organisations with limited resources. Even in data-rich areas, simple methods are useful for designing more detailed modelling and analysis campaigns. Their application for informing rapid decision-making and general groundwater planning and conversation was emphasised.
- The National Groundwater Information System (NGIS) being developed by the Bureau of Meteorology will be useful since it will provide nationally consistent time series groundwater monitoring data.
- The national-scale assessment of the vulnerability of coastal aquifers highlights the potential issues of SWI and the importance of its management.
- Correlating tree roots to surface vegetation using DNA in GDE assessment (i.e. deep roots drawing water close to the saturated zone may be sampled in boreholes and matched to existing surface vegetation to identify groundwater dependent species and assess the water table drawdowns that will affect such communities).

Lessons learnt from recent projects to be considered in future work:

- Ongoing targeted and strategic monitoring is required. To prevent funding cuts to long-term monitoring programs, the specific strategic purposes of monitoring should be explicitly explained to decision makers (e.g. the direct protection of town water supplies). Monitoring data must be regularly used to inform decision makers and thereby maintain relevance and value.
- The establishment of groundwater management plans prior to or early in the development of groundwater systems is imperative for their sustainable use and to avoid the considerable expense of rehabilitation or sourcing alternative water supplies when they become degraded or compensating water entitlement holders for the loss of previously granted property rights.
- Groundwater management plans should be matched to the scale of the hydrogeological system, allowing more effective, holistic management.
- Problem identification and sufficient hydrogeological system understanding are imperative in groundwater management (e.g. relict salinity versus modern salinity in the case of the Darwin peri-urban area).
- Water user education, communication and management are important components of effective groundwater management.
- Tools developed from research (e.g. the Burdekin modelling toolkit) should not be forgotten but maintained for ongoing use and assistance with future management and research.
- Information and knowledge must be integrated into an adaptive water planning and management framework and reviewed following uniform guidelines.
- Decision makers should be provided with appropriate information and informed to ensure that appropriate management practices are implemented and required investigation, research and monitoring are undertaken.

- Trans-disciplinary investigative approaches are valuable and data mining may prove effective at using existing data to examine relevant issues (e.g. relationships between hydrochemistry, geophysics, hydrogeology etc.). Techniques developed for other industries may prove effective in coastal groundwater assessment and monitoring.
- There is a strong need to develop specific SWI monitoring guidelines to ensure consistent and appropriate approaches are implemented within and between jurisdictions.

Suggestions surrounding dissemination of useful tools/methods and key project outputs:

- Ongoing feedback should be provided to decision makers on the usefulness of management and investigative monitoring to maintain its relevance.
- Communities should be empowered with factual information to encourage involvement and transparency in decision making.
- Relevant organisations should facilitate mentoring of the next generation of groundwater scientists / managers so that skills and experience are not lost.
- Scientific publications and policy and technical communication documents should be used to disseminate key information in conjunction with targeted coastal groundwater conferences, training courses, workshops and forums.
- A website should be developed and maintained to contain key coastal groundwater management tools including standard procedures, guidelines, models and information such as the NWC series of Waterlines reports. An associated smartphone application could prove useful in facilitating access and increasing usage. Issues of ownership and ongoing maintenance of such a website were raised. Were this to be effectively undertaken, such issues would need to be addressed to ensure that the website remained current and useful.

2.3 Day 2: Emerging priorities, challenges and future directions for coastal groundwater management and policy implications in Australia

Day 2 focussed on key knowledge gaps, emerging priorities in coastal groundwater management, policy implications and how future research and management should progress. To facilitate focussed discussion in the afternoon sessions, prior to the workshop attendees were asked to provide input on their perceptions of:

1. Key coastal groundwater management issues in Australia.
2. Important knowledge and information gaps in coastal groundwater management in Australia.
3. Priorities for future research in coastal groundwater management in Australia.

The responses were compiled and grouped into preliminary themes to form the basis of discussion (see Appendix D).

2.3.1 Day 2 Session 1: Emerging priorities, challenges and future directions; national and jurisdictional perspectives

Session 1 included a series of presentations focusing on policy and research perspectives and priorities relating to coastal groundwater. The earlier presentations highlighted the views of commonwealth agencies and the National Groundwater Sub Group. These were followed by a

summary presentation of the workshop participants' input gathered prior to the workshop (see Appendix D) and discussion lead by a panel consisting of the morning's presenters.

Session 1 included the following presentations:

Commonwealth water policy and research perspectives (James Hill, DSEWPaC – now Department of the Environment). This talk focussed on the National Water Knowledge and Research Platform endorsed by the Standing Council on Environment and Water (SCEW). The platform was developed by DSEWPaC with input from jurisdictions to '*establish priority research themes, ensure coordinated research effort, and ensure the best possible returns from new knowledge investments*' (DSEWPaC, 2012). It contains eight proposed themes. One of these is titled 'Groundwater' and aims to improve understanding of groundwater and GDEs. Several others are also partly applicable to groundwater such as 'Environmental Water', 'Water Quality', 'Hydrology and Hydrological Modelling', and 'Future Water Availability'. Draft groundwater research areas identified in the research platform include groundwater connectivity (with surface waters and within and between aquifers), sustainability of groundwater extraction (including offset mechanisms such as managed aquifer recharge), and aquifer and GDE protection (particularly in the context of resource development). The research platform remains subject to agreement by the Water Reform Thematic Oversight Group (Water TOG).

National Groundwater Sub Group - Strategic Plan for Groundwater (Neil Power, Chair of the National Groundwater Sub Group- NGSG). The NGSG now performs a policy advice role to SCEW via Water TOG. Their current activities were detailed including development of a National Groundwater Strategic Plan for the next ten years to build on extensive investment over the past decade (including the NWI and the NWC National Groundwater Action Plan). The plan's objectives are sustainable extraction and optimal use, confidence in investment (supported by groundwater) and planning and management now and for the future. The strategic plan incorporates aspects of definitions and concepts, groundwater and surface water connectivity, trading, groundwater value, investigating and managing poorly understood groundwater systems and using groundwater storage in water planning. Of relevance to the workshop theme, the NCGRT "Future-Issues" paper was briefly discussed. This short document will detail suggested future work directions and key policy outcomes of recent work.

Building a national groundwater database through the NGIS project (Tony Boston, Bureau of Meteorology – BoM). The National Groundwater Information System (NGIS) is being developed by BoM as a national database of groundwater information sourced from jurisdictional authorities. It will facilitate comparison across state borders by standardising data models, dictionaries and terminology (e.g. through development of the national aquifer framework to address issues of mismatch at state borders). The database will be spatially enabled and based on ArcHydro.

Groundwater in the coastal zone – strategic priorities and future directions. (Ross Brodie, GA). As outlined in Section 2.3, workshop participants' feedback on key coastal groundwater issues, knowledge gaps and priorities for future research in groundwater management were compiled prior to the workshop (see Appendix D). This talk presented these preliminary views and outlined some of the key coastal groundwater management issues in Australia to serve as the basis for the afternoon discussion sessions.

Panel discussion and Q&A session facilitated by a panel consisting of the Day 2 morning presenters (Neil Power, Tony Boston and Ross Brodie, chaired by Adrian Werner). This session provided an opportunity for the entire workshop to discuss issues raised during Day 1 and the morning presentations of Day 2. The main discussion points raised during this session included:

- *The value of water and monitoring.* To encourage Commonwealth, state and territory commitments to ongoing monitoring, the value of monitoring requires estimation so that its importance can be appropriately emphasised to relevant bodies. Several ideas were proposed for how to value groundwater monitoring and the resource it is designed to protect (it was reported that NGSG has considered evaluating this in detail):
  - A groundwater resource could be valued at the cost of finding a replacement resource if it became degraded. This would emphasise the value of protective monitoring.
  - The NWC Waterlines Report No 90 (SKM, 2012) recommended that monitoring assets be maintained. WA has placed monetary value estimates against some of their monitoring assets and this approach may prove useful.
  - Four NWC Waterlines reports were identified that could provide a basis for valuing groundwater and monitoring: Frontier Economics and SKM (2012), Marsden Jacobs Associates (2012), RPS Aquaterra (2012), and SKM (2012). They are available for download at http://archive.nwc.gov.au/library/waterlines.
- *Requirement for a core national monitoring network.* This would facilitate ongoing national monitoring to gather data that is comparable between jurisdictions and allow ongoing national assessment of coastal groundwater resources (Canada was cited as an example of how such a system may work, with national and state-scale networks). It was noted that such a system was in place in the 1980's but that responsibilities were then transferred to the jurisdictions. It may be difficult to encourage transfer of responsibility back to the Australian Government.
- *Quality assurance of groundwater data in the NGIS.* BoM will not have a QA/QC role. That responsibility will fall to the jurisdictions. They can provide a portal to the jurisdictional QA/QC data so that users can assess reliability but will not do so themselves. Although this may bring into question the usefulness of the NGIS compared to jurisdictional databases, BoM stressed that one of the main outputs of the NGIS is improved development of the jurisdictional databases.
- *Funding opportunities associated with the National Water Knowledge and Research Platform*. There is no current plan for projects to be funded under the platform. Rather, the platform focusses on setting up a research strategy for when funding becomes available in future. Such a strategy may create opportunities for funding itself and will allow focussing of resources on the most important issues. The NGSG is envisioned to be the groundwater focus group of the platform so their priorities should be aligned.
- *Importance of capacity building in coastal groundwater management.* Technical expertise to inform management of coastal groundwater resources is commonly lacking. While considerable capacity has been built in this regard over recent years, funding opportunities are now decreased and the main focus should be on sustaining capacity and avoiding the cost of rebuilding it in future. A central point of information dissemination and ongoing education on recent project outputs (such as the range of simple management and assessment tools that have been developed) is required. It was suggested that a team of SWI experts could be established for future consultation and direction setting.
- *Development of national groundwater coastal management and monitoring guidelines.* The development of guidelines covering a range of groundwater topics is another option for the dissemination of information and lessons learnt (noting that groundwater modelling guidelines incorporating SWI were published in 2012; see Barnett et al, 2012). The NGSG with Water TOG are considering the development of guidelines although this preliminary consideration is incomplete. The 2012 National Water Initiative Policy Guidelines for Water Planning and Management provide opportunities to link additional sections and case studies and may prove useful.

- *Risk-based and adaptive management.* Although such strategies have received much attention over recent years, there is a perception in some quarters that they may be a poor substitute for defining an issue more specifically or an excuse for not making a firm decision. It was suggested that strong examples of effective implementation of risk based and/or adaptive management are required. Examples include the Pioneer Valley, the Burdekin Delta, the Tomago Sand Beds and the Wellington water supply in New Zealand.

2.3.2 Day 2 Session 2: Group breakout and discussion session

Workshop participants were divided into four groups for the afternoon breakout session on Day 2 and asked to identify, in the context of coastal groundwater management in Australia, what they saw as key:

1. Current and emerging management issues
2. Knowledge and information gaps
3. Priorities for future research.

The pre-workshop responses compiled and grouped into preliminary themes included in Appendix D (see Section 2.3) were provided as context to prompt discussion. Each group presented their results to the workshop following the breakout session. The results are included in Appendix E. Several items were identified as important by more than one group and discussion among the workshop participants highlighted a number of pertinent issues. A summary and collation of the key findings and group discussion points is outlined below. There was considerable overlap between the three task themes (i.e. management issues, knowledge gaps and research priorities).

Current and emerging management issues

- Regulatory approaches to groundwater development should be holistic to appropriately manage competing demands on resources (e.g. drinking water, coal seam gas, mining, irrigation, etc.). The current regulatory framework is disjointed in many instances with different Acts being relevant to different industries. This situation should be addressed and streamlined. There are also compliance and enforcement issues surrounding groundwater resource development. Planning control must still be maintained in fully allocated systems where trading markets may be established.
- National best practice guidelines are required for water management in coastal aquifers. The development of guidelines is an economical way to improve coastal groundwater management and disseminate accumulated knowledge. Guidance on the development of review and response trigger values for groundwater quality and level should be included.
- Local community engagement is needed to raise awareness of risks associated with coastal groundwater and allow them to take ownership of management issues.
- Lack of a suitable national strategy to minimise skill erosion. Within jurisdictional organisations, staff continuity, succession planning and data archiving are required to sustain capacity, maintain corporate knowledge and reduce knowledge loss. Competing and shifting priorities within public agencies may also contribute to reduced experience. A suitable strategy for minimising knowledge loss should incorporate an independent external component and include jurisdictional data and knowledge sharing.
- Current monitoring is required for future issues such as subsidence, land use change and population pressure.
- Specific emerging factors affecting groundwater management in coastal areas include:

- increasing average and peak population demands (e.g. holiday) for coastal groundwater
- management of groundwater on small islands
- management accounts for ecological concerns
- the setting and meeting of groundwater level and quality targets
- preparing for rising sea levels and variations in rainfall due to climate change
- changes in hydrology and groundwater quality
- urban greenfield developments
- energy development.

Key knowledge and information gaps

- The location, geometry and movement of the saltwater-freshwater interface. Such knowledge is critical to improving groundwater management in many areas. It was emphasised that SGD and SWI are linked concepts, with reduction and in some cases cessation of SGD giving way to SWI. SGD location and flux are of importance in their own right for planning SGD capture and offset schemes as well as understanding the dynamics of dependent ecosystems. Knowledge of the extent of offshore groundwater resources and aquifer systems is also important in their development.
- Groundwater monitoring guidelines. The development of national, best-practice coastal groundwater monitoring guidelines is an economical way to improve the quality of coastal groundwater monitoring and allow greater comparability between areas.
- The risks and associated costs of not managing SWI appropriately. Publicising risks and costs may encourage appropriate investment in monitoring and research.
- Groundwater extraction data. Since groundwater extraction is a key driver of SWI, accurate measurements/estimates of extraction are needed. However, in some jurisdictions only limited information is available.
- The impacts of sea-level rise and climate variability which may impact recharge and SWI.
- Conceptual hydrogeological understanding and modelling of multi-layer aquifer and karst aquifer systems.
- Understanding paleo-systems and how they may affect salinity and complicate understanding of modern SWI (e.g. in the Darwin peri-urban area, NT).
- How to upscale groundwater models and assess the implications of upscaling on model uncertainty.
- Geochemical understanding of solute transport to assess the fate of substances such as agricultural chemicals in coastal systems.

Priorities for future research

- Developing national best practice monitoring and management guidelines for coastal aquifers and SWI. These would include the minimum requirements for monitoring SWI under different conditions (e.g. unconfined versus confined systems).
- Climate change and climate variability impacts and population demands on coastal groundwater resources are not well understood. These should remain continuing areas of research.
- Developing a toolkit of simple to complex methods of assessment that can be linked to the cost, risk and complexity of systems. This may partly focus on making existing methods cheaper (e.g. through smart phone remote sensing). It would include simple tools for undertaking first pass assessments of risk and vulnerability.

- A national repository for tools, procedures and modelling methods.
- Identifying the extent and location of SWI/SGD offshore in confined aquifers (geophysics may prove useful in mapping offshore aquifers).
- Synthesis of existing knowledge from relevant disciplines such as geophysics, geochemistry, geology and hydrogeology. Data mining may be useful in this regard. The development of linked models allowing calibration with other data (e.g. chemistry and temperature) in a multidisciplinary approach was also suggested.
- Long term case studies of coastal aquifers to assess their functioning and sustainable use in multidisciplinary and multi-agency collaborations.
- Collaborative arrangements between universities and government (federal and jurisdictional) authorities. Engaging with other specialists such as marine and petroleum geologists may prove helpful (such as in the case of offshore aquifers).
- Understanding the ecological importance of groundwater in coastal areas. For offshore ecosystems, this would include mapping biota and SGD occurrences to understand SGD dependent ecosystems.
- Understanding the water and salt balance of coastal aquifers (sources and sinks).
- Geochemistry, with a focus on the fate of nitrogen, phosphorous and other agricultural chemicals in coastal groundwater systems.
- Development of a national coastal aquifer typology framework.
- Geophysical mapping for coastal groundwater resource assessment and understanding the threat of SWI.
- Desalination of brackish groundwater extracted from coastal aquifers.

3 Summary and future directions

3.1 Summary

A number of key issues were raised repeatedly over the course of the National Coastal Groundwater Management Knowledge Transfer Workshop, including:

- The need for national guidelines
- The need for ongoing groundwater monitoring
- The need for further investigation and research
- The issue of knowledge loss and skill erosion

These are briefly outlined below.

Developing national guidelines

A requirement was commonly raised for national best practice guidelines covering a range of coastal groundwater topics including groundwater management, SWI monitoring and groundwater monitoring in general (groundwater modelling guidelines incorporating SWI were released in 2012; see Barnett et al, 2012). The development of consistent and practical guidelines is an economical way to improve coastal groundwater management and disseminate accumulated knowledge. Guideline documents would facilitate consistency in approach and comparability between different areas. On the management front, the need for guidance on the derivation and implementation of review and response triggers for groundwater quality and levels was emphasised.

The NGSG with Water TOG are considering the development of guidelines although this consideration is incomplete. The 2012 National Water Initiative Policy Guidelines for Water Planning and Management have opportunities to link additional sections and case studies and may prove useful in this regard.

Ongoing groundwater monitoring

There is a need for ongoing groundwater monitoring that should be targeted and strategic. To prevent funding cuts for long term monitoring programs, the specific strategic purposes of monitoring (e.g. the direct protection of town water supplies etc.) must be explicitly explained to decision makers. Monitoring data must be regularly used to inform decision makers and thereby maintain relevance and value.

To encourage commonwealth and state and territory water agencies' commitments to ongoing monitoring, the value of monitoring requires estimation in monetary terms so that its importance can be appropriately emphasised. Several ideas were proposed for how to place a value against groundwater monitoring and the resource it is designed to protect:

- A groundwater resource could be valued at the cost of finding a replacement resource if it became degraded. This would emphasise the value of protective monitoring.
- The National Groundwater Action Plan states that monitoring assets must be maintained and WA has consequently placed monetary value estimates against some of their monitoring assets and this approach may prove useful.

- Four NWC Waterlines reports were identified that could provide a basis for valuing groundwater and monitoring: Frontier Economics and SKM (2012), Marsden Jacobs Associates (2012), RPS Aquaterra (2012), and SKM (2012).

The importance of groundwater to Australia's economic security should be emphasised in general.

Investigation and research

As outlined in these proceedings, there are a range of coastal groundwater processes that are poorly understood and others that are poorly defined in certain areas. Greater understanding through further investigation and research is required for more effective coastal groundwater management. The location, geometry and movement of SWI and the saltwater-freshwater interface was one critical knowledge gap in many localities. The location and quantum of submarine groundwater discharge was also recognised as a major knowledge gap.

In addition to ongoing groundwater monitoring and general geological and hydrogeological investigations, various investigation methods were highlighted as potentially useful including geophysics and environmental tracer techniques. In the absence of funding for further research and investigation, synthesis of existing knowledge (e.g. geophysics, geochemistry, geology and hydrogeology) may still be undertaken. Data mining may be useful in this regard. The development of linked models allowing calibration with other data (e.g. chemistry and temperature) in a multidisciplinary approach was also suggested.

Knowledge loss and skill erosion

There was considerable discussion surrounding the issue of knowledge loss and skill erosion. Many projects have recently been undertaken relating to coastal groundwater during a phase of increased funding by the Commonwealth Government through the NWC. It is imperative that the outputs and lessons learnt from these projects are not lost to avoid costly repetition of work and improve future projects.

Various suggestions were made for maintaining knowledge, with the most common being development and maintenance of a website containing key coastal groundwater management tools including standard procedures, guidelines, models and information such as the NWC series of Waterlines reports. However, there are issues surrounding ownership and maintenance of such a website. Were this to be effectively undertaken, such issues would need to be addressed to ensure that the website remained current and useful.

A lack of a suitable strategy for minimising skill erosion was also raised. Within jurisdictional organisations, staff continuity, succession planning and data archiving are required to sustain capacity, maintain corporate knowledge and reduce knowledge loss. Competing and shifting priorities within public agencies may also result in skill erosion. A suitable strategy for minimising knowledge loss should therefore incorporate an independent external component and include jurisdictional data and knowledge sharing. The suggested website is one method of filling this need.

3.2 Future Directions

These workshop proceedings record recent work and lessons learnt in coastal groundwater management and stakeholder views on emerging management issues, knowledge gaps and future research priorities. Discussions during the workshop have highlighted the need for a position paper on these main issues. This position paper will be developed by the authors of the workshop proceedings

in collaboration with, and submitted to, the National Groundwater Sub Group which has a policy advisory role to the Water Reform Thematic Oversight Group (Water TOG). The position paper will be used to inform the National Groundwater Strategic Plan that is currently in development.

Acknowledgements

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Jane Coram, Geoscience Australia

Brad Degens, WA Department of Water

Justin Foley, National Water Commission

Laura Gow, Geoscience Australia

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Karen Ivkovic, Naiades Hydrogeology

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Miladin Latinovic, DPIPWE

Ken Lawrie, Geoscience Australia

Leon Leach, DSITIA

Sarah Marshall, Geoscience Australia

Stuart Minchin, Geoscience Australia

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Tim Munday, CSIRO

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Christie Silva WA Department of Water

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Baskaran Sundaram, Geoscience Australia

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Alistair Usher, National Water Commission

Luke Wallace, Geoscience Australia

Adrian Werner, National Centre for Groundwater Research and Training, Flinders University

Robyn Whipp, DSEWPaC

JohnPaul Williams, NSW Office of Water

Des Yinfoo, NT Department of Land Resource Management

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Appendix A Workshop invitation and program

NATIONAL CENTRE FOR GROUNDWATER RESEARCH AND TRAINING
sustaining a vital water resource

Australian Government
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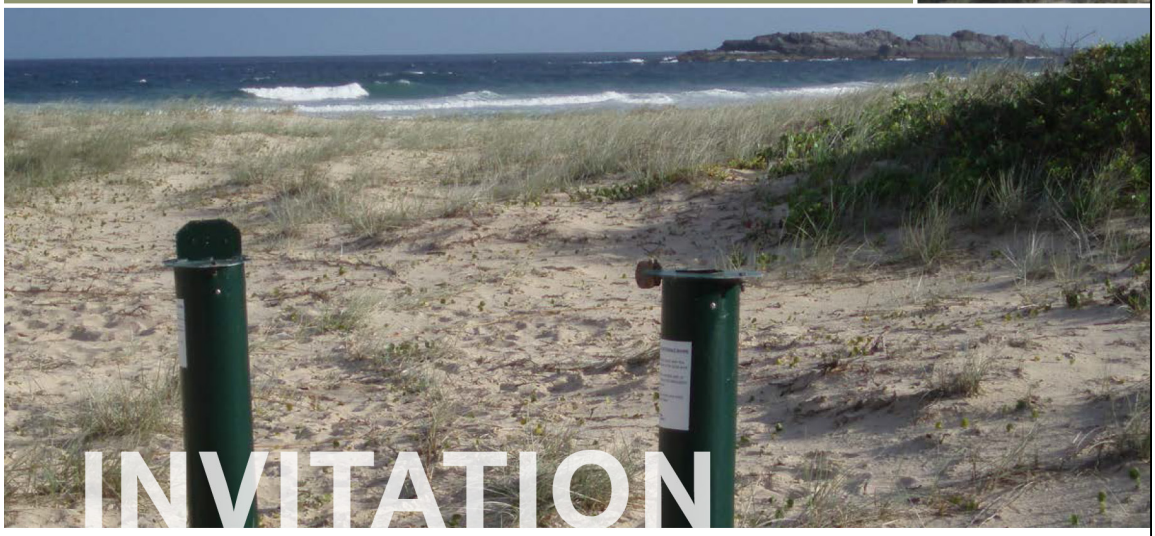
CSIRO

National Coastal Groundwater Management Knowledge Transfer Workshop



Geoscience Australia, National Centre for Groundwater Research and Training and CSIRO Water for a Healthy Country Flagship invite you to attend the 2013 National Coastal Groundwater Management Knowledge Transfer Workshop on 28 and 29 May in Canberra.

The workshop aims to support the effectiveness of investment in coastal groundwater management by facilitating a public exchange of information across the policy-research-management paradigms.

The workshop will provide an opportunity for government, community and researchers to consider the outputs of various coastal groundwater projects and how these outputs may support stakeholder interests. The main purposes of the national workshop are to:

- share results and knowledge from various coastal groundwater projects around Australia;
- promote confidence in project outputs as a source of practical information for water managers; and
- discuss priorities for future work in coastal groundwater knowledge and management.

The workshop has been designed to meet the NWI objective of assisting national efficiency and capacity by facilitating efficient information exchange between researchers and managers.

Workshop invitees have been selected to represent a wide spectrum of stakeholders in coastal groundwater resources and include government, policy, management, scientific, community and technical representatives. Findings of the workshop will be compiled in a report that will form the basis of advice to the Australian Government on priorities for future coastal groundwater management and research.

Please email Baskaran Sundaram (Baskaran.Sundaram@ga.gov.au) to advise of your intention to attend or otherwise by **15 April 2013**. If you have any questions, please email Baskaran directly.

The final workshop program will be provided to participants in mid-April.

I look forward to your response and hope you are able to be part of this important event.

Workshop:

Date: 28 and 29 May 2013

Venue: Scrivener Room, Geoscience Australia, Corner Hindmarsh Drive and Jerrabomberra Avenue, Symonston, Canberra.

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2013 National Coastal Groundwater Management Knowledge Transfer Workshop, Geoscience Australia, Canberra, ACT. WORKSHOP PROGRAM

Day 1, Tuesday 28 May: Current project activities; key achievements, outputs and lessons learnt.

TIME	TITLE	PRESENTER
9:30-10:30	**SESSION 1: WELCOME AND INTRODUCTION**	
9:30-9:40	Welcome	Stuart Minchin, GA
9:40-9:50	Opening - An update on the Groundwater Action Plan and the National Water Initiative	Kerry Olsson, NWC
9:50-10:00	Overview of workshop program	Baskaran Sundaram/Jane Coram, GA
10:00-10:30	Understanding coastal aquifers – aquifer characterisation, modelling, monitoring and management	Adrian Werner, Flinders/NCGRT
10:30-10:50	**Morning Tea**	
10:50-15:10	**SESSION 2: COASTAL PROJECT ACTIVITIES – INFORMATION SHARING SESSION**	
10:50-11:10	National-scale vulnerability assessment of seawater intrusion: a summary	Baskaran Sundaram, GA
11:10-11:30	Synthesis of recent Australian Submarine Groundwater Discharge studies using environmental tracers	Sebastien Lamontagne, CSIRO
11:30-11:50	Geophysical mapping for coastal groundwater resource assessment and understanding seawater intrusion into freshwater aquifers	Ken Lawrie, GA
11:50-12:10	Sustainable management of coastal groundwater resources: a case study from Mid North Coast of New South Wales	Jay Punthakey, Ecoseal Laura Gow, GA
12:10-12:30	NSW Groundwater Quality and coastal groundwater dependant ecosystems	John Williams, NSW Office of Water
12:30-12:50	Towards improved understanding and management of the Burdekin coastal plain groundwater system	Keith Bristow, CSIRO
12:50-13:10	Assessment and interception of submarine groundwater discharge as a national coastal-zone water resources asset	Jeffrey Turner, CSIRO
13:10-14:00	**Lunch**	
14:00-15:10	Stakeholders' and Jurisdictions' current activities in coastal aquifer management	Various
15:10-17:30	**SESSION 3: GROUP BREAKOUT AND DISCUSSION**	
15:10-15:20	Instructions for group breakout session	Baskaran Sundaram, GA
15:20-15:40	**Afternoon tea**	
15:40-16:40	Group breakout session Discussion on key achievements, outputs and lessons learnt	
16:40-17:30	Group breakout reporting and discussion	Chair to be confirmed
18:30	**Dinner- Spicy Ginger, 25 Childers Street, Canberra**	

Australian Government
Geoscience Australia

2013 National Coastal Groundwater Management Knowledge Transfer Workshop, Geoscience Australia, Canberra, ACT. WORKSHOP PROGRAM

Day 2, Wednesday 29 May: Emerging priorities, challenges and future directions for coastal groundwater management and policy implications

TIME	TITLE	PRESENTER
8:30-8:40	Summary Day 1	Baskaran Sundaram
8:40-10:30	**SESSION 1: EMERGING PRIORITIES, CHALLENGES AND FUTURE DIRECTIONS; NATIONAL AND JURISDICTIONAL PERSPECTIVES**	
8:40-9:00	Commonwealth water policy and research perspectives	James Hill, DSEWPaC
9:00-9:20	National Groundwater Working Group - Strategic Plan for Groundwater	Neil Power Chair, National Groundwater Working Group
9:20-9:40	Building a national groundwater database through the NGIS project	Tony Boston BoM
9:40-10:00	Groundwater in the coastal zone – strategic priorities and future directions.	Ross Brodie, GA
10:00-10:30	Group discussion and Q&A session facilitated by a panel consisting of the morning presenters.	Chair to be confirmed
10:30-10:50	**Tea Break**	
10:50-13:45	**SESSION 2: GROUP BREAKOUT AND DISCUSSION**	
10:50-11:00	Instructions for group breakout session	Baskaran Sundaram
11:00-12:00	Group breakout session	
12:00-13:00	**Lunch**	
13:00-13:45	Group breakout reporting and discussion	Chair to be confirmed
13:45-14:00	**SUMMARY AND CONCLUDING REMARKS**	**Jane Coram / Baskaran Sundaram**
14:00	**Workshop end**	

Appendix B Workshop presentations

The following presentations are publically available for download from the Geoscience Australia website. It is emphasised that the interpretations they contain are based on information available to the authors at the time of writing and are subject to change.

Leon Leach, DSITIA: Current activities in coastal groundwater management, Queensland

Ross Brodie, GA: Groundwater in the coastal zone – strategic priorities and future directions

Justin Foley, NWC: An update on the National Groundwater Action Plan and the National Water Initiative

Tony Boston, BoM: Building a national groundwater database through the NGIS project

Adrian Werner, NCGRT: Understanding coastal aquifers – aquifer characterisation, modelling, monitoring and management

Laura Gow, GA: Sustainable management of coastal groundwater resources: a case study from Mid North Coast of New South Wales

Keith Bristow, CSIRO: Towards improved understanding and management of the Burdekin coastal plain groundwater system

Des Yinfoo, DLRM: Northern Territory Coastal Aquifers and SWI

Sébastien Lamontagne, CSIRO: Synthesis of recent Australian submarine groundwater discharge studies using environmental tracers

Saad Mustafa, DEWNR: Preliminary investigation of seawater intrusion into a fresh water coastal aquifer – lower South East – South Australia

Baskaran Sundaram, GA: National scale vulnerability assessment of seawater intrusion: a summary

Miladin Latinovic, DPIPWE: Current status of coastal groundwater management in Tasmania

Appendix C Group breakout session reports, Day 1 Session 3

C.1 Group 1 Summary

The tools/methods from the morning information sessions considered to be the most useful by Group 1 included:

- Environmental tracers for the identification of SGD and assessing its volume and heterogeneity. Such methods were considered to provide good cost/benefit ratios when applied at suitable scales.
- The development of water level and salinity trigger levels for groundwater monitoring programs to assist with groundwater management. The limitations of such management techniques were noted (e.g. water levels in coastal bores in high permeability formations may not show large variations even as SWI occurs).
- Geophysical mapping techniques (particularly AEM and techniques providing temporal information). These were considered to provide good spatial coverage, allow integration with a variety of other data and provide a good means of communication to stakeholders.
- Matching of tree roots to surface vegetation using DNA in GDE assessment.

The lessons learnt from recent projects considered by Group 1 to be the most important included:

- SWI is a complex process and associated issues are correspondingly complex.
- GDEs may be resilient to groundwater changes and may therefore not always be good indicators of system changes. In addition, the vegetation species distribution in GDEs may shift over time in response to groundwater changes. Such species changes may be difficult to identify from remote sensing data alone and mask overall impacts to GDEs (i.e. suggest there have been no changes when in fact there have been).
- Groundwater models may be useful for answering “what if” questions.
- The development of groundwater management plans prior to or early in the exploitation of groundwater systems is imperative for their sustainable use and to avoid the considerable expense of rehabilitation or sourcing alternative water supplies when they become degraded.
- Groundwater management plans should be matched to the scale of hydrogeological systems to manage competing interests effectively and allow systems to be managed as whole.

Group 1 provided the following suggestions for disseminating useful tools/methods and key project outputs:

- Communities should be empowered with factual information to encourage involvement and transparency in decision making.
- Relevant organisations should facilitate mentoring of the next generation of groundwater scientists / managers so that skills and experience are not lost.
- Development and maintenance of a website containing key coastal groundwater management tools including standard procedures, guidelines and models etc.

C.2 Group 2 Summary

The tools/methods from the morning information sessions considered to be the most useful by Group 2 included:

- Environmental tracers, with potential specific applications of fibre optic temperature sensors in WA.
- The development of review and response trigger levels for quality and quantity including application to cumulative monitoring.
- Geophysical surveys.
- The study of nitrate accumulation / degradation in coastal systems.

The lessons learnt from recent projects considered by Group 2 to be the most important included:

- Problem identification and sufficient understanding are imperative in groundwater management (e.g. relic salinity vs modern salinity in the case of the Darwin peri-urban area).
- There is a requirement for ongoing monitoring that should be targeted and strategic. A stocktake of monitoring assets is required.
- The importance of water user education, communication and management.
- Groundwater models require refinement for scenario modelling.
- Tools developed from research (e.g. the Burdekin toolkit) should not be forgotten but rather maintained for ongoing use and assistance with future management and research where relevant.
- The importance of integrating information and knowledge into a management framework of adaptive management and review following uniform guidelines.
- Decision makers must be educated and informed to ensure that appropriate management practices are enforced and required investigation, research and monitoring are undertaken.
- Monitoring is required to serve as a baseline for future assessment but the data must be used to inform decision makers and thereby maintain monitoring relevance.

Group 2 provided the following suggestions for disseminating useful tools/methods and key project outputs:

- Stakeholder engagement.
- Development of specific SWI monitoring guidelines.
- Ongoing feedback to decision makers on the usefulness of management and investigative monitoring to maintain relevance.

C.3 Group 3 Summary

The tools/methods from the morning information sessions considered to be the most useful by Group 3 included:

- Geophysical methods are a good communication tool and useful for regional scale development and structure identification. Geophysical results require validation and the use of geochemistry to refine geophysical surveys appears helpful.
- Simple mathematical tools to describe the position and movement of the saltwater-freshwater interface are well suited to data-poor areas, for first pass assessments, and for resource poor organisations.
- Upscaling methodologies including remote sensing, environmental tracers and water chemistry are particularly useful and may be used to inform management. They serve as a way for science to validate decisions and inform stakeholders but have variable applicability.
- Temperature holds some interest as a tracer since it is cheap noting that it may have limited applications due to low temperature contrast in Australia and resolution issues in low discharge areas.
- The use of review and response trigger values to serve as early warning systems.

Group 3 provided the following suggestions for disseminating useful tools/methods and key project outputs:

- A coastal groundwater website including information such as the NWC series of Waterlines reports.
- Conferences forums, and workshops.
- A smartphone application (linked to a coastal groundwater website).

C.4 Group 4 Summary

The tools/methods from the morning information sessions considered to be the most useful by Group 4 included:

- Estimating SGD (using environmental tracers) at small scales (tens of kilometres) provides information for water budgets and informs capture and offset.
- Geophysical monitoring techniques (particularly seismic and AEM) to assess offshore resources. Techniques allow large areas of investigation, are cost effective and allow reassessment of resources.
- The national groundwater information system being developed by the Bureau of Meteorology may be useful since it will provide consistent, comparable time series data.
- The national scale assessment of the vulnerability of coastal aquifers raises awareness of the potential issues of SWI and the importance of its management.
- The usefulness of trans-disciplinary approaches to investigation were emphasised and it was suggested that data mining may prove effective at using existing data to examine relevant issues (e.g. to examine relationships between hydrochemistry, geohpyhsics, hydrogeology etc).

The lessons learnt from recent projects considered by Group 4 to be the most important included:

- Not all assessment methods are universally applicable.
- Techniques developed for other industries may prove effective in coastal groundwater assessment and monitoring.
- Each area is unique and multiple techniques are typically required for investigation and management.

Group 4 provided the following suggestions for disseminating useful tools/methods and key project outputs:

- Technical reports and scientific papers and publications.
- Good news and case studies should be publicised to raise awareness.
- Courses, conferences and short courses could be organised.
- Policy and technical communication documents.

Appendix D Coastal groundwater management issues, knowledge gaps and priorities for future research preliminarily identified by workshop participants

The following key current and emerging management issues, knowledge and information gaps, and priorities for future research were identified by participants prior to attending the 2013 National Coastal Groundwater Management Workshop. They were grouped into the preliminary themes shown below based on content to facilitate discussion during the workshop.

D.1 Key current and emerging management issues identified by participants.

General management and policy issues

- Management of the salt water interface and licensees at risk.
- Managing groundwater extraction to minimise ingress of the saltwater interface.
- A clear understanding of the management objectives.
- Is it time and is there room for implementation of adaptive management (more focus of objectives rather that perceived structural solutions).
- Balancing national management drivers and objectives with local management objectives.
- New policy/approaches to ensure orderly and equitable allocation in water limited coastal zones.
- Local area management with respect to contemporary reasons as to why local water user groups feel they want more say in management issues.
- A perceived erosion of respect for, and valuing of local water user groups.
- Identification and understanding of current issues, internal and external drivers.
- Government support for establishment of alternative sources to groundwater to meet demand.
- Maintaining access to good quality groundwater.
- Develop best practice guidelines for water management authorities dealing with coastal aquifers.
- Managing climate change impacts, alongside of increasing pressure on aquifers- particularly long term needs for water security which may lead to an increasing reliance on groundwater as surface water availability is threatened.

Population growth and land use issues

- Increasing town /community water supply demands due to population growth in coastal areas or with high summer demand due to peak visitor numbers during this period, where the groundwater resource(s) often have limited capacity.
- Population growth: Impact of current and future extraction regimes on water quality.
- Water quality risks from pollution due to urban encroachment.
- Align land planning and water planning better in coastal zones. Land planning departments consult water departments before approving land for development.
- Changing land use (urbanisation) and ownership (family to corporations)

Industry-associated groundwater extraction

- For regions with offshore petroleum/gas production (ie Gippsland Basin). What are the impacts from these extractions and their implications for near coastal groundwater resources? This could also extend to understanding the issue of near coastal subsidence from these extractions.
- Energy and power supply (Coal and CSG and electricity generation). There has been a large shift in ownership of water licences within the Hunter Valley to energy and power industry this is expanding into the Gunnedah Basin.

Ecological considerations

- Ground/surface water interaction in coastal groundwater-dependent ecosystems (wetlands rivers and estuaries on coastal plains)
- Maintaining ecological character and function of coastal wetlands
- Coastal and marine groundwater-dependent ecosystems

General knowledge/technical issues identified affecting management (overlap with knowledge gaps and future research)

- Effective monitoring of changing conditions in key areas/aquifers.
- Quantifying groundwater availability near the coast and offshore.
- Water balance of coastal aquifers.
- Saline up coning, particularly for peninsular areas (Broome, Cottesloe, Mosman, Mandurah).
- How to best determine if the interface is moving. I.e. if an interface has been detected, is it moving inland or static?
- Informed management and optimisation of treated wastewater injection (TWWI) schemes from multiple injection and recovery bores in coastal aquifers.
- Climate change: Impact of increased recharge variability and sea level rise.

D.2 Important knowledge and information gaps identified by participants.

General monitoring and data gaps

- Location of SWI (unconfined and confined aquifers).
- Extent and geometry of salt water intrusion.
- Lacking detailed field studies with long term monitoring data.
- Extraction volumes in coastal aquifers.
- Adequate data to be able to model the potential movement of saltwater interface in aquifers under water abstraction scenarios.
- Spatio-temporal behaviour of coastal aquifer systems when under pressure through extraction.
- Monitoring of groundwater quantity and quality trends with respect to internal and external impacts and consequences.
- Position of freshwater-saltwater interface now and in future i.e., improved salinity measurement and monitoring.

Modelling/characterisation considerations/suggestions

- Climate change impacts on freshwater resources in small islands.
- Scaling (up and down).
- Limited process understanding of saltwater interface dynamics under stressed conditions.
- Application of AEM for mapping salinity extents and near coastal aquifer hydrostratigraphy (i.e. NT Coastal Plains study) can be used to rapidly map. The low impact nature of this method combined with limited drilling, could be used to rapidly understand coastal systems not yet mapped or well understood as a pre-development investigation.

Monitoring strategies, guidance and management

- Standard methodology for monitoring salt water interface including acceptable level of movement, water table levels and abstraction regime to limit movement
- What is best monitoring strategy – open hole for using sondes, or piezometers with limited open intervals for pumping ?
- Robustness of the Groundwater Modelling for Coal and CSG activities versus the risks posed. 2 yr data capture period.
- How to measure management objectives. Any key performance indicators?
- Are we monitoring the right elements?
- How to measure the real impacts of water trading in the groundwater arena whilst maintaining the rights of other entitlement holders. Physical, social, farm finance verses local economy.

Ecological considerations

- Poor knowledge of ecosystem water requirements (water quality and quantity).
- Groundwater-dependency of coastal and marine ecosystems unknown.
- Understanding and quantification of the dynamics and resilience of groundwater dependant ecosystems.
- Longer term impacts of climate change on groundwater availability and GDE condition.

Offshore groundwater and submarine groundwater discharge

- Better understanding of offshore freshwater discharge for coastal aquifers needed.
- The absence of information on a national inventory of Submarine Groundwater Discharge flux estimates particularly in sectors of the Australian coastline where SGD capture has potential water resource benefits.
- The absence of information on offshore fresh groundwater trapped (by recent marine transgression) in offshore sedimentary basins (e.g Canning, Perth, Murray-Otway), in particular those have relevance to onshore SGD capture.
- Few independent estimates of SGD to calibrate groundwater models.

D.3 Priorities for future research identified by participants.

General monitoring, characterisation and modelling

- Cost effective monitoring methods.
- What needs to be monitored?
- Long term field based research and monitoring programs.
- Appropriate/effective monitoring and management for SWI.
- Improving the understanding and conceptualisation of various coastal groundwater systems in general, thus leading to better model development. This would lower the uncertainty in defining model domains, and increase confidence in model outputs.
- 3D Spatial characterisation of saltwater –freshwater interface in key areas.
- Smarter ways to calibrate coastal groundwater models.
- Implications of rising sea levels under climate change scenarios.

Management, policy and guidelines

- Empowering local water users in effective decision making based on sound information and analysis.
- A more holistic approach (integration, conjunctive use, water pricing) to management of groundwater and, surface water coastal areas.
- Process, procedures and templates for the assessment and monitoring of the effectiveness of water resource plans.
- Guidelines on the use of complex models and exchange of data inputs and outputs.
- Education and information transfer as to the understanding of coastal groundwater dynamics.
- How to balance future resource interests (water use) and the pressure this puts on our groundwater system. In particular, the limits, resilience, and interconnectedness of the groundwater system.

Ecological considerations

- Impact of abstraction (confined and unconfined) on SWI and coastal GDEs.
- Evaluate groundwater-dependency for key coastal ecosystems.
- Ecological indicators for the early detection of impact occurring.
- Detailed site investigations for different aquifer/ecosystem types.

Offshore groundwater and submarine groundwater discharge

- Extent and magnitude of offshore discharge from freshwater aquifer systems
- Quantify marine discharges off coastlines from confined aquifers and implications for aquifer management
- Developing a methodology and estimation of the national inventory of SGD flux.
- Developing numerical modelling capability to optimise Treated Wastewater Injection-SGD capture in multi-layer coastal aquifers in relation to beneficial water resource and environmental (e.g groundwater dependent ecosystem) outcomes.
- Extent off shore of freshwater in confined aquifers.
- If the interface is offshore in deeper confined aquifers, how to tell where it is. Offshore drilling is expensive.

Appendix E Group breakout session reports, Day 2 Session 2

E.1 Group 1 Summary

Current and emerging management issues considered by Group 1 to be of greatest importance included:

- The requirement for best practice guidelines for water management in coastal aquifers. With limited funding currently available, the development of guidelines represents an economical way to improve coastal groundwater management and disseminate accumulated knowledge.
- The requirement for local engagement with stakeholders to allow them to take ownership of management issues.
- The requirement for holistic regulatory approaches to groundwater development to appropriately manage competing demands on resources (e.g. drinking water, coal seam gas, irrigation etc). The current regulatory framework is disjointed in many instances with different Acts being relevant to different industries.

Knowledge and information gaps considered by Group 1 to be of greatest importance included:

- The location, geometry and movement of SWI since such knowledge is critical to management in many areas. It was emphasised that SGD and SWI are linked concepts, with reduction and ultimate cessation of SGD giving way to SWI.
- Groundwater monitoring guidelines. The development of monitoring guidelines represents an economical way to improve the quality of coastal groundwater monitoring and allow greater comparability between areas.
- Groundwater extraction data. Since groundwater extraction is a key driver of SWI, it is imperative that accurate measurements of extraction are available but in some jurisdictions only limited information is available in this regard.
- A lack of a suitable strategy for minimising skill erosion (sustaining capacity).

Group 1 considered the following priorities for future research to be of most importance:

- The extent and location of SWI/SGD offshore in confined aquifers.
- Guidelines for modelling tools and methodologies.

E.2 Group 2 Summary

Current and emerging management issues considered by Group 2 to be of greatest importance included:

- Staff continuity and succession planning to sustain capacity and reduce skill erosion.
- Compliance and enforcement issues surrounding groundwater resource development.
- The maintenance of corporate knowledge and data archiving.
- Jurisdictional data and knowledge sharing.
- Managing development pressures.
- The development of best practice guidelines for coastal groundwater management.
- Demands on staff- competing and shifting priorities within public agencies.
- The requirement to maintain planning control in fully allocated systems (trading markets).

Knowledge and information gaps considered by Group 2 to be of greatest importance included:

- SGD location and flux.
- The location and geometry of the saltwater – freshwater interface and aquifer systems, development of appropriate trigger values for protection and the associated risks and costs of not managing SWI appropriately.
- The impacts of sea level rise and climate variability which may affect recharge.
- Stakeholder awareness of coastal groundwater management issues.
- Monitoring guidelines and minimum requirements.

Group 2 considered the following priorities for future research to be of most importance:

- Synthesis of existing knowledge (e.g. geophysics).
- Collaborative arrangements between universities and government (federal and jurisdictional) authorities.
- Data mining (particularly where a lack of funds for additional data gathering is present).
- Simple tools for undertaking first pass assessments of risk and vulnerability.
- Minimum requirements for monitoring SWI under different conditions (e.g. unconfined versus confined systems).

E.3 Group 3 Summary

Current and emerging management issues considered by Group 3 to be of greatest importance included:

- Increasing average demand and peak demands (e.g. holiday) for coastal groundwater.
- The implementation of management decisions.
- Management of groundwater on small islands.
- Management accounts for ecological concerns.
- The setting and meeting of groundwater level and quality targets.
- Preparing for rising sea levels.
- Changes in hydrology and groundwater quality.
- Urban greenfield developments.
- Energy development.

Knowledge and information gaps considered by Group 3 to be of greatest importance included:

- Understanding palaeo-systems (e.g. in the Darwin peri-urban area, NT).
- Best practice guidelines.
- Cross-scale and uncertainty understanding.
- Extent of offshore resources.
- SWI and climate change.
- Geochemical understanding of solute transport.
- Conceptual understanding and modelling of multi-layer aquifer and karst aquifer systems.

Group 3 considered the following priorities for future research to be of most importance:

- Mapping offshore aquifers using geophysics.
- Development of linked models allowing calibration with other data (e.g. chemistry and temperature) in a multidisciplinary approach.
- Long term case studies of coastal aquifers to assess their functioning and sustainable use in multidisciplinary and multi-agency collaborations.
- Understanding the ecological importance of groundwater in coastal areas.
- Understanding the water and salt balance of coastal aquifers (sources and sinks).
- Geochemistry, with a focus on the fate of nitrogen, phosphorous and other agrochemicals in coastal groundwater systems.
- Development of a national coastal aquifer typology framework.
- Develop national best-practice guidelines for the management of coastal aquifers.

E.4 Group 4 Summary

Current and emerging management issues considered by Group 4 to be of greatest importance included:

- Public awareness- groundwater management to protect freshwater resources.
- Saltwater-freshwater interface position, mobility and pumping impacts etc.
- Current monitoring for future issues such as subsidence, land use change and population pressure.

Knowledge and information gaps considered by Group 4 to be of greatest importance included:

- Ecosystem (especially marine) protection and knowledge of groundwater dependency. This will be important in establishing if or how SGD may be captured without impacting ecosystems.
- Managed aquifer recharge (MAR) and associated infrastructure (e.g. SWI barriers) and water quality issues.
- Other SWI mitigation and engineering measures.

Group 4 considered the following priorities for future research to be of most importance:

- Guidelines for SWI and coastal groundwater management.
- A depository for tools, procedures and modelling methods.
- Development of a toolkit of simple to complex methods of assessment that can be linked to the cost, risk and complexity of systems. This may partly focus on making existing methods cheaper (e.g. through smart phone remote sensing).
- Mapping biota and SGD occurrences to understand SGD dependent ecosystems.
- Engaging with marine and petroleum geologists to better understand off shore aquifers.
- Desalination of brackish groundwater extracted from coastal aquifers.