Subsurface groundwater ecosystems

A briefing report on the current knowledge, monitoring considerations and future plans for South Australia

South Australia

Subsurface groundwater ecosystems – a briefing report on the current knowledge, monitoring considerations and future plans for South Australia

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Front cover: Small blind crustacean (stygofauna) from the family Meltidae collected from a spring in the Flinders Ranges (R Leijs, South Australian Museum).

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Abbreviations

EP Act	Environment Protection Act 1993
EPA	South Australian Environment Protection Authority
GDE	Groundwater dependent ecosystem
MER	Monitoring, evaluation and reporting
SGDE	Subsurface groundwater dependent ecosystem

Glossary

amphipods	An order of crustaceans that are strongly laterally compressed and have different forms of appendages. They are commonly called ‘scuds’ or ‘sideswimmers’.
aquifer	An underground geological formation that contains sufficient water to supply wells and bores.
biodiversity	A broad term that is usually used to describe the number or range of different types of plants and animals present in an area, habitat or ecosystem.
groundwater	Water that occurs below the surface in the saturated soil or aquifer.
habitat	The physical environment that plants and animals normally live in.
isopods	An order of crustaceans that are typically flattened dorso-laterally and often called ‘pillbugs’.
macroinvertebrates	Animals without backbones (eg invertebrates) that are large enough to be seen by the naked eye (eg crustaceans and insects such as beetles).
metagenomics	The study of the genetic material recovered from environmental samples. The approach typically involves evaluating all the genes from all organisms present in a sample to provide a detailed understanding of the entire community in an aquifer.
microbe	Microscopic organisms that include bacteria, bacteria-like organisms, fungi and protozoans.
prokaryotes	Primitive, single-celled organisms such as bacteria and archaea that are characterised by the absence of a membrane-bound nucleus or organelles, and by DNA that is not organised into chromosomes.
stygofauna	Defined by the prefix ‘stygo’ that relates to underground, stygofauna are aquatic animals that live underground in water.
subterranean	This term refers to underground dwelling or sometimes specific habitat features such as caves or chambers.
troglofauna	Derived from the term ‘troglodyte’ meaning cave-dweller, troglofauna are air-breathing animals that live in caves, voids and spaces below the surface.

Summary

The EPA coordinates a statewide groundwater monitoring, evaluation and reporting (MER) program in South Australia. This program is under review and subsurface groundwater ecosystems are being considered as part of that review.

In recent years, groundwater around the world have been found to contain a large and unexpected biological diversity, to such an extent that many can be considered to support quite complex ecosystems. These ecosystems have been particularly well documented in Europe, although a growing list of Australian studies has shown similar patterns of biological diversity.

Groundwaters often contain a wide variety of specifically adapted invertebrate species (stygofauna) and microbial communities and these ecosystems are increasingly being recognised as providing significant ‘ecosystem services’ that in many cases probably enhances the value of groundwater.

This new scientific information is being incorporated into policy and environmental management contexts elsewhere in Australia, notably in New South Wales and Western Australia.

The state of knowledge with regard to subsurface groundwater ecosystems (SGDEs) in South Australia is limited, yet there are indications that the species distribution and biodiversity are similar to those found elsewhere. The EPA will be engaging with academia and other government agencies to improve the understanding of groundwater ecosystems, their ecosystem services, monitoring and evaluation design and potential policy directions.

1 Introduction

In South Australia, the Environment Protection Authority (EPA) is the lead government agency responsible for assessing the quality of the state's groundwater resources. To date, this assessment has consisted primarily of physical and chemical measurements, and comparing data against various guidelines to provide an assessment of condition, as part of a statewide water quality monitoring, evaluation and reporting (MER) program. However, a review of the groundwater MER program during 2010–13 identified the need for the EPA to develop a more detailed program that assists in understanding the risks and processes affecting groundwater quality, which should contribute towards better management of our groundwater resources.

This report presents the EPA's perspective on subsurface groundwater dependent ecosystems (SGDEs) or simply subsurface groundwater ecosystems. It discusses possible policy implications and outlines an approach that will generate new knowledge about the ecosystem services that are provided by stygofauna and microbial communities in groundwaters in South Australia.

Objectives of this report

- To summarise the current scientific understanding (international, interstate and South Australian) of subsurface groundwater ecosystems
- To briefly explain the policy and management implications of considering and assessing the condition of subsurface groundwater ecosystems
- To explain the EPA legislative responsibility to consider groundwater ecosystems within the general context of assessing aquatic environments
- To outline the direction the EPA will be taking to improve our understanding of subsurface groundwater ecosystems and the services provided by biological organisms.

2 The science of subsurface groundwater ecosystems

What is a subsurface groundwater ecosystem?

A subsurface (ie in-situ or subterranean) groundwater ecosystem is an aquatic ecosystem occurring below the surface of the ground that supports aquatic life and can be significantly altered by changing the chemistry, volume and/or temporal distribution of its groundwater supply (Tomlinson and Boulton 2010).

Historically, groundwaters have not been considered to have any significant ecosystem features due to their perceived low habitat variability and lack of primary production (ie plants) [Marmonier *et al* 1993]. However, from the 1970s onwards the general concept of ecosystem structure and function have been described in the scientific literature relating to subsurface aquatic ecology (see review by Gibert *et al* 1994), particularly as studies started to reveal the often complex array of specialised animals (eg crustaceans such as copepods, syncarids and amphipods, as well as worms, nematodes, rotifers, beetles and even blind species of fish and salamanders in some cave environments) and microbes (eg bacteria, bacteria-like organisms, protozoans, viruses and fungi) that inhabit many groundwater habitats (Danielopol *et al* 2000, Humphreys 2006, Danielopol and Griebler 2008, Griebler and Lueders 2009).

Subsurface groundwater ecosystems obviously differ from surface ecosystems in many ways, including both the types of biota present and the major processes that drive such habitats. The absence of light means that there are usually no primary producers (eg higher plants and algae) driving the food webs of subsurface groundwater ecosystems, although a small amount of primary production can occur through chemo-autotrophic bacteria and protozoa that derive their energy through chemical reactions with inorganic molecules such as hydrogen sulfide, elemental sulfur and ammonia under an anaerobic or low oxygen environment (Hose and Lategan 2011).

Groundwater ecosystems actually depend on the processing of carbon filtering down from the surface and metabolised by bacteria and fungi at the base of the aquifer food web (Boulton 2000). In some cases, conditions have enabled higher-order invertebrates to adapt to living in saturated sediments well below the surface, largely by grazing on the biofilms and particulate organic matter produced by microbial communities. This indicates that groundwater fauna may provide an important role for groundwater ecosystems because they prevent the small channels and pores from clogging by their feeding and burrowing habits, and through this action may also help to purify groundwater (eg Thulin and Hahn 2008 and references cited therein).

The term 'stygofauna' is typically used for those aquatic animals (mostly invertebrates) that live their entire lives below the surface in groundwater. They are broadly characterised by the following features: they lack eyes and are blind, whitish or translucent in appearance, with an elongate shape (adaptation to burrowing movement), low reproductive rate, generally long life-span and slow metabolic rate that makes them well adapted to low-oxygen, groundwater environments (Marmonier *et al* 1993; Thulin and Hahn 2008).

Sometimes additional animal groups are occasionally found in groundwaters that have eyes, are pigmented and typically been referred to in the scientific literature as either 'stygophilous' or 'stygoxenous' species. Stygophilous refers to widely found species that use both groundwater and surface waters as part of their life cycles, and stygoxenous include surface-dwelling species that are occasionally transported to groundwaters.

There are other groundwater species which are air-breathing species living in caves and voids called 'troglofauna'. They include arachnids, millipedes, beetles, crickets, cockroaches and many other invertebrate species. They are not considered further in this report which is focused only on subsurface groundwater ecosystems (eg aquifers). Similarly, the report does not consider other types of groundwater dependent ecosystems which rely on the surface expression of groundwater to sustain terrestrial and riparian plants (eg River Red Gums), wetlands or baseflows in streams (Tomlinson 2011).

Groundwater biodiversity

Biodiversity is a measure of species richness (number of different species) and is generally used to describe the range of living organisms occupying or present in an ecosystem. At the landscape level, species diversity in groundwater is typically high with hundreds to thousands of invertebrate species present, and comparable to the biodiversity of overlying surface waters (Thulin and Hahn 2008, Humphreys 2008 and Hose and Lategan 2011). However, at the individual borehole or site scale, species diversity is generally very low with only a few species (usually <5 species) present (Hose and Lategan 2011). Many species are considered to be very rare, possibly due to a combination of limited dispersal capabilities, fragmentation and isolation of most groundwater habitats, and the methods and approaches used to describe species, eg DNA molecular profiling (Hose and Lategan 2011).

Site diversity tends to increase with increasing availability of food and oxygen but this generally results in larger numbers of surface-dwelling species temporarily colonising affected waters and a decline in the presence and abundance of true stygofauna. This pattern has been incorporated into recent attempts to predict the diversity and health of groundwater communities, eg GW–Fauna–Index by Hahn (2006) and a tiered assessment framework by Korbel and Hose (2011).

The pattern relating to microbial assemblages and increasing levels of disturbance is similar with very low diversities and activities of attached organisms typically recorded from undisturbed aquifers, whereas organically enriched groundwaters generally have high diversities and activities of suspended organisms (Griebler and Lueders 2009, Griebler *et al* 2010 and Hose and Lategan 2011). These responses have been incorporated into a recently published health assessment by Korbel and Hose (2011).

Unlike stygofauna no evidence has been presented to date for the presence of unique, endemic groundwater microbes; all microbial organisms found so far are ubiquitously distributed across both surface and groundwater ecosystems (Danielopol and Griebler 2008).

Furthermore, a newly published metagenomic analysis of a metal contaminated groundwater microbial community indicates that human sources of contamination can significantly reduce microbial diversity at the site scale and alter key bio-geochemical functional processes such as denitrification, sulfate reduction, nitrification and methane oxidation, so identifying clear patterns relating to human disturbance will need careful assessment relative to well identified background or reference condition sites (Hemme *et al* 2010).

Groundwater food webs

Ecosystems are not simply a collection of organisms. They also comprise a complex set of interactions between organisms, as well as between organisms and their physical surroundings. The concept of an ecosystem food web has been described for surface water ecosystems dating back to the late 1800s and evidence has recently emerged that similar energy transfer via food webs also occurs in subterranean groundwater systems.

There are several lines of evidence for groundwater food webs including:

- stable isotope tracers passing through the whole food web, from microbial biofilms to grazers such as snails, amphipods and isopods, and finally to the top predators (another species of amphipod and a flatworm) [Simon *et al* 2003]
- protozoan grazers of prokaryotes recycling limiting nutrients through an ecosystem (Brad *et al* 2008)
- isopods and amphipods consuming natural and contaminant microbes sourced from a wastewater treatment plant effluent (Fenwick *et al* 2004).

Groundwater food webs can be substantial and to place this into a wider context, the study by Fenwick *et al* (2004) estimated that groundwater invertebrates alone, ignoring lower trophic levels, processed up to 28 tonnes of sediment per hectare per year.

Ecosystem services

There are several important processes or ecosystem services that may be provided by or occur within groundwater ecosystems that can impact on water quality and hydrological flow, influencing the extent to which groundwater can be used for various human uses. Table 1 summarises some of the more significant ecosystem services that have been described in the recent groundwater literature.

Table 1 Main types of groundwater ecosystem services [modified from Tomlinson and Boulton (2010) and Millennium Ecosystem Assessment (2005)]

Type of service	Examples
Maintenance of flow paths	The feeding and burrowing behaviour of stygofauna prevents the clogging of pores and maintains flow paths, which increase the ability for microbes to process contaminants present in groundwater.
Supporting role	Bioremediation which refers to the process, either naturally occurring or managed, of degrading or transforming contaminants by living organisms, usually by bacteria and fungi, into less toxic or non-toxic products (Chapelle 2000); ecosystem engineering; nutrient cycling; denitrification; provision of water quality indicators; and refugia for fauna.
Provisioning of water	Water available for drinking, irrigation, stock and industrial uses. For example, approximately 20% of the total consumptive water use in Australia is sourced from groundwater (Commonwealth of Australia 2007).
Regulating role	Aquifers assist in the mitigation of flooding and erosion of surface ecosystems by absorbing and storing rainfall and runoff (aquifer recharge). They can also supply surface ecosystems with base flows in stream environments and provide wetted habitats for wetlands and associated water-dependent vegetation.
Cultural and other broader roles	Maintenance of indigenous spiritual values, scientific values, and contributing to cave tourism.

The provisioning of water that is suitable for consumptive use is an obvious and tangible function, whereas the other services are not so readily apparent, although their significance can be just as important for human needs. Many species of stygofauna actively graze on the organic material in biofilms which can reduce groundwater clogging (Mattison *et al* 2002), an important consideration for the success of managed aquifer recharge and recovery projects around the world. Microbial action probably provides most of the water purification functions that occur as water infiltrates from the surface to groundwater ecosystems (Steube *et al* 2009); for instance, heterotrophic bacteria are able to remove nitrate from groundwater (Mermillod-Blondin *et al* 2005). Some of the other listed services are only indirectly related to biological or chemical processes and included to highlight the significant role of aquifers in enabling people to inhabit much of the land's surface (Brunke and Gonser 1997).

International studies

In-situ groundwater biodiversity has been documented most extensively from Europe (Humphreys 2006), with groundwater ecological studies going back to the mid-20th century. There is now abundant evidence that subterranean ecosystems are often as dynamic and complex as surface aquatic ecosystems (Gibert *et al* 1994 and Danielopol *et al* 2000).

Most groundwater biota are found relatively close to the surface, although specialised invertebrates can be found at depths as great as 1,000 m in Morocco (Essafi *et al* 1998) and 800 m in the United States (Longley 1992).

A large European project, covering groundwater aquifers in six countries, with several thousand groundwater sampling grids (each 500 km^2) was completed in 2004 and the results were summarised by Deharveng *et al* (2009). They recorded 930 obligate stygofauna species, and many had very restricted distributions and were endemic to one or only a few localities. Furthermore, the distribution of stygofauna was highly heterogeneous—only 26% of groundwater sampling grids contained stygofauna but the majority showed no evidence of the presence of any stygofauna using the methods employed during the project.

There are numerous international studies of groundwater fauna in the published literature that span taxonomy, evolutionary biology, biodiversity and distribution, among other topics, and it is clear that groundwater biology and ecology are now internationally entrenched concepts that are worthy of investigation. These ideas are described in the following list of references that may be of interest to some readers: Botosaneanu (1986); Danielopol (1989); Rouch and Danielopol (1997); Brad *et al* (2008); Des Chatelliers *et al* (2009); Galassi *et al* (2009a); Galassi *et al* (2009b); Griebler and Lueders (2009); Martin *et al* (2009).

Australian studies

Knowledge of Australian groundwater ecosystems was almost non-existent prior to the mid-1990s. However, in the last 15 years, numerous studies have generated a growing understanding that Australian groundwater biodiversity mirrors the overseas experience, and is possibly even more variable and rich in some locations.

Recent reviews of the literature describe Australian groundwater biodiversity, regional distribution and what is known about their water quality preferences (Humphreys 2008, Tomlinson and Boulton 2008 and Tomlinson and Boulton 2010). These studies have clearly shown that Australia is home to a wide variety of subterranean species and it is gaining international renown. At least 750 Australian stygofauna species have been found so far, which represents about 22% of the global total and highlights Australia as a groundwater biodiversity hot zone (Humphreys 2008).

Most groundwater ecosystem studies have been focused in Western Australia, particularly from areas such as the Pilbara and Yilgarn that are undergoing large-scale exploration and mining developments. However, surveys in recent years have also shown significant biological richness in alluvial, fractured rock, karstic and calcrete aquifers across the Northern Territory, New South Wales, Queensland and Tasmania (Tomlinson and Boulton 2008).

The spatial distributions of Australian stygofauna typically appear to be very restricted and they comprise many species that are considered to be connected to ancient lineages (Poore and Humphreys 1992, Humphreys 2000 and Jaume *et al* 2001).

South Australian studies

A research project titled *Development and implementation of biodiversity information for sustainable management of South Australian groundwater* was initiated in 2007 with the aim of describing stygofaunal and microbial diversity in South Australian aquifers [Australian Research Council (ARC) Linkage project LP 00776478]. Since that time, the project has sampled 547 sites, with approximately half containing stygofauna and all of them containing micro-organisms (Figure 1). Over 100 new stygofauna species have been identified so far, predominantly from the Mount Lofty Ranges and Flinders Ranges (see Leijs and Mitchell 2009[1]).

This project was the first of its type in South Australia and it has successfully added to the international and national knowledge that groundwater can provide a significant ecological habitat for a diverse range of biota.

1 www.scieng.flinders.edu.au/current/biology/msl/StygoNewsletter2.pdf

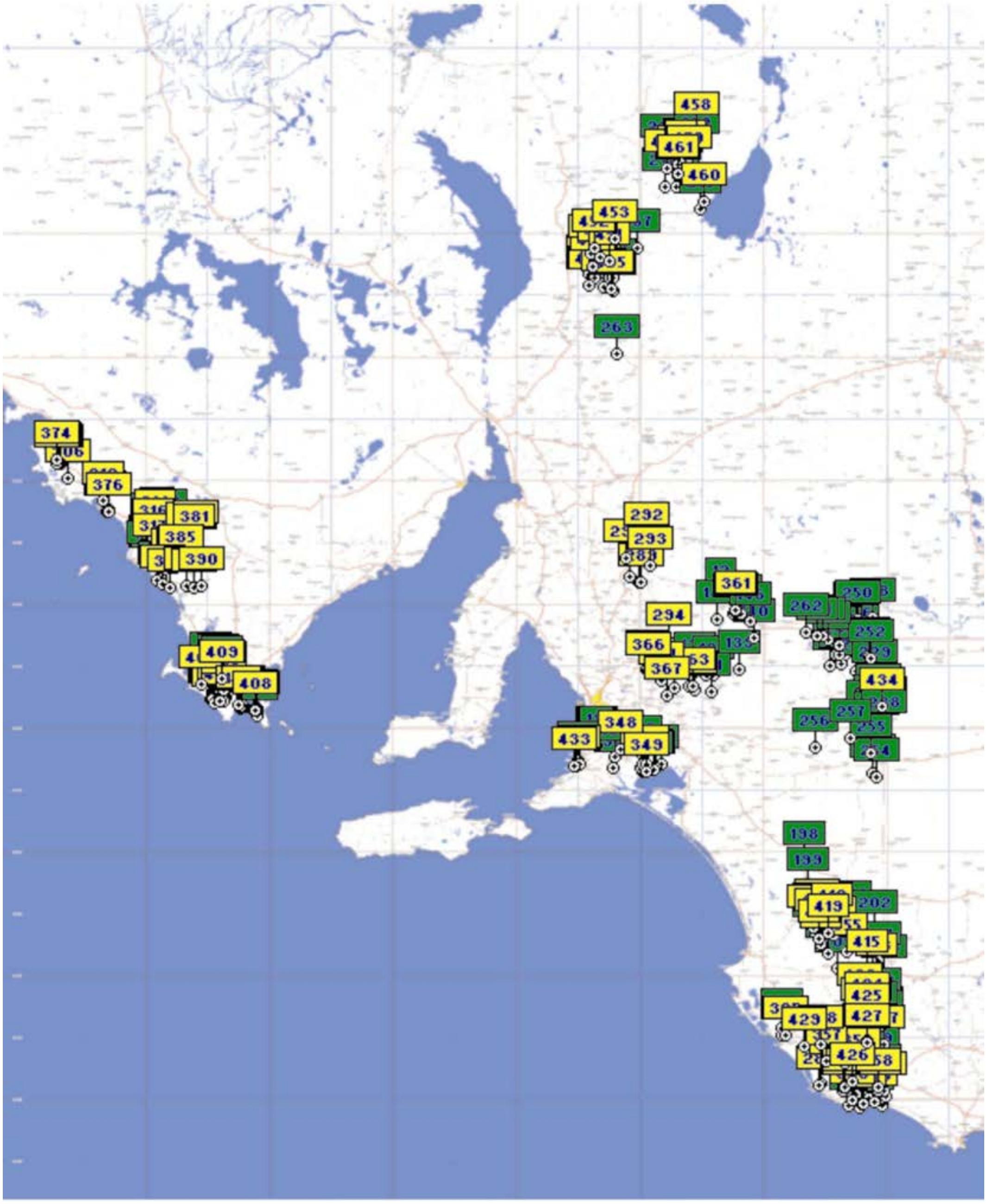

Figure 1 Localities sampled for groundwater fauna from 2007–09. Light-coloured (yellow) markers show localities with stygofauna and dark-coloured (green) markers show localities where fauna was absent. Stygofauna were present in approximately half of the 547 sites.

While the evidence supporting South Australian subsurface groundwater ecology is consistent with that found elsewhere, the knowledge base about its significance, the ecosystem services it provides and risks from human activities is still too limited and insufficient to establish policy, management criteria or to design monitoring and evaluation programs that report on the condition of different groundwaters over time in this state.

3 Management and policy implications of groundwater ecosystems

Having established that groundwater can and often does possess ecosystem values, some jurisdictions (interstate and overseas) have started to develop environmental management strategies and policies relating to the protection of groundwater from different types of development.

International and interstate

Internationally, the *European Union Water Framework Directive* established in 2000 and its daughter directive dealing with groundwater quality that was adopted in 2006 include the ecological objective to keep the living environment in a natural state (European Commission 2000, 2006). Significantly, the groundwater directive states that 'research should be conducted in order to provide better criteria for ensuring groundwater ecosystem quality and protection'.

New South Wales developed the *NSW State Groundwater Dependent Ecosystems Policy* as a guidance paper designed to manage the State's groundwater resources by sustaining environmental, social and economic uses (NSW Department of Land and Water Conservation 2002). This policy has been considered useful because it sets out principles and a general framework for the management of all groundwater dependent ecosystems (including surface and subsurface) but it lacks a detailed work plan (Tomlinson and Boulton 2008). More recent work has focused on developing a series of risk management guidelines to help manage land and water use activities that have the potential to affect groundwater dependent ecosystems[2].

The Western Australian EPA published a guideline for the assessment of environmental factors, including the possible presence of subterranean fauna, as part of any environmental impact assessments in that state (WA EPA 2003). The purpose of the guidance was to advise development proponents of the minimum requirements for environmental management with respect to subterranean fauna. Specifically, the guidance document stated that 'the proponent should show, to the satisfaction of the EPA, whether or not the proposal is likely to pose a threat to stygofauna' and that proponents should establish 'a management plan to conserve stygofauna within an impact area (or approval on the basis that likely groundwater impacts will not be significantly detrimental to stygofauna)'.

However, a review of the process used to assess the impacts of development on subterranean fauna identified a number of limitations and led the EPA to conclude they needed to adopt more of a strategic and risk-based approach to future assessments; a discussion paper was subsequently released for public comment in 2012 that examined the options for undertaking future assessments and how they may be applied (WA EPA 2012). This resulted in the release in March 2013 of a draft environmental assessment guideline to provide guidance on the relevant impact assessment methods to be used when subterranean fauna are likely to be present. The document is intended to provide proponents with clear requirements that would demonstrate whether any impacts associated with major developments would be acceptable or require further work, and also avoid uncertainty about the scope of information required to allow the timely assessment of any proposals[3].

Policy development with respect to groundwater ecosystems in Australia is clearly still in its infancy and awaiting a more detailed understanding of subterranean ecosystem characteristics, services and risks that threaten the maintenance of any existing environmental values. It has been suggested current environmental policy relating to groundwater dependent ecosystems (surface and subsurface) has generally been achieved through managing groundwater exploitation and recognising the functions and values of these ecosystems should be specifically built into future water allocation and management (MacKay 2006). This change in focus would potentially provide for the explicit protection of groundwater ecosystems and the services they provide in those groundwaters that are accepted and valued by society.

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2 www.water.nsw.gov.au/Water-management/Water-availability/Risk-assessment/Groundwater-dependent-ecosystems/Risk-assessment-guidelines-for-groundwater-dependent-ecosystems

3 www.epa.wa.gov.au/announcements/Pages/Draft_subterranean_fauna_EAG.aspx?pageID=29&url=announcements

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The evaluation of subsurface groundwater ecosystems is inherently difficult to achieve due to problems associated with sampling and developing a detailed understanding of the structure and functioning of each groundwater system. Recognising and valuing the ecosystem services they provide is probably going to be the most likely direction for policy development in this state, given the range of managed aquifer recharge and recovery schemes already in place and numerous proposed mining developments involving groundwater extraction or chemical treatment (eg in-situ mining).

The approach advocated by Murray *et al* (2006) could provide a useful valuation framework to assist in future policy development since it identifies and incorporates ecosystem services into an assessment of groundwater dependent ecosystems. This would obviously require further work to be conducted statewide to enable any such approach to be adopted and used in South Australia.

Gaining a more detailed knowledge of subsurface groundwater ecosystems and the services they provide is going to be a pre-requisite that would assist in developing any new policies relating to groundwaters in South Australia.

4 EPA responsibilities regarding groundwater monitoring and evaluation

Legislation driving monitoring activities

The legislated requirements of the EPA (or the Authority' in terms of monitoring are outlined in the *Environment Protection Act 1993* (EP Act). It provides clear direction in terms of monitoring the environment in South Australia in several different sections, including in the objects of the Act (clause 10), in the functions of the Authority (clause 13), under environmental authorisations requiring tests, monitoring or audits (clause 52), and in the preparation and publication of state of environment reports (clause 112).

Clause 10(1)(b) states that the objects of the Act are 'to ensure that all reasonable and practicable measures are taken to protect, restore and enhance the quality of the environment having regard to the principles of ecologically sustainable development'. In 10(1)(b)(vii) this is expanded to include: 'to provide for monitoring and reporting on environmental quality on a regular basis to ensure compliance with statutory requirements and the maintenance of a record of trends in environmental quality. The follow-on clause 10(1)(b)(viii) says 'to provide for reporting in the state of the environment on a periodic basis'.

In clause 13(1)(g), the Act states that one of the functions of the EPA is to 'institute or supervise environmental monitoring and evaluation programs'.

The EPA has carried out a groundwater monitoring and evaluation program in the past with the aim of characterising the water chemistry of groundwater in the state (Cugley 1995 and Goonan *et al* 2012). Within this context, the groundwater monitoring and evaluation program assisted in setting benchmarks for licensed industries to head towards in terms of minimising the impact from their operations on the environment. The results from the program also contributed towards setting the trigger values listed in south-central Australia in the national water quality guidelines (ANZECC & ARMCANZ 2000).

Groundwater monitoring, evaluation and reporting: broad design principles

All EPA water quality monitoring evaluation and reporting (MER) programs have been designed within a risk assessment framework with respect to the condition of waters (Goonan *et al* 2012). This provides the best possible information for water quality related decision support, both within the EPA and across government, industry and community sectors.

The risk assessment framework for MER design operates within a standard pressure–state–response model of environmental management:

- Pressures on the environment from human activities and natural disturbances
- Condition (or state) that prevails as a result of that pressure
- Management responses by government, industry and community to change the pressures and state of the environment.

Broadly speaking, the groundwater quality based EPA MER design for the state is based on the following:

1 Defining the significant aquifer systems in South Australia.

2 Identifying the key environmental values (purposes) that are relevant for each aquifer.

3 Developing a conceptual understanding of each aquifer system, with knowledge of its environmental values (generally based on interim values assigned by the EPA but could involve publicly agreed values set following a community consultation process). This understanding should incorporate the key processes (hydrological and geochemical) and pressures that are acting on an aquifer and how they are likely to affect groundwater condition.

4 Developing a set of indicators that include measures of the pressure, condition and management response for each aquifer.

5 Implementing a sampling design with a spatial coverage and frequency appropriate to the needs of each aquifer and suitable for data analysis purposes.

6 Developing a reporting approach that meets the information requirements of the EPA and other relevant stakeholders.

Historical groundwater monitoring and evaluation

To date, groundwater MER programs in South Australia have focused on environmental values pertaining to human uses of groundwater (drinking water, irrigation supplies, watering livestock and providing waters for mining and various other purposes). This has largely been based on:

1 Groundwater hydrology and salinity data coordinated through the Department for Environment, Water and Natural Resources

2 Groundwater physico-chemical data coordinated through the EPA.

There has also been an increasing monitoring effort applied in recent years in some regions to priority groundwaters that supply water to surface water dependent ecosystems. These include wetlands, creeks and other surface water environments that are in some way influenced by groundwater quantity and quality characteristics.

However, the groundwater MER program currently being developed for groundwater does not incorporate the concept of ecological condition.

Subsurface groundwater ecosystem environmental value

With the knowledge that groundwater usually contains a specially adapted suite of biota (particularly stygofauna and microbial communities) likely to perform important ecosystem services, it is obvious that many aquifers would possess at least some ecosystem environmental values.

This does not mean that all groundwater ecosystems should immediately be afforded a level of protection consistent with high conservation status. There will no doubt be a need for broad community debate about a mixture of environmental values and subsequent development of an appropriate sustainable management response to differences in the condition of groundwaters throughout the state.

There does, however, appear to be sufficient evidence to warrant extending the current groundwater MER program to include an assessment of the condition of each groundwater ecosystem. This will require further work to identify keystone species and key water quality indicators, develop models to turn biodiversity measures into condition ratings, and possibly also establish dose–response relationships between groundwater species and human-based toxicants likely to occur in South Australia.

5 Future plans for subsurface groundwater ecosystems in South Australia

The ARC Linkage project (Leijs and Mitchell 2009) has been successful in establishing the basis for recognising the importance of subsurface groundwater ecosystems in South Australia. Further work is now required to strengthen the knowledge gained since 2007 and demonstrate the significance of the ecosystem services provided by microbes and stygofauna and their responses to different types of disturbances that may affect groundwaters in South Australia.

To this end, the EPA has been collaborating with academic institutions and other government departments to improve the knowledge base for subsurface groundwater dependent ecosystems in previously unsampled aquifers, eg Yorke Peninsula (last sampled in 2011), Southern Fleurieu Peninsula, Northern Adelaide Plains, Kangaroo Island and Tatiara Prescribed Wells areas (last sampled in 2012); and explore the ability to integrate biological and chemical data into what would be a broad groundwater ecosystem condition assessment.

A new ARC Linkage project (LP130100508), funded by the Commonwealth from 2013–16, is developing quantitative ways to assess the state or health of groundwater ecosystems, using measures of ecosystem services, for the dual purposes of helping to ensure the sustainable extraction of water and the maintenance of these ecosystems into the near future.

This work is expected to provide important information about the biological significance and potential risks from human activities associated with each assessed groundwater environment. This should improve our understanding of the way groundwater ecosystems function and contribute new knowledge to help a wide range of government agencies, eg EPA, Department of Environment, Water and Natural Resources, Natural Resources Management Boards and potentially Primary Industries and Resources SA and local government) effectively manage the environmental values of different groundwaters in South Australia.

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