



Australian Government

Department of the Environment, Water, Heritage and the Arts

Geoscience Australia

Groundwater Quality in Australia and New Zealand: a literature review

MILESTONE REPORT

PREPARED BY GEOSCIENCE AUSTRALIA
FOR
THE AUSTRALIAN GOVERNMENT DEPARTMENT OF THE ENVIRONMENT, WATER,
HERITAGE AND THE ARTS

DECEMBER 2009

Baskaran Sundaram and Jane Coram

Department of Resources, Energy and Tourism

Minister for Resources and Energy: The Hon. Martin Ferguson, AM MP

Secretary: Mr John Pierce

Geoscience Australia

Chief Executive Officer: Dr Neil Williams PSM

© Commonwealth of Australia, 2010

This work is copyright. Apart from any fair dealings for the purpose of study, research, criticism, or review, as permitted under the *Copyright Act 1968*, no part may be reproduced by any process without written permission. Copyright is the responsibility of the Chief Executive Officer, Geoscience Australia. Requests and enquiries should be directed to the **Chief Executive Officer, Geoscience Australia, GPO Box 378 Canberra ACT 2601**.

Geoscience Australia has tried to make the information in this product as accurate as possible. However, it does not guarantee that the information is totally accurate or complete. Therefore, you should not solely rely on this information when making a commercial decision.

Contents

CONTENTS	III
EXECUTIVE SUMMARY	V
1. INTRODUCTION	1
1.1 AIMS AND SCOPE OF THE REVIEW	1
1.2 UNDERSTANDING GROUNDWATER	1
1.2.1 <i>What is groundwater?</i>	1
1.2.2 <i>Groundwater in Australia - availability</i>	2
1.2.3 <i>Groundwater Management Units</i>	3
1.2.4 <i>Groundwater in New Zealand</i>	3
1.2.5 <i>Groundwater Use in Australia</i>	3
1.2.6 <i>Groundwater as a resource</i>	4
1.2.7 <i>Groundwater extraction on water availability and quality</i>	5
1.2.8 <i>Connectivity – groundwater and surface water</i>	6
1.2.9 <i>Groundwater contamination</i>	6
1.3 GROUNDWATER QUALITY PROTECTION GUIDELINES	6
2. REVIEW OF CURRENT KNOWLEDGE ON GROUNDWATER QUALITY ISSUES	8
2.1 GROUNDWATER QUALITY	8
2.2 SALINITY	8
2.2.1 <i>Salinity in Australian groundwater</i>	8
2.2.2 <i>Salinity in New Zealand groundwater</i>	10
2.3 NUTRIENTS	11
2.3.1 <i>Nitrogen in Australian groundwater</i>	11
2.3.2 <i>Nitrogen in New Zealand groundwater</i>	13
2.4 PESTICIDES	14
2.4.1 <i>Pesticides in Australian groundwater</i>	14
2.4.2 <i>Pesticides in New Zealand groundwater</i>	15
2.5 TRACE ELEMENTS	16
2.5.1 <i>Trace elements in Australian groundwater</i>	16
2.5.2 <i>Trace elements in New Zealand groundwater</i>	17
2.6 OTHER CONTAMINANTS	18
2.7 ACIDITY	18
3. CURRENT AND EMERGING GROUNDWATER QUALITY ISSUES	20
3.1 GROUNDWATER – SURFACE WATER INTERACTION AND IMPLICATIONS FOR WATER QUALITY.....	20
3.2 GROUNDWATER DEPENDENT ECOSYSTEMS.....	22
3.2.1 <i>Surface Groundwater Dependent Systems</i>	22
3.2.2 <i>Subsurface Groundwater Dependent Systems</i>	22
3.2.3 <i>Impacts of groundwater quality on groundwater dependent ecosystems</i>	22
3.3 IMPACTS OF CLIMATE CHANGE ON GROUNDWATER QUALITY	24
4. MANAGEMENT RESPONSE FOR GROUNDWATER QUALITY PROTECTION	25
4.1 GROUNDWATER QUALITY PROTECTION STRATEGIES	25
4.1.1 <i>Bore Construction Considerations</i>	25
4.1.2 <i>Tools for Groundwater Quality Protection</i>	25
4.1.2.1 <i>Groundwater Vulnerability Mapping</i>	25
4.1.3 <i>Groundwater Quality Monitoring and Guidelines</i>	26
4.2 NATIONAL POLICIES AND PROGRAMS.....	27
4.3 STATE-WIDE POLICIES AND PROGRAMS	28

5. GROUNDWATER QUALITY GUIDELINES AND GROUNDWATER QUALITY ISSUES	29
5.1 GROUNDWATER QUALITY GUIDELINES.....	29
5.2 RELEVANCE OF GROUNDWATER QUALITY GUIDELINES AND GROUNDWATER QUALITY ISSUES..	29
6. SUMMARY OF RESULTS.....	30
6.1 SUMMARY OF RESULTS	30
6.2 RECOMMENDATIONS.....	32
7. REFERENCES.....	33

Executive Summary

This report provides a summary of a literature review that has been undertaken to assess the current and emerging groundwater quality issues in Australia and New Zealand. The review considered a range of groundwater quality issues and management implications. The review results presented in this report have been solicited mainly through existing publicly available web resources to enable a rapid overview of the various groundwater quality issues.

In Australia, states and territories agencies are responsible for groundwater quality monitoring. Quite often it is the Environmental Protection Agencies (EPA) that undertakes monitoring, but sometimes the Water departments have this role. The frequency of groundwater quality sample collection, the sampling methods, the number of sites sampled and the groundwater quality parameters measured vary between the states and territories. There is no consistent national program on groundwater quality monitoring in Australia to provide a national picture. Much of the groundwater quality monitoring has been short term and non-ongoing and it is difficult to ascertain clear long-term trends. In contrast, groundwater quality monitoring is routinely carried out by 15 regional councils and also by the National Groundwater Monitoring Programme (NGMP) in New Zealand.

Current groundwater quality issues in Australia

Salinity is a major groundwater quality issue in Australia followed by acidity, trace elements, nutrients and pesticides. Wetlands and surrounding native vegetation and aquatic ecosystem health are at high risk due to saline groundwater discharge in a number of locations. Coastal groundwater salinity and acidity is also becoming an issue in a number of locations and many wetlands are acidified. In general, nutrients and pesticides have been detected in groundwater in the most intensively farmed irrigated agriculture regions. Groundwater contamination by industrial organic and inorganic contaminants is largely associated with existing and former industrial areas, and occurs mainly in urbanised areas. The information available on groundwater quality issues is very limited; therefore it is difficult to ascertain clear trends on contamination levels or potential.

Current groundwater quality issues in New Zealand

In New Zealand, nitrates and trace elements (iron, manganese and arsenic) are the two major national groundwater quality issues. Nitrate contamination is a major issue in shallow groundwater due to anthropogenic sources. However, naturally elevated concentrations of iron, manganese and arsenic found in deeper groundwater. In some coastal aquifers, high salinity levels arise from seawater intrusion, which is a serious issue for groundwater resource management in some regions.

Emerging groundwater quality issues

The connectivity between streams and aquifers can have significant implications for water quality. Increased groundwater extraction has resulted in decreased groundwater quality and impacted on groundwater-dependent ecosystems (GDEs) and woodlands in a number of locations. Both surface and subsurface GDEs are threatened by over-extraction and poor groundwater quality in some areas. Particular groundwater quality threats include increases in salinity, trace elements, acidity and nitrates.

Climate change is likely to increase the stress on groundwater already under pressure from salinity, over-allocation and declining water quality. Shallow aquifers will be more vulnerable to changes in recharge, temperatures and sea level rise and ultimately affect water quality. Increased extraction and sea level rise will result in increased salinisation of coastal fresh groundwater, resulting in reduced water quality, possibly threatening GDEs associated with coastal aquifer.

Management responses

A broad range of national and state-wide policies and programs are currently implemented across all states and territories to protect groundwater from contamination. However, some of the current and emerging groundwater quality issues are not adequately addressed in the current national groundwater quality protection guidelines.

This literature review recommends that the current Guidelines for Groundwater Protection in Australia (ARMCANZ/ANZECC, 1995) be revised to incorporate current and emerging groundwater quality issues. Addressing these issues will ensure that the Guidelines remain relevant into the future, and provide a useful source of guidance for jurisdictions to effectively manage risks to groundwater quality.

1. Introduction

1.1 AIMS AND SCOPE OF THE REVIEW

The purpose of this review is to assess the existing published information relating to groundwater quality in Australia and New Zealand. Firstly, the review considered the range of relevant groundwater quality issues including: salinity, nutrients, pesticides, industrial contaminants and acidity; groundwater dependent ecosystems; and groundwater-surface water interactions. Secondly, the review considered the management implications and the relevance of the Guidelines for Groundwater Protection in Australia (ARMCANZ/ANZECC, 1995) to these issues. The information on various groundwater quality issues provided in this review report has been solicited mainly through publicly available web sources. While the collation of publicly available information from different sources is valuable, it needs to be noted that reports on groundwater quality are often unpublished and not publicly available.

1.2 UNDERSTANDING GROUNDWATER

1.2.1 What is groundwater?

Groundwater is the water stored underground in rock fractures and pores that lay beneath the surface of the earth (AWA, 2007). Groundwater is a vast and slow moving resource that greatly exceeds the volume of other available freshwater sources (although much groundwater is saline rather than fresh). Geological formations composed of permeable materials and capable of storing and yielding large quantities of water are called aquifers. Aquifers typically consist of gravel, sand, sandstone or fractured rocks.

There are two types of aquifers – unconfined and confined (Figure 1). An unconfined aquifer has no confining layers between the saturated zone and the land surface. Groundwater is in direct contact with the atmosphere through the open pore spaces of the overlying soil or rock. The water table forms the upper boundary of the unconfined aquifer. In an unconfined aquifer, the water level in a well rests at the water table. A confined aquifer is an aquifer that is overlain by a relatively impermeable layer of rock or substrate such as an aquitard. Confined aquifers are usually under pressure because they occur at depth from the surface and are compressed by the overlying confining rock and substrate. Groundwater that is under sufficient pressure to allow it to flow to the surface is referred to as artesian water.

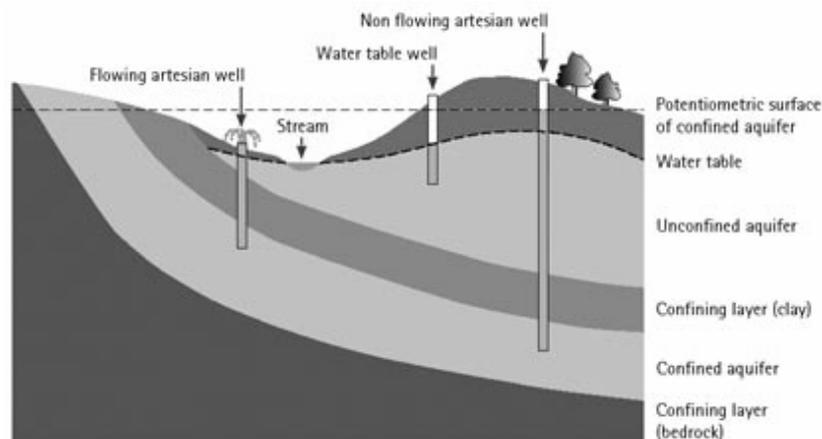


Figure 1: Types of aquifers (adapted from Plazinska, 2007)

1.2.2 Groundwater in Australia - availability

Groundwater is found in various aquifers in Australia. The geology of Australia is diverse, so there are different types of aquifers. Groundwater can be found beneath most land in Australia, however the resources are unevenly distributed and vary in quality and aquifer yield (Lau et al. 1987; Figure 2). In some regions groundwater provides for the majority of water needs, while other regions have no access to viable groundwater resources. Many of the potentially high-yielding aquifers represent a limited resource as they are located in arid and semi-arid areas of the continent and receive relatively low rates of natural recharge compared with the volume of water they store. Poor groundwater quality (high salt content) can be a major impediment to development of the resource in other areas. It has been estimated that the total volume of drinking quality groundwater that can be sustainably extracted is about 25 000 GL/year (NLWRA, 2001).

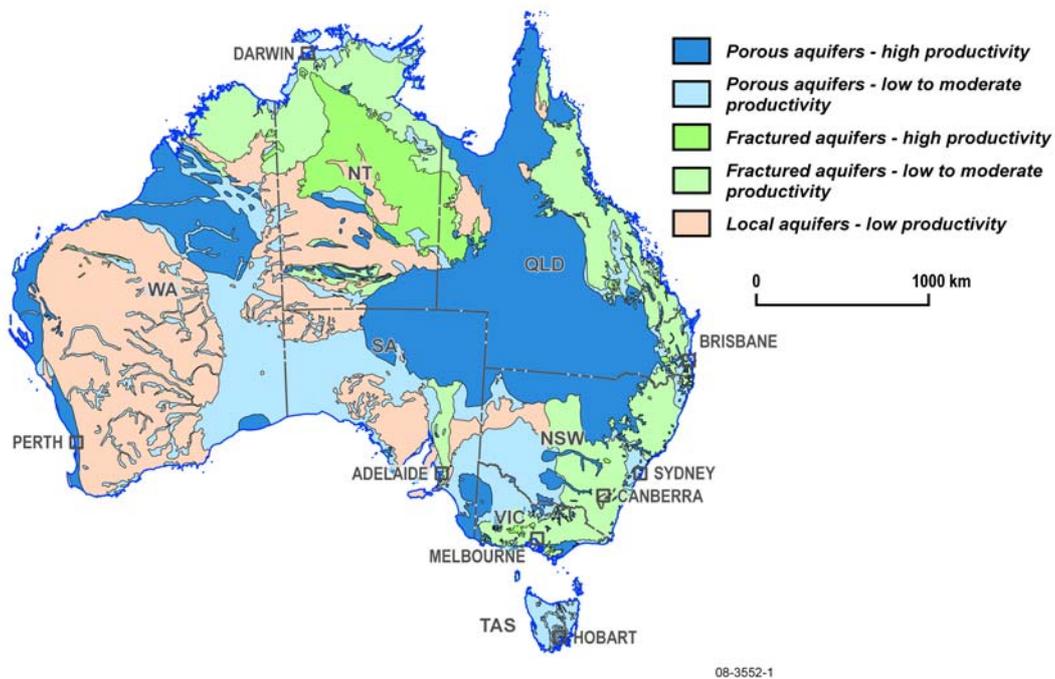


Figure 2: Groundwater basins in Australia

About 20% of all bores in Australia are in alluvial systems and they account for 60% of Australia’s groundwater extraction. Alluvial aquifers are a major source of irrigation, town, stock and domestic users. Due to their shallow and unconfined nature, alluvial aquifers are susceptible to contamination and pollution. Approximately 33% of all bores in Australia are in fractured systems, representing 10% of total groundwater extraction. The quality of groundwater is highly variable in fractured system. Groundwater contained in coastal aquifers represents a vital component of freshwater resources in Australia.

The Great Artesian Basin underlies arid and semi-arid regions across 1.7 million km² or one-fifth of Australia and stores over 60 000 000 GL of water (Habermehl, 2007). The Great Artesian Basin is one of the largest groundwater basins in the world. Eight of the ten provinces with the highest groundwater use are in eastern Australia. It covers 22% of the Australian continent and contains water that is up to two million years old. Artesian groundwater quality is good and suitable for domestic, town water supply and stock use.

1.2.3 Groundwater Management Units

Australia has 61 major groundwater provinces – areas of broad uniformity of hydrogeological and geological conditions with reasonably uniform water-bearing characteristics (predominantly sediment or fractured rock).

For the purposes of better and more efficient groundwater management, smaller groundwater management units (GMU) have been used. There are 422 GMUs in Australia. Groundwater management units are defined by state and territory governments and are based on areas where groundwater has a low salinity and high use or where groundwater is used in environmentally sensitive areas. Groundwater management units include one or more hydraulically connected aquifers; and one unit may lie below or above many other units. Since the states and territories undertake groundwater management, groundwater management units do not cross state or groundwater province boundaries. Areas outside of groundwater management units are called ‘unincorporated areas’.

1.2.4 Groundwater in New Zealand

All of the major aquifers in New Zealand are sedimentary (Thorpe, 1992). The aquifers in Canterbury, Hawke's Bay, Wellington, and Gisborne are composed of gravels and sands, mostly derived from greywacke boulders eroded into valleys by rivers and alluvial fans. In the Tasman District, many of the sedimentary aquifers have been derived from granitic material. Other important aquifers are composed of fractured basalts (Waikato, Auckland, Northland), pumice (Bay of Plenty), and limestones (Tasman), although these aquifers are minor in comparison to the alluvial gravel aquifers.

Many of the aquifers are unconfined and shallow (42%) or semi- confined (18%), but 40% are confined and deep. The average thickness of the aquifers is 19 m, and the average depth to the top of the aquifers is 38 m. However, 38% of the bores have water levels <10 m below the surface. The areal extent of most aquifers in New Zealand is relatively small on a world scale, but they are relatively complex due to the active tectonic regime in New Zealand (Thorpe, 1992). The Canterbury Plains gravel aquifer system is the largest in the country, and covers about 8000 km² and may be up to 500 m thick.

1.2.5 Groundwater Use in Australia

Groundwater makes up approximately 17% of Australia's accessible water resources and accounts for over 30% of our total water consumption (NWC, 2008). Groundwater use across Australia's States and Territories has increased 58% from 2600 GL to 4200 GL between 1983/84 to 1996/97 (NLWRA, 2001). The total groundwater use across Australia's States and the Territories in 2004/05 is estimated to have been 3500 GL/year (AWR 2005; Table 1). Groundwater use represents a greater fraction of total water use during dry periods. With the imposition of caps on surface water use and recent drought, current groundwater use is estimated to be around 6000 - 8000 GL/year. This increase in groundwater use will have greater impact on groundwater quality.

In the Murray-Darling Basin (MDB) the introduction of a surface water Cap in 1995 has caused many communities to switch to using groundwater for irrigation (MDBC, 2003). Over large areas of the MDB, groundwater levels have declined during the last decade due to the combined effect of the drought and excessive groundwater pumping (MDBC, 2004). The estimated groundwater use for the MDB is 1832 GL/year during 2004/05 and future groundwater extraction could double (according to current groundwater management plans) and reach 3956 GL/year by 2030 (CSIRO, 2008). Available data suggest that, there are now large areas of MDB where groundwater is being used above a sustainable rate; groundwater levels are declining as a consequence of over use and drought.

Table 1: Mean annual groundwater use (GL) in 1983-84, 1996-97 and 2004-05

STATE OR TERRITORY	TOTAL GROUNDWATER USE (GL) 1983-84 ¹	TOTAL GROUNDWATER USE (GL) 1996/97 ¹	TOTAL GROUNDWATER USE (GL) 2004-05 ²
New South Wales	318	1008	800
Victoria	206	622	401
Queensland	1121	831	222 ³
Western Australia	373	1138	1501
South Australia	542	419	518
Tasmania	9	20	21
Northern territory	65	128	65
ACT	n/a	5	0.7
Total	2634	4171	3528.7

¹Source: NLWRA (2001)

²Source: AWR (2005)

³only metered bores in Queensland GMUs

1.2.6 Groundwater as a resource

Groundwater resources support many urban, rural and remote communities around Australia. Groundwater has provided great benefits for many communities in recent decades through its direct use as a drinking water source, for irrigated agriculture, industrial development and, indirectly, through ecosystem and stream flow maintenance. About 32% of groundwater is extracted for urban-industrial use, 51% for irrigation and 17% for stock watering and rural use but this varies by state (Ball et al. 2001). There is a considerable variation in groundwater usage between states and territories. For example, South Australia, New South Wales and Victoria use more than 60% of extracted groundwater for irrigation, whereas Western Australia uses 72% for urban and industrial purposes. Queensland uses a third of groundwater for rural stock and domestic uses.

Australian capital cities and some of the major urban centres also benefit from groundwater. In recent years, groundwater use in major urban centres and cities increased significantly due to reduced surface water availability. Figure 3 shows the amount of surface water and groundwater used for some of Australia's capital cities (AWR, 2005). Figure 3 highlights the importance of groundwater to the Perth urban centre where groundwater accounts for about 80% of all the water used. Other capital cities such as Sydney, Darwin and Adelaide also uses groundwater that account for 25, 32 and 20% respectively, of the total water used.

Most of the remote communities of Australia are in the arid and semi-arid regions and are heavily reliant on groundwater resource for their survival. However, limited information is available on the groundwater quality, recharge, or on the total volumes being extracted by the dependant communities and other users. Groundwater supply security in some remote communities has been compromised by increases in salinity due to drought. In Australia up to 4 million people is depending totally or partially on groundwater for domestic water supplies (AWA, 2007). The Northern Territory and Western Australia have the highest proportions of distributed water originating from groundwater resources, making up approximately 70% of their total water use (AWA, 2007).

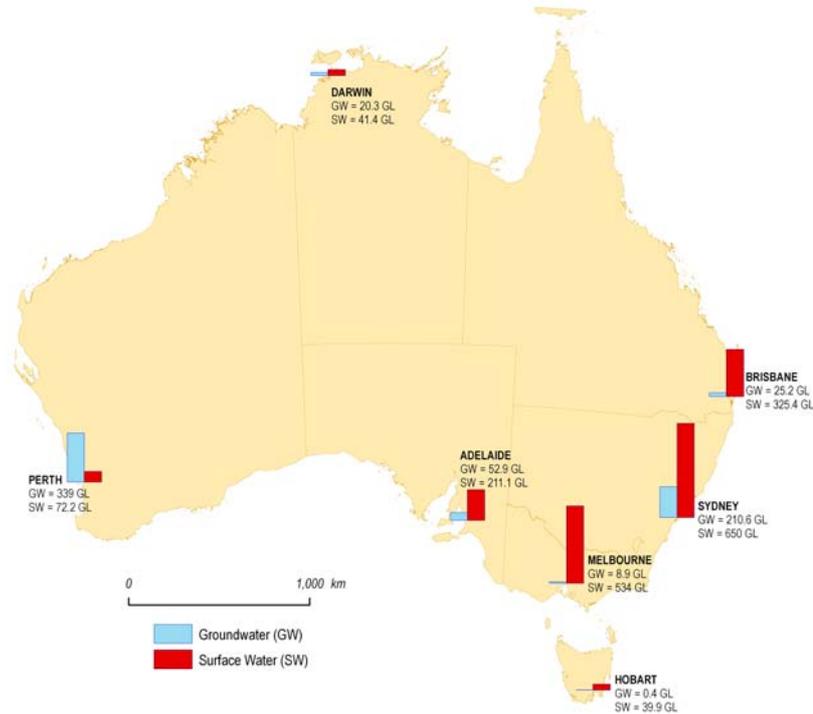


Figure 3: Groundwater and surface water use in some major capital cities of Australia

The reliance on groundwater for irrigation and public water supply in the United States and many European countries is even higher than in Australia. For example, groundwater is an important source of drinking water for every state in the United States. During 2000, 85% of the population in the United States obtained drinking water from public supplies and the percentage of groundwater use for public supply is about 40% (Hutson et al., 2004). In many European Union (EU) countries groundwater is the main source for public supply and the groundwater use for public supply in different EU countries ranges from 21 to 100% (Krinner et al., 1999).

1.2.7 Groundwater extraction on water availability and quality

Groundwater is increasingly being seen as an alternative source to surface water supplies in recent years in Australia and New Zealand. When groundwater extraction from the aquifer exceeds the average long-term recharge from rainfall, groundwater levels will steadily decline. If groundwater levels fall, the water availability and quality may be affected. For example:

- Lower yields mean less water is available for domestic water supply, stock drinking water, irrigation and other uses.
- Springs, wetlands, streams and rivers that are fed by groundwater may partially or completely dry up, causing adverse ecological effects; whole ecosystems with their diverse animal and plant life may be destroyed.
- Low flows of rivers may not be sufficient for proper dilution of discharged wastewater, resulting in greater surface water pollution.
- An increased threat of saltwater intrusion into fresh groundwater supplies in coastal regions.
- Deterioration of groundwater quality.

To avoid irreversible damage to groundwater systems the extraction amount for any aquifer should be established based on the long-term sustainable yield assessment, i.e. a volume of groundwater that can be extracted annually from a groundwater basin without causing adverse effects.

1.2.8 Connectivity – groundwater and surface water

Groundwater and surface water are usually interconnected and interchangeable resources in many regions of Australia (Brodie et al. 2007). In many cases it is actually the same water: groundwater becomes surface water, and surface water becomes groundwater. Nearly all surface water features (streams, lakes, wetlands and estuaries) interact with groundwater. As a result, withdrawal of water from streams can deplete groundwater or conversely, extraction of groundwater can deplete water in streams, lakes or wetlands. Contamination of surface water can cause degradation of groundwater quality; and, conversely, contamination of groundwater can degrade surface water (Figure 4).

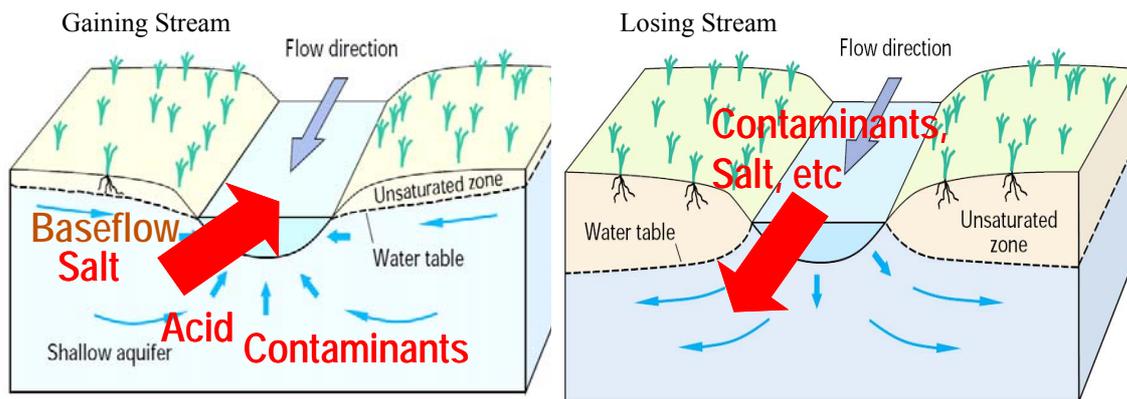


Figure 4: Groundwater-surface water interaction and water quality (source: Winter et al.1998)

1.2.9 Groundwater contamination

Contamination of groundwater may be associated with specific point sources or may occur over a wide area (non-point source). The sources of groundwater contamination are numerous and diverse, including: improper disposal, use and storage of chemicals; poor installation and maintenance of septic tanks; landfills; leaking or poorly located storage lagoons used by industries, farms, mining operations, oil and gas producers; over and improper application of fertilisers and pesticides; land application of sludges and wastewater or urban runoff. Contaminants can be extremely hard to remediate, with pollution often resulting in permanent damage to the aquifer. It is better to prevent groundwater contamination than risk contamination and subsequently spend large resources to clean it up.

Point source contamination of groundwater is generally controlled by Environmental Protection Agencies (EPA) in the states and territories in Australia. Great improvements in groundwater pollution prevention have occurred in the last few decades, but diffuse source contamination (for example, pesticides, fertilisers, and septic tanks) remains poorly controlled in some jurisdictions (Harris, 2006). In New Zealand, regional councils, through the Resource Management Act, are responsible for the management of groundwater resources.

1.3 GROUNDWATER QUALITY PROTECTION GUIDELINES

The National Water Quality Management Strategy (NWQMS) provides national policies, guidelines, information and tools to help government and communities manage water resources to meet current and future needs. The Guidelines for Groundwater Protection in Australia were published in 1995 by ARMCANZ and ANZECC. The primary purpose of the Groundwater Guidelines was to provide a national framework for protecting groundwater from contamination in Australia. Many jurisdictions have used the Groundwater Guidelines to develop groundwater policy and regulations designed to

improve the management of groundwater resources. Currently, the 1995 Groundwater Protection Guidelines is the only national document specifically covering groundwater quality protection.

“The goal of groundwater protection is to protect the groundwater resources of the nation so that these resources can support their identified beneficial uses and values in an economically, socially, and environmentally sustainable and acceptable manner” (ARMCANZ/ANZECC, 1995).

The guidelines for groundwater quality protection recommend identification of existing or potential beneficial use for each groundwater resource that will assist in determining the level of protection afforded to that resource. The classification of beneficial use will depend both on the quality and the potential values of that groundwater (ARMCANZ/ANZECC, 1995). It is noted that potential uses may not be presently evident or may change with technological or economic developments and that this is not explicitly considered in current groundwater management planning.

Environmental values are particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health and which require protection from the effects of pollution, waste discharges and deposits (ANZECC/ARMCANZ, 2000). The environmental values of groundwater that are recognised in these guidelines are:

- aquatic ecosystems,
- primary industries (irrigation and general water uses, stock drinking water, aquaculture and human consumption of aquatic foods),
- recreation and aesthetics,
- drinking water,
- industrial water (no water quality guidelines are provided for this environmental value), and
- cultural and spiritual values.

2. Review of Current Knowledge on Groundwater Quality Issues

2.1 GROUNDWATER QUALITY

The chemical quality of groundwater affects its suitability for different uses. Poor management of groundwater can cause many significant water quality problems. Major threats to groundwater quality include: increased levels of salinity, nutrients, acidity, trace elements, pesticides and other industrial contaminants. These can occur either as the result of direct contamination or through changes in groundwater behaviour as a result of over-extraction or reduced groundwater recharge. Knowledge of the present status of groundwater quality and its improvement or degradation with time is a key fundamental to improving water quality management. There is, however, a paucity of information available on the quality of Australia's groundwater resources. The available information is summarised and presented below.

2.2 SALINITY

2.2.1 Salinity in Australian groundwater

Salinity is a major groundwater quality issue in Australia. Salts are a natural component of the Australian landscape and are derived from different sources. Salinisation of groundwater includes three processes: dryland salinity, irrigation salinity and seawater intrusion. A review of the salinity status of groundwater revealed that approximately 72% of Australia's readily accessible groundwater supply is suitable for drinking water (NLWRA, 2001; Table 2). The limited availability of data and the intensity of monitoring coverage limit comprehensiveness of the groundwater salinity assessment done for the National Land and Water Resources Audit (NLWRA) in 2001. There is no comprehensive assessment of the status of national groundwater salinity since this report.

Table 2: Groundwater sustainable yield (GL) by salinity status (mg/L)
(adapted from NLWRA, 2001)

STATES	<500	500-1000	1000-1500	1500-3000	3000-5000	5000-14000	>14000	TOTAL
NSW	554	4237	129	790	480	-	-	6189
VIC	302	422	244	367	207	1377	797	3717
QLD	1422	1030	113	160	35	23	-	2784
WA	514	1162	1150	1500	766	841	371	6304
SA	-	290	709	102	21	25	-	1146
TAS	1585	767	-	178	-	-	-	2531
NT	5785	186	324	141	5	-	-	6441
ACT	103	-	-	-	-	-	-	103

Shallow groundwater salinity is highly variable in Western Australia (WA) and most is naturally brackish to saline (Figure 5). Pockets of shallow fresh groundwater are found along the Swan Coastal Plain, the South West corner of the State and parts of the Pilbara and Kimberley. Groundwater salinity tends to be stable in the last few years, except where catchment hydrology has been altered or high rates of water extraction occur in WA (EPA WA, 2007). Shallow groundwater levels across the South West agricultural zone are generally rising and no trends of decreasing groundwater have been detected on a broad scale (Ghuri, 2004). Irrigation salinity is also a problem in some irrigated areas of the southern Swan Coastal Plain, from Gingin to Dunsborough and also in the Ord River irrigation area (Smith et al. 2007).



Figure 5: Groundwater salinity of shallow aquifers across Western Australia
(adapted from EPA WA, 2007)

In New South Wales (NSW), the salinity of groundwater is highly variable and there are many areas where groundwater is not suitable for consumption or irrigation (DEC NSW, 2006). Activities such as over-pumping can result in the salinisation of good quality groundwater resources. Many areas of south-western NSW are underlain by sediments of marine origin which yield regionally saline groundwater (DEC NSW, 2006).

Groundwater salinity in Queensland (QLD) may be increasing in some areas, but decreasing in others. For example, coastal areas of the Burdekin as well as parts of the other larger catchments such as the Fitzroy, Burnett, Condamine and Lockyer groundwater salinity is rated poor to moderate for general use, although moderate to good for irrigation (EPA QLD, 2007). Groundwater salinity is increasing in coastal catchments due to salt water intrusion. Groundwater salinity in the Moonie, Border Rivers (west of Goondiwindi) and Lower Balonne has significant, though variable salinity (Biggs et al. 2005). Salinity induced by irrigation (horticulture) and leaky dams was observed at many sites in the Granite Belt in southern Queensland (Biggs et al. 2005).

Groundwater salinity in the South East of South Australia, Northern Adelaide Plains, Adelaide Plains, Barossa Valley, Willunga Basin and Eyre Peninsula are rated as poor for salinity (EPA SA, 2008). Groundwater salinity has increased in some regions due to continued pressure from heavy extractions and poor irrigation practices in SA. A broad assessment of groundwater monitoring across SA during the period 2002-07 indicated that 44% of samples exceeded the drinking water quality criteria.

Groundwater salinity is a major issue in Victoria and approximately 240,000 of land are known to be affected by discharge of saline groundwater (Vic SoE, 2008). Salinisation of surface water is also an

important consequence of rising saline groundwater. Saline groundwater may emerge in sensitive areas of remnant native vegetation, arable land, under towns or directly into rivers and streams. Wetlands and surrounding native vegetation is particularly at risk because of their low elevation coincides with saline groundwater discharge areas. Victoria has 11 Ramsar wetland sites (DSE, 2008) and five of these (45%) may be at risk of damage from salinity and shallow saline groundwater by 2020 (Table 3).

Table 3: Victoria assets at risk of damage from salinity and shallow saline groundwater (Adapted from NLWRA, 2001)

ASSEST AT RISK	YEAR	
	2000	2020
Agricultural land (ha)	555,000	1,170,000
Perennial vegetation (ha)	6,200	11,830
Length of stream or perimeter of wetlands (km)	10,121	18,146
Ramsar wetlands (number)	4	5
Towns (number)	10	21
Roads (km)	3,896	8,054
Railway (km)	131	303

Wetland habitats and species are at particular risk from salinity as a result of intrusion of saline groundwater. Wetlands in Goulburn Broken and Corangamite catchments are considered to be most at risk. Many rare or threatened species occur in areas that have or are predicted to develop shallow groundwater tables in Victoria and these species will come under further pressure as a result of loss or change of habitat due to salinity (Vic SoE, 2008).

2.2.2 Salinity in New Zealand groundwater

Salinity is not a major issue in New Zealand aquifers. The relevant aesthetic guideline values are exceeded at only 2–4% of all sites tested for groundwater during 2006 (Ministry for the Environment, 2007). High-salinity groundwaters are found in certain regions, notably Gisborne but also in northern Hawke’s Bay, central Manawatu, south Wairarapa, Auckland (especially deep aquifers), and south Canterbury around Oamaru (Figure 6). In some coastal aquifers high salinity arises from seawater intrusion is a serious issue in regions such as Northland, Bay of Plenty and Horowhenua (Ministry for the Environment, 2007).

Significant increasing and decreasing trends in salinity are detectable at roughly equal proportions of monitoring sites (16.5% and 14.2%, respectively) during 1995-2006. Sites with increasing trends in salinity are found in most areas of New Zealand, especially Waikato, Southland and Wellington (Ministry for the Environment, 2007).

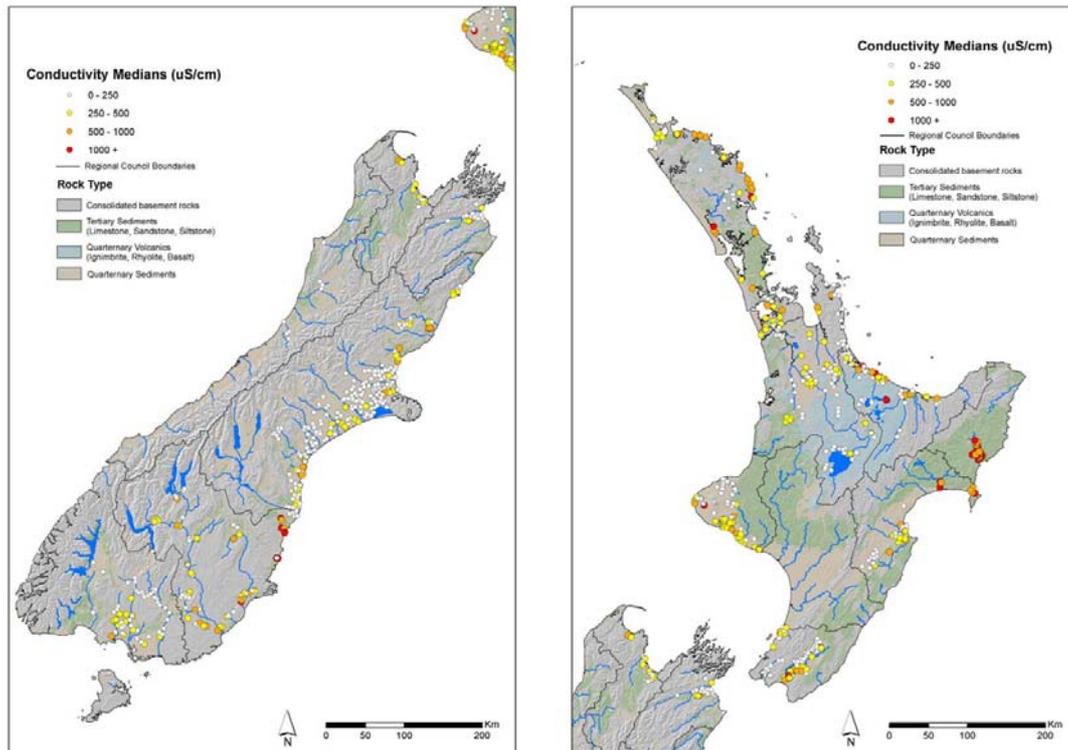


Figure 6: Median salinity in New Zealand groundwater
(adapted from Ministry for the Environment, 2007)

2.3 NUTRIENTS

2.3.1 Nitrogen in Australian groundwater

Among the nutrients nitrate is perhaps the most widespread contaminant in Australian and New Zealand groundwater. Nitrate is highly soluble and very mobile, which facilitates plant uptake, but also makes it highly susceptible to leaching to groundwater. There are many sources of nitrate, natural and anthropogenic, that can contribute to groundwater contamination. The anthropogenic sources includes intensive agriculture (nitrogen-containing fertilisers), dairy and sewage effluent.

Data on nitrogen in Australian groundwater is very limited. As the nitrate concentration map shows (Figure 7) there is a patchy occurrence of nitrate detections in groundwater in some areas of Australia. The major sources of data produced in Figure 7 are generally related to specific research and investigation projects from 1995-2008 (eg. Watkins et al. 1998; Baskaran et al. 2001; Rasiyah et al. 2005; Smith et al. 2007). Typically these data sets are restricted to the length and scope of the project. There is no consistent program of nitrate monitoring of groundwater throughout most parts of Australia.

A key source of nitrate concentration data is the one-off analysis of groundwater samples obtained from newly constructed bores. Although not providing an indication of any temporal variability, this information continues to provide data on the spatial distribution of nitrate contamination. This is particularly the case for broad scale diffuse source monitoring. This contrast with smaller scale point source or multiple point source plumes which can be more readily identified by more targeted observation bore networks.

In some states there is routine monitoring of town water supply bores for health purposes for nitrate and a range of other parameters. The length of record varies considerably although these data sets are not publicly available.

The nitrate-N concentrations range from 0.001 to 29 mg/L. Although the median nitrate-N concentration was low, groundwater from some locations recorded elevated concentrations. In general the groundwater which had elevated nitrate-N concentrations were surrounded by intensive agriculture that has repeated nitrogenous fertiliser application over the years resulted in high concentrations of nitrate-N.

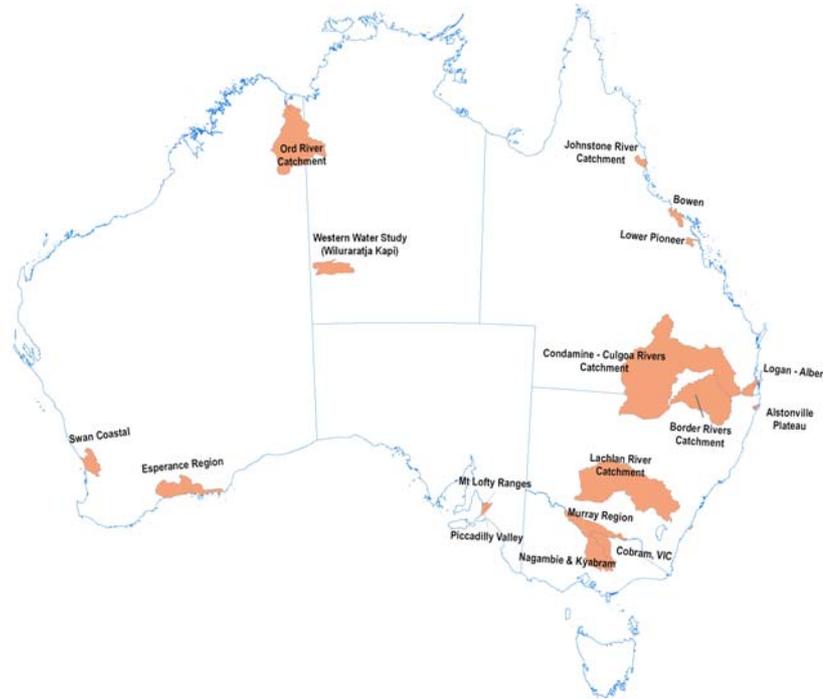


Figure 7: Areas of Australia where Nitrate-N have been detected in groundwater

Nitrate-N concentrations in groundwater exceeded the Drinking Water Health Guideline Value of 11.3 mg/L-N (NHMRC/NRMMC, 2004) in some areas. Some groundwater also exceeded the long term trigger value (5 mg/L) for nitrate in irrigation water (ANZECC/ARMCANZ, 2000). However, these are the results of one limited sampling program at a single point in time in terms of weather conditions, growing season and fertiliser application. Vulnerability of groundwater to nitrate contamination depends on a combination of factors such as geology, soil, land use, land and water management practices and hydrology. It is not appropriate to assume that groundwater in the study area is not vulnerable to nutrient contamination, given suitable conditions. Studies have shown that nutrient concentrations vary seasonally, largely in response to changes in precipitation and stream flow and in differences in time since fertiliser application.

A broad assessment of groundwater monitoring across SA state during the period 2002-07 shows that in most cases, groundwater was rated as poor for nitrate in the South East, Northern Adelaide Plains, Adelaide Plains, Barossa Valley, Willunga Basin and Eyre Peninsula (EPA SA, 2008). Nitrogen levels sometimes exceeded ecosystem protection guidelines in the irrigated catchments such as the Burdekin, Fitzroy, Burnett, Condamine and Lockyer in QLD, but did not exceed health guidelines (EPA QLD, 2007).

Time series data are usually inadequate to establish seasonal and other variability in groundwater nitrate contamination. This is particularly the case for rural areas outside key groundwater supply areas. There is no systematic approach to data collection of nitrate across Australia. The absence of

regularly collected long-term data makes it difficult to determine long-term patterns in nitrate contamination and does not allow adequate interpretation of the rate of any increase or decrease in nitrate concentrations.

2.3.2 Nitrogen in New Zealand groundwater

Nitrate contamination is widespread in shallow unconfined aquifers in New Zealand. The calculated national median for nitrate-N in groundwater during 2006 is 1.3 mg/L (Ministry for the Environment, 2007). Previous studies have provided estimates of 0.3–1.0 mg/L for median nitrate-N concentration in unaffected groundwater in New Zealand (Burden, 1982; Morgenstern et al. 2004; Daughney and Reeves, 2005). Of the 956 sites at which a site-specific median could be calculated, 4.9% exceed the Maximum Acceptable Value (MAV) based on the Drinking Water Standards for New Zealand (DWSNZ) (11.3 mg/L), 10.3% exceed the trigger value (TV) for ecosystem protection based on the ANZECC guidelines (7.2 mg/L), and none exceed the ANZECC TV for stock drinking-water (400 mg/L).

A previous study defined a threshold value of > 1.6 mg/L (about twice the estimated background, or around quarter of the TV) as a probable indicator of human influence (Daughney and Reeves, 2005). The same study defined a threshold of > 3.5 mg/L (about four times the estimated background, or around half the TV) as an almost certain indicator of human influence. The elevated nitrate-N concentrations in groundwater are due to anthropogenic sources. The sites with elevated nitrate-N concentrations are found in many regions of New Zealand, especially Waikato, southern Manawatu–Wanganui (Horowhenua), Canterbury and Southland (Figure 8).

Significant increasing trends in nitrate-N concentration are detectable at around 13% of the monitoring sites considered for the national study during 1995-2006 (Ministry for the Environment, 2007). Significant decreasing trends in nitrate-N concentration are detectable at a roughly equivalent percentage of monitoring sites. In agreement with the trend-based categorisation, sites with detectable trends in nitrate-N are found in all regions of the country, especially in Waikato and Southland, but also in regions such as the West Coast, where water quality is generally good, and Gisborne, where many groundwater systems are oxygen-poor and would not be expected to contain significant concentrations of nitrate-N (Ministry for the Environment, 2007).

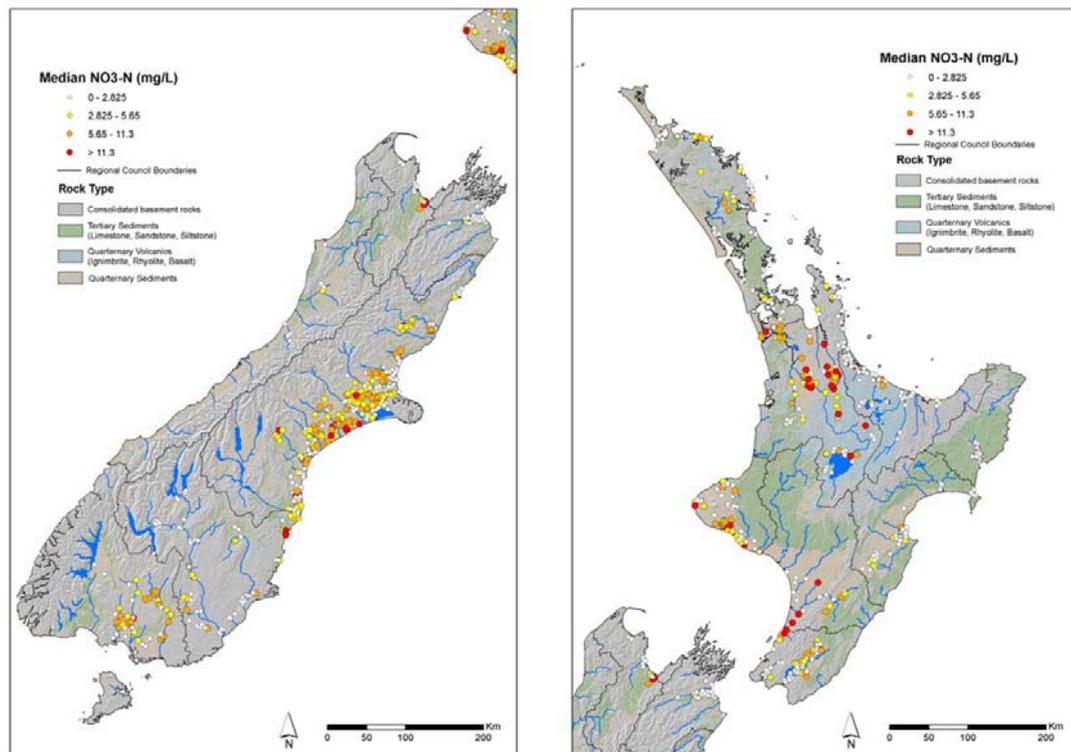


Figure 8: Median nitrate-N concentrations in New Zealand groundwater
(adapted from Ministry for the Environment, 2007)

2.4 PESTICIDES

2.4.1 Pesticides in Australian groundwater

Data on pesticides in Australian groundwater are very limited. However, results from various studies conducted across Australia during 1996-2007 showed detections for 9 herbicides along with 1 degradation product and two insecticides (Figure 9) (Watkins and Bauld, 1999; Please et al. 2000; CBWC, 2002 and Smith et al. 2007). More recently in 2009, the Department of Primary Industries, Parks, Water and Environment (DPIPWE) in Tasmania conducted Ground Water Monitoring across Tasmania. This involved a one off sample being taken from 58 bores and tested for 19 pesticides. The results showed detections for 4 herbicides (2,4-D, atrazine, MCPA and hexazinone) in four locations (<http://www.dpiw.tas.gov.au/inter.nsf/webpages/cart-69stwk?open#dd>). The majority of compounds detected in groundwater were herbicides that are most frequently used to control weeds either in various crops or irrigation channels (Tomlin, 1997). Atrazine, desethyl atrazine, ametryn, bromacil, fluometuron, diuron, hexazinone, metolachlor, prometry and simazine herbicides were detected along with 2 insecticides (chlordane and chlorpyrifos) in one or more groundwaters at low concentrations. Among the pesticides, atrazine has been detected in the majority of studies. Although pesticide concentrations versus depth to water table showed no statistical relationship, 50% of pesticide samples were found in relatively shallow groundwater.

The concentrations of pesticides and number of detections in groundwater varied with locations. In general, herbicide use is likely to be moderate to high in irrigated agriculture areas; furthermore, soil and geologic conditions would tend to favour rapid movement of herbicides to groundwater. The majority of the herbicides detected in groundwater from various locations can be characterised as highly mobile, allowing them to move rapidly to the water table, and with moderate to long environmental half-lives, enabling them to persist in the subsurface environment (USGS, 1999; CBWC, 2002). The pesticides detected in Australian groundwater were below the Australian Drinking Water Health Guidelines (NHMRC/NRMMC, 2004).

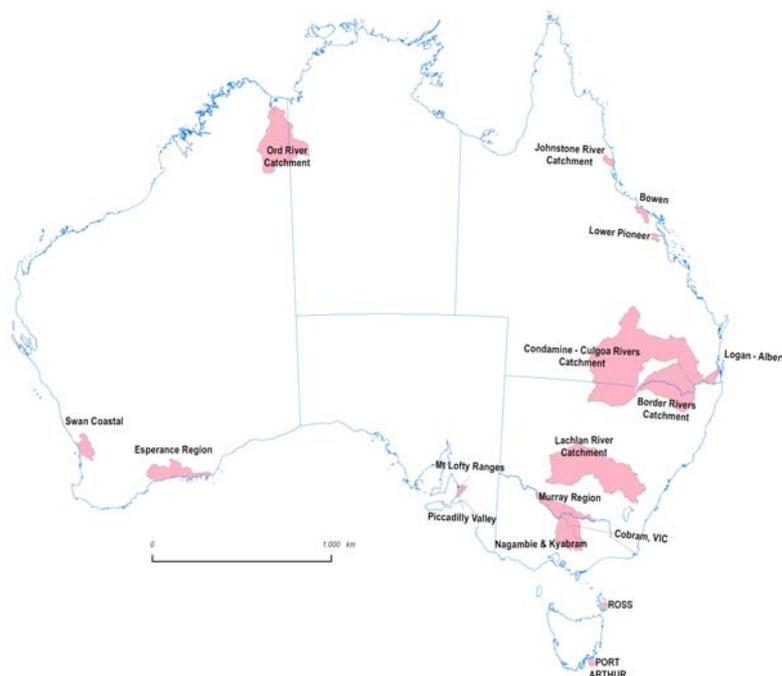


Figure 9: Areas of Australia where pesticides have been detections in groundwater

Much of the groundwater pesticide detections presented in Figure 9 have been obtained from either one-year studies or ad hoc monitoring, therefore it is difficult to ascertain clear trends on contamination potential. There are, however, temporal and spatial variations of contaminants in aquifers, and in some cases, poor agricultural land and water management practices are creating groundwater contamination risks. Therefore, it is important to continue monitoring Australian groundwater for pesticides.

2.4.2 Pesticides in New Zealand groundwater

National surveys of pesticides in New Zealand groundwater have been carried out at 4-yearly intervals since 1990 (Close and Flintoft, 2004). Previous national and regional groundwater surveys in New Zealand have shown low levels of pesticides in some groundwater systems, particularly those shallow unconfined systems that are vulnerable to pollution. The results of the national survey showed that pesticides were detected in 28 groundwater sites (21%), with 13 groundwater sites (10%) having two or more pesticides (Close and Flintoft, 2004). There were one or more wells with pesticides detected in nine of the 15 regions. No pesticides were detected in wells from the Northland, Hawke's Bay, Manawatu-Wanganui, Taranaki, Wellington, and West Coast regions.

None of the groundwater in the 2002 survey had pesticides at levels above the maximum acceptable value (MAV) for drinking water (Close and Flintoft, 2004). Twenty-one different pesticides were detected, including two triazine metabolites, usually at very low concentrations. Thirty-nine out of the 58 pesticide detections (67%) belonged to the triazine group. It is interesting to note that lower groundwater temperatures and higher nitrate levels were associated with the increased detection of pesticides in those surveys. A comparison with earlier surveys indicates that pesticide detections have been relatively stable over the past 12 years. The overall frequency of pesticide detections in the 4-yearly surveys were as follows: 1990 (7%), 1994 (13.6%), 1998 (11%), and 2002 (9%).

2.5 TRACE ELEMENTS

2.5.1 Trace elements in Australian groundwater

Data on trace elements in Australian groundwater are very limited and the extent of groundwater contamination due to trace elements is unknown at this stage. Fifteen trace elements were detected (at very low concentrations) in one or more locations. Figure 10 displays locations where trace elements have been detected during 1996-2008 and the source of data produced are from specific research and investigations (eg. Hostetler et al. 1998; Watkins et al. 1998; Baskaran et al. 2001). Among the trace elements, arsenic, boron, barium, iron, manganese, lead, iron, selenium and uranium and Fluoride have been detected in many locations. In some locations the trace element concentrations exceeded the NHMRC health guidelines and in others it exceeded the ANZECC guidelines for ecosystem protection.

Recent monitoring in the City of Stirling and some parts of the Gnangara Mound in WA showed some bores are contaminated with arsenic, aluminium and other heavy metals in response to acidification events (Appleyard et al. 2004). Sampling of deep drains in the agricultural wheatbelt has also shown high levels of heavy metals including iron, aluminium, cobalt, copper, zinc, lead and uranium have leached under acidic conditions (Rogers and George, 2005). Similarly, trace elements have been found in some inland waters following acid mine drainage and where acid sulfate soils are found.

Arsenic in groundwater systems is a problem in many parts of the world owing to ever-increasing extraction of groundwater resources to meet the needs of growing populations. Water quality monitoring in Australian sandy aquifers is usually limited to a small suite of major elements and salinity measurements to determine the quality of groundwater and to identify any potential problems from seawater intrusion as a result of over extraction. Minor and trace elements, particularly toxic elements, have largely been ignored in regular monitoring programs.



Figure 10: Areas of Australia where trace elements have been detected in groundwater

Trace elements in groundwater come from natural as well as anthropogenic sources. Elements that are naturally introduced come primarily from rock weathering and other geochemical processes involving leaching of continental rocks and sediments. Anthropogenic inputs, particularly due to the application of fertilisers and pesticides to agricultural land, could also lead to significant leaching to groundwater. Some elements are essential, in low concentrations, for proper metabolism in all living organisms, yet toxic at high concentrations; other elements currently thought of as non-essential are toxic even at relatively low concentrations. Table 4 lists some elements according to their toxicity to human and ecosystem health.

Table 4: Classification of naturally occurring elements according to their toxicity and availability in the hydrologic environment (adopted from Wood, 1974)

NON-TOXIC	LOW TOXICITY	MODERATE TO HIGH TOXICITY
Aluminium	Barium	Arsenic
Calcium	Tin	Boron
Iron		Cadmium
Magnesium		Chromium
Manganese		Cobalt
Molybdenum		Lead
Potassium		Mercury
		Nickel
		Selenium
		Uranium

Major sources of toxic elements arising from human activities are domestic and industrial wastewaters, together with their associated solid wastes, and the application of synthetic fertilisers and pesticides to agricultural lands. In recent years solid waste or sewage sludge has been commonly disposed in agricultural fields or sold as fertiliser. Trace elements can also be released through leaching of sewage sludge in agricultural fields. In addition, natural processes such as erosion, weathering or dissolution of mineral salts also add metals and trace elements to groundwater.

The data presented for trace elements in Figure 10 are restricted to the length and scope of the project. There is no consistent program of trace element monitoring of groundwater throughout most parts of Australia.

2.5.2 Trace elements in New Zealand groundwater

Trace metals in New Zealand groundwater are generally present at low concentrations and thus do not pose a risk to human health (Ministry for the Environment, 2007). Among the trace elements, iron and manganese have been detected in many locations during 2006. The calculated national medians during 2006 for iron and manganese are 0.03 and 0.01 mg/L, respectively, which is in good agreement with previously reported values (Rosen, 2001; Daughney, 2003; Daughney and Reeves, 2005). Elevated concentrations of dissolved iron and/or manganese can impart an unpleasant taste to drinking-water and can lead to staining and clogging of pipes, and so the DWSNZ includes aesthetic GVs of 0.2 and 0.04 mg/L for iron and manganese, respectively. Due to risks to human health and freshwater ecosystems, manganese has a MAV of 0.4 mg/L and a TV of 1.9 mg/L (there is no MAV or TV for iron).

Of the monitoring sites at which median concentrations could be determined, 27% exceeded the GVs for iron and 33% for manganese, 15% exceeded the MAV for manganese, and 2% exceeded the TV for manganese (Ministry of the Environment, 2007). Elevated concentrations of dissolved iron and/or manganese generally arise from natural microbial respiration in oxygen-poor aquifers which are found in many regions of New Zealand. Groundwater with high concentrations of iron and/or manganese are found in many regions of New Zealand, especially Gisborne, Auckland and Manawatu–Wanganui, but also in western Northland, coastal Bay of Plenty, northern Hawke’s Bay, south Wairarapa, and some parts of Otago and Southland (Ministry of the Environment, 2007).

From the results it is difficult to determine whether or not trace metal concentrations in groundwater pose a serious threat to ecosystem health. This is because, for many heavy metals, the ANZECC TV is near or below the detection limit of many analytical methods.

Arsenic has been detected in some groundwater. Arsenic concentrations in New Zealand groundwater are typically less than the health-related MAV (0.01 mg/L). However, of all sites at which median arsenic concentrations could be determined (n = 157), 10% exceeded the MAV.

2.6 OTHER CONTAMINANTS

Organic and inorganic contaminants are sometimes inadvertently released to the groundwater by many activities, such as manufacturing, transport, storage and waste disposal. The extent of groundwater contamination by industrial chemicals is very limited. Some of the available information is presented below.

In WA, leaking underground storage tanks at petrol stations are a widespread threat to groundwater, due to their large number and distribution (EPA WA, 2007). Leaks may go undetected for long periods and, on reaching groundwater, contaminants may affect drinking water supplies, residential or production bores, and eventually wetlands and waterways. Of about 6500 licensed premises in WA with dangerous goods, an estimated 57% have underground storage tanks. Nearly half of these are located in the Perth metropolitan area. Just over 3% (or 217) of premises have leaking tanks and many of the sites involved are being investigated and undergoing remediation.

In NSW, groundwater contamination is largely associated with long-standing existing and former industrial areas, and occurs at about 90 of the currently regulated sites (DEC NSW, 2006). These tend to be in urbanised areas and concentrated in Sydney, Newcastle and Wollongong. The sources of contamination are distributed between purpose-built hydrocarbon storage sites such as service stations and depots (30%), industrial sites (38%), and landfills, gasworks and other land uses (32%). The main contaminants at 46% of sites are hydrocarbons – including total petroleum hydrocarbons; benzene, toluene, ethyl benzene and xylenes; and polycyclic aromatic hydrocarbons. Twenty-five per cent are affected by heavy metals, 9% by chlorinated solvents and 7% by nutrients. Several sites are affected by more than one contaminant.

2.7 ACIDITY

Acidification of groundwater has been considered as an important environment issue in recent years in Australia. Acidification of groundwater may be caused by internal processes in the soil zone or by external factors imposed on the soil water system. The information on groundwater acidity in Australia is very limited.

Groundwater in some parts of the WA wheatbelt is saline, very acidic with pH commonly between 3 and 4. The acidic groundwater contain high concentrations of dissolved aluminium, iron and trace metals like lead, nickel, copper and zinc (Shand and Degens 2008). More than 50 per cent of

groundwater observation sites in the Avon basin and about 46 per cent in the Esperance coastal basin are acidic. The groundwater acidity hazards include the transport and accumulation of trace elements such as lead, cadmium, uranium, arsenic and selenium in surface environments. This carries longer-term risks of accumulation in lakes and waterways, producing toxic effects on aquatic life and possible longer-term bioaccumulation through aquatic food chains.

Coastal groundwater acidity became a prominent issue in Perth in 2002 with the discovery that water from some household bores in the suburb of Stirling was killing garden plants (EPA WA, 2007). The groundwater was found to be acidic (with a pH as low as 1.9 in some places) and had become contaminated with aluminium and arsenic released from the soil (Appleyard et al. 2004). Nearby urban wetlands (Spoonbill Lakes) had also acidified. Heavy use of garden bores and dewatering of a nearby wetland for a housing development caused the acidification.

Investigations have also shown that extensive acidification of shallow groundwater is also occurring on the crests of the Gnangara and Jandakot mounds, with pH levels as low as 2.4 and high levels of dissolved aluminium and arsenic present (Appleyard, 2004 and 2005). High aluminium levels can kill plants and wetland aquatic fauna. High arsenic levels pose a risk to human health if the groundwater is used for drinking water, and represents a long-term toxicological problem for ecosystems.

Several wetlands on the Gnangara Mound are now permanently acidified. For example, Lake Gnangara has been acidified to a pH of less than 4 since the late 1970s, and Mariginiup and Jandabup lakes have both had temporary acidification events (McHugh, 2004). In other wetlands and waterways the source of acidity is likely to be disturbed acid sulfate soils, which have been detected in wetlands and waterways adjacent to the Swan-Canning, Peel-Harvey, Leschenault and Vasse-Wonnerup estuaries, the Scott Coastal plain and low lying coastal areas on the south coast near Albany (Department of Environment, 2004).

Groundwater in Moonie and Border Rivers west of Goondiwindi (at shallow depths) and Lower Balonne (at variable depths) has significant, though variable, acidity (Biggs et al. 2005).

3. Current and Emerging Groundwater Quality Issues

3.1 GROUNDWATER – SURFACE WATER INTERACTION AND IMPLICATIONS FOR WATER QUALITY

Groundwater-surface water interaction is important for both water availability as well as water quality. In areas where groundwater quality is good, it has beneficial impacts on streams and on aquatic ecosystem health. Conversely, if groundwater is contaminated, and inflows increase due to raised groundwater levels caused by factors such as land use change and river regulation, then this may have detrimental impacts on the stream water quality, ecology of a wetland and its surrounding areas. Movement of water between aquifers and surface water features such as rivers, lakes and estuaries can also mean movement of salt, acid, nutrients or contaminants. Hence, an understanding of surface water – groundwater interactions is important in the management of river salinity, acid sulfate soils and algal blooms.

This section provides some examples of groundwater –surface water interaction and effects on water quality.

Salinity

The role of groundwater processes in both dryland and irrigation–induced salinity has long been recognised in Australia in recent years. Across significant areas of Australia, land clearing and cropping have increased groundwater recharge, raised the watertable and driven increased discharge of saline groundwater into nearby streams. The NLWRA estimated that about 25,000 km² of salt-affected lands could potentially increase to 170,000 km² by 2050. The current annual cost in terms of lost agricultural production and infrastructure damage has been estimated at \$250m with degradation of ecological assets undefined (NLWRA, 2001). Of concern are increasing trends in stream salinity in the Murray-Darling Basin and the south-west of Western Australia. About a third of divertible surface water in streams in south-west WA is classified as brackish and saline, with only a half of streams classified as potable in terms of salinity (WA Government, 2000).

Shallow acid groundwater discharge, Tuckean Swamp, North Coast NSW

The Tuckean Swamp is a large estuarine back swamp on the north coast of New South Wales that has been highly modified with construction of drains and a tidal barrage to manage frequent flooding. The drainage network is efficient in reducing the incidence of flooding and waterlogging, but it also tends to lower the shallow watertable. The swamp contains significant acid sulfate soils and the watertable decline has caused the oxidation of pyrite within the previously waterlogged shallow estuarine sediments, a chemical reaction that generates sulfuric acid. Following major rainfall events, the store of acid migrates into the drains and is exported into the estuary. The consequences of this acidity are fish kills, poor water quality, land degradation, reduced agricultural productivity, loss of estuarine fisheries habitat, and degraded vegetation and wildlife values (Hagley, 1996).

Figure 11 provides an overview of drain pH in the Tuckean Swamp (Brodie, 2007). The results highlight the north-eastern quadrant as a priority area in terms of discharge of shallow acidic groundwater. For Meerscham Drain in the northeast, the pH gradually decreases from near-neutral (pH 6.9) in its upper reaches to about 4.1, before quickly dropping to 3.1 with acid conditions maintained down-drain. In contrast, the Tucki and Marom Drains in the western half of the swamp contained good quality water.

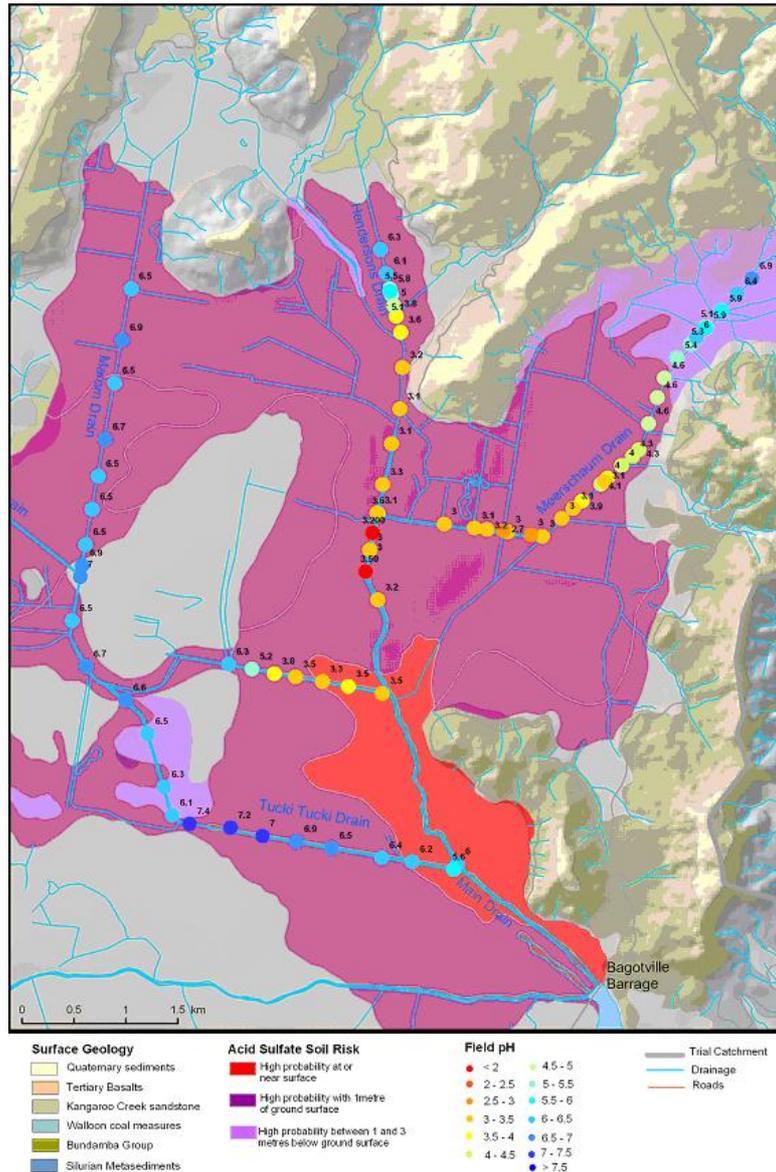


Figure 11: Field pH of Tuckean Swamp drains, September 2004. Meerschaum Drain and Hendersons Drain are a priority in terms of discharge of shallow acid groundwater (adapted from Brodie, 2007).

Groundwater nitrate-N on aquatic ecosystem health

The impact of fertilised cropping on nitrate-N in groundwater has been assessed in the wet tropical Johnstone River catchment in northeast Queensland during 1999-2002 (Rasiah et al. 2005). The Johnstone River estuary discharges into the Great Barrier Reef lagoon. The results of the study indicated that in 90% of the bores the 80th percentile or 80% of the nitrate-N values exceeded the maximum trigger value provided in the ANZECC guidelines for sustainable health of different aquatic ecosystem. Nitrate-N increased with increasing rainfall at the beginning of the rainy season and then a rapid decrease observed after the rain ceased. The results suggested that there is a potential for nitrate-N in groundwater to be discharged as a lateral flow into streams and can impact on aquatic ecosystems down stream (Rasiah et al. 2005).

3.2 GROUNDWATER DEPENDENT ECOSYSTEMS

3.2.1 Surface Groundwater Dependent Systems

Groundwater plays a vital role in sustaining both surface and subsurface ecosystems. Groundwater dependent ecosystems (GDE) are a diverse and important component of biological diversity. The ecosystems may rely on specific groundwater flows, or on specific ranges of fluctuations in level or pressure, or on specific groundwater quality parameters such as temperature or mineral content.

Clifton and Evans (2001) identified six major types of surface GDEs in Australia:

- terrestrial vegetation
- wetlands
- river baseflow systems
- aquifer and cave ecosystems
- terrestrial fauna
- estuarine and near shore marine ecosystems.

The dependency of ecosystems on groundwater is based on one or more of four basic groundwater attributes (SKM, 2001):

- flow or flux - the rate and volume of supply of groundwater;
- level - for unconfined aquifers, the depth below surface of the water table;
- pressure - for confined aquifers, the potentiometric head of the aquifer and its expression in groundwater discharge areas; and
- quality - the chemical quality of groundwater expressed in terms of pH, salinity and/or other potential constituents, including nutrients and contaminants.

3.2.2 Subsurface Groundwater Dependent Systems

Subsurface groundwater dependent ecosystems (SGDEs) are ecosystems occurring below the surface of the ground that would be significantly altered by a change in the chemistry, volume and/or temporal distribution of its groundwater supply (Parsons and Wentzel, 2007). A recent report (Tomlinson and Boulton, 2008) provides current knowledge of the biodiversity, ecological processes and ecosystem services of SGDEs in Australia.

The stygofauna are present across a variety of Australian subsurface environments and are generally characterised by high diversity and local scale endemism (Tomlinson and Boulton, 2008). Microbes are a key component of SGDEs, forming the basis of the food chain and mediating the metabolism of carbon and other nutrients. Microbial activity degrades contaminants and delivers energy and nutrients to aquifer food webs and to biota in connected systems. Microbially mediated bioremediation and metabolism are examples of ecosystem services provided by SGDEs.

Knowledge of SGDEs has improved in recent years in Australia, with many explanatory surveys being conducted, particularly in WA as part of the environmental impact assessment for mining activities. Existing surveys cover some coastal and inland alluvial, fractured rock and arid zone karstic and calcrete aquifers and caves in NT, NSW, QLD, Tasmania, WA and Christmas Island (Tomlinson and Boulton, 2008). Much of Australia's stygofaunal biodiversity still remains unsurveyed and there is lack of taxonomic capacity despite the efforts of the last decade (Humphreys, 2008).

3.2.3 Impacts of groundwater quality on groundwater dependent ecosystems

The use of groundwater resources increased in Australia in the last decade, both as the result of surface water caps in the Murray-Darling Basin (MDB) and declining rainfall that may be associated with regional climate change. As a consequence of these factors, it is increasingly important to

understand what level of groundwater use is sustainable in any given aquifer and what are the potential environmental impacts of excessive groundwater use on groundwater quality.

Management of groundwater resources may become much less effective if declining rainfall and increasing groundwater extraction can cause large regional declines in groundwater levels. Under these conditions, some of the trace elements in the aquifer material can be oxidised by exposure to the atmosphere and can cause an increase in groundwater acidity. This will lead to environmental problems in groundwater-dependent wetlands and woodland. Both surface and subsurface GDEs are threatened by over-extraction and poor groundwater quality. Particular groundwater quality threats include increases in salinity, contaminants (eg. trace elements) in discharging groundwater, acidity and nitrates. In addition urban development, intensive irrigation, clearing of vegetation and filling or draining of wetlands is also a threat to GDEs. In some caves and peat bogs, scientific research into past environments relies upon the fossil record, however fluctuating water levels and changes in water quality can destroy this record.

Recently it has been shown that the groundwater has become acidic in areas of high drawdown in a sandy unconfined aquifer on the Gnangara Mound in WA (Appleyard and Cook, 2009). The combined effects of low rainfall, groundwater use in excess of 300 GL/year and reduced recharge in area covered by pine plantations has caused the water table on the Gnangara Mound to drop by 5 m. The result is that the groundwater has become acidic in areas of high drawdown with pH values typically less than 5.0 at the water table and elevated concentrations of trace elements such as aluminium, iron, zinc, copper, nickel and lead (Appleyard and Cook, 2009). Monitoring has indicated that at least eight groundwater-dependent wetlands in the Gnangara Mound area have become either permanently or episodically acidic in recent years, particularly in areas where there has been a large decline in water table. Gnangara Lake was the first wetland in the area to have acidified in recent times (in the last 1970s), but other lakes in the area are now showing similar trend of declining pH and biodiversity (Sommer and Horwitz, 2001).

Input of saline groundwater is a substantial threat to the biodiversity of surface wetlands and rivers in south-west WA (Halse et al. 2003). Elevated salinities have already caused substantial changes to the biological communities of aquatic ecosystems. In addition to salinity, increased water volumes, longer periods of inundation and more widespread acidity are also likely to be detrimental to the biota in the south-west WA (Halse et al. 2003).

Coastal aquifers provide base flow to creeks and rivers during dry periods, thus supporting diverse ecosystems. Salinisation occurs in the Australian coastal aquifers due to seawater intrusion. The degree to which productivity of the coastal irrigation is reliant on groundwater supplies is yet to be fully quantified. Fresh water contaminated by seawater at a level of only 5% renders it unsuitable for many important uses including drinking water supplies, irrigation of crops, parks and gardens and sustaining GDEs.

Elevated concentrations of nitrates leached from agricultural fertilisers, urban and industrial point sources have been detected in Australian groundwater. Increased nitrate levels in drinking water affects human health, and together with increases in phosphate levels in discharging groundwater, is likely to contribute to eutrophication in freshwater, estuarine and marine discharging zones (Linderfelt and Turner, 2001; Slomp and Van Cappellen, 2004; Rasiyah et al. 2005). Eutrophication causes a loss in ecosystem goods and services.

3.3 IMPACTS OF CLIMATE CHANGE ON GROUNDWATER QUALITY

Climate models suggest that drought could be as much as 20 percent more common by 2030 over much of Australia and up to 80 percent more common in south-western Australia by 2070 (Commonwealth of Australia, 2003). There is also a predicted increase in frequency in extreme weather events with associated increased incidence and severity of flooding and erosion. Climate change is likely to increase the stress on groundwater already under pressure from salinity, over-allocation and declining water quality. Higher water temperatures and reduced stream flows will tend to adversely affect groundwater quality. Highly transmissive, sandy coastal aquifers will be more sensitive to changes in recharge, temperatures and sea level rise than deep inland aquifers with low rates of recharge (Crosbie, 2007).

In general, reduction in groundwater recharge is the most direct impact of climate change. Groundwater storage volumes are expected to decrease due to reduction in recharge, with a parallel decrease in capillary rise in vegetation and a loss of discharge to springs and streams (Tomlinson and Boulton, 2008). Lowered groundwater input to streams could alter the hydraulic gradient between the stream and the connected aquifers. Drought attenuates the flushing of nitrates and dissolved organic carbon into groundwater, limiting microbial metabolism and reducing the supply of energy and nutrients to streams (Dahm et al. 2003).

Higher surface water temperatures can be expected to be particularly strong in summer in groundwater-fed streams, with increases in mean annual oxygen consumption, rates of mineralisation and higher bacterial biomass (Sand-Jensen et al. 2007). Higher groundwater temperatures will be associated with a decrease in viscosity and a resulting increase in hydraulic conductivity (Freeze and Cherry, 1979), with implications for enhanced transport of contaminants. In areas where rainfall and severity of storms is expected to increase, higher rates of recharge will result in increases in the rate of flow of water in aquifers and potentially elevate rates of nitrates and other contaminants leaching.

The impacts of climate change and sea level rise have the potential to affect both the yield and quality of important strategic water resources provided by coastal aquifer systems. Sea level rise will result in increased salinisation of coastal groundwater and surface water, resulting in reduced water quality, possibly threatening GDEs associated with coastal aquifers. Climate change and sea-level rise can potentially impact coastal groundwater resources in the following ways:

- Seawater intrusion and inland migration of the fresh-saline interface.
- Seawater inundation (surface flow into low-lying areas) and flooding of unconfined aquifers by seawater.
- Contamination of bores by storm surges and flooding of surface fittings.
- Changing recharge due to variable rainfall and evapotranspiration resulting in an altered distribution of freshwater in the aquifer.
- Changing discharge patterns that can generate waterlogged conditions and may impact on aquatic and wetland ecosystems.
- High water table can also impact on infrastructure including leakage to septic tanks, sewer systems, and basements and causing instability of swimming pools, tanks and other subsurface structures that are not anchored.

4. Management Response for Groundwater Quality Protection

4.1 GROUNDWATER QUALITY PROTECTION STRATEGIES

The Guidelines for Groundwater Protection (NWQMS Guidelines #8; ARMCANZ and ANZECC, 1995) is the only national document specifically covering groundwater quality protection in Australia. The current Guidelines' focus is mainly on the broad-scale protection of groundwater quality from contamination and also from land-based management of groundwater resources. Groundwater quality protection in Australia varies across states and territories and is generally inconsistent and uncoordinated. However, there are a variety of strategies that have been implemented to protect groundwater quality. Some of the strategies are discussed below.

4.1.1 Bore Construction Considerations

Water agencies in each of the state and territories have responsibility for the management of groundwater resources. The owner or legal occupier of the land on which a bore is to be constructed must obtain the appropriate licence or permit from the licensing authority in the relevant state or territory. After the bore has been constructed, the driller must provide the drilling logs, construction details of the bore and decommissioning report to the state and territory water agencies.

In Australia, all groundwater bores should be drilled, cased and equipped according to national construction standards defined in Minimum Construction Requirements for Water Bores in Australia (ARMCANZ, 2003). This document deals with a broad scope of issues pertaining to water bore construction from licensing to construction, development and decommissioning for bores, water sampling, casing and recording and reporting data.

4.1.2 Tools for Groundwater Quality Protection

Jurisdictions have developed a number of tools to protect groundwater quality. The tools include groundwater vulnerability maps, beneficial use maps, wellhead protection plans, groundwater management plans, education and community awareness programs. The tools are valuable resources that should be used by groundwater managers, planners, developers, and regulatory agencies to make better informed judgements on where to locate potentially polluting activities so as to minimise the risk to groundwater.

4.1.2.1 *Groundwater Vulnerability Mapping*

Groundwater vulnerability mapping is used as a guide in determining which areas are more susceptible to groundwater contamination. The preparation of groundwater vulnerability maps involves the simplification of complex geologic and hydrogeologic characteristics of a particular site using a rating index approach. The parameters in the development of a groundwater vulnerability map included: depth to watertable, recharge, aquifer media, soil media, topography, and impact of Vadose Zone. Three classes of vulnerability ranking have been normally chosen to describe the relative assessment of the probability of a groundwater resource to contamination: low, medium and high. These classes are shown as distinct colours on the final vulnerability map.

Jurisdictions have developed a groundwater vulnerability map for a number of catchments. An example of a vulnerability map developed for Lachlan catchment is presented below (Figure 12).

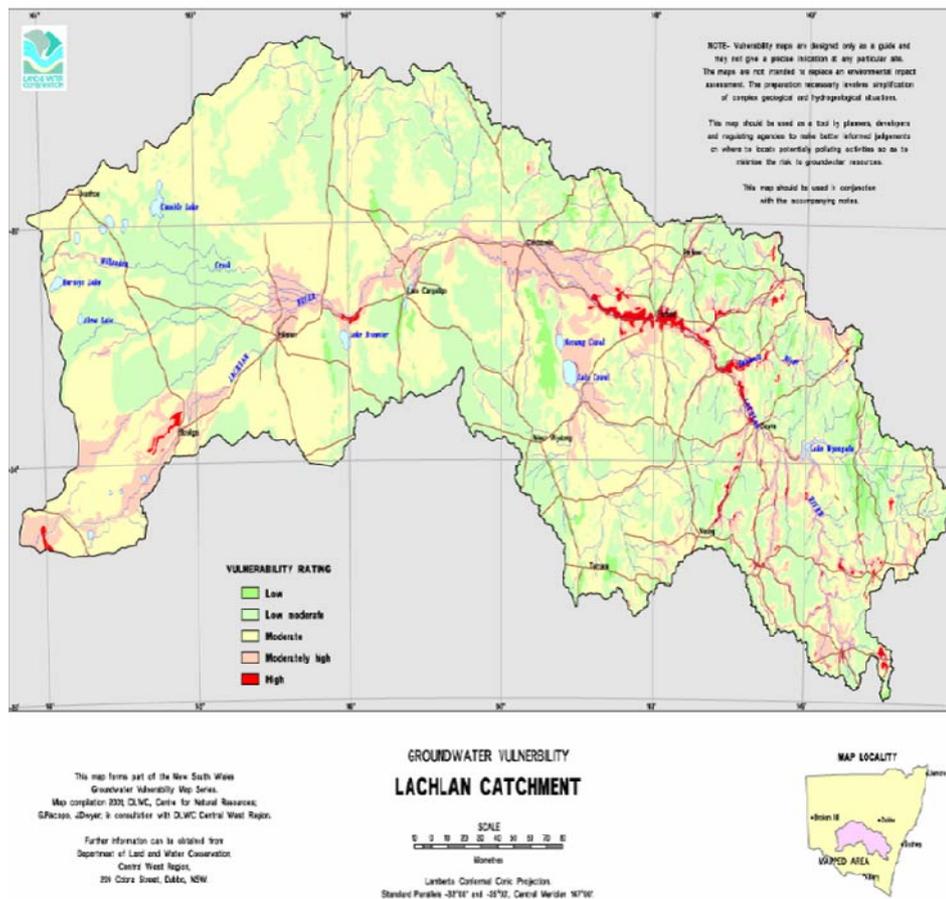


Figure 12: Groundwater vulnerability map for Lachlan Catchment (source: NSW DLWC, 2001)

4.1.3 Groundwater Quality Monitoring and Guidelines

Monitoring is the reality check for managers. Groundwater quality monitoring is a critical component of overall groundwater resource management programs. Groundwater quality monitoring is defined as an integrated activity for obtaining and evaluating information on the physical, chemical, and biological characteristics of ground water in relation to human health, aquifer conditions, ecosystem health, and designated ground and surface water uses. Ideally, groundwater quality monitoring should be carried out on a regular basis where groundwater is being extracted for a variety of uses. It should be an integral aspect of groundwater management.

In Australia, states and territories agencies are responsible for groundwater quality monitoring. Quite often it is the Environmental Protection Agencies (EPA) that undertakes monitoring, but sometimes the Water departments have this role. Among the various water quality parameters, electrical conductivity (EC) is one of the most important and commonly measured parameters in groundwater. Other parameters such as nutrients, pesticides, trace elements and acidity are measured less frequently or not measured. The frequency of groundwater quality sample collection, the sampling methods, the number of sites sampled and the groundwater quality parameters measured, vary between the states and territories. There is no consistent national program on groundwater quality monitoring in Australia.

Groundwater quality is monitored in every region of New Zealand. Groundwater quality monitoring is routinely carried out in 15 regional councils and also by the National Groundwater Monitoring Programme (NGMP). The monitoring programmes conducted in different regions vary in terms of

the number of sites sampled, the frequency of sample collection, the sampling methods and the groundwater quality parameters measured.

National water quality guidelines place specific constraints on the quality of water that is intended for specific uses. The Guidelines for Groundwater Protection in Australia (ARMCANZ/ANZECC, 1995) provide a national framework for protecting groundwater from contamination. Many states and territories have used the national groundwater guidelines to develop groundwater policy and regulations designed to improve the management of groundwater resources.

A broad range of measures are currently implemented across all jurisdictions to protect groundwater water quality. Some of the national and state-wide policies and programs that are implemented are discussed below.

4.2 NATIONAL POLICIES AND PROGRAMS

National Water Quality Management Strategy (NWQMS): provides national policies, guidelines, information and tools to help government and communities manage water resources to meet current and future needs. It includes 24 nationally endorsed, non-mandatory guideline documents covering topics such as water quality management and monitoring, the treatment and management of sewage and groundwater protection. The Australian Government works collaboratively with the states and territories and the New Zealand Government to develop and implement the NWQMS.

Guidelines for Groundwater Quality Protection in Australia: provide a national framework for protecting groundwater from contamination in Australia. Many jurisdictions have used the Groundwater Guidelines to develop groundwater policy and regulations designed to improve the management of groundwater resources.

National Water Initiative: is the primary and enduring blueprint for water reform agenda in Australia. The National Water Initiative (NWI) represents a shared commitment by all governments to increase the efficiency of Australia's water use, leading to greater certainty for investment and productivity, for rural and urban communities and for the environment.

Specific groundwater objectives under NWI are:

- 23 (iv) Return over-allocated systems to environmentally sustainable level of extraction
- 23 (x) Recognise connectivity between surface and groundwater and manage as a single resource
- 25 (iv) Provide adaptive management of surface and groundwater for productive, environmental and other public benefit outcomes
- 25 (x) Acknowledge, manage and protect groundwater systems of high conservation value
- 82 (iii) Accounting systems must integrate ground and surface water use where close interaction between groundwater aquifers and stream exists.
- 98 Knowledge and capacity building

Water for the Future: is the Australian Government's framework to secure long-term water supply for all Australians. It is the first ever nationwide plan that addresses both rural and urban water. Australian Government's framework, Water for the Future, provides national leadership in water reform for all Australians

National Groundwater Action Plan: Through the \$82 million National Groundwater Action Plan, the National Water Commission will undertake projects to address groundwater knowledge gaps and

progress the groundwater reforms agreed to under the National Water Initiative. The plan consists of three major components:

- a National Groundwater Assessment Initiative (\$50 million) to improve the understanding of groundwater resources and support NWI implementation, harmonise groundwater terminology and foster best practice management;
- a National Centre for Groundwater Research and Training (\$30 million) to develop research skills and expertise including the training of a new generation of groundwater managers and experts; and
- a Knowledge and Capacity Building component (\$2 million) to communicate learning from the Plan and raise public awareness of the challenges to adequately manage our groundwater resources.
- the National Water Commission will undertake projects to address groundwater knowledge gaps and progress the groundwater reforms agreed to under the National Water Initiative.

To reinforce the Groundwater Action Plan, the National Water Commission has developed the following themes under the National Groundwater Assessment Initiative:

- Harmonisation of groundwater definitions
- Northern Australia groundwater stock-take
- Managed Aquifer Recharge
- Groundwater Dependent Ecosystems
- Groundwater-surface water connectivity
- Strategic aquifer characterisation
- Deep fresh, saline and brackish groundwater
- Managing risks to groundwater quality

Great Artesian Basin Sustainability Initiative (GABSI): is the Australian Government initiative to accelerate work on the rehabilitation of uncontrolled artesian bores and the replacement of wasteful open earthen bore drains with piped water reticulation systems. The GABSI Initiative is being delivered through state agencies and the Australian Government makes its contributions jointly with other key stakeholders, state governments and pastoral bore owners.

Basin Salinity Management Strategy 2001–2015 (MDBMC 2001): are important responses that will help to manage groundwater quality across states in the MDB.

4.3 STATE-WIDE POLICIES AND PROGRAMS

Various policies and programs have been implemented at state and territory level that provide a framework for improving groundwater quality across the state. In general all states and territories have implemented the key elements of the groundwater quality protection guidelines. The groundwater protection strategies are set out in three frameworks:

the **Groundwater Management Framework**, which comprises legislation, regulation and policy about water management plans, allocation, bores, and public water supply;

the **Environment Protection Framework**, which comprises legislation, regulation and policy about waste management, environmental assessment, agricultural chemicals, dangerous goods, and environment protection in the resources industries; and

the **Land-Use Planning Framework**, which comprises legislation, regulation and policy about land use and development, and in some cases, land clearing.

Further details on the States legislation, regulation and policy on groundwater protection can be accessed from a regulatory review report (Nelson, 2009).

5. Groundwater quality guidelines and groundwater quality issues

5.1 GROUNDWATER QUALITY GUIDELINES

The Guidelines for Groundwater Protection in Australia (NWQMS Guidelines #8) were published in 1995 by ARMCANZ and ANZECC. The goal of groundwater protection is to protect the groundwater resources of the nation so that these resources can support their identified beneficial uses and values in an economically, socially, and environmentally sustainable and acceptable manner” (ARMCANZ/ANZECC, 1995).

Chapters 1 and 2 of the Groundwater Guidelines introduce the Guidelines’ objective, scope, and context, and outline the need for groundwater protection. Chapter 3 outlines the underlying principles of the Groundwater Guidelines, being the concepts of beneficial uses and values, and the polluter pays principle.

General approaches to groundwater protection are described in Chapter 4. Three forms of “intervention” are outlined in Chapter 4.1: first, intervention by command, that is, by laws which directly control actions and activities; second, intervention through market mechanisms; and third, intervention through public participation and education. Three types of “protection strategies” or types of legislative tools, within which particular protection measures are undertaken are outlined in Chapters 4.2 to 4.6: first, groundwater management; second, land-use planning; and third, environment protection.

Chapter 5 describes a general approach to groundwater planning, which involves assessing the resource, setting beneficial uses and accompanying criteria, developing protection measures, setting contingency measures and monitoring requirements, and implementing the plan.

5.2 RELEVANCE OF GROUNDWATER QUALITY GUIDELINES AND GROUNDWATER QUALITY ISSUES

The Groundwater Guidelines provide a national framework for protecting groundwater from contamination in Australia. Many jurisdictions have used the Groundwater Guidelines to develop groundwater policy and regulations designed to improve the management of groundwater resources.

Since 1995, groundwater use in Australia has increased significantly due to increase in water demand and decrease in surface water availability. Also there have been considerable gains in knowledge of groundwater systems and renewed interest in the groundwater resource in Australia over the last decade. Although the current Groundwater Guidelines provide a framework for protecting groundwater from contamination in Australia, some of the current and emerging groundwater quality issues presented in this report are not adequately addressed.

6. Summary of Results

6.1 SUMMARY OF RESULTS

Groundwater is increasingly being seen as an alternative source to surface water in recent years in Australia and New Zealand. Knowledge of the present status of groundwater quality and identifying the future emerging issues are key fundamentals to improving water quality management. This report provides the results of the review that was undertaken to assess the existing status and emerging groundwater quality issues.

The information on various groundwater quality issues provided in this review report has been solicited mainly through publicly available web sources. While the collation of publicly available information from different sources is valuable, it needs to be noted that reports on groundwater quality are often unpublished and not publicly available.

Key groundwater quality issues in Australia

- Monitoring of groundwater quality in Australia is limited and is carried out in an ad hoc manner. There is no consistent national program on groundwater quality monitoring and much of the monitoring has been short term therefore it is difficult to ascertain long-term trends.
- Salinity is a major groundwater quality issue, particularly in south-west WA and south-east Australia. Groundwater salinity has increased in some regions due to continued pressure from increased extractions and poor irrigation practices. Groundwater salinity is increasing in coastal catchments due to seawater intrusion.
- Wetlands and surrounding native vegetation, wetland habitats and species are at particular risk from salinity as a result of intrusion of saline groundwater. Victoria has 11 Ramsar wetland sites and five of these (45%) may be at risk of damage from salinity and shallow saline groundwater by 2020. Input of saline groundwater is also a substantial threat to the biodiversity of surface wetlands and rivers in south-west WA.
- Nitrate is perhaps the most widespread contaminant in groundwater. Nitrate levels sometimes exceeded the Drinking Water Health Guideline and ANZECC ecosystem protection guidelines in the irrigated catchments. Time series data are usually inadequate to establish seasonal and other variability in groundwater nitrate contamination potential.
- Results from various groundwater quality studies conducted during 1996-2008 showed detections for 9 herbicides along with two insecticides in groundwater. Atrazine herbicide has been detected in majority of the studies.
- Arsenic, boron, barium, iron, manganese, lead, iron, selenium, uranium and Fluoride have been detected in groundwater in many locations. Trace element concentrations exceeded the Drinking Water Health Guideline and ANZECC ecosystem protection guidelines in some locations.
- Acidification of groundwater has been considered as an important environment issue in recent years. Groundwater in some parts of the WA wheatbelt and some coastal groundwater are very acidic with pH commonly between 3 and 4. Several wetlands in WA are now permanently acidified.

- Organic and inorganic contaminants are a widespread threat to groundwater, mostly from industrial sites around urbanised areas.

Key current groundwater quality issues in New Zealand

- Groundwater quality monitoring is routinely carried out in 15 regional councils and also by the National Groundwater Monitoring Programme (NGMP) in NZ.
- High salinity in coastal aquifers is a serious issue in regions such as Northland, Bay of Plenty and Horowhenua due to seawater intrusion.
- Nitrate contamination is a major groundwater quality issue, particularly in shallow groundwater. Of the 956 sites investigated, 4.9% exceed the Maximum Acceptable Value (MAV) based on the Drinking Water Standards for New Zealand (DWSNZ), 10.3% exceed the trigger value (TV) for ecosystem protection based on the ANZECC guidelines, and none exceed the ANZECC TV for stock drinking-water.
- Trace elements such as iron, manganese and arsenic have been detected in many locations, mainly in deep groundwater.
- Previous national and regional groundwater surveys have shown low levels of pesticides in some groundwater systems, particularly those shallow groundwater that are vulnerable to pollution.

Emerging groundwater quality issues

- Increased groundwater extraction has resulted in decreased groundwater quality, particularly salinity, acidity and trace elements that have impacted on groundwater-dependent wetlands and woodlands in a number of locations.
- Both surface and subsurface Groundwater Dependent Ecosystems (GDEs) are threatened by over-extraction and poor groundwater quality in some areas. Particular groundwater quality threats include increases in salinity, trace elements, acidity and nitrates.
- Climate change is likely to increase the stress on groundwater already under pressure from salinity, over-allocation and declining water quality. Higher water temperatures and reduced stream flows will tend to adversely affect groundwater quality. Shallow aquifers will be more vulnerable to changes in recharge, temperatures and sea level rise and ultimately affect water quality.
- Increased extraction and sea level rise will result in increased salinisation of coastal fresh groundwater, resulting in reduced water quality, possibly threatening GDEs associated with coastal aquifer.
- A broad range of national and state-wide policies and programs are currently implemented across all states and territories to protect groundwater from contamination.
- Some of the current and emerging groundwater quality issues are not adequately addressed in the current national guidelines.

6.2 RECOMMENDATIONS

This literature review recommends that the current Groundwater Quality Guidelines be revised to incorporate current and emerging groundwater quality issues. Addressing these issues will ensure that the Groundwater Guidelines remain relevant into the future, and provide a useful source of guidance for jurisdictions to effectively manage risks to groundwater quality.

Specifically, the Groundwater Guidelines should be revised to:

- update groundwater use information which have become obsolete in relation to urban and community reliance on groundwater in Australia and overseas;
- ensure the Guidelines addresses current and emerging issues such as groundwater-surface water connectivity, acid sulfate soils, surface and sub-surface groundwater dependent ecosystems, managed aquifer recharge and climate change;
- include appropriate links to other NWQMS guidelines;
- include discussion on recent Australian Government water policy initiatives such as NWI, Water for the Future, Water Act 2007, National Groundwater Action Plan, and also directions undertaken at the State and Territory levels;
- update Tables in Appendices; and
- update bibliography and include references that appeared since the Guidelines were published.

7. References

ANZECC and ARMCANZ 2000. Australian and New Zealand guidelines for fresh and marine water quality. National Water Quality Management Strategy Paper No 4, Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Appleyard, S.J. 2004. Acidification of the superficial aquifer in the Perth metropolitan region, Progress report, no. 1, unpublished discussion paper, Department of Environment, Perth.

Appleyard, S.J. 2005. Acidification of the superficial aquifer in the Perth metropolitan region: Causes, distribution and information gaps, Progress report, no. 3, unpublished discussion paper, Department of Environment, Perth.

Appleyard, S.J, Wong, S, Willis-Jones, B, Angeloni, J and Watkins, R. 2004. Groundwater acidification caused by urban development in Perth, Western Australia: Source, distribution and implications for management, Australian Journal of Soil Research, 42, 579-85.

Appleyard, S.J. and Cook, T. 2009. Reassessing the management of groundwater use from sandy aquifers: acidification and base cation depletion exacerbated by drought and groundwater withdrawal on the Gnangara Mound, Western Australia. Hydrogeology Journal. 17, 579-588.

ARMCANZ 2003. Minimum construction requirements for water bores in Australia. National Minimum Bore Specifications Committee, Agriculture and Resource Management Council of Australia and New Zealand.

ARMCANZ/ANZECC (Agriculture and Resource Management Council of Australia and New Zealand/Australian and New Zealand Environment and Conservation Council), 1995. Guidelines for groundwater protection in Australia. National Water Quality Management Strategy.

Australian Water Resources 2005. <http://www.water.gov.au/default.aspx>.

Australian Water Association 2007. Water in Australia: Facts and Figures, Myths and Ideas. Australian Water Association, Sydney.
http://www.awa.asn.au/AM/Template.cfm?Section=Water_in_Australia.

Ball, J., Donnelley, L., Erlanger, P., Evans, R., Kollmorgen, A., Neal, B. and Shirley, M., 2001. Inland Waters. Australia State of the Environment Report 2001 (Theme Report), CSIRO Publishing on behalf of the Department of the Environment and Heritage, Canberra.

Baskaran S, Brodie, R.S., Budd, K.L. and Plazinska, A.J. 2001. Assessment of groundwater quality and origin of saline groundwaters in the coastal aquifers of Bowen area, North QLD. Bureau of Rural Sciences, Canberra.

Biggs, A.J.W., Power, R.E., Silburn, D.M., Owens, J.S., Burton, D.W.G. and Hebbard, C.L. 2005. Salinity Audit: Border Rivers and Moonie Catchments, Queensland Murray Darling Basin, Department of Natural Resources and Mines, Brisbane.

Brodie, R. 2007. Integrated Water Management in the Lower Richmond Catchment. PhD Thesis submitted to The Australian national University, Canberra.

Brodie, R, Sundaram, B, Tottenham, R, Hostetler, S, and Ransley, T. 2007. An adaptive management framework for connected groundwater-surface water resources in Australia. Bureau of Rural Sciences, Canberra.

Burden, R.J. 1982. Nitrate contamination of New Zealand aquifers: a review. *New Zealand Journal of Science* 25: 205–20.

CBWC. 2002. Fate of Nutrient and Pesticides in the Riverine Environment. “Fate of Nutrients” and “Minimising Pesticides in the Riverine Environment” – Final Report. Condamine Balonne Water Committee Inc., Dalby, Queensland.

Close, M.E. and Flintoft. 2004. National survey of pesticides in groundwater in New Zealand-2002. *New Zealand Journal of Marine and Freshwater Research*. 38: 288-299.

Clifton, C. and Evans, R. 2001. Environmental Water Requirements of Groundwater Dependent Ecosystems, Environmental Flows Initiative Technical Report No. 2, Commonwealth of Australia, Canberra.

Commonwealth of Australia. 2003. *Climate Change: An Australian Guide to the Science and Potential Impacts*. Australian Greenhouse Office, Canberra.

Crosbie, R. 2007. ‘The hydrological impacts of climate change on groundwater’, In a *Symposium on Hydrological Consequences of Climate Change*. CSIRO, Canberra.

CSIRO 2008. Water availability in the Murray-Darling Basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 67pp.

Dahm, C.N. Baker, M.A., Moore, D.I. and Thibault, J.R. 2003. Coupled biogeochemical and hydrological responses of streams and rivers to drought. *Freshwater Biology*, 48, 1219–1231.

Daughney, C.J. 2003. Iron and manganese in New Zealand’s groundwater. *Journal of Hydrology (NZ)* 42: 11–26.

Daughney, C.J. and Reeves, R.R. 2005. Definition of hydrochemical facies in the New Zealand National Groundwater Monitoring Programme. *Journal of Hydrology (NZ)* 44: 105–30.

DEC [Department of Environment and Conservation] NSW 2006. *New South Wales State of the Environment 2006*, Department of Environment and Conservation, Sydney.

Department of Sustainability and Environment (DSE), Ramsar Wetlands. 2008. Parks Victoria Website, Victorian Government.
www.dse.vic.gov.au/DSE/nrence.nsf/fid/FOE25269458B2BEBCA2572D400160DEA.

EPA [Environmental Protection Authority] WA 2007. *State of the Environment Report: Western Australia 2007*, website, Department of Environment and Conservation, Perth, Western Australia.

EPA [Environmental Protection Authority] SA 2008. *The State of our Environment*, South Australia, 2008. Environmental Protection Authority, Adelaide, SA.

EPA [Environmental Protection Authority] Queensland 2007. *State of the Environment Queensland 2007*. Environmental Protection Agency, Brisbane.

Freeze, R.A. and Cherry, J.A. 1979. *Groundwater*, Prentice-Hall, Englewood Cliffs.

- Ghauri, S. 2004. Groundwater trends in the central agricultural region, Resource management technical report, no. 269, Department of Agriculture, Perth.
- Habermehl, M.A. 2007. Managing Non-Renewable Groundwater Resources. Science for Decision Makers Series, Bureau of Rural Sciences, Canberra.
- Hagley, R. 1996. The Tuckean Project. Proceedings 2nd National Conference on Acid Sulfate Soils. Coffs Harbour, 5-6 September 1996.
- Halse, S.A., Ruprecht, J.K. and Pinder, A.M. 2003. Salinisation and prospects for biodiversity in rivers and wetlands of south-west Western Australia. *Australian Journal of Botany* 51:673–688.
- Harris, G. 2006. Inland Waters, theme commentary prepared for the 2006 Australian State of the Environment Committee, Department of the Environment and Heritage, Canberra.
<http://www.environment.gov.au/soe/2006/publications/commentaries/water/index.html>.
- Hostetler, S., Wischusen, J. and Jacobson, G. 1998. Groundwater quality in the Papunya - Kintore region, Northern Territory. Australian Geological Survey Organisation Record 1998/17.
- Hutson, S.S., Barber, N.L., Kenny, J.F., Linsey, K.S., Lumia, D.S. and Maupin, M.A. 2004. Estimated use of water in the United States in 2000. U.S. Geological Circular 1268, 46 p.
- Krinner, W., Lallana, C., Estrela, T., Nixon, S., Zabel, T., Laffon, L., Agences De L'eau, Rees, G., Cole, G., Niels Thyssen and Cover Bysted. 1999. Sustainable water use in Europe; Part 1: Sectoral use of water. European Environment Agency, Environmental Assessment Report No. 1, Copenhagen, 91 p.
- Linderfelt, W.R. and Turner, J.V. 2001. Interaction between shallow groundwater, saline surface water and nutrient discharge in a seasonal estuary: the Swan-Canning system. *Hydrological Processes*. 15, 2631–2653.
- Lau, J.E., Commander, D.P. and Jacobson, G. 1987. Hydrogeology of Australia. Bulletin 227. Bureau of Mineral Resources, Canberra.
- McHugh, S. 2004. Causes and history of acidification of wetlands on the Gnangara Mound, Perth, presentation to Murdoch University Iron and Sulfur Bacteria Workshop, University of Western Australia, Perth, February.
- MDBC (Murray-Darling Basin Commission) 2003. Projections of groundwater extraction rates and implications for future demand and competition for surface water. Report No. 04/03, Murray-Darling Basin Commission, Canberra.
- MDBC (Murray-Darling Basin Commission) 2004. Murray-Darling Basin Groundwater Status Report No. 32/04, Murray-Darling Basin Commission, Canberra.
- Ministry for the Environment 2007. Groundwater quality in New Zealand. State and trends 1996-2006. Publication No. ME831, Ministry for the Environment, New Zealand.
- Nelson, R. 2009. The guidelines for groundwater protection in Australia. Regulatory Review. Unpublished report, Geoscience Australia, Canberra.
- NLWRA [National Land and Water Resources Audit]. 2001. Australian Water Resources Assessment 2000, Commonwealth of Australia, Canberra.

NWC, 2008. Groundwater position paper. National Water Commission.
<http://www.nwc.gov.au/resources/documents/Grounwater-PS-240608.pdf>.

NHMRC/NRMMC (National Health and Medical Research Council/Natural Resource Management Ministerial Council), 2004. Australian Drinking Water Guidelines. Available at:
<http://www.nhmrc.gov.au/publications/synopses/eh19syn.htm>.

Parsons, R. and Wentzel, J. 2007. Groundwater Resource Directed Measures Manual, Water Research Commission, South Africa. WRC Report No TT 299/07.

Plazinska, A. 2007. Understanding Groundwater. Science for Decision Makers Series, Bureau of Rural Sciences, Canberra.

Please, P.M., Watkins, K.L., Cresswell, R.G. and Bauld, J., 2000. A groundwater quality assessment of the alluvial aquifers in the Border Rivers Catchment (Qld/NSW). BRS, Canberra.

Rasiah V, Armour, J.D. and Cogle, A.L. 2005. Assessment of variables controlling nitrate dynamics in groundwater: Is it a threat to surface aquatic ecosystems?. *Marine Pollution Bulletin* 51:60–69.

Rogers, S and George, R. 2005. WA Wheatbelt drainage - Acidic groundwater, not just a salt issue. *Focus on Salt*, 33, 8-9, June.

Rosen, M.R. 2001. Hydrochemistry of New Zealand's aquifers. In: Rosen MR, White PA (eds). *Groundwaters of New Zealand*. New Zealand Hydrological Society: Wellington.

Sinclair Knight Merz Pty Ltd. 2001. Environmental Water Requirements of Groundwater Dependent Ecosystems, Technical Report No. 2, Environment Australia, Canberra,
<<http://www.deh.gov.au/water/rivers/nrhp/groundwater>>.

Slomp, C.P. and Van Cappellen, P. 2004. Nutrient inputs to the coastal ocean through submarine groundwater discharge: controls and potential impact. *Journal of Hydrology*. 295, 64–86.

Sommer, B, Horwitz, P. 2001. Water quality and macroinvertebrate response to acidification following intensified summer droughts in a Western Australian wetland. *Journal of Marine Freshwater Resources*. 52:1015–1021.

Smith, A., Pollock, D., Palmer, D. and Price, A. 2007. Ord River Irrigation Area (ORIA) Groundwater Drainage and Discharge Evaluation: Survey of Groundwater Quality 2006. CSIRO Land and Water Science Report 44/07.

State of the Environment Victoria 2008. The State of Victoria, Commissioner for Environmental Sustainability 2008, Melbourne.

Thorpe, H. 1992. Groundwater - the hidden resource, In *Waters of New Zealand*, ed. Mosley, P., New Zealand Hydrological Society. 167-186.

Tomlinson, M. and Boulton, A. 2008. Subsurface groundwater dependent ecosystems: a review of their biodiversity, ecological processes and ecosystem services. National Water Commission Occasional Paper No.8. Canberra.

Tomlin, C. 1997. The Pesticide Manual, 11th Edition. British Crop Protection Council, Surrey GU9 7PH, UK.

U.S. Geological Survey. 1999. The quality of our Nation's waters – Nutrients and Pesticides. U.S. Geological Survey Circular 1225.

Watkins, K.L., Kulatunga, N. and Bauld, J. 1998. Groundwater Quality of the Murray-Riverina Catchment, NSW: Wakool-Cadell and Denimein-Berriquin Regions. Australian Geological Survey Organisation Record 1998/32.