A Review of Urban Groundwater in Melbourne : Considerations for WSUD

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Abstract

An important area of the urban hydrologic cycle is the links between groundwater, surface water and land use. The infiltration of stormwater runoff, changes in landscape structure associated with urbanisation, interactions with wetlands, as well as leaks in water and wastewater infrastructure can all lead to changes in the recharge-discharge behaviour of groundwater and impacts on the quality of groundwater. The issue of sustainability is also becoming a critical policy need in the design and operation of urban water systems. Some researchers have demonstrated high levels of risk to groundwater, from polluted stormwater infiltrating from stormwater treatment measures. It is therefore essential that 'Water Sensitive Urban Design' (WSUD) incorporate an understanding of the groundwater component of the urban hydrologic cycle, if these systems are to provide genuine sustainability.

In general, the urban city of Melbourne, Australia, has not been dependent on groundwater for potable supply or other uses, although this could be expected to gradually change in the long-term. The hydrogeology is quite varied, and includes Tertiary volcanic basalt sequences in the west and north, Mesozoic sedimentary (sandstone, siltstone, mudstone, conglomerate) sequences in the northeast and Quaternary alluvials and sediments in the southeast. Thus the hydrogeologic controls on groundwater in the Melbourne urban context are quite varied. There remain many substantive opportunities to optimise the links between Melbourne's urban groundwater resources and WSUD, including aquifer storage and recovery (ASR), wetlands, reducing potable water demand, improving water-use efficiency, and the like.

This paper will present a review of the hydrogeology of the greater Melbourne urban region as it relates to WSUD. The outcome will be an analysis of the risks of WSUD to groundwater (specific to Melbourne) as well as identifying priority areas for future research.

1. INTRODUCTION : THE IMPORTANCE OF URBAN GROUNDWATER

The significant role that groundwater plays in the urban cycle is well established in many countries around the world, both in terms of quantity and quality. A recent United Nations Environment Programme report (Morris *et al*, 2003) outlined many aspects of groundwater in urban cycles, highlighting its particular susceptibility to degradation if not managed appropriately. The several case studies presented included significant impacts due to wastewater, overexploitation, hazardous waste disposal, landfills as well as water infrastructure (potable and wastewater). Thus, it is very important to consider urban groundwater in terms of quantity, quality and the links between these two facets.

In Australia, the role of groundwater in the urban water cycle has often been undervalued and underutilised (eg. Hancock, 2000). The principal urban centres which have valued and more pro-actively managed urban groundwater are Perth and regional and rural Australia, with Adelaide more recently increasing the role of groundwater in its urban water cycle. Typically, major urban population centres along the eastern coast of Australia have not needed to take account of groundwater for water supply due to abundant forested catchments nearby. In the case of Melbourne, it is now recognised by the Victorian Government, on both economic and environmental grounds, that these catchments should not be further exploited in the forseeable future and that water conservation and other alternatives need to be developed to maintain long-term water supply security (DSE, 2003).

The potential importance of groundwater in the water cycle across all urban centres in Australia is now being more widely appreciated (Williams *et al*, 1996; Smith, 1998; Hancock, 2000). At the same time, a major theme in the current focus on water is that of sustainability – the environmental, economic and social aspects of water management. The principal field for this within an urban context is 'Water Sensitive Urban Design" or WSUD. To ensure that new WSUD systems adopted over the coming years are truly sustainable, there is a need to learn from the past and have sound research on which to base the engineering design, operation and maintenance of such systems. Given the increasing need to include groundwater in future water systems, and the technical difficulties often associated with remediating contaminated groundwater, it is imperative that WSUD include groundwater sustainability as a key aspect in its broad implementation.

This paper will review the various roles of groundwater in the urban water cycle, based around considerations of quantity and quality, followed by a review of the hydrogeology of Melbourne and the ways in which groundwater can be incorporated into future water strategy.

2. URBAN GROUNDWATER : COMMON ISSUES AND CHALLENGES

There are many ways in which urban groundwater is used and abused. This revolves around both quantity and quality, and especially the links between these two aspects, shown conceptually in Figure 1. Some common examples include Foster & Lawrence (1996); Chilton (1997, 1999); Burke & Moench (2000); Kim *et al* (2001); Lerner (2002); Sharp & Krothe (2002); Morris *et al* (2003); Lerner (2004) :

<u>Quantity :</u>

- water pipe infrastructure;
- water supply borefields;
- pumping bores (construction, etc.)
- artificial recharge;
- stormwater infiltration basins.

<u>Quality :</u>

- solid waste disposal (municipal, hazardous, etc.);
- liquid waste disposal (industrial, sewage, etc.);
- stormwater runoff;
- natural and artificial wetlands;
- seawater intrusion.

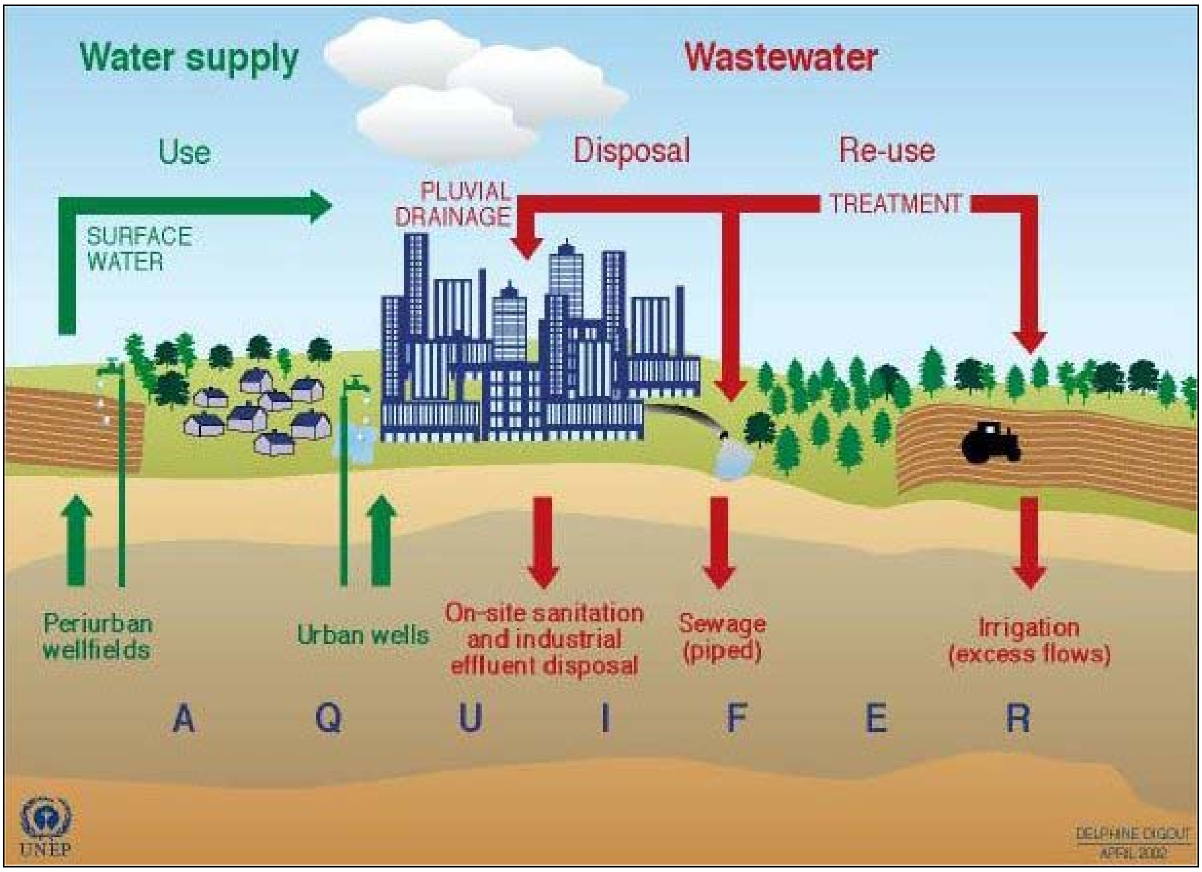

Figure 1 Groundwater within an urban water cycle (UNEP, 2002)

2.1. Urban Groundwater – *Quantity*

The impacts on groundwater quantity in urban centres are primarily twofold – decreasing due to abstraction impacts on aquifer storage or increasing due to injection, seepage and leaks. Some case studies are summarised in brief below.

In the city of Seoul, South Korea, major extraction of groundwater occurs to maintain the water table below the subway system as well as for municipal water supply (Kim *et al*, 2001). For the subway system, it is estimated that pumping rates are about 200 to 250 ML/day. The municipal water supply is derived primarily from the Han River, with leakage rates recharging groundwater of approximately 1,800 ML/day. For comparison, there were 16,169 wells operated during 1995 which pumped an average of 111 ML/day. Overall, there was considered a net recharge of the groundwater system.

A case study of Bangkok was presented by Ramnarong (1996). The rapid rise in groundwater pumping over the past 50 years for municipal and industrial use has led to widespread land subsidence, significantly impacting on infrastructure as well as major economic and social impacts. A similar problem of over-extraction and subsidence has also occurred in the Mexican city of Querétaro, increasing pollution problems and overall groundwater vulnerability (Morris *et al*, 2003).

The city of Christchurch on New Zealand's South Island is totally reliant on groundwater for its potable and industrial water supplies (van Toor, 1996). A key challenge is the future management of groundwater quantities extracted in relation to surface water resources.

A major problem in many cities across the Middle East is that of rising water tables due to increased recharge from leaking water mains, septic tank systems and over-irrigation of parks and gardens (Morris *et al*, 2003). A pattern of rising groundwater levels was also noted for London and Liverpool.

The Western Australian city of Perth is constantly reviewing the sustainability of its urban groundwater – a major supply source. At present, 750 GL/year is licensed for extraction (excluding domestic and stock bore use), compared to the likely sustainable yield of 1,900 GL/year (Commander *et al*, 2002).

An emerging area of augmenting groundwater quantity is through 'aquifer storage and recovery' or ASR. Typically, stormwater (or reclaimed wastewater) is injected into an aquifer during periods of high flow and is extracted when needed. The quantity of water that can be stored in this manner is dependent on local hydrogeological conditions, but can be significant.

2.2. Urban Groundwater – *Quality*

Impacts on groundwater quality in urban centres can occur from numerous point and diffuse sources. The impacts can be derived from industrial sources (accidental and deliberate), pipe infrastructure, impacts related to declining or rising water tables, land use and stormwater impacts, and so on. In many industrialised regions of the world, it is without doubt that there remains a significant legacy of groundwater contamination. The types of contaminants range the full spectrum of modern industry, including innumerable organics (especially hydrocarbons), heavy metals, nutrients, pathogens, radionuclides and salts (Fetter, 2001). Some case studies are below.

In Seoul, the average depth of groundwater bores has increased from about 10 m in the late 1970s to several hundred metres in the 1990s due to groundwater quality degradation from point-source and diffuse sources (Kim *et al*, 2001). The degradation was not related to abstraction. A major source of impacts on groundwater quality is leaking sewer mains, though these also act as sinks for groundwater discharge also (estimated at 1,500 ML/day, including some component of stormwater).

For Bangkok, the subsidence issues have also been compounded by saline intrusion and leakage of poorer quality groundwater between aquifers induced by the pumping (Ramnarong, 1996).

A case study of the Kathmandu Valley in Nepal was presented by Bauld *et al* (1998). A broad survey of groundwater quality showed widespread indications of faecal contamination, considered most likely due to leaking sewer mains and septic tanks. There was some evidence of a seasonal effect on contamination, with higher concentrations during and immediately after the monsoon.

3. HYDROGEOLOGY OF MELBOURNE

The hydrogeology of the 'Greater Melbourne' urban region, despite the general lack of groundwater use, is relatively well established. This section is based primarily on the work of Douglas & Ferguson (1988); Lane *et al* (1992); Leonard (1992); Peck *et al* (1992); O'Rourke & Shugg (1998).

3.1. Geology

The regional geology can be simplified into two major divisions – (i) basement rocks comprised mainly of folded and fractured Palaeozoic sediments and igneous intrusives; and (ii) Cainozoic sediments and extrusives of varying thickness and distribution. This gives rise to three major provinces across Greater Melbourne, namely :

- the Older and Newer Volcanics basaltic plains to the north and west;
- Palaeozoic-Mesozoic sandstones, mudstones and shales to the northeast and east;
- Tertiary to Quaternary sediments along the southeast and in the Yarra and Werribee River deltas.

Locally there can be important differences and distinctions, however, most of the near-surface geology of the Melbourne region can be categorised into these provinces. Geological maps are shown in Figures 2 and 3.

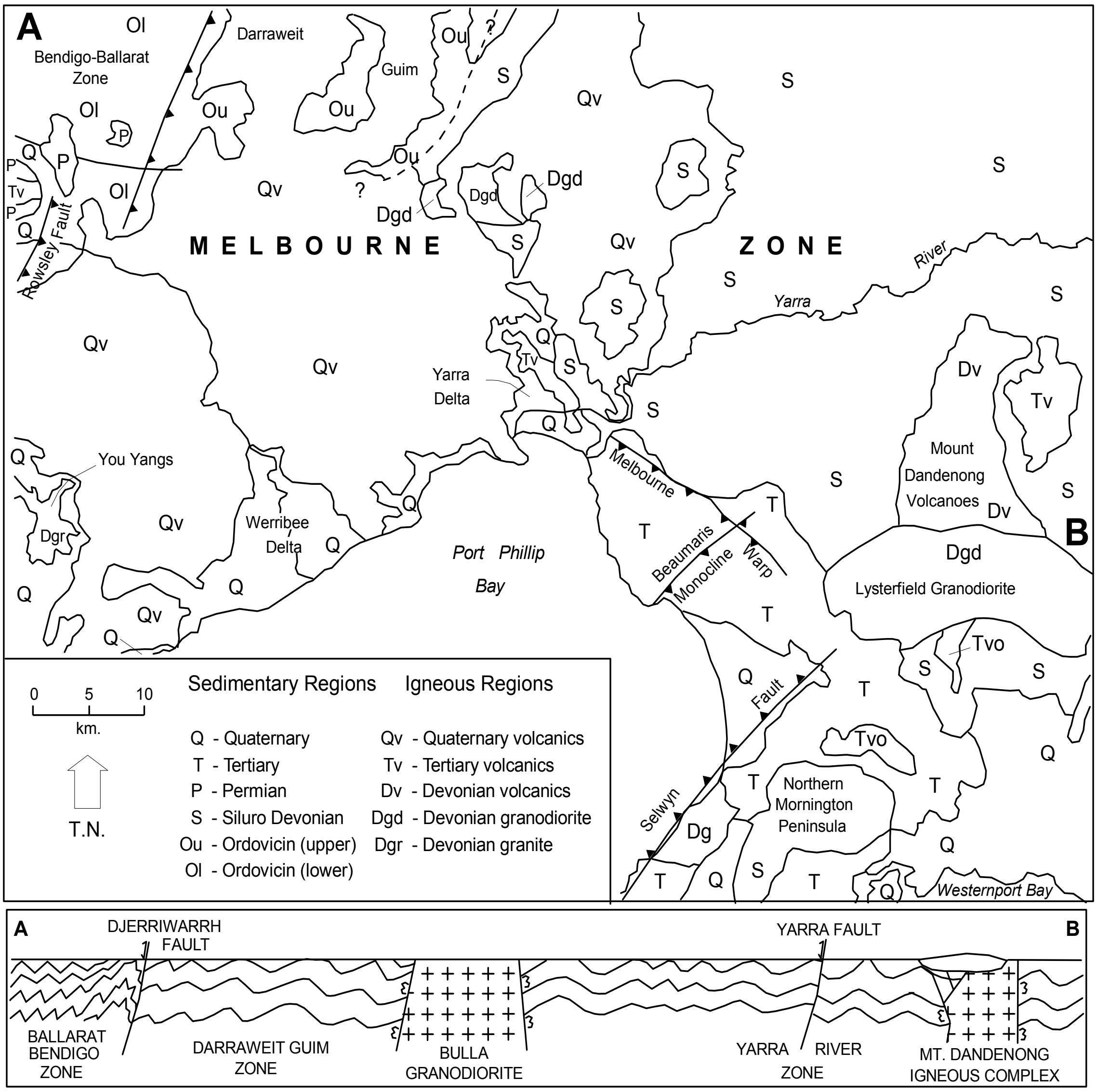

Figure 2 Simplified geologic map of the Melbourne region (redrawn from Archbold, 1992)

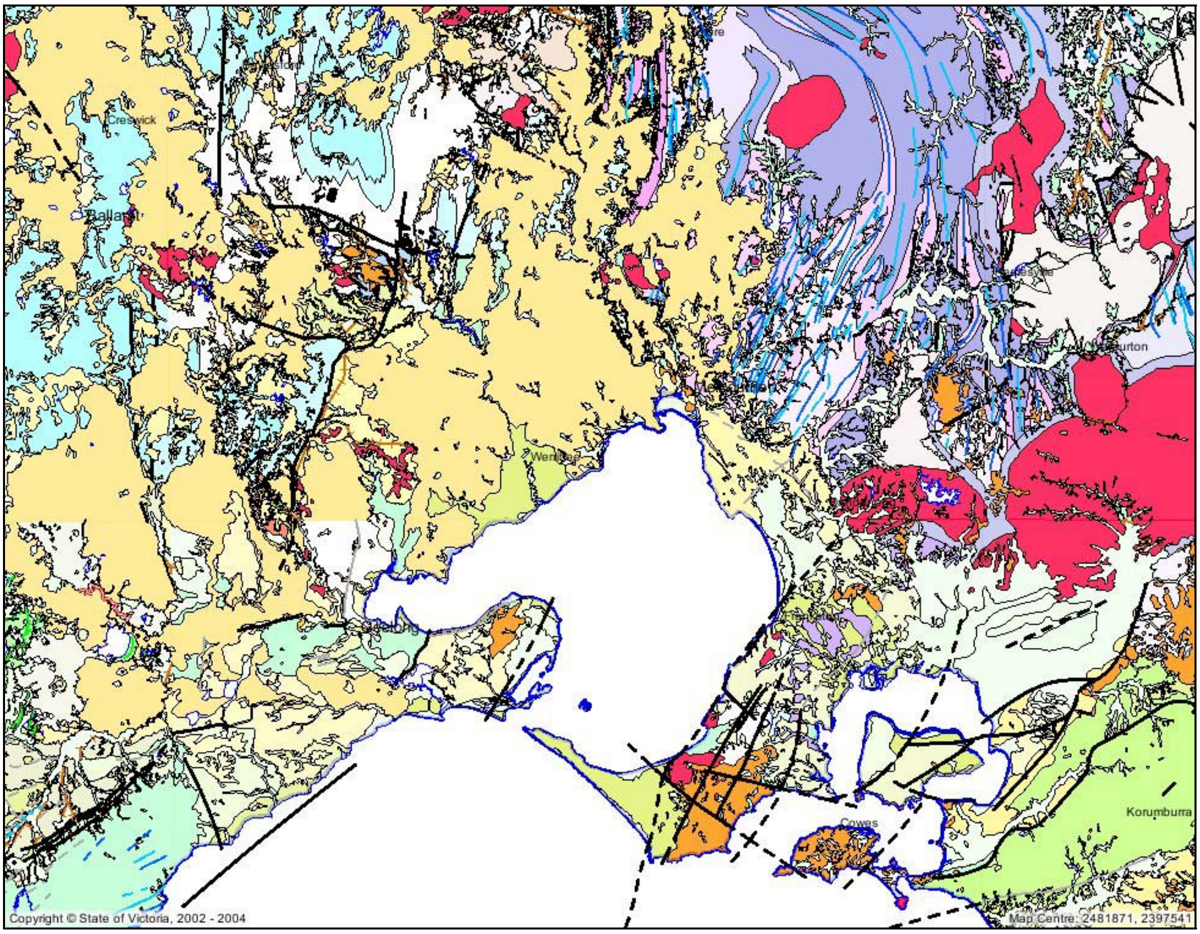

Figure 3 Detailed geologic map of the Melbourne region (DPI, 2004)

(cross-reference Figures 2 and 3 for the legend; plus see the DPI website listed in the references for more detail)

3.2. Hydrogeology

The hydrogeology of Melbourne is broadly aligned with the underlying geology, with the depths to an aquifer ranging from several hundred metres to less than one metre. There have been a number of different classifications or broad groupings of Melbourne's aquifers by different workers, however, the grouping presented by Lane *et al* (1992) will be used within this paper. The principal aquifers and their properties are summarised in Table 1. A general map of the hydrogeologic provinces is shown in Figure 4. Further details can be found in the references listed previously, though there remains a degree of conjecture over the nature of some aquifers and their properties.

3.3. Groundwater Quality

In general, the quality of groundwater across the Greater Melbourne urban region is fresh to slightly brackish, summarised in Table 2 and shown in Figure 5. The primary regulatory control of groundwater quality rests with the Environment Protection Authority of Victoria (EPAV). The EPAV now has in place a State Environment Protection Policy (or SEPP) called 'Groundwaters of Victoria' (EPAV, 1997). This SEPP sets a "beneficial use" of groundwater, based on segments of salinity, for various applications of groundwater. This includes ecosystem protection, potable and mineral water supply, industrial use, agriculture, primary contact recreation and infrastructure. Only ecosystem protection, industry and infrastructure are protected by the SEPP under all salinity segments. The SEPP also refers to the national water quality guidelines for specific contaminants to protect drinking water quality and freshwater and marine ecosystems. The salinity ranges in Figure 5 broadly correspond to those specified by the SEPP. In general, linking urban development and groundwater has not been considered important except on a project-specific basis (Hancock, 2000).

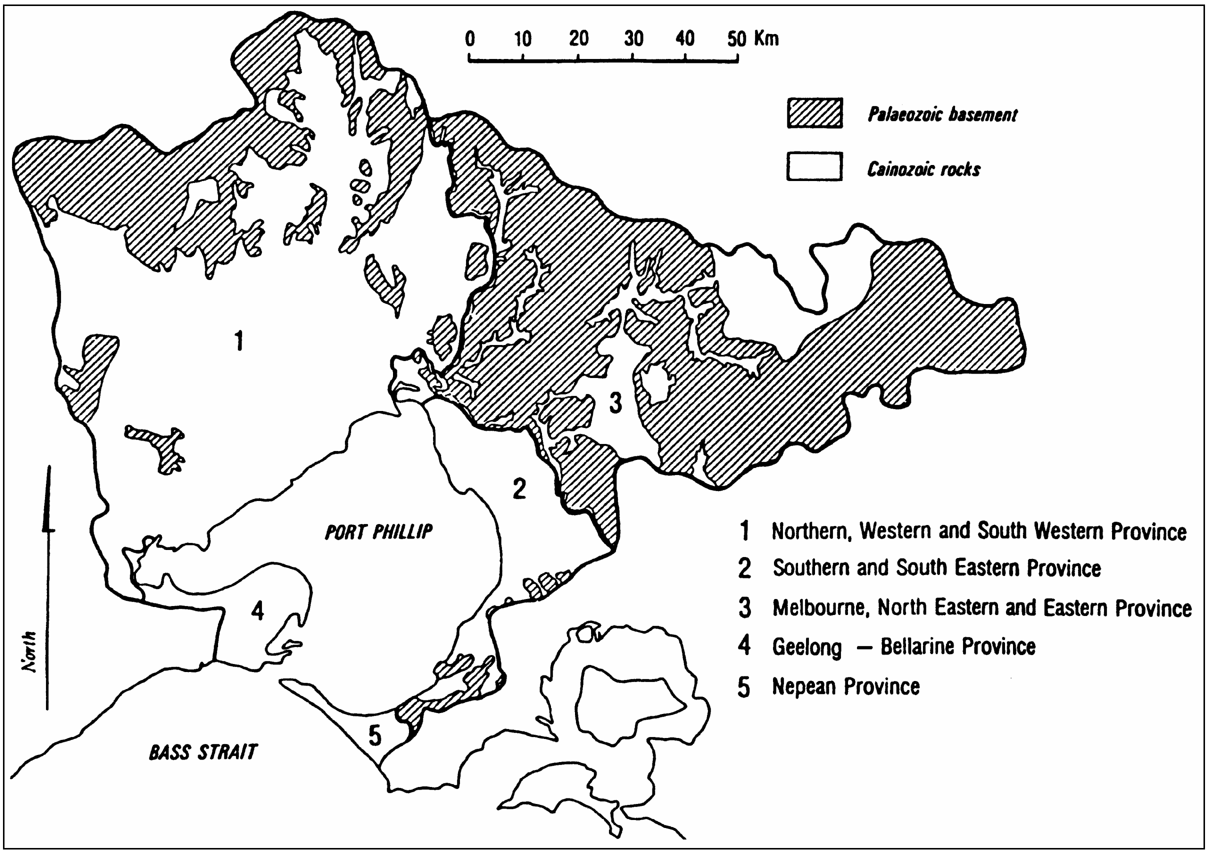

Figure 4 Hydrogeologic provinces of Melbourne (Lane *et al*, 1992)

Table 1. Principal Melbourne aquifers and typical properties (Leonard, 1992)

Aquifer	**Aquifer Depth** (m)	**Conf'd - Unconf. / ASR** ‡	**Depth to Water / thickness** † (m) / (m)	**Bore Yields** (L/s)	**Hydraulic Conduct-ivity** (m/day)	**Effective Porosity**	**Sust-ainable Yield** (ML/yr)
Werribee Delta	outcrop	UC-SC / P	3-10 / 5-40	up to 15 mostly <5	1-15 mostly 5	0.05-0.25 mostly 0.10	3,000
Yarra Delta §	<50	C / Sur	~5 / 15-20	~1-5	~5-10	~0.1-0.2	ID
Dune Deposits	outcrop	UC / NS	<5 / <6	<0.2	~1-5	~0.1-0.2	ID
Bridgewater Formation	mostly outcrop	UC / Sur	0.5-20 100-150	up to 25 mostly <10	5-30 mostly 10	0.15-0.35 mostly 0.2	5,000
Newer Volcanics	outcrop	UC-SC-C / P	5-50 10-100	up to 40 mostly <1	up to 35 mostly 1-6	0.01-0.3 mostly 0.02	14,300-24,200
Brighton Group (& equivalents)	0-80 mostly <50	UC-SC-C / NS	<30 5-30	up to 15 mostly <3	0.1-2 mostly <0.5	0.05-0.2 mostly 0.1	ID
Fyansford Formation	0-10	UC-SC-C / P	~5-20 / 15-85	up to 18 mostly <2	0.1-2 mostly 0.4	up to 0.3 mostly 0.10	17,500
Batesford Limestone	10-200 mostly <60	C / Inj	ID / 25-75	up to 30	2-15	up to 0.35	ID
Older Volcanics	0-60	UC-SC-C / P	2-40 / 5-60	up to 32 mostly <5	<2-10	~0.1-0.2	5,420
Werribee Formation	0-900	UC-SC-C / Inj	~5-20 / 10-250	up to 50 mostly 10-20	3-15 mostly 5	0.15-0.3 mostly 0.2	~14,340
Basement	0-1,000	UC-SC-C / NS	20-50 / >100	up to 32 mostly <1	0.02-1	0.02-0.1 mostly <0.1	ID

§ Also called the Moray St Gravel. ID Insufficient data. † Saturated aquifer thickness.
‡ Confined (C) / Semi-Confined (SC) / Unconfined (UC); ASR Potential – P possible, NS not suitable Sur surface basins, inj injection.

Table 2. Groundwater quality of principal Melbourne aquifers (Leonard, 1992)

Aquifer		pH	TDS (mg/L)	Cl (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)
Werribee Delta	min	7.8	500	362	59	<0.1	359	7	7
	max	9.5	6,000	4,470	743	39	2,473	102	395
	median	8.3	3,200	1,400	255	15	940	45	115
Bridgewater Formation	min	7.0	47	55	3	<0.1	11	8	1
	max	8.5	1,824	886	271	81	450	124	164
	median	7.9	635	185	25	15	102	45	65
Newer Volcanics	min	5.5	73	14	<1	<0.1	11	2	1
	max	9.0	25,000	9,400	1,884	61	5,384	1,223	851
	median	7.9	3,180	1,390	285	8.5	705	195	65
Brighton Group (& equivalents)	min	7.2	2,694	767	235	<0.1	764	58	25
	max	8.6	8,085	3,700	429	68	1,601	378	186
	median	7.6	4,265	2,090	270	4	1,135	215	110
Fyansford Formation	min	4.4	113	39	<1	<0.1	27	2	1
	max	8.6	6,868	4,146	265	96	1,365	362	217
	median	7.4	1,570	742	50	18	435	70	50
Older Volcanics	min	4.6	116	9	<1	<0.1	9	1	2
	max	8.7	4,919	2,890	283	29	671	2,111	211
	median	7.5	1,900	1,030	55	2.5	525	150	82
Werribee Formation	min	5.8	157	36	3	<0.1	100	3	1
	max	8.5	11,188	6,010	963	30	3,265	418	333
	median	7.7	4,090	2,120	275	4	1,200	245	100
Basement	min	4.5	94	7	<1	<0.1	5	1	<0.1
	max	8.7	2,769	819	46	16	266	92	143
	median	7.4	460	125	6	0.3	60	40	35

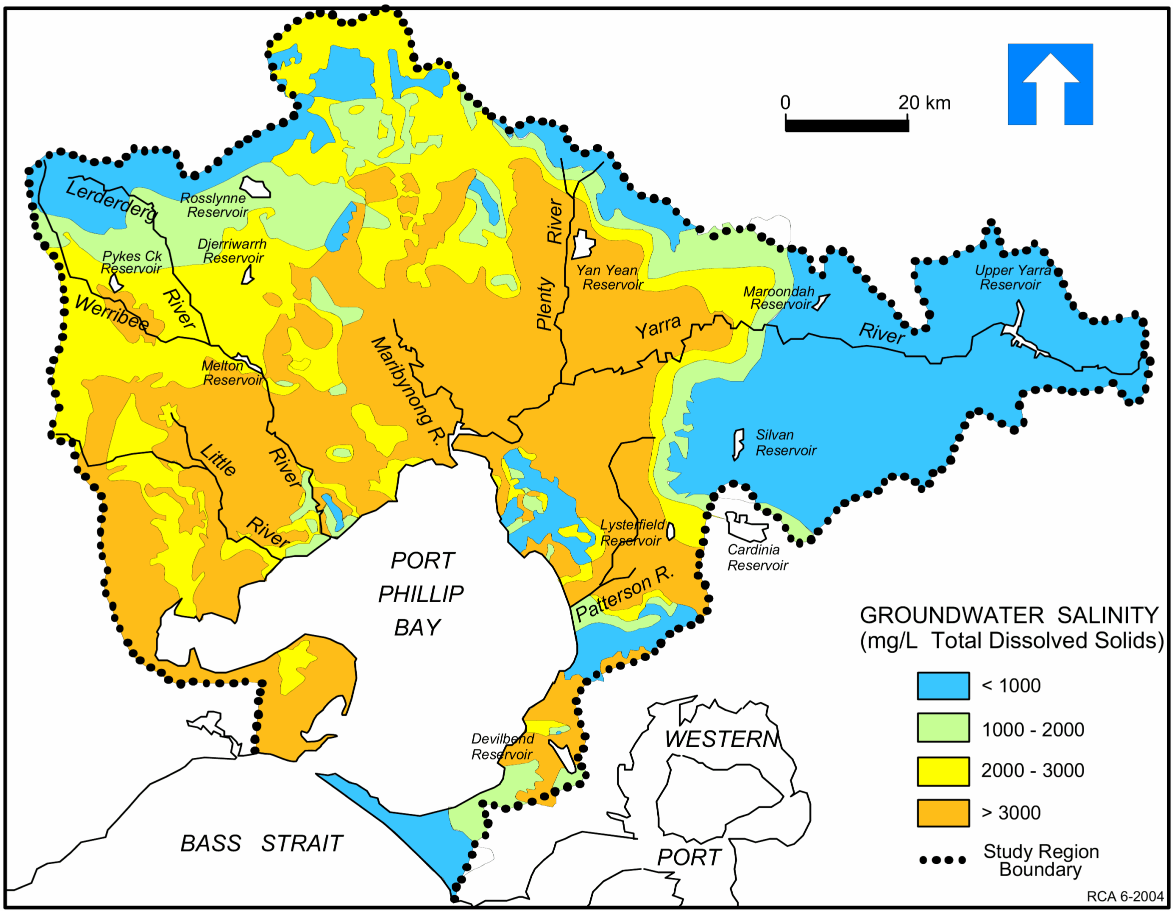

Figure 5 Groundwater salinity in the water table of Melbourne (redrawn from Leonard, 1992)

A major problem in some areas of Melbourne is the historic legacy of contaminated groundwater (Lane *et al*, 1992; Leonard, 1992; Evans, 1994; Finegan *et al*, 1998; O'Rourke & Shugg, 1998). For example, the Newer Volcanics basalt aquifers of western Melbourne are seriously polluted due to previous discharges of liquid industrial wastes, leaks and seepage. Other common sources include landfills, septic tanks and underground petroleum storage facilities. A major concern with this contaminated groundwater is that it discharges significant pollutant loads into Port Phillip Bay.

4. GROUNDWATER AND WSUD IN MELBOURNE

To date, there is no extensive use of groundwater within urban Melbourne. Given the need to find a more sustainable future water strategy, however, it is very likely that groundwater will rise very strongly in importance. There are many aspects of WSUD that either directly use groundwater or feature unresolved questions about the long-term effects on groundwater quantity and quality. Some examples of the connections between WSUD and groundwater in Melbourne are below.

4.1. WSUD and Water Infrastructure

As discussed previously, there are many large urban centres around the world which have seriously impacted their groundwater resources due to poor management and maintenance of primary water infrastructure, such as potable water and sewerage systems.

A case study of groundwater contamination by septic tanks at the regional Victorian towns of Benalla and Venus Bay was presented by Hoxley & Dudding (1994), although it is not possible to place any significance on this for Melbourne. There is some anecdotal evidence for sewer mains acting as both a source of groundwater contamination or as a sink for groundwater discharge (thereby affecting sewerage salinity, depending upon groundwater salinity). The Nepean Peninsula has had a problem with septic tanks contaminating groundwater (Lane *et al*, 1992). The overall performance of Melbourne's sewer system with regards to groundwater does not appear to be publicly documented.

Another major cause of groundwater degradation identified in overseas case studies is leaks from potable water infrastructure. This can dramatically increase the recharge rates to groundwater and cause rising water tables. Potable pipe leakage is not believed to be a widespread issue in Melbourne, but there is little public reporting on this aspect of urban water management. The recent re-organisation of the water industry in Melbourne has helped to achieve a 50% reduction in system losses over the past five years (ECITA, 2002). Although the leakage rate is generally considered minor and more of an economic issue, it may be a significant total volume nonetheless which could be locally important in low-lying areas and/or shallow water tables.

In certain parts of Melbourne, small scale groundwater extraction is undertaken for facilities such as golf courses. There is no technical reason, however, given the hydraulic properties and salinities of the various aquifers, that groundwater extraction could not be increased significantly in the future. This would most likely be for particular industries or farm irrigation, alleviating some pressure on potable supplies and infrastructure.

4.2. WSUD, Wetlands and Groundwater

The use of wetlands in urban design and development has increased significantly in recent years, primarily as a measure for stormwater control. The design of such wetlands is reasonably well understood, however, there is distinct lack of understanding of the hydrogeology of such systems – that is, surface water-groundwater interactions. In a recent project investigating these links, there was no specific groundwater monitoring data available for two wetlands examined in Melbourne's eastern and southeastern suburbs (Weil, 2004). At other Melbourne wetlands, there is emerging evidence of elevated nitrate during base flow (between storm events) which is thought to be related groundwater quality. This may be due to old, unused septic tanks in the area, another source, or natural processes. At present, there is no requirement to include groundwater monitoring bores as part of wetlands. To be sufficient, a minimum of three separate bores should be installed (depending on local hydrogeology).

4.3. WSUD and Aquifer Storage and Recovery (ASR)

The recent success of 'Aquifer Storage and Recovery' (ASR) in Adelaide, South Australia, has highlighted a promising new technique for integrating groundwater more fully into the urban water cycle across Australia (Dillon *et al*, 2002). The experience of ASR overseas is considerable (Hancock, 2000), and this should help to target the research focus and facilitate implementation in a range of scenarios.

In Melbourne, there are two principal directions for ASR – stormwater and reclaimed wastewater. The use of reclaimed wastewater is under active investigation at present, considering both major sewerage treatment plants at Werribee (Western Treatment Plant) and Bangholme (Eastern Treatment Plant). The consistent and high flow rates, which presently discharge most of their effluent to ocean outfalls, provide a basis for regular discharge and later extraction. A small project has recently commenced on investigating the feasibility of using stormwater and reclaimed water for ASR in Melbourne (pers. comm., P Dillon, CSIRO).

Based on the available aquifers and their storage characteristics, reviewed earlier, there are many sites potentially suitable for ASR across Melbourne. Before this occurs, however, there are many technical issues which need to carefully considered. This includes the potential for clogging of bores, buildup and potential mobilisation of contaminants (eg. heavy metals), aquifer permeability interactions with biogeochemistry and, most importantly, the setting of groundwater quality standards with respect to ASR (Hancock, 2000). This latter aspect will be a major determinant of the engineering feasibility of ASR across the various hydrogeologic zones of Melbourne. A key aspect of this issue is whether ASR systems could degrade groundwater quality in the long-term, either through pathogens, nutrients or other contaminants. Given the numerous applications of ASR overseas and increasingly within Australia and the remedies developed to address this issue (Hancock, 2000; Dillon, 2002), it should largely be one of thorough prior research and investigation and therefore not a regulatory barrier to implementation.

5. DISCUSSION & CONCLUSION

There is an increasing awareness of the importance of groundwater within the urban water cycle. In many large cities around the world this has been developed through a difficult pollution burden, while in others it has been achieved through necessity. For many of Australia's eastern urban regions, groundwater has often only been considered on a local scale when it has become polluted. Due to critical water supply problems, the potential future role for groundwater is now beginning to be appreciated more fully. A review of the hydrogeology of Melbourne shows significant variety in the hydraulic properties, depths to groundwater, water quality (salinity) and degree of pollution of aquifer systems. This suggests that prospective sites could be identified for various opportunities, such as aquifer storage and recovery (ASR), water supply and the groundwater-surface water links with wetlands. Research into this field in Melbourne is still in its infancy and clearly has a long way to move forward to achieve a significant impact on the urban water cycle of Melbourne. To address this knowledge gap, further detailed and site-specific information on soils, aquifer sediments and local hydrogeological conditions is clearly needed to facilitate these opportunities. In order to help move towards a sustainable urban water cycle, it is imperative that comprehensive groundwater data be collected, analysed and reported in much the same fashion as stormwater and other water-related data is now being publicly reported. A key issue is the need for thorough groundwater research and investigation so that long-term, sustainable performance can be addressed at the outset.

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