State and Condition of the Adelaide Plains Sub-Aquifers

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FOREWORD

South Australia's natural resources are fundamental to the economic and social well being of the State. One of the State's most precious natural resources, water, is a basic requirement of all living organisms and is one of the essential elements ensuring biological diversity of life at all levels. In pristine or undeveloped situations, the condition of water resources reflects the equilibrium between rainfall, vegetation and other physical parameters. Development of these resources changes the natural balance and may cause degradation. If degradation is small, and the resource retains its utility, the community may assess these changes as being acceptable. However, significant stress will impact on the ability of the resource to continue to meet the needs of users and the environment. Understanding the cause and effect relationship between the various stresses imposed on the natural resources is paramount to developing effective management strategies. Reports of investigations into the availability and quality of water supplies throughout the State aim to build upon the existing knowledge base enabling the community to make informed decisions concerning the future management of the natural resources, thus ensuring conservation of biological diversity.

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The deep Tertiary aquifer systems beneath the plains area of urban Adelaide (Adelaide Plains Sub-basin and Golden Grove - Adelaide Embayment aquifers) are experiencing increasing demand pressure as drought and rising costs for reticulated water make groundwater a more economically attractive option for water supply.

The Tertiary sedimentary aquifers constitute the largest and most important groundwater resource. The Quaternary aquifers are relatively thin and of limited extent. In recent years the first and second Tertiary aquifers have become the target aquifers for Aquifer storage and recovery (ASR) projects because of the favourable hydraulic and geological conditions.

The aquifer at greatest risk of over exploitation is the first Tertiary (T1) aquifer. A significant portion of this aquifer occurs as semi-confined or unconfined sandy aquifers in the northern and northeastern areas of the embayment.

Currently there are no management controls on the taking of groundwater from aquifers within the plains area of urban Adelaide.

Information available on groundwater usage indicates that annual extraction from the Tertiary aquifers in the mid-1980s was ~4,750 ML and 600 ML from fractured rock aquifers. All but 8 ML of the Tertiary aquifer extraction was considered to be from the T1 Aquifer.

In more recent years extraction from the T1 Aquifer by several western-suburb golf clubs and by industrial users has increased significantly. Currently, the larger golf clubs abstract an estimated 1,250 – 1,500 ML/y. Total current use is estimated to be between 6,000 and 10,000 ML/y.

ASR is also gaining greater acceptance as an alternative method to augment available water supplies.

It is suggested that the plains area of urban Adelaide should be considered for prescription to ensure the preservation and sustainable use of the Tertiary aquifer groundwater resources. The identified area falls within the Adelaide and Mount Lofty Ranges Natural Resources Management Board region. The water resource management issues have recently been administered largely by the Patawalonga and Torrens Catchment Water Management Boards.

The aquifer units of the Adelaide Plains sub-basin are laterally continuous with those in the Northern Adelaide Plains Prescribed Wells Area (NAP PWA). It would be appropriate, for effective management of the resource, to include the entire southern extent of this aquifer system under single prescription. Thus it is suggested that any newly prescribed area should join contiguously with the NAP PWA.

1. INTRODUCTION

The deep Tertiary aquifer systems beneath the greater urban area of Adelaide (Adelaide Plains Sub-basin and Golden Grove - Adelaide Embayment (Fig. 1) aquifers) are experiencing increasing demand pressure as drought and rising costs for reticulated water make groundwater a more economically attractive option for water supply.

A review of departmental records shows that over 700 wells to depths >25 m have been sunk during the past 10 years. In many cases groundwater is being sourced to meet industrial demands that require continuous supplies of water, and large drawdown cones are developing, indicating that the aquifer system cannot sustain this perpetual demand. The taking of water from these aquifers is currently unregulated and actual use volumes are not known nor reported. The Patawalonga and Torrens Catchment Water Management Boards are currently undertaking a preliminary survey of known users in an attempt to better quantify use.

Large irrigation users such as schools and golf courses are also tapping into groundwater supplies for irrigation purposes to reduce costs of mains water. Some golf courses that have traditionally used treated wastewater from Glenelg Sewerage Treatment Works are reviewing their options for water supply as a result of recent price increases to access treated waste-water.

ASR is also gaining some currency as a means to managing available water resources and reducing demand on piped water and unchecked, may result in unfavourable outcomes such as reactivation of disused or poorly abandoned wells where injection pressures result in artesian conditions.

The aquifer at greatest risk of over exploitation is the first Tertiary (T1) aquifer system in the Golden Grove - Adelaide Embayment (referred to hereafter as the Golden Grove Embayment) and Adelaide Plains Sub-basin. In order to ensure that the resource does not become over exploited it is recommended that appropriate management through prescription be introduced as soon as practical in order to ensure the long-term viability of this resource.

In recent months the Department has received well construction applications for industrial purposes seeking to take a total of 9,000 ML from groundwater supplies on an annual basis. These applications seek to take water from approximately the same location and target the same aquifer that is already experiencing large drawdown cones as a result of existing use. As the resource is unregulated there is no mechanism in place to effectively manage the taking of water in this locality to ensure all users, current and future, maintain an appropriate equity of use.

Whilst there are currently relatively few total users, problems concerning the long-term sustainability of this aquifer to meet demand in certain areas are emerging. Two areas, Thebarton and Wingfield, show long-term declines in groundwater levels of 0.5 and 0.7 m/y respectively. If it is deemed that this resource is of significant value to meet future demand such as ASR or underpinning the Water Proofing Adelaide strategy, then prescription may be warranted to manage the activities and the taking of water for the higher value use.

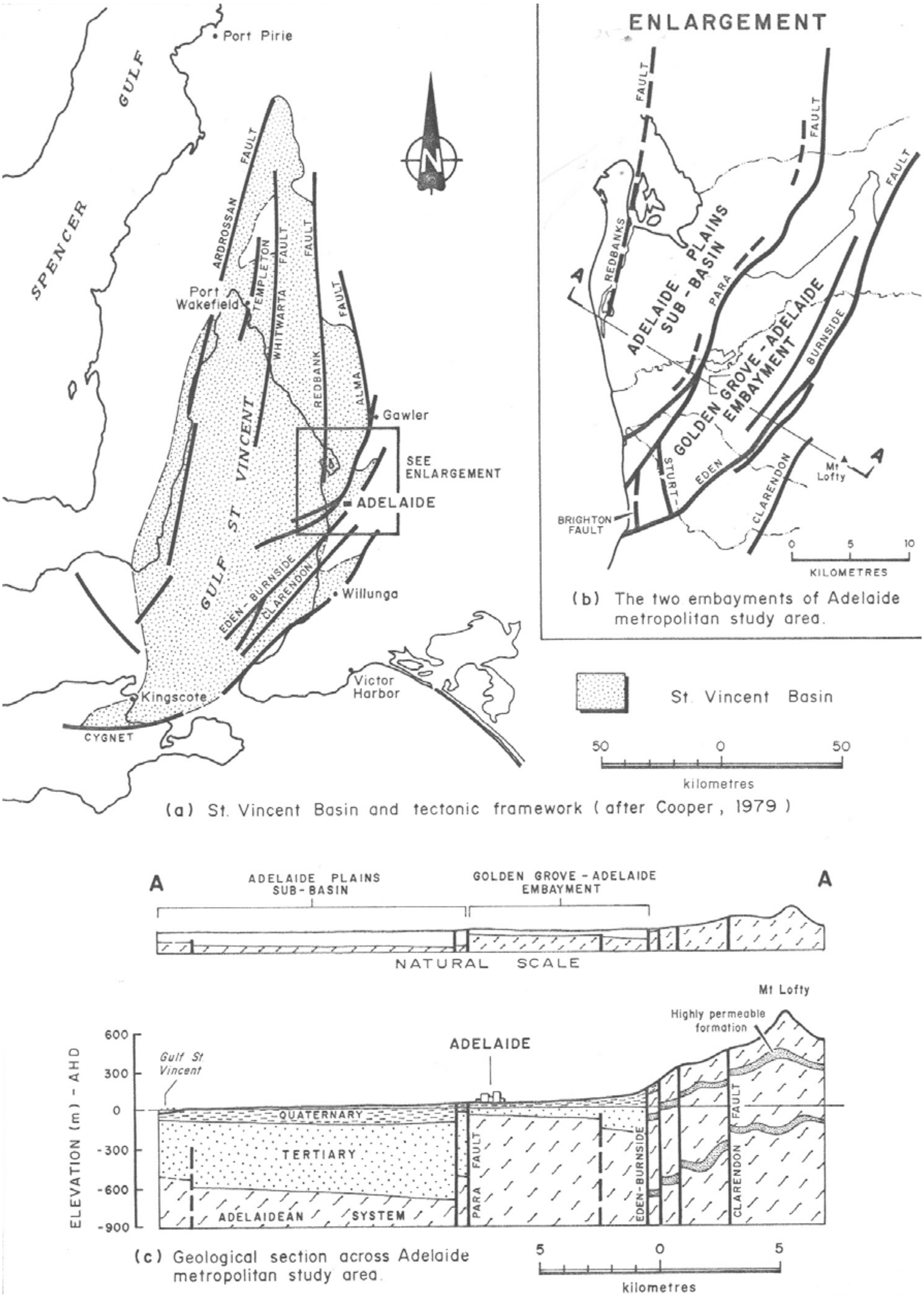


Figure 1 Physiographic features of the Adelaide Plains Sub-Basin and Golden Grove Embayment

2. HYDROGEOLOGY

The study area occupies ~560 km^2 of the Adelaide Coastal Plain and is divided geologically into the Golden Grove Embayment and the Adelaide Plains Sub-basin (Fig. 1). The plains are formed by Tertiary and Quaternary sediments up to 600 m thick and may contain up to ten aquifer systems, overlying a Precambrian fractured rock aquifer. Table 1 illustrates the various aquifer units across the two regions.

Throughout each embayment of the St Vincent Basin, the Tertiary sedimentary aquifers constitute the largest and most important groundwater resource. The hydrostratigraphy nomenclature is presented in Table 1 for the Adelaide Sub-basin and Golden Grove Embayment.

The Quaternary aquifers are relatively thin and of limited extent. Small-scale users, for stock and domestic purposes, have typically developed supplies from these aquifers in favourable areas.

The hydrostratigraphy of the Golden Grove Embayment is complicated by the degree of faulting and lateral facies changes present in the embayment. Several geological units thus often form a single aquifer system. A significant portion of the T1 Aquifer occurs as semi-confined or unconfined sandy aquifers in the northern and northeastern areas of the embayment.

The hydrostratigraphy of the Adelaide Plains Sub-basin uses the same nomenclature as the Golden Grove Embayment, but is less complex because of the greater aquifer continuity and uniformity. The Q4 Aquifer consists entirely of the sandy Carisbrooke Sand formation, which may be of late Tertiary age, and is often in direct hydraulic connection with the underlying T1 Aquifer.

The T1 Aquifer can be subdivided into two sub-aquifers, which, whilst often in direct hydraulic connection, have different lithological properties. The T1B Sub-aquifer is a sandy unit and requires well screening, whilst the T1B Sub-aquifer occurs as semi-consolidated or consolidated limestones. Many groundwater users, as a result of typically higher well yields and the ability to complete the well with an open-hole production interval, prefer the T1B Sub-aquifer.

On six occasions since 1915, it has been necessary to augment the metropolitan water supply with groundwater. The latest occasion was in the 1967-68 summer, when between 9,500 and 10,700 ML was pumped from Tertiary aquifers into the distribution system during a seven-month period.

Present extraction is estimated to be between 6,000 to 10,000 ML/y occurring from ~200 to 250 wells completed in the first Tertiary aquifer. Most of the water is used for industry, schools and recreation grounds. In more recent years the first and second Tertiary aquifers have become the target aquifers for ASR projects because of the favourable hydraulic and geological conditions.

Table 1. Stratigraphy and Hydrostratigraphy of the Adelaide Plains Sub-Basin and Golden Grove Embayment

Age		Golden Grove Embayment			Adelaide Plains Sub-Basin		
		Stratigraphy	Hydrostratigraphy	Description	Stratigraphy	Hydrostratigraphy	Description
Quaternary	Holocene	Semaphore Sand, modern alluvium and beach gravels	Unconfined Aquifer	thin sand aquifers restricted mainly to coastal areas	Semaphore Sand, modern alluvium and beach gravels	Unconfined Aquifer	thin sand aquifers near coast
					Saint Kilda Formation	Unconfined Aquifer	thin sand, shell aquifers near coast
	Pleistocene	Pooraka Formation	Aquitard		Pooraka Formation	Aquitard	
		Keswick Clay	Aquitard		Keswick Clay	Aquitard	
		Hindmarsh Clay	Aquitard, Q1 - Q5 Aquifers	predominantly clay aquitard with interbedded thin sandy confined aquifers	Hindmarsh Clay	Aquitard, Q1 - Q6 Aquifers	predominantly clay aquitard with interbedded thin sandy confined aquifers
Tertiary	Pleistocene / Pliocene?	Carisbrooke Sand	T1 Aquifer: Aquifer	thin sandy mainly confined aquifer with restricted extent	Carisbrooke Sand	Aquifer	confined sandy aquifer, most significant in eastern side of NAP PWA
	Pliocene	Hallett Cove Sandstone and Dry Creek Sand	T1 Aquifer: T1A Aquifer	thin sand y confined aquifer restricted to western areas	Dry Creek Sand	T1 Aquifer: T1A Aquifer	confined sandy aquifer, thickening to the south-west
		Croydon Facies	T1 Aquifer: T1A Aquifer	semi-confining bed	Croydon Facies	T1 Aquifer: T1A Aquifer	semi-confining bed
	Miocene to Oligocene	Port Willunga Formation: Upper Limestone	T1 Aquifer: T1B Aquifer	confined aquifer, mainly limited to area between Para Fault splinters	Port Willunga Formation: Upper Limestone	T1 Aquifer: T1B Aquifer	confined aquifer, thickening to south and south-west
		Port Willunga Formation: Munno Para Clay Member	Aquitard	confining bed limited to western areas	Port Willunga Formation: Munno Para Clay Member	Aquitard	confining bed, absent in north of NAB PWA
		Port Willunga Formation: Lower Limestone (Pirramimma Sand Member)	T1 or T2 Aquifer	confined aquifer , extent limited to south-west areas	Port Willunga Formation: Lower Limestone (Pirramimma Sand Member)	T2 Aquifer	thick confined aquifer, sandy and thinning in north and north-east of NAB PWA
		Port Willunga Formation: Ruwarung Member (Pirramimma Sand Member)	Aquitard	mainly confining bed, restricted extent	Port Willunga Formation: Ruwarung Member (Pirramimma Sand Member)		
		Port Willunga Formation: Aldinga Member (Pirramimma Sand Member)	T1, T2 or T3 Aquifer, Aquitard	variable sand and clay unit	Port Willunga Formation: Aldinga Member (Pirramimma Sand Member)		
	Eocene	Chinaman Gully Formation	T1, T2 or T3 Aquifer, Aquitard	variable sand and clay unit	Chinaman Gully Formation	T3 Aquifer Aquitard,	mainly a confining bed, minor occurrence as a thin sandy aquifer
		Blanche Point Formation	Aquitard	mainly confining bed	Blanche Point Formation	Aquitard	mainly confining bed
		Tortachilla limestone	T1 – T4 Aquifer	thin confined aquifer	Tortachilla limestone	T4 Aquifer	thin confined aquifer
		South Maslin Sand	T1 – T4 Aquifer	thin confined aquifer, thickest in the east areas	South Maslin Sand	T4 Aquifer	thin confined aquifer
		Clinton Formation	Aquitard	confining bed, restricted extent	Clinton Formation	Aquitard	confining bed, restricted extent
		North Maslin Sands	T1 - T4 Aquifer	thin confined sandy aquifer	North Maslin Sands	T4 Aquifer	confined sandy aquifer
Proterozoic		Undifferentiated Adelaidean	Fractured Rock Aquifer	mostly localised confined or semi-confined aquifers	Undifferentiated Adelaidean	Fractured Rock Aquifer	mostly localised confined or semi-confined aquifers

Modified from Hodgkin (2004)

2.1 Golden Grove Embayment

The Golden Grove Embayment is defined as that portion of the St Vincent Basin bounded by the Eden - Burnside and Para Faults (Fig. 1). The most recent detailed hydrogeological studies of the embayment have been by Gerges (1996; and 1999).

Tertiary and Quaternary sediments within the Golden Grove Embayment thicken to the southwest and reach over 400 m near the coast. However, they are typically only 10 to 100 m thick north and east of the Adelaide Central Business District and between 100 to 250 m thick south of it.

QUATERNARY AQUIFER

Within the Golden Grove Embayment, Quaternary aquifers generally occur as thin confined or semi-confined aquifers within sandy interbeds of the Pooraka Formation or Hindmarsh Clay. These formations are of a Pleistocene age and comprise largely mottled clay and silt of fluvial and alluvial origin. The aquifers have considerable variation in thickness (1–18 m) and extent. Thickness rarely exceeds two to three metres.

Gerges (1996) indicates that the Quaternary aquifers are not laterally extensive and there may be up to five units across the Embayment within the Hindmarsh Clay sequence. Wells intersecting these aquifers are generally low yielding (< 3 L/s) and variable, reflecting the low aquifer transmissivity and inhomogeneity. The most transmissive sections of these aquifers are usually located adjacent to major bedrock structures or surface drainage (for the shallowest aquifers).

The salinity of the Quaternary aquifers is also variable, ranging from <500 to ~3,500 mg/L TDS. The lower salinity areas usually correlate to the higher transmissivity areas described above. Use from these aquifers is generally confined to small domestic bores and the low yields preclude large industrial or irrigation use.

T1 AQUIFER

Within the Golden Grove Embayment, as within the Adelaide Plains Sub-basin, the T1 Aquifer is defined as the shallowest Tertiary aquifer system present. Within the embayment, the T1 Aquifer can consist of any one or several formations of the entire Tertiary sequence (Table 1).

Depending on the nature of the bounding faults, the T1 Aquifer in the Golden Grove Embayment can be hydraulically connected to fractured rock aquifers along the hills face zone and to Quaternary or Tertiary aquifers west of the Para Fault.

T2 AQUIFER

The T2 Aquifer is defined as the second Tertiary aquifer intersected, confined beneath the T1 Aquifer by an aquitard. Like the T1 Aquifer, it is well distributed throughout the Golden Grove Embayment and can consist of various geological units (Table 1), however, it is generally thinner than the T1 Aquifer.

The T2 Aquifer occurs mainly as a confined aquifer comprising sandy beds of the Chinaman Gully Formation and/or South Maslin Sand. The aquifer is relatively thin, ranging from about 3 to 15 m, but is effectively absent across a 5 km corridor extending from approximately the Adelaide Central Business District northeast towards Tea Tree Plaza.

T3 AND T4 AQUIFERS

The T3 Aquifer mainly consists of South Maslin Sand. It occurs at depths in excess of 190 m, is generally thin (< 10 m) and contains brackish to saline groundwater (salinities of the order of 2,000 to 16,000 mg/L TDS).

In the small area west of the inferred Brighton Fault, the T3 Aquifer comprises sandy beds of the Aldinga Member and Chinaman Gully Formation, whilst the T4 Aquifer occurs within South Maslin Sand. Fine-grained sediments of the Chinaman Gully Formation separate the aquifers.

FRACTURED ROCK AQUIFERS

Fractured rock aquifers within the Golden Grove Embayment predominantly occur within the fractured and quartz-veined shales, slates, siltstones and quartzites of the Burra Group formations. Most water wells within these aquifers occur in the northeastern parts of the embayment and along the western edge of the Adelaide Hills Face Zone where shallow depths of sedimentary cover and numerous faults enhance the well yield potential.

Within the embayment, the fractured rock aquifers can be unconfined or confined and in direct hydraulic connection with sedimentary aquifers west of the Para Fault and fractured rock aquifers east of the Eden - Burnside Fault.

2.2 Adelaide Plains Sub-Basin

The Adelaide Plains Sub-basin is the most extensive portion of the St Vincent Basin within the study area, extending from the Para Fault in the south and east to beyond the northern limit of the Northern Adelaide Plains Prescribed Well Area (NAP PWA). Schematic hydrogeological cross-sections of the NAP region are shown in Figures 2 and 3.

Quaternary and Tertiary sediments thicken to the south, reaching a maximum thickness of about 120 and 500 m respectively in the metropolitan area between the River Torrens and the Para Fault. The hydrostratigraphy of the sub-basin is much simpler than the Golden Grove Embayment because of the greater uniformity and extent of the key geological units (Fig. 4).

The most recent broad-scale investigations of the area include those by Evans (1990), Gerges (1996; 1999; and 2001) and Zulfic (2002). The following brief aquifer descriptions are sourced from these reports.

QUATERNARY AQUIFERS

In coastal margins, thin unconfined aquifers or perched watertable aquifers can occur within quartz-sand sediments of the Semaphore Sands or shelly sands of the St Kilda Formation. Small-scale stock and domestic users in areas of low salinity have predominantly accessed these aquifers. The aquifers can be in direct connection with the sea and consequently at risk of seawater intrusion.

In the western metropolitan area, up to six thin confined aquifers occur within the Hindmarsh Clay. These are designated Q1 to Q6 in order of increasing depth (Gerges, 1996). The Hindmarsh Clay consists of mottled clays and silts of fluviatile and estuarine origin. Within this sequence, the aquifers occur as interbeds of sand and gravel that range in thickness from 1 to 18 m, but are typically rarely thicker 2 m. The continuity and extent of individual aquifers is uncertain.

In the NAP region, a shallow perched Quaternary aquifer is present in the area between Virginia and Gawler River. Elsewhere, three Quaternary aquifers (Q1 to Q3) are generally recognised in the NAP region with thicknesses ranging from about 3 to 15 m. They can be quite discontinuous, as indicated by Evans (1990), with lateral extents <2,000 m. Overall, the thickness of the enclosing Hindmarsh Clay diminishes northwards and can be as little as 20 to 30 m near the northern limit of the NAP PWA. Clay generally underlies the Q3 Aquifer and forms a confining bed, however there are localised occurrences where the Q3 Aquifer is in hydraulic continuity with the underlying aquifer.

CARISBROOKE SAND AQUIFER

The Carisbrooke Sand Aquifer in the Adelaide Plains Sub-basin is a sandy confined aquifer that extends throughout most of the NAP region, but is absent within two to five km of the coastline north of St Kilda and in the western and northwestern metropolitan suburbs.

The Carisbrook Sand Aquifer averages ~20 m thickness, except near the Little Para River, where it is 40 to 60 m (Gerges, 2001). The aquifer consists of multi-coloured, poorly sorted, fine to medium-grained quartz sand and silt, with some clay and thin gravel beds (Zulfic, 2002). Wells within the aquifer are typically low yielding and require screening and extensive development to minimise the production of fine sands.

Over much of its extent, the aquifer has partial hydraulic connection with the underlying T1 Aquifer. However, in the northern and northeastern parts of the study area, the Q4 Aquifer directly overlies the T2 Aquifer.

T1 AQUIFER

The hydrostratigraphy of the T1 Aquifer in the Adelaide Plains Sub-basin is relatively simple and comprises the Hallett Cove Sandstone, Dry Creek Sand, Croydon facies and upper limestone units of the Port Willunga Formation above the Munno Para Clay Member. It has also been considered to include the Carisbrooke Sand where the units are in direct hydraulic connection. For consistency in reference the Carisbrooke Sand is deemed to constitute a 'separate' aquifer.

The T1 Aquifer is absent in the northern and northeastern areas of the NAP PWA and thickens to the south and southeast to attain a maximum thickness of about 100 to 110 m beneath the western suburbs of Adelaide.

The Hallett Cove Sandstone and Dry Creek Sand are of a shallow marine origin and comprise shelly, dark grey to brown sand, silt and clay, often highly fossiliferous (Gerges, 1996). In the Adelaide Plains Sub-basin, the shelly Dry Creek Sand underlies and inter-tongues with the Hallett Cove Sandstone. In the Dry Creek area, drilling beneath the Dry Creek Sand indicates the sequence becomes finer grained and silty (Drexel and Preiss, 1995). This sequence is known as the Croydon facies and is recognised elsewhere as typically fossiliferous and glauconitic silts and sands (Gerges, 1996).

The Hallett Cove Sandstone and Dry Creek Sand are generally considered as the T1A Sub-aquifer, as the Croydon facies has the potential to act in places as a weak semi-confining bed. However, detailed information on the extent of the Croydon facies and its hydrogeological nature is very limited (Zulfic, 2002).

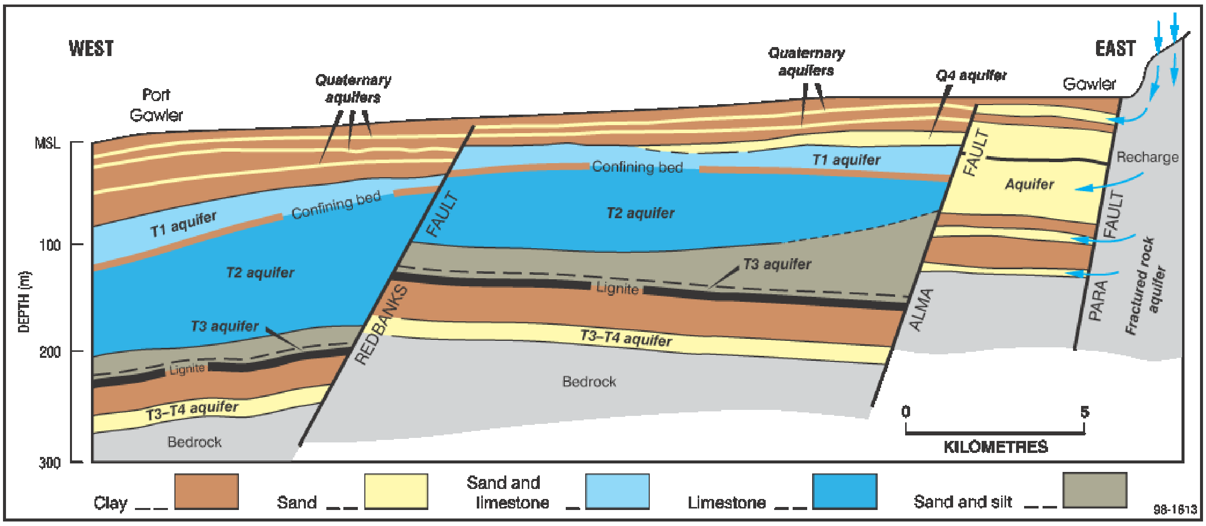


Figure 2. **Schematic Cross Section (East-West) of the Northern Adelaide Plains portion of the Adelaide Plains Sub-Basin (after Zulfic,2002)**

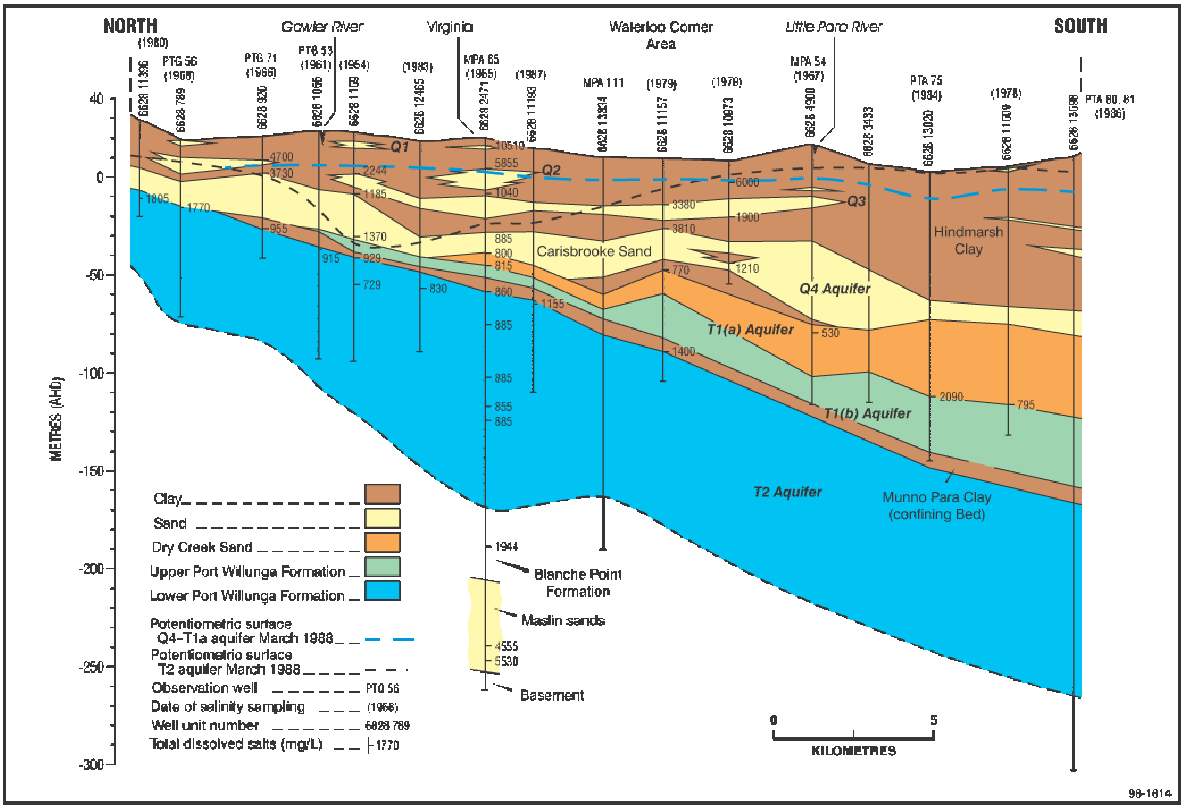


Figure 3. **Schematic Cross Section (North-South) of the Northern Adelaide Plains portion of the Adelaide Plains Sub-Basin (after Zulfic, 2002)**

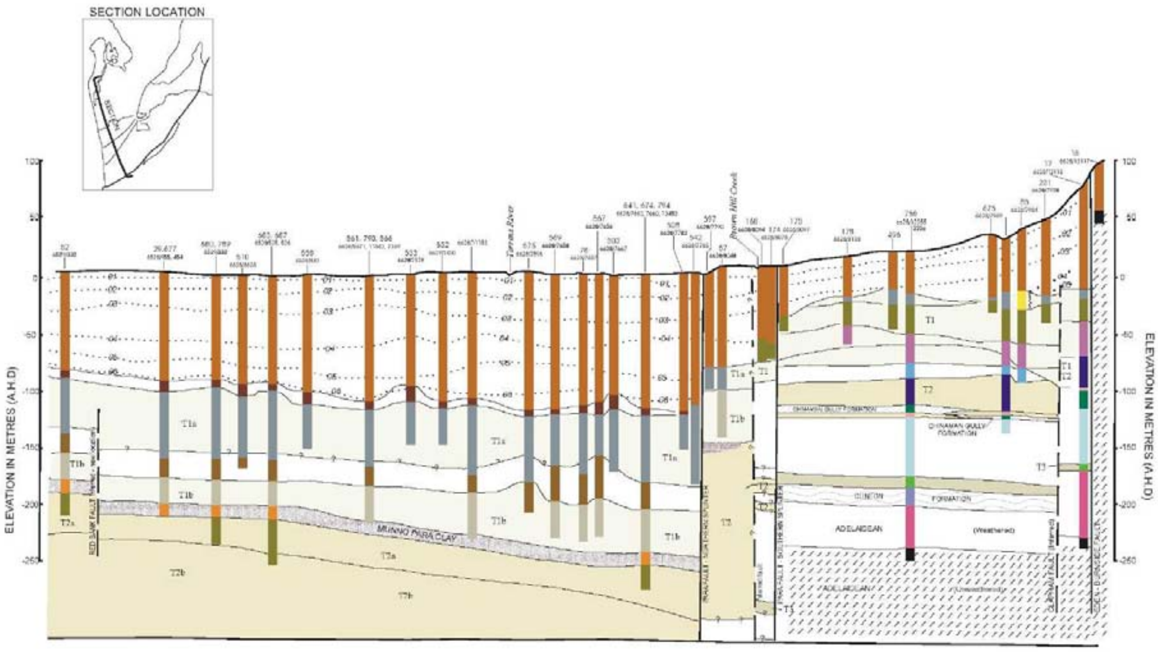


Figure 4. Schematic Cross Section (North-South) of the Adelaide Plains portion of the Adelaide Plains Sub-Basin and Golden Grove Embayment

The T1B Sub-aquifer consists of yellow fossiliferous sands and limestones of the Port Willunga Formation above the Munno Para Clay Member. It often enables high-yielding bores with open-hole production intervals, making it a preferred aquifer for industrial and horticultural users and ASR projects.

T2 AQUIFER

The T2 Aquifer in the Adelaide Plains Sub-basin is usually separated from the overlying T1 Aquifer by the Munno Para Clay Member; a highly effective confining bed of about 5 to 10 m thickness. The clay member consists of stiff blue-grey calcareous clay, often separated by two thin interbeds of white to grey limestone.

Throughout most of the study area, the aquifer consists of well-cemented limestones of the lower Port Willunga Formation. Gerges (2001) recognises three sub-divisions of the T2 Aquifer in the NAP region based on lithological characteristics:

- T2A Sub-aquifer – mostly pale-grey to white well cemented limestone/sandstone.
- T2B Sub-aquifer – a pale yellow to orange brown limestone/sandstone, friable to moderately cemented and occasionally interbedded with highly calcareous fossiliferous sand.
- T2C Sub-aquifer – mainly interbedded sand and very friable limestone with occasional silt and clay.

In the northeastern areas of the NAP PWA and within the Kangaroo Flat area, the T2 Aquifer consists mainly of quartz sand and minor clay (James-Smith and Gerges, 2001). These sands may represent the Pirramimma Sand shown in Table 1.

The T2 Aquifer thins to the north and northeast of Gawler River, where it ranges from about 20 to 70 m thickness. In this area, the Munno Para Clay Member is absent and Quaternary sediments directly overlie the aquifer.

In the metropolitan area, very few wells intersect the T2 Aquifer, whereas in the NAP PWA, the upper section of the T2 Aquifer forms the main groundwater supply.

T3 AND T4 AQUIFERS

Within the Adelaide Plains Sub-basin, the Ruwarung and Aldinga members of the Port Willunga Formation underlie the T2 Aquifer. Although limited intersections exist, these units are predominantly fine-grained marine sediments that act as confining beds with a combined thickness that ranges from about 50 to 150 m.

The T3 Aquifer is formed by sandy sections of the Aldinga Member or underlying Chinaman Gully Formation. It is relatively thin, being of the order of 5 m in the NAP region, and up to 20 m in the metropolitan area adjacent to the Para Fault.

The T4 Aquifer consists mainly of South Maslin Sand and occasionally North Maslin Sand (Gerges, 1996) and is separated from the overlying T3 Aquifer by thick confining beds of the Blanche Point Formation. The aquifer is well distributed in the study area but of uncertain thickness. South of the Little Para River, Gerges (1996, 2001) indicates thicknesses ranging from about 20 to 60 m.

Both the T3 and T4 Aquifers are saline; levels up to 80,000 mg/L TDS have been recorded in the deeper T4 Aquifer.

FRACTURED ROCK AQUIFERS

Fractured rock aquifers are generally not accessed in the study area portion of the Adelaide Plains Sub-basin due to the great thickness of overlying sediments, even immediately adjacent to the Para Fault.

However, in the northeastern parts of the study area, it is likely that Proterozoic basement rock occur at depths of <100 m.

2.3 HYDROGEOLOGICAL ZONES

Gerges (1996) subdivided the metropolitan area into several zones based on geological setting and the major groundwater extraction domains. These zones are shown in Figure 5 and have been simplified to show only a zonation based on geological settings.

As identified earlier, the hydrostratigraphy of the Golden Grove Embayment is complicated as a result of erosional and depositional boundaries, lateral facies changes and faulting. Consequently, multiple geological formations can be juxtaposed together and form effectively single aquifer systems, or result in aquifers laterally abutting against aquitards. The major fault systems are considered to be transmissive in many areas, permitting significant lateral groundwater throughflow from fractured rock aquifers in the Adelaide Hills westwards into the adjoining Tertiary aquifers (Gerges, 1996).

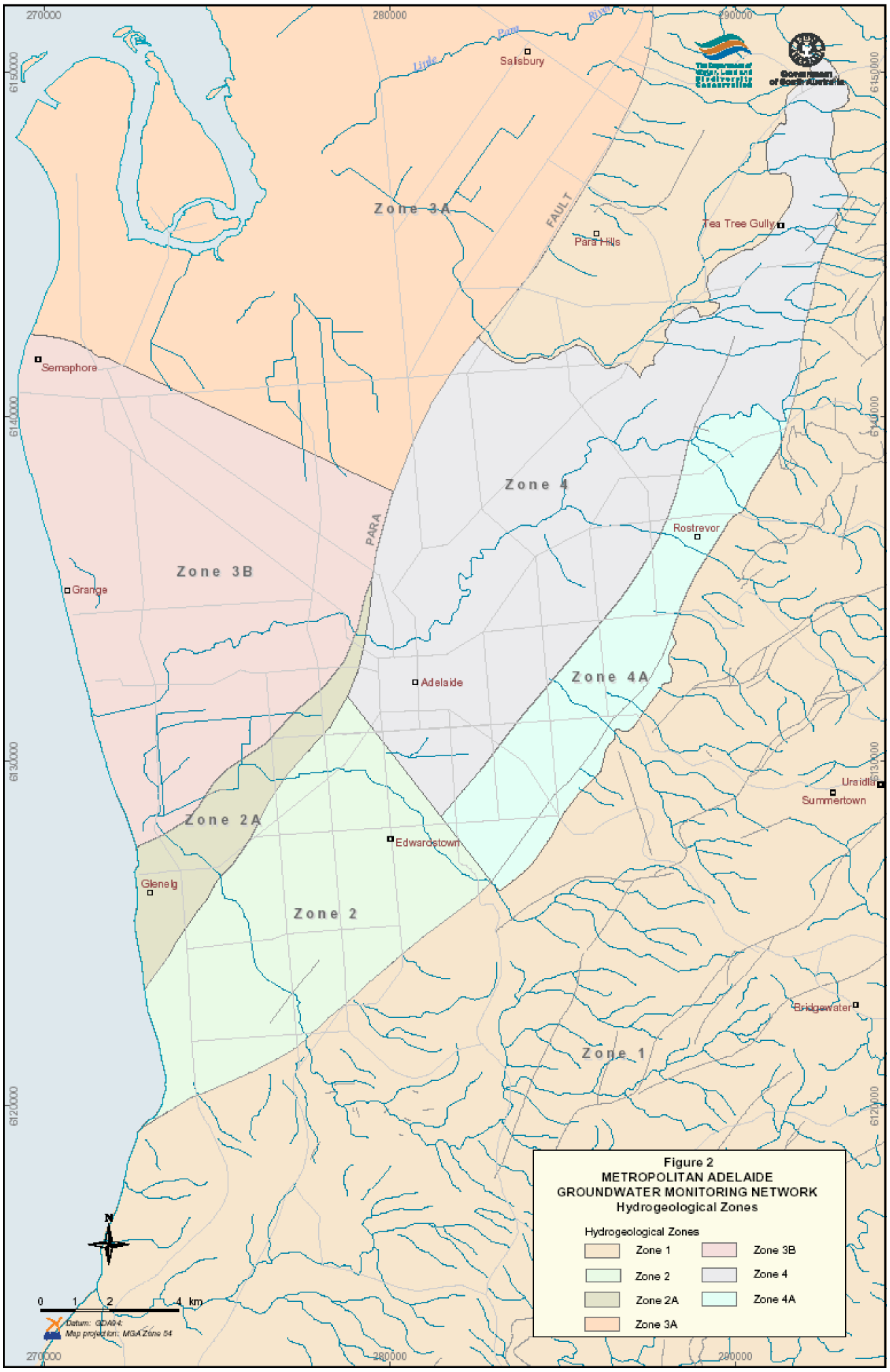


Figure 5. **Hydrogeological Zones of the Adelaide Plains Sub-basin and Golden Grove Embayment (after Gerges 1996)**

ZONE 1

This zone covers the basement rocks of the Adelaide Hills and contains fractured rock aquifers.

ZONE 2

This zone covers the area between Brown Hill Creek and Gulf St Vincent. It contains from two to four Quaternary aquifers and from two to four Tertiary aquifers. Only one of the two Tertiary aquifers is used significantly; the first aquifer (T1) consists mainly of highly permeable formations (sandy limestone) and contains water of low salinity. Major pumping occurs from this aquifer.

ZONE 2A

This hydrogeologically important, highly faulted zone connects Zone 2 with Zone 3. Limited information is available for the deep aquifers hence interpretation of major structures is speculative. Major features include up to four Quaternary aquifers and possibly three or four Tertiary aquifers.

ZONE 3

This zone contains five to six Quaternary aquifers and also three to four, almost flat lying, Tertiary aquifers. The first and second Tertiary aquifers are the thickest and the most productive, with relatively low salinity. The greatest proportion of abstracted groundwater for industrial and recreational use comes from the first Tertiary aquifer.

ZONE 4

This zone covers a large portion of the Golden Grove Embayment. It contains up to three Quaternary and two Tertiary aquifers, and a fractured rock aquifer. Each Tertiary aquifer consists mainly of thin layers of fine sand with low yield. Most of the Quaternary and Tertiary aquifers become thin, shallow and interconnected in the vicinity of the River Torrens. The shallow fractured rock aquifer near the River Torrens contains groundwater of low salinity and significant yield.

ZONE 4A

This zone is located between the Eden - Burnside Fault and the extension of the proposed Hope Valley Fault. It contains up to five Quaternary aquifers, one thick Tertiary aquifer (up to 130 m thick) and also one fractured rock aquifer.

This zone is interpreted to act as a conduit for surface infiltration and groundwater flow from the fractured rock aquifers of Zone 1 into Zone 2 and Zone 4.

3. GROUNDWATER MONITORING AND USE

There are currently 39 observation wells monitoring the various Quaternary aquifer systems (Fig. 6) in the Golden Grove Embayment and Adelaide Plains Sub-basin and 58 observation wells (Fig. 7) monitoring the first Tertiary aquifer. A recent survey of these assets has indicated that a number of the wells require basic maintenance and that some wells may need to be backfilled and replaced. The network has reduced over the past decade as a result of loss of access through land sub-divisions and a number of wells have been cemented over, as new landowners were unaware of the significance of the monitoring wells.

A program of works has been identified to secure access to many of the wells through easements to prevent ongoing losses of assets, and also to maintain and upgrade the network as required. The upgrade and maintenance of the metropolitan Adelaide groundwater-monitoring network will be carried out over the next several years as funding permits.

The groundwater resources of the Golden Grove Embayment and much of the urban area within the Adelaide Plains Sub-basin are not prescribed. Hence, an accurate database of recent groundwater extraction is unavailable. The most recent studies of groundwater extraction in these areas have been by Edwards et al. (1987) and Gerges (1996; and 1999).

The largest groundwater users in the metropolitan region in the past few decades have been industrial users, local government and schools for irrigation of reserves and sporting grounds and by golf clubs in the western suburbs. Industrial users include:

- Penrice Soda Products (Penrice), Osborne;
- Coopers Brewery, Regency Park;
- Samcor, Gepps Cross;
- Coca-Cola Amatil, Thebarton;
- Cadbury Schweppes, Payneham; and
- Hallett Bricks, Golden Grove.

The location of major groundwater users in the mid-1980s as identified by Edwards et.al. (1987) are shown in Figure 8. Excluding sites that occur within the NAP PWA (notably Penrice – Dry Creek Salt Fields operations), the Edwards et al. survey revealed that annual extraction from the Tertiary aquifers in the mid-1980s was about 4,750 ML and 600 ML from fractured rock aquifers. All but 8 ML of the Tertiary aquifer extraction was considered to be from the T1 Aquifer.

In more recent years extraction from the T1 Aquifer by several western-suburb golf clubs and by Penrice at their Osborne operation has increased significantly. Currently, the Riverside, Glenelg, Kooyonga, Grange and Royal Adelaide golf clubs abstract an estimated 1,250 to 1,500 ML/y. Total current use is estimated to be between 6,000 and 10,000 ML/y.

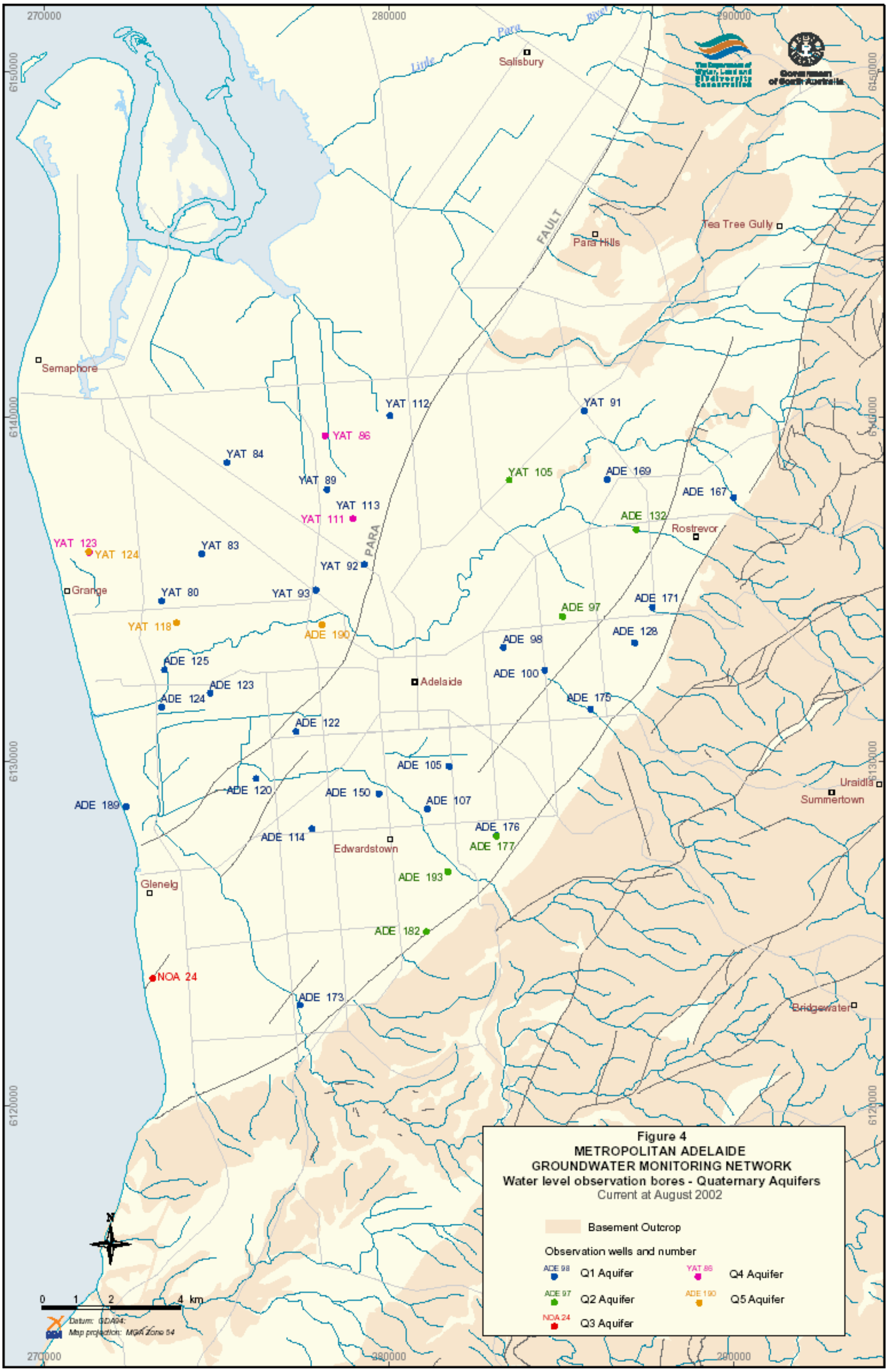


Figure 6. Quaternary Aquifer Systems Monitoring Well Network Locations

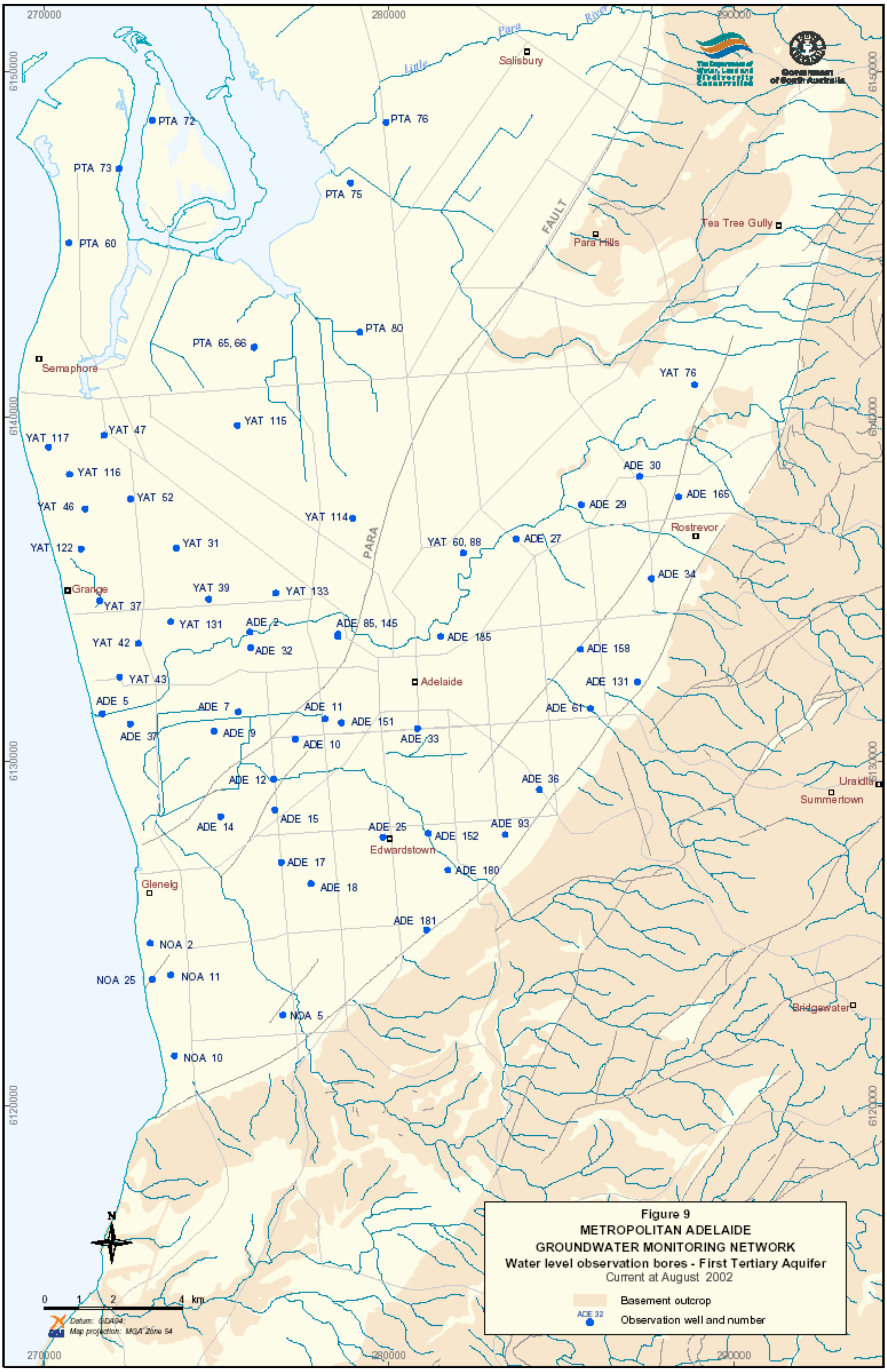


Figure 7. First Tertiary Aquifer Monitoring Well Network Locations

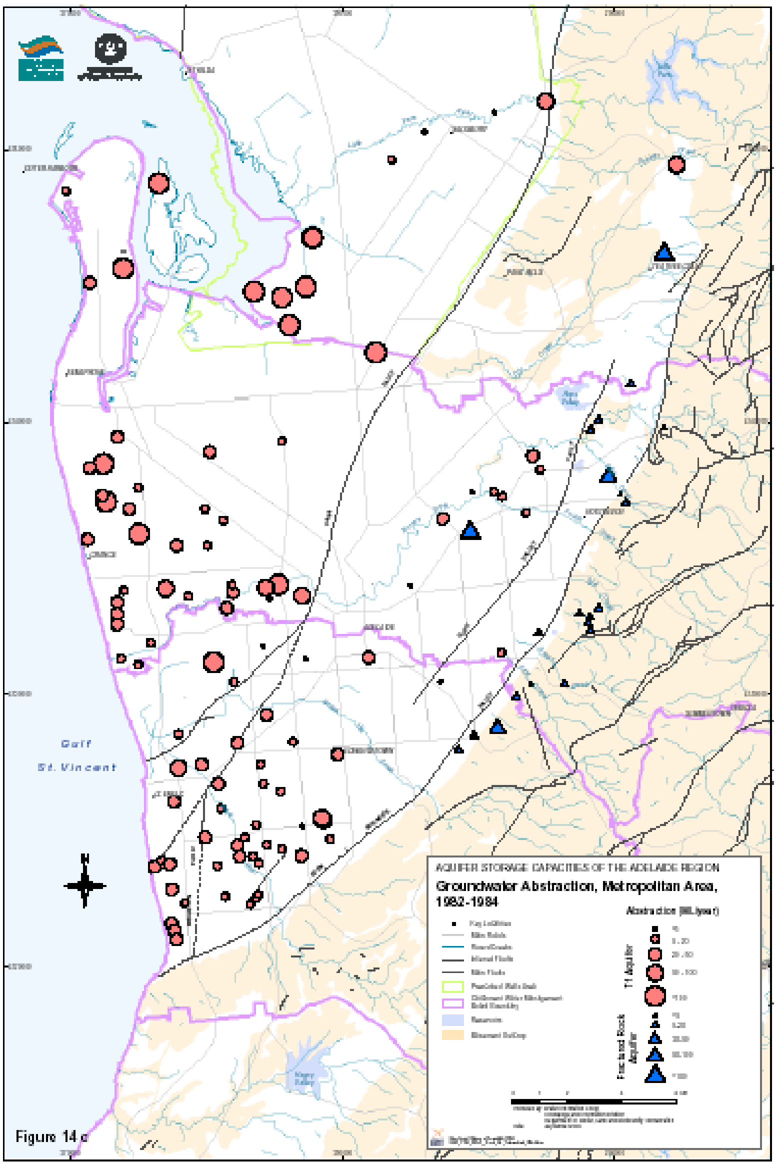


Figure 8. Location of known groundwater users (after Edwards et.al., 1987)

Current extraction from the T2 Aquifer in the Metropolitan area is considered limited. In the Regency Park area, where Regency Park Golf Course has undertaken minor extraction, and about 300 to 400 ML/year is extracted by Cooper's Brewery

T1 AQUIFER

Groundwater level contours for the T1 Aquifer for March 2003 are shown in Figure 9. The contours are considered to be only approximate due to the limited data available. However, they are reasonably consistent with regional groundwater flow patterns determined by Gerges (1999) for earlier periods.

Groundwater flow direction in the Golden Grove Embayment is predominantly westerly and not affected by any significant extraction. In northeastern areas of this embayment, where the T1 Aquifer is unconfined or semi-confined, groundwater levels and flow paths would be strongly controlled by the undulating topography present.

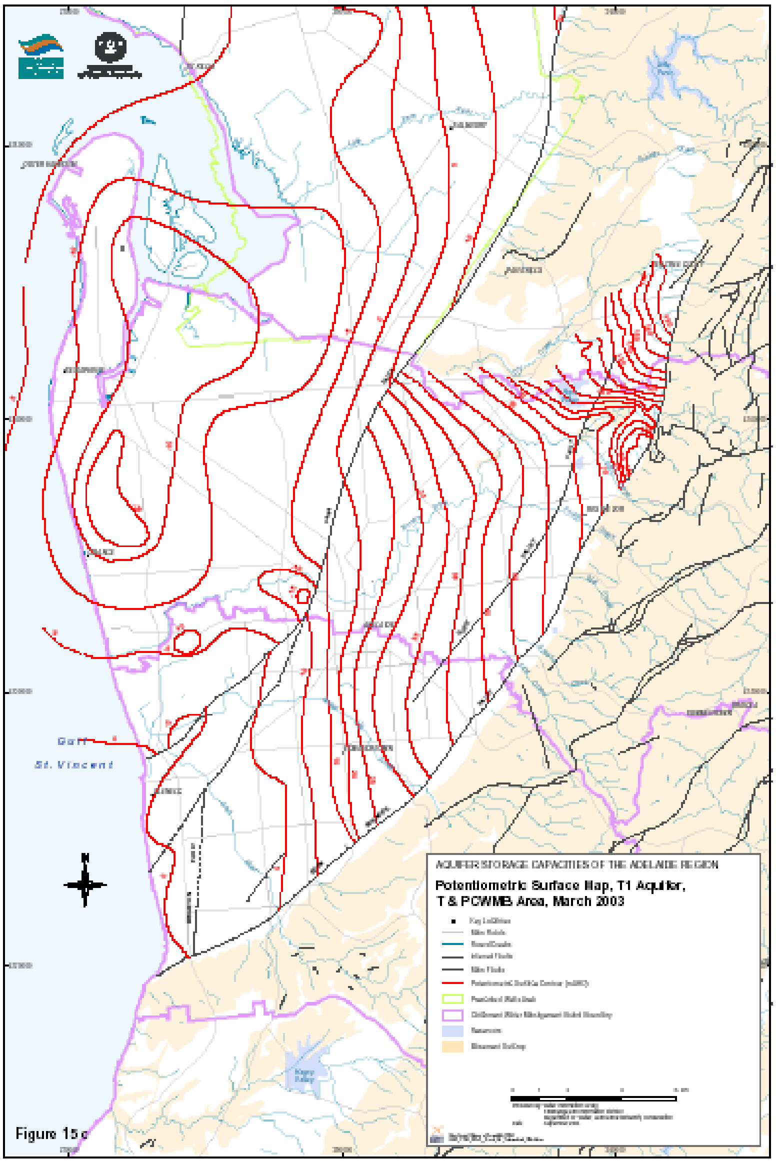


Figure 9. Potentiometric surface for T1 aquifer March 2003 (after Hodgkin 2004)

In the Adelaide Plains Sub-basin region a marked drawdown cone has developed as a result of the combined effects of:

- summer extraction by several golf clubs in the western suburbs;
- large-scale perennial extraction by Penrice at Osborne and the Dry Creek Salt Field operations; and
- extraction from the Thebarton industrial area.

Groundwater levels surrounding the golf course extraction centre recover by ~10 to 15 m during winter and spring but remain depressed around the industrial extraction centres as a result of the perennial pumping demand.

Another significant feature is the drawdown cone that has developed in the first Tertiary aquifer adjacent to the Para Fault in the Thebarton area. This drawdown cone currently at –15 m AHD is associated with the pumping demand by Coca Cola and Cooper's Brewery. Groundwater levels are not necessarily continuous across the Para Fault due to the juxtaposition of different aquifer and aquitard units. In some areas, the T1 Aquifer in the Golden Grove Embayment is considered hydraulically connected to Quaternary aquifers in the Adelaide Plains Sub-basin.

T2 AQUIFER

Groundwater levels for the T2 Aquifer at March 2003 in the metropolitan area are shown in Figure 10. There are few T2 Aquifer monitoring wells in the Golden Grove Embayment, consequently the contours are considered interpretive only in this area and are based partly on historical patterns (Gerges, 1999).

Within the Adelaide Plains Sub-basin part of the metropolitan area, groundwater levels indicate northerly flows resulting from the regional impacts of long-term extraction in the NAP PWA. A minor drawdown cone is thought to occur near Regency Park in response to extraction by Coopers Brewery in recent years. Winter-spring groundwater levels in the metropolitan area are similar to the summer-autumn levels.

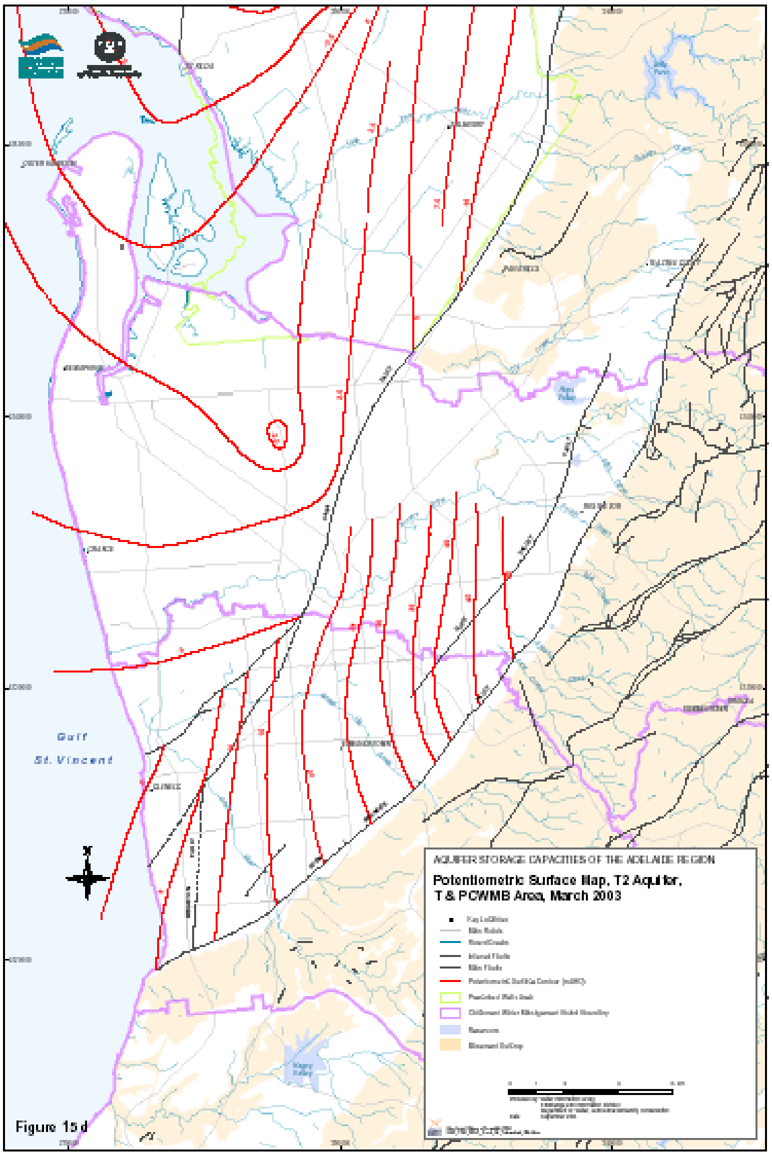


Figure 10. Potentiometric surface for T2 aquifer March 2003 (after Hodgkin 2004)

4. GROUNDWATER DEMAND & POTENTIAL RISK

A review of Departmental records indicates that over 700 wells to depths >25 m have been sunk in the past 10 years (Figs. 11a, 11b, 11c). The arbitrary cut-off depth of 25 m was selected with the expectation that most users would be completing wells in the deeper more highly prospective aquifer units. Indicative uses based on permit applications show that 460 wells were for domestic purposes, 20 wells for irrigation, 90 wells for industrial and 142 wells have no defined purpose on the application for a drilling permit.

The interest to source groundwater to meet industrial demand is of concern. Industrial demand is generally required throughout the year unlike irrigation demand, which is seasonal and; therefore, allows the aquifer a chance to recover during the winter period when not being pumped. The continuous industrial demand around Thebarton and Wingfield areas has resulted in perpetual drawdown cones that do not recover. Monitoring of adjacent observation bores has shown annual declines in groundwater levels of 0.5 and 0.7 m/y respectively for the past 20 years.

Currently there are no management controls on the taking of groundwater from aquifers within the Golden Grove Embayment or Adelaide Plains Sub-basin.

In recent months three applications seeking to take up to a further 9,000 ML of water for industrial use from the Tertiary aquifers have been received by the Department for consideration. These applications have been focused in areas where the major drawdown cones have already developed. As there are no management controls in place the Department has no means by which to effectively manage the resource and ensure equity of use for current and future demand is preserved.

ASR is also gaining greater acceptance as an alternative method to augment available water supplies. The recent Waterproofing Adelaide Strategy identifies ASR of stormwater as a viable mechanism to supplement Adelaide’s future water supply. However, if there are a large number of users taking groundwater, future ASR operations may be compromised, as it is unlikely that existing users would have wells appropriately constructed to withstand artesian conditions that may be generated through operation of a nearby ASR scheme. The scheme would have to be limited to sub-artesian injection pressures, thereby potentially reducing the storage capacity of the ASR scheme.

It is also apparent that as the unit cost for reticulated water increases then alternative sources such as groundwater become economically viable for large industrial and irrigation users.

Whilst there are currently relatively few total users, problems concerning the long-term sustainability of this aquifer to meet demand in certain areas are emerging. If it is deemed that this resource is of significant value to meet future demand, such as ASR or underpinning the Waterproofing Adelaide Strategy, then prescription may be warranted to manage the activities and the taking of water for the higher value use.

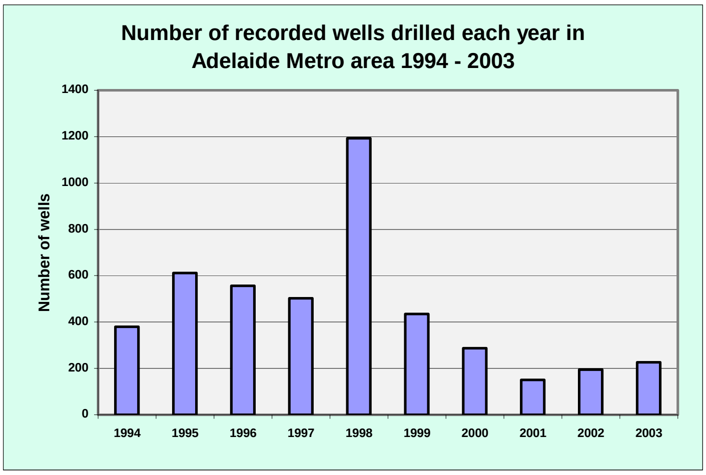


Figure 11a. Total number of recorded wells drilled per year in Adelaide Metro area

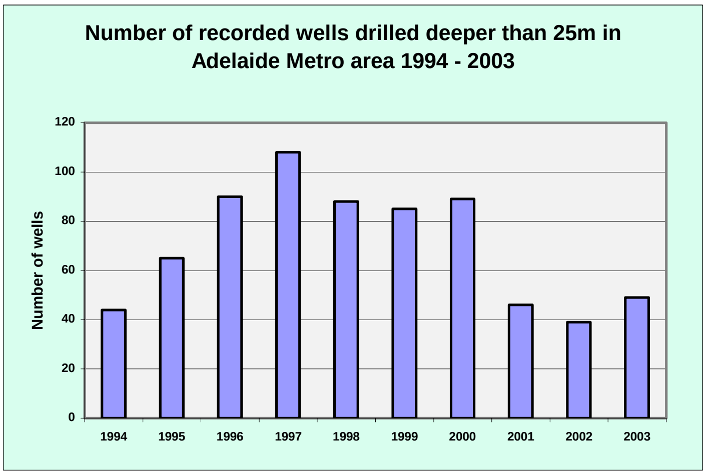


Figure 11b. Number of recorded wells drilled to depths greater than 25 metres

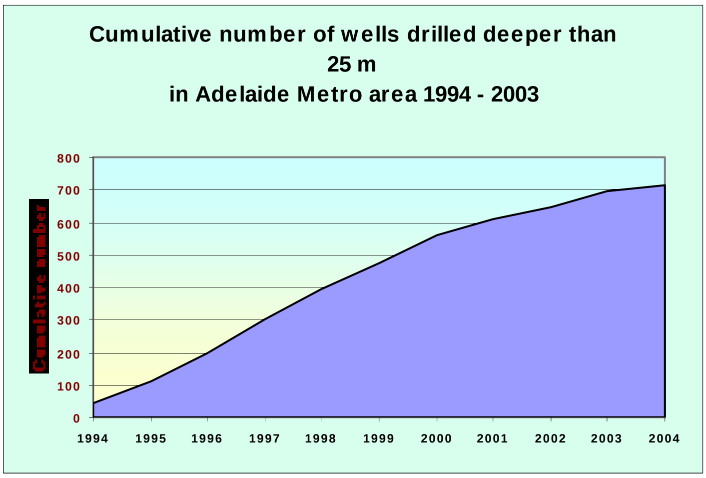


Figure 11c. Cumulative number of wells drilled to depths greater than 25 metres

5. PROPOSED AREA FOR PRESCRIPTION

It is suggested that the Adelaide Plains Sub-basin and the Golden Grove Embayment region (Fig. 12) should be considered for prescription to ensure the preservation and sustainable use of the Tertiary aquifer groundwater resources. The prescription should essentially incorporate all the aquifer units within this area, including the fractured rock aquifers of the Hills Face Zone.

The identified area falls within the Adelaide and Mount Lofty Ranges Natural Resources Management Board region. Water resource management issues were administered largely by the Patawalonga and Torrens Catchment Water Management Boards. A small area however, falls within the southeastern portion of the region administered by the Northern Adelaide and Barossa Catchment Water Management Board. It is recommended that effective management of the resource should not be constrained by these administrative boundaries.

The aquifer units of the Adelaide Plains sub-basin are laterally continuous with those in the NAP PWA and it would be appropriate for effective management of the resource to include the entire southern extent of this aquifer system for prescription. Thus any newly prescribed area should join contiguously with the current NAP PWA.

Past experience has demonstrated that if small adjoining areas are not included (e.g. Kangaroo Flat to the north of the NAP PWA, or Saunders Creek on the eastern Mount Lofty Ranges) at the outset, users quickly exploit these regions and they invariably become stressed. As users concentrate in these areas prescription inevitably results in later years at considerable cost and over-exploitation of the resource.

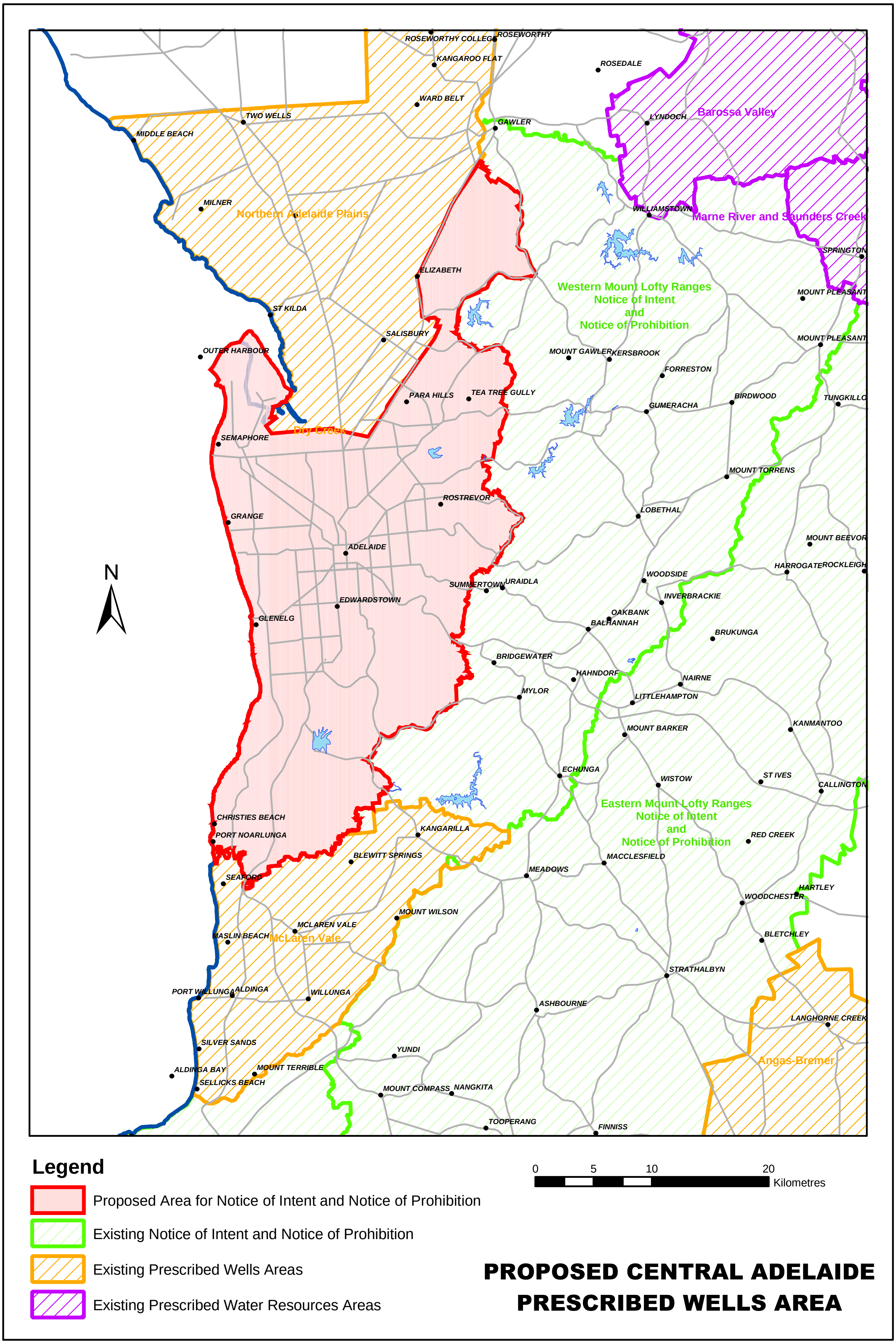
Consideration should also be given to extending the boundary to meet with the existing McLaren Vale PWA boundary. There is potentially a number of large irrigators (namely golf courses and schools) situated within this area which, if not already using or seeking to use groundwater, will soon do so as the unit price per kilolitre of mains water increases.

The proposed area should also adjoin to the proposed boundary of the Western Mount Lofty Ranges prescribed area to encapsulate the Hills Face Zone. The Hills Face Zone is considered to be an area of major recharge to the aquifer systems of the Adelaide Plains, and therefore incorporating this area into the prescription would ensure that the quality and quantity of recharge is preserved.

The sub-division of the Golden Grove Embayment and Adelaide Plains Sub-basin into hydrogeological zones provides a preliminary basis for the development of effective management policies to ensure that the resource is sustainable. Using these existing zones would also avoid potential concentrations of demand into small areas thereby preventing future stresses.

Next Page:

Figure 12. **Proposed area for prescription of Adelaide Plains Sub Basin and Golden Grove Embayment aquifer aystems (extending to adjoin McLaren Vale and the proposed Western Mount Lofty Ranges PWRA)**



Northern Adelaide Plains
Barossa Valley
Marne River and Saunders Creek
Western Mount Lofty Ranges Notice of Intent and Notice of Prohibition
Eastern Mount Lofty Ranges Notice of Intent and Notice of Prohibition
McLaren Vale
Angas-Bremer
Dry Creek
ROSEWORTHY COLLEGE
ROSEWORTHY
KANGAROO FLAT
ROSEDALE
WARD BELT
TWO WELLS
MIDDLE BEACH
GAWLER
LYNDOCH
MILNER
WILLIAMSTOWN
SPRINGTON
ELIZABETH
MOUNT PLEASANT
ST KILDA
SALISBURY
OUTER HARBOUR
MOUNT GAWLER
KERSBROOK
FORRESTON
PARA HILLS
TEA TREE GULLY
GUMERACHA
BIRDWOOD
TUNGKILLO
SEMAPHORE
MOUNT TORRENS
ROSTREVOR
LOBETHAL
GRANGE
ADELAIDE
MOUNT BEEVOR
HARROGATE
ROCKLEIGH
WOODSIDE
SUMMERTOWN
URAIDLA
INVERBRACKIE
EDWARDSTOWN
OAKBANK
BALHANNAH
GLENELG
BRUKUNGA
BRIDGEWATER
HAHNDORF
NAIRNE
MYLOR
LITTLEHAMPTON
KANMANTOO
MOUNT BARKER
ECHUNGA
WISTOW
ST IVES
CALLINGTON
CHRISTIES BEACH
PORT NOARLUNGA
KANGARILLA
RED CREEK
BLEWITT SPRINGS
MACCLESFIELD
MEADOWS
SEAFORD
HARTLEY
WOODCHESTER
MOUNT WILSON
MCLAREN VALE
MASLIN BEACH
BLETCHLEY
STRATHALBYN
PORT WILLUNGA
ALDINGA
WILLUNGA
ASHBOURNE
LANGHORNE CREEK
SILVER SANDS
YUNDI
ALDINGA BAY
MOUNT TERRIBLE
SELLICKS BEACH
MOUNT COMPASS
NANGKITA
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N
0
5
10
20
Kilometres
Legend
Proposed Area for Notice of Intent and Notice of Prohibition
Existing Notice of Intent and Notice of Prohibition
Existing Prescribed Wells Areas
Existing Prescribed Water Resources Areas
PROPOSED CENTRAL ADELAIDE PRESCRIBED WELLS AREA

6. CONCLUSIONS AND RECOMMENDATIONS

Whilst there are currently relatively few total users, problems concerning the long-term sustainability of the first Tertiary aquifer to meet demand in certain areas are emerging.

Two areas, Thebarton and Wingfield show long-term declines in groundwater levels of 0.5 and 0.7 m/y respectively. The large drawdown cones in the T1 Aquifer in these areas do not recover.

As the unit value of reticulated water increases, then large users will seek to source alternative water supplies. This is already apparent with recent applications for well construction totalling in excess of 9,000 ML/y.

Records indicate that over the past decade industrial demand has resulted in 90 new wells being established (a small number of these may be replacement wells).

Industrial demands pose significant long-term risks to the sustainability of aquifer systems, as the demand to meet industrial needs is a constant one whereas irrigation generally provides some opportunity for aquifer systems to recover in winter months.

Previous prescription of areas (eg NAP, Marne, Willunga Basin) have demonstrated that gaps left between areas are quickly exploited by users resulting in subsequent prescription of adjacent areas at considerable additional cost.

It is recommended that:

- If this resource is deemed to be of significant value to meet future demand such as ASR or underpinning the Waterproofing Adelaide strategy then prescription is warranted to manage the activities and the taking of water for the higher value use;
- Any prescription of the Golden Grove Embayment and Adelaide Plains Sub-basin should abut against (and ideally join with) the NAP PWA boundary; and
- Consideration should also be given to extending the boundary to meet with the existing McLaren Vale PWA boundary and also adjoin the proposed boundary of the Western Mount Lofty Ranges PWRA.

SHORTENED FORMS

Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^{6} m^{3}	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^{4} m^{2}	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^{3}	volume
kilometre	km	10^{3} m	length
litre	L	10^{-3} m^{3}	volume
megalitre	ML	10^{3} m^{3}	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^{3}	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^{3}	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	356 or 366 days	time interval

AHD	Australian Height Datum
ASR	Aquifer Storage and Recovery
NAP	Northern Adelaide Plains
PWA	Prescribed Wells Area
PWRA	Prescribed Water Resources Area
TDS	total dissolved solids (mg/L)

GLOSSARY

Act. The *Natural Resources Management Act 2004* (South Australia).

Aquifer. An underground layer of rock or sediment which holds water and allows water to percolate through.

Aquifer, confined. Aquifer in which the upper surface is impervious and the water is held at greater than atmospheric pressure. Water in a penetrating well will rise above the surface of the aquifer.

Aquifer, storage and recovery (ASR). The process of recharging water into an aquifer for the purpose of storage and subsequent withdrawal.

Aquifer test. A hydrological test performed on a well, aimed to increase the understanding of the aquifer properties, including any interference between wells, and to more accurately estimate the sustainable use of the water resource available for development from the well.

Aquifer, unconfined. Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure.

Aquitard. A layer in the geological profile that separates two aquifers and restricts the flow between them.

Artesian. Under pressure such that when wells penetrate the aquifer water will rise to the ground surface without the need for pumping.

Artificial recharge. The process of artificially diverting water from the surface to an aquifer. Artificial recharge can reduce evaporation losses and increase aquifer yield. *(See recharge, natural recharge, aquifer.)*

Basin. The area drained by a major river and its tributaries.

Bore. *See well.*

Catchment. A catchment is that area of land determined by topographic features within which rainfall will contribute to runoff at a particular point.

Catchment water management board. A statutory body established under Part 6, Division 3, s. 53 of the former *Water Resources Act 1997* whose prime function under Division 2, s. 61 is to implement a catchment water management plan for its area.

Catchment water management plan. The plan prepared by a CWMB and adopted by the Minister in accordance with Part 7, Division 2 of the former *Water Resources Act 1997*.

Cone of depression. An inverted cone-shaped space within an aquifer caused by a rate of groundwater extraction which exceeds the rate of recharge. Continuing extraction of water can extend the area and may affect the viability of adjacent wells, due to declining water levels or water quality.

Conjunctive use. The utilisation of more than one source of water to satisfy a single demand.

CWMB. Catchment Water Management Board.

Domestic purpose. The taking of water for ordinary household purposes and includes the watering of land in conjunction with a dwelling not exceeding 0.4 hectares.

EC. Abbreviation for electrical conductivity. 1 EC unit = 1 micro Siemen per centimetre (µS/cm) measured at 25 degrees Celsius. Commonly used to indicate the salinity of water.

Gigalitre (GL). One thousand million litres (1,000,000,000).

Groundwater. *See underground water.*

Hydrogeology. The study of groundwater, which includes its occurrence, recharge and discharge processes and the properties of aquifers. *(See hydrology.)*

Hydrology. The study of the characteristics, occurrence, movement and utilisation of water on and below the earth's surface and within its atmosphere. *(See hydrogeology.)*

Integrated catchment management. Natural resources management that considers in an integrated manner the total long-term effect of land and water management practices on a catchment basis, from production and environmental viewpoints.

Irrigation. Watering land by any means for the purpose of growing plants.

Megalitre (ML). One million litres (1,000,000).

Model. A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions. Examples include estimating storm runoff, assessing the impacts of dams or predicting ecological response to environmental change.

Natural recharge. The infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc.) *(See recharge area, artificial recharge.)*

PIRSA. (Department of) Primary Industries and Resources South Australia.

Potable water. Water suitable for human consumption.

Potentiometric head. The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer.

Prescribed area, surface water. Part of the State declared to be a surface water prescribed area under the Water Resources Act 1997.

Prescribed lake. A lake declared to be a prescribed lake under the Water Resources Act 1997.

Prescribed water resource. A water resource declared by the Governor to be prescribed under the Act, and includes underground water to which access is obtained by prescribed wells. Prescription of a water resource requires that future management of the resource be regulated via a licensing system.

Prescribed watercourse. A watercourse declared to be a prescribed watercourse under the Water Resources Act 1997.

Prescribed well. A well declared to be a prescribed well under the Water Resources Act 1997.

PWA. Prescribed wells area.

PWCA. Prescribed watercourse area.

PWRA. Prescribed water resource area.

Recharge area. The area of land from which water from the surface (rainfall, streamflow, irrigation, etc.) infiltrates into an aquifer. *(See artificial recharge, natural recharge.)*

Stock Use. The taking of water to provide drinking water for stock other than stock subject to intensive farming (as defined by the Act).

Surface water. (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir.

To take water. From a water resource includes (a) to take water by pumping or syphoning the water; (b) to stop, impede or divert the flow of water over land (whether in a watercourse or not) for the purpose of collecting the water; (c) to divert the flow of water in a watercourse from the watercourse; (d) to release water from a lake; (e) to permit water to flow under natural pressure from a well; (f) to permit stock to drink from a watercourse, a natural or artificial lake, a dam or reservoir.

Underground water (groundwater). Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground.

Volumetric allocation. An allocation of water expressed on a water licence as a volume (e.g. kilolitres) to be used over a specified period of time, usually per water use year (as distinct from any other sort of allocation).

Water allocation. (a) in respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence; (b) in respect of water taken pursuant to an authorisation under s. 11 means the maximum quantity of water that can be taken and used pursuant to the authorisation.

Waterbody. Waterbodies include watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers.

Watercourse. A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; and a lake through which water flows; and a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse.

Well. (a) an opening in the ground excavated for the purpose of obtaining access to underground water; (b) an opening in the ground excavated for some other purpose but that gives access to underground water; (c) a natural opening in the ground that gives access to underground water.

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