Pakenham East Precinct – Groundwater Study

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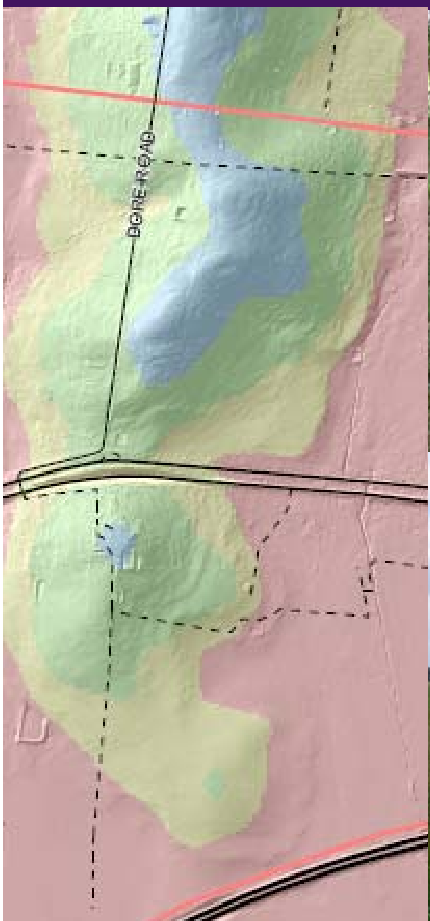

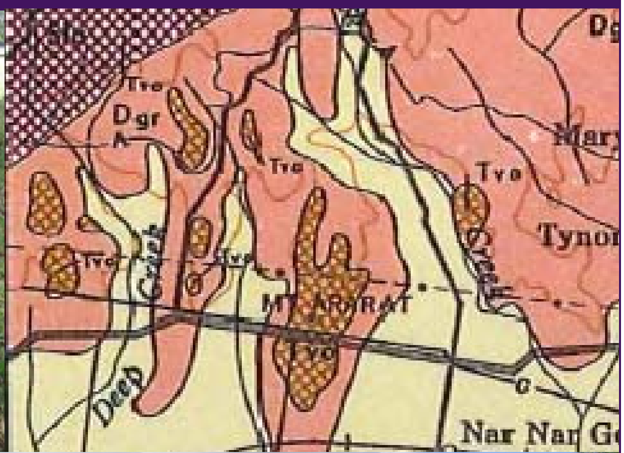

Pakenham East Precinct – Groundwater Study

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Executive summary

Cardinia Shire Council engaged Sinclair Knight Merz to undertake a groundwater study of the Pakenham East Precinct. The Precinct is part of an extension to the Melbourne Urban Growth Boundary announced by the Victorian Minister for Planning in June 2012.

A review of groundwater conditions onsite was completed through assessment of existing reports and data. Reviewed water level data was confirmed with water level data collected during a site visit to local groundwater bores.

Site hydrogeology

The watertable aquifer of the Pakenham East Precinct is comprised of shallow Quaternary alluvials. Water levels are typically around 1 to 2 m below the surface, with the depth to water increasing as elevation rises. Groundwater salinity in the watertable aquifer on the site is expected to range between around 6,000 and 8,500 µS/cm. The regional groundwater flow is north to south, with the site sitting on the boundary between the Westernport Plain Intermediate and Regional Flow System and the Granitic Rocks Local and Intermediate Flow System (Dahlhaus et al., 2004).

Groundwater risks

- Water logging has been identified as the major groundwater risk to the site. Waterlogging of lower lying areas on the plain is a common problem in the wetter months. SKM (2005) rated the eastern half of the study area as 'highly constrained' for development due to shallow groundwater level.
- The Pakenham East Precinct has been rated as a high salinity risk (CLPR 2002) due to shallow groundwater levels. Land salinity has been observed in the area, and it has relatively successfully been managed by the planting of salt tolerant vegetation.
- Acid sulphate soils are not predicted to be of particular concern on the site, however the risk should be monitored if any large developments are planned for the site.

Recommendations

- The potential impact on groundwater level from the effect of development on groundwater recharge at the site should be considered during development design.
- Development at the site should account for watertable depths ranging from1.5 m below the surface of the plain, to 0.5 m in the topographical lows during winter and spring.
- A range of groundwater risk mitigation and management measures to address the issues associated with shallow groundwater levels should be implemented across the site, depending on the type and scale of development planned.
- Additional groundwater monitoring bores are recommended to be installed in specific locations across the site to address data gaps.
- Quarterly monitoring of water levels and annual monitoring of water quality (salinity) is recommended for the new groundwater bores and the existing bores on the site.

1. Introduction

1.1 Project context

Cardinia Shire Council engaged Sinclair Knight Merz (SKM) to undertake a groundwater study of the Pakenham East Precinct, located around 60 km south east of Melbourne on the Princes Highway in Victoria. The Precinct is part of an extension to the Melbourne Urban Growth Boundary announced by the Victorian Minister for Planning in June 2012. The site, the majority of which is currently farmland, has been identified as a future residential precinct, proposed to include a Neighbourhood Activity Centre and associated community facilities.

This study forms a background report to the Pakenham East Precinct Structure Plan (PSP), which will culminate in a Planning Scheme Amendment for the area.

1.2 Study objectives

The objective of this study was to describe the groundwater conditions at the Pakenham East Precinct site, particularly groundwater levels, and to advise Cardinia Shire Council on the implications of these conclusions for development in the Precinct.

The main tasks undertaken in this project include:

- Review existing reports, maps and databases to gather information on the study site.
- Undertake a site visit to gather water level data from local groundwater bores.
- Identify the groundwater related risks associated with development at the study site.
- Report on findings and recommend future actions to manage groundwater risks.

2. Site overview

2.1 Site location

The Pakenham East Precinct study site is located around 5 km to the east of Pakenham town centre. The site is bordered on the south by the Princes Freeway, to the west by Ryan Road, and to the east by Mt Ararat Road (Figure 2-1). The Princes Highway runs through the centre of the site along an east-west alignment.

2.2 Land use

The majority of the study area is currently zoned as farm land, with a small section on the western boundary which is a low density residential zone (DPI 2012b).

2.3 Topography and surface water features

The study area sits in the Bunyip River Catchment, with the topography generally rising from the Westernport Plain in the south to the foothills of the Great Dividing Range in the north. Figure 2-2 shows the study area with local topographical contours. A ridge bisects the site from the north with local peaks lying off the western and eastern boundaries of the site, creating two north-south aligned valleys running down the western and eastern halves of the site. The maximum elevation on the site is over 110 m AHD on the top of the ridge, falling away to around 30 m AHD on the southern site boundary.

Deep Creek, which runs along the western boundary, also lies in the western valley topographical low. This water course, which is a tributary of the Toomuc Creek, is gauged on the western boundary of the site (gauging station 228363A). The minor water course of Hannock's Gully cuts through the site north to south, forming the eastern valley.

A number of farm dams are sited within the study area, with surface areas under 0.6 hectares. There are also three large water storages in the area; a large farm dam on the northern site boundary of around 2.8 hectares, a dam and a lake off the eastern and western boundaries of around 2.1 and 3.1 hectares respectively, and a South East Water treated water storage pond off the southwest corner of the study area of around 17 hectares surface area. Irrigated cropping occupies the land surrounding the larger water storages.

2.4 Groundwater management

The Koo Wee Rup Water Supply Protection Area (WSPA) covers the Pakenham East Precinct study site below the Princes Hwy (Figure 2-3). WSPAs are set up to manage groundwater aquifers in areas of heavy groundwater use, in order to assure the long term sustainable use of the resource. No WSPA or GMA covers the study area above the Princes Hwy. The maximum amount of groundwater licensed for pumping (the Permissible Consumptive Volume – PCV) for this WSPA is currently 12,915 ML per year (stock and domestic bores are excluded from extraction licensing limitations).

Groundwater use in the catchment has diminished since a peak in the 1970s and early 1980s where the water supplied crop and pasture irrigation (SKM 2008a).

There are thought to be at least two registered groundwater bores currently used for consumptive purposes (stock watering) on the study site. It is unknown how much water these bores consume annually, although given the stock watering use, the volume is expected to be low (<5 megalitres per year).

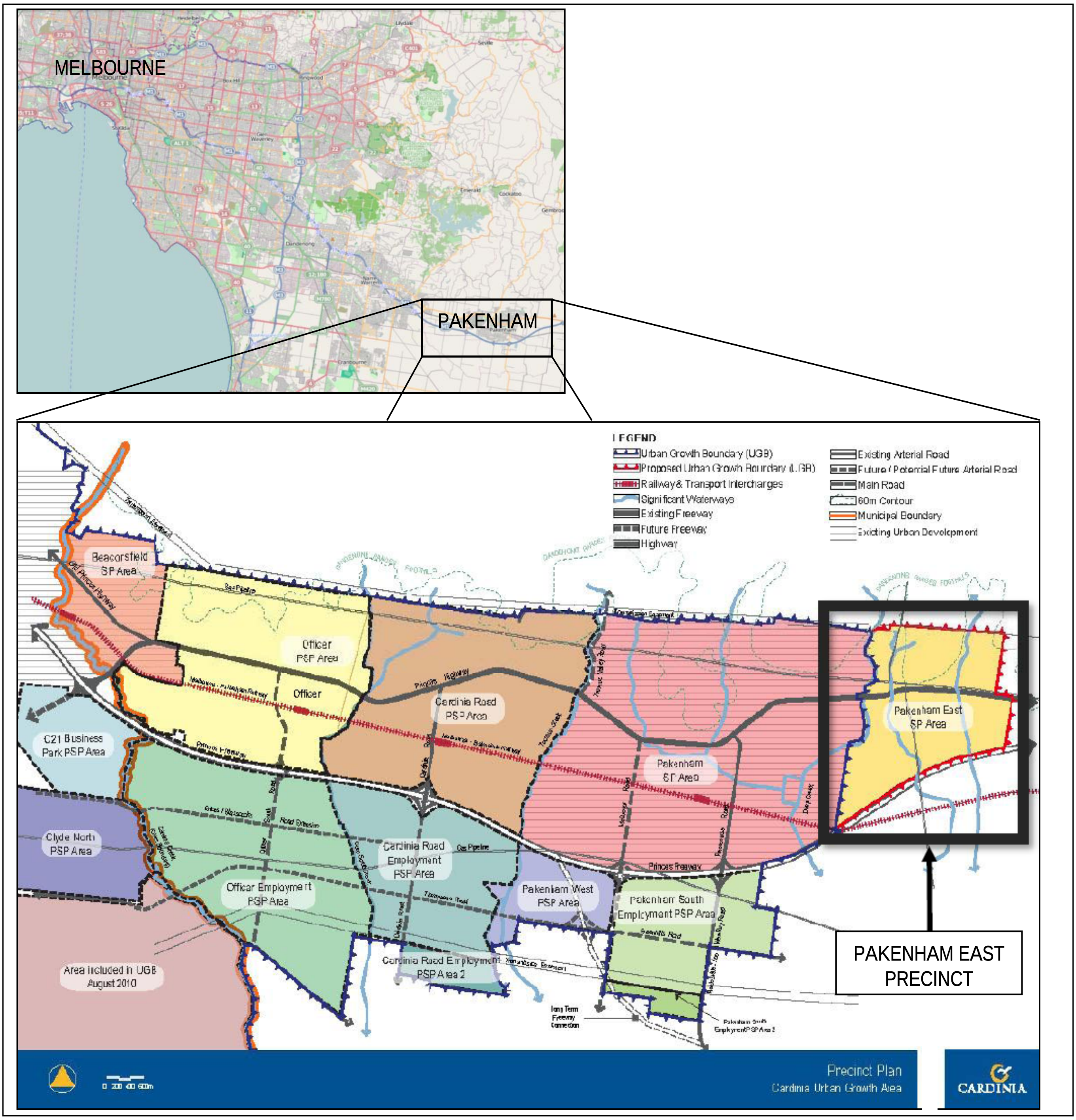
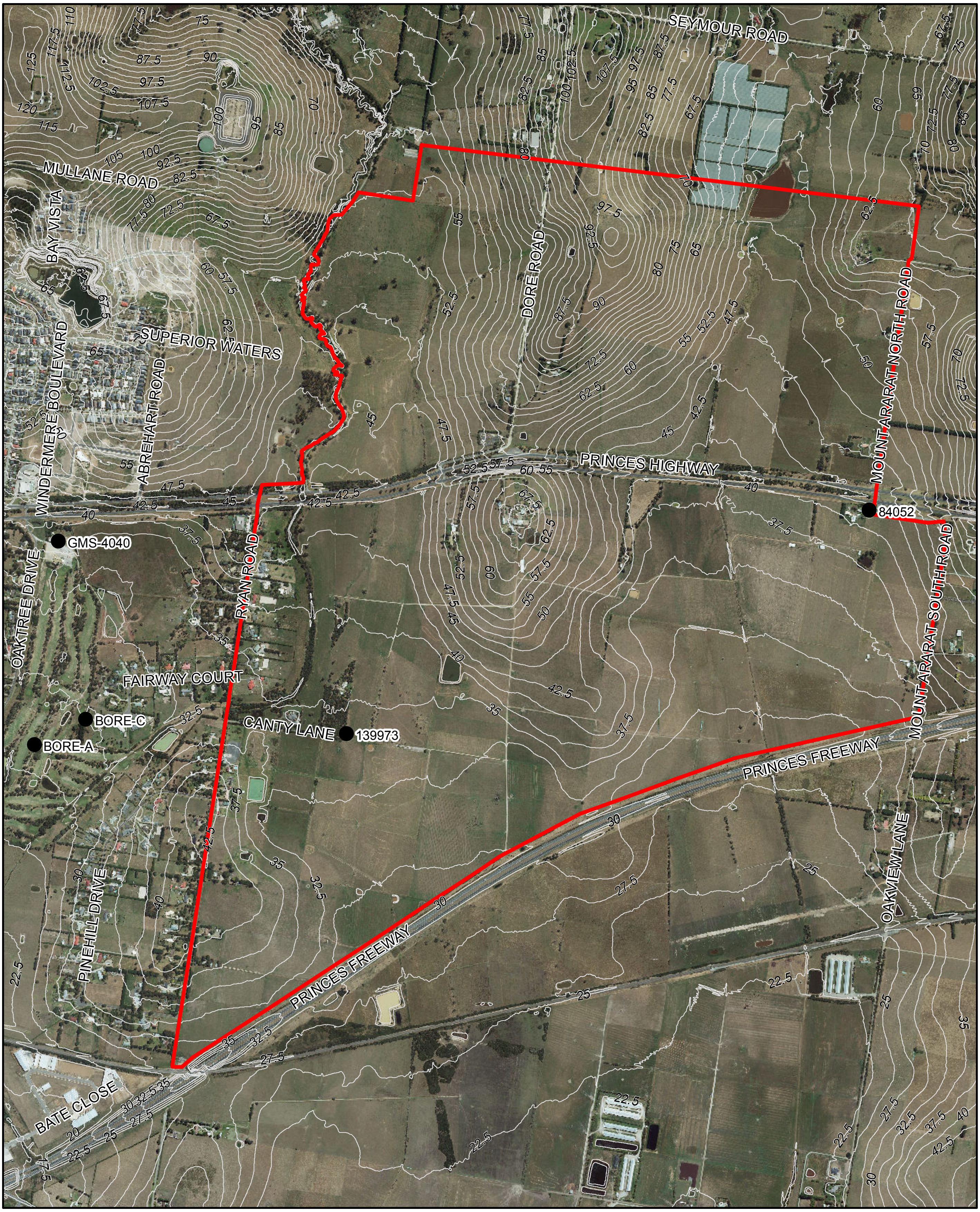


Figure 2-1 Map of Cardinia Urban Growth Area showing Pakenham East Precinct (adapted from Cardinia Shire Council 2012)



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Cardinia Shire Council
Pakenham East Precinct Groundwater Study

GROUND ELEVATION
(metres AHD)

Metres
0 125 250 500 750 1,000

Figure 2-2: Map of the study site showing topography

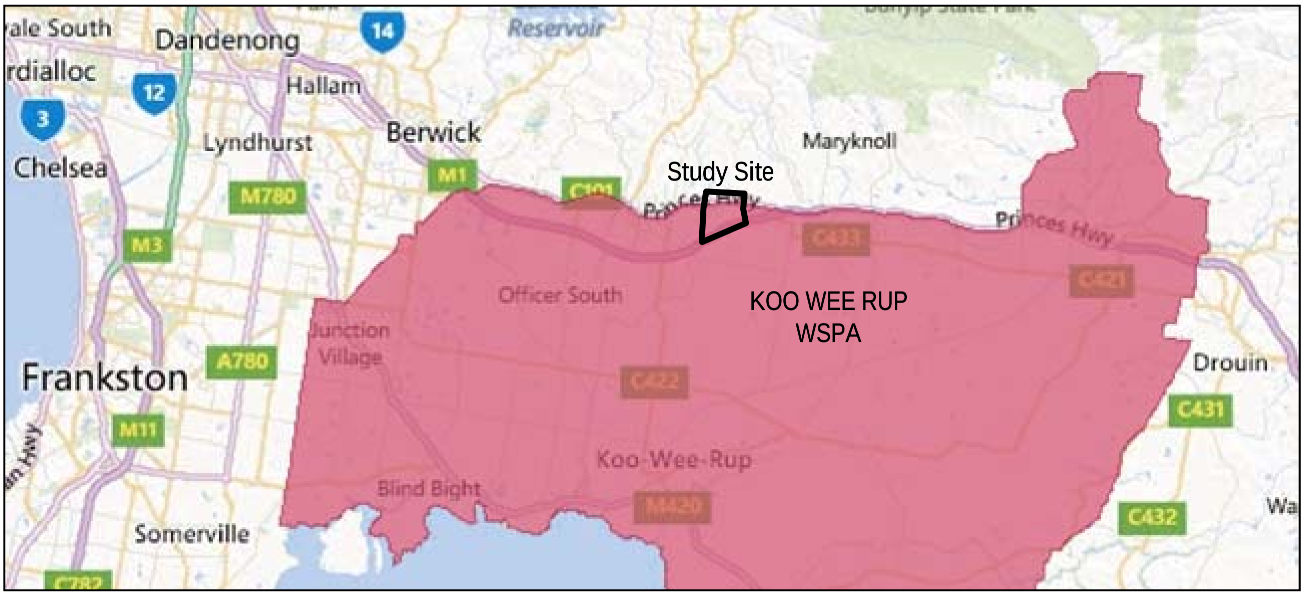


Figure 2-3 : Map showing the boundary of the Koo Wee Rup WSPA (adapted from DSE 2008)

2.5 Rainfall

Rainfall recharge plays a major role in driving groundwater level changes in the region's watertable aquifer. A plot of the rainfall records for the last 15 years for the gauging station at Pakenham is shown in Figure 2-4 (station number 086394). The peak rainfall period of the year is typically late winter, where the region receives more than double the rainfall of dryer periods of the year.

The seasonality of the watertable levels in the area in relation to seasonal rainfall trends is discussed further in Section 3.2.

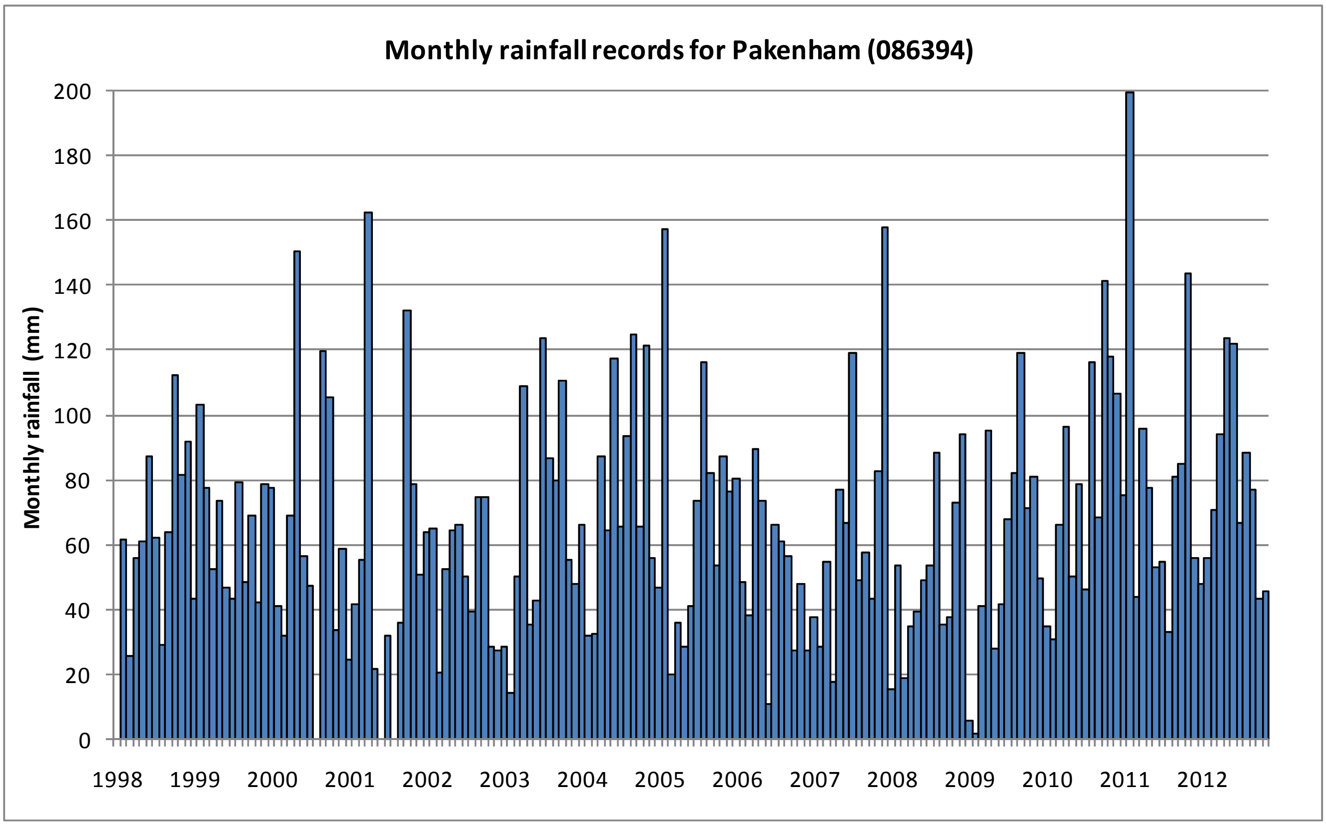


Figure 2-4 : Chart of rainfall records for Pakenham (BoM 2012b)

3. Desktop review

3.1 Geology and hydrogeology

3.1.1 Groundwater data sources

The following reports and databases were reviewed to develop an understanding of the geological and hydrogeological conditions at the site:

- Cardinia Road Employment Precinct – Groundwater and Salinity Investigation; Cardinia Shire Council (SKM 2008a)
- Cardinia Rd. Employment Precinct – Installation of Shallow Groundwater Bores; Melbourne Water (SKM 2008b)
- Identification and assessment of salinity risk in the growth corridor area of Cardinia Shire (CLPR Report No. 8); Victorian Department of Natural Resources and Environment (DNRE 2002)
- Pakenham Bypass Groundwater and Salinity Study; VicRoads (URS 2003a)
- Pakenham Bypass Water Quality Study; VicRoads (URS 2003b)
- Victorian Groundwater Beneficial Use Map Series - Eastern Victoria Water Table Aquifers and Regional Aquifer Systems; Victorian Department of Natural Resources and Environment (DCNR 1995a; b)
- Port Phillip and Westernport Groundwater Flow Systems; Victorian Department of Natural Resources and Environment (Dahlhaus *et al*. 2004)
- Atlas of Groundwater Dependent Ecosystems; Bureau of Meteorology (BoM 2012a)
- Cardinia Shire Salinity Project – Extent and Severity of Salinity in the Cardinia Shire Council; Cardinia Shire Council (SKM & RPD 2003)
- Melbourne Groundwater Directory; Smart Water Fund Victorian Government (SKM 2009)
- Victorian Groundwater Management System (GMS 2012).

3.1.2 Geology

The regional surface geology of the valleys and the plains, south of the Princes Highway, is dominated by recent alluvium. The elevated areas of foothills of the Great Dividing Range are comprised of Devonian age granite (350-420 millions years old), predominantly to the north of the Highway. Tertiary aged Older Volcanics basalt (23-65 million years old) outcrops on the hilltops, and Devonian age hornfels and Silurian age mud- and sandstones (420-440 million years old) occur in pockets amongst the granite.

Figure 3-1 shows the local surface geology at the site. Quaternary age alluvium (Qra – cream) covers the plain and dominates study area. Devonian age granite (Dgr – pink) forms the ridges down the centre and along the eastern boundary of the site, with Tertiary age Older Volcanics basalt (Tvo – brown) outcropping on the tops of the local peaks. The basement unit in the region is a Silurian age mudstone, claystone and sandstone.

In shallow groundwater bores on the plain around the study site, typical lithology is topsoil, overlying silty clay to around 5 m depth with some sand lenses around 4 – 5 m, then silty clay and clayey sand between around 5 – 10 m below the surface (SKM 2008a). Weathered granite in the form of clay underlies the alluvial clay.

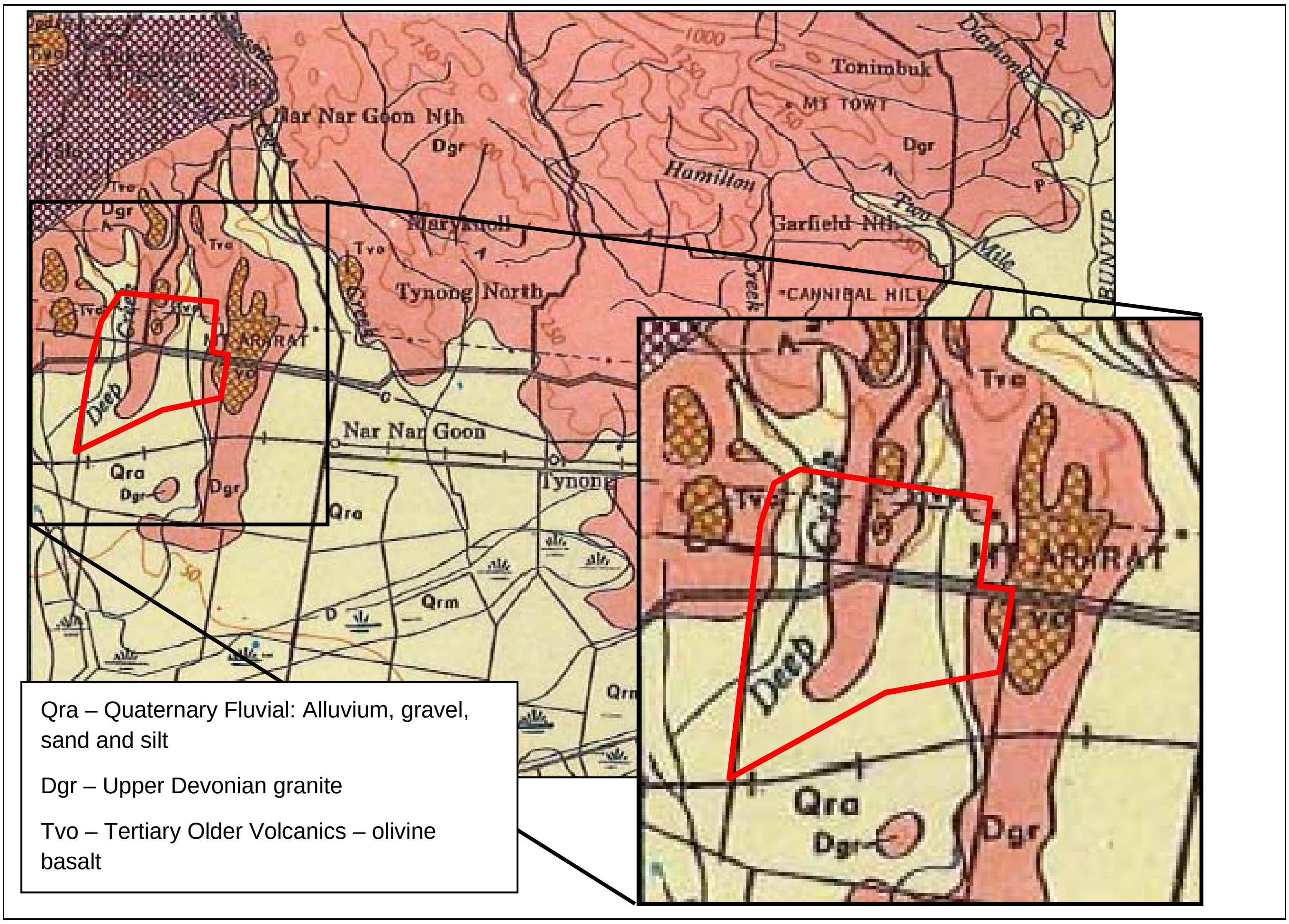


Figure 3-1 : Surface geology at the study site (red border) (adapted from Geological Survey of Victoria, 1971

3.1.3 Hydrogeology

The hydrogeology of the area is closely related to the geological units present, the topography and the drainage system in place. The study area south of the Princes Highway is situated in the Western Port Basin, while the north area is in the Highlands Basin (DPI 2012a). The Highlands Basin aquifers consist of consolidated basement rocks of Palaeozoic and Mesozoic age (65-540 million years old) through which groundwater moves mainly through fractures. Recharge to this Basin is in the higher areas of the Great Dividing Range and discharge of groundwater occurs mainly as base flow in rivers. The units generally yield only minor volumes of water. The Western Port Basin consists of weathered units, calcareous sediments and volcanic forming an important smaller basin in the region (DPI 2012a).

At the site, the main hydrogeological units at the surface are (from youngest to oldest):

- Quaternary age alluvium
- Tertiary age Older Volcanics
- Fractured Bedrock Aquifer consisting of Devonian Age Granites and Silurian Age Sediments

These aquifers are each shown on the geological map to be outcropping at the site, however the exact extent and depth of each is unknown. The groundwater characteristics of each of these surface units is described in the following table (Table 3-1).

Table 3-1 Groundwater characteristics of main surface hydrogeological units on the site

Attribute	Quaternary Alluvium	Tertiary Older Volcanics	Fractured Bedrock
Aquifer extent	Extensive over the lower lying areas in the west, south and east of the site.	A small outcrop in the north of the site at the top of the ridge. Also small outcrop to the very east of the site.	Devonian Granites outcrop forms the central ridge running north to south. Also small outcrop to the very east of the site.
Aquifer nature	Clay at surface with some sand lenses found at depth in the area, however these occur infrequently and are unlikely to provide a preferential path for groundwater flow for distances of greater than around 1 km (SKM 2008a).	Heavily weathered to clay at the surface (up to 2m of basalt weathered to clay at the surface (URS 2003a). Beneath the clay is hard, fractured basalt. Groundwater flow occurs through fractures.	Heavily weathered at the surface to clay. One bore located on the granite outcrop in the study area encountered over 10m of weathered granite clay (URS 2003a). Beneath the clay the basement rocks consist of granite where groundwater flow occurs through fractures.
Water quality	2,500 to 3,700 mg/L TDS pH between 5.9 and 6.6	1,001 to 3,500 mg/L TDS.	1,001 to 3,500 mg/L TDS.
Yield	Low (slow recharge to bores drilled in the surface clays)	Low to medium (depending on weathering of basalt).	Low to medium (depending on weathering and clay content).
Hydraulic conductivity (from URS 2003a)	9×10^{-3} m/day	8×10^{-1} m/day (in heavily weathered basalt – thought to be gravel pack biased result).	3×10^{-3} m/day (in heavily weathered granite / clay).
Relationship to surface water systems	Limited interaction due to clay at surface. During levels of high groundwater there may be drainage to waterways from groundwater. (URS 2003a)		

It is understood that most groundwater extraction bores source deeper aquifers, which are thought to be more productive for water extraction (URS 2003a; SKM 2009b). The Victorian Groundwater Beneficial Use Map (DNRE 1995a) suggests that the Upper Tertiary aquifer system may lie under a portion of the south-west corner of the study area, however the coarseness of the mapping makes it difficult to tell (DNRE 1995b). The presence of deeper aquifers would be best determined by further site investigation in the area, however the watertable remains the aquifer of most local importance for groundwater issues at the site.

A search of local groundwater bores was undertaken using the Victorian Groundwater Management System (GMS) and other bores drilled as part of previous studies. These bores are shown on a map of the area in Figure 3-2. Three groundwater bores are known to be located within the boundaries of the Pakenham East Precinct site. Only two State Observation Bore Network bores were found within 5 km of the site, however these are at a distance from the site and so of little use to watertable modelling.

Details of bores found within around 6 km of the site are provided in Appendix A. Bores found included bores that were drilled for the Pakenham Bypass and Cardinia Road Employment Precinct groundwater projects, and monitoring bores on the South East Water (SEW) Bald Hill Road site.

Refer to Sinclair Knight Merz document; I:\VWES\Projects\VW06981\Technical\Spatial\Working\ArcGIS\Groundwater_Bores.mxd

Cardinia Shire Council
Pakenham East Precinct
Groundwater Study

GROUNDWATER BORES
(in the vicinity of the study site)

Metres
0 250 500 1,000

Figure 3-2: Map of known groundwater bores in the vicinity of the study site

3.2 Groundwater level

3.2.1 Depth to watertable

In 2002, the Department of Natural Resources and Environment (DNRE 2002) produced a depth to watertable map for the Cardinia Shire Growth Corridor (Figure 3-3).This map indicates depth to watertable across the site as follows:

- 0 – 2 m below natural surface (BNS) in the very south of the site
- >10m BNS as land elevation rises up the ridge (central north of site)
- 2 – 5 m BNS over the majority of the lower lying site area

This pattern of very shallow watertable level is seen throughout the Cardinia Shire Growth Corridor on the DNRE map, with the shallowest levels roughly following the Melbourne-Sale railway alignment, and generally shallow levels over the Westernport Plain (Figure 3-3).

Other studies in the area confirm this approximate level of groundwater on the Westernport Plain and around the study site as shown in Table 3-2.

Bores screened in deeper aquifers at around 5 m and 20 - 30 m show similarly shallow groundwater levels, suggesting that the watertable and the deeper units from which water is sourced for consumptive use are hydraulically connected.

Table 3-2 Summary of available depth to watertable information in the study area

Study	**Depth to Water Table ranges (m below natural surface)**
Cardinia Road Employment Precinct Groundwater and Salinity Investigation (SKM 2008a)	1 to 5
Cardinia Road Precinct Development Installation of Shallow Groundwater Bores (SKM 2008b)	1.5 to 5.5
Centre for Land Protection Mapping (CLPR 2002)	>2
Melbourne Groundwater Directory Watertable Mapping (SKM 2009)	5 to 10

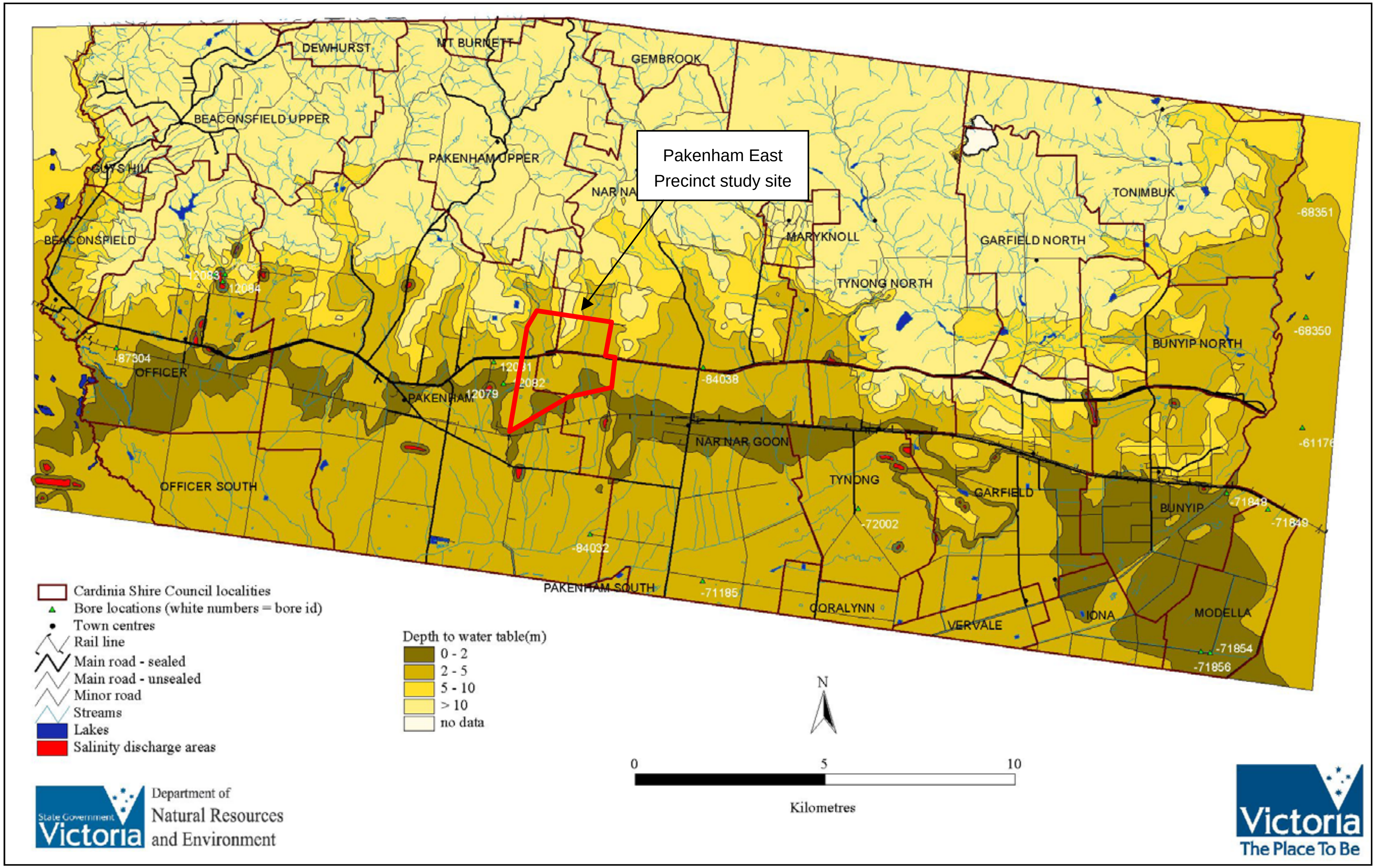


Figure 3-3 : Depth to water table (DNRE 2002)

3.2.2 Bore hydrographs

The hydrographs of the available water level data are presented in Appendix B – this includes two State Observation Bore Network (SOBN) bores to the east and south of the site, and monitoring bores on the Pakenham and District Golf Course to the west of the study area. The location of these bores is given in Figure 3-2.

Figure 3-4 is the hydrograph plot for GMS-4041, which is indicative of other hydrograph plots in the area. Recorded levels in this bore are consistent with mapped depth to watertable levels (DNRE 2002). The plots in Appendix B and Figure 3-4 show distinct seasonal fluctuations of 1 - 1.5 m each year, with a change of 4 m across the duration of record. Declining water level exhibited over the period of 1996 to 2010 is indicative of the low rainfall and drought conditions prevalent at the time. The bores have recovered to almost mid-1990s water levels since 2010.

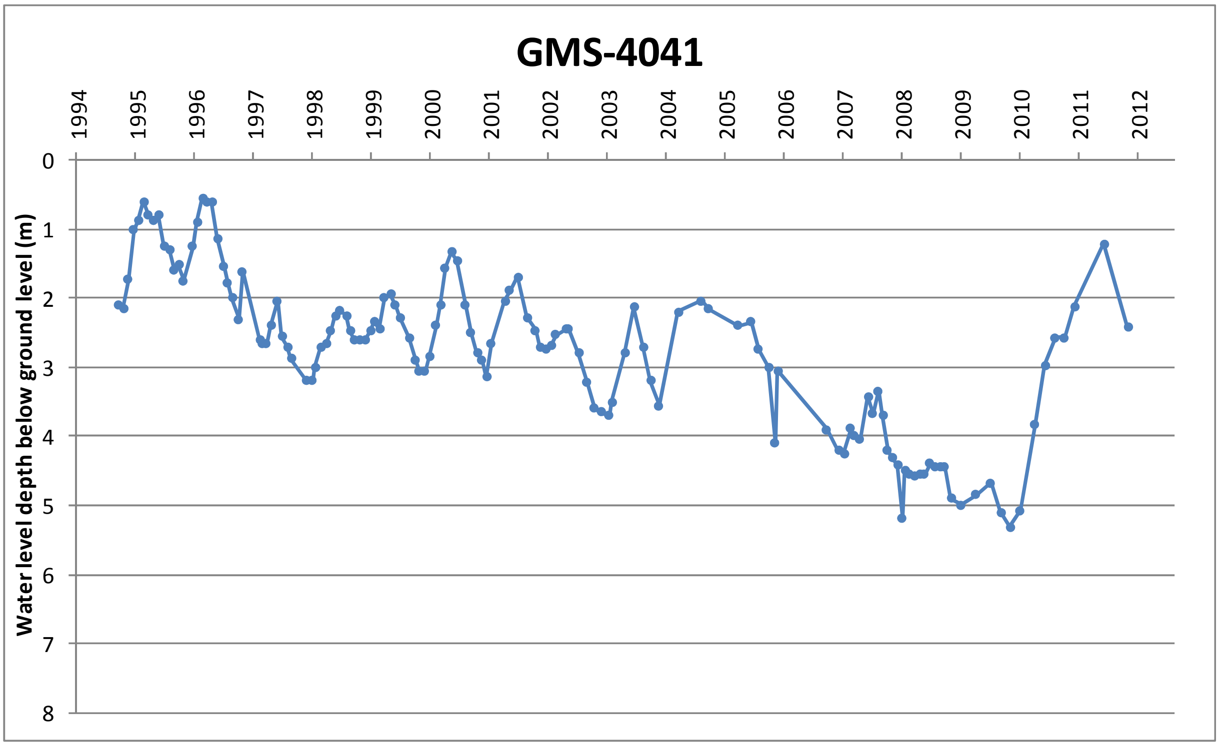


Figure 3-4 : Hydrograph of bore showing typical seasonal fluctuations

3.3 Groundwater quality

Table 3-3 below summarises a range of groundwater salinity results tested in the vicinity of the study area. The mapping of regional salinity reported as the Beneficial Use Map for Eastern Victoria watertable aquifers is shown in Figure 3-5 (DNRE 1995a). The results range from between around 800 and 13,000 mg/L. Based on the spread of these results, groundwater salinity in the watertable aquifer on the site is expected to range between around 6,000 and 8,500 µS/cm (2,500 to 3,700 mg/L TDS) in the plain, and potentially of better quality on the ridges. Water in this high range is classed in Segment C of the SEPP beneficial use categories and suitable for stock watering, industrial water use, buildings and infrastructure and primary recreational contact (EPA 1997).

Values for groundwater pH sampled in the region of the study site range between 5.9 and 6.6 (URS 2003a; SMG 2008b). These results suggest the groundwater in the watertable is slightly acidic.

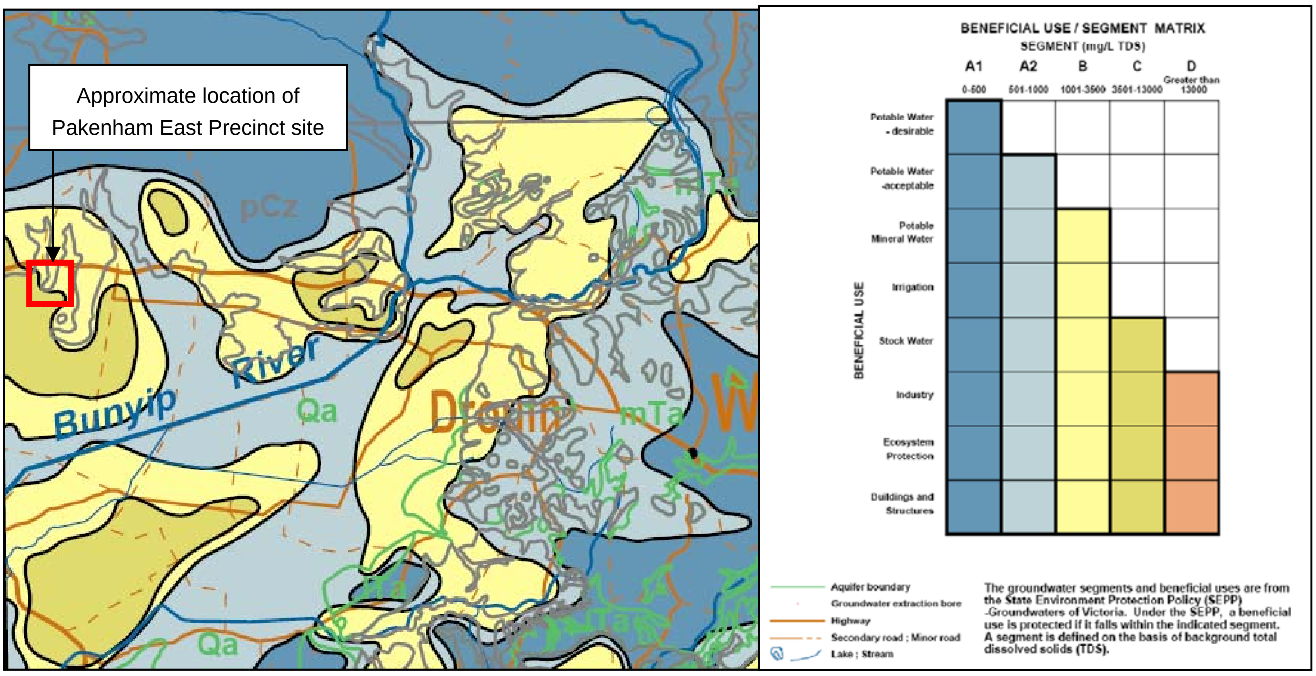


Figure 3-5 : Beneficial Use Map for Eastern Victoria water table aquifers (adapted from DNRE 1995a)

Table 3-3 Summary of salinity results for groundwater tested in the study site area

Source	Min. Range TDS (mg/L)	Max. Range TDS (mg/L)	Min. Range EC (mS/cm)	Max. Range EC (mS/cm)	Reference
Beneficial Use Map (by portion of study site)	1,000 (south)	13,000 (south)	N/A	N/A	DNRE 1995a
	3,500 (north)	13,000 (north)	N/A	N/A	
Melbourne Groundwater Directory	1001	3500	N/A	N/A	SKM 2009
Cardinia Road Employment Precinct project	940	6950	1.6	11.6	SKM 2008b
Pakenham Bypass Groundwater and Salinity Study	790	7,640	0.93	10.6	URS 2003a

Comparison with surface water quality

Some water quality results for local surface water courses are available, generally showing salinities significantly lower than the groundwater, ranging between around 0.25 – 3.5 mS/cm EC (or approximately 150-2100 mg/L TDS) (SKM 2008b; URS 2003b). This result is expected when comparing groundwater and surface water in most temperate climate systems.

3.4 Groundwater flow systems

Regionally, the Pakenham East Precinct site sits on Groundwater Flow System (GFS) 17 Westernport Plain Intermediate and Regional Flow System and GFS 9 Granitic Rocks Local and Intermediate Flow System (Dahlhaus *et al.*, 2004). The boundary of these systems is roughly the Princes Highway, with the Granitic Rocks system to the north. It is likely that minor areas of GFS 1 Quaternary sediments Local and Intermediate Flow

System and GFS 7 Older Volcanics fractured basalt Local and Intermediate Flow System areas occur to the north side of the site.

The Westernport Plain Intermediate and Regional Flow System is noted to have extremely variable hydraulic conductivity of between 10^{-5} to 10^{2} m/day, with less than 1 m/day in the clayey facies, and very low to low hydraulic gradients. The Granitic Rocks Local and Intermediate Flow System is reported as having variable hydraulic conductivity, generally between 10^{-3} to 10^{-1} m/day, and low to moderate hydraulic gradient with local steepness (Dahlhaus *et al.*, 2004).

An investigation as part of the Pakenham Bypass project mapped local groundwater flow directions around the study site, suggesting that local groundwater flow is from the topographic highs down into the valleys. The flow lines then follow the valleys south out onto the plain which. On the Pakenham East site this flow runs generally south-south, as seen in Figure 3-7.

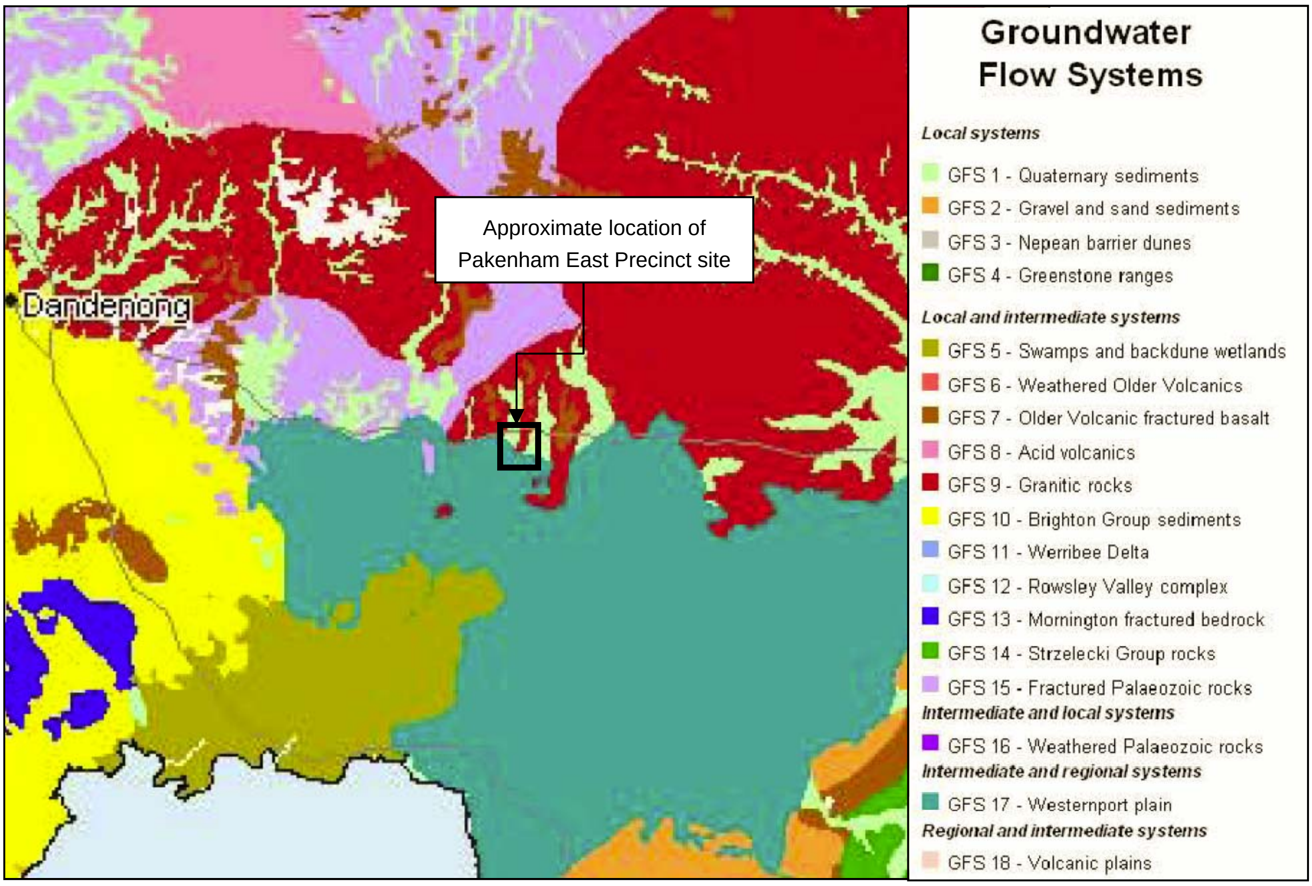


Figure 3-6 : Mapped groundwater flow systems in the region of the Pakenham East Precinct site (adapted from Dahlhaus *et al.* 2004)

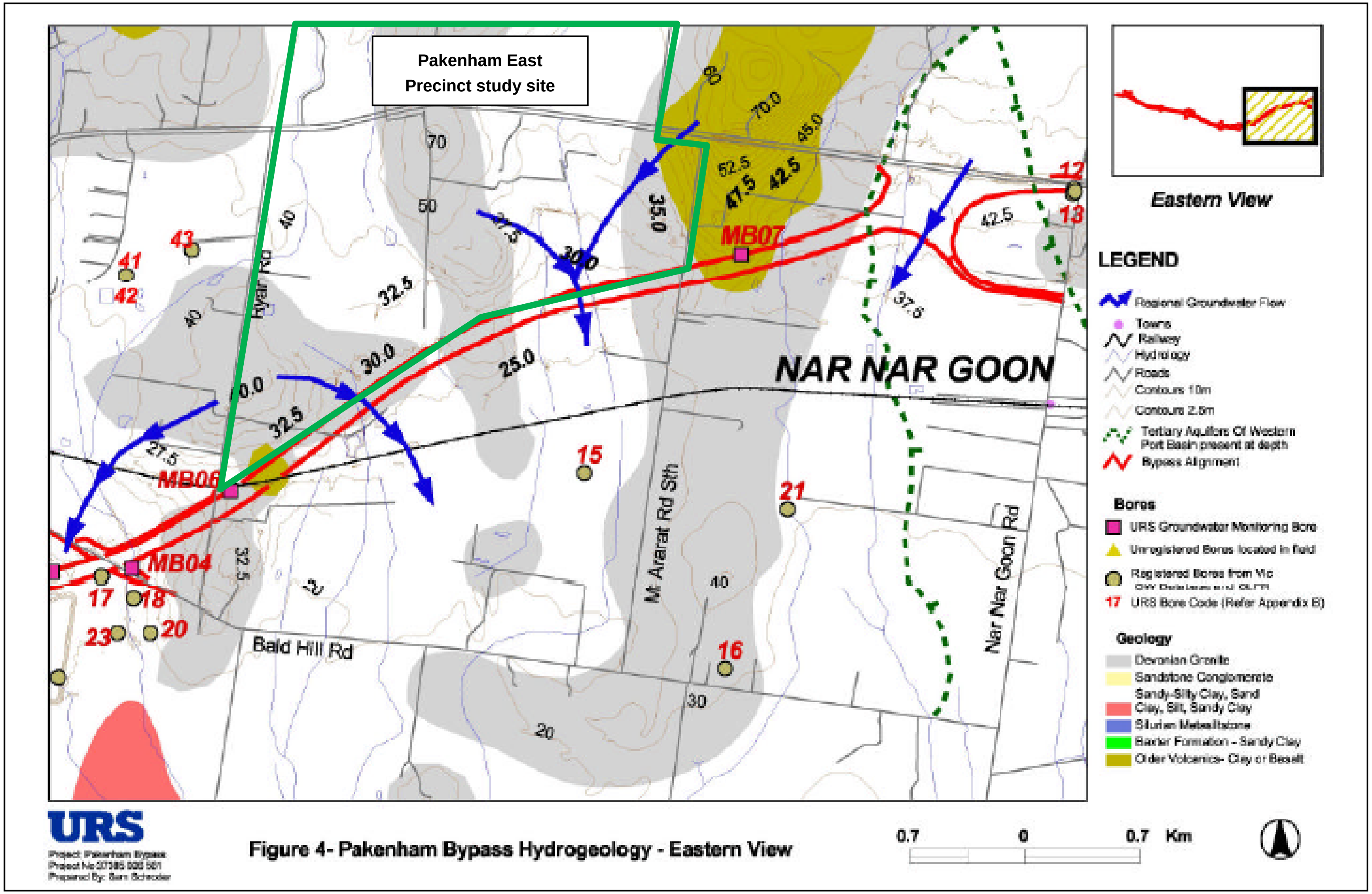


Figure 3-7 : Mapping of regional groundwater flow directions from Pakenham Bypass project (adapted from URS 2003a)

3.5 Groundwater Dependent Ecosystems (GDEs)

There are several areas of vegetation with the potential to be reliant on subsurface groundwater (potential rates as low to high) (BoM 2012a).This vegetation is typically swamp scrub and swamp woodland and primarily follows the water courses (BoM 2012a). All the water courses in the area have been identified as GDEs reliant on the surface expression of groundwater. Figure 3-8 shows the mapped GDEs across the study area.

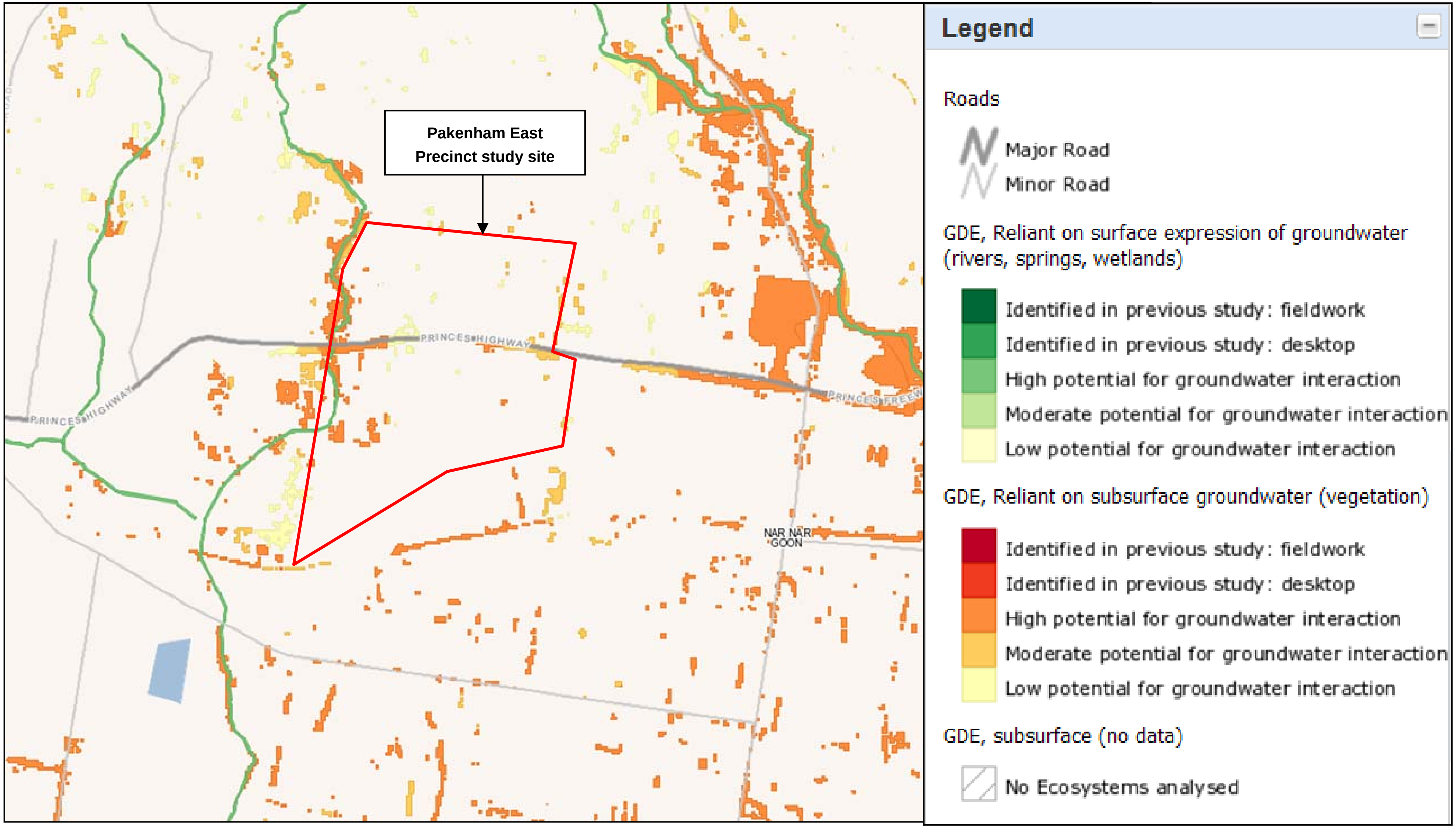


Figure 3-8 : Atlas of Groundwater Dependent Ecosystems search results for the study site (adapted from BoM 2012a)

3.6 Groundwater risks

3.6.1 Shallow groundwater

The major hydrogeological risk to the development of the study site is related to shallow groundwater levels. While shallow groundwater can cause other issues, which will be discussed below, shallow water levels can cause water logging of land and require active management solutions when developing a site.

Previous research suggests that land at lower elevations on the study site has groundwater levels of between 1 and 5 m below ground level. A study into hydrogeological constraints on urban development in the Cardinia Growth Corridor noted that that shallow watertables in the area should be considered a “potential constraint to urban development” (SKM 2005). Dahlhaus *et al.* suggest in the a report presenting Westernport Groundwater Flow Systems groundwater management options for the Western Port plain, which encompasses the site, that it was “unrealistic to expect that waterlogging and elevated watertables can be significantly abated by any reasonable means” (Dahlhaus *et al.* 2004). The report does suggest, however, that the reestablishment of water logging and salt tolerant veneration where native vegetation had been removed will assist in minimising the impacts of water logging and help to maintain an unsaturated soil profile to allow the leaching of shallow soil salt build-up (Dahlhaus *et al.* 2004).

The Cardinia Road Employment Precinct groundwater investigation report (SKM 2008a) also suggested that the expected low hydraulic conductivities in the surface soil layers can lead to the development of very localised groundwater mounding of the watertable. Additionally, localised increased recharge to groundwater from changes to the infiltration and runoff patterns in the area from development may raise the watertable closer to the surface in places (SKM 2008b). The low hydraulic conductivities expected in the area may mean that this may take years to develop.

SKM (2005) rated the Pakenham East study area as from ‘not significantly constrained’ to ‘highly constrained’ for development due to shallow groundwater level across the study area. The highly constrained area is roughly the eastern half of the study area, following the eastern drainage line north-south across the site. The rating was given based on likelihood of occurrence of shallow groundwater, groundwater salinity and soil type (SKM 2005).

Modelling undertaken by SKM (2005) also suggested that development in the area would increase recharge to groundwater in autumn and decrease recharge in spring. This potential impact on shallow watertables should be investigated further before the site is developed.

3.6.2 Acid sulphate soils

A report written in 2008 after the installation of new groundwater monitoring bores on the Cardinia Road Employment Precinct site (SKM 2008b) concluded that acid sulphate soils (ASS) were not present at the site.

Given the proximity to the Cardinia Road site (approximately 9 km to the northeast) and that similar geological, hydrogeological and topographical conditions encountered at the Pakenham East Precinct site, it is likely that acid sulphate soils are not a significant risk. Further investigation into the pH of the groundwater at the Pakenham East study area and analysis of soil samples for metal sulphide would help to confirm this assessment.

Acid Sulphate Soil (ASS) Potential results for BH7 (in SKM 2005) on the Pakenham East study site were below detection limits and not of concern. However, SKM 2005 recommends that, while ASS is not of particular concern in the area, soil analysis for ASS potential should be required as part of planning applications on the site (SKM 2005).

3.6.3 Salinisation

SKM & RPD Group 2003 identifies the process of salinisation within the local area as:

1. ‘Widespread clearing of deep-rooted vegetation in the elevated areas and replacement with shallow rooted pasture
2. Reduced use of water by vegetation

3. Increased water entering the groundwater system (recharge)
4. Rise in watertable which dissolves naturally occurring salts stored in rocks mobilising them towards the surface where they are concentrated by evaporation.' (SKM & RPD Group 2003)

A Centre for Land Protection Research study in 2002 rated the overall salinity risk in the Pakenham area as high, based on criteria including depth to watertable and waterlogging risks (DNRE 2002). However, Dahlhaus *et al.* (2004) in their mapping noted the risk of soil salinity on the site to be low to moderate.

SKM (2005) warned that inefficient use of third pipe (recycled) water supply systems has the potential to increase the risks of increased salinity in the summer and autumn months (because of the increased volume of water used). This should be a consideration for future development.

During the field work undertaken to establish new bores as part of SKM 2005, dead or salt affected trees were observed along Dore Road and Princes Hwy, with some salt affected land observed south of Princes Hwy. The notes were made for a bore on Dore Rd near the Princes Hwy which is on the Pakenham East study site (SKM 2005). Bore BH7 on the study site showed soil pH results of 6.2-6.6, and soil EC much less than 4 dS/cm (limit for being classed as saline). A soil sample at 3 m in this bore showed a Sodium Absorbtion Ratio of 25, which suggests that plants tapping this level of soil would have difficulty absorbing water (SKM 2005).

Anecdotal information communicated to SKM during the site visit to the Pakenham Golf Club as part of this study indicated that salinisation is already affecting some of the low lying areas around the study site. Some of these areas are being managed by the introduction of salt-tolerant vegetation.

3.7 Data gaps

The main data gap identified from a review of the previous studies in the area was water level data from within the study area and current water level data more regionally. The GMS search of local bores returned temporal groundwater level data for six bores within five kilometres of the study site, for which the most recent monitoring was undertaken in March and November 2012. Very little water level or lithological data is available for bores on the site.

In order to address the lack of water level data on the site, a program of field work was planned to gather water level data from a number of government owned and private bores within and near the study area. This field program is discussed in Section 4.

4. Field data collection

The aim of the field work program was to address the identified data gap of the lack of current and spatially relevant groundwater levels.

Prior to visiting the site, available groundwater bores were prioritised for data collection by proximity to the study site and availability of access. Bore owners and landholders were contacted to gain access to the bores for the purposes of monitoring.

The following bores within vicinity of the site could not be monitored due to lack of access:

- Privately owned bores outside of the study area.
- Bores drilled for the Pakenham Bypass project (URS 2003a).
- SEW monitoring bores on Bald Hill Road (Chamberlain 2012).

A site visit was conducted on Thursday 20 December 2012 to record the level of groundwater in the bores using an electronic water level meter. Bore 139973 was pumping during the site visit (pressure gauge on the extraction line read 155 psi). As such, the water level measured was a pumping water level. Bore 84052 is thought to be a supply bore for stock water, and it is unknown how recently it was last pumped. Given the depth of the water in this bore, this level was taken as a standing water level.

Photographs of the bores taken during the site visit are included in Appendix C.

In regard to the condition of the land at the Pakenham Golf Course the site contact mentioned that waterlogging was a significant issue all over the site during winter, and that salt tolerant vegetation was planted on areas of the site in response to assumed land salinisation issues. The Golf Course has many dams and ponds on the site, and during the site visit, water levels in these were observed to be around 1.2 – 1.5 m below ground level.

During the site visit, no waterlogging of low lying areas or road drains of up to 1 m deep was noticed, and the water level in the local creeks and water courses was between 1.2 and 2.5 m below the surface of the neighbouring landscape (refer Appendix D).

The results of the monitoring are given in Table 4-1. The screened lithology and elevations are given where possible from the GMS records for the bores.

Table 4-1 : Results of water level monitoring

Bore ID	Location	Total depth (m bgl)	Screened lithology (interval (m bgl)	Surface Elevation (m AHD)[a]	Water level (m bgl)	Water level (m AHD)	Comments
139973	1550 Princes Hwy, Nar Nar Goon	28.0	Sandy drift (26.9 - 27.5)	34.24	7.50^	26.75^	
84052	32 Mt Ararat South Road, Nar Nar Goon	28.6	Unknown	41.62[b]	1.88	39.75[b]	
BORE-A*	Pakenham Golf Club, 25 Oaktree Drive, Pakenham	2.03‘	(Likely undifferentiated alluvium)	28.27	1.13	27.14	Drilled for previous Golf Course development investigation
BORE-B*	Pakenham Golf Club, 25 Oaktree Drive, Pakenham	0.86’	(Likely undifferentiated alluvium)	28.27	DRY	DRY	Drilled for previous Golf Course development investigation

Bore ID	Location	Total depth (m bgl)	Screened lithology (interval (m bgl)	Surface Elevation (m AHD)a	Water level (m bgl)	Water level (m AHD)	Comments
BORE-C*	Pakenham Golf Club, 25 Oaktree Drive, Pakenham	4.08'	(Likely undifferentiated alluvium)	29.80	1.87	27.93	Drilled for previous Golf Course development investigation
GMS-4040	Pakenham Golf Club, 25 Oaktree Drive, Pakenham	2.58'	(Likely undifferentiated alluvium)	35.99	0.57	35.42	Drilled for previous Golf Course development investigation
GMS-4038	Pakenham Golf Club, 25 Oaktree Drive, Pakenham	Could not access as bore was locked					
GMS-4039	Pakenham Golf Club, 25 Oaktree Drive, Pakenham	Could not access as bore was locked					
WRK052086	Dore Rd, Nar Nar Goon	Could not locate					
GMS-4041	7 Fairway Crt, Pakenham	Could not access as found to be on private land					

Notes: bgl – below ground level

* assigned ID

^ pumping water level

' as measured on site

[a] elevations from topographic surface mapping

[b] The topographic mapping of this bore location gave an elevation that was slightly higher than observed on site. The difference between the monitored water level and the modelled level used in the watertable mapping (the error) was significantly more than for the other bores, however this did not change the water level mapping category shown in Figure 5.1.

The water levels recorded, all in the lower lying areas of the plain, show the level of the watertable to be between 0.5 and 2 m below surface level. The pumping water level in bore 139973 was around 7.5 m below ground level. The water level recorded in bore GMS-4040 is consistent with levels recorded from previous monitoring visits in recent months, increasing slightly since the previous monitoring in March 2012 (GMS 2012). This is the only bore with available historical groundwater level records. The similarity in levels between shallow (1 – 5 m deep) bores and the deeper production bores monitored (~ 28 m deep) suggests that the first few tens of metres of lithology is hydrogeologically connected. Drilling and pumping observations suggest, however, that the creation of perched water tables around pumping bores may be possible, as the pressure in lower layers is reduced by extraction of groundwater and the shallower denser clays retards the movement of groundwater to lower levels.

5. Conceptual hydrogeological model

The information gathered from the review of previous studies, as well as the data collected in the site visit was used to formulate a conceptual hydrogeological model of the Pakenham East Precinct study area.

5.1 Hydrogeological setting

The watertable aquifer on the site sits within the shallow Quaternary alluvial layers. It is thought that the presence of minor sand lenses facilitates the movement of groundwater in the area. However, in general, the surface layers of dense clays have relatively low hydraulic conductivities (around 1×10^{-2} m/day (URS 2003a)). Production bores are generally screened around 25 to 30 m below the surface where the alluvial units are more conducive to groundwater flow than shallower layers. The low lying areas on the Westernport Plain are subject to water logging in winter.

Little information is available on the deeper aquifers, other than the estimate from the Beneficial Use mapping that the Upper Tertiary aquifer system is present under some of the site, although this mapping is too coarse to give much specific information and there are few deep bores in the study area.

5.2 Groundwater levels

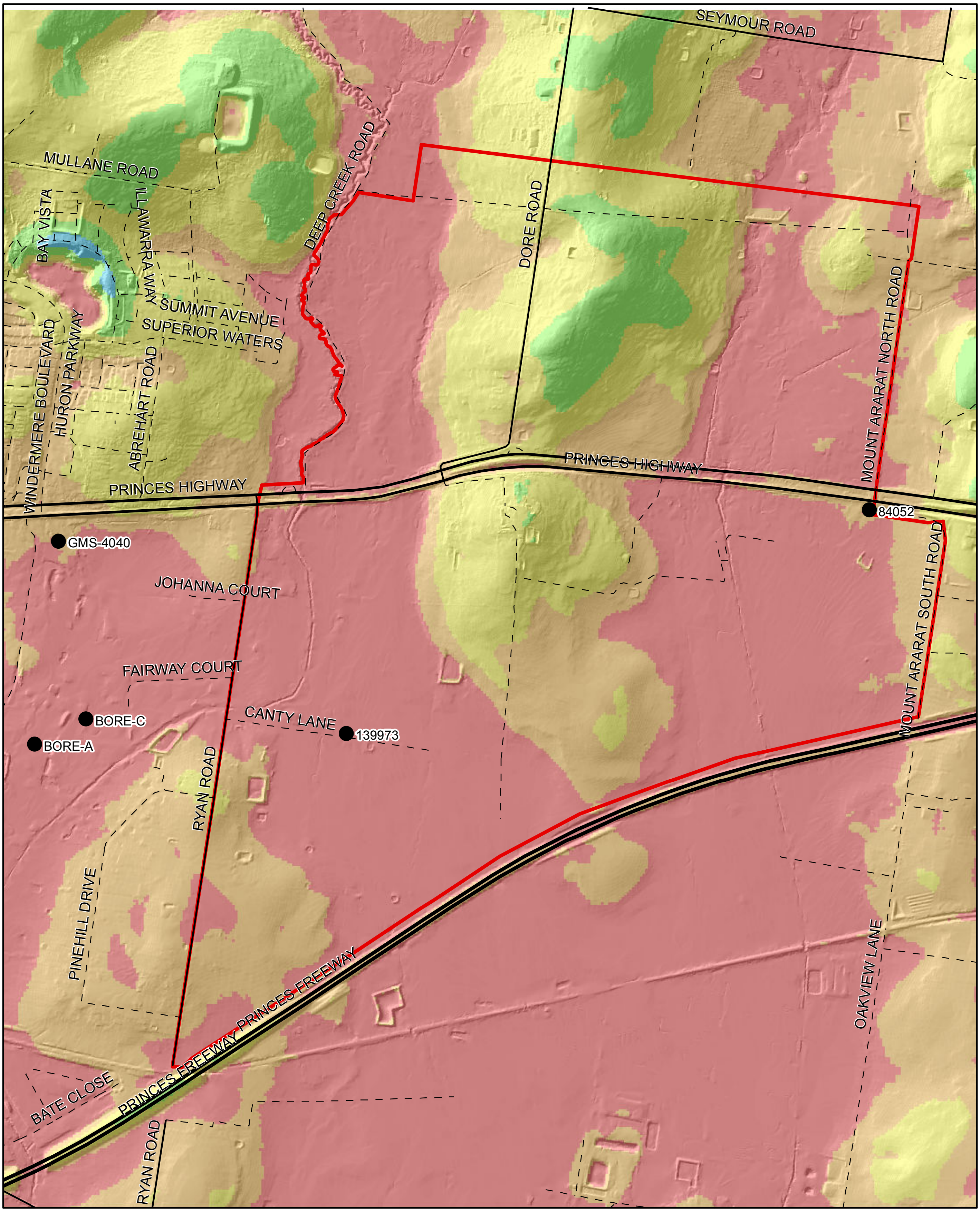
The data gathered during the site visit was used to plot maps of indicative depth to groundwater and groundwater elevation using an algorithm that utilises topographical data to calculate the height of the watertable surface. The results of this analysis are shown in Figure 5.1 and Figure 5.2.

The levels of the watertable on the site are predicted to be between 1.1 and 2 m below ground level in the lower lying areas of the plain, and in excess of 20 m below the surface on the peaks of the hills. Generally, watertable elevation follows the topography of the site. Anecdotal information suggests that these levels increase to above ground level in the lowest lying areas of the plain during winter, and this is thought to be due to higher recharge and slow groundwater floes. The slow infiltration of groundwater through the dense clays in the soil contributes to waterlogging.

Measured watertable levels are higher than those mapped by the Department of Natural Resources and Environment for the majority of the study area on the plains, at less than 2 m compared with between 2 and 5 m as mapped (DNRE 2002).

Groundwater levels in the area show a distinct seasonal fluctuation, with the months April and May tending to show the lowest groundwater levels (refer to Appendix B).

In the lower lying areas across the Westernport Plain, areas of land salinisation have been observed and waterlogging is known to be a seasonal problem.



SINCLAIR KNIGHT MERZ
SKM

Refer to Sinclair Knight Merz document;
I:\VWES\Projects\VW06981\Technical\Spatial\Working\ArcGIS\swl.mxd

● Bore site (ID)

PEP Boundary

Depth (m)

- < 2
- 2 - 5
- 5 - 10
- 10 - 20
- > 20

Cardinia Shire Council
Pakenham East Precinct Groundwater Study

INDICATIVE WATERTABLE DEPTH (metres)

Metres
0 125 250 500 750 1,000

Figure 5-1: Map of indicative depth to watertable at the study site

SINCLAIR KNIGHT MERZ SKM

Refer to Sinclair Knight Merz document;
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Bore site (ID)
PEP Boundary
Contour (mAHD)

Cardinia Shire Council
Pakenham East Precinct Groundwater Study

INDICATIVE WATERTABLE ELEVATION (metres AHD)

Metres
0 125 250 500 750 1,000

Figure 5-2: Map of indicative elevation of the watertable at the study site

5.3 Groundwater quality

Groundwater salinity in the watertable aquifer on the site is expected to range between around 6,000 and 8,500 µS/cm (2,500 to 3,700 mg/L TDS), however salinities of as low as 930 µS/cm (790 mg/L) has been recorded very close to the study site (URS 2003a; SKM 2005). Water in this range is classed in Segments B and C of the SEPP beneficial use categories and suitable for stock watering, irrigation of some crops, industrial water use, buildings and infrastructure and primary recreational contact (EPA 1997). This is generally consistent with (although on the lower side of) the salinity range mapped for the site by the Beneficial Use mapping (between 1,000 and 13,000 mg/L TDS; DNRE 1995a). Figure 3-5 above gives a guide to regional groundwater salinity in the region of the study site.

Values for groundwater pH locally in the aquifer sit between 5.9 and 6.6, which is out of the range of risk of acid sulphate soils (URS 2003a; SMG 2008b).

Water quality measurements in local water courses suggest that the groundwater is a significant source of salt load in the area's creeks (URS 2003b).

Groundwater quality results for other parameters from bores in the area have shown elevated levels of chromium, copper, nickel, zinc and lead above the freshwater ecosystem guidelines (ANZECC/ARMCANZ 2000; EPA 2003; SKM 2008b), however remaining below drinking water guideline levels (SKM 2008b).

5.4 Groundwater flow systems

The regional groundwater flow is north to south, with the site sitting on the boundary between the Westernport Plain Intermediate and Regional Flow System and the Granitic Rocks Local and Intermediate Flow System (Dahlhaus *et al.*, 2004). More locally on the site, groundwater flows downhill toward the south-south west of the plain from the local topographical high points (URS 2003a).

6. Conclusions

The following conclusions can be made about the Pakenham East Precinct study area:

- The watertable aquifer sits around 1 to 2 m below the surface in predominantly dense clays across the low lying plain on the site, with the depth to water increasing as elevation rises. As noted in previous studies, development of Greenfields sites like the Pakenham East Precinct site can increase groundwater recharge and has the potential to impact groundwater levels.
- Deeper watertables are present in the elevated areas to the north (and in the ridges) – these areas are expected to have lower salinisation risk.
- The deeper, less dense, sandier clays form the source units of local groundwater extraction; it is likely that bores139973 and 84052 on the study site are screened in this type of unit.
- Salinity of the watertable in the lower lying areas is around 6,000 to 8,500 µS/cm EC, or around 2,500 to 3,700 mg/L TDS, on the site, although salinity may be significantly lower than this in some places, especially in the elevated areas.
- Across the site, groundwater generally flows in a southerly direction, downhill slopes into the valleys and toward the southern boundary of the site.
- The major groundwater risks on the site are related to areas of shallow groundwater are:
  - Land salinisation
    - The study site has been rated as a high salinity risk.
    - Land salinity has been observed in the area, and it has relatively successfully been controlled by the planting of salt tolerant vegetation.
  - Waterlogging
    - Waterlogging of lower lying areas on the plain is a common problem in the wetter months.
    - Areas in the eastern half of the study area, following the eastern drainage line north-south on the site, have been rated as ‘highly constrained’ for development due to shallow groundwater levels. The remainder of the site is rated as having ‘no significant constraints’.
- Acid sulphate soils are not predicted to be of particular concern on the site, although large developments that may dramatically alter watertable levels should be monitored to ensure they don’t lead to the creation of acid sulphate conditions.
- In general, the condition of groundwater at the site (i.e. shallow watertable) has been noted as being a constraint to urban development across the low-lying areas in the southern parts of the site.

7. Recommendations

- The potential impact on groundwater level from the effect of development on groundwater recharge at the site should be considered during development design.
- Development at the site should account for watertable depths ranging from1.5 m below the surface of the plain, to 0.5 m in the topographical lows during winter and spring.
- Groundwater risk mitigation and management measures should be incorporated into any plans for future development of the site. Mitigation and management measures for shallow groundwater and the associated risks of waterlogging and land salinisation may include:
  - Planting of salt tolerant/deep rooted vegetation.
  - Collection (via pumping or interceptor drains) and disposal of groundwater.
  - Appropriate design of and scheduling of irrigation systems, for example, at sports fields and other large facilities that required additional watering.
  - Interception, storage and/or reuse of rainfall runoff and stormwater.
  - Appropriate design of building foundations to minimise the impact of shallow watertables.
  - Installation of groundwater monitoring bores and a monitoring program (see below).
- The study area is large and exhibits a wide elevation range. Groundwater levels are deep across the ridges and other topographically high areas, whilst shallow watertables exist mainly in the lower-lying areas within the drainage depressions and in the southern parts of the site. Additional groundwater monitoring bores are recommended to be installed in the following areas to fill in data gaps (all bores should be screened in the watertable):
  - 1 bore just to the east of Deep Creek, between the Princes Hwy and the northern boundary of the study site (depth to approximately 5-10m).
  - 1 bore between Deep Creek and Dore Road on the eastern edge of the creek valley, between the Princes Hwy and the northern boundary of the study site (depth to approximately 5-10m).
  - 1 bore on Dore Road, between the Princes Hwy and the northern boundary of the study site (depth to approximately 20-30m).
  - 1 bore between Dore Road and Mount Ararat North Road on the western edge of the creek valley, between the Princes Hwy and the northern boundary of the study site (depth to approximately 5-10m).
  - 1 bore on the north end of Mount Ararat Rd North (depth to approximately 10-15m).
  - 1 bore on the Princes Fwy at the southern end of the eastern drainage line on the site, at around 500 m west of the intersection with Mount Ararat South Road (depth to approximately 10-15m).
  - Optional: 1 bore on the south side of the local peak just south of the intersection of the Princes Hwy and Dore Road (depth to approximately 15-25m).

  This spread of bores allows for an understanding of the local hydrogeology through transects of the northern half of the study site as well as the centre on an east-west line, and the east of the site on a north-south line.

  Extra bores in addition to those listed above may be required at a site-specific scale, depending on the exact type of development to be undertaken at properties across the site.
- Monitoring of groundwater levels and quality across the site (2 existing bores on the site plus the recommended new bores above) will provide valuable information on the extent and rate of change of watertable levels and salinity. It is recommended that the bore network be monitored quarterly for water levels and annually for water quality (salinity).

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Appendix A. Local groundwater bores

SITE NO	East.	North.	Total depth (m)	Elevation (m AHD)	Use	WL data available	Most recent WL reading	WL (m AHD)	Screened lithology	Screened from / to (m bgl)		EC (mS/cm)	TDS (mg/L)	Source
84032	371770.7	5780933	67	14.07	Observation	Yes - time series	7/11/2012	12.71	-	-	-	-	-	GMS 2012
84038	375094.5	5785560	48	44.66	Observation	Yes - time series	7/11/2012	43.7	-	-	-	-	-	GMS 2012
84052*	372256.2	5785781	28.6	41	Stock and domestic	-	-	-	-	-	-	-	-	GMS 2012
84061	368253.2	5786624	19.2	70.78	Stock and domestic	-	-	-	Clay	11.58	12.19	-	-	GMS 2012
84064	374136	5786606	55.47	52.33	Stock, domestic, irrigation and dairy	-	-	-	-	-	-	-	-	GMS 2012
84066	368556.2	5787584	53	91.97	Stock and domestic	-	-	-	Granite	48.8	53	-	-	GMS 2012
84067	373793.2	5786424	53.34	50.64	Stock, domestic, irrigation and dairy	-	-	-	Sand	46.32	49.98	-	-	GMS 2012
84068	371634.2	5782016	42.6	17.68	Stock and domestic	-	-	-	-	-	-	-	-	GMS 2012
84079	370173.2	5788424	18	86.45	Irrigation	-	-	-	-	-	-	-	-	GMS 2012
84080	370173.2	5788424	25	86.45	Unknown	-	-	-	-	-	-	-	-	GMS 2012
84081	374363.2	5785114	40	40.6	Stock	-	-	-	-	-	-	-	-	GMS 2012
84082	368653.2	5788264	14.7	81.28	Irrigation	-	-	-	-	-	-	-	-	GMS 2012
84088	373683.2	5783765	31.76	31.32	Stock and domestic	-	-	-	Clay	29.59	31.76	-	-	GMS 2012
84099	374393.2	5787134	52.73	56.71	Stock and domestic	-	-	-	-	-	-	-	-	GMS 2012
84116	373928.2	5786522	30.4	53.53	Stock	-	-	-	-	-	-	-	-	GMS 2012
84118	371761.2	5783760	0	21.32	Stock	-	-	-	-	-	-	-	-	GMS 2012
84119	373003.2	5783540	0	29.86	Unknown	-	-	-	-	-	-	-	-	GMS 2012
84121	372621.2	5782566	0	33.84	Unknown	-	-	-	-	-	-	-	-	GMS 2012
84123	367719.2	5782248	0	16.7	Stock	-	-	-	-	-	-	-	-	GMS 2012
84124	375612.2	5783782	26.2	30.51	Stock	-	-	-	-	-	-	-	-	GMS 2012
84130	374133.2	5786448	0	52.04	Stock	-	-	-	-	-	-	-	-	GMS 2012
87468	369665.2	5788110	24.3	66.24	Unknown	-	-	-	-	-	-	-	-	GMS 2012
112889	371983.2	5783094	28	20.32	Stock and domestic	-	-	-	Granite	22	28	-	-	GMS 2012

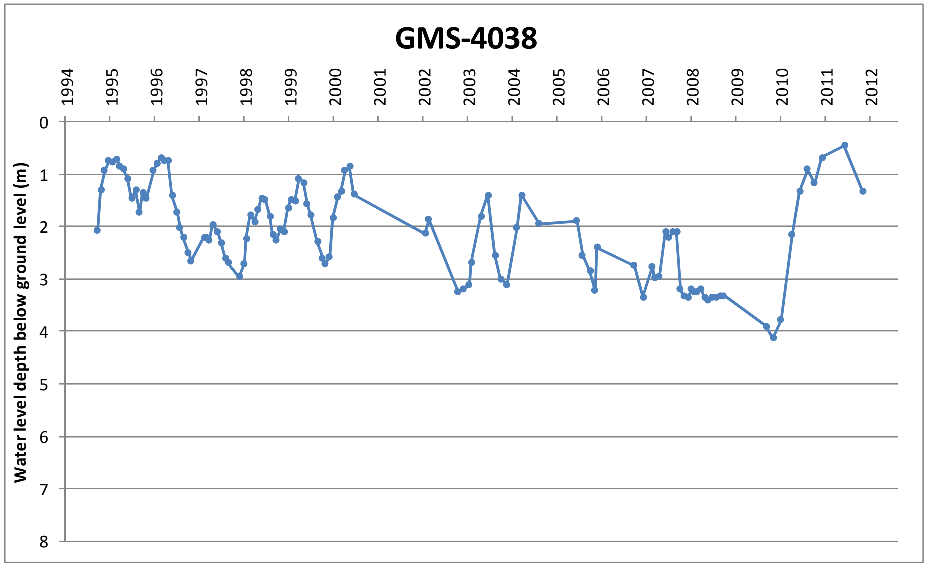
SITE NO	East.	North.	Total depth (m)	Elevation (m AHD)	Use	WL data available	Most recent WL reading	WL (m AHD)	Screened lithology	Screened from / to (m bgl)		EC (mS/cm)	TDS (mg/L)	Source
115261	374751.2	5785506	7.5	43.33	Observation	-	-	-	-	-	-	-	-	GMS 2012
115262	374745.2	5785476	5	43.92	Observation	-	-	-	-	-	-	-	-	GMS 2012
115263	374758.2	5785491	7.5	43.84	Observation	-	-	-	-	-	-	-	-	GMS 2012
132510	368553.2	5782514	6	16.28	Observation	-	-	-	-	-	-	-	-	GMS 2012
137072	368813.2	5783134	5	16.91	Observation	-	-	-	Sand	2	5	-	-	GMS 2012
137074	369013.2	5782984	5	16.19	Observation	-	-	-	Clay	2	5	-	-	GMS 2012
137075	369113.2	5782784	5	17.31	Observation	-	-	-	Clay	2	5	-	-	GMS 2012
137076	368913.2	5782784	5	15.64	Observation	-	-	-	Clay	2	5	-	-	GMS 2012
139973*	370238.2	5785004	28	34.16	Stock and domestic	-	-	-	Sandy drift	26.9	27.5	-	-	GMS 2012
141863	372713.2	5785184	51.5	43.45	Stock and domestic	-	-	-	Basalt	35.5	47	-	-	GMS 2012
142636	366763.2	5785034	7	35.91	Observation	-	-	-	-	-	-	-	-	GMS 2012
142637	366663.2	5785034	8	35.78	Observation	-	-	-	-	-	-	-	-	GMS 2012
142638	366713.2	5785134	8	38.52	Observation	-	-	-	-	-	-	-	-	GMS 2012
142639	366763.2	5784684	8	32.95	Observation	-	-	-	-	-	-	-	-	GMS 2012
144511	374253.2	5788124	25	64.28	Stock and domestic	-	-	-	-	-	-	-	-	GMS 2012
325925	367883.2	5785284	2.44	34.92	Observation	-	-	-	-	-	-	-	-	GMS 2012
325926	367943.2	5785244	2.44	34.52	Observation	-	-	-	-	-	-	-	-	GMS 2012
325927	367943.2	5785204	0.91	33.35	Observation	-	-	-	-	-	-	-	-	GMS 2012
325928	367843.2	5785264	0.91	34.35	Observation	-	-	-	-	-	-	-	-	GMS 2012
GMS-366	374742.5	5785484	6	43.9	Unknown	-	-	-	-	-	-	-	-	GMS 2012
GMS-4038*	369013	5784934	17.5	28.21	Observation	Yes - time series	15/04/2012	26.76	-	-	-	-	-	GMS 2012
GMS-4039*	369013	5784934	5	28.21	Observation	Yes - time series	15/04/2012	26.90	-	-	-	-	-	GMS 2012
GMS-4040*	369106	5785728	20	36.19	Observation	Yes - time series	15/04/2012	35.59	-	-	-	-	-	GMS 2012
GMS-4041	369367	5785141	15	31.32	Observation	Yes - time series	15/04/2012	28.90	-	-	-	-	-	GMS 2012
S9021817/1	367643	5782311	4.5	17.1	Stock and domestic	-	-	-	-	-	-	-	-	GMS 2012
S9022838/1	367650	5783650	7	24	Stock and domestic	-	-	-	-	-	-	-	-	GMS 2012

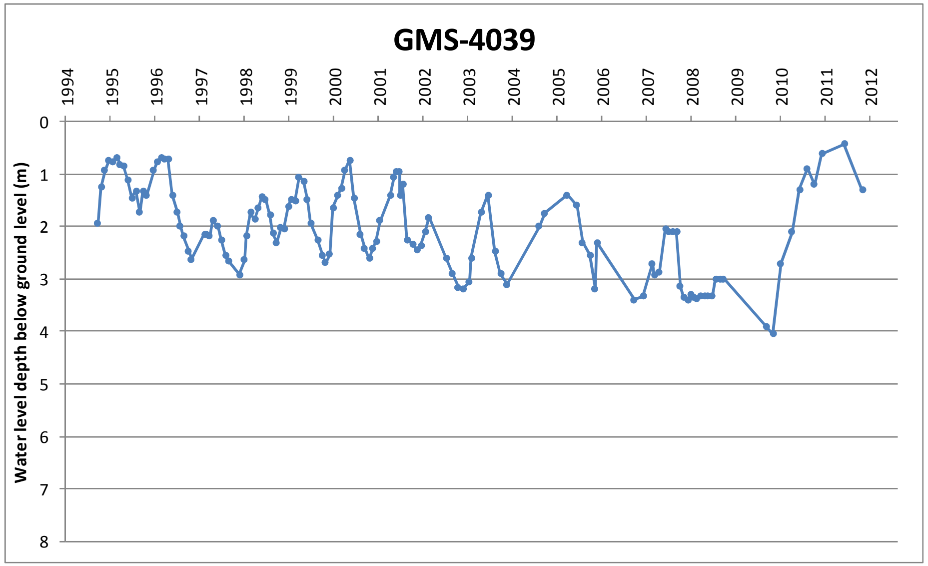
SITE NO	East.	North.	Total depth (m)	Elevation (m AHD)	Use	WL data available	Most recent WL reading	WL (m AHD)	Screened lithology	Screened from / to (m bgl)		EC (mS/cm)	TDS (mg/L)	Source
S9022838/2	367600	5783600	7	24.29	Stock and domestic	-	-	-	-	-	-	-	-	GMS 2012
S9022838/3	367600	5783700	7	24.13	Stock and domestic	-	-	-	-	-	-	-	-	GMS 2012
S9022838/4	367700	5783600	7	23.43	Stock and domestic	-	-	-	-	-	-	-	-	GMS 2012
S9026462/1	368209	5782813	6.5	17.16	Stock and domestic	-	-	-	-	3.5	6.5	-	-	GMS 2012
S9030684/1	367363	5784776	100	29.34	Unknown	-	-	-	-	-	-	-	-	GMS 2012
S9033481/1	374760	5783853	37	32.52	Unknown	-	-	-	-	-	-	-	-	GMS 2012
S9036341/1	369493	5785254	27.5	32.9	Domestic	-	-	-	-	-	-	-	-	GMS 2012
WRK041629	369653.2	5788244	24.7	68.49	Irrigation	-	-	-	Clay	21	24.7	-	-	GMS 2012
WRK052081	370900	5787600	8	78.88	Observation	-	-	-	Clay	2	8	-	-	GMS 2012
WRK052082	367891	5786597	8	58.48	Observation	-	-	-	-	-	-	-	-	GMS 2012
WRK052086*	370900	5786600	15	74.37	Observation	-	-	-	-	-	-	-	-	GMS 2012
WRK054928	374787	5783858	37	32.27	Irrigation	-	-	-	-	-	-	-	-	GMS 2012
WRK055859	366130	5785455	31	39.89	Irrigation	-	-	-	-	-	-	-	-	GMS 2012
1	361346	5783753	5	23.02	Observation	Yes - single data	3/07/2008	20	Clay?	-	-	1.57	942	SKM 2008b
2	361782	5783761	9	23.05	Observation	Yes - single data	3/07/2008	18.42	Clay?	-	-	5.18	3108	SKM 2008b
3	362239	5783767	5	22.07	Observation	Yes - single data	3/07/2008	18.84	Clay?	-	-	3.24	1944	SKM 2008b
4	362216	5783557	5	21.16	Observation	Yes - single data	3/07/2008	18.07	Clay?	-	-	5.43	3258	SKM 2008b
5	361681	5782722	5	18.84	Observation	Yes - single data	3/07/2008	15.98	Clay?	-	-	9.41	5646	SKM 2008b
6	361729	5782920	5	19.68	Observation	Yes - single data	3/07/2008	16.1	Clay?	-	-	11.59	6954	SKM 2008b
7	362461	5783060	10	19.53	Observation	Yes - single data	3/07/2008	14.33	Clay?	-	-	4.06	2436	SKM 2008b
8	362681	5782847	5	18.4	Observation	Yes - single data	2/07/2008	15.77	Clay?	-	-	2.05	1230	SKM 2008b
9	363467	5783138	5	20.67	Observation	Yes - single data	2/07/2008	Dry	Clay?	-	-	-	-	SKM 2008b
10	363902	5783100	10	21.45	Observation	Yes - single data	2/07/2008	18.13	Clay?	-	-	5.08	3048	SKM 2008b
11	364273	5783070	5	22.21	Observation	Yes - single data	2/07/2008	17.88	Clay?	-	-	5.66	3396	SKM 2008b
12	363932	5782405	6	17.83	Observation	Yes - single data	2/07/2008	Dry	Clay?	-	-	-	-	SKM 2008b

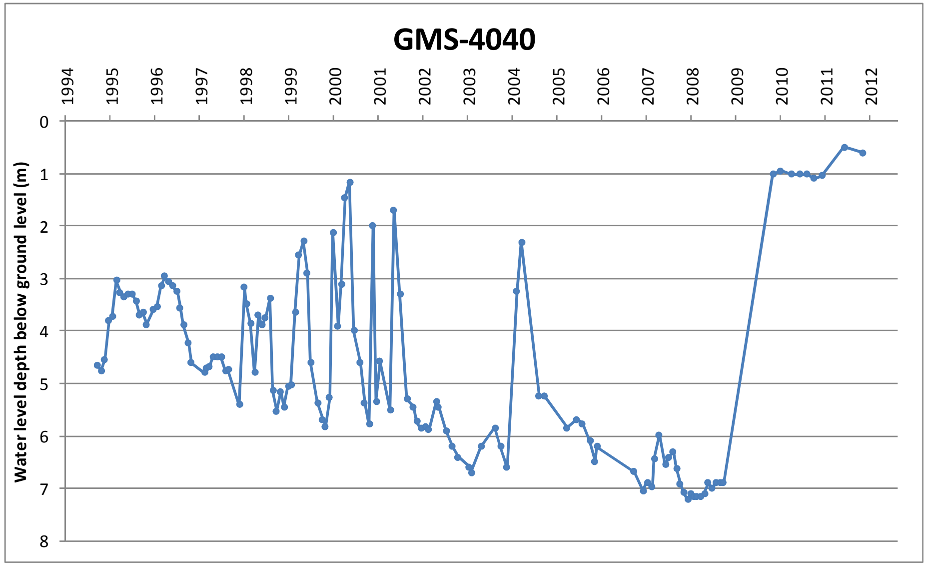
SITE NO	East.	North.	Total depth (m)	Elevation (m AHD)	Use	WL data available	Most recent WL reading	WL (m AHD)	Screened lithology	Screened from / to (m bgl)		EC (mS/cm)	TDS (mg/L)	Source
13	362625	5782372	5	15.96	Observation	Yes - single data	2/07/2008	12.81	Clay?	-	-	2.26	1356	SKM 2008b
14	363053	5781655	10	13.92	Observation	Yes - single data	2/07/2008	12.52	Clay?	-	-	5.07	3042	SKM 2008b
15	363800	5781590	5	13.82	Observation	Yes - single data	2/07/2008	10.09	Clay?	-	-	10.24	6144	SKM 2008b
MB01	5785217	357824	5	37.5	Observation	Yes - single data	14-15/01/2003	35.3	Clay and sand	2	5	4.4	2040	URS 2003a
MB02	5784428	360117	6	28.5	Observation	Yes - single data	14-15/01/2003	25.7	Clay and sand	3	6	10.6	7640	URS 2003a
MB03	5783248	364153	10	23.5	Observation	Yes - single data	14-15/01/2003	21.6	Clay	4	10	3.9	1720	URS 2003a
MB04	5782996	368887	5	17	Observation	Yes - single data	14-15/01/2003	15.3	Clay	2	5	6.7	3730	URS 2003a
MB05	5782972	368397	10	22.5	Observation	Yes - single data	14-15/01/2003	15.8	Clay	7	10	5.4	5970	URS 2003a
MB06	5783467	369489	10	28	Observation	Yes - single data	14-15/01/2003	20.3	Weathered basalt	7	10	3.4	2510	URS 2003a
MB07	5784932	372605	10	42.5	Observation	Yes - single data	14-15/01/2003	38.3	Clay	7	10	0.93	790	URS 2003a
PA15	369074	5782450	5.5	13.82	Observation	Yes - single data	17/05/2012	12.72	Clay	2	5	9.008	-	Chamberlain 2012
PA16	369437	5781398	5.7	10.97	Observation	Yes - single data	17/05/2012	8.41	Clay	2	5	12.595	-	Chamberlain 2012
PA17	368815	5781496	5.5	10.97	Observation	Yes - single data	17/05/2012	10.23	Clay	2	5	9.178	-	Chamberlain 2012
PA18	368321	5782999	7.5	17.75	Observation	Yes - single data	17/05/2012	15.33	Clay	3.5	6.5	8.824	-	Chamberlain 2012

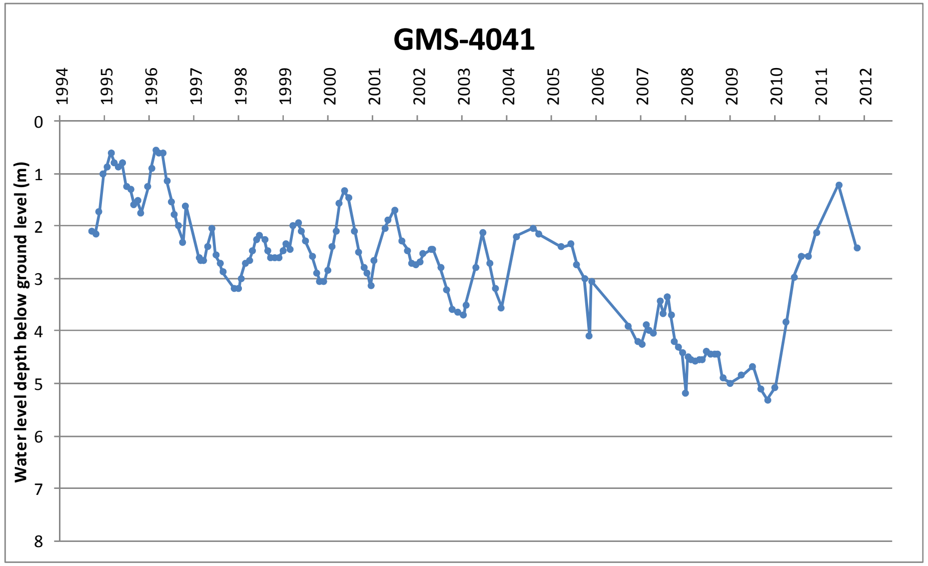
Notes: * indicates bores visited during site visit

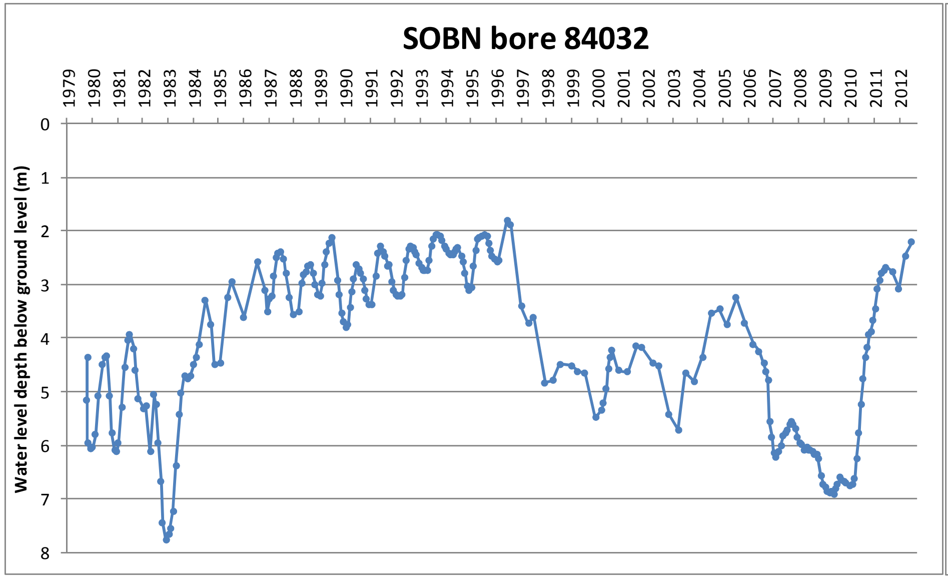
Appendix B. Bore hydrographs

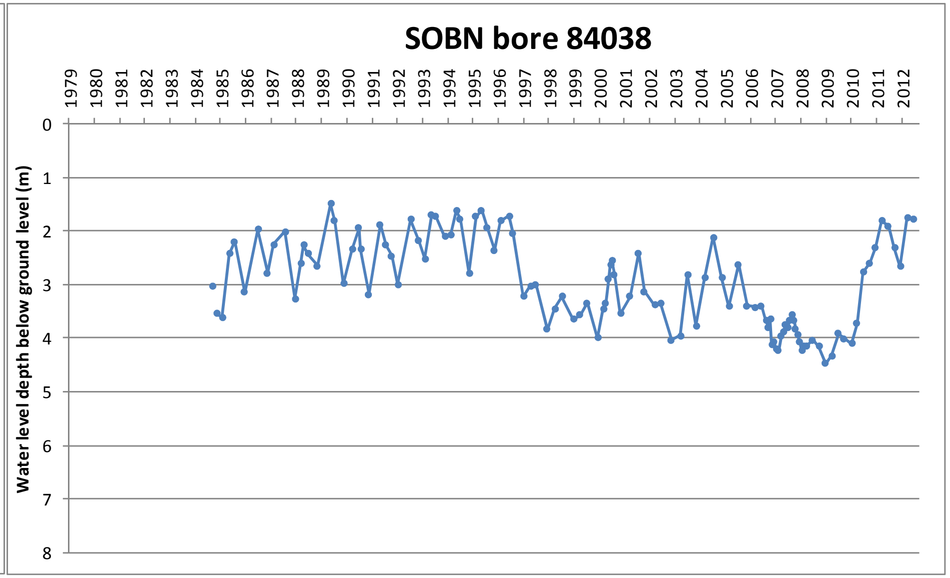






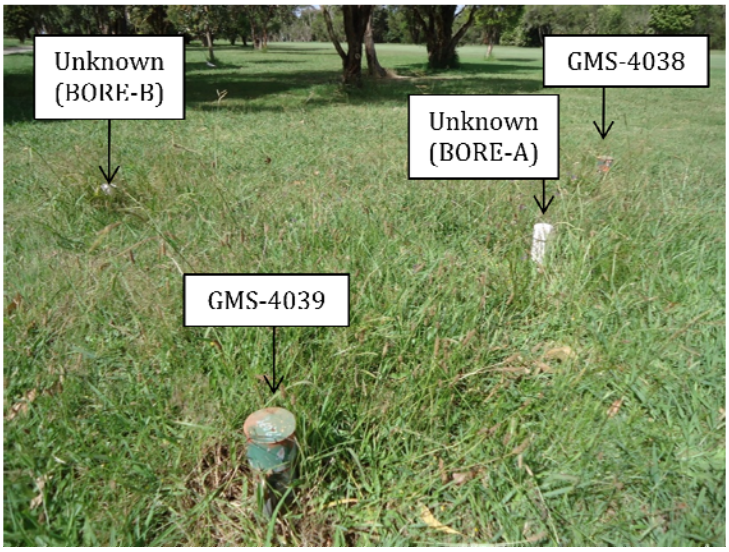


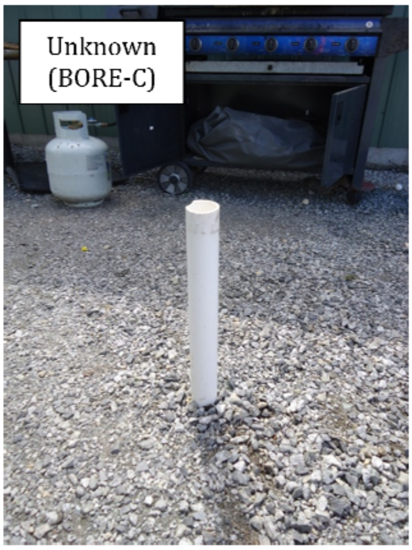




Note: The similarity of many data entries in bores GMS-4038 and GMS-4039 at this nested site is likely due to the bores reading water levels in the same aquifer although they are drilled to different depths. (The bores are known to have been drilled to between 5 and 20 m below the ground surface, however other construction and screened lithology information for these bores is not available.)

Appendix C. Photographs of bores from site visit





Appendix D. Photographs of surface water features from site visit

Clockwise from top left; dry drain (~1m deep) near bore 139973; water in Deep Creek at the Ryan Rd crossing (~1.2m bgl); water level in a Golf Course pond (~1.5m bgl); water in Deep Creek at Princes Hwy crossing (~2.5m bgl).