

Onshore natural gas water science studies

# Otway Region

## Groundwater sampling and characterisation for hydrocarbons

June 2015

# Onshore natural gas water science studies

## **Acknowledgements**

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## Executive summary

This study is part of the onshore natural gas water science studies being undertaken jointly by the Department of Environment, Land, Water and Planning (DELWP) and the Department of Economic Development, Jobs, Transport and Resources (DEDJTR).

The purpose of groundwater sampling project was to characterise the groundwater chemistry, particularly with presence or not of hydrocarbons, and to provide an indication of baseline, that is the concentration of hydrocarbons in groundwater.

This report focusses on the Otway region. A parallel study of the Gippsland region is covered in a companion report (DELWP (2015)). It includes a review of the literature on previous groundwater chemistry studies in the Otway Basin and conclusions on likely hydrocarbon movements through the profile. The literature review provides input to the selection of sampling bores and analytes and also provides the context for interpretation of results. Key observations from the literature review include:

- A potentially prospective formation for coal seam gas in the Otway Basin is the Killara Coal Measures in the Cretaceous geology located north of Warnambool and west of Hamilton.
- A potentially prospective formation for tight gas in the Otway Basin is the Cretaceous aged Eumeralla Formation underlying the Waaree Formation south-east of Warnambool and the Cretaceous aged Pretty Hill Formation, north-west of Portland.
- A potentially prospective formation for shale gas in the Otway region is the Casterton Formation to the far west of the state.
- Naturally occurring hydrocarbons have been found in the following units:
  - the Cretaceous aged sediments of the Sherbrook Group in the Port Campbell Embayment
  - the Lower Tertiary aged Wangerrip Group in the Port Campbell Embayment with particular localities in the Port Campbell area and the Barwon Downs region west of Geelong
  - Cretaceous aged sediments of the Sherbrook Group and the Lower Tertiary aged sediments of the Wangerrip Group in the Portland Trough.
- The presence or absence of major aquitards is likely to have a significant impact on the vertical movement of hydrocarbons through the vertical profile and the potential impact on overlying groundwater and surface water assets. The two major aquitards across the region include:
  - the Narrawaturk Marl and Upper Mepunga Formation of the Nirranda Group
  - the Gellibrand Marl of the Heytesbury Group.

A representative number of bores for sampling were selected from aquifers known to have, or suspected of having, hydrocarbon concentrations (from the literature review) and/or within or near groundwater or surface water assets. Priority was given to nested sites which provide vertical information on variations in groundwater chemistry and sites with known construction details.

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This report presents the results from 30 bores sampled in the Otway region between 19<sup>th</sup> January 2015 and 29<sup>th</sup> January 2015 using low flow sampling techniques.

The results indicate that dissolved methane in groundwater occurs naturally at low concentrations across the Otway region. The median concentration from the 30 samples collected was 0.01 mg/L. A single outlier was observed for bore 111786, which indicated dissolved methane in the Lower Tertiary Aquifer of 5.8 mg/L.

Total Recoverable Hydrocarbons were also detected in 5 of the 30 samples, although most detections were low (equal to the detection limit) and the detections were not in the fraction range for Benzene, Toluene, Ethylbenzene and Xylene (BTEX). The lack of BTEX detection suggests that BTEX compounds are not a natural occurrence in any of the sampled aquifers and any future detection is likely to reflect an anthropogenic origin.

The role of aquitards in limiting the vertical movement of hydrocarbons through the vertical profile is currently difficult to ascertain in the Otway region, given the inherent low concentrations of methane in groundwater across all aquifers. The only elevated methane concentration was recorded for the Lower Tertiary Aquifer (5.8 mg/L) and this bore is located north-east of Colac and is nested with bore 111787 which screens the Newer Volcanic Basalt and did not record any methane in its groundwater. In this area the combined thickness of the Upper and Lower Mid Tertiary Aquitard is approximately 450 m. In this area it can be tentatively concluded that vertical hydrocarbon migration is reduced where a significant aquitard thickness exists. This is consistent with the conceptual hydrogeological model for the Otway region.

It should be noted that whilst the primary prospective formations for potential oil and gas deposits reside in the deep Eumeralla Formation, Waarre Formation and Casterton Formation, only one groundwater bore was available for sampling these units and it was located away from likely prospective areas and was quite shallow. Although the groundwater chemistry information associated with the units that contain the natural gas prospectivity is limited, the negligible methane concentration observed in the overlying units implies that the vertical hydraulic conductivity of the Cretaceous fractured rock is low and there is little opportunity for gas migration to shallower overlying units.



# 1 Introduction

This study is part of the onshore natural gas water science studies being undertaken jointly by the Department of Environment, Land, Water and Planning (DELWP) and the Department of Economic Development, Jobs, Transport and Resources (DEDJTR).

The purpose of groundwater sampling project was to characterise the groundwater chemistry, particularly with presence or not or not of hydrocarbons, and to provide an indication of baseline, that is the concentration of hydrocarbons in groundwater.

This report focuses on the Otway region with the results in the Gippsland region covered in DELWP (2015).

Natural gas includes conventional gas, coal seam gas, tight gas and shale gas. Figure 1 shows a representation of the typical geological formations potentially bearing natural gas resources in the Otway region and the relative depth of the different potential gas sources.

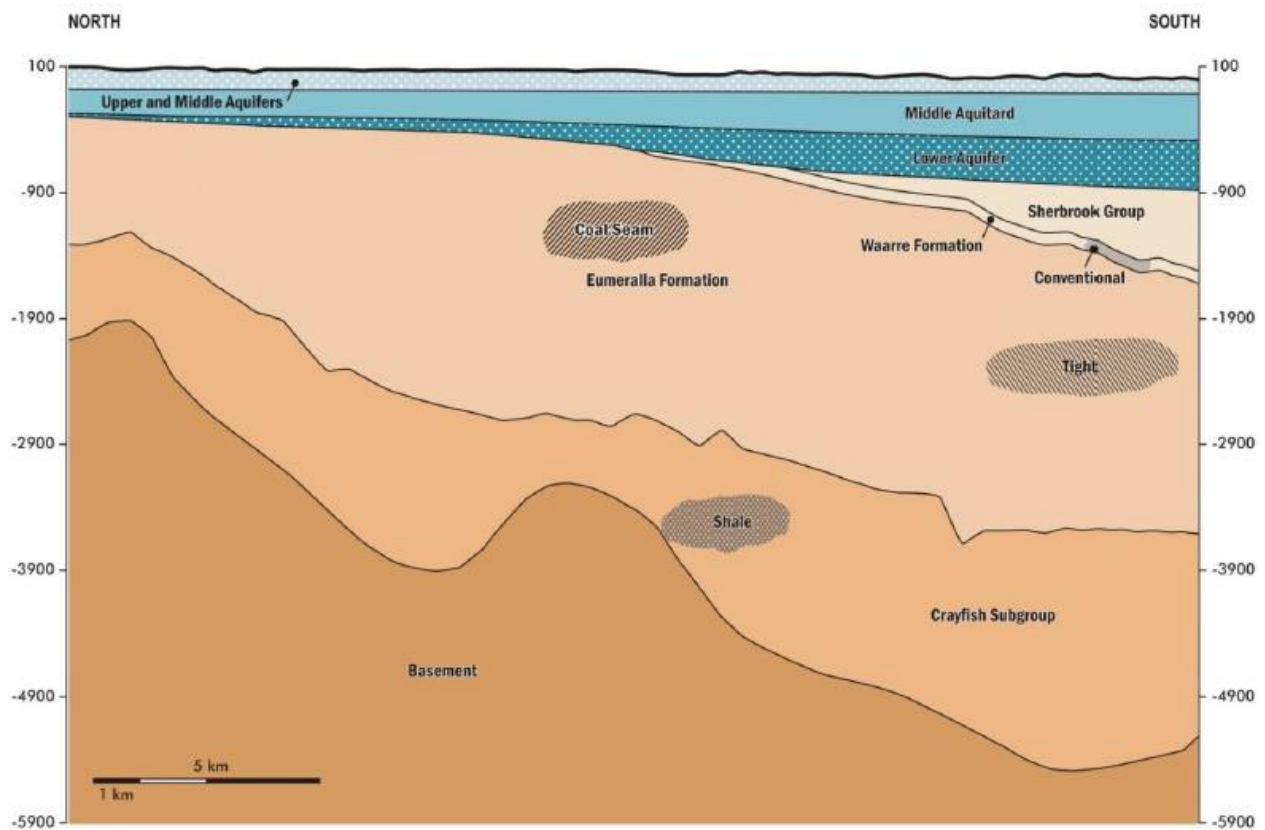


Figure 1 Typical geological formations potentially bearing onshore natural gas in the Otway region (depth shown in metres)

This report presents the sampling results from the groundwater monitoring program in the Otway region.

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The work undertaken for this study has been documented as follows:

Chapter 2 Literature review

Chapter 3 Bore selection

Chapter 4 Sampling method

Chapter 5 Quality assurance procedures and results

Chapter 6 Groundwater sampling – summary of results by analyte

Chapter 7 Groundwater sampling – aquifer characterisation

Chapter 8 Conclusions and implications for conceptual model.

## 2 Literature review of hydrocarbon occurrence in groundwater

A literature review has been undertaken to determine whether any previous studies have detected occurrences of methane, BTEX or other hydrocarbons in the groundwater resources of the Otway Basin and how these results have been interpreted in the context of the conceptual model of the basin. The literature review provided input to the selection of sampling bores and analytes and also provides the context for interpretation of results.

This chapter begins with a summary of the hydrogeology of the Otway region, including the main aquifers and structural features (Section 2.1). Section 2.2 reviews the literature on hydrocarbon occurrence and movement in the Otway region. Potential areas for onshore natural gas prospectivity are discussed in Section 2.3 and the implications of the literature review for the selection of groundwater chemistry parameters for this study is discussed in Section 2.4.

The approach to the literature review included the following components:

- Review literature that identifies the occurrence of methane, BTEX or other hydrocarbons in the groundwater resources of the Otway Basin, where coal and oil and gas are potentially present including: DSE (2010), Geological Society of Victoria (1995), GHD (2009), Hawkins and Dellenbach (1971), Hyder Consulting (2009), Laing *et. al.* (1989), Leeder Consulting (2009), Woollands and Wong (2001).
- The querying of readily available databases for additional groundwater data that might help to identify the location of hydrocarbon occurrence in the region:
  - Geoscience Australia Petroleum Wells Database (<http://dbforms.ga.gov.au/www/npm.well.search>) viewed October 2014.
  - Victorian Water Management Information System (queried the laboratory chemistry information, however no relevant groundwater hydrocarbon information was stored in this database).
- Review national and international literature regarding coal seam gas monitoring programs to understand industry standards including CSIRO (2011), Claytor and Shaw (2008), Alberta Environment (2006) and QGC (2012).

### 2.1 Otway Basin – aquifer overview

The Otway Basin is a NE-SW striking passive margin rift basin approximately 500 km long located in eastern South Australia (25% of the basin), southern Victoria (50% of the basin) and northern Tasmania (25% of the basin). The basin covers an area of roughly 155,000 km<sup>2</sup>, 80% of which is located offshore. Petroleum exploration in the basin began in 1892 but the basin failed to yield any hydrocarbons until 1959 when an onshore sub-commercial quantity of gas was discovered at Port Campbell. No commercial quantities were discovered until 1978 with larger commercial quantities discovered in 1993 and 2001 both on and offshore (Woollands & Wong, 2001).

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The Otway Basin consists of a 10 km thick sequence of Mesozoic and Cenozoic sedimentary and volcanic rocks including a number of significant aquifers. The primary units in the Otway Basin that have been associated with hydrocarbon exploration include:

- the Otway Group (Mesozoic and Palaeozoic Bedrock Aquifer 114 ) – oil and gas was encountered at multiple levels within the sequence
- the Sherbrook Group (Cretaceous and Permian Sediments 113) – gas and weak oil was encountered in the lower half of sequence
- the Wangerrip Group (Lower Tertiary Aquifer 111) – oil and gas at different levels within the sequence
- the Eastern View Group (Lower Tertiary Aquifer 111) – weak gas encountered in some wells but nothing commercial discovered.

No hydrocarbon accumulations have been reported in the overlying units. A generalised stratigraphic section is shown in Figure 2. The Victorian Aquifer Framework (VAF) (SKM, 2011) simplified the aquifer and aquitard units of Victoria for the purposes of water resource management. The VAF aquifer nomenclature is used throughout this report to describe the aquifers across the Otway Basin. The relationship between the Otway Formation names shown in Figure 2 and the VAF nomenclature is shown in Figure 3. A brief description of each of the units listed above is provided below.

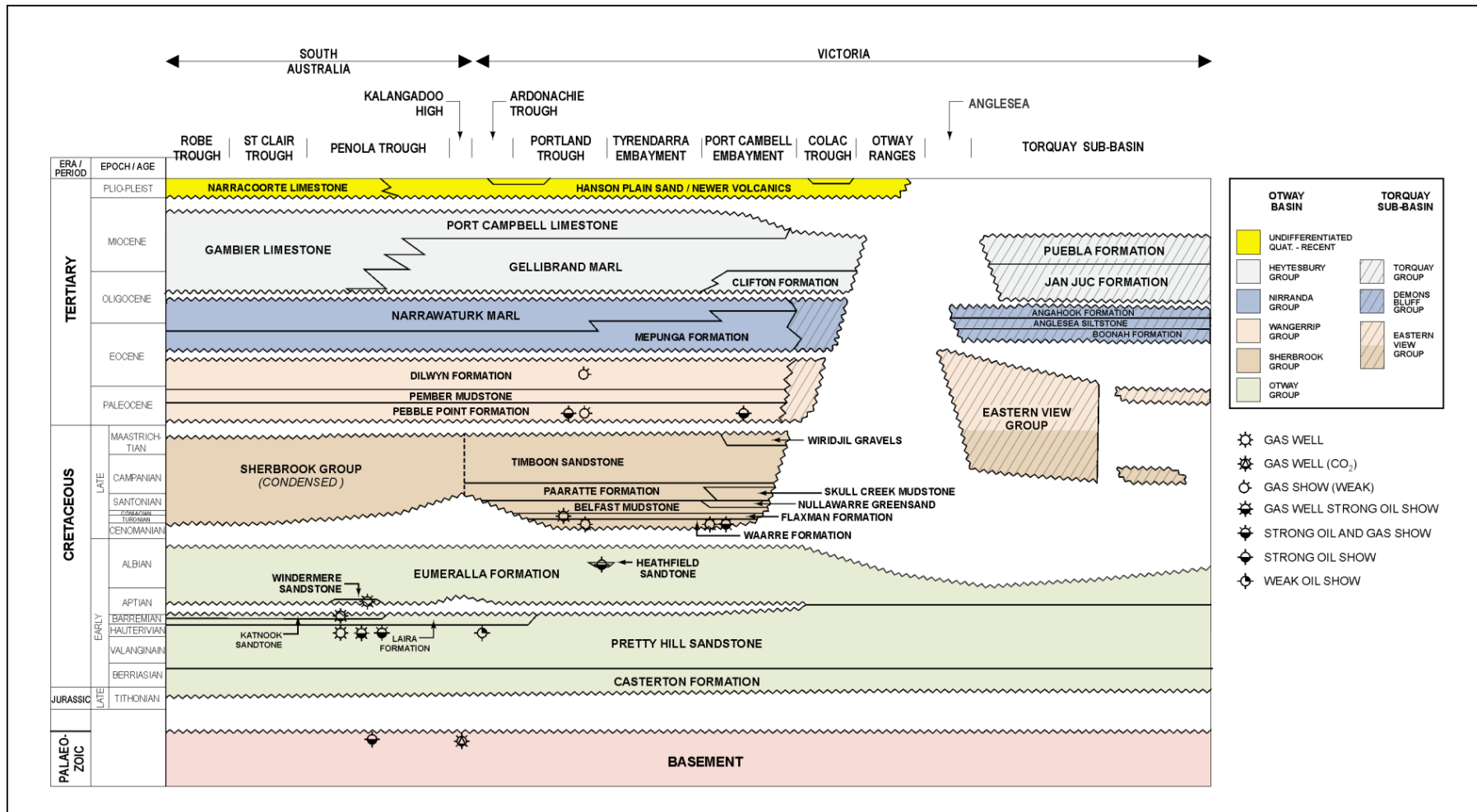


Figure 2 Stratigraphy of the Otway basin (from the Petroleum Atlas of Victoria (source: Woollands & Wong, 2001)).

Stratigraphic Group	Formation	Aquifer Name	Aquifer Code	Aquifer Number
Various Quaternary Deposits		Quaternary Aquifer	QA	100
Newer Volcanics		Upper Tertiary /Quaternary Basalt	UTB	101
Upper Tertiary Sediments	Whalers Bluff Formation	Upper Tertiary Aquifer (marine)	UTAM	104
	Moorabool Viaduct Formation			
	Hanson Plain Sand			
	Dorodong Sands			
	Grange Burn Formation			
	Undifferential Fluvial Tertiary Sediments	Upper Tertiary Aquifer (fluvial)	UTAF	105
Heytesbury Group	Port Campbell Limestone	Upper Mid - Tertiary Aquifer	UMTA	107
	Gellibrand Marl	Upper Mid - Tertiary Aquitard	UMTD	108
	Clifton Formation	Lower Mid - Tertiary Aquifer	LMTA	109
Nirranda Group	Narrawaturk Formation	Lower Mid - Tertiary Aquitard	LMTD	110
	Upper Mepunga Formation			
	Lower Mepunga Formation			
Wangerrip Group	Dilwyn Formation	Lower Tertiary Aquifer	LTA	111
	Pember Mudstone			
	Pebble Point Formation			
Sherbrook Group	Timboon Sandstone	Cretaceous and Permian Sediments	CPS	113
	Paaratte Formation			
	Belfast Mudstone			
	Flaxmans Formation			
	Waarree Formation			
Eumerella Formation		Cretaceous and Palaeozoic Bedrock	BSE	114
Crayfish Group	Katnook Sandstone			
	Laira Formation			
	Pretty Hill Formation			
Casterton Formation				

Figure 3: Otway Basin Formations categorised by Victorian Aquifer Framework names, codes and numbers (source: modified from GHD, 2012).

### 2.1.1 The Otway Group (Mesozoic and Palaeozoic Bedrock Aquifer 114)

The Otway Group consists of a thick sequence (up to 8 km thick) of sandstone and shale with minor interbedded coal and volcanics. The youngest formation in the Otway Group is the Eumeralla Formation which consists of fluvial sandstone interbedded with mudstone, fine sandstone and shale. The Eumeralla Formation is not considered to be a viable fractured rock aquifer and is generally considered to form the impermeable basement of the younger Otway Basin sediments (SKM & GHD, 2009). The Eumeralla Formation is unconformably underlain by the Pretty Hill Formation from which commercial quantities of gas are extracted in South Australia (Woollands & Wong, 2001).

### 2.1.2 The Sherbrook Group (Cretaceous and Permian Sediments 113)

The Sherbrook Group unconformably overlies the Eumeralla Formation of the Otway Group and consists of sandstone, shale, mudstone and minor coal up to 5 km thick. This sequence is restricted to the western portion of the Otway Basin and is not present in the Torquay sub-basin. The upper Cretaceous sediments present in the Torquay sub-basin are assigned to the Eastern View Group. The result of a long period of variable depositional environments, the hydrostratigraphy of the Sherbrook Group is complex. The

stratigraphic formations from oldest to youngest are: the Waarre Formation, the Flaxman Formation, the Belfast Mudstone, the Paaratte Formation and the Timboon Sandstone.

The Waarre and Flaxman Formations consist of sandstone, mudstone and minor coal and have relatively good porosity. However, their potential as aquifers is low due to the high salinity formation waters associated with the hydrocarbon reserves. Most of the known hydrocarbon occurrences in the Sherbrook Group are located within these two formations, with the commercial onshore gas extraction at Port Campbell extracting from the Waarre Formation. Weak oil accumulations have also been reported in this formation (Woollands & Wong, 2001).

The Belfast Mudstone is a low hydraulic conductivity aquitard and the overlying Paaratte Formation and Timboon Sandstone are confined aquifers consisting of weakly-cemented sandstone with some pebble and gravel beds and minor siltstone that host good quality water (SKM & GHD, 2009). No hydrocarbons occurrences have been reported in these units.

In the Port Campbell Embayment there are two additional formations: the Nullawarre Greensand and the Skull Creek Mudstone. The Nullawarre Greensand is up to 388 m thick and consists of fine to coarse grained glauconitic sandstone (Hawkins and Dellenbach, 1971 and Geological Society of Victoria, 1995). This formation passes into equivalents of the Paaratte Formation and the Belfast Mudstone. The Skull Creek Mudstone (Laing *et al.*, 1989) is up to 208 m thick and consists of pale grey to black silty mudstone that unconformably overlies the Nullawarre Greensand.

### **2.1.3 The Wangerrip Group (Lower Tertiary Aquifer 111)**

The Wangerrip Group consists of a sequence of gravel, sand, silt and mudstone up to 350 m thick (Woollands & Wong, 2001). This sequence is restricted to the western portion of the Otway Basin and is not present in the Torquay Sub-basin. The Lower Tertiary sediments present in the Torquay Sub-basin are assigned to the Eastern View Group. The Wangerrip Group consists of three formations from oldest to youngest: the Pebble Point Formation, the Pember Mudstone and the Dilwyn Formation. The Pebble Point and Dilwyn Formations are aquifers that have both unconfined and confined portions and the Pember Mudstone is an aquitard consisting of siltstone, mudstone and shale.

The Pebble Point Formation consists of ferruginous sandstone and gravel with some conglomerate and is where the majority of gas and oil has been reported in the Wangerrip Group. Weak gas accumulations have also been reported in the Dilwyn Formation which is characterised by marine sandstone and minor shale and siltstone.

### **2.1.4 The Eastern View Group (Lower Tertiary Aquifer 111)**

The Eastern View Formation consists of mostly unconsolidated sand with minor carbonaceous silt and brown coal up to 450 m thick. The Eastern View Group overlaps in time of deposition with the upper Sherbrook Group and Wangerrip Group and is restricted to the Colac and Torquay Sub Basins in the eastern end of the Otway Basin (Woollands & Wong, 2001). Small amounts of gas have been reported in this group but no commercial quantities of gas have been discovered.

## 2.2 Otway region - hydrocarbon occurrence

Figure 4 (Woollands & Wong, 2001) shows where gas and oil have been reported in each formation and Figure 2 shows the location of oil and gas occurrences. The commercial hydrocarbon discoveries in the Otway Basin to date have largely been found in just two units: The Pretty Hill Formation and the Waarre Formation. The commercial onshore gas fields in Victoria are restricted to the Port Campbell area where Waarre Formation is the reservoir rock. The Port Campbell gas fields are located on the Port Campbell Embayment, a stratigraphic structural feature approximately 50 km wide and 15 – 20 km deep. This structure is defined by the northern extent of the Waarre Formation onshore at Port Campbell (Woollands & Wong, 2001).

To the west of the Port Campbell Embayment there are weak and strong oil and gas reserves in the Portland Trough in both the Wangerrip Group (gas in the Dilwyn Formation and oil and gas in the Pebble Point Formation) and the Sherbrook Group (gas in the Waarre and Flaxman Formations) as well and oil in the Sherbrook Sandstone, a member of the Eumeralla Formation. There are no commercial gas fields between the South Australian border and the Port Campbell gas fields.

Routine monitoring of observation bores near the Barwon Water bore field, located approximately 10 km southeast of Colac, identified a strong smell of hydrocarbons. The groundwater was sampled and analysed from five groundwater observation bores in 2009 by Hyder Consulting (2009) who concluded that the source was likely to be anthropogenic (i.e. an act of waste disposal or vandalism). The groundwater was found to contain TPH, BTEX and some PAHs in four of the five bores. TPH was detected at 13,390 µg/L in bore 64233 (standing water column) with the representative aquifer sample recording TPH at 2,940 µg/L at this bore. One bore had no discernible hydrocarbons and TPH concentrations were between 200 and 500 µg/L in the remaining three bores.

Subsequent assessment by GHD (2009), Leeder Consulting (2009) and Department of Sustainability (2010) gave varying opinions on the source of the hydrocarbons present in the groundwater. The overall conclusions appears to be that although the TPH concentrations in bore 64233 are likely to be due to an act of waste disposal, the hydrocarbon concentrations in the other three bores may be natural. There is insufficient information to fully determine the source of these hydrocarbons, but based on the carbonaceous materials in the bores, the absence of free product and the low concentrations, natural sources could be the source of these TPHs.

The bores that recorded low level (potentially naturally occurring) hydrocarbons during the low flow groundwater sampling included:

- Bore 109113: screened in the Pebble Point Formation and recorded a TPH below detection and a toluene concentration of 25 µg/L
- Bore 82840:; screened in the Pebble Point Formation and recorded a TPH concentration of 200 µg/L and a toluene concentration of 18 µg/L
- Bore 48249; screened in the Dilwyn Formation and recorded a TPH concentration of 500 µg/L.

There have been no identified hydrocarbons through exploration drilling in this area (Figure 4). The Petroleum Atlas of Victoria states that the top of the Wangerrip Group (i.e. the Group containing the aquifers sampled in the Barwon Water bore field) has so far only been mapped seismically offshore in the Otway Basin as it is not considered by exploration companies to be an exploration target onshore.



## 2.2.1 Potential for vertical migration of hydrocarbons

The literature review identified a number of areas of naturally occurring hydrocarbons with particular focus areas being:

- the Cretaceous aged sediments of the Sherbrook Group in the Port Campbell Embayment
- the Lower Tertiary aged Wangerrip Group in the Port Campbell Embayment with particular hot spots in the Port Campbell area and the Barwon Downs region west of Geelong
- Cretaceous aged sediments of the Sherbrook Group and the Lower Tertiary aged sediments of the Wangerrip Group in the Portland Trough.

In addition to those units and areas which are known to host hydrocarbon deposits, there is the potential for vertical migration of hydrocarbons into overlying or underlying aquifers. The presence or absence of major aquitards is likely to have a significant impact on the vertical movement of hydrocarbons through the vertical profile and the potential impact on overlying groundwater and surface water assets. The two major aquitards across the region include:

- the Narrawaturk Marl and Upper Mepunga Formation of the Nirranda Group
- the Gellibrand Marl of the Heytesbury Group.

Vertical hydrocarbon migration is most likely where these aquitards are thinnest or absent, or where structural features such as faulting or cinder cones can cause vertical conduits. The thickness of these units has been mapped by SKM and GHD (2009). The risk of impact to important overlying aquifers is a combination of this likelihood of vertical migration, combined with the consequence of impact (as defined by the usability of the groundwater resource or the value of the groundwater dependent ecosystems).

Figure 5 shows the mapped thickness of the Narrawaturk Marl aquitard unit (SKM and GHD, 2009). This confining unit directly overlies the shallowest unit of known hydrocarbon occurrence, the Wangerrip Group (111 aquifer). Figure 5 indicates that the aquitard is relatively thin across the Otway Basin, only reaching a thickness of greater than 200 m in isolated areas around the Portland and Colac Troughs.

Figure 6 shows the mapped thickness of the Gellibrand Marl aquitard unit (SKM and GHD, 2009). This is a shallower confining unit comprised of marine shelf deposits and is more significant in terms of thickness, relative to the deeper Narrawaturk Marl. A thickness of between 200 to 500 m is more widespread across the basin.

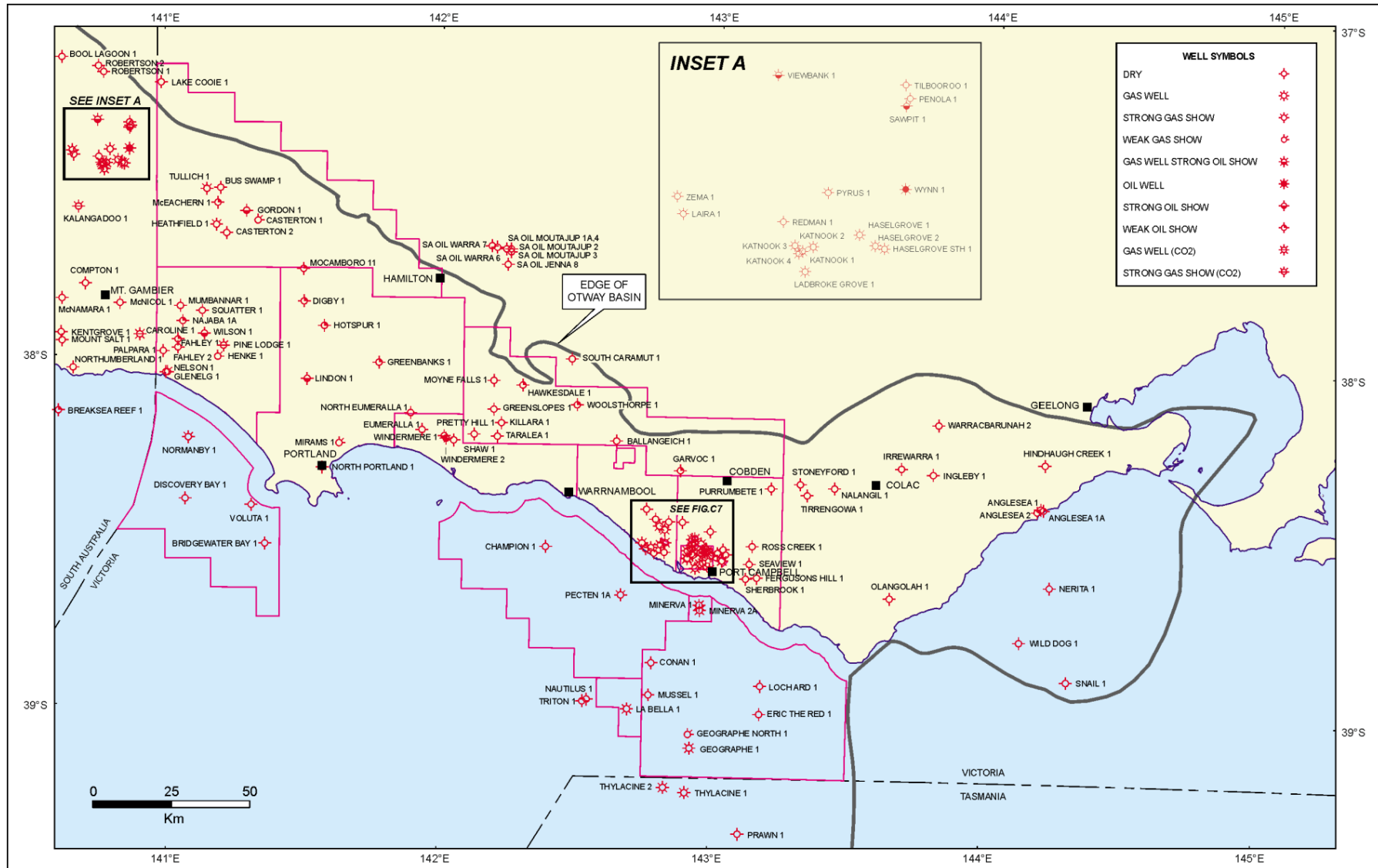


Figure 4 Location of gas exploration and discovery bores in the Otway Basin (from the Petroleum Atlas of Victoria (source: Woollands & Wong, 2001)

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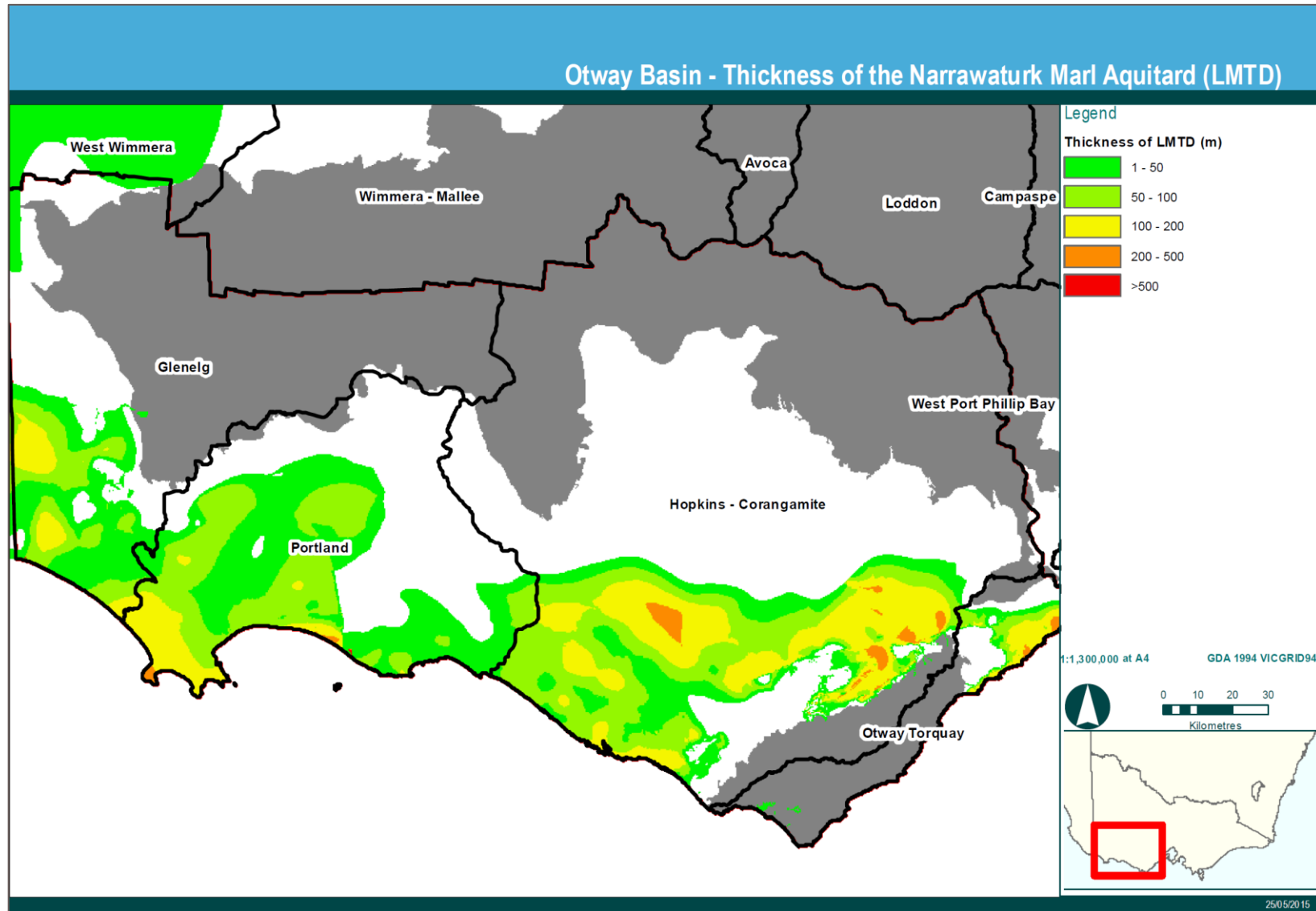


Figure 5 Review of the thickness of the Narrawaturk Marl Aquitard

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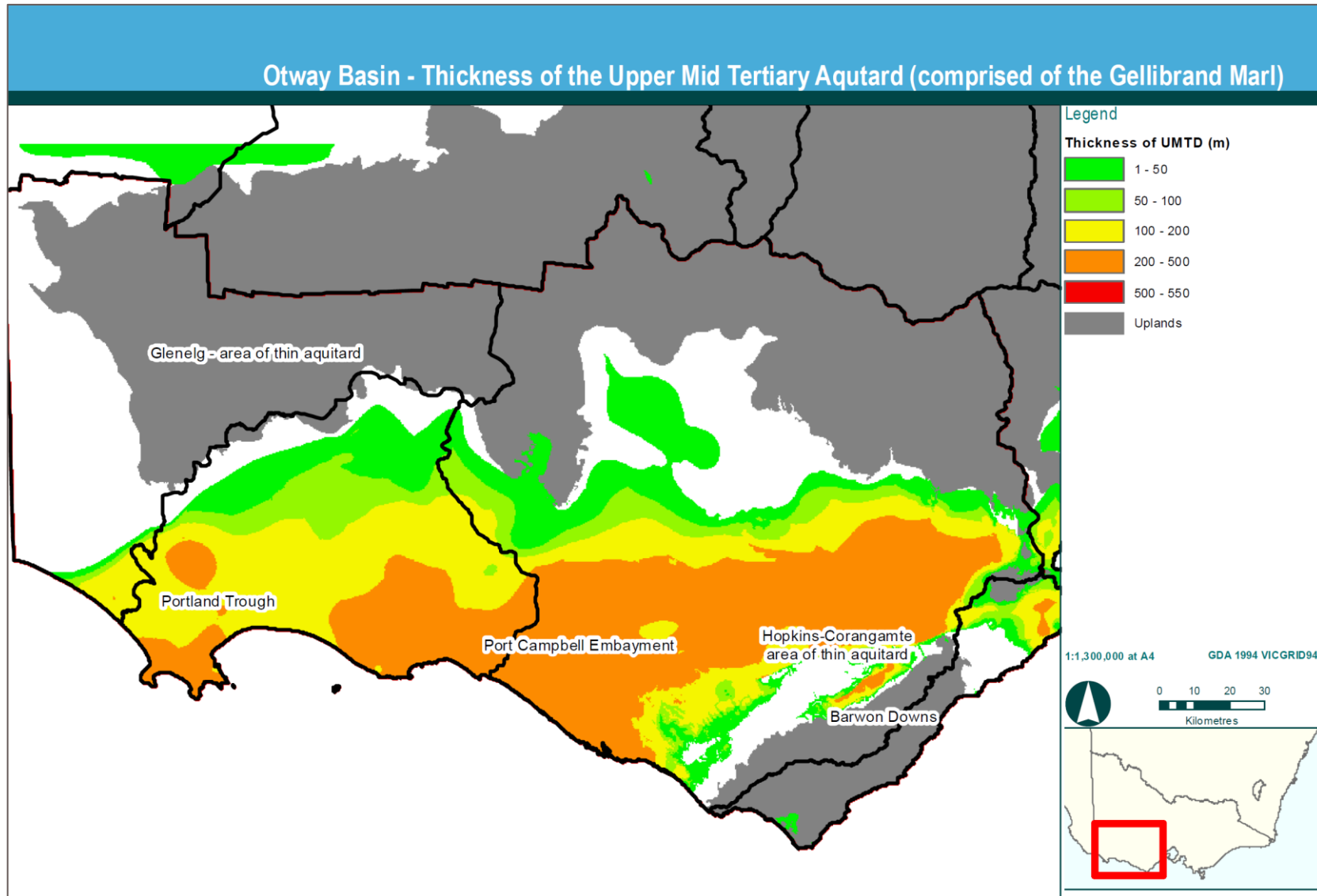


Figure 6 Review of the thickness of the Gellibrand Marl Aquitard

## 2.3 Onshore natural gas prospectivity

### 2.3.1 Coal seam gas prospectivity

Coal seam gas extraction is governed by the Langmuir isotherm, relating gas content to reservoir pressure. Once the reservoir hydrostatic pressure is reduced to a critical point, the gas is liberated from the coal seams. Unlike conventional oil and gas reserves, it is not necessary to have a ‘seal’ above the coal seams but rather the gas is held in the coal beds by adsorption on to the coal surfaces and by hydrostatic pressure. However, the presence of low permeability material above the coal seam can be beneficial in reducing the groundwater pumping required to liberate the coal seam gas.

A prospective formation for coal seam gas in the Otway region is the Killara Coal Measures in the Cretaceous hydrogeological basement, located north of Warrnambool and west of Hamilton (Figure 7).

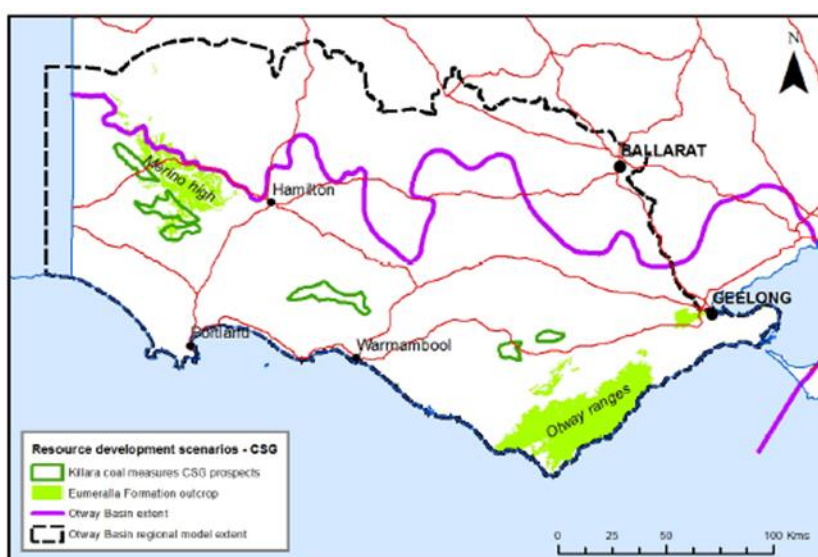


Figure 7 Otway Basin coal seam gas development scenarios (source: Goldie Divko, 2014)

### 2.3.2 Tight gas prospectivity

Tight gas is held in low permeability and low porosity rocks. The lack of permeability does not allow the gas to migrate out of the rock. Unlike coal seam gas where depressurisation of the coal seams is essential for gas migration, much smaller volumes of groundwater are required to be extracted in the development of tight gas deposits.

A prospective formation for tight gas in Otway region is the Cretaceous aged Eumeralla Formation underlying the Waaree Formation and the Cretaceous aged Pretty Hill Formation. Tight gas development scenarios from Goldie Divko (2014) are shown in Figure 8.

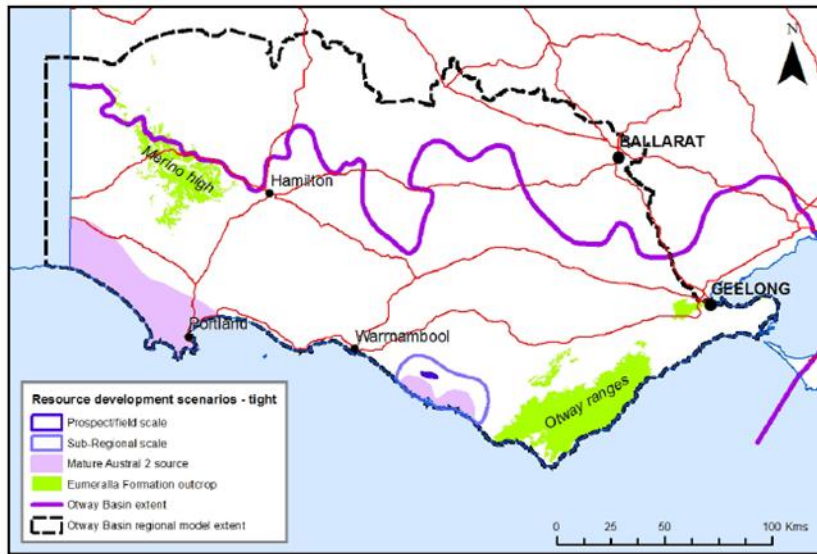


Figure 8 Otway Basin tight gas development scenarios (source: Goldie Divko, 2014)

### 2.3.3 Shale gas prospectivity

Shale gas is natural gas found trapped in shale formations. A prospective formation for shale gas in the Otway region is the Casterton Formation in the far west of the state. Tight gas development scenarios from Goldie Divko (2014) are shown in Figure 9.

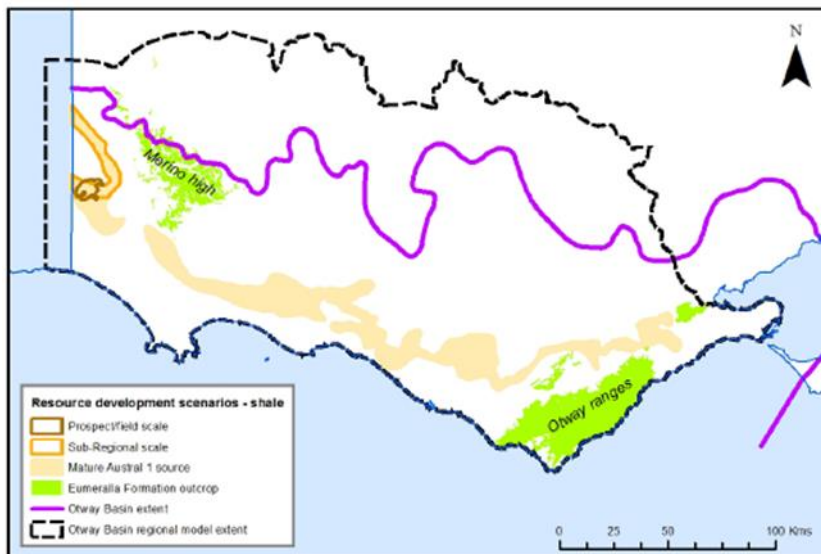


Figure 9 Otway Basin shale gas development scenarios (source: Goldie Divko, 2014)

### 2.3.4 Conventional gas prospectivity

Conventional gas fields have been developed and depleted in a number of locations in the Port Campbell Embayment. Conventional gas development scenarios from Goldie Divko (2014) are shown in Figure 10.

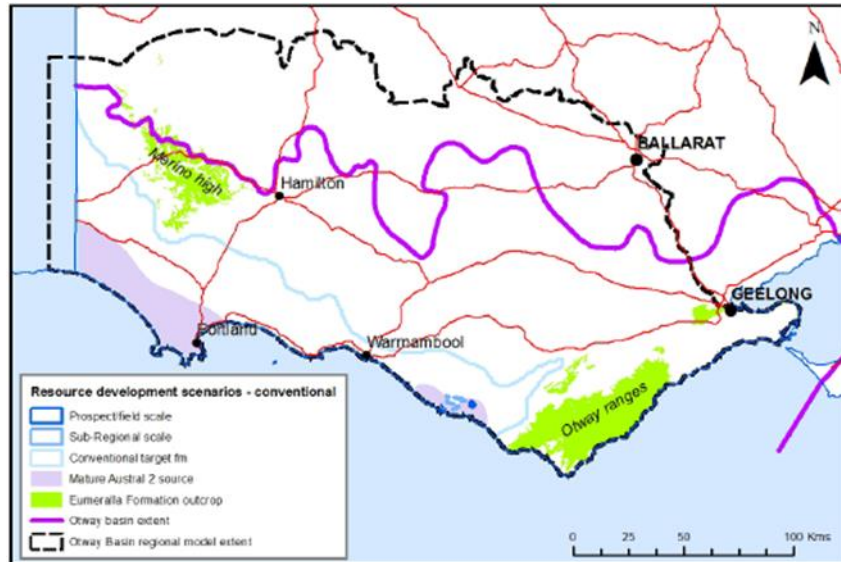


Figure 10 Otway Basin conventional gas development scenarios (source: Goldie Divko, 2014)

## 2.4 Groundwater chemistry sampling suite

In developing sampling approach a range of literature has been used to understand the most efficient and informative monitoring suite.

A number of natural gas exploration companies are currently operating in Queensland, Australia. The groundwater quality monitoring program undertaken by QGC for Queensland Curtis LNG (QCLNG) has been considered in development of this monitoring suite. International baseline groundwater monitoring protocols associated with natural gas have also been reviewed and used to inform the proposed monitoring suite. Protocols for Alberta and British Columbia, Canada have particularly provided useful basis from which to assess the groundwater parameters (Alberta Environment (2006), Chaytor, S. and Shaw, R., (2008)).

### 2.4.1 Groundwater characterisation

Monitoring of physical and inorganic properties of groundwater will be used to characterise the existing variability in aquifer chemistry. This will be done by assessing the unique chemical characteristics of the different aquifers, which can then be used as tracers to provide qualitative estimates of the degree of mixing between multiple aquifers.

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Inorganic minerals are those derived from geological systems as opposed to organic minerals that are derived from biological systems. Groundwater contact with rocks and soils will lead to dissolution of inorganic minerals, namely major cations and major anions. The proposed suite of inorganic parameters to use in this project is:

- Calcium
- Sodium
- Magnesium
- Potassium
- Chloride
- Sulphate
- Fluoride
- Total alkalinity, carbonate / bicarbonate
- Total Nitrogen, Nitrate / Nitrite.

The above proposed suite of inorganics is largely consistent with the ALS Environmental basic coal seam gas suite. The extended coal seam gas suite (which is adopted by QGC in their baseline groundwater sampling programs) incorporates dissolved and total metals. This assessment has not recommended the inclusion of metals, as the objectives of this program can be achieved without their inclusion.

The following inorganic indicators are also proposed to be calculated to assist in aquifer characterisation;

- hardness: expressed as mg/L of CaCO<sub>3</sub> and used to classify waters as soft -> hard
- Total Dissolved Solids (TDS): a measure of the salt dissolved in a water sample after the removal of suspended solids. TDS is the residue remaining after evaporation of the water and it is related to the specific conductance.
- Specific Conductance (or electrical conductivity uS/cm). Specific conductance measures the capacity of water to transmit electrical current and is proportional to salt content.
- Sodium Adsorption Ratio: used to evaluate the hazard in irrigation waters caused by sodium. It relates the concentration of sodium ions to magnesium and calcium ions. An increasing SAR relates to less favourable irrigated soil conditions.
- pH
- Physical water quality characteristics include those that relate to temperature, colour, taste and odour. The physical characteristics can be collected in the field and will be based on observations of such things as:
  - odour
  - water colour
  - effervescence.



## 2.4.2 Isotopes

Incorporation of isotope chemistry into the suite would be useful, however not vital to aquifer characterisation. Stable isotopes of oxygen and hydrogen and strontium in groundwater are routinely used to characterise groundwater and to investigate mixing between aquifers.

DSDBI (2013) recommended the inclusion of groundwater isotope analysis to investigate groundwater age and therefore flow paths. This would suggest inclusion of either Chlorine or Carbon isotopes.

## 2.4.3 Naturally occurring hydrocarbons

Organic chemistry in this study focuses on the organic geochemical properties of coal with particular focus on hydrocarbon associated chemicals such as:

- hydrocarbon gases (natural gas)
- hydrocarbon liquids (petroleum hydrocarbons).

Hydrocarbon gases include Methane (C1), Ethane (C2), Propane (C3) and Butane (C4). Measurement of the four gases means that gas component ratios can be used to help establish the role that hydrocarbon-oxidizing bacteria play in altering the original source gas composition. This ratio (referred to as the Bernard Parameter) can be used to indicate a likely thermogenic hydrocarbon source for any gas fields.

Methane occurs naturally in the atmosphere and is commonly found at trace levels as a dissolved component of groundwater. It can also be released by anthropogenic activities including agriculture, landfills. There is no authoritative guidance for methane concentrations in groundwater, given it is practically non-toxic. A 2012 National Methane Baseline Study was undertaken by the British Geological Survey (BGS) and was defined as the 'current background range of methane concentrations in UK groundwater before any significant exploitation of unconventional hydrocarbons, such as shale gas, takes place'. This study found maximum Methane concentrations of 14.2 mg/L and 132 mg/L in the two study regions. Analysis of methane concentration from nearly 4,000 samples indicated a median Methane concentration of <0.5 mg/L. The study analysed only potable water and observation bores within Cretaceous, Jurassic and Triassic carbonates and sandstones.

The protocols for baseline groundwater sampling reported for both British Columbia and the state of Colorado indicate that if dissolved methane levels exceed 2 mg/L, gas composition analysis and stable isotope analysis of the methane (i.e. carbon and deuterium) should be performed to assess the potential origins of the gas. Stable carbon and deuterium isotopes of methane provide an independent means to determine the origin of gases and are conventionally used to differentiate between biogenic and thermogenic methane sources. Both chromatographic composition and isotope ratios are used to differentiate naturally occurring gas sources.

It is noted that DSDBI (2013) found methane in a number of sampled groundwater bores, yet the origin of this gas was unknown and was noted to require further investigation. For this reason it is proposed that measurement of all four gases (C1-C4) is undertaken and consideration for stable isotopes be given to later rounds of sampling where elevated methane concentrations are observed.

Sampling for petroleum hydrocarbons typically includes samples for:

- aromatic hydrocarbons benzene, ethylbenzene, toluene and xylene (BTEX)
- total petroleum hydrocarbons (TPH)
- polynuclear aromatic hydrocarbons (PAH).

A National Methane Baseline Study was undertaken by the British Geological Survey (BGS, 2012) and was defined as the 'current background range of methane concentrations in UK groundwater before any significant exploitation of unconventional hydrocarbons, such as shale gas, takes place'. This study found maximum methane concentrations of 14.2 mg/L and 132 mg/L in the two study regions. Analysis of methane concentration from nearly 4,000 samples indicated a median methane concentration of <0.5 mg/L. The study analysed only potable water and observation bores within Cretaceous, Jurassic and Triassic carbonates and sandstones.

BTEX compounds are naturally found in crude oil, coal and gas deposits. Leusch and Bartkow (2011) concluded that BTEX compounds may therefore be naturally present at low concentrations in groundwater associated with these deposits.

Total petroleum hydrocarbons (TPH) are defined as carbon chains in the range of C6 through to C35. Products containing TPH include a wide variety of mixtures that may contain hundreds to thousands of hydrocarbon compounds including aliphatic (straight carbon chain) and aromatic (carbon ring) compounds. Evaluating hundreds to thousands of compounds is not usually practical. Evaluations for overall TPH are common and is generally accepted practice.

Sampling for BTEX and TPH is recommended as part of this suite given that national and international protocols for baseline groundwater sampling all include TPH and BTEX and BTEX compounds are used in hydraulic fracturing activities.

PAHs are produced in coal and the presence of PAHs in groundwater is due to the leaching of coals. Orem *et al.* (2007) tested produced waters from coal seam gas wells in the Powder River Basin, Wyoming, and concluded that the probable source of the PAHs was leaching from sub-bituminous coals, based on the similarities between the spectrum of PAHs present in the produced water and those found in the coal.

The international baseline sampling protocols reviewed did not include PAHs (i.e. the Colorado oil and gas conservation commission statewide groundwater baseline sampling and monitoring rules (2014), the Alberta Environment standard for baseline water well testing (2006) or the protocols developed for British Columbia (Chaytor & Shaw, 2008)). The groundwater monitoring program adopted in Queensland by QGC however did include PAHs.

The sampling of PAHs has not been included in the recommended sampling suite.

## 2.5 Summary of literature review

### 2.5.1 Groundwater sample locations informed by hydrocarbon occurrence

The monitoring program should target observation bores in the following locations where hydrocarbons have been observed:

- Cretaceous aged sediments of the Sherbrook Group in the Port Campbell Embayment
- Lower Tertiary aged Wangerrip Group in the Port Campbell Embayment with particular hot spots in the Port Campbell area and the Barwon Downs region west of Geelong
- Cretaceous aged sediments of the Sherbrook Group and the Lower Tertiary aged sediments of the Wangerrip Group in the Portland Trough.

In addition to these units and areas which are known to host hydrocarbon deposits, monitoring bores should target areas where the Narrawatruk and Gellibrand Marl is known to be thin as there could be an increased risk of vertical migration of hydrocarbons into overlying aquifers.

These conclusions were taken into account in the selection of bores for sampling (chapter 3).

## **2.5.2 Summary of groundwater sampling parameters**

Based on the above literature review, in order to characterise the groundwater chemistry of chosen aquifers and to determine the natural occurrence of hydrocarbons in groundwater, groundwater samples should be analysed for the following parameters:

- major ions: Calcium, Sodium, Magnesium, Potassium, Chloride, Sulphate, Fluoride, Total alkalinity, carbonate, bicarbonate, Total Nitrogen, Nitrate, Nitrite
- inorganic indicators: Hardness, Total Dissolved Solids (TDS) , Specific Conductance (or electrical conductivity uS/cm), Sodium Adsorption Ratio, pH
- physical water quality characteristics (identified in the field): odour, water colour, effervescence
- hydrocarbons: Methane (C1), Ethane (C2), Propane (C3), Butane (C4), Benzene, Toluene, Ethylbenzene, Xylene, Total Petroleum Hydrocarbons.

## 3 Bore selection

The sampling program has the following objectives:

- to characterise the groundwater chemistry, particularly with presence or not or not of hydrocarbons, in prospective onshore natural gas areas, and
- to provide an indication of baseline groundwater quality, in particular the concentration of hydrocarbons in groundwater.

This project utilised low flow techniques to sample a representative number of bores screened within aquifers known to have, or suspected of having, hydrocarbon concentrations and/or within or near key groundwater or surface water assets. Low flow sampling is a recognised technique for sampling small volumes of groundwater from the bore (Geoscience Australia, 2009). The technique relies on knowledge of the bore construction especially the screen interval and also the diameter and condition of the bore. Reliability of results also requires knowledge of which aquifer and interval the sample represents. For this reason, this project chose state observation bores (SOBs) for sampling due to the reliable data on bore construction and condition. The alternative of using private bores was discounted due to the variable nature of bore construction and casing condition data. and the problems with already installed pumps and obtaining access.

### 3.1 Selection criteria

The following criteria were used to select bores for the monitoring program:

- bores in the prospective units for unconventional gas development especially in areas of identified high prospectivity
- watertable bores chosen in or around groundwater dependent ecosystem assets particularly above zones of high unconventional gas prospectivity
- bores in areas of either high potential or actual use
- nested bores which highlight the vertical differences in groundwater chemistry at the same location
- bores with known hydrocarbon concentrations determined from the above literature review
- bores in aquifers above known seals and also where the seal is absent to allow analysis of the effectiveness of the seal for capping vertical hydrocarbon migration
- bores should not be chosen if they have one or more of the following characteristics:
  - failed bores or bores of poor condition
  - bores with lack of construction data.

The Otway prospectivity areas (Section 2.3) and the locations of the state observation bores have been used to inform the monitoring program by comparing with:

- key groundwater dependent ecosystems and surface water assets
- aquifers
- naturally occurring hydrocarbon locations identified by the literature review.

A recent review of the State Observation Bore Network (SOBN) undertaken by GHD (2014) included an assessment and scoring of bore condition. Bores were scored from 1 (good) through to 5 (poor) and it was noted that bores with a final score of 4 or 5 were least preferred for inclusion as an SOBN asset. Bores with a poor condition ranking (4 or 5) were excluded from the initial round of bore selection and only considered for inclusion in the monitoring network if an obvious gap in the remaining SOBAs was observed.

## 3.2 Groundwater dependent ecosystems and surface water assets

The Victorian Water Asset Database (VWAD) was used to identify potential Groundwater Dependent Ecosystems (GDEs), waterways and wetlands in the Otway Basin.

The VWAD ranks assets from the perspective of habitat, economic, recreation and cultural value, whereby the following scores were applied:

- Neutral = 1, Low = 10, Moderate = 20, High = 40, Extreme = 100

Based on these criteria the following rules were applied to VWAD to generate datasets of potential groundwater dependent ecosystems for potential bore monitoring target sites in the monitoring program:

- GDE score = 100. A score of 100 implies a potential groundwater dependent ecosystems has been identified.
- Water source = 100. A score of 100 implies the water source is groundwater.
- Habitat score = 100. This implies extremely valuable rivers and wetlands were selected from the VWAD. Examples include Iconic Rivers, Living Murray Icon Sites, Nationally Important Wetlands, Victorian Biodiversity Atlas, Highly Localised Asset sites of significance etc.
- Economic score = 100. This implies extremely valuable rivers and wetlands were selected from the VWAD. Examples include Town Supply Reservoirs, features used for urban water supply, features located in Designated Water Supply Catchment etc.
- Recreation score = 100. This includes rivers and wetlands where recreational activities have been observed.
- Cultural score = 40 (there were no score = 100 in the Otway Basin). As a result, highly valuable rivers and wetlands were selected from the VWAD. Examples include features listed in the Victorian Heritage Register or AVIRA for National Heritage Sites etc.

There were no springs identified in the Basin or Basin Margin catchment system of the Otway Basin. Springs were only present in the upland valley and upland layered valley region in the north east corner of the Corangamite CMA area.

Identified potential groundwater dependent ecosystems were compared to the locations of the field scale and sub-regional scale prospectivity for conventional gas, coals seam gas and tight/shale gas localities, as defined by Goldie Divko (2014) and described in Section 2.3.

The analysis was undertaken at a Groundwater Catchment Unit (GCU) scale, which includes the Hopkins-Corangamite, Portland and Glenelg GCUs. The absence of prospectivity in the Otway-Torquay GCU meant it was excluded from further assessment.

### 3.2.1 Hopkins Corangamite Groundwater Catchment Unit

Within the Hopkins Corangamite Groundwater Catchment Unit (GCU), there are a number of field scale and sub-regional scale conventional gas, tight gas and coal seam gas prospective areas. These areas were intersected with key waterways and wetlands as identified from VWAD to identify bores for inclusion in the monitoring program. Figure 11 shows the proposed sampling bores which are summarised in Table 1.

**Table 1 Proposed monitoring bores in areas of prospectivity and potential groundwater dependent environmental assets**

Bore	Details	Justification
115872	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and key rivers and wetlands</li> </ul>
113467	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and key rivers and wetlands</li> </ul>
54925	Upper Tertiary/Quaternary Basalt Aquifer (101)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and key rivers and wetlands</li> <li>Monitors the watertable aquifer</li> </ul>
142660	Upper Tertiary/Quaternary Basalt Aquifer (101)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and key rivers and wetlands (including RAMSAR wetland site Lake Corangamite)</li> </ul>
141241	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and key rivers and wetlands</li> </ul>
141242	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and key rivers and wetlands</li> </ul>

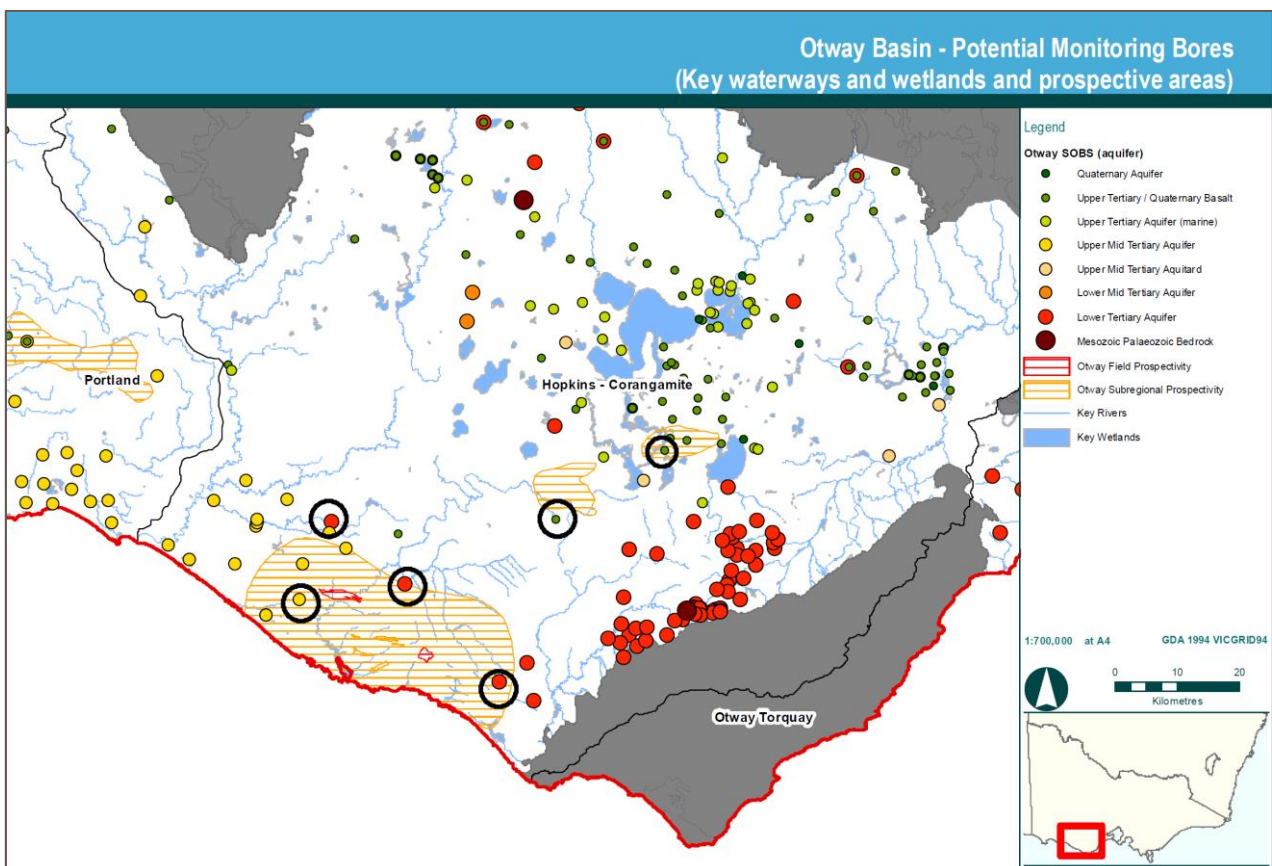


Figure 11 Hopkins-Corangamite Groundwater Catchment Unit showing prospective natural gas areas and proposed monitoring bores (black circles)

### 3.2.2 Portland Groundwater Catchment Unit

Within the Portland GCU, the Killara coal seam gas prospect near Hawkesdale and Digby present the primary prospect areas for natural gas. These areas were intersected with key waterways and wetlands as identified from VWAD to identify bores for inclusion in the monitoring program. Figure 12 shows the proposed sampling bores which are summarised in Table 2.

**Table 2 Proposed monitoring bores in areas of prospectivity and high value Groundwater Dependent Environmental Assets**

Bore	Details	Justification
111524	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and key rivers and wetlands</li> </ul>
111525	Upper Tertiary/Quaternary Basalt Aquifer (101))	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and key rivers and wetlands</li> <li>Monitors the watertable aquifer in the vicinity of environmental assets</li> </ul>
122677	Lower Mid-Tertiary Aquifer (109)	<ul style="list-style-type: none"> <li>Located adjacent to the area of prospectivity and key rivers and wetlands</li> </ul>

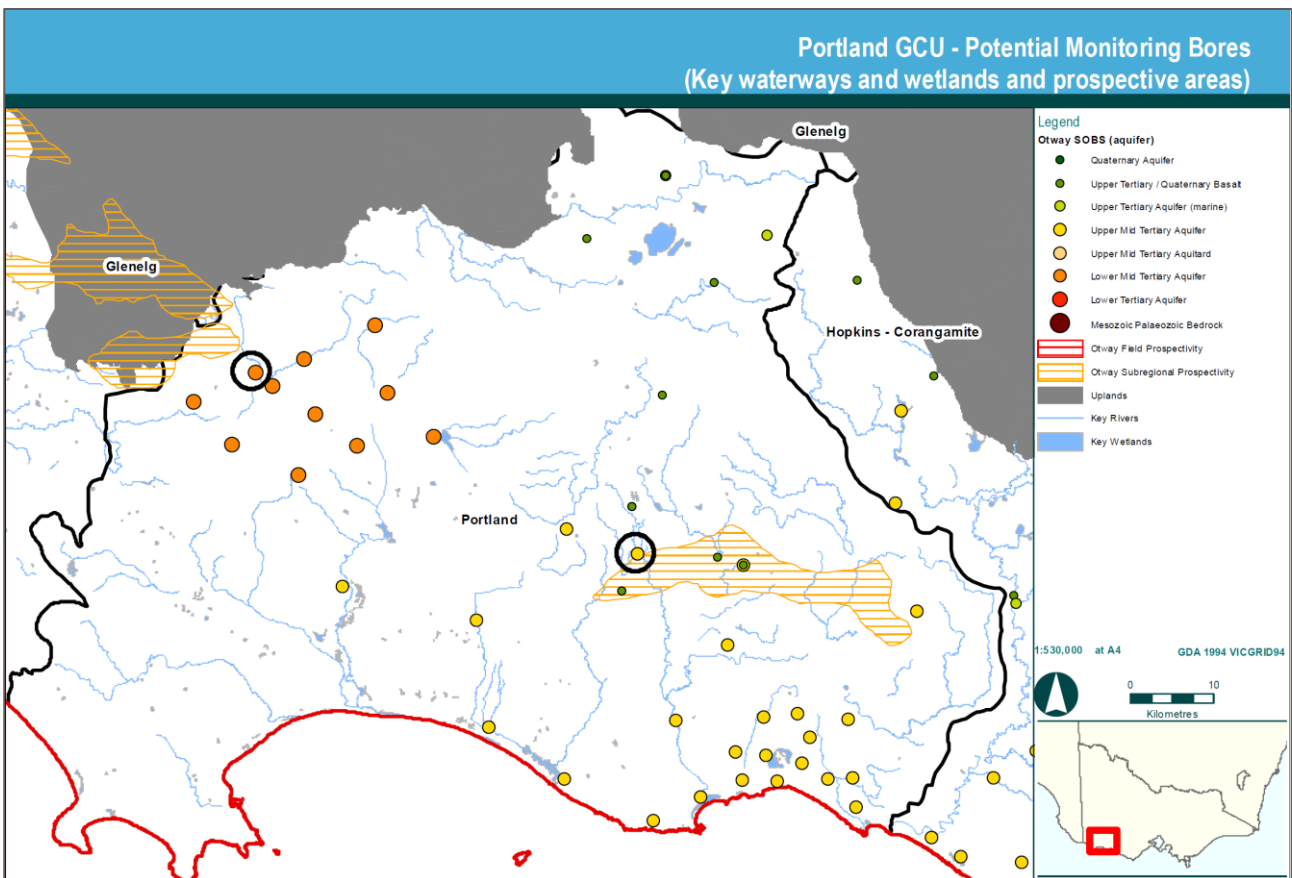


Figure 12 Portland Groundwater Catchment Unit showing prospective natural gas areas and proposed monitoring bores (black circle)

## 3.2.3 Glenelg Groundwater Catchment Unit

Within the Glenelg GCU, there are a number of coal seam gas and shale gas field prospects and the sub-regional shale gas prospect area. These areas were intersected with high value waterways and wetlands as identified from VWAD to identify bores for inclusion in the monitoring program.

**Table 3 Proposed monitoring bores in areas of prospectivity and high value Groundwater Dependent Environmental Assets**

Bore	Details	Justification
83446	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands (including wetlands protected by the Directory of Important Wetlands)</li> </ul>
83447	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands</li> </ul>
S61557-2	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands. Including the Directory of Important Wetland 'McCallums Swamp'</li> <li>Monitors the watertable aquifer</li> </ul>
102621	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands</li> </ul>
83729	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands</li> </ul>
S61557-3	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands. Including Directory of Important Wetlands (Mundi-Selkirk Wetlands) and the Glenelg River</li> <li>Monitors the watertable aquifer</li> </ul>
S61557-1	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands. Including Directory of Important Wetlands (Mundi-Selkirk Wetlands, Pig Swamp and Lake Mundi)</li> <li>Monitors the watertable aquifer</li> </ul>



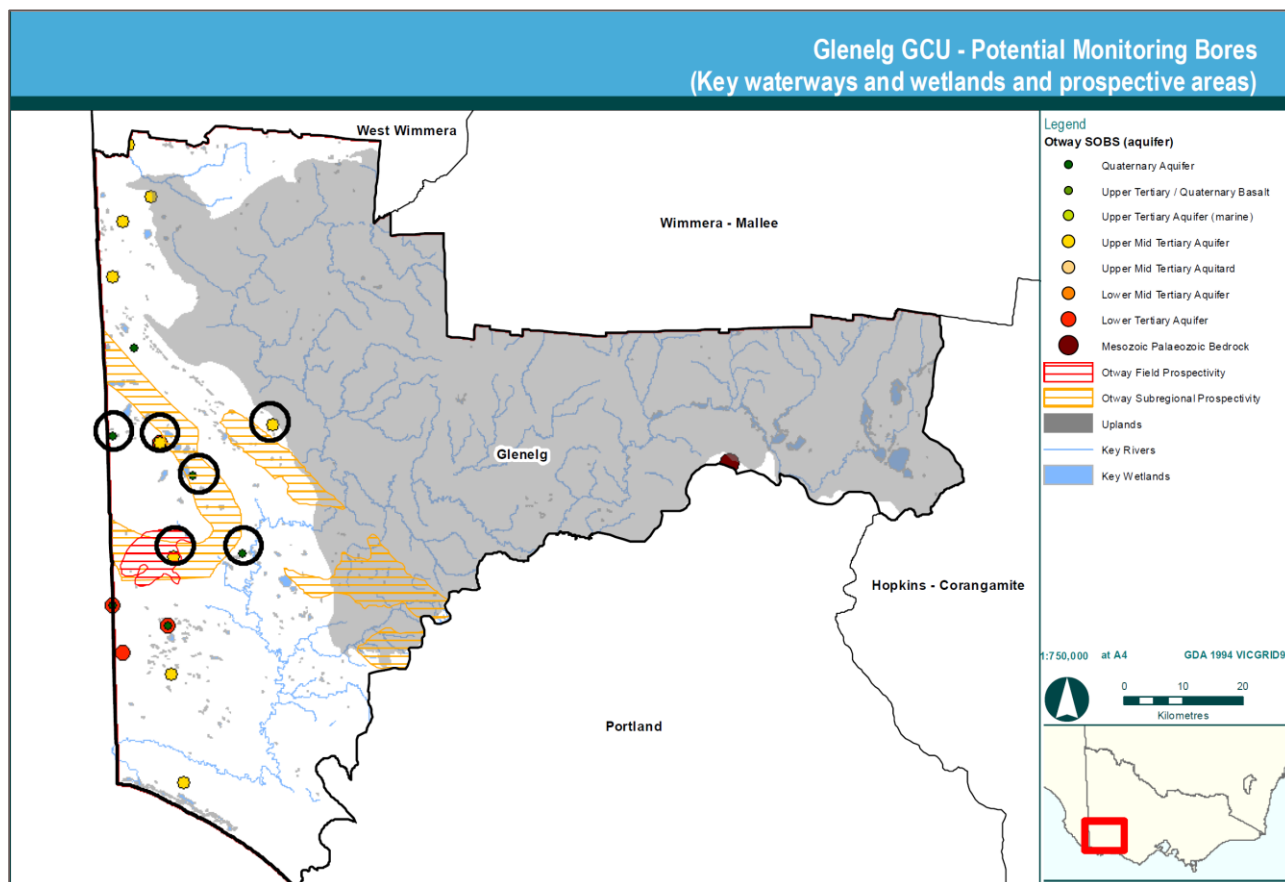


Figure 13 Glenelg Groundwater Catchment Unit showing prospective natural gas areas and proposed monitoring bores (black circle)

### 3.3 Aquifers

Across Victoria, areas where groundwater is either a high potential or actual use are defined by Groundwater Management Areas (GMAs) and Water Supply Protection Areas (WSPAs). In the Otway Basin there are multiple GMAs and WSPAs and these are summarised below in Table 4. The target aquifers for these high value groundwater areas have been used to develop the monitoring network.

Table 4 Summary of GMAs and WSPAs in the Otway region

GCU	GMA/WSPA	Depth Criteria	Target Aquifer	Code
Glenelg	Glenelg	All	Port Campbell Limestone and Dilwyn Formation	Upper Mid-Tertiary Aquifer (107) and Lower Tertiary Aquifer (111)
Portland	Portland	>200	Dilwyn Formation	Lower Tertiary Aquifer (111)1
Portland	Condah	70-200	Clifton Formation	Lower Mid-Tertiary Aquifer (109)
Portland	Yangery	<100	Port Campbell Limestone	Upper Mid-Tertiary Aquifer (107)
Portland	Hawkesdale	Zone 1 <200 and zone 2 all	Port Campbell Limestone	Upper Mid-Tertiary Aquifer (107)
Portland	Heywood	<70	Quaternary volcanics, Bridgewater and Whalers Bluff Formations and the Port Campbell Limestone Aquifer.	Upper Tertiary/Quaternary Basalt Aquifer (101) and Upper Tertiary Aquifer (marine) (104)and Upper Mid-Tertiary Aquifer (107)

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GCU	GMA/WSPA	Depth Criteria	Target Aquifer	Code
Hopkins - Corangamite	Newlingrook	All	Dilwyn Formation	Lower Tertiary Aquifer (111)
Hopkins - Corangamite	Nullawarre	<250	Port Campbell Limestone	Upper Mid-Tertiary Aquifer (107)
Hopkins - Corangamite	Paaratte	>120	Dilwyn Formation	Lower Tertiary Aquifer (111)
Hopkins - Corangamite	Warrion	All	Newer Volcanics	Upper Tertiary/Quaternary Basalt Aquifer (101)
Hopkins - Corangamite	Colongulac	<60	Newer Volcanics	Upper Tertiary/Quaternary Basalt Aquifer (101)
Hopkins - Corangamite	Gellibrand	All	Dilwyn Formation	Lower Tertiary Aquifer (111)
Hopkins - Corangamite	Gerangamete	>60	Dilwyn Formation and Pebble Point	Lower Tertiary Aquifer (111)
Hopkins - Corangamite	Glenormiston	<60	Hanson Plain Sands and Newer Volcanics	Upper Tertiary/Quaternary Basalt Aquifer (101)

### 3.3.4 Hopkins Corangamite Groundwater Catchment Unit

The Hopkins Corangamite GCU includes the following GMAs and WSPAs:

- Newlingrook
- Nullawarre
- Paaratte
- Warrion
- Colongulac
- Gellibrand
- Gerangamete
- Glenormiston.

SRW (2014) provides an overview of the target aquifers for groundwater use within each of the above management areas in the Hopkins Corangamite GCU and this information was used to target bores for inclusion in the monitoring network. Bores identified for inclusion in the network are summarised in Table 5 and shown in Figure 14.

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**Table 5 Selected monitoring bores in areas of high value groundwater asset (as indicated by GMAs and WSPAs)**

GCU	GMA/WSPA	Target Aquifer	Bore	Justification
Hopkins - Corangamite	Newlingrook	Lower Tertiary Aquifer (111)	75070	Closest bore monitoring the Dilwyn Formation to the prospectivity area. No nested sites to present alternative option.
Hopkins - Corangamite	Nullawarre	Upper Mid-Tertiary Aquifer (107)	141241* 141242*	Monitors the target aquifer (PCL) in the Nullawarre WSPA
Hopkins - Corangamite	Paaratte	Lower Tertiary Aquifer (111)	115872* 113467*	Both bores monitor the target aquifer (Dilwyn Formation) in the Paaratte GMA
Hopkins - Corangamite	Warrion	Newer Volcanics (101)	142660*	Monitors the target aquifer (Newer Volcanics) in the Warrion WSPA
Hopkins - Corangamite	Colongulac	Newer Volcanics (101)	89040	Only available SOB in the GMA. No nested sites to present alternative option.
Hopkins - Corangamite	Gellibrand	Lower Tertiary Aquifer (111)	114169	No nested sites to present alternative option.
Hopkins - Corangamite	Gerangamete	Lower Tertiary Aquifer (111)	114167	Monitors the target aquifer (Dilwyn Fmn) in the Gerangamete GMA
Hopkins - Corangamite	Glenormiston	Upper Tertiary/Quaternary Basalt Aquifer (101) and Upper Tertiary Aquifer (marine) (104)	NA	No SOB (including poor condition bore check)

*\*bores have already been included in the monitoring network based on other selection criteria*

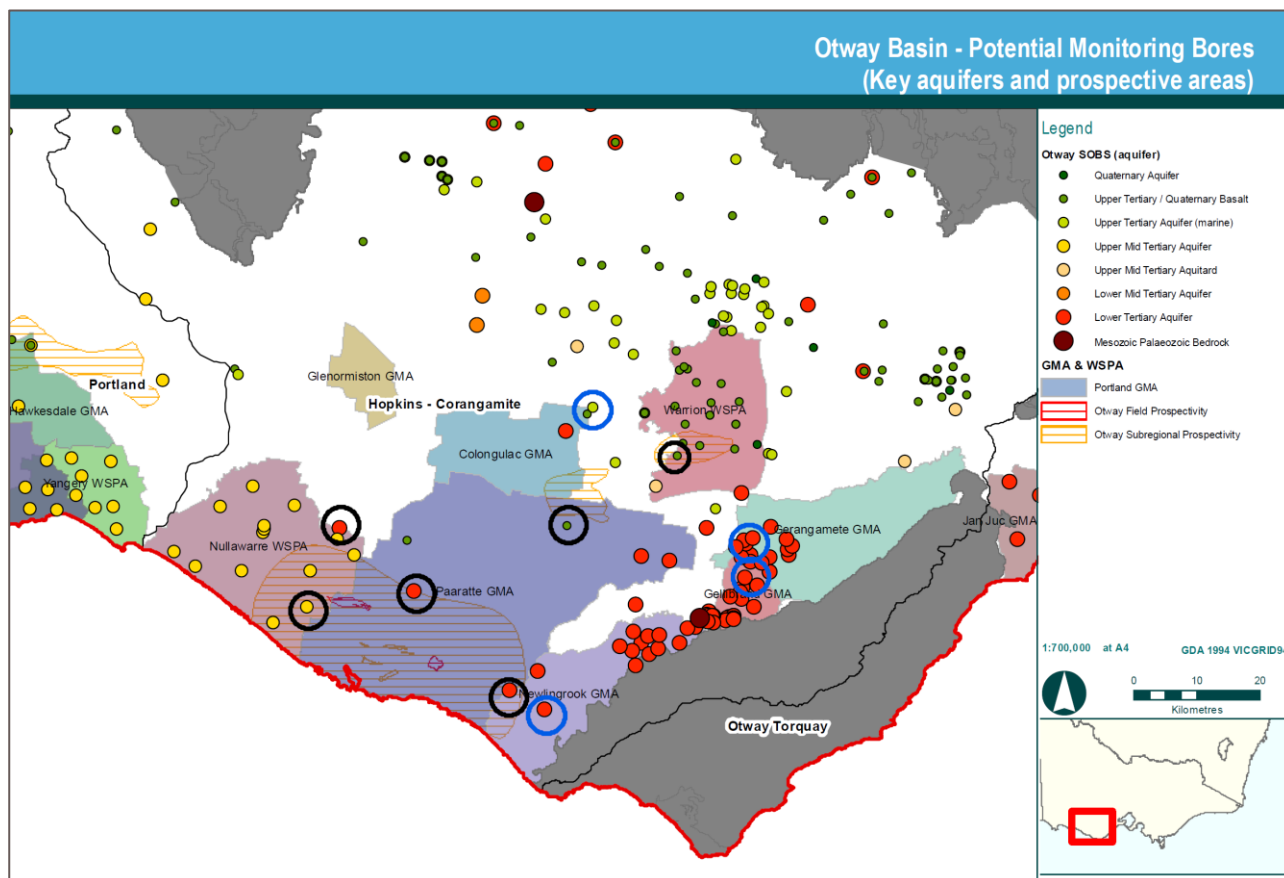


Figure 14 GMAs and WSPAs and targeted monitoring bores (new selected bores based on this criteria indicated in blue)

### 3.3.5 Portland Groundwater Catchment Unit

The Portland GCU includes the following GMAs and WSPAs:

- Portland
- Condah
- Yangery
- Hawkesdale
- Heywood.

SRW (2014b) provides an overview of the target aquifers for groundwater use within each of the above management areas in the Portland GCU and this information was used to target bores for inclusion in the monitoring network. Bores identified for inclusion in the network are summarised in Table 6 and shown in Figure 15.

# Onshore natural gas water science studies

**Table 6 Selected monitoring bores in areas of high value groundwater asset (as indicated by GMAs and WSPAs)**

GCU	GMA/WSPA	Target Aquifer	Bore	Justification
Portland	Portland	Lower Tertiary Aquifer (111)	NA	There are no SOBs monitoring the Dilwyn Formation aquifer in this GMA with suitable condition criteria.
Portland	Condah	Lower Mid-Tertiary Aquifer (109)	122677*	Monitors the target aquifer (Clifton Fmn) in the Condah WSPA
Portland	Yangery	Upper Mid-Tertiary Aquifer (107)	141308	Monitors the target aquifer in the Yangery WSPA.
Portland	Hawkesdale	Upper Mid-Tertiary Aquifer (107)	111524*	Monitors the target aquifer (PCL) in the Hawkesdale GMA
Portland	Heywood	Newer Volcanics, Bridgewater and Whalers Bluff Formations and the Port Campbell Limestone Aquifer. (101, 104 and 107)	S9037242-1	Bore included to provide information for the PCL aquifer in this GMA.

\*bores have already been included in the monitoring network based on other selection criteria

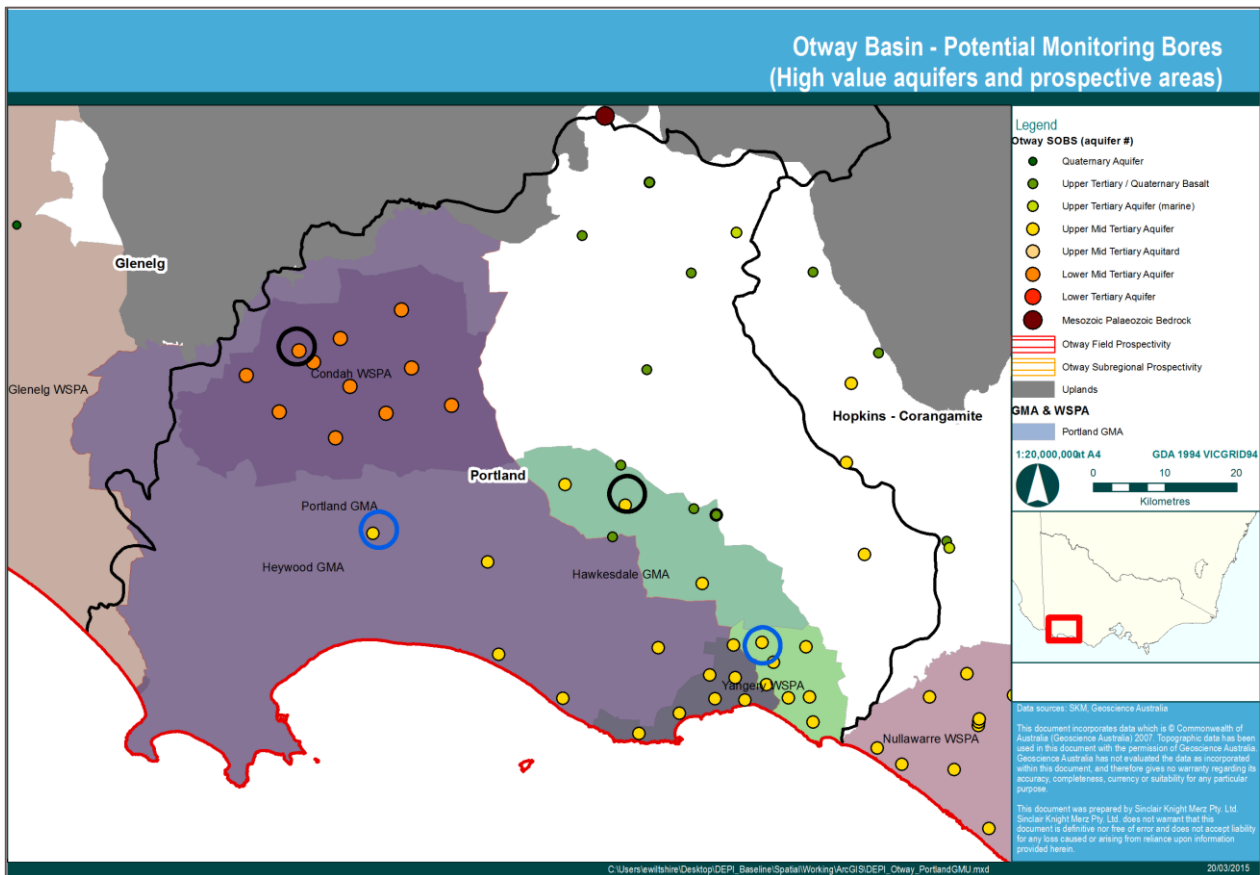


Figure 15 GMAs and WSPAs and targeted monitoring bores (new selected bores based on this criteria indicated in blue)

### 3.3.6 Glenelg Groundwater Catchment Unit

Within the Glenelg GCU there is a single WSPA – the Glenelg, which represents groundwater sourced from aquifers at all depths. The target aquifers in this area however are the Port Campbell Limestone and the Dilwyn Formation (SRW, 2013). Bores identified for inclusion in the network are summarised in Table 7 and shown in Figure 16.

**Table 7 Selected monitoring bores in areas of high value groundwater asset (as indicated by GMAs and WSPAs)**

GCU	GMA/WSPA	Target Aquifer	Bore	Justification
Glenelg	Glenelg	Upper Mid-Tertiary Aquifer (107) and Lower Tertiary Aquifer (111)	83446*	• Monitors the target aquifer (Dilwyn) in the Glenelg WSPA
			83447*	• Monitors the target aquifer (PCL) in the Glenelg WSPA
			102621*	• Monitors the target aquifer (PCL) in the Glenelg WSPA
			83729*	• Monitors the target aquifer (PCL) in the Glenelg WSPA
Glenelg	Glenelg	Quaternary Aquifer (100) and Lower Tertiary Aquifer (111)	82347 (111) S61557-4 (100)	Bores will monitor the Dilwyn Formation Aquifer and the watertable aquifer and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.

\*bores have already been included in the monitoring network based on other selection criteria

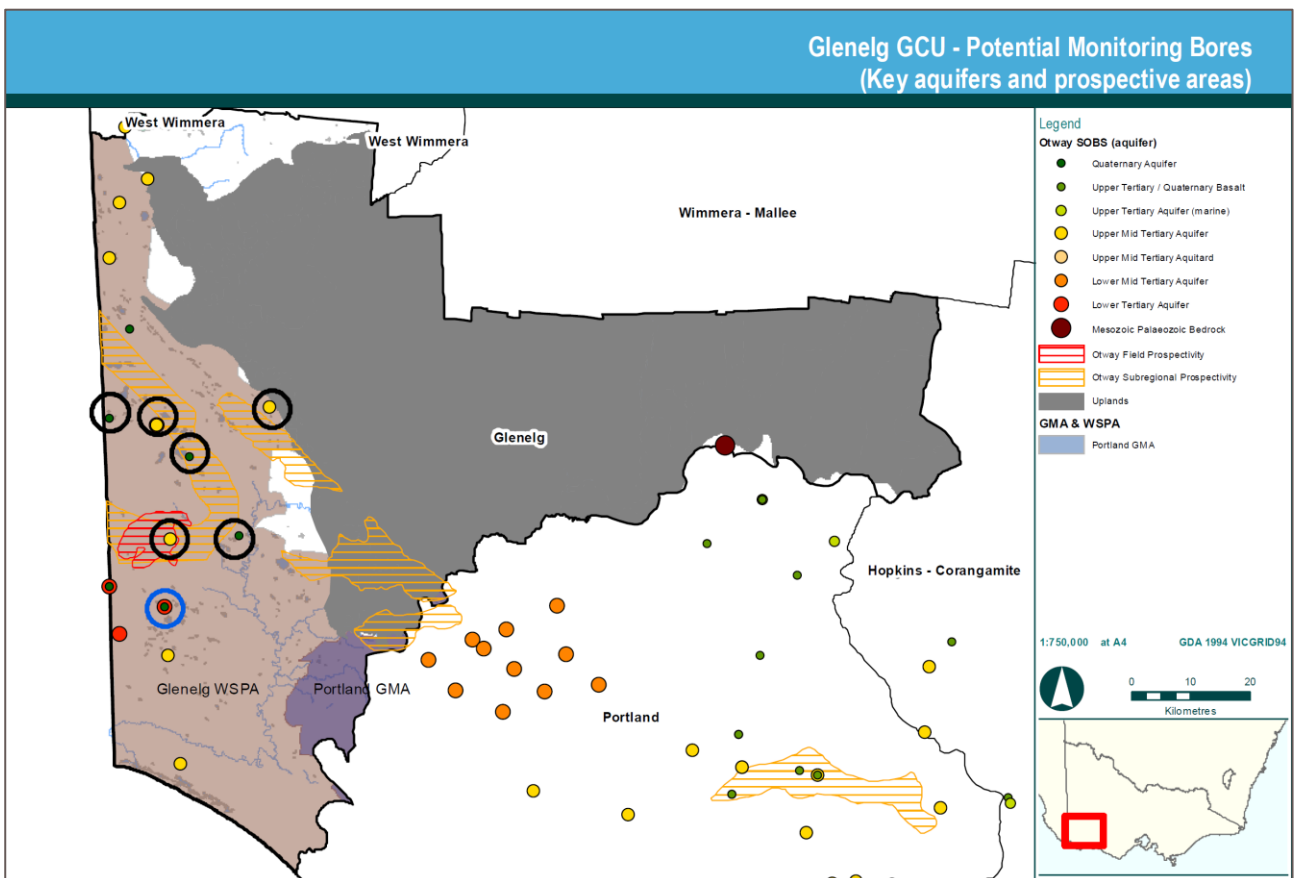


Figure 16 GMAs and WSPAs and targeted monitoring bores (new selected bores based on this criteria indicated in blue)

### 3.4 Naturally occurring hydrocarbon sites and potential vertical migration

The monitoring program aimed to target observation bores in the locations identified in the literature review as areas of naturally occurring hydrocarbon presence and also areas where the overlying aquitards are thin and there is an increased risk of vertical migration of hydrocarbons. Bores identified for inclusion in the network are summarised in Table 8 and shown in Figure 17.

**Table 8 Summary of intersection between areas identified as potential hydrocarbon occurrence and selected monitoring bores**

Area	Bore	Justification
The Cretaceous aged sediments of the Sherbrook Group (113) in the Port Campbell Embayment	115872* 113467*	There are no SOBs monitoring the 113 aquifer. Two bores overlying this formation (i.e. the 111 aquifer) have already been included in the program.
The Wangerrip Group (111) in the Port Campbell Embayment with particular hot spots in the Port Campbell area	115872* 113467*	These Wangerrip Group (111) bores are the closest suitable SOBs to the Port Campbell locality.
Sherbrook Group (113) and Wangerrip Group (111) in the Portland Trough.	NA	There are no SOBs monitoring these units in the Portland Trough. Only SOBs with poor condition codes exist in this area.
Glenelg – area of thin / absent aquitard	83446 (111)* 83447 (107)*	This nested site represents a Wangerrip Group (111) bore and an overlying Limestone bore (107). These units straddle the marl aquitards and hence this nested site will provide information regarding aquifer chemistry where the marl is absent/thin.
Hopkins-Corangamite – area of thin / absent aquitard	NA	Although there is a significant density of SOBs in this area, all bores monitor the Wangerrip (111) aquifer and there are no sites with a shallow nested bore. Hence a recommendation has not been made in this area, as a shallow aquifer bore was the target.

*\*bores have already been included in the monitoring network based on other selection criteria*

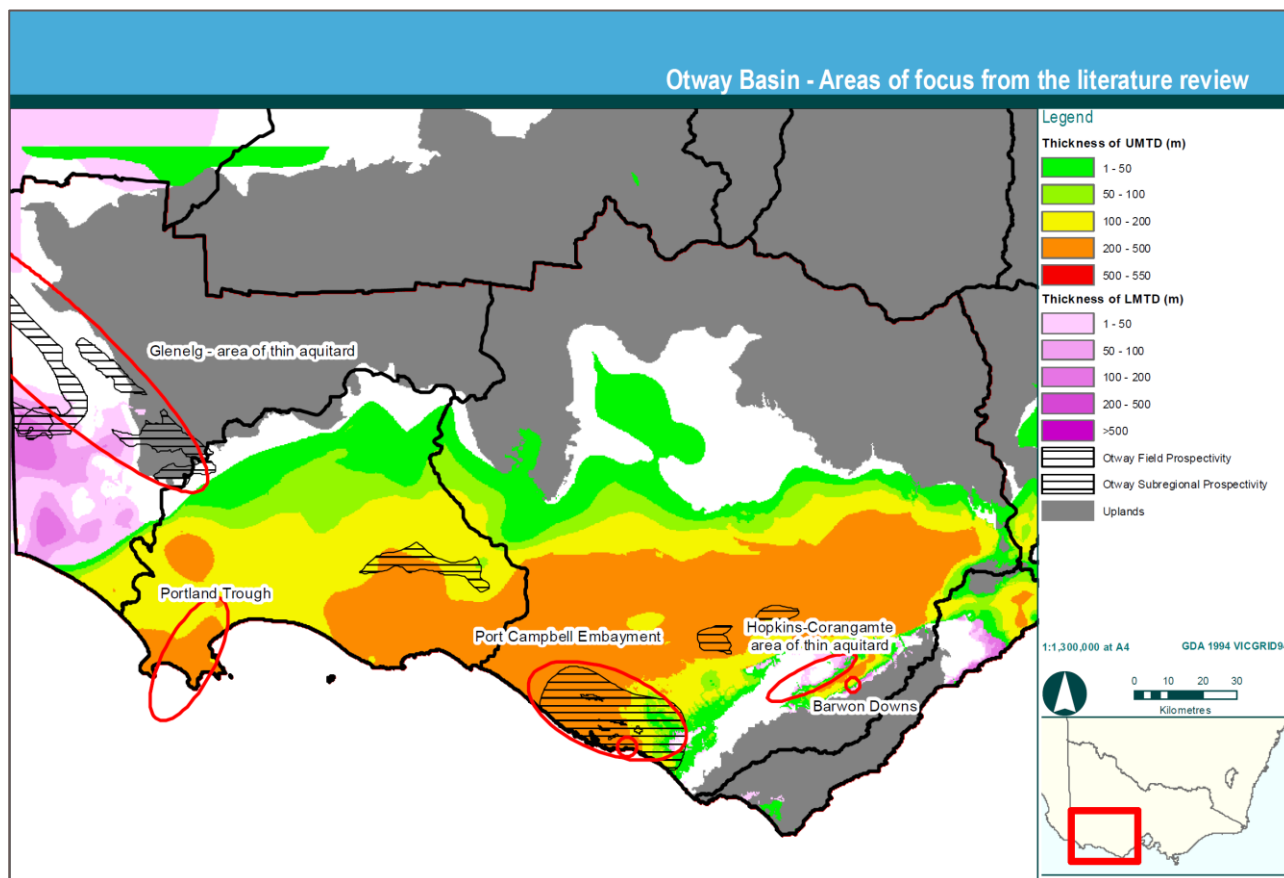


Figure 17 Areas identified in literature review

## 3.5 Nested sites

Targeting nested bore sites for inclusion in the monitoring network assists in the aquifer characterisation process and also informs the potential for mixing of groundwater from multiple aquifers. Any future natural gas investigations will target deep aquifers that underlie the aquifers that are currently used extensively for private groundwater extraction purposes (e.g. irrigation, stock and domestic) and by the environment (e.g. GDEs). Hence, understanding the amount of connection between the deep and shallow aquifers is important and this can potentially be informed by interpreting groundwater chemistry information for multiple aquifers at a single site (i.e. at a nested site).

A review has been undertaken to identify the nested sites in the Otway region. A total of 47 sites remained after the poor condition bores were removed from the dataset and the nested sites that appeared to monitor the same aquifer were also removed. Three of these sites were already included in the program from previous selection criteria. Figure 18 shows the distribution of the nested sites (coloured by nested aquifers) and also shows the location of the Ramsar listed western district wetlands. Three additional nested sites of bores have been included in the monitoring program. One site has been included so that the potential for mixing of groundwater between aquifers that straddle the Gellibrand Marl aquitard can be compared in an area where the marl is significantly thick (this site) and absent (the Glenelg nested site). The other two sites focus around two important Ramsar listed wetlands. The nested sites are summarised in Table 9.



## Onshore natural gas water science studies

**Table 9 Summary of nested sites targeting well recognised assets in the Otway region**

Bore	Target Aquifer	Justification
111524* 111525*	Upper Mid-Tertiary Aquifer (107) and Upper Tertiary/Quaternary Basalt Aquifer (101)	<ul style="list-style-type: none"> <li>Nested site will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>
111787 111786	Watertable aquifer (101 Newer Volcanics) and Dilwyn Formation (111)	<ul style="list-style-type: none"> <li>Nested site located in the vicinity of the Lake Murdeduke Ramsar listed site.</li> <li>Nested site will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>
83446* 83447*	Lower Tertiary Aquifer (111) Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>Nested site will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing. Also located in an area where the aquitard is thin/absent</li> </ul>
110985 110984	Watertable aquifer (101 Newer Volcanics) and Whalers Bluff/Hanson Plain Sand (104)	<ul style="list-style-type: none"> <li>Nested site located in the vicinity of the Lake Corangamite Ramsar listed site.</li> <li>Nested site will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>
141307 141308*	Upper Tertiary/Quaternary Basalt Aquifer (101) Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>Bores will monitor the high value PCL aquifer and the watertable aquifer (101 Newer Volcanics) and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>
82347* S61557-4*	Lower Tertiary Aquifer (111) Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>Bores will monitor the Dilwyn Formation Aquifer and the watertable aquifer and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>

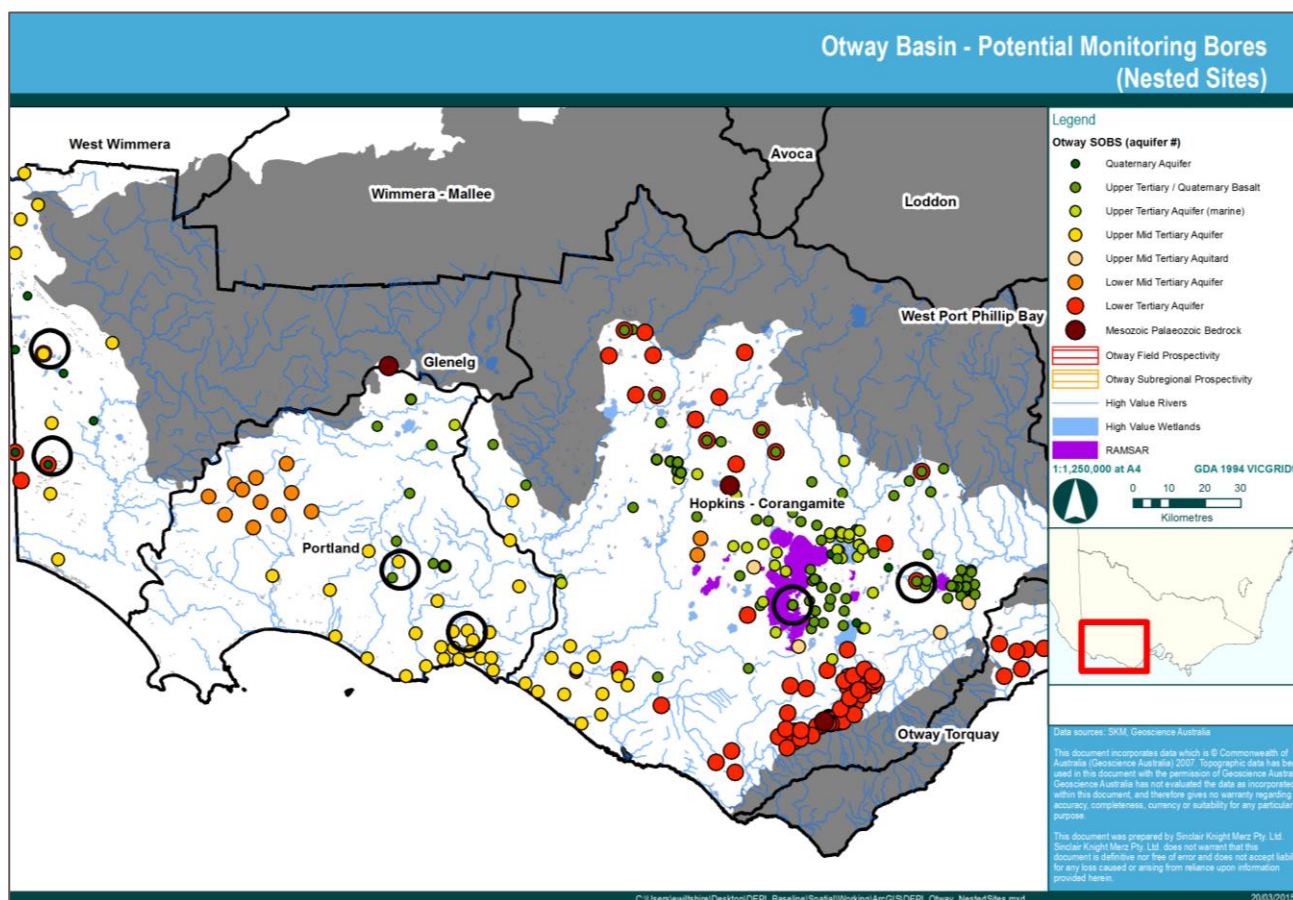


Figure 18 Nested SOB sites across the Otway region selected for inclusion in the monitoring program

## 3.6 Summary of selected monitoring network

Table 10 provides a summary of the selected bores for the Otway monitoring network. A total of 30 bores were selected for inclusion in the monitoring program. These bores were selected because they meet one or more of the following selection criteria:

- located in a prospectivity area and near a high value groundwater dependent ecosystems
- monitors the target aquifer in a proclaimed groundwater area
- monitors the watertable aquifer near a high value groundwater dependent ecosystems
- targets areas identified in literature review
- includes a nested site
- located near a Ramsar listed site.

Upon review of the final set of monitoring bores, a single additional bore (69455) was incorporated. This is the only State Observation Bore in the Otway Basin constructed into the Mesozoic and Palaeozoic Bedrock aquifer. Although this bore did not meet any of the selection criteria listed above, it was included to provide groundwater chemistry information for the primary target aquifers in the region. The network is shown in Figure 19 and summary comments provided in Table 10.

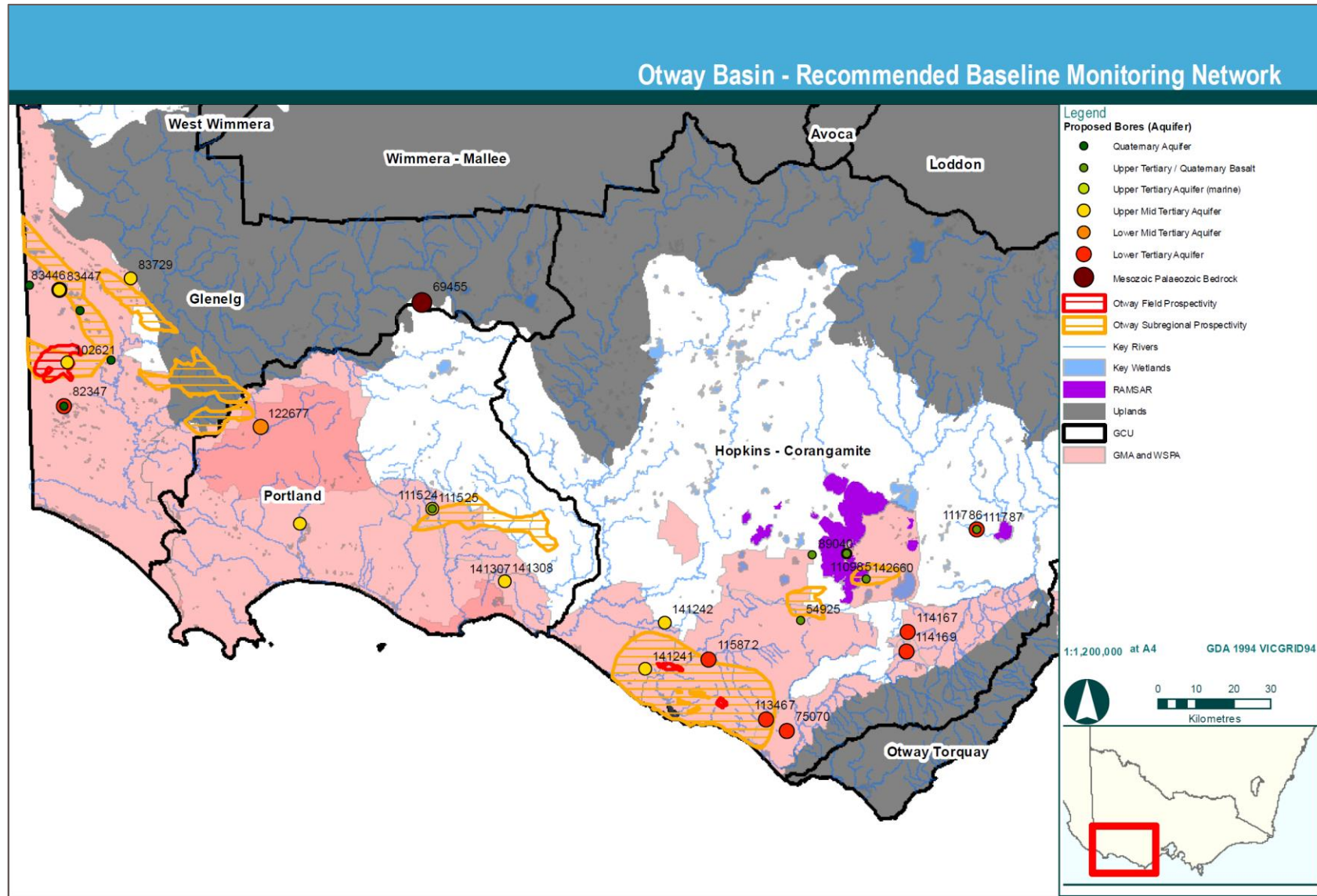


Figure 19 Selected monitoring network for the Otway region

Otway region groundwater sampling and characterisation for hydrocarbons

## Onshore natural gas water science studies

**Table 10 Summary of selected bores for the Otway monitoring network**

Bore	Aquifer Monitored	Justification for inclusion in the monitoring network
111524	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and high value rivers and wetlands</li> <li>• Monitors the target aquifer (PCL) in the Hawkesdale GMA</li> <li>• Nested with 111525 and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>
111525	Upper Tertiary/Quaternary Basalt Aquifer (101)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and high value rivers and wetlands</li> <li>• Monitors the watertable aquifer in the vicinity of environmental assets</li> <li>• Nested with 111524 and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>
83446	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and high value rivers and wetlands (including wetlands protected by the Directory of Important Wetlands)</li> <li>• Monitors the target aquifer (Dilwyn) in the Glenelg WSPA</li> <li>• Nested with 83447 and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> <li>• Also located in an area where the aquitard is thin/absent</li> </ul>
83447	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and high value rivers and wetlands</li> <li>• Monitors the target aquifer (PCL) in the Glenelg WSPA</li> <li>• Nested with 83446 and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> <li>• Also located in an area where the aquitard is thin/absent</li> </ul>
111787	Upper Tertiary/Quaternary Basalt Aquifer (101)	<ul style="list-style-type: none"> <li>• Nested site located in the vicinity of the Lake Murdeduke Ramsar listed site. Nested with 111786 and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing</li> </ul>
111786	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>• Nested site located in the vicinity of the Lake Murdeduke Ramsar listed site. Nested with 111787 and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>
110985	Upper Tertiary/Quaternary Basalt Aquifer (101)	<ul style="list-style-type: none"> <li>• Nested site located in the vicinity of the Lake Corangamite Ramsar listed site.</li> <li>• Nested with 110984 and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>
110984	Upper Tertiary Aquifer (marine) (104)	<ul style="list-style-type: none"> <li>• Nested site located in the vicinity of the Lake Corangamite Ramsar listed site.</li> <li>• Nested with 110985 and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>
122677	Lower Mid-Tertiary Aquifer (109)	<ul style="list-style-type: none"> <li>• Located adjacent to the area of prospectivity and high value rivers and wetlands</li> <li>• Monitors the target aquifer (Clifton Fmn) in the Condah WSPA</li> </ul>
115872	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and high value rivers and wetlands</li> <li>• Monitors the target aquifer (Dilwyn Formation) in the Paaratte GMA</li> </ul>
113467	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and high value rivers and wetlands</li> <li>• Monitors the target aquifer (Dilwyn Formation) in the Paaratte GMA</li> </ul>

## Onshore natural gas water science studies

Bore	Aquifer Monitored	Justification for inclusion in the monitoring network
54925	Upper Tertiary/Quaternary Basalt Aquifer (101)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands</li> <li>Monitors the watertable aquifer</li> </ul>
142660	Upper Tertiary/Quaternary Basalt Aquifer (101)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands (including RAMSAR wetland site Lake Corangamite)</li> <li>Monitors the target aquifer (Newer Volcanics) in the Warrion WSPA</li> </ul>
141241	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands</li> <li>Monitors the target aquifer (PCL) in the Nullawarre WSPA</li> </ul>
S61557-2	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands.</li> <li>Including the Directory of Important Wetland 'McCallums Swamp' Monitors the watertable aquifer</li> </ul>
102621	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands</li> <li>Monitors the target aquifer (PCL) in the Glenelg WSPA</li> </ul>
83729	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands</li> <li>Monitors the target aquifer (PCL) in the Glenelg WSPA</li> </ul>
S61557-3	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands.</li> <li>Including Directory of Important Wetlands (Mundi-Selkirk Wetlands) and the Glenelg River</li> <li>Monitors the watertable aquifer</li> </ul>
S61557-1	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands.</li> <li>Including Directory of Important Wetlands (Mundi-Selkirk Wetlands, Pig Swamp and Lake Mundi)</li> <li>Monitors the watertable aquifer</li> </ul>
141307	Upper Tertiary/Quaternary Basalt Aquifer (101)	<ul style="list-style-type: none"> <li>Located in the Yangery WSPA.</li> <li>Nested with 141308.</li> <li>Bores will monitor the high value PCL aquifer and the watertable aquifer (101 Newer Volcanics) and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>
141308	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>Located in the Yangery WSPA. Nested with 141307.</li> <li>Bores will monitor the high value PCL aquifer and the watertable aquifer (101 Newer Volcanics) and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>
82347	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Located in the Glenelg WSPA. Nested with S61557-4.</li> <li>Bores will monitor the Dilwyn Formation Aquifer and the watertable aquifer and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>
S61557-4	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>Located in the Glenelg WSPA. Nested with 82347.</li> <li>Bores will monitor the Dilwyn Formation Aquifer and the watertable aquifer and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>

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Bore	Aquifer Monitored	Justification for inclusion in the monitoring network
S9037242-1	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>Heywood GMA.</li> <li>Bore included to provide monitoring information for the PCL aquifer in the Heywood GMA.</li> </ul>
75070	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Newlingrook GMA. Closest bore monitoring the Dilwyn Formation to the prospectivity area.</li> <li>No nested sites to present alternative option.</li> </ul>
89040	Upper Tertiary/Quaternary Basalt Aquifer (101)	<ul style="list-style-type: none"> <li>Only available SOB in the Colongulac GMA.</li> <li>No nested sites to present alternative option.</li> </ul>
114169	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Gellibrand GMU.</li> <li>No nested sites to present alternative option.</li> </ul>
141242	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands.</li> <li>Monitors the target aquifer (PCL) in the Nullawarre WSPA.</li> </ul>
114167	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Monitors the target aquifer (Dilwyn Formation) in the Gerangamete GMA.</li> </ul>
69455	Mesozoic and Palaeozoic Bedrock (114)	<ul style="list-style-type: none"> <li>Only SOB available that monitors the Mesozoic Palaeozoic bedrock.</li> </ul>

## 4 Sampling method

Sampling of groundwater and gas from DELWP monitoring bores was conducted by HydroTerra personnel, subcontracted by Jacobs.

All groundwater purging, sampling and manual water level monitoring activities undertaken by HydroTerra were completed under their Standard Operating Procedure (SOP) for Groundwater Sampling, a copy of which is included in Appendix A. The SOP includes a detailed methodology for the following activities:

- Field instrument calibration: instruments were routinely checked for calibration at the start and end of the day in accordance with equipment procedures.
- Water level monitoring.
- Water quality monitoring: field parameters were routinely monitored during purging.
- Water sample collection: water samples were collected once field parameter stabilisation was achieved (three consecutive readings within 10%). Groundwater samples were collected into approved ALS Environmental supplied glass containers.
- Handling, storage and Chain of Custody procedures for collected samples: groundwater samples, including QA/QC samples, were stored on ice between the bore and delivery to the laboratory.
- Gas sampling was conducted in accordance with HydroTerra's technical work instruction for Collection of Dissolved Gas and Groundwater Samples from Coal Seam, included in Appendix B. The instruction includes a detailed methodology for the following activities:
  - Gas monitoring: gas was monitored onsite using a gas analyser.
  - Gas sample collection: when all the groundwater sample containers required for analysis were filled, a gas sample was collected. Gas samples were collected into ALS Environmental supplied summa canisters.
  - Handling, storage and Chain of Custody procedures for collected samples.

Samples were collected using a low flow pump installed at depth, which pumped water to the surface. Water was diverted into two lines – one for measurement of field parameters, one for water sample and gas sample collection. A flow diagram of the sampling lines is shown in Figure 20. Pump installation, operation and maintenance were conducted in accordance with HydroTerra's technical work instruction for Solinst 408 Double Valve Pump Deployment and Operation, included in Appendix C.

Between bore sites, all equipment was decontaminated to prevent cross-contamination between bores and samples. Equipment was decontaminated by rinsing with tap water, chemical detergent, tap water and then de-ionised water. The methodology used by HydroTerra personnel is described in full in Appendix A.

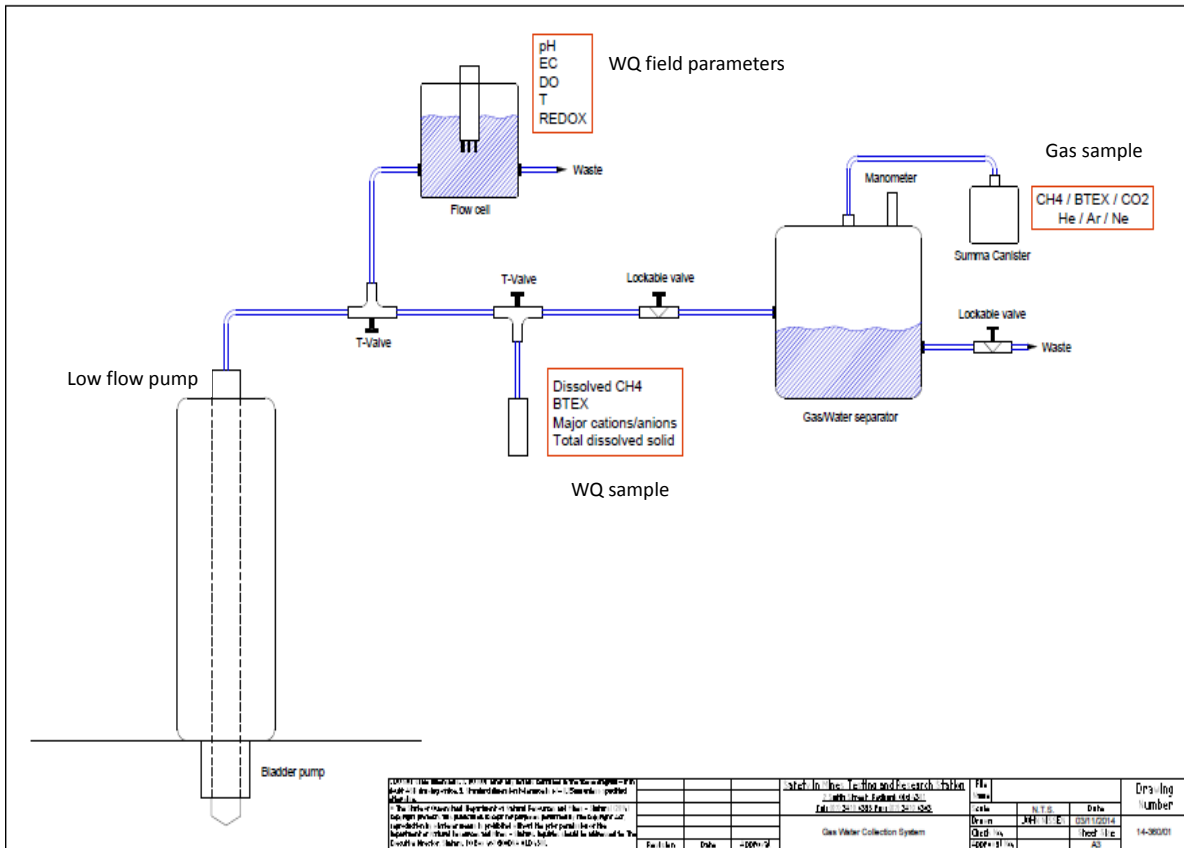


Figure 20 Flow diagram showing water sample collection, field parameter measurement and gas sample collection



Figure 21 Example of gas collection and sampling procedure in the field





*Figure 22 Example of gas collection and sampling procedure in the field*

## 4.1 Reporting of gas concentrations

Unlike water samples, the mass of a particular analyte in a gas sample is dependent on the pressure and temperature of the sample. For this reason, the laboratory reports the following parameters in the methane analysis of gas samples collected in summa canisters:

- concentration of methane (in  $\text{mg/m}^3$ )
- molar percentage of methane (as Mol %)
- pressure as received (in kPa)
- pressure – Laboratory Atmosphere (in kPa)
- temperature as received (as  $^{\circ}\text{C}$ ).

The concentration of methane in the gas samples cannot be easily combined with the concentration of methane in water samples collected from the same bore. Therefore, the two results are reported separately in this study.

## 5 Quality control and quality assurance

### 5.1 Quality control and quality assurance types

Water quality sampling from all bores included in this monitoring program was undertaken in accordance with Hydroterra standard operating procedures (as described in Section 4), EPA guidelines 'A Guide to Groundwater Sampling' (2000) and Australian Standard AS/NZS 5667.11 (1998). The following QA/QC samples were collected as part of the monitoring program:

#### **Duplicate sample (also known as an intra-lab sample)**

One duplicate sample was collected for every thirty samples collected. To collect a duplicate sample, water collected from the selected bore was separated into three bottle sets – one as the 'primary' sample, one as the 'duplicate' and one as the 'triplicate'. The purpose of a 'duplicate' sample is to validate the consistency of the sampling technique and laboratory analysis procedures. To assess results, the relative percentage difference (RPD) between the duplicate and primary is calculated for each analyte where observed concentration is greater than five times the Limit of Reporting (LOR) and compared to acceptance criteria.

#### **Triplicate sample (also known as an inter-lab sample)**

One triplicate sample was collected for every thirty samples collected. The triplicate was collected at the same site as the duplicate sample. To collect a triplicate sample, water collected from the selected bore was separated into three bottle sets – one as the 'primary' sample, one as the 'duplicate' and one as the 'triplicate'. The purpose of a 'triplicate' sample is to validate the results and analysis procedure of the primary lab. To assess results, the RPD between the duplicate and triplicate is calculated for each analyte where observed concentration is greater than five times the LOR and compared to acceptance criteria.

#### **Field blank**

One field blank was collected for every thirty samples collected. The purpose of the field blank is to validate the onsite sampling method. Sample bottles were filled with deionised water using the same method as filling bottles with groundwater. This includes field filtration, where required. If all tested analytes for the field blank are returned with results below detection levels, then the onsite sampling technique is verified.

#### **Transport blank (also known as trip blank)**

The purpose of a transport blank is to detect any sample contamination that may occur during transportation, namely in the form of volatile organics. A transport blank consists of a vial filled with deionised water that is stored in the esky by the laboratory. The vial remains in the esky during the field program and is not removed until the esky and samples are returned to the laboratory. If no contamination has occurred during transport, then the transport blank will return results below detection limits for all analytes tested.

## 5.2 Acceptance criteria for quality control samples

The calculation for RPD for quality control samples follows the methodology outlined in AS 4482.1-2005 (sampling at contaminated sites). Acceptance criteria used in this assessment are outlined in Table 11.

**Table 11 Acceptance criteria for QA/QC samples**

QA/QC sample	Typical RPD for QA/QC sample where observed concentration is greater than five time LOR (see Notes 1 and 2)
Duplicate	30% - 40% of mean concentration of analyte. See Note 3.
Triplicate	30% - 50% of mean concentration of analyte determined by both laboratories. See Note 3.

Notes:

- 1) *Relative Percentage Difference RPD* =  $\frac{\text{Result No.1} - \text{Result No.2}}{\text{Mean result}} \times 100$
- 2) The significance of RPD of results should be evaluated on the basis of sampling technique, sample variability, absolute concentration relative to criteria and laboratory performance.
- 3) This variation can be expected to be higher for organic analysis than for inorganics, and for low concentration of analytes.
- 4) Cation and Anion balance.

## 5.3 Quality control and quality assurance assessment

### 5.3.1 Primary, duplicate and triplicate samples

The RPD has been calculated for the QA/QC samples shown in Table 12.

**Table 12 QA/QC samples**

Primary	Duplicate	Triplicate
110984	QA02	QA03
114169	QA01	-

The laboratory results and calculation of RPD are shown in

Table 13 described the anomalies (duplicate RPD>40% and triplicate RPD>50%) identified through QA/QC assessment.

**Table 13: Anomalies determined through QA/QC assessment**

Sample	%RPD and analyte	Comment
QA03 Triplicate of 110984	199.7 for Total Nitrogen	All other duplicate and triplicate RPD results are within acceptable limits. Hence, this result is expected to be laboratory error.
QA01 Duplicate of 114169	168.85 for ionic balance	Difference in ionic balance not considered significant as major cation and anion results were within RPD limits.
QA01 Duplicate of 114169	124.64 for sulphate	Both the primary and duplicate were re-analysed by the laboratory following re-preparation. Actual difference between results not considered significant.
QA01 Duplicate of 114169	77.68 for TDS	Both the primary and duplicate were re-analysed by the laboratory following re-preparation. Actual difference between results not significant.

### 5.3.2 Rinsates

Two rinsate samples were collected following bore sampling and decontamination of equipment. All results indicate that decontamination methods were satisfactory.

### 5.3.3 Trip blanks

Trip blanks were included in all eskies. All results are below detection limits and as such, contamination during transport is considered unlikely.

## 6 Groundwater sampling – summary of results

A total of 30 bores were sampled in the Otway region. The bores were sampled between 19<sup>th</sup> January 2015 and 29<sup>th</sup> January 2015. The chemistry results as obtained from ALS Environmental are included in Appendix D. This chapter presents a summary of the results.

### 6.1 Semi volatile organic compounds

Semi volatile Organic Compounds (SVOCs) include organic compounds that vaporise under normal pressure and temperature conditions. Seven SVOCs were analysed in water samples, including: butane, butene, propane, propene, ethane, ethene and methane. Only dissolved methane was detected in the sampled bores.

In addition, methane concentrations were analysed in collected gas samples as per the procedure detailed in the Standing Operating Procedure (Appendix B).

Figure 23 shows the spatial distribution of the dissolved methane concentrations detected across the Otway region. The methane concentrations observed across the 30 sites in the Otway region ranged from 0 mg/L to 5.8 mg/L (Table 14). The median concentration was 0.01 mg/L. Methane was detected in one of the gas samples collected (Bore 111786 in the Lower Tertiary Aquifer)

The range of methane concentrations in water samples in this study is consistent with methane concentrations determined from baseline studies in other parts of the world (BGS, 2012).

The detection limit for dissolved methane in groundwater is 0.01 mg/L. No methane was detected in the Upper Tertiary Aquifer (marine) or the Lower Mid Tertiary Aquifer. Low methane concentrations were detected in the remaining aquifers, all with a maximum of <1 mg/L dissolved methane. The exception to this is a single reading obtained from the Lower Tertiary Aquifer, which records a methane concentration of 5.8 mg/L.

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**Table 14 Methane concentration by aquifer (water samples)**

Aquifer	Number of Bores Sampled	Minimum Methane (mg/L)	Maximum Methane (mg/L)	Average Methane (mg/L)
Quaternary Aquifer (100)	4	0.00	0.01	0.00
Upper Tertiary / Quaternary Basalt Aquifer (101)	7	0.00	0.64	0.11
Upper Tertiary Aquifer (marine) (104)	1	0.00	0.00	0.00
Upper Mid Tertiary Aquifer (107)	8	0.00	0.04	0.01
Lower Mid Tertiary Aquifer (109)	1	0.00	0.00	0.00
Lower Tertiary Aquifer (111)	8	0.00	5.75	0.76
Mesozoic and Palaeozoic Bedrock (114)	1	0.38	0.38	0.38

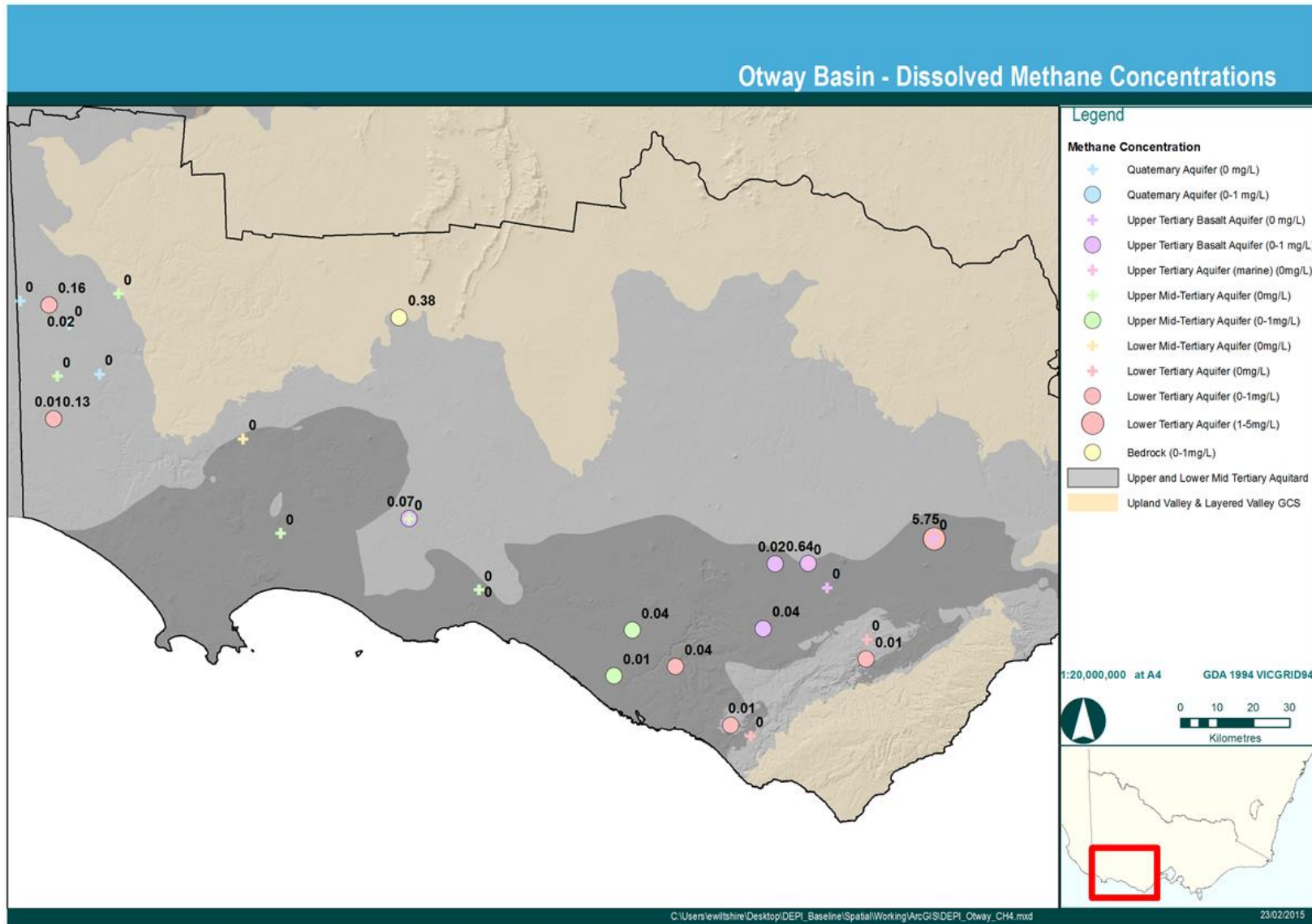


Figure 23 Spatial distribution of dissolved methane in groundwater

Otway region groundwater sampling and characterisation for hydrocarbons



## 6.2 Total petroleum hydrocarbons

Total Petroleum Hydrocarbons (TPH) include any mixture of hydrocarbons that can be found in crude oil. TPH in groundwater can be either naturally occurring or can have anthropogenic origins. TPH analysis is often reported as Total Recoverable Hydrocarbons (TRH) which represents a mixture of compounds without the specific identification of individual compounds. Any detected organic compounds are reported against one of a limited number of ranges (or fractions). The lower fraction is often referred to as the petrol range of organics, whilst the higher fractions are called the diesel range organics.

Of the 30 groundwater samples collected for the Otway region, five bores recorded detectable concentrations of dissolved hydrocarbons. The laboratory has reported total recoverable hydrocarbons (TRH) according to the industry standard assessment criteria defined by the National Environment Protection Measures (Australian Government, 2013).

The bores where detection was identified are shown in Table 15. Generally these detections are minor, with 110985 and S61557/2 recording hydrocarbons at the detection limit of the analytical technique for TRH. The majority of the detected hydrocarbons are in the medium to heavy fraction range, with S61557/2 detecting a light (volatile) range of hydrocarbons. This volatile detection is not a BTEX compound (no BTEX detected in the sample). These techniques generally act as a screening method and further analysis (e.g. gas chromatography-mass spectrometry) of the sample can identify the organic compound. The low levels detected across the Otway region do not warrant further investigation.

The three bores that record TRH greater than detection limits are all screened in the Lower Tertiary Aquifer (111). There is no evidence of a spatial correlation with these bores (i.e. they do not occur in a particular part of the region). The fact that the TRH detection occurs primarily in a deep coal bearing aquifer with little interaction with the surface and the detections are quite low, indicates the hydrocarbons may be of natural origin.

**Table 15 Concentrations of Total Recoverable Hydrocarbons for bores where detection occurred (µg/L)**

Fraction	Detection Limit	S61557/2 (Quaternary Aquifer)	110985 (Upper Tertiary / Quaternary Basalt)	111786 (Lower Tertiary Aquifer)	115872 (Lower Tertiary Aquifer)	82347 (Lower Tertiary Aquifer)
C6-C10	20	20	<20	<20	<20	<20
>C10-C16	100	<100	<100	<100	260	<100
>C16-C34	100	<100	100	380	110	400
>C34-C40	100	<100	<100	<100	<100	<100
>C10-C40 (sum)	100	<100	100	380	370	400

### 6.2.1 BTEX

All samples were analysed for the presence of Benzene, Toluene, Ethylbenzene, and Xylene (collectively known as BTEX). BTEX compounds are volatile organic compounds that can be naturally found in crude oil, coal and gas deposits. BTEX falls within the C6-C10 fraction of TRHs. There was no BTEX detected in groundwater in the Otway region.

### 6.3 Inorganic analytes and indicators

#### 6.3.2 Major ion chemistry

The ratio of various cations and anions in any one aquifer is often reasonably constant and provides a chemical signature of that aquifer. Changes in these ratios over time can signal chemical mixing of aquifers or addition of a new source of water. One graphical method for characterising the geochemistry of aquifers is the use of Piper diagrams (Piper, 1953), which plot anions and cations separately and combine using trilinear and quadrilinear plots. A Piper diagram plot showing the ratios of the analysed cations and anions by aquifer is shown in Figure 24.

The Piper diagram shows that the sampled groundwater ranges from sodium-chloride type to mixed bicarbonate-chloride type, but with low sulphate levels. There are no obvious vertical (aquifer) trends in the data, though data from the Quaternary Aquifer show clustering. The similarity of groundwater above and below major aquitards suggests lateral flow originates from similar sources and undergoes similar processes.

An indication of chemical processes is provided using Schoeller diagrams, as shown in Figure 26 a and b. Thus, the Quaternary groundwater show an evaporated rainfall signature, while deeper formation show the effect of cation exchange with reduced calcium and increased sodium, typical of exchange on swelling clays in the aquifer matrix. Sulphate remains low throughout, suggesting a lack of sulphur-bearing minerals in the aquifer sediments.

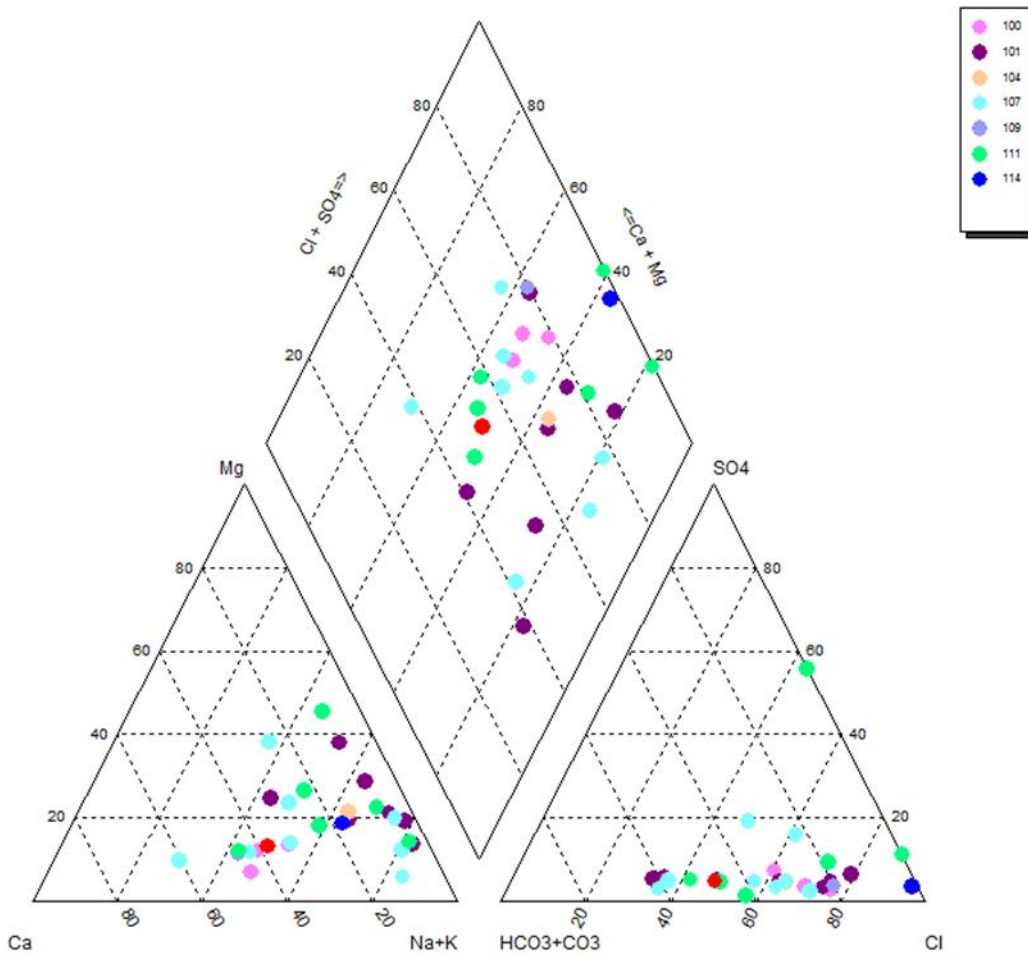


Figure 24 Piper diagram showing major ion concentrations

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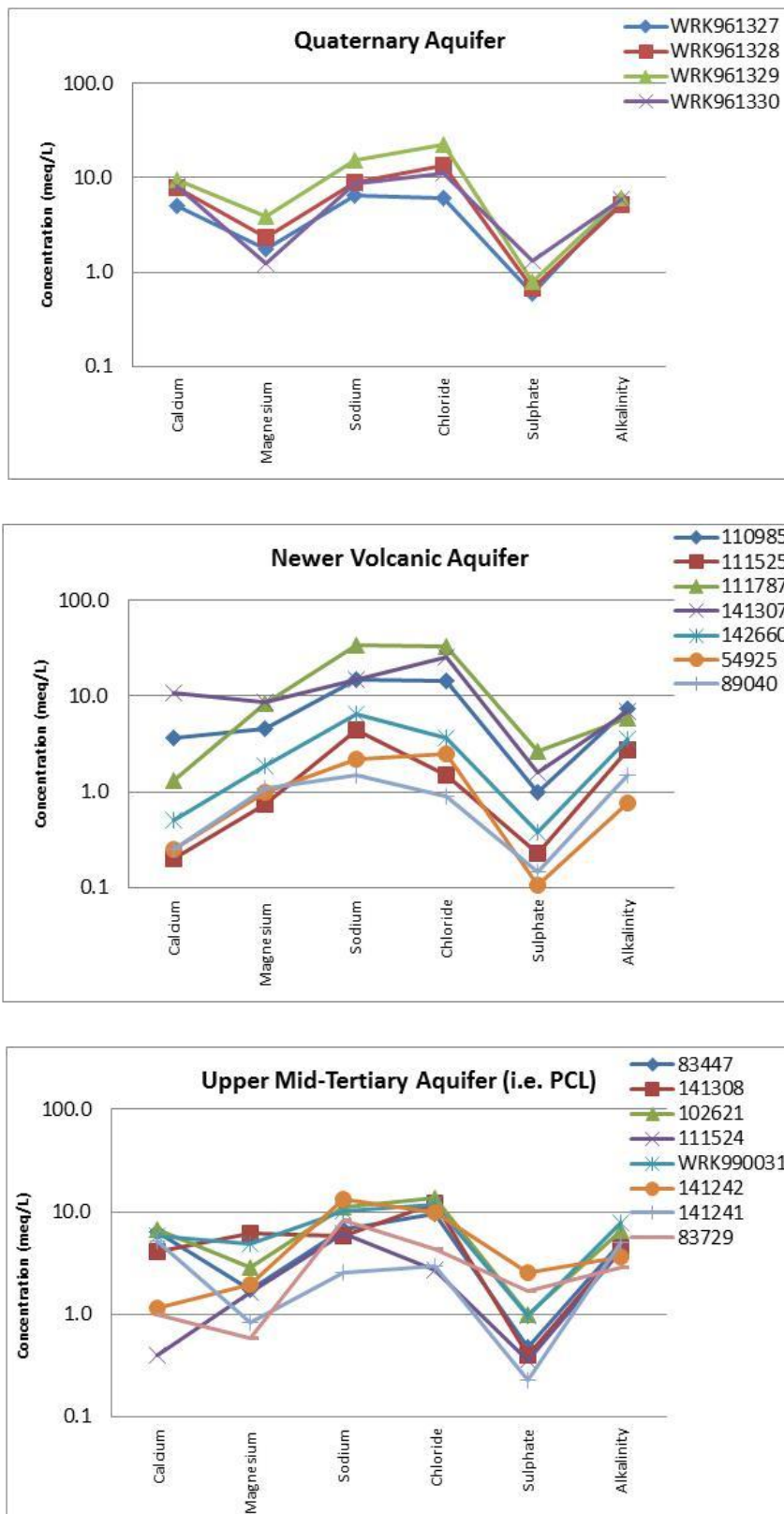


Figure 25a Schoeller plots showing major ion chemistry by aquifer

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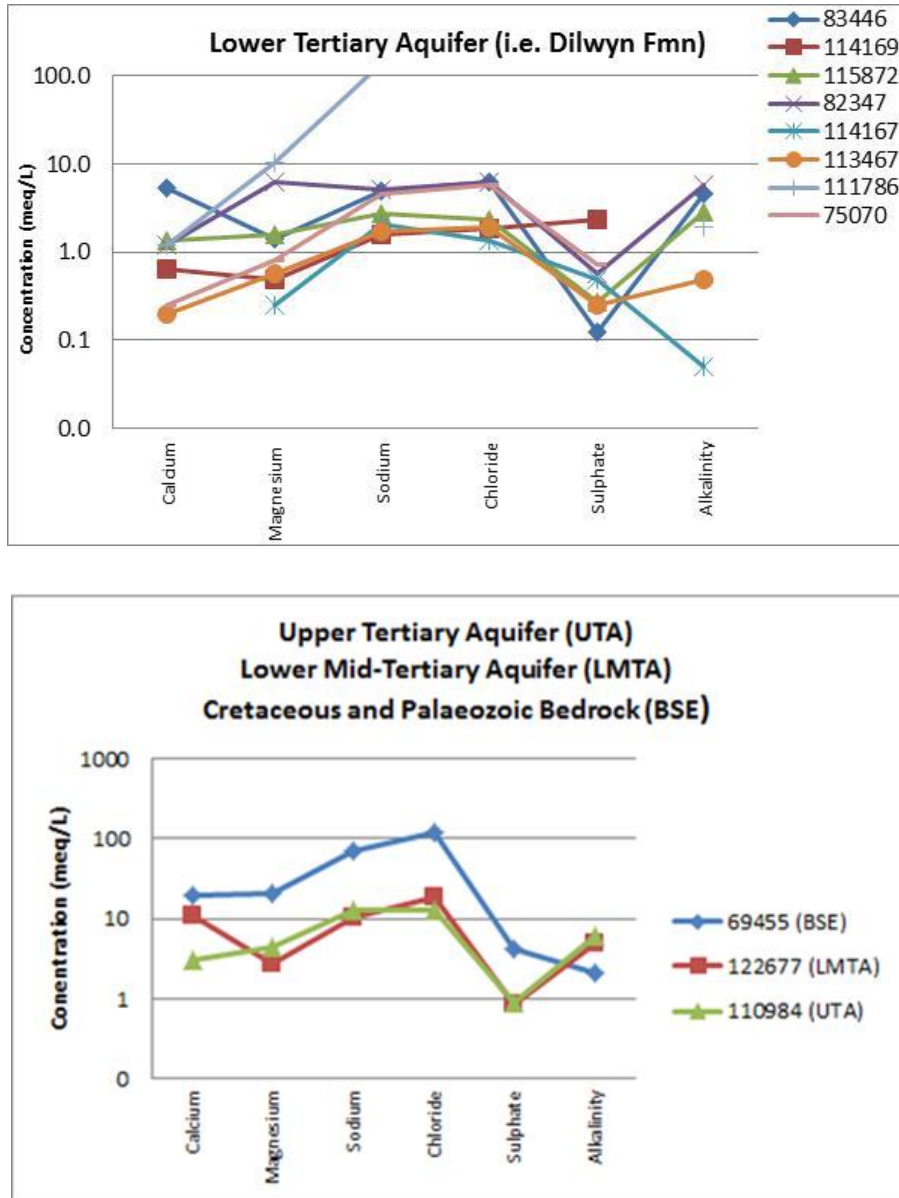


Figure 26b Schoeller plots showing major ion chemistry by aquifer

### 6.3.3 Groundwater salinity

Groundwater salinity is described using concentration of Total Dissolved Solids (TDS). The average groundwater salinity for all aquifers is classified as marginal to brackish (1,003 – 2,130 mg/L TDS) with the exception of the Mesozoic and Palaeozoic Bedrock which is classified as saline (>5,000 mg/L TDS). Salinity is dominated by sodium chloride, with minor calcium and magnesium salt. Groundwater salinity ranges per aquifer are summarised in Table 16.

**Table 16 Groundwater salinity**

Aquifer	Number of Samples Collected	Minimum Groundwater TDS (mg/L)	Maximum Groundwater TDS (mg/L)	Mean Groundwater TDS (mg/L)
Quaternary Aquifer (100)	4	860	2,210	1,425
Upper Tertiary / Quaternary Basalt Aquifer (101)	7	221	2,790	1,178
Upper Tertiary Aquifer (marine) (104)	1	1,160	1,160	1,160
Upper Mid Tertiary Aquifer (107)	8	568	1,390	1,003
Lower Mid Tertiary Aquifer (109)	1	2,130	2,130	2,130
Lower Tertiary Aquifer (111)	8	241	9410	1,637
Mesozoic and Palaeozoic Bedrock (114)	1	8,640	8,640	8,640

### 6.3.4 Nitrogen

Groundwater samples were analysed for Kjeldahl Nitrogen, oxidised Nitrogen and total Nitrogen (the sum of the two). The results for total Nitrogen, by aquifer, are summarised in Table 17.

**Table 17 Total Nitrogen Concentrations**

Aquifer	Number of Samples Collected	Minimum Nitrogen (mg/L)	Maximum Nitrogen (mg/L)	Mean Nitrogen (mg/L)
Quaternary Aquifer (100)	4	0.0	1.4	0.5
Upper Tertiary / Quaternary Basalt Aquifer (101)	7	0.0	10.9	2.9
Upper Tertiary Aquifer (marine) (104)	1	0.4	0.4	0.4
Upper Mid Tertiary Aquifer (107)	8	0.0	13	2.3
Lower Mid Tertiary Aquifer (109)	1	0.7	0.7	0.7
Lower Tertiary Aquifer (111)	8	0.0	4.6	1.5
Mesozoic and Palaeozoic Bedrock (114)	1	1.2	1.2	1.2

## 6.3.5 Field indicators

The following field parameters were measured at the time of groundwater sample collection: pH, redox, dissolved oxygen, temperature and odour. The field parameter values for each aquifer are summarised in Table 18.

The median Dissolved Oxygen (DO) concentration for each aquifer ranges from 0.3 to 3.7 mg/L (Table 6), which is low relative to atmospheric oxygen (~10 mg/L). This means the atmospheric oxygen that was originally present in the infiltrating rainwater has been consumed in the soil and unsaturated zone by microbial activity and decomposition of organic matter (Rose and Long, 1998). The median DO of 3.7 mg/L in the Lower Mid Tertiary Aquifer indicates that either the microbial reduction of oxygen is limited in some aquifers, or oxygen can move to saturated aquifers from overlying unconfined aquifers.

Mean temperature for each aquifer is fairly consistent, ranging from 15.8 to 17.8 degrees Celsius (Table 18). No observation of increasing temperature with depth was observed.

Hydrogen sulphide odour was noted on six occasions (Table 18) including for the shallow Upper Tertiary / Quaternary Basalt Aquifer, the Upper Mid Tertiary Aquifer, the Lower Tertiary Aquifer and the Bedrock Aquifer. Hydrogen sulphide is generally associated as a by-product of sulphate-reducing bacteria activity and generally requires an adequate organic carbon source to facilitate fermentation. While some groundwater held measurable TRH and sulphate, many did not. The source of the hydrogen sulphide for some of the samples is indeterminant at this time.

Groundwater pH is essentially neutral across all aquifers, ranging from 6.15 - 7.2 (Table 18).

Redox conditions are measured as the standard redox potential and this indicates the tendency of the groundwater to either gain or lose electrons. Negative potentials are indicative of reducing conditions and are usually found when air supply is limited. Positive potentials are typical of aerated surface waters and indicate oxidising conditions. Both negative and positive redox potentials are found throughout the Otway region (Table 18), though values are generally low suggesting that both oxidising and reducing conditions exist. The values indicate that the Lower Tertiary Aquifer and the Bedrock Aquifer exhibits stronger reducing conditions than other shallower aquifers as indicated by the lower median redox potential values, the lower dissolved oxygen values and the smell of hydrogen sulphide gas at the surface.

**Table 18 Summary of indicator parameters measured in the field**

Aquifer	Mean pH	Median Redox (mV)	Median DO (mg/L)	Mean Temp (°C)	Odour
Quaternary Aquifer (100)	6.7	2.2	2.2	16.1	None
Upper Tertiary / Quaternary Basalt Aquifer	6.7	1.0	1.0	16.5	H <sub>2</sub> S smell (x2)
Upper Tertiary Aquifer (marine) (104)	7.2	-34.0	-0.3	16.4	None
Upper Mid Tertiary Aquifer (107)	6.7	1.1	1.1	16.0	H <sub>2</sub> S smell (x2)
Lower Mid Tertiary Aquifer (109)	6.6	87.6	3.7	15.8	None
Lower Tertiary Aquifer (111)	6.1	0.5	0.5	16.8	H <sub>2</sub> S smell (x1)
Mesozoic and Palaeozoic Bedrock (114)	7.2	-122.1	0.5	17.8	H <sub>2</sub> S smell (x1)

## 7 Groundwater sampling – aquifer characterisation

This chapter provides comments on the sampling results, by aquifer, relating back to the justification for bore selection.

### 7.1 Quaternary Aquifer (100)

Four observation bores were sampled from the Quaternary Aquifer (Table 19). The Quaternary Aquifer is comprised of various aeolian, fluvial, lacustrine, alluvial and colluvial sediments. These observation bores are located in areas of shale gas prospectivity and important wetlands and rivers such as McCallums Swamp, Mundi-Selkirk Wetlands, Lake Mundi and the Glenelg River.

Groundwater salinity for this aquifer ranges from 860 mg/L TDS to 2,210 mg/L TDS. The average groundwater salinity is marginal (1,425 mg/L TDS). Total Nitrogen concentration for this aquifer ranges from 0 mg/L to 1.4 mg/L. The average nitrogen concentration is 0.5 mg/L. The groundwater is near-neutral with an average pH of 6.7.

Dissolved methane and TRH (which includes BTEX) detection is negligible for this aquifer. A single observation of TRH and methane was observed and both results were low concentration (equivalent to the level of reporting).

**Table 19 Quaternary Aquifer monitoring Bores**

Bore	Aquifer Monitored	Justification for inclusion in the monitoring network	Comment
S61557-2	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity</li> <li>• Located in area of key rivers and wetlands, including the Directory of Important Wetland 'McCallums Swamp'</li> <li>• Monitors the watertable aquifer</li> </ul>	<ul style="list-style-type: none"> <li>• Watertable aquifer in area of prospectivity and key assets is characterised by; no methane and trace amounts of TRH (i.e. equal to detection limit) and no BTEX</li> </ul>
S61557-3	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity</li> <li>• Located in the area of key rivers and wetlands. Including Directory of Important Wetlands (Mundi-Selkirk Wetlands) and the Glenelg River</li> <li>• Monitors the watertable aquifer</li> </ul>	<ul style="list-style-type: none"> <li>• Watertable aquifer in area of prospectivity and key assets is characterised by; no methane, no TRH and no BTEX</li> </ul>
S61557-1	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity</li> <li>• Located in the area of key rivers and wetlands, including Directory of Important Wetlands (Mundi-Selkirk Wetlands, Pig Swamp and Lake Mundi)</li> <li>• Monitors the watertable aquifer</li> </ul>	<ul style="list-style-type: none"> <li>• Watertable aquifer in area of prospectivity and high value assets is characterised by; no methane, no TRH and no BTEX</li> </ul>
S61557-4	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>• Located in the Glenelg WSPA. Nested with 82347.</li> <li>• Bores will monitor the Dilwyn Formation Aquifer and the watertable aquifer and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing</li> </ul>	<ul style="list-style-type: none"> <li>• In the Glenelg WSPA a downward vertical hydraulic gradient occurs from the Quaternary Aquifer to the Lower Tertiary Aquifer.</li> <li>• Low level methane detected (equal to the detection limit). Methane was also detected in the Lower Tertiary Aquifer at this location. Methane concentration decreases from the deep to the shallow aquifer.</li> <li>• No TRH or BTEX detected</li> </ul>

## 7.2 Upper Tertiary / Quaternary Basalt Aquifer (101)

Seven observation bores were sampled from the Upper Tertiary / Quaternary Basalt Aquifer, which comprises the Newer Volcanics basalt in this area (Table 20). These sampled bores are outside of the sub-regional areas of the natural gas prospectivity, but do occur in areas of high value rivers and wetlands, including Ramsar listed Lake Corangamite. Parts of this aquifer are covered by the Warrion WSPA.

Groundwater salinity for this aquifer ranges from 221 mg/L TDS to 2,790 mg/L TDS. The average groundwater salinity is marginal; 1,178 mg/L TDS. Total Nitrogen concentration for this aquifer ranges from 0 mg/L to 10.9 mg/L. The average nitrogen concentration is 2.9 mg/L.

The highest nitrogen concentration is associated with a bore located within the Warrion WSPA. Oxidised nitrogen (the sum of nitrate and nitrite) makes up most of the total nitrogen for this sample. Fertilizers mainly contain nitrite and hence it is likely that the source of the elevated concentration in groundwater is leaching of nutrients through the unsaturated zone to the watertable. The Upper Tertiary / Quaternary Basalt Aquifer is the watertable aquifer in this area.



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The groundwater is near neutral with an average pH of 6.7. An odour indicative of hydrogen sulphide gas was noted on two occasions for this aquifer.

Dissolved methane and TRH (which includes BTEX) detection is negligible for this aquifer. Average methane concentration was 0.11 mg/L and a single occurrence of TRH was observed, equal to the detection limit for the carbon fraction.

**Table 20 Upper Tertiary / Quaternary Basalt Aquifer**

Bore	Aquifer Monitored	Justification for inclusion in the monitoring network	Comment
S61557-2	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity</li> <li>Located in area of key rivers and wetlands, including the Directory of Important Wetland 'McCallums Swamp'</li> <li>Monitors the watertable aquifer</li> </ul>	<ul style="list-style-type: none"> <li>Watertable aquifer in area of prospectivity and key assets is characterised by; no methane and trace amounts of TRH (i.e. equal to detection limit) and no BTEX</li> </ul>
S61557-3	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity</li> <li>Located in the area of key rivers and wetlands. Including Directory of Important Wetlands (Mundi-Selkirk Wetlands) and the Glenelg River</li> <li>Monitors the watertable aquifer</li> </ul>	<ul style="list-style-type: none"> <li>Watertable aquifer in area of prospectivity and key assets is characterised by; no methane, no TRH and no BTEX</li> </ul>
S61557-1	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity</li> <li>Located in the area of key rivers and wetlands, including Directory of Important Wetlands (Mundi-Selkirk Wetlands, Pig Swamp and Lake Mundi)</li> <li>Monitors the watertable aquifer</li> </ul>	<ul style="list-style-type: none"> <li>Watertable aquifer in area of prospectivity and key assets is characterised by; no methane, no TRH and no BTEX</li> </ul>
S61557-4	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>Located in the Glenelg WSPA. Nested with 82347.</li> <li>Bores will monitor the Dilwyn Formation Aquifer and the watertable aquifer and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing</li> </ul>	<ul style="list-style-type: none"> <li>In the Glenelg WSPA a downward vertical hydraulic gradient occurs from the Quaternary Aquifer to the Lower Tertiary Aquifer.</li> <li>Low level methane detected (equal to the detection limit). Methane was also detected in the Lower Tertiary Aquifer at this location. Methane concentration decreases from the deep to the shallow aquifer.</li> <li>No TRH or BTEX detected</li> </ul>

### 7.3 Upper Tertiary Aquifer (marine) (104)

A single bore was sampled for the Upper Tertiary Aquifer (marine) (Table 21). This aquifer comprises a number of formations including: Whalers Bluff Formation, Moorabool Viaduct Formation, Hanson Plain Sand, Dorodong Sand and Grange Burn Formation. Groundwater salinity is brackish for this aquifer and nitrogen concentration is low (0.4 mg/L). Groundwater pH is near neutral (7.2) and redox potential indicates reducing conditions.

There was no methane detected in groundwater for the Upper Tertiary Aquifer (marine) and no TPH (including BTEX).

**Table 21 Upper Tertiary Aquifer (marine)**

Bore	Aquifer Monitored	Justification for inclusion in the monitoring network	Comment
110984	Upper Tertiary Aquifer (marine) (104)	<ul style="list-style-type: none"> <li>Nested site located in the vicinity of the Lake Corangamite Ramsar listed site.</li> <li>Nested with 110985 and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>	<ul style="list-style-type: none"> <li>The Upper Tertiary Aquifer (marine) near Lake Corangamite did not contain dissolved methane, TRH or BTEX</li> <li>The underlying Newer Volcanic basalt aquifer contains low methane concentrations (0.64mg/L).</li> </ul>

## 7.4 Upper Mid-Tertiary Aquifer (107)

Eight bores were sampled from the Upper Mid-Tertiary Aquifer, which includes a number of limestone units, including the Port Campbell Limestone and the Gambier Limestone (Table 22). Some of these observation bores are located in sub regional potential onshore natural gas development areas. Most bores also intersect an area of groundwater, covered by the Glenelg, Hawkesdale, Heywood, Nullawarre and Yangery GMUs.

Groundwater salinity for this aquifer ranges from 568 mg/L TDS to 1,390 mg/L TDS. The average groundwater salinity is marginal (1,003 mg/L TDS). Total Nitrogen concentration for this aquifer ranges from 0 mg/L to 13 mg/L. The average nitrogen concentration is 2.3 mg/L. An elevated nitrogen concentration is associated with a bore located within the Glenelg WSPA. Oxidised nitrogen (the sum of nitrate and nitrite) makes up most of the total nitrogen for this sample. Fertilizers mainly contain nitrite and hence it is likely that the source of the elevated concentration in groundwater is leaching of nutrients through the unsaturated zone to the watertable. The Upper Mid-Tertiary Aquifer is essentially at the surface in this area and forms the watertable aquifer.

The groundwater is near neutral with an average pH of 6.7. An odour indicative of hydrogen sulphide gas was noted on two occasions for this aquifer. A positive redox potential was noted for this aquifer, indicating oxidising groundwater conditions.

Five bores did not detect any methane in groundwater and three bores recorded low concentrations of methane, all less than 0.05 mg/L (detection is 0.01 mg/L). No TPHs (including BTEX) were detected in groundwater from this aquifer.

**Table 22 Upper Mid-Tertiary Aquifer**

Bore	Aquifer Monitored	Justification for inclusion in the monitoring network	Comment
83447	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and key rivers and wetlands</li> <li>• Monitors the target aquifer (PCL) in the Glenelg WSPA</li> <li>• Nested with 83446 and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> <li>• Also located in an area where the aquitard is thin/absent</li> </ul>	<ul style="list-style-type: none"> <li>• In the Glenelg WSPA, the Port Campbell Limestone (PCL) aquifer is characterised by groundwater with low methane concentration (0.02 mg/L), no TPH or BTEX.</li> <li>• Underlying the PCL is the Lower Tertiary Aquifer with a measured methane concentration of 0.16 mg/L. A reduction in methane is observed in an upward vertical direction.</li> <li>• There is no aquitard present in this area (equivalent to the Gelibrand Marl or Narrawaturk Marl).</li> </ul>
111524	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and key rivers and wetlands</li> <li>• Monitors the target aquifer (PCL) in the Hawkesdale GMA</li> <li>• Nested with 111525 and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>	<ul style="list-style-type: none"> <li>• The Port Campbell Limestone in the Hawkesdale GMA does not contain methane, TRHs or BTEX</li> </ul>
141241	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and key rivers and wetlands</li> <li>• Monitors the target aquifer (PCL) in the Nullawarre WSPA</li> </ul>	<ul style="list-style-type: none"> <li>• The Port Campbell Limestone in the Nullawarre WSPA does not contain methane, TRHs or BTEX</li> </ul>
102621	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and key rivers and wetlands</li> <li>• Monitors the target aquifer (PCL) in the Glenelg WSPA</li> </ul>	<ul style="list-style-type: none"> <li>• In the Glenelg WSPA, the Port Campbell Limestone aquifer does not contain methane, TPHs or BTEX.</li> </ul>
83729	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and key rivers and wetlands</li> <li>• Monitors the target aquifer (PCL) in the Glenelg WSPA</li> </ul>	<ul style="list-style-type: none"> <li>• In the Glenelg WSPA, the Port Campbell Limestone aquifer does not contain methane, TPHs or BTEX.</li> </ul>
141308	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>• Located in the Yangery WSPA. Nested with 141307.</li> <li>• Bores will monitor the key PCL aquifer and the watertable aquifer (101 Newer Volcanics) and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>	<ul style="list-style-type: none"> <li>• In the Yangery WSPA, the Port Campbell Limestone aquifer does not contain methane, TPHs or BTEX.</li> <li>• There is no methane in groundwater or TRH or BTEX in the Newer Volcanic Basalt aquifer or the underlying Port Campbell Limestone aquifer at this location.</li> </ul>
S9037242-1	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>• Heywood GMA.</li> <li>• Bore included to provide monitoring information for the PCL aquifer in the Heywood GMA.</li> </ul>	<ul style="list-style-type: none"> <li>• In the Heywood GMA, the Port Campbell Limestone does not contain methane, TRH or BTEX</li> </ul>

## 7.5 Lower Mid Tertiary Aquifer (109)

A single bore was sampled for the Lower Mid Tertiary Aquifer which comprises the Clifton Formation in the Otway region (Table 23). This bore is located away from sub-regional prospectivity areas but does reside in the Condah WSPA. Groundwater salinity for the Clifton Formation aquifer is brackish (2,130 mg/L TDS) and total nitrogen concentration is low (0.7 mg/L). The groundwater is near neutral with a pH of 6.6. A positive redox potential was noted for this aquifer, suggesting oxidising groundwater conditions.

There was no methane detected in groundwater for this aquifer and no TPH (including BTEX).

**Table 23 Lower Mid-Tertiary Aquifer**

Bore	Aquifer Monitored	Justification for inclusion in the monitoring network	Comment
122677	Lower Mid-Tertiary Aquifer (109)	<ul style="list-style-type: none"> <li>Located adjacent to the area of prospectivity and key rivers and wetlands</li> <li>Monitors the target aquifer (Clifton Fmn) in the Condah WSPA</li> </ul>	<ul style="list-style-type: none"> <li>The Clifton Formation aquifer in the Condah WSPA does not contain methane, TPH or BTEX</li> </ul>

## 7.6 Lower Tertiary Aquifer (111)

Eight bores were sampled from the Lower Tertiary Aquifer, which includes the Dilwyn Formation, Pebble Point Formation, Wangerrip Group and the Knight Group (Table 24).

Some of these observation bores intersect sub-regional areas of natural gas prospectivity. Most bores also intersect an area of groundwater, covered by the Glenelg, Paaratte, Newlingrook and Gellibrand GMUs.

Groundwater salinity for this aquifer ranges from 241 mg/L TDS to 9,410 mg/L TDS. The average groundwater salinity is brackish (1,637 mg/L TDS). A single high groundwater salinity reading from bore 111786 does not appear characteristic of this aquifer.

Total Nitrogen concentration for this aquifer ranges from 0 mg/L to 4.6 mg/L. The average nitrogen concentration is 1.5 mg/L.

The groundwater is slightly acidic with an average pH of 6.1. An odour indicative of hydrogen sulphide gas was noted on one occasion for this aquifer. A positive redox potential was noted for this aquifer, indicating oxidising groundwater conditions.

Six of the eight bores detected methane in groundwater, albeit the average concentration (0.76 mg/L) is low. TRH was detected for three bores, though no BTEX was detected in any samples.

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**Table 24 Lower Tertiary Aquifer**

Bore	Aquifer Monitored	Justification for inclusion in the monitoring network Comment	Comment
83446	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and key rivers and wetlands (including wetlands protected by the Directory of Important Wetlands)</li> <li>• Monitors the target aquifer (Dilwyn) in the Glenelg WSPA</li> <li>• Nested with 83447 and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> <li>• Also located in an area where the aquitard (UMTD and LMTD) is thin/absent</li> </ul>	<ul style="list-style-type: none"> <li>• The Dilwyn Formation in the Glenelg WSPA has low methane concentration (less than 0.5 mg/L).</li> <li>• Low methane was also detected in overlying Upper Mid-Tertiary Aquifer at this location.</li> <li>• A reduction in methane is observed in an upward vertical direction. Aquitard is absent in this area.</li> </ul>
111786	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>• Nested site located in the vicinity of the Lake Murdeduke Ramsar listed site. Nested with 111787 and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>	<ul style="list-style-type: none"> <li>• Highest methane concentration detected in this area (northeast of Colac).</li> <li>• Methane is detected in the Lower Tertiary Aquifer (5.8 mg/L) and is not detected in the overlying basalt aquifer.</li> <li>• Only bore sampled where methane gas was detected in analysed gas sample.</li> <li>• Approximately 450 m of aquitard associated with the Upper and Lower Mid Tertiary Aquitard units resides between the Lower Tertiary Aquifer and the Quaternary Tertiary Basalt Aquifer and hence may be providing an effective seal to the vertical migration of methane in this area.</li> <li>• This bore records low TRH concentration, though no BTEX.</li> </ul>
115872	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and key rivers and wetlands</li> <li>• Monitors the target aquifer (Dilwyn Formation) in the Paaratte GMA</li> </ul>	<ul style="list-style-type: none"> <li>• The Dilwyn Formation in the Paaratte GMA has low methane concentration (0.04 mg/L) and low TRH detected, though not in the range for BTEX</li> </ul>
113467	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and key rivers and wetlands</li> <li>• Monitors the target aquifer (Dilwyn Formation) in the Paaratte GMA</li> </ul>	<ul style="list-style-type: none"> <li>• The Dilwyn Formation in the Paaratte GMA has low methane concentration (equal to detection limit)</li> </ul>
82347	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>• Located in the Glenelg WSPA. Nested with S61557-4.</li> <li>• Bores will monitor the Dilwyn Formation Aquifer and the watertable aquifer and will inform groundwater chemistry of multiple aquifers at one site and allow for interpretation of potential mixing.</li> </ul>	<ul style="list-style-type: none"> <li>• The Dilwyn Formation in the Glenelg WSPA has low methane concentration (0.13 mg/L) and low TRH (though not in the BTEX fraction)</li> <li>• A downward vertical hydraulic gradient occurs from the Quaternary Aquifer to the Lower Tertiary Aquifer at this location</li> <li>• Methane detected in both the Lower Tertiary Aquifer and the Quaternary Aquifer.</li> </ul>

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Bore	Aquifer Monitored	Justification for inclusion in the monitoring network Comment	Comment
			<ul style="list-style-type: none"> <li>Methane concentration decreases from the deep to the shallow aquifer</li> </ul>
75070	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Newlingrook GMA. Closest bore monitoring the Dilwyn Formation to the prospectivity area.</li> <li>No nested sites to present alternative option.</li> </ul>	<ul style="list-style-type: none"> <li>The Dilwyn Formation in the Newlingrook GMA does not contain methane, TRH or BTEX.</li> </ul>
114169	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Gellibrand GMU.</li> <li>No nested sites to present alternative option.</li> </ul>	<ul style="list-style-type: none"> <li>The Dilwyn Formation in the Gellibrand GMU has low methane (equal to detection limit), no TRH or BTEX</li> </ul>
114167	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Monitors the target aquifer (Dilwyn Fmn) in the Gerangamete GMA</li> </ul>	<ul style="list-style-type: none"> <li>The Dilwyn Formation in the Gerangamete GMA does not contain methane, TRH or BTEX</li> </ul>

### 7.7 Mesozoic and Palaeozoic Bedrock (114)

A single bore was sampled for the Mesozoic and Palaeozoic Bedrock aquifer which forms the basement unit in the Otway region (Table 25). This bore resides away from any sub-regional natural gas prospectivity areas and is also shallow compared to the depths associated with likely natural gas occurrence (bore middle screen depth is 74 m below natural surface). There were no more suitable monitoring bores available for sampling.

The highest groundwater salinity in the region was recorded for this aquifer and groundwater is classified as saline. Total Nitrogen concentration for this aquifer is 1.2 mg/L and groundwater is approximately neutral in terms of pH (7.2). An odour indicative of hydrogen sulfide gas was noted at this bore. A negative redox potential was noted for this aquifer, indicating reducing groundwater conditions.

A low concentration of dissolved methane was detected (0.4 mg/L) but no TPH (including BTEX).

**Table 25 Mesozoic and Palaeozoic Bedrock**

Bore	Aquifer Monitored	Justification for inclusion in the monitoring network	Comment
69455	Mesozoic and Palaeozoic Bedrock (114)	<ul style="list-style-type: none"> <li>Only SOB available that monitors the Mesozoic Palaeozoic bedrock</li> </ul>	<ul style="list-style-type: none"> <li>Low methane detected and no TPH (including BTEX)</li> <li>Saline groundwater</li> </ul>

## 8 Conclusions

Dissolved methane in groundwater occurs naturally at low concentrations across the Otway region. The median concentration from the 30 samples collected was 0.01 mg/L. A single outlier was observed for bore 111786, which indicated dissolved methane in the Lower Tertiary Aquifer of 5.8 mg/L and is the only bore sampled in the Otway region with methane concentrations of collected gas samples above detection.

Total Recoverable Hydrocarbons were also detected in 5 of the 30 samples, although most detections were low (equal to the detection limit) and the detections were not in the fraction range for BTEX. The lack of BTEX detection suggests that BTEX compounds are not a natural occurrence in any of the sampled aquifers and any future detection is likely to reflect an anthropogenic origin.

The role of aquitards in limiting the vertical movement of hydrocarbons through the vertical profile is currently difficult to ascertain in the Otway region, given the inherent low concentrations of methane in groundwater across all aquifers. The only elevated methane concentration was recorded for the Lower Tertiary Aquifer (5.8 mg/L) and this bore is located north-east of Colac and is nested with bore 111787 which screens the Newer Volcanic Basalt and did not record any methane in its groundwater. In this area the combined thickness of the Upper and Lower Mid Tertiary Aquitard is approximately 450 m. In this area it can be tentatively concluded that vertical hydrocarbon migration is reduced where a significant aquitard thickness exists. This is consistent with the conceptual hydrogeological model for the Otway region.

It should be noted that whilst the primary prospective formations for potential oil and gas deposits reside in the deep Eumeralla Formation, Waarre Formation and Casterton Formation, only one groundwater bore was available for sampling these units and it was located away from likely prospective areas and the bore was quite shallow. Although the groundwater chemistry information associated with the units that contain the Natural Gas prospectivity is limited, the negligible methane concentration observed in the overlying units is an important piece of information for the conceptual hydrogeological model for the Otway region. This information implies that the vertical hydraulic conductivity of the Mesozoic and Palaeozoic fractured rock is low and that there is little opportunity for gas migration to shallower overlying units.

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# Appendices

Appendix A. Standard operating procedure for groundwater sampling in the Otway region



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## HYDROTERRA STANDARD OPERATING PROCEDURE FOR GROUNDWATER SAMPLING

Revision 0

**15 May 2015**



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Reviewer: RSC



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## STANDARD OPERATING PROCEDURE P00228 FOR GROUNDWATER SAMPLING

### Section 1 Introduction

#### 1.1 Purpose

The purpose of this Standard Operating Procedure (SOP) is to provide sufficient guidance to detail the procedures and requirements for assessing groundwater level and the collection of groundwater samples from bores within a monitoring program.

In general, the groundwater sampling procedure can be subdivided into the following activities:

- (i) Field preparation;
- (ii) Purging;
- (iii) Sampling;
- (iv) Quality Assurance/Quality Control; and
- (v) Sample Shipment.

#### 1.2 Scope

This SOP applies to groundwater purging, sampling and manual water level monitoring activities undertaken by HydroTerra personnel. It is intended that this document guides personnel in the development of groundwater sampling methods and provides information on the general principles involved in the collection of physical and chemical parameters of groundwater samples from groundwater wells and bores using either low flow or purge methods. An overview of the different types of samples and field parameters that are commonly monitored is included in addition to the methodology employed in their measurement, collection, preservation, and transport.

#### 1.3 References

- EPA Guidelines: Regulatory monitoring and testing; Groundwater Testing (SA EPA 2)
- Groundwater Sampling and Analysis – A Field Guide (Geoscience Australia 2009)
- AS/NZS 5667.11: Water quality – sampling – guidance on sampling of groundwater
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### 1.4 Related Procedures

- Health and Safety Environmental Plan (HASEP)
- Job Safety Analysis (JSA)
- Technical Work Instructions (TWIs)

### 1.4 Groundwater Sampling Overview

Groundwater sampling relates to the purging and subsequent collection of groundwater from monitoring wells for laboratory analysis. Sampling may be by one of or a combination of the following methods:

- Low flow – pneumatic bladder pump or Double Valve Pump; and
- Purged sampling – electrical submersible pump.

The method used will be selected in the field based on bore specific details including – construction, condition, depth to groundwater, analytes to be tested, water column present and groundwater inflow rates.

Each groundwater bore will be dipped and groundwater depth recorded. The bore will be sampled by a low flow method (Bladder pump) or a purging method (Monsoon Pump or Bailers) if required.

During both purge and low flow sampling method, physical water quality parameters will be recorded using a calibrated water quality meter. Parameters to be measured include Electrical Conductivity (EC), pH, Dissolved oxygen (DO), temperature and redox potential (ORP).

Once groundwater physical parameters have stabilised samples will be taken in the required laboratory supplied bottles and dispatched to a NATA accredited laboratory.

### 1.6 Personal Qualifications

The minimum competencies required to undertake groundwater gauging and sampling activities are listed below:

- In house training by suitably qualified personnel with experience in groundwater sampling and monitoring events;
- Having read and understand the procedures within this SOP and the associated Technical Work Instructions (TWI) and Health, Safety and Environment Plan (HASEP);
- Site Specific Induction if required.

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### 1.7 Documentation

Documentation shall include specifics of field instrument calibration, water-level measurements, purge operations, and sample collection and processing (including QA/QC procedures). All field observations and any deviations from this sampling procedure should be documented by the field personnel using the standard field-data forms provided with this SOP (**see Appendices**). These Templates may be completed electronically in the field or using the iPads or on a physical hard copy.

### 1.7 Responsibility of Personnel

Table 1 Responsibility of Personnel

Personnel	Responsibility
HydroTerra Project Manager	<p>To review the SOP with project staff and finalise that the hazards associated with the proposed works have been identified either in the SOP or the Accompanying HASEP or work plan and that adequate controls have been proposed to enable the works to be undertaken safely;</p> <p>To ensure that the field personnel possess sufficient training and understand the work procedures required to undertake the works; and</p> <p>To ensure that the field staff assigned to conduct the proposed works have received the required health and safety training.</p>
HydroTerra Field Personnel	<p>To follow this procedure and other relevant documents for the proposed works;</p> <p>To ensure works are completed in a safe and competent manner; and</p> <p>To ensure that the proposed area of works is cleared for access and safe to undertake the proposed works.</p>

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### Section 2 Equipment

#### 2.1 General Equipment Overview

Use only specified equipment, including sample containers and other sampling equipment. In particular, laboratory supplied containers must be used as specified: the use of alternative sample containers or sampling methods will make the sample unusable and the laboratory may reject incorrect samples.

Things to be aware of:

1. Care needs to be taken with selection of low flow tubing. LDPE should always be food grade as inferior products can cause cross contamination.
2. Read Technical Work Instructions pertaining to groundwater sampling methods. Specifically low flow pneumatic pumps cannot operate if the Standing Water Level (SWL) is greater than 150m below top of casing (TOC).
- 3.

#### 2.2 Equipment Cleaning/Decontamination

Ensure that sampling equipment is clean and is maintained in good working order before use and at the end of sampling. It's essential that we clean the probes with demineralised water after each use (each sample location), prior to mobilising into the field and once field works are complete. This is especially true if a site is known to be contaminated (e.g. if the site smells strongly of hydrocarbons, sewage or something else); in this instance the sampling equipment must be thoroughly cleaned and rinsed prior to sampling at the next site; or ideally leave that site until the end of the sampling run in order to avoid cross contamination with subsequent samples. Keep some spare deionised/distilled/filtered water for this purpose. Equipment must be cleaned periodically to prevent a build-up of dirt. To do this:

- 1) Rinse the equipment well in tap water;
- 2) Clean with Quantum Clean;
- 3) Rinse well with tap water;
- 4) Rinse three times with de-ionised water; and
- 5) Allow to dry.

#### 2.3 Equipment List

Table 2 HydroTerra List of Groundwater Sampling related Items

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<p><b>General Items:</b></p> <ul style="list-style-type: none"> <li>• Field Clip board</li> <li>• Pencils, Pens and other stationary needed</li> <li>• Knife/ Scissors</li> <li>• Keys – for well cover and any site keys</li> <li>• Camera</li> <li>• Garbage Bags</li> <li>• Allen Key Set</li> <li>• Screwdriver</li> </ul>	<p><b>Reference Documents</b></p> <ul style="list-style-type: none"> <li>• Health, Safety and Environmental Protection Plan (HSEP Plan)</li> <li>• Safe Work Method Statement (SWMS)</li> <li>• Field Work Instructions</li> <li>• Site map and any additional site specific information documents</li> </ul>
<p><b>Personal Protective Equipment:</b></p> <ul style="list-style-type: none"> <li>• Steel Capped Boots</li> <li>• Long Sleeve Shirt</li> <li>• Long Pants</li> <li>• Hard Hat with Sunshade</li> <li>• Nitrile Gloves</li> <li>• Drinking Water</li> <li>• Sunscreen</li> <li>• Mobile Phone</li> <li>• Barricades (if needed)</li> </ul>	<p><b>Sampling Equipment:</b></p> <ul style="list-style-type: none"> <li>• Water Level Meter/Interface Meter</li> <li>• Low Flow Solinst Pump Controller with hoses</li> <li>• Low Flow Pump unit</li> <li>• Compressor or Gas bottle with regulator</li> <li>• 10L measuring bucket</li> <li>• YSI Water Quality Meter</li> <li>• Flow Cell</li> <li>• Filter unit and hand pump (if needed)</li> <li>• Bailers and bailer cord</li> <li>• Laboratory Prepared Bottles</li> <li>• Low Flow Tubing</li> </ul>
<p><b>Decontamination Equipment:</b></p> <ul style="list-style-type: none"> <li>• Quantum Clean</li> <li>• 3 large buckets for washing equipment</li> <li>• Scrubbing Brush</li> <li>• Paper Towel</li> </ul>	<p><b>Sample Shipment</b></p> <ul style="list-style-type: none"> <li>• Chain of Custody Form</li> <li>• Esky with Ice Bricks or Ice</li> <li>• Packing Materials</li> </ul>

## 2.4 Equipment Calibration

Ensure all field measurement instruments are fully calibrated before starting sampling (pre-field) and again once all sampling has been completed (post-field). The results and time/date of the calibration should be recorded on the HydroTerra Field Calibration Sheets.

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### Section 3 Purging and Sampling

#### 3.1 Purging

In most groundwater monitoring wells there is a column of stagnant water that remains within the well casing between the sampling rounds. This stagnant water is generally not representative of formation water as it no longer part of the aquifer flow and may be in contact with the air which can cause chemical changes to the water. This stagnant water can have different parameters to those in the surrounding aquifer. Purging is the process in which this stagnant water is removed from a well before sampling occurs to ensure minimal disturbance to the groundwater flow regime.

There are generally two main methods accepted for purging:

- Removal of three well volumes of groundwater until chemical equilibrium is reached
- Low flow purging until chemical equilibrium is reached

The choice of purging method will be determined on a case by case basis and depends on aquifer parameters and analytes of concern.

#### 3.2 Sampling Methodology

The following procedure is to be undertaken after arrival at a chosen groundwater monitoring bore. Additionally, confirmation of the groundwater bore with the use of figures, markings at the bore location or with GPS coordinates should be undertaken before proceeding with works.

##### 3.2.1 Pre-start Checks

1. Daily vehicle pre-start checks are to be undertaken prior to departing for site, pre-start checks are to ensure that the vehicle is fit for use. Inspection should be undertaken as per Vehicle Pre-start Checklist and filed accordingly (**See Appendix B**);
2. Inspection of equipment and consumables is to be undertaken prior to mobilising to the field in order to ensure that equipment is in good working order and that sufficient consumables (e.g. sampling bottles, bailers, tubing) area available for works;
3. Personnel are to conduct a prestart meeting prior to commencing works each day to confirm work plan for the day, to discuss the hazards and mitigation measures associated with tasks to be conducted, to alert personnel to any changes in conditions and to alert all personnel to any previously unidentified hazards. Additional tailgate/toolbox meetings will be conducted should conditions (weather, task environment) change during the task. Topic discussed and any decisions made will be documented in field record sheets and on appropriate safety documents; and
4. At each location the field staff will check for biological hazards around or in the well monument (e.g. snakes, spiders, wasps).

##### 3.2.2 Set Up

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1. Ensure that the sampling area is as clean as possible. Aim to park the field vehicle next to the well and if necessary place a drop sheet of plastic next to well to ensure equipment is kept clean.
2. Decontaminate all reusable equipment following the procedure set out in Section 2.2

### 3.2.3 Site Photographs

1. It is important to take photos of the site that you are sampling. Best practice includes any photos relevant to the sample site (e.g. outlet pipes, nearby roads, overhanging vegetation, woody debris in water etc). Also note any observations such as evident disturbance by fauna, level of degradation or erosion, any strong odours, any obvious oily films or discolorations). Etc.

### 3.2.4 Gauging the Standing Water Level (SWL) and the Water Column

1. Inspect monument/headworks and take note of any damage, prior to gaining access to bore;
2. Inspect well and take note of general bore condition. Remove cap and place it in a secure location;
3. Using a calibrated dip tape, measure the standing water level (SWL) by lowering the dip tape into the well. Once contact is made with water and either the buzzer and/or light are activated record the SWL directly from the tape at both the top of casing and at ground level;
4. After the SWL has been recorded proceed to measure the total depth of the well by lowering the dip meter until it reaches the bottom of the well (slackening of the tape will be a general indicator of this). Record the total depth of the well directly from the tape at both the top of casing and at ground level;
5. Once measurements have been recorded on a HydroTerra groundwater field sheet reel in the dip tape;
6. Decontaminate the dip tape using a phosphate free laboratory detergent (e.g. Decon 90) and then rinse with potable water and allow to dry; and
7. If no further works are to be undertaken at the bore return cap to well, ensuring that it is the bore is left in the same of better condition than the condition in which it was found.

### 3.2.5 Groundwater Sampling Procedure

1. General Field observations and results from groundwater gauging will be used to determine the appropriate sampling method in consultation with a senior hydrogeologist and the project manager. Low Flow sampling– pneumatic bladder pump
2. Ensure the pump has been decontaminated and that a fresh bladder has been installed within the pump intake;
3. Using the information gained in section 3.2.4 coupled with bore construction details select a pump intake depth which is within the screened section of the bore;

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4. Lower the pump to the designated depth with the bore. This can be achieved either in situ with the use of a dip tape, or by measuring the tubing prior to lowering the pump into the well;
5. Select a pump rate at a level which limits drawdown. To establish that minimum drawdown or that no draw down is occurring continually dip the bore with a dip tape recording the levels. If the drawdown rate does not stabilise, seek advice from a senior hydrogeologist and consider implementing purged sampling method;
6. Pumped water should be collected into a graduated bucket such that the volume purged may be recorded;
7. Set up WQM with flow cell such that field parameters may be continually monitored during pumping;
8. Continually monitor physical parameters (pH, temperature, redox, electronic conductivity and dissolved oxygen) while purging until such time as the temperature, pH and electronic conductivity stabilise. Stabilisation is considered to be when 3 consecutive readings are within 10%;
9. Once parameters have stabilised record the data on a HydroTerra groundwater field sheet and collect sample from a point in the sampling system as close to the pump as possible. If samples are to be analysed for dissolved metals samples should be filtered using an in line 0.45micron disposable filter;
10. Remove the pump from the well once the sample has been collected, remove the used bladder and decontaminate the pump using a phosphate free laboratory detergent (e.g. Decon 90). Allow the pump to then dry and install a fresh bladder for the next use; and
11. If no further works are to be undertaken at the bore return cap to well, ensuring that it is the bore is left in the same of better condition than the condition in which it was found.

### 3.2.6 Collection and Field Storage of Groundwater Samples

1. Put on a fresh pair of nitrile gloves before the commencement of the sampling procedure
2. Label the sample containers with waterproof marking pen as follows:
  - HydroTerra Job Number
  - Sample ID
  - Date
  - Initials of Sample Collector
3. Take care when handling bottles to avoid touching the inside of lid and container
4. Detach sampling tubing from flow cell and allow discharge to flow directly from sampling tubing into sample container. Ensure that flow rate during the sampling is equal to or less than the flow rate during pumping
5. Fill appropriate sample bottles provided by laboratory take care to ensure that any bottles that have a preservative in them are not flushed out or overfilled
6. For samples that require filtering, allow groundwater to discharge directly into disposable filter unit and filter the sample using hand pump and then decant filtered liquid into appropriate sample containers.
7. Place all labelled sample bottles securely into a chilled esky. Take care to avoid any breaking of small vials.

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### Section 4 Quality Assurance/Quality Control

The QA/QC program will be detailed in the site specific groundwater sampling program. The following table provides a summary of the QC samples that should be taken.

Table 3 Field QA/QC summary table

Field Duplicate or Intra-Laboratory Duplicate	
Purpose	To assess precision of sampling and analysis procedure
Characteristics	An homogeneous sample split in the field and analysed anonymously by the primary laboratory
Provides a measure of	Combined field and laboratory precision
Frequency	Generally 10% (5% stated in NEPM) - mandatory
Reported as	Concentrations for each target analyte and assessed by reference to % RPDs
Accepted Limits	Generally <20 to 30% when concentrations >20 LOR NOTE: May be higher close to MDLs, eg <50% may be acceptable where the concentration is >10 LOR; but no limit may be acceptable where concentrations are <10 LOR
Field Triplicate or Inter-Laboratory Duplicate	
Purpose	To assess precision of sampling and analysis procedure
Characteristics	An homogeneous sample split in the field and analysed anonymously by both the primary and secondary laboratory
Provides a measure of	Combined field and laboratory precision and an indicator of accuracy
Frequency	Generally 5% - mandatory
Reported as	Concentrations for each target analyte and assessed by reference to % RPDs
Accepted Limits	Generally <20 to 30% when concentrations >20 LOR NOTE: May be higher close to MDLs, eg <50% may be acceptable where the concentration is >10 LOR; but no limit may be acceptable where concentrations are <10 LOR
Field Blanks	
Purpose	To assess potential introduction of contaminants whilst sampling
Characteristics	Taking a simulated sample to the site and handling it in the same manner as environmental samples
Provides a measure of	Contaminants that may have been introduced during the sampling program
Frequency	Generally 1 per sampling event or day
Reported as	Concentrations for each target analyte
Accepted Limits	Non-detects for critical chemicals of potential concern
Equipment Blanks or Rinsate Blanks	
Purpose	To assess potential introduction of contaminants whilst sampling
Characteristics	Water or solvent passed over or through sampling equipment after cleaning
Provides a measure of	Contaminants that may have been introduced during the sampling program
Frequency	Generally 1 per sampling event or day

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Reported as	Concentrations for each target analyte
Accepted Limits	Non-detects for critical chemicals of potential concern
<b>Trip Blanks</b>	
Purpose	To assess potential introduction of contaminants after samples have been collected and during storage and transport to the laboratory
Characteristics	Similar to samples to be analysed (eg. Distilled, deionised water for groundwater sampling programs)
Provides a measure of	Contaminants that may have been introduced during the storage and transport of samples
Frequency	Generally 1 per sampling event or day
Reported as	Concentrations for each target analyte
Accepted Limits	Non-detects for critical chemicals of potential concern

NOTES: LOR – Level of reporting (EQL, PQL) The concentration that can be quantified above which the results have >95% confidence. The LOR is required to be significantly greater than the site criteria adopted for each chemical of potential concern  
MDL – Method detection level (limit of detection). The lowest concentration that a method can detect. Cannot be quantified, however.  
PQL – Practical Quantitation level (LOR, EQL)  
EQL – Estimated Quantitation level (LOR, PQL)

Author: DC 13 <sup>th</sup> September 2013
Reviewer: RSC

STANDARD OPERATING PROCEDURE P00228 FOR GROUNDWATER SAMPLING



Revision 0  
6 September 2013

## STANDARD OPERATING PROCEDURE P00228 FOR GROUNDWATER SAMPLING

### Section 5 Sample Shipment

#### 5.1 Laboratories

While the rest of this document gives detailed standard operating procedures for collecting, handling and storing samples, there are subtle differences between different laboratories; for example, different laboratories may require different sample volumes for the same chemical measurement. When developing a program it is essential that the analytical laboratory is consulted regarding all aspects of sample handling and storage (e.g. sample volume, container type and even use of preservatives). Because of the difference in the analytical techniques used by different laboratories, it is also very important that a laboratory that is both accredited by the National Association of Testing Authorities (NATA) and that has also been independently audited by DEHP.

The choice of lab will depend on the location of the sample site, type of analysis required, client preference and availability of couriers. However, generally HydroTerra's preferred Labs are:

- Envirolab Services ([www.envirolabservices.com.au](http://www.envirolabservices.com.au)).
- ALS Laboratory Group ([www.alsglobal.com](http://www.alsglobal.com)).

Sample containers will be provided by the analytical laboratory. These bottles should have a label on them which indicates what parameters will be analysed from each bottle and if there are any preservatives in each bottle.

#### 5.2 Holding Times

Holding times for most analytes will range from 24 hours to 28 days. However many key parameters have a holding time of 24 hours which should be taken into consideration when planning a groundwater sampling program. Table 4 below provides a summary of Holding times for common parameters analysed during groundwater sampling programs

Table 4 Holding Times for Parameters Commonly Analysed in Groundwater

24 Hours	7 Days	28 Days
TDS	Ions	Metals
TKN	COD	
BOD	TOC	
Cyanide	MAHs	
Ammonia	OCPs	
Nitrate	OPPp	
Hydrocarbons	PCPs	
Chromium VI	PAHs	

Author: DC 13<sup>th</sup> September 2013

Reviewer: RSC

STANDARD OPERATING PROCEDURE P00228 FOR GROUNDWATER SAMPLING

Appendix B. Standard operating procedure for collection of dissolved gas and groundwater samples from coal seams



Technical Work Instruction T0230

## **Technical Work Instruction (T0230)** **Collection of Dissolved Gas and Groundwater Samples from Coal Seam**

### **1.0 Purpose**

The purpose of this Technical Work Instruction is to describe a two phase (gas/liquid) sampling technique for the collection of dissolved gas and groundwater samples from monitoring wells installed between 300m to a maximum depth of 1200m Below Ground Surface (BGS) in sedimentary aquifers containing coal horizons.

A two phase (gas/liquid) sampling procedure is proposed to quantify the portion of dissolved gas evolving into the gas phase due to the drop in pressure between the aquifer and the surface.

### **2.0 Scope**

This Technical work Instruction is applicable to the collection of representative dissolved gas and groundwater samples from a coal bearing aquifer.

The samples collected will be analysed according to the plan outlined below:

#### **2.1 Field parameters**

pH, Electrical Conductivity (EC), Dissolved Oxygen (DO), Redox potential and Temperature

#### **2.2 Groundwater samples**

Groundwater samples will be collected and analysed for:

- Total dissolved solids;
- Major cations (Ca, Na, K, Mg);
- Major anions (Cl, SO<sub>4</sub>, Alkalinity);
- BTEX (benzene, toluene, ethylbenzene and xylene);
- Dissolved methane; propane, ethane;
- Dissolved gases (CO<sub>2</sub>, CH<sub>4</sub>, He, Ar, Ne);
- Isotopes of water (H & O);
- Radio Carbon 14C;
- Isotopes methane (C and H); and
- Isotopes of dissolved inorganic carbon.

#### **2.3 Gas samples**

Gas samples will be collected and analysed for:

- Isotopes methane (C and H);
- CO<sub>2</sub>, CH<sub>4</sub>, He, Ar, Ne; and
- BTEX





## Technical Work Instruction T0230

### 3.0 Equipment and Materials

The proposed sampling set-up is shown in Figure 1 “Gas Water Collection System” and it comprises of three main sampling points:

- Flow-through cell and multi-parameter water quality meter;
- Groundwater samples collection T- valve; and
- Gas samples collection including a Gas/water separator connected to a summa canister (3.2-6 L).

Additional parts include:

- Quick Connects;
- Sufficient 1/4 inch Teflon (or Polypropylene coated with Teflon) tubing of appropriate length to be dedicated to each bore;
- T-valve no. 1 located immediately upstream of the flowthrough cell to divert the groundwater sample from the low-flow system to the flow -through cell;
- T-valve no2 to divert the groundwater sample to the water sampling out-flow point;
- Lockable valve no.1 and no.2;
- Manometers (installed at the summa canister and at the Gas/Water separator);
- 2X 1/4 inch swagelocks to connect the in-flow and out-flow tubes to the gas/water separator vessel;
- 1X 1/4 inch swagelocks to connect gas outflow to the summa canister in-let; and
- 1X 1/4 inch swagelocks to connect summa canister in-let to gas outflow.

Water sample containers:

- 2 x 40ml Amber vials with sulfuric acid preservative with polytetrafluoroethylene (PTFE)-lined septa lids for dissolved gas analysis;
- 1 x 250ml plastic bottle with no preservative for major cations (Ca, Na, K, Mg) and major anions (Cl, SO<sub>4</sub>, Alkalinity);
- Isoflasks; and
- 1 x 500ml plastic bottles no preservative for total dissolved solids, Isotopes of water (H & O); Radio Carbon 14C and Isotopes of dissolved inorganic carbon.

Gas sample containers:

- Summa canisters;
- Isoflasks; and
- Tedlar bags.

Additional instruments include:

- Electronic water level meter;
- GA5000 Gas analyser fitted with PTFE pre-filter and bump tested prior to use;
- Picarro isotope analyser; and
- Hand held pump.

PPE

- Personal gas monitor bump tested prior to use; and
- Gloves, long sleeve shirt, steel cap boots, long pants, sun glasses, protective sun-cream.



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## 4.0 Sampling methodology

### 4.1 Water-Level Measurement

The Water-level measurement is obtained by lowering the electronic water level detector into the well casing.

- Open the well head;
- In the case of using a non dedicated low flow pump, or when dedicating the pump for the first time, dip the well prior to installation of the pump
- Standing water level- Lower the electronic water level detector into the bore until it hits the water (when the probe is in contact with the water a signal is sent back to the reel. This activates a buzzer and a light);
- The standing water level is then determined by taking a reading directly from the tape, at the top of the bore casing.
- Total depth of the well- Lower the weight into the casing until it reaches the bottom of the hole – as this happens the tape will become slack;
- Install the dedicated pump;
- Lower the electronic water level detector into the well casing to measure water level drawdown during pumping;
- Water level drawdown should also be used as a guide to flow rate adjustment with the goal being minimal drawdown.

### 4.2 Low –flow line purging

The volume of water to be cleared before commencing field parameter measurements is calculated with the following equation:

$$V = 0.041 \times d^2 \times H$$

Where:

V = volume of water in the length of tube located between the pump and the sampling port (in gallons);

d = inside diameter of the tube (in inches);

H = length of tubing between the pump and sampling port (in feet);

(Note that a conversion to litres is:  $V/0.264 =$  volume in litres.)

### 4.3 Field parameters

The field parameters are collected using a flow-through cell and multi-parameter water quality meters.

- Adjust low-flow console dry/vent time (typical flow rates on the order of 0.1-0.5 L/min);
- When groundwater sample starts to flow into the sampling system, open T-valve no.1 to divert the sample to the flow -through cell;
- Monitor and record every 5 minutes the values of pH, EC, DO, ReDox and T;
- Monitor and record groundwater elevation;

#### 4.3.1 Performance criteria

The stabilisation of water quality parameters will be defined as no consistent increasing or decreasing trend among the previous five readings and/or changes among the previous three readings of no more than:

- $\pm 0.1$  unit for pH
- $\pm 3\%$  for EC (%)



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- $\pm 0.2$  °C for temperature
- $\pm 10$  mv for ReDox
- $\pm 5\%$  for dissolved oxygen (%)

An additional criterion for determination of stabilization is based on minimal water-level drawdown (ideally 0.1 m; however, for low flow aquifer this may not be practical to achieve).

### **4.4 Groundwater samples collection**

When the water quality parameters have stabilised and the water-level drawdown is negligible, the groundwater sample can be considered representative of aquifer conditions, it is the appropriate time to proceed with the collection of the groundwater samples:

- Close T-valve no.1 to divert the groundwater flow to T-valve no. 2;
- Open T-valve no. 2 to divert the sample to the sampling out-flow port;
- Prepare the appropriate sample containers, as described below:



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Analyte	Container	Sampling advise
Total dissolved solids	500mL plastic bottle with no preservative	
Major cations (Ca, Na, K, Mg)	250mL plastic bottle with acid preservative	
Major anions (Cl, SO <sub>4</sub> , Alkalinity)	250mL plastic bottle with no preservative	
BTEX (benzene, toluene, ethylbenzene and xylene) butane, ethane and propane.	40mL Amber vials with sulfuric acid preservative.	Quickly fill with gently flowing sample water and immediately cap the sample without air-bubble inclusion.
Dissolved gases (CO <sub>2</sub> , CH <sub>4</sub> ,)		A minimum of 2 vials are required for each sampling location.
Dissolved gases (He-4, Ar, Ne, Kr)	0.1L gas-tight copper tubes	The copper tubes will be crimped at surface.
Stable isotopes of water ( $\delta^{18}\text{O}$ , $\delta^2\text{H}$ )	0.25L HDPE bottle;	Cool storage; Filter your sample.
Radiocarbon ( <sup>14</sup> C)	1-2L (depending on alkalinity); HDPE or glass bottle;	Filter your sample.
Isotopes methane (C and H)	600ml Isoflask bags with bactericide	Quickly fill with gently flowing sample water and immediately cap the sample.
Isotopes of dissolved inorganic carbon	0.125L HDPE bottle;	Cool storage; Filter your sample.
CO <sub>2</sub> and alkalinity titrations on site	250mL using appropriate kit	

- Label samples with date, monitoring location and project reference;
- Place sample containers in an esky filled with ice to keep the temperature around 4 ° C.

### 4.5 Gas samples collection

When all the groundwater samples containers required for the analysis are filled, it is the appropriate time to proceed with the collection of the gas samples:

#### 4.5.1 Summa Canister

- Before connecting the summa canister to the gas/water separator vessel check the pressure on the pressure gauge (pressure should be approximately -30" Hg) and record these data;
- If vacuum is less than -20"Hg, canister is not valid for analysis;
- Open On/off valve no.1 and no.2;
- Open T-valve no.2 to divert the groundwater sample to the gas/water separator vessel;
- Close On/off valve no.2 to start collecting the groundwater sample into the gas/water separator vessel;
- When the water level in the gas/water separator vessel is 1L close On/off valve no. 1;
- Activate sparging line of N<sub>2</sub> at a flow rate of 0.1 to 0.3 v/v for 3 s to strip the residual dissolved gas from the groundwater sample;
- Switch gas analyser (GA5000) on and proceed with the bump test;
- Record the bump test output;
- Record methane reading on the gas analyser;
- Switch the gas analyser off;
- Attach ¼ " sample line to the gas/water separator sampling point using a Quick Connect valve;
- Connect this sampling line to the Summa canister swagelok valve;



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- Purge the sampling line using a hand held pump. Sampling line should be purged by connecting the pump to the sample line and drawing a volume equal to at least three times the volume of the sample line;
- Open the summa canister main valve to start collecting the gas sample. Over the sampling period, the differential pressure showed in the Summa canister pressure gauge will decrease.
- Record canister vacuum after sampling. The final pressure should be between -5"Hg and 0 but in some cases it may not reach this value. A residual pressure above -10"Hg indicate sufficient sample for testing.
- Close the Summa canister main valve;
- Record sample start and stop time;
- Label samples with date, monitoring location and project reference; and
- Place summa canister in a box. Summa canisters do not require chilling.

### 4.5.2 Tedlar Bag

- Open Lockable valve no. 1 and no. 2;
- Open T-valve no. 2 to divert the groundwater sample to the gas/water separator vessel;
- Close Lockable valve no. 2 to start collecting the groundwater sample into the gas/water separator vessel;
- When the water level in the gas/water separator vessel is 1L close Lockable valve no. 1;
- Activate sparging line of N<sub>2</sub> at a flow rate of 0.1 to 0.3 v/v for 30 s to strip the residual dissolved gas from the groundwater sample;
- Switch gas analyser (GA5000) on and proceed with the bump test;
- Record the bump test output;
- Record methane reading on the gas analyser;
- Switch the gas analyser off;
- Attach ¼ " sample line to the gas/water separator sampling point using a Quick Connect valve;
- Connect this sampling line to the Tedlar bag in-let valve;
- Start to collect the gas sample using the hand held pump;
- Label samples with date, monitoring location and project reference; and
- Tedlar bag must be analysed within 24hours and/or in the field using the Picarro analyser.

## 5.0 Quality Assurance /Quality Control

### 5.1 Trip Blanks

A trip blank is a clean sample of a matrix that is taken from the laboratory to the sampling site and transported back to the laboratory without having been exposed to sampling Technical work Instructions. This sample needs to be analysed only for volatile compounds.

Purpose: Assess contamination introduced during shipping and field handling Technical work Instructions.

Frequency: 1 blank/chiller containing volatiles.

### 5.2 Field Blanks

A sample of analyte-free water poured into the container in the field, preserved and shipped to the laboratory with field samples.

Purpose: Assess contamination from field conditions during sampling.

Frequency: 1 blank/day

### 5.3 Equipment Blanks

This sample is collected by pouring over or running analyte-free water through the sample collection equipment after decontamination and before sample collection.



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Purpose: assess contamination from the total sampling, sample preparation and measurement process, when decontaminated sampling equipment is used to collect samples.  
Frequency: 1 blank/day.

### 5.4 *Field Duplicates*

Two or more samples collected at the same sampling location. Field replicates should be samples collected side by side or by collecting one sample and immediately collecting the second sample.  
Purpose: field replicates represent the precision of the whole method, site heterogeneity, field sampling and the laboratory analysis.  
Frequency: 1 sample/20 samples.

## 6.0 **Decontamination**

The equipment requiring decontamination is:

- the gas/water separator;
- the flow -through cell; and
- multi-parameter water quality meter.

The decontamination should take be undertaken at the beginning of each day of field work, between each boring and monitor point, at the end of each day of field work, and whenever the equipment is suspected of having been contaminated.

- Prepare a 2% to 5% solution of Decon 90 with water.
- Fully immerse the items to be cleaned.
- The cleaned items must be rinsed thoroughly with deionised water as soon as they are removed from the cleaning solution

## 7.0 **Health and safety considerations**

In the coal seam the gas is held in place by water pressure. As part of the extraction process for Coal Seam Gas (CSG), water is removed from the coal seams to facilitate the release of gas. When water is extracted from the well the groundwater level may decline in the surrounding area allowing gas to be more freely released from the coal. This may increase the chance of encountering gas when sampling coal seams.

CSG present in the formation can start to flow into the bore hole. This may result in what is commonly called a 'kick'. In this situation, if the down-hole fluids pressure is not controlled, a kick can quickly escalate into a 'blowout' where the gas reaches the surface. A 'blowout' can create a plume of gas that can be easily ignited. Depending on the force of the escaping gas, the equipment installed in the bore case can be ejected from the well casing increasing the risk of injury.

### 7.1 *Gas monitoring*

It is recommended the use a portable multi-gas detector on site. The detector should be, as a minimum, able to detect methane and hydrogen sulphide. Methane concentration can be displayed as parts per million (PPM), % of methane in air or % of low explosion limit (LEL) (or low flammability limit –LFL). Methane concentrations in air of between 50,000 and 150,000 ppm or between 5% and 15% are flammable. The table 1 below provides the conversion factors.



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**Table 1: Conversion factors for methane concentrations.**

Unit	Alarm setting limit	Low explosion limit	Upper explosion limit
PPM	2500	50,000	150,000
% in Air	0.25	5	15
% of LEL	5	50	-

## **7.2 Hazardous situations**

Continuous readings greater than 20% LFL on the personal gas detector may be indicative of a possible sustained gas leak and the potential for build-up of a flammable atmosphere.

- Stop any activity.
- Shut down all equipment (if safe to do so).
- Alert other people working or present in the immediate area.
- If the gas leak does not subside or is not contained, evacuate people to a safe area upwind of the operation area.
- Immediately establish an exclusion zone around the operation area.



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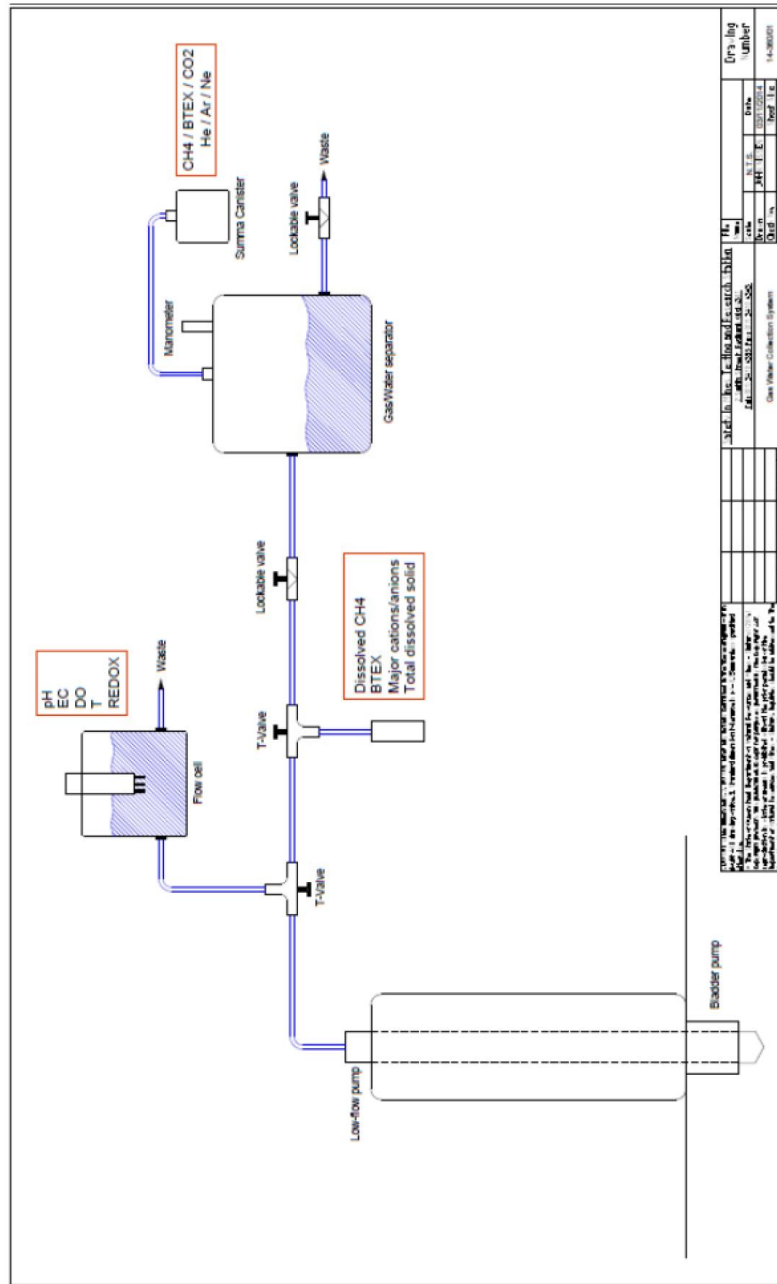


Figure 1 Gas Water Collection System

Technical Work Instruction (T0230) for Collection of Dissolved Gas and Groundwater from Coal Seam, V3



Appendix C. Standard operating procedure for the deployment and operation of double valve pumps



Technical Work Instruction T0229

## **Technical Work Instruction for Solinst 408 Double Valve Pump Deployment & Operation**

### **1.0 Purpose**

The purpose of this Technical Work Instruction (TWI) is to describe a groundwater sampling technique for the collection of groundwater samples from monitoring wells using a pneumatically driven Solinst 408 Double Valve Pump. The document discusses the use of both portable and dedicated systems.

### **2.0 Scope**

This Technical Work Instruction is applicable to the collection of low flow groundwater samples using a Solinst 408 Double Valve Pump.

#### **2.1 Operating Principles**

When the Solinst Double Valve Pump (DVP) is placed in a well or borehole, water rises inside the pump and the twin tubes to static level. A Control Unit is used to deliver compressed gas to the pump. During the drive period the gas pushes down on the water column contained in the drive line tubing, closing the check valve at the base of the pump. This forces water up the sample line tubing. A vent period, during which the gas is released, allows hydrostatic pressure to refill the pump and drive line with sample water. The top check valve prevents water in the sample line from falling back into the pump body. This pressurization and vent cycle is repeated manually or automatically as set by the timers on the Control Unit. The cycle may be regulated for purging or sampling.

#### **2.2 Groundwater Sampling Depth Considerations**

A Double Valve Pump allows water to flow into both the drive line and the vent line during deployment. The lift potential of the pump is limited, not by the deployment depth of the pump but by the standing water level. That is the lift required to top of casing from the SWL. The maximum lift for stainless steel (SS) 407 Double Valve Pumps is 500 ft. (150 m), and 100 ft. (30 m) for the PVC model.

The pressure required to lift the groundwater depends on the SWL and the length of the drive cycle. It is very important to note that when operating the pump DO NOT exceed an operating pressure of 250 psi for the SS model and 50 psi for the PVC model.

The maximum deployment depth is theoretically unlimited. Tubing becomes an important consideration, when deploying the pumps. It is possible to tangle the tubing around the pumps when deploying these in the field causing the hole to become permanently blocked. For this reason deploying of pumps is undertaken slowly using manual reels and wire line/tagline or Kevlar suspension line.

#### **2.3 Off Gassing Considerations**

Samples from a Double Valve Pump move to the surface along 1/4 inch or 3/8 inch tubing to the surface. As the samples move toward the surface the pressure reduces. In waters containing dissolved gasses this can cause bubbling to occur as the gases equilibrate to the lower pressure. The dissolved gas composition at the surface is potentially lower than the *insitu* gas composition. In order to estimate the *insitu* gas composition it is necessary to collect the gases rising to the surface. *TWI- Dissolved & Entrained Gas Sampling.- Bubbler*. Provides a methodology for collecting these gases.

#### **2.4 Tubing Considerations**



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### 3.0 Equipment and Materials

The 408 Double Valve Pump set-up is shown in Figure 1 which is comprised of the following main sampling components:

- Double Valve Pump;
- Tubing;
- Pneumatic controller and regulator;
- Compressed gas source;
- Deployment Reels;
- Airline & Sample Line Connectors.
- Water Level Meter

Additional parts include:

- Quick Connects;
- Sufficient 1/4 inch LDPE tubing to be dedicated to each bore;
- T-valve no. 1 located immediately upstream of the flowthrough cell to divert the groundwater sample from the low-flow system to the flow-through cell;

Note: in the case of dissolved gas sampling. Please see the HydroTerra Technical Work Instruction (T0230) for Collection of Dissolved Gas, Evolving Gas and Groundwater Samples.

PPE

- Personal gas monitor; and
- Gloves, long sleeve shirt, steel cap boots, long pants, sun glasses, protective sun-cream.

### 4.0 Methodology

#### 4.1 Pump Installation

There are two methods of operation Portable and Dedicated.

**Portable:** The Pump will be attached to skip-bonded, 1/4" and 3/8" OD LDPE tubing, mounted on a reel.

- a) Push the tubing inserts into the end of the tubing and into the drive and sample compression fittings of the DVP (the nuts of the compression fittings may have to be loosened before inserting the tubing). Tighten the nut 1-1/4 turns past finger tight for proper seal.
- b) Lower the assembled DVP into the well, using a stainless steel safety line. A Tag Line can be used for this purpose.
- c) Connect the supply line with the in-line dryer from the compressed gas source to the Control Unit. The drive line connects from the Control Unit to the reel.
- d) Attach 3/8"OD sample line to the flow cell.

**Dedicated:** The Pump will come with a roll of tubing to be cut to length, as required, for attachment to a Wellhead.

- a) Push the tubing inserts into the end of the tubing and into the drive and sample compression fittings of the DVP (the nuts of the compression fittings may have to be loosened before inserting the tubing). Tighten the nut 1-1/4 turns past finger tight for proper seal.
- b) Lower the DVP into the well, using a stainless steel or Kevlar safety line. Attach the safety line to the suspension hook on the underside of the Wellhead. Push the Wellhead firmly onto the riser casing.
- c) Where the riser casing is >50mm diameter, install the wellhead using the custom made flat HDPE extension plate. Trim the plate to size so that it fits within the outer, lockable cover.



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- d) For lowering the pump use two reels – 1 will hold the Kevlar suspension cord and 1 will hold the tubing. Allow the reels to unspool in a controlled manner using the winch handles on each reel.
- e) Attach the sample and drive lines to the appropriate Push Fittings on the underside of the Wellhead.
- f) Attach the Kevlar cord to an eyelet that has been bolted into the underside of the well cap assembly.

### 4.2 Methodology Pump Operation

The Model 464 Electronic Control Unit controls the supply of compressed gas to pneumatic pumps. Drive (pressure) and vent periods are cycled to provide water flow. During pressurization periods, water is forced into the sample tubing. The vent period allows water to re-enter (recharge) the pump. Cycle repetition may be controlled manually or automatically using pre-set pumping rates.

### 4.3 Sampling Setup (Dedicated Pumps)

1. Connect the drive line (included with the Control Unit) to the compressed gas supply regulator. Note: Do not turn the pressure on at this time. If pressure is applied, it will be difficult to insert the line to the regulator.
2. Turn on the compressed gas supply and set the regulator to supply no more than 125 psi to the control unit.
3. Connect the tubing to the control unit at the "Air In".
4. Adjust the control unit "Pressure Regulator" to the appropriate value [(depth below grade in feet to SWL x 0.43 psi/ft) + 10 psi].

### 4.4 Control Unit Operation Recommendations

For details on how to set up the Solinst Controller please see Solinst Publication: *Model 464 Electronic Pump Control Unit User Guide (Attachment A)*.

Selecting the desired flow rate: The flow rate must not cause appreciable draw down in the well.

For Guidance on sampling flow rate please see HydroTerra *STANDARD OPERATING PROCEDURE P00228 FOR GROUNDWATER SAMPLING and for Coal Seam Gas wells or wells with off gassing Technical Work Instruction (T0230) for Collection of Dissolved Gas, Evolving Gas and Groundwater Samples*.

Select and start your desired flow rate from the User Flow Rates menu on the Solinst 466 Controller. If a higher flow rate is required, stop the drive/vent cycle to allow editing of the set up. Slowly increase the drive time to increase the flow rate. If air is expelled, decrease the drive time. To further optimize the flow rate, increase or decrease the vent time until the highest flow rate is achieved. Once optimization has been done, remember to save the settings for subsequent sampling events.

Measure the rate of discharge into a graduated bucket or container to calculate volume of water purged from the system.

## 5.0 Quality Assurance /Quality Control

### 5.1 Pump Decontamination

Pump decontamination to be undertaken in accordance with *STANDARD OPERATING PROCEDURE P00228 FOR GROUNDWATER SAMPLING*. Reproduced below for purposes of clarity:

Ensure that sampling equipment is clean and is maintained in good working order before use and at the end of sampling. It's essential that we clean the pump with demineralised water after each use (each sample location), prior to mobilising into the field and once field works are complete.



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This is especially true if a site is known to be contaminated (e.g. if the site smells strongly of hydrocarbons, sewage or something else); in this instance the sampling equipment must be thoroughly cleaned and rinsed prior to sampling at the next site; or ideally leave that site until the end of the sampling run in order to avoid cross contamination with subsequent samples. Keep some spare deionised/distilled/filtered water for this purpose. Equipment must be cleaned periodically to prevent a build-up of dirt. To do this:

- 1) Rinse the equipment well in tap water;
- 2) Clean with Quantum Clean;
- 3) Rinse well with tap water;
- 4) Rinse three times with deionised water; and
- 5) Allow to dry.

### **5.2 Pump Disassembly**

1. Remove the Top Platen from the Pump Body and Riser. Remove the Pump Body from the Bottom Platen and slide it off the Riser.
2. Remove the Riser from the Valve Body, being careful not to lose the Check Ball.
3. Remove the Valve Body from the Bottom Platen, being sure not to lose the second Check Ball.
4. Remove the Filter Retainer from the Bottom Platen, and then remove the Filter Mesh from the Filter Retainer.

### **5.3 Pump Reassembly**

1. Slide the Filter Mesh over the Filter Retainer until seated.
2. Thread the Bottom Platen onto the Filter Retainer until the
3. O-ring is seated and the parts are finger tight.
4. Insert a Teflon® Check Ball into the top of the Bottom Platen.
5. Take the Valve Body and insert into the Bottom Platen until the O ring firmly seats.
6. Insert a Teflon Check Ball into the top of the Valve Body.
7. Insert the bottom end of the Riser (hole downward) into the Valve Body.
8. Slide the Pump Body over the Riser and thread onto the Bottom
9. Platen.
10. Take the Top Platen and while lining up the top of the Riser into the centre of the Top Platen, thread the Pump Body to the Top Platen.

### **5.4 Tubing Disposal**

Tubing disposal must be to a landfill approved to accept this material. Note: bio-degradable tubing can be used to provide a more sustainable solution. In no circumstance should tubing be used in one well and transferred to another well without thorough decontamination of the inside and outside of the tubing.

## **6.0 Health and Safety Considerations**

All groundwater sampling operations will need to be undertaken in accordance with STANDARD OPERATING PROCEDURE P00228 FOR GROUNDWATER SAMPLING. This includes the preparation of a site specific Health Safety Environment Plan (HSEP).

Additional Guidance on safely sampling for Coal Seam Gas wells or wells with off gassing Technical Work Instruction (T0230) for Collection of Dissolved Gas, Evolving Gas and Groundwater Samples.

### **6.1 Hazardous situations**

Continuous readings greater than 20% LFL on the personal gas detector may be indicative of a possible sustained gas leak and the potential for build-up of a flammable atmosphere.



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- Stop any activity.
- Shut down all equipment (if safe to do so).
- Alert other people working or present in the immediate area.
- If the gas leak does not subside or is not contained, evacuate people to a safe area upwind of the operation area.
- Immediately establish an exclusion zone around the operation area.

## 7.0 References

Reference 1.	Solinst Canada: Model 464 Electronic Pump Control Unit User Guide
Reference 2.	EPA Publication 669 <i>GROUNDWATER SAMPLING GUIDELINES</i> , April 2000, Environment Protection Authority (Victoria).
Reference 3.	<i>Geoscience Australia Groundwater Sampling and Analysis – A Field Guide</i> . Record 2009/27 95, 2009 .Sundaram, B., Feitz, A., Caritat, P. de, Plazinska, A., Brodie, R., Coram, J. and Ransley, T., 2009.
Reference 4.	Minimum standards for the construction and reconditioning of water bores that intersect the sediments of artesian basins in Queensland NRM (Natural Resource Mines & Water 2004).
Reference 5.	HydroTerra <i>STANDARD OPERATING PROCEDURE P00228 FOR GROUNDWATER SAMPLING</i>
Reference 6.	<i>Work Instruction (T0230) for Collection of Dissolved Gas, Evolving Gas and Groundwater Samples.</i>



Technical Work Instruction T0229

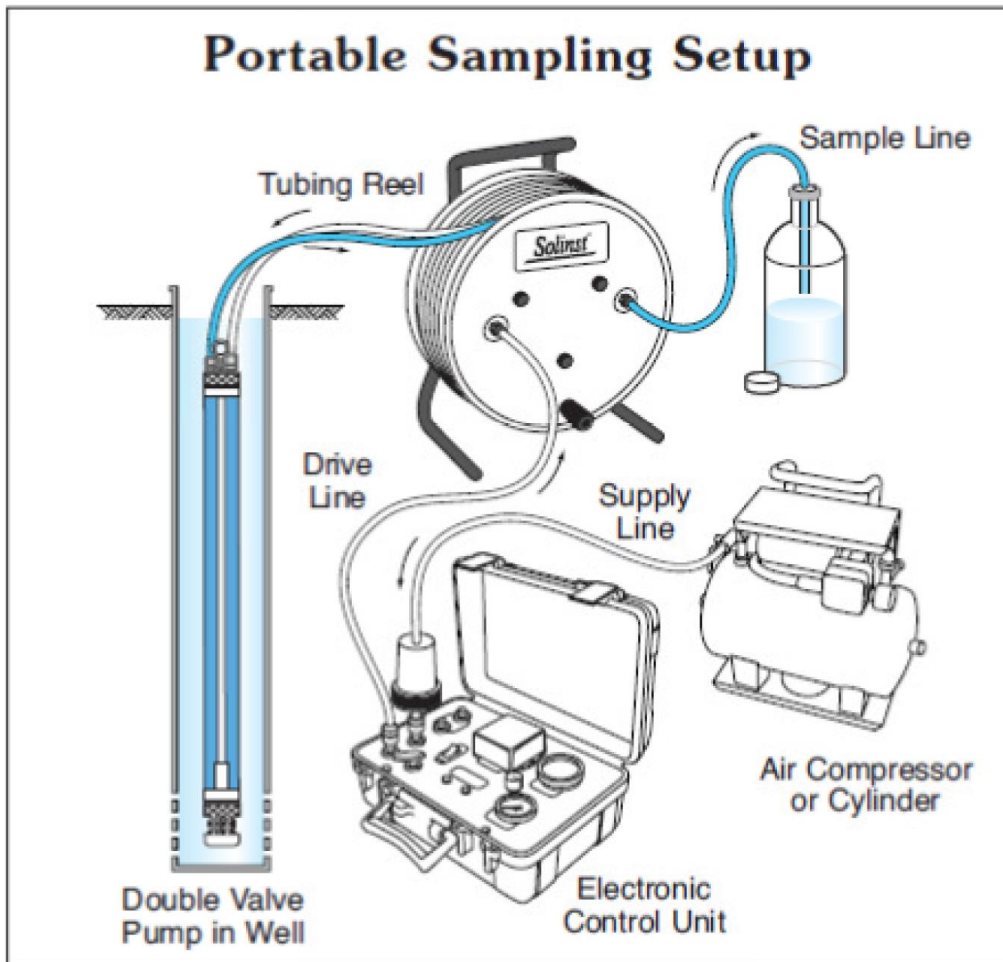


Figure 1 Portable Double Valve Pump Setup



Technical Work Instruction T0229

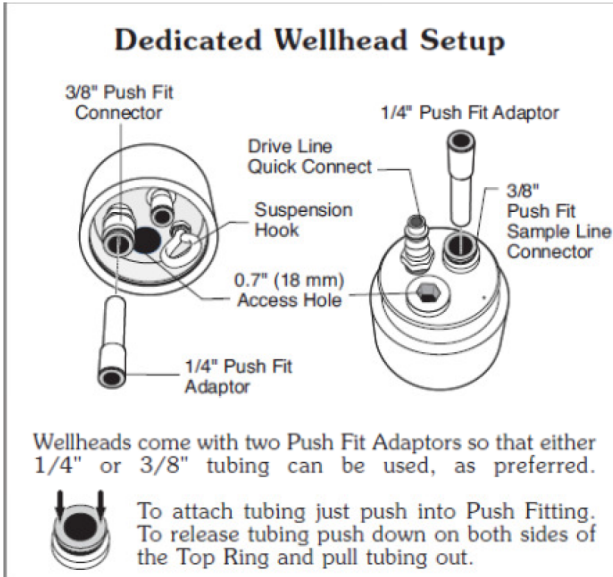


Figure 2 Dedicated Well Head Setup.





Technical Work Instruction T0229

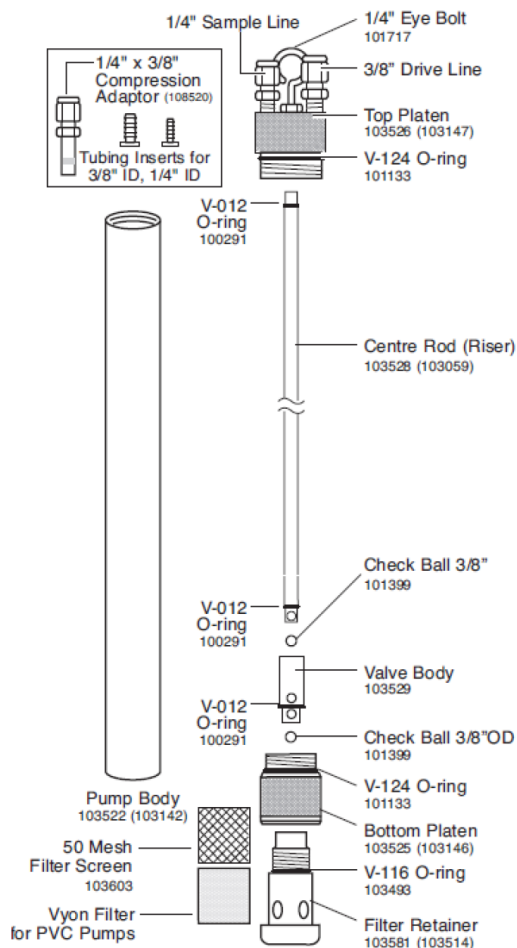
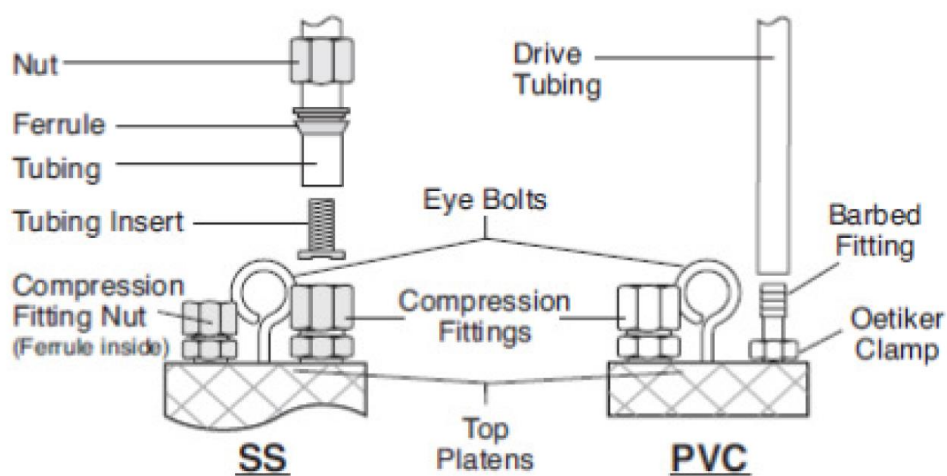


Figure 3 Double Valve Pump Components



Technical Work Instruction T0229

### Stainless Steel and PVC Tubing Connections



**Note:** Be careful not to lose the two pieces of the ferrule if loosening or removing the nut from the compression fitting.

Figure 4 Pump Tubing Connectors

## Appendix D. Laboratory Results

## Appendix D. Laboratory Results

		Bore ID	102621	110984	110985	111524	111525	111786	111787	113467	114167	114169	115872	122677	141241	141242	141307
		Sample Date	28/01/15	22/01/15	22/01/15	27/01/15	27/01/15	20/01/15	20/01/15	21/01/15	19/01/15	20/01/15	21/01/15	29/01/15	22/01/15	22/01/15	23/01/15
		Aquifer	107	104	101	107	101	111	101	111	111	111	111	109	107	107	101
		ChemName	Units	EQL													
TPH/TRH	C6 - C9	µg/L	20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
	C10 - C14	µg/L	50	<50	<50	<50	<50	<50	<50	<50	<50	<50	120	<50	<50	<50	<50
	C15 - C28	µg/L	100	<100	<100	<100	<100	380	<100	<100	<100	<100	240	<100	<100	<100	<100
	C29-C36	µg/L	50	<50	<50	80	<50	<50	60	<50	<50	<50	<50	<50	<50	<50	<50
	+C10 - C36 (Sum of total)	µg/L	50	<50	<50	80 - 155	<50	<50	440 - 465	<50	<50	<50	<50	360 - 385	<50	<50	<50
	C10 - C40 (Sum of total)	µg/L	100	<100	<100	100	<100	<100	380	<100	<100	<100	<100	370	<100	<100	<100
	C6-C10	mg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
	>C10-C16 Fraction	mg/L	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.26	<0.1	<0.1	<0.1
	>C10 - C16 Fraction minus Naphthalene	mg/L	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.26	<0.1	<0.1	<0.1
	>C16-C34 Fraction	mg/L	0.1	<0.1	<0.1	0.1	<0.1	<0.1	0.38	<0.1	<0.1	<0.1	<0.1	0.11	<0.1	<0.1	<0.1
>C34-C40 Fraction	mg/L	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	
C6-C10 less BTEX (F1)	mg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	
PAH	Naphthalene	µg/L	5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	
Semi Volatile Organic Compounds	Butane	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
	Butene	µg/L	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	
	Propane	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
	Propene	µg/L	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	
	Ethane	µg/L	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	
	Ethene	µg/L	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	
	Methane	mg/L	0.01	<0.01	<0.01	0.638	<0.01	0.067	5.75	<0.01	0.01	<0.01	0.014	0.043	<0.01	0.012	0.036
BTEX	Benzene	µg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	Ethylbenzene	µg/L	2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	
	Toluene	µg/L	2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	
	Xylene (m & p)	µg/L	2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	
	Xylene (o)	µg/L	2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	
	Xylene Total	µg/L	2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	
	Total BTEX	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Inorganics	Alkalinity (Bicarbonate as CaCO3)	mg/L	1	393	370	446	257	167	118	361	30	3	<1	176	293	307	222
	Alkalinity (Carbonate as CaCO3)	mg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Alkalinity (Hydroxide) as CaCO3	µg/L	1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
	Alkalinity (total) as CaCO3	mg/L	1	393	370	446	257	167	118	361	30	3	<1	176	293	307	222
	Chloride	mg/L	1	489	453	512	96	53	5950	1170	69	48	66	82	659	104	349
	Fluoride	mg/L	0.1	0.3	0.5	0.3	0.2	0.2	0.2	0.5	<0.1	<0.1	<0.1	<0.1	0.2	0.3	<0.1
	Sulphate (Filtered)	mg/L	1	47	43	48	17	11	<1	126	12	23	112	13	41	11	121
	Anions Total	meq/L	0.01	22.6	21.1	24.4	8.2	5.06	170	42.8	2.8	2.18	4.19	6.1	25.3	9.3	16.8
	Calcium (Filtered)	mg/L	1	135	61	74	8	4	24	26	4	<1	13	27	222	104	23
	Magnesium (Filtered)	mg/L	1	35	53	55	20	9	126	102	7	3	6	19	33	10	24
	Potassium (Filtered)	mg/L	1	6	4	3	4	3	574	14	4	<1	2	12	2	<1	<1
	Sodium (Filtered)	mg/L	1	255	296	342	142	101	3180	786	39	47	36	62	236	59	304
	Cations Total	meq/L	0.01	20.9	20.4	23.2	8.32	5.41	164	44.2	2.57	2.29	2.76	5.91	24.1	8.58	16.4
	Ionic Balance	%	0.01	4.05	1.66	2.5	0.73	3.29	1.69	1.58	4.13	2.29	20.6	1.55	2.38	3.99	1.4
	Kjeldahl Nitrogen Total	mg/L	0.1	0.8	0.4	2.6	0.1	0.2	3.8	0.1	0.2	0.5	<0.1	0.2	<0.1	<0.1	0.3
	Nitrogen (Total Oxidised)	mg/L	0.01	2.81	0.05	0.45	0.71	<0.01	0.03	0.67	<0.01	4.14	<0.01	0.01	0.7	<0.01	0.64
	Nitrogen (Total)	µg/L	100	3600	400	3000	800	200	3800	800	200	4600	<100	200	700	<100	900
TDS	mg/L	10	1290	1160	1390	568	337	9410	2600	253	241	479	617	2130	613	1060	

	Bore ID	141308	142660	54925	69455	75070	82347	83446	83447	83729	89040	S61557/1	S61557/2	S61557/3	S61557/4	S9037242/1		
	Sample Date	23/01/15	22/01/15	22/01/15	29/01/15	21/01/15	28/01/15	29/01/15	29/01/15	28/01/15	22/01/15	29/01/15	28/01/15	28/01/15	28/01/15	28/01/15	27/01/15	
	Aquifer	107	101	101	114	111	111	111	107	107	101	100	100	100	100	107		
	ChemName	Units	EQL															
TPH/TRH	C6 - C9	µg/L	20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	
	C10 - C14	µg/L	50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	
	C15 - C28	µg/L	100	<100	<100	<100	<100	<100	260	<100	<100	<100	<100	<100	<100	<100	<100	
	C29-C36	µg/L	50	<50	<50	<50	<50	<50	150	<50	<50	<50	<50	<50	<50	<50	<50	
	+C10 - C36 (Sum of total)	µg/L	50	<50	<50	<50	<50	<50	410 - 435	<50	<50	<50	<50	<50	<50	<50	<50	
	C10 - C40 (Sum of total)	µg/L	100	<100	<100	<100	<100	<100	400	<100	<100	<100	<100	<100	<100	<100	<100	
	C6-C10	mg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.02	<0.02	<0.02	
	>C10-C16 Fraction	mg/L	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	
	>C10 - C16 Fraction minus Naphthalene	mg/L	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	
	>C16-C34 Fraction	mg/L	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	
	>C34-C40 Fraction	mg/L	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	
	C6-C10 less BTEX (F1)	mg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.02	<0.02	<0.02	
PAH	Naphthalene	µg/L	5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5		
Semi Volatile Organic Compounds	Butane	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		
	Butene	µg/L	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10		
	Propane	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		
	Propene	µg/L	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10		
	Ethane	µg/L	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10		
	Ethene	µg/L	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10		
	Methane	mg/L	0.01	<0.01	<0.01	0.038	0.376	<0.01	0.133	0.155	0.016	<0.01	0.015	<0.01	<0.01	0.011		
BTEX	Benzene	µg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1			
	Ethylbenzene	µg/L	2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2			
	Toluene	µg/L	2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2			
	Xylene (m & p)	µg/L	2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2			
	Xylene (o)	µg/L	2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2			
	Xylene Total	µg/L	2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2			
	Total BTEX	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			
Inorganics	Alkalinity (Bicarbonate as CaCO3)	mg/L	1	269	217	46	127	<1	354	280	307	174	90	364	317	375	363	475
	Alkalinity (Carbonate as CaCO3)	mg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Alkalinity (Hydroxide) as CaCO3	µg/L	1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	
	Alkalinity (total) as CaCO3	mg/L	1	269	217	46	127	<1	354	280	307	174	90	364	317	375	363	475
	Chloride	mg/L	1	432	131	88	4270	202	221	224	336	154	32	216	487	795	401	419
	Fluoride	mg/L	0.1	0.1	0.3	<0.1	0.2	<0.1	1.1	0.1	0.1	0.5	0.2	0.7	0.2	0.3	0.1	0.6
	Sulphate (Filtered)	mg/L	1	19	18	5	200	34	27	6	23	82	7	28	32	38	64	46
	Anions Total	meq/L	0.01	18	8.41	3.51	127	6.41	13.9	12	16.1	9.53	2.85	14	20.7	30.7	19.9	22.3
	Calcium (Filtered)	mg/L	1	82	10	5	402	5	24	106	128	20	5	101	158	190	162	117
	Magnesium (Filtered)	mg/L	1	75	23	12	255	10	75	17	21	7	13	21	28	47	15	60
	Potassium (Filtered)	mg/L	1	4	4	1	18	9	40	2	2	<1	1	2	2	4	<1	8
	Sodium (Filtered)	mg/L	1	134	149	50	1650	104	119	113	155	193	34	148	208	355	199	231
	Cations Total	meq/L	0.01	16.2	8.98	3.44	113	5.83	13.6	11.6	14.9	9.97	2.82	13.3	19.3	28.9	18	21
	Ionic Balance	%	0.01	5.15	3.24	1	5.77	4.75	1.11	1.6	3.8	2.23	0.43	2.54	3.61	3.04	5.06	2.86
	Kjeldahl Nitrogen Total	mg/L	0.1	<0.1	0.8	<0.1	1.2	0.1	2.7	0.3	0.2	1	0.2	0.1	<0.1	<0.1	0.2	<0.1
	Nitrogen (Total Oxidised)	mg/L	0.01	<0.01	10.1	<0.01	<0.01	0.01	0.01	<0.01	<0.01	12	<0.01	1.32	0.04	0.17	<0.01	<0.01
	Nitrogen (Total)	µg/L	100	<100	10,900	<100	1200	100	2700	300	200	13,000	200	1400	<100	200	200	<100
TDS	mg/L	10	1390	608	302	8640	422	928	745	1020	755	221	860	1420	2210	1210	1330	

Matrix:	SOIL GAS	Sample Type:	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG
Workgroup:	EN1510362	ALS Sample number:	EN1510362001	EN1510362002	EN1510362003	EN1510362004	EN1510362005	EN1510362006	EN1510362007	EN1510362008	EN1510362009	EN1510362010	EN1510362011	EN1510362012	EN1510362013	EN1510362014	EN151030300	EN151030300	
Project name/number:	IS089500	Sample date:	28/01/2015	27/01/2015	28/01/2015	27/01/2015	27/01/2015	27/01/2015	27/01/2015	27/01/2015	27/01/2015	27/01/2015	27/01/2015	28/01/2015	28/01/2015	27/01/2015	22/01/2015	22/01/2015	
		Client sample ID (1st):	1095	1084	1305	1123	713	813	1096	1024	743	1285	1304	839	834	730	SN 704	SN 859	
		Client sample ID (2nd):	82347	83447	83729	122677	83446	69455	S61557/3	111524	S61557/2	S9037242/1	S61557/1	S61557/4	102621	111525	110985	54925	
		Client sample ID (3rd):							WRK961329		WRK961328	WRK990031	WRK961327	WRK961330					
		Depth Type:																	
		Depth (m):																	
		Site:																	
		Purchase Order:																	
Analyte grouping/Analyte	CAS Number	Units	LOR																
<b>EP104: Light Hydrocarbons</b>																			
Methane	74-82-8	Mol %	0.05	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.15	<0.15	
<b>EP104: Light Hydrocarbons (Calc Conc)</b>																			
Methane	74-82-8	mg/m <sup>3</sup>	330	<660	<660	<660	<660	<660	<660	<660	<660	<660	<660	<660	<660	<660	<990	<990	
<b>Sampling Quality Assurance</b>																			
Pressure - As received	PRESSURE	kPa	0.1	88.7	101	93.6	97.8	90.5	89.6	83.6	101	91.9	97.4	89.5	79.6	94.4	95.9	68.9	63.2
Pressure - Laboratory Atmosphere		kPa	0.1	102	102	102	102	102	102	102	102	102	102	102	102	102	102	101	101
Temperature as Received		°C	0.1	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	22	22
<b>Matrix:</b>				REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG
<b>Workgroup:</b>	EN1510362	<b>ALS Sample number:</b>	EN1510303003	EN1510303004	EN1510304001	EN1510304002	EN1510304003	EN1510304004	EN1510304005	EN1510304006	EN1510304007	EN1510305001	EN1510305002	EN1510305003	EN1510305004	EN1510305005	EN1510305006		
<b>Project name/number:</b>	IS089500	<b>Sample date:</b>	22/01/2015	22/01/2015	20/01/2015	21/01/2015	21/01/2015	21/01/2015	19/01/2015	20/01/2015	20/01/2015	22/01/2015	22/01/2015	23/01/2015	22/01/2015	22/01/2015	23/01/2015		
		<b>Client sample ID (1st):</b>	SN 3016	SN 812	991	1315	707	3025	1016	1116	734	1311	1015	860	701	1107	822		
		<b>Client sample ID (2nd):</b>	142660	89040	114169	75070	115872	113467	114167	111787	111786	141241	141242	141308	110984	110984	141307		
		<b>Client sample ID (3rd):</b>																	
		<b>Depth Type:</b>			ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500		
		<b>Depth (m):</b>																	
		<b>Site:</b>																	
		<b>Purchase Order:</b>																	
Analyte grouping/Analyte	CAS Number	Units	LOR																
<b>EP104: Light Hydrocarbons</b>																			
Methane	74-82-8	Mol %	0.05	<0.15	<0.15	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.14	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	
<b>EP104: Light Hydrocarbons (Calc Conc)</b>																			
Methane	74-82-8	mg/m <sup>3</sup>	330	<990	<990	<660	<660	<660	<660	<660	<660	920	<660	<660	<660	<660	<660	<660	
<b>Sampling Quality Assurance</b>																			
Pressure - As received	PRESSURE	kPa	0.1	62.4	61.6	90.2	92.6	95.1	93.8	89.8	92.8	93	91.8	87.2	93.8	88	88.4	93.1	
Pressure - Laboratory Atmosphere		kPa	0.1	101	101	101	101	101	101	101	101	101	102.2	102	102	102	102	102	
Temperature as Received		°C	0.1	22	22	24	24	24	24	24	24	24	24	20	20	20	20	20	

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