

Onshore natural gas water science studies

# Gippsland Region

## Groundwater sampling and characterisation for hydrocarbons

June 2015

**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 Gippsland region. A parallel study of the Otway region is covered in a companion report (DELWP (2015)). This report includes a review of the literature on previous groundwater chemistry studies in the Gippsland region and possible 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:

- The Traralgon Formation coal seams (part of the Latrobe Group) is the most prospective unit for coal seam gas in the Gippsland region (particularly the Longford/ Woodside/ Seaspray region).
- The Cretaceous aged Strzelecki Group is the most prospective unit for tight gas in the Gippsland region (particularly the Longford/Holey Plains/Seaspray region). The Strzelecki Group forms a hydrogeological basement, along with the Palaeozoic rocks in the Gippsland region.
- The Upper Mid-Tertiary Aquitard comprising the Lakes Entrance Formation, the Tambo River Formation and the Gippsland Limestone is a key regional aquitard likely to restrict the upward movement of hydrocarbons from the underlying Lower Tertiary Aquifer (Latrobe Group or Traralgon Formation).
- Structural features such as the Lake Wellington depression, and Darriman Fault systems and the Rosedale monocline are likely to breach seals above the Lower Tertiary Aquifer resulting in conduits for hydrocarbons to the surface (Goldie Divko *et al.*, 2010). This conclusion is largely based on soil geochemistry studies which show anomalous results over these structural features.

A representative number of bores for sampling were selected from aquifers known or suspected of having hydrocarbon concentrations (from the literature review) and/or within or near high value 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.

This report presents the results from 29 bores sampled in Gippsland between 9th December 2014 and 17th January 2015 using low flow sampling techniques. The interpretation of results focuses on spatial variations of analytes (both between aquifers and within aquifers).

The main conclusions from the analysis of the groundwater sampling results include:

### Major ions

- The sampled groundwater is sodium chloride dominated. There are no vertical trends in major ion chemistry. The similar ratios of major ions in the various sampled aquifers suggest lateral flow originates from a similar source and undergoes a similar process.

## **Methane**

- Methane concentrations tend to be highest in the coal bearing units of the Lower Tertiary Aquifer (Latrobe Group) and the Upper Mid-Tertiary Aquifer (Latrobe Valley Coal Measures and Balook Formation). The methane concentrations in these units are likely to be sourced from the organic content of the coals.
- There is a decreasing methane concentration upwards above the coal bearing units (for example all watertable bores had undetected or negligible methane concentrations). All nested sites exhibit this trend. The methane concentrations in upper aquifers in areas where the Upper Mid-Tertiary Aquitard is absent is slightly higher than in areas where it is present suggesting the Upper Mid-Tertiary Aquitard partially restricts upwards flow of methane.
- There is no apparent increasing trend in methane concentrations near faults.
- Methane was only detected in analysed gas samples from bores screened in the Lower Tertiary Aquifer and only in bores with significant methane concentrations in water samples. The higher confined pressures in the Lower Tertiary Aquifer are likely to result in the gas coming out of solution during the sampling process.

## **Ethane, Ethene, Butane, Butene, Propane and Propene**

- There were no observations of Ethene, Butane, Butene, Propane and Propene in the 29 sampled bores suggesting that these compounds are not a natural occurrence in any of the sampled aquifers and any future detection is likely to reflect an anthropogenic origin.

## **Benzene, Toluene, Ethylbenzene and Xylene (BTEX)**

- BTEX was detected in the Lower Tertiary Aquifer and the Upper Tertiary Aquifer. No BTEX was detected in the quaternary aquifers, suggesting that BTEX compounds are unlikely to be a natural occurrence in these quaternary aquifers and any future detection is likely to reflect an anthropogenic origin.

## **Total Petroleum Hydrocarbons (TPH)**

- TPH was detected in 8 of the 29 bores sampled and 7 of these bores are screened in the coal bearing units of the Lower Tertiary Aquifer (Latrobe Group) and the Upper Mid-Tertiary Aquifer (Latrobe Valley Coal Measures and Balook Formation). Although no definitive conclusion can be drawn on the source of the hydrocarbons, the depth of the bores, the presence of coals and the likely lack of interaction with the surface suggest a natural origin.

## **Naphthalene**

- The lack of detection of naphthalene in any of the 30 sampled bores suggests that these compounds are not a natural occurrence in any of the sampled aquifers and any future detection is likely to reflect an anthropogenic origin.

## **Nitrogen**

- The Quaternary Aquifer contains the highest nitrogen concentrations, likely to be the result of leaching from fertiliser rich surface soils to the watertable.
- Slightly higher values were found in the Lower Tertiary Aquifer compared to other confined aquifers which is likely to be an inherent characteristic of the aquifer, rather than leaching from the surface. Potentially the nitrogen is associated with the presence of natural gas in this coal bearing aquifer.

## **Implications for conceptual model**

The groundwater chemistry results presented in this report are generally consistent with the prevailing conceptual model of groundwater flow in the Gippsland region. The upwards decrease in methane concentrations is consistent with the general upwards groundwater flow across the region. Although not definitive, the upwards reduction in methane levels suggests that the detected methane in the upper units (especially the Upper Tertiary Aquifer (Boisdale Formation)) is likely to be sourced from the underlying coal bearing units of the Lower Tertiary Aquifer and the Upper Mid-Tertiary Aquifer.

The results are consistent with the Upper Mid-Tertiary Aquitard (Lakes Entrance Formation) being a seal on top of the Lower Tertiary Aquifer although the methane results show that upwards seepage through the aquitard to overlying aquifers is possible and that the seal is imperfect. Similarly, the results suggest that areas of aquitard absence are likely to exhibit greater inter-aquifer connection as evidenced by the greater methane concentrations in surface aquifers.

There is no apparent increase in hydrocarbon concentrations near faults although there is not enough data to indicate whether faults provide conduits for fluid flow as suggested by the conceptual model.

# 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 focusses on the Gippsland region with the results in the Otway 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 and the relative depth of the different potential gas sources.

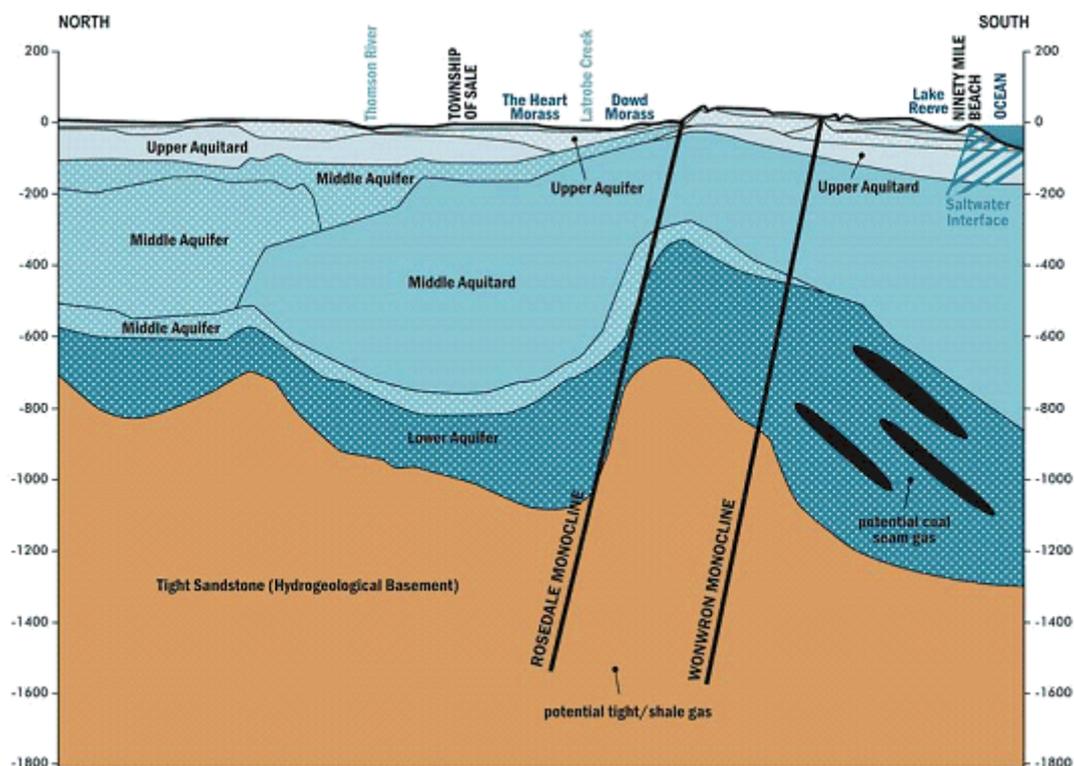


Figure 1 Typical geological formations bearing prospective onshore natural gas in the Gippsland region (depth shown in metres)

In the Gippsland onshore region, there is no significant potential for conventional gas based on current information. Tight and shale gas are assessed as a single resource in the Gippsland region as they are expected to be in the same geological formation (tight sandstones and shales of the Strzelecki Group).

# Onshore natural gas water science studies

This report presents the sampling results from the groundwater monitoring program in the Gippsland region. 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 Gippsland region, and how these results have been interpreted in the context of the conceptual model of the basin. The literature review provides input as recommendations regarding the selection of sampling bores and analytes and also provides the context for interpretation of results.

There is limited published or publically available information on the organic hydrochemistry of groundwater associated with coal seams (CSIRO, 2011). Some of the first instances of organic information collection in the Gippsland region only recently occurred, in 2013, as part of a science program to investigate the potential impacts on groundwater of possible future coal mining and on-shore natural gas development. The lessons learned regarding sampling procedures for organic chemistry in particular, and the identified knowledge gaps, have been incorporated into this sampling program.

A number of the reviewed reports are focused on the potential for CO<sub>2</sub> storage in the Gippsland region and the common stratigraphic interval of interest (the Latrobe and Strzelecki groups) for both hydrocarbon production and CO<sub>2</sub> storage plans. While the challenge of understanding and managing these operations is not the focus of this report, these studies discuss and identify critical information relevant to this review, including:

- potential hydrocarbon locations
- mechanisms of hydrocarbon migration
- location of fracture or high permeability zones that can potentially act as fluid conduits.

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 Gippsland region, where coal and oil and gas are potentially present including Divko *et al.*, (2010), Nahm (2002), O'Brien *et al.*, (2008), Varma and Michael (2011), Woollands and Wong (2001) and DSDBI (2013).
- Interrogate 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).

# Onshore natural gas water science studies

This chapter includes the following discussion:

- Section 2.1 Aquifer overview - a summary of the hydrogeology of the Gippsland region including the main aquifers and structural features
- Section 2.2: Literature review of hydrocarbon occurrence and movement in the Gippsland region
- Section 2.3: Onshore natural gas prospectivity
- Section 2.4: Discussion about the appropriate analytes for this project
- Section 2.5: Discussion about potential areas for on-shore natural gas prospectivity
- Section 2.6: Summary of the implications of the literature review for the selection of groundwater chemistry parameters for this study.

## 2.1 Gippsland region – aquifer overview

The Gippsland region containing the Gippsland Basin an approximate East-West trending sedimentary region bounded by major fault systems from southern and northern margins. Approximately two thirds of the basin is located offshore. Although oil was found in the 1920s in onshore wells, all producing fields were discovered after 1965 and are located offshore in water depths ranging from 45 m to 450 m (Woolands & Wong, 2001).

The hydrogeology of the Gippsland Basin is complex with a number of differing hydro stratigraphic units inter-fingering other units. 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 Gippsland region (Figure 1).

## Onshore natural gas water science studies

Aquifer		GIPPSLAND AND TARWIN BASINS HYDROGEOLOGICAL UNITS (HGUs)		Groundwater Management Units
Aquifer Name	Aquifer Number	HGU No.	HGU Name	
Quaternary Aquifer	100	1001	Quaternary Aeolian	Denison, WaDeLock, WyYung, Tarwin, Orbost
		1002	Quaternary Fluvial/ lacustrine/	
Upper Tertiary/ Quaternary Aquifer	102	1015	Haunted Hills Formation	
		1016	Eagle Point Sand	
Upper Tertiary/ Quaternary Aquitard	103	1017	Boisdale Formation (Nuntin Clay)	
Upper Tertiary Aquifer (fluvial)	105	1036	Boisdale Formation (Wurruk Sand)	Sale, Giffard
Upper Tertiary Aquitard	106	1056	Hazlewood Formation	
		1058	Yallourn Formation	
		1061	Sale Group / Jemmys Point Formation	
		1057	Yarragon Formation	
Upper Mid-Tertiary Aquifer	107	1059	Morwell Formation / Morwell seams	Yarram (Balook), Rosedale (Balook and Morwell Fm)
		1060	Balook Formation	
		1064	Alberton Fm, Alberton Coal Seams	
		1053	Cobia Sub-Group	
		1053	Gurnard Formation	
		1053	Turrum Formation	
Upper Mid Tertiary Aquitard	108	1062	Seaspray Group	
		1063	Lakes Entrance Formation	
		1062	Tambo River Formation	
		1063	Gippsland Limestone	
		1062	Giffard Sandstone Member	
Lower Mid -Tertiary Aquifer	109	1141	M2C Aquifer	
		1141	Seaspray Sand	
Lower Tertiary Aquifer	111	1104	Latrobe Group	Yarram (Latrobe Group), Stratford, Moe
		1104	Traralgon Formation	
		1105	Yarram Formation	
		1106	Honeysuckle Gravels	
		1107	Childers Formation	
		1108	Burrong Fm/ Traralgon Seam	
		1142	M2/M2C Aquifer (when basal aquifer)	
Lower Tertiary Basalts	112	1110	Older Volcanics Group (Phase 1)	Leongatha
		1112	Thorpdale Volcanics	
		1113	Carrajung Volcanics	
Mesozoic and Palaeozoic Bedrock	114	1125	Strzelecki Group	
		1124-28	All Palaeozoic Rocks	

Figure 1 Victorian Aquifer Framework relationship between aquifers and hydrogeological units in the Gippsland Basin (source: modified from GHD, 2012).

The primary units noted to be associated with natural gas resources include:

- The Lower Tertiary Aquifer (Aquifer 111) – hosts all currently known major hydrocarbon accumulations including offshore conventional oil and gas deposits and potential on-shore coal seam gas deposits.
- The Strzelecki Group (Aquifer 114) – hosts on-shore tight gas occurrences

Of particular importance to the vertical migration of groundwater and hydrocarbons through the Basin is the presence or absence of the Seaspray Group (Aquifer 108) – Lakes Entrance Formation which forms a regional seal across the region.

A generalised stratigraphic column is shown in Figure 2 and a description of each of the key units is provided below. For additional information on the Gippsland Basin stratigraphy, the reader is directed to the following literature; James and Evans (1971), Rahmanian *et al.*, (1990) and Bohacs and Suter (1997), Smith *et al.* (2000), Bernecker *et al.*(2001) and Bernecker and Partridge (2001), cited in Woodlands & Wong (2001).

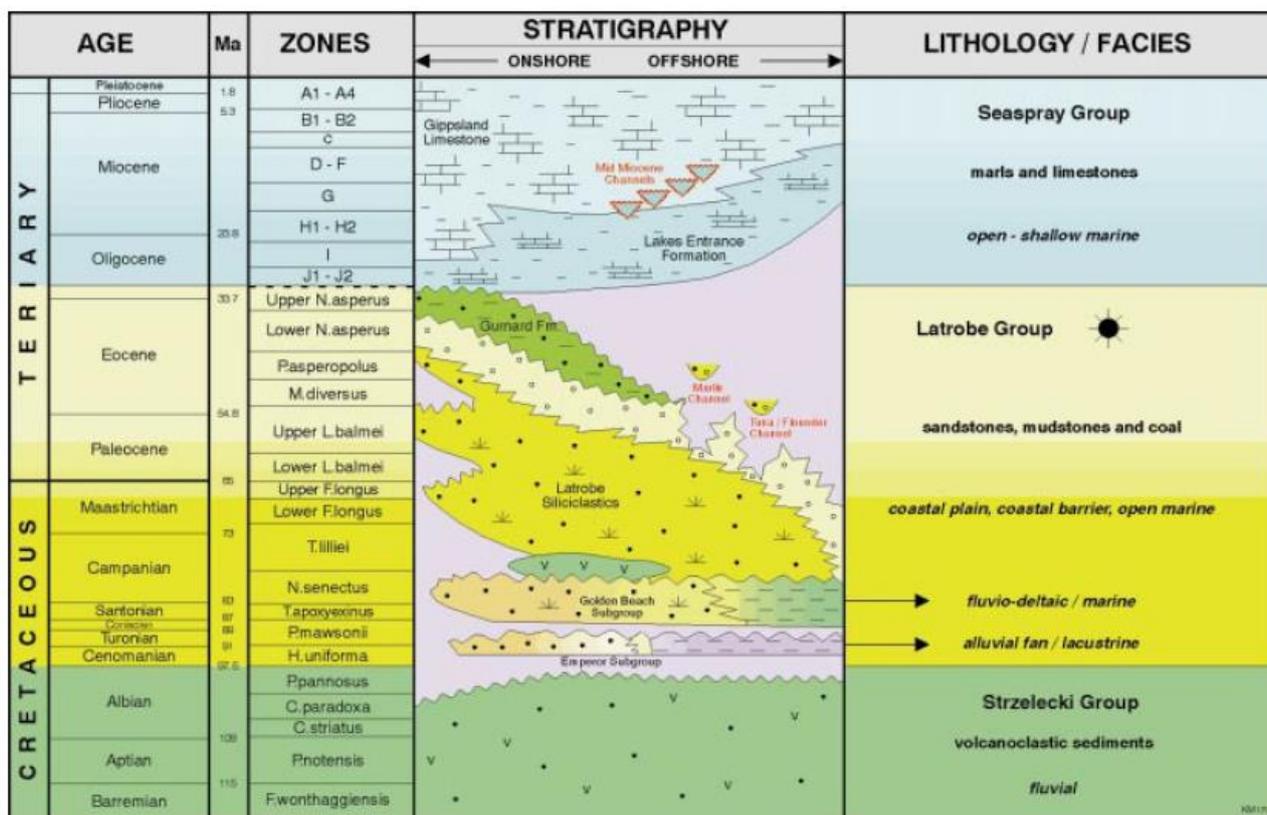


Figure 2 Generalised stratigraphy for the Gippsland Basin (source: Malek and Mehin, 1998)

### 2.1.1 The Strzelecki Group

The Strzelecki Group forms part of the Palaeozoic basement rocks of the Gippsland Basin. The Strzelecki Group consists of interbedded lithic, volcanoclastic sandstones and mudstones, including several coal-rich horizons. Comparisons have been made between the Strzelecki Group and the Eumeralla Formation in the Otway region (which is a significant gas source) in that it may contain good quality gas-prone source rocks (O'Brien, 2008). The Strzelecki Group has previously been identified as a target for exploration for tight gas by Lakes Oil.

### 2.1.2 The Latrobe Group

The Latrobe Group forms the lowermost sedimentary aquifer in the Gippsland Basin and is underlain by the consolidated sandstones and shales of the Strzelecki Group. The Latrobe Group aquifer itself is formed by alluvio-fluvial sediments at the bottom, to marginal-marine, deltaic and increasingly marine sediments toward the top. The Latrobe Group forms a confined aquifer that dips from the area of onshore outcrop, to several kilometres depth in the offshore area of the Basin. The depth to the top of the Latrobe Group aquifer is shown in Figure 3. The Latrobe Group may have coal seam gas potential and is also being considered for its CO<sub>2</sub> storage potential. The Latrobe Group is the most important reservoir for oil and gas in both the onshore and offshore parts of the Basin (Varma & Michael, 2012).

The formations overlying the Latrobe Group (e.g. the Latrobe Valley coal measures- T0, T1 and T2) contain substantial coal resources that are being mined in the onshore part of the Basin and as part of these mining process substantial volumes of groundwater are extracted from the Latrobe Group to facilitate the mining operations.

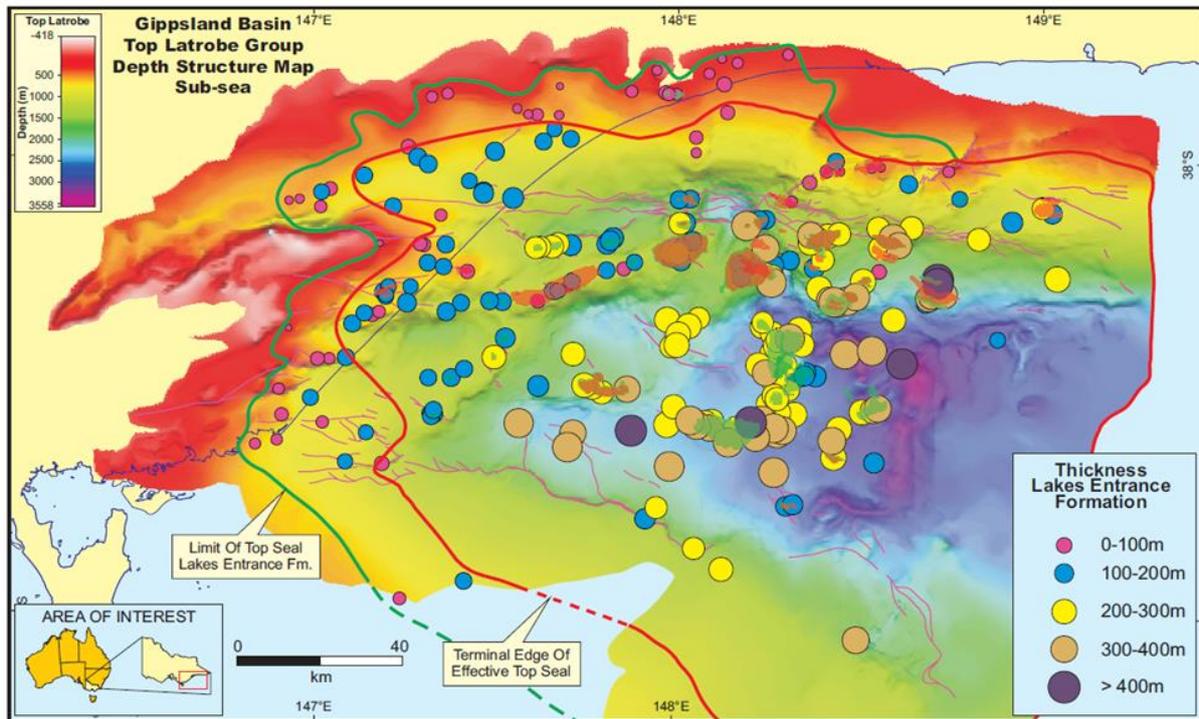


Figure 3 Lakes Entrance Formation thickness (points) and depth to top of Latrobe Group structure map (source: O'Brien *et al.* 2008)

### 2.1.3 The Seaspray Group

#### Lakes Entrance Formation

The Seaspray Group is a carbonate dominated mega-sequence and the basal Lakes Entrance Formation forms a regional seal across the eastern part of the Basin. The Seaspray Group is the lateral marine equivalent to the barrier dune deposits of the Balook Formation and the terrestrial deposits of the Latrobe Valley Coal measures.

Hocking (1976) identified the onshore units that comprise the Lakes Entrance Formation to be: the Cunningham Greenstone Member, Giffard Sandstone Member, Colquhoun Sandstone Member, Seacombe Marl and the Metung Marl.

Figure 3 shows the thickness of the Lakes Entrance Formation, increasing from the on-shore to the offshore parts of the region. O'Brien *et al.* (2008) undertook a regional quantitative assessment of the sealing capacity of the Lakes Entrance Formation. The study found that onshore; the top-seal is relatively thick, in particular around the Lake Wellington and Seaspray depressions (locations of depressions can be seen in Figure 4). Outside of these areas in the onshore part of the region, the Lakes Entrance Formation seal is thin or absent and there is an absence of conventional gas accumulations at the top of the Latrobe Group aquifer. Where the aquitard is absent, there is potential connection between the Latrobe Group aquifer and overlying aquifers (especially the sand dominated Balook Formation). The sealing capability of intra-Latrobe facies (i.e. low permeability units found within the Latrobe Group itself) was found to be poor on a regional scale and largely ineffective in preventing the migration of hydrocarbons to the base of the regional seal.

## **The Gippsland Limestone**

The Gippsland Limestone is a thick sequence of limestone and marl that overlies the Lakes Entrance Formation in the Gippsland region. Goldie Divko *et al.* (2009) recommended further investigation into the role of the Gippsland Limestone in providing an adequate top seal to the Latrobe Group aquifer, especially at the region margins where the Lakes Entrance Formation is absent.

## **2.2 Gippsland region - hydrocarbon occurrence**

The Gippsland Basin is one of Australia's most productive oil and gas provinces. Ongoing hydrocarbon production has until now focused on oil and conventional gas (mainly offshore); however interest in unconventional hydrocarbon resources is growing.

Conventional gas relates to gas that is sourced from an organic rock that has been compacted by layers of overlying rocks over a long period of time, such that the high pressure and temperature at depth has produced hydrocarbons to form and to migrate towards an area of lesser pressure until it reaches a trap (or an impermeable layer of rock). The reservoir is the rock of high porosity and permeability that holds the hydrocarbon beneath the trap.

Unconventional gas doesn't require the geological precursors described for conventional gas above. It is gas that is trapped in impermeable rock and cannot migrate to a trap as would occur in a conventional gas deposit. It may be trapped in the source rock from which it was generated. Unconventional gas includes: coals seam gas, shale gas and tight gas.

The occurrence of hydrocarbons in the Gippsland Basin is typically described in terms of the main fault-bounded structures (Figure 4). Offshore these include (from north to south): Northern Platform, Northern Terrace, Central Deep, Southern Terrace and the Southern Platform. Onshore they are described as (north to south): the Lakes Entrance Platform, the Lakes Wellington Depression, the Seaspray Depression and the Alberton Depression.

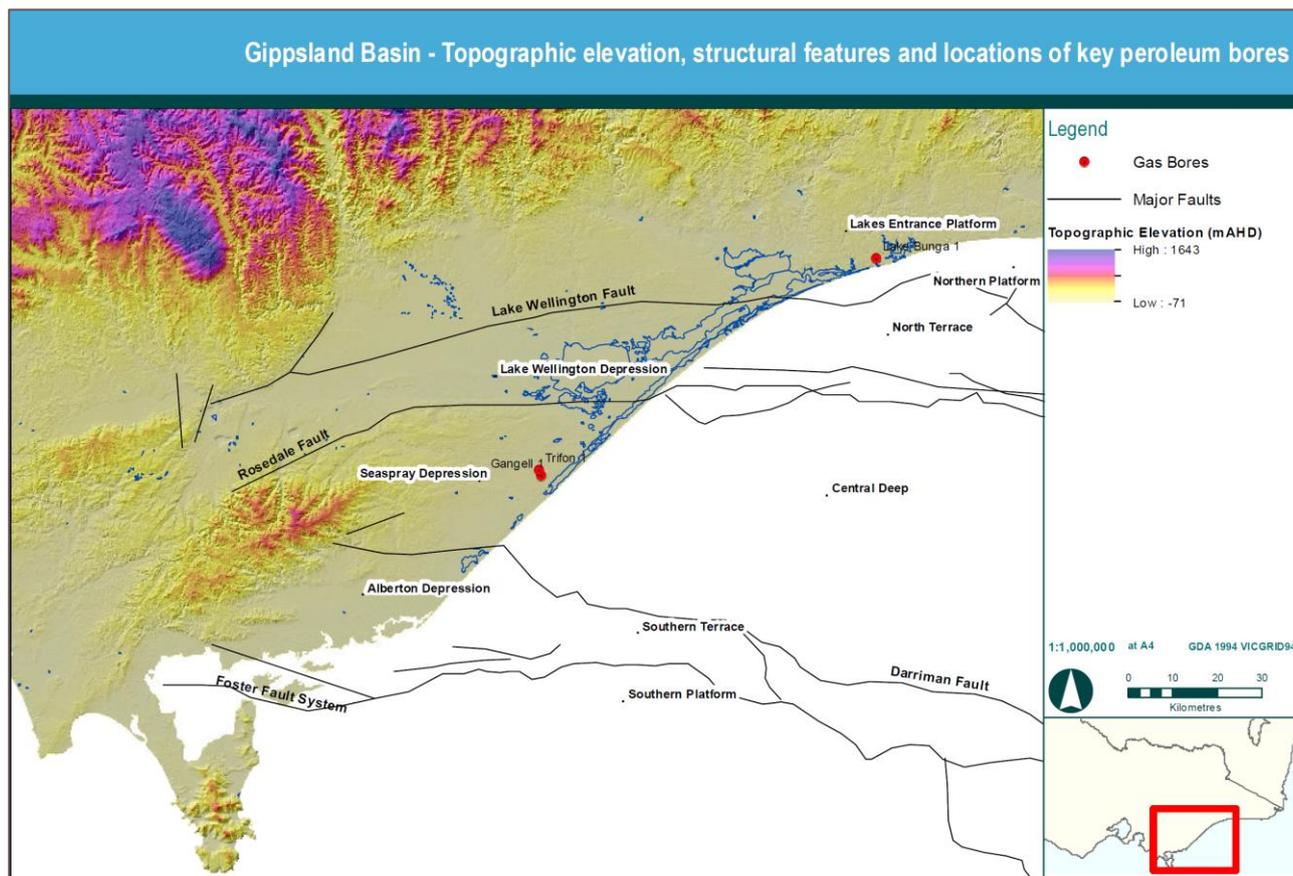


Figure 4 Fault bounded structures in the Gippsland region

## 2.2.4 Lakes Entrance Platform

Varma & Michael (2011) hypothesise potential connection between the shallower aquifers and the Latrobe Group Aquifer from an interpreted absence or thinning of the Lakes Entrance aquitard, in the area around the northern part of the Gippsland Lakes. This could allow groundwater to migrate upward, possibly unimpeded by the Rosedale and the Lake Wellington faults due to aquifer-aquifer juxtapositions along the fault planes. Geochemical seepage indicators reported by Goldie Divko et al. (2010) suggest potential for vertical upward flow along the fault systems.

Secondary migration of hydrocarbons in the Basin is believed to be largely through large scale vertical migration along faults, although significant lateral migration can also be demonstrated by the occurrence of the small accumulation at the onshore Lakes Entrance Field (Woollands & Wong, 2001). The Lake Bunga 1 exploration hole location is shown in Figure 5 and represents the first discovery of oil in this area in 1924. The oil was found at the base of the Lakes Entrance Formation. Gas reports for the Lake Bunga 1 well indicate methane composition of between 44 and 94 mol %. No other discoveries have indicated the presence of hydrocarbons in this area (Goldie Divko et al. 2009).

**Recommendation for the selection of sampling bores and analytes:** *Monitoring program should target bores in the area around the northern part of the Gippsland Lakes to better understand the implications of thin or absent Lakes Entrance aquitard and the potential for mixing between Latrobe Group and shallower aquifers.*

*Monitoring program should also target bores located near the Rosedale & Lake Wellington faults to better understand the potential for vertical upward flow along the fault systems. Monitoring program should also target bores near the Lake Bunga 1 bore that has records of methane.*

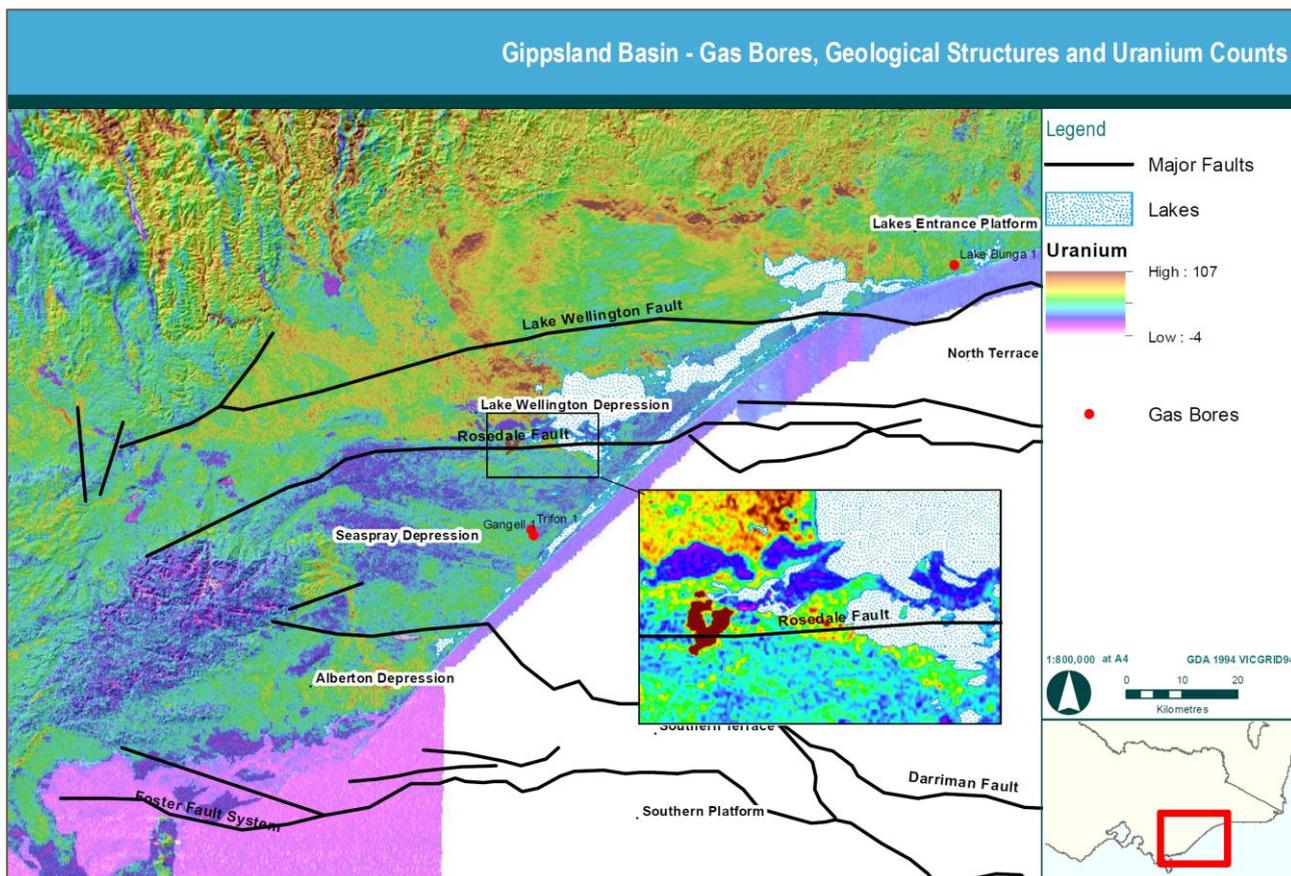


Figure 5 Uranium counts and gas bores in the Gippsland region

### 2.2.5 Lake Wellington Depression

O'Brien (2008) indicated a likely good sealing capacity of the Lakes Entrance Formation in the Lake Wellington Depression and an adequate seal in the Seaspray Depression (Figure 6). Across the rest of the onshore Gippsland region the Lakes Entrance Formation is thinner (<100 m thick).

Murray (1997) detected petroleum in sediments in the floor of Lake Wellington and the oil was thought to be similar geochemically to that found in one of the offshore fields. Although there is no unequivocal proof, it is possible that the seepage represents migration from the northern spill-fill chain across the Rosedale Fault and into the Lake Wellington Depression.

DSDBI (2013) sampled 53 bores across Gippsland for methane concentration and of the 53 bores tested, two bores recorded high levels at 10.4 mg/L and 26.4 mg/L in bores 109044 and 110724 respectively. Bore 109044 is screened in the Boisdale Formation and is located to the North of the Lake Wellington Depression, near the Lake Wellington Fault. The fault may provide a gas pathway for methane movement from the offshore gas system. However, it was noted that the ionic chemistry was at the Calcium Sulphate end of the spectrum for Boisdale and was not considered an outlier. Bore 110724 is screened in the Latrobe Group aquifer located near Port Welshpool in the Yarram WSPA.

**Recommendation for the selection of sampling bores and analytes:** *Monitoring program should target bores in the Lake Wellington Depression and / sample for petroleum hydrocarbons.*

*Monitoring program should target bores in the Lake Wellington Depression near the Lake Wellington Fault and near Port Welshpool and sample for methane gas.*

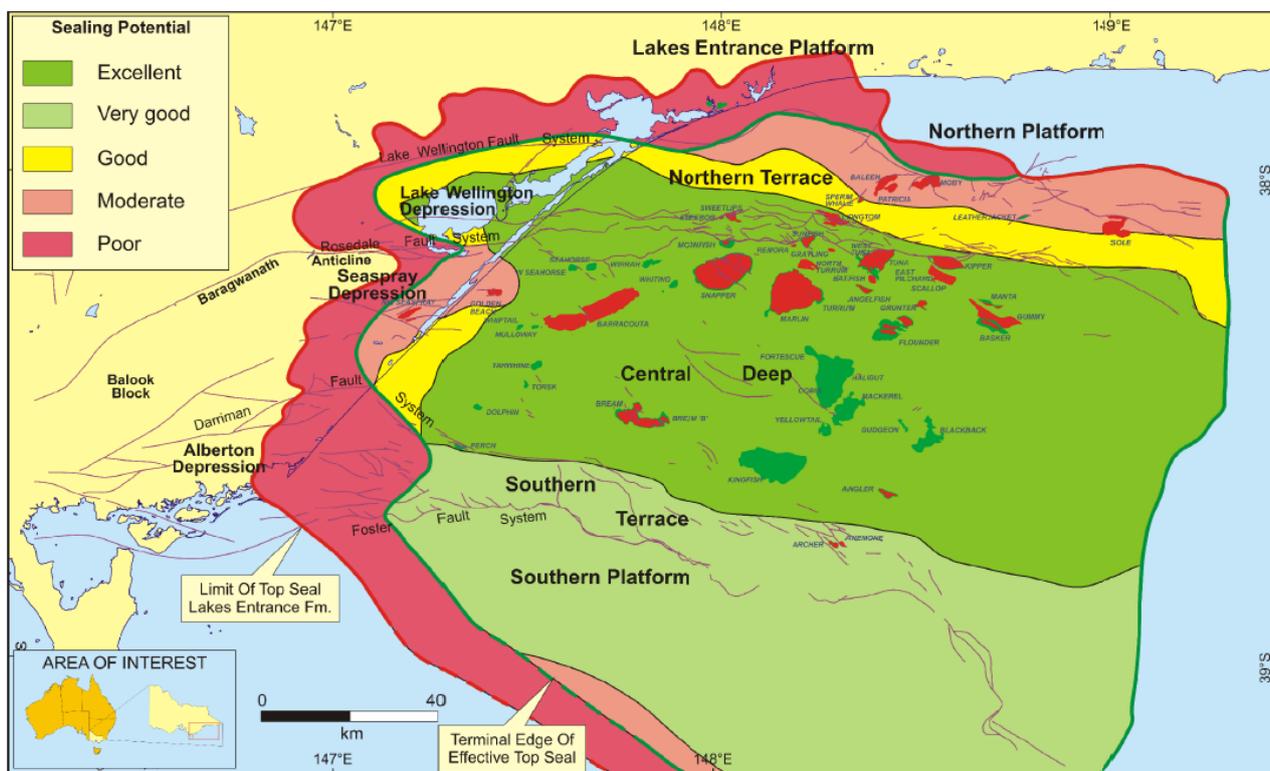


Figure 6 Sealing potential of the Lakes Entrance Formation and oil and gas fields (shown in green and red respectively). (source: Goldie Divko et al., 200)

## 2.2.6 Baragwanath Anticline

The Lakes Entrance Formation is absent over the Baragwanath Anticline. An active hydrocarbon seep, located approximately 10 km southeast of Sale, has been confirmed by Lakes Oil (Mulready, 2002). The location of this seep is indicated in Figure 5, whereby peaks in the statewide uranium survey dataset were used to identify the hydrocarbon seeps along the fill-spill chain at the top of the Latrobe Group. The trend of enriched uranium was interpreted by O'Brien (2008) to potentially indicate hydrocarbons in a broad east-south-east direction away from the confirmed seep. The seep may have originated from seepage up the Rosedale Fault.

**Recommendation for the selection of sampling bores and analytes:** Monitoring program should target bores in the vicinity of the interpreted hydrocarbon seep and the Rosedale Fault.

## 2.2.7 Seaspray Depression

There are no known hydrocarbon accumulations at the base of the regional Lakes Entrance Formation seal in the Seaspray Depression (Goldie Divko et al. 2009). Onshore, gas accumulations of the North Seaspray and Gangell fields are held in the Strzelecki Group sands (Goldie Divko et al. 2009) rather than the Latrobe Group aquifer. It is likely that the lack of gas in the Latrobe Group in this area is due to the lack of regional seal in this area. The location of the petroleum bore Gangell 1 indicates the location of these gas accumulations (see Figure 4).

Gangell 1 and Trifon 1 were drilled in 2000 under the onshore permit PEP157 to test the Strzelecki oil play. Information for these bores was sourced from the Geoscience Australia petroleum well database. Gangell 1 has a recorded depth of 2350 m and Trifon 1 to 2570 m and both of these wells include gas composition analysis that indicates more than 95% methane (Figure 7).

Hydrocarbon gases are formed from either microbial decay or thermogenic alteration of organic matter. Microbial gases are essentially enriched in methane (C1) with respect to other higher molecular weight hydrocarbon gases (e.g. ethane (C2) and propane (C3)). The Bernard Parameter ( $C1/(C2+C3)$ ) range from 1,000-100,000 would indicate microbial gases, while values less than 50 are typical for thermogenic hydrocarbon gases (Grassa et al. 2004).

For the gas samples from Gangell 1 and Trifon 1 the ratios have been calculated at 45 and 40, respectively. This indicates that the gas is not biodegraded and that it is of thermogenic origin. O'Brien et al. (2008) concluded that the gases were reservoirised in the tight sandstones of the Strzelecki Group and that they are produced from fractures as opposed to within a matrix. A similar conclusion was drawn by Woollands & Wong (2001) whereby, in the Seaspray Depression, burial history and geochemical modelling was thought to suggest that the Early Cretaceous Strzelecki Group, rather than the Latrobe Group, was the source for the onshore hydrocarbon.

There are numerous gas chimneys and anomalous readings of seismic reflection data in the near shore Seaspray Depression which may imply active hydrocarbon migration, leakage, seepage. The onshore gas chimneys have been correlated with anomalous mapped soil geochemistry (Goldie Divko et al., 2009).

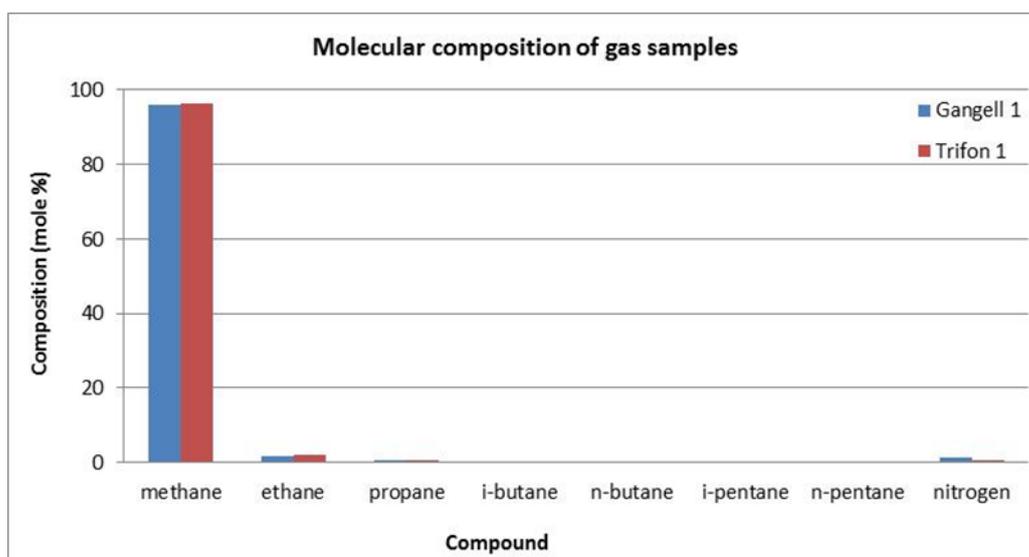


Figure 7 Gas composition for petroleum wells in the Seaspray Depression (source: Geoscience Australia Petroleum Wells Database)

**Recommendation for the selection of sampling bores and analytes:** Monitoring program should target Strzelecki Group aquifer in the Seaspray Depression. If State Observation Bore Network bores are not available for this stratigraphic layer, an overlying aquifer in the area should be targeted to monitor for potential occurrence of methane gas.

## 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 potentially prospective formation for coal seam gas in Gippsland is the brown coal seams of the Traralgon Formation within the Latrobe Group. Goldie-Divko (2015) provides an analysis of coal seam gas prospectivity at the following three different scales:

- Field scale: the extent of the top of the Traralgon seams within the Burong structure
- Sub-regional scale: where the roof of the Upper Traralgon coal seam (T1) sub-crops between 400 and 800 metres depth inside the Seaspray Depression
- Regional scale: where the Traralgon coal seams sub-crop below 200 metres down-hole depth within the Seaspray Depression and the Latrobe Valley.

Areas of the above scales of coal seam gas prospectivity are shown in Figure 8.

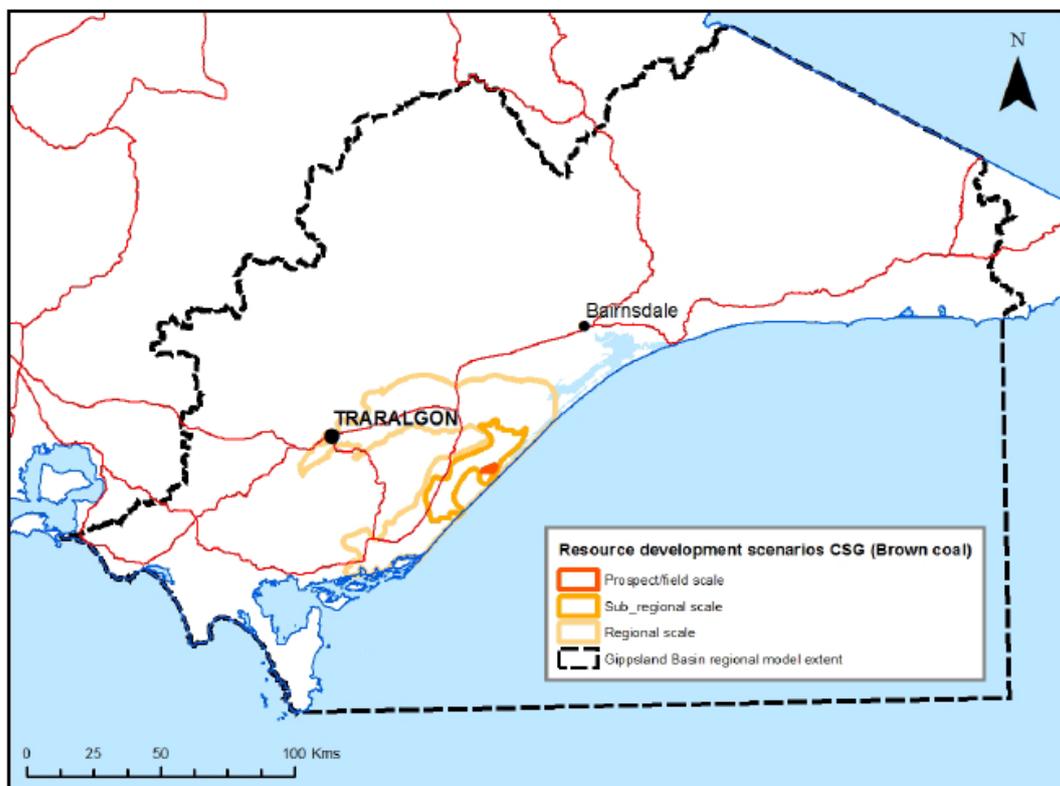


Figure 8 Gippsland region coal seam gas development scenarios (source: Goldie Divko, 2015)

## 2.3.2 Tight gas prospectivity

Tight gas is held in relatively 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.

Goldie-Divko (2015) notes that since the late 1990s the Strzelecki Group has been the target of some tight gas exploration, and provides an analysis of tight gas prospectivity at the following three different scales:

- Field scale: area denoted by structural traps at the top of the Strzelecki Group (and potentially the Golden Beach Sub-group) in the Wombat, Trifon and Gangell fields, as well as a number of smaller scale prospects (Echidna, Steele and Carrs Creek).

# Onshore natural gas water science studies

- Sub-regional scale: areas of potential tight gas prospectivity covering the field scale areas noted above and all areas in between.
- Regional scale: all tight/shale sub-crop areas in the onshore Gippsland Basin and Latrobe Valley (including the entire area of buried Strzelecki Group underlying the Gippsland region).

Areas of the above scales of tight gas prospectivity are shown in Figure 9.

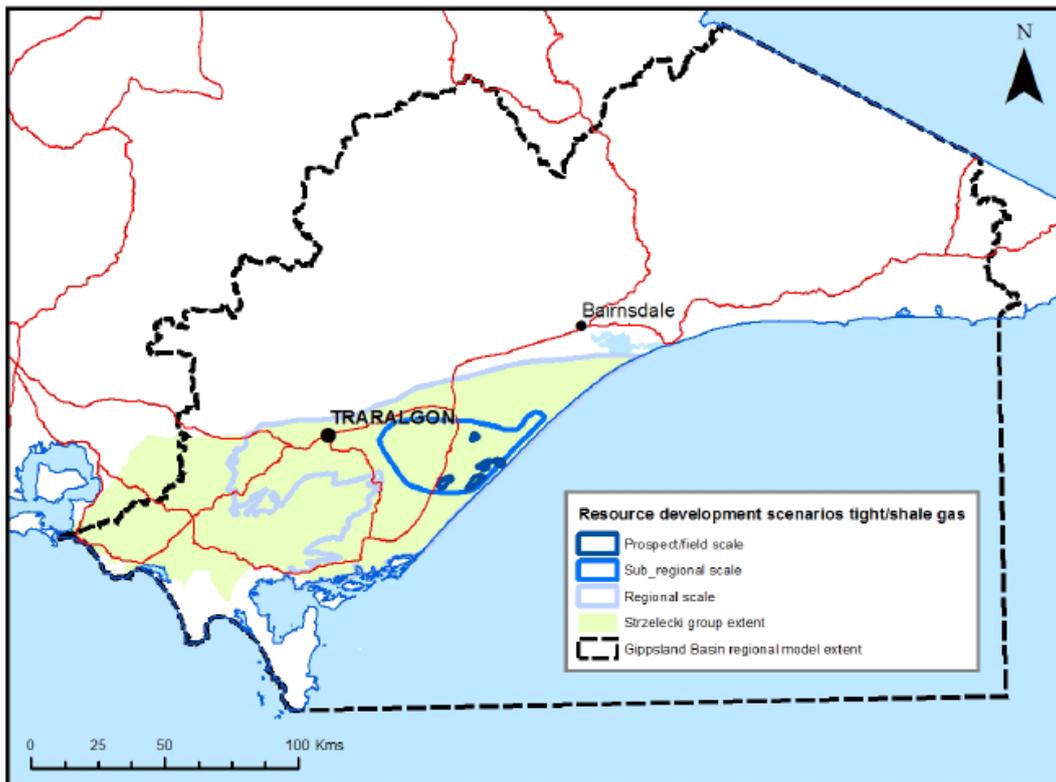


Figure 9 Gippsland region tight/shale gas development scenarios (source: Goldie Divko, 2015)

## 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.

## Onshore natural gas water science studies

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 typical major ions are included in the proposed sampling program.

Nahm (2002) undertook an analysis of the inorganic chemistry in the Gippsland region, using 937 laboratory results of the available 2289 in the Gippsland region (a 5% ionic balance error margin criterion was used to filter the results used in the analysis). The average concentration of major ions: calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulphate and chloride, were plotted on a piper diagram. The piper plot analysis indicated there were three groundwater types present in the region: calcium-sodium-chloride, sodium-chloride and sodium-bicarbonate-chloride types.

A Schoeller diagram was used to plot the major ions and some additional ions/compounds, including: iron, silicate and nitrate. The Schoeller diagram was used to identify differences in groundwater chemistry for each of the hydrostratigraphic units defined by Nahm (2002). The Schoeller plot indicated that analysis of iron and dissolved silica did not prove useful in distinguishing between aquifers, however, analysis of nitrate proved useful as significant variation was observed between the aquifers.

Based on the results of the literature review, the following analytes were chosen for the sampling of the Gippsland region:

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

The above proposed suite of inorganics is consistent with the ALS Environmental basic coal seam gas suite, with the exception of exclusion of dissolved silicate and the addition of nitrate and nitrite. The extended coal seam gas suite (which is adopted by QGC) 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). 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 qualities as:

- odour
- water colour
- bubbles
- 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, 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.

RMIT will be undertaking sampling of a number of the same bores (approximately 10 and including one nested site) identified in this monitoring program, including isotope analysis. Although not undertaken in this study due to time constraints, it is recommended that both datasets be analysed together.

### 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).

#### 2.4.3.1. Hydrocarbon gases

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) was mentioned in section 2.2.4 to indicate a likely thermogenic hydrocarbons source for the North Seaspray and Gangell 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.

### **2.4.3.2. Petroleum Hydrocarbons**

Sampling for petroleum hydrocarbons typically includes samples for:

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

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 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 for the following reasons:

- DSDBI (2013) found raised BTEX and TPH concentrations in a number of bores sampled in the Gippsland region. It was concluded that the elevated concentrations occurred as single peaks within their chromatograms and this suggested that refined hydrocarbon products are likely to be attributed to contamination of the bores or near surface (e.g. fuel tanks) seepage.
- The national and international protocols for baseline groundwater sampling all include TPH and BTEX.
- The Gippsland region literature review indicated potential hydrocarbon seeps near Sale.
- The use of BTEX compounds 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 region, 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 state wide 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.

A recent groundwater sampling program in Victoria (DSDBI, 2013) sampled 53 groundwater bores across Gippsland for PAHs and none of the bores recorded concentrations above detection limits. For this reason, 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 hydrocarbon occurrences have been identified:

- in the area around the northern part of the Gippsland Lakes to better understand the implications of thin or absent Lakes Entrance aquitard and the potential for mixing between Latrobe Group and shallower aquifers
- located near the Rosedale & Lake Wellington faults to better understand the potential for vertical upward flow along the fault systems
- near the Lake Bunga 1 bore that has records of methane
- in the Lake Wellington Depression and sample for petroleum hydrocarbons
- in the Lake Wellington Depression near the Lake Wellington Fault and sample for methane gas
- in the vicinity of the interpreted hydrocarbon seep (10 km southeast of Sale) and the Rosedale Fault
- in the Strzelecki Group aquifer in the Seaspray Depression. If State Observation Bore Network bores are not available for this stratigraphic layer, an overlying aquifer in the area should be targeted to monitor for potential occurrence of methane gas.

These conclusions will be taken into consideration in Chapter 3, which details the bore selection method.

### 2.5.2 Summary of groundwater sampling parameters

Based on the above literature review, 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), 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 will utilise low flow techniques to sample a representative number of bores screened within aquifers known, or suspected of having hydrocarbon concentrations, and/or within or near high value 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 will only choose state observation bores 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 ecosystems particularly above zones of high unconventional gas prospectivity
- bores in aquifers of 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 (relevant to the WG CMA bores).

The Gippsland 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 surface water assets
- areas of high groundwater use or potential use
- naturally occurring hydrocarbon locations (from the literature review).

A recent review of the state observation bore network was undertaken by GHD (2014) which 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 a state observation bore network asset. Bores with poor condition ranking (of 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 state observation bores was observed.

## 3.2 Water asset identification

The Victorian Water Asset Database (VWAD) was used to identify potential Groundwater Dependent Ecosystems (GDEs), waterways and wetlands in the Gippsland 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 GDEs for potential bore monitoring target sites in the monitoring program:

- GDE score = 100. A score of 100 implies a potential GDE has been identified. Applying this rule means that only the potential GDE rivers (91% of total) and wetlands (31% of total) in the Gippsland region were selected from the VWAD.
- 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 a 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 Gippsland). This means 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.

Note: there were no springs identified in the region or region margin catchment system of the Gippsland region. Springs were only present in the upland valley (i.e. the outcropping fractured rock) area of the Gippsland region.

These GDEs were then compared to the locations of the field scale and sub-regional scale prospectivity for coal seam gas and tight/shale gas localities as defined by Goldie-Divko (2015) and described in Section 2.3.

Within the Gippsland region the prospectivity areas intersect a number of key assets including potential groundwater dependent ecosystems, waterways and wetlands as identified from VWAD. State observation bore locations have been compared to these features and prospectivity areas and specific bores have been selected for inclusion in the monitoring network. Figure 10 shows the selected sampling bores which are summarised in Table 1.

## Onshore natural gas water science studies

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

Bore	Details	Justification
145092	Upper Tertiary Aquifer (fluvial) (105)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and key rivers and wetlands</li> <li>• Monitors the target aquifer (Boisdale Formation) in the Giffard GMU</li> </ul>
105483	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>• Monitors the target aquifer (Latrobe Group) in the Yarram GMU</li> <li>• Located in the area of prospectivity and key rivers and wetlands</li> <li>• Located in the Seaspray depression area of interest.</li> <li>• Nested with 105483</li> </ul>
105484	Upper Tertiary Aquifer (fluvial) (105)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and key rivers and wetlands</li> <li>• Monitors the target aquifer (Boisdale Formation) in the Giffard GMU.</li> <li>• Located in the Seaspray depression area of interest.</li> <li>• Nested with 105483</li> </ul>
WRK059120	Upper Tertiary Aquitard (106)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and key rivers and wetlands</li> <li>• Nested with WRK059119 and will inform groundwater chemistry of multiple aquifers at one location and will inform potential for mixing.</li> <li>• Located in Seaspray Depression area of interest</li> </ul>
WRK059119	Upper Mid-Tertiary Aquitard (108)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and key rivers and wetlands</li> <li>• Nested with WRK059119 and will inform groundwater chemistry of multiple aquifers at one location and will inform potential for mixing.</li> <li>• Located in Seaspray Depression area of interest</li> </ul>
64835	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>• Located in Seaspray Depression area of interest</li> </ul>
67442	Upper Tertiary Aquifer (fluvial) (105)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and key rivers and wetlands</li> <li>• Monitors the target aquifer (Boisdale Formation) in the Sale GMU</li> <li>• Located along Rosedale Fault</li> </ul>
67441	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 (Latrobe Group) in the Stratford GMU</li> <li>• Located along Rosedale Fault</li> </ul>
90148	Upper Tertiary Aquifer (fluvial) (105)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and key rivers and wetlands</li> <li>• Monitors the target aquifer (Boisdale Formation) in the Sale GMU</li> <li>• Located in the lake wellington depression area of interest and hydrocarbon seep</li> </ul>
145093	Upper Tertiary Aquifer (fluvial) (105)	<ul style="list-style-type: none"> <li>• Located in the area of prospectivity and key rivers and wetlands, including Ramsar listed Lake Reeve</li> <li>• Monitors the target aquifer (Boisdale Formation) in the Giffard GMU</li> </ul>
90323	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>• Located along Rosedale Fault area of interest</li> </ul>
WRK059121	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>• Located outside of sub regional prospectivity</li> <li>• Located along Darriman Fault</li> <li>• Located outside of regional seal</li> </ul>

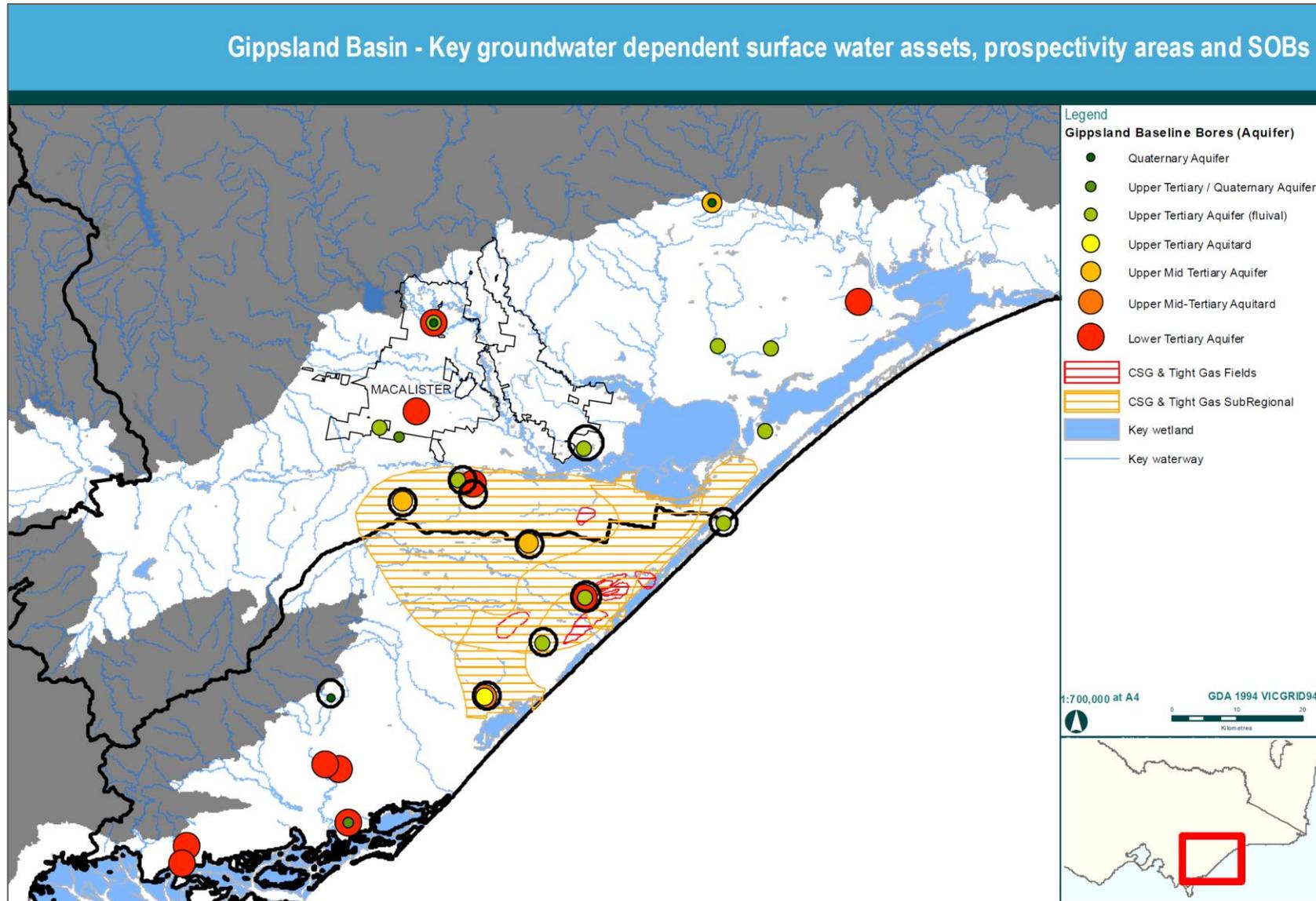


Figure 10 Prospective natural gas areas, key assets and selected monitoring bores to target surface water assets (black circles)

Gippsland region groundwater sampling and characterisation for hydrocarbons

## 3.3 Aquifers

Across Victoria, aquifers with either a high potential or actual use, are covered by Groundwater Management Areas (GMAs) and Water Supply Protection Areas (WSPAs). In the Gippsland region there are a number of proclaimed groundwater areas (Table 2). The targeted state observation bores are shown in Figure 11 with the objective to provide coverage of the target aquifer in each of the proclaimed areas. A summary of the state observation bores that target each of these high value areas and aquifers is listed in Table 3.

In order to obtain adequate coverage of the watertable aquifer in the Macalister irrigation district the West Gippsland CMA was approached for access to their network of shallow groundwater monitoring bores. Access was granted and these bores have been included in the bore selection process.

**Table 2 GMAs and WSPAs in the Gippsland region**

GCU	GMA/WSPA	Target Aquifer	Code
Central Gippsland	Wa De Lock	Quaternary Alluvium	100
Central Gippsland	Denison	Quaternary Alluvium	100
Central Gippsland	Wy Yung	Quaternary Alluvium	100
Central Gippsland	Sale	Boisdale Formation	105
Central Gippsland/Seaspray	Giffard	Boisdale Formation	105
Central Gippsland	Rosedale	Balook Formation	107
Central Gippsland/Seaspray	Stratford	Latrobe Group	111
Central Gippsland/Seaspray	Yarram	Latrobe Group	111

## Onshore natural gas water science studies

**Table 3 Summary of selected state observation bore in aquifers of high potential or actual use**

GMA/WSPA	Target Aquifer	Code	Bore
Wa De Lock	Quaternary Alluvium	100	<ul style="list-style-type: none"> <li>• 95489</li> </ul>
Denison	Quaternary Alluvium	100	<ul style="list-style-type: none"> <li>• No 100 bores (45762 is a 102 bore)</li> </ul>
Wy Yung	Quaternary Alluvium	100	<ul style="list-style-type: none"> <li>• 105479 (100 AQ)</li> </ul>
Sale	Boisdale Formation	105	<ul style="list-style-type: none"> <li>• 67442*</li> <li>• 90148*</li> <li>• 90615</li> <li>• 140691</li> <li>• 140692</li> </ul>
Giffard	Boisdale Formation	105	<ul style="list-style-type: none"> <li>• 105484</li> <li>• 145092</li> <li>• 145093*</li> </ul>
Rosedale	Balook Formation	107	<ul style="list-style-type: none"> <li>• No Balook state observation bore is available</li> </ul>
Stratford	Latrobe Group	111	<ul style="list-style-type: none"> <li>• 47063</li> <li>• 58937</li> <li>• 67441*</li> </ul>
Yarram	Latrobe Group	111	<ul style="list-style-type: none"> <li>• 110724</li> <li>• 147173</li> <li>• WRK059110</li> <li>• WRK059112</li> <li>• 105483*</li> <li>• 105222</li> </ul>
Macalister ID	Watertable aquifer	100	<ul style="list-style-type: none"> <li>• 95489 (WG CMA bore targeting watertable aquifer)</li> </ul>

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

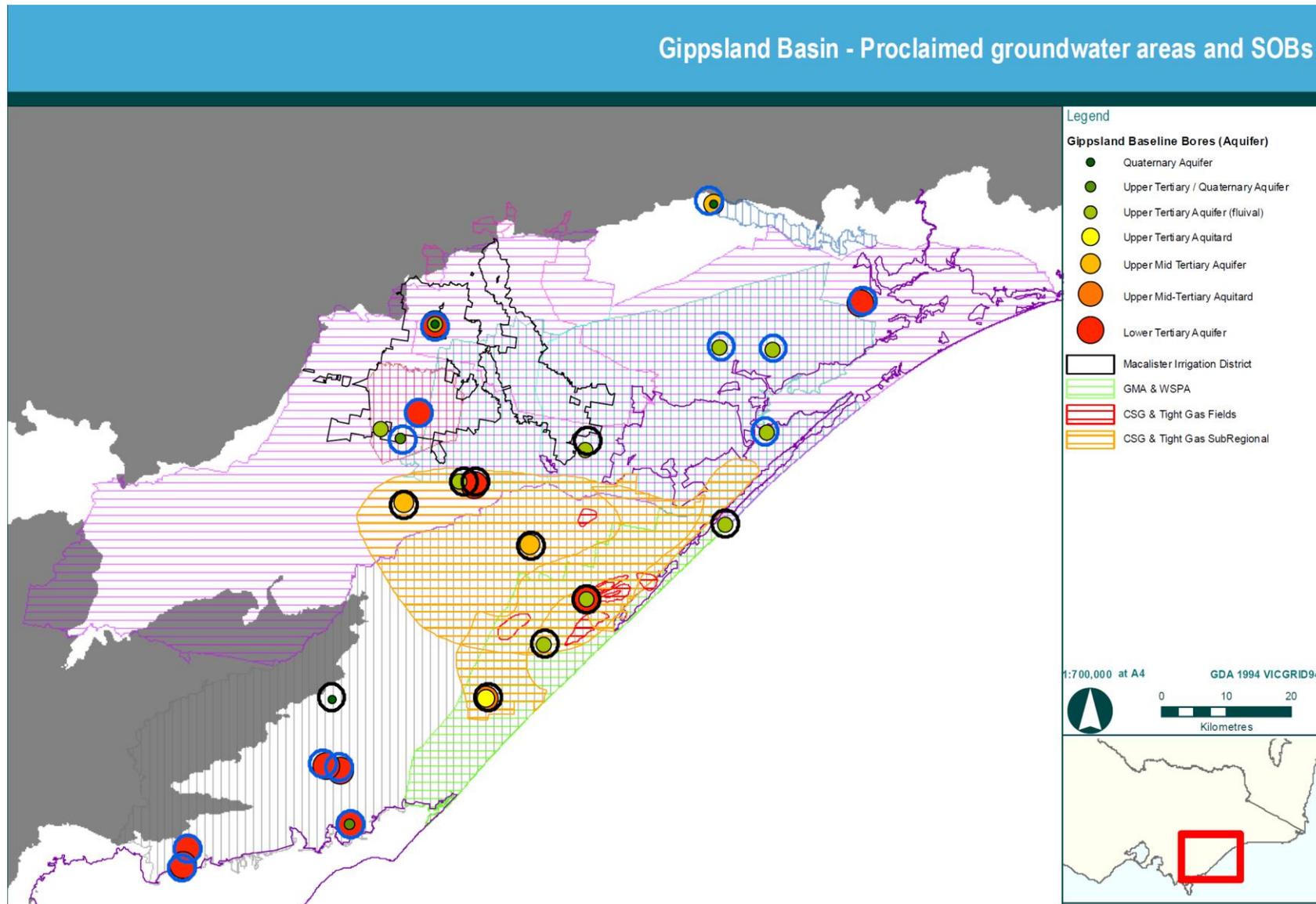


Figure 11 Prospective natural gas areas, groundwater management units and selected monitoring bores to target high value aquifers (blue circles)

Gippsland region groundwater sampling and characterisation for hydrocarbons

### 3.4 Naturally occurring hydrocarbon sites

The literature review presented in Section 2.2 identified a number of areas of naturally occurring hydrocarbons. These sites are shown in Figure 12 and recommended sampling bores targeting these sites are summarised in Table 4. The thickness of the Upper Mid Tertiary Aquitard is also shown in order to approximate the thin edge of the Lakes Entrance Formation (the aquitard seal overlying the Latrobe and Strzelecki Formation target units).

**Table 4 Summary of intersection between areas identified as potential hydrocarbon occurrence and selected monitoring bores**

Area	Bore	Justification
Near the Lake Bunga 1 bore	None in the vicinity	NA
The area around the northern part of the Gippsland Lakes where the Lakes Entrance Formation is thin or absent	WRK059126 (111 AQ)* WRK059127 (105 AQ) (nested site)*	Located where the regional seal is absent. Includes a Latrobe Aquifer bore and a Boisdale Fmn Aquifer bore
Lake Wellington Fault	103822 (105 AQ) 58937* (111 AQ) 140692* (105 AQ) 140691* (105 AQ)	Located along the Lake Wellington Fault and also comparison of Boisdale Fmn aquifer chemistry in area of absent regional seal
Lake Wellington Depression	90148* (105 AQ) 90615* (105 AQ)	Bores in vicinity of Lake Wellington
Rosedale Fault	67442* (105 AQ)* 67441* (111 AQ)*	Latrobe Group aquifer and Boisdale Aquifer along Rosedale Fault
Near the interpreted hydrocarbon seep (10 km southeast of Sale)	None in the vicinity	NA
Seaspray Depression	105483* 105484* WRK059120* WRK059119* 64835* 145092*	

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

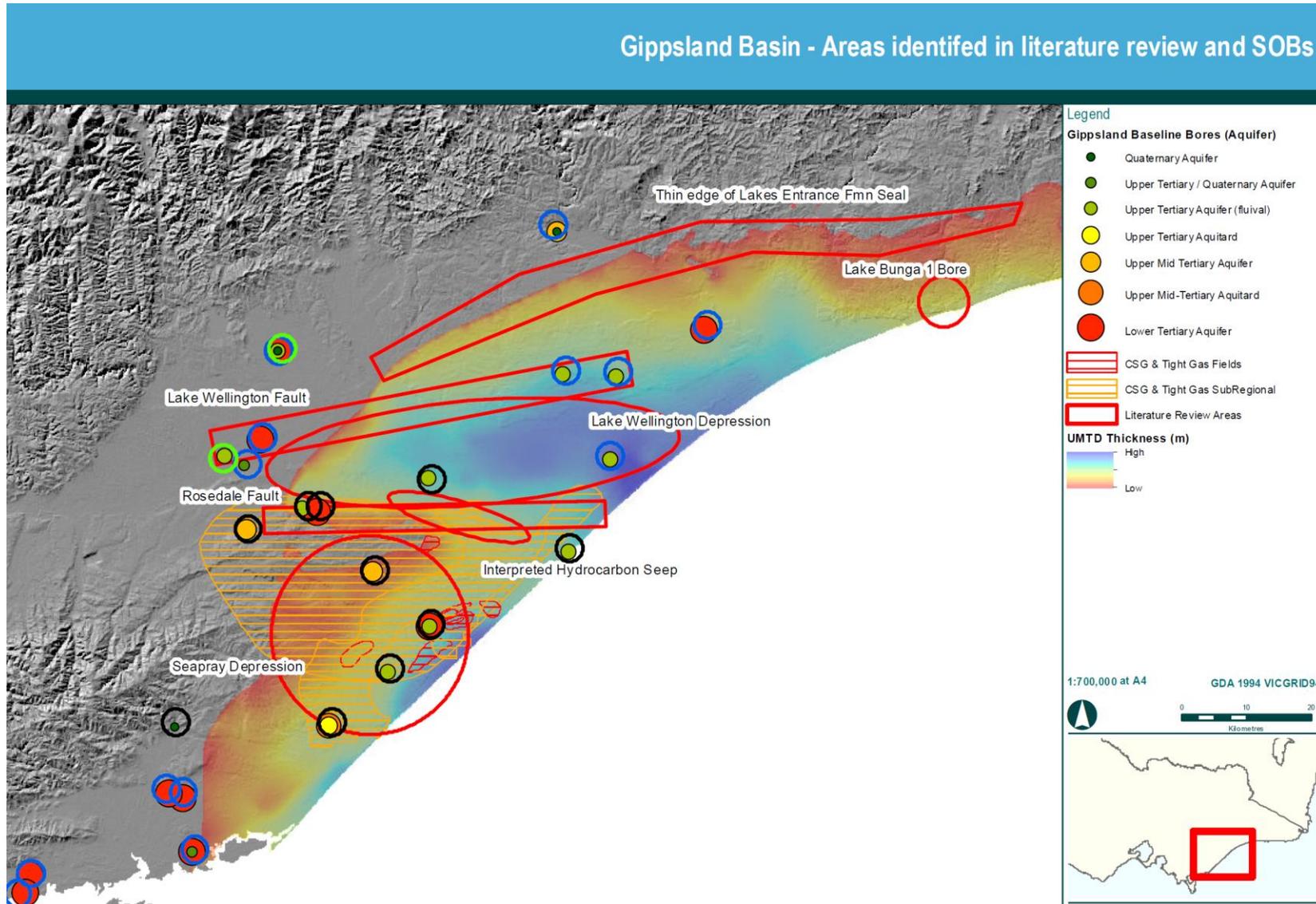


Figure 12 Areas identified in literature review and selected monitoring bores to target these areas of interest (green circles)

Recent work undertaken by DSDBI (2013) and field observations noted by DELWP, have identified hydrocarbon occurrences in groundwater bores and groundwater samples in the Gippsland region (summarised in Table 5). Bore 110724 was incorporated into the sampling program.

**Table 5 Hydrocarbon occurrences measured in groundwater bores and samples in the Gippsland region**

Bore ID	Details	Hydrocarbon Observation
109044 <sup>1</sup>	109044: screened in the 105 aquifer, located about 15 km north of Lake Wellington. This bore was removed from the working state observation bore list as it has a condition ranking of 5	Elevated hydrocarbons were measured in this bore and recommendation was made for a resample for hydrocarbons.
110724 <sup>1</sup>	Screened in the 111 aquifer, located near Port Welshpool in the Yarram WSPA and intersecting the regional tight gas prospectivity area.	
90400 <sup>2</sup>	Latrobe Group (111 AQ). Removed from the working state observation bore list because of a condition ranking of 5.	hydrocarbon sheen noted
90614 <sup>2</sup>	Latrobe Group (111 AQ). Removed from the working state observation bore list because of a condition ranking of 5.	>100% LEL
103583 <sup>2</sup>	Latrobe Group (111 AQ). Removed from the working state observation bore list because of a condition ranking of 5.	>100% LEL
110722 <sup>2</sup>	Balook Formation (107 AQ). Removed from the working state observation bore list because of a condition ranking of 5.	>100% LEL
110725 <sup>2</sup>	Latrobe Group (111 AQ). Removed from the working state observation bore list because of a condition ranking of 5.	7% LEL

<sup>1</sup>DSDBI (2013)

<sup>2</sup>DELWP – current state observation bore condition assessment project

## 3.5 Nested sites

Targeting nested bore sites for inclusion in the monitoring network will assist in the aquifer characterisation process and will also inform 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. groundwater dependent ecosystems). 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 was undertaken to identify the nested sites in the Gippsland region area to ensure relevant nested sites had been included in the network. Table 6 summarises the nested sites and notes whether they have been included in the monitoring program. Note that this table does not include an additional six sites where one or more of the bores within the nest was noted as having poor condition. In summary, four of the five available nested sites (with suitable bore condition records) were incorporated into the proposed monitoring network.

**Table 6 Summary of nested sites selected for the monitoring program**

Comment	Bore ID	AQ	Likely HGU
Yes - NESTED SITE 1	WRK059110	111	Latrobe Grp
	WRK059111	102	Haunted Hill
Yes - NESTED SITE 2	WRK059120	106	Hazelwood/Yallourn Formation
	WRK059119	108	Seaspray Group
Yes - NESTED SITE 3	WRK059126	111	Latrobe Grp
	WRK059127	105	Boisdale Fmn
Yes - NESTED SITE 4	105479	100	Quaternary Alluvium
	110978	107	Balook Fmn
No - COMMENTS SUGGEST THIS NEST LIKELY MONITORS SAME AQUIFER	WRK059121	100	Quaternary Alluvium
	WRK059122	102	Haunted Hill
	WRK059123	100	Quaternary Alluvium

### 3.6 Summary of selected monitoring network

Table 7 provides a summary of the selected bores for the Gippsland Monitoring network. A total of 30 bores have been selected and are shown in Figure 13. These bores provide the following information:

- groundwater near a prospectivity area
- groundwater near high potential groundwater dependent ecosystems (including Ramsar listed sites)
- groundwater near a proclaimed groundwater area
- groundwater near an 'area of interest' as identified in the literature review or recent field studies
- groundwater of multiple aquifers at a single site (i.e. nested sites).

The medium priority bores are those that met two of the selection criteria listed above. The low priority bores met only one of the selection criteria.

**Table 7 Summary of selected bores for the Gippsland monitoring network**

Bore	Aquifer Monitored	Justification for inclusion in the monitoring network
145092	Upper Tertiary Aquifer (fluvial) (105)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands</li> </ul>
90615	Upper Tertiary Aquifer (fluvial) (105)	<ul style="list-style-type: none"> <li>Located near Gippsland Lakes Ramsar site.</li> <li>Monitors the target aquifer (Boisdale Formation) in the Sale WSPA.</li> <li>Located in Lake Wellington Depression area of interest</li> </ul>
105484	Upper Tertiary Aquifer (fluvial) (105)	<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 (Boisdale Formation) in the Giffard GMU.</li> <li>Located in the Seaspray depression area of interest.</li> <li>Nested with 105483</li> </ul>
105483	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Monitors the target aquifer (Latrobe Group) in the Yarram GMU</li> <li>Located in the area of prospectivity and high value rivers and wetlands</li> <li>Located in the Seaspray depression area of interest.</li> <li>Nested with 105483</li> </ul>
WRK059120	Upper Tertiary Aquitard (106)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands</li> <li>Nested with WRK059119 and will inform groundwater chemistry of multiple aquifers at one location and will inform potential for mixing.</li> <li>Located in Seaspray Depression area of interest</li> </ul>
WRK059119	Upper Mid-Tertiary Aquitard (108)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands</li> <li>Nested with WRK059120 and will inform groundwater chemistry of multiple aquifers at one location and will inform potential for mixing.</li> <li>Located in Seaspray Depression area of interest</li> </ul>
64835	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>Located in Seaspray Depression area of interest</li> </ul>
67442	Upper Tertiary Aquifer (fluvial) (105)	<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 (Boisdale Formation) in the Sale GMU</li> <li>Located along Rosedale Fault</li> </ul>
67441	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 (Latrobe Group) in the Stratford GMU</li> <li>Located along Rosedale Fault</li> </ul>
WRK059111	Upper Tertiary/Quaternary Aquifer (102)	<ul style="list-style-type: none"> <li>Located near Ramsar listed corner inlet Nested with WRK059110</li> </ul>
WRK059110	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Monitors the target aquifer (Latrobe Group) in the Yarram WSPA</li> <li>Nested with WRK059111</li> </ul>
90148	Upper Tertiary Aquifer (fluvial) (105)	<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 (Boisdale Formation) in the Sale GMU</li> <li>Located in the lake wellington depression area of interest and hydrocarbon seep</li> </ul>
145093	Upper Tertiary Aquifer (fluvial) (105)	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands, including Ramsar listed Lake Reeve</li> <li>Monitors the target aquifer (Boisdale Formation) in the Giffard GMU</li> </ul>
45762	Upper Tertiary/Quaternary Aquifer (102)	<ul style="list-style-type: none"> <li>WG CMA bore targeting watertable aquifer in Denison GMU</li> <li>Located in the lake wellington fault area of interest</li> </ul>
105479	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>Monitors the watertable aquifer in the Wy Yung GMU and nested with 110978</li> </ul>
110978	Upper Mid-Tertiary Aquifer (107)	<ul style="list-style-type: none"> <li>Monitors the Upper Mid Tertiary Aquifer in the Wy Yung GMU</li> <li>Nested with 105479</li> </ul>

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Bore	Aquifer Monitored	Justification for inclusion in the monitoring network
147173	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Monitors the target aquifer (Latrobe Group) in the Yarram GMU and located in close proximity to Yarram township</li> </ul>
105222	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Monitors the target aquifer (Latrobe Group) in the Yarram GMU and located in close proximity to Yarram township</li> </ul>
95489	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>Located in the MID and nested with WRK059126 and WRK059127.</li> <li>Also located where the regional seal is absent</li> </ul>
WRK059126	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Located in the MID and forms nested site with 95489 and WRK059127</li> <li>Also located where the regional seal is absent</li> </ul>
WRK059127	Upper Tertiary Aquifer (fluvial) (105)	<ul style="list-style-type: none"> <li>Located in the MID and forms nested site with 95489 and WRK059126</li> <li>Also located where the regional seal is absent</li> </ul>
103822	Upper Tertiary Aquifer (fluvial) (105)	<ul style="list-style-type: none"> <li>Located along the Lake Wellington Fault</li> <li>Provides information on Boisdale Fmn aquifer chemistry in area of absent regional seal</li> </ul>
58937	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Located along the Lake Wellington Fault</li> </ul>
140692	Upper Tertiary Aquifer (fluvial) (105)	<ul style="list-style-type: none"> <li>Located along the Lake Wellington Fault</li> <li>Provides information on Boisdale Fmn aquifer chemistry in area of regional seal</li> </ul>
140691	Upper Tertiary Aquifer (fluvial) (105)	<ul style="list-style-type: none"> <li>Monitors the target aquifer (Boisdale Formation) in the Sale GMU</li> <li>Located along the Lake Wellington Fault in the vicinity of bore 109044 which had elevated hydrocarbon readings but could not be sampled due to poor bore condition.</li> </ul>
110724	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Elevated hydrocarbons were measured in this bore and recommendation was made for a resample for hydrocarbons.</li> <li>Located along Forster Fault.</li> </ul>
47063	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Monitors the target aquifer (Latrobe Group) in the Stratford GMU</li> </ul>
90323	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>Located along Rosedale Fault area of interest</li> </ul>
WRK059112	Lower Tertiary Aquifer (111)	<ul style="list-style-type: none"> <li>Monitors the target aquifer (Latrobe Group) in the Yarram WSPA</li> <li>Located along Forster Fault.</li> </ul>
WRK059121	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>Located outside of sub regional prospectivity</li> <li>Located along Darriman Fault</li> <li>Located outside of regional seal</li> </ul>

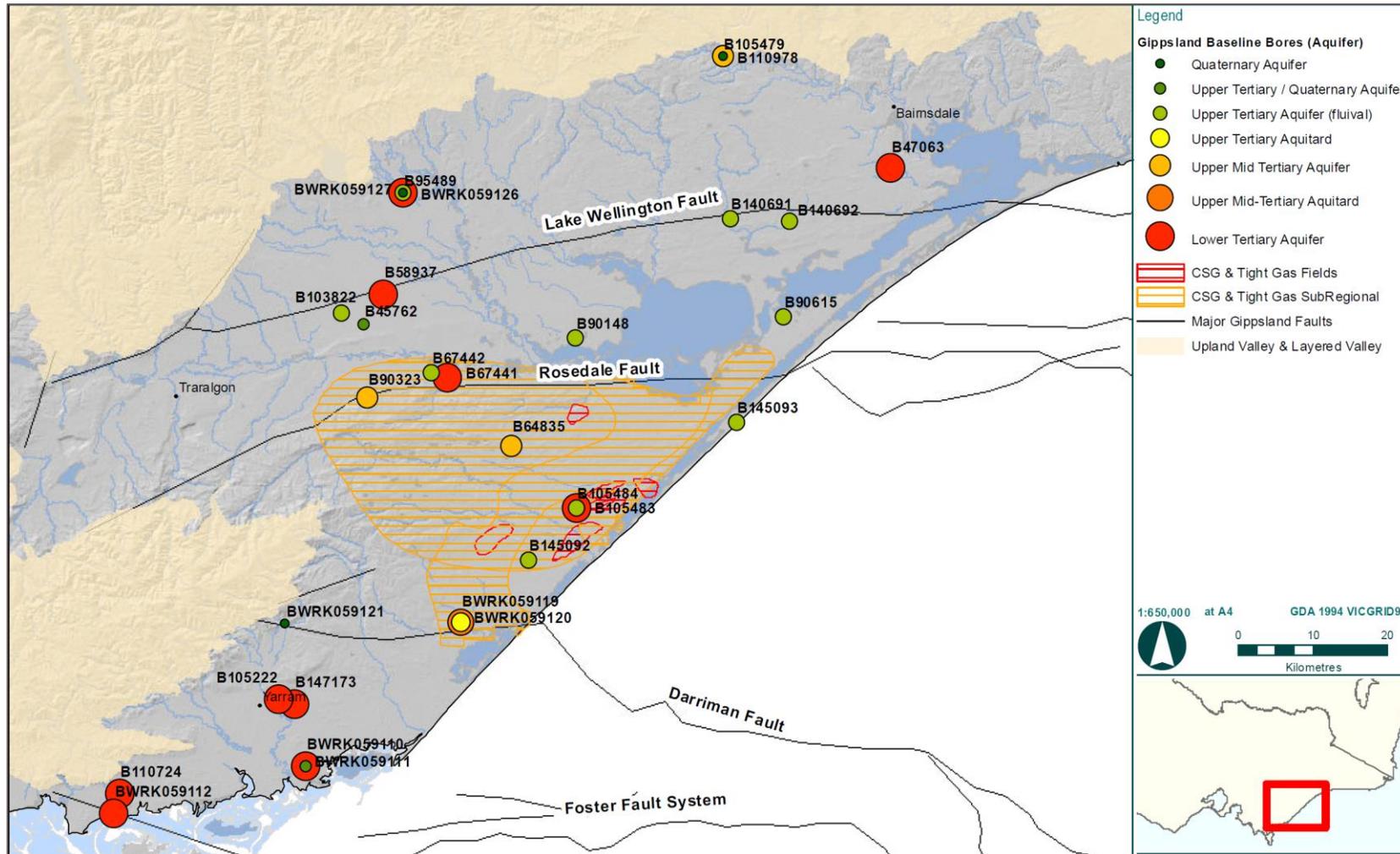


Figure 13 Locations of Gippsland region monitoring bores

## 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 developed for this project, 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 14 and examples of gas collection and sampling setup is shown in Figure 15 and Figure 16. 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.

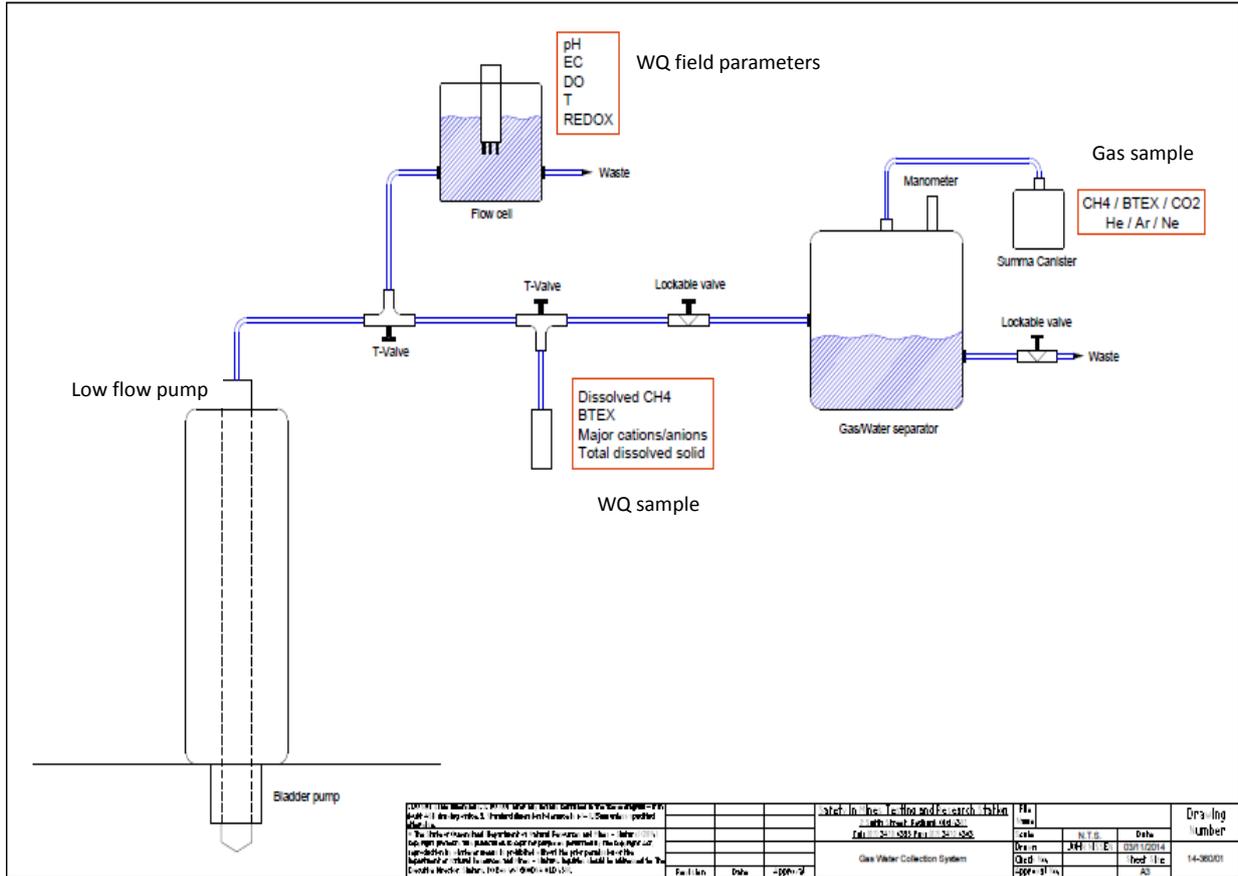


Figure 14 Flow diagram showing water sample collection, field parameter measurement and gas sample collection



Figure 15 Example of gas collection and sampling procedure in the field



*Figure 16 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/quality assurance types

Water quality sampling from all bores included in this program was undertaken in accordance with HydroTerra standard operating procedures (Appendices A and B), 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 included 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 is 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 8.

**Table 8 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.

## 5.3 QA/QC assessment

Duplicate samples were collected for three bores (WRK059112, WRK059120 and WRK059127). The calculated RPD values were within the guideline value of 30% to 50% and therefore, there is no concern regarding consistency of the sampling technique or laboratory analysis procedures.

Analysis of the two rinsate samples collected shows that the rinsate water does not contain any analytes which would impact on the results of the groundwater samples.

Analysis of the eight trip blank samples for hydrocarbons showed that no contamination occurred during transportation.

## 6 Groundwater sampling – summary of results

A total of 30 bores were sampled in the first round of Gippsland bore sampling. An error occurred in the sampling of one of these bores (90615) associated with bore location and hence the results obtained from this sample have been removed from analysis. The bores were sampled between 9th December 2014 and 17th January 2015. The second round of sampling was undertaken in March 2015 and the third round is scheduled to be undertaken in June 2015. This report will be up-dated with Round 2 and 3 results including any conclusions on temporal variations after all sampling is completed. The interpretation of Round 1 results focuses on spatial variations of analytes (both between aquifers and within aquifers).

The chemistry results as obtained from ALS Environmental are included in Appendix D.

### 6.1 Semi-volatile organic compounds

Seven dissolved Semi-volatile Organic Compound (SVOCs) were analysed in water samples, including; methane, ethane, propane, butane, propene, butane and ethene. Of these analytes multiple observations were recorded for dissolved methane and there was no detection of the other SVOCs in groundwater. The methane concentrations observed across the Gippsland region ranged from 0 mg/L to 33.4 mg/L. The median concentration is 2.4 mg/L.

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

Figure 17 shows the spatial distribution of the dissolved methane concentrations in analysed water samples detected across the Gippsland region.

Methane levels in each aquifer are summarised below.

#### **Lower Tertiary Aquifer (Latrobe Group) (111)**

Ten groundwater samples were collected from the Latrobe Group Aquifer and nine of the ten samples recorded dissolved methane. Six of the samples recorded concentrations less than 10 mg/L. The maximum concentration recorded was 33 mg/L.

The three high methane concentrations in groundwater associated with the Latrobe Group Aquifer occur to the southwest of the region, in close proximity to the township of Yarram and near the Foster Fault System.

Methane gas was detected in gas samples collected at the surface in five of the ten samples from the Lower Tertiary Aquifer. All samples with detected methane gas also had significant concentrations of dissolved methane in water samples.

#### **Upper Mid-Tertiary Aquitard (Seaspray Gp including Lakes Entrance Formation) (108) and Upper Tertiary Aquitard (Jemmys Point Formation/Yallourn Fm/ Hazelwood Fm) (106)**

A single groundwater sample was collected from the two aquitard units. There was no methane detected in the Upper Mid-Tertiary Aquitard and a low concentration (0.12 mg/L) was detected in the Upper Tertiary Aquitard.

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### **Upper Mid-Tertiary Aquifer (Balook Formation/ Latrobe Valley Coal Measures) (107)**

Three groundwater samples were collected from the Upper Mid-Tertiary Aquifer and the dissolved methane ranged from not detected in groundwater to 5.1 mg/L.

### **Upper Tertiary Aquifer (105)**

Nine groundwater samples were collected from the Upper Mid-Tertiary Aquifer. Seven of the samples were collected from areas where the aquifer resides above the Upper Mid-Tertiary Aquitard (Lakes Entrance Formation) and two of the samples were collected where the Aquitard is absent.

Where the aquitard was present the average methane concentration was 1.8 mg/L and where it is absent the average was 4.7 mg/L.

### **Quaternary Aquifer (100) and Upper Tertiary/Quaternary Aquifer (Haunted Hills Formation) (102)**

Five groundwater samples were collected from the shallow Quaternary Aquifer and Haunted Hills Formation Aquifer. Four samples did not detect any methane in groundwater and a single sample recorded 0.4 mg/L.

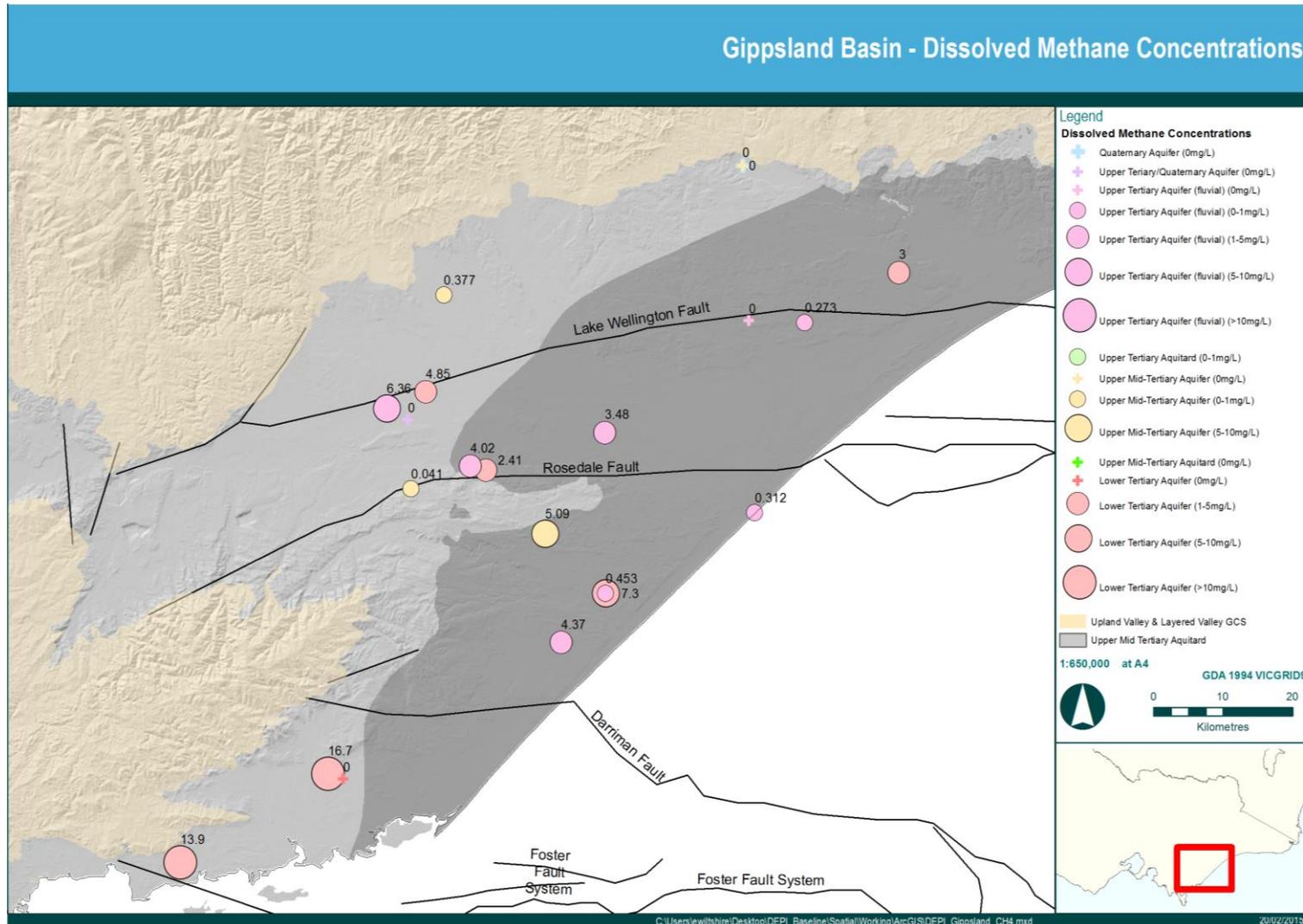


Figure 17 Distribution of dissolved methane concentration by aquifer

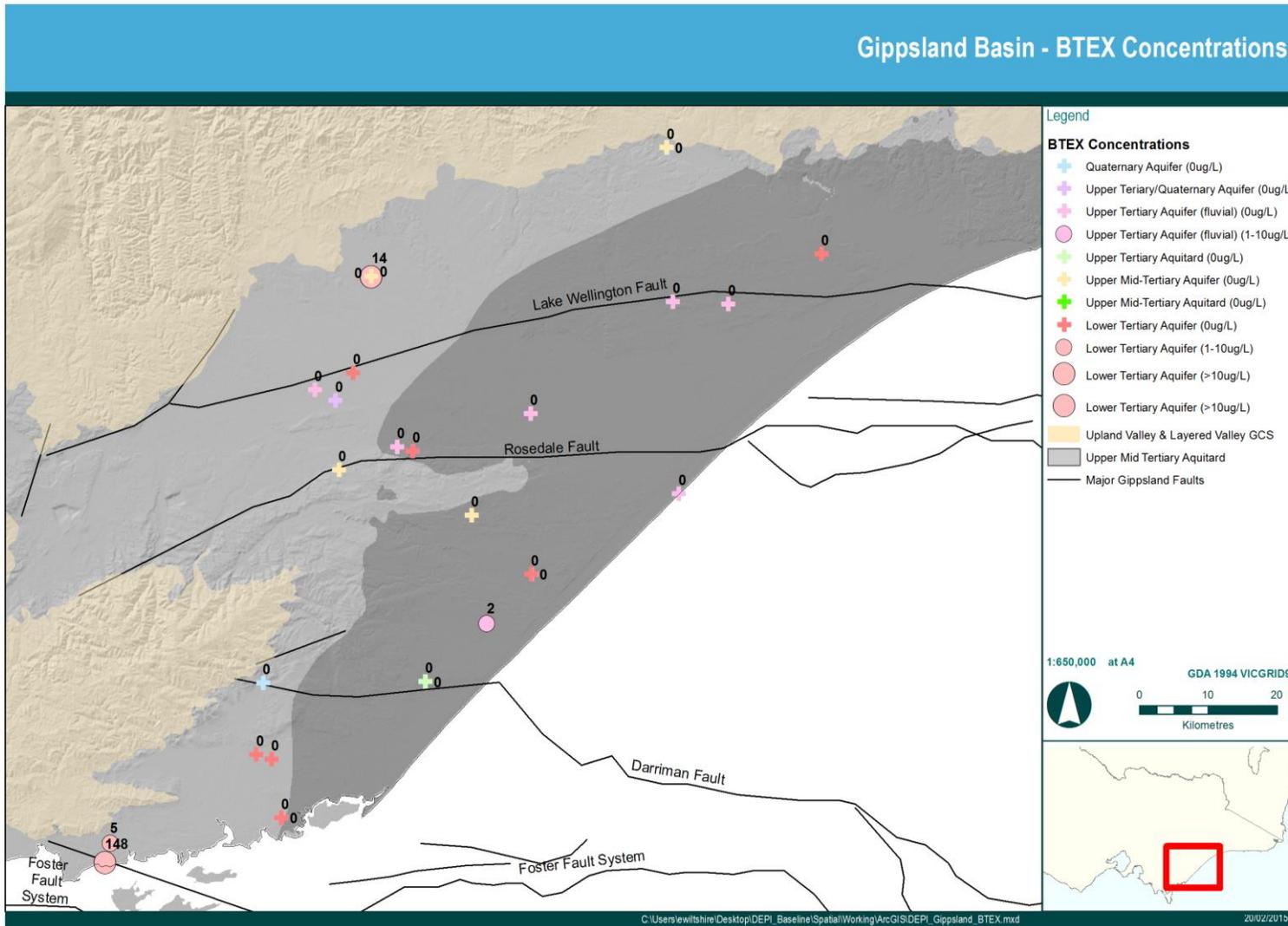


Figure 18 Distribution of BTEX results by aquifer

## 6.2 Total petroleum hydrocarbons

Total petroleum hydrocarbons (TPH) are defined as carbon chains in the range of C6 through C35. TPH in groundwater can be either naturally occurring or can have anthropogenic origins.

TPH was detected in 8 of the 30 bore sampled and 7 of these bores are screened in the coal bearing units of the Lower Tertiary Aquifer (Latrobe Group) and the Upper Mid-Tertiary Aquifer (Latrobe Valley Coal Measures and Balook Formation). The samples mostly contain hydrocarbons in the C10 to C28 fraction although this provides no evidence of source. Although no definitive conclusion can be drawn on the source of the hydrocarbons, the depth of the bores, the presence of coals and the likely lack of interaction with the surface, suggest a natural origin.

### 6.2.1 BTEX

All samples were analysed for the presence of Benzene, Toluene, Ethylbenzene, and Xylene (collectively known as BTEX). BTEX compounds are naturally found in crude oil, coal and gas deposits. The spatial distribution of analysed BTEX compounds in the analysed samples is given in Figure 18.

Four groundwater samples in the Gippsland region indicate the presence of a BTEX compound. Three of these bores are screened in the Lower Tertiary Aquifer (out of 10 Lower Tertiary Aquifer bores sampled) and one in the Upper Tertiary Aquifer (Boisdale Formation) (out of 10 Upper Tertiary Aquifer bores sampled). DSDBI (2013) also analysed three of these bores for BTEX and also recorded the presence of BTEX in groundwater samples.

These bores are screened in the Latrobe Group Aquifer and the Boisdale Formation Aquifer. Concentrations of Ethylbenzene, Toluene and Xylene are lower than guideline values for health; however concentrations of Benzene exceed health guidelines in two instances.

There are two potential sources of BTEX in groundwater: either contamination from an external source, or natural occurrence. One line of evidence to indicate that the BTEX is naturally occurring is that one sample was collected from an artesian bore, which reduces the likelihood of oil or petrol residue in the bore itself, generating the elevated reading. The readings suggest that BTEX may be naturally occurring in some areas of the Lower Tertiary Aquifer and possibly the Boisdale Formation.

## 6.3 Inorganic analytes and indicators

A number of inorganic analytes and indicators were analysed to help characterise the chemistry of each aquifer.

### 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. One method for characterising the geochemistry of aquifers is the use of Piper diagrams (Piper, 1953). A Piper diagram plot showing the ratios of the analysed cations and anions by aquifer is shown in Figure 19. Scholler diagrams have also been generated to analyse major ion chemistry for each aquifer (Figure 21).

These plots indicate that the aquifers show similar ranges for major ions with few outliers. The groundwater is of sodium chloride type. The aquitards show similar salinity to the aquifers' water, but contain significantly more magnesium and sulphate than the aquifers. Some samples show elevated sulphate and one of these samples is also acidic and has a high redox potential (bore 47063 from the Lower Tertiary Aquifer). This may indicate acid sulphate production at this bore.

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The Upper Tertiary Aquifer Fluvial and Lower Tertiary Aquifer had higher chloride to sulphate ratios due to low calcium and magnesium, not due to exchanges.

There are no vertical trends in major ion chemistry. The similarity of groundwater above and below the aquitards suggests lateral flow originates from a similar source and undergoes similar processes.

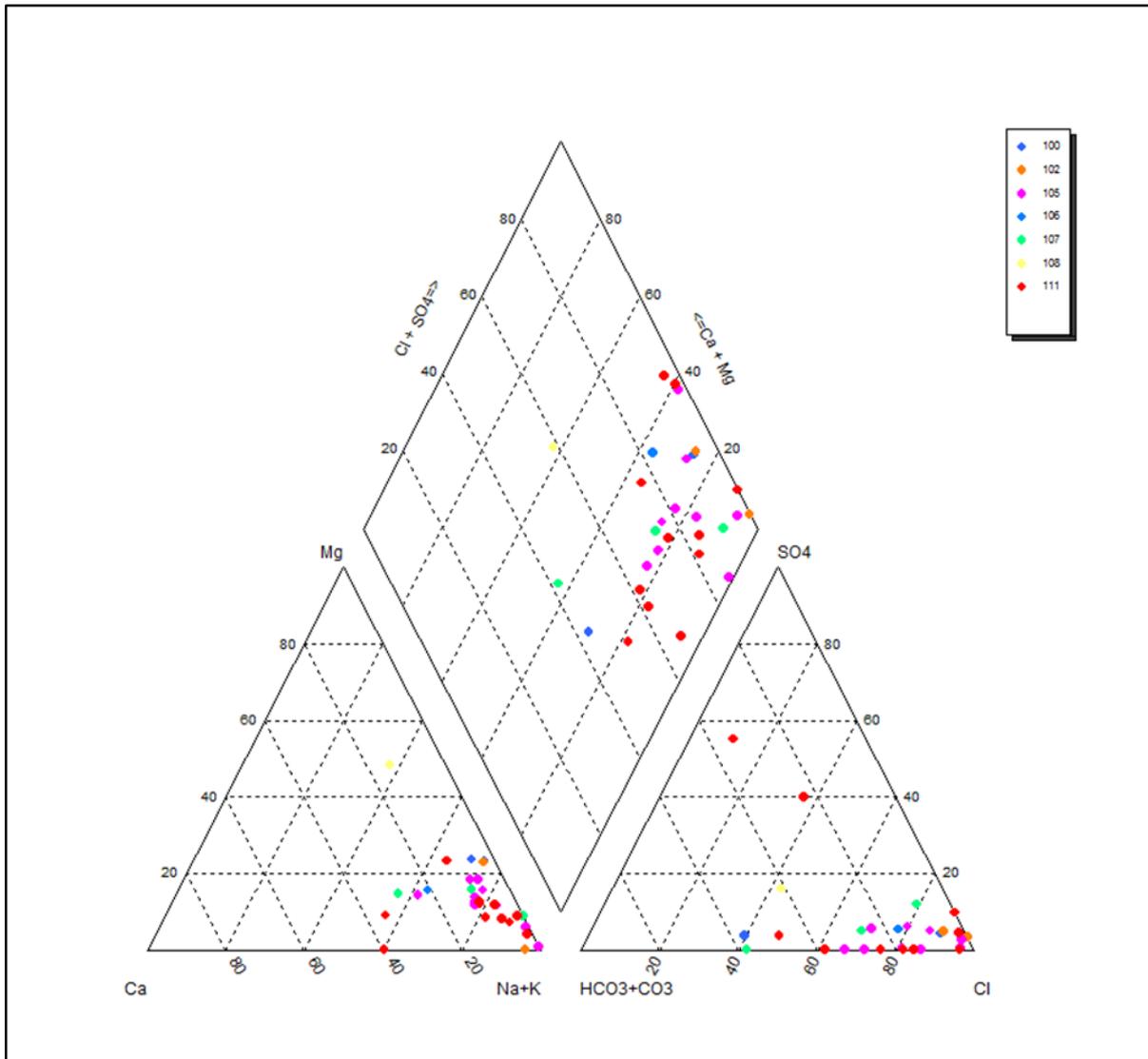


Figure 19 Piper diagram of major ion analyses by aquifer

# Onshore natural gas water science studies

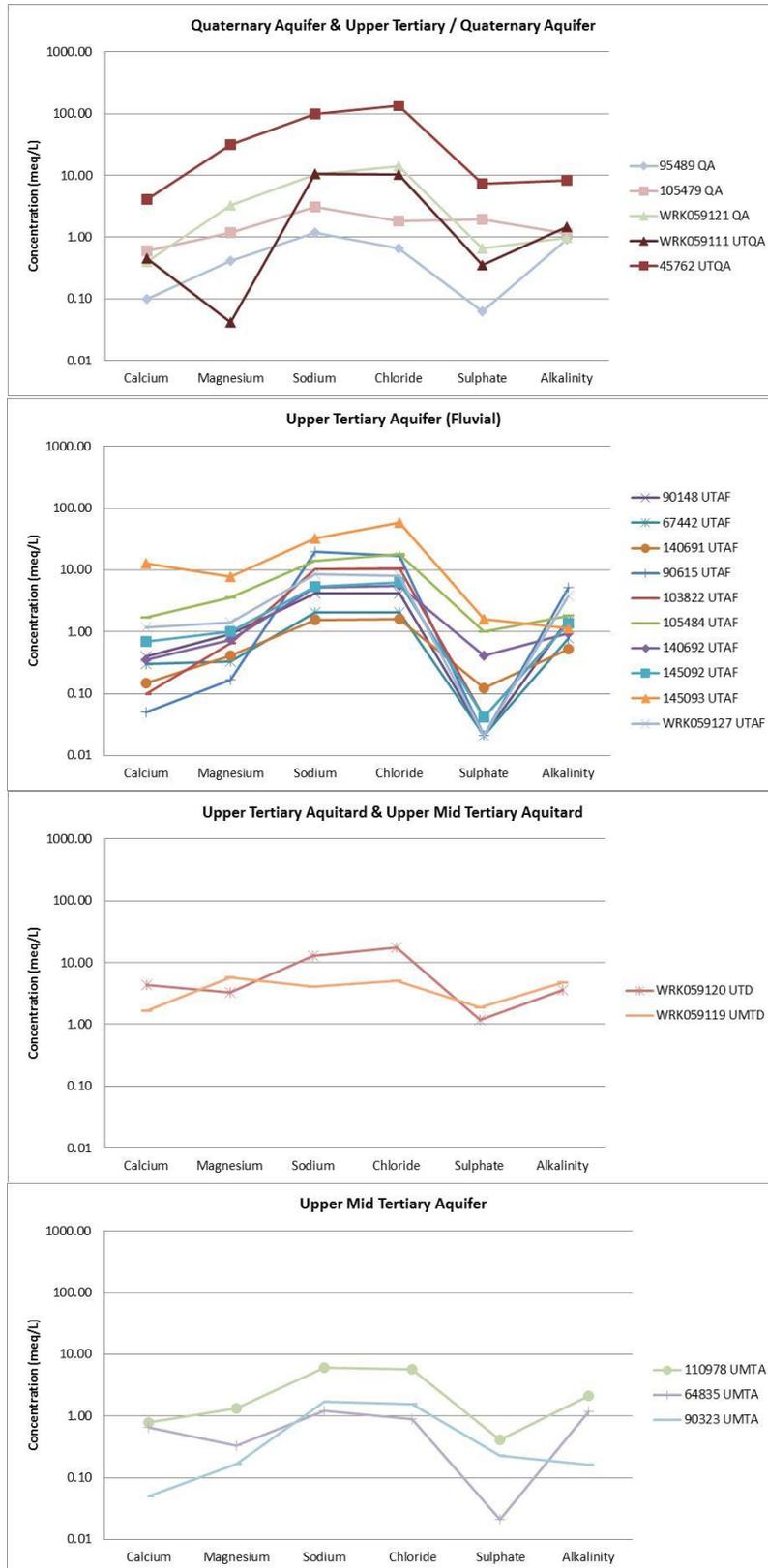


Figure 20A Schoeller diagrams showing major ion chemistry for each aquifer

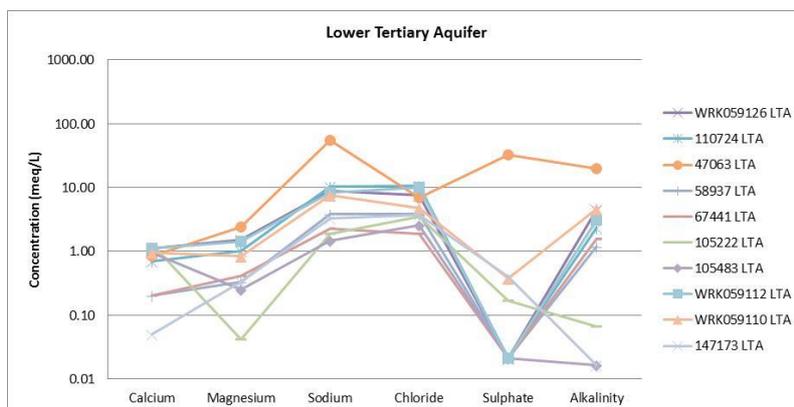


Figure 21B Schoeller diagrams showing major ion chemistry for each aquifer

### 6.3.3 Salinity

Groundwater salinity has been measured according to Total Dissolved Solids (TDS) concentration. The average groundwater salinity for all aquifers ranges from fresh to brackish (324 to 4,130 mg/L). The qualitative salinity classifications are according to the Water and Rivers Commission (1998). Groundwater salinity ranges per aquifer are summarised in Table 9.

Table 9 Summary of salinity results by aquifer (Total Dissolved Solids – TDS)

Aquifer	Number of bores sampled	Minimum Groundwater TDS (mg/L)	Maximum Groundwater TDS (mg/L)	Average Groundwater TDS (mg/L)
Quaternary Aquifer (100)	3	151	923	500
Upper Tertiary Quaternary Aquifer (102)	2	859	7,400	4,130
Upper Tertiary Aquifer (fluvial) (105)	9	239	5,090	1,057
Upper Mid Tertiary Aquitard (106)	1	1,250	1,250	1,250
Upper Mid Tertiary Aquifer (107)	3	170	515	324
Upper Mid Tertiary Aquitard (108)	1	773	773	773
Lower Tertiary Aquifer (111)	10	252	3,620	821

### 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 are summarised by aquifer in Table 10. The highest nitrogen content was found in samples taken from the Quaternary Aquifer (or watertable). This is an expected result given the likely leaching of nutrients through the unsaturated zone to the watertable from land which is often heavily fertilised (especially in the Macalister Irrigation District in the Sale/ Maffra area). Lower nitrogen levels were found in other aquifers although slightly higher values were found in the Lower Tertiary Aquifer which is likely to be an inherent characteristic of the aquifer rather than leaching from the surface. Natural Gas composition can include small quantities of nitrogen among other things.

Nahm (2002) indicated that nitrate provided significant variation in distinguishing aquifers in the Gippsland region. The results from this study are consistent with Nahm’s (2002) observations with significant variation in average nitrogen values between aquifers.

**Table 10 Summary of Nitrogen results by aquifer (total Nitrogen)**

Aquifer	Number of Samples Collected	Minimum Nitrogen (mg/L)	Maximum Nitrogen (mg/L)	Average Nitrogen (mg/L)
Quaternary Aquifer (100)	3	0.2	8.4	2.9
Upper Tertiary Quaternary Aquifer (102)	2	0.2	1.1	0.7
Upper Tertiary Aquifer (fluvial) (105)	9	0.2	1.6	0.6
Upper Mid Tertiary Aquitard (106)	1	0.0	0.0	0.0
Upper Mid Tertiary Aquifer (107)	3	0.2	0.7	0.4
Upper Mid Tertiary Aquitard (108)	1	0.7	0.7	0.7
Lower Tertiary Aquifer (111)	10	0.0	3.3	1.2

### 6.3.5 Field indicators

Field parameters were collected in the field including: pH, redox, dissolved oxygen, temperature and odour. Averages for each aquifer are summarised in Table 11.

The median Dissolved Oxygen (DO) concentration for each aquifer ranges from 0.3 to 2.6 mg/L (Table 11), 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 relatively high median dissolved oxygen value in the Lower Tertiary Aquifer combined with the relatively low median redox value possibly suggests limited microbial reduction of oxygen despite the apparent reducing conditions or movement of oxygen from overlying aquifers.

Average temperature for each aquifer is fairly consistent, ranging from 16.1 to 18°C (Table 11). No observation of increasing temperature with depth was observed.

Hydrogen sulphide odour was noted at three of the Lower Tertiary Aquifer bores (Table 11). Natural Gas composition can include hydrogen sulphide and so it is reasonable that the odour of this gas was detected where the major coal bearing aquifer was being sampled. Natural gas that contains significant amounts of hydrogen sulphide is often referred to as sour gas.

Groundwater pH ranges from weakly acidic (5.8) to weakly alkali (8.6) across the aquifer in the Gippsland region (Table 11).

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**Table 11 Summary of indicator parameters collected in the field**

Aquifer	Average pH	Median Redox (mV)	Median DO (mg/L)	Average Temperature (° C)	Odour
Quaternary Aquifer (100)	5.8	53	1.29	16.6	Three occurrences of hydrogen sulphide (egg) odour in the 111 aquifer only.
Upper Tertiary Quaternary Aquifer	8.6	25.7	2.35	16.6	
Upper Tertiary Aquifer (fluvial) (105)	6.6	-66.7	0.32	18.0	
Upper Mid Tertiary Aquitard (106)	6.2	12	0.29	16.5	
Upper Mid Tertiary Aquifer (107)	6.1	-59.7	0.74	17.2	
Upper Mid Tertiary Aquitard (108)	7.5	-158	0.67	16.1	
Lower Tertiary Aquifer (111)	7.4	-73.5	2.58	17.5	

## 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) and Upper Tertiary/Quaternary Aquifer (102)

The Quaternary Aquifer and the Upper Tertiary Quaternary Aquifer contain the watertable. Five watertable bores were sampled and comments on the results are provided in Table 12.

The salinity of the five sampled watertable bores is variable, ranging from 151 mg/L to 7,400 mg/L. The analysis indicates that the salinity is sodium chloride dominated. Four of the bores record salinity <1,000 mg/L TDS and only a single bore located in the Macalister Irrigation District has returned a significantly higher salinity value.

There is no detection in any of the measured organic compounds in four of the five watertable bores sampled, suggesting that the upwards migration of organic compounds from deeper coal bearing units does not reach the watertable. The exception is bore 95489 located north-west of Maffra where methane was detected but in concentrations less than the underlying Upper Tertiary Aquifer and Lower Tertiary Aquifer. This is likely to be a result of the absence of the regional Upper Mid-Tertiary Aquifer seal and/or the relatively shallow depth of the Lower Tertiary Aquifer at this site (less than 100 m from the surface). The methane results for the watertable are consistent with the conceptual model that the Upper Mid-Tertiary Aquitard inhibit upwards groundwater movement and areas of aquitard absence are likely to exhibit greater inter-aquifer connection.

**Table 12 Summary of Round 1 results for sampled watertable bores**

Bore	Aquifer Monitored	Justification for inclusion in the monitoring network	Comments
WRK059111	Upper Tertiary/Quaternary Aquifer (102)	<ul style="list-style-type: none"> <li>Located near Ramsar listed Corner Inlet.</li> <li>Nested with WRK059110</li> </ul>	<ul style="list-style-type: none"> <li>No organics detected suggesting no upwards migration of compounds from underlying coal bearing units despite being on edge of aquitard extent</li> <li>Relatively high alkalinity</li> </ul>
45762	Upper Tertiary/Quaternary Aquifer (102)	<ul style="list-style-type: none"> <li>WG CMA bore targeting watertable aquifer in Denison GMU</li> <li>Located in the lake wellington fault area of interest</li> </ul>	<ul style="list-style-type: none"> <li>No organics detected suggesting no upwards migration of compounds from underlying coal bearing units despite being west of aquitard extent and over Lake Wellington Fault</li> <li>Salinity is sodium chloride dominated</li> </ul>
105479	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>Monitors the watertable aquifer in the Wy Yung GMU</li> <li>Nested with 110978 (Balook)</li> </ul>	<ul style="list-style-type: none"> <li>No organics detected suggesting no upwards migration of compounds from underlying coal bearing units despite being west of aquitard extent and over Lake Wellington Fault</li> </ul>
WRK059121	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>Located outside of subregional prospectivity</li> <li>Located along Darriman Fault</li> <li>Located outside of regional seal</li> </ul>	<ul style="list-style-type: none"> <li>No organics detected suggesting no upwards migration of compounds from underlying coal bearing units despite being west of aquitard extent and over Darriman Fault</li> </ul>
95489	Quaternary Aquifer (100)	<ul style="list-style-type: none"> <li>Located in the MID</li> <li>Nested with WRK059126 and WRK059127.</li> <li>Also located where the regional seal is absent</li> </ul>	<ul style="list-style-type: none"> <li>Methane detected although lower concentration than bores in deeper Lower Tertiary Aquifer and Upper Tertiary Aquifer at the same site suggesting upwards decay in methane levels</li> <li>Bore located in area where Lower Tertiary Aquifer is closest to the surface relative to the other bores.</li> </ul>

## 7.2 Upper Tertiary Aquifer (fluvial) (105)

In the Gippsland region, the Upper Tertiary Aquifer (fluvial) consists of the Wurruk Sand member of the Boisdale Formation. A total of nine bores screened in the Upper Tertiary Aquifer were sampled and comments on the results are provided in Table 13.

Methane concentrations were detected in most samples and are either sourced from the aquifer itself, or the result of upwards migration from underlying aquifers. Given that the Wurruk Sand member of the Boisdale Formation is a fluvial unit and contains little carbonaceous material, the most likely source is the underlying coal bearing units of the Upper Mid-Tertiary Aquifer (where present) or the Lower Tertiary Aquifer. The higher average methane concentration for the two samples collected away from the Upper Mid-Tertiary Aquitard seal relative to eight samples collected above the aquitard suggests that the aquitard is restricting upwards movement although this is a tentative conclusion based on a small sample size.

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**Table 13 Summary of Round 1 results for sampled Upper Tertiary Aquifer bores (Boisdale Formation)**

Bore	Justification for inclusion in the monitoring network	Comments
145092	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands</li> </ul>	<ul style="list-style-type: none"> <li>Methane concentration detected but significantly lower concentration than underlying Lower Tertiary Aquifer suggesting some upwards leakage of methane through Lower Tertiary Aquitard seal</li> <li>Minor concentration of BTEX – anomalous relative to lack of detection in any other Upper Tertiary Aquifer bore</li> </ul>
90615	<ul style="list-style-type: none"> <li>Located near Gippsland Lakes Ramsar site.</li> <li>Monitors the target aquifer (Boisdale Formation) in the Sale WSPA.</li> <li>Located in Lake Wellington Depression area of interest</li> </ul>	<ul style="list-style-type: none"> <li>Groundwater sample not included in the analysis due to an error in the sample location.</li> <li>Other analyses undertaken at the same time by RMIT at the correct location indicate a methane concentration of 0.11mg/L. The negligible methane concentration suggests little or no upwards leakage of methane through Lower Tertiary Aquitard seal which is particularly thick in this area.</li> </ul>
105484	<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 (Boisdale Formation) in the Giffard GMU.</li> <li>Located in the Seaspray depression area of interest.</li> <li>Nested with 105483</li> </ul>	<ul style="list-style-type: none"> <li>Methane concentration detected but significantly lower concentration than Lower Tertiary Aquifer bore 105483 at the same site suggesting some upwards leakage of methane through Lower Tertiary Aquitard seal</li> <li>No other organics detected</li> </ul>
67442	<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 (Boisdale Formation) in the Sale GMU</li> <li>Located along Rosedale Fault</li> </ul>	<ul style="list-style-type: none"> <li>Methane concentration detected were slightly lower than nearby Lower Tertiary Aquifer bore 67441 at the same site suggesting some upwards leakage of methane through regional seal</li> <li>Suggests the location on western edge of seal is providing a vertical conduit for methane</li> </ul>
90148	<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 (Boisdale Formation) in the Sale GMU</li> <li>Located in the lake wellington depression area of interest and hydrocarbon seep</li> </ul>	<ul style="list-style-type: none"> <li>Methane concentration of 3.48 mg/L suggests suggesting some upwards leakage of methane through Lower Tertiary Aquitard seal (or small amounts of methane sourced from the aquifer itself which is unlikely given the lack of organic material in the aquifer)</li> <li>No other organics detected</li> </ul>
145093	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and high value rivers and wetlands, including Ramsar listed Lake Reeve</li> <li>Monitors the target aquifer (Boisdale Formation) in the Giffard GMU</li> </ul>	<ul style="list-style-type: none"> <li>Methane concentration of 0.312 mg/L suggests suggesting possible upwards leakage of methane through Lower Tertiary Aquitard seal although smaller concentrations relative to other bores away from seal suggest seal is restricting vertical flow</li> <li>No other organics detected</li> <li>Anomalously high calcium result</li> </ul>

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Bore	Justification for inclusion in the monitoring network	Comments
WRK059127	<ul style="list-style-type: none"> <li>Located in the MID and forms nested site with 95489 and WRK059126</li> <li>Also located where the regional seal is absent</li> </ul>	<ul style="list-style-type: none"> <li>Methane concentration is lower than underlying Lower Tertiary Aquifer bore WRK059126 and higher than overlying Upper Mid-Tertiary Aquifer bore 95489 suggesting an upward migration of methane</li> <li>No other organics detected</li> </ul>
103822	<ul style="list-style-type: none"> <li>Located along the Lake Wellington Fault</li> <li>Provides information on Boisdale Fmn aquifer chemistry in area of absent regional seal</li> </ul>	<ul style="list-style-type: none"> <li>Methane elevated relative to Boisdale bores overlying Lower Tertiary Aquitard seal suggesting absence of seal and/or presence of fault maybe promoting upwards migration of methane</li> <li>No other organics detected</li> </ul>
140692	<ul style="list-style-type: none"> <li>Located along the Lake Wellington Fault</li> <li>Provides information on Boisdale Fmn aquifer chemistry in area of regional seal</li> </ul>	<ul style="list-style-type: none"> <li>Small methane concentration suggesting small amount of leakage from underlying coal bearing formations</li> <li>No other organics detected</li> </ul>
140691	<ul style="list-style-type: none"> <li>Monitors the target aquifer (Boisdale Formation) in the Sale GMU</li> <li>Located along the Lake Wellington Fault in the vicinity of bore 109044 which had elevated hydrocarbon readings but could not be sampled due to poor bore condition.</li> </ul>	<ul style="list-style-type: none"> <li>No detected methane suggesting effectiveness of Lower Tertiary Aquitard for sealing underlying coal bearing deposits</li> <li>No other organics detected</li> </ul>

### 7.3 Upper Tertiary Aquitard (106) and Upper Mid-Tertiary Aquitard (108)

One Upper Tertiary Aquitard bore and one Upper-Mid Tertiary Aquitard bore was sampled and comments on the results are provided in Table 14.

**Table 14 Summary of Round 1 results for sampled Upper Tertiary Aquitard bore**

Bore	Justification for inclusion in the monitoring network	Comments
WRK059120 (106) and WRK059119 (108)	<ul style="list-style-type: none"> <li>These two bores are nested</li> <li>Located in the area of prospectivity and high value rivers and wetlands</li> <li>Located in Seaspray Depression area of interest</li> </ul>	<ul style="list-style-type: none"> <li>Methane concentration for 106 bore is low (0.122 mg/L)</li> <li>Methane not detected for 108 bore</li> <li>Possible methane source within the Upper Tertiary Aquitard (106) although concentrations suggest only a minor source</li> <li>No other organics detected</li> </ul>

## 7.4 Upper Mid-Tertiary Aquifer (107)

The Upper Mid-Tertiary Aquifer contains the Balook Formation and the Latrobe Valley Coal Measures (Yarragon and Yallourn Formations). Three bores were sampled screening the Upper Mid-Tertiary Aquifer and comments on the results are provided in Table 15.

**Table 15 Summary of Round 1 results for sampled Upper Mid-Tertiary Aquifer bores**

Bore	Justification for inclusion in the monitoring network	Comments
64835	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and key rivers and wetlands</li> <li>Located in Seaspray Depression area of interest</li> </ul>	<ul style="list-style-type: none"> <li>Methane concentration of 5.09 mg/L is likely to be sourced from either leakage from underlying Lower Tertiary Aquifer and/or from local coal seams within the Latrobe Valley Coal Measures and Balook Formation</li> <li>No other organics detected</li> </ul>
90323	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and key rivers and wetlands</li> <li>Located along Rosedale Fault area of interest</li> </ul>	<ul style="list-style-type: none"> <li>Methane and TPH concentrations are likely to be sourced from coal seams within the aquifer</li> </ul>
110978	<ul style="list-style-type: none"> <li>Monitors the Upper Mid-Tertiary Aquifer in the Wy Yung GMU</li> <li>Nested with 105479 (watertable aquifer bore)</li> </ul>	<ul style="list-style-type: none"> <li>Methane was not detected in this bore or the overlying shallow bore with which it is nested.</li> <li>This is consistent with the conceptual model, given that the primary methane source (the Lower Tertiary Aquifer) is absent in this area.</li> </ul>

## 7.5 Lower Tertiary Aquifer (111)

The Lower Tertiary Aquifer includes the Traralgon Formation coals and sands and the Yarram Formation. A total of ten bores screened in the Lower Tertiary Aquifer were sampled. The Traralgon Formation coal seams within the Lower Tertiary Aquifer are potentially prospective for coal seam gas development. Therefore, it is particularly important to characterise the groundwater chemistry of this unit for later comparison if coal seam gas development were to occur. Comments on the results of each bore are given in Table 16.

In general, the methane concentrations in the Lower Tertiary Aquifer are significantly higher than in sampled overlying aquifers. Also, BTEX was detected in 3 of the 10 bores and TPH in 6 of the 10 bores. Given the significant depth of the aquifer and the separation from any anthropogenic source, the most likely source of the detected hydrocarbons is likely to be the coal deposits within the aquifer.

The average salinity of the 10 samples was 821 mg/L suggesting that the aquifer contains low salinity water consistent with its use for irrigation especially in the Yarram area. The major ion concentrations suggest that the salinity is sodium chloride dominated.

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**Table 16 Commentary on Round 1 results for sampled Lower Tertiary Aquifer bores**

Bore	Justification for inclusion in the monitoring network	Comments
105483	<ul style="list-style-type: none"> <li>Monitors the target aquifer (Latrobe Group) in the Yarram GMU</li> <li>Located in the area of prospectivity and key rivers and wetlands</li> <li>Located in the Seaspray depression area of interest.</li> <li>Nested with 105484</li> </ul>	<ul style="list-style-type: none"> <li>Higher methane concentration than Boisdale bore 105484 at same site suggests Upper Mid-Tertiary Aquitard is an effective seal for upwards migration of methane</li> <li>Methane detected in collected gas sample.</li> <li>TPH detected</li> </ul>
67441	<ul style="list-style-type: none"> <li>Located in the area of prospectivity and key rivers and wetlands</li> <li>Monitors the target aquifer (Latrobe Group) in the Stratford GMU</li> <li>Located along Rosedale Fault</li> </ul>	<ul style="list-style-type: none"> <li>Methane concentration of 4.41 mg/L is consistent with other LTA bores and suggests high coal content of unit may be the source</li> <li>TPH detected – likely to be natural source associated with coal deposits</li> </ul>
WRK059110	<ul style="list-style-type: none"> <li>Monitors the target aquifer (Latrobe Group) in the Yarram WSPA</li> <li>Nested with WRK059111</li> </ul>	<ul style="list-style-type: none"> <li>Methane concentration of 4.65 mg/L is consistent with other LTA bores and suggests high coal content of unit may be the source</li> <li>Comparison with &lt;0.01 mg/L for nested watertable bore WRK05911 suggests Upper Mid-Tertiary Aquitard is an effective seal above coal deposits</li> <li>No other organics detected</li> </ul>
147173	<ul style="list-style-type: none"> <li>Monitors the target aquifer (Latrobe Group) in the Yarram GMU and located in close proximity to Yarram township</li> </ul>	<ul style="list-style-type: none"> <li>No organics detected which is anomalous given the methane detected in many of the other LTA bores</li> </ul>
105222	<ul style="list-style-type: none"> <li>Monitors the target aquifer (Latrobe Group) in the Yarram GMU and located in close proximity to Yarram township</li> </ul>	<ul style="list-style-type: none"> <li>High methane reading of 16.7 mg/L – on the high side of concentrations in other LTA bores</li> <li>Methane detected in collected gas sample.</li> <li>TPH detected – likely to be natural source associated with coal deposits</li> </ul>
WRK059126	<ul style="list-style-type: none"> <li>Located in the MID and forms nested site with 95489 and WRK059127</li> <li>Also located where the regional seal is absent</li> </ul>	<ul style="list-style-type: none"> <li>Methane concentration of 8.52 mg/L is consistent with other LTA bores and suggests high coal content of unit may be the source</li> <li>TPH and BTEX detected – likely to be natural source associated with coal deposits</li> <li>Higher methane levels than shallower bores 95489 and WRK059126 suggest upward reduction in methane concentration associated with vertical migration</li> <li>Methane detected in collected gas sample.</li> </ul>
58937	<ul style="list-style-type: none"> <li>Located along the Lake Wellington Fault</li> </ul>	<ul style="list-style-type: none"> <li>Methane concentration of 4.85 mg/L is consistent with other LTA bores and suggests high coal content of unit may be the source</li> <li>TPH detected – likely to be natural source associated with coal deposits</li> </ul>

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Bore	Justification for inclusion in the monitoring network	Comments
110724	<ul style="list-style-type: none"> <li>Elevated hydrocarbons were measured in this bore and recommendation was made for a resample for hydrocarbons.</li> <li>Located along Forster Fault.</li> </ul>	<ul style="list-style-type: none"> <li>High methane reading of 13.9 mg/L – on the high side of concentrations in other LTA bores</li> <li>Methane detected in collected gas sample.</li> <li>Minor TPH detected – likely to be natural source associated with coal deposits</li> <li>BTEX detected although low concentration</li> </ul>
47063	<ul style="list-style-type: none"> <li>Monitors the target aquifer (Latrobe Group) in the Stratford GMU</li> </ul>	<ul style="list-style-type: none"> <li>Methane concentration of 3 mg/L is consistent with other LTA bores and suggests high coal content of unit may be the source</li> <li>TPH detected – likely to be natural source associated with coal deposits</li> </ul>
WRK059112	<ul style="list-style-type: none"> <li>Monitors the target aquifer (Latrobe Group) in the Yarram WSPA</li> <li>Located along Forster Fault.</li> </ul>	<ul style="list-style-type: none"> <li>High methane reading of 33.7 mg/L – highest concentrations of the LTA bores</li> <li>Methane detected in collected gas sample.</li> <li>TPH detected – likely to be natural source associated with coal deposits</li> <li>BTEX detected – significantly higher than all other bores</li> </ul>

## 8 Conclusions

The main conclusions from the analysis of the groundwater sampling results from 30 bores in the Gippsland region are given below.

### Major ions

- The sampled groundwater are sodium chloride dominated. There are no vertical trends in major ion chemistry. The similarity of groundwater above and below the aquitards suggests lateral flow originates from a similar source and undergoes a similar process.

### Methane

- Methane concentrations tend to be highest in the coal bearing units of the Lower Tertiary Aquifer (Latrobe Group) and the Upper Mid-Tertiary Aquifer (Latrobe Valley Coal Measures and Balook Formation). The methane concentrations in these units are likely to be sourced from the organic content of the coals.
- There is a decreasing methane concentration upwards above the coal bearing units (for example all watertable bores had undetected or negligible methane concentrations). All nested sites exhibit this trend. The methane concentrations in upper aquifers in areas where the Upper Mid-Tertiary Aquitard is absent is slightly higher than in areas where it is present suggesting the Upper Mid-Tertiary Aquitard partially restricts upwards flow of methane.
- There is no apparent increasing trend in methane concentrations near faults.
- The methane levels detected in the Gippsland region are largely consistent with other study results, whereby the median value is low, with occasional higher concentration occurrences.
- Methane was only detected in analysed gas samples from bores screened in the Lower Tertiary Aquifer and only in bores with significant methane concentrations in water samples. The higher confined pressures in the Lower Tertiary Aquifer is likely to result in the gas coming out of solution during the sampling process.

### Ethane, Ethene, Butane, Butene, Propane and Propene

- There were no observations of Ethene, Butane, Butene, Propane and Propene in 29 of the 30 sampled bores and this suggests that these compounds are not a natural occurrence in any of the sampled aquifers and any future detection is likely to reflect an anthropogenic origin.

### BTEX

- BTEX was detected in the Lower Tertiary Aquifer and the Upper Tertiary Aquifer. The lack of BTEX in the shallower aquifers suggests that BTEX compounds are unlikely to be a natural occurrence in these aquifers and any future detection is likely to reflect an anthropogenic origin.
- The source of the detected BTEX in some of the Lower Tertiary Aquifer bores is unknown and could be either anthropogenic or natural.

## **Total Petroleum Hydrocarbons (TPH)**

- TPH was detected in 8 of the 30 bores sampled and 7 of these bores are screened in the coal bearing units of the Lower Tertiary Aquifer (Latrobe Group) and the Upper Mid-Tertiary Aquifer (Latrobe Valley Coal Measures and Balook Formation). The samples mostly contain hydrocarbons in the C10 to C28 fraction although this provides no evidence of source. Although no definitive conclusion can be drawn on the source of the hydrocarbons, the depth of the bores, the presence of coals and the likely lack of interaction with the surface suggest a natural origin.
- The TPH detected in Upper Tertiary Aquifer bore WRK059127 is an anomalous result. All of the other nine samplings of Upper Tertiary Aquifer returned a TPH result below detection. If the TPH result in Bore WRK059127 is confirmed in the second and third sampling rounds, then the detection may indicate upward movement of TPH from underlying coal bearing units in an area where the Upper Mid-Tertiary Aquitard seal is absent.
- Aside from the anomalous result in WRK059127, the lack of TPH in the shallower units above the Lower Tertiary Aquifer and the Upper Mid-Tertiary Aquifer suggests that TPH compounds are unlikely to be a natural occurrence in these aquifers and any future detection is likely to reflect an anthropogenic origin.

## **Napthalene**

- The lack of detection of naphthalene in any of the 30 sampled bores suggests that these compounds are not a natural occurrence in any of the sampled aquifers and any future detection is likely to reflect an anthropogenic origin.

## **Nitrogen**

- The Quaternary Aquifer contains the highest nitrogen concentrations likely to be result of leaching from fertiliser rich surface soils to the watertable.
- Slightly higher values were found in the Lower Tertiary Aquifer compared to other confined aquifers which is likely to be an inherent characteristic of the aquifer rather than leaching from the surface. Potentially the nitrogen is associated with the presence of natural gas in this coal bearing aquifer.

The Round 1 groundwater chemistry results presented in this report are generally consistent with the prevailing conceptual model of groundwater flow in the Gippsland region summarised in Chapter 2. The upwards decrease in methane concentrations is consistent with the general upwards groundwater flow across the region. Although not definitive, the upwards reduction in methane levels suggests the detected methane in the upper units (especially the Upper Tertiary Aquifer (Boisdale Formation)) is likely to be sourced from the underlying coal bearing units of the Lower Tertiary Aquifer and the Upper Mid-Tertiary Aquifer.

The results are consistent with the Upper Mid-Tertiary Aquitard (Lakes Entrance Formation) being a seal on top of the Lower Tertiary Aquifer although the methane results show that upwards seepage through the aquitard to overlying aquifers is possible and that the seal is imperfect. Similarly, the results suggest that areas of aquitard absence are likely to exhibit greater inter-aquifer connection.

There is no apparent increase in hydrocarbon concentrations in aquifers overlying coal bearing units near faults although there is not enough data to indicate whether faults provide conduits for fluid flow as suggested by the conceptual model.

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# Appendices

Appendix A. Standard operating procedure for groundwater sampling



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STANDARD OPERATING PROCEDURE  
P00228 FOR GROUNDWATER SAMPLING

# HYDROTERRA STANDARD OPERATING PROCEDURE FOR GROUNDWATER SAMPLING

Revision 0

**15 May 2015**



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



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6 September 2013

## 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)

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### 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	

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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



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### 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.



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



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## **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 ¼ 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>



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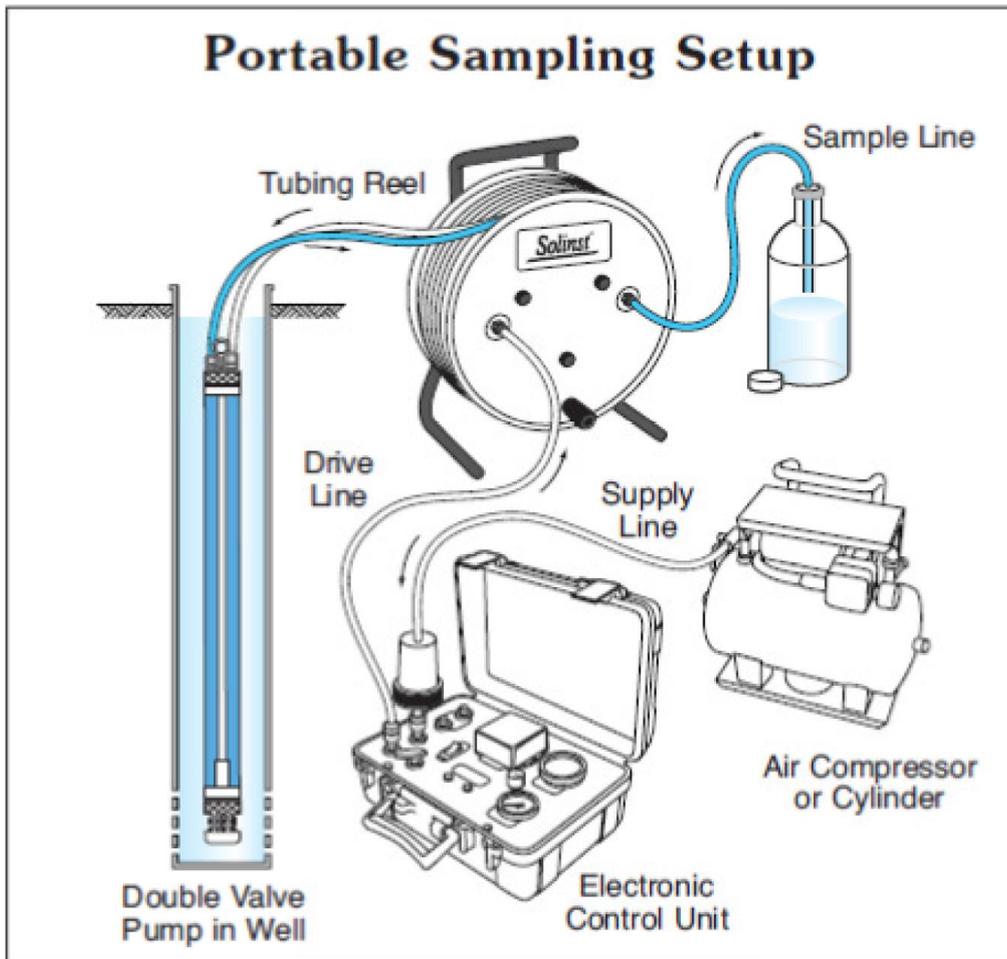


Figure 1 Portable Double Valve Pump Setup



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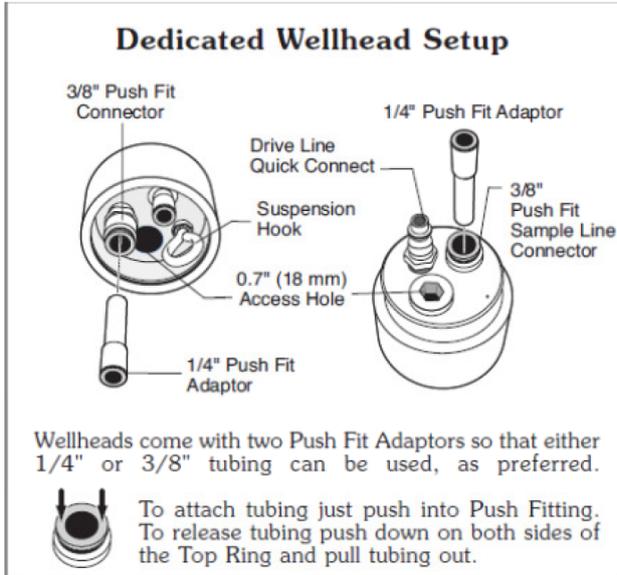


Figure 2 Dedicated Well Head Setup.



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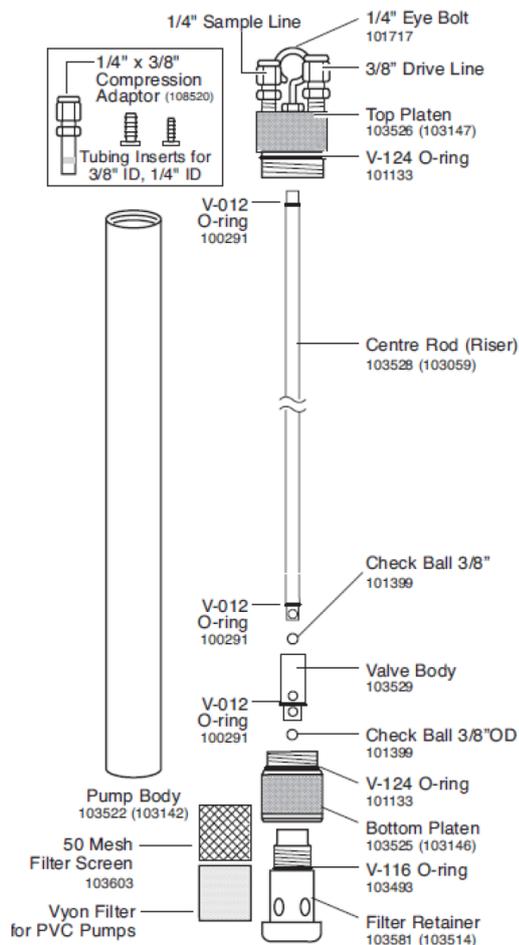
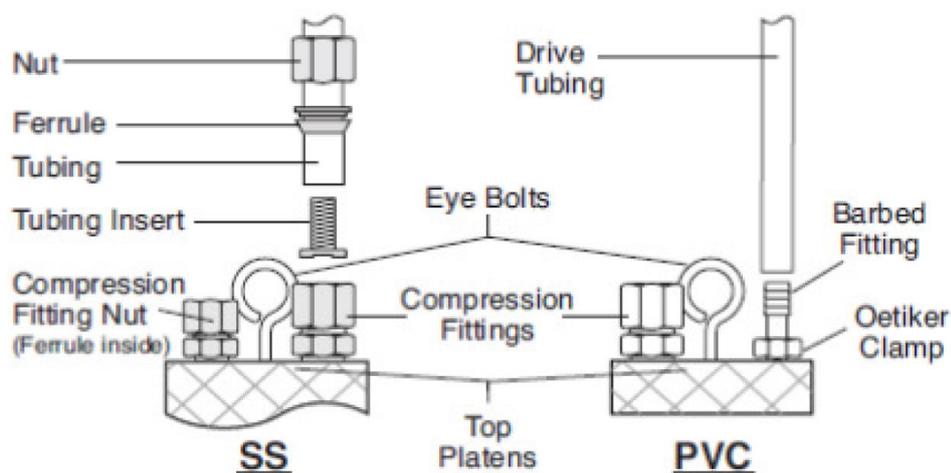


Figure 3 Double Valve Pump Components



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### 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

		Bore ID		WRK059126	110724	90615	105222	105483	WRK059112	103822	105484	140692	145092	145093	WRK059127	WRK059120	47063	58937
		Sample Data		9/12/2014	10/12/2014	16/12/2014	18/01/2015	19/01/2015	16/01/2015	16/12/2014	8/12/2014	15/12/2014	12/12/2014	16/12/2014	9/12/2014	12/12/2014	16/12/2014	17/01/2015
Chem_Group	ChemName	Units	EQL															
TRH	>C10 - C16 Fraction	µg/L	100	<100	<100	<100	<100	1010	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
	>C10 - C16 Fraction minus Naphthalene (F2)	µg/L	100	<100	<100	<100	<100	1010	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
	>C16 - C34 Fraction	µg/L	100	<100	<100	<100	340	1670	<100	<100	<100	<100	<100	<100	200	<100	110	250
	>C34 - C40 Fraction	µg/L	100	<100	<100	<100	<100	180	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
Semi Volatice 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	<0.01	<0.01
	Butene	µg/L	10	<10	<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	<0.01	<0.01
	Propene	µg/L	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Metals	Calcium (Filtered)	µg/L	1000	22,000	14,000	1000	26,000	19,000	22,000	2000	34,000	7000	14,000	260,000	24,000	86,000	17,000	4000
	Magnesium (Filtered)	mg/L	1	18	12	2	<1	3	17	8	43	9	12	94	17	39	29	4
	Potassium (Filtered)	µg/L	1000	9000	9000	32,000	2000	2000	29,000	8000	7000	5000	2000	22,000	7000	5000	28,000	8000
TPH	C6 - C9	µg/L	20	<20	20	<20	<20	50	210	<20	<20	<20	<20	<20	<20	<20	<20	<20
	C10 - C14	µg/L	50	<50	<50	<50	<50	810	<50	<50	<50	<50	<50	<50	<50	<50	60	100
	C15 - C28	µg/L	100	<100	<100	<100	260	1950	<100	<100	<100	<100	<100	<100	170	<100	110	240
	C29-C36	µg/L	50	<50	<50	<50	110	50	<50	<50	<50	<50	<50	<50	80	<50	<50	<50
	+C10 - C36 (Sum of total)	µg/L	50	<50	<50	<50	370	2810	<50	<50	<50	<50	<50	<50	250	<50	170	340
	C10 - C40 (Sum of total)	µg/L	100	<100	<100	<100	340	2860	<100	<100	<100	<100	<100	<100	200	<100	110	250
	C6-C10	mg/L	0.02	<0.02	0.04	<0.02	<0.02	0.05	0.21	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
BTEX	Benzene	µg/L	1	<1	<1	<1	<1	<1	3	<1	<1	<1	2	<1	<1	<1	<1	<1
	Ethylbenzene	µg/L	2	14	<2	<2	<2	<2	145	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Toluene	µg/L	2	<2	5	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Total BTEX	mg/L	0.001	0.014	0.005	<0.001	<0.001	<0.001	0.148	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001
	Xylene (m & p)	µg/L	2	<2	<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	<2	<2
	Xylene Total	µg/L	2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	C6-C10 less BTEX (F1)	mg/L	0.02	<0.02	0.04	<0.02	<0.02	0.05	0.06	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Inorganics	Alkalinity (Hydroxide) as CaCO3	µg/L	1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
	Alkalinity (total) as CaCO3	mg/L	1	273	144	318	4	6	191	88	110	58	84	70	238	223	1220	72
	Anions Total	meq/L	0.01	12.8	13.5	23	3.74	2.63	13.8	12.4	21	7.05	7.9	61.1	12.7	22.9	64	5.25
	Alkalinity (Bicarbonate as CaCO3)	mg/L	1	273	118	159	4	6	191	22	110	58	84	70	238	223	1220	51
	Alkalinity (Carbonate as CaCO3)	mg/L	1	<1	26	159	<1	<1	<1	67	<1	<1	<1	<1	<1	<1	<1	21
	Cations Total	meq/L	0.01	11.8	12.2	20.8	3.26	2.73	11.6	11.2	19.3	6.39	7.17	54.1	11.3	20.6	58.8	4.6
	Chloride	mg/L	1	262	376	589	124	89	355	375	631	194	219	2060	283	612	239	135
	Fluoride	mg/L	0.1	0.8	0.4	1.4	<0.1	<0.1	<0.1	0.4	0.1	0.2	0.2	<0.1	2	0.4	1.2	0.4
	Ionic Balance	%	0.01	4.39	5.09	4.92	6.85	1.79	8.64	4.9	4.18	4.88	4.81	6.1	6.19	5.32	4.33	6.54
	Kjeldahl Nitrogen Total	mg/L	0.1	1	2.7	2.6	0.4	0.1	1.7	0.4	0.3	0.2	1.2	0.8	1.6	<0.1	3.3	0.9
	Nitrogen (Total Oxidised)	mg/L	0.01	0.03	<0.01	<0.01	<0.01	0.01	0.03	<0.01	0.02	0.01	0.01	<0.01	0.01	0.02	0.01	0.02
	Nitrogen (Total)	µg/L	100	1000	2700	2600	400	100	1700	400	300	200	1200	800	1600	<100	3300	900
	Sodium (Filtered)	mg/L	1	206	236	455	44	34	193	236	320	119	125	754	195	298	1260	89
	Sulphate (Filtered)	mg/L	1	<1	<1	<1	8	<1	<1	2	49	20	2	77	<1	57	1580	<1
	TDS	mg/L	10	744	1010	1330	271	252	780	701	1190	502	465	5090	667	1250	3620	324
PAH/Phenols	Naphthalene	µg/L	5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	
Organic	Ethane	µg/L	10	<10	<10	100	<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	<10	
	Methane	mg/L	0.01	8.52	13.9	34.7	16.7	7.3	33.4	6.36	0.453	0.273	4.37	0.312	2.94	0.122	3	4.85
Gas Samples	Methane	mg/L	0.33	0.85	2.81	7.46	1.9	1.44	9.29									

		Bore ID	64835	67441	67442	90323	95489	B90148	WRK059110	110978	140691	147173	45762	WRK059111	WRK059119	105479	WRK059121	
		Sample Data	16/12/2014	17/01/2015	11/12/2014	11/12/2014	9/12/2014	9/12/2014	10/12/2014	15/12/2014	15/12/2014	10/12/2014	11/12/2014	10/12/2014	12/12/2014	15/12/2014	21/01/2015	
Chem_Group	ChemName	Units	EQL															
TRH	>C10 - C16 Fraction	µg/L	100	<100	<100	<100	180	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	
	>C10 - C16 Fraction minus Naphthalene (F2)	µg/L	100	<100	<100	<100	180	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	
	>C16 - C34 Fraction	µg/L	100	<100	160	<100	590	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	
	>C34 - C40 Fraction	µg/L	100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	
Semi Volatice 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	<0.01	
	Butene	µg/L	10	<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	<0.01	
	Propene	µg/L	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	
Metals	Calcium (Filtered)	µg/L	1000	13,000	4000	6000	<1000	2000	8000	19,000	16,000	3000	1000	81,000	9000	33,000	12,000	8000
	Magnesium (Filtered)	mg/L	1	4	5	4	2	5	11	10	16	5	4	378	<1	68	14	40
	Potassium (Filtered)	µg/L	1000	2000	22,000	3000	<1000	2000	13,000	17,000	5000	4000	<1000	18,000	8000	12,000	2000	4000
TPH	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	190	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	
	C15 - C28	µg/L	100	<100	140	<100	500	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	
	C29-C36	µg/L	50	<50	<50	<50	160	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	
	+C10 - C36 (Sum of total)	µg/L	50	<50	190	<50	850	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	
	C10 - C40 (Sum of total)	µg/L	100	<100	160	<100	770	<100	<100	<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	
BTEX	Benzene	µg/L	1	<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	<2	
	Toluene	µg/L	2	<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	<0.001	
	Xylene (m & p)	µg/L	2	<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	<2	
	Xylene Total	µg/L	2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	
	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	
Inorganics	Alkalinity (Hydroxide) as CaCO3	µg/L	1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	45,000	<1000	<1000	<1000
	Alkalinity (total) as CaCO3	mg/L	1	73	96	49	10	56	98	285	132	32	<1	501	91	293	69	60
	Anions Total	meq/L	0.01	2.33	3.78	3.04	1.95	1.83	6.1	10.8	8.78	2.37	4.03	152	12.6	12.8	5.09	15.7
	Alkalinity (Bicarbonate as CaCO3)	mg/L	1	73	69	49	10	56	98	285	132	32	<1	501	<1	293	69	60
	Alkalinity (Carbonate as CaCO3)	mg/L	1	<1	27	<1	<1	<1	<1	<1	<1	<1	<1	<1	46	<1	<1	<1
	Cations Total	meq/L	0.01	2.25	3.48	2.79	1.86	1.74	5.81	9.77	8.29	2.23	3.68	136	11.3	11.6	4.93	14.3
	Chloride	mg/L	1	31	66	73	54	23	147	169	203	57	129	4780	368	178	63	490
	Fluoride	mg/L	0.1	<0.1	0.5	0.1	0.2	0.4	0.2	0.1	2.8	<0.1	0.1	0.7	0.4	3	0.2	<0.1
	Ionic Balance	%	0.01	1.89	4.16	4.22	2.42	2.65	2.47	5.18	2.9	3.12	4.55	5.77	5.23	4.76	1.6	4.72
	Kjeldahl Nitrogen Total	mg/L	0.1	0.2	1.3	0.3	0.7	0.2	0.3	0.8	0.2	0.2	<0.1	0.2	0.7	0.7	1.1	0.2
	Nitrogen (Total Oxidised)	mg/L	0.01	<0.01	0.02	<0.01	<0.01	0.05	0.01	0.03	0.02	0.01	0.02	0.01	0.41	<0.01	7.28	0.02
	Nitrogen (Total)	µg/L	100	200	1300	300	700	200	300	800	200	200	<100	200	1100	700	8400	200
	Sodium (Filtered)	mg/L	1	28	53	48	39	27	96	174	139	36	76	2300	245	93	72	241
	Sulphate (Filtered)	mg/L	1	<1	<1	<1	11	3	<1	18	20	6	19	354	17	90	93	32
	TDS	mg/L	10	287	282	295	170	151	361	568	515	239	358	7400	859	773	426	923
PAH/Phenols	Naphthalene	µg/L	5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	
Organic	Ethane	µg/L	10	<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	<10	
	Methane	mg/L	0.01	5.09	2.41	4.02	0.041	0.377	3.48	4.65	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Gas Samples	Methane	mg/L	0.33															

Matrix:	AIR	Sample Type:	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG
Workgroup:	EN1410971	ALS Sample number:	EN1410971001	EN1410971002	EN1410971003	EN1410971004	EN141096900	EN141096900	EN141096900	EN141096900	EN141097000							
Project name/number:	IS089500	Sample date:	15/12/2014	15/12/2014	15/12/2014	15/12/2014	10/12/2014	10/12/2014	10/12/2014	10/12/2014	16/12/2014	16/12/2014	16/12/2014	16/12/2014	16/12/2014	16/12/2014	12/12/2014	12/12/2014
		Client sample ID (1st):	C1111	C1122	C1018	C1115	C1093	C1110	C1106	C0878	C1099	C0699	C0827	C1081	C0700	C0724	C1024	
		Client sample ID (2nd):	140691	110978	140692	105479	147173	WRK059110	110724	WRK059111	103822	47063	64835	90615	145093	WRK059120	WRK059120	
		Depth Type:																
		Depth (m):																
		Site:																
		Purchase Order:	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500
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	0.43	<0.10	<0.10	<0.10	<0.10	1.14	<0.10	<0.10	<0.10
<b>EP104: Light Hydrocarbons (Calc Conc)</b>																		
Methane	74-82-8	mg/m <sup>3</sup>	330	<660	<660	<660	<660	<660	<660	2810	<660	<660	<660	<660	7460	<660	<660	<660
<b>Sampling Quality Assurance</b>																		
Pressure - As received	PRESSURE	kPa	0.1	77.9	88.6	94.1	68.3	99.6	97.1	67.4	64.5	85.8	95.6	91.4	78.2	71.7	92.1	91.7
Pressure - Laboratory Atmosphere		kPa	0.1	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101
Temperature as Received		°C	0.1	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0

Matrix:	AIR	Sample Type:	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG	REG
Workgroup:	EN1410971	ALS Sample number:	EN1410928003	EN1410928004	EN1410927001	EN1410927002	EN141092700	EN141092500	EN141092500	EN141092500	EN141092500	EN141092500	EN141092500	EN151022300	EN151022300	EN151022300	EN151022300	EN1510223004
Project name/number:	IS089500	Sample date:	12/12/2014	12/12/2014	11/12/2014	11/12/2014	11/12/2014	09/12/2014	09/12/2014	09/12/2014	09/12/2014	08/12/2014	18/01/2015	17/01/2015	16/01/2015	17/01/2015		
		Client sample ID (1st):	C1290	C0822	C0704	C0841	C2916	C2917	C1123	C0681	C0872	C1015 - 10548	1086	1113	863	721		
		Client sample ID (2nd):	145092	WRK059119	45762	90323	67442	WRK059127	95489	WRK059126	90148	105484	105222	58937	WRK059112	67441		
		Depth Type:																
		Depth (m):																
		Site:																
		Purchase Order:	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500	ISO89500
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	0.13	<0.10	<0.10	0.29	<0.10	1.42	<0.10	
<b>EP104: Light Hydrocarbons (Calc Conc)</b>																		
Methane	74-82-8	mg/m <sup>3</sup>	330	<660	<660	<660	<660	<660	<660	<660	850	<660	<660	1900	<660	9290	<660	
<b>Sampling Quality Assurance</b>																		
Pressure - As received	PRESSURE	kPa	0.1	96.2	64.4	99.0	84.5	67.6	89.1	85.3	91.6	65.7	62.9					
Pressure - Laboratory Atmosphere		kPa	0.1	101	101	101	101	101	101	101	101	101	101					
Temperature as Received		°C	0.1	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0					

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