Direct comparison of bore purge and low-flow groundwater sampling techniques in high yield areas

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Abstract

The objective of groundwater sampling is to extract a representative water sample from underground; however this is difficult due to its inaccessibility. Two methods are used routinely to obtain groundwater samples; the bore purge and the low-flow methods. The bore purge method has been shown to be highly disruptive, introducing turbulence to the groundwater and mobilising contaminants. The low-flow method was introduced to provide more accurate results. Bores in three high yield areas in Maribyrnong, Victoria; Dunmore, New South Wales and Queanbeyan, New South Wales were sampled to compare the two methods. The bores were sampled using the low-flow method and then immediately after using the bore purge method. Any excessive disruption using the bore purge should result in significantly different contamination levels. Several analytes such as BOD, COD, ammonia, TOC and total dissolved solids were analysed and the average relative percentage difference in results across the 10 different bores was only 14.2 and not considered to be significantly different. The low-flow method returned slightly higher readings 100 times, and the bore purge method, 84 times. Even results were returned 112 times. This finding is unexpected and significant, and differs from the results of earlier studies. However, issues associated with the bore purge method may be more pronounced in areas with low recharge and this could be tested in a later study.

Key words

Groundwater, groundwater sampling, bore purge, micropurge, analysis, low-flow sampling, aquifer, groundwater sampling methods, end results, relative percentage difference.

Disclaimer

This thesis does not state that any of the field sites are in any way contaminated, with all the results below investigation levels. The results obtained are used solely as a way to compare the results obtained from the bore purge and the low-flow groundwater sampling methods.

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Table of Contents   **Page**

1 – Introduction

Groundwater sampling is a necessary and vital part of environmental monitoring and management projects throughout the world. The primary goal of groundwater sampling is to provide groundwater for laboratory analysis that is representative of the aquifer (Barcelona and Helfrich, 1986). Methods used to obtain the groundwater include the bailer method, the bore purge method, the low flow method and the diffusion method (Robin and Gilham, 1987; Konecny, 2003; NEPC, 2013). Several disconnected ground water zones may exist in the subsurface and great care is taken to ensure that bores are constructed so that they only intercept water from the zone of interest.

Groundwater contaminants are both inorganic and organic in origin and can come from a number of different sources including ; oil spills, landfill leachate, settled air pollution, fossil fuel runoff, leaking fuel tanks, pollution runoff after storm events and from mining practices (Puls and Powell, 1995). Some of these contaminants pose no, or minimal threat, whereas others can cause serious problems for both humans and the wider ecosystem, for example ammonia and lead (Puls et al., 1990).

Two main methods used to monitor groundwater contamination are currently utilised in the field; the bore purge and the low-flow sample methods (NEPC, 2013). These methods differ in the process used to obtain the groundwater sample but both claim to deliver a groundwater sample that is representative (Puls and Barcelona, 1996; Sundaram et al., 2009) and with minimal disturbance of the aquifer (Sundaram et al., 2009). There are many uncertainties in the monitoring of groundwater, such as geochemical anomalies, hydrological gradients, time frames, plume size, volume and concentration, and it is essential that the sampling method does not introduce further disruptions (Powell and Puls, 1993; Puls and Barcelona, 1996; Konecny, 2003).

The bore purge sampling method was an already well-established method before the low-flow sampling method was first suggested in 1987 and remains the most widely used in the industry (Robin and Gilham, 1987; Puls and Barcelona, 1996). All existing bores were constructed so the bore purge method could be utilised. The bore purge method requires that three times the volume of the bore is purged of water before a sample is taken (Sundaram et al, 2009). The low-flow sampling method, developed in the late 1980's, uses very low purging rates, under 1L/min, to purge a small amount of water from the screened interval of the bore before sampling takes place (Robin and Gilham, 1987). There has been debate as to whether the methods provide similar analytical results. This uncertainty provides an

opportunity to determine if the sampling methods themselves are affecting the end analytical results and to provide valuable insights into future groundwater monitoring projects.

1.1 – Aims

The aim of this project is to investigate the two main groundwater sampling methods currently used in Australia, the bore purge and low-flow sampling methods, and to determine if they produce similar end analytical results in high yield conditions. The bore purge and the low-flow sampling methods will be tested in field conditions, following industry-standard sampling practices and replicating a field sampling program.

Three different field sites, each with high-recharge aquifers, but having slightly different geology (Section 2.5) were chosen as the sampling locations.

Results of this study will provide useful information to field practitioners when deciding on field sampling methods. A secondary aim of the project is to determine if there is an optimal sampling method to use when undertaking a field sampling program.

1.2 – Objectives

The objectives of this project are to;

- Conduct a literature review in the areas of; groundwater characteristics and recharge, sources of groundwater contamination, and the general characteristics, advantages and disadvantages of the bore purge and low-flow sampling techniques;
- Determine if the bore purge and low-flow sampling methods give different end analytical results; and
- Determine, if possible, the optimal sampling method for high yield areas.

2 – Background

2.1 – Historical background

Prior to the industrial revolution, groundwater was considered a safe and reliable source of clean potable water (Geyh and Sofner, 2006). However, since then, increasing amounts of toxic waste and pollution have been created and disposed of via landfills, which often connect directly to the groundwater system (Kostecki et al., 1991). For example, in 2010, hazardous waste output in China was 15.87 million tons (Li et al., 2012); an increase of approximately 66% since 2001. Many other countries around the world are experiencing similar increases in their waste and pollution output (Li et al., 2012) and much of this waste is also disposed of in poorly designed landfills which leak leachate directly into the groundwater system (Bagchi, 1987; Chen, 1996; Kjeldsen et al., 2002; Barnswell, 2012). At the same time, groundwater is becoming an increasingly utilised resource due to a combination of a rapidly increasing world population and increasingly longer periods of drought that affect many countries' freshwater supplies (Geyh and Sofner, 2006). Monitoring these groundwater supplies to ensure that they are clean and uncontaminated is of vital importance.

New groundwater sampling methods are constantly being developed and old ones improved because of the increasing level of pollution and the desire for more detailed, accurate and efficient monitoring programs. However, the two main techniques currently used remain the purge and low-flow sampling methods (Puls and Powell, 1995; LeBlanc and Vroblesky, 2008; Sundaram et al., 2009). During most long term monitoring and remediation projects a large number of monitoring wells are installed to both help identify the spatial extent of contamination and to determine the hydrogeology of the area in order that the appropriate remediation measures can be designed and implemented (LeBlanc and Vroblesky, 2008; Sundaram et al., 2009). Once these wells are installed, monitoring may continue for many years to study the spatial and temporal trends of the contaminants and to determine if there is any natural attenuation (LeBlanc and Vroblesky, 2008; Sundaram et al., 2009). Such studies require samples taken to be representative of the aquifer (Puls and Paul; 1995) and there is some debate as to whether the purge and low-flow sampling methods meet this requirement (Kostecki et al., 1991; Puls and Powell, 1992; Powell and Puls, 1993; Puls and Barcelona, 1996; Vrollesky and Hyde, 1997; Stutter et al., 2006; LeBlanc and Vroblesky, 2008).

2.2 – Bore purge method

The bore purge method was the first groundwater sampling technique to be developed and remained the only available method until 1987 (Robin and Gilham, 1987). In an idle groundwater well, water from the aquifer fills the bore between sampling events. This groundwater can react with the well casing inducing chemical change in the water (Puls and Powell, 1995). These changes may include oxidation, due to exposure to oxygen in the water column, leading to significant leaching of iron if the casing material is stainless steel (Barcelona and Helfrich, 1986); contamination by organic material if the bore is not capped and left exposed; and microbial contamination that can alter the chemical makeup of the water (Barcelona and Helfrich, 1986; Powell and Puls, 1993; Puls and Powell, 1995; Puls and Paul, 1995; Puls and Barcelona, 1996). Water in the well casing, therefore is considered stagnant and not representative of the aquifer (Figure 1). To avoid sampling this potentially contaminated water, the bore is heavily purged before the sampling (Powell and Puls, 1993; Sundaram et al., 2009; Li et al., 2012).
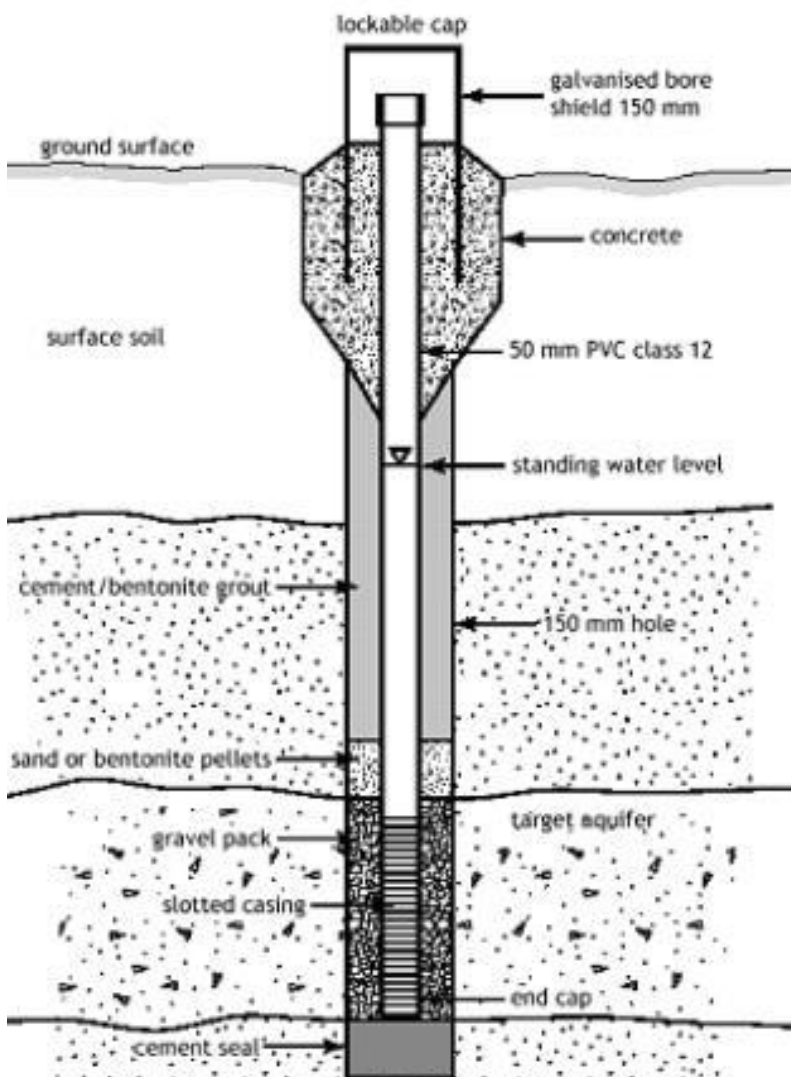

Figure 1: Diagram displaying the location of the screened interval (slotted casing) on the bore casing (after Sundaram et al., 2009). Groundwater enters the bore through this screened interval. The location of the well screen is carefully placed to only allow flow from the aquifer or contamination plume.

During sampling events, the bore is either purged with a hand operated bailer or a high-speed pump capable of purging the well as fast as 9L/min. The bore purge method requires that anywhere from 20L to 250L of water, depending upon the length and diameter of the bore, is purged from the well before sampling takes place (Sundaram et al., 2009). This purging typically requires 3-5 well volumes of water to be purged before sampling takes place. The premise of the bore purge method is relatively simple; in order to gain a sample as representative as possible of the surrounding aquifer, the bore is purged of all stagnant well water allowing the surrounding aquifer water to flow into the bore for subsequent sampling (Sundaram et al., 2009). If the purging is done properly the water taken for sampling should be representative of the surrounding aquifer.

While some purging of the well is necessary to clear the well of the accumulated stagnant water, the process of purging can potentially have unintended negative consequences for the aquifer and for the water to be sampled (Robin and Gilham, 1987).

The purging of such large quantities of water can lead to a significant lowering of the water level in the well, especially in areas of slow recharge conditions (Sevee et al., 2000). This extensive purging may lower the water table sufficiently to result in an increase in the groundwater velocity, leading to significant levels of disturbance near the well during recharge (Robin and Gilham, 1987; McCarthy and Zachara, 1989; Sevee et al., 2000). This turbulence has been shown to result in normally immobile soil particles and/or colloids becoming mobile (McCarthy and Zachara, 1989; Powell and Puls, 1993; Sevee et al., 2000), resulting in artificially inflated levels of contamination.

An increase in groundwater velocity can also have a negative impact on the surrounding aquifer zones. As groundwater is not a single large mass of water, there can be several distinct and disconnected aquifer zones at a single site. Great care must be taken in bore construction to ensure that only the aquifer of interest is intersected by the well screen and to ensure that there is no unintended mixing of the aquifer zones (Barcelona and Helfrich, 1986; Puls and Paul, 1995; Puls and Barcelona, 1996). However, an increase in the groundwater velocity can lead to mixing of aquifer zones due to a rush of water into the site to fill the void, leading to water from different aquifer zones converging on the well screen (Powell and Puls, 1993; Sevee et al., 2000). This mixing of aquifer zones can cause a significant change in the actual contaminant levels and therefore the analytical results, potentially leading to the wrong management advice (Powell and Puls, 1993; Sevee et al., 2000).

The increase in groundwater velocity can also cause elevated levels of turbidity within the well (McCarthy and Zachara, 1989). This turbulence can mobilise otherwise immobile contaminants and also lead to the creation of new colloids during sampling, in particular iron oxides (McCarthy and Zachara, 1989). The turbulence can cause the metals to aggregate and form larger particles (Powell and Puls, 1993; Sevee et al., 2000). The aim of groundwater sampling is only to sample the mobile contaminants and not the immobile ones; with the rapid rates of purging and high amounts of artificial turbulence being created this may not always be the case (McCarthy and Zachara, 1989).

Large amounts of purging, especially in areas with low recharge potential, can also lead to desaturation of the well screen (Barcelona and Helfrich, 1986). If the well screen is not kept completely saturated, the screen can dry out and become clogged with fines, stopping or significantly reducing the flow of water in these areas (Barcelona and Helfrich, 1986).

A bailer may be used to purge the well during the bore purge method. The use of a bailer has caused controversy and some authors suggest it is an inappropriate technology (Puls and Powell, 1995; Puls and Barcelona, 1996). The bailer is lowered into the recharge zone, draws water in through an intake valve at a rapid rate, and is then hauled to the surface to be emptied. This process is repeated until the well is sufficiently purged. The stop-start nature of the purging and the lack of an explicit sampling methodology, may lead to stagnant water being left within the bore when sampling takes place, possibly affecting the results (Puls and Powell, 1992). The use of bailers to remove bore water has been shown to be particularly ineffective and highly prone to operator error, however it is still approved as a sampling method (NEPC, 2013). The improper purging of the well can lead to contaminants present in the stagnant water remaining prior to sampling (Barcelona and Helfrich, 1986). Errors introduced by improper purging can be significantly larger than typical plume heterogeneities, as large as 50% in just 3cm (Ronen et al., 1987), or laboratory analytical error. As the bailer is operated by hand, there is also a high risk that the operator can be exposed to elevated levels of potentially harmful contaminants, something which can be avoided almost completely with the use of a high speed pump (Sundaram et al., 2009).

Filtration of the water sample is required when using the bore purge method to sample metals (Puls and Powell, 1992). The rapid rates of purging and the creation of excessive turbulence introduce the need to filter the samples in an effort to separate the particulate and dissolved metals from each other. As the purging rates mobilise immobile constituents of the soil and potentially stir up silt at the base of the bore the readings can become meaningless

(Puls and Powell, 1992). This filtration adds to the disturbance already experienced at the site, and contributes another step where sampling handling artefacts can be introduced to the sample (Puls and Powell, 1992). When comparing filtered and unfiltered samples taken using the bore purge method, the differences are significant (Table 1).

Table 1: Arsenic concentrations obtained from selected wells in the USA (after Puls and Powell, 1992). The large differences in filtered and unfiltered arsenic concentrations are an indication of disturbance cause by the bore purge method on the well and surrounding aquifer.

Arsenic (µg/L)		
Well	July 1990 0.45 µm Filtered	July 1990 Unfiltered
101	51	107
103	85	177
111b	24	223
112a	40	85
114b	52	107

A great deal of time and effort has been used to ensure there are clear, concise and uniform procedures for laboratory analysis of samples. However, there has been relatively little effort to establish a uniform set of bore purge sampling procedures (Puls and Powell, 1992). Therefore as procedures may vary, it is almost impossible to compare results from samples taken at different locations, by different companies, and even between different sampling events (Puls and Powell, 1992). This lack of uniformity and large variation in purging methods may lead to irrelevant and highly variable data sets; and with no way to easily compare the results from the different methods, correlation between data sets is virtually impossible.

2.3 – Low flow method

The low flow sampling method was developed as a response to concerns surrounding the negative effects that the rapid and extensive purging of wells was having on analytical results as outlined in Section 2.2 above (Robin and Gilham, 1987). It is also now the industry standard for groundwater sampling (NEPC, 2013). Low flow sampling refers to the velocity that water enters the pump intake within the well; it does not relate to the rate at which water is discharged at the surface from the pump. This can be affected by flow regulators or other pump restrictions (Puls and Barcelona, 1996). Low flow sampling strategies aim to pump in a way that minimises the drawdown on the surrounding aquifer by maintaining the level of water in the well within 0.1m of the standing water level (Puls and Barcelona, 1996). In ideal

situations there will be no change to the water level within the well throughout the sampling event as the water will flow into the well at the same rate that it is pumped out, however in areas with low recharge potential this is not always possible and some minor drawdown may occur. Flow rates for low flow sampling can range from 0.1 L/min – 1 L/min depending on site specific conditions.

While the bore purge method can result in as much as 3-5 well volumes of water being purged from the well, as little as 20% of the well volume can be purged in a sampling event utilising low flow technology (Robin and Gilham, 1987). This should result in much less contaminated water requiring disposal and much less strain on the surrounding aquifers. While the bore purge method needs extensive purging to ensure field parameters are stabilised before sampling, the low flow method was shown by Puls and Powell (1992) to stabilise within one well volume of water being purged. The slow pumping rates associated with the low flow sampling regime can result in sampling at a specific site taking significantly longer than when utilising the bore purge method, as long as two hours in larger bores (Puls and Barcelona, 1996). However, the field parameters are far more likely to have stabilised, leading to a more representative sample of the surrounding groundwater (Figure 2; Robin and Gilham, 1987; Puls and Powell, 1992; Puls and Barcelona, 1996).
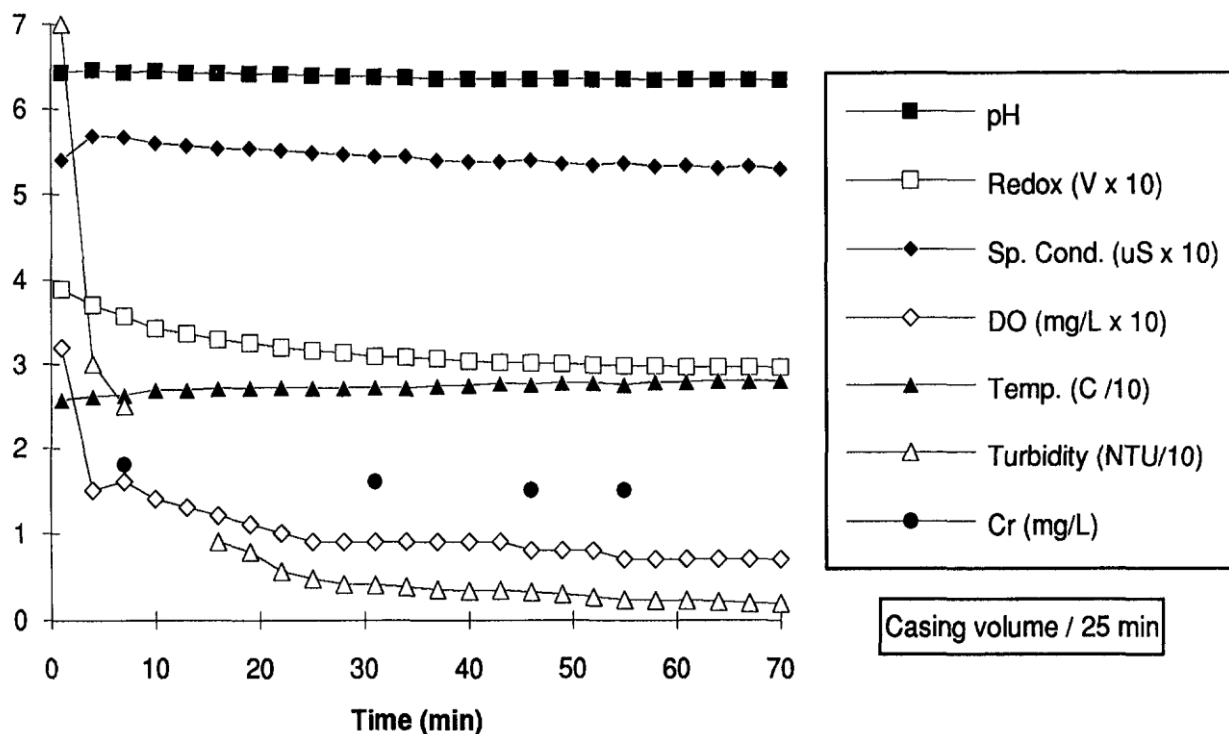
Figure 2: Stabilisation of groundwater field parameters under low flow (0.2L/min) conditions (after Puls and Powell, 1992). The image clearly shows that all field parameters, except for the most sensitive, turbidity, have equilibrated after only purging one well volume worth of water.

Robin and Gilham (1987) first proposed the low flow method to reduce the potential errors that may be introduced due to the excessive amounts of water purged under bore purge sampling regimes. They suggested that the water within the screened interval of the well (Figure 1) was constantly purged by the natural flow of groundwater; meaning that instead of becoming stagnant in the well casing, the water in the screened interval was in fact representative of the surrounding aquifer (Figure 3; Robin and Gilham, 1987). The constant flow of water from the aquifer refreshes it constantly, enabling a representative groundwater sample to be taken directly from the screened interval with a minimal of purging (Robin and Gilham, 1987).
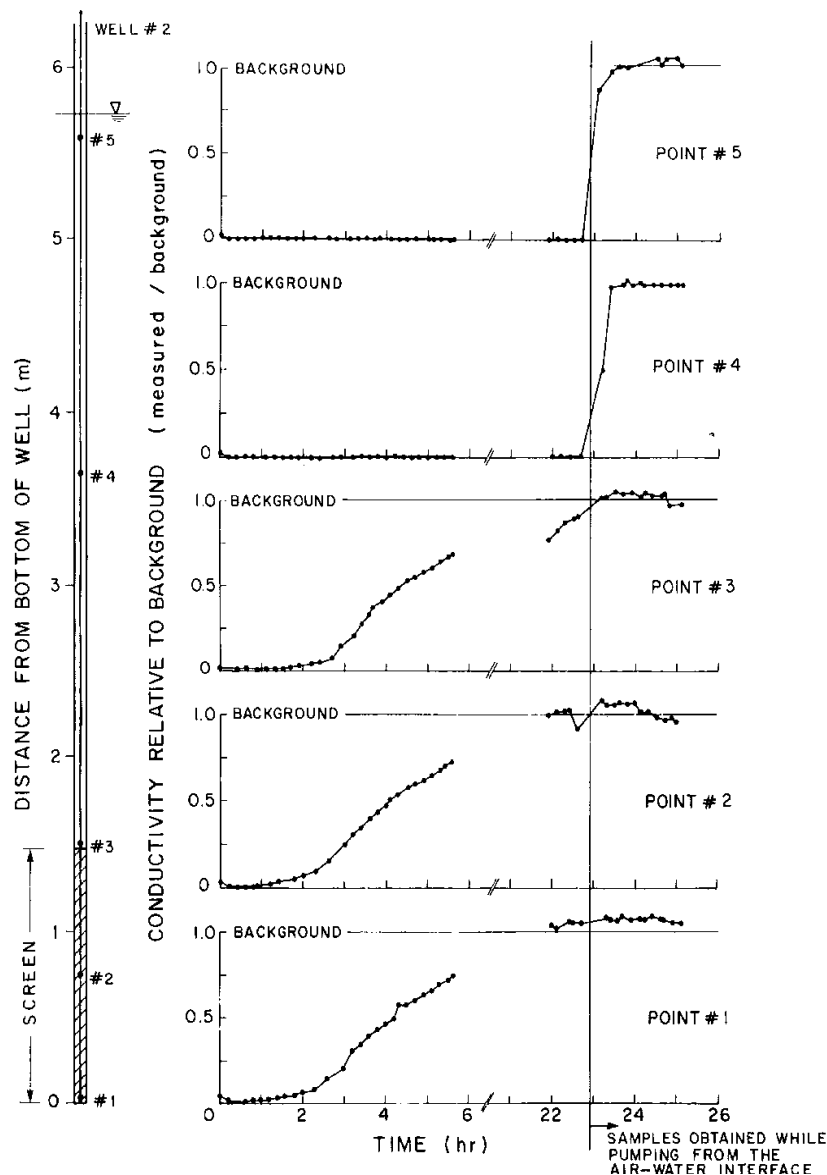
Figure 3: Results of the deionised tracer tests carried out by Robin and Gilham (1987). Deionised water was injected into the well at different levels and the electrical conductivity was monitored throughout the experiment. The water within the well screen was within 25% of background after only 4 hours. Points above the well screen were still significantly lower than background after 24 hours. This indicates a constant flow of fresh water into the well through the screen, indicating that the water within the well screen would be representative of the surrounding aquifer without any major purging. Don't split the figure caption with the figure.

The low flow rates utilised during the purging process (below 1L/min) enable minimal drawdown to ensure there is no stress and minimal disturbance on the surrounding aquifer (Robin and Gilham, 1987; McCarthy and Zachara, 1989; Sevee et al., 2000). The lack of disturbance ensures that otherwise immobile colloids and other contaminants in the surrounding soil are not mobilised (McCarthy and Zachara, 1989; Powell and Puls, 1993; Sevee et al., 2000) helping to minimise the risk of artificially inflating the analytical results and reducing the total uncertainty in the end results (Puls and Powell, 1992).

Purging water from the aquifer as fast as it flows in greatly reduces the risk of the purging event creating a void and causing the surrounding aquifer zones to become artificially mixed (Barcelona and Helfrich, 1986; Puls and Paul, 1995; Puls and Barcelona, 1996; Powell and Puls, 1993; Sevee et al., 2000). This method also eliminates the risk of the well screen becoming desaturated, except possibly in areas of extremely low recharge potential (Barcelona and Helfrich, 1986). It also reduces the risk of the screen becoming clogged with fines, thus extending the life of the well significantly (Barcelona and Helfrich, 1986).

The low flow system does not use a bailer, removing the risk of mixing stagnant bore water with the sample (Puls and Barcelona, 1996; Sundaram et al., 2009) and reducing the chance of exposing the operator to highly contaminated groundwater, making it a more efficient and safer option for the field (Puls and Barcelona, 1996; Sundaram et al., 2009). The low flow system is relatively straightforward and consistent to use and there is less risk of operator error. By comparison the bailer can be operated variably by different operators and between wells. This consistency reduces analytical uncertainty (Barcelona and Helfrich, 1986; Puls and Powell, 1992; Sundaram et al., 2009).

Puls and Powell (1992) demonstrated that there is no need for filtration when sampling at low flow rates of 0.2-0.3L/min as both the filtered and unfiltered samples are consistent (Table 2). Removing the need to filter samples, minimises the potential physical and chemical alteration of the sample as well as sample handling, and provides a reliable sample of both the dissolved and mobile particulate metals within groundwater samples (Puls and Powell, 1992). Filtering groundwater can also introduce filtration related artefacts via filter clogging, variable particle size retention, the leaching of metals and aeration from the filter media. Aeration of samples can lead to precipitation of metals and a loss of volatile contaminants, which is particularly important when sampling in anoxic environments and in areas with petroleum rich contamination concerns (Puls and Powell, 1992; NEPC, 2013). These results in Table 2 are indicative of repeated experiments by Puls and Powell (1992) over a number of years and

indicate that filtration of low flow samples is unnecessary as the metals present in the groundwater are representative of the mobile and dissolved loads, with no issues associated with the excessive sampling rates of the bore purge method, however filtration is still considered a necessary component of groundwater sampling programs, however in high yield wells with a low turbidity the need is less pronounced (NEPC, 2013).

Table 2: Arsenic concentrations obtained from selected wells in the USA (after Puls and Powell, 1992).

Arsenic (µg/L)				
Well	0.1 µm	0.45 µm	5.0 µm	Unfiltered
101	68	71	71	68
103	202	230	232	241

2.4 – Current usage

The bore purge method is the most widely used method of groundwater sampling, largely as it was developed first and has been in use for a significant period of time. Most people use this method as they are familiar with it rather than because of any inherent positive or negative attribute (Robin and Gilham, 1987; Puls and Powell, 1992; Puls and Barcelona, 1996; Sundaram et al., 2009). There is a general reluctance to change to or adopt a new sampling strategy for two main reasons. Firstly the costs of sampling systems are very high and many small consultancies do not have the funds to upgrade to the newest sampling system. Secondly there is the belief among some scientists that changing from one method to another could lead to different end analytical results and trigger the need for expensive and long term remedial action (Puls and Powell, 1992; Puls and Paul, 1995).

Field sampling devices that are left in the well and are capable of both purging and sampling are the preferred choice over portable devices (Puls and Barcelona, 1996; Sundaram et al., 2009; NEPC, 2013). The use of dedicated sampling devices completely removes the risk of cross contamination from one sampling well to the other (Puls and Paul, 1995; Reilly and LeBlanc, 1998) as contaminants can get caught in the pump or pipe of the sampling mechanism. While the purging process is designed to give the pumps time to clean and flush away any cross contaminants, the risk is still present. Insertion of the purging device into the well can cause significant mixing of the stagnant water in the well casing above the screened interval and that of the screened interval (Puls and Powell, 1992). The insertion of the sampling device has also been shown to cause resuspension of solid particles that have settled

onto the bottom of the well casing (Puls and Powell, 1992). Both of these factors have been shown to increase the amount of time required for purging making dedicated sampling systems the preferred option for sampling programs (Puls and Powell, 1992; Puls and Paul, 1995; Reilly and LeBlanc, 1998).

Dedicated sampling devices may be too expensive to utilise during a large scale monitoring and sampling program, and so portable devices are by far the most widely utilised. As such, all guidelines recommend that portable sampling devices be lowered into the middle of the screened interval very slowly and carefully to try and minimise disturbance and resuspension of solids (Puls and Powell, 1992). However even with very controlled insertion there may be still highly significant amounts of mixing and resuspension (Puls and Powell, 1992).

Even though the potential issues associated with the use of the bore purge sampling method are becoming increasingly well documented, it is still a commonly utilised method of sampling (NEPC, 2013). The most recent guidelines specify that the low-flow sampling method is the industry standard and preferred method for sampling, however the bore purge method is still capable of being utilised despite the myriad above mentioned issues (NEPC, 2013).

3 – Site Background

3.1. – Site 1 – Defence Site Maribyrnong

3.1.1 – Brief Site History

The Defence Site Maribyrnong is located approximately 10 km northwest of central Melbourne, Victoria, Australia. The site is bounded to the north, east and west by the Maribyrnong River (Figure 4 and 5) and encompasses an area greater than 100 hectares. The land was traditional aboriginal land until the 1830's when, with European settlement, it was converted to pastoral land before being subdivided into two lots in the 1840's. In the early 1900's the site was purchased and became a military and explosives manufacturing site for the next 80 years with cordite, TNT (trinitrotoluene) and mercury fulminate being some of the main products manufactured on site. The site was decommissioned in the 1990's.
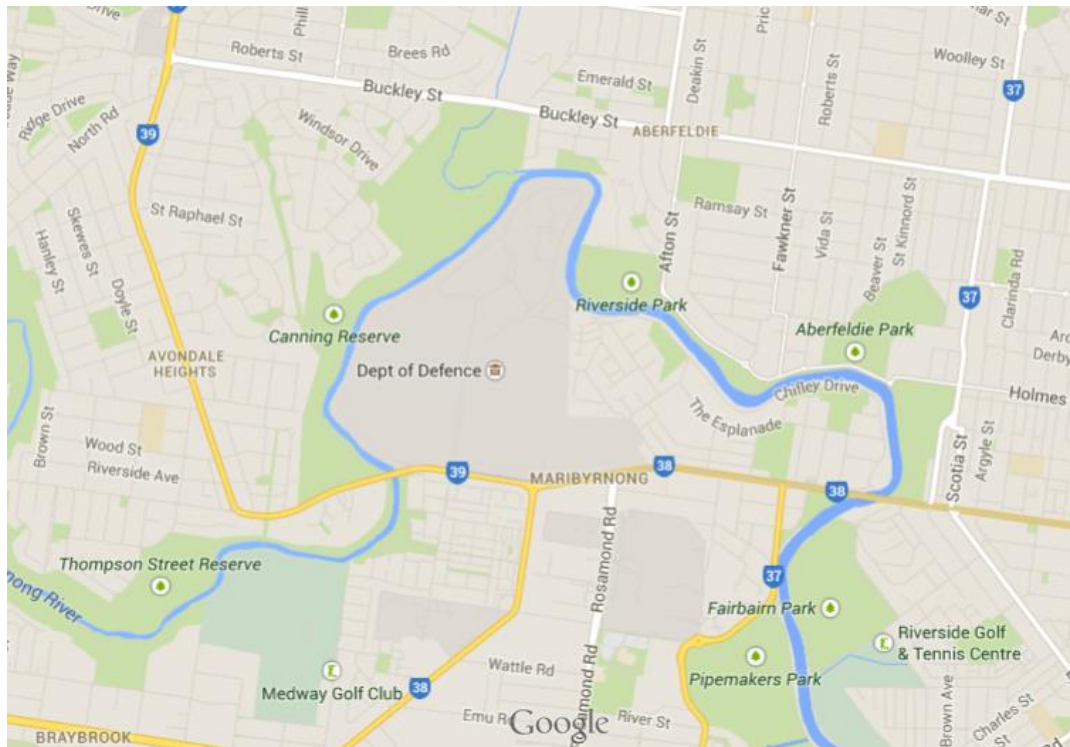
Figure 4: Location of the Defence site (encompassing the whole of the grey area at the centre of the map) where the groundwater monitoring program is in place (Google maps, 2014).

3.1.2 Potential contaminants

The Defence site's history as an explosives and manufacturing facility has created the potential for significant contamination issues to be present. With the on-site production of cordite there is the potential for nitric acid as well as nitro-glycerine to be present on site throughout the soil profile. TNT was also produced on the site for a number of years so toluene, sulphuric acid and sodium sulphite may also be present. With the production of military grade explosives on site a number of heavy metals, most likely lead, mercury, copper, zinc and aluminium, may also play a role in site contamination. A number of buildings were built on site to house the manufacturing process along with the construction of air raid shelters during the Second World War so there may also be traces of asbestos on the site. As is the case with manufacturing sites, there would have been a large number of transport vehicles on site so petrol/diesel leaks may have occurred, potentially contributing to the contamination. These factors comprise the main potential contaminants with lead, mercury, copper, zinc, aluminium asbestos and TNT being the contaminants to cause the most significant health issues.

3.1.3 – Geology

The geological units intersected on the site are summarised in Table 3; from youngest at the top to the oldest unit at the bottom.

Table 3. An outline of the geological units at the Defence Site Maribyrnong. The geological units confine the groundwater at the site into two separate aquifer zones.

Geological Unit	Aquifer zone	Description
Floodplain Silts	Upper aquifer	Comprised of silt and clay with minor sand interspersed with organic-rich layers. Formed by the deposition of organic-rich sediment in a low flow environment
Terrace Silts		Comprised of silt, clay and minor sand and gravel. Deposited in the river in a low energy environment when the sea level was higher than its current level. This unit extends across much of the site.
Alluvial Sands and Gravel		Comprised of sand and gravel with minor silt and clay. Deposited in a high energy environment when the sea level was lower than its present level.
Newer Volcanics	Aquiclude	Olivine basalt, which is highly vesicular, blue-grey when fresh and red-grey-brown when weathered. No bores are screened in this unit as it is not considered to be water bearing, this is the oldest unit to outcrop on the site.
Brighton Group	Aquitard	Red-white fluvial sand, silt, gravel with minor clay of the Tertiary period. The Brighton Group does not outcrop on the site and is often encountered between the Newer and Older Volcanics.
Older Volcanics		Comprised of highly weathered, low vesicularity, black extrusive tholeiitic and alkaline basalt with phenocrysts of olivine and titanaugite. Tertiary age.
Werribee Formation	Lower aquifer	Comprised of brown/grey fluvial sand, silt and clay that is carbonaceous and occasionally pyritic and lignitic. Tertiary age.
Dargile Formation		Comprised of grey mudstone, siltstone and shale with minor quartz veining. This is the basement unit at the site and is Silurian in age. No bores are screened in this unit.

3.1.4 – Hydrogeology

On the site there are two distinct aquifer units: the upper aquifer which includes the Floodplain Silts, Terrace Silts and the Alluvial Sands and Gravel, and the lower aquifer made up of the Werribee Formation. The Brighton Group and the Older Volcanics act as the aquitard between these two aquifer units. All of the bores included as part of this

investigation sample the upper aquifer layer. The upper aquifer is relatively unconfined and consists of various loose silts, clays, sands and gravels with the large pore spaces ensuring rapid groundwater flow throughout these units. The on-site bore numbers and their corresponding geological units are listed below (Table 4).

Table 4: List of the bores sampled on site and the geological unit they intersect.

Bore name	Geological unit
MW113	Alluvial sands and gravels
MW120	Alluvial sands and gravels
MW125	Alluvial sands and gravels
MW142	Floodplain silts
MW305	Terrace silts
MW308	Alluvial sands and gravels

With the site having a gentle downward slope of approximately 2 metres from the south to north, the general direction of groundwater flow on site is from the south to the south-east to the north-west with the groundwater flowing towards the river (Figure 5).

Figure 5: Map of the defence site and the locations of all the bores throughout the site (Provided by Environmental Earth Sciences).

3.2 – Site 2 - The Dunmore Waste and Resource Recycling Depot

3.2.1 – Brief site history

The Dunmore Waste and Resource Recycling Depot and landfill is located approximately 4 km south of the township of Shellharbour and 20 km to the south of Wollongong (Figure 6), NSW, Australia. The landfill site commenced operation in the mid 1970's at the north of the site. The current landfill cell which has been in operation since the site opened has reached capacity and is being capped. There are a further 10 landfill cells planned for the site which will provide over 1.5 million cubic metres of extra filling space (Golder, 2011).

Figure 6: Map depicting the location of the Dunmore Waste and Resource Recycling Depot (adapted from Golder, 2011).

Waste is placed on site, compacted in layers no more than 2 metres thick and then covered at the end of each day. Once a landfill cell is filled, it is capped with between 1-2 metres of clay and then rehabilitated. Some of the historical cells on the site are unlined, allowing leachate to flow freely away from the site (Golder, 2011).

3.2.2 – Potential Contaminants

The Dunmore Waste and Recycling Depot is a general-purpose municipal landfill that accepts a wide variety of waste from the Shellharbour City Council. With approximately 43 000 tonnes of waste accepted in 2008/2009 this amounts to a substantial variety of potential contaminants (Golder, 2011).

While the landfill itself prohibits the disposal of hazardous wastes such as petrol, paints, solvents, gas bottles and electronics there is always the possibility that some may slip through and into the landfill. Also historically, landfills generally in the 1970's were less heavily regulated than they are now so there is the potential that there may be hazardous waste in the historical sections of the landfill. Also while a recycling centre on site accepts eWaste, sump oil, cooking oil and all metal free of charge, there is always the possibility that some may be disposed of in the regular garbage collection and end up in the landfill.

Landfill leachates contain extremely elevated concentrations of dissolved organic matter with up to a factor of 1000 to 5000 times higher than concentrations found in groundwater, making the organic component the largest component of landfill leachate (Kjeldsen et al., 2002; Slack et al., 2009). Kjeldsen et al. (2002) and Oman and Junestedt (2008) suggest that the greatest issue within the inorganic component of leachate is long-term ammonia release (in the form of NH_4^+). Ammonia is released by the breakdown of protein and since there is no methanogenic process to break down ammonia the only way it can be removed is via the leaching process; expelling it into the groundwater and surrounding soils (Kjeldsen et al., 2002; Oman and Junestedt, 2008). Humans can naturally excrete excess ammonia in urine, however, fish and amphibians are unable to excrete excess ammonia and as such even extremely dilute concentrations can be deadly (Kjeldsen et al., 2002; Oman and Junestedt, 2008; Laner et al., 2012).

Ammonia and elevated organic matter output from the landfill therefore would be the two main contaminants of concern, along with small trace amounts of hydrocarbons potentially leaching out of the site from oils, solvents and petrol being illegally dumped. However landfill leachate is especially variable so it can be hard to specifically quantify a set of potential contaminants (Kjeldsen et al., 2002).

3.2.3 – Geology and Hydrogeology

The water table is very shallow, only about one metre below natural ground level, which leads to the creation of large ponds during landfill operations (Golder, 2011; Figure 7). Rates of groundwater flow are high at the site due to the high water table and the porous soil and sand of the aquifer. This enables the bores to recharge rapidly during and after a sampling event (McCarthy and Zachara, 1989; Kjeldsen et al., 2002), demonstrating the site's suitability for this research.

Figure 8 shows a bore log for bore hole number 3 (BH3). The first 1.5 m of the log is composed of compacted household waste from the landfill. The lower, 7.5m is comprised primarily of fine grained yellow-brown quartz sand, with some plagioclase and minor shell content. The log for bore hole 4 (BH4) shows that the ground surrounding the bore is completely composed of this fine grained yellow-brown quartz sand, with some plagioclase and minor shell content reaching down to the base of the bore at 9m (Figure 9). Groundwater flow is south towards the river (Figure 7).

Figure 7: Aerial view of the Dunmore Waste and Resource Recycling Depot and the locations of the two bores sampled in the research: BH3 being the first bore sampled and BH4 being the second (Map provided by Environmental Earth Sciences). The river at the base of this image controls the groundwater flow towards the south on this site.
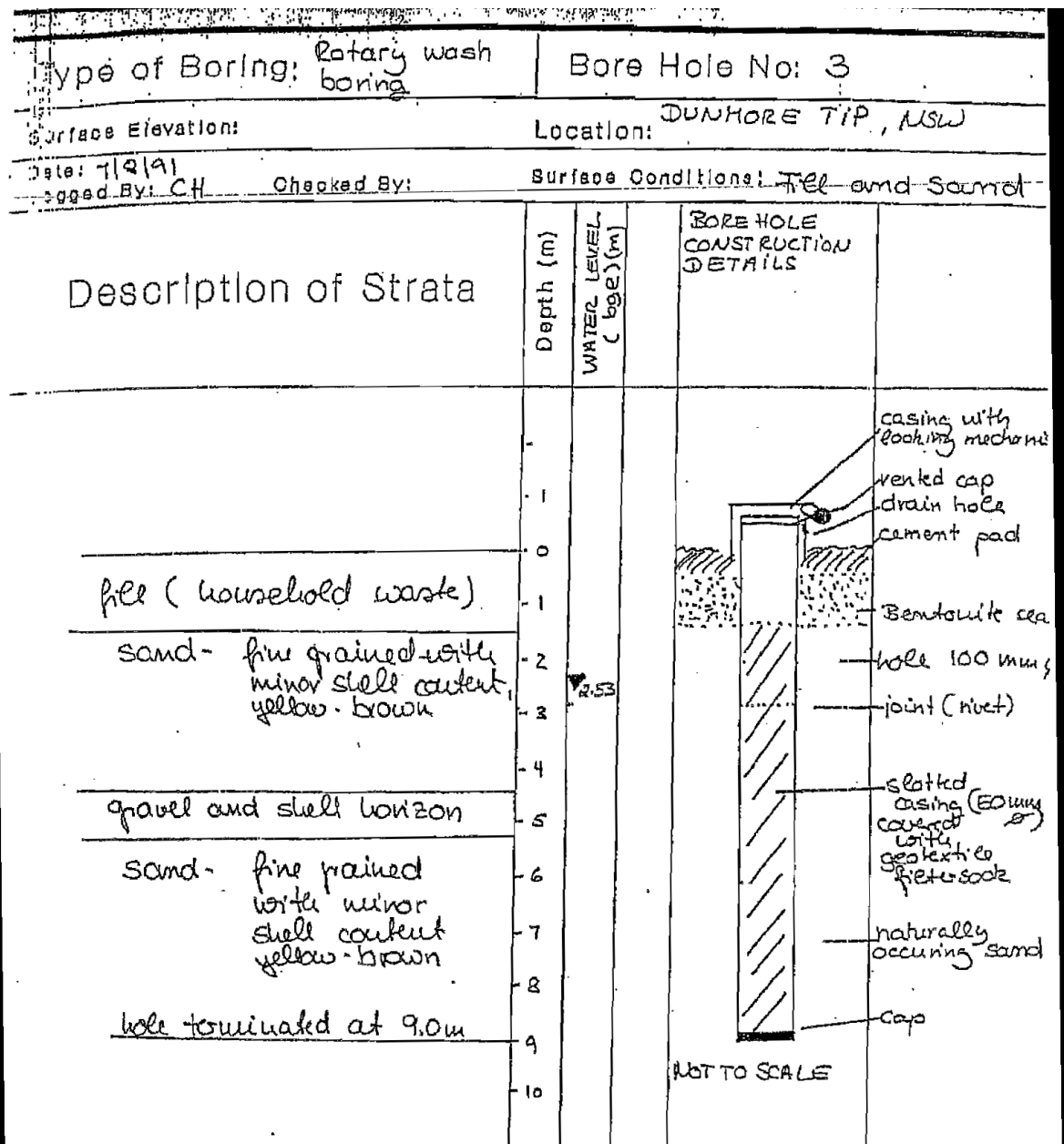
Figure 8: Bore log of sample location 1 from site 2; labelled as Bore hole No: 3. Log Provided by Environmental Earth Sciences.
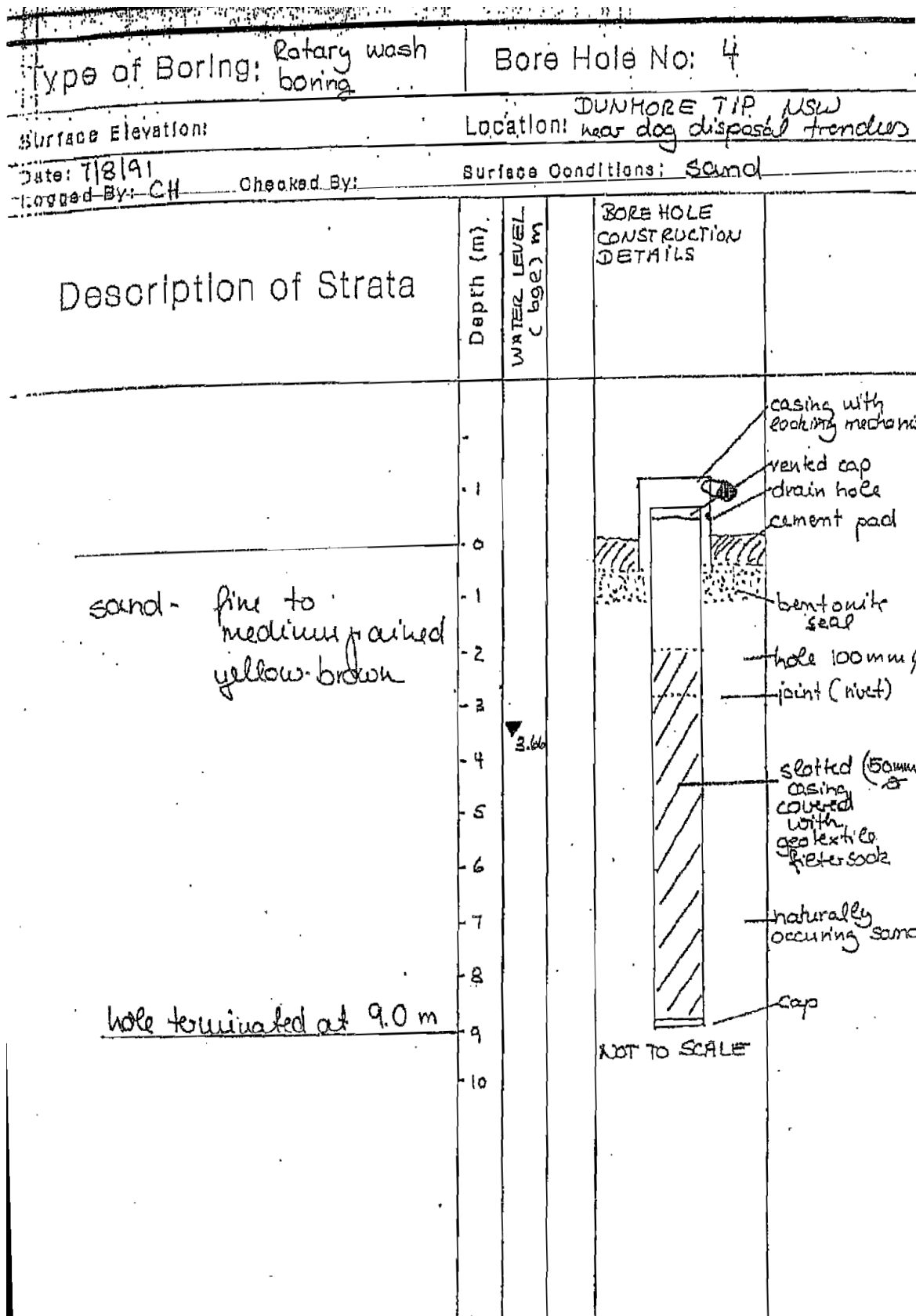
Figure 9: Bore log of sample location 2 from site 2; labelled as Bore hole No: 4. Log Provided by Environmental Earth Sciences.

3.3 – Site 3 – Queanbeyan Construction Site

3.3.1 – Brief site history

This is the site of a new housing development located approximately 15km south of Queanbeyan, NSW, Australia. The region was previously undeveloped and is in close proximity to National Parklands so no industry was previously present on the site. Construction is currently ongoing and as such monitoring bores have been set up to monitor any potential contamination that many arise from the work, or that could be pre-existing on the site (Figure 10).
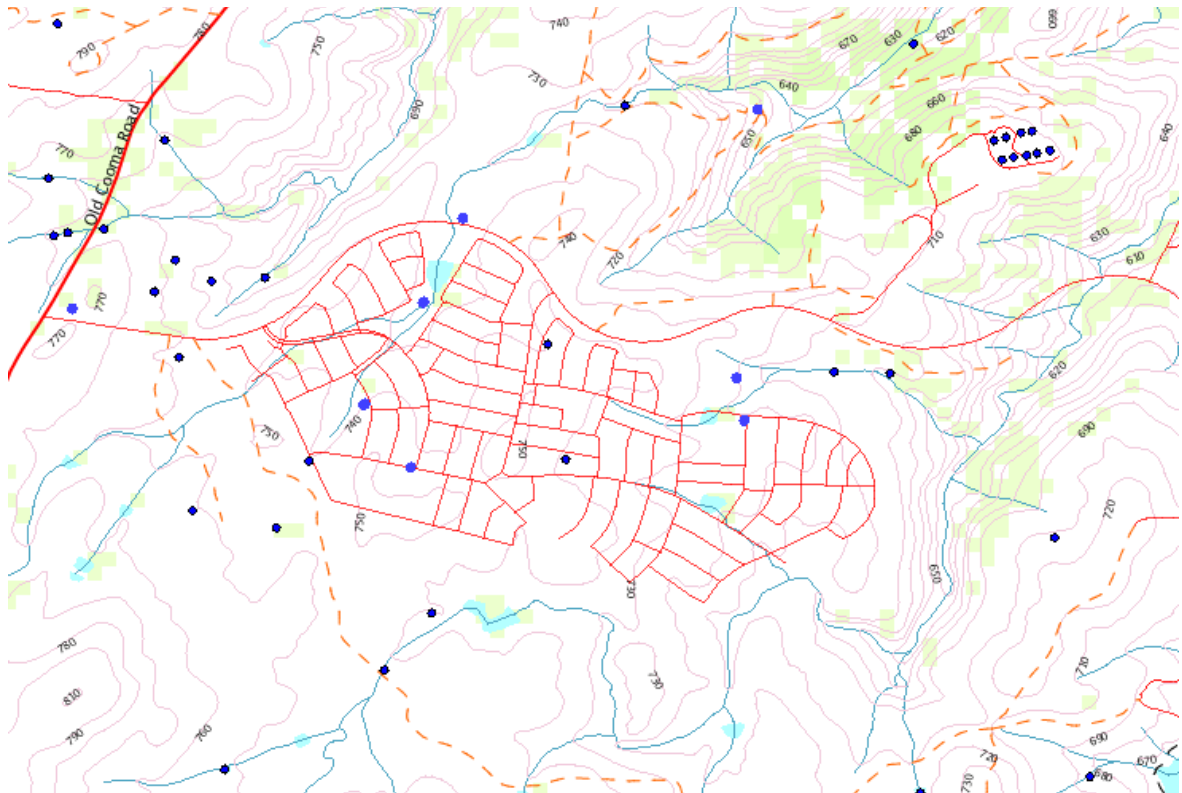
Figure 10: Site map of the construction site. Due to the nature of the monitoring program and stakeholders involved this is as much detail as can be given (NSW Resource Atlas, 2014).
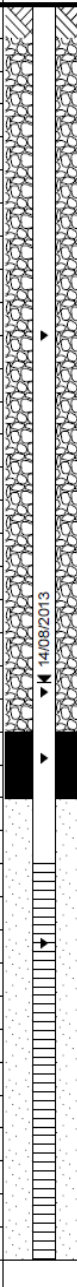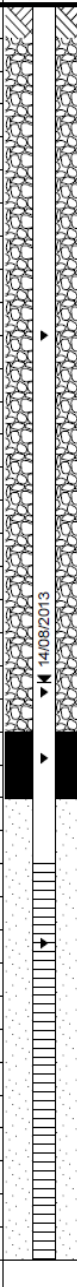
3.3.2 – Geology and Hydrogeology

The geology of the bores used at this site is outlined in Figures 11 and 12. The bore at Location 1 has a 40 cm layer of topsoil above weathered dacite (which has been misidentified on Figure 11 as adamellite), which extends for six metres and overlies fresh dacite. The dacite extends to the bottom of the bore at 26 m and is progressively less weathered down section. The bore at Location 2 has a 30 cm layer of topsoil, overlying highly weathered shale

to 10.3 m, limestone and moderately weathered shale to the end of the bore at 19 m (Figure 12). The weathering of the rocks in the bores has created pores, which allows the groundwater to flow at a much higher rate than would normally be possible. This leads to the site having the high yield characteristics suitable for this research.

Drilling		Depth		Well Construction		SUBSTANCE					Testing		OTHER OBSERVATIONS
Method	Support	Elev. (RL m)	Depth (mbgl)	Well Construction Details	Construction notes	Graphic Log	Description NAME: grain size / plasticity, color, structure, minor components	Moisture	Density	Weathering	Type	Result (L/sec)	Notes (Structure, origin, etc)
RAB 125 mm		720 / 718 / 716 / 714 / 712 / 710 / 708 / 706 / 704 / 702 / 700 / 698 / 696 / 694 / 692	1–28	19/08/2013 Backfill 0.5m to 15m; Bentonite seal 15m to 16m; Filter pack 16m to 26m; Screen interval 18m to 26m			TOPSOIL: low plasticity sandy clay, brown to becoming black with extremely weathered rock	M					Googong Granite
							ADAMELLITE: tan to white, quartz rich with foliation, extremely weathered and minor clay seam at 3m						
							DACITE: blue grey, hard, siliceous with epidote and minor quartz fragments at 12m and becoming softer	D					
							soft, becoming tan then green blue from 15m	Dm					Colinton Volcanics
							with black siliceous bands and becoming blue grey and coarse from 25m	D					
								Dm					
								M					
								W					
							Bore discontinued at 26.00m				ALT	0.03	

Notes: mbgl = metre below ground level; m.a.s.l. = metre above sea level, RL m = Relative Level in metre (here m.a.s.l.), HW=Highly Weathered, EW=Extremely Weathered, MW=Moderately Weathered, SW=Slightly Weathered, FR=Fresh, D=Dry (moisture), M=Moist, W=Wet, ALT=Air Lift Test, D=Dense (density), MD=medium dense ▶ Inflow ▼ Standing Water Level

Figure 11: Bore log of sample location 1 from site 3; labelled as Bore GGW 3D. Log provided by SMEC.

Drilling		Depth		Well Construction			SUBSTANCE					Testing		OTHER OBSERVATIONS
Method	Support	Elev. (RL m)	Depth (mbgl)	Well Construction Details	Construction notes	Graphic Log	Description / NAME: grain size / plasticity, color, structure, minor components	Moisture	Density	Weathering		Type	Result (L/sec)	Notes (Structure, origin, etc)

Drilling method: RR 110 mm, RAB 125 mm

Well Construction notes:
- Backfill 0.5m to 11m
- 14/08/2013
- Bentonite seal 11m to 12m
- Filter pack 12m to 19m
- Screen interval 13m to 19m

Substance descriptions:
- TOPSOIL: silty clay, red brown with minor sand and gravel
- SHALE: yellow brown extremely weathered — D
- SHALE: yellow grey to grey brown, highly weathered to moderately weathered — M, D
- LIMESTONE: dark grey, fresh with minor veins of pyrite — M, D
- SHALE: brown grey moderately weathered, minor quartz vein — D, M
- SHALE: grey brown with minor fractures, some quartz veins — W
- Bore discontinued at 19.00m

Testing: ALT, 0.2

Other observations: Colinton Volcanics

Notes: mbgl = metre below ground level; m.a.s.l. = metre above sea level, RL m = Relative Level in metre (here m.a.s.l.), HW=Highly Weathered, EW=Extremely Weathered, MW=Moderately Weathered, SW=Slightly Weathered, FR=Fresh, D=Dry (moisture), M=Moist, W=Wet, ALT=Air Lift Test, D=Dense (density), MD=medium dense ▶ Inflow ▼ Standing Water Level

Figure 12: Bore log of sample location 2 from site 3. Labelled as bore GGW 1D. Log provided by SMEC.

4 – Methodology

4.1 – Choice of analytes

Analytes were chosen that are commonly included in groundwater sampling programs. Table 4 below summarises what was sampled at each site and the sampling dates of each location.

Table 4: Table summarising the analytes sampled at each field site and the dates of the sampling events

FIELD SITE	ANALYTES SAMPLED FOR	SAMPLING DATES
1 – Defence site Maribyrnong	Heavy metals, cyanide, Ionic Balance, Perchlorate, Explosives, SVOC, VOC, PAHSs, Organic Nitrogen, Insecticides	October 2009
2 – Dunmore Waste and Resource Recycling Depot and Landfill	BOD, COD, PAHs, Insecticides, Ionic Balance and Organic Nitrogen	27/05/2014
3 - Queanbeyan Construction Site	BOD, COD, PAHs, Ionic Balance and Organic Nitrogen	05/06/2014

Sampling for heavy metals (e.g., arsenic, copper, zinc) was considered for sites 2 and 3 but was not included due to budget concerns. Furthermore the typically low levels of heavy metals occurring in landfill leachate (typically below 0.1 mg/L; Cassel, 1988; Bozkurt et al., 1999; Matura, 2010), and the general lack of heavy metal movement away from landfills in leachate (Cassel, 1988; Bozkurt et al., 1999; Kjeldsen et al., 2002; Sang-Yul et al., 2005) along with the undeveloped nature of site 3 make heavy metal contamination unlikely. Cassel (1988) and Bozkurt et al. (1999) show that after 30 years less than 0.2% of the heavy metals disposed of within landfills have been leached. These generally low levels within the leachate are due to the very strong sorptive capacity of the soils preventing movement away from the source at the neutral pH often found in the landfill, and the high content of organic matter within the landfill (Cassel, 1988; Bozkurt et al., 1999; Kjeldsen et al., 2002; Sang-Yul et al., 2005). In addition, many of the metals have extremely low solubilities making it unlikely they will be incorporated into the leachate and end up within the sampling bores (Bozkurt et al., 1999; Kjeldsen et al., 2002; Sang-Yul et al., 2005).

4.2 – Field sampling methodology

Field sampling was conducted at the three sites using slightly different sampling methods that were dependent on the equipment available at each site. However, this is not expected to have a significant impact on the findings. The methods used at each site are outlined below.

4.2.1 – Site 1 (Defence Site Maribyrnong) sampling methodology

During the large scale sampling program undertaken by Environmental Earth Sciences (EES) at the Defence Site Maribyrnong, duplicate sampling events were undertaken on six of the chosen monitoring bores using the low flow and bore purge sampling methods. The bores were selected based on their historical capacity for high rates of recharge and because of the presence of contaminants of concern. The bores that were selected on the site are named MW113, MW120, MW125, MW142, MW305, and MW308.

The bores were first sampled using a Micropurge sampling system and groundwater field parameters (pH, dissolved oxygen, reduction potential (redox), temperature, turbidity and electrical conductivity) were monitored using an in-line flow cell. The groundwater was purged at a rate of 0.3L/min until parameters had stabilised to within 10 % variation over three consecutive readings, for these sites this occurred after 6 or 7 readings. Once the field parameters were stabilised sampling took place. Water was stored in the appropriate sampling bottles provided by the EES laboratory of choice.

Following sampling using the micropurge sampling system, the equipment was immediately removed and the submersible pump inserted to sample the bore using the bore purge method. After three bores worth of water was purged from the well, the groundwater was sampled. The purged groundwater was collected in drums at the sampling points and stored in a number of intermediate bulk containers. The waste water was disposed of by Chemsal, a waste collection and disposal agency. The results of the analysis were provided by EES following their large scale investigation of the site.

4.2.2 – Site 2 (Dunmore Waste and Resource Recycling Depot and landfill) sampling methodology

The bores were sampled first using a peristaltic pump purging at a rate of 0.4 L/min to fill the role of the low flow sampling system. A peristaltic pump is a positive displacement pump

that operates on the alternating compression and relaxation of a flexible tube drawing in the groundwater and drawing it up at a constant rate. Groundwater field parameters (pH, dissolved oxygen, temperature, turbidity and electrical conductivity) were monitored using an in-line flow cell. Groundwater was purged until all parameters had stabilised to within 10 % variation over three consecutive readings, for these sites this occurred after 8 readings. The minimal drawdown method was used during sampling to ensure the flow rate into the bore was the same as the purge rate, ensuring the depth of the water did not change. Once the field parameters were stabilised, sampling took place. Water was stored in the appropriate sampling bottles provided by the National Measurement Institute (NMI). Following the sampling using the peristaltic pump, the equipment was removed and a whale pump was inserted to sample the bore using the bore purge method. After three bore volumes of water was purged from the well, the groundwater was sampled again and stored in the appropriate sampling bottles.

Water samples for analysis collected under both the bore purge and micropurge sampling methods were collected in 1L amber glass bottles and 1L plastic bottles, chilled immediately in an ice-filled Esky on site, and then delivered to the NMI within 24 hours. Since regulations on site specify that waste groundwater is not to be removed from the grounds, the purged water was immediately poured onto the ground when sampling was complete and all appropriate measurements had been taken.

4.2.3 – Site 3 (construction site, Queanbeyan) sampling methodology

The bores were sampled using a bore purge pump purging at 1L/min to fill the role of the low flow sampling method. Groundwater field parameters (pH, dissolved oxygen, temperature, turbidity and electrical conductivity) were monitored using an in-line flow cell. Groundwater was purged until parameters had stabilised to within 10 % variation over three consecutive readings, which occurred after 15-17 readings. The minimal drawdown method was used during sampling to ensure the flow rate into the bore was the same as the purge rate, ensuring the depth of the water did not change. Once the field parameters were stabilised, sampling took place. Water was stored in the appropriate sampling bottles provided by the National Measurement Institute (NMI).

Following the sampling using the slowest speed setting (1L/min), the whale pump was then turned to the highest speed setting of 5L/min to sample the bore using the bore purge method.

After three bore volumes of water was purged from the well, the groundwater was sampled and stored in the appropriate sampling bottles.

Water samples for analysis collected under both the bore purge and micropurge sampling methods were collected in 1L amber glass bottles and 1L plastic bottles, chilled immediately in an ice-filled Esky on site, and then delivered to the NMI at the end of the day. Since regulations on site specify that waste groundwater is not to be removed from the grounds, the purged water was immediately poured onto the ground once sampling was complete and all appropriate measurements had been taken.

4.3 – Laboratory analysis of groundwater

Results obtained for Site 1, the Defence Site Maribyrnong, were provided by Environmental Earth Sciences. The groundwater samples from Sites 2 and 3 were analysed by liquid Gas Chromatography at the National Measurement Institutes (NMI) North Ryde laboratory, a NATA (National Association of Testing Authorities) certified laboratory. A total of eight groundwater samples were processed for Sites 2 and 3. At Site 2, BOD, COD, PAHs, Insecticides, Ionic Balance and Organic Nitrogen testing was carried out. At Site 3 BOD, COD, PAHs, Ionic Balance and Organic Nitrogen was carried out.

5 – Experimental Results

The results for field parameters for Sites 1, 2 and 3 are presented in Tables 4 to 10. The field parameters are obtained routinely as it is essential that these variables have equilibrated prior to sampling with the low-flow method (Puls and Powell, 1996). For Site 1, the field parameters were only provided for bores MW113 (Table 4), MW120 (Table 5) and MW125 (Table 6), however, it can be assumed that the other three bores, MW142, MW305 and MW308, had been sampled after the field parameters had stabilised. Apart from turbidity, which was highly variable, the entire range of field parameters varied less than 10 % over three successive readings before samples were taken.

The field parameters for Site 2 (Tables 7 and 8) and Site 3 (Tables 9 and 10) are also given for the two bores sampled at each location.

Table 4. Site 1 bore MW113 -Field Parameters									
Flow rate	pH	Volume Purged	SWL*	DO ppm	EC (µs/cm)	pe (mV)	Temp	Turbidity (NTU)	Time
0.3L/min	7.07	3	14.02	5.39	6380	193	18.4	20.8	11:47
0.3L/min	7.14	5	14.02	5.3	6500	196	18.3	16.7	11:52
0.3L/min	7.16	7	14.02	5.32	6450	199	18.2	14.4	12:00
0.3L/min	7.19	10	14.02	5.67	6430	200	18.3	13.1	12:11
0.3L/min	7.2	13	14.02	5.6	6430	200	18.4	9	12:23
0.3L/min	7.2	15	14.02	5.62	6430	200	18.4	11.3	12:31
0.3L/min	7.21	19	14.02	5.98	6430	196	19.1	24.2	12:50
									*Samples taken at 12:50

Table 5. Site 1 bore MW120 - Field Parameters									
Flow rate	pH	Volume Purged	SWL*	DO ppm	EC (µs/cm)	pe (mV)	Temp	Turbidity (NTU)	Time
0.3L/min	6.87	3	15.85	1.49	9280	204	17.5	4840	8:38
0.3L/min	7	6	15.92	3.95	9340	209	17.9	851	8:48
0.3L/min	7.04	9	15.93	5.39	9390	207	18	645	8:57
0.3L/min	7.07	12	15.95	5.71	9380	206	18.2	400	9:05
0.3L/min	7.09	15	15.95	5.75	9380	208	18.1	255	9:12
0.3L/min	7.09	17	15.95	6.75	9370	207	18.1	216	9:18
0.3L/min	6.98	21	15.96	6.73	9370	199	18	306	9:28
									*Samples taken at 9:28

Table 6. Site 1 bore MW 125 - Field Parameters									
Flow rate	pH	Volume Purged	SWL*	DO ppm	EC (µs/cm)	pe (mV)	Temp	Turbidity (NTU)	Time
0.4L/min	7.13	4	1009	2.31	8010	182	18.4	321	13:59
0.4L/min	7.14	7	1012	1.93	7820	177	18.5	117.4	14:06
0.4L/min	7.17	10	1012	1.75	7910	175	18.3	66	14:12
0.4L/min	7.14	13	1013	1.68	7860	174	18.5	88.2	14:19
0.4L/min	7.17	16	1014	1.62	7860	174	18.2	44.1	14:25
0.4L/min	7.16	18	1014	1.63	7860	173	18.2	24.5	14:30
									*Samples taken at 14:30

Table 7. Site 2 bore 3 (first sample location)						
Volume (L)	T˚C	DO ppm	pH	mV	EC (µs)	Time
0.1	20.4	1.4	6.72	209	2166	12:59
0.4	20.3	1.39	6.7	207	2167	1:00
1.2	20.1	0.74	6.88	207	2170	1:02
2	19.9	0.7	6.93	207	2172	1:04
2.8	19.6	0.51	7.02	206	2189	1:06
3.6	19.6	0.4	7.04	204	2188	1:08
4.4	19.5	0.38	7.05	204	2188	1:10
5.2	19.5	0.37	7.05	203	2187	1:12
						*Samples taken at 1:13

Table 8. Site 2 bore 4 (second sample location)						
Volume (L)	T˚C	DO ppm	pH	mV	EC (µs)	Time
0.1	n/a	n/a	n/a	n/a	n/a	1:42
0.4	n/a	n/a	n/a	n/a	n/a	1:43
1.2	19.1	0.74	7.03	30	1615	1:45
2	18.8	0.64	7.15	49	1600	1:47
2.8	18.8	0.27	7.18	67	1640	1:49
3.6	18.7	0.29	7.18	70	1635	1:51
4.4	18.7	0.28	7.18	72	1625	1:53
4.8	18.6	0.28	7.18	74	1619	1:54
						*Samples taken at 1:55

Table 9. Site 3 bore GGW 3D (first sample location)				
Volume (L)	T˚C	EC (µs)	pH	Time
0				10:00
5	15.4	1933	6.57	10:05
10	15.8	1949	7.11	10:10
15	16.2	1927	7.19	10:15
20	16.2	1829	7.26	10:20
25	16.3	1742	7.19	10:25
30	16.4	1628	7.24	10:26
35	16.4	1544	7.27	10:27
40	16.4	1545	7.28	10:28
45	16.5	1545	7.31	10:29
50	16.5	1541	7.35	10:30
55	16.6	1545	7.39	10:31
60	16.6	1228	7.34	10:32
65	16.6	1255	7.35	10:33
70	16.6	1264	7.32	10:34
75	16.6	1230	7.36	10:35
80	16.6	1155	7.37	10:36
85	16.6	1180	7.41	10:37
				*Low-flow sample taken at 10:25
				*High flow sample taken at 10:37

Table 10. Site 3 bore GGW 1D (second sample location)				
Volume (L)	T˚C	EC (µs)	pH	Time
0	n/a	n/a	n/a	11:00
5	16.2	690	6.66	11:05
10	16.1	979	6.69	11:10
15	16.1	885	6.71	11:15
20	16.1	884	6.68	11:20
25	16.1	892	6.68	11:21
30	16.2	842	6.68	11:22
35	16.1	842	6.7	11:23
40	16.1	821	6.71	11:24
45	16.1	832	6.72	11:25
50	16.1	833	6.73	11:26
55	16.1	835	6.75	11:27
60	16.2	837	6.78	11:28
65	16.2	720	6.8	11:29
70	16.2	736	6.81	11:30
*Low-flow sample taken at 11:20				
*High flow sample taken at 11:30				

Summary results for the laboratory measurements of the groundwater samples are provided in Tables 11, 12 and 13. The results were compared using relative percentage differences (RPDs) to determine the extent, if any, of differences between the two groundwater sampling methods.

Table 11. Results of the laboratory analysis between the two different sampling methods for Site 1 (Defence Site Maribyrnong)

Analyte	Unit	MW113 Low-Flow	MW113 Purge	RPD %	MW120 Low-Flow	MW120 Purge	RPD %	MW125 Low-flow	MW125 Purge	RPD%
INORGANIC ANALYTES										
pH	pH Unit	7.2	7.32	1.7	7.13	7.06	1.0	7.35	7.23	1.6
Electrical Conductivity	µS/cm	7370	8050	8.8	9740	9710	0.3	7520	7500	0.3
Total Dissolved Solids	mg/L	5010	5620	11	6280	6300	0.3	5450	5440	0.2
Bicarbonate Alkalinity	mg/L	489	505	3.2	333	345	3.5	611	618	1.1
Total Alkalinity	mg/L	489	505	3.2	333	345	3.5	611	618	1.1
Sulfate as SO$_4$	mg/L	438	464	5.8	21	20	4.9	684	679	0.7
Chloride	mg/L	2040	2090	2.4	2960	2980	0.7	1670	1610	3.7
Calcium	mg/L	128	142	10	244	243	0.4	109	107	1.9
Magnesium	mg/L	238	262	9.6	368	366	0.5	175	174	0.6
Sodium	mg/L	1160	1210	4.2	1310	1290	1.5	1330	1320	0.8
Potassium	mg/L	22	23	4.4	21	21	0.0	16	16	0.0
Fluoride	mg/L	0.3	0.3	0.0	0.2	0.2	0.0	0.2	0.3	40
Nitrite as N	mg/L	<0.01	<0.01	0.0	<0.01	<0.01	-	0.01	0.01	0.0
Nitrate as N	mg/L	5.77	6.4	10	0.28	0.26	7.4	21.5	20.1	6.7
Nitrite + Nitrate as N	mg/L	5.77	6.4	10	0.28	0.26	7.4	21.5	20.2	6.2
TKN as N	mg/L	<0.1	<0.1	-	<0.1	<0.1	-	0.5	0.1	133
Reactive Phosphorus	mg/L	0.19	0.17	11	0.03	0.03	0.0	0.82	0.74	10
IONIC BALANCE										
Total Anions	meq/L	76.3	78.6	3.0	90.5	91.4	1.0	73.6	72	2.2
Total Cations	meq/L	77	81.8	6.0	99.9	98.9	1.0	78.2	77.3	1.2
Ionic Balance	%	0.45	1.95	-	4.95	3.92	-	2.99	3.53	-

Table 11 (continued)

Analyte	Unit	MW113 Low-flow	MW113 Purge	RPD %	MW120 Low-flow	MW120 Purge	RPD %	MW125 Low-flow	MW125 Purge	RPD%
DISSOLVED METALS										
Arsenic	mg/L	<0.001	<0.001	-	0.001	<0.001	0.0	0.003	0.003	0.0
Barium	mg/L	0.087	0.086	1.2	0.084	0.087	3.5	0.026	0.024	8.0
Cadmium	mg/L	0.0002	<0.0001	67	<0.0001	0.0005	133	<0.0001	<0.0001	0.0
Chromium	mg/L	0.028	0.031	10	<0.001	<0.001	0.0	<0.001	<0.001	0.0
Hexavalent Chromium	mg/L	0.016	0.012	29	<0.010	<0.010	0.0	<0.010	<0.010	0.0
Cobalt	mg/L	<0.001	<0.001	0.0	<0.001	<0.001	0.0	0.002	0.002	0.0
Copper	mg/L	0.004	0.002	67	0.005	0.002	86	0.004	0.003	29
Manganese	mg/L	<0.001	<0.001	0.0	0.006	0.004	40	0.199	0.27	30
Molybdenum	mg/L	0.002	0.002	0.0	0.001	<0.001	0.0	0.005	0.006	18
Nickel	mg/L	0.002	<0.001	67	0.007	0.005	33	0.002	0.001	67
Selenium	mg/L	<0.01	0.01	0.0	<0.01	<0.01	0.0	0.06	0.05	18
Tin	mg/L	0.003	<0.001	100	0.009	<0.001	160	<0.001	<0.001	0.0
Vanadium	mg/L	<0.01	<0.01	0.0	<0.01	<0.01	0.0	0.02	0.02	0.0
Zinc	mg/L	0.012	0.008	40	0.02	0.009	76	0.009	0.005	57
ORGANIC ANALYTES										
Carbon Tetrachloride	µg/L	4	4	0.0	<1	<1	0.0	198	300	41
Trichloroethene	µg/L	142	130	8.8	<1	<1	0.0	6	6	0.0
Chloroform	µg/L	2	2	0.0	<1	<1	0.0	42	41	2.4
TPH C_6-C_8 Fraction	µg/L	150	140	6.9	<20	<20	0.0	250	350	33
Perchlorate	µg/L	118	144	20	<0.2	<0.2	0.0	138	154	11

Table 11 (continued)

INORGANIC ANALYTES

Analyte	Unit	MW142 Low-flow	MW142 Purge	RPD	MW305 Low-flow	MW305 Purge	RPD	MW308 Low-flow	MW308 Purge	RPD
pH	pH Unit	6.32	6.77	6.9	7.71	7.61	1.3	7.1	7.01	1.3
Electrical Conductivity	µS/cm	8420	8710	3.4	1630	1830	12	12600	12800	1.6
Total Dissolved Solids	mg/L	5860	5700	2.8	918	1030	11	8310	8420	1.3
Carbonate Alkalinity	mg/L	<1	<1	0.0	7	<1	150	<1	<1	0.0
Bicarbonate Alkalinity	mg/L	662	636	4.0	431	445	3.2	664	661	0.5
Total Alkalinity	mg/L	662	636	4.0	438	445	1.6	664	661	0.5
Sulfate as SO$_4$	mg/L	722	732	1.4	50	52	3.9	612	574	6.4
Chloride	mg/L	2380	2420	1.7	209	202	3.4	3820	3640	4.8
Calcium	mg/L	200	192	4.0	12	14	15	247	249	1.0
Magnesium	mg/L	317	317	0.0	20	23	14	427	428	0.0
Sodium	mg/L	1180	1180	0.0	324	331	2.1	1980	1990	1.0
Potassium	mg/L	42	42	0.0	6	6	0.0	14	14	0.0
Total Cyanide	mg/L	0.004	0.005	22	<0.004	<0.004	0.0	0.004	0.004	0.0
Fluoride	mg/L	0.2	0.2	0.0	0.4	0.4	0.0	0.4	0.3	29
Ammonia as N	mg/L	17	16.2	4.8	<0.01	<0.01	0.0	<0.01	<0.01	0.0
Nitrate as N	mg/L	0.01	<0.01	0.0	2.15	2.46	13	0.04	0.03	29
Nitrite + Nitrate as N	mg/L	0.01	<0.01	0.0	2.15	2.46	13	0.04	0.03	29
TKN as N	mg/L	17.7	18.5	4.4	<0.1	<0.1	0.0	<0.1	<0.1	0.0
Reactive Phosphorus	mg/L	0.99	1.13	13	0.57	0.47	19	0.24	0.23	4.3
Total Anions	meq/L	95.5	96.2	0.7	15.7	15.7	0.0	134	128	4.6
Total Cations	meq/L	88.6	88.3	0.3	16.5	17.1	3.6	134	134	0.0
Ionic Balance	%	3.8	4.32	-	2.59	4.38	-	0.14	2.54	-

Table 11 (continued)

Analyte	Unit	MW142 Low-flow	MW142 Purge	RPD	MW305 Low-flow	MW305 Purge	RPD	MW308 Low-flow	MW308 Purge	RPD
DISSOLVED METALS										
Aluminium	mg/L	0.02	<0.01	67	<0.01	<0.01	0.0	<0.01	<0.01	0.0
Arsenic	mg/L	<0.001	<0.001	0.0	0.002	0.002	0.0	0.003	0.002	40
Barium	mg/L	0.124	0.114	8.4	0.035	0.049	33	0.238	0.244	2.5
Cadmium	mg/L	<0.0001	0.0004	120	<0.0001	<0.0001	0.0	0.0002	0.0002	0.0
Chromium	mg/L	<0.001	<0.001	0.0	0.009	0.009	0.0	<0.001	<0.001	0.0
Copper	mg/L	0.006	0.005	18	0.002	0.006	100	0.007	0.003	80
Manganese	mg/L	0.209	0.396	62	<0.001	<0.001	0.0	0.002	0.002	0.0
Molybdenum	mg/L	<0.001	<0.001	0.0	0.004	0.004	0.0	0.004	0.004	0.0
Nickel	mg/L	0.023	0.003	154	<0.001	<0.001	0.0	0.007	0.008	13
Selenium	mg/L	0.01	0.01	0.0	<0.01	<0.01	0.0	<0.01	<0.01	0.0
Tin	mg/L	0.004	<0.001	120	0.004	<0.001	120	0.001	<0.001	0.0
Vanadium	mg/L	<0.01	<0.01	0.0	<0.01	<0.01	0.0	0.02	0.02	0.0
Zinc	mg/L	0.008	0.01	22	0.012	0.01	18	0.016	0.007	78
ORGANIC ANALYTES										
Toluene	µg/L	<1	1	0	<1	<1	0.0	<1	<1	0.0
Carbon disulfide	µg/L	8	6	29	<1	<1	0.0	<1	<1	0.0
cis-1,2-Dichloroethene	µg/L	<1	<1	0.0	<1	<1	0.0	4	4	0.0
Trichloroethene	µg/L	<1	<1	0.0	96	107	11	17	17	0.0
Chloroform	µg/L	<1	<1	0.0	2	2	0.0	<1	<1	0.0
TPH C_6-C_8 Fraction	µg/L	<20	<20	0.0	100	120	18	<20	<20	0.0
TPH C_{16}-C_{23} Fraction	µg/L	<100	<100	0.0	<100	<100	0.0	100	100	0.0
TPH C_{10}-C_{38} Fraction sum	µg/L	ND	ND	0.0	ND	ND	0.0	200	200	0.0
Perchlorate	µg/L	<0.2	<0.2	0.0	3.1	8.6	94	<0.2	<0.2	0.0

Various polycyclic aromatic hydrocarbons, organochlorine (OC) pesticides and organophosphate pesticides(OP) were analysed at Site 2. However all returned results below detection limits. The full results for Site 2 can be found in Supplementary Materials, Section 1.

Table 12. Results of the laboratory analysis between the two different sampling methods for Site 2 (The Dunmore Waste and Resource Recycling Depot)

Analyte	Unit	Bore Hole 3 Low-Flow	Bore Hole 3 Purge	RPD %	Bore Hole 4 Low-flow	Bore Hole 4 Purge	RPD %
Chloride	mg/L	43	140	106	180	170	6
Bicarbonate	mg/L	350	360	3	570	570	0
Carbonate	mg/L	<5	<5	N/A	<5	<5	N/A
Hydroxide	mg/L	<5	<5	N/A	<5	<5	N/A
BOD	mg/L	<4	<4	N/A	<4	<4	N/A
COD	mg/L	54	51	6	71	140	65
Total Dissolved Solids	mg/L	1500	900	50	960	930	3
Sulphate	mg/L	140	110	24	66	69	4
Nitrogen - Total Kjeldahl	mg/L	16	30	61	10	8	19
Total Organic Carbon	mg/L	16	14	13	20	18	11
Nitrate -N	mg/L	140	41	109	0	0	0
Calcium	mg/L	180	140	25	180	180	0
Magnesium	mg/L	39	25	44	35	31	12
Potassium	mg/L	300	110	93	14	12	15
Sodium	mg/L	78	68	14	160	130	21
Total Anions	meq/L	21	16	27	18	18	0
Total Cations	meq/L	23	15	42	17	19	11
Ionic Balance	%	4.5	3.2	-	2.7	2.9	-

Various polycyclic aromatic hydrocarbons were analysed at Site 3, however all returned results below detection limits. The full results for Site 3 can be found in Supplementary Materials, Section 2.

Table 13. Results of the laboratory analysis between the two different sampling methods for Site 3 (The construction site)

Analyte	Unit	Bore Hole GGW 3D Low-Flow	Bore Hole GGW 3D Purge	RPD %	Bore Hole GGW 1D Low-flow	Bore Hole GGW 1D Purge	RPD %
Chloride	mg/L	180	190	5	40	40	0
Bicarbonate	mg/L	640	670	5	280	280	0
Carbonate	mg/L	<5	<5	N/A	<5	<5	N/A
Hydroxide	mg/L	<5	<5	N/A	<5	<5	N/A
BOD	mg/L	<4	<4	N/A	<4	<4	N/A
COD	mg/L	41	35	16	18	15	18
Total Dissolved Solids	mg/L	820	840	2	470	470	0
Sulphate	mg/L	33	34	3	120	120	0
Nitrogen - Total Kjeldahl	mg/L	0.5	0.5	0	<0.05	0.1	67
Total Organic Carbon	mg/L	9.2	8.1	13	1.9	1.8	5
Nitrate - N	mg/L	3.8	3.6	5	2.5	2.6	4
Calcium	mg/L	82	78	5	83	83	0
Magnesium	mg/L	110	110	0	33	34	3
Potassium	mg/L	1.4	1.3	7	0.36	0.36	0
Sodium	mg/L	120	130	8	39	40	3
Total Anions	meq/L	19	20	5	9	9	0
Total Cations	meq/L	18	19	5	9	9	0
Ionic Balance	%	2.7	2.6	-	0	0	-

Table 14 summarises the average relative percentage differences (RPD) from each set of laboratory analyses along with the overall RPD across the 298 analyses where it was appropriate for an RPD to be measured.

Table 14. Relative Percentage Difference statistics from each field site	
Site 1 average RPD	13.5
Site 2 average RPD	28.0
Site 3 average RPD	6.4
Overall average RPD (across 298 total analysis)	14.2

Table 15 summarises the number of times that each sampling method returned a higher reading than the other, or if both methods returned an identical reading.

Table 15: Key statistics on which method provided a higher end analytical outcome at each site			
	Number of results where purge returned higher readings	Number of results where low-flow returned higher readings	Number of results where the results were identical
Site 1	67	75	87
Site 2	6	19	9
Site 3	11	6	16

Figure 13 below summarises the difference between the results obtained from the bore purge method and the low-flow method in key potential contaminants; cations, Total Dissolved Solids, anions, bicarbonate alkalinity, nitrate – N, Chemical Oxygen Demand, Total Organic Carbon and Total Kjeldahl Nitrogen. These analytes are all key indicators of potential contamination and are often analysed within sampling programs.
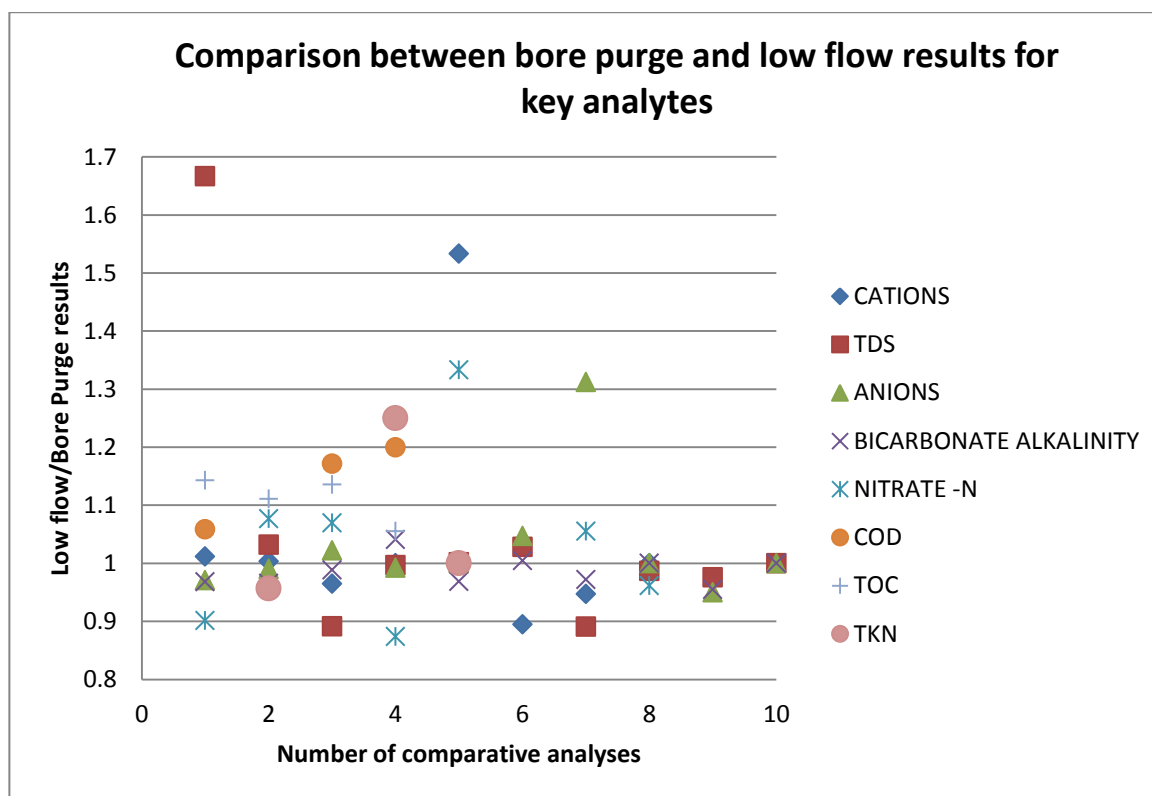
Figure 13: Comparison between the results obtained from the bore purge method and the low-flow sampling method. The results obtained from the low-flow method were divided by the results obtained from the bore purge method to obtain the graphed value. If the number is over 1 it indicates that the low-flow method returned a higher result while if the number is less than 1 it means that the bore purge method returned a higher result. In total 52 comparative results are plotted on the figure with 47 within 1.0 ± 0.2 and 5 falling outside of this range.

6 – Discussion

The Relative Percentage Difference (RPD) was calculated in order to compare the differences between the two field sampling methods. The Standards Australia (2005) guidelines for field duplicate samples state that an RPD 30 is acceptable for groundwater samples, any more than this and the field sampling and laboratory procedures need to be investigated. In accordance with these guidelines a maximum average variation of 30 in the results between the two groundwater sampling methods is considered acceptable while anymore would be considered a significant variation. RPD was used to compare the results as it is the best way to compare data between two results; the smaller the RPD the closer the readings are to each other.

This study reveals no statistically significant differences between results obtained by the bore purge or the low-flow sampling method in samples from the three field sites in New South Wales. Despite many apparent disadvantages being described for the bore purge

42

method over the low-flow sampling method (eg. Robin and Gilham, 1987; McCarthy and Zachara, 1989; Powell and Puls, 1993; Sevee et al., 2000; Puls and Barcelona, 1996; Sundaram et al., 2009), there is no apparent difference in the results obtained by the two methods (Table 14; Table 15).

Across the 298 comparative analyses between the bore purge and the low-flow sampling method, where it was appropriate to calculate the relative percentage difference (RPD), the average RPD was only 14.2 (Table 14). This is a relatively small number with an RPD of 30 being considered the maximum accepted variation for this study, and shows how small the difference between the two sampling methods is (Standards Australia, 2005). Based on previous studies, it was assumed that the results of this study would give a much larger significant difference between the two methods (Robin and Gilham, 1987; Puls and Powell, 1992; Powell and Puls, 1993; Konecny, 2003).

Site 1 (Table 11) had the most samples taken and also the most representative RPD of only 13.5 across 229 comparative analysis (Table 14). Such a small RPD across so many samples is indicative of the two methods being comparable in field conditions and indicates, in terms of field sampling, that there would be no substantial impact on the possible management strategies because of the sampling method used. However, with many of the analyte levels being so close to the limit for reporting the readings do become less and less reliable. While the RPD was only calculated using results above detection limits with so many low levels of analytes the results have to be read with this in mind. Some analytes did return RPD readings well above this average, for example Ni at bore MW125 has an RPD of 67, but the analyte levels themselves only varied by 0.1mg/L. Another example is at bore MW120, where the RPD for Zn is 76 but the actual analyte readings are 0.02 mg/L for the low-flow method and 0.009 mg/L for the bore purge method, a difference of only 0.011mg/L. This is also true for other analytes; the average RPD is high but the actual readings and difference are so low that they significantly skew the results (Table 11).

Table 15 shows the number of times each method returned a higher result than the other. Based on the literature, the results were unexpected, with the bore purge method returning higher analyte levels 67 times and the low flow method returning higher analyte levels 75 times. The results were even 38 times, with the results returning concentrations below the detection limit 49 times.

The results variation is not consistent across the range of elements at any Site. For example; at bore MW113 at Site 1 (Table 11) the low-flow method returned Mg

concentrations of 238mg/L while the bore purge method returned higher Mg levels of 262mg/L. However at bore MW120 also at Site 1 (Table 11), the RPD is reversed with the low-flow method returning higher Mg levels 368mg/L against 366mg/L. Instances like this are common across the Site 1 bores. These results further reinforce that there is no difference in the results obtained from the two methods. There is also no discernible pattern to this variation where one method constantly produces higher abundances than the other.

Site 2 (Table 12) has the highest average RPD with 28, however this result may be skewed by a few results with unusually high RPDs; for example chloride in BH3 has an RPD of 106 while the Nitrate-N has an RPD of 109. These large values are not representative of the Site overall as BH 4 only a few hundred metres away from BH 3, the chloride had an RPD of 6 and the Nitrate-N was 0. While the average RPD for the Site is 28, this is still within the Standards Australia (2005) guideline of 30 for duplicate sampling. This RPD, significantly higher than the other sites, can likely be related to larger plume heterogeneities being present on the site than at the others, resulting in larger variations in the end results between the two methods (Ronen et al., 1987).

Site 2 also has a greater number of results with higher analyte levels recorded using the low-flow method than the bore purge method. The low-flow method returned higher levels 19 times while the bore purge method returned higher analyte levels six times, and there were nine results where the levels were exactly the same (Table 15). These results, and the low average RPD of 28, are most likely indicative of variation due to the heterogeneity of the groundwater and not a result of sampling method choice. As at Site 1, the differences in analyte concentrations given by the bore purge and low-flow sampling method were not constant and had no discernible pattern (Table 12).

Site 3 (Table 13) has the lowest average RPD of 6.4 (Table 14). Apart from one anomalous result where the RPD was 67 (Nitrogen - Total Kjeldahl in BH GGW 1D), the next highest RPD was 18 for COD (BH GGW 1D). Most analyte concentrations are approximately equal or vary only by a few mg/L, leading to lower RPDs than for the other two sites. Where there is variation in analyte concentrations between the two sampling methods, the differences are very small and can be considered statistically insignificant. The variation between the results could also be attributed to the heterogeneity of groundwater and not related to the sampling method (Ronen et al., 1987: Stutter et al., 2006). With Ronen (et al., 1987) previously demonstrating that analytes within groundwater can vary by as much as 50% over scales of only 3cm, this demonstrates just how heterogeneous groundwater can be.

At Site 3 (Table 15) the bore purge method returned higher results 11 times, the low-flow method 6 times and the results were even 16 times. As at the other sites, the variation in groundwater results all fall within the Standards Australia (2005) guidelines for duplicate sampling and can be considered acceptable levels of variation.

When all results from each field site are combined, it is clear that neither the bore purge method nor the low-flow sampling method return analytical results that are significantly different to the other. While the average RPD of 14.2 (Table 14) does indicate that there are some small differences in the analytical results these are well within the acceptable levels of variation for duplicate groundwater sampling and are more than likely the result of the inherent heterogeneities in the groundwater than any deficiencies in the sampling methods themselves (Ronen et al., 1987). When the RPD is combined with the almost even split of each method returning higher results than the other, it becomes apparent that there is no significant difference in the end results obtained from the two methods (Table 15).

Figure 13 further reinforces the similar nature of the results obtained from the two sampling methods. Across 8 key analytes 52 comparative analyses were analysed with the results obtained from the low-flow method divided by the results obtained by the bore purge method; if a result was then higher than 1 it indicated that the low-flow method returned a higher result while if the number is less than 1 it means that the bore purge method returned a higher result. In total 47 of the results were within 1.0 ± 0.2 and only 5 fell outside of this range. This small spread of values in these key analytes indicates that the two sampling methods consistently return similar results. When this small spread is taken in contrast with the average RPD of 14.2, which is well within the Standards Australia (2005) guidelines for duplicate sampling, across the 298 comparative analyses it further reinforces the insignificant differences in the end analytical results that are obtained from the two methods.

7 – Conclusions and recommendations for further work

This study investigated two different groundwater-sampling techniques, the low-flow and the bore purge method, at three different field sites with high rates of groundwater flow and aimed to determine if they produce similar end analytical results. Liquid gas chromatography was used to determine the concentration of various potential groundwater contaminants such as bicarbonate alkalinity, hydroxide, total dissolved solids, nitrogen - total kjeldahl, nitrate – N, total organic carbon, cations and anions and, in addition, an array of heavy metals at Site 1.

These are all some of the most common contaminates or indicators of contamination at sites of interest.

Relative percentage differences (RPD) were calculated for the bore purge and the low-flow method for each analytical result. At each site the overall average was calculated. The overall RPD of 14.2 for 298 comparative analyses indicates that while the methods returned slightly different concentrations of analytes, the differences were minimal and not statistically relevant. An average RPD of less than 15 can be attributed to statistical variation in the groundwater itself and not a result of the chosen sampling method. There was no apparent pattern in results for the different groundwater-sampling methods indicating that neither was more effective nor gave more accurate analyte concentrations than the other. The ability of monitoring wells to recharge quickly in this study probably helped to minimise the turbulent and disruptive effects of the fast purging of the wells. This study indicates that in sites with high-flow capacity both methods can be utilised and there will be no noticeable impact on the end analytical results, with the bore purge method allowing for faster sampling of the site. The differences observed in the groundwater analyte levels could likely be attributed to the heterogeneity of the groundwater and not to any deficiencies in the analytical methods.

The study began with a hypothesis that the bore purge method would return analyte concentrations that were significantly higher than for the low-flow sampling method due to the mobilisation of normally immobile contaminants and the mixing of aquifer zones. However, the bore purge method returned higher contaminant concentrations 84 times while the low-flow method returned higher concentrations 100 times. These statistics, when combined with the small RPD (14.2) across the large number of samples in the study, indicates that there is no significant difference in the end results between the two sampling methods. This indicates that in high yield areas either method could be reliably used.

Future research in this field should first repeat this study in areas with similar high-recharge rates to validate the results, followed by a similar study in areas of low recharge potential. The disruptive effects of the bore purge method are well documented in the literature and it is possible that these effects may be more prominent in areas with low recharge potential.

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9 – Supplementary Material

9.1 – Full results report for field site 2

Australian Government

National Measurement Institute

NATA

REPORT OF ANALYSIS

Page: 1 of 4

Report No. RN1023734

Client	: MACQUARIE UNIVERSITY	Job No.	: MACQ15/140528
	ENVIRONMENTAL SCIENCE	Quote No.	: QT-02018
	FACULTY OF SCIENCE	Order No.	:
	NORTH RYDE NSW 2109	Date Sampled	:
		Date Received	: 28-MAY-2014
Attention	CAMERON PIPER	Sampled By	: CLIENT
Project Name :			
Your Client Services Manager	: RICHARD COGHLAN	Phone	: (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
N14/012486	1.1	WATER (NON-SALINE) 27/5/2014 13:13
N14/012487	1.2	WATER (NON-SALINE) 27/5/2014 13:59
N14/012488	2.1	WATER (NON-SALINE) 27/5/2014 14:46
N14/012489	2.2	WATER (NON-SALINE) 27/5/2014 15:03

Lab Reg No.		N14/012486	N14/012487	N14/012488	N14/012489	
Sample Reference		1.1	1.2	2.1	2.2	
	Units					Method
Polycyclic Aromatic Hydrocarbons						
Naphthalene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Acenaphthylene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Acenaphthene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Fluorene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Phenanthrene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Anthracene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Fluoranthene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Pyrene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Benz(a)anthracene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Chrysene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Benzo(b)&(k)fluoranthene	ug/L	<1	<1	<1	<1	NGCMS_1111
Benzo(a)pyrene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Indeno(1,2,3-cd)pyrene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Dibenz(ah)anthracene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Benzo(ghi)perylene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Surrogate: TER-D14	%REC	77	92	80	96	NGCMS_1111
Organochlorine (OC) Pesticides						
HCB	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
Heptachlor	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
Heptachlor epoxide	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
Aldrin	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
gamma-BHC (Lindane)	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
alpha-BHC	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
beta-BHC	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
delta-BHC	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
trans-Chlordane	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
cis-Chlordane	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
Oxychlordane	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19

Accredited for compliance with ISO/IEC 17025

105 Delhi Road, North Ryde NSW 2113 Tel: +61 2 9449 0111 Fax: +61 2 9449 1653 www.measurement.gov.au

REPORT OF ANALYSIS

Lab Reg No.		N14/012486	N14/012487	N14/012488	N14/012489	
Sample Reference		1.1	1.2	2.1	2.2	
	Units					Method
Organochlorine (OC) Pesticides						
Dieldrin	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
p,p-DDE	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
p,p-DDD	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
p,p-DDT	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
Endrin	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
Endrin Aldehyde	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
Endrin Ketone	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
alpha-Endosulfan	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
beta-Endosulfan	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
Endosulfan Sulfate	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
Methoxychlor	ug/L	<0.01	<0.01	<0.01	<0.01	NR_19
Surrogate: DF-DDE	%REC	73	82	94	84	NR_19
Organophosphate (OP) Pesticides						
Dichlorvos	ug/L	<0.1	<0.1	<0.1	<0.1	NR_19
Demeton-S-Methyl	ug/L	<0.1	<0.1	<0.1	<0.1	NR_19
Diazinon	ug/L	<0.1	<0.1	<0.1	<0.1	NR_19
Dimethoate	ug/L	<0.1	<0.1	<0.1	<0.1	NR_19
Chlorpyrifos	ug/L	<0.1	<0.1	<0.1	<0.1	NR_19
Chlorpyrifos Methyl	ug/L	<0.1	<0.1	<0.1	<0.1	NR_19
Malathion	ug/L	<0.1	<0.1	<0.1	<0.1	NR_19
Fenthion	ug/L	<0.1	<0.1	<0.1	<0.1	NR_19
Ethion	ug/L	<0.1	<0.1	<0.1	<0.1	NR_19
Fenitrothion	ug/L	<0.1	<0.1	<0.1	<0.1	NR_19
Chlorfenvinphos (E)	ug/L	<0.1	<0.1	<0.1	<0.1	NR_19
Chlorfenvinphos (Z)	ug/L	<0.1	<0.1	<0.1	<0.1	NR_19
Parathion (Ethyl)	ug/L	<0.1	<0.1	<0.1	<0.1	NR_19
Parathion Methyl	ug/L	<0.1	<0.1	<0.1	<0.1	NR_19
Pirimiphos Methyl	ug/L	<0.1	<0.1	<0.1	<0.1	NR_19
Pirimiphos Ethyl	ug/L	<0.1	<0.1	<0.1	<0.1	NR_19
Azinphos Methyl	ug/L	<0.1	<0.1	<0.1	<0.1	NR_19
Azinphos Ethyl	ug/L	<0.1	<0.1	<0.1	<0.1	NR_19
Surrogate: TPP	%REC	96	98	98	98	NR_19
Dates						
Date extracted		3-JUN-2014	3-JUN-2014	3-JUN-2014	3-JUN-2014	
Date analysed		3-JUN-2014	3-JUN-2014	3-JUN-2014	3-JUN-2014	

Luke Baker, Analyst
Organics - NSW
Accreditation No. 198

6-JUN-2014

REPORT OF ANALYSIS

Report No. RN1023734

Lab Reg No.		N14/012486	N14/012487	N14/012488	N14/012489	
Sample Reference		1.1	1.2	2.1	2.2	
	Units					Method
Filtered Trace Elements by ICP						
Calcium Filtered	mg/L	180	180	140	180	NT2_47
Magnesium Filtered	mg/L	39	35	25	31	NT2_47
Potassium Filtered	mg/L	300	14	110	12	NT2_47
Sodium Filtered	mg/L	78	160	68	130	NT2_47
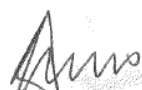
Andrew Evans, Analyst
Inorganics - NSW
Accreditation No. 198

6-JUN-2014

Lab Reg No.		N14/012486	N14/012487	N14/012488	N14/012489	
Sample Reference		1.1	1.2	2.1	2.2	
	Units					Method
Miscellaneous						
Chloride	mg/L	43	180	140	170	NW_D3_B14
Anions	meq/L	21	18	16	18	CALC_IONS
Cations	meq/L	23	19	15	17	CALC_IONS
Cation/Anion Balance	%	4.5	2.7	3.2	2.9	CALC_IONS
Bicarbonate as CaCO3	mg/L	350	570	360	570	NW_B1
Carbonate as CaCO3	mg/L	<5	<5	<5	<5	NW_B1
Hydroxide as CaCO3	mg/L	<5	<5	<5	<5	NW_B1
BOD	mg/L	<4	<4	<4	<4	NW_S2
COD	mg/L	54	71	51	140	NW_S3
Conductivity	uS/cm	2300	1500	1400	1300	NW_B9
Dissolved Solids - Total	mg/L	1500	960	900	830	NW_B10A
Sulphate	mg/L	140	66	110	69	NW_D10_B14
Nitrogen - Total Kjeldahl	mg/L	16	9.7	30	8.0	NW_B23_B19
Carbon - Total Organic	mg/L	16	20	14	18	NW_S15
Nitrate-N	mg/L	140	0.02	41	0.043	NW_B19
pH	pH_unit	6.7	6.8	7.2	7.1	NW_S11

Andrew Evans, Analyst
Inorganics - NSW
Accreditation No. 198

6-JUN-2014

QUALITY ASSURANCE REPORT

Client: Macquarie University Environmental Science

NMI QA Report No: MACQ15/140528 QA

Sample Matrix: Water

Analyte	Method	LOR	Blank	Duplicates			Recoveries	
				Sample	Duplicate	RPD	Matrix spk	LCS
		mg/L	mg/L	mg/L	mg/L	%	%	%
Waters Section				N14/012486			N14/012486	
Carbon - Total Organic	NW_S15	0.5	<0.5	16	NA	NA	NA	100
Bicarbonate as CaCO3	NW_B1	5	<5	350	NA	NA	NA	105
Carbonate as CaCO3	NW_B1	5	<5	<5	NA	NA	NA	105
Hydroxide as CaCO3	NW_B1	5	<5	<5	NA	NA	NA	105
Sulphate	NW_D10_B14	0.1	<0.1	140	NA	NA	NA	95
Chloride	NW_D3_B14	0.1	<0.1	43	NA	NA	NA	115
Conductivity (uS/cm)	NW_B9	1	<1	2300	NA	NA	NA	107
Dissolved Solids - Total	NW_B10A	1	<1	1500	NA	NA	NA	107
pH (pH units)	NW_S11	NA	NA	6.7	NA	NA	NA	99
BOD	NW_S2	4	<4	<4	NA	NA	NA	91
COD	NW_S3	3	<3	54	NA	NA	NA	97
Waters Section				N14/012487			N14/012487	
Nitrogen - Total	NW_B23	0.05	<0.05	9.7	NA	NA	NA	106
NOx	NW_B19	0.01	<0.01	0.02	NA	NA	NA	102
Nitrate-N	NW_B19	0.005	<0.005	0.02	NA	NA	NA	103

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Legend

Acceptable recovery is 80-120%.

Acceptable RPDs on duplicates is 30% at > 5 times LOR. Greater RPD may be expected at < 5 LOR.

LOR = Limit Of Reporting

RPD = Relative Percent Difference

LCS = Laboratory Control Sample.

ND = Not Determined

NA = Not Applicable

Comments

This report shall not be reproduced except in full.

Results greater than ten times LOR have been rounded to two significant figures.

Signed:

Dr Michael Wu
Inorganics Manager, NMI-North Ryde

Date: 6/06/2014

QUALITY ASSURANCE REPORT

Client: MACQUARIE UNIVERSITY

NMI QA Report No: MACQ15/140528   **Sample Matrix:** Liquid

Analyte	Method	LOR	Blank	Sample Duplicates			Recoveries	
				Sample	Duplicate	RPD	LCS	Matrix Spike
		ug/L	ug/L	ug/L	ug/L	%	%	%
Organics Section								
PAH								
Naphthalene	NGCMS_1111	0.5	<0.5	NA	NA	NA	85	NA
Acenaphthylene	NGCMS_1111	0.5	<0.5	NA	NA	NA	-	NA
Acenaphthene	NGCMS_1111	0.5	<0.5	NA	NA	NA	-	NA
Fluorene	NGCMS_1111	0.5	<0.5	NA	NA	NA	84	NA
Phenanthrene	NGCMS_1111	0.5	<0.5	NA	NA	NA	89	NA
Anthracene	NGCMS_1111	0.5	<0.5	NA	NA	NA	-	NA
Fluoranthene	NGCMS_1111	0.5	<0.5	NA	NA	NA	-	NA
Pyrene	NGCMS_1111	0.5	<0.5	NA	NA	NA	-	NA
Benz[a]anthracene	NGCMS_1111	0.5	<0.5	NA	NA	NA	-	NA
Chrysene	NGCMS_1111	0.5	<0.5	NA	NA	NA	89	NA
Benzo[b]&[k]fluoranthene	NGCMS_1111	1	<1	NA	NA	NA	-	NA
Benzo[a]pyrene	NGCMS_1111	0.5	<0.5	NA	NA	NA	87	NA
Indeno[1_2_3-cd]pyrene	NGCMS_1111	0.5	<0.5	NA	NA	NA	-	NA
Dibenz[ah]anthracene	NGCMS_1111	0.5	<0.5	NA	NA	NA	87	NA
Benzo[ghi]perylene	NGCMS_1111	0.5	<0.5	NA	NA	NA	-	NA
Surrogate: TER-D14	NGCMS_1111	-	-	NA	NA	NA	74	NA

Results expressed in percentage (%) or ug/L wherever appropriate.
Acceptable Spike recovery is 50-150% (PAH).
Maximum acceptable RPDs on spikes and duplicates is 40%.
'NA ' = Not Applicable.
RPD= Relative Percentage Difference.

Signed:

Danny Slee
Organics Manager, NMI-North Ryde

Date: 4/06/2014

QUALITY ASSURANCE REPORT

Client: MACQUARIE UNIVERSITY

NMI QA Report No: MACQ15/140528

Sample Matrix: Liquid

Analyte	Method	LOR	Blank	Sample Duplicates			Recoveries	
				Sample	Duplicate	RPD	LCS	Matrix Spike
		ug/L	ug/L	ug/L	ug/L	%	%	%
Organics Section								
OC Pesticides								
HCB	NR19	0.01	<0.01	NA	NA	NA	-	NA
Heptachlor	NR19	0.01	<0.01	NA	NA	NA	57	NA
Heptachlor epoxide	NR19	0.01	<0.01	NA	NA	NA	-	NA
Aldrin	NR19	0.01	<0.01	NA	NA	NA	54	NA
gamma-BHC (Lindane)	NR19	0.01	<0.01	NA	NA	NA	63	NA
alpha-BHC	NR19	0.01	<0.01	NA	NA	NA	-	NA
beta-BHC	NR19	0.01	<0.01	NA	NA	NA	-	NA
delta-BHC	NR19	0.01	<0.01	NA	NA	NA	-	NA
trans-Chlordane	NR19	0.01	<0.01	NA	NA	NA	-	NA
cis-Chlordane	NR19	0.01	<0.01	NA	NA	NA	-	NA
Oxychlordane	NR19	0.01	<0.01	NA	NA	NA	-	NA
Dieldrin	NR19	0.01	<0.01	NA	NA	NA	60	NA
pp-DDE	NR19	0.01	<0.01	NA	NA	NA	-	NA
pp-DDD	NR19	0.01	<0.01	NA	NA	NA	-	NA
pp-DDT	NR19	0.01	<0.01	NA	NA	NA	58	NA
Endrin	NR19	0.01	<0.01	NA	NA	NA	57	NA
Endrin Aldehyde	NR19	0.01	<0.01	NA	NA	NA	-	NA
Endrin Ketone	NR19	0.01	<0.01	NA	NA	NA	-	NA
alpha-Endosulfan	NR19	0.01	<0.01	NA	NA	NA	-	NA
beta-Endosulfan	NR19	0.01	<0.01	NA	NA	NA	-	NA
Endosulfan Sulfate	NR19	0.01	<0.01	NA	NA	NA	-	NA
Methoxychlor	NR19	0.01	<0.01	NA	NA	NA	-	NA
Surrogate : DF-DDE	NR19	-	-	NA	NA	NA	63	NA
OP Pesticides								
Dichlorvos	NR19	0.1	<0.1	NA	NA	NA	-	NA
Demeton-S-Methyl	NR19	0.1	<0.1	NA	NA	NA	-	NA
Diazinon	NR19	0.1	<0.1	NA	NA	NA	55	NA
Dimethoate	NR19	0.1	<0.1	NA	NA	NA	-	NA
Chlorpyrifos	NR19	0.1	<0.1	NA	NA	NA	56	NA
Chlorpyrifos Methyl	NR19	0.1	<0.1	NA	NA	NA	-	NA
Malathion (Maldison)	NR19	0.1	<0.1	NA	NA	NA	-	NA
Fenthion	NR19	0.1	<0.1	NA	NA	NA	-	NA
Ethion	NR19	0.1	<0.1	NA	NA	NA	56	NA
Fenitrothion	NR19	0.1	<0.1	NA	NA	NA	-	NA
Chlorfenvinphos (E)	NR19	0.1	<0.1	NA	NA	NA	-	NA
Chlorfenvinphos (Z)	NR19	0.1	<0.1	NA	NA	NA	-	NA
Parathion (Ethyl)	NR19	0.1	<0.1	NA	NA	NA	56	NA
Parathion Methyl	NR19	0.1	<0.1	NA	NA	NA	-	NA
Pirimiphos Ethyl	NR19	0.1	<0.1	NA	NA	NA	-	NA
Pirimiphos Methyl	NR19	0.1	<0.1	NA	NA	NA	-	NA
Azinphos Methyl	NR19	0.1	<0.1	NA	NA	NA	-	NA
Azinphos Ethyl	NR19	0.1	<0.1	NA	NA	NA	-	NA
Surrogate : TPP		-	-	NA	NA	NA	53	NA

Results expressed in percentage (%) or ug/L wherever appropriate.
Acceptable Spike recovery is 50-150%
Acceptable RPDs on spikes and duplicates is 40%.
'NA ' = Not Applicable.
RPD= Relative Percentage Difference.
This report shall not be reproduced except in full.

Signed:

Danny Slee
Organics Manager, NMI-North Ryde

Date: 4/06/2014

9.2 – Full results for field site 3

REPORT OF ANALYSIS

Report No. RN1024472

Client	: MACQUARIE UNIVERSITY	Job No.	: MACQ15/140605
	ENVIRONMENTAL SCIENCE	Quote No.	: QT-02018
	FACULTY OF SCIENCE	Order No.	:
	NORTH RYDE NSW 2109	Date Sampled	:
		Date Received	: 5-JUN-2014
Attention	CAMERON PIPER	Sampled By	: CLIENT
Project Name :			
Your Client Services Manager	: RICHARD COGHLAN	Phone	: (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
N14/013181	1	WATER (NON-SALINE) 05/06/14 10:13
N14/013182	2	WATER (NON-SALINE) 05/06/14 10:45
N14/013183	3	WATER (NON-SALINE) 05/06/14 11:17
N14/013184	4	WATER (NON-SALINE) 05/06/14 11:41

Lab Reg No.		N14/013181	N14/013182	N14/013183	N14/013184	
Sample Reference		1	2	3	4	
	Units					Method
Polycyclic Aromatic Hydrocarbons						
Naphthalene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Acenaphthylene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Acenaphthene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Fluorene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Phenanthrene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Anthracene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Fluoranthene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Pyrene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Benz(a)anthracene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Chrysene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Benzo(b)&(k)fluoranthene	ug/L	<1	<1	<1	<1	NGCMS_1111
Benzo(a)pyrene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Indeno(1,2,3-cd)pyrene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Dibenz(ah)anthracene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Benzo(ghi)perylene	ug/L	<0.5	<0.5	<0.5	<0.5	NGCMS_1111
Surrogate: TER-D14	%REC	72	85	80	81	NGCMS_1111
Dates						
Date extracted		11-JUN-2014	11-JUN-2014	11-JUN-2014	11-JUN-2014	
Date analysed		11-JUN-2014	11-JUN-2014	11-JUN-2014	11-JUN-2014	

Luke Baker, Analyst
Organics - NSW
Accreditation No. 198

13-JUN-2014

REPORT OF ANALYSIS

Lab Reg No.		N14/013181	N14/013182	N14/013183	N14/013184	
Sample Reference		1	2	3	4	
	Units					Method
Filtered Trace Elements by ICP						
Calcium Filtered	mg/L	82	78	83	83	NT2_47
Magnesium Filtered	mg/L	110	110	33	34	NT2_47
Potassium Filtered	mg/L	1.4	1.3	0.36	0.36	NT2_47
Sodium Filtered	mg/L	120	130	39	40	NT2_47

Andrew Evans, Analyst
Inorganics - NSW
Accreditation No. 198

13-JUN-2014

Lab Reg No.		N14/013181	N14/013182	N14/013183	N14/013184	
Sample Reference		1	2	3	4	
	Units					Method
Miscellaneous						
Chloride	mg/L	180	190	40	40	NW_D3_B14
Anions	meq/L	19	20	9	9	CALC_IONS
Cations	meq/L	18	19	9	9	CALC_IONS
Cation/Anion Balance	%	2.7	2.6	0.0	0.0	CALC_IONS
Bicarbonate as CaCO3	mg/L	640	670	280	280	NW_B1
Carbonate as CaCO3	mg/L	<5	<5	<5	<5	NW_B1
Hydroxide as CaCO3	mg/L	<5	<5	<5	<5	NW_B1
BOD	mg/L	<4	<4	<4	<4	NW_S2
COD	mg/L	41	35	18	15	NW_S3
Conductivity	uS/cm	1280	1320	730	740	NW_B9
Dissolved Solids - Total	mg/L	820	840	470	470	NW_B10A
Sulphate	mg/L	33	34	120	120	NW_D10_B14
Nitrogen - Total Kjeldahl	mg/L	0.50	0.50	<0.05	0.10	NW_B23_B19
Carbon - Total Organic	mg/L	9.2	8.1	1.9	1.8	NW_S15
Nitrate-N	mg/L	3.8	3.6	2.5	2.6	NW_B19
pH	pH_unit	6.7	6.8	7.1	7.1	NW_S11

Andrew Evans, Analyst
Inorganics - NSW
Accreditation No. 198

13-JUN-2014

QUALITY ASSURANCE REPORT

Client: MACQUARIE UNIVERSITY

NMI QA Report No: MACQ15/140605   **Sample Matrix:** Liquid

Analyte	Method	LOR	Blank	Sample Duplicates			Recoveries	
				Sample	Duplicate	RPD	LCS	Matrix Spike
		ug/L	ug/L	ug/L	ug/L	%	%	%
Organics Section								
PAH								
Naphthalene	NGCMS_1111	0.5	<0.5	NA	NA	NA	81	NA
Acenaphthylene	NGCMS_1111	0.5	<0.5	NA	NA	NA	-	NA
Acenaphthene	NGCMS_1111	0.5	<0.5	NA	NA	NA	-	NA
Fluorene	NGCMS_1111	0.5	<0.5	NA	NA	NA	81	NA
Phenanthrene	NGCMS_1111	0.5	<0.5	NA	NA	NA	77	NA
Anthracene	NGCMS_1111	0.5	<0.5	NA	NA	NA	-	NA
Fluoranthene	NGCMS_1111	0.5	<0.5	NA	NA	NA	-	NA
Pyrene	NGCMS_1111	0.5	<0.5	NA	NA	NA	-	NA
Benz[a]anthracene	NGCMS_1111	0.5	<0.5	NA	NA	NA	-	NA
Chrysene	NGCMS_1111	0.5	<0.5	NA	NA	NA	79	NA
Benzo[b]&[k]fluoranthene	NGCMS_1111	1	<1	NA	NA	NA	-	NA
Benzo[a]pyrene	NGCMS_1111	0.5	<0.5	NA	NA	NA	80	NA
Indeno[1_2_3-cd]pyrene	NGCMS_1111	0.5	<0.5	NA	NA	NA	-	NA
Dibenz[ah]anthracene	NGCMS_1111	0.5	<0.5	NA	NA	NA	79	NA
Benzo[ghi]perylene	NGCMS_1111	0.5	<0.5	NA	NA	NA	-	NA
Surrogate: TER-D14	NGCMS_1111	-	-	NA	NA	NA	82	NA

Results expressed in percentage (%) or ug/L wherever appropriate.
Acceptable Spike recovery is 50-150% (PAH).
Maximum acceptable RPDs on spikes and duplicates is 40%.
'NA ' = Not Applicable.
RPD= Relative Percentage Difference.   **Signed:**

    Date:

Danny Slee
Organics Manager, NMI-North Ryde
13/06/2014

QUALITY ASSURANCE REPORT

Client: **MACQUARIE UNIVERSITY**

NMI QA Report No: **MACQ15/140605T1**

Sample Matrix: Water

Analyte	Method	LOR	Blank	Duplicates			Recoveries	
				Sample	Duplicate	RPD	LCS	Matrix Spike
		mg/L	mg/L	mg/L	mg/L	%	%	%
Inorganics Section				N14/013184				N14/013184
Calcium Filtered	NT2.47	0.005	<0.005	84	83	1	100	99
Magnesium Filtered	NT2.47	0.005	<0.005	34	33	ND	100	98
Potassium Filtered	NT2.47	0.05	<0.05	0.36	0.35	3	103	100
Sodium Filtered	NT2.47	0.05	<0.05	40	40	0	101	99

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Legend:
Acceptable recovery is 75-120%.
Acceptable RPDs on duplicates is 44% at concentrations >5 times LOR. Greater RPD may be expected at <5 times LOR.
LOR = Limit Of Reporting   ND = Not Determined
RPD = Relative Percent Difference   NA = Not Applicable
LCS = Laboratory Control Sample.
#: Spike level is less than 50% of the sample's concentration, hence the recovery data is not reliable.

Comments:
Results greater than ten times LOR have been rounded to two significant figures.
This report shall not be reproduced except in full.

Signed:

Dr Michael Wu
Inorganics , NMI-North Ryde
Date: 13/06/2014

QUALITY ASSURANCE REPORT

Client: Macquarie University Environmental Science

NMI QA Report No: MACQ15/140605 QA   **Sample Matrix:** Water

Analyte	Method	LOR	Blank	Duplicates			Recoveries	
				Sample	Duplicate	RPD	Matrix spk	LCS
		mg/L	mg/L	mg/L	mg/L	%	%	%
Waters Section				N14/013181			N14/013181	
Bicarbonate as CaCO3	NW_B1	5	<5	640	NA	NA	NA	100
Carbonate as CaCO3	NW_B1	5	<5	<5	NA	NA	NA	100
Hydroxide as CaCO3	NW_B1	5	<5	<5	NA	NA	NA	100
Sulphate	NW_D10_B14	0.1	<0.1	33	NA	NA	NA	104
Chloride	NW_D3_B14	0.1	<0.1	180	NA	NA	NA	110
Conductivity (uS/cm)	NW_B9	1	<1	1280	NA	NA	NA	92
Dissolved Solids - Total	NW_B10A	1	<1	820	NA	NA	NA	92
pH (pH units)	NW_S11	NA	NA	6.7	NA	NA	NA	100
BOD	NW_S2	4	<4	<4	NA	NA	NA	92
Waters Section				N14/013184			N14/013184	
Carbon - Total Organic	NW_S15	0.5	<0.5	1.9	1.7	11.1	90	103
COD	NW_S3	3	<3	12	18	40.0	104	97
Nitrogen - Total	NW_B23	0.05	<0.05	2.7	2.6	3.8	92	112
NOx	NW_B19	0.01	<0.01	2.6	2.6	0.0	99	108
Nitrate-N	NW_B19	0.005	<0.005	2.6	2.6	0.0	102	119

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Legend

Acceptable recovery is 80-120%.

Acceptable RPDs on duplicates is 30% at > 5 times LOR. Greater RPD may be expected at < 5 LOR.

LOR = Limit Of Reporting   ND = Not Determined

RPD = Relative Percent Difference   NA = Not Applicable

LCS = Laboratory Control Sample.

Comments

This report shall not be reproduced except in full.

Results greater than ten times LOR have been rounded to two significant figures.

Signed:

Dr Michael Wu
Inorganics Manager, NMI-North Ryde
Date: 12/06/2014