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Groundwater chemistry and salinity processes in the Myalup region



Groundwater chemistry and salinity processes in the Myalup region

Resource management technical report 404

Adam M Lillicrap and Richard George

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Cover: Groundwater sampling in the Myalup region (photo: R George)



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Contents

Acknowledgements	iv
Summary	v
1 Introduction	1
2 Background and methods	4
2.1 Hydrogeology and hydrochemistry	4
2.2 Licensee and multiport bore data	12
2.3 Baseline groundwater chemistry	13
3 Results	19
3.1 Licensee data	19
3.2 Saltwater interface	26
3.3 Regional groundwater sampling	32
4 Discussion	61
4.1 Trends in groundwater quality	61
4.2 Salinity processes	72
4.3 The dominant salinity processes and spatial variability	77
4.4 Longer-term risks of salinity to agriculture	81
5 Conclusion	83
6 Recommendations	85
Appendix A Groundwater sampling sites	87
Appendix B Analytical methods and detection limits	91
Appendix C Groundwater quality from licensee monitoring (2007–15)	94
Appendix D Summary statistics of major ions and nutrients in surficial geological units	99
Appendix E Groundwater compared to aquatic ecosystem guidelines	106
Appendix F Suitability of groundwater for irrigation	117
Appendix G Groundwater chemistry analysis	127
Appendix H Change in groundwater chemistry through time	169
Appendix I Change in rainfall and groundwater levels	174
Appendix J Change in water quality and type along groundwater flow paths	177
Shortened forms	180
References	181

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Summary

The Myalup region, which incorporates the Myalup Irrigated Agriculture Precinct (MIAP), is located about 100 kilometres (km) south of Perth between the southern end of Lake Clifton and the northern tip of the Leschenault Inlet. It covers 17 800 hectares (ha), with about 2100ha being irrigated. The precinct produces mainly carrots, onions, potatoes and leafy vegetables. In 2016–17, the total value of agricultural production for the MIAP, including on-farm processing and packaging, was more than \$120 million.

Irrigation water is mainly from the surficial Myalup aquifer, with limited abstraction from the underlying Leederville aquifer. The total licensed groundwater allocation for the Myalup region is 19.3 gigalitres per year (GL/y), with an allocation limit of 4000 kilolitres per hectare per year (kL/ha/y). The total groundwater usage in 2016 was 16.3GL/y.

Average annual rainfall is about 800 millimetres (mm), but rainfall has been declining since the 1970s and has reduced by about 13% since 2000. Groundwater levels have fallen by about 1m in localities such as Mialla Lagoon, but most have fallen by about 0.5m.

Salinity levels were increasing in some irrigated areas with ions, such as sulfate and chloride, reaching levels of concern to growers and regulators. DWER was also concerned about the saltwater intrusion risk into the superficial aquifer from salt lakes and the ocean to the west, and the source of increasing salinity in areas to the east.

There is a growing water demand in the MIAP as a result of horticultural relocation to the area from Perth and other areas. Diversifying existing sources of fresh food and vegetable production and securing the long-term sustainability of water supplies are essential to maintaining and growing food production. Salinisation of the superficial aquifer poses a risk to production and a potential constraint on the future development of agriculture in the area. As part of the Water for Food program funded through Royalties for Regions, DPIRD investigated the likely causes of salinisation in the MIAP.

Previous investigations showed there was considerable spatial and temporal variability of salinity in the superficial aquifer, with the origins of the salinity poorly understood. Possible sources of salinity were thought to include: recycling of groundwater for irrigation with evapotranspiration causing an increase in salinity; application of fertiliser; oxidation of shallow acid sulfate soils known to be present in the area; and saltwater intrusion from adjoining lakes or seawater.

To better understand the controls on salinity in the Myalup aquifer, licensee water quality data from 200 sites were collated in a database. The database analysis was complemented with two phases of groundwater sampling across the Myalup region, covering a broader range of water quality parameters than the licensee data.

Water quality in the Bassendean Sand and the Spearwood Dunes was good (total dissolved solids [TDS] less than 500 milligrams per litre [mg/L]). However, average salinity increased to 1000mg/L in the Tamala Limestone where most of the irrigated agriculture occurs. The salinity of groundwater also increased with depth towards the base of the aquifer.

The licensee and groundwater data showed there were multiple geochemical processes contributing to the increased salinity along the groundwater flow path in the Myalup aquifer. Salinity trends at sites with irrigated agriculture were statistically analysed using groundwater licensee data (140 sites out of 200) to determine the extent of increased salinity in the Myalup aquifer. Only 30 of the 140 sites showed increased salinity, while six sites showed decreased salinity. Within the sites showing an increase in salinity, oxidation of pyrite in acid sulfate soils was the dominant source of salinity at 19 sites (63% of 30 sites). In two localised areas (nine sites), recirculation was the main salinity process, and intrusion of saline groundwater was the main process in just one locality (two sites).

Pyrite oxidation, the source of sulfate, was the main cause of increased salinity across most of the agricultural area. About three-quarters of irrigated agriculture licensee sites were considered to be affected by pyrite oxidation, and sulfate was the principle component of TDS at 40% of sites. The pyrite oxidation is associated with acid sulfate soils, which are mainly concentrated in wetlands that have been gradually drying, although these soils occur throughout the MIAP.

The wetlands act as windows to the groundwater. Where the groundwater is exposed to the atmosphere, there are greater water losses through increased evaporation, and there is increased salinity in the groundwater. Consequently, groundwater salinity was higher downgradient of wetlands, such as Myalup Swamp and Mialla Lagoon. However, over the last 20 years water levels in the wetlands have declined. Additionally, the groundwater levels have declined across the Myalup region, with a greater decline under native vegetation and forestry (average decline 0.63m) than agricultural land uses (average decline 0.47m). The regional decline is considered to be primarily due to decreasing rainfall as well as being exacerbated by groundwater abstraction and the planting of pines in recharge areas. The decline in water levels in the wetlands has led to increased evapotranspiration and pyrite oxidation in the wetlands, contributing to increased salinity in the aquifer. These processes have also occurred in wetlands under native vegetation.

The salinity effects from oxidising acid sulfate soils are likely to be self-limiting. Pyrite oxidation in the Myalup region is accompanied by the dissolution of calcite, which leads to increased concentrations of calcium and sulfate in the groundwater. When the concentrations of calcium and sulfate become too high, they precipitate out as gypsum. In the area where gypsum is precipitating, salinity due to sulfate has stabilised and fluctuates around an equilibrium. In addition, where sulfate is the dominant source of salinity, growers have been able to use high salinity water (greater than 2000mg/L TDS) to irrigate crops because sulfate salts have a lower toxicity on plants. However, using such water has required careful management, such as only irrigating during winter so that salinity is diluted by rainfall. Also, the effect of salinity on agricultural production is limited by the sandy soils in these areas, because any accumulated salts could be leached below the root zone. However, salinity still constrains production where sulfate is precipitating as gypsum and so requires ongoing monitoring and management.

In localised areas of the MIAP, recirculation of groundwater due to irrigation practices was the main cause of increased salinity. Groundwater recirculation occurs in areas with a shallow watertable, high irrigation rates and a low hydraulic gradient. While

nitrogen and excess potassium (from fertilisers) were found in the groundwater, this was not a major source of contamination across most of the aquifer, except in areas where there was groundwater recirculation. The areas with the highest concentrations of nitrogen had previous land uses such as growing of lucerne (a legume), and intensive livestock (sheep) production, which may have contributed to the high concentrations.

The intrusion of more-saline groundwater leading to salinisation of the upper part of the aquifer was observed in only one area south-east of Lake Preston, where saline groundwater is shallow as a result of being near a salt lake. This saline intrusion was also adjacent to the Harvey River Diversion Drain, which intercepts the shallow saline groundwater from the salt lakes, and saline water could have been drawn in from the drain. There was no other evidence of movement of the saltwater interface between the hypersaline groundwater beneath Lake Preston and the superficial aquifer in the licensee data or the Lake Clifton multiport bores. Movement of the saltwater interface therefore appears to be only a minor source of salinity risk to growers.

We recommend the following to better understand and manage the salinity processes into the future:

- Re-establish the multiport bores required to confirm there has only been limited movement of the saltwater interface and to allow further monitoring.
- Continue the licensee water quality monitoring and re-evaluate licensee data in 2020 for trends in water quality data.
- Replace TDS with chloride as a management trigger in groundwater allocation planning and licensing. Chloride is a major limiting factor for crop growth and an indicator of processes, such as the movement of the saltwater interface and evapoconcentration of solutes.
- Establish a uniform set of water quality parameters to be used by all groundwater licensees: groundwater quality samples are collected from production or monitoring bores, rather than excavations, to ensure groundwater conditions are being measured; electrical conductivity and pH are measured quarterly; and TDS (by gravimetry), sulfate, chloride, total phosphorus, total nitrogen, total oxidised nitrogen (NO_x) and ammonia are measured annually.
- Investigate the feasibility of clearing pines and pumping drainage water into the wetlands at the base of Spearwood Dunes as part of the Myalup Primary Industries Reserve project to minimise pyrite oxidation and salinity risks, restore environmental values to the wetlands and provide additional water sources for agricultural expansion.

1 Introduction

The Myalup region, which incorporates the Myalup Irrigated Agriculture Precinct (MIAP), is located about 100km south of Perth between the southern end of Lake Clifton and the northern tip of the Leschenault Inlet (Figure 1.1). Horticulture commenced in the MIAP in 1963 and during the 1980s, agricultural production started to shift from localised horticulture, beef grazing, lucerne hay and tree farms to predominantly higher-value intensive horticulture for export (Wright et al. 2002). The trend towards intensification has occurred particularly in the last 20 years (Wright et al. 2002, Qureshi et al. 2013). The MIAP produces mainly carrots, onions, potatoes, leafy vegetables and lucerne, with an annual in-field production value of about \$62 million (vegetablesWA 2012). The total value of business turnover for the MIAP, including on-farm processing and packaging, was more than \$120m in 2016–17. Population growth, industry demand and climate variability has led to additional demand for horticultural production in the MIAP (Qureshi et al. 2013).

Although the MIAP occupies about 17 800ha, only about 2100ha are irrigated. Crops are mainly irrigated from the superficial coastal limestone aquifer. Property location, land tenure, groundwater allocation and licensing rules restrict expansion of irrigated horticulture (vegetablesWA 2012). The licensed groundwater allocation from the surficial Myalup aquifer, which is in the Tamala Limestone and has a saturated thickness of 20–40m, is 19.3GL/y and 16.3GL was used in 2016. There is also a 500 megalitre (ML) annual allocation from the underlying Leederville aquifer. The water allocation per irrigation property is based on 4000kL/ha (Water Authority of Western Australia [WAWA] 1989). The Myalup region contains three groundwater subareas (GWSA): Lake Preston North, Lake Preston South and Myalup. Lake Preston South and Myalup GSWAs are fully allocated (vegetablesWA 2012). Average annual rainfall is about 800mm, but it has been as low as 482mm (in 2010). Since the early 2000s, annual rainfall has fallen by about 15% and groundwater levels have fallen by up to 1m in some locations (GHD 2005).

The spatial distribution of groundwater salinity varies across the Myalup region and is fresh (less than 500mg/L) in the Spearwood Dunes and eastwards from the MIAP. The salinity underlying the main irrigation areas is spatially more variable and ranges from less than 500mg/L to more than 2000mg/L (very high salinity for irrigation) near the coast and coastal lakes, with a median salinity around 1000mg/L (Commander 1984).

Groundwater salinity has been increasing at some locations in the MIAP since the 1980s (WAWA 1989, Kern 1998, Watson 2015). Qureshi et al. (2013) proposed that the main reason for the salinity increase was due to recycling of groundwater, where a proportion of the groundwater pumped for irrigation returns to the aquifer as recharge carrying salts, nutrients and pesticides from the root zone. Fertiliser application was also proposed to be important source of salinity, particularly for sulfate in the aquifer (WAWA 1989, Kern 1998, Watson 2015). Salinity levels were also noted to be increasing in the older irrigated areas and in areas near salt lakes and the coast where the deeper groundwater is more saline. Ions, such as sulfate, nitrogen and chloride, had reached levels of concerns to growers and regulators (Qureshi et al. 2013).

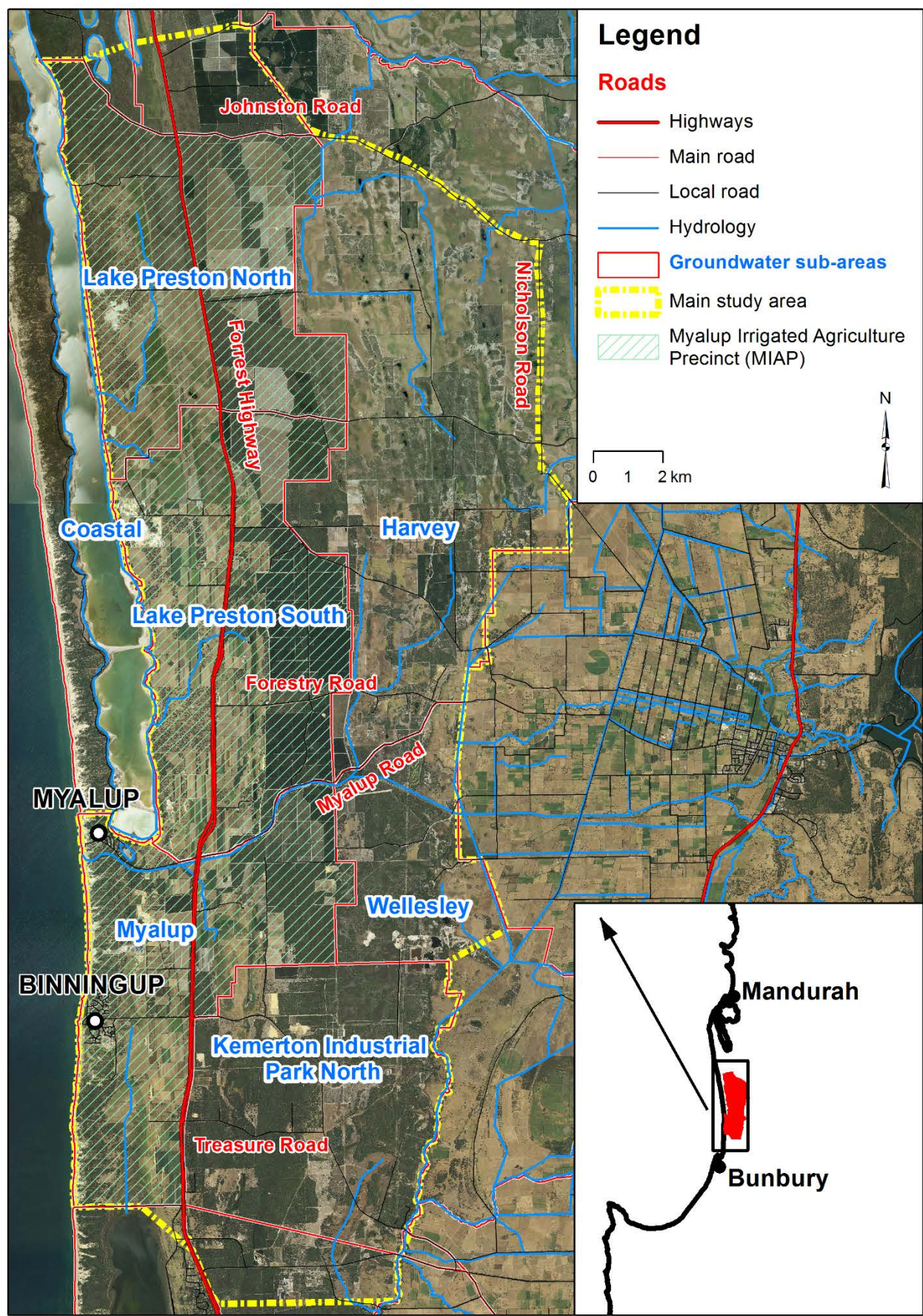


Figure 1.1 The Myalup region

There are acid sulfate soils in the MIAP and there is evidence of iron sulfide, principally pyrite, oxidation (Degens 2009a). Falling groundwater levels due to irrigation-based abstraction and decreasing rainfall could cause deterioration of groundwater quality including increased salinity, due to exposure of acid sulfate soils, making it unsuitable for irrigation of horticultural crops (Qureshi et al. 2013). There is considerable spatial and temporal variability of salinity in the superficial aquifer and the origins of the salinity are poorly understood (URS 2009).

Demand is growing for expanding horticulture in the MIAP and growers would increase their production if suitable land and irrigation water was available (vegetablesWA 2012). Therefore, advancing irrigated production in the Myalup region, including high-value horticulture, would significantly boost regional and economic development.

As part of the Myalup–Wellington Water for Food project, funded by Royalties for Regions, DPIRD was tasked with investigating the land resources available for expansion, and reviewing the water quality trends, aquifer conditions and salinity processes that could affect future growth.

This report describes the water quality investigations. Although there has been some chemical analysis of groundwater in the Myalup region, mainly as a part of early exploration reports and more recently to meet groundwater licence conditions, there has not been a comprehensive groundwater sampling program to characterise the baseline groundwater chemistry of the area or to assess licensee data. Therefore, the aims of the project reported here were to:

- characterise the baseline groundwater chemistry of the Myalup region
- characterise the geochemical processes causing changes in the water quality of the surficial aquifer.

2 Background and methods

2.1 Hydrogeology and hydrochemistry

The Myalup region is located on the western margin of the Swan Coastal Plain, where the physiography is dominated by sets of stabilised dunes that run parallel to the coastline. Lakes and swamps occur in the low-lying interdunal areas (Commander 1984).

The Bassendean Sand formation (early- to mid-Pleistocene) is the most easterly dune system, forming low hills with swamps and adjoining the Harvey and Wellesley rivers. The Bassendean Sand consists of highly leached siliceous sands, often with iron or iron-humus podsols (Degens 2009b) and sulfide minerals (potential acid sulfate soils, PASS) in association with shallow watertables (Degens 2009a).

The Tamala Limestone (late Pleistocene) is the main geological unit in the region and consists of limestone, calcarenite and sand. Regionally, marine and lacustrine sediments make up the bulk of the formation below 3m above Australian Height Datum (mAHD) and frequently contain sulfide minerals (PASS) in association with shallow watertables (Degens 2009a). The main outcropping of the marine and lacustrine sediments occurs as limestone on the Yoongarillup Plain, a coastal plain in the western part of the region. The mainly calcite-cemented aeolian sands that overlie the marine and lacustrine sediments to the east of Yoongarillup Plain are known as the Spearwood Dune System, though are part of the Tamala Limestone geological unit (Commander 1984, Degens 2009b), and can form prominent parallel ridges up to 70m high with a distinct scarp at the boundary of the Bassendean Sand.

Holocene formations include the Safety Bay Sand, also known as Quindalup Dunes, which consist of calcareous sands (calcarenite), located on the western margin adjoining the coast (Figure 2.1). Low-lying areas have been accumulating sediments over the late-Holocene (Commander 1984, Degens 2009b).

Coastal lakes have formed in the Tamala Limestone - Spearwood Dune System. Lake Clifton forms the northern boundary of the study area and Lake Preston forms the western boundary. The Yoongarillup Plain forms a flat-lying area only a few metres above lake level on the eastern shores of Lake Preston and Lake Clifton. There are no natural drainage systems in the study area. A series of drains have been constructed in the Bassendean Sand. Flows from the Harvey River, along with other drains, have been diverted down the Harvey River Diversion Drain (HRDD) to protect Harvey from flooding. The HRDD is a major drainage channel built in the 1930s to discharge at the ocean near Myalup (Figure 2.1). Local drains have also been constructed to manage surface water and lower the watertables on low-lying parts of the Yoongarillup Plain east of Lake Preston (Commander 1984).

These surficial formations are hydraulically connected to form an unconfined aquifer known as the Myalup aquifer. The saturated thickness of this aquifer is between 30 and 40m in the east and thins to 20 to 25m in the west. The aquifer is mainly recharged in the Bassendean Sand to the east in the Yanget and Mialla mounds. Recharge can also occur, depending on land use, on the Spearwood Dunes and Yoongarillup Plain. The superficial aquifer discharges to the coastal lakes (Preston and Clifton) and the

Leschenault Inlet (Figure 2.1). There is potential for groundwater to flow between the superficial formations and the underlying Leederville Formation particularly in the south where the unconformity is sandy (Commander 1984).

According to historic data from DWER's WIN database, groundwater salinity is lowest in the Bassendean Sand and Spearwood Dunes (about 450mg/L TDS) and increases along the flow path westwards to about 940mg/L TDS on the Yoongarillup Plain (Tamala Limestone), east of Lake Preston (Table 2.1, Figure 2.1). Higher salinity groundwater is found in and downgradient of lacustrine areas, such as Myalup Swamp and Mialla Lagoon, with a median salinity of about 1100mg/L (Table 2.1). The higher salinity around swamps has been noted in earlier reports and is attributed to substantial groundwater discharge by evaporation from the swamps (Commander 1984, Kern 1998). The coastal lakes, such as Lake Preston and Lake Clifton, are groundwater sinks and the only water loss from the lakes is through evaporation. Consequently, the groundwater beneath the lakes ranges from fresh to hypersaline (up to 70 000mg/L TDS). As a result of density differences in the groundwater, there is a hydraulic boundary between the groundwater derived from the hypersaline lake and the fresher overlying meteoric-derived groundwater (Commander 1984). The average salinity of groundwater near the interface between the saline groundwater originating from the salt lakes or sea and the overlying fresher aquifer is about 14 000mg/L (Table 2.1).

The hydrochemistry of the Myalup aquifer is highly variable, as can be seen in the Piper diagram showing the relative concentrations of the major ions (Figure 2.2). The aquifer can have sodium-chloride dominated waters as well as being enriched in calcium and bicarbonate. The enrichment with calcium and bicarbonate is readily explained by the dissolution of calcite found in the limestone of the Spearwood Dunes. The aquifer also shows enrichment of sulfate, the origin of which is less obvious. Possible sources of sulfate enrichment include fertiliser application (Watson 2015, WAWA 1989) or the oxidation of acid sulfate soils (Qureshi et al. 2013). These processes will be discussed more fully in the next section.

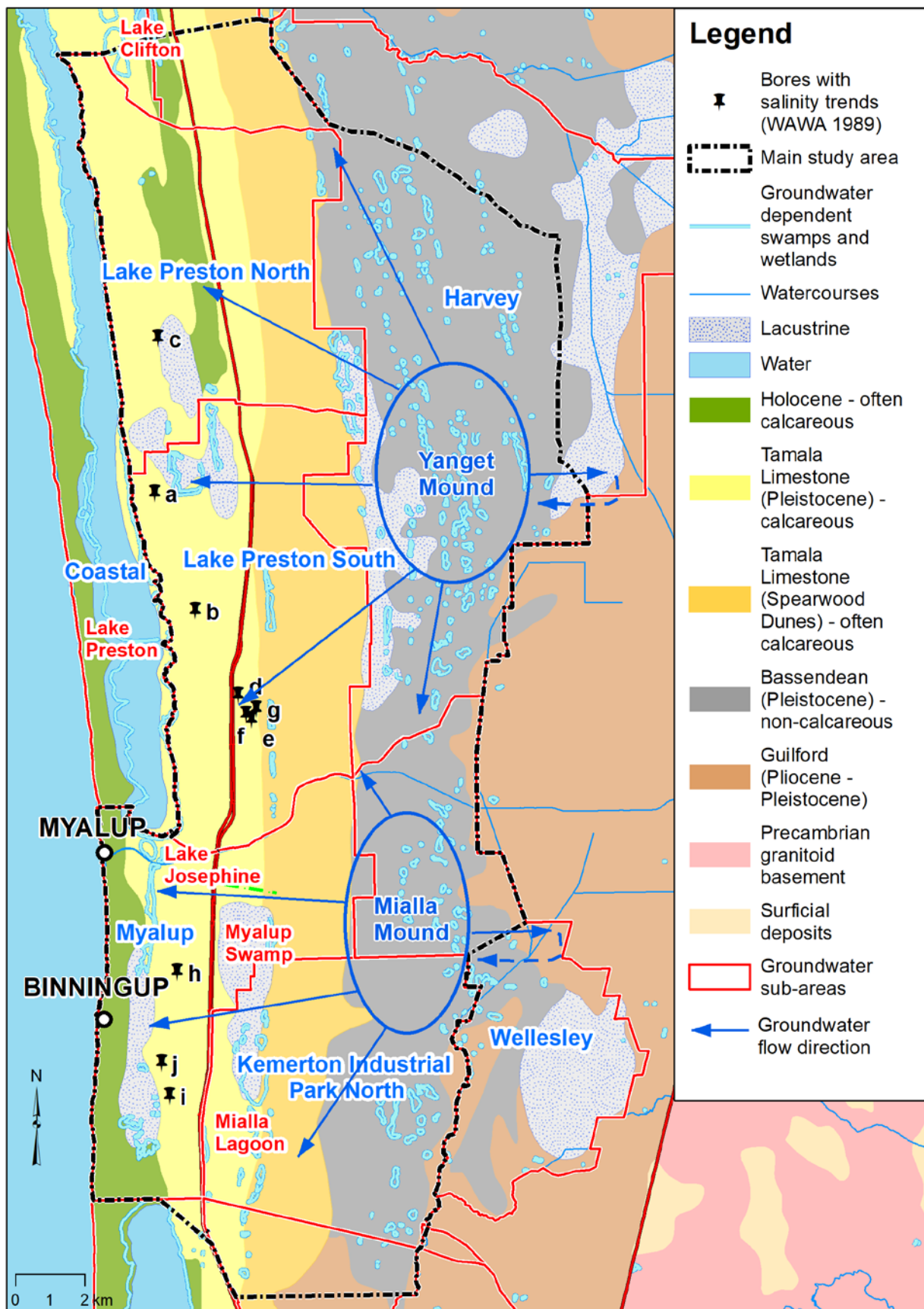


Figure 2.1 The surficial geology, recharge mounds and groundwater dependent wetlands within the Myalup region. The location of groundwater bores with historic salinity trends (Figure 2.3) are also shown

Table 2.1 Salinity, as total dissolved solids (TDS), statistics for the surficial geology of the Myalup region

Surficial geology	Number of bores	Average TDS (mg/L)	Minimum TDS (mg/L)	Maximum TDS (mg/L)
Safety Bay Sand	19	880	210	2 670
Spearwood Dunes	48	460	90	1 000
Tamala Limestone	115	940	440	2 630
Lacustrine	10	1 090	330	2 810
Saltwater interface	7	13 980	3 600	31 060

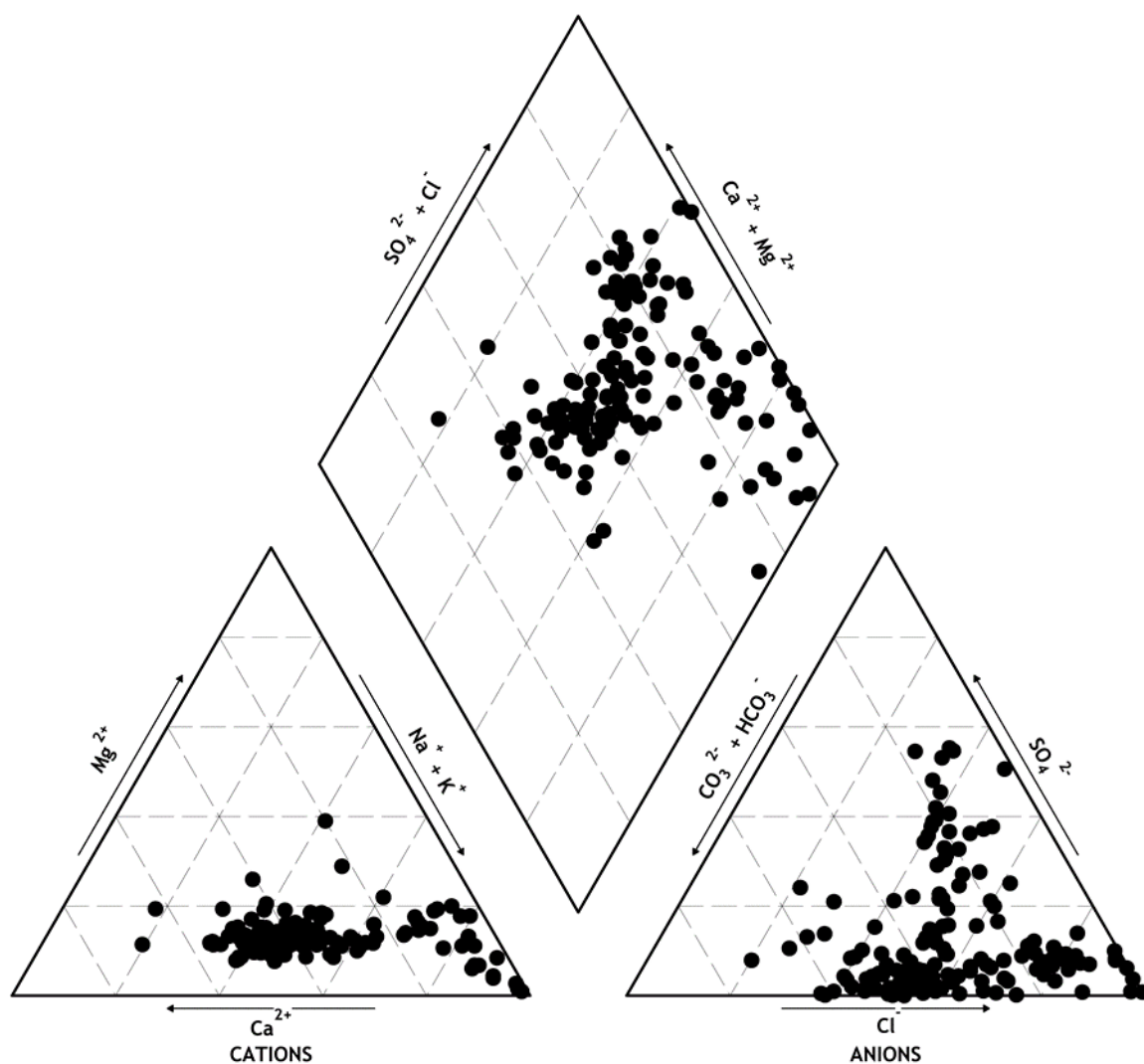


Figure 2.2 Piper diagram for the Myalup Irrigation Area Precinct

2.1.1 Salinity trends, processes and chemical indicators

There is considerable spatial and temporal variability of salinity in the Myalup aquifer (Kern 1998). Historical groundwater records show that the salinity of the surficial aquifer in the Myalup region has increased in areas, but not uniformly (Figure 2.1, Figure 2.3). The reasons for the salinity increases are not fully understood. Possible sources of salinity are recycling of groundwater used for irrigation, the application of fertiliser, oxidation of sulfides in acid sulfate soils, upconing of deeper more-saline groundwater, and saltwater intrusion from adjoining lakes or seawater.

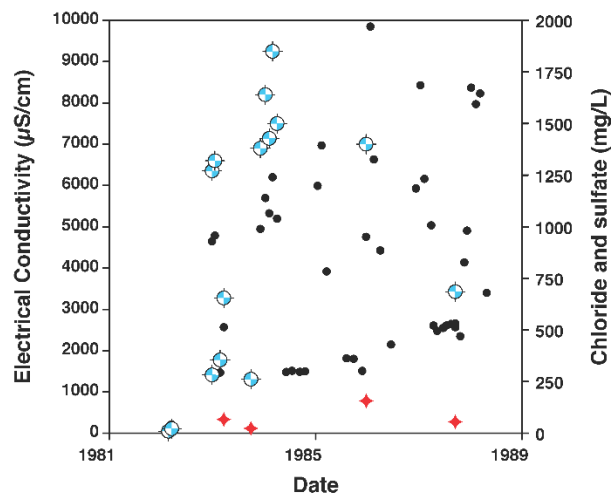
The main process previously thought to be responsible for the increase in salinity was the recycling of groundwater (WAWA 1989). This occurs when a proportion of the groundwater pumped for irrigation returns to the aquifer as recharge carrying salts concentrated through evaporation, nutrients and pesticides from the root zone (Qureshi et al. 2013). Irrigation salinity is well documented and has been known to occur for thousands of years. When groundwater is affected by evapoconcentration, it retains the same chemical composition and the major ions increase in the same relative proportions¹ (Appelo & Postma 2005, Hem 1985). Therefore, a chemical indicator for evapoconcentration would be similar increases in the concentrations of chloride and other major ions (Table 2.2).

Table 2.2 Unique chemical indicators for processes resulting in groundwater

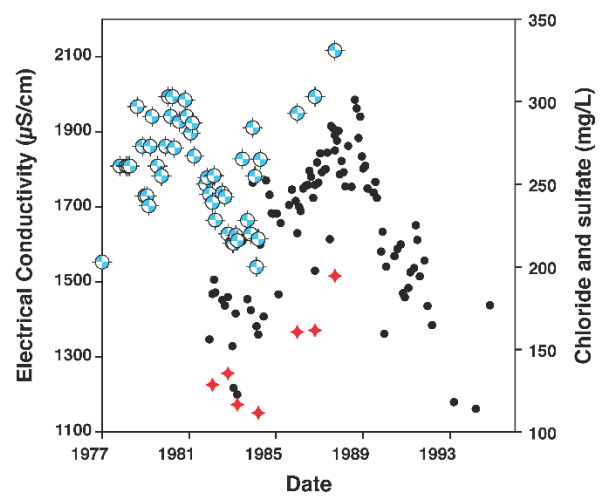
Salinity process	Chemical indicator of process in groundwater
Evapoconcentration	Concentration of chloride and other major ions are increasing through time, with no change in water type (i.e. chemical composition)
Fertiliser contamination	High nitrogen and/or increasing concentration of nitrogen (nitrate or ammonia)
Sulfate from fertiliser application	Correlation between nitrogen and sulfate; and/or increasing concentration of sulfate and nitrogen relative to chloride
Sulfate from oxidising pyrite	Correlation between calcium and sulfate; chloride to sulfate ratio less than two; increase in concentration of sulfate relative to chloride, without an increase in nitrogen
Saltwater intrusion	Shift in groundwater composition towards seawater (sodium chloride) type water

¹ Assuming the major ions are below the saturation limits for mineral precipitation, such as calcite or gypsum.

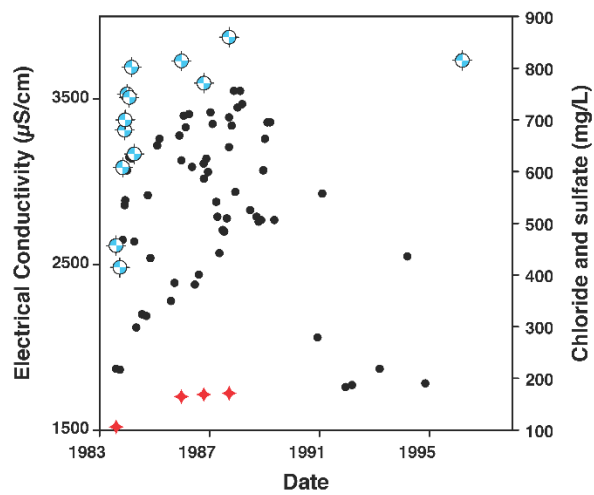
Legend: ● Total Dissolved Solids ◆ Sulfate ◇ Chloride



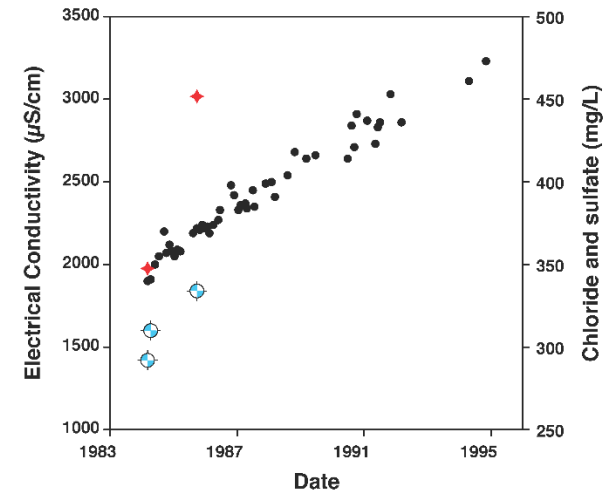
a) L&R Armstrong Bore D



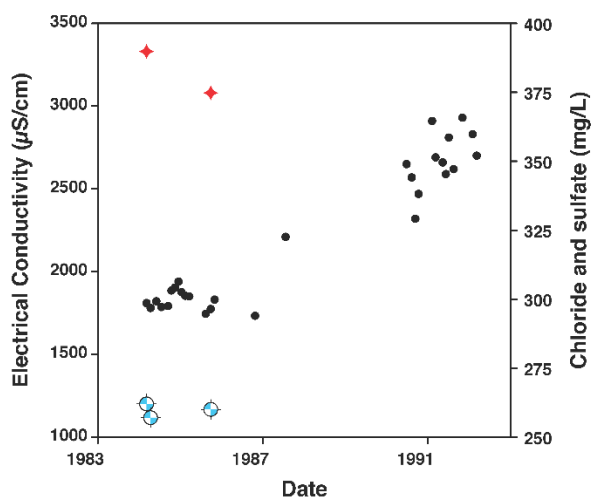
b) Rose Bore G



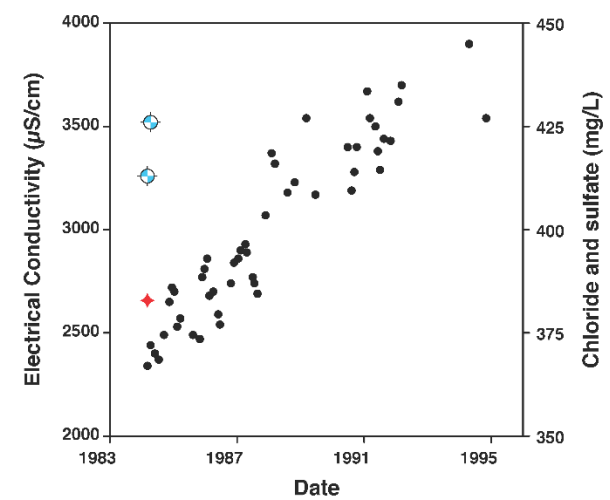
c) T.W. Pearson



d) L.Sumich & Sons 1C



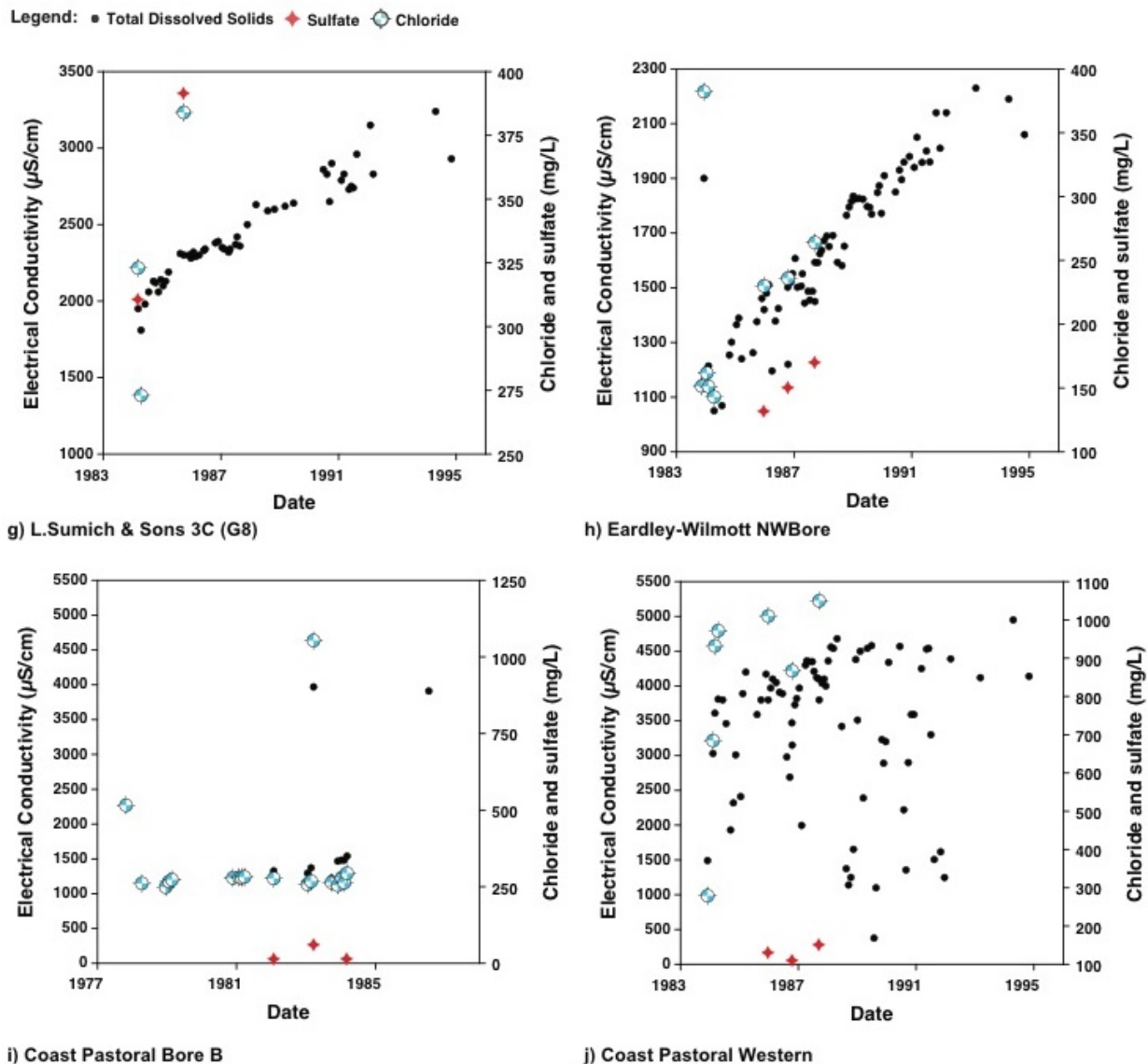
e) L.Sumich & Sons 2D (G5)



f) L.Sumich & Sons 2B (G3)

(continued)

Figure 2.3 Salinity trends in groundwater bores in the Myalup region. Locations of the bores are shown in Figure 2.1



Source: WAWA (1989)

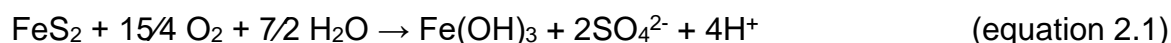
Figure 2.3 continued

Fertiliser application could be another source of salinity, particularly for the increased sulfate concentrations observed in the Myalup aquifer (Hirschberg & Appleyard 1996, Kern 1998, Pionke et al. 1990, WAWA 1989). Contamination of aquifers through fertiliser application is well documented around the world from Europe, North America, Asia and Africa to Australia (Power & Schepers 1989, Spalding & Exner 1993, Strebel et al. 1989). The main contaminant of fertiliser application is nitrogen and in highly contaminated aquifers, nitrogen as nitrate ($\text{NO}_3\text{-N}$) exceeds the World Health Organization limit for water supplies of 10mg/L, often by two or more times (Power & Schepers 1989, Spalding & Exner 1993, Strebel et al. 1989). Globally, the nitrogen concentration in many aquifers has been increasing by up to 1mg/L per year as a result of fertiliser application (Spalding & Exner 1993, Strebel et al. 1989). However, aquifers with $\text{NO}_3\text{-N}$ concentrations less than 3mg/L are considered uncontaminated (Power & Schepers 1989).

In contrast, on the Swan Coastal Plain south of Perth the nitrate concentrations in groundwater are low because of denitrification, except in areas with intensive agriculture (Hirschberg & Appleyard 1996, Pionke et al. 1990). The areas with low nitrate concentrations, however, had high concentrations of reduced nitrogen (ammonia, $\text{NH}_3\text{-N}$). Reduced nitrogen concentrations of more than 0.25mg/L are thought to be due to anthropogenic influences (Hirschberg & Appleyard 1996). A low chloride to sulfate ratio was considered evidence of fertiliser contamination (Hirschberg & Appleyard 1996, Pionke et al. 1990). However, a low chloride to sulfate ratio could also result from sulfide oxidation (Pionke et al. 1990), and sulfides occur in the Myalup region.

If the Myalup aquifer has been contaminated with fertilisers, high nitrogen concentrations and potassium enrichment would be found. There might also be increasing nitrogen concentrations in the aquifer through time as a result of fertiliser application (Table 2.2). If the high sulfate concentrations in the aquifer were the result of fertiliser application, there would be a correlation between nitrogen and sulfate, and possibly of increasing sulfate and nitrogen concentrations relative to chloride, a conservative ion.

The other potential source of sulfate in the groundwater is the oxidation of sulfides found in acid sulfate soils present in the area (Degens 2009a, Degens 2009b, Qureshi et al. 2013). The overall oxidation of pyrite by oxygen is summarised in equation 2.1.



Note that the oxidation of one part pyrite produces two parts sulfate (SO_4^{2-}) and four parts acid (H^+). The acid generated is buffered by calcite dissolution because of the abundance of limestone in the Myalup aquifer. The pH of the groundwater determines the calcite dissolution products. In weakly acid to alkaline environments bicarbonate is produced (equation 2.2). Whereas carbonic acid, which can dissociate to water and carbon dioxide, is produced in strongly acid environments (equation 2.3).



The oxidation of pyrite and the subsequent dissolution of calcite will produce calcium to sulfate ratios between one (equation 2.3) and two (equation 2.2). A chloride to sulfate ratio less than four is often used as evidence of sulfide oxidation (Mulvey 1993, Stone et al. 1998). However, the Perth shallow groundwater systems investigations used a chloride to sulfate ratio less than two as an indicator of sulfide oxidation (Clohessy 2012). Therefore, chemical indicators of pyrite oxidation in the Myalup aquifer are a correlation between calcium and sulfate as well as chloride to sulfate ratios less than two. There could also be increasing sulfate concentrations relative to chloride, but there should not be any correlations between nitrogen and sulfate (Table 2.2).

Another potential source of salinity in the Myalup superficial aquifer is the incursion of more-saline groundwater from beneath the salt lakes or from seawater. The saline groundwater from the salt lakes and seawater are dominated by the ions sodium and chloride (Commander 1984). In contrast, the fresher overlying groundwater has a different chemical signature, one relatively more enriched in calcium and bicarbonate

than the hypersaline groundwater. Therefore, a chemical indicator of the intrusion of more-saline groundwater into the fresher upper aquifer is the shift in the chemical composition of the upper aquifer to a more seawater (sodium chloride) type water, as evidenced by increasing chloride concentrations relative to other ions (Table 2.2).

2.2 Licensee and multiport bore data

2.2.1 Licensee data

Water quality data for the Myalup region is provided to DWER by 5C licence holders (*Rights in Water and Irrigation Act 1914*), as part of their licence requirements. These data were compiled into a single database for analysis (200 sites). Starting from 2007, though more extensively from 2009, the main water quality parameters provided by the licensees have been: electrical conductivity (EC), pH, TDS (estimated from EC)², chloride, sulfate, total nitrogen, oxidised nitrogen (NO_x-N) and total phosphorus. The data analysed was from the period 2007–15.

Descriptive statistics were calculated for the dataset as a whole as well as for individual sites using Data Desk 6.1 (Data Description) and Microsoft Excel. Correlations between the water quality parameters, including time as a variable, were calculated for the whole dataset and individual sites.

Statistical analysis of data trends was carried out for the irrigated agriculture licensee sites (140 sites), for the period 2007–15. Sites were considered to have a trend if the coefficient of determination (r^2) was greater than 0.45.³ To help determine the source of any salinity increases, correlations were also calculated for the other parameters. Correlations between ions were corrected for evapoconcentration effects by dividing by chloride (assumed to be conservative). Relationships identified in Table 2.2 were the main focus in the analysis. Sites were considered to be affected by pyrite oxidation if the chloride to sulfate ratio was less than two, similar to the Perth shallow groundwater investigations.

Note, only generalised trends and grouped data are reported here, rather than individually identifiable sites, because of the legislative confidentiality requirements for using licensee water quality data.

2.2.2 Multiport data

A series of bores with multiple ports at different depths were drilled in the Lake Preston area during 1984 to monitor movement of the interface between the more-saline groundwater beneath Lake Preston and the fresher overlying groundwater. Changes in salinity through time (1984–2000) at different depths for these bores were analysed to identify any movement in the saltwater interface.

² EC was converted to TDS using a factor of 0.55 (TDS = 0.55 x EC). The conversion factor varies depending on the ionic composition of the water and can underestimate TDS.

³ r^2 describes the variation in the dependent variable, salinity, that can be explained by the independent variable, time. An r^2 greater than 0.45 meant 45% of the variability could be explained by the independent variable, and that the correlation coefficient (r) was greater than 0.67, which meant the data was highly correlated.

2.3 Baseline groundwater chemistry

2.3.1 Groundwater sampling

During the first phase of groundwater sampling in 2016, monitoring or production bores, rather than soaks or excavated pits, were selected for sampling to minimise the risk of contamination and to ensure the samples were representative of actual groundwater conditions. The selection of sampling sites was designed to provide a broad geographic coverage across the region. Sites were mainly selected on farms in the irrigation areas and these sites included a mix of high salinity and low salinity areas, and areas with high and low sulfate concentrations. Sites were also selected from known recharge and discharge areas, in particular along east–west transects, to gain an understanding of changes in water quality along groundwater flow paths. The underlying Leederville aquifer and related formations were sampled at five locations to gain an understanding of its water quality. Six sites were selected on Bassendean Sand, of which only one was irrigated. Comparison sites under native vegetation were selected outside of the irrigation areas to provide a reference to natural conditions. Crops are irrigated from the Harvey River Diversion Drain, so two surface water samples were collected from the drain and an additional sample was collected from a storage dam. In total 68 sites were selected for the first phase of sampling (Figure 2.4 and Appendix A).

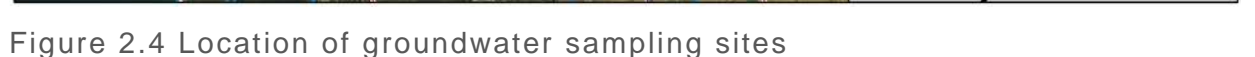
In the second phase of groundwater sampling (2017), sites were identified using a similar method to the first phase. Sampling sites included all the sites that had high salinity or increased salinity in the first phase. Also, more attention was paid to sampling depth, with only sites where the depth of the bores could be determined were used. Bores were also selected along east–west transects to understand changes in water quality along groundwater flow paths at different depths. A total of 45 bores were selected (Figure 2.4 and Appendix A).

2.3.2 Chemical analysis

The selection of inorganic analytes was determined by the water quality guidelines of ANZECC and ARMCANZ (2000). Ions specified in the aquatic ecosystem and primary production guidelines, and major ions and nutrients were included in the analysis. The laboratory analysis included general chemistry (acidity, alkalinity, EC, hardness, pH), major ions (calcium, magnesium, sodium, potassium, bicarbonate/carbonate, sulfate and chloride), minor ions (silicon, fluoride, bromide, boron, dissolved organic carbon), metals and metalloids (aluminium, antimony, arsenic, barium, beryllium, bismuth, cadmium, chromium, cobalt, copper, gallium, iron, lanthanum, lead, lithium, manganese, mercury, molybdenum, nickel, selenium, silver, thallium, tin, titanium, uranium, vanadium, zinc) and nutrients (total nitrogen, nitrate, nitrite, total oxidised nitrogen, ammonia, total phosphorus, soluble reactive phosphorus).

The organic compounds selected for laboratory analysis were determined by identifying the common compounds used by growers and then determining the toxicity of these compounds and the risk of their leaching to the aquifer (Moore & Moore 2014).

Compounds that had a high toxicity and a high risk of leaching were selected: metalaxyl, methyl isothiocyanate, metalachlor and atrazine.



During the second phase of sampling, similar parameters were analysed. TDS by gravimetry was included, and organic compounds and any parameters where all measurements were below the limit of reporting (LoR) during the first phase of analysis were omitted. All samples were analysed by ChemCentre. Appendix B contains the laboratory methods and limits of detection.

2.3.3 Field sampling

Groundwater level and total bore depth were measured when possible using an electronic water level meter and/or a manual depth plover. These recordings were taken before in situ measurement and sampling. During the second phase of sampling, where the water level and total depth could not be measured for any bore, another bore within 500m was used instead. All depth measurements were referenced to the 'top of casing' or 'inner casing'. The depth from the top of casing to the ground surface was also measured.

Before sample collection, all bores were purged, at a rate that did not cause a significant drawdown of the bore, either by pumping three times the volume of the bore or until field parameters — EC, pH, oxidation reduction potential and dissolved oxygen — had stabilised (within 10% for a period greater than five minutes).

The bores were sampled using a plastic submersible pump or, if the casing diameter was too narrow, by a foot pump fitted with LDPE (low-density polyethylene) tubing. If the bores had an irrigation pump attached, water samples were taken from the irrigation pump once field parameters had stabilised.

Once the bores had been purged, EC, temperature, pH, oxidation reduction potential and dissolved oxygen were measured directly in the field. During the first phase of sampling, dissolved oxygen was recorded as a percentage. During the second phase of sampling, dissolved oxygen was measured in milligrams per litre, alkalinity was measured in the field, and oxidation reduction potential was reported as standard hydrogen electrode (Eh). Field measurements were taken using methods that permitted direct measurement of water pumped from a bore but did not allow contact with air. All instruments were calibrated according to the manufacturer's instructions before use.

Groundwater samples were handled as per laboratory requirements (Table 2.3). Samples were filtered and preserved (where necessary) within 15 minutes of collection and immediately placed in refrigeration. Samples that required freezing were later frozen. Sample containers were rinsed several times with purged water before sample collection to minimise risk of contamination. However, if the bottle contained preservatives, they were filled directly. For samples that required filtering, at least 50 millilitres (mL) was flushed through the filter before collecting the filtrate. Sample containers were rinsed with filtrate before sample collection. No blanks or duplicates were collected during sampling.

Table 2.3 Laboratory requirements followed for collected water samples

Analysis	Bottle	Preservation	Temperature
General chemistry (not otherwise listed)	500mL plastic bottle	Fill to exclude air	Chilled
Dissolved organic carbon (DOC)	40mL glass vial or 125mL plastic bottle	DOC must be filtered through 0.45 micrometre (μm) cellulose acetate membrane	Chilled or frozen (if plastic bottle)
Ammonia, nitrate, nitrite, soluble reactive phosphorus	125mL plastic bottle	Filter through 0.45 μm membrane, three-quarter fill	Frozen
Total nitrogen, total phosphorus	125mL plastic bottle	Three-quarter fill	Frozen
Dissolved metals	100mL acid-washed plastic bottle	Filter through 0.45 μm membrane – the laboratory acidified the sample	
Metalachlor	50mL amber glass	Fill	Chilled
Metalaxyl	1L amber glass	Fill	Chilled
Methyl isothiocyanate	2 x 40mL VOA glass vial	Fill to exclude air	Chilled
Atrazine	50mL amber glass	Fill	Chilled

2.3.4 Analysis of groundwater data

Results from both phases of groundwater sampling plus additional data collected during 2015 were used in the analysis. The 2015 sampling locations and site details are shown in Figure 2.4 and Appendix A. Statistical analysis (descriptive statistics and correlations) were performed on groundwater chemistry using Data Desk 6.1 (Data Description) and Microsoft Excel. For statistical analysis, any chemistry data that was below the laboratory LoR was assigned the value of half the LoR, consistent with the ANZECC and ARMCANZ (2000) guidelines. Correlations, corrected for evapoconcentration, were calculated for major ions and nutrients. Relationships identified in Table 2.2 were the major focus of the analysis.

Maps showing the spatial distribution of groundwater concentrations for species with samples greater than 40% above the LoR were developed. The maps were created using superficial groundwater bores. Bores drilled into the saltwater interface were excluded. If there were nested bores, the shallowest bore was used. The individual concentrations at each site were interpolated in ArcGIS 10 (ESRI) to create grids using the inverse distance weighting method. If a site was sampled multiple times, then the averaged value was used.

The superficial geology was assigned to each sampling location in ArcGIS 10. Depths for the sampling locations were assigned based on drill logs or field measurements. The deep bores were drilled to the base of the formation. All sampling locations on private land that did not have depth information were assumed to be shallow, based on local knowledge of drilling practices. The sampling locations were divided into the superficial

geological units and, where there was sufficient data ($n > 5$), depth. Statistical analysis (descriptive statistics) were performed for the different superficial units using Data Desk 6.1 (Data Description) and Microsoft Excel. To validate the depth trends within the geological units, the results were compared against the nested bores within the units.

Groundwater data was compared to the ANZECC and ARMCANZ (2000) aquatic ecosystem and irrigation guidelines. A map showing the suitability of groundwater for direct irrigation based on salinity criteria (Taylor 1996) was created. The suitability of groundwater for direct irrigation was assessed using the Richards (1954) classification system based on salinity and sodium hazard. High salinities can cause loss of production and death in plants, and high sodium levels in irrigation water can cause a decline in soil structure (Richards 1954). Although high sodium levels are not a significant issue for sands, Wilcox diagrams are a standard method for assessing the suitability of water for irrigation. The sodium hazard is measured by the sodium adsorption ratio (SAR), with the concentration of the ions expressed as milliequivalents per litre (meq/L):

$$\text{SAR} = \frac{[\text{Na}^+]}{\sqrt{\frac{[\text{Mg}^{2+}] + [\text{Ca}^{2+}]}{2}}}$$

There are five salinity classifications, C1 to C5, and four sodium hazard classifications, S1 to S4 (Table 2.4 and Table 2.5). The class of sodium hazard depends on the salinity hazard of the water.

Table 2.4 Salinity hazard classes

Class	Electrical conductivity ($\mu\text{S}/\text{cm}$)	Description
C1	<280	Low salinity water can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices, except in soils of extremely low permeability.
C2	281–800	Medium salinity water can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.
C3	801–2300	High salinity water cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.
C4	2301–5500	Very high salinity water is not suitable for irrigation under ordinary circumstances, but may be occasionally used under very special circumstances. The soil must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and salt-tolerant crops should be selected.
C5	>5500	Extremely high salinity water. Not suitable for irrigation.

$\mu\text{S}/\text{cm}$ = microsiemens per centimetre

Source: adapted from Richards (1954)

Table 2.5 Sodium hazard classes

Class	Description
S1	Low sodium water can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium.
S2	Medium sodium water will present an appreciable sodium hazard in fine-textured soils having high cation exchange capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.
S3	High sodium water may produce harmful levels of exchangeable sodium in most soils and will require special soil management — good drainage, high leaching and organic matter additions. Gypsiferous soils might not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, though amendments may not be feasible with waters of very high salinity.
S4	Very high sodium water is generally unsatisfactory for irrigation, except at low and perhaps medium salinity, where solution of calcium from the soil, or use of gypsum or other amendments, makes the use of these waters feasible.

Source: adapted from Richards (1954)

3 Results

3.1 Licensee data

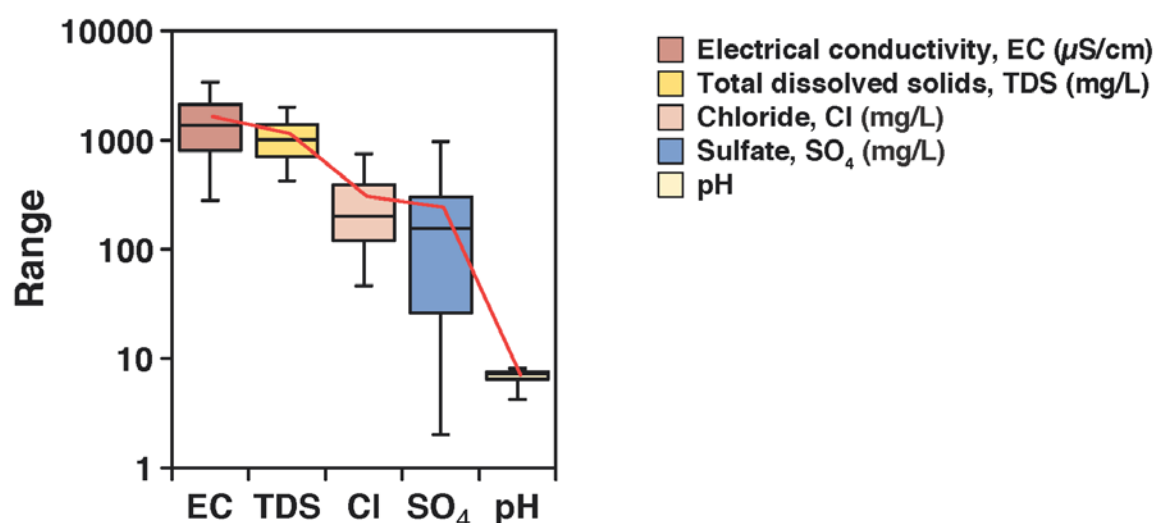
The Myalup licensee statistics are summarised below.

The median salinity was just above 1000mg/L TDS, but ranged from about 100mg/L to more than 4000mg/L. The lowest salinities were on the Bassendean Sand and the highest salinities occurred to the east of Lake Preston and in the wetlands between the Leschenault Inlet and Lake Preston (Figure 3.1, Table 3.1, Figure C1).

The median chloride concentration was about 200mg/L and ranged from less than 10mg/L to about 2200mg/L. The lowest chloride concentrations were on the Bassendean Sand and the highest concentrations were to the east of Lake Preston and in the wetlands between the Leschenault Inlet and Lake Preston (Figure 3.1, Table 3.1, Figure C1).

Sulfate had a median concentration of 160mg/L and ranged from being not detectable to nearly 2000mg/L. The highest sulfate concentrations were around wetlands (Figure 3.1, Table 3.1, Figure C2). These areas also coincided with areas that had chloride to sulfate ratios less than two — the marker for pyrite oxidation — and a moderate to high risk of acid sulfate soils, based on DWER mapping classification (Figure 3.2).

The median pH was about 7 and ranged from 2.9 to 9.7 (Figure 3.1, Table 3.1). Most sites had a pH between 7 and 8, with low pH sites occurring in the wetlands to the east of the Yoongarillup Plain and on the Bassendean Sand (Figure 3.3). These areas had lower buffering capacities than surrounding areas.



Note: The plots show the median, 25th and 75th percentiles in the shaded boxes, and the lines represent the 5th and 95th percentiles. The red solid line shows the average values.

Figure 3.1 Concentration of the main analytes from licensee data, mainly from the period 2007–15

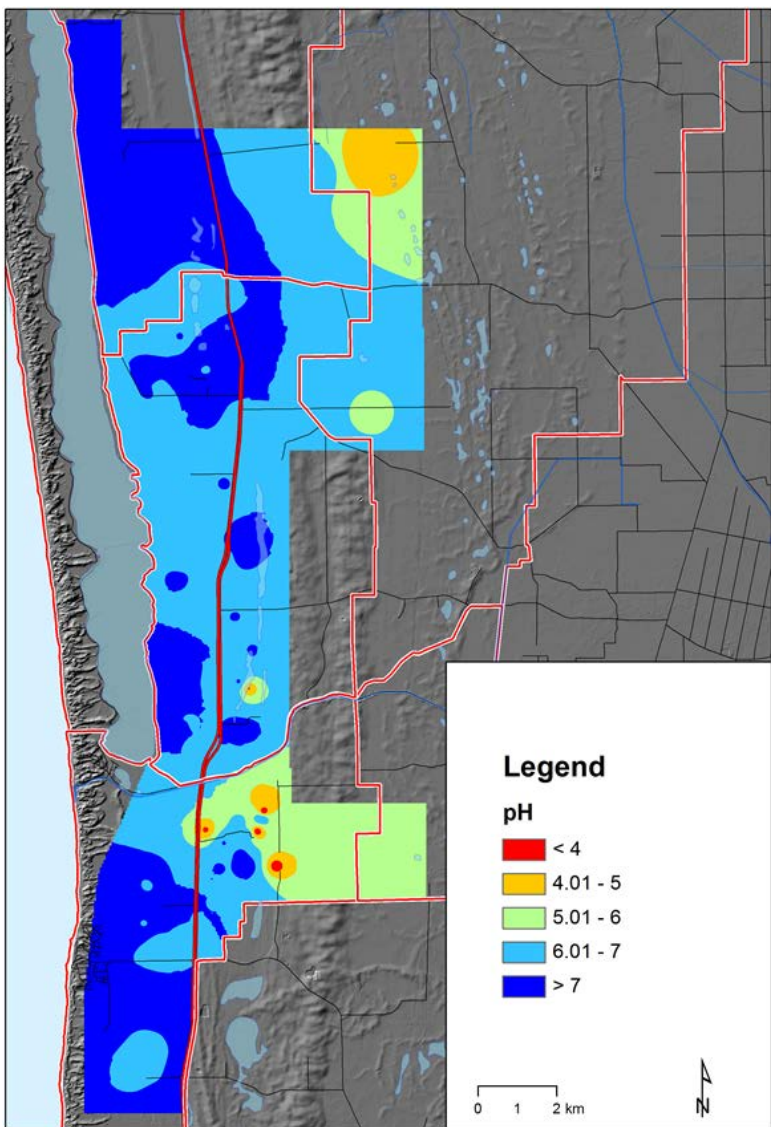


Figure 3.3 Minimum pH from groundwater licensee monitoring

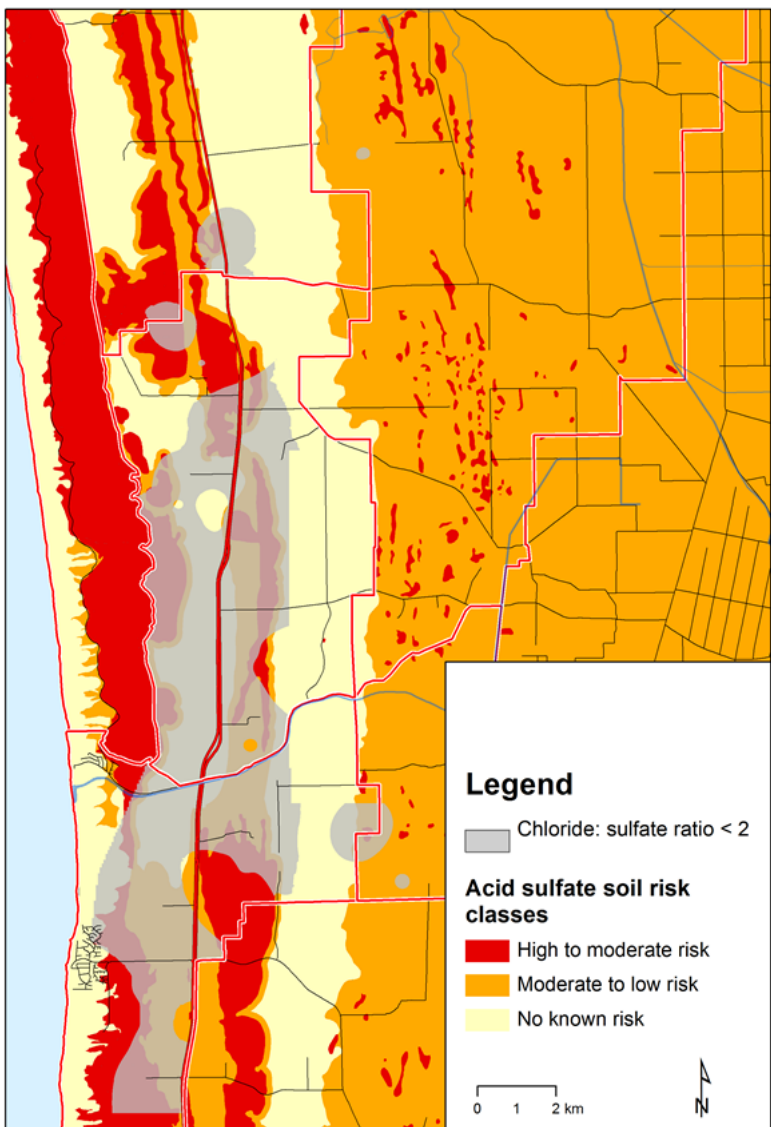


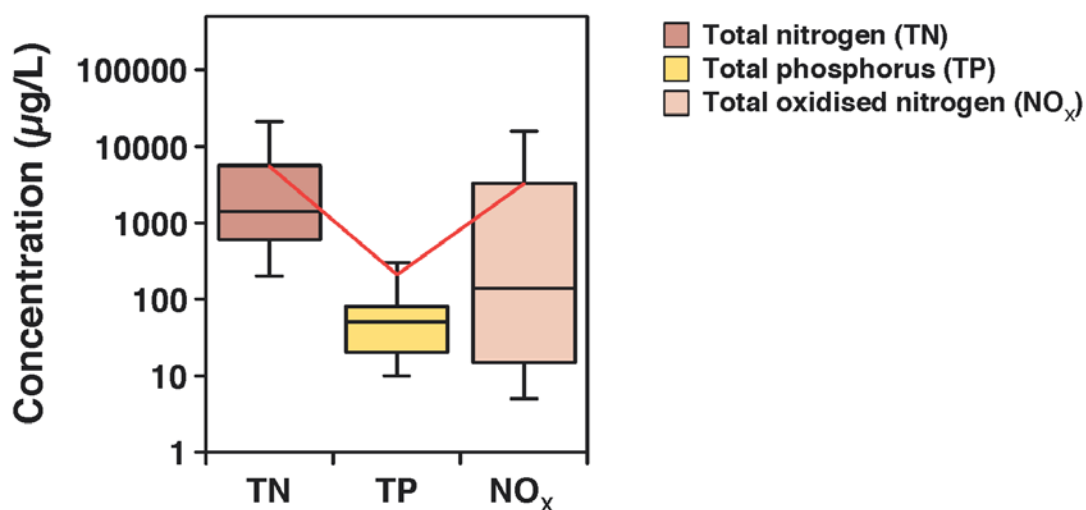
Figure 3.2 Areas with an average chloride to sulfate ratio less than two (based on licensee monitoring data)

Table 3.1 Summary statistics for the main water quality parameters for the Myalup licensee data

Parameter	Unit	Count	Mean	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
pH		4 962	6.9	7.3	1.1	2.9	9.7	6.0	7.7
Electrical conductivity (EC)	µs/cm	4 957	1 548	1 355	1 000	1	8 080	670	2 340
Total dissolved solids, TDS (calculated from EC)	mg/L	3 966	1 086	1 003	511	77	4 444	645	1 487
Total dissolved solids (gravimetric)	mg/L	2 086	427	350	359	40	3 900	180	590
Sulfate	mg/L	1 458	237	160	287	0	1 952	20	370
Chloride	mg/L	1 446	294	203	276	5	2 249	100	450
Nitrogen (total)	µg/L	1 255	4 890	1 450	8 690	10	95 000	540	7 200
Phosphorus (total)	µg/L	1 243	140	50	1 351	1	45 000	20	100
Nitrogen (NO _x)	µg/L	853	3 044	150	6 415	2	52 000	10	5 000

The median total nitrogen concentration was about 1500 micrograms per litre ($\mu\text{g/L}$) and ranged from 10 $\mu\text{g/L}$ to 95 000 $\mu\text{g/L}$. The median oxidised nitrogen (nitrate) concentration was 150 $\mu\text{g/L}$ and ranged from 2 to 52 000 $\mu\text{g/L}$ (Figure 3.4, Table 3.1). The highest nitrogen concentrations (greater than 10 000 $\mu\text{g/L}$) occurred at the south-eastern edge of Lake Preston (Figure C2).

Total phosphorus had a median concentration of 50 $\mu\text{g/L}$ and ranged from 1 to 45 000 $\mu\text{g/L}$ (Figure 3.4, Table 3.1). The highest concentrations occurred on the Bassendean Sand and swampy areas (Figure C3).



Note: The plots show the median, 25th and 75th percentiles in the shaded boxes, and the lines represent the 5th and 95th percentiles. The red solid line is the average values.

Figure 3.4 Concentration of nutrients from licensee data, mostly from the period 2007–15

One hundred and forty licensee sites with irrigated agriculture were analysed for salinity trends and for correlations between other water quality parameters. Thirty of the 140 sites had increased salinity, and six sites had decreased salinity (Table 3.2). Nineteen of the 30 sites with increased salinity showed increased sulfate relative to chloride (Figure 3.5, Figure 3.6b, c, e, f); at nine sites, sulfate and chloride had increased at similar rates (Figure 3.5, Figure 3.6a); and at two sites, there was an increase in chloride relative to other parameters (Figure 3.5, Figure 3.6d).

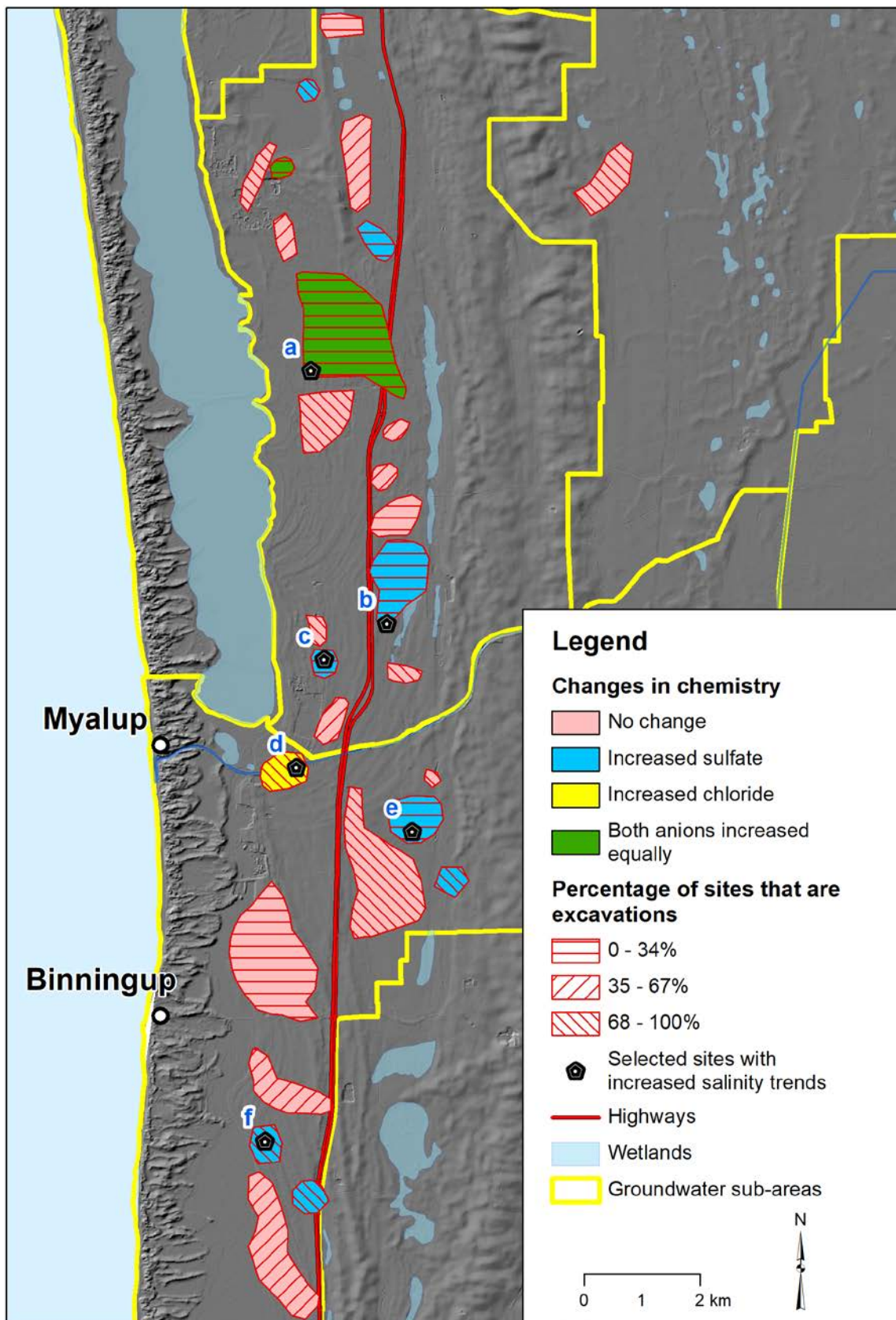
No sites had a statistically significant increase in nitrogen through time. When corrected for evapoconcentration, there were also no statistically significant correlations at any sites between nitrogen and sulfate. Of the 136 sites with chloride and sulfate data, 72% had chloride to sulfate ratios less than two, indicating they were potentially affected by acid sulfate soils, and at 40% of the sites sulfate was the dominate anion by mass.

Overall, there were no differences between sites with increased salinity and those with no change for TDS, chloride, sulfate, pH and NO_x, whereas there were differences at the sites with decreased salinity (Table 3.2). The average salinity of sites with increased salinity was 1000mg/L, whereas the sites with no change in salinity had an average

salinity of 1050mg/L. The sites with decreased salinity had an average salinity of 670mg/L, as well as a much lower pH and chloride to sulfate ratio.

Table 3.2 Comparison of average water quality for sites with increased salinity, sites with decreased salinity and sites with no trend in salinity

Parameters	Sites with increased salinity	Sites with decreased salinity	Sites with no change	Average of total
Count	30	6	104	140
Total dissolved solids (mg/L)	1000	668	1050	1023
Chloride (mg/L)	317	158	356	339
Sulfate (mg/L)	272	202	284	278
pH	7.38	6.51	7.43	7.38
Oxidised nitrogen, NO _x (µg/L)	4800	3400	4800	4700



Note: Letters relate to sites that have their groundwater trends shown in Figure 3.6.

Figure 3.5 Areas with increased salinity and changes in groundwater chemistry over time, and the percentage of licensee sites that are excavations

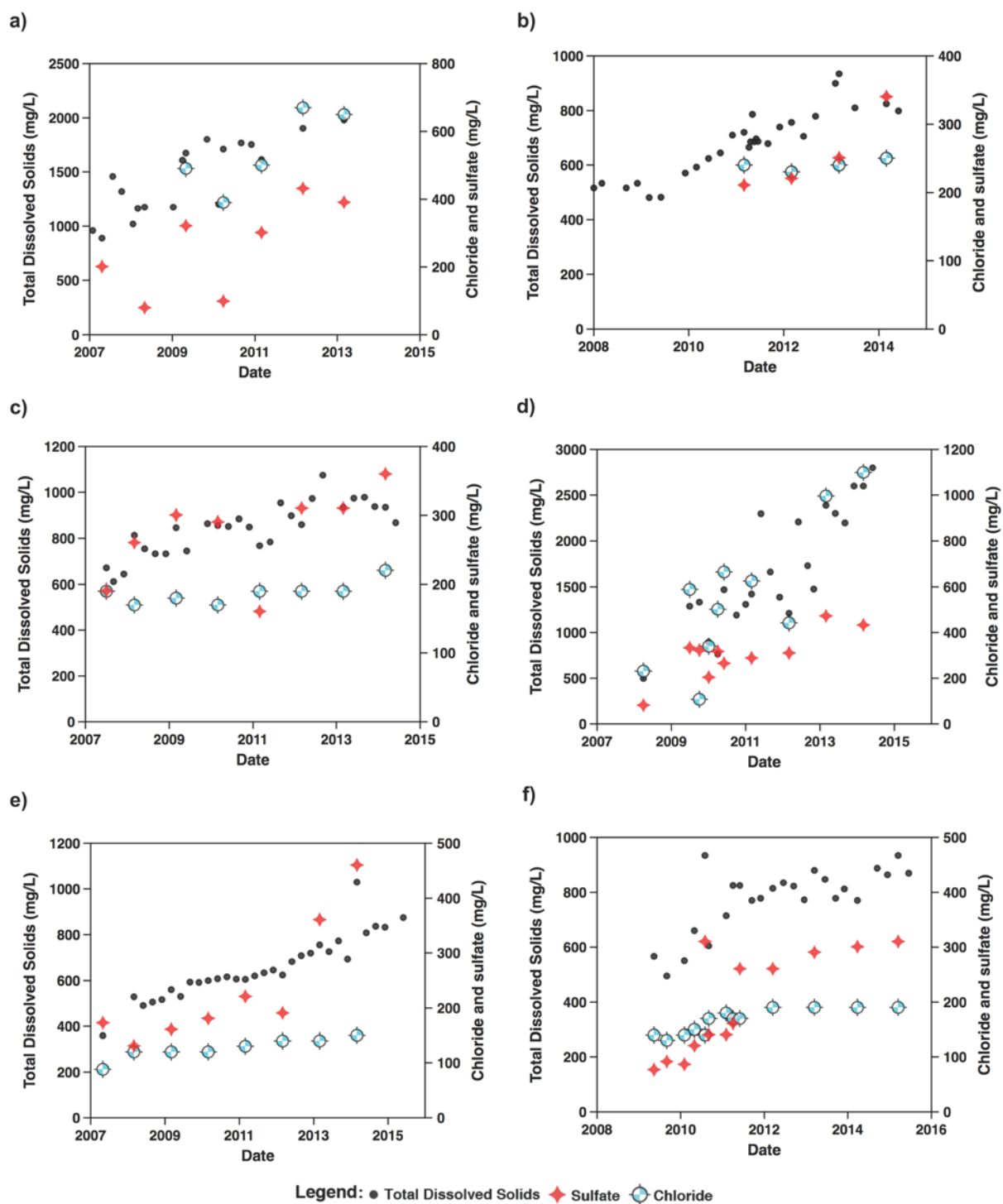


Figure 3.6 Total dissolved solids, chloride and sulfate concentrations at selected sites shown in Figure 3.5 to illustrate different trends in groundwater chemistry, 2007–15

3.2 Saltwater interface

Interpreted salinity data at depths –5 to 0m and –30 to –25mAHD, resulting from an airborne electromagnetic (AEM) survey conducted in the Myalup region during 2016, are shown in Figure 3.7. The data at –5 to 0mAHD shows the salinity of the shallow aquifer. The highest salinity was beneath the salt lakes and there were also large regions of moderate salinity below the low-lying areas at the eastern margins of Lake Preston (Figure 3.7 left). Salinity in the shallow aquifer was also evident to the east of the Forrest Highway, associated with wetlands such as Myalup Swamp and Mialla Lagoon. Saline plumes can be seen extending downgradient (roughly north-west) from the wetlands (Figure 3.7).

Data from –30 to –25mAHD shows the salinity near the base of the aquifer and indicates the highly saline plume from Lake Preston has moved eastward at depth because of differences in water density. The groundwater salinity generally increases with depth towards the base of the aquifer across the area. Data from the Lake Clifton multiport bores (Figure 3.7) drilled into the interface between the saline groundwater beneath the salt lake and the overlying fresher aquifer were analysed to investigate changes in the saltwater interface during the mid-1980s to 2000 (Figure 3.8 to Figure 3.11).

In most of the bores groundwater salinity increased with depth, matching trends in the AEM data (Figure 3.7). Only two bores, 5-84 and 9-84, showed increased salinity over this period (Figure 3.8, Figure 3.10). Bore 10-84 (Figure 3.11) showed increased salinity at depth, but the bore had a low salinity (<2000mg/L) so the cause of the rise cannot be determined. The increased salinity in bore 6-84 was not the result of the landward movement of the saltwater interface because there was no increase in salinity in bore 7-84, which is downgradient (Figure 3.9). Rather, the increase in salinity was probably due to the movement of brackish groundwater from wetlands located upgradient.

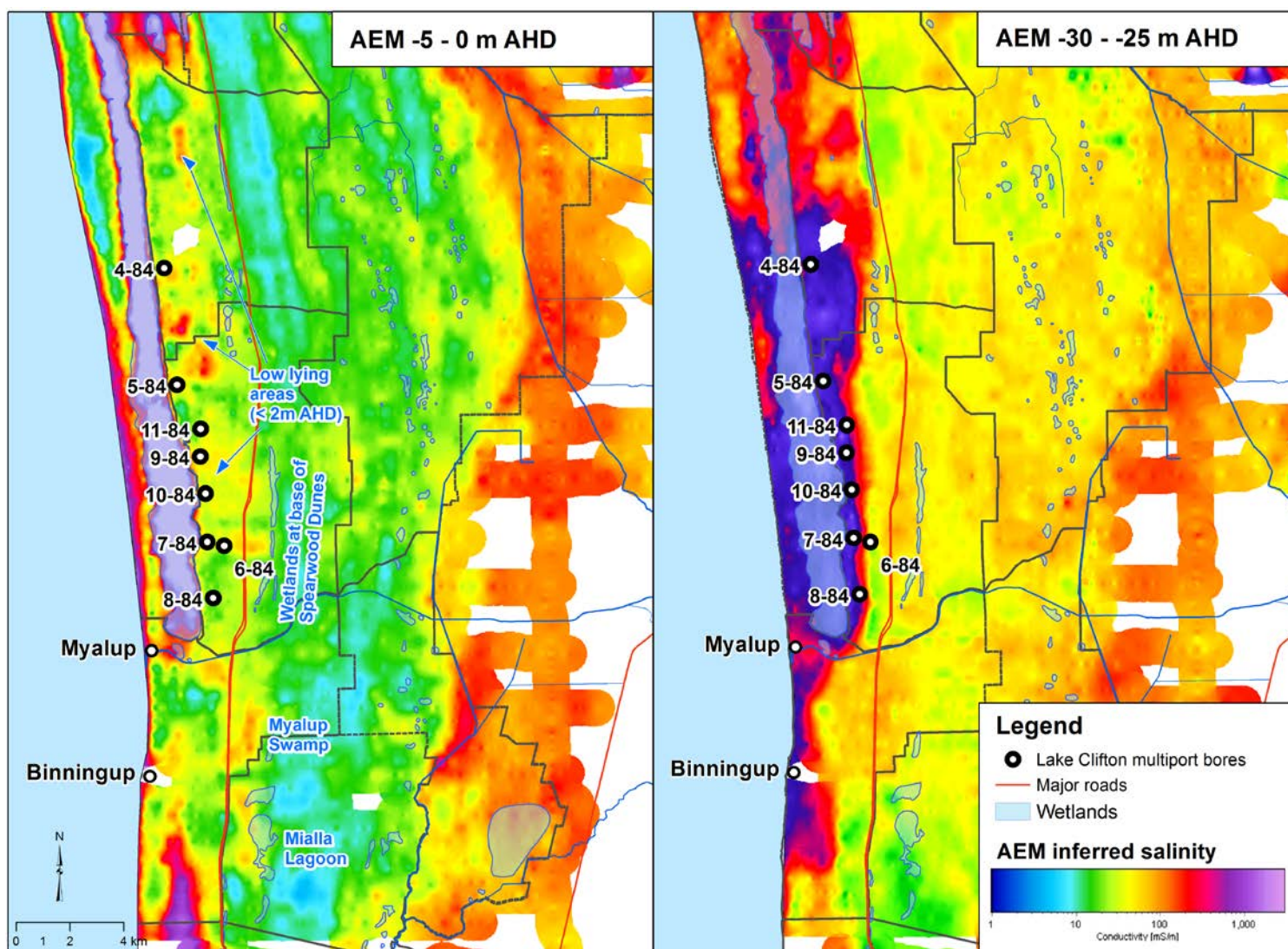


Figure 3.7 Inferred salinity derived from airborne electromagnetic (AEM) survey, and the location of the Lake Clifton multiport bores

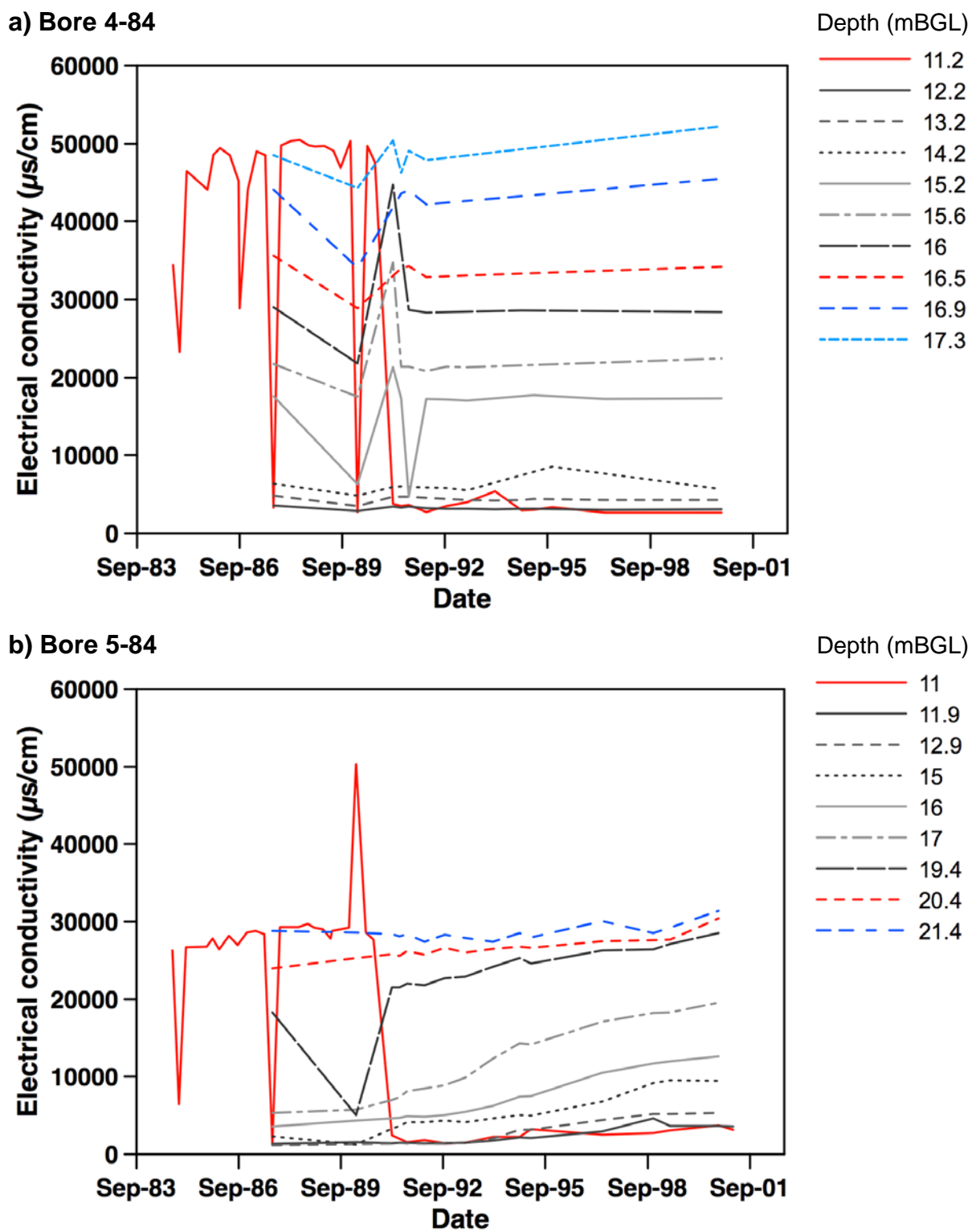
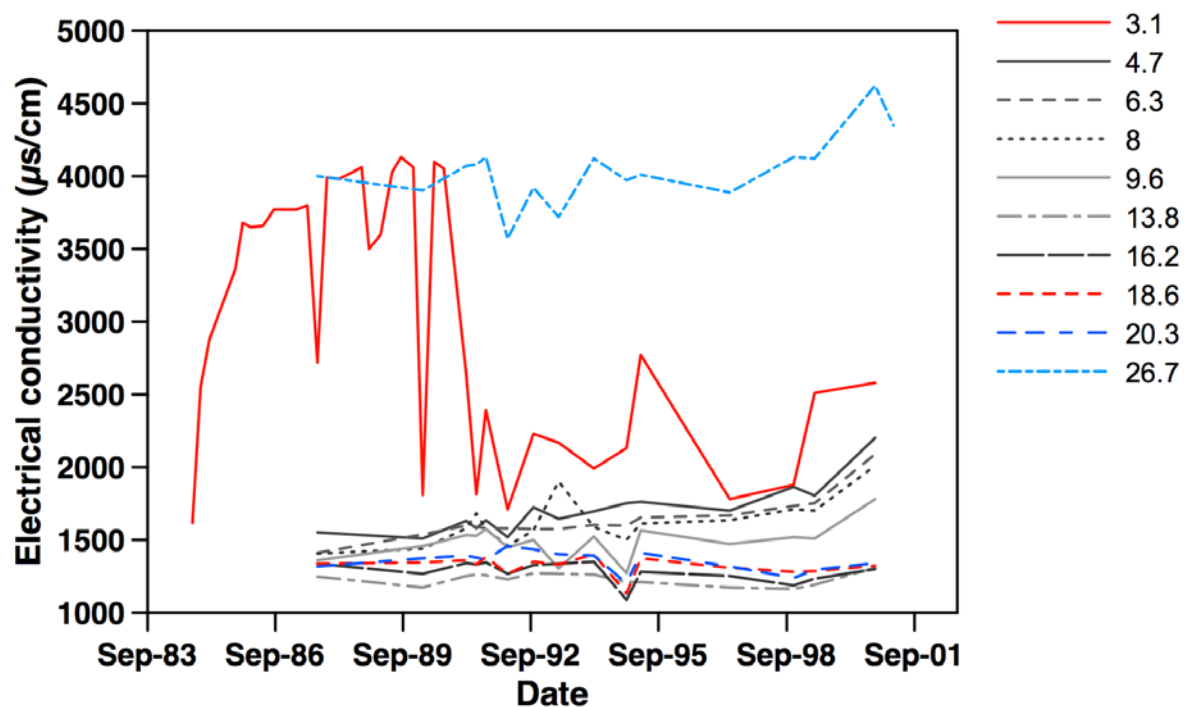


Figure 3.8 The change in salinity over time at different depths in the Lake Clifton multiport bores: a) 4-84, and b) 5-84

a) Bore 6-84



b) Bore 7-84

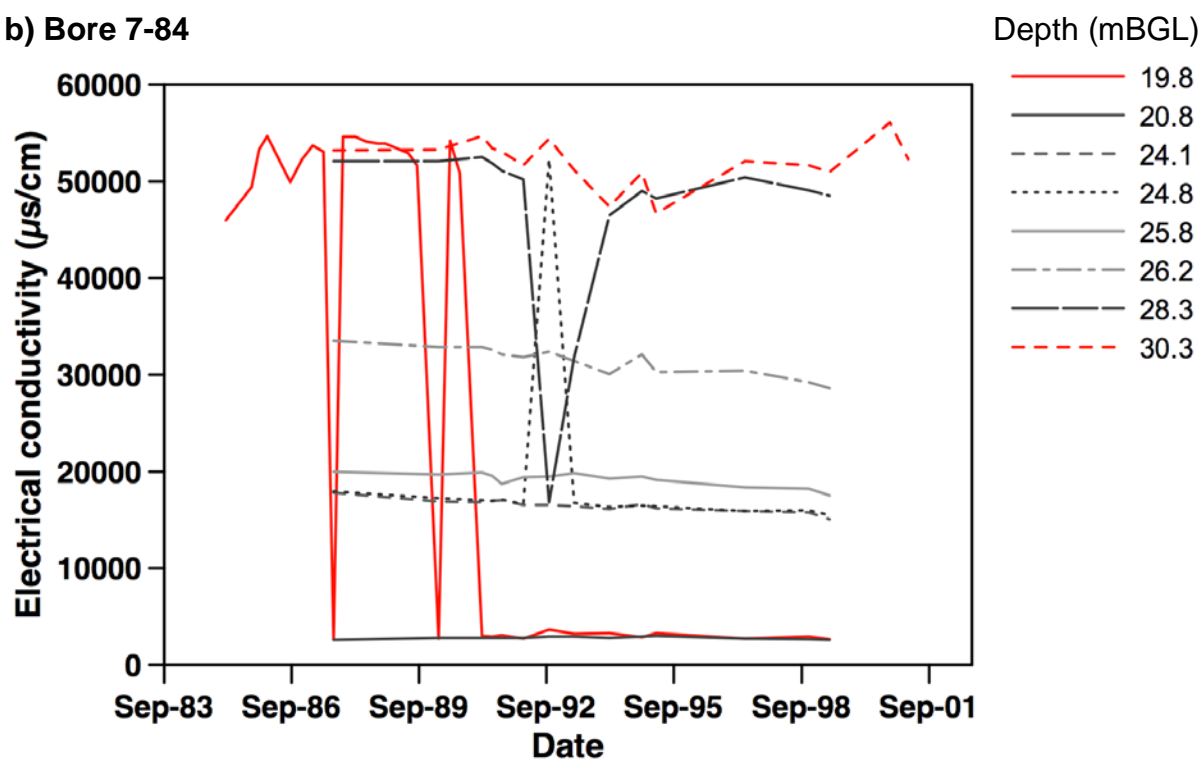


Figure 3.9 The change in salinity over time at different depths in the Lake Clifton multiport bores: a) 6-84, and b) 7-84

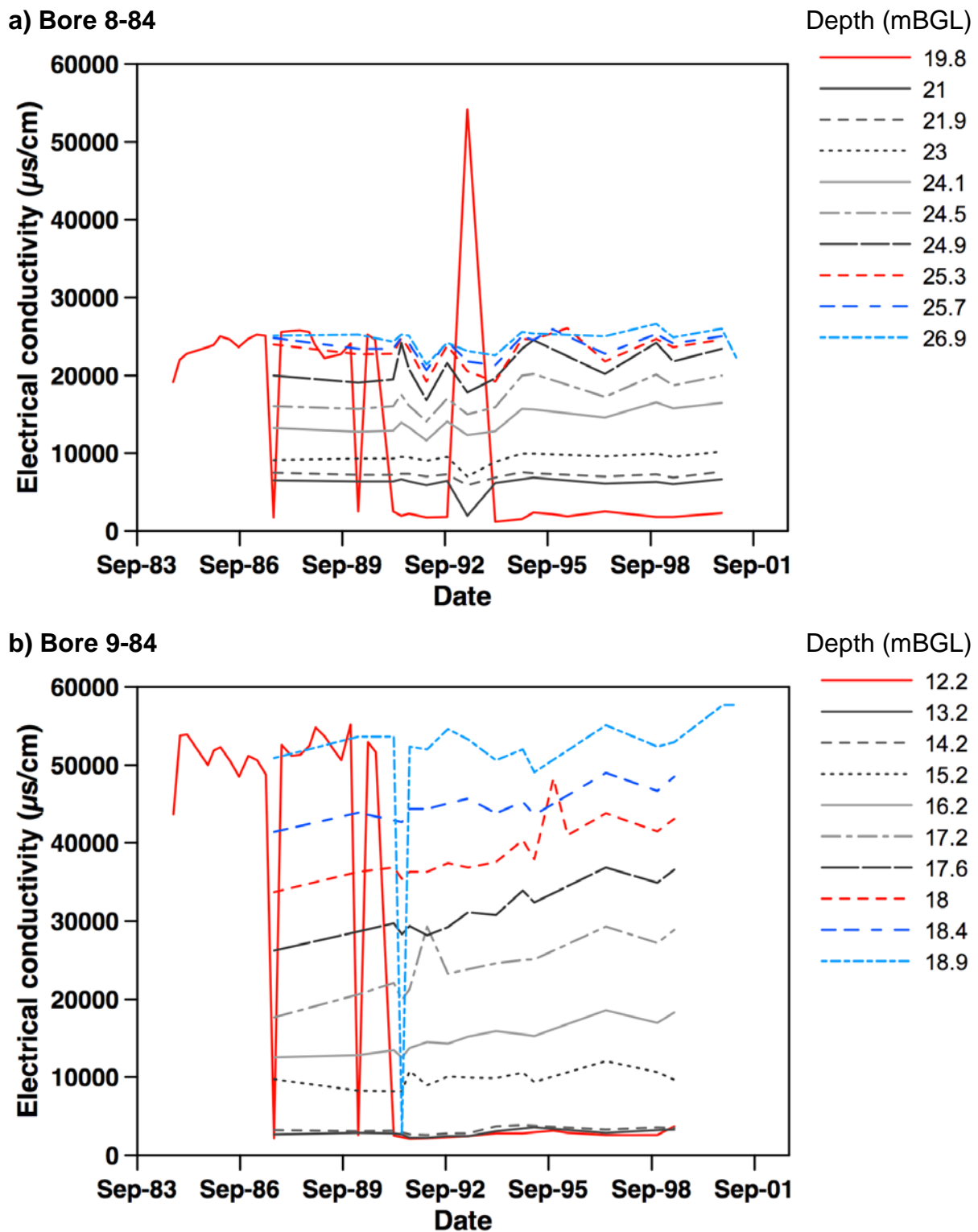
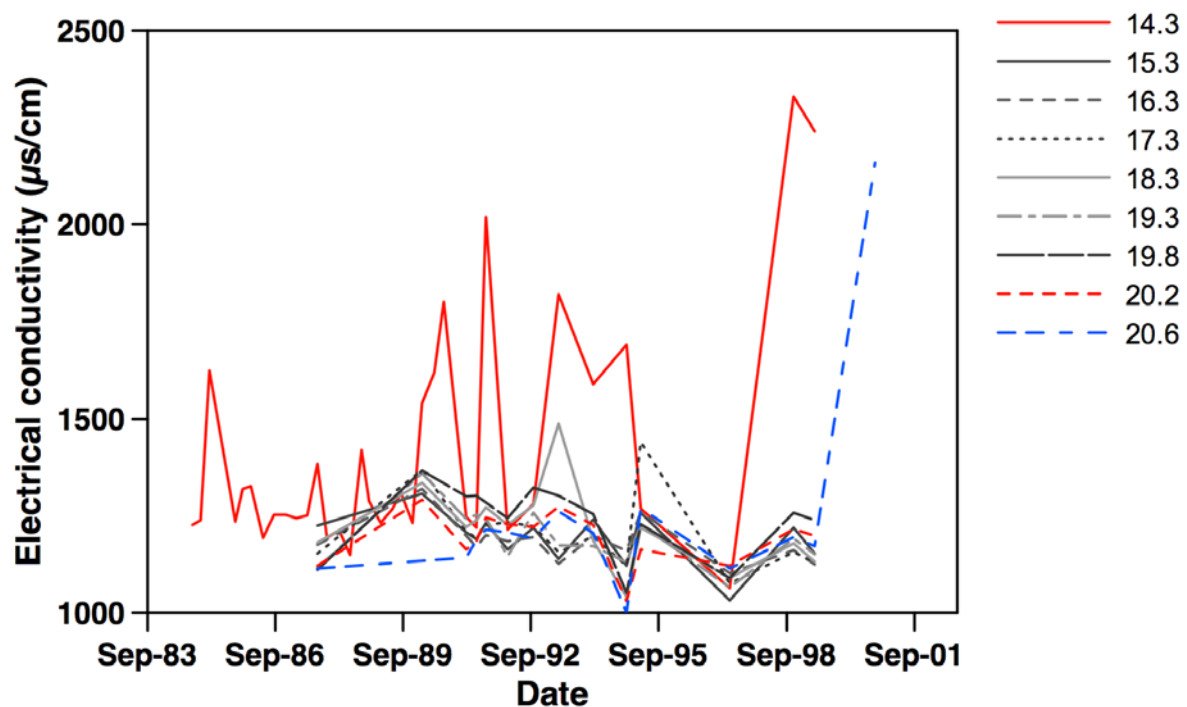


Figure 3.10 The change in salinity over time at different depths in the Lake Clifton multiport bores: a) 8-84, and b) 9-84

a) Bore 10-84



b) Bore 11-84

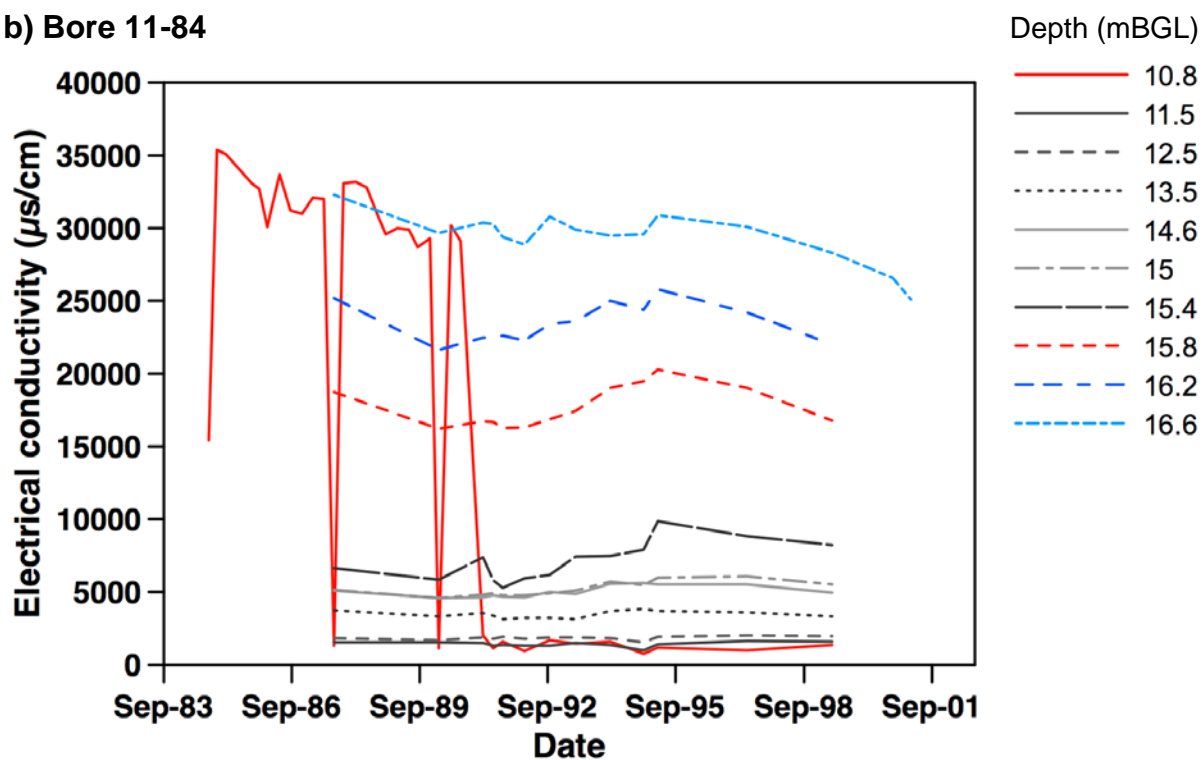
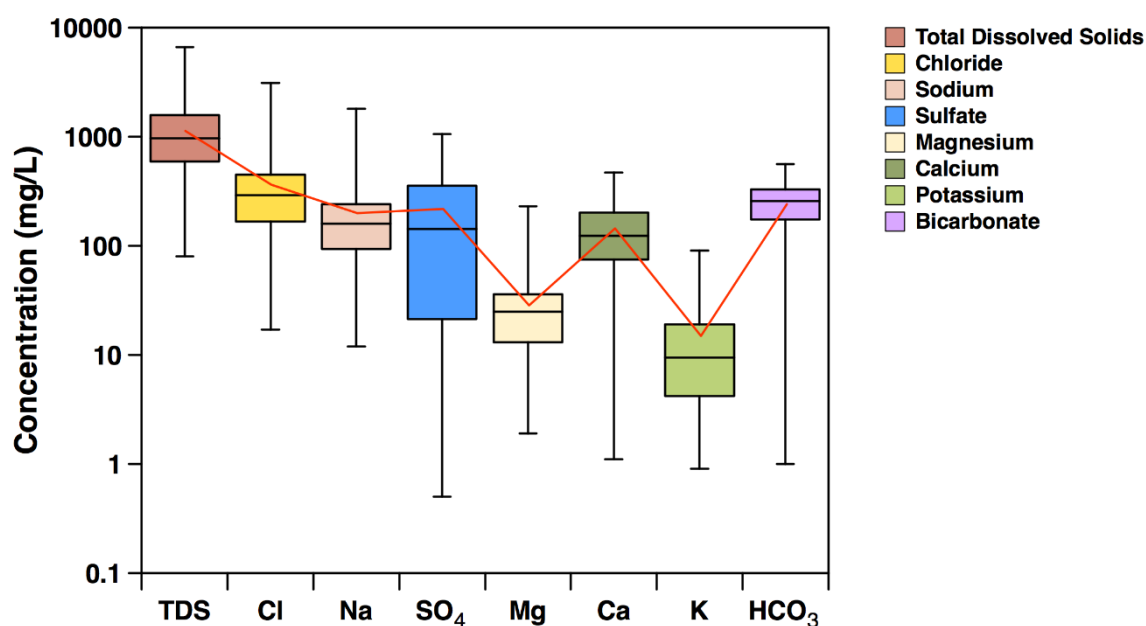


Figure 3.11 The change in salinity over time at different depths in the Lake Clifton multipoint bores: a) 10-84, and b) 11-84

3.3 Regional groundwater sampling

3.3.1 Total dissolved solids and major ions

Similar to the licensee data, the median TDS of groundwater samples was about 1000mg/L. TDS ranged from about 100 to nearly 6000mg/L (Figure 3.12, Table 3.3). The highest concentrations of TDS were located in bores drilled into the saltwater interface, between the hypersaline groundwater beneath Lake Preston and the overlying fresher aquifer. Groundwater recharges mainly in the Bassendean Sand and moves along a flow path from east to west through the Spearwood Dunes to the outcropping basal marine and lacustrine sediments of the Tamala Limestone on the coastal plain. TDS was lowest in the Bassendean Sand with a median TDS of 160mg/L, although this increased to 450mg/L at depth (Figure 3.13, Table 3.4, Appendix D). The median salinity of groundwater increased to about 400mg/L in the Spearwood Dunes. The median salinity was highest in the Tamala Limestone at 1100mg/L, and the median salinity increased with depth to 1600mg/L at the base of the aquifer (Figure 3.13, Table 3.4, Appendix D). The highest concentrations of TDS were along the western margins of the aquifer (Figure 3.14).



Note: The plots show the median, 25th and 75th percentiles in the shaded boxes, and the lines represent the 5th and 95th percentiles. The red solid line is the average concentration.

Figure 3.12 Concentration of total dissolved solids and major ions from the regional groundwater sampling

Table 3.3 Summary statistics for laboratory analyses of groundwater samples from all bores

Parameter & unit	Number of samples	Number of samples above LoR	Average	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Acidity, as CaCO ₃ (mg/L)	109	109	13	10	10	2	55	6	20
Alkalinity, total (mg/L)	109	109	210	213	95	3	459	133	297
Aluminium (µg/L)	109	77	96	9	453	5	3 900	5	46
Antimony (µg/L)	68	17	0.2	0.2	0.2	0.1	0.7	0.1	0.3
Arsenic (µg/L)	109	54	3.9	2.0	6.7	1.0	43.0	1.3	4.0
Atrazine ^a (µg/L)	68	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Barium (µg/L)	109	109	191	100	281	11	1 800	59	200
Beryllium (µg/L)	109	12	0.2	0.2	0.1	0.1	0.2	0.1	0.2
Bicarbonate (mg/L)	109	109	256	259	115	4	559	161	362
Bismuth (µg/L)	109	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Boron (µg/L)	109	108	122	60	159	8	770	27	160
Bromide (µg/L)	109	109	1 159	910	1 218	120	9 300	439	1470
Cadmium (µg/L)	109	6	0.2	0.2	0.1	0.1	0.3	0.1	0.2
Calcium (mg/L)	109	109	157.7	137.0	107.4	2.8	470.0	71.6	249.4
Carbonate (mg/L)	109	0	<1	<1	<1	<1	<1	<1	<1
Chloride (mg/L)	109	109	393	317	386	20	2 790	147	538
Chromium (µg/L)	109	63	1.9	1.3	1.4	0.5	5.7	0.6	3.1
Cobalt (µg/L)	109	27	0.3	0.2	0.3	0.1	1.4	0.1	0.4
Copper (µg/L)	109	79	1.6	0.5	5.8	0.1	51.0	0.3	1.1
Dissolved organic carbon (mg/L)	109	105	13	9	13	2	98	4	19

(continued)

Table 3.3 continued

Parameter & unit	Number of samples	Number of samples above LoR	Average	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Electrical conductivity (µS/cm)	109	109	1 976	1 700	1 422	140	9 930	966	2 844
Fluoride (µg/L)	109	95	139	100	111	60	760	70	170
Gallium (µg/L)	68	8	0.3	0.2	0.2	0.1	0.7	0.1	0.3
Hardness, total (mg/L)	109	109	519	460	342	18	1500	233	767
Hydroxide (mg/L)	109	0	<1	<1	<1	<1	<1	<1	<1
Iron (µg/L)	109	107	2 091	770	3 439	5	23 000	104	3 510
Lanthanum (µg/L)	68	37	0.8	0.4	0.9	0.1	3.6	0.2	1.2
Lead (µg/L)	109	25	0.4	0.3	0.5	0.1	2.4	0.1	0.5
Lithium (µg/L)	109	109	3.2	2.1	3.8	0.2	27.0	1.1	4.5
Magnesium (mg/L)	109	109	31	25	26	2	189	13	41
Manganese (µg/L)	109	108	58.9	39.5	60.0	0.8	350.0	12.2	96.9
Mercury (µg/L)	109	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Metalaxyl ^a (µg/L)	68	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Methyl isothiocyanate ^a (µg/L)	68	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Metolachlor ^a (µg/L)	68	0	<1	<1	<1	<1	<1	<1	<1
Molybdenum (µg/L)	68	9	2	2	3	1	9	1	2
Nickel (µg/L)	109	6	1	1	0	1	1	1	1
Nitrogen, total (µg/L)	109	109	2 745	940	5 028	120	31 000	443	3 100
Nitrogen, ammonia (µg/L)	109	97	435	340	538	10	4 400	79	591
Nitrogen, nitrate (µg/L)	109	57	3 203	220	5 990	10	28 000	30	4 810

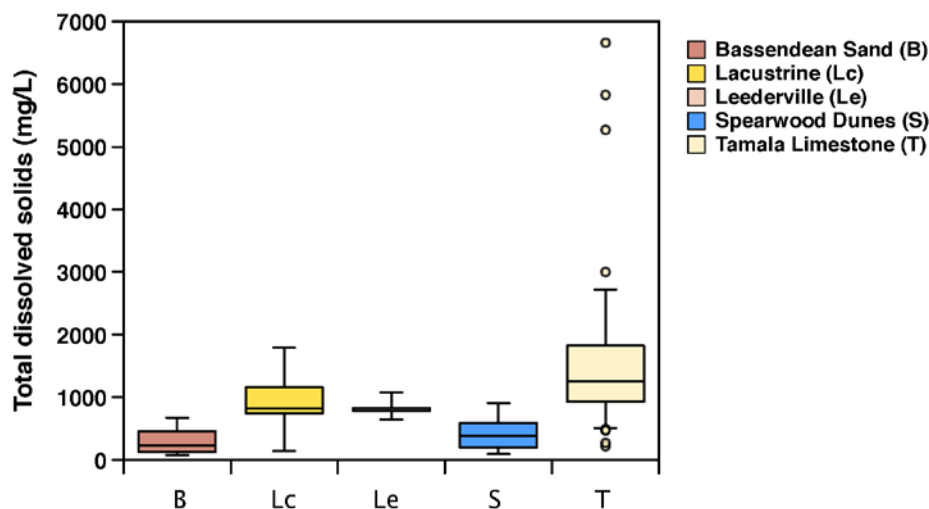
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Table 3.3 continued

Parameter & unit	Number of samples	Number of samples above LoR	Average	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Nitrogen, nitrite (µg/L)	109	32	68	35	73	10	230	10	141
Oxidised nitrogen, (µg/L)	109	70	2 643	150	5 544	10	28 000	20	3 850
pH	109	109	7.5	7.6	0.4	5.4	8.1	7.3	7.8
Phosphorus, soluble reactive (µg/L)	109	53	32	20	47	10	320	10	40
Phosphorus, total (µg/L)	109	81	50	32	84	10	600	16	52
Potassium (mg/L)	109	109	16	11	17	2	82	4	21
Selenium (µg/L)	109	14	2	2	2	1	6	1	3
Silica, from silicon (mg/L)	109	109	15	14	6	6	46	10	20
Silver (µg/L)	109	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sodium (mg/L)	109	109	213	167	219	15	1 570	93	275
Sulfate (from sulfur) (mg/L)	109	109	247	181	260	1	1 060	21	431
TDS by gravimetry (mg/L)	41	41	1 351	1 100	904	130	5 100	644	2 000
TDS by summation (mg/L)	109	109	1 191	990	892	73	5 800	508	1 800
Thallium (µg/L)	68	7	0.2	0.1	0.1	0.1	0.3	0.1	0.3
Tin (µg/L)	68	7	0.6	0.3	0.6	0.1	1.8	0.2	0.8
Titanium (µg/L)	68	8	7	4	7	2	22	3	10
Uranium (µg/L)	109	54	2.2	0.6	4.4	0.1	24.0	0.1	3.3
Vanadium (µg/L)	109	97	4.0	2.2	5.3	0.1	33.0	0.6	6.4
Zinc (µg/L)	109	105	23	12	69	2	700	6	20

LoR = limit of reporting; CaCO₃ = calcium carbonate; TDS = total dissolved solids

a Organic compound



Note: The plots show the median, 25th and 75th percentiles in the shaded boxes, and the lines represent the 5th and 95th percentiles. The circles are outliers greater than the 95th or less than the 5th percentiles.

Figure 3.13 Comparison of total dissolved solids in groundwater samples from the surficial geology units

Table 3.4 Median values for the major ions and nutrients in the surficial geology units

Geology unit	Total dissolved solids (mg/L)	pH	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Nitrogen, total (µg/L)	Oxidised nitrogen (µg/L)	Nitrogen, ammonia (µg/L)	Phosphorus, total (µg/L)	Phosphorus, soluble reactive (µg/L)
Bassendean Sand	150	5.9	14	6	34	2	34	32	17	2250	15	455	60	41
Bassendean Sand (Deep)	450	7.2	40	9	59	4	107	120	13	1500	60	560	54	50
Bassendean Sand (Total)	155	6.6	20	6	38	3	53	48	14	1550	25	508	57	46
Spearwood Dunes	370	7.2	34	10	77	4	74	130	26	773	9	240	16	20
Spearwood Dunes (Deep)	555	7.3	46	12	105	4	153	196	4	780	9	400	19	13
Spearwood Dunes (Total)	380	7.3	34	10	79	4	96	137	21	773	9	280	16	20
Tamala Limestone	1105	7.6	168	30	165	17	269	309	311	1104	45	233	20	5
Tamala Limestone (Deep)	1610	7.5	180	35	268	11	395	476	210	907	8	345	32	13
Tamala Limestone (Total)	1120	7.6	170	31	174	15	274	332	309	1075	33	237	25	8
Lacustrine	640	7.2	106	12	84	4	205	140	9	1483	8	390	27	22
Lacustrine (Lake Preston)	1338	7.7	140	38	284	22	373	487	165	3070	2690	129	37	9
Lacustrine (Total)	815	7.6	120	19	110	5	319	188	75	1483	17	295	31	12
Leederville	780	7.9	86	21	165	5	323	306	7	480	5	420	25	10
Safety Bay Sand	1905	7.7	142	61	456	15	443	793	203	545	13	320	11	5
Surface	420	7.5	24	19	98	14	88	169	44	2400	490	280	280	110

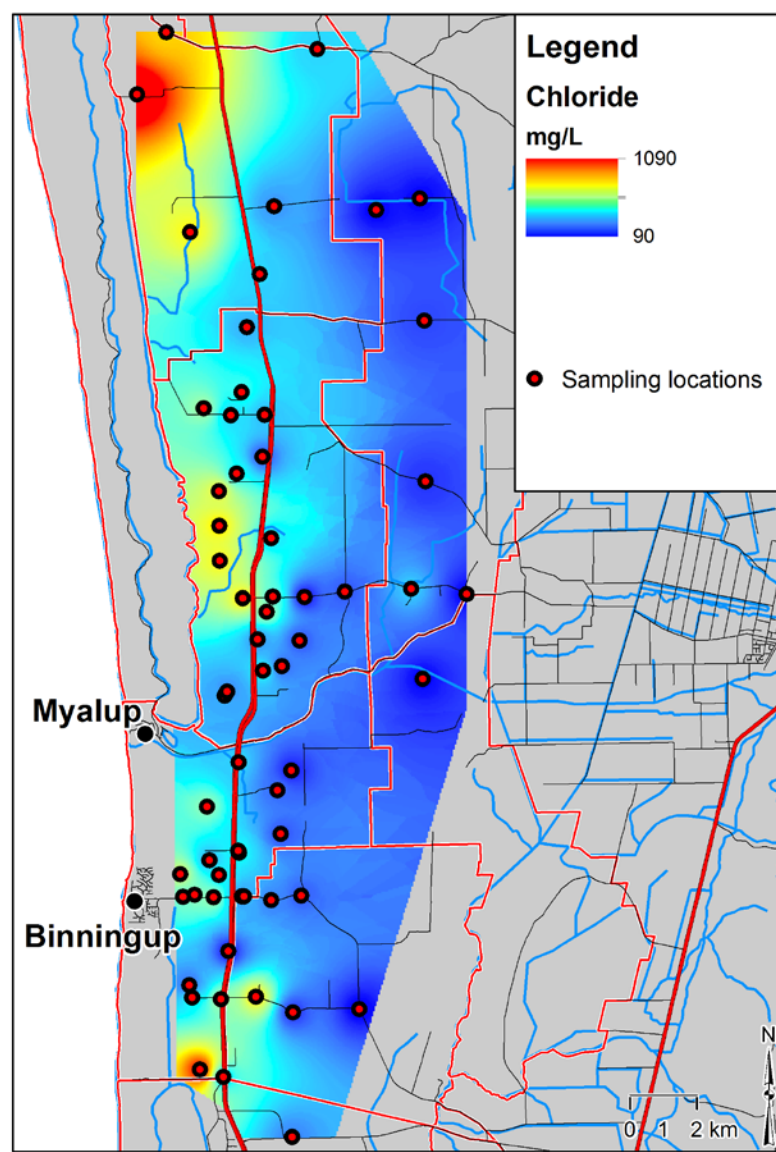
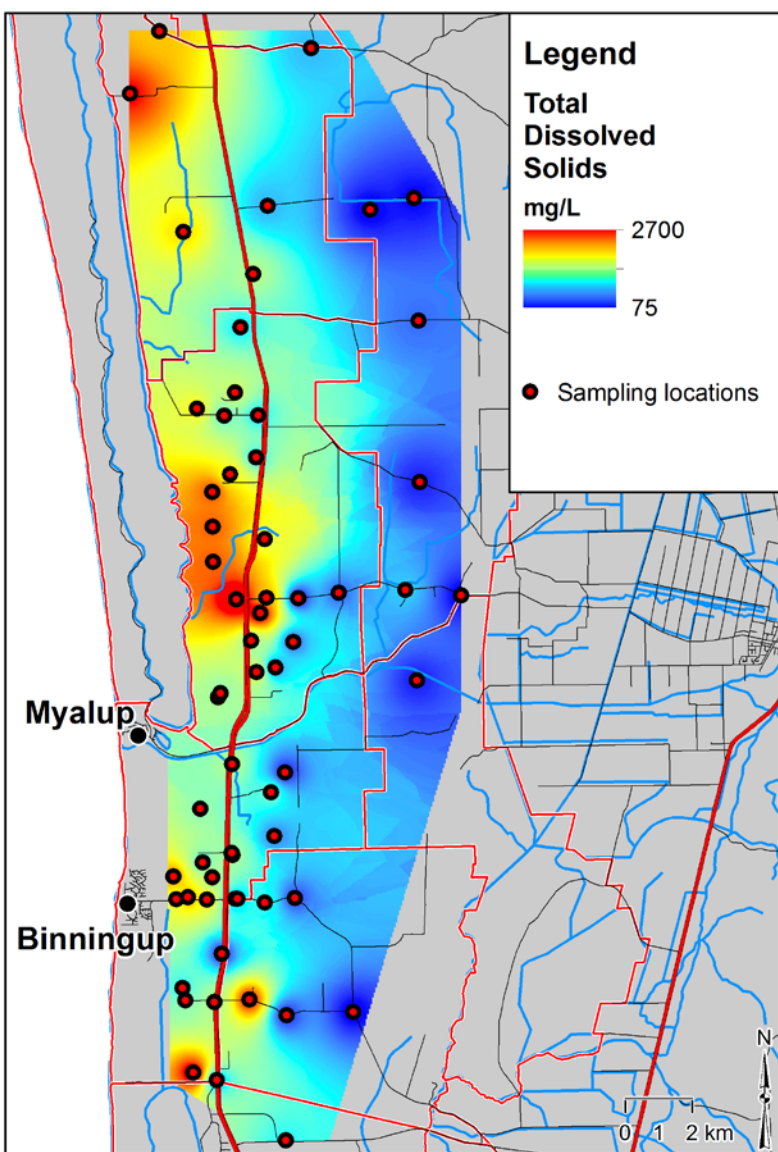


Figure 3.14 Average concentration of total dissolved solids (left) and chloride (right) from regional groundwater sampling

Chloride was the dominant anion with a median concentration of about 320mg/L, which was higher than the median chloride concentration for the licensee data. The chloride concentrations ranged from 20 to nearly 2800mg/L at the saltwater interface, but only reached a maximum of 1100mg/L in the farm bores (Figure 3.12, Table 3.3). Chloride increased in concentration along the groundwater flow path from a median of 50mg/L in the Bassendean Sand to 140mg/L in the Spearwood Dunes to 330mg/L in the Tamala Limestone (Table 3.4, Appendix D). Chloride concentrations were highest in the low-lying saline wetlands next to Lake Preston (Figure 3.14 right).

Bicarbonate was overall the next most dominant anion with a median concentration of 260mg/L and a range of 4 to 560mg/L (Figure 3.12, Table 3.3). However, bicarbonate was the dominant anion in the Bassendean Sand with a median of 50mg/L, increasing to 100mg/L in the Spearwood Dunes. The highest concentrations of bicarbonate occurred in the Tamala Limestone with a median concentration of about 280mg/L (Table 3.4, Appendix D). The areas with the highest concentrations of bicarbonate were on the western margins in the discharge areas (Figure 3.15 left). Bicarbonate also showed enrichment relative to seawater (Figure 3.16).

Sulfate had a median concentration of 180mg/L, which was higher than the median concentration for the licensee data. Sulfate concentrations ranged from 1 to 1000mg/L. The lowest sulfate concentrations were in Bassendean Sand and Spearwood Dunes at about 20mg/L, and in some locations sulfate was depleted relative to seawater (Figure 3.16). The highest sulfate concentrations were found in the Tamala Limestone with a median of about 310mg/L, making it the second-most dominant anion in that geological unit (Table 3.4, Appendix D). The areas with the highest concentrations occurred south-east of Lake Preston extending to the wetlands at the base of the Spearwood Dunes in the east (Figure 3.15 right). Sulfate was enriched compared to seawater in the Tamala Limestone (Figure 3.16).

Sodium overall was the dominant cation with a median concentration of about 170mg/L and a range of 15 to nearly 1600mg/L (Figure 3.12, Table 3.3). Like chloride, sodium increased along the groundwater flow path from 40mg/L in the Bassendean Sand to 80mg/L in the Spearwood Dunes and 175mg/L in the Tamala Limestone (Table 3.4, Appendix D). The distribution of groundwater concentrations for chloride and sodium followed similar spatial trends to TDS (Figure 3.14 left, Figure 3.14 right and Figure 3.17 left). Sodium did not show any enrichment compared to seawater (Figure 3.16).

In general, the next most dominant cation was calcium with a median concentration of 140mg/L and a range of 3 to 470mg/L (Figure 3.12, Table 3.3). Calcium had a median concentration of 20mg/L in the Bassendean Sand, increasing to 30mg/L in the Spearwood Dunes and 170mg/L in the Tamala Limestone (Table 3.4, Appendix D). This pattern is evident in Figure 3.17 (right) with calcium at the greatest concentrations to the south-east of Lake Preston and east of the Forrest Highway. Calcium showed considerable enrichment relative to seawater (Figure 3.16).

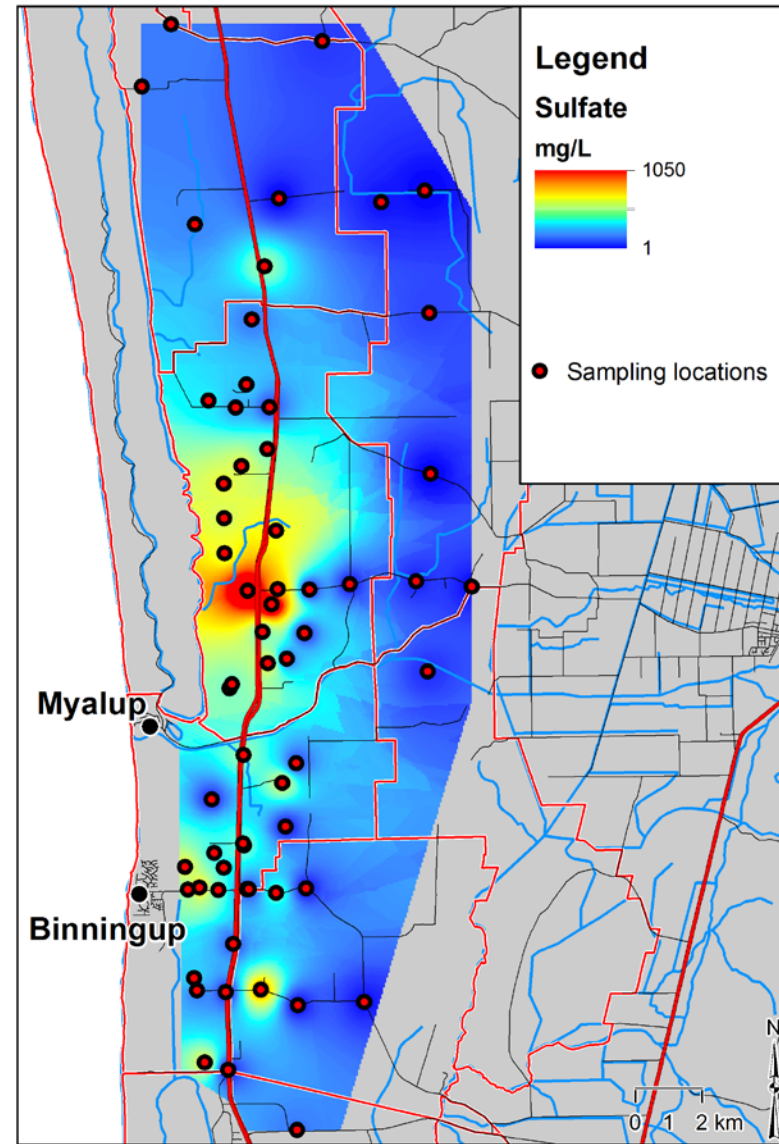
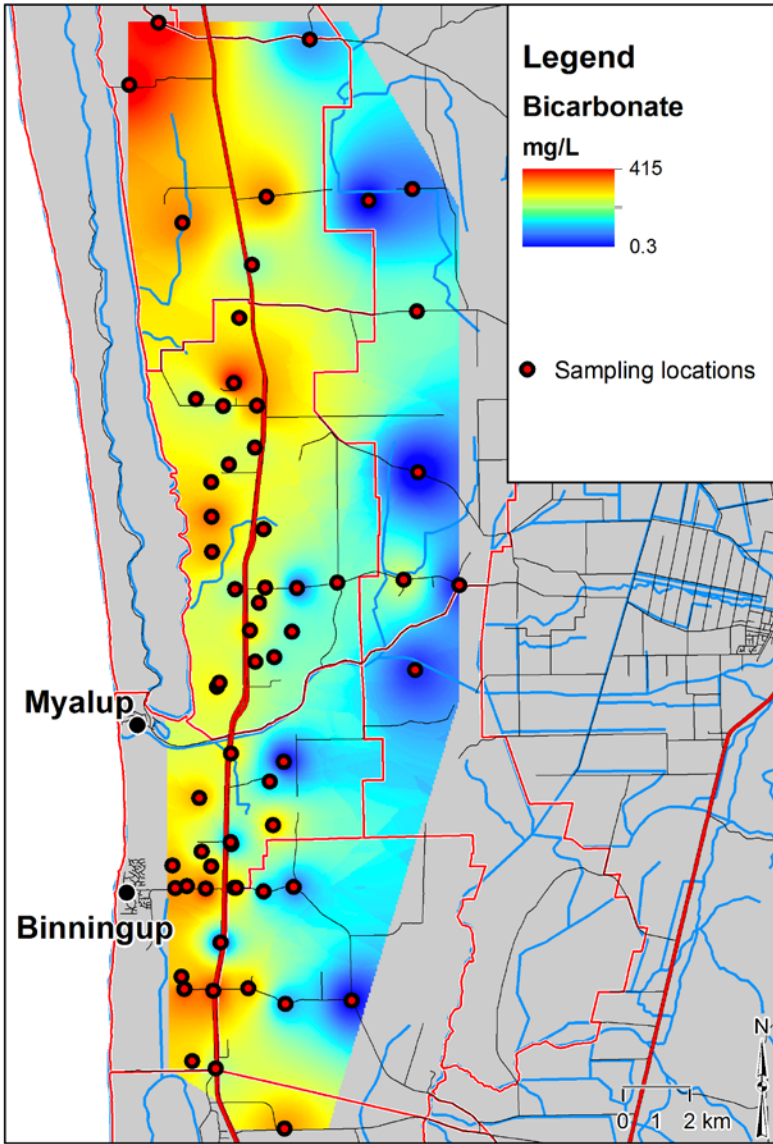
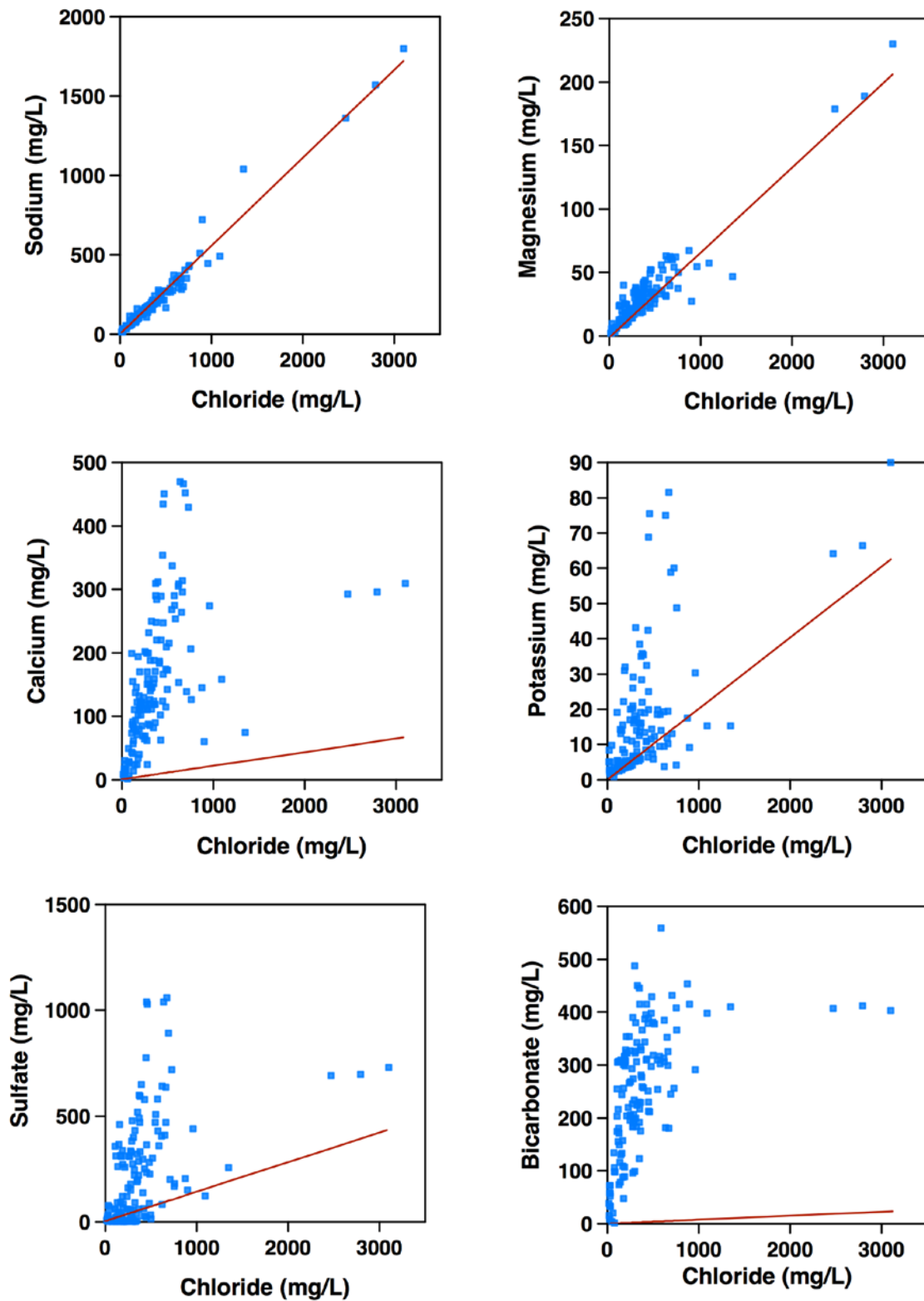


Figure 3.15 Average concentration of bicarbonate (left) and sulfate (right) from regional groundwater sampling



Note: The red line represents the seawater dilution line.

Figure 3.16 Concentration of major ions compared with chloride from the groundwater sampling

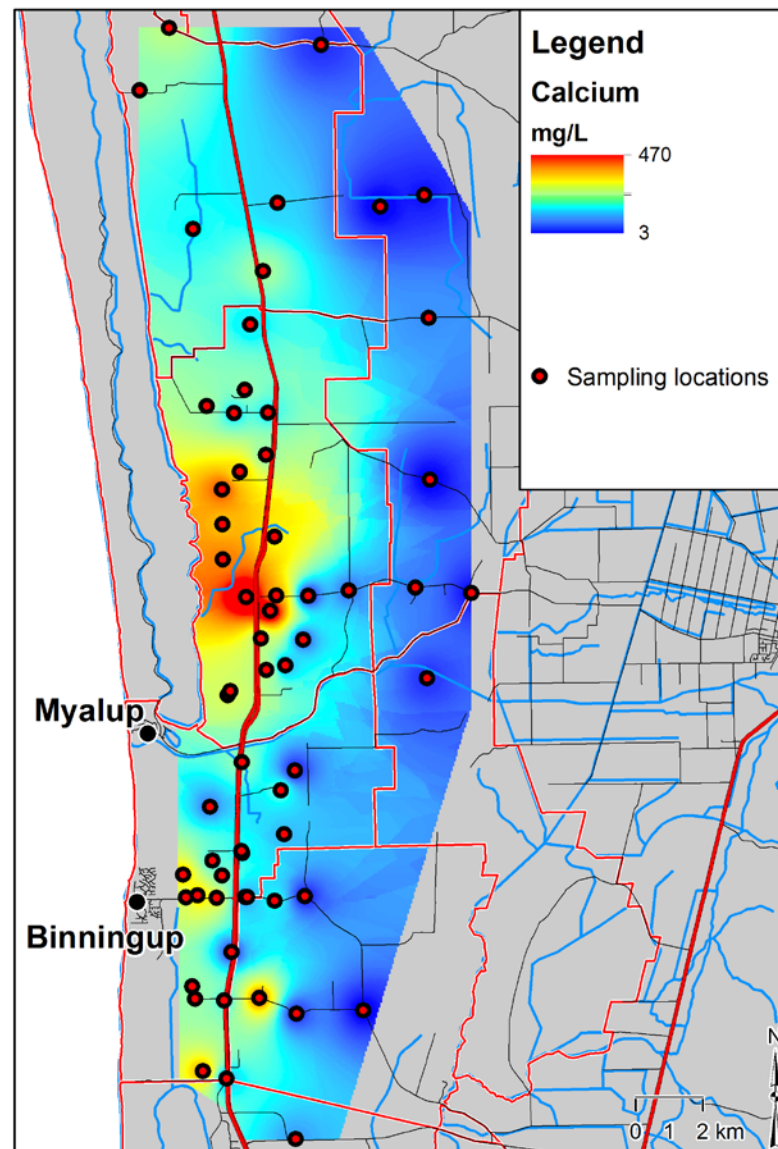
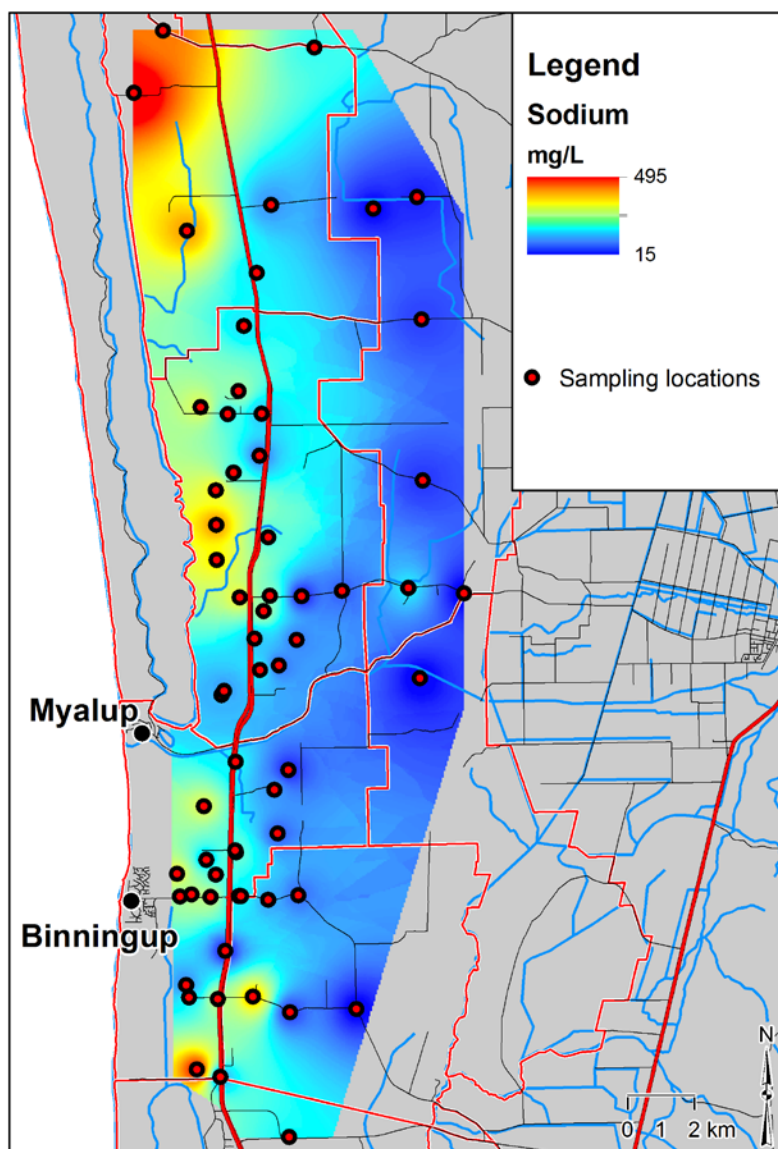


Figure 3.17 Average concentration of sodium (left) and calcium (right) from regional groundwater sampling

Magnesium had a median concentration of 25mg/L and ranged from 2 to 190mg/L (Figure 3.12, Table 3.3). Magnesium had concentrations of about 10mg/L in the Bassendean Sand and Spearwood Dunes, and 30mg/L in the Tamala Limestone (Table 3.4, Appendix D). The highest concentrations of magnesium were at the south-east margin of Lake Preston and near Lake Clifton and the Leschenault Inlet (Figure 3.18 right). The lowest concentrations were in the Bassendean Sand. Magnesium did not show any enrichment compared to seawater (Figure 3.16).

Potassium had a median concentration of 10mg/L and ranged from 2 to 80mg/L (Figure 3.12, Table 3.3). The concentration of potassium was about 4mg/L in the Bassendean Sand and Spearwood Dunes. Potassium increased in concentration to 15mg/L in the Tamala Limestone (Table 3.4, Appendix D). The highest concentrations of potassium were found around the intersection of Forestry Road and Forrest Highway (Figure 3.18 right). Potassium showed enrichment relative to seawater (Figure 3.16).

The relative proportions of major ions in the groundwater are illustrated in a Piper plot (Figure 3.19). The chemical composition of groundwater in the Myalup region was highly variable, particularly for the anions. The groundwater showed enrichment of bicarbonate relative to seawater. However, the groundwater showed enrichment as well as depletion of sulfate relative to seawater (Figure 3.16, Figure 3.19). The Leederville aquifer showed depletion of sulfate relative to seawater. With the cations, the Myalup aquifer mainly showed enrichment of calcium relative to seawater, and enrichment of sodium in some areas.

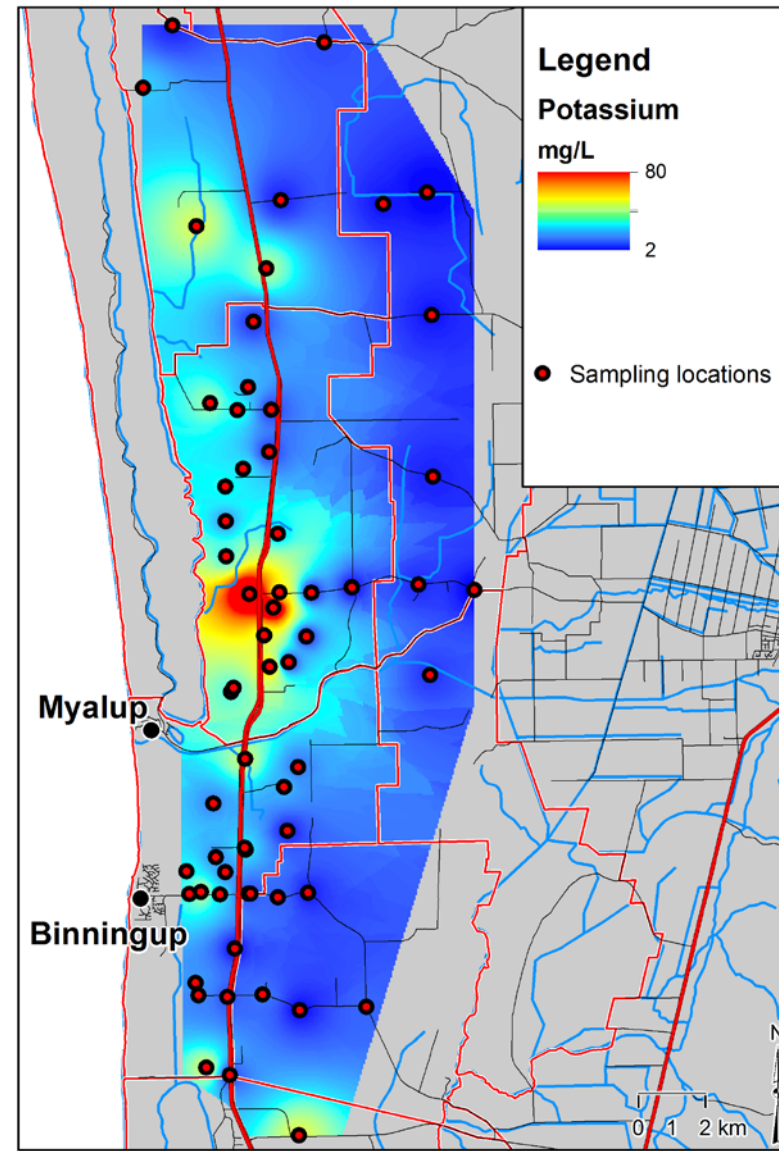
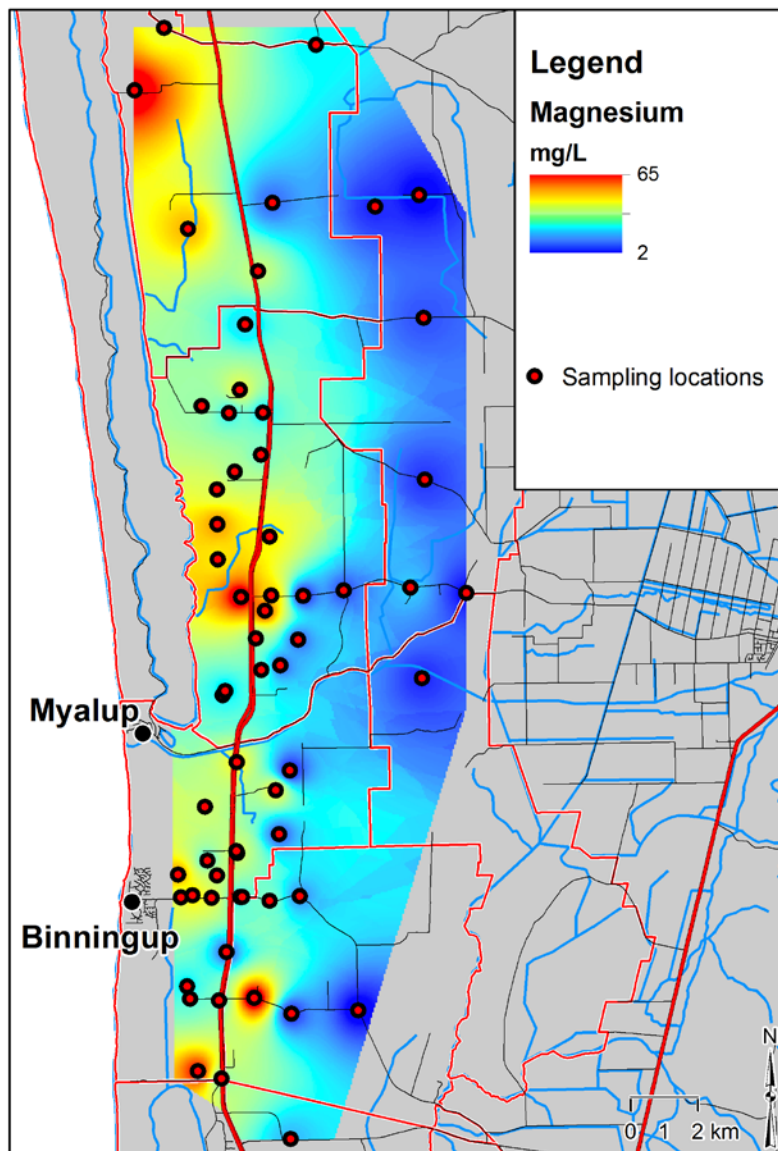


Figure 3.18 Average concentration of magnesium (left) and potassium (right) from regional groundwater sampling

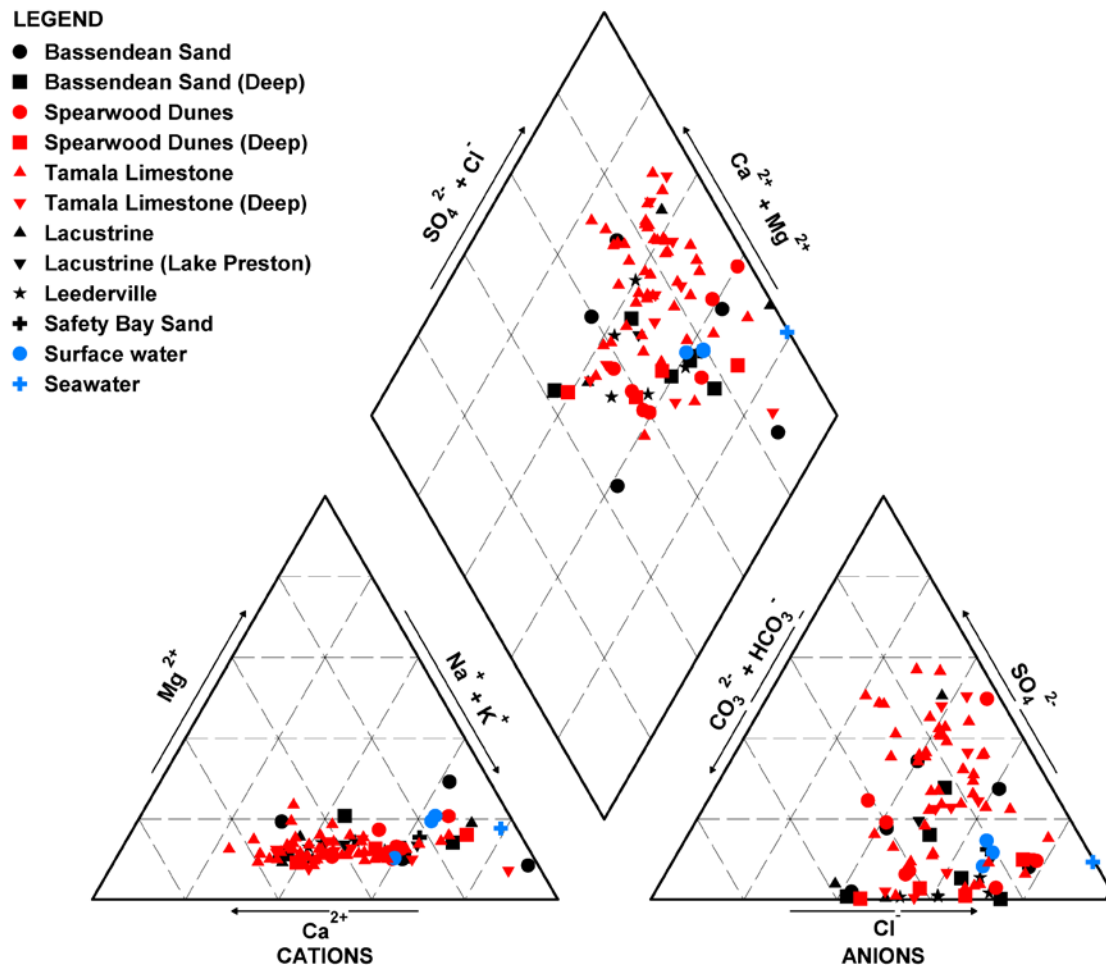


Figure 3.19 Piper diagram of major ions from the regional groundwater sampling

Along transects that approximated flow paths, the groundwater changed in chemical composition with highly variable water types (Figure 3.20, Table 3.5). Along the transect E, groundwater had Na-Ca-Cl-HCO₃ composition in the Bassendean Sand and Spearwood Dunes, but changed to a Ca-Na-SO₄-Cl type water in the Tamala Limestone and more than doubled in salinity from less than 500mg/L TDS to more than 1300mg/L TDS. Near Lake Preston, the groundwater changed to a Na-Cl type water and increased in salinity to more than 6000mg/L (Figure 3.13, Table 3.5). In transect F, the Spearwood Dunes contained a Ca-Na-HCO₃-Cl type water, with TDS around 500mg/L. This changed to a Ca-Na-SO₄-Cl type water at Myalup Swamp, and salinity increased to 850mg/L. Downgradient of Myalup Swamp, groundwater increased in TDS to 1400mg/L and changed to a Na-Ca-Cl-HCO₃ type water (Figure 3.13, Table 3.5). Around Parkfield, groundwater changed in composition again to a Na-Ca-Cl-SO₄-HCO₃ type. On transect G, groundwater in the Bassendean Sand had a salinity less than 100mg/L and was a Na-Cl-SO₄-HCO₃ type water. In the Spearwood Dunes, groundwater had a salinity of 220mg/L and was a Na-Ca-Cl-HCO₃ type water. In the Tamala Limestone, salinity increased 10-fold to 2200mg/L and groundwater changed composition to a Na-Ca-Cl-SO₄ type water. Further downgradient the groundwater decreased in salinity to 900mg/L and changed composition to a Na-Ca-Cl-HCO₃ type (Figure 3.13, Table 3.5). Of note, bores G5 and G4 are in native vegetation representing natural conditions.

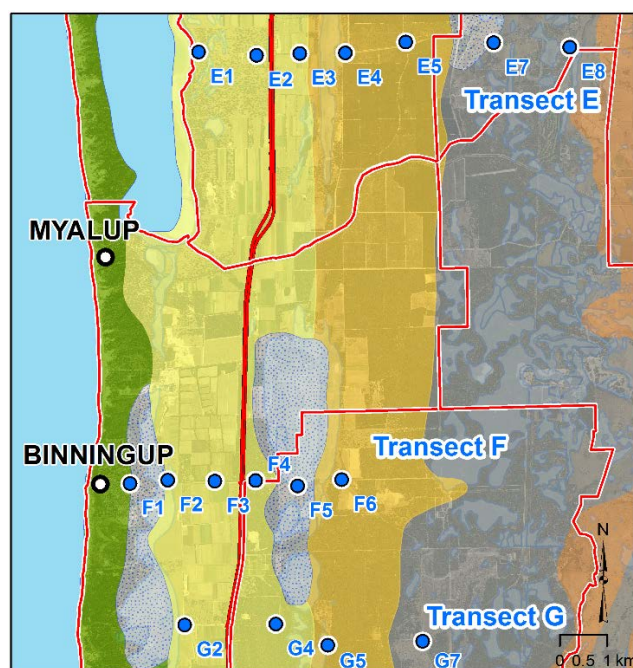
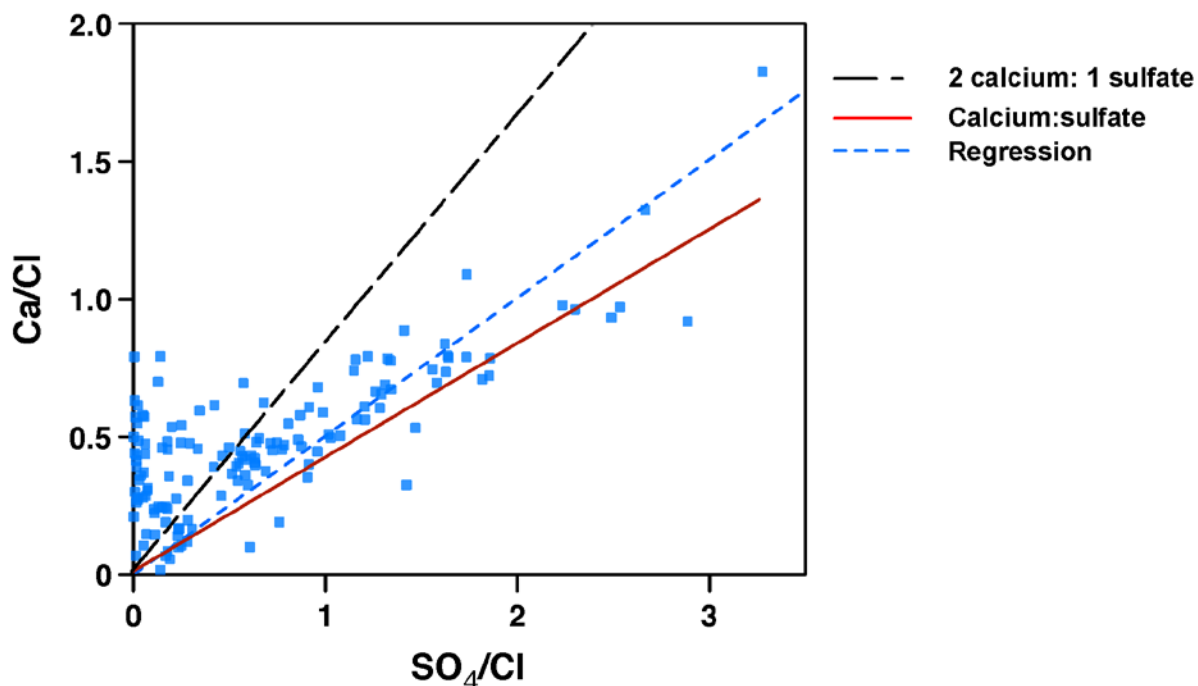


Figure 3.20 Location of groundwater transects outlined in Table 3.5

Table 3.5 Changes in water quality and type along the east–west groundwater flow paths represented by three transects

Bore	Geology	TDS	Water type
Transect E			
E8	Bassendean Sand	100	Na-Ca-Mg-Cl-HCO ₃
E7	Bassendean Sand	650	Na-Ca-Cl-HCO ₃
E5	Spearwood Dunes	455	Na-Ca-Cl-HCO ₃
E4	Spearwood Dunes	140–645	Na-Ca-Cl-HCO ₃
E3	Tamala Limestone	1300–1800	Ca-Na-SO ₄ -Cl
E2	Tamala Limestone	2700	Ca-Na-SO ₄ -Cl
E1	Tamala Limestone	6250	Na-Cl
Transect F			
F6	Spearwood Dunes	300–500	Ca-Na-HCO ₃ -Cl
F5	Lacustrine	850	Ca-Na-SO ₄ -Cl
F4	Tamala Limestone	1100	Na-Ca-Cl-HCO ₃
F3	Tamala Limestone	1400	Na-Ca-Cl-HCO ₃
F2	Tamala Limestone	1200–1500	Na-Ca-Cl-SO ₄ -HCO ₃
F1	Safety Bay Sand	1700	Na-Ca-Cl-HCO ₃
Transect G			
G7	Bassendean Sand	75	Na-Cl-SO ₄ -HCO ₃
G5	Spearwood Dunes	220	Na-Ca-Cl-HCO ₃
G4	Tamala Limestone	2200	Na-Ca-Cl-SO ₄
G2	Tamala Limestone	900	Na-Ca-Cl-HCO ₃

When the effects of evapoconcentration were corrected for by dividing the major ions by chloride, analyses of correlations between major ions showed only calcium (Ca/Cl) and sulfate (SO₄/Cl) had a statistically significant correlation ($r^2=0.67$) (Figure 3.21). The trendline between calcium (Ca/Cl) and sulfate (SO₄/Cl) was between the calcium to sulfate ratios of 1 and 2 (Section 2.1.1). Spatially, the highest concentrations of calcium and sulfate occurred in, or downgradient of, the wetlands at the base of the Spearwood Dunes (Figure 3.22).



Note: The calcium to sulfate line (red solid line) is the dissolution line for gypsum. The long-dashed black line represents the ratio of two calcium to one sulfate ion.

Figure 3.21 The relationship between calcium and sulfate, when corrected for evapoconcentration by dividing by chloride

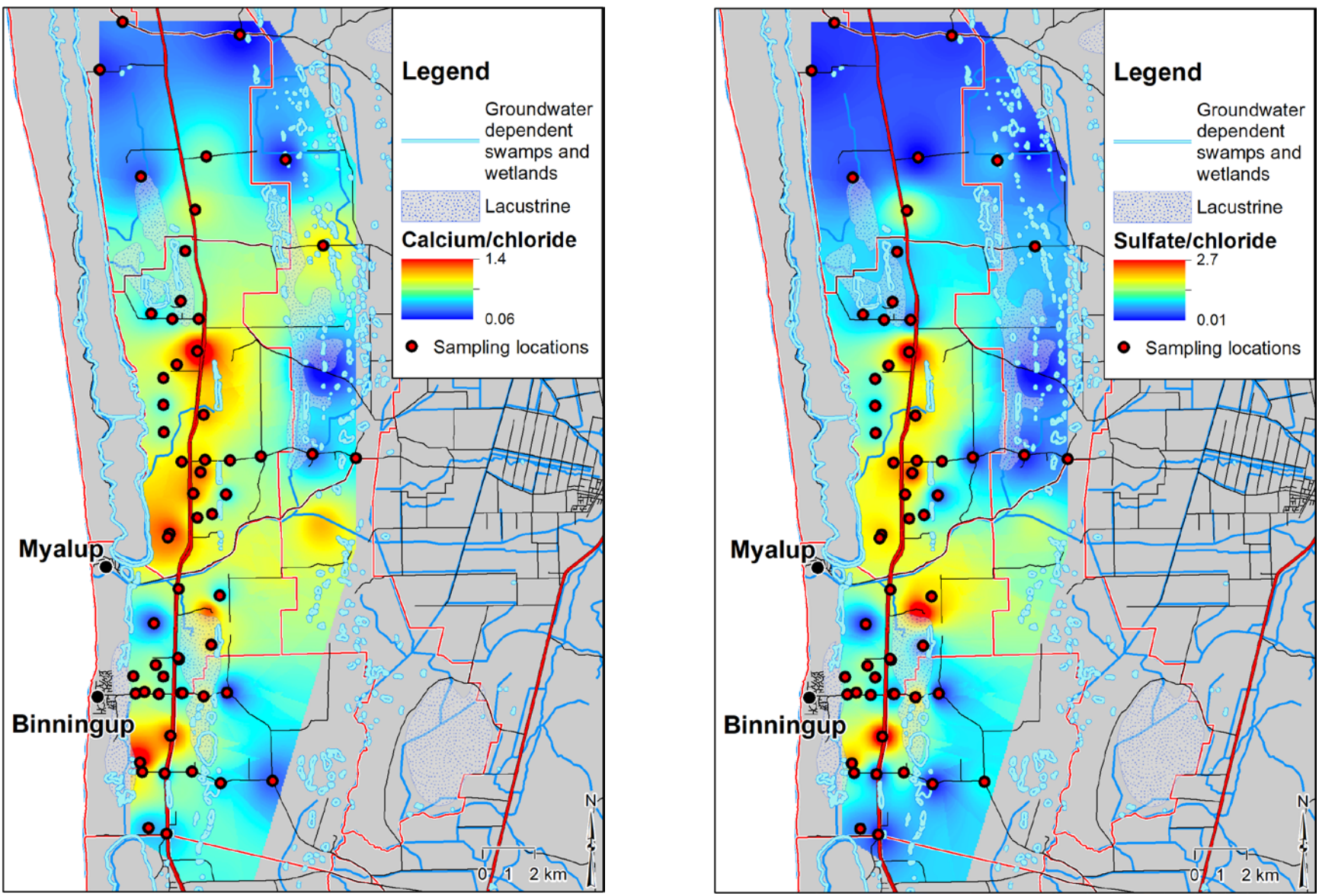
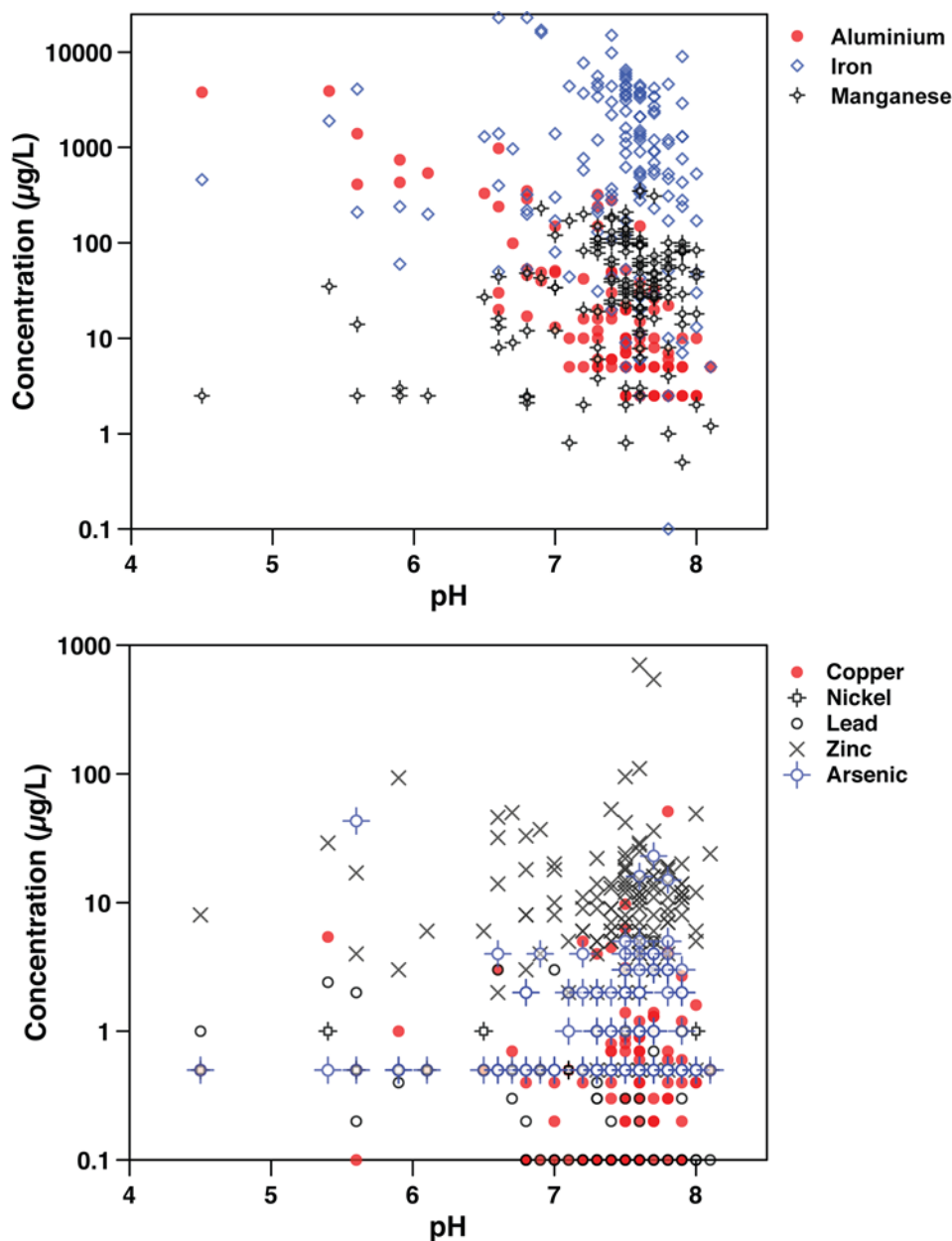


Figure 3.22 Areas of increased concentrations corrected for evapoconcentration: calcium (left) and sulfate (right)

3.3.2 Metals and minor elements

Aluminium had a median concentration of 10 µg/L and a range of 5 to 3900 µg/L, with 70% of sites having concentrations above the LoR (Table 3.3). The groundwater concentration of aluminium was controlled by pH (Figure 3.23 top). The highest aluminium concentrations were in the Bassendean Sand formation because they have the lowest buffering capacities and consequently a lower pH (Figure 3.25 right, Figure 3.24 right). About 20% of sites exceeded the ANZECC and ARMCANZ (2000) '99% aquatic ecosystem guidelines' and 10% of sites exceeded the 95% trigger value (Appendix E).



Note: The vertical axis has a log scale.

Figure 3.23 Concentration of different metals compared with pH: aluminium, iron and manganese (top) and zinc, lead, copper, nickel and arsenic (bottom)

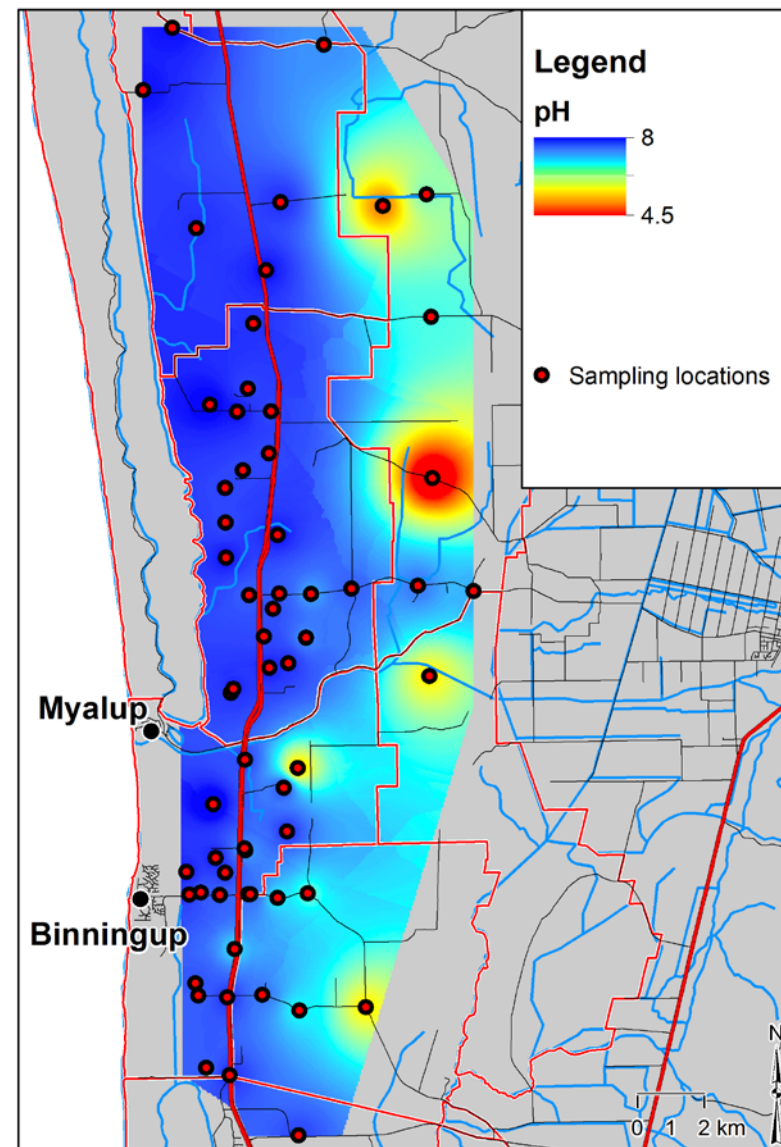
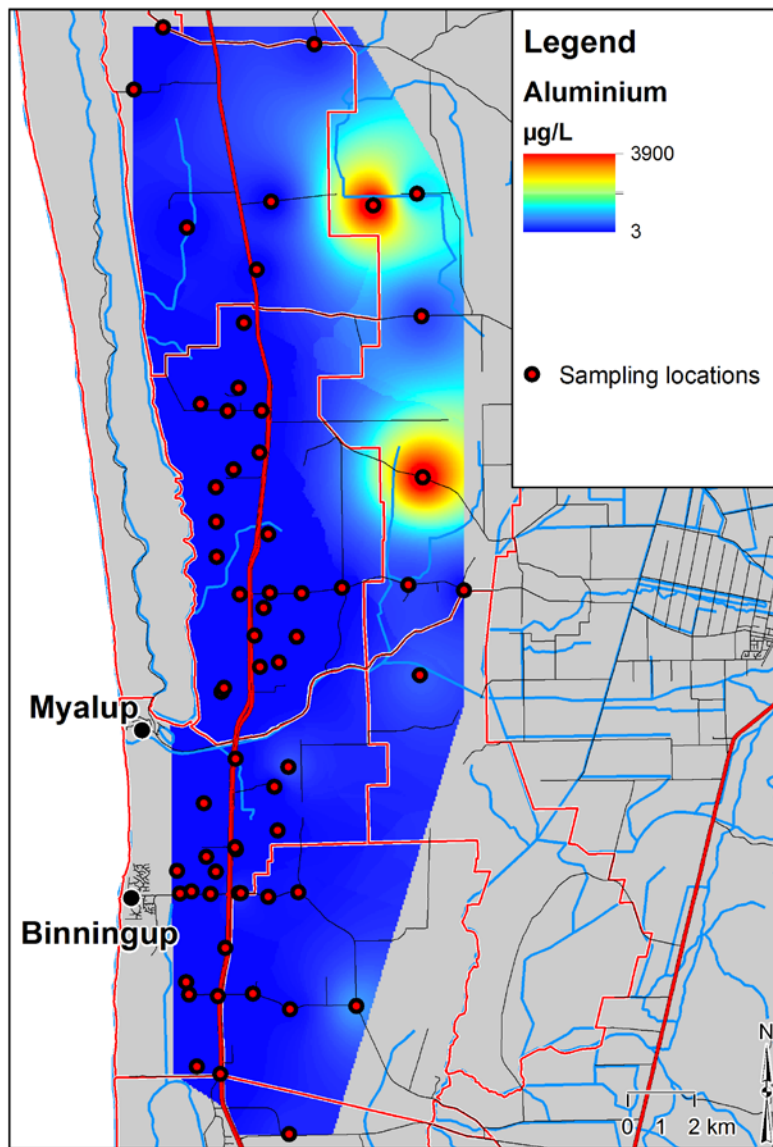


Figure 3.24 Average concentration of aluminium (left) and pH (right) from regional groundwater sampling

Iron had a median concentration of 770µg/L and a range from 5 to 23 000µg/L. Manganese had a median concentration of 40µg/L and a range from 6 to 350µg/L (Table 3.3). There was no relationship between pH and either iron or manganese (Figure 3.23 top). The highest concentrations of iron and manganese were in the southern end of the study area below Forestry Road (Figure 3.25). Groundwater in the areas with highest iron and manganese concentrations were more reducing (Appendix D) and the solubility of iron and manganese was controlled by aquifer redox conditions.

Zinc had a median concentration of 12µg/L and a range from 2 to 700µg/L (Table 3.3), with 96% of sites having concentrations above the LoR. There was no relationship between pH and zinc (Figure 3.23 bottom). Nearly all sites exceeded the ANZECC and ARMCANZ (2000) 99% aquatic ecosystem guideline trigger value, while about 70% exceeded the 95% trigger value (Appendix E). The sites that exceeded the trigger values occurred across natural and agricultural sites suggesting a natural zinc source. Zinc is also an essential nutrient and added with fertiliser, so fertiliser application may have contributed to zinc concentrations in some areas (Figure 3.26 left).

Copper had a median concentration of 0.5µg/L and ranged from 0.1 to 50µg/L (Table 3.3), with 72% of sites having concentrations above the LoR. There was no relationship between copper and pH (Figure 3.23). About 10% of sites exceeded the ANZECC and ARMCANZ (2000) 99% aquatic ecosystem guideline trigger value for copper (Appendix E). The highest concentrations occurred in the Bassendean Sand along Forestry Road at the eastern boundary of the Lake Preston South Groundwater Subarea (GWSA) (Figure 3.26 right).

The highest lead concentration was 2.4µg/L and only 23% of sites had concentrations above the LoR. Similarly, nickel had a maximum concentration of 1µg/L, with only 5% of sites having concentrations above the LoR (Table 3.3).

Arsenic had a median concentration of 2µg/L and a maximum concentration of 43µg/L, and 50% of sites had concentrations above the LoR of 1µg/L. The arsenic LoR was above the ANZECC and ARMCANZ (2000) 99% aquatic ecosystem guideline trigger value at many sites. Arsenic concentrations were highest around wetlands (Figure 3.27).

Chromium had a median concentration of 1.3µg/L and a maximum concentration of 5.7µg/L, with 58% of sites having concentrations above the LoR (Table 3.3). The chromium LoR was above the ANZECC and ARMCANZ (2000) 99% aquatic ecosystem guideline trigger value. About a third of sites exceeded the ANZECC and ARMCANZ 95% aquatic ecosystem guideline trigger value (Appendix E). These sites occurred under natural and agricultural conditions, suggesting a natural source.

Boron had a median concentration of 60µg/L and ranged from 8 to 770µg/L (Table 3.3). About a third of sites exceeded the ANZECC and ARMCANZ (2000) 99% aquatic ecosystem guidelines, and 6% of sites exceeded the 95% aquatic ecosystem guideline trigger value (Appendix E). The highest boron concentrations occurred at the south-eastern margin of Lake Preston to the Forrest Highway (Figure 3.27 right).

Fluoride had a median concentration of 100µg/L and ranged from 60 to 760µg/L. Silica had a median concentration of 14mg/L and ranged from 6 to 46mg/L in the Leederville aquifer and up to 30mg/L in the Myalup aquifer (Table 3.3). The highest fluoride concentrations occurred in the north-west and the highest silica concentrations occurred south of the Harvey River Diversion Drain (Figure 3.28).

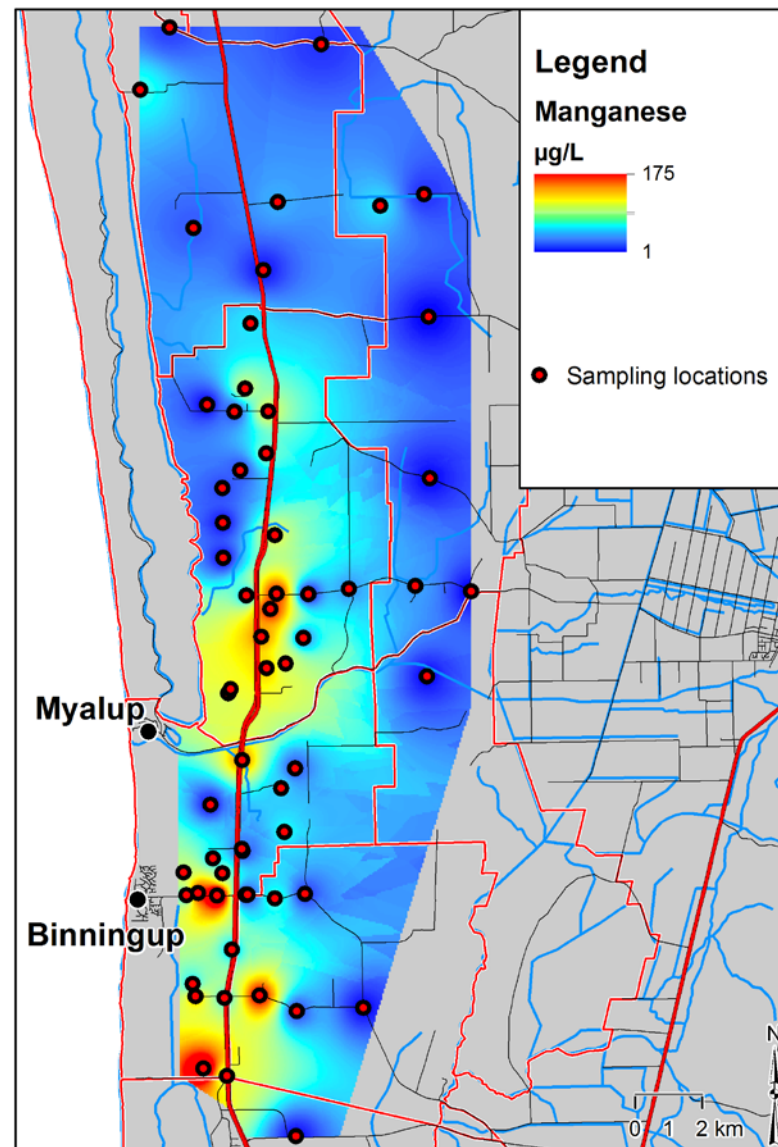
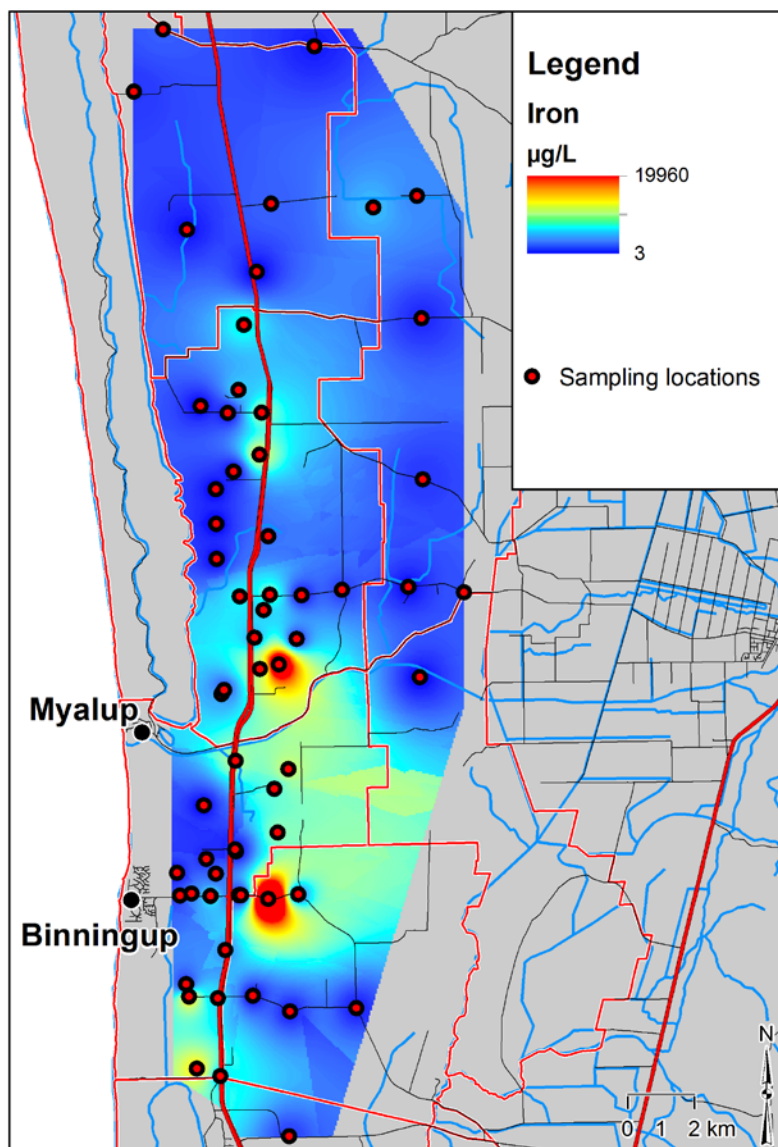


Figure 3.25 Average concentration of iron (left) and manganese (right) from regional groundwater sampling

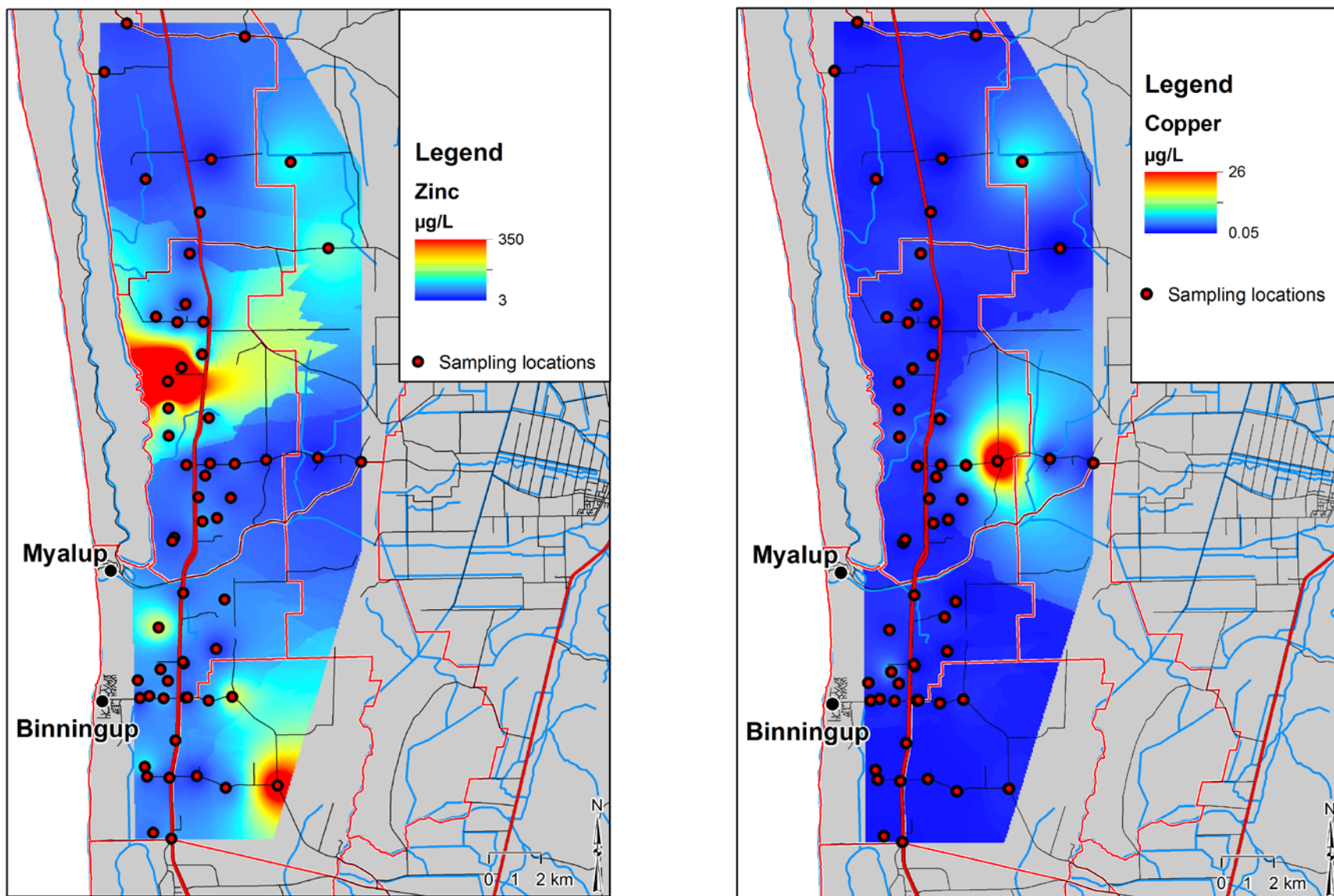


Figure 3.26 Average concentration of zinc (left) and copper (right) from regional groundwater sampling

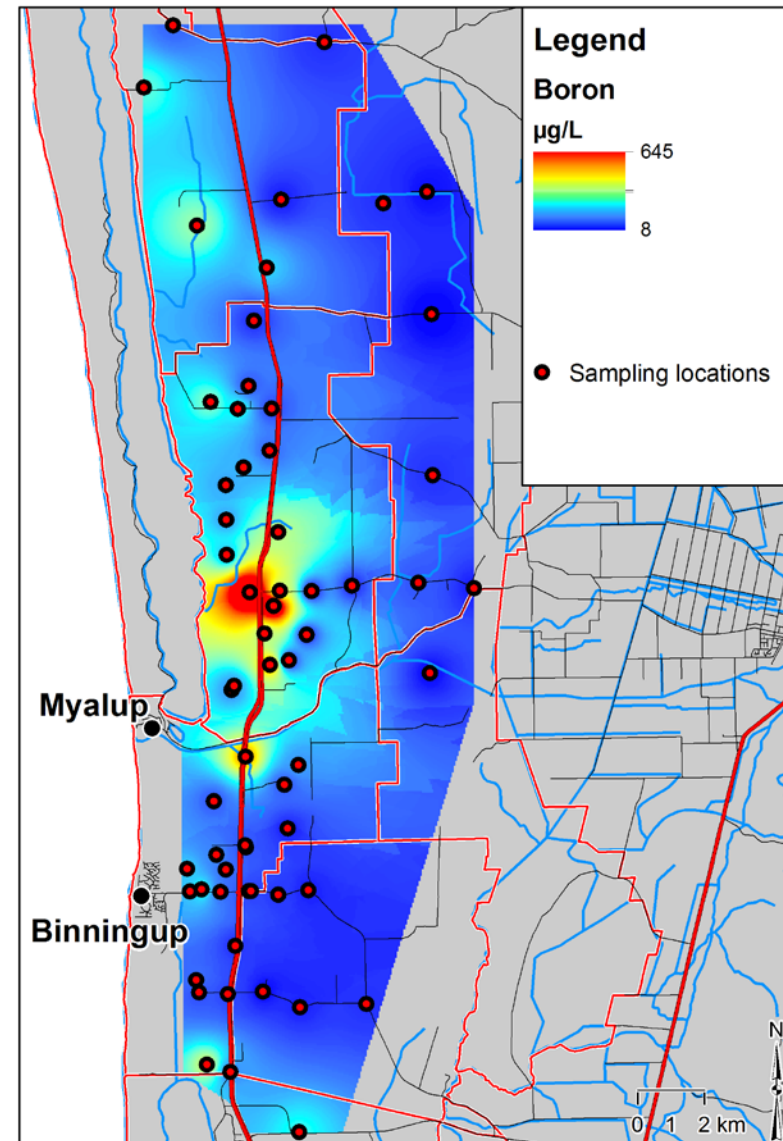
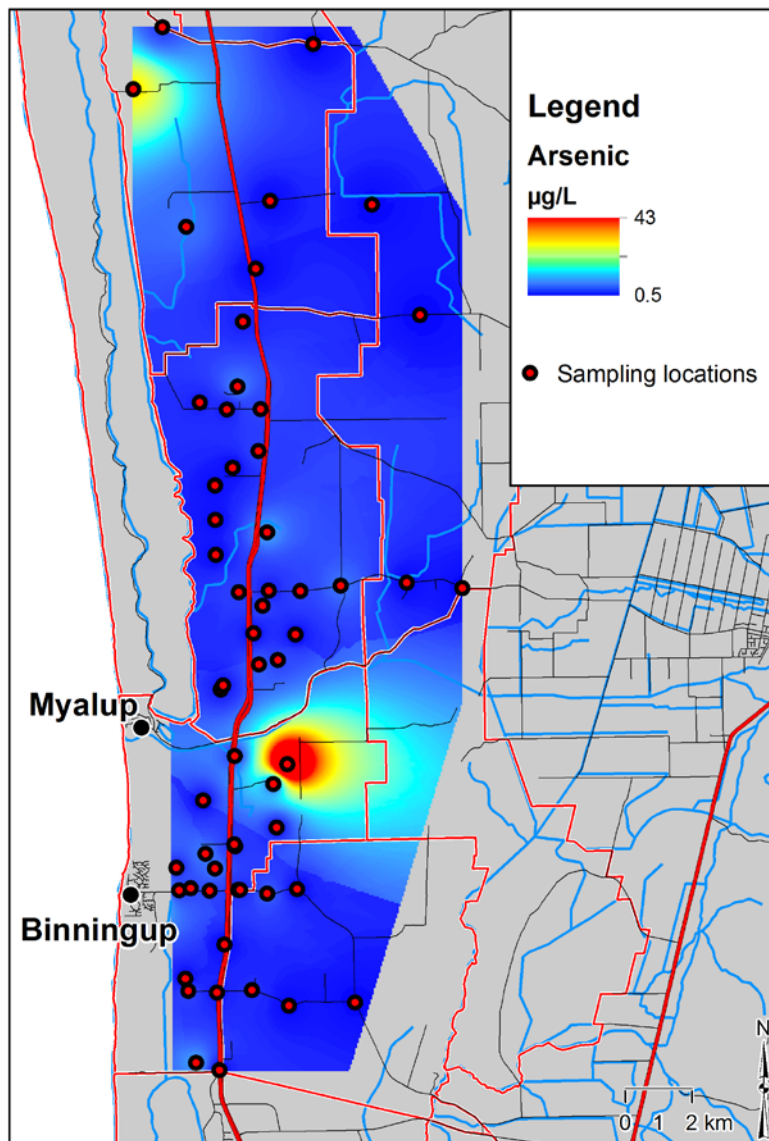


Figure 3.27 Average concentration of arsenic (left) and boron (right) from regional groundwater sampling

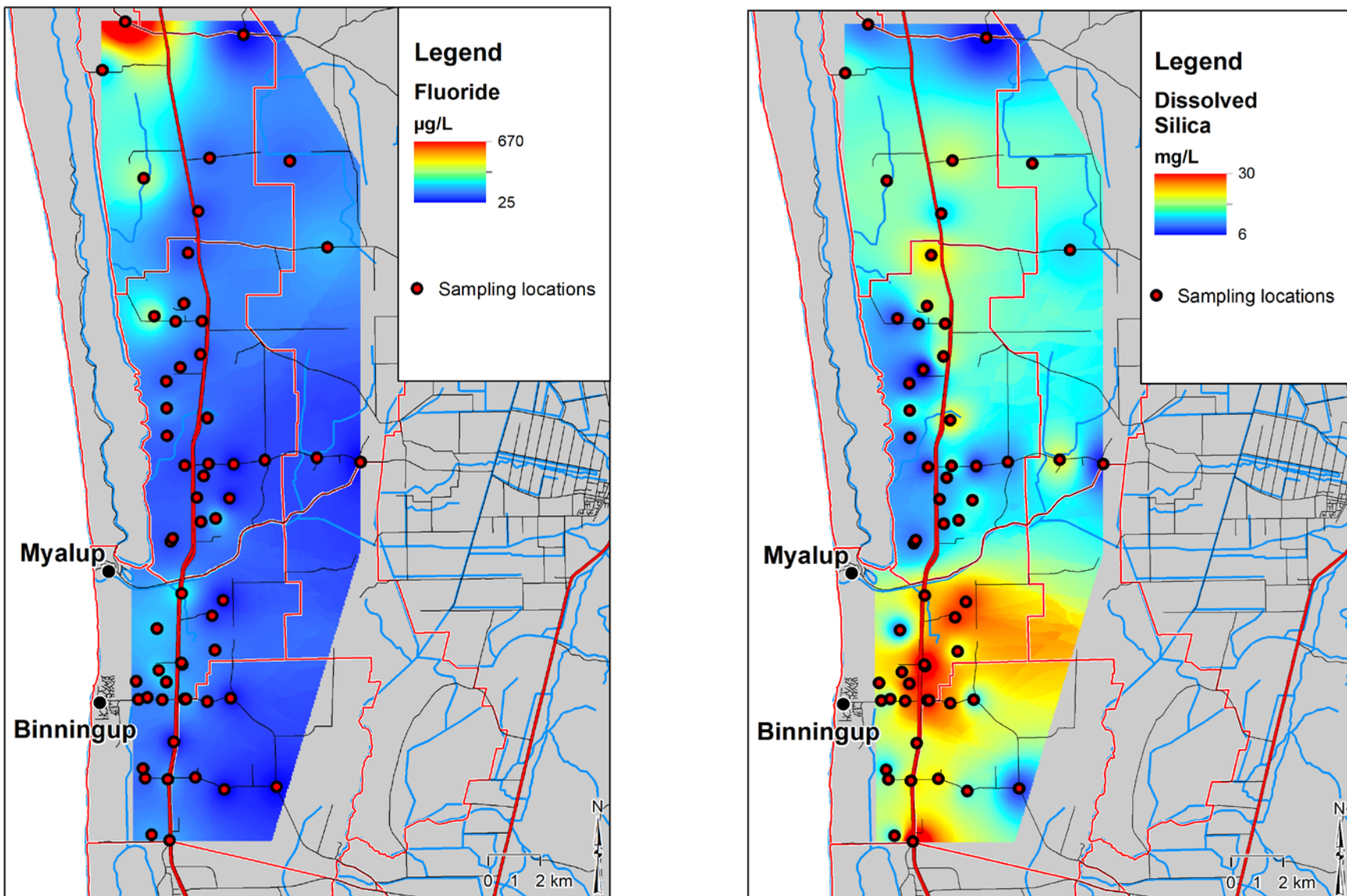


Figure 3.28 Average concentration of fluoride (left) and silica (right) from regional groundwater sampling

3.3.3 Nutrients and farm chemicals

Total nitrogen had a median concentration of 940µg/L and ranged from 120 to 31 000µg/L (Table 3.3). The median concentration of oxidised nitrogen (NO_x-N) was 150µg/L and ranged from 10 to 28 000µg/L, with 64% of sites having concentrations above the LoR (Table 3.3). More than half the sites exceeded the ANZECC and ARMCANZ (2000) 99% aquatic ecosystem guidelines, with 15% of sites exceeding the 90% aquatic ecosystem guideline trigger value (Appendix E). The highest nitrogen concentrations were to the east of Lake Preston at the boundary between Lake Preston North and Lake Preston South GWSAs and to the west of Forrest Highway (Figure 3.29). Reduced nitrogen — ammonia (NH₃) — had a median concentration of 340µg/L and ranged between 10 and 4400µg/L, with about 90% of sites having concentrations above the LoR (Table 3.3). Nearly half the sites exceeded the ANZECC and ARMCANZ (2000) 99% aquatic ecosystem guideline trigger value and about 5% exceeded the 95% aquatic ecosystem guideline trigger value (Appendix E). The highest concentrations of ammonia occurred from Forestry Road and southwards (Figure 3.30). These areas also had the lowest redox conditions.

The median concentration of total phosphorus was 20µg/L and ranged from 10 to 320µg/L, with 75% of sites having concentrations above the LoR (Table 3.3). Whereas, the median concentration of soluble reactive phosphorus was 30µg/L and ranged from 10 to 600µg/L, with just under half of the sites having concentrations above the LoR (Table 3.3). The highest concentrations of phosphorus occurred on the Bassendean Sand in the east of the study area (Figure 3.30 right, Figure 3.31 left).

Dissolved organic carbon had a median concentration of 9mg/L and ranged from 2 to 98mg/L. The highest concentrations of dissolved organic carbon occurred on the Bassendean Sand in the east of the study area where organic-rich hardpans can occur in the soil profile (Figure 3.31 right). All organic agricultural chemicals analysed were below the LoR of 0.1µg/L.

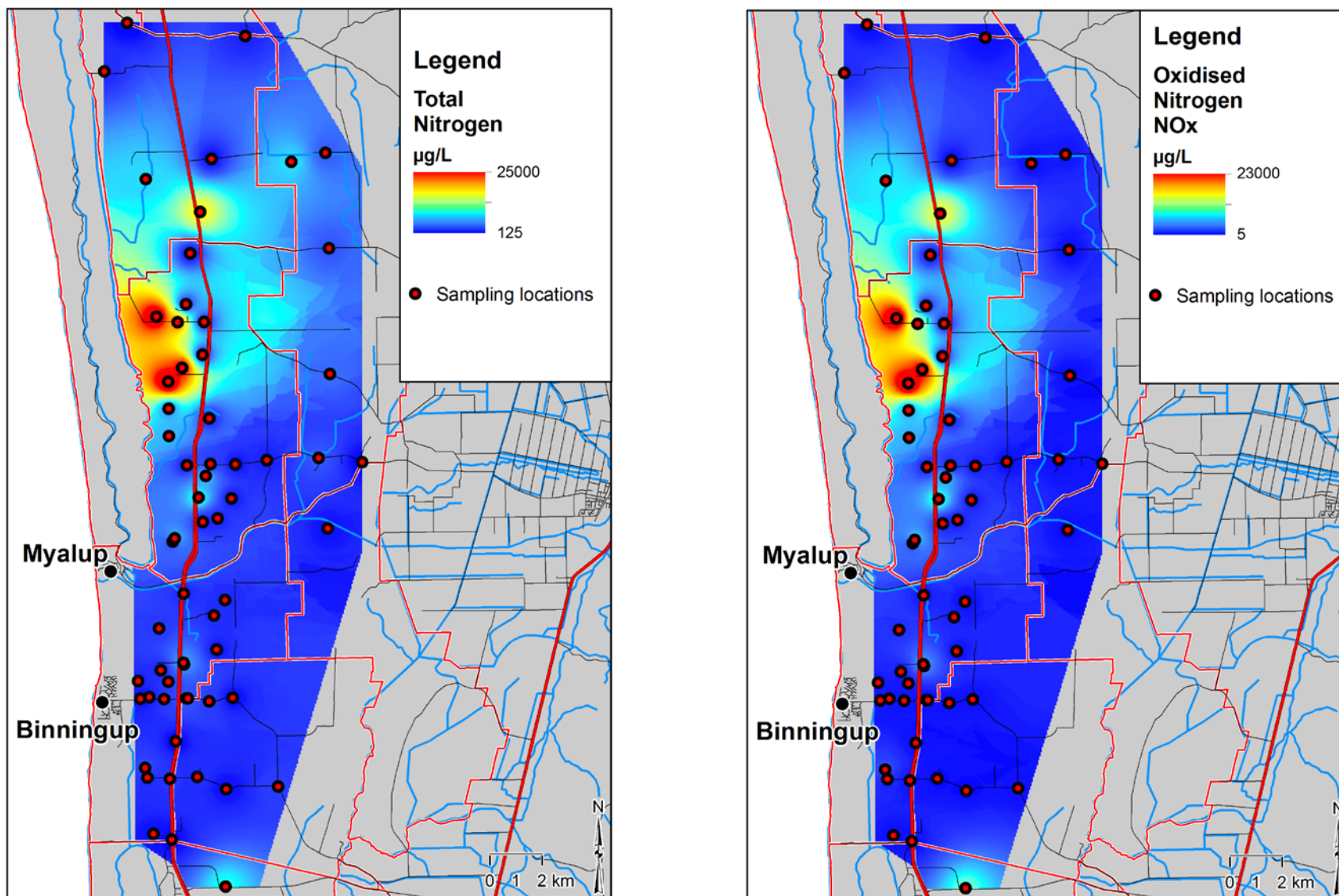


Figure 3.29 Average concentration of total nitrogen (left) and oxidised nitrogen, NO_x (right) from regional groundwater sampling

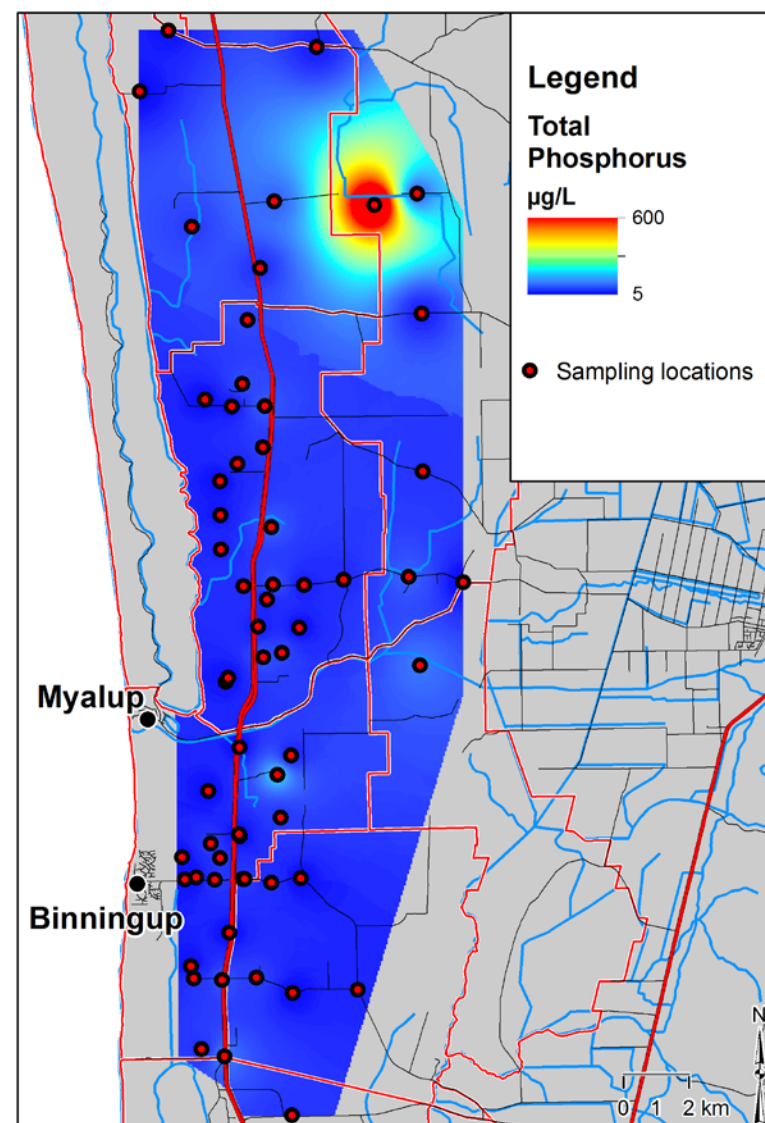
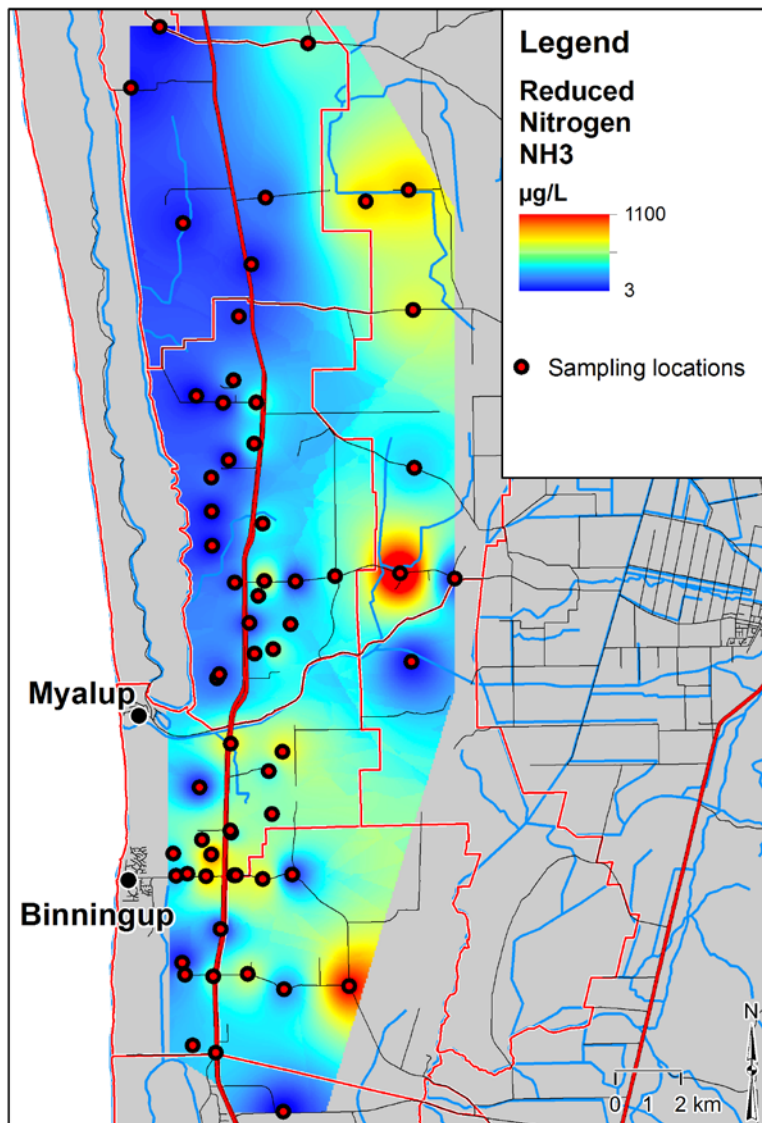


Figure 3.30 Average concentration of reduced nitrogen, NH_3 (left) and total phosphorus (right) from regional groundwater sampling

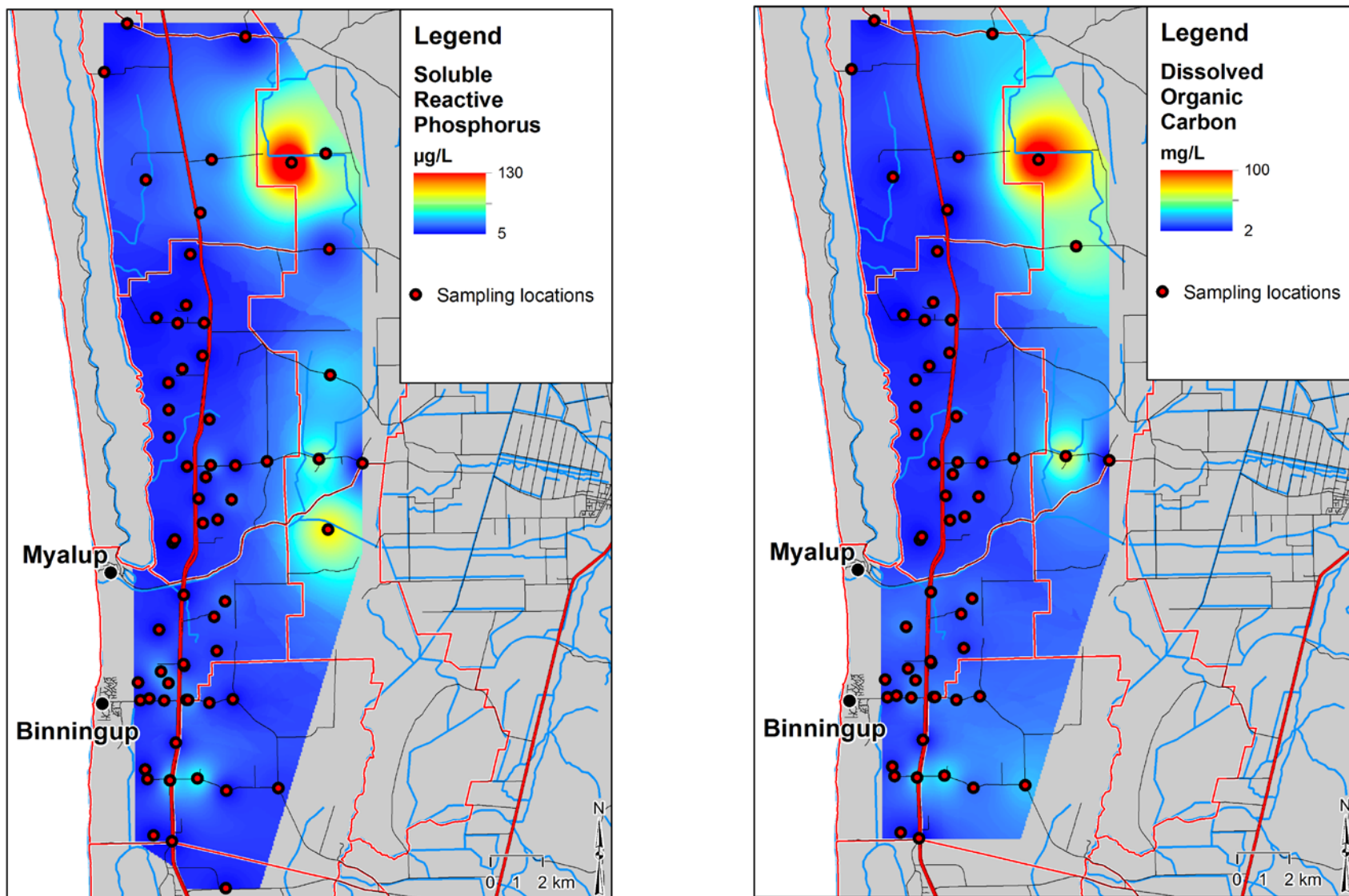


Figure 3.31 Average concentration of soluble reactive phosphorus (left) and dissolved organic carbon (right) from regional groundwater sampling

3.3.4 Groundwater suitability for irrigation

High salinity groundwater occurred mostly across the main irrigation areas and the best-quality water occurred on the Bassendean Sand (Figure 3.32). When using the Richards (1954) criteria, most sites were in the high salinity (C3) category with a low sodium hazard (S1). As groundwater salinity increased, the sodium hazard also increased as a result of the salinity in some areas being caused by sodium-chloride type waters (Figure 3.33). The risks from higher salinity in other areas were mitigated to some extent because the calcium-sulfate type waters have a lower toxicity than sodium-chloride type waters; however, there are still the osmotic effects of high salinity. The only ion that could be problematic for irrigation was iron, which exceeded the long-term trigger value at nearly a third of sites (Appendix F). Boron also exceeded the long-term trigger values at some sites, but the high salinities at these sites make them unsuitable for irrigation.

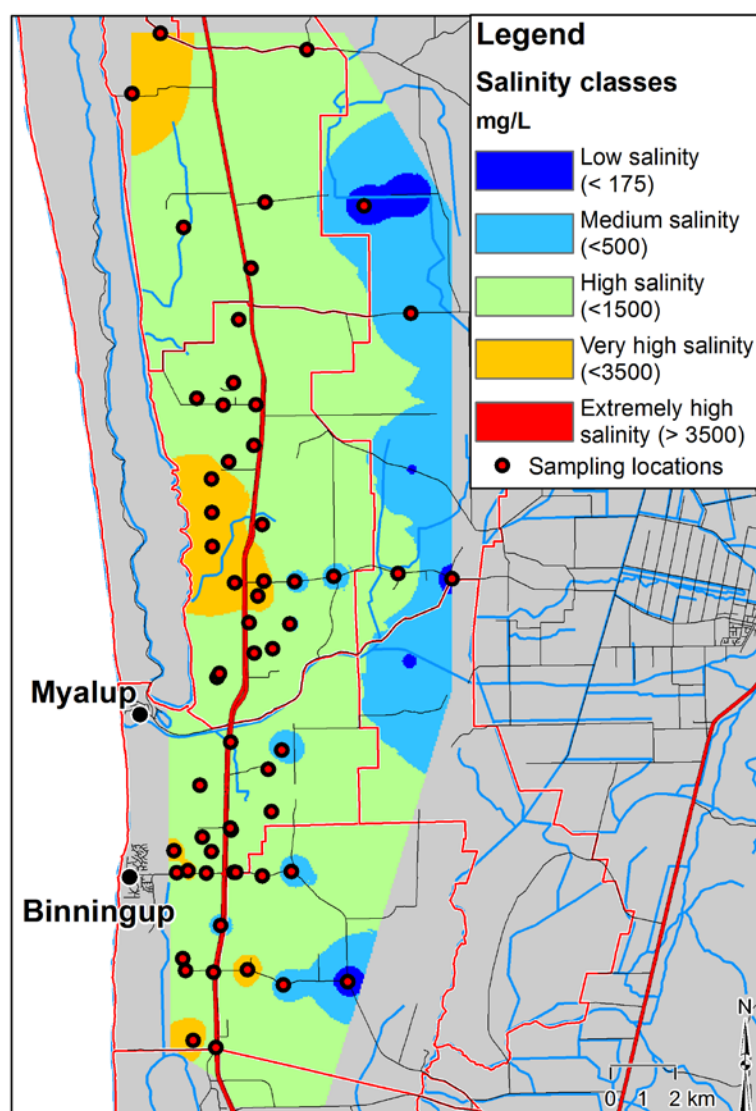


Figure 3.32 Irrigation salinity classes for the Myalup region

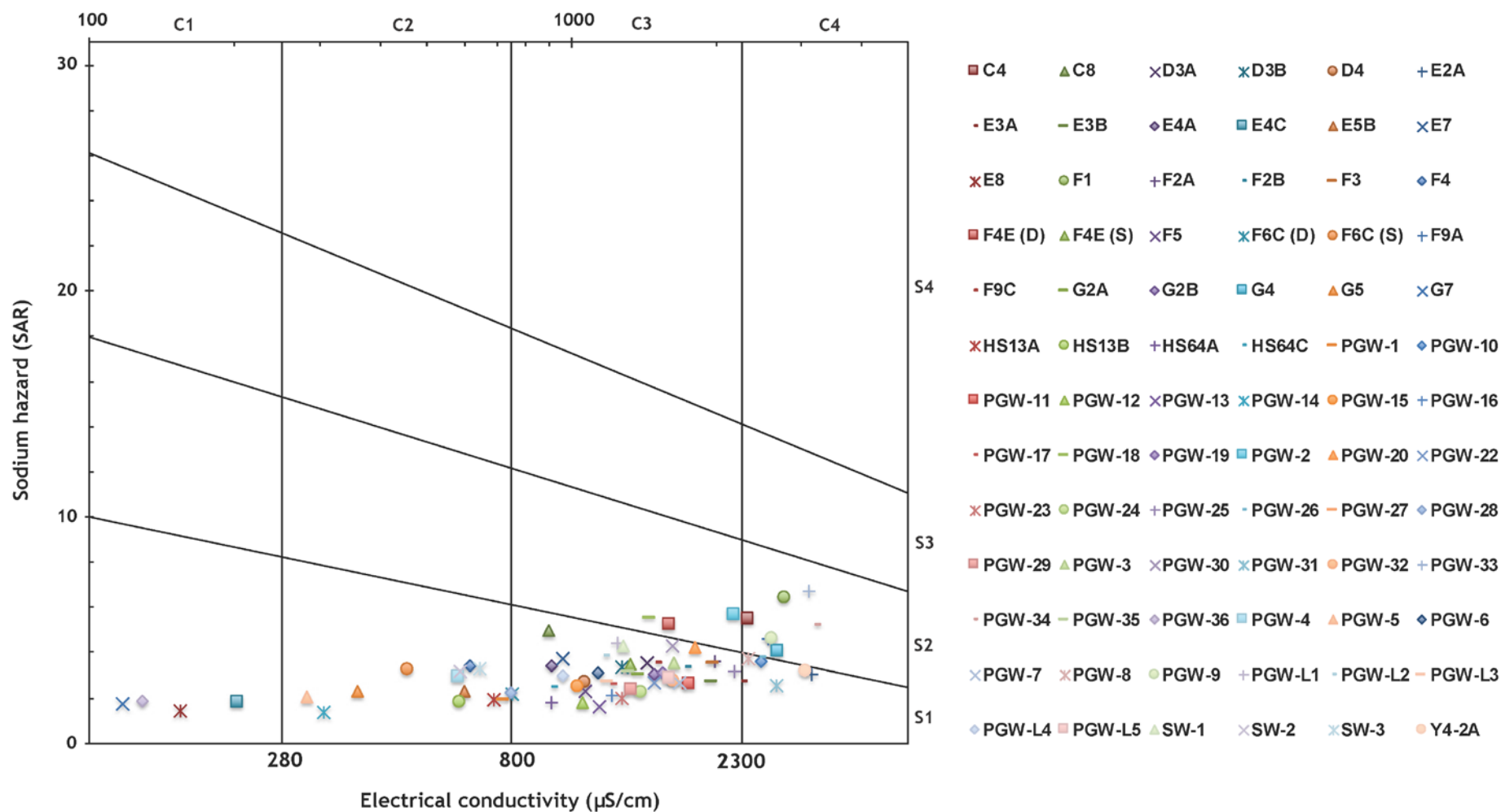


Figure 3.33 Wilcox diagram showing salinity and sodicity classes of groundwater that is below 5500 $\mu\text{S}/\text{cm}$ in the Myalup region

4 Discussion

4.1 Trends in groundwater quality

4.1.1 Total dissolved solids and major ions

The licensee data and regional groundwater sampling data showed similar trends. The median TDS for the Myalup aquifer was about 1000mg/L, and ranged from about 100 to nearly 6000mg/L (Table 3.3). Salinity generally increased along the aquifer flow path. The lowest TDS concentrations were on the Bassendean Sand with a median concentration around 100mg/L, however, this increased with depth to about 450mg/L. Salinity of groundwater in the Spearwood Dunes had a median TDS concentration of about 380mg/L, but increased with depth to about 550mg/L. The median salinity on the Tamala Limestone forming the Yoongarillup Plain was 1100mg/L and salinity increased to 1800mg/L at depth. The highest concentration of TDS (5800mg/L) was in a bore drilled into the saline groundwater interface near Lake Preston.

The spatial distribution of TDS, derived from the licensee and regional groundwater sampling data, shows the salinity in the Tamala Limestone increases along the western margin (Figure 3.14 left, Figure C1). A finer spatial distribution of TDS can be inferred from the AEM surveys. The AEM data shows the same broad trends as the water quality data with salinity increasing westwards (Figure 3.7). However, the areas of high salinity in the AEM data are more spatially discrete. The highest concentrations of salinity occurred in low areas around the lake margins and in wetlands, such as Myalup Swamp and Mialla Lagoon, and the chain of wetlands north of the Harvey River Diversion Drain. Saline plumes downgradient from the wetlands are also evident in the AEM data. Commander (1984) and Kern (1998) also noted that groundwater beneath wetlands had higher salinities.

The salinity trends are spatially and temporally variable. Of the 140 licensee sites using water for agricultural purposes, only 30 had increasing salinity ($r^2 > 0.45$) through time (2007–15) (Table 3.2), which is similar to the historical trends in salinity (Figure 2.3). The current sites with increased salinity also have differences in groundwater chemistry (Figure 3.5), indicating there are multiple processes responsible for the increase in salinity.

Spatial variability is also evident in the major ions. The dominant cations were sodium and calcium. Sodium had a median concentration of about 180mg/L and increased along the regional flow path (east to west) from about 40mg/L in the Bassendean Sand to 170mg/L in the Tamala Limestone (Table 3.4). Sodium fell mainly on the seawater trendline indicating it only increases through evaporation. In contrast, calcium increased westwards along the groundwater flow path and showed considerable enrichment relative to seawater (Figure 3.16). The median concentration of calcium was 140mg/L, with a range in concentration from 20mg/L in the Bassendean Sand to 170mg/L in the Tamala Limestone (Table 3.3, Table 3.4). The increase in calcium was due to the dissolving of limestone (calcite) along the groundwater flow path.

The dominance of major anions across the Myalup aquifer is highly variable (Figure 3.12 and Figure 3.19), indicating there are multiple geochemical processes controlling water quality. Chloride was, overall, the dominant anion with a median concentration of

about 300mg/L and a range from 50mg/L in the Bassendean Sand to 330mg/L in the Tamala Limestone (Table 3.3, Table 3.4). Chloride had the highest concentrations at the western margins near the coast and salt lakes. The only source of chloride over most of the aquifer was assumed to be rainfall and the increase along the flow path was due to evaporation.

Low-lying areas along the eastern shore of Lake Preston are subject to inundation over winter and as a result have formed wetlands (areas in white in Figure 4.1). The groundwater is brackish beneath these seasonally inundated wetlands and the dominant anion is chloride (Figure 4.2). The salinity of the groundwater in the upper aquifer of these low-lying areas, as shown in shallow production bores and excavations, is highly variable (Figure 4.2). This suggests that the salinity of the upper aquifer is controlled by localised evaporation and dilution processes in these areas. However, in these areas salinity also increased with depth because of the landward movement of the highly saline groundwater beneath Lake Preston which is denser than the fresher overlying aquifer (Figure 3.7).

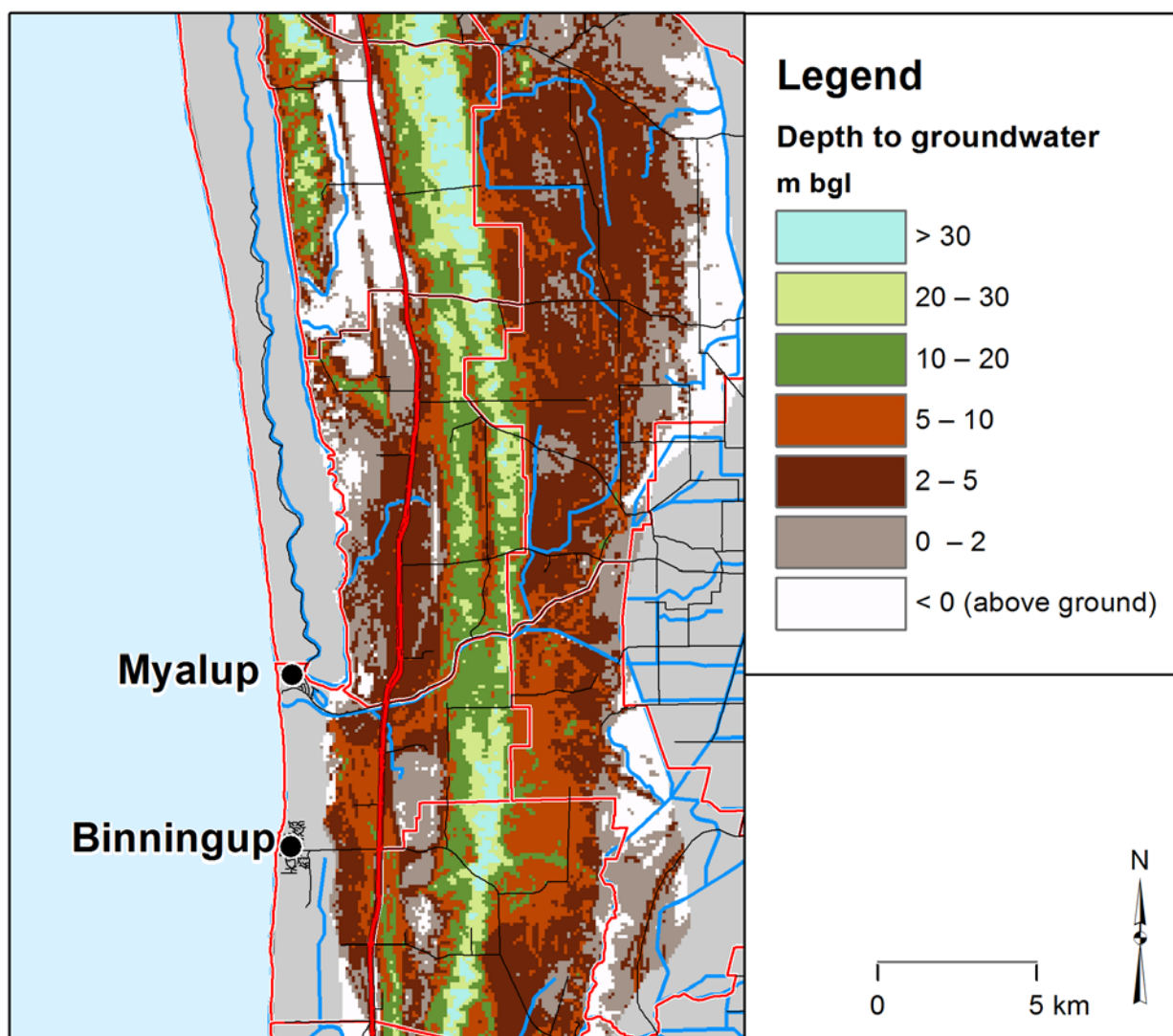


Figure 4.1 Average depth to groundwater in the Myalup region

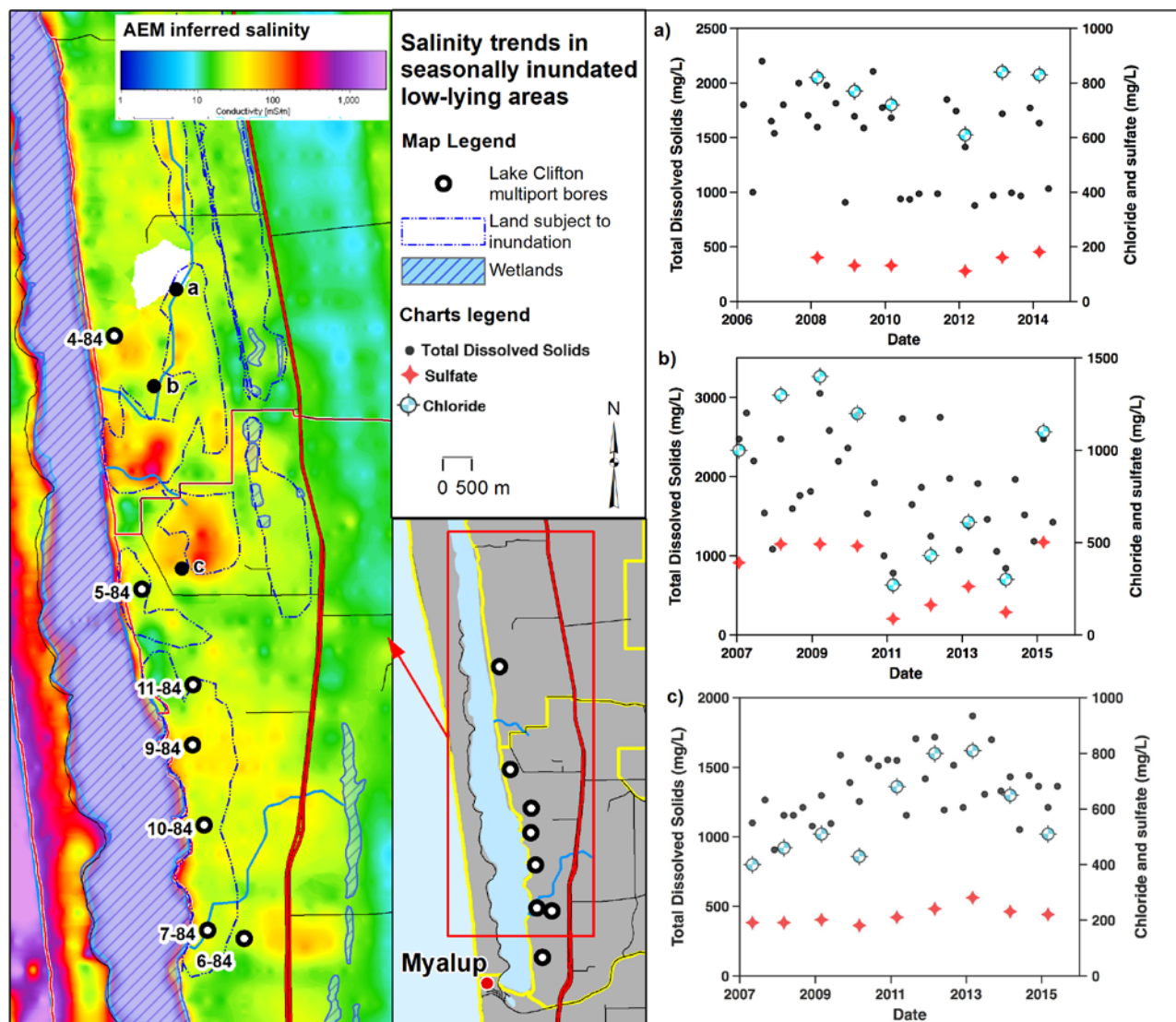


Figure 4.2 Location of multiport bores and seasonally inundated low-lying areas, as well as trends in shallow production bores and excavations

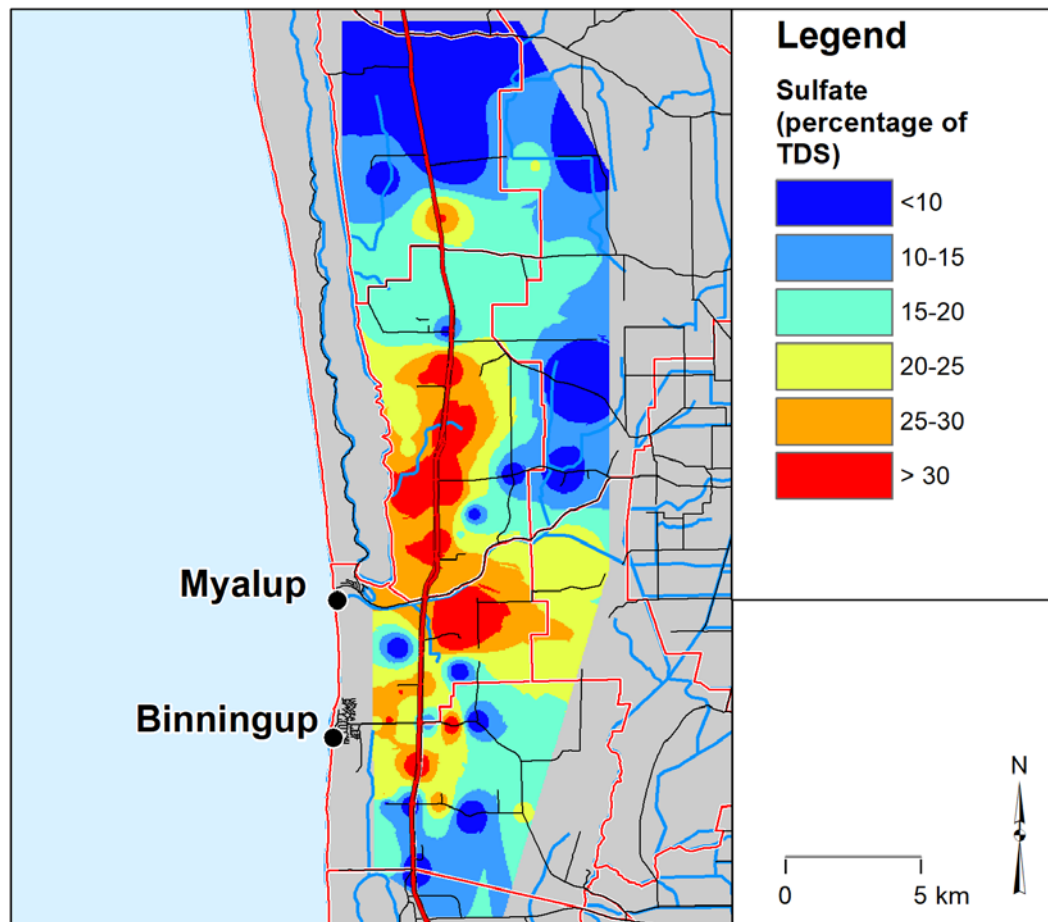
Mixing could potentially cause chloride concentrations to increase in the Myalup aquifer at the interface between the fresher upper aquifer and the deeper, more-saline part of the aquifer near the coast and salt lakes. However, up until 2000, salinity had increased in only two of the multiport bores, 5-84 and 9-84, installed to monitor the movement of the saltwater interface (Figure 3.8, Figure 3.10). In both these bores, the middle part of the aquifer increased in salinity suggesting that groundwater abstraction is the potential driver. Bore 5-84 is located in a quarry (Figure 4.2) and mine activities could have contributed to the salinity increase in this bore. However, for most irrigated agriculture in this area, groundwater abstraction is confined to the upper aquifer and salinity processes are likely controlled by superficial processes (Figure 4.2).

Bicarbonate was the next most dominant anion with a median concentration of 260mg/L, and a range from 50mg/L in the Bassendean Sand to 275mg/L in the Tamala Limestone (Figure 3.15, Table 3.4). Bicarbonate also showed enrichment relative to seawater because of calcite dissolution along the flow path (Figure 3.16, Table 3.4).

Sulfate showed the most variability in concentration: it was depleted in some areas of the Spearwood Dunes and Bassendean Sand, and enriched in areas of the Tamala Limestone, relative to the seawater dilution line (Figure 3.16). The highest sulfate concentrations occurred around the middle of the Lake Preston South GWSA where sulfate was the dominant anion and the main component of TDS (Figure 4.3). Increased sulfate levels in the groundwater was the principle cause of increased TDS in about two-thirds of bores with increased salinity (Figure 3.5).

4.1.2 Nutrients and farm chemicals

Nitrogen concentrations in the Myalup aquifer are highly variable. The median concentration of oxidised nitrogen ($\text{NO}_x\text{-N}$) was 150 $\mu\text{g/L}$, with a maximum concentration of 28 000 $\mu\text{g/L}$ (Table 3.4). The highest oxidised nitrogen concentrations mainly occurred along the western margins of the aquifer, with the highest concentrations (>10 000 $\mu\text{g/L}$) occurring in the north-western areas of the Lake Preston South GWSA (Figure 3.29). In this area, the superficial aquifer was typically about 2mBGL (Figure 4.1) where oxidising conditions limit the anaerobic biota from attenuating the nitrogen. Historically, the area with high nitrates also had lucerne crops (1963–2010), a legume that produces nitrates. Additionally, the area also had high sheep numbers that were grazed over autumn. Urine from the livestock could have contributed to the nitrates in the groundwater.



Note: Sulfate is typically about 8% of seawater salinity.

Figure 4.3 Sulfate concentrations as a percentage of total dissolved solids in groundwater

Nitrogen can be a chemical marker for fertiliser contamination of aquifers (Power & Scheper 1989). High concentrations of nitrogen, more than 3000µg/L nitrogen as nitrate, are considered evidence of fertiliser contamination (Power & Scheper 1989). However, aquifers on the Swan Coastal Plain can have low oxidised nitrogen levels because of denitrification, and nitrogen is more commonly found in its reduced form, ammonia (Hirschberg & Appleyard 1996, Pionke et al. 1990).

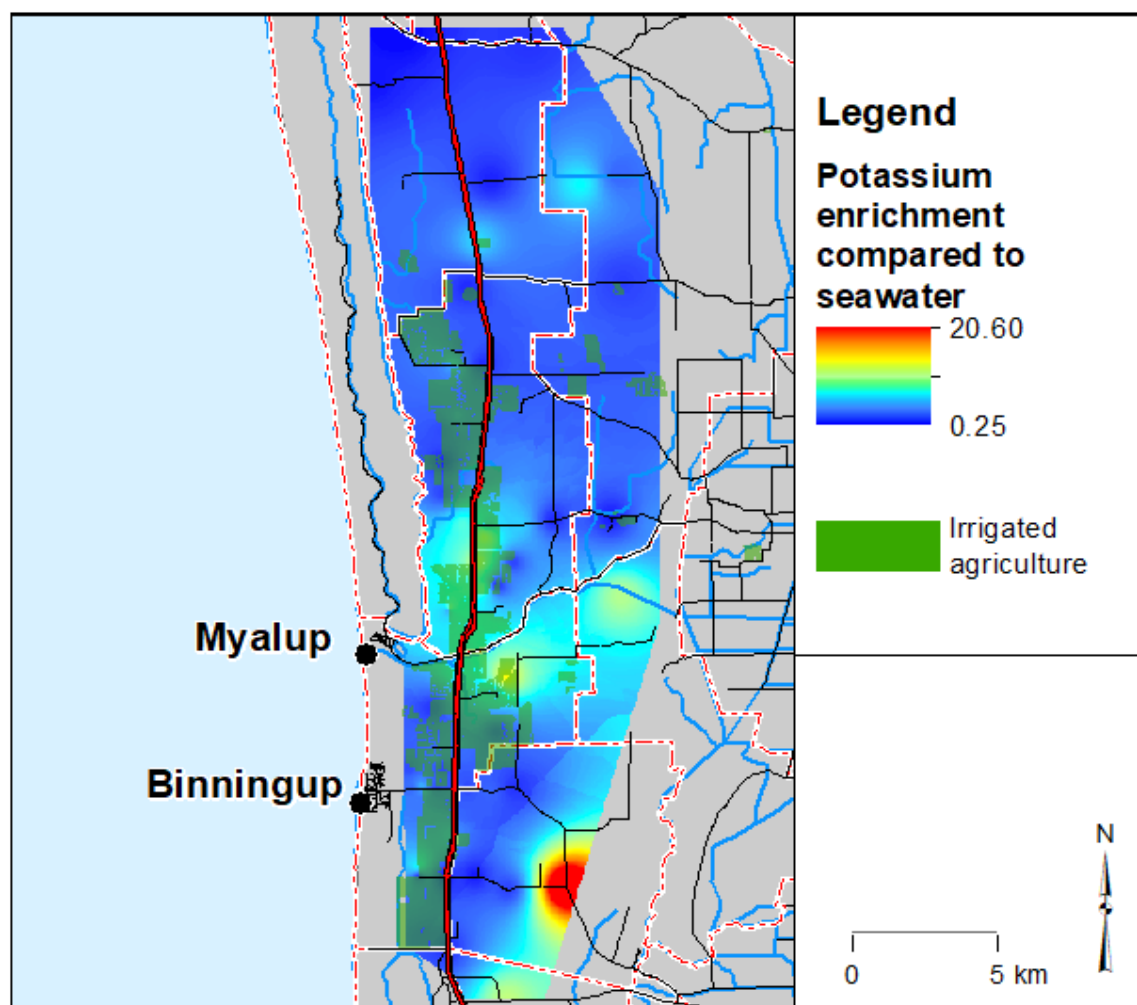
The superficial Myalup aquifer was mostly reducing (Appendix G) and consequently nitrogen was mostly in the reduced form. Reduced nitrogen (ammonia) had a median concentration of 340µg/L and a maximum concentration of 4400µg/L (Table 3.4). Reduced nitrogen concentrations above 250µg/L are considered an indication of anthropogenic influences (Hirschberg & Appleyard 1996).

Pionke et al. (1990) considered low chloride to sulfate ratios as potential indicators of fertiliser application in areas of denitrification; however, they also noted that low chloride to sulfate ratios could be caused by pyrite oxidation. The source of increased sulfate in the Myalup aquifer was thought to be from fertiliser application (Kern 1998, WAWA 1989). However, there were no correlations between sulfate and nitrogen species within any of the datasets. In addition, areas with highest nitrogen concentrations only partially

overlapped with areas with the highest sulfate concentrations (Figure 3.15 right, Figure 3.29 and Figure 3.30 left).

Another important fertiliser input is potassium. However, potassium inputs from fertiliser are likely to be more conservative than nitrogen because of the reducing conditions over most of the aquifer. Potassium, also a major ion, had a median concentration of 10mg/L and a maximum concentration of about 80mg/L. Potassium also showed enrichment relative to seawater (Figure 3.16). The spatial variation in potassium enrichment relative to seawater is shown in Figure 4.4 and poorly correlates to the areas of irrigated agriculture and high nitrogen concentrations (Figure 3.29). Sulfate also poorly correlated with potassium, and spatially there was little correlation between potassium enrichment (Figure 4.4) and sulfate corrected for evapoconcentration (Figure 3.22 right).

Therefore, although there is evidence of minor fertiliser contamination in the aquifer, fertiliser application is unlikely to be the major source of sulfate in the aquifer. Also, all pesticides sampled (metalaxyl, methyl isothiocyanate, metalachlor and atrazine) were below their detection limit, indicating that they are possibly being bound in the soil or broken down by biological processes.



Note: Areas greater than one show enrichment.

Figure 4.4 Areas of increased potassium concentration corrected for evapoconcentration

4.1.3 pH and metals

Another potential source of sulfate in the aquifer is from pyrite oxidation. The most common indicators for pyrite oxidation are low pH (acidification) and low chloride to sulfate ratios (Department of Environment Regulation 2015, Mulvey 1993, Stone et al. 1998). Most sites had a pH between 7 and 8, however, some sites had a pH of less than 4 (Table 3.1, Figure 3.3). The acidified sites, with pH less than 4, occurred in the wetlands to the east of the Yoongarillup Plain (Figure 3.3). Acidification also occurred on the Bassendean Sand because these areas are not buffered by calcareous deposits (calcite). Any acid resulting from pyrite oxidation on the Tamala Limestone or Spearwood Dunes would be buffered by calcite dissolution (equations 2.1–2.3, Section 2.1.1).

The pH of groundwater also impacts on the solubility of metal species. However, only aluminium showed any relationship with pH, with the highest concentrations occurring in areas with the lowest pH (Figure 3.23, Figure 3.24). Neither iron nor manganese showed any relationship with pH, so their concentrations are likely being controlled by aquifer redox conditions.

The only other metals that had high groundwater concentrations were zinc and chromium, which exceeded the ANZECC and ARMCANZ (2000) aquatic ecosystem guidelines (Appendix E). Although zinc is an essential mineral for crops and is applied with fertiliser, the high concentrations of zinc and chromium occurred under agricultural areas and native vegetation, suggesting the source of these metals is natural. High zinc and chromium concentrations occurred on the Spearwood Dunes and Tamala Limestone and these formations contain shell fragments (Davidson 1995). Shells contain high concentrations of zinc and chromium (Bertine & Goldberg 1972) and dissolution of shell fragments is therefore the most likely source of high zinc and chromium concentrations in the groundwater.

4.1.4 Changes in water quality across wetlands at the base of Spearwood Dunes

Groundwater showed some of the greatest changes in salinity and water type as it moved across the wetlands from the Spearwood Dunes to the Tamala Limestone (Table 3.5). Commander (1984) and Kern (1998) also noted that salinity increased in groundwater beneath wetlands such as Myalup Swamp and Mialla Lagoon.

To gain a clearer understanding of the geochemical processes impacting water quality in the wetlands, historical changes in water quality across wetlands in Lake Clifton bore transects G, F and E (see Figure 3.20 for locations) are shown in Figure 4.5, Figure 4.6 and Figure 4.7, and the data are shown in Appendix H. Transects G and F are in nonirrigated areas and transect E is in an irrigated area. Statistical analysis could not be done because of the limited frequency of data collection; however, the patterns and changes in the data give useful insights.

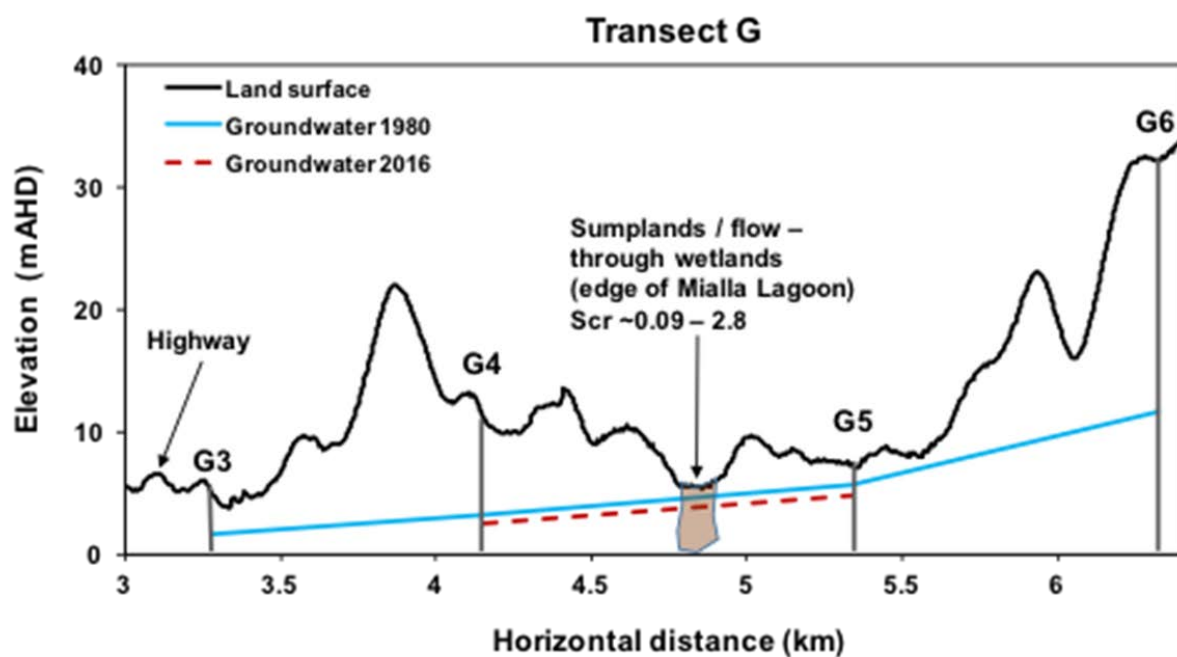
Transect G, located in the Kemerton Industrial Park, consists mostly of natural vegetation with no irrigated agriculture (Figure 3.20, Figure 4.5). Groundwater levels at bore G4 have declined since the 1980s, and particularly in the late 1990s when it dropped about 1m (Watson 2015; Appendix I). Overall, groundwater levels have declined across the region, with an average decline of 0.47m under agriculture and 0.63m under native vegetation and forestry. Rainfall has declined about 7% since the

mid-1970s and 13% since 2000 and this has likely led to the lower watertable (Appendix I). Upgradient of the wetland in transect G (bore G5), salinity (TDS) was 500mg/L, chloride was less than 100mg/L, sulfate was less than 50mg/L, and oxidised nitrogen was less than 1000µg/L (Figure 4.5).

Downgradient of the wetland (bore G4), TDS has historically been greater than 1000mg/L; however, it has doubled to about 2300mg/L since 1996. Chloride was historically around 400mg/L, but has nearly doubled to about 700mg/L since 1996. Sulfate concentrations have historically been low at less than 40mg/L, but have increased about 20-fold to about 600mg/L since 1996. Nitrogen levels have remained at less than 100µg/L at bore G4 (Figure 4.5). The increase in chloride across the wetland from bore G5 to bore G4 is most likely due to increased evapotranspiration of groundwater and less flushing from recharge. The increase in sulfate at bore G4 since 1996 is likely due to the exposure and oxidation of pyrite (equation 2.1 in Section 2.1.1) in the wetlands from declining groundwater levels. This is supported by Mialla Lagoon having chromium-reducible sulfur levels from 0.09% to 2.8% sulfur (Degens 2009a). Chromium-reducible sulfur percentages greater than 0.03% sulfur are considered to have a high pyrite risk (Department of Environment Regulation 2015). Oxidation of sulfides has also been observed in Perth wetlands as a result of declining rainfall (Bourke et al. 2015, Clohessy 2012, Searle et al. 2011).

The AEM image (Figure 3.7 left) shows a shallow saline plume in the groundwater downgradient of the wetland. Therefore, the increase in groundwater salinity observed at bore G4 since 1996 would have dispersed into the aquifer downgradient of bore G4.

The bores in transect F are sited along Wellesley Road, which runs on a small ridge through the Myalup Lagoon, except bore F5 which is located on the ridge in the middle of the wetland (Figure 3.20, Figure 4.6). Although cleared, there was no irrigated agriculture along this transect. Upgradient of the wetlands, bore F6 had salinity that has increased slightly since 1983, although it remained less than 500mg/L TDS, while chloride was less than 150mg/L, sulfate less than 20mg/L and nitrogen (NO_x) less than 1000µg/L. At bore F5, salinity has increased from about 500 to 900mg/L since 1983. Since 1996, chloride has remained at about 200mg/L, while sulfate has increased fivefold from 60 to 300mg/L (Figure 4.6). Exposure and oxidation of sulfides are the likely source of the increase in sulfate at bore F5, although the effect is likely to be shallow and less evident towards the base of the aquifer. Chromium-reducible sulfur levels in Myalup Swamp ranged from 0.07% to 0.12% sulfur (Degens 2009a). Downgradient of the wetland (bore F4) groundwater salinity has remained around 1100–1200mg/L since 1983, while chloride has remained at about 400mg/L and sulfate at 70–80mg/L. Bore F4 has a different water type to bore F5 (Table 3.5). Groundwater at bore F4 is likely influenced by evaporated groundwater from Myalup Lagoon, while the groundwater at bore F5 is influenced by recharge waters that have been exposed to oxidised pyrites during recharge. Based on modelling, density differences between groundwater at bores F4 and F5 could have limited mixing.



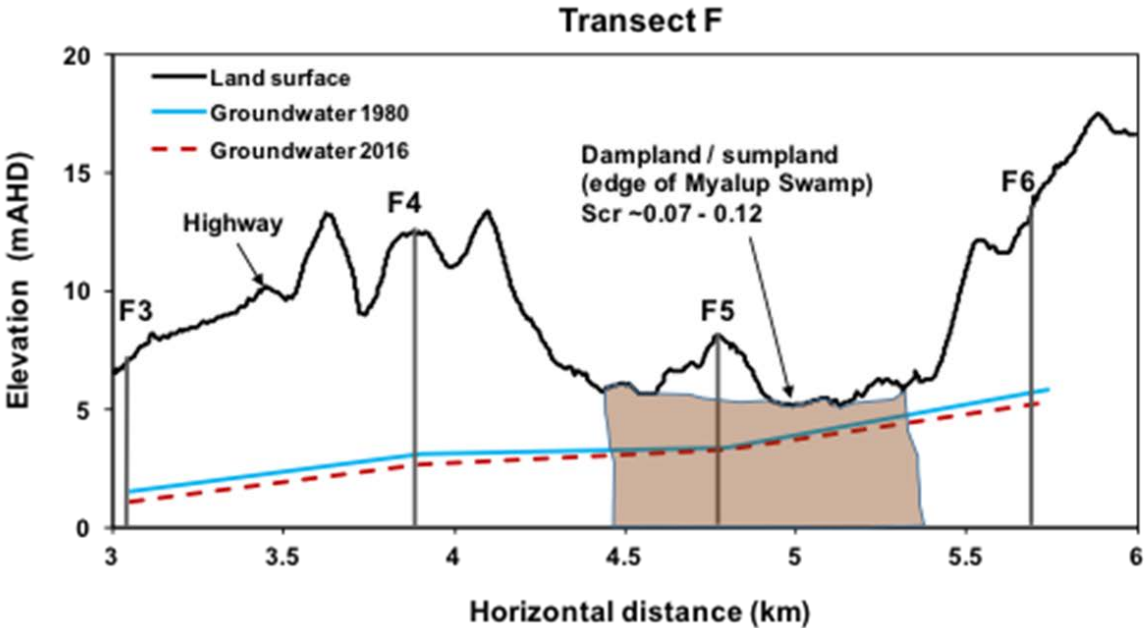
Notes:

1. Groundwater bores are shown as vertical grey lines.
2. Chromium-reducible sulfur (S_{Cr}) range was 0.09–2.8%.

Year	Bore G4				Bore G5			
	Chloride	Sulfate	Nitrogen NO_x	TDS	Chloride	Sulfate	Nitrogen NO_x	TDS
1983	380	40	80	1200	60	37	30	430
1996	380	35	100	1150	60	10	200	300
2016	665	640	<10	2320	75	5	20	270

Note: All units are in mg/L, except nitrogen NO_x which is in $\mu\text{g/L}$.

Figure 4.5 Changes in groundwater quality along transect G

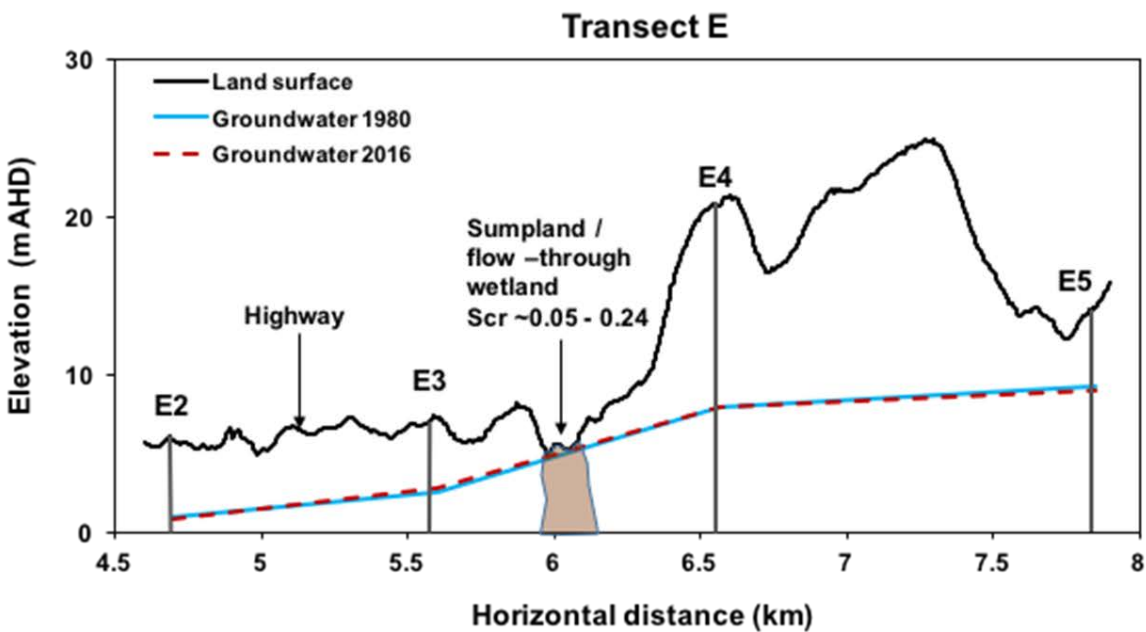


- Notes:
- 1. Groundwater bores are shown as vertical grey lines.
 - 2. Chromium-reducible sulfur (S_{Cr}) range was 0.07–0.12%.

Year	Bore F4				Bore F5				Bore F6			
	Chloride	Sulfate	Nitrogen NO_x	TDS	Chloride	Sulfate	Nitrogen NO_x	TDS	Chloride	Sulfate	Nitrogen NO_x	TDS
1983	425	70	<1000	1100	–	–	–	470	115	18	<1000	340
1996	–	–	–	–	200	56	100	730	–	–	–	–
2016	370	80	<10	1200	186	338	10	890	140	4	<10	470

– = no data
Note: All units are in mg/L, except nitrogen NO_x which is in $\mu\text{g/L}$.

Figure 4.6 Changes in groundwater quality along transect F



- Notes:
1. Groundwater bores are shown as vertical grey lines.
 2. Chromium-reducible sulfur (S_{Cr}) range was 0.05–0.24%.

Year	Bore E2				Bore E3				Bore E4			
	Chloride	Sulfate	Nitrogen NO_x	TDS	Chloride	Sulfate	Nitrogen NO_x	TDS	Chloride	Sulfate	Nitrogen NO_x	TDS
1980	–	–	–	–	263	51	<1000	770	–	–	–	420
1983	–	–	–	770	290	200	200	1130	90	19	60	220
2016	640	1040	170	2750	390	620	10	1850	120	16	100	350

– = no data
 Note: All units are in mg/L, except nitrogen NO_x which is in $\mu\text{g/L}$.

Figure 4.7 Changes in groundwater quality along transect E

Transect E occurs north of the Harvey River Diversion Drain and irrigated agriculture occurs downgradient of the wetlands (Figure 3.20, Figure 4.7). Upgradient of the wetlands at E4, salinity has remained at less than 500mg/L since 1980, while chloride has remained at about 100mg/L, sulfate about 20mg/L and nitrogen (NO_x) less than 100µg/L. As observed in the other transects, the groundwater salinity downgradient of the wetlands at bore E3 has increased from 770mg/L in 1980 to 1850mg/L in 2016. At bore E3, chloride has increased by about 25% from 300 to 400mg/L since 1983, while sulfate has increased threefold from 200 to about 600mg/L and nitrogen has remained at less than 1000µg/L (Figure 4.7). Chromium-reducible sulfur levels in the wetlands along the base of the Spearwood Dunes near Forestry Road ranged from 0.05% to 0.25% sulfur (Degens 2009a). Based on this data, about two-thirds of the increase in salinity at bore E3 can be attributed to sulfide oxidation and the remainder to evapoconcentration.

Along transect E, the saline plume from the wetlands is evident in the AEM image (Figure 3.7, Figure 4.2). There was a 5.5m drop in head over 1000m between bores E4 and E3 (Figure 4.6), which would help to disperse the saline plume into the aquifer. An area east of bore 6-84 (Figure 4.2) and south of bore E3, located in the centre of the plume, also experienced large increases in salinity during the 1980s (Figure 2.3 d–g). Historical chemistry data for bore PGW-31, located in the area (Appendix H), showed little increase in chloride from 1984 to 2016, but sulfate increased from about 400 to more than 1000mg/L, suggesting that pyrite oxidation is the main source of the salinity increase. Historic irrigation rates in the area were around 8ML/ha (twice the current apply rate) which might have produced a drawdown in the swamps to the east that resulted in oxidation of pyrite in acid sulfate soils in the wetlands.

Further downgradient on the western side of the Forrest Highway, salinity at bore E2 tripled from about 800mg/L in 1983 to 2700mg/L in 2016. Sulfate concentrations at bore E2 are more than 1000mg/L, and nitrogen is less than 200µg/L. The increase in salinity at bore E2 is likely due to the migration of the saline plume from the wetlands.

The controls on the salinity in the Myalup aquifer are the result of complex interactions at a regional and local (agricultural) scale. Conceptual models of the salinity processes occurring in the Myalup aquifer are presented in Section 4.2.

4.2 Salinity processes

4.2.1 Seasonal inundation adjacent to Lake Preston

Some of the highest salinities in the superficial aquifer (Figure 3.7, Figure 3.14) occurred on the eastern shoreline of Lake Preston where it interacts with the underlying more-saline groundwater beneath the lake. It is evident from the interpreted AEM data that there are large extents of high salinity in the shallow aquifer associated with low-lying areas at the margins of the lake (Figure 3.7, Figure 4.2). Data from the Lake Clifton multiport bores, drilled into the saltwater interface (Figure 3.8 to Figure 3.11), showed that salinity increased with depth in most of the bores, and this was also evident in the AEM data. Only two bores, 5-84 and 9-84, showed an increase in salinity to the year 2000, but these increases occurred at depths 13–20m below ground level. This increase in salinity at depth could potentially be attributed to pumping, but it cannot explain the high salinity in the shallow groundwater.

Historical salinity data from bores near Lake Preston (Figure 2.3 a–c) as well as more recent examples (Figure 4.2) shows the salinity of the shallow groundwater fluctuates through time. The sites mentioned above are either in, or close to, areas that are seasonally inundated (Figure 4.1, Figure 4.2). This implies that the salinity is being controlled by surface processes of evaporation (increase in salinity) and inundation and recharge (decrease in salinity).

The large extents of high salinity in the shallow aquifer associated with wetlands at the margins of Lake Preston and Lake Clifton are spatially associated with sediments resulting from higher lake levels during the mid-Holocene highstand, when sea levels were around 2m above the current mean sea level (Lewis et al. 2013, Moore 1993). A conceptual model to explain the development of the shallow groundwater salinity is shown in Figure 4.8. During the mid-Holocene highstand, lakes Preston and Clifton had larger areal extents than the current lake levels because of the higher sea levels, increased rainfall or both. With the higher lake levels and consequent increased lake area, low-lying land (<2mAHD) had been flooded with saline lake water. During these higher lake levels, lake sediments accumulated on the low-lying land forming limestone marls. The saline lake water would have also recharged the aquifer and provided potential for the saltwater interface to move landwards.

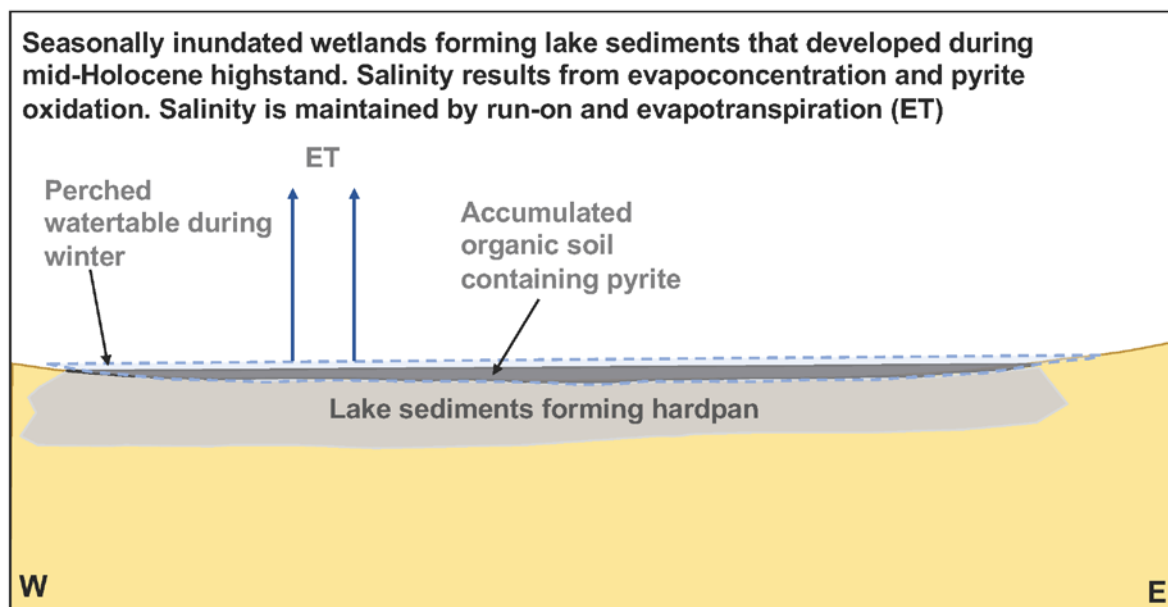


Figure 4.8 Conceptual model to explain the shallow saline groundwater in low-lying areas around the margin of Lake Preston detected in the interpreted AEM data (Figure 4.2)

When the lake levels receded as sea levels dropped, a legacy of salinity was left. The lake sediments formed limestone hardpans that inhibited drainage, resulting in perched watertables and wetland development on the sediments in low-lying areas. The wetlands also received run-on from surrounding areas. Evapotranspiration in the wetlands allowed salinity to accumulate through evapoconcentration as well as maintaining any legacies of salinity. Additionally, higher lake levels during wetter periods would have inundated these wetlands with saline lake water. As a result of the inundation, organic soils developed in the wetlands. The build-up of organic matter and

sulfate from salt accumulation enabled biogenic pyrite to accrue in the soils. During the drier periods, salinity increased in the shallow groundwater because of evapoconcentration, and to a lesser extent the oxidation of pyrite. Then during wetter periods, salinity was diluted by increased recharge and other dilution processes. This model explains the trends in groundwater quality in these areas.

Commander (1984) and Kern (1998) reported that saline water exists beneath the wetlands (Mialla Lagoon and Myalup Swamp) in the Myalup region. Shallow groundwater with salinity greater than 1100mg/L was evident downstream of the wetlands (Figure 3.7). The AEM data also showed that the increased salinity was associated with shallow groundwater near larger wetlands, such as Myalup Swamp and Mialla Lagoon, as well as smaller wetlands, for example the wetland chain (called Long Swamp) extending north of the Harvey River Diversion Drain and wetlands across the plain towards Lake Preston. Myalup Swamp is similar to the aforementioned conceptual model as it becomes seasonally inundated and evapotranspiration is the main mechanism for salinity increase (bores F4 and F9, Figure 4.6, Appendix G). Whereas other wetlands, such as Mialla Lagoon (Figure 4.5) and the wetlands north of the diversion drain (Figure 4.7) represent flowthrough wetlands that act as windows to groundwater (Section 4.2.2).

4.2.2 Salinity in flowthrough wetlands of the Spearwood Dunes

Like the previous conceptual model, the flowthrough wetlands interact with shallow groundwater and evapotranspiration processes increase the salinity of groundwater recharged downgradient from the wetlands (Figure 4.5, Figure 4.7). This is observed in the AEM data with the increased salinity downgradient of the wetlands (Figure 3.7, Figure 4.2). Hydraulic conductivities can decrease in wetlands by up to several orders of magnitude (Johnson et al. 2009, Nath et al. 2013). The slowing of groundwater movement across wetlands, due to reduced hydraulic conductivities, would also enhance evapotranspiration from the wetlands.

The wetlands in the Myalup region also contain sulfides which are known to be oxidising (Degens 2009a). With declining rainfall over the past 30 years, along with groundwater abstraction and the planting of pines in the recharge areas, groundwater levels across the flowthrough wetlands have progressively declined (Appendix I). For example, the decline in groundwater levels at Mialla Lagoon (bore G4 shown in Watson 2015) would have led to exposure and oxidation of the sulfides. Wetlands in the Myalup region were found to contain oxidising acid sulfate soils (sulfides) in 2004 (Degens 2009a). The quantity of sulfur, as sulfides, in the shallow sediments of most wetlands and the shallow aquifer is equivalent to more than 100 years of application of sulfur through fertilisers (Degens 2009a). Because of the extensive amount of calcite present in the aquifer, the acid generated from the oxidation of pyrite is neutralised, leaving the groundwater enriched in calcium and sulfate, which in turn increases TDS. The oxidation of sulfides due to declining rainfall has also been observed in Perth wetlands (Bourke et al. 2015, Clohessy 2012, Searle et al. 2011).

There are hydraulic gradients across flowthrough wetlands (Figure 4.5, Figure 4.7) and this has led to the shallow saline plumes forming downgradient, as observed in the AEM data — for example, the saline plume east of bore 6-84 and south of Forestry Road

(Figure 4.2). A conceptual model to explain the increased salinity of the flowthrough wetlands located between the Spearwood Dunes and Tamala Limestone and the associated downgradient plumes is shown in Figure 4.9. The wetlands are windows to groundwater and evapotranspiration from the wetlands has resulted in increased salinity and brackish plumes downgradient of the wetland (for example, Mialla Lagoon). The decline in groundwater levels has also resulted in the oxidation of pyrite in the wetlands contributing to the increased salinity downgradient. In some instances, pyrite oxidation could be the dominant source of salinity from the wetlands.

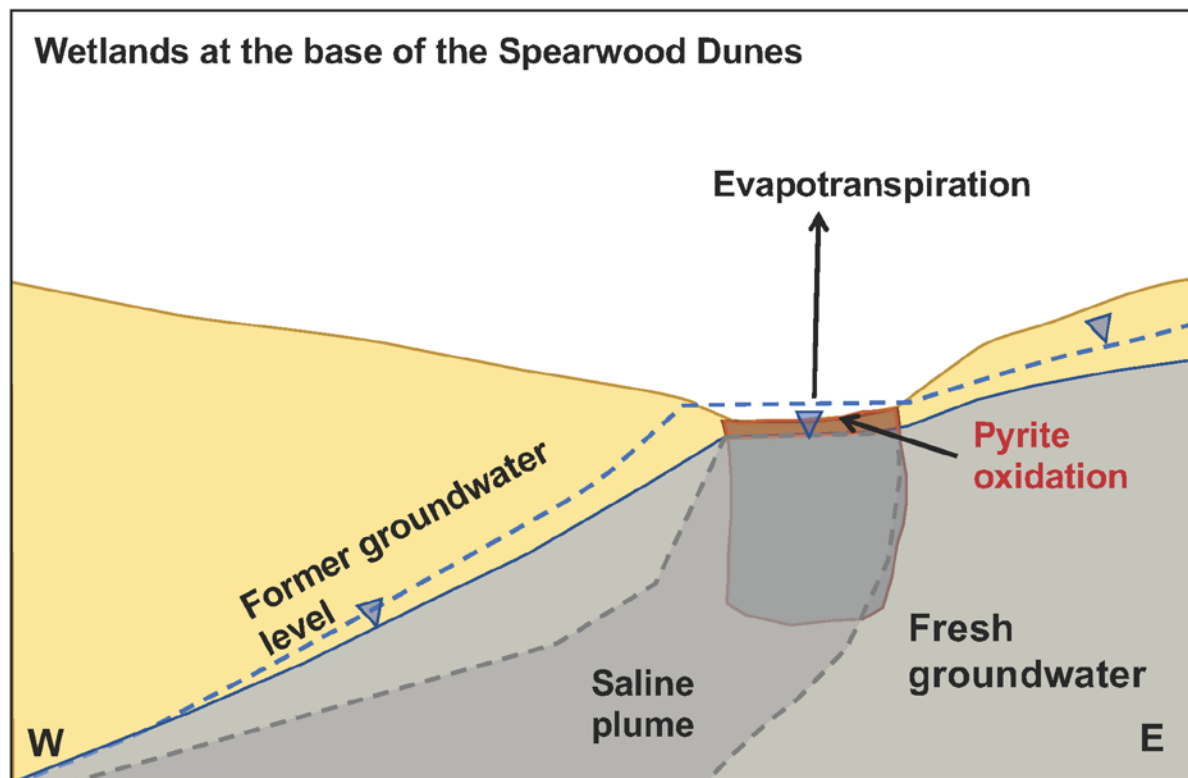


Figure 4.9 Conceptual model of the flowthrough wetlands located between the Spearwood Dunes and Yoongarillup Plain on the Tamala Limestone

4.2.3 Salinity due to direct agricultural practices

Several agricultural practices were previously thought to be responsible for increased salinity in the Myalup aquifer, including fertiliser application, recirculation of groundwater and groundwater abstraction causing intrusion of more-saline groundwater that occurs at depth. The results from this investigation show these are not the major sources of salinity. For example, nitrogen and potassium concentrations found in the groundwater indicate some fertiliser inputs but these are not a major source of contamination across most of the aquifer. However, high nutrient concentrations do exist in areas of the Yoongarillup Plain with shallow groundwater and low hydraulic gradients, such as in the Lake Preston South GWSA, west of the Forrest Highway. In these areas, growers had mainly sited their bores or excavations on the western perimeters of their properties, downgradient of the groundwater flow. In addition, because of the sandy soils in the Myalup region, growers use overhead irrigation to ensure adequate coverage of water to crops, which leads to increased evapotranspiration and concentration of solutes in irrigation return water.

In these areas, with shallow groundwater and low hydraulic gradients, applications of large amounts of irrigation water could lead to a build-up of salinity in the root-zone water that is then flushed to the groundwater, leading to an increase in groundwater salinity. The recirculation of groundwater is further exacerbated by the siting of pumps downgradient of the crops. A conceptual model of this process is outlined in Figure 4.10.

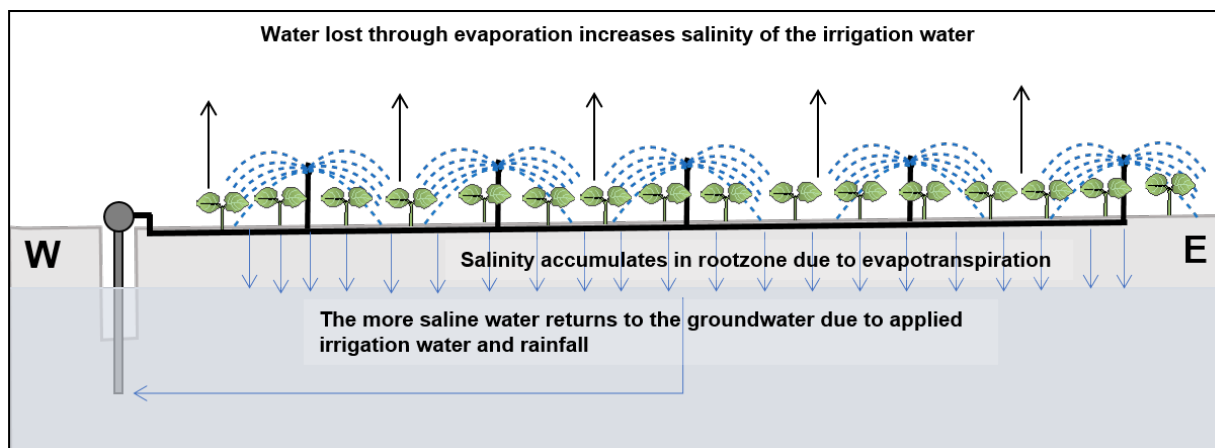


Figure 4.10 Conceptual model of increased salinity caused by irrigation

The areas where increased salinity caused by irrigation occurred also had high nitrogen concentrations in the groundwater. Recirculation of irrigation water could have also contributed to the high nitrogen levels in these locations (Figure 3.29). These areas also grew leguminous lucerne crops between 1963 and 2010 which could have contributed to high nitrate concentrations in the groundwater. Additionally, urine from the livestock grazing could also have contributed to the nitrates in the groundwater.

In most areas of the Myalup aquifer, the salinity of the groundwater increases with depth (Figure 3.7, Table 3.5). From the interpreted AEM data, saline plumes from wetlands can occur at depth as a result of the higher density of the saline groundwater. When irrigators abstract water from the aquifer, particularly if abstracting large volumes of water or using deeper bores, they can draw up the deeper more-saline water into the pumps, particularly near the saltwater interface. This leads to an increase in salinity in the upper aquifer.

A conceptual model of this process is shown in Figure 4.11. Because of the potential detrimental impacts this process can have on crops, growers in the Myalup region mainly irrigate from shallow excavations and bores.

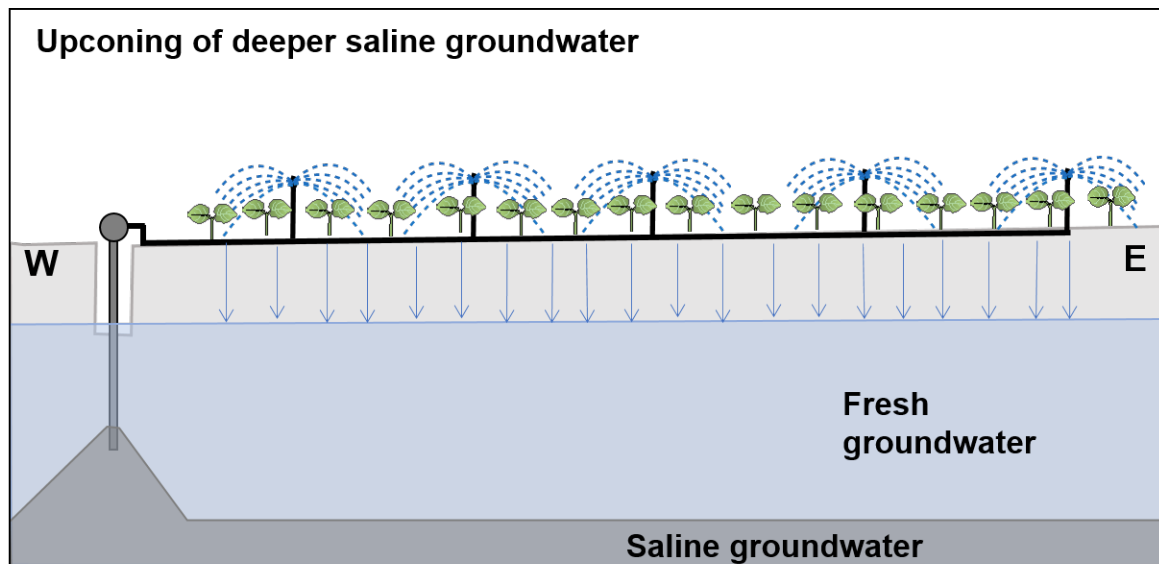


Figure 4.11 Conceptual model of inverting salinity caused by irrigation

Several processes contribute to increased salinity in the Myalup aquifer and this section presented conceptual models to explain these processes. In the next section the dominant processes causing the increased salinity in the Myalup aquifer are explained.

4.3 The dominant salinity processes and spatial variability

Statistical analysis of salinity trends for the irrigated agriculture sites, using groundwater licensee data, found only 30 out of 140 sites had increased salinity. Furthermore, an additional six sites had decreased salinity (Table 3.2). Out of the 30 sites with increased salinity, increased sulfate concentrations (attributed to pyrite oxidation) were the dominant driver of the salinity increase at 19 sites (63%) (Figure 3.5 and Figure 3.6). At nine sites (30%) the major ions were increasing at roughly equal rates and recirculation of groundwater (Figure 4.10) was considered the main reason for the increase in salinity at these sites. At the last two sites (7%) with increased salinity, chloride concentrations were increasing relative to other ions and this was attributed to intrusion of more-saline groundwater. This has occurred in an area where the saltwater interface was shallow, possibly as a result of the influence of salt lakes, such as Lake Josephine (Figure 3.7). The areas where these processes occurred are shown in Figure 4.12.

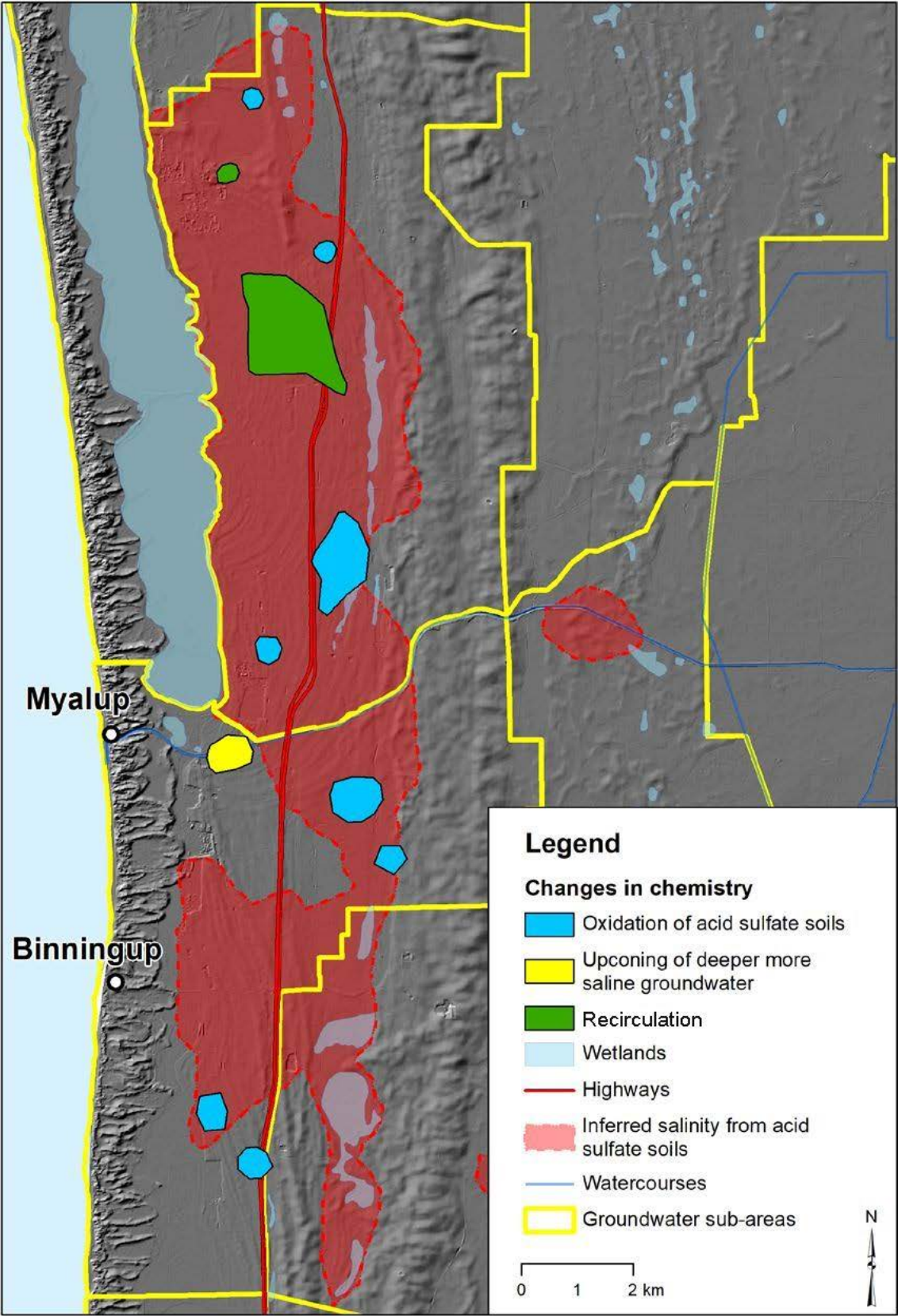


Figure 4.12 The dominant salinity processes in areas with increased salinity

The influence of acid sulfate soil oxidation was evident in the data, with declining chloride to sulfate ratios indicating pyrite oxidation is a major contributor to salinity. In the Perth shallow groundwater investigations, sites were deemed to be affected by pyrite oxidation if the chloride to sulfate ratios were less than two (Clohessy 2012) and we used the same benchmark. Of the 140 sites investigated for salinity trends, 72% had chloride to sulfate ratios less than two and were therefore considered to be affected by pyrite oxidation in acid sulfate soils (Figure 4.12). At 40% of these sites sulfate was the dominant anion by mass. Therefore, in the agricultural areas, the dominant source of salinity was from the salts of pyrite oxidation. This process was most evident near wetlands (Figure 4.9), but may have also occurred as a result of watertable decline across the region because pyrite occurs in the aquifer (Degens 2009a). The oxidation of pyrite and evapoconcentration have also occurred in areas that have not been subject to irrigated agriculture, such as wetlands in the Kemerton Industrial Park (Figure 4.5).

Rising groundwater salinity during the 1980s in the saline area east of bore 6-84 and south of Forestry Road (Figure 4.2) was one of the main reasons for salinity concern in the Myalup region. The increase in salinity was originally attributed to evapoconcentration (URS 2009). However, the increase in salinity was also coupled with a change in groundwater composition where calcium and sulfate became the dominant species by mass (Figure 2.2, Figure 2.3 d–g, Appendix H). Therefore, the source of calcium and sulfate, which was responsible for the increasing salinity, was pyrite oxidation and calcite dissolution in the wetlands to the east and upgradient of the property.

Like other areas on the Swan Coastal Plain, the Myalup region has experienced declining rainfall since the late 1970s. Other areas of the Swan Coastal Plain, particularly around Perth, have also experienced declining water levels in wetlands and subsequent pyrite oxidation. As a consequence, many wetlands around Perth have become acidified (Bourke et al. 2015, Clohessy 2012, Searle et al. 2011). Declining water levels in wetlands in the Myalup region have been exacerbated by groundwater abstraction and the planting of pines in dunes that form the recharge areas. Paradoxically, while there has been widespread pyrite oxidation, there has been only localised acidification (Figure 3.5) because the limestone aquifer neutralises the acidity. Consequently, the pyrite oxidation is mainly causing salinity issues.

In other localised areas the recirculation of groundwater is the main process increasing salinity. Groundwater recirculation tends to be associated with intensive irrigation in areas with shallow watertables (Figure 4.2, Figure 4.12). Where the watertable is deeper, the time taken for recharge to move through the unsaturated zone is longer and possibly different irrigation practices provide sufficient time for solutes to be flushed.

The intrusion of more-saline water has occurred in one area between Lake Preston and Myalup Swamp (Figure 4.12). In Figure 3.7, shallow highly saline groundwater from salt lakes is evident in the locality. Irrigators may have drawn this more-saline groundwater into the pumps through overabstraction. The lower reaches of the Harvey River Diversion Drain is a window to saline groundwater from salt lakes, and pumping could have drawn in water from the drain.

For the most part, irrigators have avoided low-lying areas where historically there has been salinity. However, where there has been groundwater abstraction in these low-

lying areas, monitoring data shows that the salinity levels fluctuate (Figure 2.3 a–c, Figure 4.2). In addition, there is no evidence in the licensee data of movement of the saltwater interface between the hypersaline groundwater beneath Lake Preston and the superficial aquifer, except in one area shown in Figure 4.12. Therefore, movement of the saltwater interface does not appear to be a major source of salinity.

4.3.1 Changes in water type along the groundwater flow path

Multiple geochemical processes contribute to increased salinity in the Myalup aquifer. Groundwater moving along the flow path is subject to different geochemical processes between the recharge and discharge areas, and this makes modelling changes in solutes and salinity difficult. Changes in water quality, water type and chemical processes along the groundwater flow paths for the Lake Clifton bore transects E, F and G are shown in Appendix H.

Water quality is fresh in the Bassendean Sand and Spearwood Dunes, with TDS less than 500mg/L. The main geochemical processes in these dune systems are the weathering and dissolving of limestone (calcite dissolution) and the main water type is Na-Ca-Cl-HCO₃. As groundwater moves across the wetlands at the base of the Spearwood Dunes, salinity increases and the water type changes to Na-Ca-Cl-SO₄ because of pyrite oxidation and evapoconcentration. In transect F, bore F5 shows evidence of pyrite oxidation, while bores F4 and F3 located downgradient of Myalup Swamp only show evidence of evapoconcentration. This suggests pyrite oxidation is a recent occurrence. Pyrite oxidation being a recent process is further evidenced by changes in water quality in bore G4. Pyrite oxidation was only evident in bore G4 in the 2016 sampling, not any of the previous samplings (1996 and earlier).

Further downgradient of the wetlands, the groundwater below the saline plumes can exhibit a signature typical of a limestone aquifer, with Na-Ca-Cl-HCO₃ type water, as found in bore G2. However, when the groundwater is influenced by the saltwater interface, it exhibits a Na-Cl marine signature (bore E1).

The groundwater in the superficial aquifer is influenced by several complex processes, which cause changes in water quality and water type. Most of the processes are natural, but have been exacerbated by a changing climate, groundwater abstraction and forestry in the recharge areas. Thirty of the 140 sites are increasing in salinity, with different processes causing the salinity. Irrigated agriculture has probably affected water quality in some areas, but it is not the dominant process. However, the longer-term salinity risks for irrigated agriculture in the Myalup region are uncertain.

4.4 Longer-term risks of salinity to agriculture

Areas of the MIAP increased in salinity through the 1980s and these areas provide insight into the likely future salinity trends for other areas in the region. An area south of Forestry Road and east of Forrest Highway (see the saline plume east of bore 6-84 in Figure 4.2) increased in salinity until the mid-1990s, but from 2006 until 2016 the groundwater fluctuated around an equilibrium (Figure 4.13, bore PGW-31 in Appendix H).

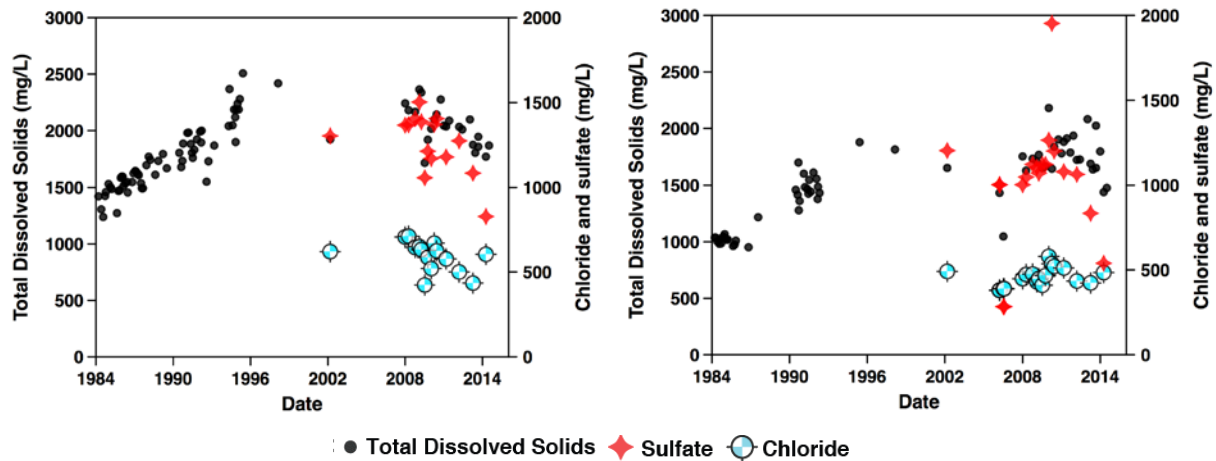


Figure 4.13 Salinity trends in the saline plume east of bore 6-84 (see Figure 4.2)

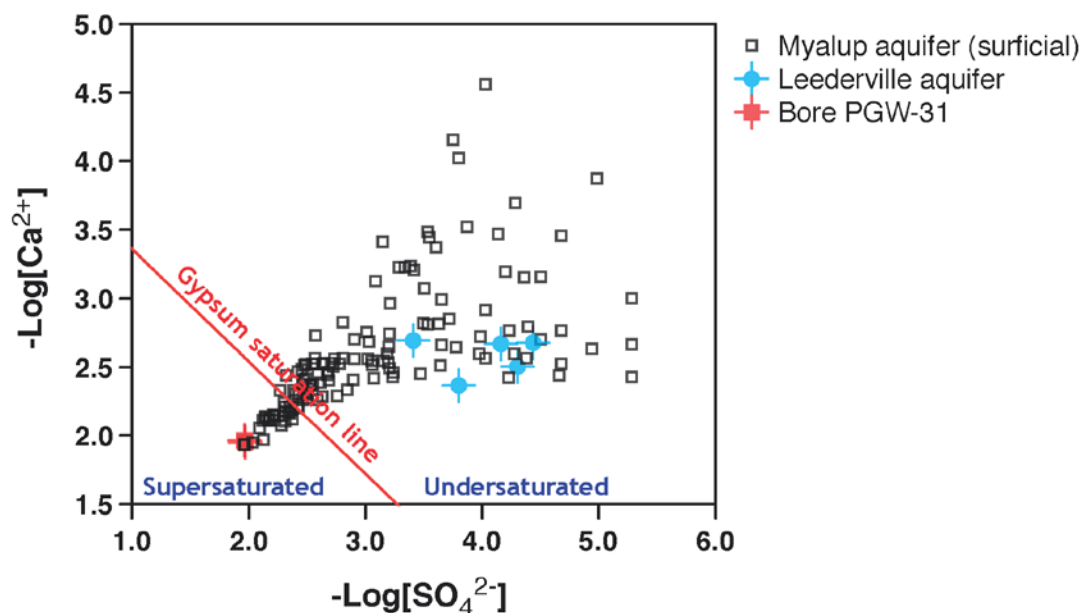
The salinity increase in the groundwater in the area was due to increasing calcium and sulfate concentrations (bore PGW-31 in Appendix H) resulting from pyrite oxidation and calcite dissolution (equations 2.1 and 2.2). However, chloride and sodium remained relatively constant, indicating that evapotranspiration had little influence on the groundwater salinity.

Calcium and sulfate will precipitate as gypsum when concentrations become sufficiently high (equation 4.1).



The saturation index of gypsum, which indicates the likelihood of gypsum precipitating, was calculated for bore PGW-31 and other bores sampled (Figure 4.14). Many bores, including bore PGW-31, were supersaturated with respect to gypsum, and gypsum would therefore be precipitating in these areas. Consequently, gypsum precipitation is the likely control on TDS and the reason for TDS fluctuating around an equilibrium. Therefore, where the salinity increase is being driven by pyrite oxidation and calcite dissolution, TDS will keep increasing until gypsum saturation⁴ is reached and then TDS will reach an equilibrium, as observed in bore PGW-31.

⁴ Groundwater becomes saturated with respect to gypsum when calcium concentrations reach 200mg/L and sulfate concentrations reach 480mg/L.



Note: The red line is the gypsum saturation line. Gypsum is undersaturated to the right of the line, and supersaturated to the left of the line.

Figure 4.14 Gypsum saturation for groundwater bores

Even though bore PGW-31 has high salinities (about 2000mg/L TDS) the water is still used to irrigate salt-sensitive crops, such as carrots. This is possible because the chemical composition of the irrigation water, as well as salinity, affects crops. The groundwater salinity at bore PGW-31 is mainly due to sulfate salts, which have lower toxicity on plants than chloride and sodium, and concentrations of chloride and sodium are below the critical thresholds for irrigated crops at bore PGW-31 (ANZECC & ARMCANZ 2000). Additionally, with irrigation only occurring during winter months on the sandy soils, there might be adequate drainage where any build-up of salts may be able to be leached below the root zone with sufficient watering (Ayers & Westcot 1985). However, salinity still constrains production and limits the type of crops that can be grown. Successful production does and will continue to need careful management of salinity risks.

In the future, in areas with groundwater salinity caused mainly by sulfate type waters, moderately chloride-sensitive crops, such as carrots and potatoes, may be able to be grown. Higher salinity groundwater, with careful management, may be able to be used because of the low to zero toxicity of sulfate and the ability to leach salinity below the root zone.

However, where sulfate and chloride are both increasing, for example wetlands (Figure 4.6, Figure 4.7, Figure 4.8), there could be future constraints on irrigated agriculture. Increasing chloride, and consequently sodium, have toxic effects on crops. Therefore, careful management of the groundwater resource is required.

5 Conclusion

Early investigations showed there was considerable spatial and temporal variability of salinity in the Myalup aquifer, with increasing groundwater salinity in some areas of Myalup region over the last 30 years, particularly under the irrigated agriculture areas. Possible reasons for the increasing salinity in these areas were thought to be: recycling of irrigation return water, the application of fertiliser, oxidation of sulfides in shallow acid sulfate soils, upconing of deeper more-saline groundwater, and saltwater intrusion from adjoining salt lakes or seawater.

To better understand the controls on salinity in the Myalup aquifer, groundwater licensee water quality data from nearly 200 sites were collated and analysed. The analysis was complemented with two phases of groundwater sampling across the Myalup region, using a broad range of water quality parameters.

Results showed that water quality was good (TDS less than 500mg/L) on the Bassendean Sand and the Spearwood Dunes, and increased to 1000mg/L in the Tamala Limestone where most of the irrigated agriculture and increased salinity occurred. The salinity of groundwater also increased with depth towards the base of the aquifer.

The licensee and groundwater sampling data showed there were multiple geochemical processes contributing to the increased salinity along the groundwater flow path in the Myalup aquifer. Statistical analysis of salinity trends at sites with irrigated agriculture, using groundwater licensee data (140 sites out of 200), determined the extent of increased salinity in the Myalup aquifer. Only 30 of the 140 sites showed increased salinity, while six sites showed decreased salinity. Within the sites showing increased salinity, oxidation of pyrite in acid sulfate soils was the dominant source of salinity at 19 sites (63% of 30 sites). In two localised areas (nine sites), recirculation was shown to be the main salinity process, and intrusion of saline groundwater was the main process in one locality (two sites).

Pyrite oxidation, the source of sulfate, was therefore the main cause of increased salinity across most of the agricultural area. About three-quarters of irrigated agriculture licensee sites were considered to be affected by pyrite oxidation and in 40% of the sites, sulfate was the principle component of TDS. The pyrite oxidation is associated with acid sulfate soils, which are mainly concentrated in wetlands that have been gradually drying, although they occur extensively in the Myalup region.

The wetlands act as windows to the groundwater and where the groundwater is exposed to the atmosphere, greater water losses occur through increased evaporation. This also results in increased salinity in the groundwater. Consequently, groundwater salinity was higher downgradient of wetlands, such as Myalup Swamp and Mialla Lagoon. However, water levels in the wetlands have declined over the last 20 years. Additionally, groundwater levels have declined across the Myalup region with a greater decline under native vegetation and forestry (average decline of 0.63m) than agricultural land uses (average decline of 0.47m). The regional decline is considered to be primarily due to decreasing rainfall, as well as being exacerbated by groundwater abstraction and pine plantations in recharge areas. The decline in water levels in the wetlands has led to increased evapotranspiration and pyrite oxidation in the wetlands,

contributing to increased salinity in the aquifer. These processes have also occurred in wetlands under native vegetation.

The salinity effects from oxidising acid sulfate soils are likely to be self-limiting. Pyrite oxidation in the Myalup region is accompanied by the dissolution of calcite, which leads to increased concentrations of calcium and sulfate in the groundwater. When the concentrations of calcium and sulfate become too high, they precipitate out as gypsum. In the area where gypsum is precipitating, salinity due to sulfate has stabilised and fluctuates around an equilibrium. In addition, since sulfate salts have a lower toxicity on plants, it has enabled growers in these areas to use higher salinity water (greater than 2000mg/L TDS) to irrigate crops. However, using such water has required careful management, such as only irrigating during winter so salinity is diluted by rainfall. Additionally, because of the sandy soils in these areas, salinity has had lesser impact on agricultural production because any accumulated salts could be leached below the root zone. However, where sulfate is precipitating as gypsum, salinity still constrains production and careful continued monitoring and management of the groundwater resource is required.

In localised areas of the MIAP recirculation of groundwater due to irrigation practices was the main cause of increased salinity. Groundwater recirculation occurs in areas with a shallow watertable, high irrigation rates and a low hydraulic gradient. While nitrogen and excess potassium (from fertilisers) were found in the groundwater, this was not a major source of contamination across most of the aquifer, except in areas where there was recirculation of groundwater. The high concentration of nitrogen in the groundwater in affected areas may also have resulted from previous land uses, such as growing lucerne, which is a legume, and intensive livestock (sheep) production.

The intrusion of more-saline groundwater leading to salinisation of the upper aquifer was observed in only one area south-east of Lake Preston where saline groundwater was shallow because of a salt lake in the vicinity. This saline intrusion was also adjacent to the Harvey River Diversion Drain, which intercepts the shallow saline groundwater from the salt lakes and saline water could have been drawn in from the drain. Apart from this example, there was no evidence of movement of the saltwater interface between the hypersaline groundwater beneath Lake Preston and the superficial aquifer. The movement of the saltwater interface therefore appears to be only a minor source of salinity risk to growers.

6 Recommendations

Based on the findings of our investigation in the Myalup region, we recommend the following to better understand and manage the salinity processes into the future:

- Re-establish the multiport bores required to confirm there has only been limited movement of the saltwater interface and to allow further monitoring.
- Continue the licensee water quality monitoring and re-evaluate licensee data in 2020 for trends in water quality data.
- Replace TDS with chloride as a management trigger in groundwater allocation planning and licensing. Chloride is a major limiting factor for crop growth and an indicator of processes, such as the movement of the saltwater interface and evapoconcentration of solutes.
- Establish a uniform set of water quality parameters to be used by all groundwater licensees: groundwater quality samples are collected from production or monitoring bores, rather than excavations, to ensure groundwater conditions are being measured; electrical conductivity and pH are measured quarterly; and TDS (by gravimetry), sulfate, chloride, total phosphorus, total nitrogen, total oxidised nitrogen (NO_x) and ammonia are measured annually.
- Investigate the feasibility of clearing pines and pumping drainage water into the wetlands at the base of Spearwood Dunes as part of the Myalup Primary Industries Reserve project to minimise pyrite oxidation and salinity risks, restore environmental values to the wetlands and provide additional water sources for agricultural expansion.

Appendices

A Groundwater sampling sites

B Analytical methods and detection limits

C Groundwater quality from licensee monitoring (2007–15)

D Summary statistics of major ions and nutrients in surficial geological units

E Groundwater compared to aquatic ecosystem guidelines

F Suitability of groundwater for irrigation

G Groundwater chemistry analysis

H Change in groundwater chemistry through time

I Change in rainfall and groundwater levels

J Change in water quality and type along groundwater flow paths

Appendix A Groundwater sampling sites

Table A1 Location and details of the groundwater sampling sites

Site name	Site code	AWRC	Easting	Northing	Total depth (mBGL)	Geology	Water type	Sampling year
Lake Clifton C4	C4	61319138	378671	6357470	25	Tamala Limestone (Deep)	Na-Ca-Cl-HCO ₃	2016, 2017
Lake Clifton C8	C8	61319142	383198	6356962	40	Spearwood Dunes (Deep)	Na-Cl	2016
Lake Clifton D2	D2	61319145	379695	6346005	42	Tamala Limestone (Deep)	Na-Cl	2015, 2017
Lake Clifton D3A	D3A	61319146	380602	6345984	45	Tamala Limestone (Deep)	Na-Ca-Cl-SO ₄	2015, 2016, 2017
Lake Clifton D3B	D3B	61319147	380604	6345984	26	Tamala Limestone	Na-Ca-Cl-SO ₄ -HCO ₃	2015, 2016, 2017
Lake Clifton D4	D4	61319148	381616	6345998	35.5	Tamala Limestone	Ca-Na-Cl-HCO ₃	2015, 2017
Lake Clifton E2A	E2A	61319152	380958	6340487	40	Tamala Limestone (Deep)	Ca-Na-SO ₄ -Cl	2016, 2017
Lake Clifton E3A	E3A	61319154	381863	6340518	28	Tamala Limestone (Deep)	Ca-Na-SO ₄ -Cl	2015, 2016, 2017
Lake Clifton E3B	E3B	61319155	381864	6340548	19	Tamala Limestone	Ca-Na-SO ₄ -Cl	2016, 2017
Lake Clifton E4A	E4A	61319157	382823	6340530	38.5	Spearwood Dunes (Deep)	Na-Ca-Cl-HCO ₃	2015, 2016, 2017
Lake Clifton E4C	E4C	61319159	382817	6340534	15	Spearwood Dunes	Na-Ca-HCO ₃ -Cl-SO ₄	2015, 2016, 2017
Lake Clifton E5B	E5B	61319161	384024	6340686	12	Spearwood Dunes	Na-Ca-Cl-HCO ₃	2015, 2016, 2017
Lake Clifton E7	E7	61319163	386006	6340775	40	Bassendean Sand (Deep)	Na-Ca-Cl-HCO ₃	2016
Lake Clifton E8	E8	61319164	387671	6340611	34.5	Bassendean Sand (Deep)	Na-Ca-Mg-Cl-HCO ₃	2016
Lake Clifton F1	F1	61319165	378293	6331480	25	Safety Bay Sand	Na-Ca-Cl-HCO ₃	2016, 2017
Lake Clifton F2A	F2A	61319166	379089	6331548	30	Tamala Limestone (Deep)	Na-Ca-Cl-HCO ₃ -SO ₄	2016, 2017
Lake Clifton F2B	F2B	61319167	379175	6331529	10	Tamala Limestone	Na-Ca-Cl-SO ₄ -HCO ₃	2016, 2017
Lake Clifton F3	F3	61319168	380082	6331516	36	Tamala Limestone	Ca-Na-Cl-HCO ₃ -SO ₄	2016, 2017
Lake Clifton F4	F4	61319169	380935	6331543	15.8	Tamala Limestone	Na-Ca-HCO ₃ -Cl	2017
Lake Clifton F4E (deep)	F4E (D)	–	380995	6331547	–	Tamala Limestone (Deep)	Na-Ca-Cl-HCO ₃	2016
Lake Clifton F4E (shallow)	F4E (S)	–	380995	6331547	–	Tamala Limestone	Na-Ca-Cl-HCO ₃	2016
Lake Clifton F5	F5	61319170	381811	6331435	20	Lacustrine	Ca-Na-SO ₄ -Cl	2016, 2017

(continued)

Table A1 continued

Site name	Site code	AWRC	Easting	Northing	Total depth (mBGL)	Geology	Water type	Sampling year
Lake Clifton F6C (deep)	F6C (D)	–	382711	6331572	–	Spearwood Dunes (Deep)	Ca-Na-HCO ₃ -Cl	2016
Lake Clifton F6C (shallow)	F6C (S)	–	382711	6331572	–	Spearwood Dunes	Na-Mg-Cl-HCO ₃	2016
Lake Clifton F9A	F9A	61319235	380858	6332857	24.5	Tamala Limestone (Deep)	Na-Ca-Cl-HCO ₃ -SO ₄	2017
Lake Clifton F9C	F9C	61319236	380858	6332857	8	Tamala Limestone	Na-Ca-Cl-SO ₄	2017
Lake Clifton G2A	G2A	61319174	379441	6328509	25	Tamala Limestone (Deep)	Ca-Na-Cl-HCO ₃	2016, 2017
Lake Clifton G2B	G2B	61319175	379443	6328507	10.5	Tamala Limestone	Ca-Na-Cl-HCO ₃	2016, 2017
Lake Clifton G4	G4	61319179	381353	6328533	29	Tamala Limestone (Deep)	Ca-Na-Cl-SO ₄	2016, 2017
Lake Clifton G5	G5	61319180	382468	6328072	34.5	Spearwood Dunes (Deep)	Na-Ca-Cl-HCO ₃	2016, 2017
Lake Clifton G7	G7	61319182	384459	6328165	32	Bassendean Sand (Deep)	Na-Cl-SO ₄ -HCO ₃	2016
HS11A	HS11A	61330009	386439	6343991	39	Lacustrine	Ca-Na-Cl-HCO ₃	2015
HS11B	HS11B	61330010	386439	6343991	6.6	Lacustrine	Na-Mg-Cl	2015
HS13A	HS13A	61330013	386410	6348827	39	Bassendean Sand (Deep)	Ca-Na-HCO ₃ -Cl	2015, 2017
HS13B	HS13B	61330014	386410	6348827	9	Bassendean Sand	Ca-Na-Cl-HCO ₃	2015, 2017
HS15A	HS15A	61330017	386279	6352489	31	Bassendean Sand (Deep)	Na-Ca-Cl-HCO ₃	2015
HS15C	HS15C	61330018	386273	6352489	5.7	Bassendean Sand	Na-Ca-HCO ₃ -Cl	2015
HS1B	HS1B	61230002	382447	6324323	33	Spearwood Dunes	Na-Ca-Cl-HCO ₃	2015
HS64A	HS64A	61330108	381904	6352254	34.5	Tamala Limestone (Deep)	Ca-Na-Cl-HCO ₃	2015, 2017
HS64C	HS64C	61330111	381904	6352254	27.5	Tamala Limestone	Ca-Na-Cl-HCO ₃	2015, 2017
HS8B	HS8B	61330002	386352	6338076	14	Bassendean Sand	Na-Cl	2015
HS8C	HS8C	61330003	386352	6338076	6	Bassendean Sand	Ca-Na-Mg-Cl-SO ₄ -HCO ₃	2015
Bore (110)	PGW-1	–	382102	6333417	–	Lacustrine	Ca-Na-HCO ₃ -Cl	2016
C3.1	PGW-10	–	380246	6343705	5.3	Tamala Limestone	Ca-Na-Cl-SO ₄	2016, 2017
C4.4	PGW-11	–	380775	6344235	–	Tamala Limestone	Ca-Na-Cl-SO ₄	2016

(continued)

Table A1 continued

Site name	Site code	AWRC	Easting	Northing	Total depth (mBGL)	Geology	Water type	Sampling year
C5.A1	PGW-12	–	381555	6344740	–	Tamala Limestone	Ca-Na-SO ₄ -HCO ₃ -Cl	2016
C5.A2	PGW-13	–	379356	6328879	5.66	Tamala Limestone	Ca-Na-SO ₄ -HCO ₃ -Cl	2017
MB2 (305)	PGW-14	–	380535	6329900	–	Tamala Limestone	Ca-Na-Mg-SO ₄ -Cl-HCO ₃	2016
MB4 (2)	PGW-15	–	379357	6328880	6.5	Tamala Limestone	Ca-Na-Cl-HCO ₃	2016, 2017
West bore (61)	PGW-16	–	382005	6334729	14	Tamala Limestone	Ca-Na-SO ₄ -Cl	2016, 2017
Green ford	PGW-17	–	379960	6332634	–	Tamala Limestone	Ca-Na-Cl-SO ₄ -HCO ₃	2016
Bore (24)	PGW-18	–	379885	6334237	–	Tamala Limestone	Na-Cl-HCO ₃	2016
Shorties (M1)	PGW-19	–	380246	6332192	–	Tamala Limestone	Na-Ca-Cl-SO ₄ -HCO ₃	2016
Bore C2	PGW-2	–	379385	6351479	17	Lacustrine (Lake Preston)	Na-Ca-Cl-HCO ₃	2016, 2017
West bore (2417)	PGW-20	–	379786	6346194	–	Tamala Limestone	Na-Ca-Cl-SO ₄	2016
SE bore (7)	PGW-21	–	380379	6326124	–	Tamala Limestone	Na-Ca-Cl-HCO ₃	2016
Tank bore	PGW-22	–	381469	6350211	–	Tamala Limestone	Ca-Na-Cl-SO ₄	2016
Bore 2 (5)	PGW-23	–	380492	6337692	–	Tamala Limestone	Ca-Na-SO ₄ -Cl-HCO ₃	2016
Carrot bore (5)	PGW-24	–	380419	6337568	12	Tamala Limestone	Ca-Na-Cl-SO ₄ -HCO ₃	2017
Pump 1 (6)	PGW-25	–	379524	6331600	4.05	Tamala Limestone	Ca-Na-Cl-SO ₄	2017
Windmill bore	PGW-26	–	380275	6341615	4.6	Tamala Limestone	Ca-Na-Cl-SO ₄	2016, 2017
Bore 7 (4424)	PGW-27	–	381571	6338320	–	Tamala Limestone	Ca-Na-SO ₄ -Cl	2016, 2017
MB (4424)	PGW-28	–	382134	6338451	23.5	Tamala Limestone	Ca-Na-Cl-HCO ₃ -SO ₄	2016, 2017
Bore 8 (Carrots)	PGW-29	–	381413	6339254	–	Tamala Limestone	Ca-Na-SO ₄ -Cl-HCO ₃	2016
Bore 6 (2417)	PGW-3	–	380927	6346678	–	Lacustrine (Lake Preston)	Na-Ca-Cl-HCO ₃	2016
MB3 (14)	PGW-30	–	380309	6328459	–	Tamala Limestone	Na-Ca-Cl-HCO ₃	2016, 2017
G3 (2)	PGW-31	61319211	381677	6340080	–	Tamala Limestone	Ca-Na-SO ₄ -Cl	2016, 2017
NW bore (3)	PGW-32		380834	6335571	–	Tamala Limestone	Ca-Na-Cl-SO ₄ -HCO ₃	2016
SE bore 2	PGW-33		377797	6355611	15.5	Tamala Limestone	Na-Ca-Cl	2016, 2017

(continued)

Table A1 continued

Site name	Site code	AWRC	Easting	Northing	Total depth (mBGL)	Geology	Water type	Sampling year
Bore (Dom.)	PGW-34	61319203	379678	6326349	–	Tamala Limestone	Na-Ca-Cl-SO ₄	2016
Timber mill bore	PGW-35	–	380827	6332919	–	Tamala Limestone	Na-Ca-Cl-SO ₄	2016
MB-N (2)	PGW-36	–	384964	6352144	–	Bassendean Sand	Na-Mg-Cl-SO ₄	2016
PB1 (1238)	PGW-4	–	382665	6339226	–	Spearwood Dunes	Na-Ca-Cl-HCO ₃	2016
MB (23)	PGW-5	–	382423	6335322	–	Spearwood Dunes	Na-Ca-SO ₄ -Cl	2016
Bore 3 (EB)	PGW-6	–	381088	6348618	–	Tamala Limestone	Na-Ca-Cl-HCO ₃	2016
NB (6)	PGW-7	–	381813	6342300	–	Tamala Limestone	Ca-Na-SO ₄ -Cl	2016
House pump	PGW-8	–	379087	6332213	–	Tamala Limestone	Ca-Na-Cl-SO ₄	2016
C1.1	PGW-9	–	380258	6342670	–	Tamala Limestone	Na-Ca-Cl-SO ₄	2016
PB NE	PGW-L1	–	380309	6328459	–	Leederville	Na-Ca-Cl-HCO ₃	2016
PB	PGW-L2	–	382580	6333823	–	Leederville	Na-Ca-Cl-HCO ₃	2016
Bore (4424)	PGW-L3	–	381791	6338584	–	Leederville	Ca-Na-Cl-HCO ₃	2016
NE bore (53)	PGW-L4	–	381300	6334030	–	Leederville	Na-Ca-Cl-HCO ₃	2016
G1 (2)	PGW-L5	–	381451	6340072	–	Leederville	Ca-Na-Cl-HCO ₃	2016
NE-Ex (14)	SW-1	–	380262	6328439	–	Surface	Na-Ca-Cl-HCO ₃	2016
Myalup Drain (1)	SW-2	–	381456	6336218	–	Surface	Na-Mg-Cl	2016
Myalup Drain (2)	SW-3	–	388141	6337393	–	Surface	Na-Mg-Cl-HCO ₃	2016
Y4-1A	Y4-1A	61319520	379648	6340461	8.45	Tamala Limestone	Na-Cl	2015, 2016, 2017
Y4-2A	Y4-2A	61319521	380970	6340502	17.5	Tamala Limestone	Ca-Na-Cl-SO ₄	2015, 2017
Y4-3B	Y4-3B	61319522	381889	6340518	19	Tamala Limestone	Ca-Na-Cl-SO ₄ -HCO ₃	2015
Y4-3C	Y4-3C	61319523	381889	6340518	12	Tamala Limestone	Ca-Na-Cl-SO ₄	2015
Y4-4B	Y4-4B	61319524	382823	6340530	30	Spearwood Dunes	Na-Ca-Cl	2015

– = no data

Appendix B Analytical methods and detection limits

Table B1 Analytical methods and detection limits for groundwater samples sent for laboratory analysis

Analyte	Method code	Description	Limit of reporting	Unit
Acidity, as CaCO ₃	iACID1WATI	Acidity by titration (APHA 2310B)	2	mg/L
Alkalinity, total	iALK1WATI	Alkalinity (as CaCO ₃) and constituents by acid titration (APHA 2320B)	1	mg/L
Aluminium	iMET1WCICP	Total dissolved metals by inductively coupled plasma atomic emission spectroscopy (ICPAES) (APHA 3120)	0.005	mg/L
Antimony	iMET1WCMS	Total dissolved metals by inductively coupled plasma mass spectroscopy (ICPMS) (APHA 3125)	0.0001	mg/L
Arsenic	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.001	mg/L
Boron	iMET1WCICP	Total dissolved metals by ICPAES (APHA 3120)	0.02	mg/L
Boron	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.005	mg/L
Barium	iMET1WCICP	Total dissolved metals by ICPAES (APHA 3120)	0.002	mg/L
Barium	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.0001	mg/L
Beryllium	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.0001	mg/L
Bicarbonate	iALK1WATI	Alkalinity (as CaCO ₃) and constituents by acid titration (APHA 2320B)	1	mg/L
Bismuth ^a	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.0001	mg/L
Bromide	iBRLow1WAIC	Low level bromide in water by ion chromatography (APHA 4110B)	0.02	mg/L
Carbonate	iALK1WATI	Alkalinity (as CaCO ₃) and constituents by acid titration (APHA 2320B)	1	mg/L
Cadmium	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.0001	mg/L
Calcium	iMET1WCICP	Total dissolved metals by ICPAES (APHA 3120)	0.1	mg/L
Chloride	iCO1WCDA	Colorimetric analysis by discrete autoanalyser (DA) (APHA and in-house methods)	1	mg/L
Chromium	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.0005	mg/L
Cobalt	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.0001	mg/L
Copper	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.0001	mg/L
Dissolved organic carbon	iCTO1WDCO	Dissolved organic carbon (DOC), dissolved non-purgeable organic carbon (DNPOC) or total dissolved carbon (DTC) by combustion (APHA 5310 B)	1	mg/L

(continued)

Table B1 continued

Analyte	Method code	Description	Limit of reporting	Unit
Electrical conductivity	iEC1WZSE	Electrical conductivity in water compensated to 25°C (APHA 2510B)	0.2	mS/m
Fluoride	iF1WASE	Fluoride in water by ion specific electrode (ISE) (APHA 4500F-C)	0.05	mg/L
Gallium	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.0001	mg/L
Hardness, total	iHTOT2WACA	Total hardness as CaCO ₃ by calculation from calcium and magnesium (APHA 2340 B)	1	mg/L
Hydroxide	iALK1WATI	Alkalinity (as CaCO ₃) and constituents by acid titration (APHA 2320B)	1	mg/L
Iron	iMET1WCICP	Total dissolved metals by ICPAES (APHA 3120)	0.005	mg/L
Lanthanum ^a	iMET1WCICP	Total dissolved metals by ICPAES (APHA 3120)	0.005	mg/L
Lanthanum ^a	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.0001	mg/L
Lead	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.0001	mg/L
Lithium	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.0001	mg/L
Magnesium	iMET1WCICP	Total dissolved metals by ICPAES (APHA 3120)	0.1	mg/L
Manganese	iMET1WCICP	Total dissolved metals by ICPAES (APHA 3120)	0.001	mg/L
Manganese	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.0001	mg/L
Mercury	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.0001	mg/L
Molybdenum	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.001	mg/L
Nickel	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.001	mg/L
Nitrogen, ammonia	iAMMN1WFIA	Ammonia expressed as nitrogen by automated flow injection analysis colorimeter (FIA) (APHA 4500NH3-H)	0.01	mg/L
Nitrogen, nitrate	iNTAN1WCALC	Nitrate expressed as nitrogen by FIA (APHA 4500NO3-I)	0.01	mg/L
Nitrogen, nitrate + nitrite	iNTAN1WFIA	Nitrate + nitrite expressed as nitrogen by FIA (APHA 4500NO3-I)	0.01	mg/L
Nitrogen, nitrite	iNTRN1WFIA	Nitrite expressed as nitrogen by FIA (APHA 4500NO3-I)	0.01	mg/L
Nitrogen, total	iNP1WTFIA	Total nitrogen by persulfate digestion and analysis by FIA (APHA 4500N-C,I)	0.01	mg/L
pH	iPH1WASE	pH in water by pH meter (APHA 4500H+)	0.1	

(continued)

Table B1 continued

Analyte	Method code	Description	Limit of reporting	Unit
Phosphorus, soluble reactive	iP1WTFIA	Phosphorus soluble reactive as phosphorus in water by FIA (APHA 4500P-G)	0.01	mg/L
Phosphorus, total	iPP1WTFIA	Total phosphorus by persulphate digestion and FIA (APHAP-J,G)	0.005	mg/L
Potassium	iMET1WCICP	Total dissolved metals by ICPAES (APHA 3120)	0.1	mg/L
Selenium	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.0001	mg/L
Silica (from silicon)	iMET1WCMS	Total dissolved metals by ICPAES (APHA 3120)	0.001	mg/L
Silver	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.0001	mg/L
Sodium	iMET1WCICP	Total dissolved metals by ICPAES (APHA 3120)	0.1	mg/L
Sulfate (from sulfur)	iMET1WCICP	Total dissolved metals by ICPAES (APHA 3120)	0.1	mg/L
Thallium	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.0001	mg/L
Tin	iMET1WCICP	Total dissolved metals by ICPMS (APHA 3125)	0.1	mg/L
Titanium	iMET1WCICP	Total dissolved metals by ICPAES (APHA 3120)	0.002	mg/L
Total dissolved solids (gravimetry)	iSOL1WDGR	TDS by gravimetry, dried at 178–182°C	10	mg/L
Total dissolved solids (summation)	ixTDS_Sum	TDS by summation of major ions (APHA 1030 E)	1	mg/L
Uranium	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.0001	mg/L
Vanadium	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.0001	mg/L
Zinc	iMET1WCMS	Total dissolved metals by ICPMS (APHA 3125)	0.001	mg/L
Atrazine ^a	ORG013W	Pesticides by liquid chromatography – quadruple linear ion traps (LC-QTRAP) (Kinetex, ph3-MeOH)	0.1	µg/L
Methyl isothiocyanate ^a	ORG013W	Pesticides by LC-QTRAP (Kinetex, ph3-MeOH)	0.1	µg/L
Metolachlor ^a	ORG002W	Volatile organic compound in water by purge and trap gas chromatography–mass spectrometry	1	µg/L
Metalaxyl ^a	ORG013W	Pesticides by LC-QTRAP (Kinetex, ph3-MeOH)	0.1	µg/L

CaCO₃ = calcium carbonate

a All samples were below the limit of reporting.

Appendix C Groundwater quality from licensee monitoring (2007–15)

Table C1 Summary statistics for the major water quality parameters for the Myalup licensee data

Parameter	Unit	Count	Mean	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Nitrogen (nitrate)	µg/L	361	1 700	200	7 000	0	97 000	100	500
Field TDS (from EC)	µs/cm	279	1 764	1 650	691	498	3 870	1 150	2 444
Total acidity (in calcium carbonate)	mg/L CaCO ₃	235	31	27	22	1	98	11	50
Phosphorus (filterable reactive)	µg/L	221	61	10	255	2	2 700	5	40
Iron (soluble)	µg/L	220	1 950	450	9 580	20	130 000	140	1 200
Manganese	µg/L	163	349	38	2 207	5	20 520	9	50
Total alkalinity (in calcium carbonate)	mg/L CaCO ₃	140	101	38	108	6	320	14	230
Field pH		117	7.8	7.9	0.6	6.2	9.2	7.4	8.3
Cobalt	µg/L	114	25	10	19	5	50	10	50
Nickel	µg/L	109	15	5	19	5	70	5	50
Nitrogen (reduced)	µg/L	67	255	100	499	3	3 000	20	300
Copper	µg/L	65	21	10	21	5	50	5	50
TDS (unknown)	mg/L	53	1 420	1 100	870	720	6 200	1 000	1 800
Nitrogen (Kjeldahl)	µg/L	25	600	600	400	200	1 700	300	1 000
Aluminium	µg/L	23	10	10	6	5	30	5	10
Arsenic	µg/L	23	5	4	4	1	14	1	9
Sodium	mg/L	21	204	200	41	80	260	180	240

(continued)

Table C1 continued

Parameter	Unit	Count	Mean	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Calcium	mg/L	14	329	330	119	145	530	200	400
Magnesium	mg/L	14	43	43	11	18	57	35	54
Potassium	mg/L	14	47	53	29	6	85	8	75
Bicarbonate	mg/L	13	214	220	40	160	300	180	230
Carbonate	mg/L	13	5	5	0	5	5	5	5
Hydroxide	mg/L	13	5	5	0	5	5	5	5
Nitrogen (nitrite)	µg/L	13	60	10	110	10	300	10	60
Hardness (in calcium carbonate)	mg/L CaCO ₃	3	292	250	128	190	436	196	417
Boron	µg/L	1	90	90	–	90	90	90	90
Zinc	µg/L	1	20	20	–	20	20	20	20

– = no data

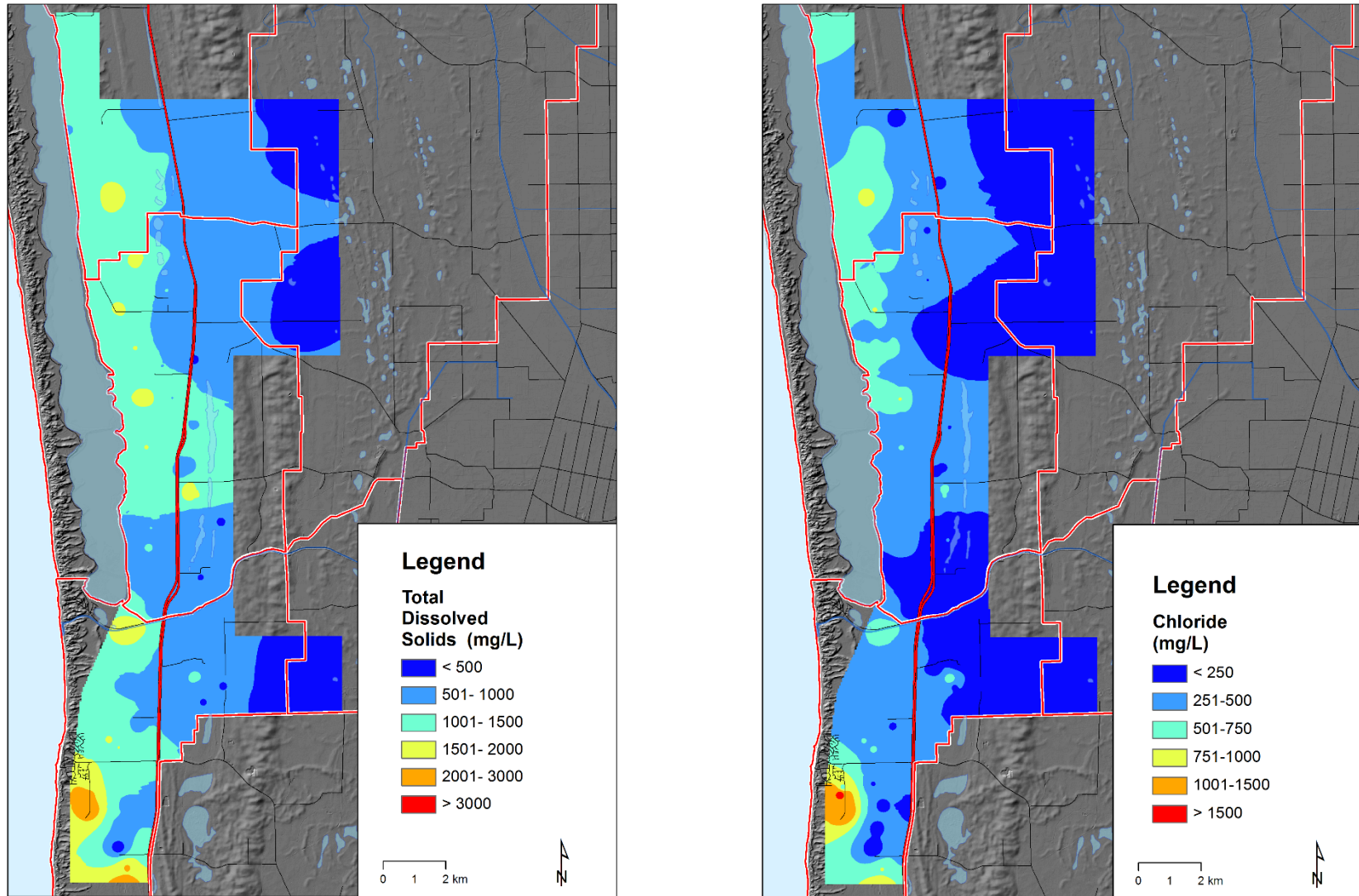


Figure C1 Average concentration of total dissolved solids (left) and chloride (right)

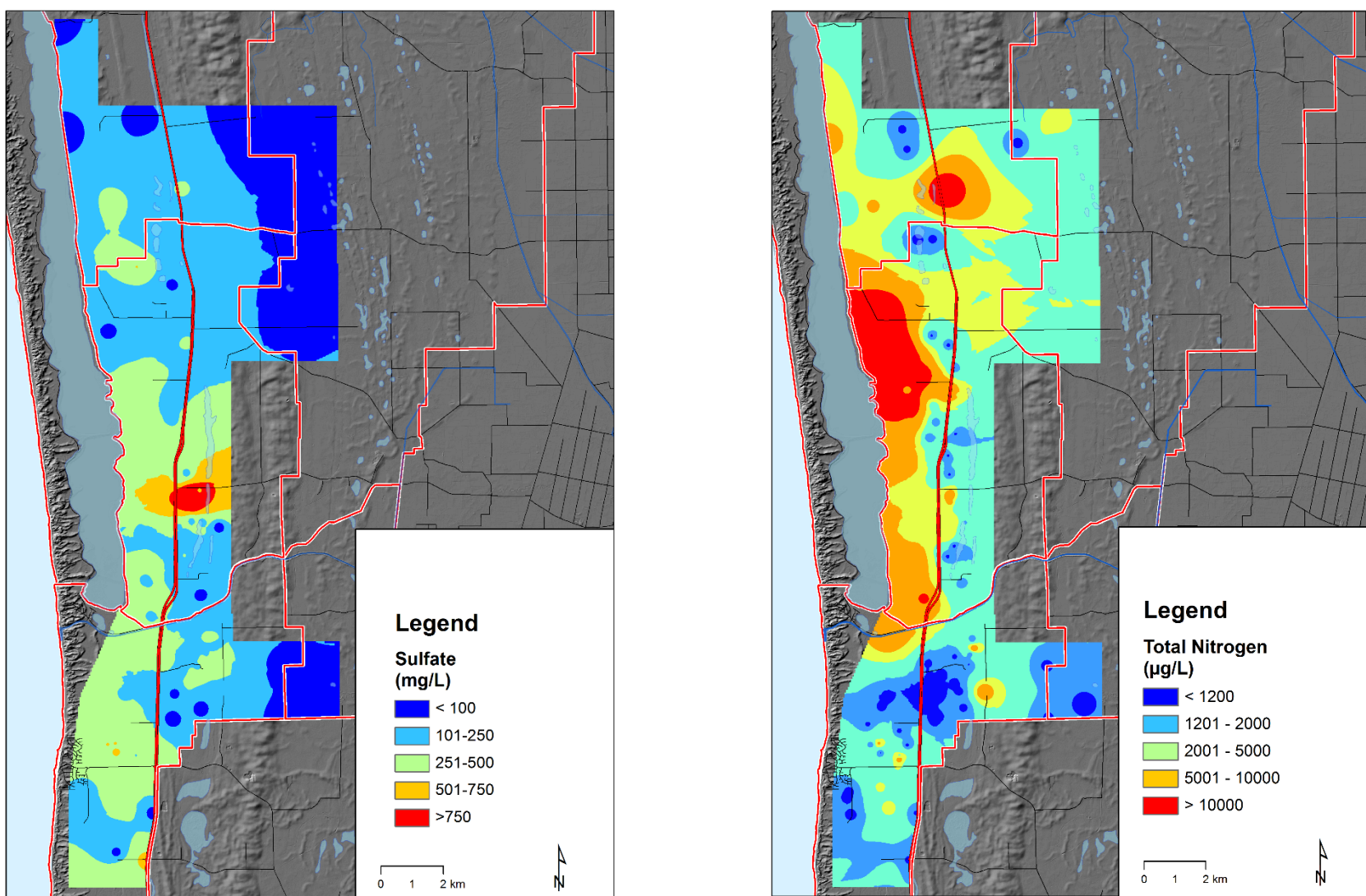


Figure C2 Average concentration of sulfate (left) and total nitrogen (right)

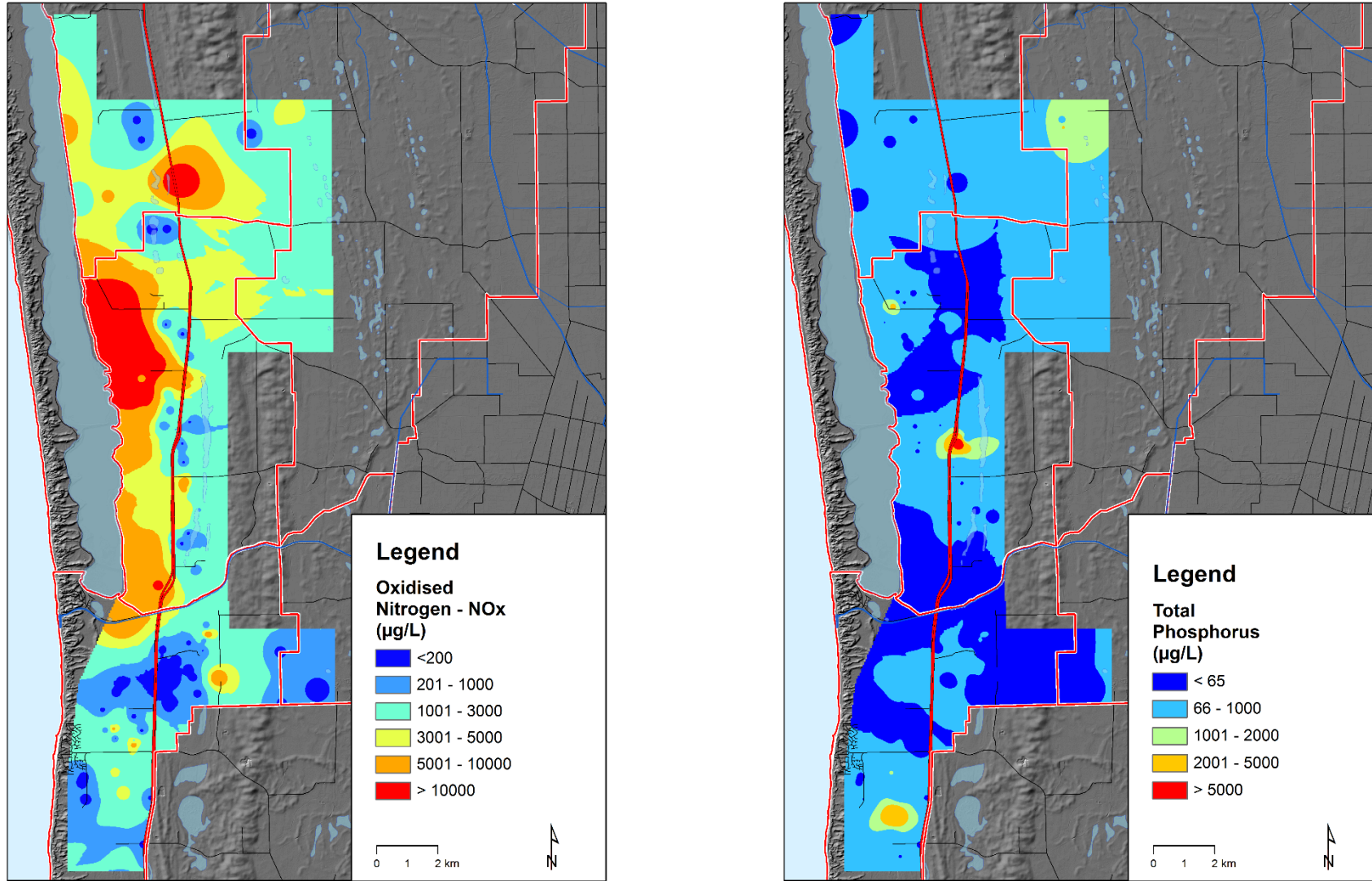


Figure C3 Mean concentration of oxidised nitrogen (left) and total phosphorus (right)

Appendix D Summary statistics of major ions and nutrients in surficial geological units

Table D1 Summary statistics for total dissolved solids (mg/L)

Geological unit	Count	Mean	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Bassendean Sand	5	182	150	97	100	350	125	255
Bassendean Sand (Deep)	5	363	450	262	80	670	90	593
Bassendean Sand (Total)	10	273	155	209	80	670	100	483
Spearwood Dunes	7	393	370	251	150	910	195	499
Spearwood Dunes (Deep)	4	478	555	202	183	617	281	612
Spearwood Dunes (Total)	11	424	380	228	150	910	195	605
Tamala Limestone	44	1340	1105	884	220	5920	849	1801
Tamala Limestone (Deep)	11	1620	1610	655	660	2695	1026	2164
Tamala Limestone (Total)	55	1396	1120	845	220	5920	875	1870
Lacustrine	4	560	640	324	140	820	239	817
Lacustrine (Lake Preston)	2	1338	1338	194	1200	1475	1200	1475
Lacustrine (Total)	6	819	815	481	140	1475	371	1283
Leederville	5	820	780	157	640	1070	710	950
Safety Bay Sand	1	1905	1905	no data	1905	1905	1905	1905
Surface	3	560	420	278	380	880	384	834

Table D2 Summary statistics for chloride (mg/L)

Geological unit	Count	Mean	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Bassendean Sand	5	49	32	26	28	88	30	76
Bassendean Sand (Deep)	5	127	120	108	20	276	26	233
Bassendean Sand (Total)	10	88	48	85	20	276	30	155
Spearwood Dunes	7	118	130	61	27	190	46	181
Spearwood Dunes (Deep)	4	182	196	100	58	279	85	269
Spearwood Dunes (Total)	11	142	137	79	27	279	55	206
Tamala Limestone	44	410	309	423	31	2787	198	466
Tamala Limestone (Deep)	11	518	476	249	189	1125	340	664
Tamala Limestone (Total)	55	431	332	395	31	2787	208	567
Lacustrine	4	142	140	57	79	210	90	197
Lacustrine (Lake Preston)	2	487	487	188	354	620	354	620
Lacustrine (Total)	6	257	188	202	79	620	104	434
Leederville	5	335	306	105	217	503	261	424
Safety Bay Sand	1	793	793	no data	793	793	793	793
Surface	3	227	169	121	145	366	147	346

Table D3 Summary statistics for bicarbonate (mg/L)

Geological unit	Count	Mean	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Bassendean Sand	5	58	34	59	8	154	14	113
Bassendean Sand (Deep)	5	137	107	126	15	306	24	267
Bassendean Sand (Total)	10	98	53	102	8	306	17	191
Spearwood Dunes	7	123	74	108	4	317	43	210
Spearwood Dunes (Deep)	4	173	153	108	78	310	83	280
Spearwood Dunes (Total)	11	141	96	106	4	317	58	240
Tamala Limestone	44	263	269	82	52	407	203	334
Tamala Limestone (Deep)	11	347	395	118	181	559	235	427
Tamala Limestone (Total)	55	280	274	95	52	559	204	366
Lacustrine	4	191	205	167	1	354	32	339
Lacustrine (Lake Preston)	2	373	373	59	332	415	332	415
Lacustrine (Total)	6	252	319	162	1	415	74	372
Leederville	5	304	323	41	230	326	274	325
Safety Bay Sand	1	443	443	no data	443	443	443	443
Surface	3	132	88	84	78	229	79	215

Table D4 Summary statistics for sulfate (mg/L)

Geological unit	Count	Mean	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Bassendean Sand	5	20	17	15	2	37	6	36
Bassendean Sand (Deep)	5	12	13	12	1	31	1	23
Bassendean Sand (Total)	10	16	14	14	1	37	2	33
Spearwood Dunes	7	41	26	40	7	120	16	73
Spearwood Dunes (Deep)	4	15	4	23	1	50	2	37
Spearwood Dunes (Total)	11	32	21	36	1	120	5	55
Tamala Limestone	44	309	311	218	7	1035	86	454
Tamala Limestone (Deep)	11	312	210	318	3	1050	46	528
Tamala Limestone (Total)	55	310	309	238	3	1050	81	457
Lacustrine	4	81	9	149	1	304	1	217
Lacustrine (Lake Preston)	2	165	165	45	133	197	133	197
Lacustrine (Total)	6	109	75	125	1	304	2	229
Leederville	5	14	7	14	4	37	4	26
Safety Bay Sand	1	203	203	no data	203	203	203	203
Surface	3	48	44	11	39	61	40	59

Table D5 Summary statistics for sodium (mg/L)

Geological unit	Count	Mean	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Bassendean Sand	5	33	34	15	15	51	18	47
Bassendean Sand (Deep)	5	68	59	57	15	149	15	125
Bassendean Sand (Total)	10	50	38	44	15	149	16	79
Spearwood Dunes	7	77	77	44	25	160	33	94
Spearwood Dunes (Deep)	4	103	105	57	37	167	50	156
Spearwood Dunes (Total)	11	87	79	48	25	167	36	139
Tamala Limestone	44	220	165	230	23	1577	113	264
Tamala Limestone (Deep)	11	305	268	208	96	880	180	372
Tamala Limestone (Total)	55	237	174	227	23	1577	118	286
Lacustrine	4	84	84	33	47	120	53	114
Lacustrine (Lake Preston)	2	284	284	98	214	353	214	353
Lacustrine (Total)	6	150	110	115	47	353	61	256
Leederville	5	162	165	29	129	201	133	189
Safety Bay Sand	1	456	456	no data	456	456	456	456
Surface	3	130	98	63	91	203	91	192

Table D6 Summary statistics for calcium (mg/L)

Geological unit	Count	Mean	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Bassendean Sand	5	21	14	24	1	61	2	43
Bassendean Sand (Deep)	5	40	40	33	4	83	8	72
Bassendean Sand (Total)	10	30	20	29	1	83	3	61
Spearwood Dunes	7	38	34	26	14	80	15	66
Spearwood Dunes (Deep)	4	51	46	35	21	94	22	86
Spearwood Dunes (Total)	11	43	34	29	14	94	15	71
Tamala Limestone	44	186	168	91	30	443	115	265
Tamala Limestone (Deep)	11	200	180	117	67	469	105	275
Tamala Limestone (Total)	55	189	170	96	30	469	112	265
Lacustrine	4	84	106	55	5	121	31	121
Lacustrine (Lake Preston)	2	140	140	27	121	159	121	159
Lacustrine (Total)	6	103	120	52	5	159	65	133
Leederville	5	110	86	39	82	173	83	150
Safety Bay Sand	1	142	142	no data	142	142	142	142
Surface	3	46	24	38	23	90	23	83

Table D7 Summary statistics for magnesium (mg/L)

Geological unit	Count	Mean	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Bassendean Sand	5	5	6	2	3	8	3	7
Bassendean Sand (Deep)	5	9	9	6	2	17	3	14
Bassendean Sand (Total)	10	7	6	5	2	17	3	10
Spearwood Dunes	7	10	10	4	4	16	5	13
Spearwood Dunes (Deep)	4	12	12	6	5	20	6	18
Spearwood Dunes (Total)	11	11	10	5	4	20	5	15
Tamala Limestone	44	34	30	28	9	199	20	39
Tamala Limestone (Deep)	11	36	35	14	10	61	24	48
Tamala Limestone (Total)	55	34	31	26	9	199	21	42
Lacustrine	4	14	12	7	7	23	8	21
Lacustrine (Lake Preston)	2	38	38	6	34	42	34	42
Lacustrine (Total)	6	22	19	14	7	42	9	36
Leederville	5	23	21	4	18	29	19	27
Safety Bay Sand	1	61	61	no data	61	61	61	61
Surface	3	18	19	1	16	19	16	19

Table D8 Summary statistics for potassium (mg/L)

Geological unit	Count	Mean	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Bassendean Sand	5	3	2	1	2	5	2	4
Bassendean Sand (Deep)	5	4	4	2	2	8	3	6
Bassendean Sand (Total)	10	3	3	2	2	8	2	5
Spearwood Dunes	7	8	4	10	2	31	3	12
Spearwood Dunes (Deep)	4	4	4	2	3	7	3	6
Spearwood Dunes (Total)	11	7	4	8	2	31	3	8
Tamala Limestone	44	20	17	16	2	74	6	28
Tamala Limestone (Deep)	11	18	11	22	4	78	6	21
Tamala Limestone (Total)	55	19	15	17	2	78	6	28
Lacustrine	4	4	4	2	3	7	3	6
Lacustrine (Lake Preston)	2	22	22	12	14	30	14	30
Lacustrine (Total)	6	10	5	11	3	30	3	19
Leederville	5	6	5	0	5	6	5	6
Safety Bay Sand	1	15	15	no data	15	15	15	15
Surface	3	12	14	5	6	16	7	15

Table D9 Summary statistics for pH

Geological unit	Count	Mean	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Bassendean Sand	5	6.1	5.9	0.6	5.4	6.8	5.5	6.7
Bassendean Sand (Deep)	5	7.0	7.2	0.8	5.9	7.8	6.2	7.6
Bassendean Sand (Total)	10	6.5	6.6	0.8	5.4	7.8	5.8	7.3
Spearwood Dunes	7	6.9	7.2	0.7	5.6	7.6	6.5	7.6
Spearwood Dunes (Deep)	4	7.2	7.3	0.4	6.6	7.6	6.8	7.5
Spearwood Dunes (Total)	11	7.0	7.3	0.6	5.6	7.6	6.6	7.6
Tamala Limestone	44	7.6	7.6	0.2	6.9	8.0	7.4	7.8
Tamala Limestone (Deep)	11	7.5	7.5	0.2	7.1	7.9	7.4	7.8
Tamala Limestone (Total)	55	7.6	7.6	0.2	6.9	8.0	7.4	7.8
Lacustrine	4	6.6	7.2	1.5	4.5	7.7	5.2	7.7
Lacustrine (Lake Preston)	2	7.7	7.7	0.1	7.6	7.7	7.6	7.7
Lacustrine (Total)	6	7.0	7.6	1.3	4.5	7.7	6.1	7.7
Leederville	5	7.9	7.9	0.0	7.9	8.0	7.9	8.0
Safety Bay Sand	1	7.7	7.7	no data	7.7	7.7	7.7	7.7
Surface	3	7.6	7.5	0.4	7.3	8.0	7.3	8.0

Table D10 Summary statistics for total nitrogen (µg/L)

Geological unit	Count	Mean	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Bassendean Sand	5	2 370	2 250	2 071	500	5 800	750	4 050
Bassendean Sand (Deep)	5	1 410	1 500	731	270	2 300	825	1 950
Bassendean Sand (Total)	10	1 890	1 550	1 549	270	5 800	750	2 300
Spearwood Dunes	7	1 553	773	2 427	280	7 000	304	1 780
Spearwood Dunes (Deep)	4	845	780	243	653	1 167	655	1 087
Spearwood Dunes (Total)	11	1 295	773	1 918	280	7 000	365	1 177
Tamala Limestone	44	3 725	1 104	6 117	120	25 000	553	5 050
Tamala Limestone (Deep)	11	1 814	907	1 950	170	6 000	522	2 880
Tamala Limestone (Total)	55	3 343	1 075	5 576	120	25 000	545	4 933
Lacustrine	4	1 547	1 483	977	420	2 800	714	2 430
Lacustrine (Lake Preston)	2	3 070	3 070	3 507	590	5 550	590	5 550
Lacustrine (Total)	6	2 054	1 483	1 911	420	5 550	539	3 625
Leederville	5	470	480	95	350	570	375	560
Safety Bay Sand	1	545	545	no data	545	545	545	545
Surface	3	2 057	2 400	1 642	270	3 500	483	3 390

Table D11 Summary statistics for oxidised nitrogen (µg/L)

Geological unit	Count	Mean	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Bassendean Sand	5	57	15	97	3	230	5	130
Bassendean Sand (Deep)	5	61	60	52	3	130	11	111
Bassendean Sand (Total)	10	59	25	74	3	230	5	111
Spearwood Dunes	7	1 034	9	2 632	4	7 000	5	883
Spearwood Dunes (Deep)	4	18	9	21	5	50	6	38
Spearwood Dunes (Total)	11	665	9	2 102	4	7 000	5	96
Tamala Limestone	44	2 822	45	5 796	4	23 000	8	4 095
Tamala Limestone (Deep)	11	465	8	1 375	4	4 600	5	181
Tamala Limestone (Total)	55	2 350	33	5 292	4	23 000	6	3 475
Lacustrine	4	10	8	9	3	23	3	19
Lacustrine (Lake Preston)	2	2 690	2 690	3 762	30	5 350	30	5 350
Lacustrine (Total)	6	904	17	2 178	3	5 350	4	1 626
Leederville	5	9	5	7	5	20	5	15
Safety Bay Sand	1	13	13	no data	13	13	13	13
Surface	3	387	490	308	40	630	85	616

Table D12 Summary statistics for nitrogen, as ammonia (µg/L)

Geological unit	Count	Mean	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Bassendean Sand	5	371	455	257	20	600	105	595
Bassendean Sand (Deep)	5	583	560	403	60	1100	213	965
Bassendean Sand (Total)	10	477	508	338	20	1100	125	715
Spearwood Dunes	7	207	240	202	3	550	21	346
Spearwood Dunes (Deep)	4	399	400	123	260	537	284	514
Spearwood Dunes (Total)	11	277	280	196	3	550	28	483
Tamala Limestone	44	270	233	304	5	1700	20	414
Tamala Limestone (Deep)	11	787	345	1264	18	4400	65	946
Tamala Limestone (Total)	55	373	237	642	5	4400	25	522
Lacustrine	4	382	390	120	230	517	269	488
Lacustrine (Lake Preston)	2	129	129	129	38	220	38	220
Lacustrine (Total)	6	297	295	170	38	517	165	449
Leederville	5	444	420	103	330	590	355	545
Safety Bay Sand	1	320	320	no data	320	320	320	320
Surface	3	380	280	293	150	710	163	667

Table D13 Summary statistics for total phosphorus (µg/L)

Geological unit	Count	Mean	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Bassendean Sand	5	155	60	250	20	600	22	335
Bassendean Sand (Deep)	5	57	54	51	5	130	10	106
Bassendean Sand (Total)	10	106	57	178	5	600	17	106
Spearwood Dunes	7	16	16	9	5	25	5	25
Spearwood Dunes (Deep)	4	25	19	17	12	49	12	42
Spearwood Dunes (Total)	11	19	16	12	5	49	10	25
Tamala Limestone	44	28	20	26	5	127	5	49
Tamala Limestone (Deep)	11	41	32	23	10	72	20	67
Tamala Limestone (Total)	55	31	25	26	5	127	5	52
Lacustrine	4	47	27	42	22	110	23	86
Lacustrine (Lake Preston)	2	37	37	7	32	42	32	42
Lacustrine (Total)	6	43	31	33	22	110	24	62
Leederville	5	22	25	10	5	29	14	29
Safety Bay Sand	1	11	11	no data	11	11	11	11
Surface	3	235	280	201	16	410	42	397

Table D14 Summary statistics for soluble reactive phosphorus (µg/L)

Geological unit	Count	Mean	Median	Standard deviation	Minimum	Maximum	20th percentile	80th percentile
Bassendean Sand	5	53	41	49	10	130	13	101
Bassendean Sand (Deep)	5	51	50	45	5	110	8	96
Bassendean Sand (Total)	10	52	46	45	5	130	10	96
Spearwood Dunes	7	14	20	8	5	23	6	21
Spearwood Dunes (Deep)	4	12	13	9	4	20	4	20
Spearwood Dunes (Total)	11	14	20	8	4	23	5	20
Tamala Limestone	44	11	5	10	3	40	5	18
Tamala Limestone (Deep)	11	22	13	21	5	70	6	38
Tamala Limestone (Total)	55	13	8	13	3	70	5	22
Lacustrine	4	34	22	34	10	83	11	68
Lacustrine (Lake Preston)	2	9	9	5	5	13	5	13
Lacustrine (Total)	6	26	12	30	5	83	9	47
Leederville	5	16	10	13	5	30	5	30
Safety Bay Sand	1	5	5	no data	5	5	5	5
Surface	3	150	110	154	20	320	29	299

Appendix E Groundwater compared to aquatic ecosystem guidelines

Table E1 Aquatic ecosystem water quality trigger values from ANZECC and ARMCANZ (2000)

Parameter	Level of protection (% of species)	Value	Parameter	Level of protection (% of species)	Value
Aluminium, Al (µg/L) (pH>6.5)	99	27	Arsenic, As III (µg/L)	99	1
	95	55		95	24
	90	80		90	94
	80	150		80	360
Arsenic, As V (µg/L)	99	0.8	Boron, B (µg/L)	99	90
	95	13		95	370
	90	42		90	680
	80	140		80	1300
Cadmium, Cd (µg/L)	99	0.06	Chromium, Cr VI (µg/L)	99	0.01
	95	0.2		95	1
	90	0.4		90	6
	80	0.8		80	40
Copper, Cu (µg/L)	99	1	Lead, Pb (µg/L)	99	1
	95	1.4		95	3.4
	90	1.8		90	5.6
	80	2.5		80	9.4
Manganese, Mn (µg/L)	99	1200	Mercury, Hg (µg/L)	99	0.06
	95	1900		95	0.6
	90	2500		90	1.9
	80	3600		80	5.4

(continued)

Table E1 continued

Parameter	Level of protection (% of species)	Value	Parameter	Level of protection (% of species)	Value
Nickel, Ni (µg/L)	99	8	Nitrogen as ammonia, NH ₃ (µg/L)	99	320
	95	11		95	900
	90	13		90	1430
	80	17		80	2300
Nitrogen as nitrate, NO ₃ (µg/L)	99	17	pH	upper	8
	95	700		lower	6.5
	90	3400	Phosphorus (filterable reactive), FRP (µg/L)	lowland river	40
	80	17000	Phosphorus (total), TP (µg/L)	lowland river	65
Selenium, Se (µg/L)	99	5	Silver, Ag (µg/L)	99	0.02
	95	11		95	0.05
	90	18		90	0.1
	80	34		80	0.2
Zinc, Zn (µg/L)	99	2.4			
	95	8			
	90	15			
	80	31			

Table E2 Groundwater sampling sites compared to ANZECC and ARMCANZ (2000) aquatic ecosystem guidelines. Parameter codes are in Table E1. Parameters marked with an asterisk (*) have a limit of reporting above the trigger value so all measured values exceed the criteria. Y (yes) = exceeds criteria, N (no) = meets criteria.

Parameter code & protection level (%)	Bore																											
	C4	C8	D2	D3A	D3B	D4	E2A	E3A	E3B	E4A	E4C	E5B	E7	E8	F1	F2A	F2B	F3	F4	F4E (D)	F4E (S)	F5	F6C (D)	F6C (S)	F9A	F9C	G2A	G2B
Al 99	N	Y	N	N	N	N	N	N	N	Y	N	N	Y	Y	N	N	N	N	Y	N	Y	Y	N	Y	N	N	N	N
Al 95	N	Y	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	Y	N	N	N	N	Y	N	N	N	N
Al 90	N	Y	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	Y	N	N	N	N	Y	N	N	N	N
Al 80	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N
As 99	Y	N	Y	N	N	Y	Y	N	N	N	Y	Y	N	N	Y	Y	Y	Y	Y	N	N	Y	N	N	Y	Y	N	Y
As 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N
As 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
As 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
B 99	N	N	N	Y	Y	N	Y	Y	Y	N	N	N	N	N	Y	N	Y	N	N	N	N	N	N	N	N	N	N	N
B 95	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N
B 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
B 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cd 99	N	N	Y	Y	Y	Y	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N
Cd 95	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cd 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cd 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cr 99*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Cr 95	N	Y	N	N	N	Y	N	Y	Y	Y	N	Y	Y	N	N	Y	N	Y	Y	Y	Y	N	Y	Y	N	N	N	N
Cr 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cr 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

(continued)

Table E2 continued

Parameter code & protection level (%)	Bore																											
	C4	C8	D2	D3A	D3B	D4	E2A	E3A	E3B	E4A	E4C	E5B	E7	E8	F1	F2A	F2B	F3	F4	F4E (D)	F4E (S)	F5	F6C (D)	F6C (S)	F9A	F9C	G2A	G2B
Cu 99	N	N	N	N	N	N	N	N	N	Y	Y	Y	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N
Cu 95	N	N	N	N	N	N	N	N	N	Y	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cu 90	N	N	N	N	N	N	N	N	N	Y	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cu 80	N	N	N	N	N	N	N	N	N	N	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pb 99	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pb 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pb 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pb 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Mn 99	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Mn 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Mn 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Mn 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Hg 99	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Hg 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Hg 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Hg 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ni 99	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ni 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ni 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ni 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
NH ₃ 99	N	Y	N	N	N	Y	N	Y	Y	Y	N	Y	Y	N	N	Y	N	Y	Y	Y	Y	Y	Y	N	Y	N	Y	N
NH ₃ 95	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	Y	N	Y	N

(continued)

Table E2 continued

Parameter code & protection level (%)	Bore																											
	C4	C8	D2	D3A	D3B	D4	E2A	E3A	E3B	E4A	E4C	E5B	E7	E8	F1	F2A	F2B	F3	F4	F4E (D)	F4E (S)	F5	F6C (D)	F6C (S)	F9A	F9C	G2A	G2B
NH ₃ 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	Y	N
NH ₃ 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	N
NO ₃ 99	N	Y	Y	Y	Y	Y	Y	N	N	N	Y	N	Y	Y	N	N	Y	Y	N	Y	N	N	N	N	N	Y	N	Y
NO ₃ 95	N	N	N	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N
NO ₃ 90	N	N	N	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
NO ₃ 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
pH upper	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
pH lower	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
FRP	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	Y	N	N	N	N	Y	N	N	N
TP	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	Y	N	N	N
Se 99	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Se 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Se 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Se 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ag 99*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Ag 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ag 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ag 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Zn 99	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Zn 95	N	Y	N	Y	Y	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y	N	Y	Y	Y	Y	Y	N	N	N	N
Zn 90	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	Y	N	N	Y	N	N	N	Y	N	Y	N	N	N	N
Zn 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N

Table E3 Groundwater sampling sites compared to ANZECC and ARMCANZ (2000) aquatic ecosystem guidelines. Parameter codes are in Table E1. Parameters marked with an asterisk (*) have a limit of reporting above the trigger value so all measured values exceed the criteria. Y (yes) = exceeds criteria, N (no) = meets criteria.

Parameter code & protection level (%)	Bore																											
	G4	G5	G7	HS13A	HS13B	HS64A	HS64C	PGW-1	PGW-10	PGW-11	PGW-12	PGW-13	PGW-14	PGW-15	PGW-16	PGW-17	PGW-18	PGW-19	PGW-2	PGW-20	PGW-21	PGW-22	PGW-23	PGW-24	PGW-25	PGW-26	PGW-27	PGW-28
Al 99	N	Y	Y	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Al 95	N	N	Y	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Al 90	N	N	Y	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Al 80	N	N	Y	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
As 99	Y	N	N	N	N	N	N	N	N	N	Y	N	N	N	Y	Y	N	Y	Y	Y	N	N	N	Y	Y	N	Y	Y
AS 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
As 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
As 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
B 99	N	N	N	N	N	N	N	N	Y	Y	N	N	N	N	N	N	N	N	Y	Y	N	Y	N	N	Y	Y	Y	N
B 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
B 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
B 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cd 99	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cd 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cd 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cd 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cr 99*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Cr 95	Y	Y	N	Y	N	N	N	N	N	N	Y	N	N	N	N	Y	N	Y	N	N	N	N	N	N	N	N	Y	Y
Cr 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cr 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

(continued)

Table E3 continued

Parameter code & protection level (%)	Bore																											
	G4	G5	G7	HS13A	HS13B	HS64A	HS64C	PGW-1	PGW-10	PGW-11	PGW-12	PGW-13	PGW-14	PGW-15	PGW-16	PGW-17	PGW-18	PGW-19	PGW-2	PGW-20	PGW-21	PGW-22	PGW-23	PGW-24	PGW-25	PGW-26	PGW-27	PGW-28
Cu 99	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	Y	N	N	N	N	N	Y	N	N
Cu 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	Y	N	N
Cu 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N
Cu 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N
Pb 99	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pb 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pb 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pb 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Mn 99	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Mn 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Mn 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Mn 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Hg 99	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Hg 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Hg 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Hg 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ni 99	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ni 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ni 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ni 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
NH ₃ 99	Y	N	Y	Y	Y	N	N	Y	N	N	Y	N	N	N	N	Y	N	Y	N	N	N	N	N	N	N	N	N	Y
NH ₃ 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

(continued)

Table E3 continued

Parameter code & protection level (%)	Bore																											
	G4	G5	G7	HS13A	HS13B	HS64A	HS64C	PGW-1	PGW-10	PGW-11	PGW-12	PGW-13	PGW-14	PGW-15	PGW-16	PGW-17	PGW-18	PGW-19	PGW-2	PGW-20	PGW-21	PGW-22	PGW-23	PGW-24	PGW-25	PGW-26	PGW-27	PGW-28
NH ₃ 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
NH ₃ 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
NO ₃ 99	N	N	Y	N	N	N	N	N	Y	Y	Y	Y	N	Y	Y	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y	Y	N
NO ₃ 95	N	N	N	N	N	N	N	N	Y	Y	N	Y	N	N	N	N	N	N	Y	Y	N	Y	Y	N	N	Y	N	N
NO ₃ 90	N	N	N	N	N	N	N	N	Y	Y	N	N	N	N	N	N	N	N	Y	Y	N	Y	Y	N	N	Y	N	N
NO ₃ 80	N	N	N	N	N	N	N	N	Y	Y	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N
pH upper	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
pH lower	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
FRP	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
TP	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	Y	N	N	N	N	N	N	N
Se 99	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Se 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Se 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Se 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ag 99*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Ag 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ag 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ag 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Zn 99	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Zn 95	N	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y
Zn 90	N	N	Y	N	Y	N	N	N	Y	Y	N	Y	Y	N	Y	Y	Y	Y	N	N	Y	N	N	N	Y	Y	Y	N
Zn 80	N	N	Y	N	Y	N	N	N	Y	Y	N	Y	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N

Table E4 Groundwater sampling sites compared to ANZECC and ARMCANZ (2000) aquatic ecosystem guidelines. Parameter codes are in Table E1. Parameters marked with an asterisk (*) have a limit of reporting above the trigger value so all measured values exceed the criteria. Y (yes) = exceeds criteria, N (no) = meets criteria.

Parameter code & protection level (%)	Bore																								
	PGW-29	PGW-3	PGW-30	PGW-31	PGW-32	PGW-33	PGW-34	PGW-35	PGW-36	PGW-4	PGW-5	PGW-6	PGW-7	PGW-8	PGW-9	PGW-L1	PGW-L2	PGW-L3	PGW-L4	PGW-L5	SW-1	SW-2	SW-3	Y4-1A	Y4-2A
Al 99	N	N	N	N	N	N	N	N	Y	N	Y	N	N	N	N	N	N	N	N	N	N	Y	Y	N	N
Al 95	N	N	N	N	N	N	N	N	Y	N	Y	N	N	N	N	N	N	N	N	N	N	Y	N	N	N
Al 90	N	N	N	N	N	N	N	N	Y	N	Y	N	N	N	N	N	N	N	N	N	N	Y	N	N	N
Al 80	N	N	N	N	N	N	N	N	Y	N	Y	N	N	N	N	N	N	N	N	N	N	Y	N	N	N
As 99	N	Y	N	Y	Y	Y	Y	Y	N	N	Y	Y	Y	N	N	N	N	N	N	N	N	N	N	Y	N
AS 95	N	N	N	N	N	Y	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N
As 90	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N
As 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
B 99	Y	N	N	Y	Y	Y	Y	N	N	N	N	N	Y	Y	N	N	Y	N	Y	N	N	N	Y	Y	Y
B 95	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	Y
B 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N
B 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cd 99	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N
Cd 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cd 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cd 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cr 99*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Cr 95	N	N	Y	N	Y	N	N	N	Y	Y	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N
Cr 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cr 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

(continued)

Table E4 continued

Parameter code & protection level (%)	Bore																								
	PGW-29	PGW-3	PGW-30	PGW-31	PGW-32	PGW-33	PGW-34	PGW-35	PGW-36	PGW-4	PGW-5	PGW-6	PGW-7	PGW-8	PGW-9	PGW-L1	PGW-L2	PGW-L3	PGW-L4	PGW-L5	SW-1	SW-2	SW-3	Y4-1A	Y4-2A
Cu 99	N	N	N	N	N	N	N	N	Y	N	N	Y	N	N	N	N	Y	N	N	N	Y	Y	Y	N	N
Cu 95	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	Y	N	N	N	Y	Y	Y	N	N
Cu 90	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	Y	N	N	N	N	Y	Y	N	N
Cu 80	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	Y	N	N	N	N	Y	Y	N	N
Pb 99	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pb 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pb 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pb 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Mn 99	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Mn 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Mn 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Mn 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Hg 99	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N
Hg 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Hg 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Hg 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ni 99	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ni 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ni 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ni 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
NH ₃ 99	N	N	Y	N	Y	N	N	Y	Y	N	Y	N	N	N	N	Y	Y	Y	Y	Y	N	N	Y	Y	Y
NH ₃ 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N

(continued)

Table E4 continued

Parameter code & protection level (%)	Bore																								
	PGW-29	PGW-3	PGW-30	PGW-31	PGW-32	PGW-33	PGW-34	PGW-35	PGW-36	PGW-4	PGW-5	PGW-6	PGW-7	PGW-8	PGW-9	PGW-L1	PGW-L2	PGW-L3	PGW-L4	PGW-L5	SW-1	SW-2	SW-3	Y4-1A	Y4-2A
NH ₃ 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N
NH ₃ 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
NO ₃ 99	Y	Y	Y	Y	Y	Y	N	Y	Y	N	N	Y	N	Y	Y	N	Y	N	N	N	Y	Y	Y	N	N
NO ₃ 95	Y	N	N	Y	N	N	N	Y	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N
NO ₃ 90	Y	N	N	Y	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
NO ₃ 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
pH upper	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
pH lower	N	N	N	N	N	N	N	N	Y	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N
FRP	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	Y	Y	N	N
TP	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	Y	Y	N	N
Se 99	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Se 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Se 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Se 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ag 99*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Ag 95	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N
Ag 90	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ag 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Zn 99	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
Zn 95	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N
Zn 90	N	N	N	N	N	N	N	Y	Y	N	Y	N	Y	Y	Y	N	Y	N	N	N	N	Y	Y	N	N
Zn 80	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N

Appendix F Suitability of groundwater for irrigation

Table F1 Irrigation water quality trigger values from ANZECC and ARMCANZ (2000)

Parameter	Category	Value	Parameter	Category	Value
Electrical conductivity (salinity hazard)	Low salinity (L)	See Table 2.4	Aluminium (mg/L)	Short-term trigger value (STV)	20
	Medium salinity (M)			Long-term trigger value (LTV)	5
	High salinity (H)		Arsenic (mg/L)	STV	2
	Very high salinity (VH)			LTV	0.1
	Extremely high salinity (EH)		Beryllium (mg/L)	STV	0.5
Sodium adsorption ratio (sodium hazard)	Low (L)	See Table 2.5 and Figure 3.33		LTV	0.1
	Medium (M)		Boron (mg/L)	STV	Plant specific (P)
	High (H)			LTV	0.5
	Very high (VH)		Cadmium (mg/L)	STV	0.05
Chloride (mg/L)	Sensitive (Sn)	<175		LTV	0.01
	Moderately sensitive (MS)	350	Chromium (mg/L)	STV	1
	Moderately tolerant (MT)	700		LTV	0.1
	Tolerant (T)	1000	Cobalt (mg/L)	STV	0.1
	Not suitable (NS)	>1000		LTV	0.05
Sodium (mg/L)	Sensitive (Sn)	<115	Copper (mg/L)	STV	5
	Moderately sensitive (MS)	230		LTV	0.2
	Moderately tolerant (MT)	460	Fluoride (mg/L)	STV	2
	Tolerant (T)	800		LTV	1
	Not suitable (NS)	>800			

(continued)

Table F1 continued

Parameter	Category	Value	Parameter	Category	Value
Iron (mg/L)	STV	10	Nitrogen (total) (mg/L)	STV	12–125
	LTV	2		LTV	5
Lead (mg/L)	STV	5	Phosphorus (total) (mg/L)	STV	0.8–12
	LTV	2		LTV	0.05
Lithium (mg/L)	STV	2.5	Selenium (mg/L)	STV	0.05
	LTV	2.5		LTV	0.02
Lithium (citrus) (mg/L)	STV	0.075	Uranium (mg/L)	STV	0.1
	LTV	0.075		LTV	0.01
Manganese (mg/L)	STV	10	Vanadium (mg/L)	STV	0.5
	LTV	0.2		LTV	0.1
Mercury (mg/L)	STV	0.002	Zinc (mg/L)	STV	5
	LTV	0.002		LTV	2
Molybdenum (mg/L)	STV	0.05	pH	Lower (high corrosion potential)	<5
	LTV	0.01		Upper (increased fouling potential)	>8.5
Nickel (mg/L)	STV	2			
	LTV	0.2			

Table F2 Suitability of groundwater for irrigation based on ANZECC and ARMCANZ (2000) criteria. Parameter codes are in Table F1. S (suitable) = meets criteria, NS (not suitable) = does not meet criteria, S* = nutrients exceed guideline values, but will not affect crop productivity, † suitability requires further investigation.

Parameter	Bore																				
	C4	C8	D2	D3A	D3B	D4	E2A	E3A	E3B	E4A	E4C	E5B	E7	E8	F1	F2A	F2B	F3	F4	F4E (D)	F4E (S)
Electrical conductivity	VH [†]	H [†]	VH [†]	H [†]	H [†]	H [†]	VH [†]	VH [†]	VH [†]	H [†]	L	M	H [†]	L	VH [†]	VH [†]	H [†]	VH [†]	M	H [†]	H [†]
Sodium adsorption ratio	M	M	VH [†]	L	L	L	M	L	L	L	L	L	L	L	H [†]	M	L	M	L	M	L
Chloride	MT [†]	MS	NS	MT [†]	MS	MS	MT [†]	MT [†]	MT [†]	MS	Sn	Sn	MS	Sn	T [†]	MT [†]	MT [†]	MT [†]	Sn	MT [†]	MS
Sodium	MT [†]	MS	NS	MS	MS	MS	MT [†]	MS	MS	MS	Sn	Sn	MS	Sn	MT [†]	MT [†]	MS	MT [†]	Sn	MT [†]	MS
Aluminium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Arsenic LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Beryllium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Boron LTV	S	S	S	S	S	S	NS	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Cadmium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Chromium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Cobalt LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Copper LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Fluoride LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Iron STV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Iron LTV	S	S	S	S	S	NS	NS	NS	NS	S	S	S	S	S	S	NS	S	NS	S	S	S
Lead LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

(continued)

Table F2 continued

Parameter	Bore																				
	C4	C8	D2	D3A	D3B	D4	E2A	E3A	E3B	E4A	E4C	E5B	E7	E8	F1	F2A	F2B	F3	F4	F4E (D)	F4E (S)
Lithium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Lithium (citrus) LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Manganese STV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Manganese LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	NS	S	S	S	S	S	S
Mercury LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Molybdenum LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Nickel LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Nitrogen (total) STV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Nitrogen (total) LTV	S	S	S	S	S*	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Phosphorus (total) STV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Phosphorus (total) LTV	S	S	S	S	S	S*	S	S*	S	S	S	S	S*	S	S	S	S	S	S	S*	S
Selenium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Uranium STV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Uranium LTV	S	S	S	NS	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Vanadium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Zinc LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
pH lower	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
pH upper	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

Table F3 Suitability of groundwater for irrigation based on ANZECC and ARMCANZ (2000) criteria. Parameter codes are in Table F1. S (suitable) = meets criteria, NS (not suitable) = does not meet criteria, S* = nutrients exceed guideline values, but will not affect crop productivity, † suitability requires further investigation.

Parameter	Bore																				
	F5	F6C (D)	F6C (S)	F9A	F9C	G2A	G2B	G4	G5	G7	HS13A	HS13B	HS64A	HS64C	PGW-1	PGW-10	PGW-11	PGW-12	PGW-13	PGW-14	PGW-15
Electrical conductivity	H†	H†	M	VH†	H†	H†	H†	VH†	M	L	H†	M	H†	H†	H†	VH†	H†	H†	H†	M	H†
Sodium adsorption ratio	L	L	L	M	L	L	L	M	L	L	L	L	L	L	L	M	L	L	L	L	L
Chloride	MS	Sn	Sn	MT†	MT†	MS	MT†	MT†	Sn	Sn	Sn	Sn	MS	MS	Sn	MT†	MS	Sn	Sn	Sn	MS
Sodium	Sn	Sn	Sn	MT†	MS	MS	MS	MT†	Sn	Sn	Sn	Sn	Sn	Sn	Sn	MT†	MS	Sn	Sn	Sn	Sn
Aluminium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Arsenic LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Beryllium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Boron LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Cadmium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Chromium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Cobalt LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Copper LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Fluoride LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Iron STV	NS	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Iron LTV	NS	NS	S	NS	S	NS	NS	S	S	S	S	S	S	S	NS	S	S	NS	S	S	S
Lead LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

(continued)

Table F3 continued

Parameter	Bore																				
	F5	F6C (D)	F6C (S)	F9A	F9C	G2A	G2B	G4	G5	G7	HS13A	HS13B	HS64A	HS64C	PGW-1	PGW-10	PGW-11	PGW-12	PGW-13	PGW-14	PGW-15
Lithium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Lithium (citrus) LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Manganese STV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Manganese LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Mercury LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Molybdenum LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Nickel LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Nitrogen (total) STV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Nitrogen (total) LTV	S	S	S	S*	S	S	S	S	S	S	S	S	S	S	S	S*	S*	S	S	S	S
Phosphorus (total) STV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Phosphorus (total) LTV	S	S	S	S*	S	S	S	S	S	S	S*	S	S*	S*	S	S	S	S	S	S	S
Selenium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Uranium STV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Uranium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Vanadium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Zinc LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
pH lower	S	S	S	S	S	S	S	S	S	NS	S	S	S	S	S	S	S	S	S	S	S
pH upper	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

Table F4 Suitability of groundwater for irrigation based on ANZECC and ARMCANZ (2000) criteria. Parameter codes are in Table F1. S (suitable) = meets criteria, NS (not suitable) = does not meet criteria, S* = nutrients exceed guideline values, but will not affect crop productivity, † suitability requires further investigation.

Parameter	Bore																				
	PGW-16	PGW-17	PGW-18	PGW-19	PGW-2	PGW-20	PGW-21	PGW-22	PGW-23	PGW-24	PGW-25	PGW-26	PGW-27	PGW-28	PGW-29	PGW-3	PGW-30	PGW-31	PGW-32	PGW-33	PGW-34
Electrical conductivity	H†	H†	H†	H†	VH†	H†	H†	H†	H†	H†	VH†	VH†	H†	H†	H†	H†	H†	VH†	H†	VH†	VH†
Sodium adsorption ratio	L	L	M	L	M	M	L	L	L	L	L	M	L	L	L	L	M	L	L	H†	M
Chloride	Sn	MS	MT†	MS	MT†	MT†	MS	MS	MS	MS	MT†	MT†	MS	Sn	MS	MT†	MT†	MT†	MS	NS	T†
Sodium	Sn	MS	MT†	MS	MT†	MT†	Sn	MS	Sn	MS	MT†	MT†	MS	Sn	MS	MS	MT†	MS	MS	T†	MT†
Aluminium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Arsenic LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Beryllium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Boron LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	NS	S	S	S
Cadmium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Chromium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Cobalt LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Copper LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Fluoride LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Iron STV	S	S	S	S	S	S	S	S	S	S	S	S	S	NS	S	S	S	S	S	S	S
Iron LTV	NS	S	S	S	S	S	NS	S	S	NS	S	S	NS	NS	S	NS	NS	S	NS	S	NS
Lead LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

(continued)

Table F4 continued

Parameter	Bore																				
	PGW-16	PGW-17	PGW-18	PGW-19	PGW-2	PGW-20	PGW-21	PGW-22	PGW-23	PGW-24	PGW-25	PGW-26	PGW-27	PGW-28	PGW-29	PGW-3	PGW-30	PGW-31	PGW-32	PGW-33	PGW-34
Lithium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Lithium (citrus) LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Manganese STV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Manganese LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Mercury LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Molybdenum LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Nickel LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Nitrogen (total) STV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Nitrogen (total) LTV	S	S	S	S	S*	S*	S	S*	S*	S	S	S	S	S	S*	S	S	S*	S	S	S
Phosphorus (total) STV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Phosphorus (total) LTV	S*	S	S	S	S	S	S*	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Selenium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Uranium STV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Uranium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Vanadium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Zinc LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
pH lower	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
pH upper	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

Table F5 Suitability of groundwater for irrigation based on ANZECC and ARMCANZ (2000) criteria. Parameter codes are in Table F1. S (suitable) = meets criteria, NS (not suitable) = does not meet criteria, S* = nutrients exceed guideline values, but will not affect crop productivity, † suitability requires further investigation.

Parameter	Bore																	
	PGW-35	PGW-36	PGW-4	PGW-5	PGW-6	PGW-7	PGW-8	PGW-9	PGW-L1	PGW-L2	PGW-L3	PGW-L4	PGW-L5	SW-1	SW-2	SW-3	Y4-1A	Y4-2A
EC	H [†]	L	M	M	H [†]	H [†]	VH [†]	VH [†]	H [†]	H [†]	H [†]	H [†]	H [†]	H [†]	M	M	E	VH [†]
Sodium adsorption ratio	L	L	L	L	L	L	M	M	M	L	L	L	L	M	L	L	VH [†]	M
Chloride	MS	Sn	Sn	Sn	MS	MS	MT [†]	MT [†]	MS	MS	MS	MS	MT [†]	MT [†]	Sn	Sn	NS	MT [†]
Sodium	MS	Sn	Sn	Sn	MS	MS	MT [†]	MT [†]	MS	MS	MS	MS	MS	MS	Sn	Sn	NS	MT [†]
Aluminium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Arsenic LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Beryllium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Boron LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	NS	S
Cadmium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Chromium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Cobalt LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Copper LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Fluoride LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Iron STV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Iron LTV	S	S	S	NS	NS	S	S	S	S	S	S	S	S	S	S	S	S	NS
Lead LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

(continued)

Table F4 continued

Parameter	Bore																	
	PGW-35	PGW-36	PGW-4	PGW-5	PGW-6	PGW-7	PGW-8	PGW-9	PGW-L1	PGW-L2	PGW-L3	PGW-L4	PGW-L5	SW-1	SW-2	SW-3	Y4-1A	Y4-2A
Lithium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Lithium (citrus) TV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Manganese STV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Manganese LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	NS	S	S
Mercury LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Molybdenum LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Nickel LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Nitrogen (total) STV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Nitrogen (total) LTV	S*	S*	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Phosphorus (total) STV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Phosphorus (total) LTV	S	S*	S	S	S	S*	S	S	S	S	S	S	S	S	S*	S*	S	S
Selenium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Uranium STV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Uranium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Vanadium LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Zinc LTV	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
pH lower	S	NS	S	NS	S	S	S	S	S	S	S	S	S	S	S	S	S	S
pH upper	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

Appendix G Groundwater chemistry analysis

Table G1 Groundwater sampling data for bores C4 to D4

Parameter & unit	Bore								
	C4	C4	C8	D2	D3A	D3A	D3B	D3B	D4
Field data									
Date	02/03/2016	03/05/2017	02/03/2016	18/04/2017	02/03/2016	18/04/2017	02/03/2016	18/04/2017	18/04/2017
Time	9:00	–	10:00	–	11:25	–	12:20	–	–
Standing water level (mBGL)	–	2.02	6.13	11.34	18.69	18.95	18.66	18.94	2.86
Field temperature	–	19.57	–	19.99	–	22.81	–	22.37	20.51
Field pH	7.19	6.95	6.75	7.3	7.4	7.43	7.2	7.16	7.07
Field electrical conductivity (µS/cm)	3045	2308	1104	4829	1783	1766	1564	1505	1229
Dissolved oxygen (%)	2.5	–	1.2	–	1.4	–	20.1	–	–
Dissolved oxygen (mg/L)	–	0.11	–	0.43	–	0.22	–	3.11	0.15
Field oxidation reduction potential, ORP (mV)	148	1.8	–132	–71.4	–29	73.5	48	85.2	–86.2
Field ORP – Eh (mV)	–	207.8	–	134.6	–	279.5	–	291.2	119.8
Field alkalinity	–	279	–	310	–	140	–	133	138
Laboratory data									
Lab Id	15S1668/033	16S2379/026	15S1668/034	16S2379/008	15S1668/035	16S2379/009	15S1668/036	16S2379/010	16S2379/011
Client Id	C4	C4	C8	D2 Finn	D3A	D3A Finn	D3B	D3B Finn	D4 Finn
Sample date	02/03/2016	03/05/2017	03/03/2016	18/04/2017	03/03/2016	18/04/2017	03/03/2016	18/04/2017	18/04/2017
Acidity, as CaCO ₃ (mg/L)	20	8	42	6	6	3	6	2	7
Alkalinity, total (mg/L)	335	316	79	336	157	143	150	157	268
Aluminium (µg/L)	<5	5	150	5	<5	5	<5	5	5
Antimony (µg/L)	<0.1	–	<0.1	–	0.4	–	0.3	–	–
Arsenic (µg/L)	2	2	<1	3	<1	<1	<1	1	2
Barium (µg/L)	150	100	80	60	93	94	76	55	270
Beryllium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Bicarbonate (mg/L)	408	385	96	410	192	175	183	192	327

(continued)

Table G1 continued

Parameter & unit	Bore								
	C4	C4	C8	D2	D3A	D3A	D3B	D3B	D4
Bismuth (µg/L)	<0.1	0	<0.1	0	<0.1	0	<0.1	0	0
Boron (µg/L)	70	49	30	34	100	90	160	140	39
Bromide (µg/L)	2400	1600	860	4200	950	860	860	720	660
Calcium (mg/L)	206	153	23.8	74.6	119	119	110	111	118
Cadmium (µg/L)	<0.1	<0.1	<0.1	0.3	<0.1	0.2	<0.1	0.2	0.1
Carbonate (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chloride (mg/L)	751	622	279	1350	350	367	280	279	247
Chromium (µg/L)	<0.5	<0.5	1.3	<0.5	<0.5	<0.5	<0.5	<0.5	1.7
Cobalt (µg/L)	0.6	0.4	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1
Copper (µg/L)	0.2	<0.1	0.5	<0.1	0.4	1.3	0.5	0.7	<0.1
Dissolved organic carbon (mg/L)	4.4	3.5	25	8.6	7.2	9.4	3.9	4.4	14
Electrical conductivity (µS/cm)	3170	2500	1090	5140	1750	1740	1580	1520	1300
Fluoride (µg/L)	760	580	<50	360	100	110	110	160	100
Gallium (µg/L)	<0.1	–	<0.1	–	<0.1	–	<0.1	–	–
Hardness, total (mg/L)	670	510	140	380	420	430	360	360	380
Hydroxide (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Iron (µg/L)	1300	490	210	1200	170	29	9	6	3500
Lanthanum (µg/L)	2.3	–	0.8	–	<0.1	–	<0.1	–	–
Lead (µg/L)	<0.1	<0.1	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Lithium (µg/L)	1.6	1.6	0.4	7.9	2.6	2.6	2	2	2.6
Magnesium (mg/L)	37.4	31.1	20	46.9	30.8	32.2	20.5	20.4	19.7
Manganese (µg/L)	14	6.3	8	54	44	26	18	7.8	68
Mercury (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Molybdenum (µg/L)	<1	–	<1	–	<1	–	<1	–	–
Nickel (µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrogen, ammonia (µg/L)	30	<10	340	190	90	20	10	<10	370

(continued)

Table G1 continued

Parameter & unit	Bore								
	C4	C4	C8	D2	D3A	D3A	D3B	D3B	D4
Nitrogen, nitrate (µg/L)	<10	<10	30	370	2800	4800	13000	4900	20
Nitrogen, nitrite (µg/L)	<10	<10	10	<10	190	220	100	120	<10
Nitrogen, total (µg/L)	160	180	900	750	3800	5500	16000	17000	700
Oxidised nitrogen, (µg/L)	<10	<10	50	380	3000	5100	13000	5000	30
pH	7.9	7.6	7.3	7.8	8	7.7	7.9	7.6	7.6
Phosphorus, soluble reactive (µg/L)	<10	<10	<10	10	<10	10	<10	10	10
Phosphorus, total (µg/L)	14	<10	13	33	<10	12	<10	10	54
Potassium (mg/L)	4.2	3.7	6.7	15.3	12.5	15	20.3	20.9	5.4
Selenium (µg/L)	<1	<1	<1	<1	<1	1	6	5	<1
Silica, from silicon (mg/L)	9.4	10	7	12	9.3	8.6	9.8	9.7	16
Silver (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sodium (mg/L)	425	331	167	1040	193	190	164	164	124
Sulfate, from sulfur (mg/L)	167	81.6	50	256	190	219	150	177	61.1
TDS by gravimetry (mg/L)	–	1400	–	2800	–	1000	–	900	760
TDS by summation (mg/L)	1800	1400	600	3000	1000	1100	900	890	740
Thallium (µg/L)	<0.1	–	0.1	–	<0.1	–	<0.1	–	–
Tin (µg/L)	<0.1	–	<0.1	–	<0.1	–	<0.1	–	–
Titanium (µg/L)	<2	–	<2	–	<2	–	<2	–	–
Uranium (µg/L)	7.1	4.6	<0.1	1.3	21	24	3.7	5.1	0.2
Vanadium (µg/L)	<0.1	<0.1	3	0.3	1.3	0.8	4.6	2.3	3.7
Zinc (µg/L)	11	5	14	4	5	36	8	11	10
Atrazine ^a (µg/L)	<0.1	–	<0.1	–	<0.1	–	<0.1	–	–
Methyl isothiocyanate ^a (µg/L)	<0.1	–	<0.1	–	<0.1	–	<0.1	–	–
Metolachlor ^a (µg/L)	<1.0	–	<1.0	–	<1.0	–	<1.0	–	–
Metalaxyl ^a (µg/L)	<0.1	–	<0.1	–	<0.1	–	<0.1	–	–

– = no data

^a Organic compound

Table G2 Groundwater sampling data for bores E2A to E4C

Parameter & unit	Bore									
	E2A	E2A	E3A	E3A	E3B	E3B	E4A	E4A	E4C	E4C
Field data										
Date	08/03/2016	04/05/2017	08/03/2016	02/05/2017	08/03/2016	02/05/2017	03/03/2016	02/05/2017	03/03/2016	02/05/2017
Time	8:50	–	10:50	–	11:30	–	12:50	–	12:15	–
Standing water level (mBGL)	5.37	5.36	3.8	3.92	3.83	3.95	9.4	9.44	9.49	9.52
Field temperature	–	20.27	–	19.62	–	19.76	–	19.91	–	20.23
Field pH	7.31	6.87	7.24	6.86	7.2	6.88	6.7	6.48	6.54	6.3
Field electrical conductivity (µS/cm)	2983	3634	2080	2655	2040	2064	1109	1032	243	228
Dissolved oxygen (%)	1.7	–	1.4	–	1.2	–	1.7	–	23.2	–
Dissolved oxygen (mg/L)	–	0.15	–	0.14	–	0.19	–	0.12	–	1.69
Field oxidation reduction potential, ORP (mV)	–70	–43.4	–116	–55.2	–107	–43	–169	–75.7	45	41.4
Field ORP – Eh (mV)	–	162.6	–	150.8	–	163	–	130.3	–	247.4
Field alkalinity	–	144	–	203	–	218	–	158	–	40
Laboratory data										
Lab Id	15S1668/046	16S2379/029	15S1668/044	16S2379/020	15S1668/045	16S2379/021	15S1668/038	16S2379/018	15S1668/039	16S2379/019
Client Id	E2A	E2A	E3A	E3A	E3B	E3B	E4A	E4A	E4C	E4C
Sample date	08/03/2016	04/05/2017	08/03/2016	02/05/2017	08/03/2016	02/05/2017	03/03/2016	02/05/2017	03/03/2016	02/05/2017
Acidity, as CaCO ₃ (mg/L)	10	8	25	11	20	10	46	10	10	3
Alkalinity, total (mg/L)	148	148	211	206	213	227	168	169	48	47
Aluminium (µg/L)	<5	5	10	6	10	6	48	49	22	17
Antimony (µg/L)	<0.1	–	<0.1	–	<0.1	–	<0.1	–	0.3	–
Arsenic (µg/L)	2	2	<1	1	<1	1	<1	<1	2	2
Barium (µg/L)	210	170	390	410	320	240	110	100	19	16
Beryllium (µg/L)	<0.1	<0.1	<0.1	<0.1	0.1	0.1	<0.1	0.1	<0.1	<0.1
Bicarbonate (mg/L)	181	180	257	251	259	277	204	206	58	57

(continued)

Table G2 continued

Parameter & unit	Bore									
	E2A	E2A	E3A	E3A	E3B	E3B	E4A	E4A	E4C	E4C
Bismuth (µg/L)	<0.1	0	<0.1	0	<0.1	0	<0.1	0	<0.1	0
Boron (µg/L)	640	650	250	230	240	140	40	16	20	11
Bromide (µg/L)	2600	2400	1200	1300	1100	950	650	580	180	180
Cadmium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Calcium (mg/L)	470	467	312	354	284	248	64.7	69.1	13.1	14.4
Carbonate (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chloride (mg/L)	639	671	396	448	381	373	247	255	26	31
Chromium (µg/L)	0.6	0.5	2.9	2.6	4.1	4.3	2.7	2.7	0.6	0.6
Cobalt (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Copper (µg/L)	0.7	<0.1	0.5	<0.1	0.5	<0.1	4.5	<0.1	9.7	<0.1
Dissolved organic carbon (mg/L)	3.9	5.4	14	16	15	19	31	33	2.6	4.1
Electrical conductivity (µS/cm)	3810	3870	2690	2850	2540	2230	1090	1120	239	250
Fluoride (µg/L)	60	60	80	70	80	70	<50	<50	<50	<50
Gallium (µg/L)	<0.1	–	<0.1	–	<0.1	–	0.3	–	<0.1	–
Hardness, total (mg/L)	1400	1400	960	1100	880	770	220	230	55	53
Hydroxide (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Iron (µg/L)	3400	1600	4400	4700	3600	3000	320	300	170	53
Lanthanum (µg/L)	0.2	–	0.2	–	0.3	–	3.1	–	0.9	–
Lead (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1
Lithium (µg/L)	4.4	4.6	4.1	4.3	3.5	3.3	0.6	0.6	0.4	0.3
Magnesium (mg/L)	60	61.5	43.9	48.9	42.4	37.8	14	14.3	5.5	4.2
Manganese (µg/L)	36	31	140	150	120	110	39	34	3	2.4
Mercury (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Molybdenum (µg/L)	1	–	<1	–	<1	–	<1	–	<1	–
Nickel (µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrogen, ammonia (µg/L)	80	60	660	630	570	570	630	600	30	20

(continued)

Table G2 continued

Parameter & unit	Bore									
	E2A	E2A	E3A	E3A	E3B	E3B	E4A	E4A	E4C	E4C
Nitrogen, nitrate (µg/L)	150	50	<10	<10	<10	<10	<10	<10	190	170
Nitrogen, nitrite (µg/L)	10	<10	<10	<10	<10	<10	10	<10	<10	<10
Nitrogen, total (µg/L)	370	590	940	980	970	940	1200	1200	360	260
Oxidised nitrogen, (µg/L)	170	50	<10	<10	10	<10	20	<10	200	170
pH	7.5	7.5	7.5	7.3	7.5	7.4	7.4	7	7.5	6.8
Phosphorus, soluble reactive (µg/L)	<10	<10	<10	30	20	40	20	<10	<10	<10
Phosphorus, total (µg/L)	25	20	50	65	48	51	25	25	18	<10
Potassium (mg/L)	75	81.5	35.4	42.4	35.8	28.4	4	3.9	2.7	2.4
Selenium (µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Silica, from silicon (mg/L)	8.4	7.7	14	14	15	15	13	13	7.8	8.1
Silver (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sodium (mg/L)	289	282	203	221	202	188	137	132	26.3	26.9
Sulfate, from sulfur (mg/L)	1040	1060	650	777	593	470	3.9	5.6	28	27.1
TDS by gravimetry (mg/L)	–	2800	–	2000	–	1400	–	630	–	130
TDS by summation (mg/L)	2700	2700	1800	2000	1700	1500	570	580	130	140
Thallium (µg/L)	<0.1	–	<0.1	–	<0.1	–	<0.1	–	<0.1	–
Tin (µg/L)	<0.1	–	<0.1	–	<0.1	–	<0.1	–	<0.1	–
Titanium (µg/L)	<2	–	<2	–	<2	–	3	–	<2	–
Uranium (µg/L)	1.1	0.2	<0.1	<0.1	0.2	0.1	0.1	0.1	0.3	0.2
Vanadium (µg/L)	0.9	0.7	7	6.4	9.1	9.1	5.5	5.1	33	29
Zinc (µg/L)	10	7	2	5	6	6	9	8	18	8
Atrazine ^a (µg/L)	<0.1	–	<0.1	–	<0.1	–	<0.1	–	<0.1	–
Methyl isothiocyanate ^a (µg/L)	<0.1	–	<0.1	–	<0.1	–	<0.1	–	<0.1	–
Metolachlor ^a (µg/L)	<1.0	–	<1.0	–	<1.0	–	<1.0	–	<1.0	–
Metalaxyl ^a (µg/L)	<0.1	–	<0.1	–	<0.1	–	<0.1	–	<0.1	–

– = no data

^a Organic compound

Table G3 Groundwater sampling data for bores E5B to F2B

Parameter	Bore									
	E5B	E5B	E7	E8	F1	F1	F2A	F2A	F2B	F2B
Field data										
Date	03/03/2016	02/05/2017	03/03/2016	03/03/2016	18/01/2016	04/05/2017	08/03/2016	27/04/2017	18/01/2016	27/04/2017
Time	11:40	–	10:20	9:15	9:00	–	–	–	2.35	–
Standing water level (mBGL)	4.95	5.02	4.76	3.35	2.64	2.60	2.88	2.65	2.35	2.31
Field temperature	–	–	–	–	–	–	–	–	–	19.49
Field pH	6.86	6.61	6.57	6.29	7.05	6.99	7.26	7.04	7.1	7.09
Field electrical conductivity (µS/cm)	740	674	1137	202	3848	3436	1972	2168	2301	1980
Dissolved oxygen (%)	1.1	–	–	1.6	12.8	–	–	–	17.6	–
Dissolved oxygen (mg/L)	–	–	–	–	–	–	–	–	–	1.51
Field oxidation reduction potential, ORP (mV)	–47	–51	–197	–17	–59	–57.2	–125	–59.6	–24	–22.5
Field ORP – Eh (mV)	–	155	–	–	–	148.8	–	146.4	–	183.5
Field alkalinity	–	134	–	–	–	355	–	290	–	289
Laboratory data										
Lab Id	15S1668/040	16S2379/017	15S1668/041	15S1668/042	15S1668/001	16S2379/027	15S1668/043	16S2379/012	15S1668/002	16S2379/013
Client Id	E5B	E5B	E7	E8	F1	F1	F2A	F2A	F2B	F2B
Sample date	03/03/2016	02/05/2017	03/03/2016	03/03/2016	18/01/2016	04/05/2017	08/03/2016	27/04/2017	18/01/2016	27/04/2017
Acidity, as CaCO ₃ (mg/L)	20	8	55	8	10	7	26	11	10	6
Alkalinity, total (mg/L)	148	141	186	26	355	373	310	326	274	282
Aluminium (µg/L)	22	16	280	42	8	5	8	5	<5	5
Antimony (µg/L)	<0.1	–	<0.1	<0.1	<0.1	–	<0.1	–	0.7	–
Arsenic (µg/L)	3	4	<1	<1	23	16	2	2	1	2
Barium (µg/L)	51	49	96	29	60	60	140	110	82	88
Beryllium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Bicarbonate (mg/L)	180	171	227	32	432	454	378	398	334	344

(continued)

Table G3 continued

Parameter	Bore									
	E5B	E5B	E7	E8	F1	F1	F2A	F2A	F2B	F2B
Boron (µg/L)	40	13	50	20	350	460	50	33	110	100
Bromide (µg/L)	360	420	620	170	2300	2000	1400	1100	880	1000
Cadmium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Calcium (mg/L)	56.6	61.7	61.3	12.1	139	145	215	174	171	184
Carbonate (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chloride (mg/L)	123	128	276	31	709	876	516	481	364	408
Chromium (µg/L)	2.1	1.9	2.9	<0.5	<0.5	<0.5	1.1	1	<0.5	<0.5
Cobalt (µg/L)	<0.1	<0.1	<0.1	0.3	0.2	0.2	<0.1	<0.1	0.1	0.1
Copper (µg/L)	51	<0.1	0.7	0.4	0.2	<0.1	1.2	<0.1	0.2	<0.1
Dissolved organic carbon (mg/L)	16	16	51	3	4.9	5.9	13	<1.0	4.7	<1.0
Electrical conductivity (µS/cm)	723	728	1160	185	3160	3620	2490	2350	2090	2140
Fluoride (µg/L)	70	60	70	<50	410	360	120	110	110	100
Gallium (µg/L)	<0.1	–	0.2	<0.1	<0.1	–	<0.1	–	<0.1	–
Hardness, total (mg/L)	180	190	220	48	570	640	690	560	550	600
Hydroxide (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Iron (µg/L)	530	580	110	770	3400	350	4300	3600	580	530
Lanthanum (µg/L)	1	–	2.6	0.1	<0.1	–	<0.1	–	<0.1	–
Lead (µg/L)	<0.1	<0.1	0.2	<0.1	0.7	<0.1	0.1	<0.1	<0.1	<0.1
Lithium (µg/L)	0.4	0.5	1.6	0.7	8.1	9.2	3.7	3.8	1.4	1.4
Magnesium (mg/L)	8.6	9	17.1	4.3	54.1	67.2	37.7	31	29.1	33
Manganese (µg/L)	27	20	25	2	310	350	110	97	27	32
Mercury (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Molybdenum (µg/L)	<1	–	<1	<1	9	–	<1	–	<1	–
Nickel (µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrogen, ammonia (µg/L)	360	290	1100	60	320	320	820	840	150	160

(continued)

Table G3 continued

Parameter	Bore									
	E5B	E5B	E7	E8	F1	F1	F2A	F2A	F2B	F2B
Nitrogen, nitrate (µg/L)	<10	<10	<10	110	10	<10	<10	<10	350	190
Nitrogen, nitrite (µg/L)	<10	<10	10	10	<10	<10	<10	<10	<10	<10
Nitrogen, total (µg/L)	790	630	2300	270	470	620	1200	1300	570	560
Oxidised nitrogen, (µg/L)	<10	<10	20	130	20	<10	10	<10	360	190
pH	7.8	7.2	7.4	7.2	7.7	7.6	7.6	7.5	7.7	7.6
Phosphorus, soluble reactive (µg/L)	20	20	50	<10	<10	<10	<10	10	<10	<10
Phosphorus, total (µg/L)	21	21	54	<10	12	10	36	31	<10	11
Potassium (mg/L)	2.7	2.4	4.2	2	13	17.5	12.2	8.6	19.1	19
Selenium (µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	1	<1
Silica, from silicon (mg/L)	11	9.5	17	7.7	12	12	21	22	14	14
Silver (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sodium (mg/L)	76.5	65.8	149	16	404	508	263	215	207	211
Sulfate, from sulfur (mg/L)	18.4	22.7	30.7	13	200	205	301	280	286	296
TDS by gravimetry (mg/L)	–	390	–	–	–	2000	–	1400	–	1300
TDS by summation (mg/L)	380	380	650	96	1700	2000	1500	1400	1200	1300
Thallium (µg/L)	<0.1	–	<0.1	<0.1	<0.1	–	<0.1	–	<0.1	–
Tin (µg/L)	<0.1	–	<0.1	<0.1	<0.1	–	<0.1	–	<0.1	–
Titanium (µg/L)	<2	–	3	<2	<2	–	<2	–	<2	–
Uranium (µg/L)	<0.1	<0.1	0.1	<0.1	0.1	<0.1	<0.1	<0.1	2.6	2.9
Vanadium (µg/L)	4.4	3.5	4.5	0.7	0.4	0.2	3	3	7.3	6.5
Zinc (µg/L)	7	6	5	9	14	28	2	7	<1	6
Atrazine ^a (µg/L)	<0.1	–	<0.1	<0.1	<0.1	–	<0.1	–	<0.1	–
Methyl isothiocyanate ^a (µg/L)	<0.1	–	<0.1	<0.1	<0.1	–	<0.1	–	<0.1	–
Metolachlor ^a (µg/L)	<1.0	–	<1.0	<1.0	<1.0	–	<1.0	–	<1.0	–
Metalaxyl ^a (µg/L)	<0.1	–	<0.1	<0.1	<0.1	–	<0.1	–	<0.1	–

– = no data

^a Organic compound

Table G4 Groundwater sampling data for bores F3 to F6C

Parameter & unit	Bore								
	F3	F3	F4	F4E (D)	F4E (S)	F5	F5	F6C (D)	F6C (S)
Field data									
Date	10/03/2016	10/04/2017	27/04/2017	10/03/2016	10/03/2016	10/03/2016	10/04/2017	10/03/2016	10/03/2016
Time	12:45	–	–	7:55	7:35	9:15	–	10:10	10:10
Standing water level (mBGL)	7.15	7.1	8.65	8.28	8.28	3.95	3.84	9.23	9.24
Field temperature	–	20.18	19.56	–	–	–	20.48	–	–
Field pH	7.12	6.82	6.89	7.3	7.31	6.74	6.44	7.27	6.43
Field electrical conductivity (µS/cm)	1825	2364	684	1450	1185	1047	1338	716	432
Dissolved oxygen (%)	1.8	–	–	2	0	1.9	–	1.5	1.8
Dissolved oxygen (mg/L)	–	0.11	1.22	–	–	–	1.28	–	–
Field oxidation reduction potential, ORP (mV)	–162	–99.3	–108.7	–120	–254	–110	–22	–133	5
Field ORP – Eh (mV)	–	106.7	97.3	–	–	–	184	–	–
Field alkalinity	–	597	192	–	–	–	89	–	–
Laboratory data									
Lab Id	15S1668/047	16S2379/001	16S2379/014	15S1668/049	15S1668/048	15S1668/050	16S2379/002	15S1668/052	15S1668/051
Client Id	F3	F3 Binn Rd	F4	F4E(D)	F4E(S)	F5	F5	F6C-D	F6C-S
Sample date	10/03/2016	10/04/2017	27/04/2017	10/03/2016	10/03/2016	10/03/2016	10/04/2017	10/03/2016	10/03/2016
Acidity, as CaCO ₃ (mg/L)	25	6	5	16	19	27	7	14	20
Alkalinity, total (mg/L)	352	319	166	324	281	73	89	255	60
Aluminium (µg/L)	6	5	320	10	38	53	49	11	99
Antimony (µg/L)	<0.1	–	–	<0.1	<0.1	<0.1	–	<0.1	<0.1
Arsenic (µg/L)	1	3	2	<1	<1	2	4	<1	<1
Barium (µg/L)	160	170	44	110	66	470	420	90	38
Beryllium (µg/L)	<0.1	<0.1	0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1
Bicarbonate (mg/L)	429	389	203	395	343	89	109	310	74
Bismuth (µg/L)	<0.1	0	0	<0.1	<0.1	<0.1	0	<0.1	<0.1

(continued)

Table G4 continued

Parameter & unit	Bore								
	F3	F3	F4	F4E (D)	F4E (S)	F5	F5	F6C (D)	F6C (S)
Boron (µg/L)	60	0	46	14	30	40	26	20	20
Bromide (µg/L)	1500	1200	390	1500	1100	520	470	430	410
Cadmium (µg/L)	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Calcium (mg/L)	209	247	43.7	102	111	132	122	93.5	13.6
Carbonate (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chloride (mg/L)	485	451	108	419	326	186	169	148	130
Chromium (µg/L)	2.1	1.4	3.3	5.7	4.4	0.8	0.8	3.1	1.2
Cobalt (µg/L)	<0.1	<0.1	<0.1	0.1	<0.1	0.1	0.1	<0.1	<0.1
Copper (µg/L)	0.7	<0.1	<0.1	1.4	0.4	0.4	<0.1	0.5	0.7
Dissolved organic carbon (mg/L)	26	19	<1.0	32	31	14	21	14	15
Electrical conductivity (µS/cm)	2420	2390	745	1940	1610	1300	1290	913	553
Fluoride (µg/L)	100	100	120	160	160	60	80	90	<50
Gallium (µg/L)	<0.1	–	–	<0.1	<0.1	<0.1	–	<0.1	0.1
Hardness, total (mg/L)	660	760	160	350	400	430	410	270	88
Hydroxide (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Iron (µg/L)	2200	3100	230	620	27	23000	17000	3300	970
Lanthanum (µg/L)	<0.1	–	–	<0.1	0.3	0.5	–	<0.1	1.7
Lead (µg/L)	<0.1	<0.1	0.4	0.1	<0.1	0.1	0.1	<0.1	0.3
Lithium (µg/L)	5.2	4.2	1.4	5.4	3.4	1.5	1.5	1.3	0.6
Magnesium (mg/L)	33.4	34.9	12.5	23.6	30.3	24.8	25.2	10	13
Manganese (µg/L)	180	170	3.8	25	17	48	43	57	9
Mercury (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Molybdenum (µg/L)	<1	–	–	<1	<1	<1	–	<1	<1
Nickel (µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrogen, ammonia (µg/L)	760	560	410	800	570	660	440	460	30
Nitrogen, nitrate (µg/L)	<10	40	<10	<10	<10	<10	10	<10	<10

(continued)

Table G4 continued

Parameter & unit	Bore								
	F3	F3	F4	F4E (D)	F4E (S)	F5	F5	F6C (D)	F6C (S)
Nitrogen, nitrite (µg/L)	10	<10	<10	20	10	20	<10	<10	10
Nitrogen, total (µg/L)	1400	1500	2900	1900	1600	1500	1400	660	280
Oxidised nitrogen, (µg/L)	10	40	<10	20	<10	10	20	<10	<10
pH	7.4	7.5	7.3	7.5	7.6	6.8	6.9	7.6	6.7
Phosphorus, soluble reactive (µg/L)	20	10	20	70	30	10	<10	20	<10
Phosphorus, total (µg/L)	19	43	19	72	37	<10	36	49	<10
Potassium (mg/L)	14.4	19.8	5.4	8.5	7.9	7.7	8.6	3.8	3.1
Selenium (µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Silica, from silicon (mg/L)	23	21	24	25	23	22	19	15	12
Silver (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sodium (mg/L)	266	233	113	278	184	112	104	79.7	76.9
Sulfate, from sulfur (mg/L)	226	364	59.2	62.9	91.8	338	313	1.1	7
TDS by gravimetry (mg/L)	–	1400	540	–	–	–	830	–	–
TDS by summation (mg/L)	1400	1500	440	1100	920	850	800	490	280
Thallium (µg/L)	<0.1	–	–	<0.1	<0.1	<0.1	–	<0.1	<0.1
Tin (µg/L)	<0.1	–	–	<0.1	<0.1	<0.1	–	<0.1	<0.1
Titanium (µg/L)	<2	–	–	10	7	<2	–	<2	<2
Uranium (µg/L)	<0.1	<0.1	0.7	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Vanadium (µg/L)	5.6	3.6	11	18	6	2.1	2.2	7.2	1.8
Zinc (µg/L)	5	42	5	15	15	3	37	15	50
Atrazine ^a (µg/L)	<0.1	–	–	<0.1	<0.1	<0.1	–	<0.1	<0.1
Methyl isothiocyanate ^a (µg/L)	<0.1	–	–	<0.1	<0.1	<0.1	–	<0.1	<0.1
Metolachlor ^a (µg/L)	<1.0	–	–	<1.0	<1.0	<1.0	–	<1.0	<1.0
Metalaxyl ^a (µg/L)	<0.1	–	–	<0.1	<0.1	<0.1	–	<0.1	<0.1

– = no data

^a Organic compound

Table G5 Groundwater sampling data for bores F9A to G5

Parameter & unit	Bore									
	F9A	F9C	G2A	G2A	G2B	G2B	G4	G4	G5	G5
Field data										
Date	02/05/2017	02/05/2017	02/03/2016	03/05/2017	18/01/2016	03/05/2017	10/03/2016	03/05/2017	22/03/2016	03/05/2017
Time	–	–	13:10	–	13:00	–	12:45	–	9:10	–
Standing water level (mBGL)	5.83	5.47	5.63	5.27	5.71	5.46	10.52	10.54	3.78	3.73
Field temperature	20.15	21.38	–	20.35	–	20.32	–	19.96	–	19.51
Field pH	6.8	6.6	7.09	6.82	6.96	6.92	7.02	6.75	6.6	6.2
Field electrical conductivity (µS/cm)	2977	1736	1690	1589	1858	1952	2497	3036	1102	390
Dissolved oxygen (%)	–	–	1	–	3	–	1.7	–	1.2	–
Dissolved oxygen (mg/L)	0.18	0.27	–	0.18	–	0.16	–	0.2	–	0.21
Field oxidation reduction potential, ORP (mV)	–39.6	57.8	–111	–57.4	–88	–70.8	–189	–96.3	–160	–16.5
Field ORP – Eh (mV)	166.4	263.8	–	148.6	–	135.2	–	109.7	–	189.5
Field alkalinity	420	410	–	385	–	340	–	219	–	74
Laboratory data										
Lab Id	16S2379/015	16S2379/016	15S1668/037	16S2379/024	15S1668/003	16S2379/025	15S1668/053	16S2379/022	15S1668/058	16S2379/023
Client Id	F9A	F9C	G2A	G2A	G2-B	G2B	G4	G4	G5	G5
Sample date	02/05/2017	02/05/2017	03/03/2016	03/05/2017	18/01/2016	03/05/2017	10/03/2016	03/05/2017	22/03/2016	03/05/2017
Acidity, as CaCO ₃ (mg/L)	19	7	24	12	10	3	25	17	28	11
Alkalinity, total (mg/L)	459	101	369	366	312	317	245	251	80	80
Aluminium (µg/L)	5	5	<5	6	9	10	16	12	51	46
Antimony (µg/L)	–	–	<0.1	–	<0.1	–	<0.1	–	<0.1	–
Arsenic (µg/L)	2	1	<1	<1	2	3	<1	2	<1	<1
Barium (µg/L)	200	73	93	92	79	120	360	340	26	29
Beryllium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	0.2
Bicarbonate (mg/L)	559	123	450	446	380	387	299	306	98	97
Bismuth (µg/L)	0	0	<0.1	0	<0.1	0	<0.1	0	<0.1	0

(continued)

Table G5 continued

Parameter & unit	Bore									
	F9A	F9C	G2A	G2A	G2B	G2B	G4	G4	G5	G5
Boron (µg/L)	46	42	50	27	40	42	12	9	30	14
Bromide (µg/L)	2200	830	910	1200	870	1200	1600	1400	310	310
Cadmium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Calcium (mg/L)	254	124	146	152	140	187	296	309	28.2	25.8
Carbonate (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chloride (mg/L)	588	352	331	350	309	410	664	623	76	82
Chromium (µg/L)	0.7	<0.5	0.5	0.6	0.7	0.6	4.4	3.9	1.7	2.2
Cobalt (µg/L)	0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Copper (µg/L)	<0.1	0.1	0.3	<0.1	0.3	<0.1	0.4	<0.1	0.4	<0.1
Dissolved organic carbon (mg/L)	38	14	16	20	12	17	29	31	13	16
Electrical conductivity (µS/cm)	3120	1830	1660	1690	1620	2000	3270	3260	427	441
Fluoride (µg/L)	180	70	70	60	80	60	80	70	<50	<50
Gallium (µg/L)	–	–	<0.1	–	<0.1	–	<0.1	–	0.3	–
Hardness, total (mg/L)	850	440	460	480	430	580	1000	1000	96	90
Hydroxide (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Iron (µg/L)	3700	44	4600	4400	6000	6500	44	31	170	220
Lanthanum (µg/L)	–	–	<0.1	–	<0.1	–	0.4	–	3.6	–
Lead (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Lithium (µg/L)	9.4	1.9	5	5	3	3.6	1.9	1.9	0.6	0.6
Magnesium (mg/L)	51.9	30.8	23.8	24.8	19.9	26.7	62.3	63.3	6.3	6.2
Manganese (µg/L)	83	0.8	100	100	81	100	130	110	12	12
Mercury (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Molybdenum (µg/L)	–	–	<1	–	<1	–	<1	–	<1	–
Nickel (µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrogen, ammonia (µg/L)	4400	20	1600	1400	490	10	480	480	160	170
Nitrogen, nitrate (µg/L)	<10	2200	<10	<10	90	<10	<10	<10	20	<10

(continued)

Table G5 continued

Parameter & unit	Bore									
	F9A	F9C	G2A	G2A	G2B	G2B	G4	G4	G5	G5
Nitrogen, nitrite (µg/L)	<10	150	<10	<10	<10	<10	<10	<10	<10	<10
Nitrogen, total (µg/L)	6000	3200	1900	2000	730	940	1200	1200	350	510
Oxidised nitrogen, (µg/L)	<10	2400	<10	<10	90	<10	<10	<10	20	<10
pH	7.2	7.1	7.8	7.4	7.5	7.5	7.4	7.3	7	6.8
Phosphorus, soluble reactive (µg/L)	50	<10	<10	<10	<10	<10	40	40	<10	<10
Phosphorus, total (µg/L)	72	10	35	35	30	35	31	37	<10	<10
Potassium (mg/L)	13.9	16	6.8	6.6	6.1	13.4	10.1	9.5	2.5	2.3
Selenium (µg/L)	<1	1	<1	<1	<1	<1	<1	<1	<1	<1
Silica, from silicon (mg/L)	46	25	22	21	16	16	18	18	14	13
Silver (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sodium (mg/L)	370	196	172	163	154	194	347	347	51.1	48.9
Sulfate, from sulfur (mg/L)	360	319	2.1	5.7	55.4	137	637	640	4.2	6.1
TDS by gravimetry (mg/L)	1800	1000	–	960	–	1200	–	2100	–	250
TDS by summation (mg/L)	1900	1100	900	920	870	1200	2200	2100	220	220
Thallium (µg/L)	–	–	<0.1	–	<0.1	–	<0.1	–	<0.1	–
Tin (µg/L)	–	–	<0.1	–	0.2	–	<0.1	–	<0.1	–
Titanium (µg/L)	–	–	<2	–	<2	–	<2	–	<2	–
Uranium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1
Vanadium (µg/L)	3.7	0.5	3.3	3	1.6	1.5	7.1	6.7	4.1	6.3
Zinc (µg/L)	6	5	<1	13	<1	8	6	4	20	8
Atrazine ^a (µg/L)	–	–	<0.1	–	<0.1	–	<0.1	–	<0.1	–
Methyl isothiocyanate ^a (µg/L)	–	–	<0.1	–	<0.1	–	<0.1	–	<0.1	–
Metolachlor ^a (µg/L)	–	–	<1.0	–	<1.0	–	<1.0	–	<1.0	–
Metalaxyl ^a (µg/L)	–	–	<0.1	–	<0.1	–	<0.1	–	<0.1	–

– = no data

^a Organic compound

Table G6 Groundwater sampling data for bores G7 to PGW-11

Parameter & unit	Bore								
	G7	HS13A	HS13B	HS64A	HS64C	PGW-1	PGW-10	PGW-10	PGW-11
Field data									
Date	22/03/2016	12/04/2017	12/04/2017	11/04/2017	11/04/2017	27/01/2016	19/01/2016	18/05/2017	19/01/2016
Time	11:55	–	–	–	–	11:30	12:15	–	11:30
Standing water level (mBGL)	3.69	3.71	3.62	14.84	14.87	–	1.68	2.23	–
Field temperature	–	19.43	21.42	20.27	20.32	–	–	20.67	–
Field pH	5.81	7.37	6.28	7.14	7.15	7.3	7.06	7.16	7.1
Field electrical conductivity (µS/cm)	137	766	673	1046	1059	958	3471	2864	2377
Dissolved oxygen (%)	9.2	–	–	–	–	6.9	10.6	–	13.9
Dissolved oxygen (mg/L)	–	0.12	0.07	0.6	0.17	–	–	2.18	–
Field oxidation reduction potential, ORP (mV)	–156	–174.6	–101.7	–62.3	–90.2	–2	115	95.1	95
Field ORP – Eh (mV)	–	31.4	104.3	143.7	115.8	–	–	301.1	–
Field alkalinity	–	231	127	238	234	–	–	178	–
Laboratory data									
Lab Id	15S1668/059	16S2379/006	16S2379/007	16S2379/005	16S2379/004	15S1668/015	15S1668/005	16S2379/036	15S1668/006
Client Id	G7	HS13A Riverdale Rd	HS13B Riverdale Rd	HS64A	HS63C	Bore Calnan Hooper	Line 3 Bore 1	Coast 3.1	Line 4 Bore 4
Sample date	22/03/2016	12/04/2017	12/04/2017	11/04/2017	11/04/2017	27/01/2016	19/01/2016	18/05/2017	19/01/2016
Acidity, as CaCO ₃ (mg/L)	41	6	8	3	5	22	8	11	5
Alkalinity, total (mg/L)	13	252	143	247	266	251	257	209	184
Aluminium (µg/L)	740	10	290	5	5	<5	<5	5	<5
Antimony (µg/L)	<0.1	–	–	–	–	<0.1	<0.1	–	0.2
Arsenic (µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Barium (µg/L)	26	49	11	58	60	210	83	86	97
Beryllium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Bicarbonate (mg/L)	15	307	174	301	324	306	313	254	224

(continued)

Table G6 continued

Parameter & unit	Bore								
	G7	HS13A	HS13B	HS64A	HS64C	PGW-1	PGW-10	PGW-10	PGW-11
Bismuth (µg/L)	<0.1	0	0	0	0	<0.1	<0.1	0	<0.1
Boron (µg/L)	30	15	8	20	20	20	100	90	100
Bromide (µg/L)	120	340	390	520	510	340	990	940	750
Cadmium (µg/L)	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Calcium (mg/L)	3.8	79.7	73	102	102	91.1	305	337	250
Carbonate (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chloride (mg/L)	20	130	105	178	210	115	618	554	322
Chromium (µg/L)	0.7	2.2	<0.5	<0.5	<0.5	0.5	<0.5	<0.5	<0.5
Cobalt (µg/L)	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1
Copper (µg/L)	0.5	<0.1	<0.1	<0.1	<0.1	0.2	0.6	0.3	0.9
Dissolved organic carbon (mg/L)	24	16	42	5.8	7.7	7.1	3.9	8.4	4
Electrical conductivity (µS/cm)	140	834	710	1100	1110	877	3110	2940	2140
Fluoride (µg/L)	<50	140	180	80	90	100	80	80	90
Gallium (µg/L)	0.1	–	–	–	–	<0.1	<0.1	–	<0.1
Hardness, total (mg/L)	18	240	220	290	300	270	890	980	740
Hydroxide (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Iron (µg/L)	240	43	320	1200	920	3400	6	5	11
Lanthanum (µg/L)	1.2	–	–	–	–	0.1	<0.1	–	<0.1
Lead (µg/L)	0.4	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Lithium (µg/L)	0.8	2.1	0.2	1.2	1.4	3	1.8	1.4	0.9
Magnesium (mg/L)	2.1	10.3	8.7	9.6	10.8	9.3	31.9	32.8	27.2
Manganese (µg/L)	3	17	2.1	27	27	40	21	0.8	12
Mercury (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Molybdenum (µg/L)	<1	–	–	–	–	<1	<1	–	<1
Nickel (µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrogen, ammonia (µg/L)	830	350	490	100	140	360	260	<10	<10

(continued)

Table G6 continued

Parameter & unit	Bore								
	G7	HS13A	HS13B	HS64A	HS64C	PGW-1	PGW-10	PGW-10	PGW-11
Nitrogen, nitrate (µg/L)	50	<10	<10	<10	<10	<10	18000	28000	19000
Nitrogen, nitrite (µg/L)	20	<10	<10	<10	<10	<10	50	<10	40
Nitrogen, total (µg/L)	1600	660	2100	280	410	420	19000	31000	20000
Oxidised nitrogen, (µg/L)	60	<10	<10	<10	<10	<10	18000	28000	19000
pH	5.9	7.6	6.8	7.6	7.7	7.7	7.6	7.5	7.6
Phosphorus, soluble reactive (µg/L)	10	80	10	20	20	10	<10	<10	10
Phosphorus, total (µg/L)	15	82	14	61	59	29	<10	<10	19
Potassium (mg/L)	8.3	3.3	3.1	3.5	3.7	3.3	19.3	19.8	17.2
Selenium (µg/L)	<1	<1	<1	<1	<1	<1	1	2	<1
Silica, from silicon (mg/L)	8.4	15	12	16	16	16	8.2	8.6	5.9
Silver (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sodium (mg/L)	14.9	61.2	52.1	98.4	103	67.5	324	263	170
Sulfate, from sulfur (mg/L)	15.2	3	60.1	10.2	5.1	16.1	405	507	431
TDS by gravimetry (mg/L)	–	490	510	650	650	–	–	2000	–
TDS by summation (mg/L)	73	440	390	550	590	450	1900	2000	1400
Thallium (µg/L)	<0.1	–	–	–	–	<0.1	<0.1	–	<0.1
Tin (µg/L)	<0.1	–	–	–	–	<0.1	<0.1	–	0.2
Titanium (µg/L)	<2	–	–	–	–	<2	<2	–	<2
Uranium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.4	1.9	4
Vanadium (µg/L)	2.1	2.8	0.7	0.5	0.7	0.9	0.2	0.1	0.5
Zinc (µg/L)	93	14	33	5	5	6	700	7	110
Atrazine ^a (µg/L)	<0.1	–	–	–	–	<0.1	<0.1	–	<0.1
Methyl isothiocyanate ^a (µg/L)	<0.1	–	–	–	–	<0.1	<0.1	–	<0.1
Metolachlor ^a (µg/L)	<1.0	–	–	–	–	<1.0	<1.0	–	<1.0
Metalaxyl ^a (µg/L)	<0.1	–	–	–	–	<0.1	<0.1	–	<0.1

– = no data

^a Organic compound

Table G7 Groundwater sampling data for bores PGW-12 to PGW-18

Parameter & unit	Bore								
	PGW-12	PGW-13	PGW-14	PGW-15	PGW-15	PGW-16	PGW-16	PGW-17	PGW-18
Field data									
Date	19/01/2016	18/05/2017	21/01/2016	21/01/2016	22/05/2017	4/02/2016	17/05/2017	27/01/2016	4/02/2016
Time	10:30	–	14:30	13:25	–	9:25	–	12:25	10:15
Standing water level (mBGL)	–	2.87	–	–	4.25	–	1.61	–	4.91
Field temperature	–	20.16	–	–	19.95	–	20.05	–	–
Field pH	7.07	7.2	6.71	7.13	7.27	7.01	6.83	7.38	7.28
Field electrical conductivity (µS/cm)	1432	1306	404	1361	1190	1683	1451	1657	2014
Dissolved oxygen (%)	12.2	–	5.9	6.4	–	77.3	–	26.5	9.6
Dissolved oxygen (mg/L)	–	0.81	–	–	1.18	–	0.15	–	–
Field oxidation reduction potential, ORP (mV)	–98	79.7	–38	–30	–17.2	169	–102.2	124	162
Field ORP – Eh (mV)	–	285.7	–	–	188.8	–	103.8	–	–
Field alkalinity	–	189	–	–	220	–	98	–	–
Laboratory data									
Lab Id	15S1668/007	16S2379/035	15S1668/009	15S1668/010	16S2379/038	15S1668/020	16S2379/034	15S1668/017	15S1668/023
Client Id	Line 5 Bore 5A1	Coast 5A2	MB2	MB4	Beta Wind	West bore EGR	EGR west	Green Ford	Lot 24 bore
Sample date	19/01/2016	18/05/2017	21/01/2016	21/01/2016	22/05/2017	4/02/2016	17/05/2017	27/01/2016	4/02/2016
Acidity, as CaCO ₃ (mg/L)	6	7	15	15	6	5	9	15	5
Alkalinity, total (mg/L)	177	209	43	250	253	106	109	168	254
Aluminium (µg/L)	11	5	13	<5	5	<5	7	<5	<5
Antimony (µg/L)	<0.1	–	<0.1	<0.1	–	0.2	–	0.2	<0.1
Arsenic (µg/L)	2	<1	<1	<1	<1	1	4	4	<1
Barium (µg/L)	95	51	21	36	42	100	250	72	100
Beryllium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Bicarbonate (mg/L)	216	255	52	305	308	130	133	204	310

(continued)

Table G7 continued

Parameter & unit	Bore								
	PGW-12	PGW-13	PGW-14	PGW-15	PGW-15	PGW-16	PGW-16	PGW-17	PGW-18
Bismuth (µg/L)	<0.1	0	<0.1	<0.1	0	<0.1	0	<0.1	<0.1
Boron (µg/L)	60	90	30	40	42	50	52	80	50
Bromide (µg/L)	420	350	230	680	820	410	460	770	890
Cadmium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Calcium (mg/L)	155	199	30.1	115	123	137	146	121	62.1
Carbonate (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chloride (mg/L)	117	109	31	193	200	147	159	215	425
Chromium (µg/L)	3.4	0.6	0.6	<0.5	<0.5	0.7	1.2	1.5	<0.5
Cobalt (µg/L)	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Copper (µg/L)	0.4	0.3	0.2	0.3	0.2	1.4	<0.1	4.1	0.5
Dissolved organic carbon (mg/L)	7.9	6.7	3.1	3.1	3.6	9.1	9.5	8.6	18
Electrical conductivity (µS/cm)	1280	1390	368	1230	1270	1400	1540	1470	1770
Fluoride (µg/L)	70	110	<50	100	100	80	<50	180	160
Gallium (µg/L)	<0.1	–	<0.1	<0.1	–	<0.1	–	<0.1	<0.1
Hardness, total (mg/L)	490	590	110	350	370	470	530	390	280
Hydroxide (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Iron (µg/L)	4500	20	1400	690	280	230	5600	170	13
Lanthanum (µg/L)	<0.1	–	0.2	<0.1	–	<0.1	–	<0.1	<0.1
Lead (µg/L)	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.5	<0.1
Lithium (µg/L)	1.4	1.4	0.4	1.4	1.3	1.8	2.5	1.7	6.8
Magnesium (mg/L)	24.1	23.5	9.5	15.7	15.4	30.1	39.9	20.3	30.3
Manganese (µg/L)	49	60	34	16	11	29	34	34	2
Mercury (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Molybdenum (µg/L)	<1	–	<1	<1	–	<1	–	<1	2
Nickel (µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	1
Nitrogen, ammonia (µg/L)	330	<10	50	10	<10	40	540	330	<10

(continued)

Table G7 continued

Parameter & unit	Bore								
	PGW-12	PGW-13	PGW-14	PGW-15	PGW-15	PGW-16	PGW-16	PGW-17	PGW-18
Nitrogen, nitrate (µg/L)	10	2900	<10	30	50	690	<10	170	690
Nitrogen, nitrite (µg/L)	<10	70	<10	<10	<10	50	<10	<10	<10
Nitrogen, total (µg/L)	440	3700	120	130	180	1300	850	550	1300
Oxidised nitrogen, (µg/L)	20	3000	<10	40	60	740	<10	170	690
pH	7.6	7.4	7	7.7	7.6	7.7	7.5	7.8	8
Phosphorus, soluble reactive (µg/L)	<10	<10	<10	<10	<10	20	<10	30	<10
Phosphorus, total (µg/L)	32	<10	<10	<10	<10	220	34	34	<10
Potassium (mg/L)	5.4	19.1	2.1	5.1	5.5	13	13.9	11.3	10.8
Selenium (µg/L)	<1	1	<1	<1	<1	<1	<1	<1	<1
Silica, from silicon (mg/L)	17	12	16	12	12	22	24	18	9.3
Silver (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sodium (mg/L)	80.7	70.9	22.9	117	109	112	97.8	124	263
Sulfate, from sulfur (mg/L)	312	357	78.6	66.8	84.4	366	459	259	28.3
TDS by gravimetry (mg/L)	–	960	–	–	720	–	1100	–	–
TDS by summation (mg/L)	800	920	200	660	690	870	980	850	980
Thallium (µg/L)	<0.1	–	<0.1	0.2	–	<0.1	–	<0.1	<0.1
Tin (µg/L)	<0.1	–	<0.1	0.1	–	<0.1	–	<0.1	<0.1
Titanium (µg/L)	<2	–	<2	<2	–	<2	–	<2	<2
Uranium (µg/L)	<0.1	0.8	<0.1	0.1	<0.1	0.1	<0.1	0.1	<0.1
Vanadium (µg/L)	9.2	0.8	0.6	<0.1	<0.1	1.3	4.8	6.9	0.2
Zinc (µg/L)	11	53	18	3	4	16	22	19	49
Atrazine ^a (µg/L)	<0.1	–	<0.1	<0.1	–	<0.1	–	<0.1	<0.1
Methyl isothiocyanate ^a (µg/L)	<0.1	–	<0.1	<0.1	–	<0.1	–	<0.1	<0.1
Metolachlor ^a (µg/L)	<1.0	–	<1.0	<1.0	–	<1.0	–	<1.0	<1.0
Metalaxyl ^a (µg/L)	<0.1	–	<0.1	<0.1	–	<0.1	–	<0.1	<0.1

– = no data

^a Organic compound

Table G8 Groundwater sampling data for bores PGW-19 to PGW-25

Parameter & unit	Bore								
	PGW-19	PGW-2	PGW-2	PGW-20	PGW-21	PGW-22	PGW-23	PGW-24	PGW-25
Field data									
Date	27/01/2016	21/01/2016	22/05/2017	10/02/2016	10/02/2016	21/01/2016	21/01/2016	22/05/2017	22/05/2017
Time	12:40	9:00	–	10:40	12:35	9:40	12:25	–	–
Standing water level (mBGL)	–	–	–	–	–	–	–	–	2.3
Field temperature	–	–	17.77	–	–	–	–	18.8	18.92
Field pH	7.44	7.1	7.16	7.65	7.32	7.39	–	7.12	7.04
Field electrical conductivity (µS/cm)	2086	2485	2907	2297	1242	1995	–	1575	2491
Dissolved oxygen (%)	75.7	47	–	94	69	81.6	–	–	–
Dissolved oxygen (mg/L)	–	–	0.81	–	–	–	–	0.29	0.34
Field oxidation reduction potential, ORP (mV)	–95	159	3	168	74	162	–	–99.6	–33.8
Field ORP – Eh (mV)	–	–	209	–	–	–	–	106.4	172.2
Field alkalinity	–	–	258	–	–	–	–	208	204
Laboratory data									
Lab Id	15S1668/016	15S1668/014	16S2379/040	15S1668/024	15S1668/025	15S1668/012	15S1668/011	16S2379/041	16S2379/039
Client Id	Shorties	Bore C2 shed/ feedlot bore	Pearson	West bore (Maiolo)	SE bore (Galati)	Tank bore Ivankovich	Bore 2 Ivankovich	Ivankovich carrot	Gmeiner
Sample date	27/01/2016	21/01/2016	22/05/2017	11/02/2016	11/02/2016	21/01/2016	21/01/2016	22/05/2017	22/05/2017
Acidity, as CaCO ₃ (mg/L)	20	10	12	2	9	4	3	6	11
Alkalinity, total (mg/L)	251	244	301	175	161	150	210	220	255
Aluminium (µg/L)	<5	<5	5	<5	<5	<5	<5	5	5
Antimony (µg/L)	<0.1	<0.1	–	<0.1	<0.1	0.1	0.2	–	–
Arsenic (µg/L)	4	2	5	1	<1	<1	<1	1	2
Barium (µg/L)	120	100	110	82	1800	170	96	140	170
Beryllium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Bicarbonate (mg/L)	306	297	366	213	196	183	256	269	311
Bismuth (µg/L)	<0.1	<0.1	0	<0.1	<0.1	<0.1	<0.1	0	0

(continued)

Table G8 continued

Parameter & unit	Bore								
	PGW-19	PGW-2	PGW-2	PGW-20	PGW-21	PGW-22	PGW-23	PGW-24	PGW-25
Boron (µg/L)	60	140	240	180	80	120	90	80	170
Bromide (µg/L)	980	1500	2600	1400	860	660	510	770	1500
Cadmium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Calcium (mg/L)	144	115	126	166	87.7	170	194	202	289
Carbonate (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chloride (mg/L)	317	483	756	453	287	279	178	255	430
Chromium (µg/L)	1.8	0.6	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Cobalt (µg/L)	<0.1	<0.1	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Copper (µg/L)	0.2	0.3	0.3	1.2	0.2	0.4	0.6	0.1	0.2
Dissolved organic carbon (mg/L)	20	<1.0	4.2	1.9	2	2.8	3.4	4.5	7
Electrical conductivity (µS/cm)	1880	2120	3200	2200	1200	1810	1550	1700	2660
Fluoride (µg/L)	180	270	260	280	130	70	80	60	90
Gallium (µg/L)	<0.1	<0.1	–	<0.1	<0.1	<0.1	<0.1	–	–
Hardness, total (mg/L)	490	430	520	520	320	550	560	590	890
Hydroxide (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Iron (µg/L)	900	<5	330	7	2300	51	310	2100	1300
Lanthanum (µg/L)	<0.1	<0.1	–	<0.1	0.7	<0.1	<0.1	–	–
Lead (µg/L)	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	0.5
Lithium (µg/L)	4.2	4.1	9.8	1	6	1.7	1.7	2.3	2.4
Magnesium (mg/L)	30.4	33.9	49.9	26.5	25.3	30.1	18.3	21.6	40.8
Manganese (µg/L)	47	1	27	<1	62	4	79	58	130
Mercury (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Molybdenum (µg/L)	<1	<1	–	<1	<1	<1	<1	–	–
Nickel (µg/L)	<1	<1	1	<1	<1	<1	<1	<1	<1
Nitrogen, ammonia (µg/L)	840	<10	70	<10	250	30	40	160	230
Nitrogen, nitrate (µg/L)	<10	8700	1900	22000	<10	11000	5900	<10	80
Nitrogen, nitrite (µg/L)	<10	<10	50	<10	<10	<10	140	<10	10

(continued)

Table G8 continued

Parameter & unit	Bore								
	PGW-19	PGW-2	PGW-2	PGW-20	PGW-21	PGW-22	PGW-23	PGW-24	PGW-25
Nitrogen, total (µg/L)	1400	8800	2300	23000	280	13000	6200	600	450
Oxidised nitrogen, (µg/L)	10	8700	2000	22000	10	11000	6100	<10	90
pH	7.7	7.8	7.6	7.9	7.7	7.8	7.8	7.6	7.5
Phosphorus, soluble reactive (µg/L)	30	20	<10	<10	<10	20	<10	<10	<10
Phosphorus, total (µg/L)	30	59	<10	<10	72	22	<10	13	<10
Potassium (mg/L)	10	11.6	48.8	24.9	6.2	26	22.2	20	32.4
Selenium (µg/L)	<1	1	<1	2	<1	2	<1	<1	<1
Silica, from silicon (mg/L)	25	14	15	8.6	30	12	8.5	11	12
Silver (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sodium (mg/L)	174	273	433	264	105	151	102	123	241
Sulfate, from sulfur (mg/L)	246	85.3	181	232	21.3	336	309	311	577
TDS by gravimetry (mg/L)	–	–	1900	–	–	–	–	1100	1800
TDS by summation (mg/L)	1100	1200	1800	1400	630	1100	980	1100	1800
Thallium (µg/L)	<0.1	<0.1	–	<0.1	<0.1	0.1	0.3	–	–
Tin (µg/L)	<0.1	<0.1	–	<0.1	<0.1	<0.1	<0.1	–	–
Titanium (µg/L)	<2	<2	–	<2	<2	<2	<2	–	–
Uranium (µg/L)	<0.1	0.9	8	0.9	<0.1	0.6	1.4	<0.1	0.3
Vanadium (µg/L)	4.1	0.3	0.6	0.7	<0.1	1.5	0.2	<0.1	0.7
Zinc (µg/L)	16	9	9	14	19	14	7	12	18
Atrazine ^a (µg/L)	<0.1	<0.1	–	<0.1	<0.1	<0.1	<0.1	–	–
Methyl isothiocyanate ^a (µg/L)	<0.1	<0.1	–	<0.1	<0.1	<0.1	<0.1	–	–
Metolachlor ^a (µg/L)	<1.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	–	–
Metalaxyl ^a (µg/L)	<0.1	<0.1	–	<0.1	<0.1	<0.1	<0.1	–	–

– = no data

^a Organic compound

Table G9 Groundwater sampling data for bores PGW-26 to PGW-30

Parameter & unit	Bore									
	PGW-26	PGW-26	PGW-27	PGW-27	PGW-28	PGW-28	PGW-29	PGW-3	PGW-30	PGW-30
Field data										
Date	16/02/2016	10/05/2017	29/03/2016	10/05/2017	25/02/2016	10/05/2017	29/03/2016	19/01/2016	21/03/2016	11/04/2017
Time	14:40	–	13:30	–	10:00	–	14:30	9:15	12:00	–
Standing water level (mBGL)	3.89	1.2	–	4.82	–	3.09	–	–	–	3.76
Field temperature	–	19.22	–	18.62	–	19.64	–	–	–	21.12
Field pH	7.08	7.08	7.49	7.03	7.29	7.03	7.34	6.91	7.3	7.11
Field electrical conductivity (µS/cm)	3115	2475	1734	1912	934	863	1493	2138	2052	1837
Dissolved oxygen (%)	32.4	–	28.1	–	2.6	–	2	18.2	3	–
Dissolved oxygen (mg/L)	–	2.71	–	0.16	–	0.25	–	–	–	0.13
Field oxidation reduction potential, ORP (mV)	169	93.7	–93	–85.6	–143	–121.9	–57	–22	–175	–119.9
Field ORP – Eh (mV)	–	299.7	–	120.4	–	84.1	–	–	–	86.1
Field alkalinity	–	221	–	168	–	141	–	–	–	283
Laboratory data										
Lab Id	15S1668/027	16S2379/030	15S1668/068	16S2379/032	15S1668/031	16S2379/031	15S1668/061	15S1668/008	15S1668/056	16S2379/003
Client Id	Windmill-Rose	Lot 10 100 Windmill bore	Bore 7	Bore 7 Patane	Monitoring bore Rigg Rd	Lot 4424 monitoring bore	Carrot Washer	Bore 6	MB3	MB3 Galati
Sample date	16/02/2016	10/05/2017	29/03/2016	10/05/2017	25/02/2016	10/05/2017	29/03/2016	19/01/2016	21/03/2016	11/04/2017
Acidity, as CaCO ₃ (mg/L)	28	7	12	8	18	8	22	15	18	6
Alkalinity, total (mg/L)	266	249	164	178	122	129	244	341	312	311
Aluminium (µg/L)	<5	5	<5	5	19	10	<5	<5	33	15
Antimony (µg/L)	0.3	–	<0.1	–	<0.1	–	<0.1	0.1	<0.1	–
Arsenic (µg/L)	<1	<1	3	3	2	2	<1	4	<1	1
Barium (µg/L)	130	110	240	200	130	110	91	170	120	90
Beryllium (µg/L)	<0.1	<0.1	<0.1	<0.1	0.2	0.2	<0.1	<0.1	0.2	0.1
Bicarbonate (mg/L)	325	303	200	217	149	157	298	415	381	379

(continued)

Table G9 continued

Parameter & unit	Bore									
	PGW-26	PGW-26	PGW-27	PGW-27	PGW-28	PGW-28	PGW-29	PGW-3	PGW-30	PGW-30
Bismuth (µg/L)	<0.1	0	<0.1	0	<0.1	0	<0.1	<0.1	<0.1	0
Boron (µg/L)	120	90	340	330	17	21	200	50	50	27
Bromide (µg/L)	1400	970	830	700	520	420	940	1100	1700	1100
Cadmium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Calcium (mg/L)	314	275	188	188	83	71	170	159	142	124
Carbonate (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chloride (mg/L)	660	576	311	353	133	166	192	354	497	444
Chromium (µg/L)	<0.5	<0.5	1.3	1.2	4.5	4.3	<0.5	0.6	5.2	3.8
Cobalt (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1
Copper (µg/L)	3.1	0.5	0.7	<0.1	<0.1	0.1	0.7	0.4	0.5	<0.1
Dissolved organic carbon (mg/L)	5.4	5.4	6.9	7.7	7.9	11	4.3	9.1	32	30
Electrical conductivity (µS/cm)	3210	2820	1910	2080	905	907	1620	1990	2080	1870
Fluoride (µg/L)	80	90	70	70	180	200	80	110	130	150
Gallium (µg/L)	<0.1	–	<0.1	–	<0.1	–	<0.1	<0.1	<0.1	–
Hardness, total (mg/L)	950	830	580	570	250	210	530	540	460	400
Hydroxide (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Iron (µg/L)	9	5	3800	2900	15000	9000	1500	2100	2400	2100
Lanthanum (µg/L)	<0.1	–	0.1	–	0.2	–	<0.1	0.1	0.1	–
Lead (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1
Lithium (µg/L)	2.2	2.1	1.1	1.4	1.7	1.7	1	3.2	2.8	2.8
Magnesium (mg/L)	39.5	36	25.7	23.9	10.1	8.7	25.1	34	25.2	21.6
Manganese (µg/L)	2	1.2	92	80	67	55	96	62	49	37
Mercury (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Molybdenum (µg/L)	<1	–	<1	–	<1	–	<1	<1	<1	–
Nickel (µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrogen, ammonia (µg/L)	<10	<10	230	190	430	400	20	220	440	380
Nitrogen, nitrate (µg/L)	4100	3600	20	50	<10	<10	7600	30	50	<10

(continued)

Table G9 continued

Parameter & unit	Bore									
	PGW-26	PGW-26	PGW-27	PGW-27	PGW-28	PGW-28	PGW-29	PGW-3	PGW-30	PGW-30
Nitrogen, nitrite (µg/L)	<10	<10	<10	<10	<10	<10	180	<10	10	<10
Nitrogen, total (µg/L)	4900	4500	360	470	610	760	8000	590	1300	1300
Oxidised nitrogen, (µg/L)	4100	3600	20	60	<10	10	7800	30	60	<10
pH	7.5	8.1	7.6	7.9	7.4	7.9	7.6	7.6	7.7	7.6
Phosphorus, soluble reactive (µg/L)	<10	10	<10	20	<10	10	<10	<10	40	40
Phosphorus, total (µg/L)	<10	29	48	52	32	46	11	42	40	57
Potassium (mg/L)	19.5	18.6	43.2	38.4	4.1	3.2	32	13.5	7.3	6.4
Selenium (µg/L)	2	1	<1	<1	<1	<1	<1	<1	<1	<1
Silica, from silicon (mg/L)	9.4	9.3	11	10	14	14	11	17	20	18
Silver (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sodium (mg/L)	327	276	161	152	82.3	72.5	123	214	269	217
Sulfate, from sulfur (mg/L)	471	430	399	518	90.1	94	271	197	32.5	21.9
TDS by gravimetry (mg/L)	–	1800	–	1400	–	540	–	–	–	1100
TDS by summation (mg/L)	2000	1800	1200	1400	480	490	990	1200	1200	1000
Thallium (µg/L)	0.1	–	<0.1	–	<0.1	–	<0.1	<0.1	<0.1	–
Tin (µg/L)	<0.1	–	<0.1	–	<0.1	–	<0.1	<0.1	0.3	–
Titanium (µg/L)	<2	–	<2	–	<2	–	<2	<2	4	–
Uranium (µg/L)	3.2	2.7	0.1	0.3	<0.1	<0.1	0.6	0.4	0.2	0.2
Vanadium (µg/L)	2	2.3	2.2	1.8	9.2	8.5	0.3	1.6	16	15
Zinc (µg/L)	24	24	29	12	14	14	15	5	13	4
Atrazine ^a (µg/L)	<0.1	–	<0.1	–	<0.1	–	<0.1	<0.1	<0.1	–
Methyl isothiocyanate ^a (µg/L)	<0.1	–	<0.1	–	<0.1	–	<0.1	<0.1	<0.1	–
Metolachlor ^a (µg/L)	<1.0	–	<1.0	–	<1.0	–	<1.0	<1.0	<1.0	–
Metalaxyl ^a (µg/L)	<0.1	–	<0.1	–	<0.1	–	<0.1	<0.1	<0.1	–

– = no data

^a Organic compound

Table G10 Groundwater sampling data for bores PGW-31 to PGW-5

Parameter & unit	Bore								
	PGW-31	PGW-31	PGW-32	PGW-33	PGW-34	PGW-35	PGW-36	PGW-4	PGW-5
Field data									
Date	29/03/2016	18/05/2017	29/03/2016	17/05/2017	2/02/2016	25/02/2016	17/03/2016	4/02/2016	25/02/2016
Time	10:30	–	12:00	–	13:30	12:20	10:00	11:20	11:00
Standing water level (mBGL)	–	–	–	12.06	2.33	–	2.93	–	2.92
Field temperature	–	not taken	–	19.35	–	–	–	–	–
Field pH	7.27	–	7.4	7.04	7.17	7.25	5.79	6.61	5.99
Field electrical conductivity (µS/cm)	2923	–	1620	3553	4258	1526	158	793	353
Dissolved oxygen (%)	0.9	–	23.4	–	1.4	113.9	25.6	4.3	1.2
Dissolved oxygen (mg/L)	–	–	–	0.73	–	–	–	–	–
Field oxidation reduction potential, ORP (mV)	–37	–	–94	–5.8	1	71	–64	–58	86
Field ORP – Eh (mV)	–	–	–	200.2	–	–	–	–	–
Field alkalinity	–	147	–	294	–	–	–	–	–
Laboratory data									
Lab Id	15S1668/064	16S2379/037	15S1668/066	16S2379/033	15S1668/019	15S1668/032	15S1668/054	15S1668/021	15S1668/030
Client Id	G3	NEE G3	NW bore (bore 3)	Schock bore 2	Smith domestic bore	Timber Mill bore	Monitoring bore N	Prod bore 1 OCRB	Monitoring bore Pead Rd
Sample date	29/03/2016	18/05/2017	29/03/2016	17/05/2017	2/02/2016	25/02/2016	17/03/2016	4/02/2016	25/02/2016
Acidity, as CaCO ₃ (mg/L)	23	8	21	12	20	7	36	20	33
Alkalinity, total (mg/L)	189	174	225	326	239	81	7	127	3
Aluminium (µg/L)	<5	5	5	5	8	7	3900	16	410
Antimony (µg/L)	0.1	–	<0.1	–	<0.1	0.1	0.1	<0.1	<0.1
Arsenic (µg/L)	2	2	2	15	5	2	<1	<1	43
Barium (µg/L)	180	140	130	110	98	120	43	79	57
Beryllium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2
Bicarbonate (mg/L)	230	212	274	398	291	99	8	155	4

(continued)

Table G10 continued

Parameter & unit	Bore								
	PGW-31	PGW-31	PGW-32	PGW-33	PGW-34	PGW-35	PGW-36	PGW-4	PGW-5
Bismuth (µg/L)	<0.1	0	<0.1	0	<0.1	<0.1	<0.1	<0.1	<0.1
Boron (µg/L)	580	600	340	160	230	60	30	20	90
Bromide (µg/L)	1500	1200	990	2800	3100	930	300	470	340
Cadmium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Calcium (mg/L)	435	451	159	158	274	120	2.8	41	15.6
Carbonate (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chloride (mg/L)	452	461	282	1090	959	300	28	115	48
Chromium (µg/L)	1.1	0.8	1.1	<0.5	<0.5	0.6	1.5	1.6	0.8
Cobalt (µg/L)	0.2	0.2	0.1	0.3	<0.1	0.1	0.6	<0.1	0.3
Copper (µg/L)	0.9	0.3	0.9	0.5	0.2	0.1	5.4	0.5	<0.1
Dissolved organic carbon (mg/L)	8.7	15	15	6.7	5.9	8.7	98	8.9	16
Electrical conductivity (µS/cm)	3290	3230	1990	3790	3930	1600	154	704	339
Fluoride (µg/L)	70	60	200	170	130	160	90	<50	<50
Gallium (µg/L)	<0.1	–	<0.1	–	<0.1	<0.1	0.7	<0.1	<0.1
Hardness, total (mg/L)	1300	1300	540	630	910	430	30	140	57
Hydroxide (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Iron (µg/L)	2400	1400	3700	470	5200	120	1900	310	4100
Lanthanum (µg/L)	<0.1	–	<0.1	–	<0.1	1	1.3	0.4	0.5
Lead (µg/L)	<0.1	<0.1	0.3	<0.1	<0.1	<0.1	2.4	<0.1	0.2
Lithium (µg/L)	4	3.2	2.6	3.1	3.4	4	1	0.8	4.7
Magnesium (mg/L)	52.3	51.9	35.6	57.4	54.4	31.4	5.7	9.6	4.4
Manganese (µg/L)	140	100	94	42	140	29	35	19	14
Mercury (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Molybdenum (µg/L)	<1	–	<1	–	<1	2	2	<1	<1
Nickel (µg/L)	1	<1	<1	<1	<1	<1	1	<1	<1
Nitrogen, ammonia (µg/L)	400	170	530	30	220	690	590	240	550
Nitrogen, nitrate (µg/L)	2600	6700	200	540	<10	4200	10	<10	<10

(continued)

Table G10 continued

Parameter & unit	Bore								
	PGW-31	PGW-31	PGW-32	PGW-33	PGW-34	PGW-35	PGW-36	PGW-4	PGW-5
Nitrogen, nitrite (µg/L)	60	220	<10	<10	<10	30	10	<10	10
Nitrogen, total (µg/L)	3100	8000	1000	1000	460	5200	5800	390	920
Oxidised nitrogen, (µg/L)	2700	6900	200	540	<10	4200	30	10	<10
pH	7.5	7.6	7.6	7.8	7.5	7.5	5.4	7.3	5.6
Phosphorus, soluble reactive (µg/L)	<10	<10	<10	<10	<10	10	130	20	20
Phosphorus, total (µg/L)	13	15	<10	<10	21	<10	600	<10	12
Potassium (mg/L)	68.8	75.5	29.1	15.3	30.3	18.1	3	3.6	9.8
Selenium (µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Silica, from silicon (mg/L)	11	9.4	20	14	12	25	14	14	23
Silver (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sodium (mg/L)	230	215	156	491	445	167	21.2	87	33.8
Sulfate, from sulfur (mg/L)	1040	1030	328	122	439	274	17	21.3	68.3
TDS by gravimetry (mg/L)	–	2400	–	2200	–	–	–	–	–
TDS by summation (mg/L)	2400	2400	1100	2100	2300	980	83	350	180
Thallium (µg/L)	<0.1	–	<0.1	–	<0.1	<0.1	<0.1	<0.1	0.1
Tin (µg/L)	<0.1	–	<0.1	–	<0.1	<0.1	0.6	<0.1	<0.1
Titanium (µg/L)	<2	–	<2	–	<2	<2	22	<2	<2
Uranium (µg/L)	4.7	4.8	<0.1	0.3	0.1	0.2	0.1	<0.1	<0.1
Vanadium (µg/L)	1.6	1.3	5.8	0.3	0.6	1.8	4.4	4.9	1.5
Zinc (µg/L)	12	12	12	11	14	19	29	9	17
Atrazine ^a (µg/L)	<0.1	–	<0.1	–	<0.1	<0.1	<0.1	<0.1	<0.1
Methyl isothiocyanate ^a (µg/L)	<0.1	–	<0.1	–	<0.1	<0.1	<0.1	<0.1	<0.1
Metolachlor ^a (µg/L)	<1.0	–	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0
Metalaxyl ^a (µg/L)	<0.1	–	<0.1	–	<0.1	<0.1	<0.1	<0.1	<0.1

– = no data

^a Organic compound

Table G11 Groundwater sampling data for bores PGW-6 to PGW-L5

Parameter & unit	Bore								
	PGW-6	PGW-7	PGW-8	PGW-9	PGW-L1	PGW-L2	PGW-L3	PGW-L4	PGW-L5
Field data									
Date	21/01/2016	04/02/2016	21/03/2016	19/01/2016	29/03/2016	16/02/2016	29/03/2016	29/03/2016	02/02/2016
Time	10:30	12:30	13:10	13:10	11:00	13:15	13:55	12:30	11:45
Standing water level (mBGL)	–	–	–	2.13	–	24.61	–	–	–
Field pH	7.19	7.35	7.3	7.03	7.78	7.73	7.81	7.85	7.59
Field electrical conductivity (µS/cm)	1521	2269	2648	3469	1438	1476	1330	1092	2238
Dissolved oxygen (%)	38.6	83.9	24.7	7.2	62.4	85.2	76.2	78.2	82.3
Field oxidation reduction potential, ORP (mV)	–77	5	50	132	–59	122	–65	–90	35
Laboratory data									
Lab Id	15S1668/013	15S1668/022	15S1668/057	15S1668/004	15S1668/067	15S1668/026	15S1668/060	15S1668/065	15S1668/018
Client Id	Bore 3 Benzie	North bore Castro	House Pump	Line 1 Bore 1	NE bore Galati	Leederville-Ivankovich	Lot 4424 Leederville	NE bore Lot 53	G1 Leederville
Sample date	21/01/2016	04/02/2016	21/03/2016	19/01/2016	29/03/2016	16/02/2016	29/03/2016	29/03/2016	02/02/2016
Acidity, as CaCO ₃ (mg/L)	10	6	10	10	3	5	7	4	5
Alkalinity, total (mg/L)	218	192	254	289	189	267	265	265	261
Aluminium (µg/L)	26	7	6	<5	<5	<5	<5	<5	<5
Antimony (µg/L)	0.1	<0.1	0.1	0.6	<0.1	<0.1	<0.1	<0.1	<0.1
Arsenic (µg/L)	1	5	<1	<1	<1	<1	<1	<1	<1
Barium (µg/L)	100	180	130	97	1200	840	860	1100	1200
Beryllium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Bicarbonate (mg/L)	266	234	310	352	230	326	323	323	318
Bismuth (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Boron (µg/L)	30	210	120	90	80	120	90	120	70
Bromide (µg/L)	590	1100	1600	1300	1100	1000	980	760	1300
Cadmium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

(continued)

Table G11 continued

Parameter & unit	Bore								
	PGW-6	PGW-7	PGW-8	PGW-9	PGW-L1	PGW-L2	PGW-L3	PGW-L4	PGW-L5
Calcium (mg/L)	111	232	268	264	81.7	85.9	126	84.9	173
Carbonate (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chloride (mg/L)	241	292	548	650	344	306	305	217	503
Chromium (µg/L)	<0.5	2.7	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Cobalt (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Copper (µg/L)	1.3	0.3	0.7	0.7	0.4	2.7	0.6	0.4	0.5
Dissolved organic carbon (mg/L)	4.2	10	7.5	6.9	3.4	7.4	6.6	4.6	5.4
Electrical conductivity (µS/cm)	1380	2040	2830	3180	1510	1420	1440	1160	1940
Fluoride (µg/L)	70	100	110	130	140	140	140	130	110
Gallium (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Hardness, total (mg/L)	350	730	860	840	280	300	420	300	550
Hydroxide (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Iron (µg/L)	2700	1100	10	<5	430	240	760	530	1300
Lanthanum (µg/L)	<0.1	0.1	<0.1	<0.1	0.4	0.4	0.3	0.3	0.5
Lead (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	<0.1
Lithium (µg/L)	1.3	2.5	1.3	2.3	5.7	6.2	6	4.5	7.8
Magnesium (mg/L)	18	36.9	45.7	44.1	18	20.3	24.8	20.5	29
Manganese (µg/L)	36	67	58	3	100	80	84	84	92
Mercury (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Molybdenum (µg/L)	<1	<1	1	2	<1	<1	<1	<1	<1
Nickel (µg/L)	<1	<1	<1	1	<1	<1	<1	<1	<1
Nitrogen, ammonia (µg/L)	70	320	250	<10	330	500	420	380	590
Nitrogen, nitrate (µg/L)	20	<10	220	3100	<10	20	<10	<10	<10
Nitrogen, nitrite (µg/L)	<10	<10	<10	<10	<10	<10	<10	<10	<10
Nitrogen, total (µg/L)	170	560	710	3100	350	550	480	400	570
Oxidised nitrogen, (µg/L)	30	10	230	3100	<10	20	10	<10	<10
pH	7.7	7.8	7.8	7.6	7.9	7.9	7.9	8	7.9

(continued)

Table G11 continued

Parameter & unit	Bore								
	PGW-6	PGW-7	PGW-8	PGW-9	PGW-L1	PGW-L2	PGW-L3	PGW-L4	PGW-L5
Phosphorus, soluble reactive (µg/L)	<10	10	<10	10	30	30	<10	10	<10
Phosphorus, total (µg/L)	38	53	<10	11	25	28	22	<10	29
Potassium (mg/L)	5.1	16.7	18.5	11.8	5.3	6.2	5.2	5.1	5.8
Selenium (µg/L)	<1	<1	<1	3	<1	<1	<1	<1	<1
Silica, from silicon (mg/L)	19	19	18	14	24	18	18	20	16
Silver (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sodium (mg/L)	147	172	287	367	201	176	137	129	165
Sulfate, from sulfur (mg/L)	120	478	470	410	37.3	6.6	4.8	3.5	15.3
TDS by summation (mg/L)	770	1300	1800	1900	800	760	760	620	1000
Thallium (µg/L)	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	<0.1	<0.1	<0.1
Tin (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Titanium (µg/L)	<2	<2	<2	<2	<2	<2	<2	<2	<2
Uranium (µg/L)	<0.1	1.5	1	3.4	<0.1	<0.1	<0.1	<0.1	<0.1
Vanadium (µg/L)	0.3	6.8	0.1	2	<0.1	<0.1	<0.1	<0.1	<0.1
Zinc (µg/L)	8	18	19	25	11	20	10	6	12
Atrazine ^a (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Methyl isothiocyanate ^a (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Metolachlor ^a (µg/L)	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Metalaxyl ^a (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

— = no data

^a Organic compound

Table G12 Groundwater sampling data for bores SW-1 to HS15C

Parameter & unit	Bore									
	SW-1	SW-2	SW-3	Y4-1A	Y4-1A	Y4-2A	HS64A*	HS64C*	HS15A*	HS15C*
Field data										
Date	21/03/2016	29/03/2016	29/03/2016	16/02/2016	04/05/2017	16/02/2016	05/03/2015	05/03/2015	06/03/2015	06/03/2015
Time	11:15	9:30	8:25	9:45	–	10:30	8:03am	8:40am	8:05am	9:05am
Standing water level (mBGL)	–	–	–	1.97	1.99	5.21	14.89	14.89	4.39	4.38
Field temperature	–	–	–	–	20.17	–	20.1	20.2	20	23.9
Field pH	7.76	7.17	7.35	7.3	6.96	7.18	7.25	7.15	6.3	6.4
Field electrical conductivity (µS/cm)	1548	672	733	9665	8211	3574	990	997	722	249
Dissolved oxygen (%)	60.9	47.7	24.8	2	–	1.2	–	–	–	–
Dissolved oxygen (mg/L)	–	–	–	–	0.13	–	0.64	0.28	0.57	0.98
Field oxidation reduction potential, ORP (mV)	102	105	98	99	–22.5	–63	–	–	–	–
Field ORP – Eh (mV)	–	–	–	–	183.5	–	–	–	–	–
Field alkalinity	–	–	–	–	324	–	–	–	–	–
Laboratory data										
Lab Id	15S1668/055	15S1668/063	15S1668/062	15S1668/028	16S2379/028	15S1668/029	–	–	–	–
Client Id	Excav Galati	Myalup Drain Patane	Roger Rd E	Y4-1A	Y4-1A	Y4-2A	–	–	–	–
Sample date	21/03/2016	29/03/2016	29/03/2016	16/02/2016	04/05/2017	16/02/2016	–	–	–	–
Acidity, as CaCO ₃ (mg/L)	5	7	7	17	17	28	16	16	47	19
Alkalinity, total (mg/L)	188	64	72	338	334	201	270	260	88	59
Aluminium (µg/L)	<5	240	52	<5	5	6	<10	<10	330	980
Antimony (µg/L)	<0.1	<0.1	<0.1	<0.2	–	<0.1	–	–	–	–
Arsenic (µg/L)	<1	<1	<1	<2	<2	<1	<1	<1	<1	<1
Barium (µg/L)	1100	43	35	68	70	460	–	–	–	–
Beryllium (µg/L)	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	–	–	–	–
Bicarbonate (mg/L)	229	78	88	412	407	245	329	317	107	72

(continued)

Table G12 continued

Parameter & unit	Bore									
	SW-1	SW-2	SW-3	Y4-1A	Y4-1A	Y4-2A	HS64A*	HS64C*	HS15A*	HS15C*
Bismuth (µg/L)	<0.1	<0.1	<0.1	<0.2	0	<0.1	–	–	–	–
Boron (µg/L)	70	70	100	770	710	400	26	25	34	15
Bromide (µg/L)	1200	420	590	9300	7500	2700	<500	<500	<500	<500
Cadmium (µg/L)	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	–	–	–	–
Calcium (mg/L)	90	23.9	23.4	296	293	452	110	110	40	14
Carbonate (mg/L)	<1	<1	<1	<1	<1	<1	<5	<5	<5	<5
Chloride (mg/L)	366	145	169	2790	2470	691	200	190	190	32
Chromium (µg/L)	<0.5	0.9	<0.5	<10	<10	0.8	–	–	–	–
Cobalt (µg/L)	<0.1	1.3	1.4	<0.2	<0.2	<0.1	–	–	–	–
Copper (µg/L)	1.6	4	6.3	<0.2	0.8	0.8	<1	<1	<1	3
Dissolved organic carbon (mg/L)	4.5	20	19	7.7	8.4	6	–	–	–	–
Electrical conductivity (µS/cm)	1560	708	783	9930	8730	3750	1100	1100	730	180
Fluoride (µg/L)	140	170	230	400	380	80	<500	<500	<500	<500
Gallium (µg/L)	<0.1	0.2	0.1	<0.2	–	<0.1	–	–	–	–
Hardness, total (mg/L)	300	130	130	1500	1500	1400	320	315	140	47
Hydroxide (mg/L)	<1	<1	<1	<1	<1	<1	<5	<5	<5	<5
Iron (µg/L)	48	1200	1100	380	53	9800	900	1300	1300	1400
Lanthanum (µg/L)	0.3	2.2	1.1	<0.2	–	0.3	–	–	–	–
Lead (µg/L)	0.1	0.3	0.3	<0.2	0.5	<0.1	<1	<1	<1	<1
Lithium (µg/L)	6.2	0.9	0.2	27	26	4.8	–	–	–	–
Magnesium (mg/L)	18.7	16.1	18.5	189	179	59.8	11	9.9	9.3	3
Manganese (µg/L)	50	90	210	20	22	190	30	28	27	8
Mercury (µg/L)	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	–	–	–	–
Molybdenum (µg/L)	<1	1	2	<2	–	<1	–	–	–	–
Nickel (µg/L)	<1	1	<1	<2	<2	<1	<1	<1	0.001	<1
Nitrogen, ammonia (µg/L)	150	280	710	1500	1900	360	200	130	560	600
Nitrogen, nitrate (µg/L)	40	400	410	<10	<10	<10	–	–	–	–

(continued)

Table G12 continued

Parameter & unit	Bore									
	SW-1	SW-2	SW-3	Y4-1A	Y4-1A	Y4-2A	HS64A*	HS64C*	HS15A*	HS15C*
Nitrogen, nitrite (µg/L)	<10	80	230	<10	<10	<10	–	–	–	–
Nitrogen, total (µg/L)	270	2400	3500	2100	2100	550	800	1300	1500	2300
Oxidised nitrogen, (µg/L)	40	490	630	<10	<10	<10	16	24	<5	230
pH	8	7.3	7.5	7.6	7.5	7.4	7.6	7.6	6.5	6.6
Phosphorus, soluble reactive (µg/L)	20	110	320	20	10	<10	35	28	110	41
Phosphorus, total (µg/L)	16	280	410	38	18	40	70	70	130	60
Potassium (mg/L)	5.8	14.2	15.5	66.5	64.1	58.9	3.5	3.4	3.5	1.5
Selenium (µg/L)	<1	<1	<1	<2	<2	<1	–	–	–	–
Silica, from silicon (mg/L)	22	9.4	8.3	12	13	12	–	–	–	–
Silver (µg/L)	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	–	–	–	–
Sodium (mg/L)	203	90.6	97.7	1570	1360	300	94	92	100	34
Sulfate, from sulfur (mg/L)	60.7	44.2	39.4	698	690	892	4	9	<1	2
TDS by gravimetry (mg/L)	–	–	–	–	5100	–	710	670	440	110
TDS by summation (mg/L)	860	380	410	5800	5300	2600	–	–	–	–
Thallium (µg/L)	<0.1	<0.1	<0.1	<0.2	–	<0.1	–	–	–	–
Tin (µg/L)	<0.1	1.8	0.7	<0.2	–	<0.1	–	–	–	–
Titanium (µg/L)	<2	2	3	<2	–	<2	–	–	–	–
Uranium (µg/L)	<0.1	0.2	0.2	<0.2	<0.2	<0.1	–	–	–	–
Vanadium (µg/L)	<0.1	4.8	3.9	0.3	0.3	2	–	–	–	–
Zinc (µg/L)	12	22	95	4	13	<1	<1	<1	6	46
Atrazine ^a (µg/L)	<0.1	<0.1	<0.1	<0.1	–	<0.1	–	–	–	–
Methyl isothiocyanate ^a (µg/L)	<0.1	<0.1	<0.1	<0.1	–	<0.1	–	–	–	–
Metolachlor ^a (µg/L)	<1.0	<1.0	<1.0	<1.0	–	<1.0	–	–	–	–
Metalaxyl ^a (µg/L)	<0.1	<0.1	<0.1	<0.1	–	<0.1	–	–	–	–

– = no data

^a Organic compound

Note: Bores marked with an asterisk were analysed by MPL Laboratories.

Table G13 Groundwater sampling data for bores HS13A to D3B

Parameter & unit	Bore									
	HS13A	HS13B	HS11A	HS11B	HS8B	HS8C	HS1B	D2	D3A	D3B
Field data										
Date	5/03/2015	11/03/2015	7/03/2015	7/03/2015	6/03/2015	6/03/2015	11/03/2015	9/03/2015	10/03/2015	10/03/2015
Time	10:20am	1:45pm	10:30am	10:45am	1:00pm	12:35pm	1:45pm	1:20pm	7:45am	8:35am
Standing water level (mBGL)	4.48	4.38	3.35	3.4	7.38	7.4	27.5	10.86	18.39	18.37
Field temperature	19.7	21.1	18.8	19.5	19.4	20.1	23.4	20.6	21.6	22.3
Field pH	7.25	6.3	7.25	4.9	5.6	5.95	7.35	7.45	7.45	7.15
Field electrical conductivity (µS/cm)	704	442	1085	356	272	246	1180	3680	1630	1220
Dissolved oxygen (mg/L)	0.26	0.6	0.4	0.58	0.41	0.75	1.32	0.77	1.94	2.6
Laboratory data										
Acidity, as CaCO ₃ (mg/L)	12	49	26	98	38	39	10	<5	<5	<5
Alkalinity, total (mg/L)	250	110	290	<5	16	28	260	340	150	160
Aluminium (µg/L)	10	350	30	3800	1400	430	150	10	<10	<10
Arsenic (µg/L)	<1	<1	<1	<1	<1	<1	<1	3	<1	<1
Bicarbonate (mg/L)	305	134	354	<5	20	34	317	415	183	195
Boron (µg/L)	25	19	27	30	15	12	150	31	100	150
Bromide (µg/L)	<500	<500	<500	<500	<500	<500	<500	<500	700	600
Calcium (mg/L)	87	49	120	5.4	1.1	25	80	60	120	120
Carbonate (mg/L)	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Chloride (mg/L)	110	70	210	79	64	32	190	900	320	250
Copper (µg/L)	<1	<1	<1	<1	<1	1	<1	<1	<1	<1
Electrical conductivity (µS/cm)	780	450	1200	290	230	260	1300	2800	1700	1500
Fluoride (µg/L)	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500
Hardness, total (mg/L)	263	148	360	41	14	87	260	260	440	380
Hydroxide (mg/L)	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5

(continued)

Table G13 continued

Parameter & unit	Bore									
	HS13A	HS13B	HS11A	HS11B	HS8B	HS8C	HS1B	D2	D3A	D3B
Iron (µg/L)	30	200	20	460	210	60	560	1200	280	<0.01
Lead (µg/L)	<1	<1	<1	1	2	<1	2	1	1	<1
Magnesium (mg/L)	11	6.3	15	6.8	2.6	5.9	16	27	32	21
Manganese (µg/L)	18	<5	21	<5	<5	<5	<5	33	29	8
Nickel (µg/L)	<1	<1	<1	<1	<1	<1	1	<1	<1	<1
Nitrogen, ammonia (µg/L)	380	420	420	230	190	20	<5	140	50	10
Nitrogen, total (µg/L)	2100	2400	1400	2800	1000	500	7000	700	6200	14000
Oxidised nitrogen, (µg/L)	180	8	<5	23	<5	15	7000	310	5700	15000
pH	8	6.8	7.6	4.5	5.6	5.9	7.6	7.7	7.9	7.8
Phosphorus, soluble reactive (µg/L)	82	10	83	32	15	71	6	7	26	15
Phosphorus, total (µg/L)	80	<50	110	<50	<50	70	<50	60	<50	<50
Potassium (mg/L)	3.3	0.9	3.6	3.5	1.9	5	31	9.1	14	17
Sodium (mg/L)	56	32	120	47	51	15	160	720	180	150
Sulfate, from sulfur (mg/L)	<1	9	2	1	9	37	120	150	220	160
TDS by gravimetry (mg/L)	470	270	800	170	140	160	800	2200	1100	930
Zinc (µg/L)	<1	18	6	8	4	3	7	3	11	8

Note: Bores marked with an asterisk were analysed by MPL Laboratories.

Table G14 Groundwater sampling data for bores D4 to E5B

Parameter & unit	Bore									
	D4	Y4-1A	Y4-2A	Y4-3B	Y4-3C	Y4-4B	E3A	E4A	E4C	E5B
Field data										
Date	10/03/2015	6/03/2015	6/03/2015	6/03/2015	6/03/2015	5/03/2015	10/03/2015	10/03/2015	10/03/2015	10/03/2015
Time	9:30am	10:55am	11:30am	10:15am	9:55am	1:40pm	10:20am	11:05	11:50am	12:30pm
Standing water level (mBGL)	2.58	1.89	5.18	3.73	3.75	9.38	3.68	9.27	9.34	4.77
Field temperature	20.4	20.2	20.5	19.9	20.2	20.4	19.8	21.9	22.1	21.3
Field pH	7.25	7	7	7	6.7	6.35	7.15	6.8	6.8	7
Field electrical conductivity (µS/cm)	1200	7640	2600	1540	1630	619	2090	981	237	827
Dissolved oxygen (mg/L)	1.01	0.53	0.43	0.47	0.62	0.65	0.73	0.57	1.76	0.74
Laboratory data										
Acidity, as CaCO ₃ (mg/L)	11	51	22	16	30	25	14	12	5	12
Alkalinity, total (mg/L)	290	330	210	240	170	39	230	180	59	200
Aluminium (µg/L)	20	30	10	10	40	20	<10	50	20	30
Arsenic (µg/L)	3	<1	<1	<1	<1	<1	<1	<1	1	4
Bicarbonate (mg/L)	354	403	256	293	207	48	281	220	72	244
Boron (µg/L)	47	880	410	72	90	30	240	29	17	29
Bromide (µg/L)	<0.5	11000	2500	<500	<500	700	<500	600	<500	<500
Calcium (mg/L)	130	310	430	200	200	34	310	69	17	76
Carbonate (mg/L)	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Chloride (mg/L)	240	3100	730	270	290	180	370	230	25	160
Copper (µg/L)	1	<1	5	<1	<1	<1	<1	<1	<1	<1
Electrical conductivity (µS/cm)	1300	9600	2800	1400	1900	600	2500	1100	260	880
Fluoride (µg/L)	<500	<2500	<500	<500	<500	<500	<500	<500	<500	<500
Hardness, total (mg/L)	410	1700	1300	650	650	124	930	230	65	230

(continued)

Table G14 continued

Parameter & unit	Bore									
	D4	Y4-1A	Y4-2A	Y4-3B	Y4-3C	Y4-4B	E3A	E4A	E4C	E5B
Hydroxide (mg/L)	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Iron (µg/L)	4200	370	7700	3400	16000	50	4500	280	130	530
Lead (µg/L)	5	<1	<1	<1	<1	<1	<1	<1	<1	<1
Magnesium (mg/L)	21	230	62	34	38	9.6	41	14	5.2	11
Manganese (µg/L)	73	23	200	110	230	16	140	42	6	41
Nickel (µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrogen, ammonia (µg/L)	310	1700	300	420	300	280	490	380	20	320
Nitrogen, total (µg/L)	700	2300	600	1200	1400	1200	800	1100	300	900
Oxidised nitrogen, (µg/L)	6	6	<5	17	8	9	10	<5	240	<5
pH	7.7	7.4	7.2	7.3	6.9	6.6	7.5	7.4	7.3	7.7
Phosphorus, soluble reactive (µg/L)	11	11	<5	32	<5	21	<5	35	9	29
Phosphorus, total (µg/L)	80	<50	90	70	<50	<50	70	<50	<50	<50
Potassium (mg/L)	4.9	90	60	11	16	4.4	35	3.6	2.2	2.8
Sodium (mg/L)	120	1800	350	160	160	79	190	120	21	90
Sulfate, from sulfur (mg/L)	60	730	720	310	380	30	600	2	24	10
TDS by gravimetry (mg/L)	860	6700	2700	1300	1300	360	1800	720	150	530
Zinc (µg/L)	540	9	11	<1	4	2	6	7	5	11

Note: Bores marked with an asterisk were analysed by MPL Laboratories.

Table G15 Groundwater sampling data for bores F2A to G7

Parameter & unit	Bore								
	F2A	F2B	F3	F5	G2A	G2B	G4	G5	G7
Field data									
Date	13/03/2015	13/03/2015	11/03/2015	11/03/2015	11/03/2015	6/03/2015	11/03/2015	11/03/2015	11/03/2015
Time	7:55am	8:35am	8:40am	9:45am	7:45am	3:00pm	11:20am	12:05pm	12:50pm
Standing water level (mBGL)	2.59	2.25	6.72	3.78	5.49	5.73	10.23	3.52	3.19
Field temperature	19.9	20	20.7	22.7	19.4	20.7	22.7	21.9	23.9
Field pH	7.1	6.55	7.1	6.6	7.05	6.9	6.9	6.7	6.15
Field electrical conductivity (µS/cm)	2050	1906	2090	1043	1512	1345	1713	411	114
Dissolved oxygen (mg/L)	0.98	0.56	1.04	0.75	1.41	0.66	1.59	1.6	0.96
Laboratory data									
Acidity, as CaCO ₃ (mg/L)	15	14	25	31	26	20	29	22	18
Alkalinity, total (mg/L)	340	300	270	95	400	320	260	87	31
Aluminium (µg/L)	20	20	10	30	<10	<10	150	240	540
Arsenic (µg/L)	2	2	2	4	<1	2	<1	<1	<1
Bicarbonate (mg/L)	415	366	329	116	488	390	317	106	38
Boron (µg/L)	45	100	75	39	42	43	25	29	23
Bromide (µg/L)	1000	900	900	<500	700	700	1200	<500	<500
Calcium (mg/L)	220	220	290	110	150	150	290	28	8.1
Carbonate (mg/L)	<5	<5	<5	<5	<5	<5	<5	<5	<5
Chloride (mg/L)	430	380	370	140	300	280	570	78	17
Copper (µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Electrical conductivity (µS/cm)	2200	2200	2300	1100	1400	1600	3000	410	130
Fluoride (µg/L)	<500	<500	<500	<500	<500	<500	<500	<500	<500
Hardness, total (mg/L)	700	720	870	350	470	460	950	96	28

(continued)

Table G15 continued

Parameter & unit	Bore								
	F2A	F2B	F3	F5	G2A	G2B	G4	G5	G7
Hydroxide (mg/L)	<5	<5	<5	<5	<5	<5	<5	<5	<5
Iron (µg/L)	4000	870	4400	23000	4300	5600	80	400	200
Lead (µg/L)	<1	<1	2	<1	<1	<1	3	3	<1
Magnesium (mg/L)	37	39	36	20	24	21	56	6.3	1.9
Manganese (µg/L)	110	40	170	44	100	78	120	13	<5
Nickel (µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrogen, ammonia (µg/L)	660	160	220	450	860	210	320	100	450
Nitrogen, total (µg/L)	1300	600	500	1800	1800	900	900	300	1100
Oxidised nitrogen, (µg/L)	8	200	<5	<5	<5	<5	<5	6	<5
pH	7.5	7.5	7.1	6.6	7.3	7.3	7	6.6	6.1
Phosphorus, soluble reactive (µg/L)	<5	<5	9	20	26	<5	48	5	<5
Phosphorus, total (µg/L)	<50	<50	<50	<50	<50	60	<50	<50	<50
Potassium (mg/L)	11	22	16	4.9	6.4	6.4	9.5	2.3	5
Sodium (mg/L)	250	240	190	86	150	140	330	46	12
Sulfate, from sulfur (mg/L)	250	330	490	260	<1	56	580	3	5
TDS by gravimetry (mg/L)	1500	1500	1700	790	990	1000	2200	250	80
Zinc (µg/L)	7	3	2	14	11	2	10	32	6

Note: Bores marked with an asterisk were analysed by MPL Laboratories.

Appendix H Change in groundwater chemistry through time

Table H1 Change in groundwater quality through time at selected bores

Bore	Date	Calcium	Magnesium	Sodium	Potassium	Carbonate	Bicarb- onate	Chloride	Sulfate	Total dissolved solids	pH	Nitrogen, NH ₃	Nitrogen, NO _x
Lake Clifton C4	21/09/1983	116	14	113	4	0	342	194	26	640	7.4	–	0.45
Lake Clifton C4	02/03/2016	206	37.4	425	4.2	0.5	408	751	167	1800	7.9	0.03	<0.01
Lake Clifton C4	03/05/2017	153	31.1	331	3.7	0.5	385	622	81.6	1400	7.6	<0.01	<0.01
Lake Clifton C8	02/03/2016	23.8	20	167	6.7	0.5	96	279	50	600	7.3	0.34	0.05
Lake Clifton D2	18/04/2017	74.6	46.9	1040	15.3	0.5	410	1350	256	3000	7.8	0.19	0.38
Lake Clifton D3A	02/03/2016	119	30.8	193	12.5	0.5	192	350	190	990	8.0	0.09	3
Lake Clifton D3A	18/04/2017	119	32.2	190	15	0.5	175	367	219	1100	7.7	0.02	5.1
Lake Clifton D3B	29/06/1983	72	16	91	4	0	248	140	42	490	7.5	0.07	4.74
Lake Clifton D3B	21/09/1983	76	10	24	4	0	210	32	17	270	8.2	–	12.42
Lake Clifton D3B	27/03/2008	100	24	160	14	–	195	240	150	790	7.4	0.01	14
Lake Clifton D3B	02/03/2016	110	20.5	164	20.3	0.5	183	280	150	840	7.9	0.01	13
Lake Clifton D3B	18/04/2017	111	20.4	164	20.9	0.5	192	279	177	890	7.6	<0.01	5
Lake Clifton D4	18/04/2017	118	19.7	124	5.4	0.5	327	247	61.1	740	7.6	0.37	0.03
Lake Clifton E2A	08/03/2016	470	60	289	75	0.5	181	639	1040	2660	7.5	0.08	0.17
Lake Clifton E2A	04/05/2017	467	61.5	282	81.5	0.5	180	671	1060	2700	7.5	0.06	0.05
Lake Clifton E3A	29/06/1983	141	22	154	5	0	311	284	110	870	7.5	0.6	0.02
Lake Clifton E3A	21/09/1983	129	22	151	5	0	332	278	57	810	8.0	–	1.35
Lake Clifton E3A	08/03/2016	312	43.9	203	35.4	0.5	257	396	650	1770	7.5	0.66	<0.01
Lake Clifton E3A	02/05/2017	354	48.9	221	42.4	0.5	251	448	777	2000	7.3	0.63	<0.01
Lake Clifton E3B	29/06/1983	173	34	175	6	0	271	311	276	1110	7.5	0.7	0.45
Lake Clifton E3B	08/03/2016	284	42.4	202	35.8	0.5	259	381	593	1670	7.5	0.57	0.01
Lake Clifton E3B	02/05/2017	248	37.8	188	28.4	0.5	277	373	470	1500	7.4	0.57	<0.01

(continued)

Table H1 continued

Bore	Date	Calcium	Magnesium	Sodium	Potassium	Carbonate	Bicarb- onate	Chloride	Sulfate	Total dissolved solids	pH	Nitrogen, NH ₃	Nitrogen, NO _x
Lake Clifton E3B	17/12/1980	99	20	158	4	0	317	263	51	770	6.8	–	<1
Lake Clifton E3C	29/06/1983	162	45	170	7	0	256	276	365	1150	7.2	0.43	0.23
Lake Clifton E4A	03/03/2016	64.7	14	137	4	0.5	204	247	3.9	570	7.4	0.63	0.02
Lake Clifton E4A	02/05/2017	69.1	14.3	132	3.9	0.5	206	255	5.6	580	7.0	0.6	<0.01
Lake Clifton E4B	22/09/1983	13	10	50	4	0	37	91	19	210	8.0	–	0.68
Lake Clifton E4C	03/03/2016	13.1	5.5	26.3	2.7	0.5	58	26	28	130	7.5	0.03	0.2
Lake Clifton E4C	02/05/2017	14.4	4.2	26.9	2.4	0.5	57	31	27.1	140	6.8	0.02	0.17
Lake Clifton E5A	29/06/1983	68	13	73	3	0	217	133	15	410	7.6	0.34	0
Lake Clifton E5A	22/09/1983	13	4	9	1	0	39	17	11	70	8.0	–	0.23
Lake Clifton E5B	03/03/2016	56.6	8.6	76.5	2.7	0.5	180	123	18.4	380	7.8	0.36	<0.01
Lake Clifton E5B	02/05/2017	61.7	9	65.8	2.4	0.5	171	128	22.7	380	7.2	0.29	<0.01
Lake Clifton E7	03/03/2016	61.3	17.1	149	4.2	0.5	227	276	30.7	650	7.4	1.1	0.02
Lake Clifton E8	03/03/2016	12.1	4.3	16	2	0.5	32	31	13	90	7.2	0.06	0.13
Lake Clifton F1	18/01/2016	139	54.1	404	13	0.5	432	709	200	1740	7.7	0.32	0.02
Lake Clifton F1	04/05/2017	145	67.2	508	17.5	0.5	454	876	205	2000	7.6	0.32	<0.01
Lake Clifton F2A	29/06/1983	158	34	260	9	0	543	430	42	1200	7.4	1.2	1.35
Lake Clifton F2A	13/10/1996	221	39	283	10	1.8	658	427	49	1360	7.8	0.4	0.1
Lake Clifton F2A	08/03/2016	215	37.7	263	12.2	0.5	378	516	301	1530	7.6	0.82	0.01
Lake Clifton F2A	27/04/2017	174	31	215	8.6	0.5	398	481	280	1400	7.5	0.84	<0.01
Lake Clifton F2B	13/10/1996	164	39	184	10	0.5	362	240	152	970	7.2	0.2	1.38
Lake Clifton F2B	18/01/2016	171	29.1	207	19.1	0.5	334	364	286	1240	7.7	0.15	0.36
Lake Clifton F2B	27/04/2017	184	33	211	19	0.5	344	408	296	1300	7.6	0.16	0.19
Lake Clifton F3	22/09/1983	–	–	–	–	–	–	–	–	1200	–	–	–
Lake Clifton F3	13/10/1996	235	42	349	9	1.8	689	560	3	1540	7.8	0.5	0.1

(continued)

Table H1 continued

Bore	Date	Calcium	Magnesium	Sodium	Potassium	Carbonate	Bicarb- onate	Chloride	Sulfate	Total dissolved solids	pH	Nitrogen, NH ₃	Nitrogen, NO _x
Lake Clifton F3	10/03/2016	209	33.4	266	14.4	0.5	429	485	226	1450	7.4	0.76	0.01
Lake Clifton F3	10/04/2017	247	34.9	233	19.8	0.5	389	451	364	1500	7.5	0.56	0.04
Lake Clifton F4	22/09/1983	97	28	277	7	0	360	425	70	1080	8.0	–	0.23
Lake Clifton F4	27/04/2017	43.7	12.5	113	5.4	0.5	203	108	59.2	440	7.3	0.41	<0.01
Lake Clifton F4E (D)	10/03/2016	102	23.6	278	8.5	0.5	395	419	62.9	1090	7.5	0.8	0.02
Lake Clifton F4E (S)	10/03/2016	111	30.3	184	7.9	0.5	343	326	91.8	920	7.6	0.57	<0.01
Lake Clifton F5	22/09/1983	–	–	–	–	–	–	–	–	470	–	–	0.9
Lake Clifton F5	13/10/1996	121	14	117	4	0.6	220	200	56	620	7.8	0.8	0.3
Lake Clifton F5	10/03/2016	132	24.8	112	7.7	0.5	89	186	338	850	6.8	0.66	0.01
Lake Clifton F5	14/04/2017	122	25.2	104	8.6	0.5	109	169	313	800	6.9	0.44	0.02
Lake Clifton F6	29/06/1983	44	7	73	3	0	156	115	18	340	7.3	–	<1
Lake Clifton F6C (D)	10/03/2016	93.5	10	79.7	3.8	0.5	310	148	1.1	490	7.6	0.46	<0.01
Lake Clifton F6C (S)	10/03/2016	13.6	13	76.9	3.1	0.5	74	130	7	280	6.7	0.03	<0.01
Lake Clifton F8	08/11/1978	–	–	–	–	–	–	–	–	600	–	–	–
Lake Clifton F9A	02/05/2017	254	51.9	370	13.9	0.5	559	588	360	1900	7.2	4.4	<0.01
Lake Clifton F9C	02/05/2017	124	30.8	196	16	0.5	123	352	319	1100	7.1	0.02	2.4
Lake Clifton G2A	22/09/1983	136	23	165	7	0	403	314	4	850	7.8	–	1.35
Lake Clifton G2A	02/06/1996	171	28	165	7	0.6	458	361	1	960	7.2	1.2	2
Lake Clifton G2A	13/10/1996	163	26	165	7	1.8	631	293	6	980	7.7	2	0.1
Lake Clifton G2A	02/03/2016	146	23.8	172	6.8	0.5	450	331	2.1	910	7.8	1.6	<0.01
Lake Clifton G2A	03/05/2017	152	24.8	163	6.6	0.5	446	350	5.7	920	7.4	1.4	<0.01
Lake Clifton G2B	02/06/1996	182	24	139	6	0.5	444	245	79	900	7.2	6.8	1.1
Lake Clifton G2B	13/10/1996	150	22	146	6	0.6	4	253	38	620	7.5	0.2	0.1
Lake Clifton G2B	18/01/2016	140	19.9	154	6.1	0.5	380	309	55.4	870	7.5	0.49	0.09

(continued)

Table H1 continued

Bore	Date	Calcium	Magnesium	Sodium	Potassium	Carbonate	Bicarb- onate	Chloride	Sulfate	Total dissolved solids	pH	Nitrogen, NH ₃	Nitrogen, NO _x
Lake Clifton G2B	03/05/2017	187	26.7	194	13.4	0.5	387	410	137	1200	7.5	0.01	<0.01
Lake Clifton G3A	22/09/1983	146	33	228	8	0	461	419	15	1080	7.8		0.23
Lake Clifton G3B	29/06/1983	91	18	145	7	0	305	247	10	670	7.3	0.07	4.74
Lake Clifton G3C	22/09/1983	120	21	179	6	21	250	306	91	870	8.4	–	0.45
Lake Clifton G4	22/09/1983	129	29	213	8	0	390	380	40	990	8.2	–	0.9
Lake Clifton G4	02/06/1996	132	25	190	6	0.5	306	395	37	940	7.2	0.2	0.9
Lake Clifton G4	13/10/1996	162	28	204	6	4.2	394	367	29	1000	8.4	0.3	0.1
Lake Clifton G4	10/03/2016	296	62.3	347	10.1	0.5	299	664	637	2170	7.4	0.48	<0.01
Lake Clifton G4	03/05/2017	309	63.3	347	9.5	0.5	306	623	640	2100	7.3	0.48	<0.01
Lake Clifton G5	22/09/1983	34	7	67	4	0	122	109	4	290	8.2	–	<1
Lake Clifton G5	02/06/1996	36	8	20	3	0.6	173	27	10	190	6.9	0.3	1.5
Lake Clifton G5	13/10/1996	34	10	67	3	0.5	111	93	8	270	7.1	0.5	0.2
Lake Clifton G5	22/03/2016	28.2	6.3	51.1	2.5	0.5	98	76	4.2	220	7.0	0.16	0.02
Lake Clifton G5	03/05/2017	25.8	6.2	48.9	2.3	0.5	97	82	6.1	220	6.8	0.17	<0.01
Lake Clifton G6	29/06/1983	39	6	75	3	0	143	109	16	320	6.8	0.06	0.03
Lake Clifton G7	22/09/1983	29	4	11	2	0	100	16	7	120	7.6	–	0.23
Lake Clifton G7	22/03/2016	3.8	2.1	14.9	8.3	0.5	15	20	15.2	70	5.9	0.83	0.06
Y4-1A	22/11/1995	190	798	6670	220	–	402	12000	1557	21640	7.4	–	–
Y4-1A	16/02/2016	296	189	1570	66.5	0.5	412	2790	698	5820	7.6	1.5	<0.01
Y4-1A	04/05/2017	293	179	1360	64.1	0.5	407	2470	690	5300	7.5	1.9	<0.01
Y4-2A	22/11/1995	296	41.7	231	7.88	–	294	650	260.1	1630	6.9	–	–
Y4-2A	16/02/2016	452	59.8	300	58.9	0.5	245	691	892	2580	7.4	0.36	<0.01
L.SUMICH & SONS 2B (PGW31)	07/03/1984	219	35	215	42	0.5	291	413	383	1641	7.3	–	7.2

(continued)

Table H1 continued

Bore	Date	Calcium	Magnesium	Sodium	Potassium	Carbonate	Bicarb- onate	Chloride	Sulfate	Total dissolved solids	pH	Nitrogen, NH ₃	Nitrogen, NO _x
PGW-31 [G3 (2)]	14/03/2006	400	56	240	85	0.5	230	470	1200	2570	7.3	0.65	0.3
PGW-31 [G3 (2)]	27/07/2006	380	49	220	63	0.5	190	440	660	1910	7.2	0.5	0.6
PGW-31 [G3 (2)]	29/03/2016	435	52.3	230	68.8	0.5	230	452	1040	2390	7.5	2.7	0.4
PGW-31 [G3 (2)]	18/05/2017	451	51.9	215	75.5	0.5	212	461	1030	2400	7.6	0.17	6.9

– = no data

Appendix I Change in rainfall and groundwater levels

Change in rainfall

Daily rainfall since 1900 from the patched point data system (Queensland Department of Science, Information Technology and Innovation 2016) was obtained for rainfall stations near Myalup: Wokalup (9642), Bunbury Post Office (9514) and Harvey (9812). In addition, daily rainfall data since 1960 was obtained for Myalup from the Queensland Department of Science, Information Technology and Innovation.

Average annual rainfall was calculated at all sites using all available years to 2015. This represents the long-term average for the sites. The average annual rainfall was calculated at all sites between 1976 and 2015 inclusive, and between 2000 and 2015 inclusive. The percentage change in annual rainfall from the long-term average for the periods 1976–2015 and 2000–15 at all sites was also calculated (Table I1).

Table I1 Change in average annual rainfall at four rainfall stations near Myalup since 1976 and since 2000

Rainfall site	Long-term average annual rainfall 1900–2015 (mm)	Average annual rainfall 1976–2015 (mm)	Percentage change from 1900–2015 to 1976–2015 (%)	Average annual rainfall 2000–15 (mm)	Percentage change from 1900–2015 to 2000–15 (%)
Bunbury	816	729	–11	690	–15
Harvey	984	918	–7	857	–13
Myalup (since 1960)	889	839	–6	776	–13
Wokalup	1041	840	–19	814	–22

Change in groundwater levels

Groundwater level data from the DWER website was obtained for groundwater monitoring bores in the Myalup region. The average groundwater levels for the periods 1979–90 and 2004–16 were calculated. Only sites with more than 10 measurements during these periods were used. For nested sites with multiple bores, the shallowest bores were used. The average groundwater level for the period 2004–16 was subtracted from the average groundwater level for the period 1979–90, to calculate the change in average groundwater level between the 1980s and recent times (Figure I1). The land use for each bore used in the analysis was determined using GIS. The change in groundwater levels for different land uses was then determined (Figure I2).

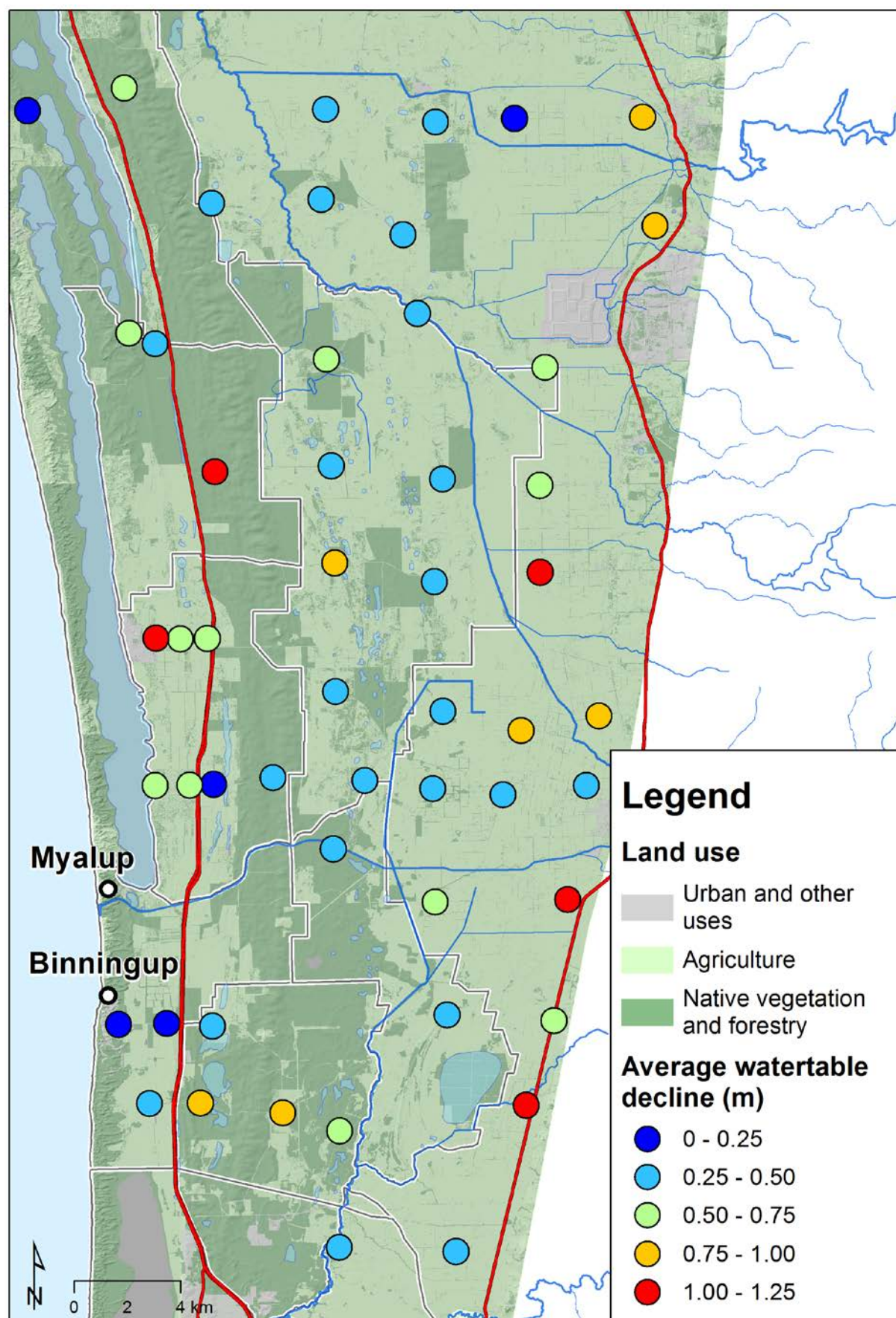


Figure I1 The average decline in groundwater levels between the periods 1979–90 and 2004–16

The average decline in groundwater level under native vegetation and forestry plantations was 0.63m (n=18), while the average decline under agriculture was 0.47m (n=21). The agriculture land-use group included irrigated and nonirrigated agriculture and had lower variability than the native vegetation and forestry land-use groups. The greater decline in groundwater levels under native vegetation and forestry land uses suggests that the decline is primarily driven by climate. If the decline was being controlled by abstraction, the greatest declines would be expected to occur under agriculture.

A possible reason for the greater decline in groundwater levels under native vegetation and forestry is that these land uses have higher evapotranspiration and lower recharge than the agricultural land uses.

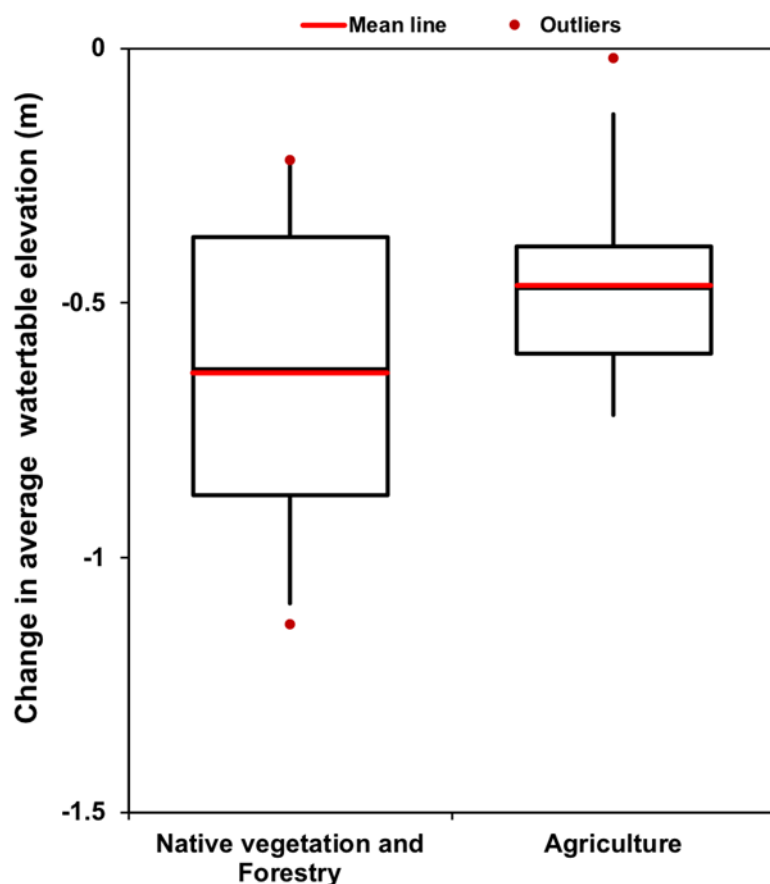
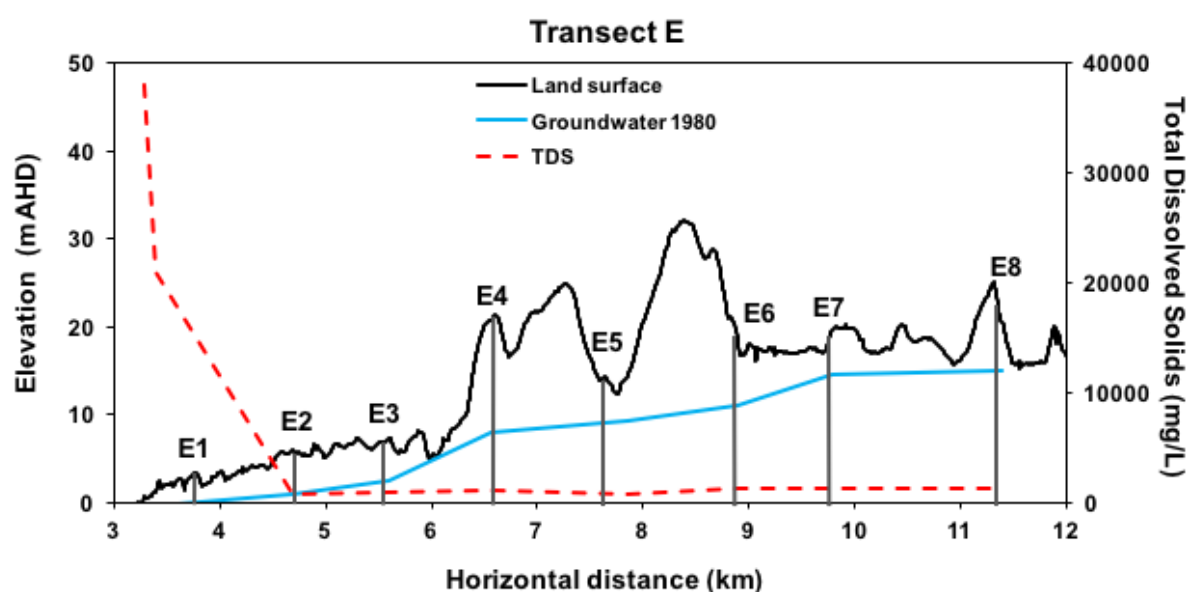


Figure I2 The average decline in groundwater level between the periods 1979–90 and 2004–16 for different land uses

Appendix J Change in water quality and type along groundwater flow paths

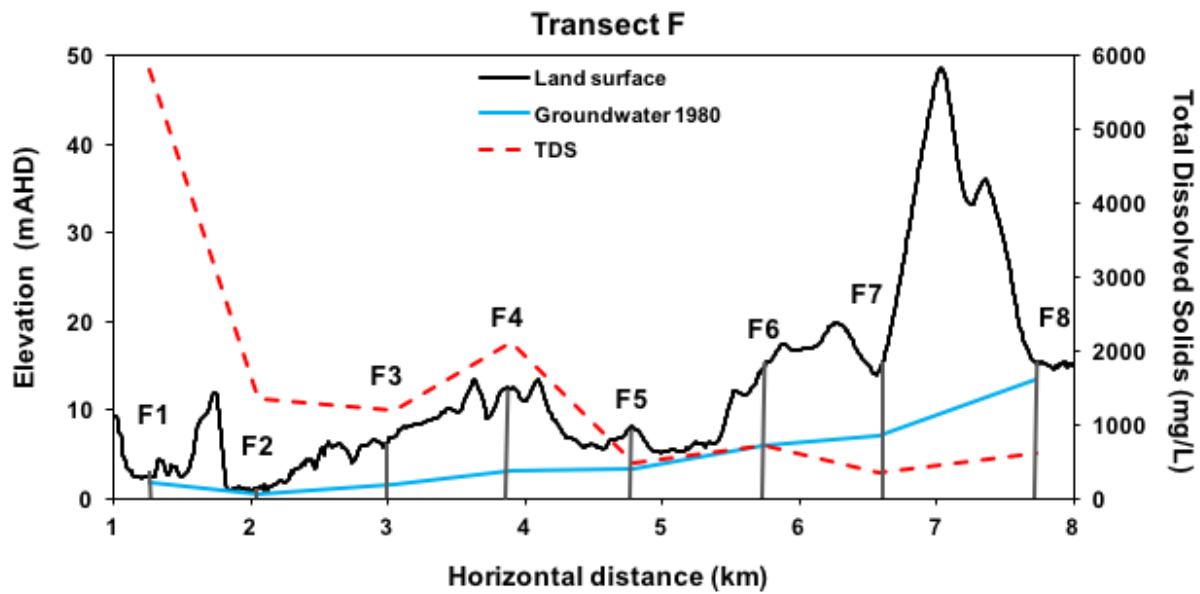


Source: Commander (1984) Note: Bores E1A and E1B show salinity at different depths

Bore	Total dissolved solids (mg/L)	Water type	Chemical process
E8	100	Na-Ca-Mg-Cl-HCO ₃	Weathering
E7	650	Na-Ca-Cl-HCO ₃	Evapoconcentration, calcite dissolution
E5	455	Na-Ca-Cl-HCO ₃	Evapoconcentration, calcite dissolution
E4	140–645	Na-Ca-Cl-HCO ₃	Evapoconcentration, calcite dissolution
E3	1300–1800	Ca-Na-SO ₄ -Cl	Pyrite oxidation, calcite dissolution, evapoconcentration
E2	2700	Ca-Na-SO ₄ -Cl	Pyrite oxidation, calcite dissolution, evapoconcentration
E1	6250	Na-Cl	Saltwater interface

Note: Bore E6 was unable to be sampled.

Figure J1 Changes in water type and quality plus dominant chemical processes along Lake Clifton transect E

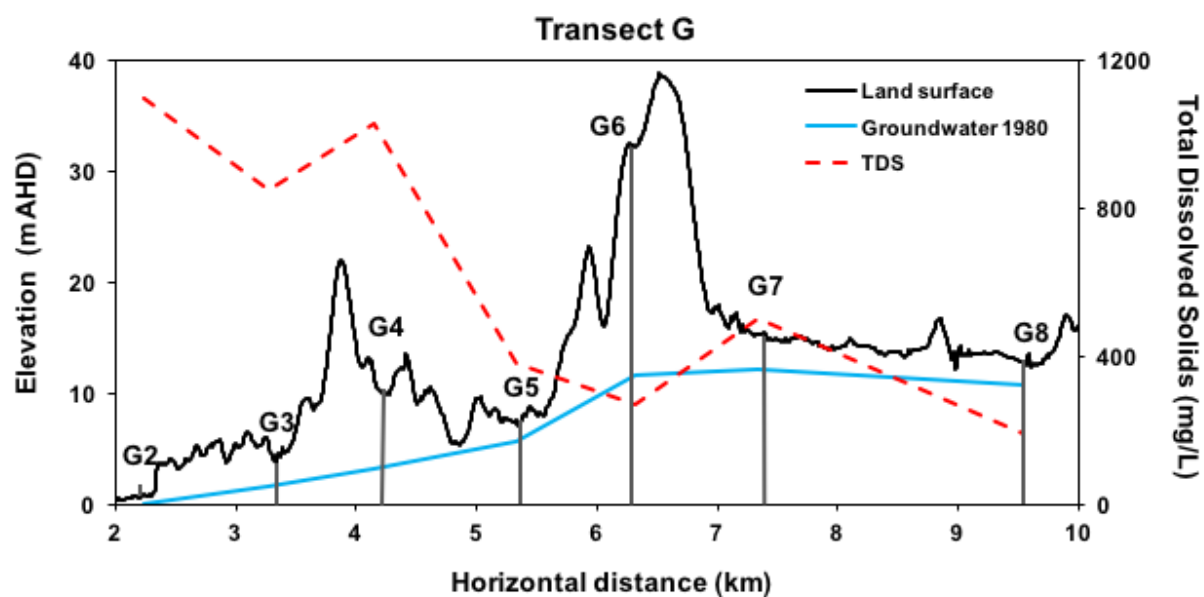


Source: Commander (1984)

Bore	Total dissolved solids (mg/L)	Water type	Chemical process
F6	300–500	Ca-Na-HCO ₃ -Cl	Calcite dissolution
F5	850	Ca-Na-SO ₄ -Cl	Pyrite oxidation, calcite dissolution, evapoconcentration
F4	1100	Na-Ca-Cl-HCO ₃	Evapoconcentration, calcite dissolution
F3	1400	Na-Ca-Cl-HCO ₃	Evapoconcentration, calcite dissolution
F2	1200–1500	Na-Ca-Cl-SO ₄ -HCO ₃	Pyrite oxidation, calcite dissolution, evapoconcentration
F1	1700	Na-Ca-Cl-HCO ₃	Evapoconcentration, calcite dissolution

Note: Bores F7 and F8 were not sampled because they are outside the study area.

Figure J2 Changes in water type and quality plus dominant chemical processes along Lake Clifton transect F



Source: Commander (1984)

Bore	Total dissolved solids (mg/L)	Water type	Chemical process
G2	900	Na-Ca-Cl-HCO ₃	Evapoconcentration, calcite dissolution
G4	2200	Na-Ca-Cl-SO ₄	Pyrite oxidation, calcite dissolution, evapoconcentration
G5	220	Na-Ca-Cl-HCO ₃	Evapoconcentration, calcite dissolution
G7	75	Na-Cl-SO ₄ -HCO ₃	Weathering reactions

Note: Some bores could not be sampled: G3 and G6 are destroyed and G8 is outside the study area.

Figure J3 Changes in water type and quality plus dominant chemical processes along Lake Clifton transect G

Shortened forms

Short form	Long form
AEM	airborne electromagnetic
Ca	calcium
Cl	chloride
DPIRD	Department of Primary Industries and Regional Development
DWER	Department of Water and Environmental Regulation
EC	electrical conductivity
Fe	iron
GIS	geographic information system
GL	gigalitre
GWSA	groundwater subarea
ha	hectare
HCO ₃	bicarbonate
K	potassium
kL	kilolitre
L	litre
LoR	limit of reporting
m	metre
mAHD	elevation, above the Australian Height Datum, in metres
mBGL	metres below ground level
Mg	magnesium
mg/L	milligrams per litre
MIAP	Myalup Irrigated Agriculture Precinct
mL	millilitre
ML	megalitre
mm	millimetre
Na	sodium
NH ₃ -N	ammonia as nitrogen
NO _x -N	total oxidised nitrogen as nitrogen
SAR	sodium adsorption ratio
SO ₄	sulfate
TDS	total dissolved solids
µg/L	micrograms per litre
µS/cm	microsiemens per centimetre
y	year

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