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Groundwater chemistry of the Weaber Plain: preliminary results

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GOVERNMENT OF WESTERN AUSTRALIA

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Cover picture: Groundwater sampling on the Weaber Plain. Photo: Adam Lillicrap

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Summary

The proposed 8000-ha Weaber Plain (Goomig) farmlands are located north-east of the existing, 14 000 ha, Ord River Irrigation Area (ORIA), 30 km from Kununurra in the East Kimberley region of Western Australia. The existing ORIA covers parts of the Ivanhoe and Packsaddle plains.

In 2008, the Ord Irrigation Expansion Project was approved by the Western Australian Government to develop irrigated agriculture on the Weaber Plain. Construction of the M2 supply channel connecting the ORIA and the Weaber Plain, and the final period of irrigation design, environmental management and related approval processes, commenced later in 2009. This process followed a protracted period of public and private industry planning and environmental assessment (Kinhill 2000).

This report summarises an analysis of groundwater salinity trends on the Ivanhoe and Weaber plains and the preliminary results of an intensive water-quality sampling program carried out in 2010 as part of Phase 1 of the project. The purpose of this report is to provide interim results to inform groundwater management plans required as part of the approval process for the development of the Weaber Plain.

The specific aims of this report are to:

- forecast the salinity of groundwater that may have to be pumped for watertable control, by assessing past and present aquifer conditions on the ORIA (Ivanhoe Plain) and the Weaber Plain
- assess the potential for disposal of this groundwater by mixing it with water from the M2 irrigation supply channel
- make recommendations on long-term monitoring requirements for groundwater consistent with the ANZECC/ARMCANZ (2000) guidelines.

The Ivanhoe Plain groundwater salinity trends between 1984 and 2009 indicate that the development of the Weaber Plain for irrigated agriculture is unlikely to result in any significant change in groundwater salinity within the Ord palaeochannel. Furthermore, where groundwater salinities in the palaeochannel are very high, as in the north-eastern portion of the Weaber Plain, they are likely to decrease due to dilution with fresh irrigation-supply water. Groundwater salinities are highest under Aquitaine soils on the Weaber Plain, and, as proposed farm lots on Aquitaine soils will be leasehold, with some subject to deferred clearing, potential increases in groundwater salinity following development will be further limited.

An analysis to assess the option of pumping groundwater from the Ord River palaeochannel and discharging it to the irrigation supply channel showed that, while most of the groundwater is unsuitable for direct irrigation, when mixed with water from the M2 supply channel at calculated ratios it is suitable (based on USDA 1954 guidelines). The analysis indicated that the mean total dissolved solids (TDS) of groundwater in the palaeochannel would be about 1162 mg/L (Table 9), which agrees well with the 1200 mg/L predicted by the solute transport model produced by KBR (2011). At the modelled pumping rates of 540 to 769 mL/day, mixing this groundwater with supply-channel water at average and peak flow rates results in water of 170 to 200 mg/L TDS.

These results demonstrate that blending groundwater into the main supply channel will provide a viable option for managing groundwater-related risks on the Weaber Plain if, at some time in the future, aquifer management is required.

A network of 58 groundwater-monitoring bores at 44 sites is recommended as the basis of an ongoing water-quality monitoring program for the life of the development. The recommended network consists of bores to be monitored at a high intensity with dataloggers and low-intensity bores, plus eight reference bores. This report includes a list of required analytes for comparison to the ANZECC/ARMCANZ (2000) water-quality guidelines and a strategy to develop a baseline water-quality data set to ensure that the environmental impacts of the development are within required limits. Trigger mechanisms and guidelines for the escalation of groundwater-quality monitoring are also recommended, should any analyte exceed a baseline level by a set amount.

1. Introduction

The Ord River Irrigation Area (ORIA) is located in the Kimberley region of the north-west of Western Australia, near the town of Kununurra (Figure 1). It was established in 1963 with the release of five farms and has developed to its current extent of 14 000 hectares.

The Weaber Plain is located north-east of the existing ORIA, 30 km from Kununurra. The area had been identified as being suitable for irrigated agriculture for many decades, but it was not until 2008 that the Ord Irrigation Expansion Project proposal, to develop 8000 ha of the Weaber Plain, was approved by the Western Australian Government. This area will be the first of several proposed areas (Ord West Bank, Mantinea, Carlton, Knox, Keep River and Cockatoo sands) to be developed, leading to the potential for irrigation of up to 52 000 ha. Annual demand for irrigation water supply from Lake Argyle has been calculated at 80 to 120 GL for the Weaber Plain, and up to 865 GL has been allocated for the entire irrigation area.After state government approval in 2008, the M2 supply channel connecting ORIA to the Weaber Plain was constructed, and the final period of irrigation design, environmental management and related approval processes began in 2009.

In late 2009, as part of this process, the Department of Agriculture and Food, Western Australia (DAFWA), with partners Kellogg Brown and Root Pty Ltd (KBR), undertook to deliver a groundwater management plan and contribute to the completion of a hydrodynamic plan to ensure sustainable development of the project area.

The requirement for these plans had been first established by the Environmental Protection Authority as part of the process of evaluating the 1998 Wesfarmers Marubeni proposal (Kinhill 2000). During this period, KBR and others had begun to address the joint issues of salinity and water quality within the proposed irrigation area, surrounding conservation buffers and the downstream Keep River. In addition to the requirement for an environmental impact statement by the State Government, the proposal has to meet commonwealth government environmental conditions, namely those related to the *Environmental Protection and Biodiversity Conservation Act 1999*, and also address any concerns of the Northern Territory Government.

Preparation of the groundwater management plan was undertaken in two stages. Stage 1, completed in February 2010 by KBR, consisted of a suite of groundwater model simulations using updated groundwater level, regolith and climate data informed by studies by Lawrie et al. (2010) and CSIRO (2009). During this work, it was determined that the existing groundwater data was inadequate for the purpose of substantiating modelled options to manage shallow watertables and salinity (KBR 2010). Some of the identified data deficiencies related directly to the proposal to pump groundwater from the Ord River palaeochannel, which runs under the Weaber Plain, to control the watertable. This included determining the suitability of the groundwater pumped from the palaeochannel, in terms of its quality, for mixing with the irrigation supply.

The conceptualisation of aquifer recharge processes was another area identified as requiring further investigation (KBR 2010), and the application of chlorofluorocarbon dating techniques was recognised as an appropriate method to improve the understanding of groundwater age and therefore recharge processes on the Weaber Plain.

Addressing the data deficiencies identified in the Stage 1 investigations formed the basis of Stage 2 of preparing the groundwater management plan. It was completed in October 2010 by the Agricultural Resource Risk Management Division of DAFWA, and consisted of a program of fieldwork and subsequent modelling by KBR.

To address the lack of data on groundwater salinity, a review of historical groundwater-quality data for the current Ord River Irrigation Area on the Ivanhoe Plain was undertaken. The rationale was that the groundwater salinity response to irrigation of the Ivanhoe Plain would provide a first-order indication of the likely response to irrigation of the Weaber Plain. A detailed field sampling program on the Weaber Plain was also carried out to:

- characterise the hydrochemistry of groundwater under the Weaber Plain
- assess the suitability of mixing groundwater and surface water for irrigation
- assist with the understanding of salinity processes
- make recommendations for future monitoring.

This report presents a review of the historical data, reports the initial results of the baseline groundwater sampling and analysis program, and on this basis recommends a program for completion of the baseline survey and ongoing monitoring. The analyses and results presented here supersede those presented in Appendices H3 and H4 of the Stage 2 modelling report (KBR 2011).

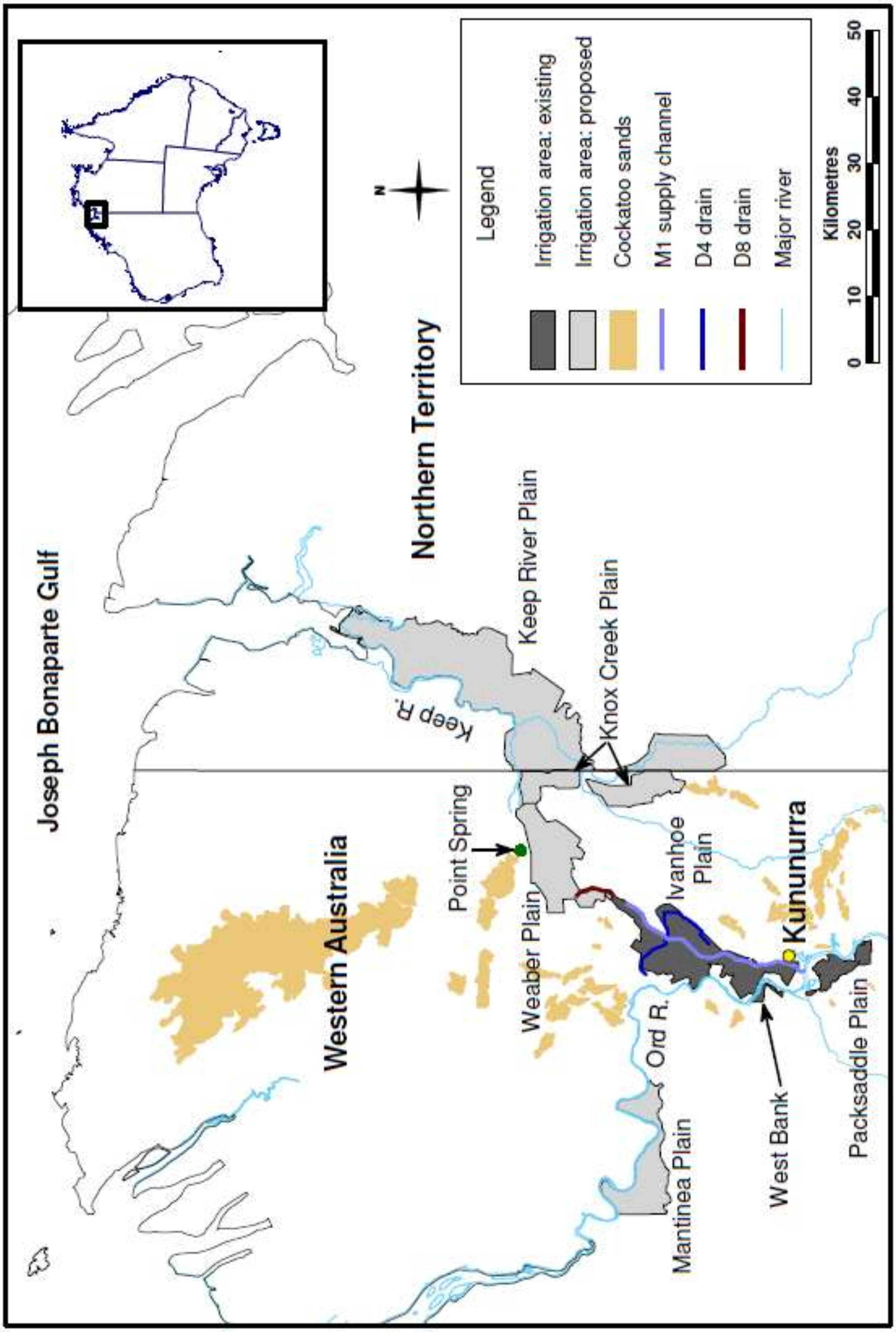

Figure 1 **Study area locality map**

2. Previous work

2.1 Ivanhoe and Packsaddle groundwater salinity trends

Previous analyses of groundwater salinity trends in the Ivanhoe and Packsaddle plain irrigation areas were undertaken by O'Boy et al. (2001) and Smith et al. (2007).

Patterns of salinity change were evident in some bores and appeared to reflect changes in local groundwater flow conditions. O'Boy et al. (2001) considered leakage from both the M1 supply channel and the D4 drain as the probable causes for observations of low salinity groundwater under parts of both the Packsaddle and Ivanhoe plains. The locations of supply channels and drains are shown in Figure 1 and Figure 8. Furthermore, Smith et al. (2007) noted that groundwater quality at several bores on the Packsaddle Plain had freshened to the point where the observed salinity was close to that of the irrigation water.

O'Boy et al. (2001) noted an inverse relationship between observed electrical conductivity (EC) and groundwater level under the southern, and parts of the northern, Ivanhoe Plain, i.e. EC increased as the watertable rose. In contrast, Smith et al. (2007) concluded that there had been no obvious trends in groundwater salinity under the Ivanhoe and Packsaddle plains during the previous twenty years.

2.2 Weaber hydrochemical data

Lawrie et al. (2010) and O'Boy et al. (2001) identified areas of saline groundwater and subsoils under the Weaber Plain. They argued that irrigation on the plain could potentially activate stored salts and impact on both agricultural production and the downstream environment. However, both acknowledged a lack of data and detailed understanding of the hydrochemistry of the ground and surface waters of the Weaber Plain to inform this risk assessment.

Basic chemical analyses of Weaber Plain groundwater have been reported in earlier hydrogeological reports (Laws 1983, Nixon 1997a, b). In these studies, the pH of all groundwater was neutral to slightly alkaline. The salinity of the groundwater (Figure 2) was highly variable, ranging from low (130 mg/L TDS) in the south-west, to very high in the north-east (19 000 mg/L TDS).

The chemical composition of groundwater is classified by the major ions: the cations sodium, potassium, calcium and magnesium, and the anions chloride, sulfate, bicarbonate and carbonate. Chloride is a conservative ion that is unreactive except for simple precipitation–dissolution. Sulfate will also behave conservatively under stable oxidation–reduction conditions and in the absence of sulfide minerals. Cation concentrations can be influenced by cation exchange with clays or by the weathering of basement rocks. The conservative nature of the anions, sulfate and chloride therefore makes them suitable for classifying water compositions.

Figure 3 shows the high variability in the chemical composition of the groundwater across the Weaber Plain. Anions showed the greatest variability, with lower salinity waters dominated by bicarbonate and higher salinity waters by chloride.

Sodium was the dominant cation in most groundwaters across the Weaber Plain. The groundwaters under the Weaber Plain showed similar characteristics to groundwaters in other sub-areas of the Ord River Irrigation Area, such as the Ivanhoe and Packsaddle plains

(Smith et al. 2007). The groundwaters under both the Ivanhoe and Packsaddle plains were also dominated by sodium. Similarly, the dominant anion in lower salinity waters was bicarbonate, and, in higher salinity waters in the Ivanhoe and Packsaddle areas, chloride was dominant.

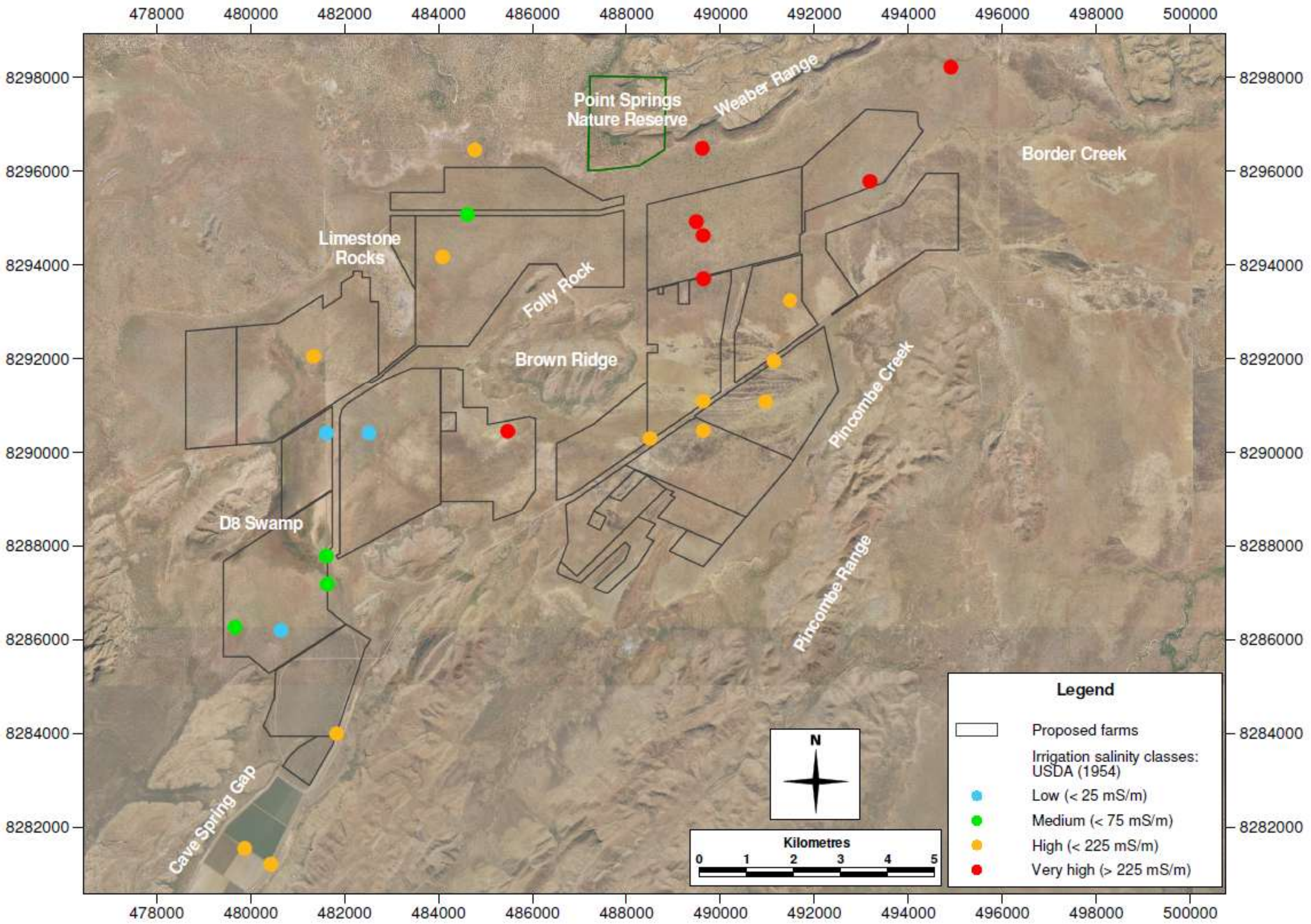

Figure 2 **Historic (pre-2010 drilling) groundwater salinity for the Weaber Plain (Map Grid of Australia, Zone 52)**

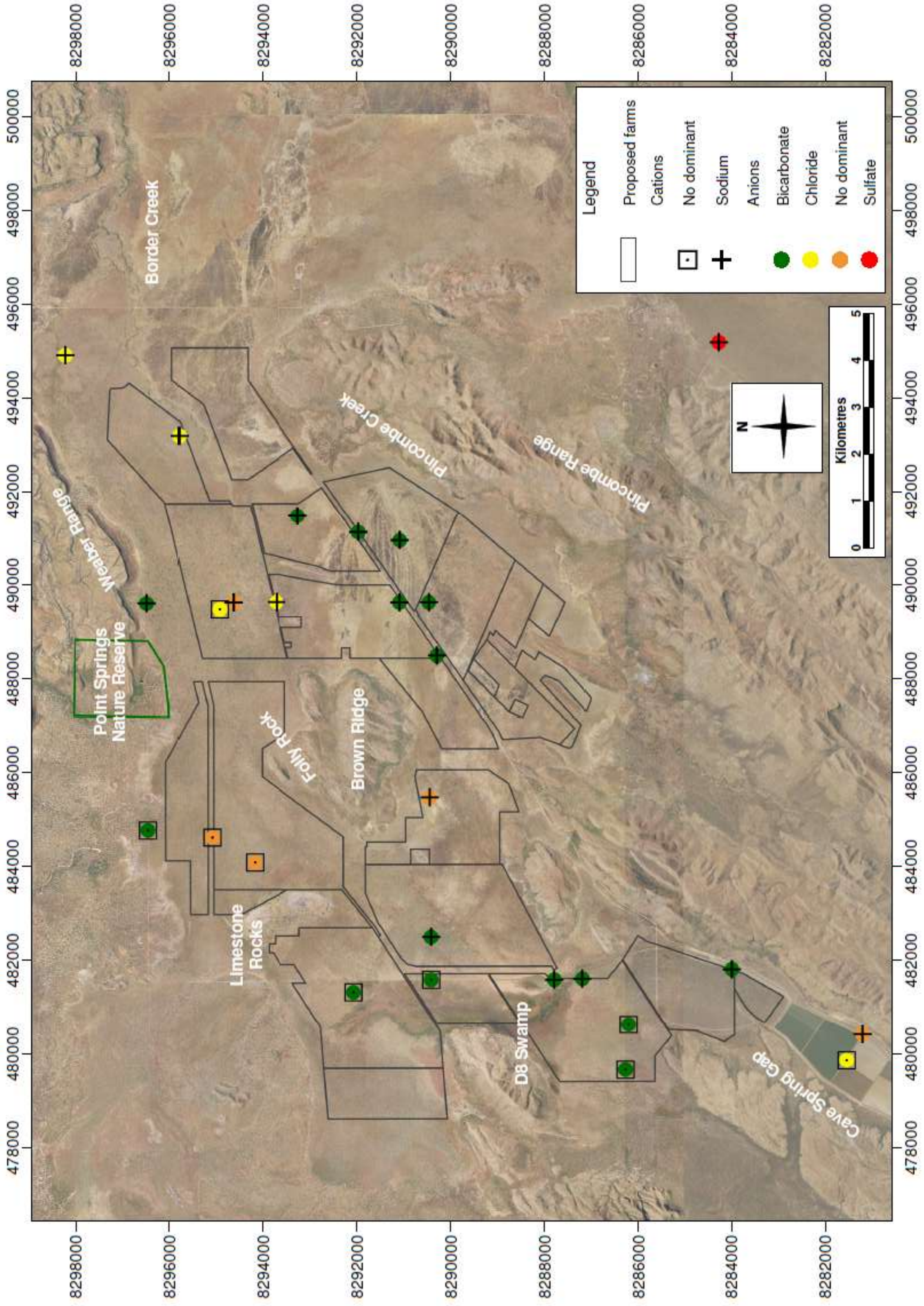

Figure 3 **Historic (pre-2010 drilling) dominant groundwater cations and anions for the Weaber Plain (Map Grid of Australia, Zone 52)**

3. Methods

3.1 Groundwater salinity trends

Groundwater level and salinity observations have been made at bores on the Ivanhoe and Weaber plains by the Department of Water (DoW) and DAFWA since the 1960s as part of the exploratory drilling program and monitoring of the irrigation development (a subset of the bores is shown in Figure 8 and Figure 9). The majority of the data is stored in the DoW's WIN database, while some was only available from DAFWA, Kununurra.

Despite some long time series, groundwater salinity data for only two bores (4C and 11C) was available back to 1964. Bore CS10, on the Weaber Plain, has the longest, most complete record of groundwater salinity data, which covers the period since August 1978. For the majority of bores for which salinity data is available, reliable records start around 1984.

Salinity was measured either as total dissolved solids (TDS, mg/L) in the laboratory or as electrical conductivity (EC). In some cases, field-measured EC values were converted to TDS and stored in the WIN database as TDS. The majority of the groundwater salinity observations after 1985 were made in the field as EC, and stored in the database in that format. To convert EC observations to TDS, a regression equation was developed using data collected from groundwater exploration bores drilled by the Geological Survey of Western Australia in the Kununurra area (O'Boy et al. 2001), as concurrent observations of TDS and EC were available in that report. All salinity data were plotted as TDS values.

Evaluations of the data quality of groundwater level and TDS time series plots for both the Ivanhoe and Weaber plains were undertaken. Many of the apparent errors in the recorded EC data were attributed to errors in the recording of EC units, e.g. values measured in mS/m recorded as µS/cm, resulting in the recorded value being an order of magnitude lower than it should be. Doubtful EC records were omitted from the analysis, as the variability in the remaining time series was often high, and arbitrary correction of data points was considered inappropriate. In some time series, there were several data points that did not form part of a recognisable pattern with the majority of the data; however, these observations were not removed from the analysis where they were not different enough from the rest of the series to be confidently identified as recording errors.

Groundwater-level data was included in the plots so that any relationship between depth to groundwater and salinity could be recognised. Bores were then classified on the basis of the groundwater salinity trend displayed, and salinity values as at 1984 and 2009 were tabulated. The proportional change in groundwater salinity was also calculated for bores with sufficiently long time series. As monitoring of many bores ceased prior to 2009, the proportional change in groundwater salinity was calculated over the longest time period available for each bore, not necessarily for the period 1984 to 2009.

The data was then separated into bores within and outside the Ord River palaeochannel. On the Ivanhoe Plain, the mapping of Lawrie et al. (2010) was used to determine which bores fall within the palaeochannel. On the Weaber Plain, the revised extent of the palaeochannel presented by George et al. (2011) was used (Figure 8). GenStat^{TM} 64-bit Release 14.1 (VSN International Ltd) was used to perform Mann-Whitney U (Wilcoxon rank-sum) tests on the data to ascertain whether there were any significant differences in salinity levels or trends between the two hydrogeological settings. In a separate analysis, the groundwater data for the Ivanhoe and Weaber plains was combined to increase statistical reliability, and the salinity data then separated on the basis of soil type, the two main types being Cununurra and Aquitaine clays. The salinity of groundwaters under these two soil types was also tested for statistically significant differences.

3.2 Water-sampling program

Thirty-two water samples were collected across the Weaber Plain and Ord River Irrigation Area (ORIA) during the 2010 dry season (August), consisting of six surface-water samples and 26 groundwater samples (Figure 4, Figure 5 and Table 1, Appendix C). Of the groundwater samples, 21 were collected from the Weaber Plain. All the bores (18 in total) that were drilled and completed in June and July 2010 for DAFWA (George et al. 2011) were sampled, along with seven existing DoW bores, to give a representative coverage of the proposed farming areas and buffer zones.

3.2.1 Sample collection

A QED MP-SP-6C low-flow pump was used to sample the existing DoW bores and four DAFWA bores that were to have the comprehensive chemical analyses (Figure 5 and Table1). Once the measured water-quality parameters (EC, pH and oxidation–reduction potential [ORP]) of the groundwater discharge had stabilised, water samples were collected. The remaining DAFWA bores were sampled with a bailer, as they had only recently been developed (less than six weeks prior to sampling), preparing them for water-quality sampling.

Surface-water samples were collected in the ORIA Stage 1 and on the Weaber Plain to provide background baseline hydrochemistry for comparison. Surface-water samples were collected with a thoroughly rinsed container. A more complete analysis of the surface-water chemistry of the Weaber Plain is presented by Bennett and George (2011).

Water samples for metal analysis were filtered and acidified. Samples for nutrient analysis were filtered. All water samples collected in the field were stored in a cooler, then transferred to a refrigerator. Nutrient samples were frozen. EC, temperature, pH, ORP and dissolved oxygen were measured in the field. Total alkalinity and total acidity were measured either in the field or within twelve hours of collection.

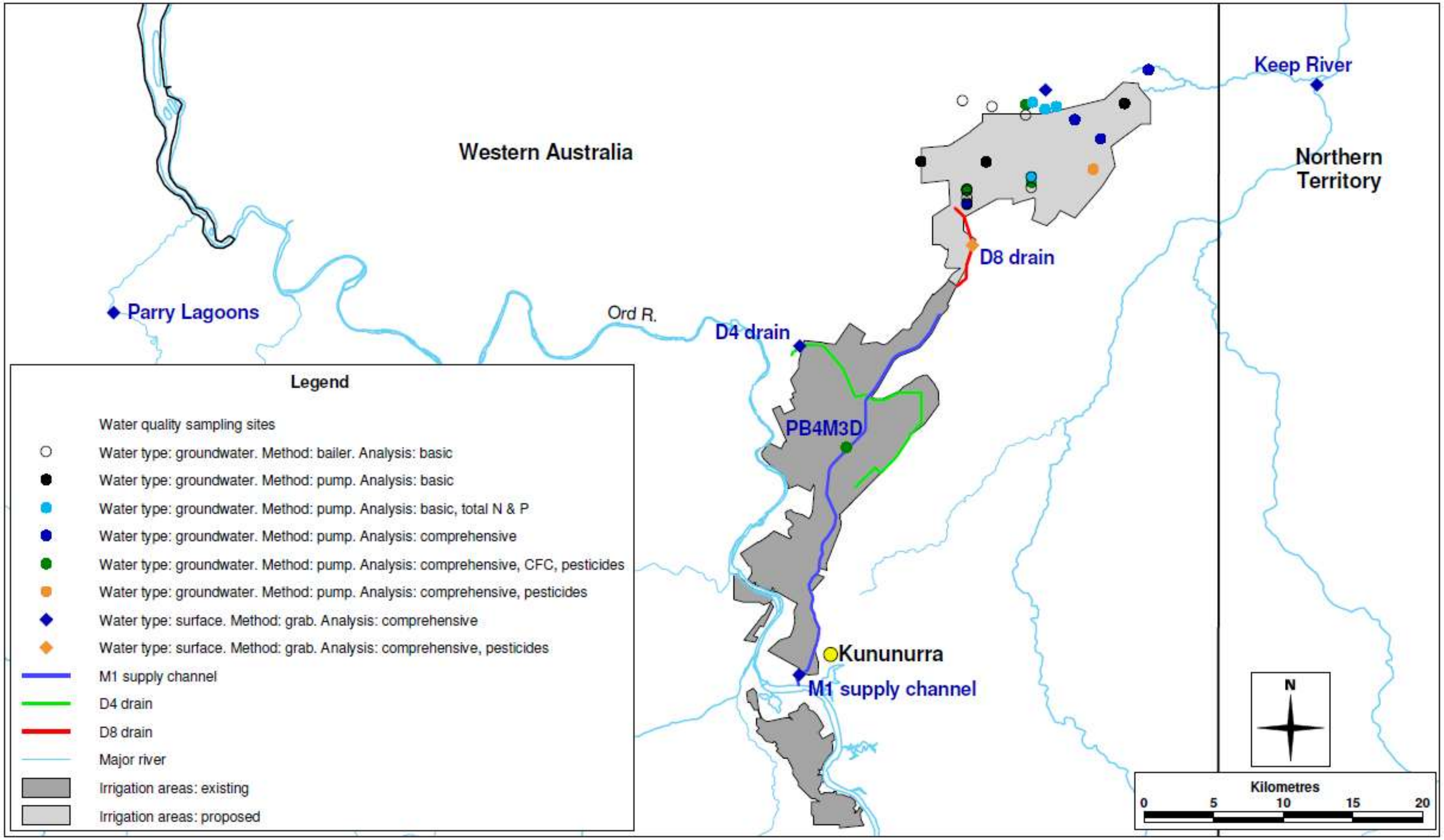

Figure 4 **Map showing the locations of sampling sites, water type (surface- or groundwater), sampling methods and type of chemical analysis. See Figure 5 for detail of Weaber Plain sampling sites.**

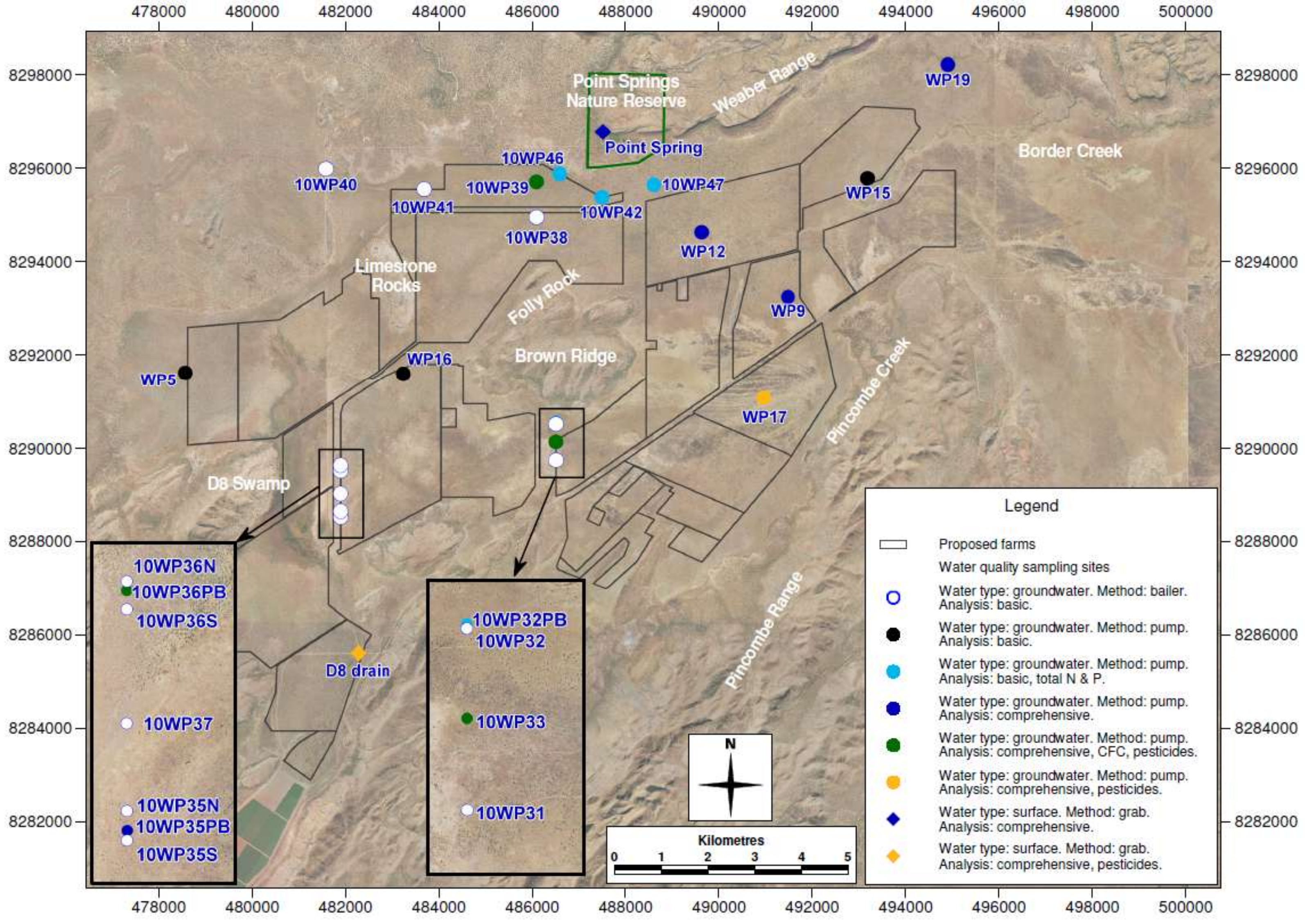

Figure 5 **Detail of Weaber Plain water-sampling sites, water type (surface- or groundwater), sampling methods and type of chemical analysis (Map Grid of Australia, Zone 52). See Figure 4 for an overview of all sampling sites.**

Table 1 **Groundwater and surface-water sites sampled**

Sampling site	Hydrology	Analysis	Sampling method	Location	Purpose
10WP39I	Groundwater	Comprehensive, pesticides, CFC	Pump	Weaber Plain	Characterise groundwater quality
PB4M3D	Groundwater	Comprehensive, pesticides, CFC	Pump	Ivanhoe Plain	Comparative groundwater quality
10WP33	Groundwater	Comprehensive, pesticides, CFC	Pump	Weaber Plain	Characterise groundwater quality
10WP36PB	Groundwater	Comprehensive, pesticides, CFC	Pump	Weaber Plain	Characterise groundwater quality
WP17	Groundwater	Comprehensive, pesticides	Pump	Weaber Plain	Characterise groundwater quality
WP12M	Groundwater	Comprehensive	Pump	Weaber Plain	Characterise groundwater quality
ORD22 (WP19)	Groundwater	Comprehensive	Pump	Weaber Plain	Characterise groundwater quality
10WP35PB	Groundwater	Comprehensive	Pump	Weaber Plain	Characterise groundwater quality
ORD20 (WP9)	Groundwater	Comprehensive	Pump	Weaber Plain	Characterise groundwater quality
ORD21 (WP15)	Groundwater	Basic	Pump	Weaber Plain	Characterise groundwater quality
WP16	Groundwater	Basic	Pump	Weaber Plain	Characterise groundwater quality
10WP32	Groundwater	Basic	Bailer	Weaber Plain	Characterise groundwater quality
10WP32PB	Groundwater	Basic, total N & P	Pump	Weaber Plain	Characterise groundwater quality
10WP35N	Groundwater	Basic	Bailer	Weaber Plain	Characterise groundwater quality
10WP35S	Groundwater	Basic	Bailer	Weaber Plain	Characterise groundwater quality
10WP36N	Groundwater	Basic	Bailer	Weaber Plain	Characterise groundwater quality
10WP36S	Groundwater	Basic	Bailer	Weaber Plain	Characterise groundwater quality
10WP37	Groundwater	Basic	Bailer	Weaber Plain	Characterise groundwater quality
10WP38	Groundwater	Basic	Bailer	Weaber Plain	Characterise groundwater quality
10WP40	Groundwater	Basic	Bailer	Weaber Plain	Characterise groundwater quality
10WP41	Groundwater	Basic	Bailer	Weaber Plain	Characterise groundwater quality
WP5	Groundwater	Basic	Pump	Weaber Plain	Characterise groundwater quality
10WP42	Groundwater	Basic, total N & P	Pump	Weaber Plain	Characterise groundwater quality

(*continued*)

Table 1 **Groundwater and surface-water sites sampled** (*continued*)

Sampling site	Hydrology	Analysis	Sampling method	Location	Purpose
10WP46	Groundwater	Basic, total N & P	Pump	Weaber Plain	Characterise groundwater quality
10WP47	Groundwater	Basic, total N & P	Pump	Weaber Plain	Characterise groundwater quality
D8 drain	Surface	Comprehensive, pesticides	Grab	Cave Spring Gap	Comparison surface-water quality
D4 drain	Surface	Comprehensive	Grab	Ivanhoe Plain	Comparison surface-water quality
Keep River	Surface	Comprehensive	Grab	Keep River	Comparison surface-water quality
M1 supply channel	Surface	Comprehensive	Grab	Ivanhoe Plain	Characterise water quality for supply channel
Parry Lagoons	Surface	Comprehensive	Grab	Parry Lagoons Nature Reserve	Comparison surface-water quality
Point Spring	Surface	Comprehensive	Grab	Weaber Plain	Comparison groundwater from spring

3.2.2 Sample analyses

Water samples were analysed for a range of inorganic parameters. There were two levels of analysis: basic and comprehensive (Table1). A list of analytes, analytical methods and detection limits is given in Appendix D. Pesticides (atrazine, simazine and related species plus endosulfan) were measured for six sites (Figure5). Water samples were analysed at the Chemistry Centre (WA) for inorganic species and pesticides.

Chlorofluorocarbon-11 (CFC-11) and Chlorofluorocarbon-12 (CFC-12) analysis was performed for four bores to estimate the relative age of these groundwaters (Figure 5 and Table 1). CFC analyses were performed by the CSIRO Land and Water Laboratory, Urrbrae (Adelaide). Triplicate samples were obtained with a low-flow pump following the methodology of Leaney (2007) and Puls and Barcelona (1996).

CFC-11 and CFC-12 concentrations in groundwater are measured by first stripping the CFC gas from the water sample under a stream of ultra-high-purity nitrogen gas. The CFC gas/nitrogen is then passed through a gas chromatograph where the CFC-11 and CFC-12 peaks are identified and measured separately. The CFC-11 and CFC-12 concentrations in the water are then converted to an age by determining the equivalent concentration in the atmosphere. The salinity of the water, recharge temperature (as determined by mean annual temperature) and surface elevation are required, and the resultant value is then matched to historically measured atmospheric data to give a CFC-11 and CFC-12 age. Analysis was undertaken by the CSIRO Isotope Analytical Service according to the method described by Busenberg and Plummer (1992).

3.3 Suitability of groundwater for irrigation

3.3.1 Assessment criteria

High salinities and sodium dominance can be problematic if the groundwaters were used for irrigation. 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 (USDA 1954). The sodium hazard is measured by the sodium absorption ratio (SAR), with the concentration of the ions expressed as milliequivalents per litre (meq/L):

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

The USDA (1954) developed a classification system to assess the suitability of water for irrigation based on a series of hazard classes for sodium and salinity. Salinity can be estimated by measuring the electrical conductivity of water. The USDA developed their classification for salinity based on electrical conductivity[1] and there are four classifications, C1 to C4. The sodium hazard is measured by SAR and also has four classifications, S1 to S4. These are shown in Table 2 and graphically in Figure 6.

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[1] Electrical conductivity is usually measured in mS/m. However the USDA (1954) used an earlier unit in developing their classification system, micromhos/cm, which is equivalent to μS/cm

Note: 1 mS/m = 10 μS/cm

Table 2 **Salinity and sodium hazard classes (after USDA 1954)**

Salinity hazard classes		
Class	**EC (µS/cm)**	**Description**
C1	< 250	**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	251–750	**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	751–2250	**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	> 2251	**Very high salinity** water is not suitable for irrigation under ordinary circumstances, but may be used occasionally 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 very salt tolerant crops should be selected.

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 may 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 purposes 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.

The USDA (1954) classification was used by Ali et al. (2002) to assess the suitability of waters for irrigation. We have also used this classification system to assess suitability of groundwaters on the Weaber Plain for irrigation both directly and indirectly.

Ali et al. (2002) used the C3 category as the upper cut-off for assessing water as suitable for irrigation. The C3, high-salinity waters (EC between 75 mS/m and 225 mS/m) cannot be used on soils with restricted drainage and, even with adequate drainage, special management for salinity control may be required (USDA 1954). Furthermore, plants with high salt tolerance should be selected when irrigating with high-salinity waters (USDA 1954). As the soils of the Weaber Plain have high clay contents and potentially restricted drainage (Smolinski et al. 2011), we also used the C3 class (i.e. greater than 75 mS/m) as the upper salinity range for the suitability of irrigation waters.

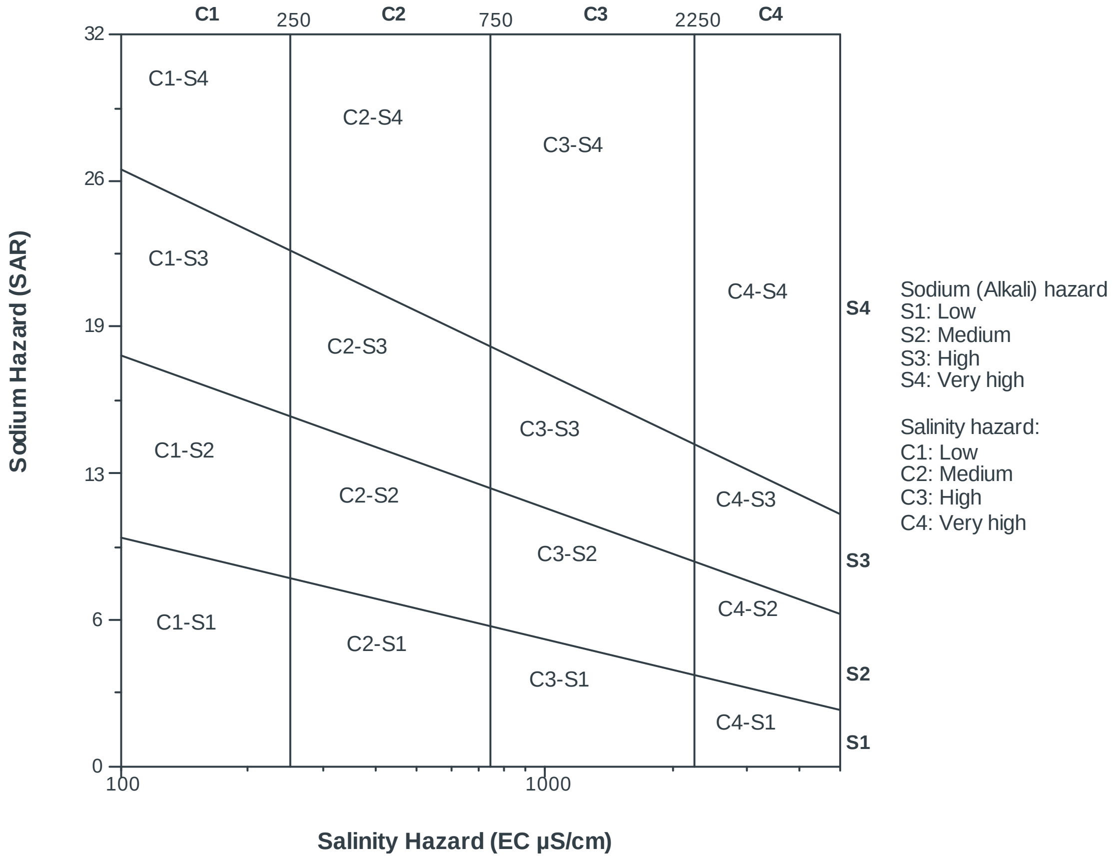

Figure 6 **USDA irrigation-water salinity and sodium hazard classes. The diagram shows hazard classes and cut-off thresholds (source: USDA 1954).**

3.3.2 Assessment of groundwater for irrigation

Groundwater chemistry data was analysed in Microsoft Excel™ and AquaChem™ by Schlumberger Water Services. AquaChem™ has the in-built functionality to calculate salinity and hazard classes as per USDA (1954) classification and plot them.

Groundwater was first investigated for its suitability for direct irrigation. Then groundwater from various bores, chosen to provide a representative cross-section of groundwater quality for the Weaber Plain, was mixed with M1 supply-channel water at various ratios until the required water quality (< 75 mS/m) was reached. This was to estimate the level of dilution that would be required before groundwater would become suitable for irrigation. Waters from different sources were mixed, based on volumes and concentrations under the assumption that there were no chemical reactions to alter the ratio of ion concentrations.

3.3.3 Modelling water quality from mixing groundwater with supply-channel water

Under irrigation, the watertables beneath the Weaber Plain are forecast to rise (KBR 2011) and so would have the potential to induce salinity impacts on soils and surface waters (Ali et al. 2002). To manage the potential salinity issues, various groundwater-management scenarios (see KBR 2011) have been modelled (Appendix G). Under these scenarios, groundwater from the Ord palaeochannel under the Weaber Plain would be pumped to control watertable levels and disposed of either into the main supply channel or to the Keep River. The quality of water resulting from the mixing of groundwater with supply-channel water was modelled to assess its suitability for irrigation.

To determine a representative composition of the pumped groundwater to be discharged into the supply channel, groundwaters from different parts of the Weaber Plain (bores: 10WP42, 10WP35PB, WP9 and 10WP32PB) were mixed in a model. The resultant water quality was then used as the groundwater quality input for further water-quality modelling.

Final water qualities were modelled for two different groundwater-pumping scenarios: the expected or most probable scenario, and the worst-case scenario. These were mixed with the supply-channel water assuming flow under both average and peak-flow conditions. Under the expected scenario, 4.4 GL of water would to be pumped from the palaeochannel over 200 days during the tropical dry season and discharged to the main supply channel (M2). Under a worst-case scenario, 6.15 GL of groundwater would be discharged to the main supply channel over 200 days. The resultant water quality of the M2 was modelled in AquaChem™ with flow rates in the supply channel of 540 ML/day under average conditions and 769 ML/day under peak-flow conditions (Table 3).

The water quality of the M2 supply channel was represented by water quality from the M1 supply channel. The supply rates of water from the ORIA Stage 1 under peak flows into the M2 supply water was determined by the total flow of the channel less groundwater inputs. The water quality was estimated by mixing total volumes and total loads from different water sources. The EC was estimated from total dissolved solids of the final water quality using a relationship developed from chemical sampling. This electrical conductivity was then used in subsequent analysis against USDA (1954) guidelines.

Table 3 **Modelling scenario mixing different water sources at different ratios**

Groundwater	Flow rate (L/s)	Period (days)
4.4 GL groundwater pumped over 200 days	255	200
6.15 GL groundwater pumped over 200 days	356	200
Scenario	**Flow rate (L/s)**	**Mixing ratio**
Average channel flow * (540 ML/day)		
Groundwater (4.4 GL for 200 days)	255	0.039
+ M1 supply channel	6 250	0.961
Total flow in channel	**6 505**	**1.0**
Groundwater (6.4 GL for 200 days)	356	0.054
M2 supply channel	6 250	0.946
Total flow in channel	**6 606**	**1.0**
Maximum channel flow (769 ML/day)		
Groundwater (5 GL for 200 days)	255	0.029
+ M1 supply channel	8 645	0.971
Total flow in channel	**8 900**	**1.0**
Groundwater (6.4 GL for 200 days)	356	0.040
M2 supply channel	8 544	0.960
Total flow in channel	**8 900**	**1.0**

* Channel flow estimates: G. Munk, pers. comm.

4. Results

4.1 Groundwater salinity trends

Figure 7 shows the linear regression describing the relationship between total dissolved solids and electrical conductivity for historical groundwater samples in the Kununurra area, based on the data presented by O'Boy et al. (2001). Besides the high R^2 value, it is notable that, even though the groundwater samples were collected from the Ivanhoe, Weaber, Knox, Packsaddle and Mantinea plains, the relationship between TDS and EC was consistent for all groundwaters. This relationship was used to convert groundwater EC data to TDS for trend analysis. The groundwater salinity and water level plots for the Ivanhoe and Weaber plains are shown in Appendices A and B, respectively.

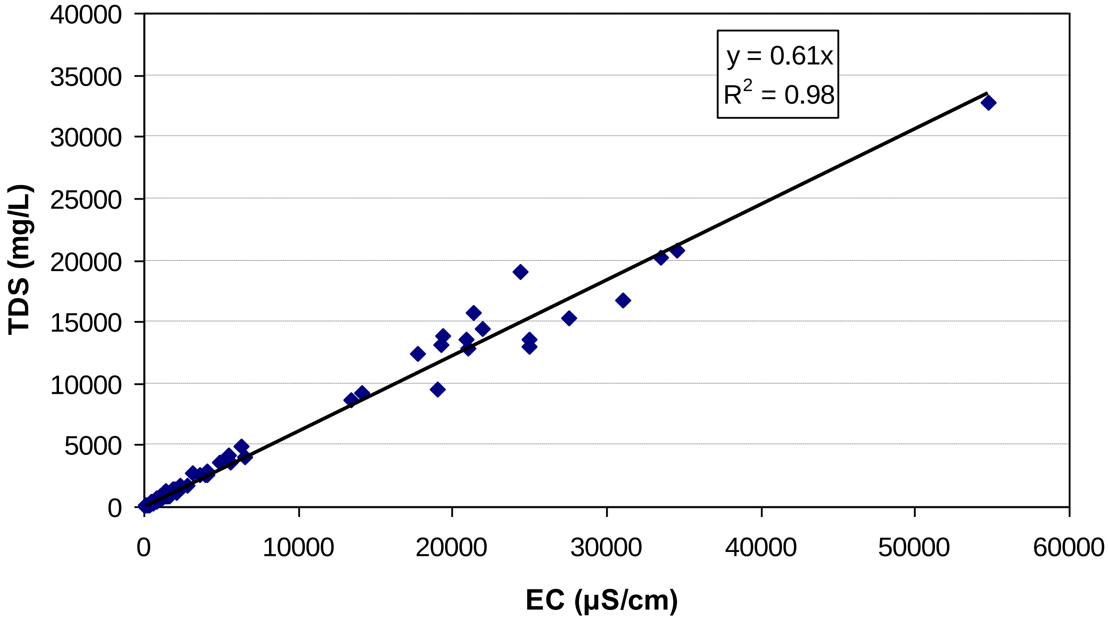

Figure 7 **Linear regression equation for the relationship between total dissolved solids and electrical conductivity for groundwater samples in the Kununurra area (data from O'Boy et al. 2001, n = 85).**

Groundwater levels under the Ivanhoe Plain have risen following clearing and development in the 1960s. They reached a new equilibrium at most bores in the late 1990s or early 2000s (Smith et al. 2007).

In response to irrigation and the increase in groundwater levels, six trend patterns were recognised in the Ivanhoe Plain groundwater salinity plots. These were:

- decreasing: TDS values decreasing, usually as groundwater levels increased
- increased variability: the variability of observed TDS values increased, usually as groundwater levels increased
- increasing: TDS values increasing, usually as groundwater levels increased
- no discernable trend: highly variable data, some possibly erroneous; the available data did not allow any trend to be confidently identified
- no trend: TDS may be variable but remains within a relatively narrow range

- spike: TDS values increased then returned to a value approximating the originally observed value, generally, as the groundwater level reached a new equilibrium.

Groundwater salinity trends for all bores analysed are shown in Table 4 and summaries of the trends on the Ivanhoe and Weaber plains are shown in Table 5 and Table 6 respectively. A map of the bore locations classified by salinity trend is presented in Figure 8, and TDS values observed in 2009 are shown in Figure 9.

Table 4 shows that the mean groundwater salinity observed within the palaeochannel under the Ivanhoe Plain was 729 mg/L in 1984 (n = 20) and 750 mg/L in 2009 (n = 24). The table also shows that the mean groundwater salinity observed in bores outside the palaeochannel was 1918 mg/L in 1984 (n = 15) and 1958 mg/L in 2009 (n = 17). However, neither the observed groundwater salinities within the palaeochannel nor those observed elsewhere under the Ivanhoe Plain were normally distributed in 1984 or in 2009. The Mann-Whitney U (Wilcoxon rank-sum) tests revealed that, despite the quite different mean values shown in Table 4, the groundwater salinities within the palaeochannel were not statistically different to those observed under other parts of the irrigated area of the Ivanhoe Plain in 1984 or in 2009. Furthermore, 2009 groundwater salinities were not statistically different to those observed in 1984.

When only data from Ivanhoe Plain bores for which salinity observations in both 1984 and 2009 were considered, the mean groundwater salinity within the palaeochannel in 1984 was 675 mg/L and 947 mg/L in 2009 (n = 12). Similarly, the mean groundwater salinity outside the palaeochannel was 858 mg/L in 1984 and 562 mg/L in 2009 (n = 6). Again, the differences were not statistically significant.

Table 4 **Groundwater salinity (as TDS) trends between 1984 and 2009 for bores on the Ivanhoe and Weaber plains grouped by hydrogeology, either within or outside the Ord palaeochannel**

Bore	Salinity observations		Salinity trend	TDS		TDS change
	From	To		1984	2009	
Ivanhoe Plain – palaeochannel						
4C	11-Jun-64	20-Oct-04	Increasing	750	1 500	100%
94-01	01-Feb-95	29-Apr-10	Spike		500	0%
94-02	01-Feb-95	29-Apr-10	Decreasing		180	-40%
94-13	01-Feb-95	30-Apr-10	Spike		230	-77%
94-24	01-Feb-95	30-Apr-10	No discernible trend		470	
94-25	01-Feb-95	04-May-10	Increasing		150	50%
94-41	29-Mar-00	28-Apr-10	Spike		160	-36%
HI1-78	08-Jun-78	21-May-08	No trend	500	600	0%
HI3-78	11-Jun-78	23-May-05	Increasing	1 100	3 500	100%
ORD1 (CG3)	02-Jun-94	10-Nov-08	Increasing		600	50%
ORD3 (CG5)	03-Jun-94	23-Nov-05	Increasing		2 000	100%
ORD5 (CG1)	04-Jun-94	10-Nov-08	Spike		1 300	0%
ORD6 (CG2)	07-Jun-94	10-Nov-08	No trend		600	0%
PB1	31-May-83	23-Nov-05	No trend	350	400	0%
PB1M1	01-Jun-83	11-Nov-08	No trend	300	300	0%
PB1M4	03-Jul-83	29-Apr-10	Increasing	180	375	108%
PB2	08-Jun-83	23-May-05	Increasing	300	1 200	50%

(*continued*)

Table 4 **Groundwater salinity (as TDS) trends between 1984 and 2009 for bores on the Ivanhoe and Weaber plains grouped by hydrogeology, either within or outside the Ord palaeochannel** (*continued*)

Bore	Salinity observations		Salinity trend	TDS		TDS change
	From	To		1984	2009	
PB2M1	08-Jun-83	23-May-05	Increased variability	300	1 000	50%
PB2M2	15-Dec-83	07-Nov-06	Increasing	276		
PB2M4	15-Dec-83	03-May-05	No trend	334		
PB4M3D	29-Mar-00	29-Apr-10	Decreasing		200	-88%
PN2D	13-May-83	24-Aug-08	Decreasing	3 800		-40%
PN2S	13-May-83	10-Nov-08	Increasing	300		39%
PN5D	11-May-83	11-Nov-08	Spike	650	730	-11%
PN5S	11-May-83	10-Nov-06	Increased variability	530		0%
PN6D	21-May-83	28-Apr-10	No trend	560		0%
PN6S	21-May-83	10-Nov-08	Decreasing	2 800	1 400	-50%
PN8D	11-May-83	10-Nov-08	Increased variability	330	120	0%
PN8S	11-May-83	23-May-05	No trend	380		0%
PN9D	06-May-83	10-Nov-08	Increased variability	540	240	0%
PN9S	06-May-83	07-Nov-06	Increasing	300		100%
PN11S	01-Apr-84	10-Nov-08	Increased variability		250	50%
Mean				**729**	**750**	**16%**
Ivanhoe Plain – non-palaeochannel						
11C	29-May-64	25-May-95	No discernible trend	1 100		
6D	07-May-82	28-Oct-92	No discernible trend	8 000		
91-02	29-Mar-00	24-Aug-08	Spike		2 000	223%
94-14	29-Mar-00	04-May-10	No trend		2 100	0%
94-22	29-Mar-00	04-May-10	spike		120	-52%
94-32	01-Feb-95	24-Aug-08	No trend		600	0%
96-05	29-Mar-00	04-May-10	No trend		5 500	0%
96-06	29-Mar-00	24-Aug-08	No discernible trend		1 400	0%
ORD10 (GS4)	17-Jun-94	10-Nov-08	Increasing		10 000	233%
ORD12 (ML3)	18-Jun-94	10-Nov-08	No trend		600	0%
ORD4 (ML1)	04-Jun-94	23-Nov-05	Spike		2 500	0%
ORD41 (ML6)	29-Mar-00	04-May-10	Spike		100	-88%
ORD9 (GS2)	16-Jun-94	10-Nov-08	Spike		5 000	0%
PB3	28-Jun-83	22-Nov-05	No discernible trend	1 500		
PB3M1	18-Jun-83	11-Nov-08	Increasing	1 500	2 000	33%
PB3M2	15-Dec-83	12-7-2000	Increasing	1 320		
PB3M3S	03-Jul-83	10-May-02	No discernible trend	900		
PN1S	18-May-83	10-Oct-08	Spike	5 300		0%
PN3D	18-May-83	06-May-93	Spike	1 200		-20%
PN3S	18-May-83	10-Nov-08	No trend	500	580	0%
PN7S	20-May-83	10-Nov-08	No trend	2 400	100	0%

(*continued*)

Table 4 **Groundwater salinity (as TDS) trends between 1984 and 2009 for bores on the Ivanhoe and Weaber plains grouped by hydrogeology, either within or outside the Ord palaeochannel** (*continued*)

Bore	Salinity observations	Salinity trend	TDS	TDS change	Bore	Salinity observations
PN12S	27-May-83	10-May-02	Increasing	300		275%
PN14S	20-May-83	10-Nov-08	No trend	80	70	0%
PN15S	23-May-83	11-Jan-96	Decreasing			-70%
V1506	03-Jul-83	10-Nov-08	No trend	70	120	0%
Mean				**1 918**	**1 958**	**25%**
Weaber Plain – palaeochannel						
CS10	8-Aug-78	27-Nov-09	Increasing	400	880	76%
ORD8 (CG4)	15-Jun-94	10-Nov-08	Increasing		1 000	60%
WBS1112	2-Jul-83	25-Nov-09	No trend	560	600	0%
WP2	29-Aug-96	25-Nov-09	Increasing		570	714%
WP6	16-Sep-96	25-Nov-09	Increasing		830	105%
WP7	27-Aug-96	24-Nov-09	No trend		190	0%
WP11D	3-Nov-96	24-Nov-09	No trend		300	0%
WP15	29-Jul-94	30-Aug-10	No trend		12 000	0%
WP19	30-Jul-94	29-Aug-10	No trend		17 000	0%
Mean				**480**	**3 708**	**106%**
Weaber Plain – non-palaeochannel						
CS2	15-Apr-84	30-Apr-04	Spike	100		0%
CS12E1R	15-Dec-83	26-Feb-05	Increasing	500	1 800	260%
CS12E2.5	2-Jul-83	25-Nov-09	Decreasing	3 000	2 100	-30%
CS13	2-Jul-83	18-Aug-88	No trend	560		0%
W2R	30-Jun-83	14-May-08	Decreasing	350	120	-76%
W5S1	4-May-83	30-Oct-08	Decreasing	2 800	400	-87%
W5S1.5	27-Jun-83	26-Oct-95	No trend	7 300		0%
W5S2R	24-Nov-06	27-Nov-09	Increasing		11 000	*
WP3	29-Aug-96	27-Nov-09	Increasing		90	29%
WP4	30-Aug-96	27-Nov-09	Increasing		90	29%
WP10	4-Nov-96	24-Nov-09	No trend		1 300	0%
WP12D	4-Nov-96	30-Aug-10	Decreasing		400	-84%
Mean				**2 087**	**1 922**	**4%**

* Strong increasing trend but time series too short to calculate % increase

Table 5 **Summary of groundwater salinity trends on the Ivanhoe Plain in response to development and irrigation**

Salinity trend	Palaeochannel bores		Other bores	
	Number	%	Number	%
Decreasing	4	13%	1	4%
Increased variability	5	16%	0	0%
Increasing	10	31%	4	15%
No discernible trend	1	3%	5	19%
No trend	7	22%	8	31%
Spike	5	16%	8	31%
Total	32		26	

Table 6 **Summary of groundwater salinity trends on the Weaber Plain**

Salinity trend	Palaeochannel bores		Other bores	
	Number	%	Number	%
Decreasing	0	0%	4	33%
Increasing	4	44%	4	33%
No trend	5	56%	3	25%
Spike	0	0%	1	8%
Total	9		12	

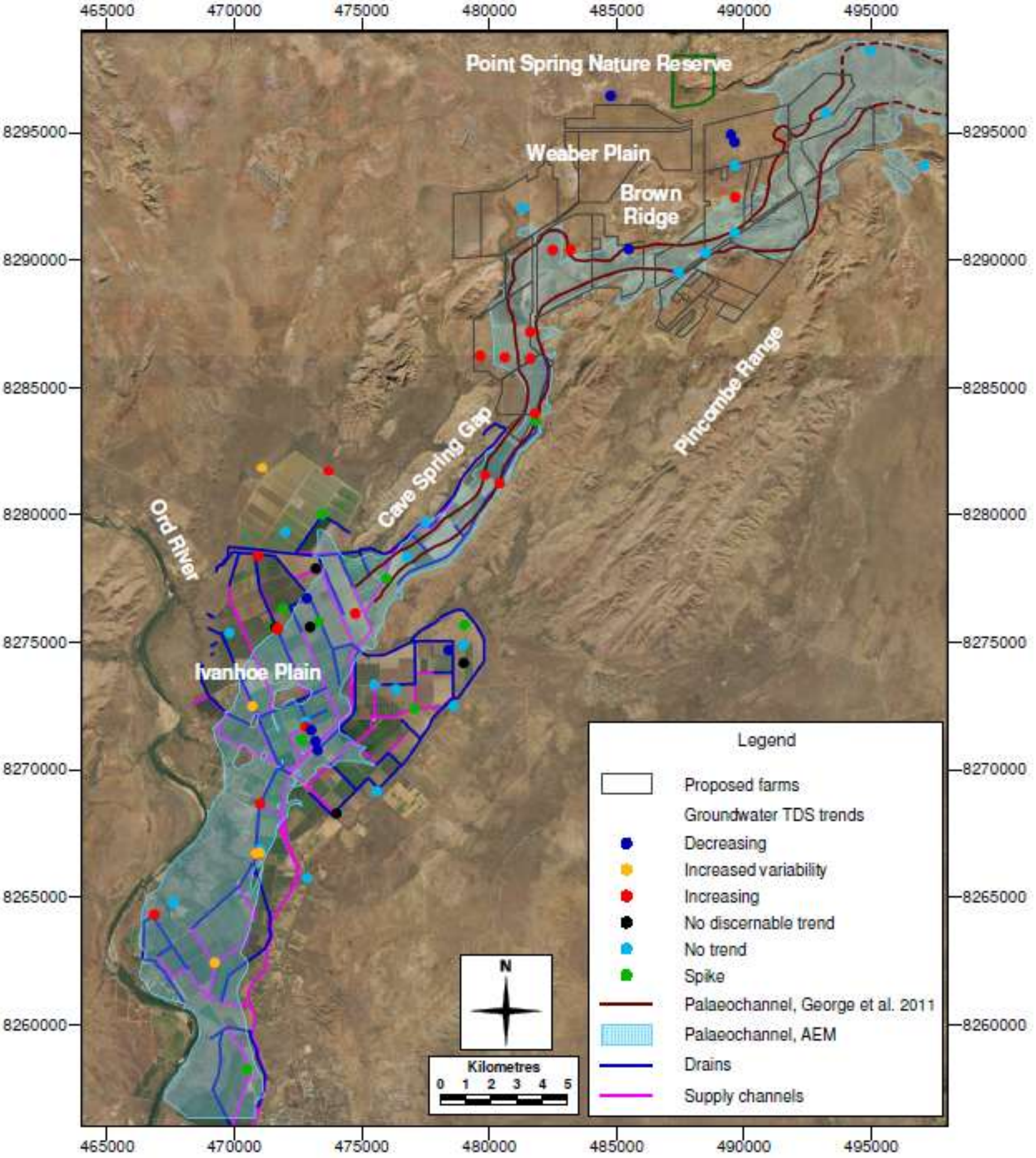

Figure 8 **Locations of groundwater bores on the Ivanhoe and Weaber plains classed by salinity trend (Map Grid of Australia, Zone 52)**

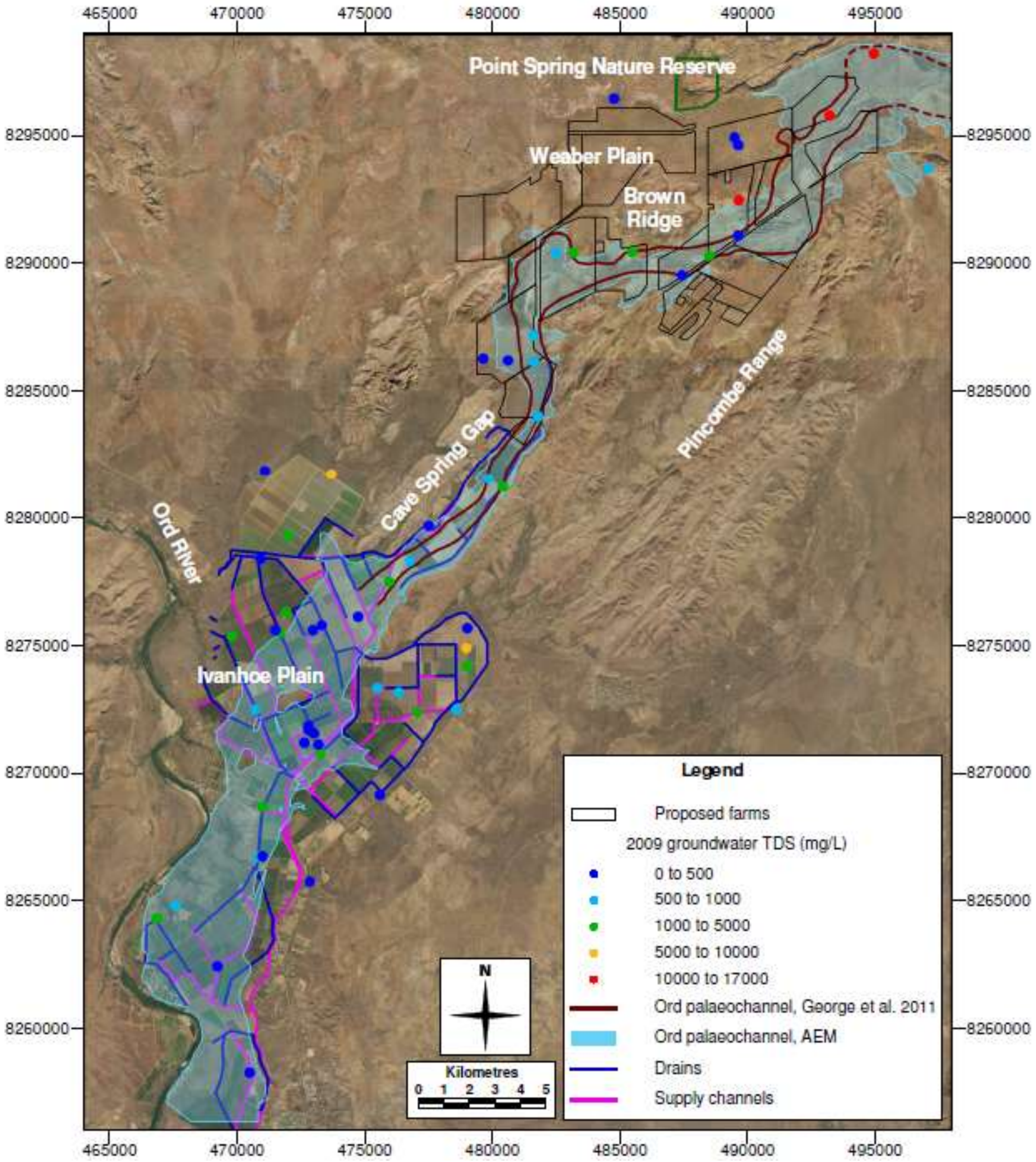

Figure 9 **Locations of groundwater bores on the Ivanhoe and Weaber plains classed by TDS (mg/L), observed in 2009, overlain on AEM conductivity (mS/m) for 2–2.4 m BGL (Lawrie et al. 2010) (Map Grid of Australia, Zone 52)**

4.2 Groundwater salinity trends by soil type

The mean observed groundwater salinity under Aquitaine soils on the Ivanhoe Plain was 2629 mg/L in 1984 (n = 7) and 2605 mg/L in 2009 (n = 11). By contrast, the mean groundwater salinities observed under Cununurra soils were 796 and 712 mg/L in 1984 (n = 21) and 2009 (n = 25) respectively. As with the analyses by hydrogeology, there was no statistically significant difference in groundwater salinity by soil type when only data from the Ivanhoe Plain were considered.

When the groundwater salinity data were separated by soil type for the Ivanhoe and Weaber plains, the sample sizes were small, which made statistical analysis problematic. All groundwater salinity data across the whole study region were therefore combined and then separated by soil type to give more statistically robust results.

The median groundwater salinity under Aquitaine soils (Figure 10) was 1300 mg/L (mean = 2492, n = 45), while that under Cununurra soils was 630 mg/L (mean = 1442, n = 68). There was a statistically significant ($p < 0.01$) difference in the observed groundwater salinities between the Aquitaine and Cununurra soil types.

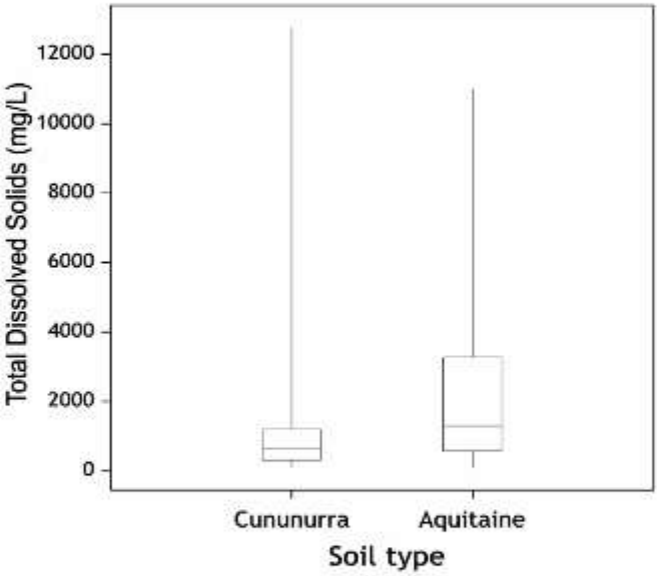

Figure 10 **Box plots (showing median, interquartile ranges, minimum and maximum) for total dissolved solids beneath Aquitaine and Cununurra soil types**

4.3 Water sampling

4.3.1 General characteristics and major ions

All field and laboratory results from the 2010 sampling program are presented in Appendices C and E. The salinity varied from 68 mg/L TDS at Point Spring to 19 000 mg/L at WP19 (ORD22), with a median of 845 mg/L TDS (Appendix E). The groundwater under the northern Weaber Plain had the highest salinities. In the palaeochannel (10WP35, 10WP33, WP17) groundwater salinities ranged between 200 and 1100 mg/L (Appendices C and E).

The pH of groundwater ranged from neutral (7) to alkaline (8.3), the median for all samples being 7.7. Surface water at Parry Lagoons and in the M1 supply channel had the highest observed pH, at 8.4. Groundwater at several bores displayed strongly reducing conditions (ORP < 0 mV) (Appendix E).

The chemical compositions of water samples are shown in Figure 12 and Appendix E. The Piper diagram (Figure 12) shows that groundwater under the Weaber Plain can be divided into two groups based on anion concentrations. One group, the groundwaters of the Ord palaeochannel (typified by bores 10WP35PB and 10WP37), was dominated by the anion bicarbonate and had lower salinities. The second group, groundwaters of the northern Weaber Plain (typified by bores WP5 and WP12), was dominated by the anions chloride and sulfate and had higher salinities. Bore 10WP47, though located on the northern Weaber Plain, has a hydrochemical signature closer to bores in the Ord palaeochannel, being of a lower salinity and dominated by bicarbonate. This is most likely due to it being drilled into alluvial sediments. Bores 10WP42, 10WP46, 10WP39 and ORD20 (WP9) had chemical compositions between that of bores located in the palaeochannel and the saline northern Weaber Plain bores. With the exception of ORD20 (WP9), these bores are drilled into similar alluvial sediments to those found at 10WP47.

The dominant cation at most bores under the Weaber Plain and the ORIA is sodium. The main exceptions were chemistries reflective of the basement geology: for example, groundwater at bore WP5 was dominated by magnesium and calcium and also had the highest iron concentration (Drever 2002). This is reflective of the basalt basement underlying this location (Appendix C, also see the geology map presented by George et al. 2011, p. 6). Ferromagnesian minerals and calcic plagioclase within the basalt are the likely source of the high proportion of iron, magnesium and calcium in the groundwater. Bores 10WP47, 10WP39 and WP16 are dominated by calcium, which is likely due to the groundwater interacting with calcarenite or limestone ($CaCO_3$) in the formation (Appendix C).

The hydrochemistry of surface waters is also variable. Bicarbonate is the dominant anion in the M1 supply channel. However, waters in the irrigation drainage network had altered slightly in composition, having higher proportions of chloride (relative to the M1) in the D4 and D8 disposal drains (Figure 12, Appendix C and Appendix E).

4.3.2 Minor ions and nutrients

Much of the groundwater exceeded the Australian and New Zealand Environment and Conservation Council / Agriculture and Resource Management Council of Australia and New Zealand (ANZECC/ARMCANZ 2000) irrigation guideline values for minor ions (see Appendix D). Nine bores exceeded the long-term trigger value for boron, which is toxic to some plants. However, most of the bores with high boron concentrations are also highly saline, and are located in the buffer areas that will not be irrigated or pumped under the proposed management plans.

The nutrient values in groundwater across Weaber Plain are generally low. The average total nitrogen of groundwater was 0.48 mg/L and the average total phosphorus was 0.11 mg/L.

4.3.3 Chlorofluorocarbons

The results of the CFC analyses are shown in Table 7. The youngest groundwaters, occurring in bores PB4M3D and 10WP33, are dated to a median origin of 1982.

The bores 10WP36PB and 10WP39 also had CFCs present at values similar to the background value, which indicates that they are relatively young waters that have received modern recharge (Fred Leaney, CSIRO, pers. comm.).

Table 7 **CFC concentrations and apparent age of groundwaters thus determined**

Sample	Measured CFC Concentration in water		Equivalent atmos. concentration		Apparent age	
	CFC11 (pg/kg)	CFC12 (pg/kg)	CFC11 (pptv)*	CFC12 (pptv)	CFC11 (years)	CFC12 (years)
10WP36PB	30	45	25	151	1965	1972
10WP39	63	31	53	103	1970	1969
10WP33	129	92	109	312	1975	1982
PB4M3D	122	92	104	316	1975	1982

*pptv – parts per trillion by volume

4.3.4 Pesticides

No pesticides (Appendix E, Table E2) were detected in groundwaters on the Weaber Plain. Low concentrations of atrazine (0.16 µg/L) found in groundwater at PB4M3D in the central Ivanhoe Plain (Figure 4) were below the ANZECC/ARMCANZ 2000 water-quality guideline trigger values.

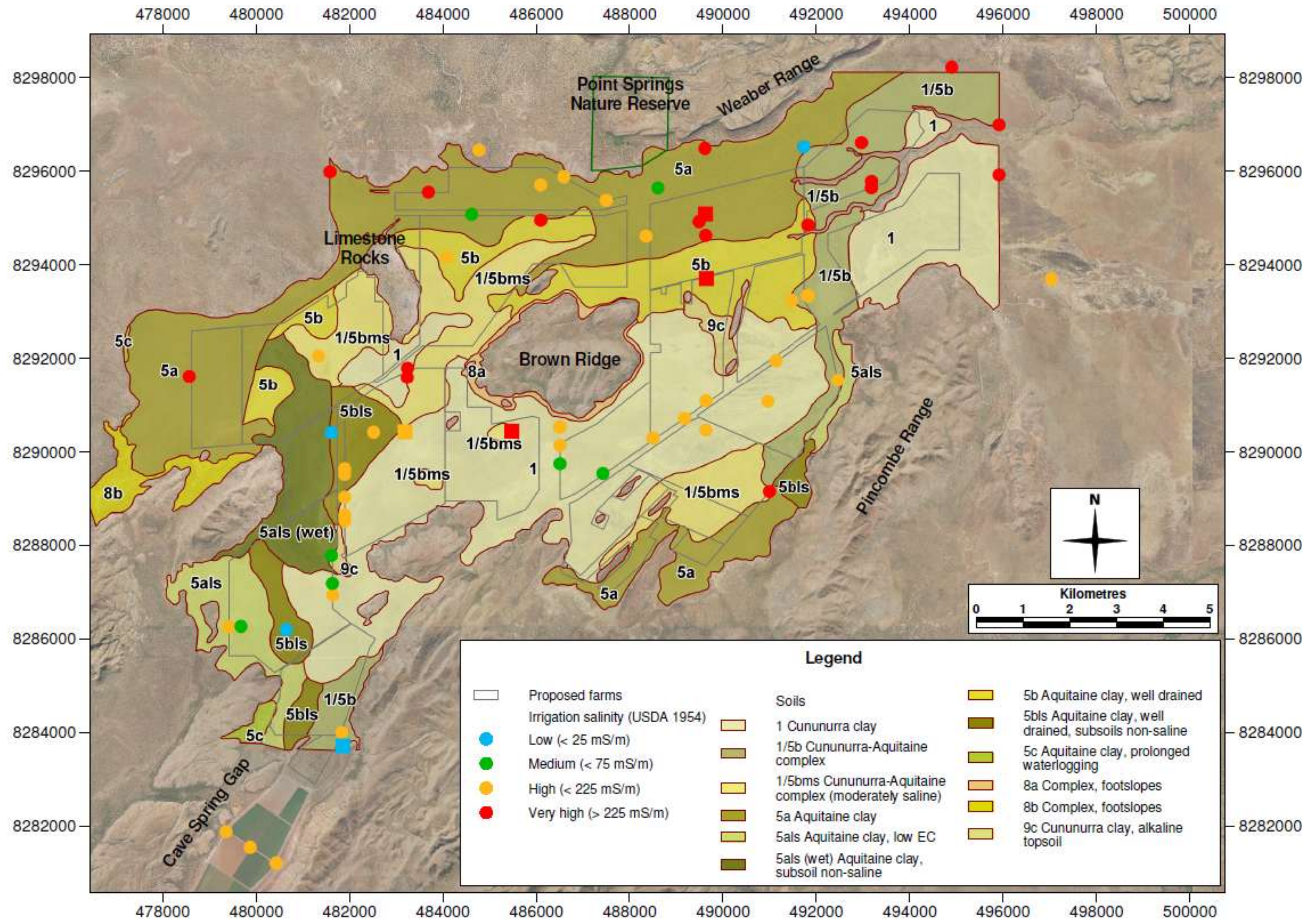

Figure 11 **Suitability of groundwater for irrigation in the Weaber Plain farmlands based on USDA (1954) salinity classifications (Map Grid of Australia, Zone 52). Circles denote recent observations (2009 or later); squares denote 1984 observations. Soils as mapped by Smolinski et al. (2012).**

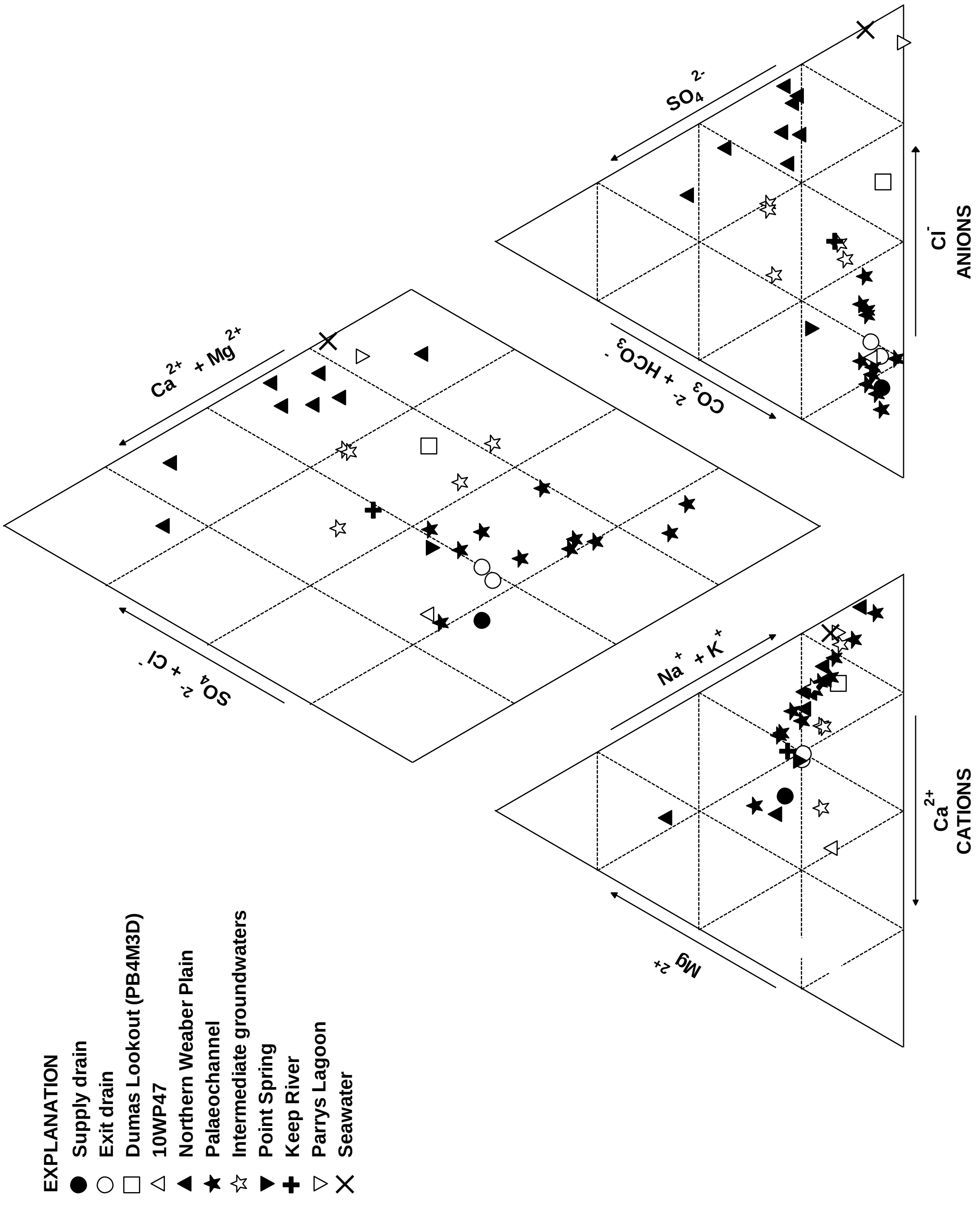

Figure 12 **Piper diagram showing the major ion composition of samples collected**

4.4 Suitability of groundwater for direct and indirect irrigation

4.4.1 Suitability of groundwater for direct irrigation

The suitability of a range of water samples for irrigation, with respect to salinity and sodicity, are shown in Figure 13. The electrical conductivities of groundwater across the Weaber Plain were mostly in the high salinity range (75 to 225 mS/m) (Figure 11), only groundwater from Point Spring being in the lowest hazard category. All surface water and drain samples are in the moderate salinity range (C2) and in the lowest sodium hazard class (S1). The lower salinity groundwaters were located in the palaeochannels, of which only 10WP31 and 10WP47 are suitable for direct irrigation (Figures 11 and 13). These bores were in the C2 moderate category.

Most groundwater in the palaeochannel was in the high salinity (C3) category (USDA1954) and unsuitable for direct use for irrigation. The groundwater must therefore be mixed with lower salinity water, such as that from the M2 supply channel, before being suitable for irrigation. The groundwaters in the northern part of the Weaber Plain have much higher salinities and would need to be diluted at even greater rates.

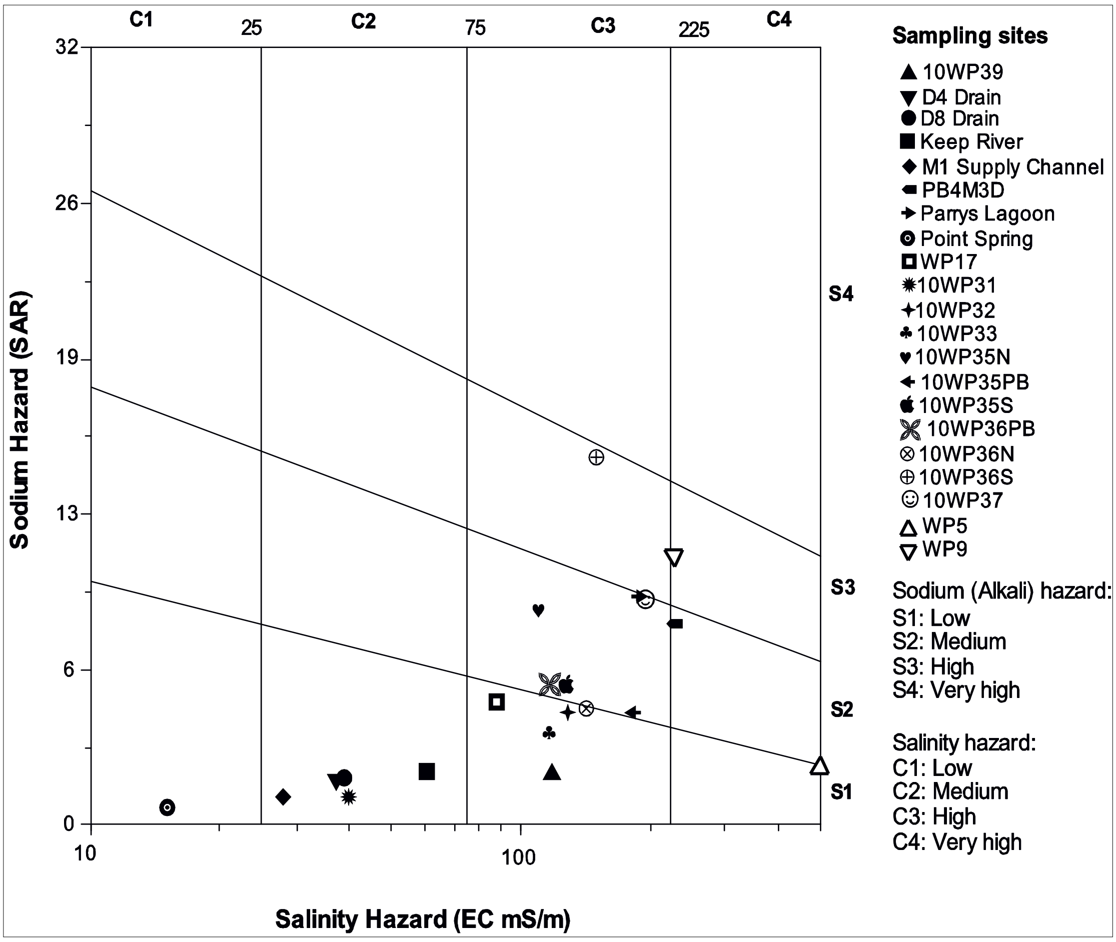

Figure 13 **The suitability of water samples for irrigation. Note: any site with an electrical conductivity above 500 mS/m exceeds the upper limit of the graph.**

To gain an understanding of the dilution rates required, groundwaters from representative bores on the Weaber Plain were mixed with M1 supply channel water in the AquaChem™ hydrochemical model. The waters were mixed at various ratios until an electrical conductivity below 75 mS/m (C3, high salinity) was reached (See Figure 11 and Figure 14). The groundwater from the palaeochannel needed to be diluted 1:1 with supply channel water before it became suitable for irrigation. Saline groundwater from the northern Weaber Plain needed be diluted by 50:1 with supply channel water before it became suitable for irrigation (Table 8).

Table 8 **The maximum rate groundwater can be mixed with the M1 supply without exceeding 75 mS/m (C3 high salinity hazard) and resulting water quality**

Bore	Mixing ratio *	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	pH	EC (mS/m)
10WP33	53:47	84.5	2.8	31.4	27.3	91.3	260.5	31.0	8.3	74.5
10WP36PB	53:47	99.9	2.1	21.9	16.3	43.0	357.5	30.3	8.1	74.5
10WP39	53:47	55.5	12.1	51.9	17.6	66.3	215.5	96.3	8.1	75.0
ORD8 (CG4)	51:49	98.9	3.2	28.4	28.0	89.4	266.7	44.5	8.3	74.7
WP5	10:90	44.3	2.6	40.5	49.5	120.4	182.3	82.6	8.3	74.2
WP12M	7:93	93.2	5.3	28.9	21.9	115.0	155.4	74.7	8.2	72.4
WP15	2:98	97.1	2.4	16.3	13.0	101.7	161.4	55.0	8.4	62.2
WP17	79:21	113.9	2.9	21.6	19.6	52.3	340.5	26.5	7.7	74.8

*volume fractions (i.e. 53:47 is 53% M1 supply water: 43% groundwater by volume)

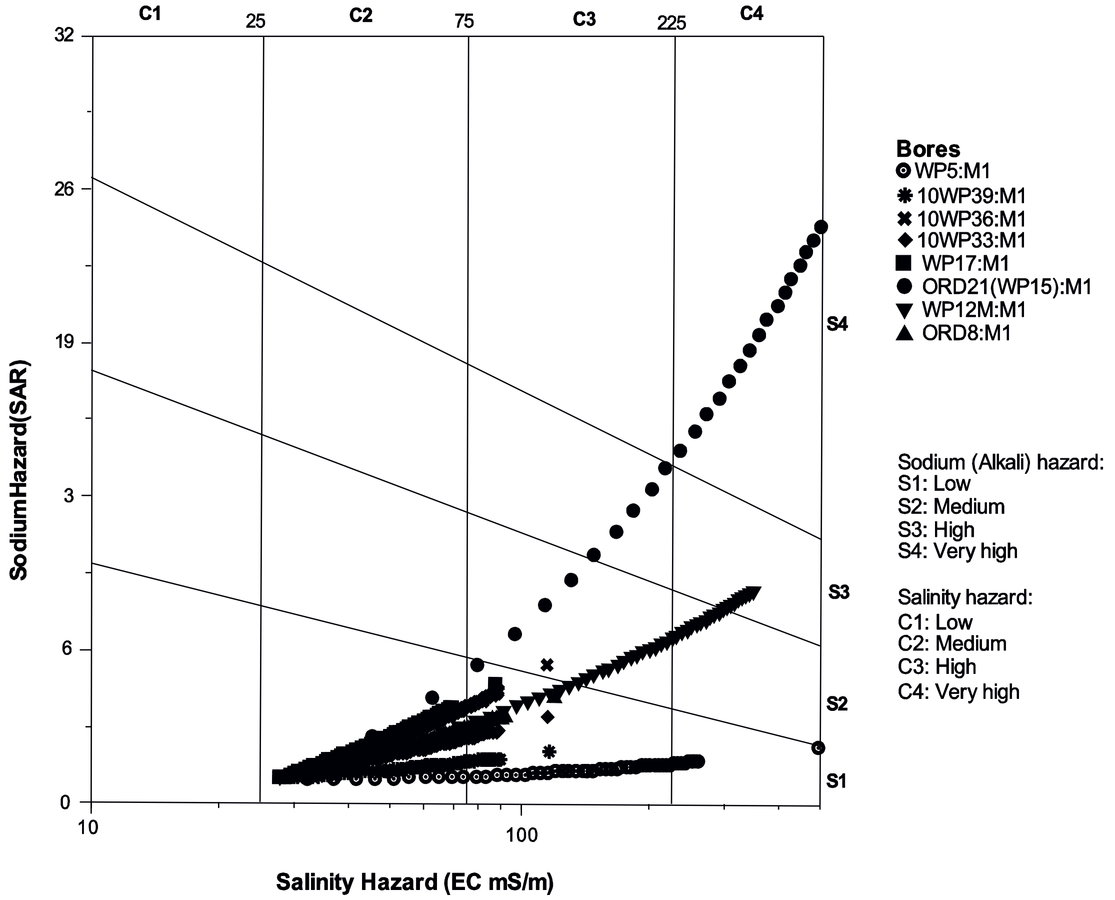

Figure 14 **The suitability for irrigation of groundwater mixed with the M1 supply-channel water at different mixing rates. Water from the supply channel is added in 1% increments to groundwater from each bore.**

4.4.2 Modelled water quality from mixing scenarios

The modelled water qualities from different groundwater pumping scenarios are shown in Table 9. Under the expected case, where groundwater is pumped into the main supply channel, at its average flow rate, over 200 days, the modelled water quality was 178 mg/L TDS. With the supply channel at peak flow, the water quality improved slightly, to 167 mg/L.

Under the worst-case scenario when groundwater is pumped at maximum rate into the supply channel under average flow conditions, the modelled water quality is 193 mg/L TDS. With maximum flow in the supply channel, it improves to 179 mg/L TDS.

The suitability of modelled water qualities was assessed against USDA (1954) irrigation classifications as shown in Figure 15.

Table 9 **Water quality resulting from hypothetically mixing different water sources in AquaChem™**

Water source	pH	TDS (mg/L)	EC (mS/m)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	SO_4 (mg/L)	HCO_3 (mg/L)
Source waters										
Average groundwater	7.8	1162	180	288.0	9.0	67.0	53.0	276.0	183.0	522.0
M1	8.4	196	25	19.7	2.3	15.3	8.2	16.0	6.5	128.0
Modelled mixing scenarios										
Groundwater (4.4 GL) average channel flow	8.4	178	32	30.2	2.6	17.3	10.0	26.2	13.4	143.4
Groundwater (6.15 GL) average channel flow	8.3	193	34	34.2	2.7	18.1	10.6	30.0	16.0	149.2
Groundwater (4.4 GL) peak channel flow	8.4	167	30	27.4	2.5	16.8	9.5	23.4	11.6	139.3
Groundwater (6.15 GL) peak channel flow	8.4	179	32	30.4	2.6	17.4	10.0	26.4	13.6	143.8

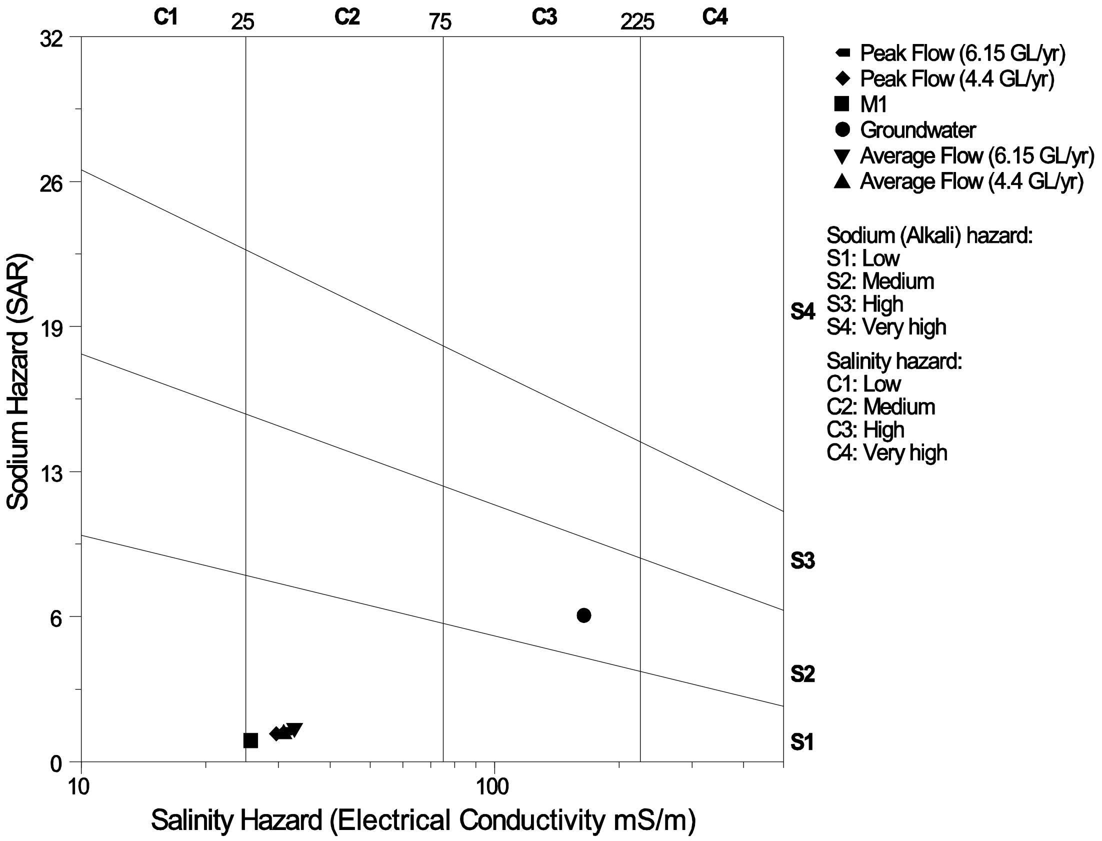

Figure 15 **The suitability of mixed water sources for irrigation**

5. Discussion

5.1 Groundwater salinity

One of the main aims of this study was to provide insight into the potential for groundwater salinity change on the Weaber Plain after development for irrigated agriculture. To meet this aim, an analysis of groundwater salinity trends within the nearby Ivanhoe Plain was undertaken. During the analysis of the time-series data, some data-quality issues became evident; some of the more important are discussed below.

Correlations between groundwater salinity and hydrogeology and between groundwater salinity and soil type were also performed. These analyses revealed that groundwater salinities under both the Ivanhoe and Weaber plains are highly variable. The implications of this high variability on determining average groundwater salinities are also discussed.

5.1.1 Data quality

Groundwater salinity trends were determined for 58 bores on the Ivanhoe Plain and 21 on the Weaber Plain, which constitute 90 per cent of the bores for which time-series data are available. Five trend patterns were recognised, but no discernible trend could be recognised for six bores on the Weaber Plain. Although the data from these bores did not contribute to the determination of temporal trends, it was included in determining mean groundwater salinities within and outside the Ord River palaeochannel, and for Cununurra versus Aquitaine soils.

For most of the bores for which no trend could be determined, the available data was highly variable and/or the sampling frequency was inadequate to allow trends to be identified as shown in Figure 16. At several bores, groundwater salinity profiles were measured on some occasions, but insufficient data was recorded to allow determination of the most representative value; see for example Figure 17.

Another issue that made determining temporal groundwater salinity trends difficult to discern occurred at five bore sites on the Ivanhoe for which an increasing variability in groundwater salinity was observed (see for example Figure 18). The potential exists that this high variability is a result of confusion between EC units (e.g. µS/m confused with mS/m), as is more obvious in the salinity plots for some other bores. While there is some doubt about the magnitude of the variability displayed, the general rising trends appear to be real.

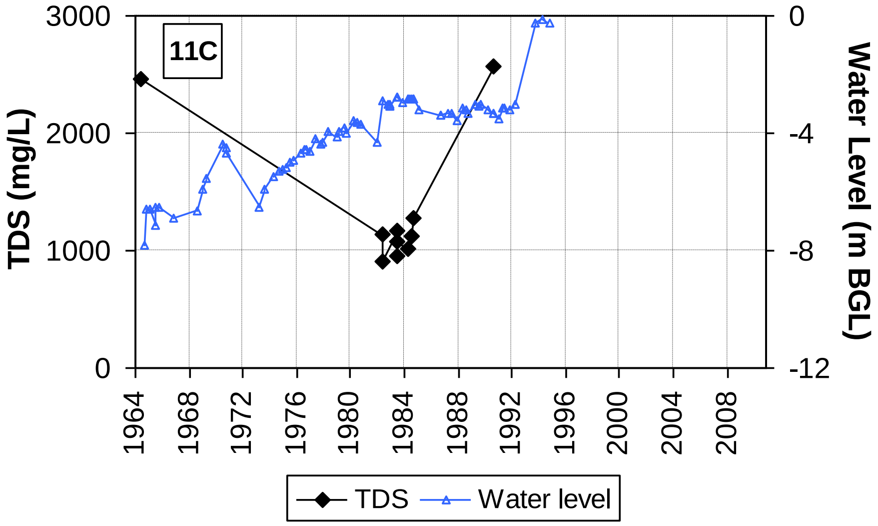

Figure 16 **Groundwater salinity and water-level trends for bore 11C on the Ivanhoe Plain, showing no discernible trend in groundwater salinity due to outliers and inadequate sampling frequency**

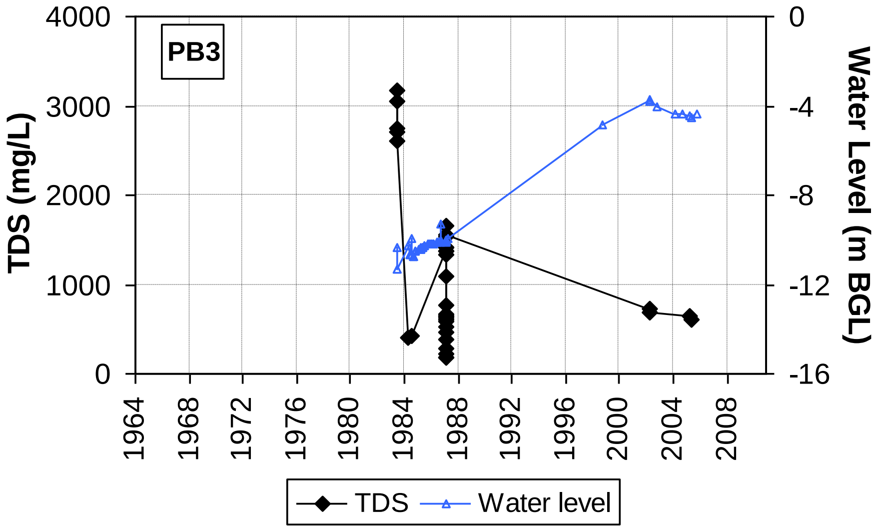

Figure 17 **Groundwater salinity and water-level trends for bore PB3 on the Ivanhoe Plain, showing no discernible trend in groundwater salinity due to profile sampling and inconsistent sampling frequency**

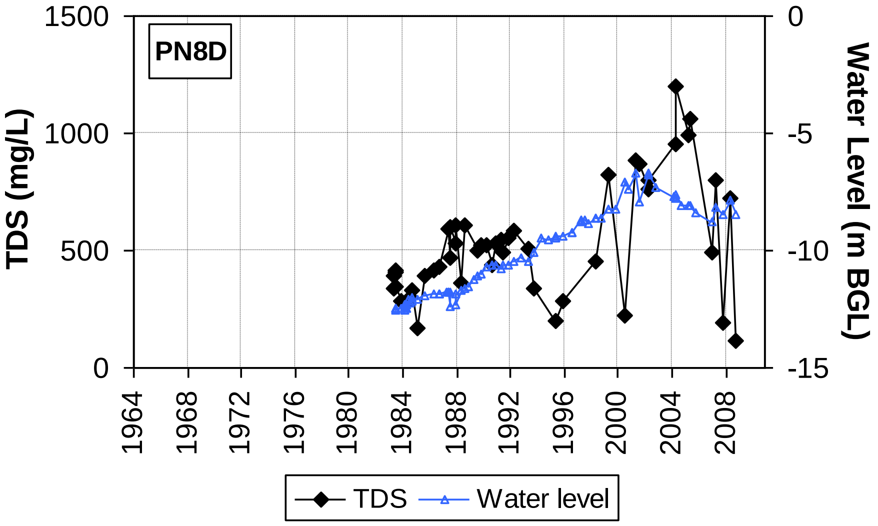

Figure 18 **Groundwater salinity and water-level trends for bore PN8D on the Ivanhoe Plain, showing increasing variability in groundwater salinity but no overall trend**

5.1.2 Ivanhoe Plain groundwater salinity

Forecasting the salinity change on the Weaber Plain under irrigation can be achieved either by using the historic record from an analogous environment (Ivanhoe Plain) or modelling (see KBR 2011). Results above show that the average salinity within the palaeochannel under the Ivanhoe Plain increased three per cent, from 729 to 750 mg/L (1984 and 2009), while the average salinity for bores outside the palaeochannel increased from 1918 to 1958 mg/L between 1984 and 2009 (a 2 per cent increase).

While considering the average is the appropriate method for forecasting future salinity change, it conceals the behaviour of individual bores or groups of bores. For example, while the Ivanhoe's salinity levels remained largely unchanged, the average of the changes at individual bores over that period varied from 16 per cent to 24 per cent (Table 4). The largest proportional increases in salinity occurred at bores where the groundwater salinity was relatively low (< 1500 mg/L) in 1984 (Figure 19). Furthermore, bores with high TDS values in 1984 displayed either no trend or a decreasing trend between 1984 and 2009.

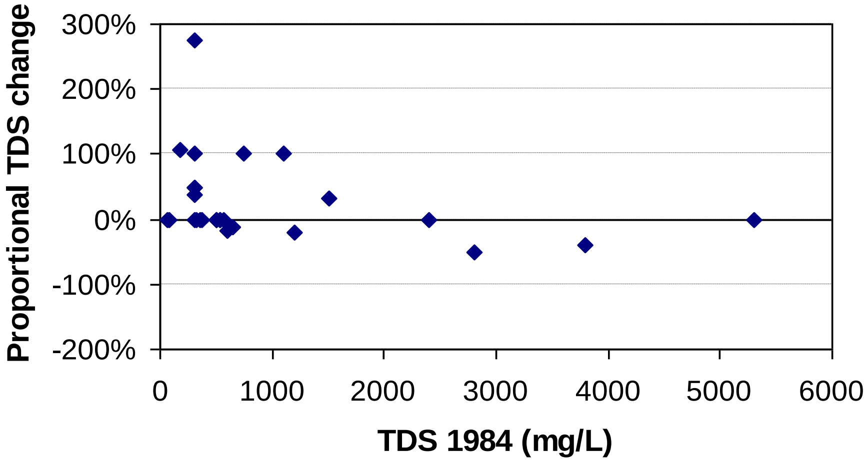

Figure 19 **Proportional groundwater salinity (as TDS) change as a function of 1984 salinity level for Ivanhoe Plain bores**

The maximum salinities observed within the palaeochannel were 3800 and 3500 mg/L in 1984 and 2009 respectively. The corresponding figures for Ivanhoe Plain bores outside the palaeochannel were 8000 and 10 000 mg/L, respectively.

This analysis highlights the fact that the averages of salinity values, either by hydrogeological setting or by time, are dominated by outliers. This is consistent with the non-normality of the distributions of TDS values and the lack of a statistically significant difference between the observed TDS values within the palaeochannel as compared to those outside it. This is despite the visual impression conveyed in Figure 9 that the groundwater in the palaeochannel was fresher than the groundwater elsewhere on the Ivanhoe Plain.

5.1.3 Groundwater interaction with supply and drainage channels

Smith et al. (2007) noted that the watertable beneath the northern Ivanhoe Plain has now intercepted the deeper, main irrigation drains, and that the drains appeared to discharge groundwater, helping to stabilise further watertable rise. There are two lines of evidence from the analyses presented here that are consistent with the groundwater being in hydraulic connection with the deeper drainage channels, and possibly the supply channels, on the Ivanhoe Plain.

Firstly, there are five bores that displayed decreasing salinity trends since about 2000, all of them being within 300 m of a main supply channel or drain (Figure 8). In most cases there had been an increasing salinity trend after irrigation commenced, followed by a distinct downward trend commencing around 2000 or 2001 (see Figure 20). The year 2000 was the wettest on record at the Kimberley Research Station rain gauge and it was when groundwater under the Ivanhoe Plain intercepted the drains and reached a new dynamic equilibrium.

Secondly, there are several nested bore sites at which the groundwater salinities observed in the deep and shallow bores have converged, as shown in Figure 21 for site PN2. Furthermore, the vertical gradient at this site reversed from being permanently downward to permanently upward at the end of the 1997 dry season, indicating that the relatively fresh water responsible for the sustained reduction in TDS at bore PN2D was not a result of vertical recharge at the site.

The most plausible explanation for this salinity response is that, once the watertable and drains were permanently hydraulically connected, the aquifer received fresh recharge from the drains and the salinity dropped. These salinity responses are consistent with the earlier conclusions of Smith et al. (2007).

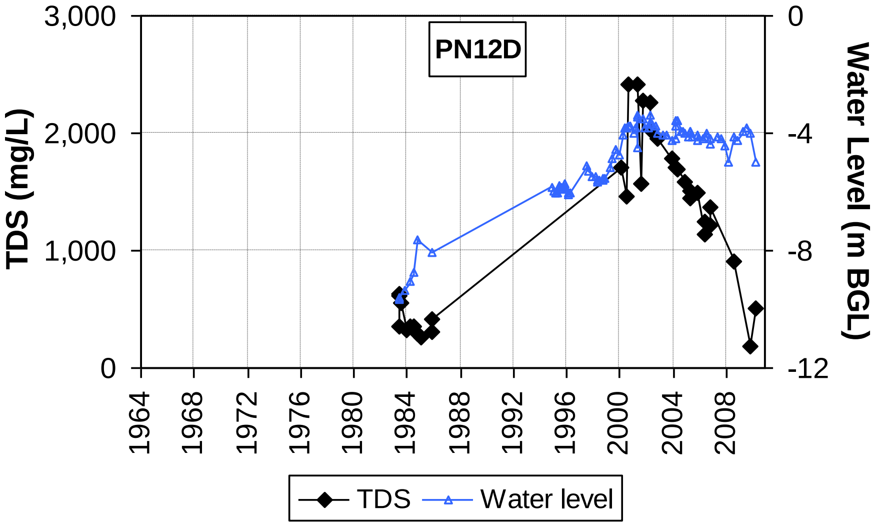

Figure 20 **Groundwater salinity and water-level trends for bore PN12D on the Ivanhoe Plain, showing spike groundwater salinity response**

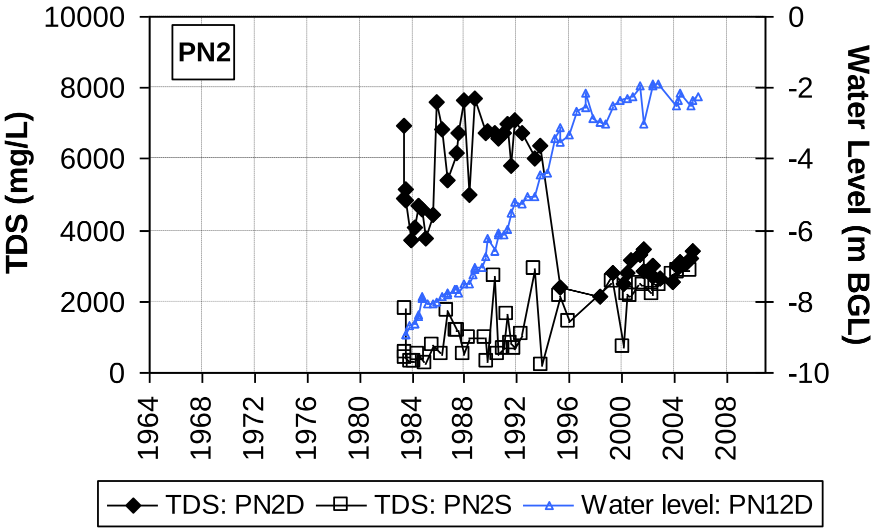

Figure 21 **Groundwater salinity and water-level trends for bores PN2D and PN2S on the Ivanhoe Plain**

5.1.4 Weaber Plain groundwater salinity

The majority of bores (62 per cent) on the Weaber Plain exhibited no trend, a decreasing trend or a spike response in groundwater salinity. Weaber Plain bores for which increasing groundwater salinity trends were observed were clustered in the western area of the plain north of Cave Spring Gap (Figure 8). Groundwater levels in this area have increased since the development of irrigated agriculture on the Ivanhoe Plain. However, there are also some bores in this area that exhibit no salinity trend despite groundwater-level increases. Most increases in groundwater salinity were of the order of 500 mg/L over the period of record, and the maximum increase was 4000 mg/L at bore W5S2R.

The mean 2009 groundwater salinity within the Ord palaeochannel under the Weaber Plain was 3708 mg/L (Table 4). This result was heavily influenced by the high observed salinities at bores WP15 and WP19, in the north-east of the plain (Figure 9), where groundwater levels are deep and there is no apparent trend in salinity. The mean of the groundwater salinities at all other bores within the palaeochannel under the Weaber Plain was 624 mg/L in 2009. The

2010 figure for a representative selection of bores on the Weaber Plain, including bores drilled in 2010, was 1162 mg/L (Table 9).

5.1.5 Summary

Despite some data-quality issues, groundwater salinity trends could be determined for 90 per cent of the bores on the Ivanhoe Plain for which time-series data were available, and the majority of them (65 per cent of the total) displayed non-increasing salinity trends (Table 5). Furthermore, only a small increase in the mean groundwater salinity under the Ivanhoe Plain between 1984 and 2009 was identified; the largest proportional increases occurred at bores with very fresh groundwater and this contributed little to the average salinity increase (Figure 19).

There is evidence to support the earlier conclusion (Smith et al. 2007) that there is now interaction between the aquifer and the deeper irrigation drains, and perhaps the supply channels. This interaction has stabilised groundwater levels and possibly acted to reduce groundwater salinity at some sites.

Groundwater salinities under the Ivanhoe and Weaber plains are much more strongly correlated to soil type than to hydrogeology, groundwater salinities under Cununurra soils being significantly lower than under Aquitaine soils. The mean groundwater salinity in the Ord palaeochannel under the Weaber Plain, from which groundwater will be pumped if watertable control is required was 1162 mg/L in 2010.

5.2 Groundwater age

Chlorofluorocarbon (CFC) analyses (Table 7) indicated that the median origin age of groundwaters sampled from bores PB4M3D and 10WP33 is about 1982. Bore PB4M3D, on the Ivanhoe Plain, would have received recharge from irrigation water. The young age of waters in 10WP33 (Weaber Plain) is likely due to the high relative vertical hydraulic conductivities of soils in the area (0.4 m/day) compared to other soils (0.04 m/day), allowing for more rapid rainfall recharge (Smolinski et al. 2011).

Tickell et al. (2007) also measured CFCs in groundwater bores located 10 to 20 kilometres east of the Weaber Plain on similar soils. They found significant concentrations in only two groundwater bores. They used these results to suggest that there has been no recent recharge to groundwater. However, some of the bores in question (for example RN029519) show seasonal changes in water level which indicate that they do receive recharge. Further evidence of recent groundwater recharge on the Weber Plain is presented by George et al. (2011).

5.3 Suitability of Weaber Plain groundwater for irrigation

Under USDA (1954) irrigation guidelines, most of the groundwater on the Weaber Plain is unsuitable for direct irrigation due to its high salinity. Only bores 10WP31 and 10WP47 were suitable for direct irrigation, though they had medium salinity (C2). Under the guidelines, medium-salinity water can be used to irrigate plants with a moderate salt tolerance, without special practices for salinity control, if a moderate amount of leaching occurs (Figure 11 and Figure 13).

Due to the high salinity of the groundwater, it needs to be diluted with lower salinity water such as that supplied to the Ord River Irrigation Area via the M1 channel. The groundwater from the Weaber Ord River palaeochannel on average becomes suitable for irrigation when diluted by half with water from the supply channel. The groundwater under the Aquitaine soils has the highest salinities on the Weaber Plain and would need to be diluted by as much as 100 times with supply-channel water before it became suitable for irrigation.

Groundwater modelling by KBR (2011) indicated that under the expected case, 4.4 GL of groundwater would need to be pumped into the main supply channel over 200 days. The resultant modelled water quality of the mixed water supplies ranged from 167 to 178 mg/L TDS depending on the flow in the supply channel. Likewise, under the worst-case scenario, where 6.15 GL of groundwater was pumped into the supply channel over 200 days, the resultant modelled quality of the mixed waters was between 179 and 193 mg/L TDS.

Under these modelled conditions, the mixed groundwater and supply channel water is suitable for irrigation according to the USDA (1954) guidelines.

5.4 Future water-quality monitoring

An ongoing water-quality monitoring program has been developed for the life of the development. Details of the recommended program, outlined below, are reflected in the groundwater and discharge management plans (Strategen 2012a, b).

A network of 58 groundwater monitoring bores at 44 sites is recommended. These bores will be monitored by the Environmental Management Entity to be established under the Ministerial Approvals process stipulated by the *Environmental Protection and Biodiversity Conservation Act 1999* (Commonwealth of Australia).

Recommendations for bore sites are based on the following criteria:

- use in risk assessment: to ensure watertable and salinity risk areas defined in the soil mapping (Smolinski et al. 2011), the groundwater modelling (KBR 2011) and Geoscience Australia salinity risk assessment (Lawrie et al. 2010) are covered
- data continuity and quality for future monitoring and modelling: existing bores were assessed and if suitable were retained, replacement bores were re-drilled as close as feasible, at a location safe from the impact of construction and clearing if required
- proximity to potential impacts on areas of Matters of National Environmental Significance (NES) (e.g. buffers, finch habitat, Keep River)
- distribution for use in enacting groundwater-management triggers and measuring the subsequent response
- site location-longevity: selected bores had to be in areas where they would not be destroyed or disturbed by clearing and would remain useful given potential longer term development in the area (e.g. mining)
- aquifer units: selected to enable the detection of impacts, including vertical variability, on the major aquifers
- bore construction: ensuring adequate records to clarify location geology, aquifer screened, regolith material and headwork/bore integrity,
- redundancy: ensuring that sufficient bores exist in key areas in case there emerges a requirement for more precise (scale) information and as a tactic to manage damage to important bores.

The network includes bores defined as high intensity, low intensity, high intensity reference and low intensity reference (Table 10, Figure 22). The high-intensity bores are distributed by aquifer type across the development area, though the majority are located in the main groundwater flow paths (e.g. palaeochannel), as these will be the focus of future groundwater management. Additional high-intensity bores (outside the Weaber development, called reference bores) will be used to assess the relative impacts of clearing and irrigation. Groundwater levels at high-intensity bores will be monitored using data loggers (Figure 22). The high-intensity bores will also be used to provide representative samples of groundwater composition for their locations and any major changes in groundwater chemistry will be first detected in these bores.

The high-intensity bores will be augmented by a well-distributed network of others that will be monitored less frequently and known as low-intensity bores. Some low-intensity bores will be nested with high-intensity bores to enable vertical hydraulic gradients and water-quality differences to be assessed. In addition, each farm will be required to have a groundwater monitoring bore.

The high-intensity bores should be monitored seasonally to collect baseline data before the commencement of irrigation and then used for future ongoing monitoring. To ensure sufficient data is collected for comparison to the ANZECC/ARMCANZ (2000) water quality guidelines, it is recommended that parameters outlined in Appendix H be analysed.

Once the baseline data is collected, the comprehensive analysis should be reviewed. Based on the initial analysis in this report, and assuming there are no significant deviations in baseline chemistry, ongoing sampling could be reduced in frequency to once every three years, with seasonal monitoring remaining for field parameters and key analytes as outlined below. Any major changes in the composition of the groundwater will be detected by changes in EC, pH or ORP. A shift in these parameters exceeding a trigger value should result in a return to comprehensive chemical analysis. A recommended trigger value would be a 20 per cent deviation from the median baseline values for ORP and EC. For pH, a trigger value of 50 per cent variation in hydrogen ion concentrations is recommended. On exceedence of the trigger values, the comprehensive analysis should resume until the variation has been explained or managed.

Sampling at the high-intensity bores should also be used as means of regional assessment for pesticides. Atrazine is suggested as the key analytical element for regular testing. This is based on the fact that atrazine is the only pesticide detected in groundwater within the existing irrigation areas by this study or by Smith et al. (2007). Atrazine is also highly mobile and is therefore an ideal indicator species. It should be tested for on a seasonal basis and, if it is detected in high-intensity bores, the monitoring should be escalated to include low-intensity bores. Other pesticides (see Smith et al. 2007) can then be tested for on the basis of their use within the irrigation area.

Comprehensive analyses for nutrient species, as outlined in Appendix H, should be performed seasonally to establish baseline conditions, and then repeated every three years. In the intervening periods, analyses for total nitrogen and total phosphorus should be performed on a seasonal basis. Any major increases in nutrients in groundwater will be detected through the analysis of total values. If there is a significant increase in totals (greater than 20 per cent) then comprehensive nutrient analysis should be undertaken.

The low-intensity bores should have comprehensive analyses undertaken during the baseline period to gain a broad picture of groundwater quality. These should then be analysed over two years on a seasonal basis for the field parameters (water levels, EC, pH, ORP), nutrients (total nitrogen, total phosphorus) and pesticides (atrazine). After the baseline assessment, it is recommended that the bores be monitored seasonally for field parameters and annually for the above nutrients and pesticides. Any deviation from baseline conditions or exceedence of trigger values will then require comprehensive analysis as per Appendix H.

The farms bores should be monitored annually at the end of each dry season for water levels, EC and pH.

Table 10 **Recommended network of groundwater-monitoring bores**

Bore	Site ID	Comment
High intensity (logger)		
10WP33	10WP33	West palaeochannel
10WP37	10WP37	West palaeochannel
10WP39	10WP39	Aquitaine, low salinity, permeable aquifer
11CS10RD	11CS10R	Re-drilled to enable continuity with records from 1960s
11CS10RS	11CS10R	Re-drilled to enable continuity with records from 1960s, shallow bore to detect recharge response
11WP11RD	11WP11R	Re-drilled 1996 bore on palaeochannel in low risk, deep watertable area
11WP11RS	11WP11R	As above, shallow bore to detect recharge response
11WP15R	11WP15R	Re-drilled 1996 bore on palaeochannel in low risk, deep watertable area
11WP43D	10WP43	Aquitaine, deep watertable, saline groundwater, longer term risk
11WP51D	11WP51	Aquitaine, Buffer, deep watertable, long-term risk
11WP51S	11WP51	As above, loggers in upper and lower aquifer to assess recharge hydraulics
11WP52D	11WP52	Eastern palaeochannel, deep watertable, low salinity risk
11WP56D	11WP56	Bore adjacent to Keep River to detect changes due to development and climate
11WP57	11WP57	Palaeochannel down-gradient from development
11WP9RS	11WP9R	Re-drilled 1996 bore on palaeochannel in low risk, deep watertable area
CG4	CG4	Palaeochannel, likely to be the first bore to respond to works and clearing
LIMESTONE	LIMESTONE	Existing shallow watertable
RN029660	RN029660	Midway between development and Keep River to measure impact
WP13	WP13	Aquitaine, medium risk, assess impact on buffer
WP5	WP5	Long term, high risk, west of area of delayed clearing
Low intensity (manual)		
10WP31	10WP31	Mid palaeochannel, in Buffer, area defined medium-term risk
10WP32	10WP32	As above
10WP32PB	10WP32	As above, 150 mm bore drilled to test aquifer
10WP35N	10WP35	West palaeochannel, short-term risk from shallow watertable, planned first pumping site
10WP35PB	10WP35	As above, this bore is a pumping bore tested at 25 L/s, < 1000 mg/L
10WP35S	10WP35	West palaeochannel, short-term risk from shallow watertable, planned first pumping site
10WP36N	10WP36	As above
10WP36PB	10WP36	As above, this bore is a pumping bore tested at 25 L/s, < 1000 mg/L
10WP36S	10WP36	West palaeochannel, short-term risk from shallow watertable, planned first pumping site

(*continued*)

Table 10 **Recommended network of groundwater-monitoring bores** (*continued*)

Bore	Site ID	Comment
10WP40	10WP40	Aquitaine, Buffer, shallow basement, shallow watertable
10WP41	10WP41	As above
10WP42	10WP42	Aquitaine, Buffer, deep watertable, long-term risk
10WP43S	10WP43	As above, drilled to basement at 13 m to determine recharge processes
10WP44	10WP44	Aquitaine, deep watertable, saline groundwater, longer term risk
10WP46	10WP46	Aquitaine, Buffer, deep existing watertable, long-term risk
10WP47	10WP47	As above
11WP16R	11WP16R	Outer margin of sedimentary aquifer, shallow limestone, record clearing impact
11WP4R	11WP4R	Medium-risk, high-watertable area
11WP50	11WP50	Aquitaine, medium term, high risk, edge of deferred lease farm
11WP52S	11WP52	Eastern palaeochannel, deep watertable, low salinity risk, shallow bore to detect recharge response
11WP53D	11WP53	On confluence with Border Ck sediments, deep watertable, medium salinity risk
11WP53S	11WP53	As above, shallow bore to detect recharge response
11WP54D	11WP54	Buffer, deep watertable, medium salinity risk
11WP54S	11WP54	As above, shallow bore to detect recharge response
11WP55	11WP55	Down-gradient of development on shallow (20 m) carbonate basement
11WP56S	11WP56	Adjacent to Keep River, shallow bore to detect recharge response
11WP9RPB	11WP9R	Drilled to undertake aquifer test on eastern palaeochannel, 150 mm casing
RN029659	RN029659	Midway between development and Keep River to measure impact
W2R	W2R	Area of shallow watertable, forecast to maintain high levels, low risk, records from 1960s
WP19	WP19	Drilled 1996, downstream of development on arm of palaeochannel
Reference (logger)		
CG1	CG1	Stage 1 farmland, comparison to bores in development area
CG2	CG2	As above, changes expected due to reversal of aquifer flow from development
KC13	KC13	Edge of basement complex as a control to Weaber bores
KC3PB	KC3	Palaeochannel, control to Weaber bores
Reference (low intensity)		
KC14	KC14	Keep catchment as control on impact of development, in area of high AEM
KC3	KC3	As KC3PB, nested bores to compare multi-aquifer responses
KC3A	KC3	As above
KCF1	KCF1	Keep catchment as control on impact of development, in area of low AEM

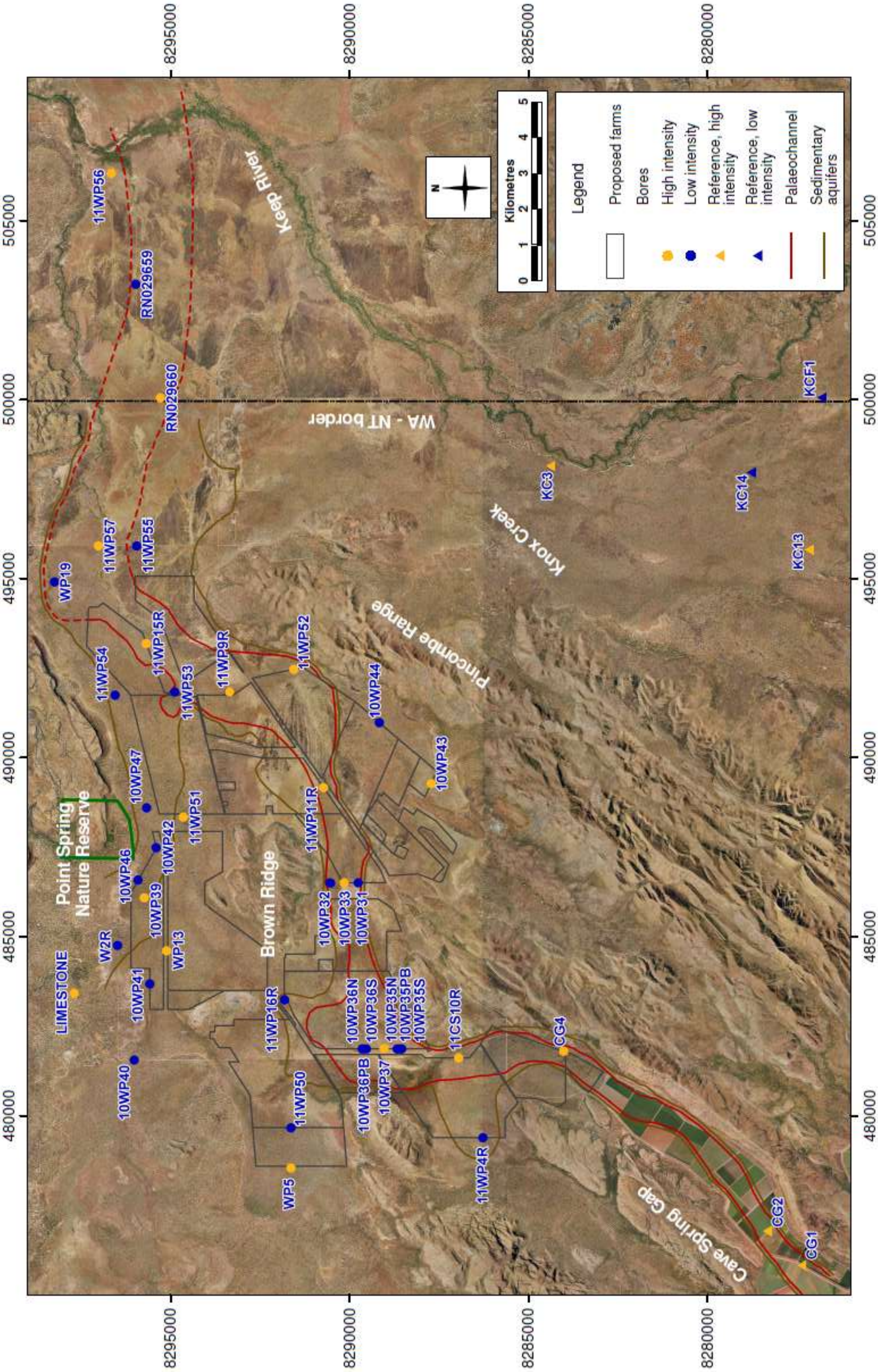

Figure 22 **Locations of recommended Weaber Plain monitoring and reference bores (Map Grid of Australia, Zone 52). Some sites have two or three bores, see Table 10 for details.**

6. Conclusions

The groundwater salinity trends determined for bores on the Ivanhoe Plain, developed for irrigation in 1964, indicate that irrigation has not led to a significant change in groundwater salinity levels.

Groundwater salinities were significantly lower under Cununurra soils than under Aquitaine soils when all data from both the Ivanhoe and Weaber plains was considered. By contrast, there was no statistical difference between groundwater salinities observed in the palaeochannel as compared to elsewhere under the Ivanhoe Plain.

Groundwater levels have also increased under the Weaber Plain since the 1990s. However, groundwater salinities have increased at only 40 per cent of the bores, and most of them are in the area immediately north of Cave Spring Gap, where groundwater levels have increased due to irrigation development on the Ivanhoe Plain.

The Ivanhoe Plain groundwater salinity trends between 1984 and 2009 indicate that the development of the Weaber Plain for irrigated agriculture is unlikely to result in any significant change in groundwater salinity within the Ord palaeochannel. Furthermore, where groundwater salinities in the palaeochannel are very high, as in the north-eastern portion of the Weaber Plain, they are likely to decrease due to dilution with fresh irrigation-supply water. Groundwater salinities are highest under Aquitaine soils on the Weaber Plain and, as proposed farm lots on Aquitaine soils will be leasehold, with some subject to deferred clearing, the potential for increases in groundwater salinity following development will be further limited.

An analysis was performed to assess the option of pumping groundwater from the Ord River palaeochannel and discharging it to the irrigation supply channel should watertable control be required following development. The analysis showed that most of the groundwater was unsuitable for direct irrigation; however, if groundwater were to be mixed with irrigation water provided from the Ord River Irrigation Scheme at calculated ratios, the mixed waters would be suitable for irrigation under USDA (1954) guidelines. The analysis indicated that the mean TDS of groundwater in the palaeochannel would be about 1162 mg/L (Table 9), which agrees well with the 1200 mg/L predicted by the solute transport model produced by KBR (2011). At the modelled pumping rates of 540 to 769 ML/day, groundwater from the palaeochannel mixed with the supply channel water at average and peak flow rates would result in a salinity range of 170 to 200 mg/L TDS.

These results demonstrate that blending pumped groundwater into the main supply channel will provide a viable option for managing salinity risks on the Weaber Plain area when irrigation commences.

A network of 58 groundwater-monitoring bores at 44 sites is recommended as the basis of an ongoing water-quality monitoring program for the life of the development. The recommended network consists of bores to be monitored at a high intensity with dataloggers, low-intensity bores and eight reference bores. This report includes a list of required analytes for comparison to the ANZECC/ARMCANZ (2000) water-quality guidelines and a strategy to develop a baseline water-quality data set to ensure that the environmental impacts of the development are within required limits. Trigger mechanisms and guidelines for the escalation of groundwater quality monitoring are also recommended should any analyte exceed baseline levels by a set amount.

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Appendix A: Ivanhoe Plain water-quality plots

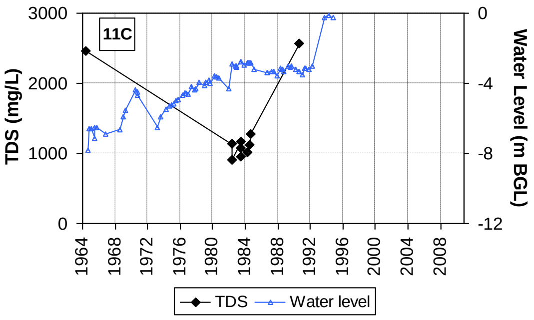


Figure A.1 **Groundwater salinity and level data for bore 11C showing no discernible trend**

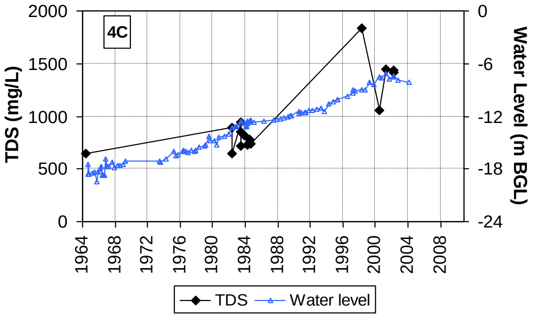


Figure A.2 **Groundwater salinity and level data for bore 4C showing increasing trend**

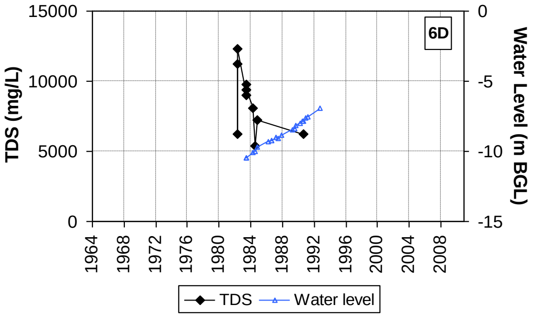


Figure A.3 **Groundwater salinity and level data for bore 6D showing no discernable trend**

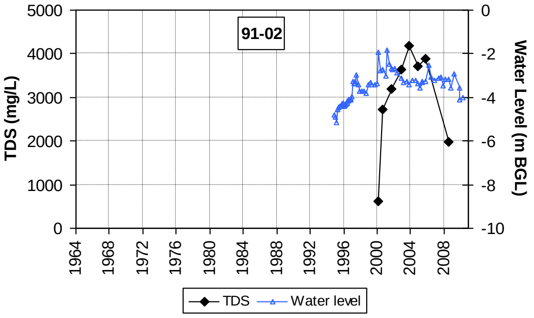


Figure A.4 **Groundwater salinity and level data for bore 91-02 showing spike response**

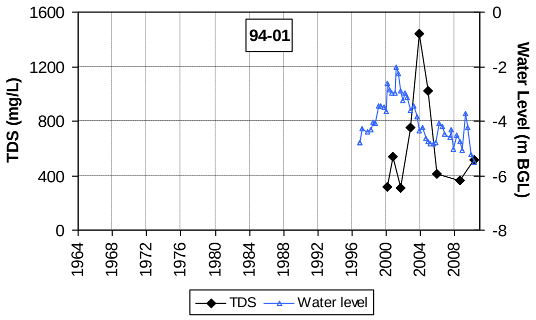


Figure A.5 **Groundwater salinity and level data for bore 94-01 showing spike response**

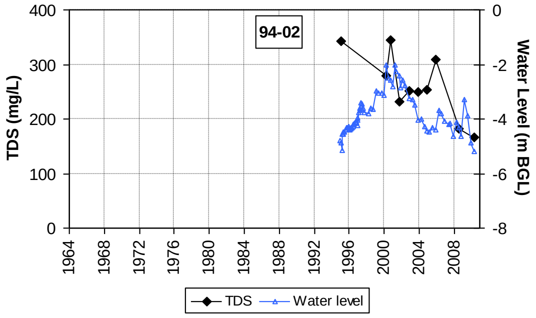


Figure A.6 **Groundwater salinity and level data for bore 94-02 showing decreasing trend**

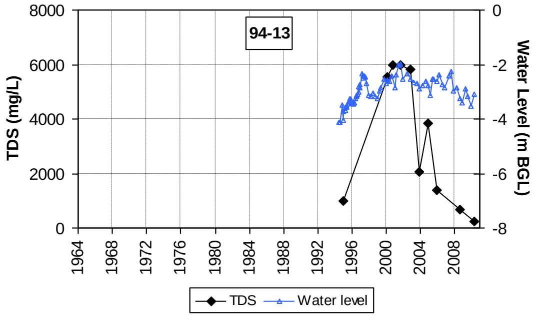


Figure A.7 **Groundwater salinity and level data for bore 94-13 showing spike response**

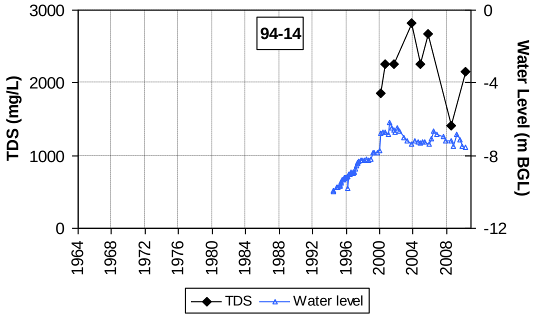


Figure A.8 **Groundwater salinity and level data for bore 94-14 showing no trend**

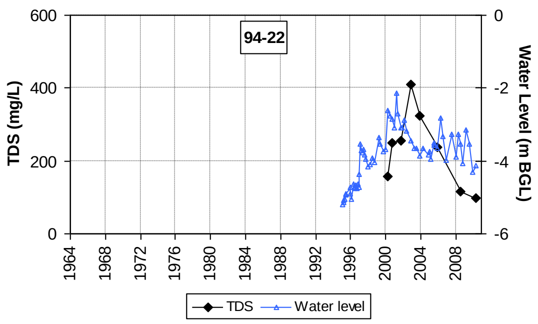


Figure A.9 **Groundwater salinity and level data for bore 94-22 showing spike response**

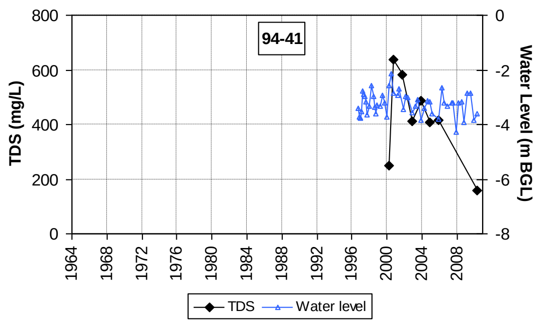


Figure A.13 **Groundwater salinity and level data for bore 94-41 showing spike response**

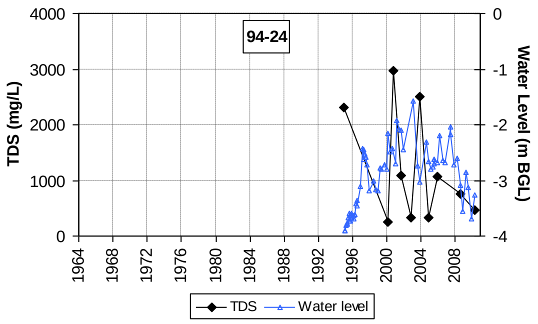


Figure A.10 **Groundwater salinity and level data for bore 94-24 showing no discernable trend**

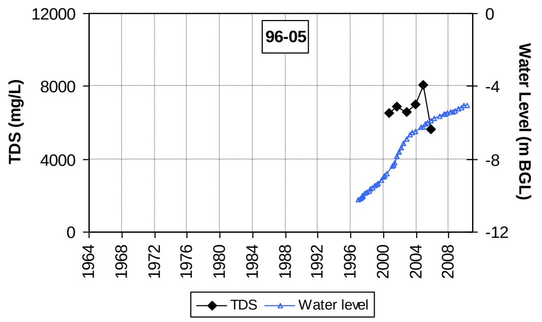


Figure A.14 **Groundwater salinity and level data for bore 96-05 showing no trend**

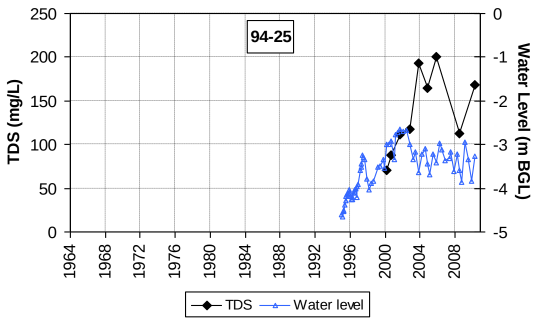


Figure A.11 **Groundwater salinity and level data for bore 94-25 showing increasing trend**

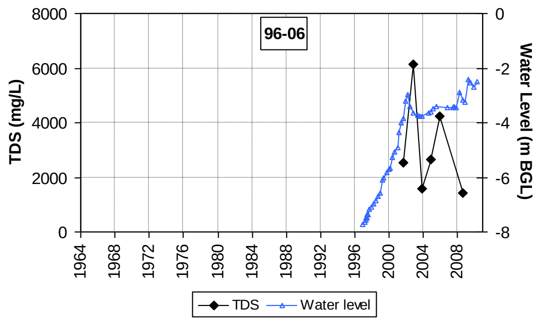


Figure A.15 **Groundwater salinity and level data for bore 96-06 showing no discernable trend**

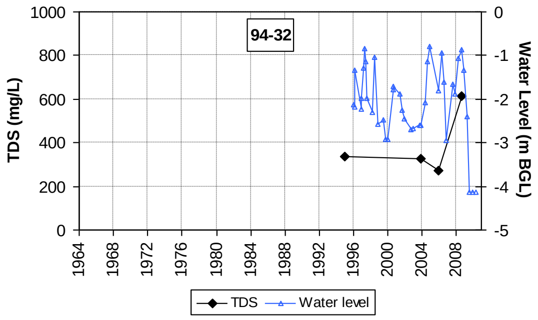


Figure A.12 **Groundwater salinity and level data for bore 94-32 showing no trend**

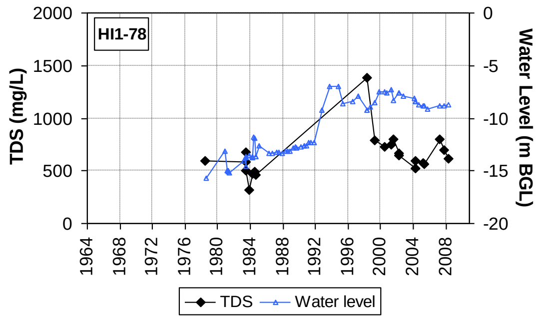


Figure A.16 **Groundwater salinity and level data for bore HI1-78 showing no trend**

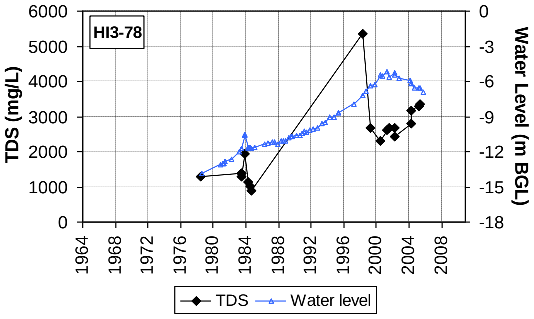


Figure A.17 **Groundwater salinity and level data for bore HI3-78 showing increasing trend**

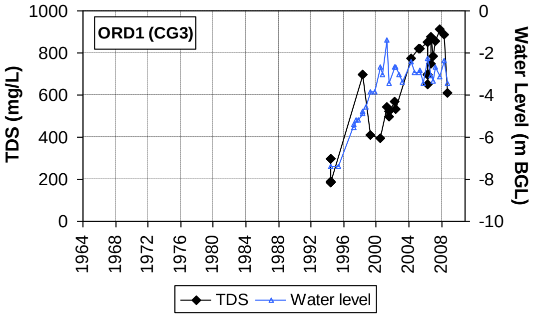


Figure A.18 **Groundwater salinity and level data for bore ORD1 (CG3) showing increasing trend**

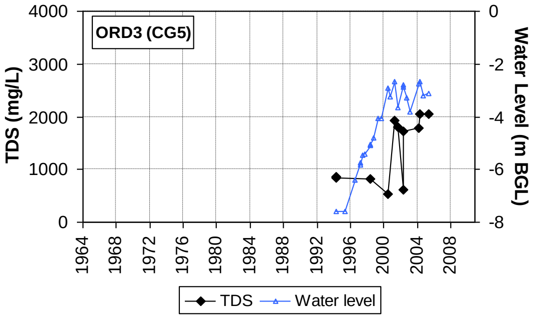


Figure A.19 **Groundwater salinity and level data for bore ORD3 (CG5) showing increasing trend**

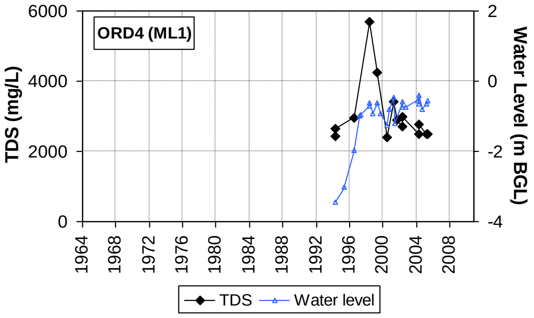


Figure A.20 **Groundwater salinity and level data for bore ORD4 (ML1) showing spike response**

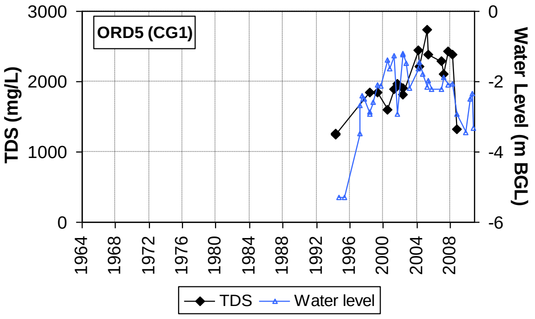


Figure A.21 **Groundwater salinity and level data for bore ORD5 (CG1) showing spike response**

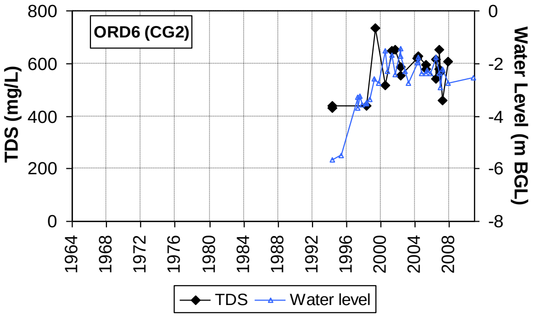


Figure A.22 **Groundwater salinity and level data for bore ORD6 (CG2) showing no trend**

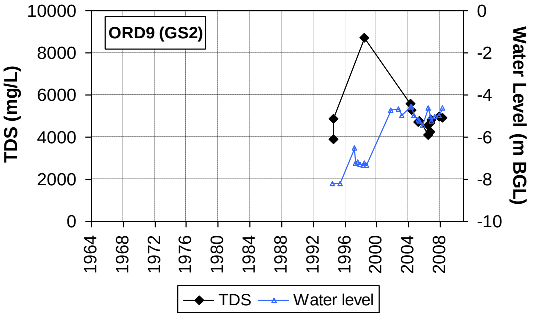


Figure A.23 **Groundwater salinity and level data for bore ORD9 (GS2) showing spike response**

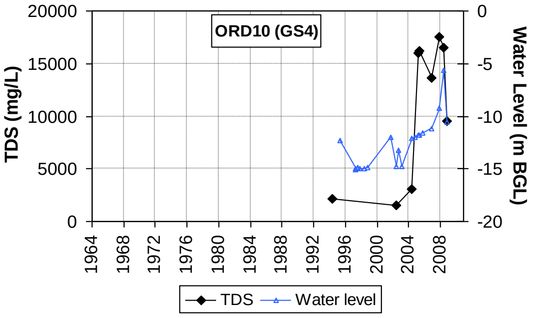


Figure A.24 **Groundwater salinity and level data for bore ORD10 (GS4) showing increasing trend**

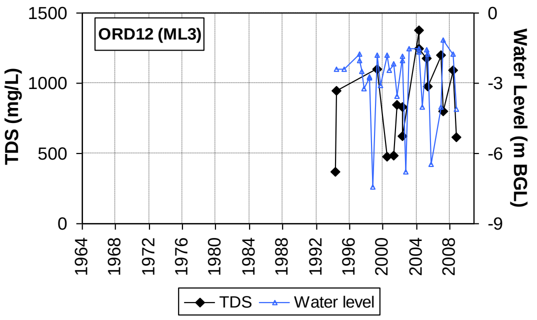


Figure A.25 **Groundwater salinity and level data for bore ORD12 (ML3) showing no trend**

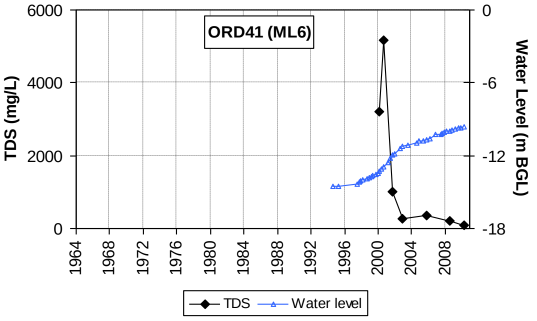


Figure A.26 **Groundwater salinity and level data for bore ORD41 (ML6) showing spike response**

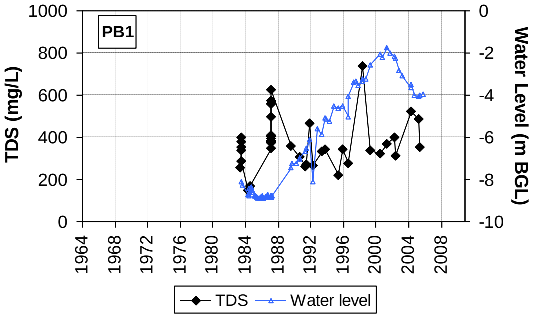


Figure A.27 **Groundwater salinity and level data for bore PB1 showing no trend**

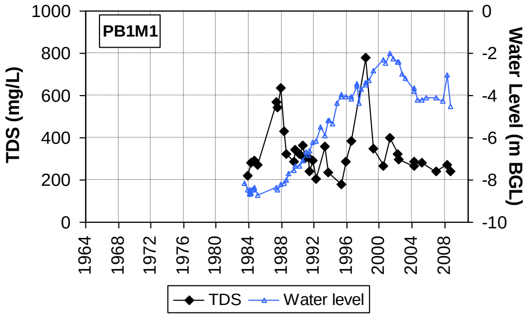


Figure A.28 **Groundwater salinity and level data for bore PB1M1 showing no trend**

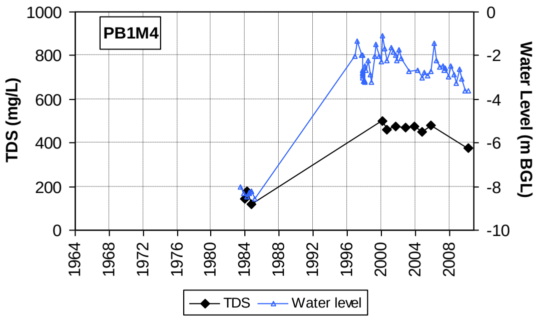


Figure A.29 **Groundwater salinity and level data for bore PB1M4 showing increasing trend**

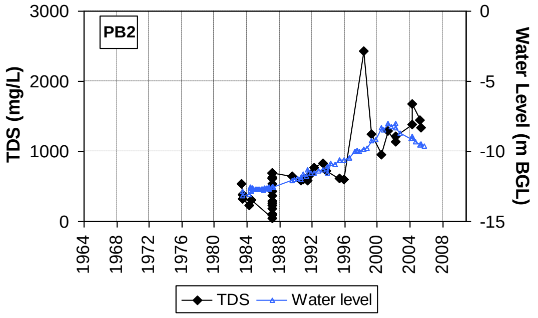


Figure A.30 **Groundwater salinity and level data for bore PB2 showing increasing trend**

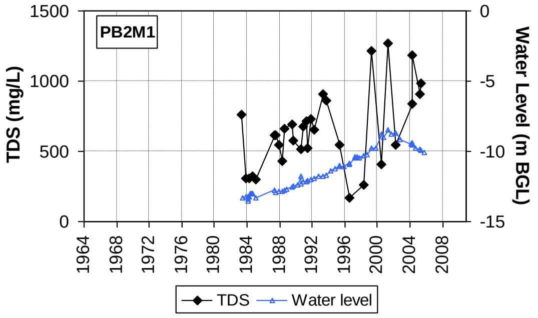


Figure A.31 **Groundwater salinity and level data for bore PB2M1 showing increased variability**

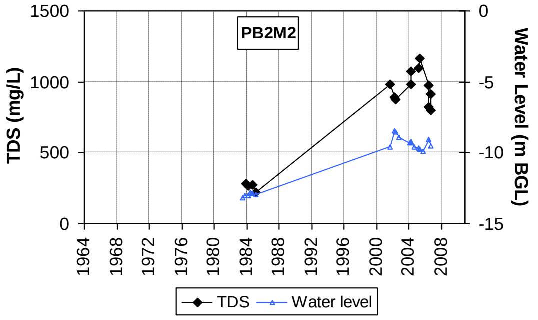
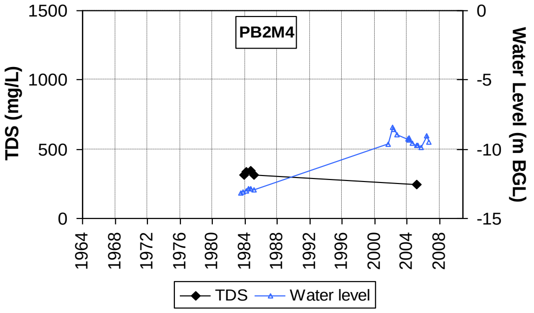


Figure A.32 **Groundwater salinity and level data for bore PB2M2 showing increasing trend**



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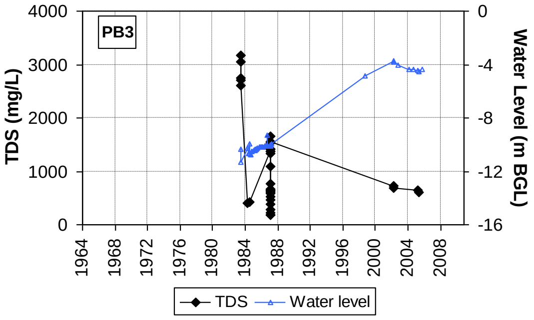
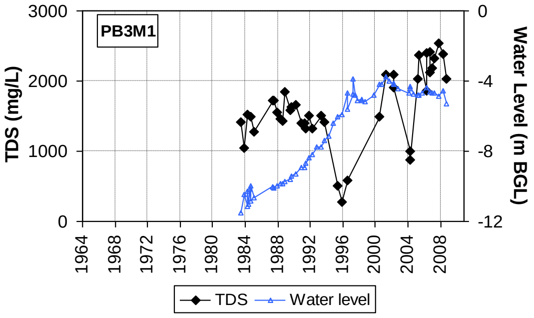


Figure A.34 **Groundwater salinity and level data for bore PB3 showing no discernable trend**



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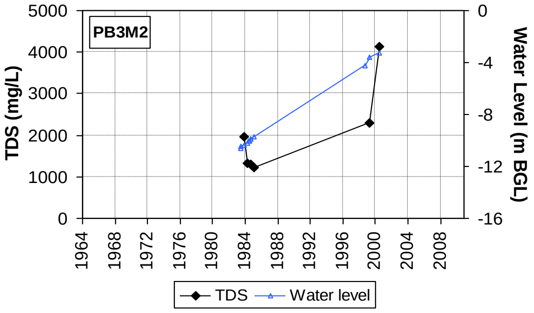
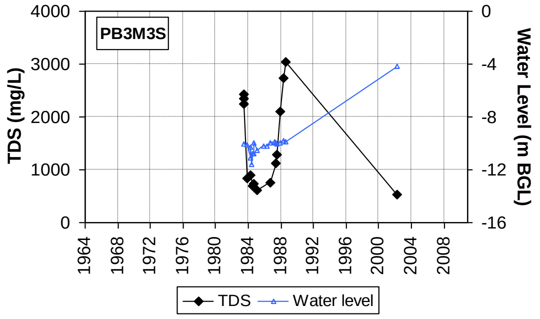


Figure A.36 **Groundwater salinity and level data for bore PB3M2 showing increasing trend**



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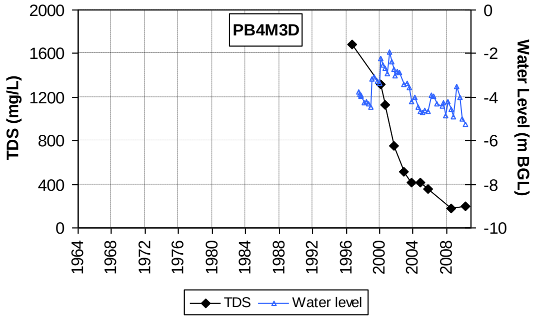

Figure A.38 **Groundwater salinity and level data for bore PB4M3D showing decreasing trend**

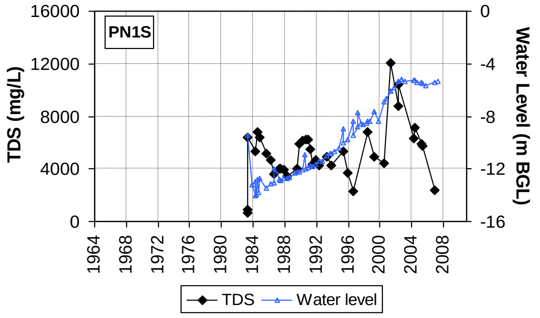

Figure A.39 **Groundwater salinity and level data for bore PN1S showing spike response**

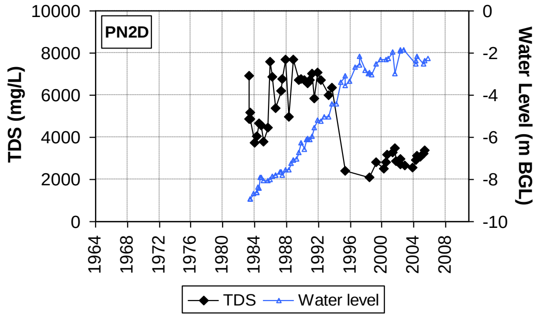

Figure A.40 **Groundwater salinity and level data for bore PN2D showing decreasing trend**

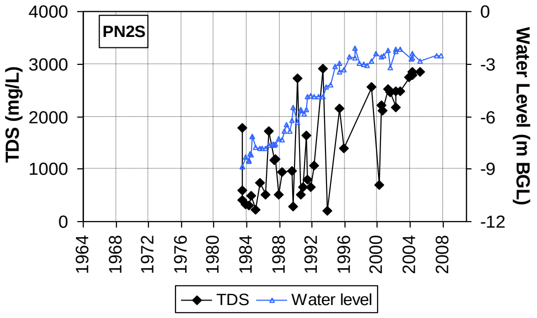

Figure A.41 **Groundwater salinity and level data for bore PN2S showing increasing trend**

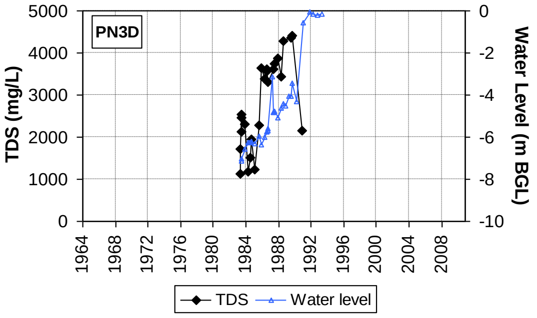

Figure A.42 **Groundwater salinity and level data for bore PN3D showing spike response**

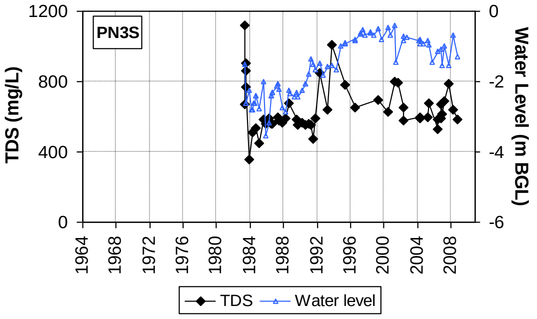

Figure A.43 **Groundwater salinity and level data for bore PN3S showing no trend**

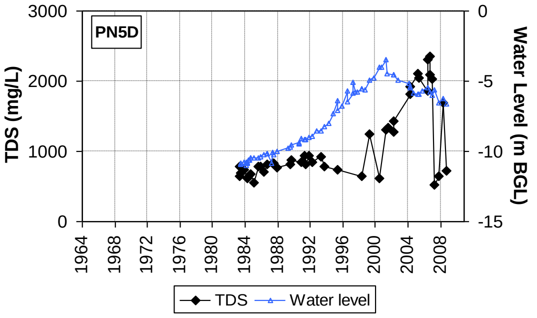

Figure A.44 **Groundwater salinity and level data for bore PN5D showing spike response**

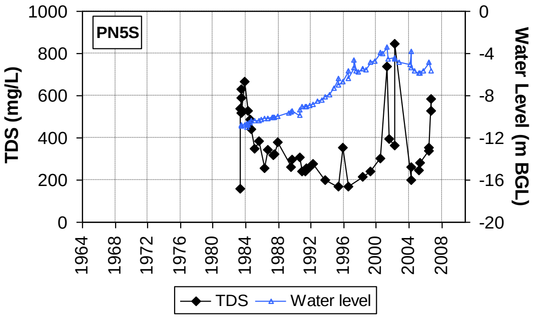

Figure A.45 **Groundwater salinity and level data for bore PN5S showing increased variability**

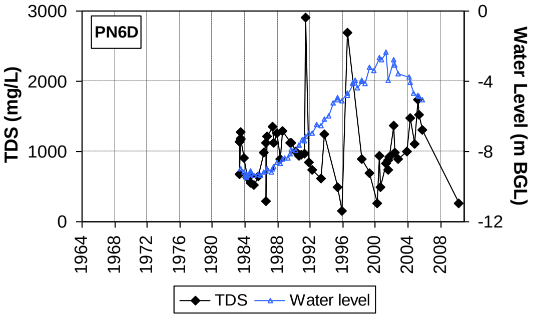

Figure A.46 **Groundwater salinity and level data for bore PN6D showing no trend**

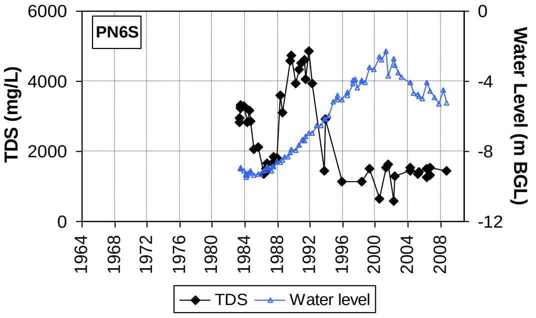

Figure A.47 **Groundwater salinity and level data for bore PN6S showing decreasing trend**

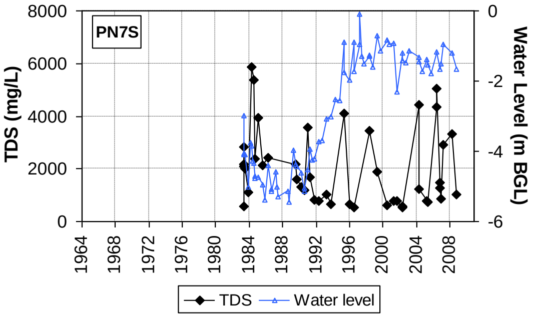

Figure A.48 **Groundwater salinity and level data for bore PN7S showing no trend**

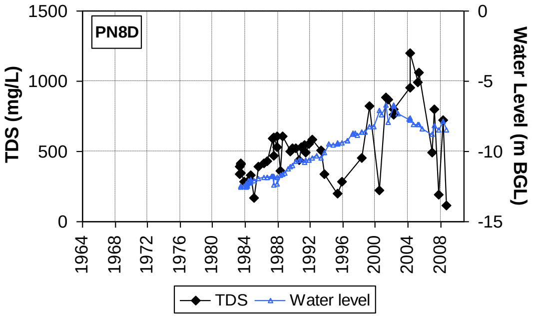

Figure A.49 **Groundwater salinity and level data for bore PN8D showing increased variability**

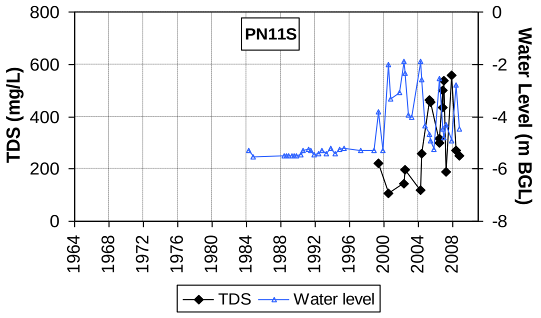

Figure A.53 **Groundwater salinity and level data for bore PN11S showing increased variability**

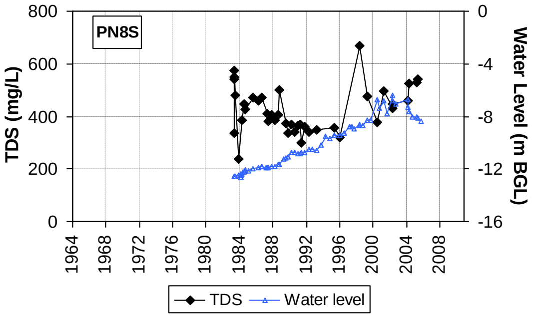

Figure A.50 **Groundwater salinity and level data for bore PN8S showing no trend**

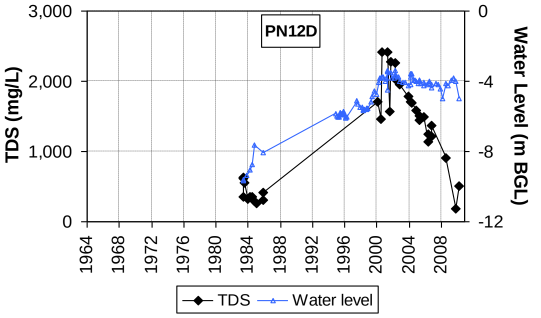

Figure A.54 **Groundwater salinity and level data for bore PN12D showing spike response**

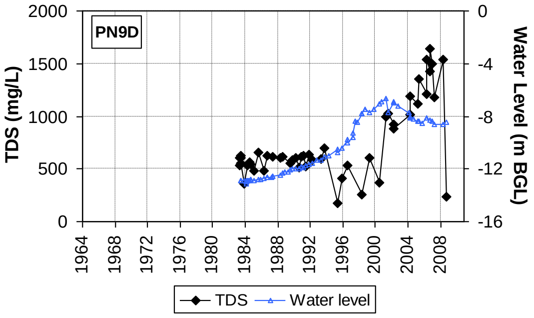

Figure A.51 **Groundwater salinity and level data for bore PN9D showing increased variability**

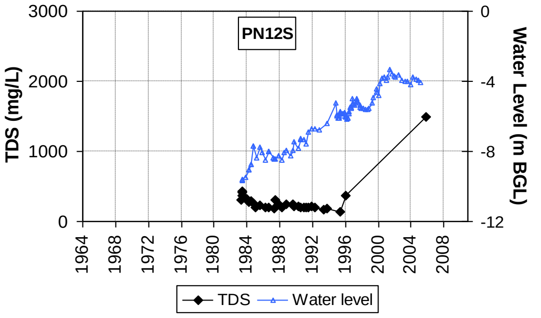

Figure A.55 **Groundwater salinity and level data for bore PN12S showing increasing trend**

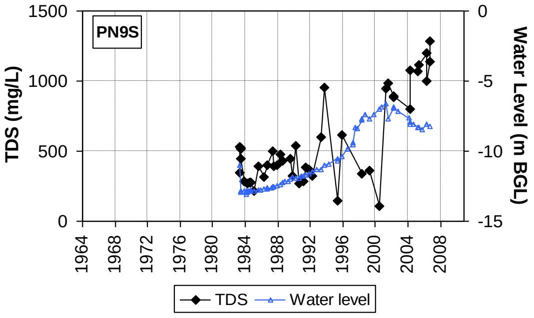

Figure A.52 **Groundwater salinity and level data for bore PN9S showing increasing trend**

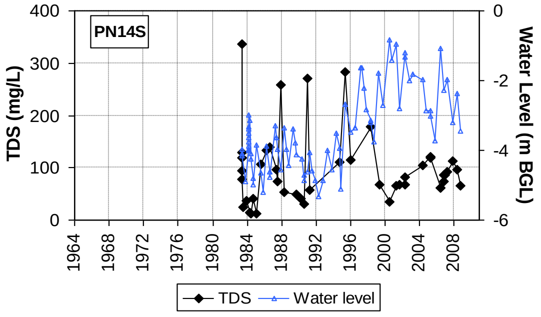

Figure A.56 **Groundwater salinity and level data for bore PN14S showing no trend**

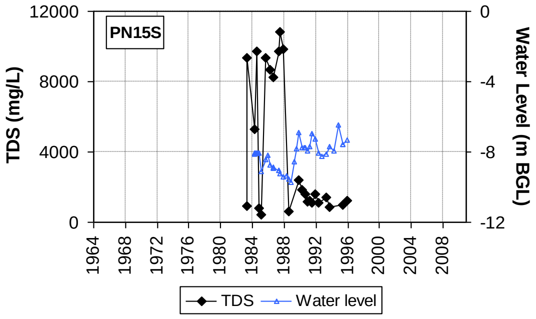

Figure A.57 **Groundwater salinity and level data for bore PN15S showing decreasing trend**

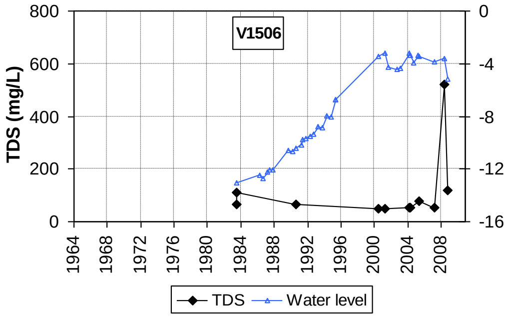

Figure A.58 **Groundwater salinity and level data for bore V1506 showing no trend**

Appendix B: Weaber Plain water quality plots

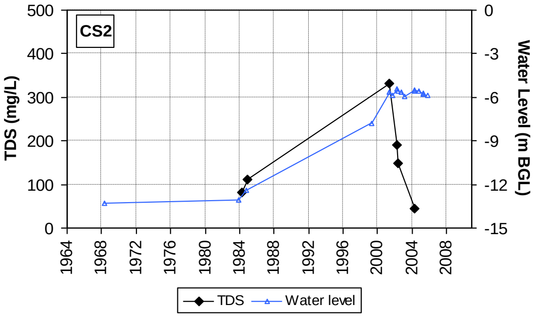

Figure B.1 **Groundwater salinity and level data for bore CS2 showing spike response**

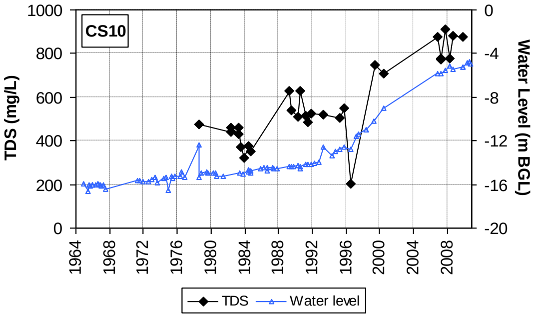

Figure B.2 **Groundwater salinity and level data for bore CS10 showing increasing trend**

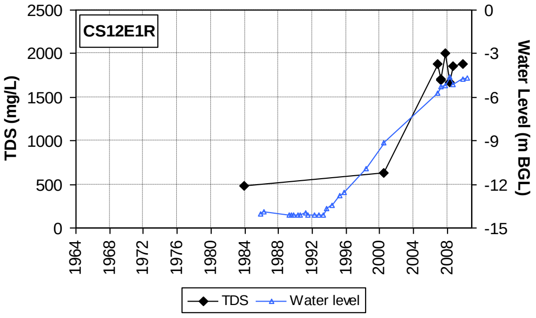

Figure B.3 Groundwater salinity and level data for bore CS12E1R showing increasing trend

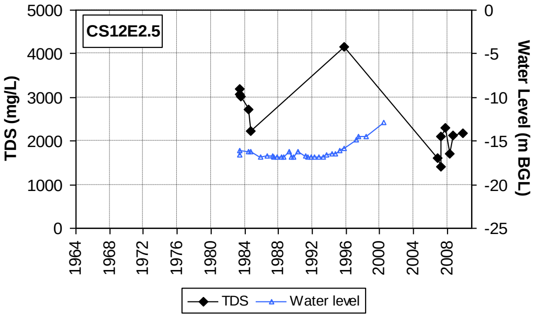

Figure B.4 **Groundwater salinity and level data for bore CS12E2.5 showing decreasing trend**

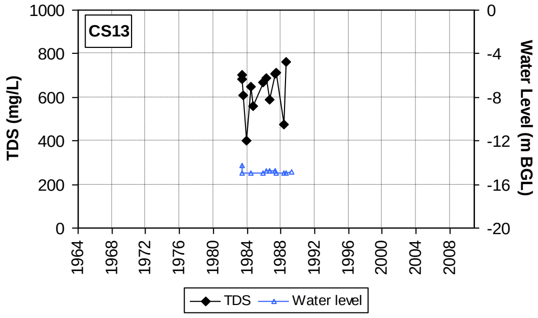

Figure B.5 **Groundwater salinity and level data for bore CS13 showing no trend**

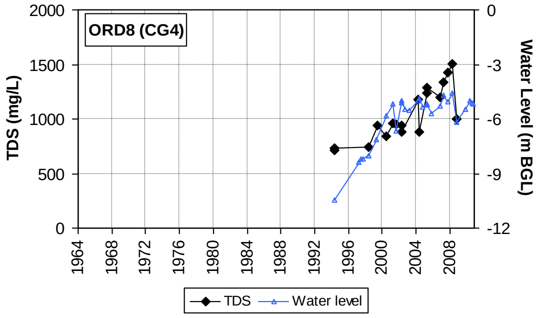

Figure B.6 Groundwater salinity and level data for bore ORD8 (CG4) showing increasing trend

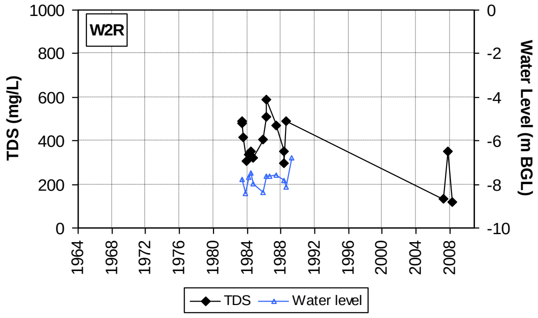

Figure B.7 **Groundwater salinity and level data for bore W2R showing decreasing trend**

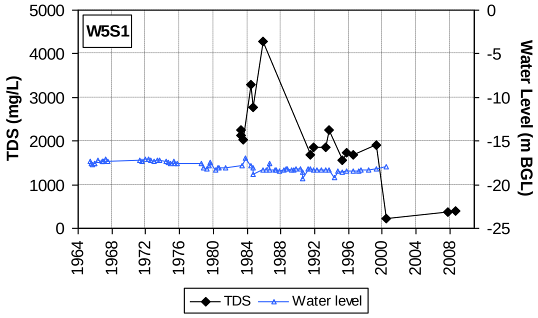

Figure B.8 **Groundwater salinity and level data for bore W5S1 showing decreasing trend**

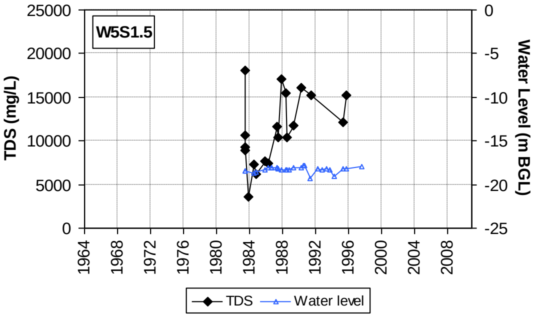

Figure B.9 **Groundwater salinity and level data for bore W5S1.5 showing no trend**

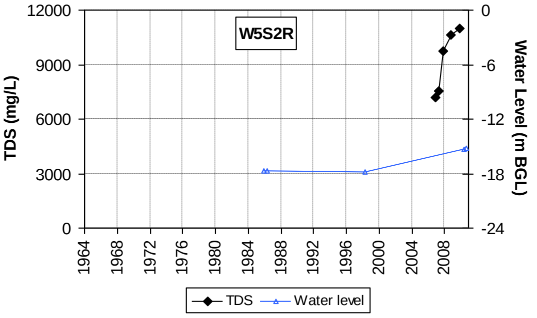

Figure B.10 **Groundwater salinity and level data for bore W5S2R showing increasing trend**

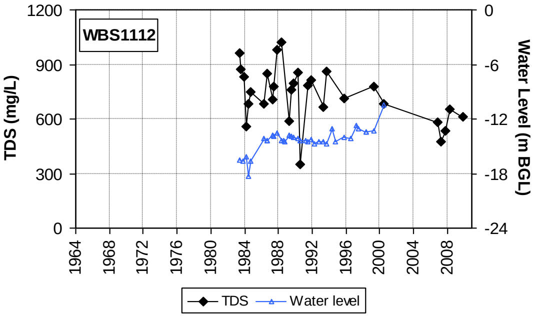

Figure B.11 **Groundwater salinity and level data for bore WBS1112 showing no trend**

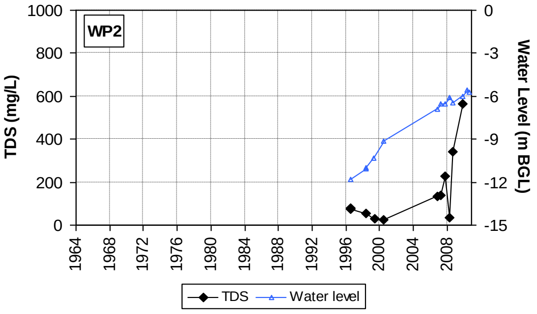

Figure B.12 **Groundwater salinity and level data for bore WP2 showing increasing trend**

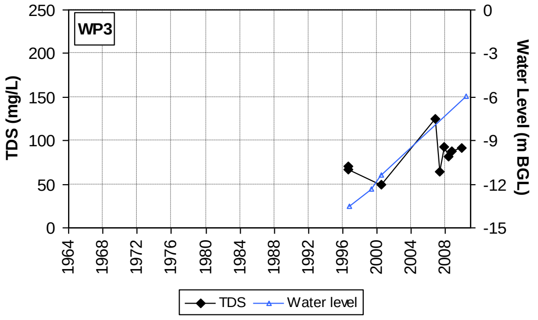

Figure B.13 **Groundwater salinity and level data for bore WP3 showing increasing trend**

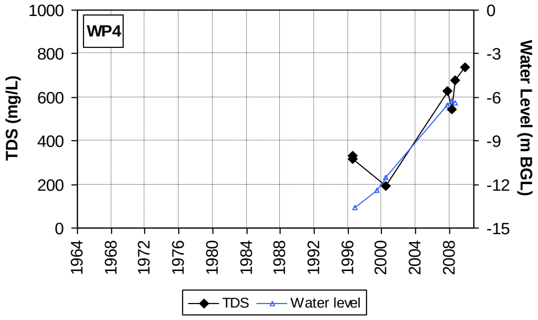

Figure B.14 **Groundwater salinity and level data for bore WP4 showing increasing trend**

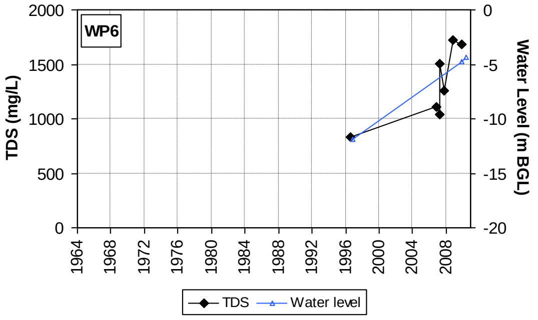

Figure B.15 **Groundwater salinity and level data for bore WP6 showing increasing trend**

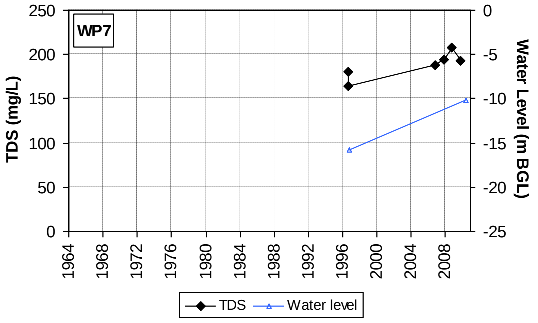

Figure B.16 **Groundwater salinity and level data for bore WP7 showing no trend**

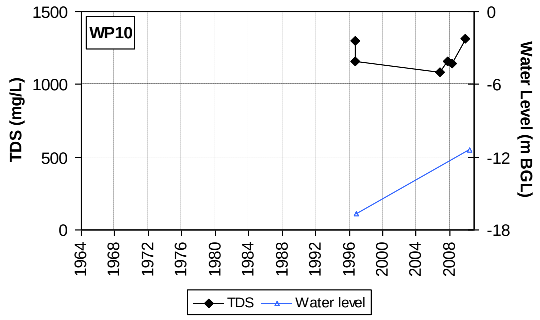

Figure B.17 **Groundwater salinity and level data for bore WP10 showing no trend**

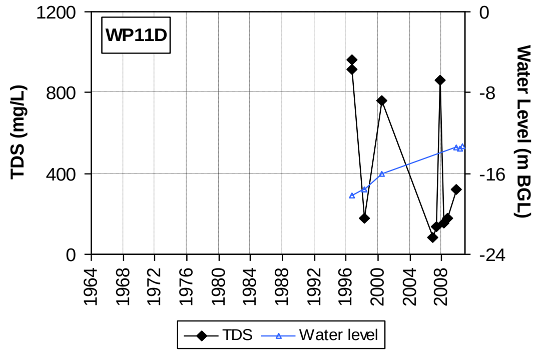

Figure B.18 **Groundwater salinity and level data for bore WP11D showing no trend**

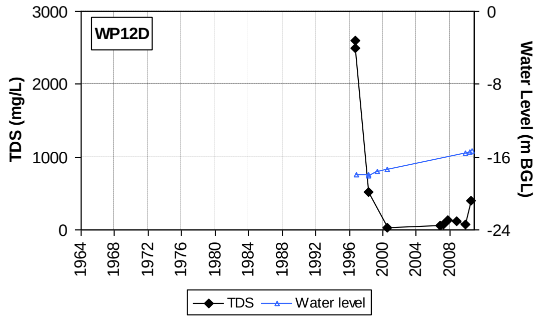

Figure B.19 **Groundwater salinity data for bore WP12D showing decreasing trend**

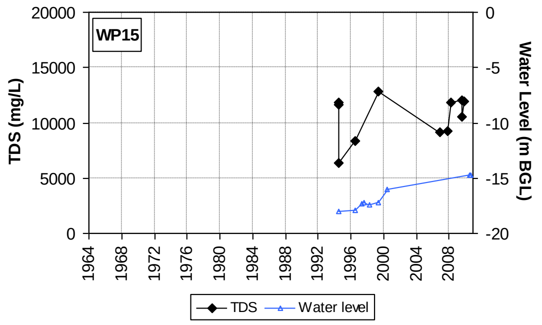

Figure B.20 **Groundwater salinity and level data for bore WP15 showing no trend**

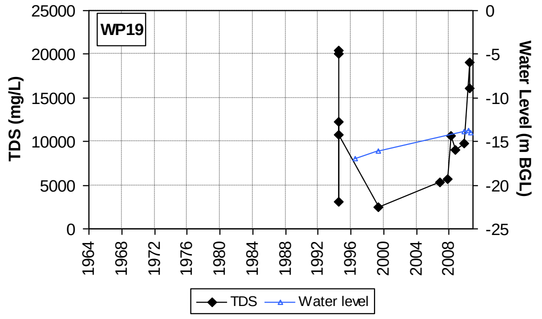

Figure B.21 **Groundwater salinity and level data for bore WP19 showing no trend**

Appendix C: Groundwater and surface-water sites sampled

Table C.1 **Groundwater and surface-water sites sampled**

Sampling site	Easting	Northing	Group description	RWL (m BGL)	Aquifer screened	Geology screened	Water type
10WP39I	486101	8295717	Intermediate	6.17	Clay sandy gravels & calcarenite	Gravels above Milligan’s Shale	Ca-Na-HCO_3-SO_4-Cl
PB4M3D	473226	8271086	Dumas Lookout	5.55	Sandy gravel	Basalt	Na-Cl-HCO_3
D4 drain	469874	8278380	Exit drain		N/A	N/A	Na-Ca-Mg-HCO_3-Cl
D8 drain	482269	8285621	Exit drain		N/A	N/A	Na-Ca-Mg-HCO_3-Cl
Keep River	506999	8297153	Keep River		N/A	N/A	Na-Mg-Ca-Cl-HCO_3
10WP38D	486102	8294961	Northern Weaber Plain	9.48	Shale/siltstone	Milligan’s Shale	Na-Mg-Cl-SO_4
10WP40D	481575	8295996	Northern Weaber Plain	2.68	Clay/quartzite	Quartzite	Na-SO_4-Cl
10WP41D	483696	8295563	Northern Weaber Plain	3.17	Clay silt and fine sand	Quartzite	Na-Cl-SO_4
10WP42	487500	8295383	Intermediate	10.57	Sandy clays, sands & gravels	Alluvial sediments	Na-Ca-Mg-Cl-SO_4-HCO_3
10WP46	486609	8295879	Intermediate	7.94	Sandy clays & sands	Alluvial sediments	Na-Ca-Cl-SO_4-HCO_3
10WP47	488298	8295577	10WP47	13.32	Sandy clay & sands	Alluvial sediments	Ca-Na-HCO_3-Cl
ORD21 (WP15)	493199	8295790	Northern Weaber Plain	14.74	Sand and gravel above sandstone	Sandstone (Langfield Group)	Na-Cl-SO_4
ORD22 (WP19)	494916	8298221	Northern Weaber Plain	13.79	Sand & gravel to mudstone	Mudstone/shale (Milligan’s)	Na-Mg-Cl-SO_4
WP12M	489629	8294638	Northern Weaber Plain	15.66	Clayey silt	Weathered Burvill Beds above mudstone/Milligan’s Shale	Na-Mg-Cl-SO_4

(*continued*)

Table C.1 **Groundwater and surface-water sites sampled** (*continued*)

Sampling site	Easting	Northing	Group description	RWL (m BGL)	Aquifer screened	Geology screened	Water type
WP16	483251	8291605	Northern Weaber Plain	5.05	Limestone	Cecil sandstone	Ca-Na-Mg-Cl-SO_4
WP5	478568	8291625	Northern Weaber Plain	10.96	Basalt	Basalt (Antrim Plateau Volcanics)	Mg-Ca-Cl-SO_4
ORD20 (WP9)	491485	8293257	Intermediate	14.77	Calcreted clay, silt, some sand	Micaceous siltstone (Pincombe Formation)	Na-HCO_3-Cl
10WP31	486515	8289743	Palaeochannel	8.66	Sands/clay & sands/ gravels	Sands and gravel	Mg-Na-Ca-HCO_3-Cl
10WP32	486515	8290518	Palaeochannel	9.18	Sand/silt and sand/gravel	Sands and gravel	Na-Mg-HCO_3-Cl
10WP32PB	486513	8290520	Palaeochannel	5.85	Sandy clay/sands & gravels	Alluvial sediments	Na-Mg-HCO_3-Cl
10WP33	486516	8290136	Palaeochannel	8.39	Coarse sand & medium gravel	Gravels above sandstone	Na-Mg-HCO_3-Cl
10WP35N	481887	8288653	Palaeochannel	4.57	Coarse sands & sub-rounded gravels	Coarse sands and sub-rounded gravels	Na-HCO_3
10WP35PB	481889	8288568	Palaeochannel	4.58	Coarse sands& sub-rounded gravels above siltstone	Siltstone	Na-Mg-HCO_3-Cl
10WP35Sth	481890	8288527	Palaeochannel	4.5	Coarse & fine sands with some medium gravels	Sandstone	Na-Mg-HCO_3
10WP36N	481885	8289637	Palaeochannel	4.29	Coarse sand & gravels	Black shale (basement)	Na-Mg-HCO_3
10WP36PB	481886	8289596	Palaeochannel	4.31	Coarse sand & gravels	Gravels	Na-HCO_3
10WP36Sth	481888	8289517	Palaeochannel	4.23	Coarse sand & gravels	Coarse sand and gravels	Na-HCO_3
10WP37	481885	8289028	Palaeochannel	4.32	Coarse sand & gravels	Coarse sand and gravels	Na-HCO_3-Cl
WP17	490959	8291076	Palaeochannel	14.24	Clayey sand & some gravel	Basalt (Antrim Plateau Volcanics)	Na-Mg-HCO_3
Parry Lagoons	420609	8280774	Parry Lagoons		N/A	N/A	Na-Cl
Point Spring	487517	8296786	Point Spring		N/A	N/A	Na-Ca-Mg-HCO_3-SO_4-Cl
M1 supply channel	469821	8254745	Supply channel		N/A	N/A	Na-Ca-Mg-HCO_3

Appendix D: Analytical methods and detection limits

Table D.1 **Analytical methods and detection limits**

Analyte	Method code	Description	Limit of reporting	Analysis type*	Units
Al	iMET1WCICP	Aluminium	0.005	B/C	mg/L
Alkalin	iALK1WATI	Alkalinity, total expressed as $CaCO_3$ mg/L	1	B/C	mg/L
As	iMET1WCMS	Arsenic	0.001	B/C	mg/L
B	iMET1WCICP	Boron	0.02	B/C	mg/L
Ba	iMET1WCICP	Barium	0.002	B/C	mg/L
Be	iMET1WCMS	Beryllium	0.0001	B/C	mg/L
Bi	iMET1WCMS	Bismuth	0.0001	B/C	mg/L
Ca	iMET1WCICP	Calcium	0.1	B/C	mg/L
Cd	iMET1WCMS	Cadmium	0.0001	B/C	mg/L
Cl	iCO1WCDA	Chloride	1	B/C	mg/L
Co	iMET1WCICP	Cobalt	0.005	B/C	mg/L
CO_3	iALK1WATI	Carbonate	1	B/C	mg/L
Cr	iMET1WCICP	Chromium	0.001	B/C	mg/L
Cu	iMET1WCICP	Copper	0.002	B/C	mg/L
DOC	iCTO1WDCO	Dissolved organic carbon as NPOC	1	C	mg/L
ECond	iEC1WZSE	Electrical Conductivity, 25° C	0.2	B/C	mS/m
F	iF1WASE	Fluoride	0.05	C	mg/L
Fe	iMET1WCICP	Iron	0.005	B/C	mg/L
Hardness	iHTOT2WACA	Hardness, total expressed as $CaCO_3$ mg/L	1	B/C	mg/L
HCO_3	iALK1WATI	Bicarbonate	1	B/C	mg/L
Hg	iHG1WCVG	Mercury		C	
Hg	iMET1WCMS	Mercury	0.0001	C	mg/L
K	iMET1WCICP	Potassium	0.1	B/C	mg/L
La	iMET1WCICP	Lanthanum	0.005	B/C	mg/L
Li	iMET1WCICP	Lithium	0.005	B/	mg/L
Mg	iMET1WCICP	Magnesium	0.1	B/C	mg/L
Mn	iMET1WCICP	Manganese	0.001	B/C	mg/L
Mo	iMET1WCMS	Molybdenum	0.001	B/C	mg/L
Na	iMET1WCICP	Sodium	0.1	B/C	mg/L
Ni	iMET1WCMS	Nickel	0.001	B/C	mg/L
N_NH_3	iAMMN1WFIA	Nitrogen, ammonia fraction by FIA	0.01	B/C	mg/L
N_NO_3	iNTAN1WFIA	Nitrogen, nitrate, nitrite fraction by FIA	0.01	B/C	mg/L
N_total	iNP1WTFIA	Nitrogen, persulfate total by FIA	0.02	C	mg/L

(*continued*)

Table D.1 **Analytical methods and detection limits** (*continued*)

Analyte	Method code	Description	Limit of reporting	Analysis type*	Units
Pb	iMET1WCMS	Lead	0.0001	B/C	mg/L
pH	iPH1WASE	pH	0.1	B/C	
P_SR	iP1WTFIA	Phosphorus, soluble reactive by FIA	0.01	B/C	mg/L
P_total	iPP1WTFIA	Phosphorus, persulfate total by FIA	0.01	C	mg/L
Sb	iMET1WCMS	Antimony	0.0001	B/C	mg/L
Se	iMET1WCMS	Selenium	0.001	B/C	mg/L
Si	iMET1WCICP	Silicon by ICPAES	0.05	B/C	mg/L
Sn	iMET1WCICP	Tin	0.02	B/C	mg/L
SO_4_S	iMET1WCICP	Sulfate, sulphur expressed as sulfate	0.1	B/C	mg/L
TDS sum	ixTDS_Sum	TDS by summation	1	B/C	mg/L
U	iMET1WCMS	Uranium	0.0001	B/C	mg/L
Zn	iMET1WCICP	Zinc	0.005	B/C	mg/L
a-Endo	RCS-OM-05	alpha-Endosulfan	0.01		µg/L
Aldrin	RCS-OM-05	Aldrin	0.01		µg/L
Atrazine	RCS-OM-31	Atrazine	0.1		µg/L
b-Endo	RCS-OM-05	beta-Endosulfan	0.01		µg/L
Dieldrin	RCS-OM-05	Dieldrin	0.01		µg/L
DIURON	RCS-OM-35	Diuron	0.5		µg/L
Endrin	RCS-OM-05	Endrin	0.01		µg/L
EndSulf	RCS-OM-05	Endosulfan sulfate	0.01		µg/L
Hexazino	RCS-OM-31	Hexazinone	2		µg/L
Lindan	RCS-OM-05	Lindane	0.01		µg/L
METCL	RCS-OM-54	Metolachlor	2		µg/L
Methoxyc	RCS-OM-05	Methoxychlor	0.01		µg/L
Simazine	RCS-OM-31	Simazine	0.5		µg/L
Tot-End	RCS-OM-05	Total endosulfan	0.03		µg/L

* C = Comprehensive analysis, B = Basic analysis

Appendix E: Water-quality analysis results

Table E.1 **Water-quality analysis results**

	Irrigation water quality (ANZECC and ARMCANZ Guidelines 2000)			**Sampling sites**												
	Long-term	**Short-term**	**Cum. loading**	**D4 Drain**	**PB4M3D**	**10WP39**	**10WP36 PB**	**10WP33**	**WP17**	**ORD22 (WP19)**	**D8 Drain**	**ORD21 (WP15)**	**ORD20 (WP9)**	**WP12M**	**10WP35 PB**	**WP5**
Site ID				D4	PB4	10WP39	WP36	WP33	WP17	WP19	D8	WP15	WP9	WP12	WP35PB	WP5
Date				27/08/10	28/08/10	28/08/10	28/08/10	29/08/10	29/08/10	29/08/10	29/08/10	30/08/10	30/08/10	30/08/10	30/08/10	31/08/10
Time				15:40	7:45	11:30	15:00	7:15	10:30	13:45	15:45	7:15	9:30	11:30	13:45	7:00
Field EC (mS/m)				40.8	232	121.8	116.9	114.8	87	2640	38.2	1727	232	650	179	486
Field pH				7.84		7.1	7.44	6.93	7.35	6.65	8.69	7.08	7.23	6.79	7.04	7.08
ORP (mV)				153	145	84	153	133	141	30	160	-302	51	210	84	116
Dissolved Oxygen (mg/L)				5.9	2.7	0.72	0.82	2.58	1.9	1	8.86	0.82	1.43	3.5	1.29	7.56
Dissolved Oxygen (%)				78.4	36.8	10.4	9.2	33.9	25.4	13.7	110	11	18.6	46	17.6	
Temperature (° C)				27.8	32	31.7	31.2	30.1	32.2	30.7	29.2	29.1	30.1	29.5	29.9	28.9
Total acidity (mg/L $CaCO_3$)				20	60	40			60	180	20	260	60		100	120
Total alkalinity (mg/L $CaCO_3$)				144	402	255	462		300		144	1590	492	462	630	600
Sample number				CD4	CPB4	C10WP39	CWP36	CWP33	CWP17	CWP19	CD8	BWP15	CWP9	CWP12	CWP35PB	BWP5
Lab Number				10E0540/ 001	10E0540/ 002	10E0540/ 003	10E0540/ 004	10E0540/ 005	10E0540/ 006	10E0540/ 007	10E0540/ 008	10E0540/ 009	10E0540/ 010	10E0540/ 011	10E0540/ 012	10E0540/ 013
Aluminium (mg/L)	5	20	N/D	0.023	0.012	0.018	<0.005	<0.005	0.009	<0.005	0.17	<0.005	<0.005	<0.005	<0.005	<0.005
Alkalinity, total expressed as CaCO3 mg/L. (mg/L)				130	400	240	460	310	325	450	130	1480	500	425	590	550

(*continued*)

Table E.1 **Water-quality analysis results** (*continued*)

	Irrigation water quality (ANZECC and ARMCANZ Guidelines 2000)			**Sampling sites**												
	Long-term	**Short-term**	**Cum. loading**	**D4 Drain**	**PB4M3D**	**10WP39**	**10WP36 PB**	**10WP33**	**WP17**	**ORD22 (WP19)**	**D8 Drain**	**ORD21 (WP15)**	**ORD20 (WP9)**	**WP12M**	**10WP35 PB**	**WP5**
Arsenic (mg/L)	0.1	2	20 kg/ha	0.001	0.002	0.006	0.004	<0.001	0.001	<0.010	<0.001	<0.005	0.002	<0.002	<0.001	0.003
Boron (mg/L)	0.5	Depends crop type	N/D	0.08	0.23	0.18	0.52*	0.11	0.12	0.94*	0.09	1.2*	0.2	0.5*	0.29	0.31
Barium (mg/L)				0.037	0.13	0.034	0.029	0.049	0.08	0.028	0.038	0.024	0.12	0.047	0.17	0.061
Beryllium (mg/L)	0.1	0.5	N/D	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0010	<0.0001	<0.0005	<0.0001	<0.0002	<0.0001	<0.0001
Bismuth (mg/L)				<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0010	<0.0001	<0.0005	<0.0001	<0.0002	<0.0001	<0.0001
Calcium (mg/L)				20	66.1	84.4	27.8	45.6	23.3	810	19.1	67.1	34.5	209	76.9	267
Cadmium (mg/L)	0.01	0.05	2 kg/ha	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0010	<0.0001	<0.0005	<0.0001	<0.0002	<0.0001	0.0002
Chloride (mg/L)				30	488	111	67	158	62	7960	35	4300	345	1430	205	1060
Cobalt (mg/L)	0.05	0.1	N/D	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.01	<0.005	<0.005
Carbonate (mg/L)				<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chromium (mg/L)	0.1	1	N/D	<0.001	0.003	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper (mg/L)	0.2	5	140 kg/ha	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.009	0.004	<0.002	<0.002	<0.002	<0.002	0.005
Dissolved organic carbon as NPOC (mg/L)				3.4	<1.0	<1.0	4.3	<1.0	<1.0	<1.0	3.1		<1.0	11	110	
Electrical Conductivity, 25°C (mS/m)				36.9	224	117	116	116	87.3	2660	38.4	1760	224	668	180	494
Fluoride (mg/L)	1	2	N/D	0.27	0.68	0.35	1.4*	0.28	0.51	<0.05	0.27		0.51	0.47	0.28	

* Exceeds guideline values

(*continued*)

Table E.1 **Water-quality analysis results** (*continued*)

	Irrigation water quality (ANZECC and ARMCANZ Guidelines 2000)			Sampling sites												
	Long-term	**Short-term**	**Cum. loading**	**D4 Drain**	**PB4M3D**	**10WP39**	**10WP36 PB**	**10WP33**	**WP17**	**ORD22 (WP19)**	**D8 Drain**	**ORD21 (WP15)**	**ORD20 (WP9)**	**WP12M**	**10WP35 PB**	**WP5**
Iron (mg/L)	0.2	10	N/D	0.02	0.008	0.016	<0.005	<0.005	<0.005	<0.005	0.065	<0.005	0.015	0.13	0.02	<0.005
Hardness, total expressed as $CaCO_3$ mg/L. (mg/L)				96	340	320	170	300	150	5900	92	1200	270	1400	500	2400
Bicarbonate (mg/L)				159	488	293	561	378	397	549	159	1800	610	519	720	671
Mercury (mg/L)	0.002	0.002	2 kg/ha	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		<0.0001	<0.0001	<0.0001	
Potassium (mg/L)				3.6	7.2	20.8	1.9	3.3	3.1	29.1	3	9.6	4.2	45.3	3.8	5.5
Lanthanum (mg/L)				<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Lithium (mg/L)	2.5 (0.075 citrus)	2.5 (0.075 citrus)	N/D	<0.005	<0.005	0.041	<0.005	<0.005	<0.005	0.08*	<0.005	0.023	<0.005	0.11*	<0.005	0.028
Magnesium (mg/L)				11.2	42.2	26	23.4	44.2	22.6	932	10.9	246	44	204	75.2	421
Manganese (mg/L)	0.2	10	N/D	0.006	0.011	0.008	<0.001	0.01	0.046	0.009	0.009	0.095	0.22*	1.8*	0.047	0.41*
Molybdenum (mg/L)	0.01	0.05	N/D	<0.001	0.002	<0.001	0.006	<0.001	0.001	<0.010	<0.001	<0.005	0.002	<0.002	<0.001	0.002
Nitrogen (ammonia fraction). (mg/L)	5	25–125 reqs. site-specific assessment		<0.01	<0.01	<0.01	<0.01	<0.01	1.8	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrogen (nitrate, nitrite) (mg/L)				<0.01	2.3	<0.01	<0.01	0.05	0.23	<0.01	0.71	<0.01	0.03	<0.01	0.06	<0.01
Nitrogen (total) (mg/L)				0.3	2.9	0.18	0.92	0.19	3.6	0.62	1.2		0.22	0.36	0.13	
Sodium (mg/L)				39.6	346	87.3	171	142	139	4580	41	3890	414	1070	234	266
Nickel (mg/L)	0.2	2	85 kg/ha	<0.001	0.001	0.002	<0.001	0.002	0.001	<0.010	<0.001	<0.005	0.001	0.005	0.002	0.004

* Exceeds guideline values

(*continued*)

Table E.1 **Water-quality analysis results** (*continued*)

	Irrigation water quality (ANZECC and ARMCANZ Guidelines 2000)			**Sampling sites**												
	Long-term	**Short-term**	**Cum. loading**	**D4 Drain**	**PB4M3D**	**10WP39**	**10WP36 PB**	**10WP33**	**WP17**	**ORD22 (WP19)**	**D8 Drain**	**ORD21 (WP15)**	**ORD20 (WP9)**	**WP12M**	**10WP35 PB**	**WP5**
Phosphorus (soluble reactive) (mg/L)	0.05 for irrigation equip only	0.8–12 reqs. site-specific assess ment		0.01	0.02	0.01	0.05*	0.03	0.32*	0.02	0.01	0.11*	0.05*	0.02	0.03	0.01
Phosphorus (total) (mg/L)				0.03	0.86*	0.48*	0.32*	0.06*	0.62*	0.16*	0.08*		0.16*	0.06*	0.1*	
Lead (mg/L)	2	5	260 kg/ha	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0010	0.0004	<0.0005	<0.0001	<0.0002	<0.0001	<0.0001
Antimony (mg/L)				0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0010	<0.0001	<0.0005	<0.0001	<0.0002	<0.0001	0.0004
Selenium (mg/L)	0.02	0.05	10 kg/ha	<0.001	0.002	<0.001	<0.001	0.002	<0.001	<0.010	<0.001	<0.005	0.002	<0.002	<0.001	<0.001
Silicon (mg/L)				6.1	32	31	36	31	30	25	6.4	27	28	16	29	21
Tin (mg/L)				<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Sulfate (mg/L)				9.5	50.6	176	51.5	52.7	31.8	4600	14.6	2430	178	981	83.4	768
TDS by summation (mg/L)				190	1200	650	620	630	480	19000	200	12000	1300	4200	1000	3100
Uranium (mg/L)	0.01	0.1	N/D	0.0005	0.0071	0.0008	0.0034	0.002	0.0012	0.048*	0.0014	0.13*	0.0024	0.02*	0.0097	0.0034
Zinc (mg/L)	2	5	300 kg/ha	0.006	0.013	0.037	0.02	0.015	0.025	0.034	0.006	0.009	0.012	0.012	0.013	0.033
pH				8	7.9	8	8	8.2	7.6	7.3	8.3	7.6	7.7	7.4	7.5	7.7

* Exceeds guideline values

(*continued*)

Table E.1 **Water-quality analysis results** (*continued*)

	Irrigation water quality (ANZECC and ARMCANZ Guidelines 2000)			Sampling sites											
	Long-term	**Short-term**	**Cum. loading**	**10WP38**	**10WP41**	**10WP40**	**10WP35S**	**10WP35N**	**10WP37**	**10WP36S**	**10WP36N**	**10WP32**	**10WP31**	**Point Spring**	**Keep River**
Site ID				WP38	WP41	WP40	WP35S	WP35N	WP37	WP36S	WP36N	WP32	WP31	PS1	KR1
Date				31/08/10	31/08/10	31/08/10	31/08/10	31/08/10	1/09/10	1/09/10	1/09/10	1/09/10	1/09/10	1/09/10	1/09/10
Time				12:30	13:30	15:00	16:00	16:30	6:20	7:00	7:45	8:50	9:30	12:00	13:30
Field EC (mS/m)				730	1496	943	129	110.3	179.6	149.3	138.9	122.1	37.7	13.9	59
Field pH				7.2	7.12	7.2	7.29	7.55	7.74	7.93	7.5	7.51	6.78	7.55	7.44
ORP (mV)				80	114	148	184	-197	-5	-82	133	173	173	199	212
Dissolved Oxygen (mg/L)				1.74	4	4.3	1.7	1.89	2.52	1.8	2.01	4.41	6.9	5.05	5.24
Dissolved Oxygen (%)				22.8	51.7	56.9	21.7	24	31	22.4	25.3	56.3	90.7	71.2	69.3
Temperature (° C)				29.1	28.6	28.9	28.3	27.2	26.9	26.3	26.7	28.1	29.5	33.2	30.5
Total acidity (mg/L CaCO$_3$)				80	140	60	40	40	40	40	60	40	40	20	20
Total alkalinity (mg/L CaCO$_3$)				90.3	684	744	465	516	576	600	537	420	147	72	120
Sample number				BWP38	BWP41	BWP40	BWP35S	BWP35N	BWP37	BWP36S	BWP36N	BWP32	BWP31	CPS1	CKR1
Lab Number				10E0540/015	10E0540/016	10E0540/017	10E0540/018	10E0540/019	10E0540/020	10E0540/021	10E0540/022	10E0540/023	10E0540/024	10E0540/025	10E0540/026
Aluminium (mg/L)	5	20	N/D	0.013	<0.005	0.026	0.012	0.021	0.01	0.017	0.005	0.006	0.01	0.007	0.033
Alkalinity, total expressed as CaCO$_3$ mg/L. (mg/L)				335	575	780	505	490	590	630	535	390	150	35	120

(*continued*)

Table E.1 **Water-quality analysis results** (*continued*)

	Irrigation water quality (ANZECC and ARMCANZ Guidelines 2000)			**Sampling sites**											
	Long-term	**Short-term**	**Cum. loading**	**10WP38**	**10WP41**	**10WP40**	**10WP35S**	**10WP35N**	**10WP37**	**10WP36S**	**10WP36N**	**10WP32**	**10WP31**	**Point Spring**	**Keep River**
Arsenic (mg/L)	0.1	2	20 kg/ha	<0.002	<0.005	0.003	0.002	0.002	0.002	0.015	0.004	0.001	<0.001	<0.001	<0.001
Boron (mg/L)	0.5	Depend. Crop type	N/D	1.3*	1.5*	1.5*	0.34	0.39	0.54*	1.1*	0.44	0.16	0.05	0.07	0.1
Barium (mg/L)				0.1	0.14	0.079	0.037	0.031	0.043	0.024	0.036	0.053	0.032	0.036	0.091
Beryllium (mg/L)	0.1	0.5	N/D	<0.0002	<0.0005	<0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Bismuth (mg/L)				<0.0002	<0.0005	<0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Calcium (mg/L)				267	353	297	39.7	18.8	38.4	15.5	57.1	42.2	24.5	5.8	22.5
Cadmium (mg/L)	0.01	0.05	2 kg/ha	0.0002	<0.0005	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chloride (mg/L)				1350	4330	1310	88	49	226	82	107	143	35	9	86
Cobalt (mg/L)	0.05	0.1	N/D	<0.005	<0.005	0.006	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Carbonate (mg/L)				<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chromium (mg/L)	0.1	1	N/D	0.007	0.015	0.022	0.018	0.023	0.009	0.011	0.008	0.009	0.007	0.003	<0.001
Copper (mg/L)	0.2	5	140 kg/ha	0.005	0.011	0.004	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.005	<0.002	<0.002
Dissolved organic carbon as NPOC (mg/L)														<1.0	<1.0
Electrical Conductivity, 25° C (mS/m)				722	1530	955	126	110	192	150	141	127	39.2	15	59.9
Fluoride (mg/L)	1	2	N/D											0.12	0.12

* Exceeds guideline values

(*continued*)

Table E.1 **Water-quality analysis results** (*continued*)

	Irrigation water quality (ANZECC and ARMCANZ Guidelines 2000)			**Sampling sites**											
	Long-term	**Short-term**	**Cum. loading**	**10WP38**	**10WP41**	**10WP40**	**10WP35S**	**10WP35N**	**10WP37**	**10WP36S**	**10WP36N**	**10WP32**	**10WP31**	**Point Spring**	**Keep River**
Iron (mg/L)	0.2	10	N/D	<0.005	<0.005	0.017	<0.005	0.01	<0.005	0.007	<0.005	<0.005	0.007	0.049	0.11
Hardness, total expressed as $CaCO_3$ mg/L. (mg/L)				1700	2700	1900	250	120	270	97	330	290	130	28	120
Bicarbonate (mg/L)				409	702	952	616	598	720	769	653	476	183	43	146
Mercury (mg/L)	0.002	0.002	2 kg/ha											<0.0001	<0.0001
Potassium (mg/L)				25.1	36.7	25.7	3.5	2.6	2.8	2.9	3.3	4	3.5	8.2	2.6
Lanthanum (mg/L)				<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Lithium (mg/L)	2.5 (0.075 citrus)	2.5 (0.075 citrus)	N/D	*0.35**	0.017	0.05	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Magnesium (mg/L)				239	442	270	37.7	18.1	42.2	14.2	46.1	45	17.7	3.4	16.6
Manganese (mg/L)	0.2	10	N/D	0.17	0.088	0.77*	0.098	0.11	0.027	0.014	0.021	0.009	0.028	0.011	0.21*
Molybdenum (mg/L)	0.01	0.05	N/D	<0.002	<0.005	0.005	0.001	0.003	0.007	0.017	0.005	0.001	<0.001	<0.001	<0.001
Nitrogen (ammonia fraction). (mg/L)	5	25–125 reqs. site-specific assessment		0.1	<0.01	<0.01	<0.01	0.09	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.01
Nitrogen (nitrate + nitrite) (mg/L)				0.01	0.01	<0.01	<0.01	0.09	<0.01	0.34	0.09	<0.01	0.04	<0.01	0.01
Nitrogen (total) (mg/L)														0.26	0.16
Sodium (mg/L)				1110	3000	1820	210	222	346	340	197	176	28.2	7.1	53.3
Nickel (mg/L)	0.2	2	85 kg/ha	0.005	<0.005	0.006	0.003	0.002	0.001	0.001	0.001	<0.001	0.001	<0.001	<0.001

* Exceeds guideline values

(*continued*)

Table E.1 **Water-quality analysis results** (*continued*)

	Irrigation water quality (ANZECC and ARMCANZ Guidelines 2000)			**Sampling sites**											
	Long-term	**Short-term**	**Cum. loading**	**10WP38**	**10WP41**	**10WP40**	**10WP35S**	**10WP35N**	**10WP37**	**10WP36S**	**10WP36N**	**10WP32**	**10WP31**	**Point Spring**	**Keep River**
Phosphorus (soluble reactive) (mg/L)	0.05 for irrigation equp only	0.8–12 reqs. site-specific assessment		<0.01	0.01	0.01	0.04	0.15*	0.09*	0.12*	0.31*	0.03	0.04	0.01	0.01
Phosphorus (total) (mg/L)														0.04	0.02
Lead (mg/L)	2	5	260 kg/ha	0.0003	<0.0005	<0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0042	<0.0001
Antimony (mg/L)				0.0006	<0.0005	<0.0002	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (mg/L)	0.02	0.05	10 kg/ha	<0.002	<0.005	<0.002	<0.001	<0.001	0.007	<0.001	<0.001	0.002	<0.001	<0.001	<0.001
Silicon (mg/L)				10	20	29	27	28	30	34	36	39	33	9.7	15
Tin (mg/L)				<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Sulfate (mg/L)				1660	2240	2820	50.5	29.8	102	50.1	75.3	56	3.3	13.9	46.4
TDS by summation (mg/L)				4900	11000	7000	730	630	1100	880	810	700	200	68	300
Uranium (mg/L)	0.01	0.1	N/D	0.0075	0.055*	0.038*	0.0056	0.0043	0.0043	0.0014	0.004	0.0016	0.0001	0.0001	0.0002
Zinc (mg/L)	2	5	300 kg/ha	0.083	0.083	0.017	0.022	0.01	0.01	0.013	0.012	0.012	0.014	0.064	0.007
pH				7.4	7.7	7.7	7.7	8.2	7.9	8.3	7.7	8	8.2	7.7	7.7

* Exceeds guideline values

(*continued*)

Table E.1 **Water-quality analysis results** (*continued*)

	Irrigation water quality (ANZECC and ARMCANZ Guidelines 2000)			Sampling Site											
	Long-term	**Short-term**	**Cum. loading**	**10WP32PB**	**10WP35PB 0730**	**10WP35PB 1255**	**10WP36PB 1530**	**10WP36PB**	**10WP36PB 0800**	**10WP42**	**10WP46**	**10WP47**	**WP16**	**M1 supply channel**	**Parry Lagoons**
Site ID				WP32PB	WP35PB	WP35PB	WP36PB	WP36PB	WP36PB	WP42	WP46	6WP47	WP16	M1	PL1
Date				2/10/2010	31/07/2010	31/07/2010	27/07/2010	29/07/2010	29/07/2010	28/09/2010	29/09/2010	1/10/2010	31/08/10	1/09/10	1/09/10
Time					7:30	12:55	15:30		8:00				9:15	15:30	16:30
Field EC (mS/m)										216	203	69.7	879	26.2	185.8
Field pH										8.26	8.3	8.5	6.53	8.43	9.4
ORP (mV)													187	176	76
Dissolved Oxygen (mg/L)													2.73	5.89	9.26
Dissolved Oxygen (%)													36.4	80	119.6
Temperature (° C)										28.7	29.6	28.3	29	30.8	28.6
Total acidity (mg/L $CaCO_3$)													120	20	0
Total alkalinity (mg/L $CaCO_3$)													501	114	96
Sample number				10WP32P	10WP35PB 0730	10WP35PB 1255	10WP36PB 1530	10WP36PB	10WP36PB 0800	10WP42	10WP46	10WP47	BWP16	CM1	CPL1
Lab number				10E0707/ 001	10E0707/ 002	10E0707/ 003	10E0707/ 004	10E0707/ 005	10E0707/ 006	10E0707/ 007	10E0707/ 008	10E0707/ 009	10E0540/ 014	10E0540/ 027	10E0540/ 028
Aluminium (mg/L)	5	20	N/D	0.12	<0.005	<0.005	<0.005	<0.005	<0.005	0.19	0.16	0.11	<0.005	0.011	0.008
Alkalinity, total expressed as $CaCO_3$ mg/L (mg/L)				375	530	530	460	510	505	285	285	235	375	105	70

(*continued*)

Table E.1 **Water-quality analysis results** (*continued*)

	Irrigation water quality (ANZECC and ARMCANZ Guidelines 2000)			**Sampling Site**											
	Long-term	**Short-term**	**Cum. loading**	**10WP32PB**	**10WP35PB 0730**	**10WP35PB 1255**	**10WP36PB 1530**	**10WP36PB**	**10WP36PB 0800**	**10WP42**	**10WP46**	**10WP47**	**WP16**	**M1 supply channel**	**Parry Lagoons**
Arsenic (mg/L)	0.1	2	20 kg/ha	0.001	<0.001	<0.001	0.006	0.005	0.006	0.002	0.002	0.001	<0.002	<0.001	0.002
Boron (mg/L)	0.5	Depend. crop type	N/D	0.06	0.25	0.24	0.56*	0.68*	0.72*	0.21	0.14	<0.02	0.17	0.07	0.14
Barium (mg/L)				0.053	0.065	0.065	0.028	0.027	0.027	0.032	0.018	0.11	0.055	0.032	0.099
Beryllium (mg/L)	0.1	0.5	N/D	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0002	<0.0001	<0.0001
Bismuth (mg/L)				<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0002	<0.0001	<0.0001
Calcium (mg/L)				35	38.5	38.5	24.7	25.1	25.1	104	96.4	67.3	726	15.3	12.7
Cadmium (mg/L)	0.01	0.05	2 kg/ha	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0002	<0.0001	<0.0001
Chloride (mg/L)				222	97	97	53	60	61	331	303	51	2400	16	582
Cobalt (mg/L)	0.05	0.1	N/D	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Carbonate (mg/L)				24	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chromium (mg/L)	0.1	1	N/D	0.002	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	0.003	<0.001
Copper (mg/L)	0.2	5	140 kg/ha	0.004	<0.002	<0.002	<0.002	<0.002	<0.002	0.004	<0.002	<0.002	<0.002	<0.002	<0.002
Dissolved organic carbon as NPOC (mg/L)														1.1	1.1
Electrical conductivity, 25° C (mS/m)				157	133	134	111	118	118	222	207	64.9	895	27.6	187
Fluoride (mg/L)	1	2	N/D											0.19	0.19

* Exceeds guideline values

(*continued*)

Table E.1 **Water-quality analysis results** (*continued*)

	Irrigation water quality (ANZECC and ARMCANZ Guidelines 2000)			Sampling Site											
	Long-term	**Short-term**	**Cum. loading**	**10WP32PB**	**10WP35PB 0730**	**10WP35PB 1255**	**10WP36PB 1530**	**10WP36PB**	**10WP36PB 0800**	**10WP42**	**10WP46**	**10WP47**	**WP16**	**M1 supply channel**	**Parry Lagoons**
Iron (mg/L)	0.2	10	N/D	0.44	0.006	0.007	<0.005	<0.005	<0.005	0.11	0.099	0.048	<0.005	0.018	0.11
Hardness, total expressed as CaCO$_3$ mg/L. (mg/L)				240	250	250	150	150	150	500	450	230	3400	72	150
Bicarbonate (mg/L)				409	647	647	561	622	616	348	348	287	458	128	85
Mercury (mg/L)	0.002	0.002	2 kg/ha											<0.0001	<0.0001
Potassium (mg/L)				4.1	2.2	2.2	1.7	1.7	1.7	23.3	24.5	11	6.1	2.3	12
Lanthanum (mg/L)				<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Lithium (mg/L)	2.5 (0.075 citrus)	2.5 (0.075 citrus)	N/D	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.05	0.037	0.008	0.009	<0.005	<0.005
Magnesium (mg/L)				37.1	37.4	38.1	20.7	21.5	20.3	57.5	49.8	14.5	389	8.2	29.5
Manganese (mg/L)	0.2	10	N/D	0.12	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.13	0.006	0.007
Molybdenum (mg/L)	0.01	0.05	N/D	0.002	<0.001	<0.001	0.009	0.009	0.009	0.001	<0.001	<0.001	<0.002	<0.001	<0.001
Nitrogen (ammonia fraction). (mg/L)	5	25–125 reqs. site-specific assessment		0.04	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.01	<0.01	<0.01	<0.01
Nitrogen (nitrate + nitrite) (mg/L)				0.14	0.11	0.09	0.57	0.6	0.44	0.06	0.05	0.01	<0.01	<0.01	<0.01
Nitrogen (total) (mg/L)				0.38	0.18	0.09	0.64	0.59	0.44	0.15	0.14	0.12		0.19	2.3
Sodium (mg/L)				204	180	183	184	203	193	301	266	45.7	796	19.7	267
Nickel (mg/L)	0.2	2	85 kg/ha	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.005	<0.001	0.001

(*continued*)

Table E.1 **Water-quality analysis results** (*continued*)

	Irrigation water quality (ANZECC and ARMCANZ Guidelines 2000)			**Sampling Site**											
	Long-term	**Short-term**	**Cum. loading**	**10WP32PB**	**10WP35PB 0730**	**10WP35PB 1255**	**10WP36PB 1530**	**10WP36PB**	**10WP36PB 0800**	**10WP42**	**10WP46**	**10WP47**	**WP16**	**M1 supply channel**	**Parry Lagoons**
Phosphorus (soluble reactive) (mg/L)	0.05 for irrigation equip only	0.8–12 reqs. site-specific assessment		0.07*	0.08*	0.08*	0.25*	0.26*	0.24*	0.03	0.03	0.05	0.01	<0.01	0.01
Phosphorus (total) (mg/L)				0.08*	0.06*	0.08*	0.24*	0.23*	0.22*	0.05*	0.04	0.05*		0.01	0.09*
Lead (mg/L)	2	5	260 kg/ha	0.0009	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0015	0.0007	0.0005	<0.0002	0.0002	0.0003
Antimony (mg/L)				<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0002	<0.0001	0.0001
Selenium (mg/L)	0.02	0.05	10 kg/ha	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001
Silicon (mg/L)				17	31	31	37	37	37	21	15	23	14	5.5	0.35
Tin (mg/L)				<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Sulfate (mg/L)				110	46	45	36	40	42	360	340	25	1340	6.5	2.4
TDS by summation (mg/L)				820	720	730	600	660	650	1400	1300	360	5900	130	950
Uranium (mg/L)	0.01	0.1	N/D	0.0035	0.015	0.016	0.0044	0.0048	0.0045	0.0075	0.0056	0.001	0.0048	0.0003	0.0003
Zinc (mg/L)	2	5	300 kg/ha	0.011	0.016	0.007	0.007	<0.005	0.014	0.011	0.009	<0.005	0.039	0.013	0.007
pH				8.4	7.7	8.1	8.3	7.9	8.3	8.2	8.2	8.3	7	8.4	8.4

* Exceeds guideline values

Table E.2 **Water-quality analysis (pesticides)**

Parameter	Sampling sites					
	PB4M3D	**10WP39**	**10WP36PB**	**10WP33**	**WP17**	**D8 Drain**
Lab number	10K0019/001	10K0019/002	10K0019/003	10K0019/004	10K0019/005	10K0019/006
Sample number	CPB4	C10WP39	CWP36	CWP33	CWP17	CD8
Dated	28/08/2010	28/08/2010	28/08/2010	29/08/2010	29/08/2010	29/08/2010
alpha-Endosulfan (µg/L)	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Aldrin (µg/L)	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Atrazine (µg/L)	**0.16**	<0.10	<0.10	<0.10	<0.10	**0.19**
beta-Endosulfan (µg/L)	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Dieldrin (µg/L)	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Diuron (µg/L)	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Endrin (µg/L)	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Endosulfan sulfate (µg/L)	<0.010	<0.010	<0.010	<0.010	<0.010	**0.015**
Hexazinone (µg/L)	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Lindane (µg/L)	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Metolachlor (µg/L)	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Methoxychlor (µg/L)	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Simazine (µg/L)	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Total endosulfan (µg/L)	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030

Bold values are above detection limits

Appendix F: Piper diagram

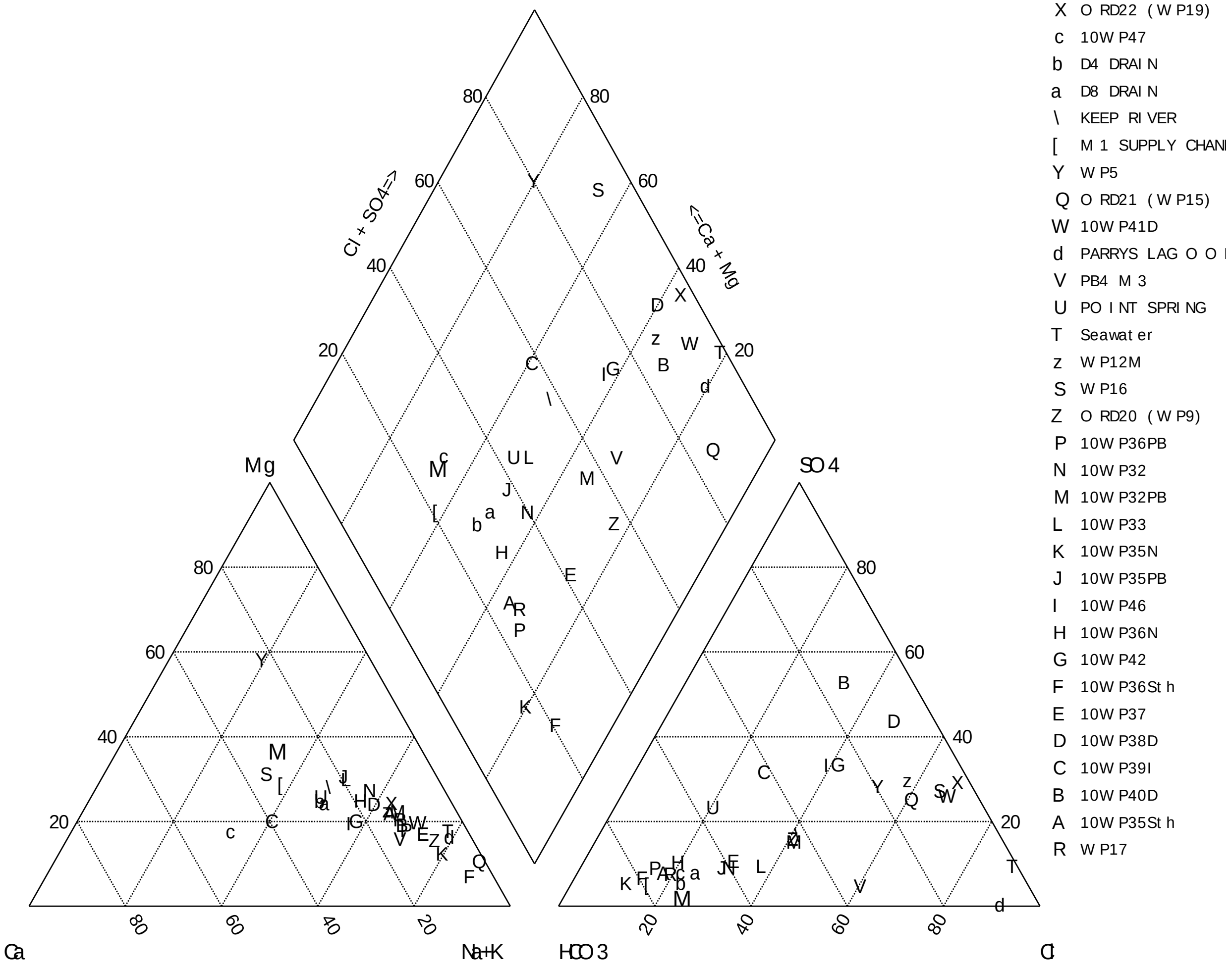

Figure F.1 **Piper diagram showing the major ion composition of samples collected**

Appendix G: Groundwater-modelling scenarios

Table G.1 **Anticipated groundwater management from KBR (2011) modelling**

	Expected	Worst case
Total required annual abstraction (GL/a)	**6.3**	**8.8**
Wet season		
Days	110	110
Destination	To Keep River	To Keep River
Total abstraction (GL)	**1.9**	**2.7**
average per day (ML/d)	17.3	24.1
average per second (L/s)	200	280
Outcome	Discharge to Keep River when flowing sufficiently	Discharge to Keep River when flowing sufficiently
Shoulder period		
Days	55	55
Outcome	No abstraction	No abstraction
Dry season		
Days	200	200
Destination	To M2 Channel	To M2 Channel
Total abstraction (GL)	3.6	4.8
Loading from not pumping in shoulder period	0.9	1.3
Total abstraction including loading (GL)	**4.4**	**6.1**
average per day (ML/d)	22.0	30.1
average per second (L/s)	255	356
Outcome	Water to be added to irrigation water in the M2 Channel	Water to be added to irrigation water in the M2 Channel

Appendix H: Modelled water quality of groundwater to be discharged to the supply channel

Table H1 **Modelled water quality of source groundwater with potential to be pumped into the M1 supply channel compared with water-quality guidelines**

Analyte	Water-Quality Guidelines (ANZECC and ARMCANZ 2000)					Modelled concentration of source groundwater
	Irrigation			Aquatic ecosystems[§]		
	Long-term	Short-term	Cum. loading	Freshwater	Marine	
Aluminium (mg/L)	5	20	N/D	0.027		**0.08**
Alkalinity, total expressed as $CaCO_3$ (mg/L)						438
Arsenic (mg/L)	0.1	2	20 kg/ha	0.001 (III) 0.0008 (V)		**0.001**
Boron (mg/L)	0.5	Depends on crop type	N/D	0.09		**0.2**
Barium (mg/L)						0.09
Beryllium (mg/L)	0.1	0.5	N/D			0.0003
Bismuth (mg/L)						0.0001
Calcium (mg/L)						63
Cadmium (mg/L)	0.01	0.05	2 kg/ha	0.00006	0.0007	**0.0001**
Chloride (mg/L)						276
Cobalt (mg/L)	0.05	0.1	N/D			0.00
Carbonate (mg/L)						1
Chromium (mg/L)	0.1	1	N/D	0.00001(VI)	0.0077 (III) 0.00014 (VI)	**0.0009**
Copper (mg/L)	0.2	5	140 kg/ha	0.001	0.00003	**0.003**
Dissolved organic carbon as NPOC (mg/L)						55
Electrical Conductivity, 25°C (mS/m)				2-25		**180**
Fluoride (mg/L)	1	2	N/D			0.4
Iron (mg/L)	0.2	10	N/D			0.15

(*continued*)

Table H.1 **Modelled water quality of source groundwater with potential to be pumped into the M1 supply channel compared with water-quality guidelines** (*continued*)

Analyte	Water-Quality Guidelines (ANZECC and ARMCANZ 2000)					Modelled concentration of source groundwater
	Irrigation			Aquatic ecosystems§		
	Long-term	Short-term	Cum. loading	Freshwater	Marine	
Hardness, total expressed as $CaCO_3$ (mg/L)						378
Bicarbonate (mg/L)						522
Mercury (mg/L)	0.002	0.002	2 kg/ha			0.0001
Potassium (mg/L)						9
Lanthanum (mg/L)						0.003
Lithium (mg/L)	2.5 (0.075 citrus)	2.5 (0.075 citrus)	N/D			0.01
Magnesium (mg/L)						53
Manganese (mg/L)	0.2	10	N/D			0.10
Molybdenum (mg/L)	0.01	0.05	N/D			0.001
Nitrogen (ammonia fraction). (mg/L)	5	25–125 requires. site-specific assessment		0.01	0.015	0.02
Nitrogen (nitrate + nitrite) (mg/L)				0.01	0.03	0.07
Nitrogen (total) (mg/L)				0.3	0.25	0.2
Sodium (mg/L)						288
Nickel (mg/L)	0.2	2	85 kg/ha			0.001
Phosphorus (soluble reactive) (mg/L)	0.05 for irrigation equip only	0.8–12 requires site-specific assessment		0.004	0.005	0.05
Phosphorus (total) (mg/L)				0.01	0.02	0.10
Lead (mg/L)	2	5	260 kg/ha	0.001	0.0022	0.0006
Antimony (mg/L)						0.0001
Selenium (mg/L)	0.02	0.05	10 kg/ha			0.002
Silicon (mg/L)						24
Tin (mg/L)						0.01
Sulfate (mg/L)						183
TDS by summation (mg/L)						1156

(*continued*)

Table H.1 **Modelled water quality of source groundwater with potential to be pumped into the M1 supply channel compared with water-quality guidelines** (*continued*)

Analyte	**Water-Quality Guidelines (ANZECC and ARMCANZ 2000)**					**Modelled concentration of source groundwater**
	Irrigation			**Aquatic ecosystems**[§]		
	Long-term	**Short-term**	**Cum. loading**	**Freshwater**	**Marine**	
Uranium (mg/L)	0.01	0.1	N/D			0.006
Zinc (mg/L)	2	5	300 kg/ha	0.0024	0.007	**0.01**
pH				6-8	7-8.5	7.8

[§] Toxicants are based on 99% level of protection. Other values are based on the default values for tropical lowland rivers and estuaries

Modelled concentrations in bold red exceed ANZECC/ARMCANZ (2000) guidelines for freshwater ecosystems

Appendix I: Proposed groundwater monitoring

Table I.1 **Proposed field and laboratory groundwater monitoring parameters**

Description	Analyte	Method code	High-intensity bore [i]	Low-intensity bore [ii]	Farm bores [iii]
Field					
Electrical conductivity, 25° C			Y	Y	Y
pH			Y	Y	Y
Oxidation–reduction potential (ORP) as standard hydrogen electrode			Y	Y	
Alkalinity (as CaCO3)			Y	Y	
Acidity, as CaCO3			Y	Y	
Laboratory					
Acidity, as $CaCO_3$	Acid	1	Y		
Silver	Ag	6	Y		
Aluminium	Al	6	Y		
Alkalinity, total expressed as $CaCO_3$ mg/L.	Alkalin	2	Y		
Arsenic	As	7	Y		
Boron	B	6	Y		
Barium	Ba	6	Y		
Beryllium	Be	7	Y		
Bismuth	Bi	7	Y		
Calcium	Ca	6	Y		
Cadmium	Cd	7	Y		
Chloride	Cl	3	Y		
Cobalt	Co	6	Y		
Carbonate	CO_3	2	Y		
Chromium	Cr	6	Y		
Copper	Cu	6	Y		
Dissolved organic carbon as NPOC	DOC	iCTO1WDC	Y		
Electrical conductivity, 25°C	ECond	4	Y	Y	
Fluoride	F	iF1WASE	Y		
Iron	Fe	6	Y		
Gallium	Ga		Y		
Hardness, total expressed as $CaCO_3$ mg/L.	Hardness	5	Y		
Bicarbonate	HCO_3	2	Y		
Mercury	Hg	iHG1WCVG	Y		
Mercury	Hg	7	Y		
Potassium	K	6	Y		
Lanthanum	La	6	Y		

(*continued*)

Table I.1 **Proposed field and laboratory groundwater monitoring parameters** (*continued*)

Description	Analyte	Method code	High-intensity bore [i]	Low-intensity bore [ii]	Farm bores [iii]
Lithium	Li	6	Y		
Magnesium	Mg	6	Y		
Manganese	Mn	6	Y		
Molybdenum	Mo	7	Y		
Sodium	Na	6	Y		
Nickel	Ni	7	Y		
Nitrogen, ammonia fraction by FIA	N_NH_3	iAMMN1WFI	Y		
Nitrogen, nitrate, nitrite fraction by FIA.	N_NO_3	9	Y		
Nitrogen, persulfate total by FIA	N_total	8	Y	Y	
Lead	Pb	7	Y		
pH	pH	11	Y		
Phosphorus, soluble reactive by FIA	P_SR	10	Y		
Phosphorus, persulfate total by FIA.	P_total	12	Y	Y	
Antimony	Sb	7	Y		
Selenium	Se	7	Y		
Silicon by ICPAES	Si	6	Y		
Tin	Sn	6	Y		
Sulfate, sulphur expressed as sulfate	SO_4_S	6	Y		
Total dissolved solids	TDS sum	13	Y		
Uranium	U	7	Y		
Zinc	Zn	6	y		
Atrazine	Atrazine	RCS-OM-31	Y	Y	

Method Codes

1 Acidity or acids by titration APHA 2310B

2 Alkalinity (as $CaCO_3$) and constituents by acid titration (APHA 2320B).

3 Colorimetric analysis by DA (discrete autoanalyser), APHA and in-house methods

4 Electrical conductivity in water compensated to 25C (APHA 2510B)

5 Total hardness as mg/L $CaCO_3$ by calculation from calcium and magnesium (APHA 2340 B)

6 Total dissolved metals by ICPAES (APHA 3120)

7 Total dissolved metals by ICPMS (APHA 3125)

8 Total nitrogen by persulphate digestion FIA (APHA 4500N-C, I)

9 Nitrate + nitrite expressed as nitrogen by FIA (APHA 4500NO3-I

10 Phosphorus soluble reactive as P in water by FIA (APHA 4500P-G)

11 pH in water by pH meter (APHA 4500H+)

12 Total phosphorus by persulphate digestion and FIA (APHAP-J, G)

13 Total dissolved solids (TDS) by summation or calculated from electrical conductivity

N_NH3 iAMMN1WFI nitrogen, ammonia fraction by FI

Frequency

i) The high-intensity bores should have full analysis seasonally for initial period to establish baseline conditions. Then seasonal monitoring for basic parameters (electrical conductivity, pH, ORP, total nutrients and atrazine) with comprehensive analysis every three years unless field parameters deviate from baseline conditions by 20 per cent.

ii) Analysis to establish baseline conditions should be seasonal, then annually, except field parameters, which should remain seasonal.

iii) Analysis should be undertaken annually.