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Hydrogeological investigations at Morestead, Twyford, 2010-2011

Groundwater Science Programme

Open Report OR/11/043



BRITISH GEOLOGICAL SURVEY

GROUNDWATER RESOURCES PROGRAMME

OPEN REPORT OR/11/043

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Foreword

This report is the published product of a study by the British Geological Survey (BGS) on the seasonal fluctuations of nitrate in groundwater at a research site in Morestead, Twyford, Hampshire. It forms the fifth output from the BGS project “Nitrate fluctuations in groundwater”, and records details of activities and results obtained during the 2010/11 campaign.

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Summary

This report describes work undertaken at Morestead, Twyford during the 2010/11 recharge season as part of a BGS research project NEE 3344S “Nitrate Fluctuations in Groundwater”. The previous recharge seasons have been reported earlier in Sorensen *et al.* (2010a; 2010b). The project uses the same site as that described in Stuart *et al.* (2008a) for the project “Nitrate Mass Balance in the Saturated Zone”.

This year a third set of data were obtained from the multi-level sampler. Additional procedures were also introduced, as recommended in Sorensen *et al.* (2010b), to further avoid the potential for sample contamination. Samples were also bailed from the water table on each visit and discrete constant depth samples were taken from Borehole A.

During the 2010/11 recharge season groundwater levels varied between 26.1 m bd in October 2010 and only 19.4 m bd in February 2011. The groundwater hydrograph was characterised by an initial rise in water level to 19.4 m bd in early February, a small decline and then a second peak in mid-March. Groundwater levels then declined following an unusually dry March and April and therefore failed to reach the typical maximum levels.

A total of 140 samples were collected from Borehole B between 25.9 and 19.4 m bd at a typical depth resolution of 0.05 m. These indicated concentrations of chloride, sulphate and nitrate (as NO₃) range between 11.6 and 27.8 mg/l, 7.3 and 24.8 mg/l, and 19.7 and 50.4 mg/l, respectively. Additionally 11 samples were retrieved in the multi-level sampler above the water table. Many of these samples were so dilute that they tend towards expected rainfall composition. Other samples which contained typical groundwater concentrations of chloride are depleted in sulphate and usually nitrate. This could be indicative of these waters been reduced at some point or possibly of an alternative contaminant source which is relatively enriched in chloride such as road salt. One sample collected above the water table contained elevated concentrations of nitrate and this has occurred in both previous recharge seasons.

Analysis of the groundwater samples indicated:

- A general rising trend in nitrate groundwater concentration with water levels between 26 and 19.4 m bd, although reductions in concentration do often follow peaks.
- Sudden increases in concentration at 24.2, 21.6, 20.7, 20.1 m bd which sometimes correspond with open fractures. This trend is similar to the 2009/10 recharge season.
- Concentrations always below the porewater concentration at the estimated same depth.
- No correlation between the observed trends and site visits indicating there are no issues with the current sampling procedure.

Constant depth samples in Borehole A suggested initial concentrations of chloride, sulphate and nitrate were similar to those recorded 26-25 m bd in Borehole B but final concentrations were lower. This is indicative of some, but not complete, mixing between shallower and deeper groundwaters.

Several recommendations to tackle remaining areas of uncertainty have also been suggested.

1 Introduction

1.1 BACKGROUND AND OBJECTIVES

Concentrations of groundwater nitrate observed in abstraction boreholes have increased significantly during the past 30-40 years in response to the intensification of farming. Many of these show within-year fluctuations of various amplitudes and forms. Where suitable continuous groundwater level records are available nearby, a close relationship between groundwater levels and nitrate concentrations can often be observed – higher concentrations being associated with higher groundwater levels. It is often the resulting transient winter peaks of nitrate that can be problematic for compliance by water companies, perhaps many years before the “average” concentration reaches a level requiring action.

The objective of this project is to determine which of the following mechanisms is resulting in rising nitrate concentrations near a public supply borehole: rapid vertical recharge and enhanced winter leaching, flushing out of “stored” unsaturated zone nitrate by the rising groundwater levels, or inactivation of shallow high transmissivity flow paths during periods of low water levels. This report summarises the activities and data collected during the 2010/11 recharge season.

1.2 SUMMARY OF PREVIOUS WORKS

This project builds upon the infrastructure and information from a previous project aimed at evaluating the role of diffusive exchange of nitrate between fracture water and porewater in the saturated zone of the aquifer. As part of this project a cored borehole (Borehole A) was drilled during May 2006 to a depth of 75 m in the Chalk at Morestead, Twyford, Hampshire. The final installation comprised separate shallow and deep, 50 mm diameter piezometers in an area of set-aside land adjacent to arable farmland.

The core obtained was fractured but most of these fractures appeared to be to be parallel to the bedding (e.g. along marl seams) and were probably drilling-induced. Some high-angle fractures with mineralised fracture faces were found in the uppermost 10 m and mineralised fractures with slickensides (possibly associated with a minor fault) were observed at 31 m depth, a few metres below the water table at the time of drilling.

The results of packer testing of the borehole confirmed that the highest permeabilities were in the zone close to the water table, with low values at depth, consistent with results from boreholes in the nearby Candover catchment. Marl seams appeared to be much more important than fractures in controlling groundwater movement to this borehole. Groundwater samples obtained during packer testing were all of similar composition and were interpreted as being drilling water which had not been fully flushed from the borehole before the test.

A detailed profile of porewater quality was obtained by centrifugation of core samples. Nitrate concentrations were mainly at and above the current drinking water standard of 50 mg/l nitrate (11.3 mg N/l) and there did not appear to be any zones of unfractured chalk where porewater had retained pre-1960s concentrations of nitrate. Zones close to major fractures did not show steep nitrate concentration gradients, suggesting that there were not large differences in quality between the fracture water and porewater. Porewater concentrations followed a typical nitrate profile for chalk overlain by arable land, with elevated concentrations (up to 78 mg/l as NO_3) in the unsaturated zone and declining concentrations in the saturated zone (up to 39 mg/l as NO_3), except in a 15 m thick zone of the Lewes Nodular Chalk at about 25 m below the water table at that time. Here a number of marl bands appear to result in a zone of slow-moving water with low nitrate concentration.

It was concluded that, if the results were representative of local conditions, and given the significant proportion of similar arable land in the immediate catchment of the Twyford Pumping Station, then groundwater nitrate concentrations are likely to continue rising under the present landuse and agricultural regime. Moreover, much of the cultivated land is located in the upper part of the catchment and nitrate is likely to be still present in the unsaturated zone and saturated groundwater flow paths. The site lies within a Nitrate Vulnerable Zone but even 'improved grassland' may have significant applications of inorganic fertiliser and organic manure, within the limits set by the Nitrate Directive. Present conditions do not therefore suggest any immediate reduction in the upward trend in groundwater nitrate concentration. For further details the reader is referred to Stuart *et al.* (2008a).

A preliminary review of the nitrate concentration fluctuation data available from Twyford PS did not lead to any firm conclusions from this site (Stuart *et al.* 2008b). Unlike the other examples reviewed, piston flow from the overlying unsaturated zone cannot be ruled out. The good correspondence between nitrate concentration and water levels throughout the time series does not suggest that the rising of the water table to a particular level triggers an increase of nitrate into the borehole.

1.3 APPROACH

The project objective is to be achieved by the following activities:

1. Drilling of a second borehole (Borehole B) at the Morestead site close to the existing piezometers. This would enable the use of existing information obtained at the site, e.g. geological information, and also allow future use of cross-borehole techniques. The hole was to be of adequate diameter to facilitate the use of geophysical techniques. Moreover, it was to remain unlined against the Chalk to allow water to enter from every fracture horizon, thus allowing an assessment of flow and nitrate contributions from individual fractures.
2. Instrumentation of Borehole B to obtain frequent nitrate samples from the water table, and continue groundwater level monitoring in Borehole A. This would determine the concentration of nitrate arriving at, and also define the location of, the water table.
3. Employing a range of borehole geophysical logging techniques to identify and characterise significant fracture horizons, including an assessment of nitrate concentrations at selected fractures.
4. Comparing the relationship between nitrate concentrations and groundwater levels, with local recharge events examined in detail, in order to improve the understanding in relation to mechanisms and processes.

Subsequently, existing models would be adapted to represent the seasonal processes identified by the study and to use these to model the magnitude and duration of future peak concentrations in different scenarios. Activity 1 has now been completed and the project is now entering the 4th recharge season and addressing activities 2-4.

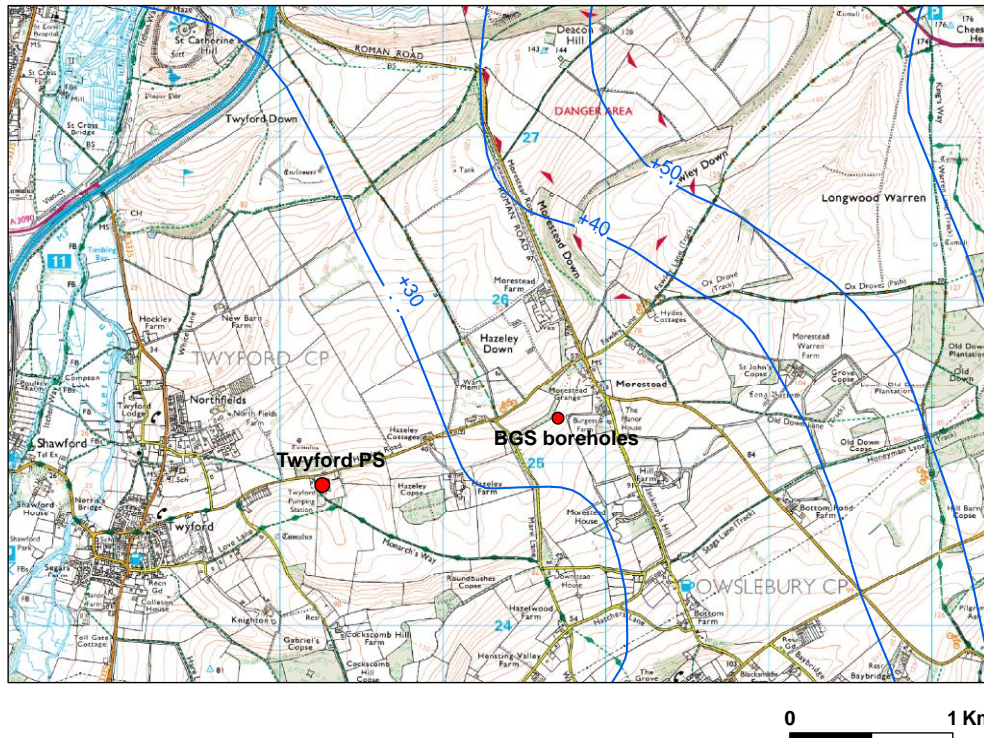
1.4 LINKS

This project falls within the Sustainable Use of Natural Resources Theme in the NERC Strategy "Next Generation Science for Planet Earth". This project was originally linked to the project "Nitrate mass balance in the saturated zone" in the use of common infrastructure. It follows on from co-funded work for UKWIR and commissioned work for Defra (see Stuart *et al.* 2007 for summary of work)

2 Research site

2.1 LOCATION

The site is located at SU 5073 2528 (Figure 2.1). It lies 1.5 km east of the public supply borehole at Twyford, Hampshire on the Chalk of the South Downs. Further details of the location and hydrogeological setting are outlined in Stuart *et al.* (2008a).

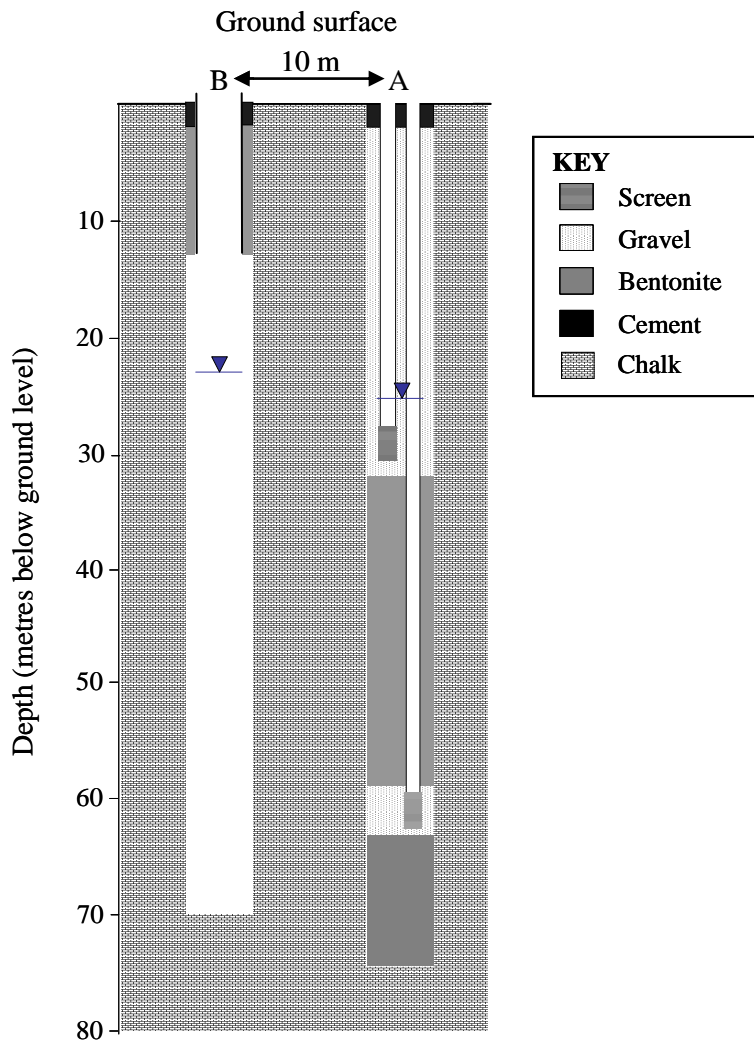


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Groundwater levels from the Hampshire and Isle of Wight hydrogeological map (IGS, 1979).

Figure 2.1 Site location and contours of autumn rest groundwater levels (1973).

2.2 INFRASTRUCTURE

Two boreholes have been drilled at the site since the commissioning of the project (Figure 2.2). Borehole A was completed with two separate 50 mm diameter piezometers in 2006 (Stuart *et al.* 2008a). Borehole B was completed with steel casing to 12.7 metres below ground level (m bgl), with the hole remaining unsupported below this depth (Sorensen *et al.* 2010a). Borehole B lies approximately 10 m west of Borehole A. The site datum is the top of the casing at Borehole B. This is 0.337 m below ground level (datum) at Borehole A. Further borehole completion details are provided in the respective reports above.



Note: water levels are shown from time of drilling; Borehole A datum (ground level) is 0.337 m above Borehole B datum (top of casing - which protrudes c. 0.16 m above ground level).

Figure 2.2 Borehole completions: A - as two 50 mm diameter piezometers; B - as 200 mm diameter and open hole below casing.

3 Testing methodology

3.1 RAINFALL

Otterbourne Water Works is the nearest station in the Met Office MIDAS database to the field site. There are two separate rainfall datasets: from an ordinary climatological station and from a rainfall station (UK Meteorological Office, 1853-current). These data were processed to remove duplicates. Data from the rainfall station were deemed the most suitable as there were no gaps in the record. It was noted that between 1st October 2006 and 1st April 2010 total precipitation differed by around 4% (over 100 mm) between the two time series.

3.2 WATER LEVEL RECORDING

A 5-m range pressure transducer (Diver) was installed in the shallow piezometer of Borehole A on 1st December 2006 to assess seasonal groundwater level changes prior to installation of water sampling equipment. Water level variations within the borehole were significant and the diver had to be frequently raised or lowered in the borehole. Additionally, on occasions, the water level exceeded the specified range of the diver. Consequently, a 30 m range CTD (conductivity, temperature, depth) Diver was deployed, instead, at the base of the shallow piezometer (c. 30 metres below ground level) on 11th April 2008. The CTD Diver failed on 16th December 2009 and was replaced on 5th August 2010. Groundwater levels were also monitored on a 3-hourly interval with a Druck PDCR 1830 from 25th November 2009 in Borehole B (see Section 3.3). This record is complete with the exception of 25th April to 19th May 2011 when the water level fell below the sensor.

On each site visit the diver data were downloaded, and the borehole was dipped manually to allow the later conversion of the pressure readings to actual groundwater level. Borehole B was also dipped manually. Pressure data from the Druck sensor was considered to be of superior quality to the CTD Diver and could be referenced against dip measurements with minimal uncertainty.

3.3 TELEMETRY SYSTEM

On 25th November 2009 a telemetry system was installed onsite. The system comprised a Druck 7-m range PDCR 1830 pressure transducer, a Cambell Scientific CR10X logger and an associated solar power supply. The Druck sensor was attached at a known depth below the base of the multi-level sampler (Figure 3.2) and logged at 3-hourly intervals. The system enabled water levels to be visualised in the office via the GPRS network, thus facilitating targeted sampling visits to site.

3.4 GEOPHYSICAL LOGGING

No further geophysical logging was undertaken during the year. The water quality sonde has not yet been successfully deployed to produce nitrate depth profiles. Moreover, the borehole has not been stressed sufficiently to allow satisfactory identification of all borehole flow horizons; this was not undertaken because of the low groundwater levels. Previous details of logging activities are reported in Sorensen et al. (2010a; 2010b) and Woods (2010).

3.5 WATER SAMPLING

3.5.1 Multi-level sampler

The multi-level sampler system comprised a series of Sterilin™ sample bottles. Each bottle contained a small ball which would rise to the top of the bottle as it was submerged, effectively sealing the sample from the surrounding groundwater (Figure 3.1). The sampler originally had 18 bottles fixed at regular intervals along two 1-m adjoining sections of slotted plastic tracking. Two additional bottles were later added in 2008 to increase the total to 20 sample bottles; the distance between sampling units was thus around 0.1 m.

In November 2009 a further two near-identical samplers were constructed. One sampler was coupled to the end of the original to increase the sampler length to 3.9 m. Additionally the third sampler was coupled to the rear of the original at a 0.05 m offset to allow sampling at 0.05 m resolution from 0.1-2.05 m (Figure 3.2).

The multi-level sampler was suspended just above the water table at the start of the 2010/11 recharge season with the aid of the Druck sensor, which was a known depth below the sampler. The water level could then be visualised in the office to assess whether samples had been captured or it was necessary to move the sampler in anticipation of a new rise in water level. After samples were retrieved the device would be re-suspended at the water table with fresh sample bottles in place.

Additional procedures were also implemented to reduce the risk of potential sample contamination:

- The Sterilin lids and balls were replaced with cleaned ones on every occasion.
- A plastic sheet was placed on the ground surface to prevent the sampler making contact with vegetation and the soil during sample recovery.
- All samples were passed through individual filters following collection, rather than sequential filtering through a large-diameter Swinnex filter holder.

During the 2010/2011 recharge season, samples were retrieved on:

- 7th and 22nd December 2010.
- 7th, 20th, 26th January 2010.
- 4th and 22nd February 2011.
- 6th March 2011.

All samples were scheduled for nitrate, chloride, sulphate, bromide, fluoride, nitrite and phosphate analysis by ion chromatography. A full list of samples results is presented in Appendix A.

3.5.2 Bailed samples

On each site visit a bailed sample was taken from the water table in Borehole B to compare with data collected from the multi-level sampler.

3.5.3 Borehole A sampling

On each site visit a discrete depth sample was taken from 29.8 m bd in the 30 m deep Borehole A piezometer. This was to investigate variations in nitrate concentrations at a specific depth in the aquifer

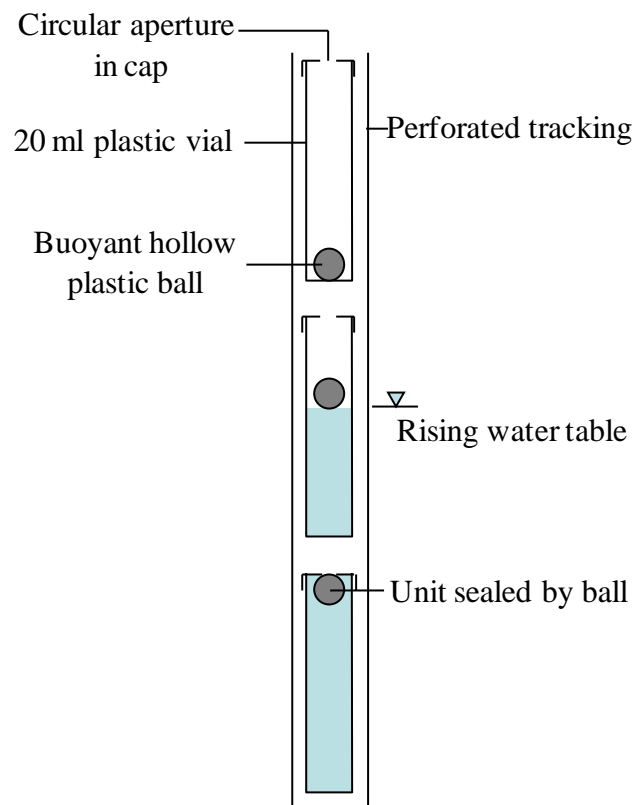


Figure 3.1 Schematic diagram of multi-level sampler bottle.



Figure 3.2 2009/10 multilevel sampler, attached Druck sensor and telemetry system.

4 Results and interpretation

4.1 GROUNDWATER LEVEL RECORDING

Groundwater level data from the two boreholes were processed to remove anomalous readings and combined to produce a more complete hydrograph (Figure 4.1). Monthly totals of the displayed rainfall data are shown in Table 4.1.

The hydrograph shows annual water level maxima in March during 2007, and in February during 2009, 2010 and 2011. There are no data available prior to mid-March in 2008, when the maximum is likely to have been that year. Annual groundwater minima occurred between mid-September and mid-November in 2008, October and mid-November in 2009, and October in 2010. There is an absence of data where the lows of 2007 are likely to have occurred.

Between December 2007 and June 2010, available water levels ranged between 26.1 and around 10.5 m bd, although a manual dip undertaken in October 2006 recorded a level of 27.6 m bd.

During the 2010/11 recharge season groundwater levels varied between 26.1 m bd in October 2010 and only 19.4 m bd in February 2011. The groundwater hydrograph was characterised by an initial rise in water level to 19.4 m bd in early February, a small decline and then a second peak in mid-March. Groundwater levels then declined following an unusually dry March and April and therefore failed to reach the typical maximum levels.

Figure 4.2 compares the relationship between groundwater level and cumulative rainfall over the 2010/11 recharge period. The rapid rise and fall of water levels associated with precipitation events is similar to that observed at the North Heath Barn borehole north of Brighton. Here, fracture flow was regarded as significant if a certain threshold of rainfall was exceeded (Adams *et al.*, 2008).

Table 4.1 Rainfall data from Otterbourne Water Works (mm/month).

2007											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
105.8	62.6	69.8	1.8	82.8	88.8	148.2	39.8	14.2	42.4	88.8	72.6
2008											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
106.2	28.8	92.8	56.8	119.8	66.4	77.2	76.8	61.6	71.4	83.0	48.0
2009											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
107.6	55.0	48.6	51.0	34.2	22.6	92.0	35.6	62.4	53.8	195.0	139.0
2010											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
81.0	79.6	82.6	24.4	18.8	22.4	27.6	94.4	42.8	94.4	97.0	46.2
2011											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
94.4	69.2	17.4	1.2	-	-	-	-	-	-	-	-

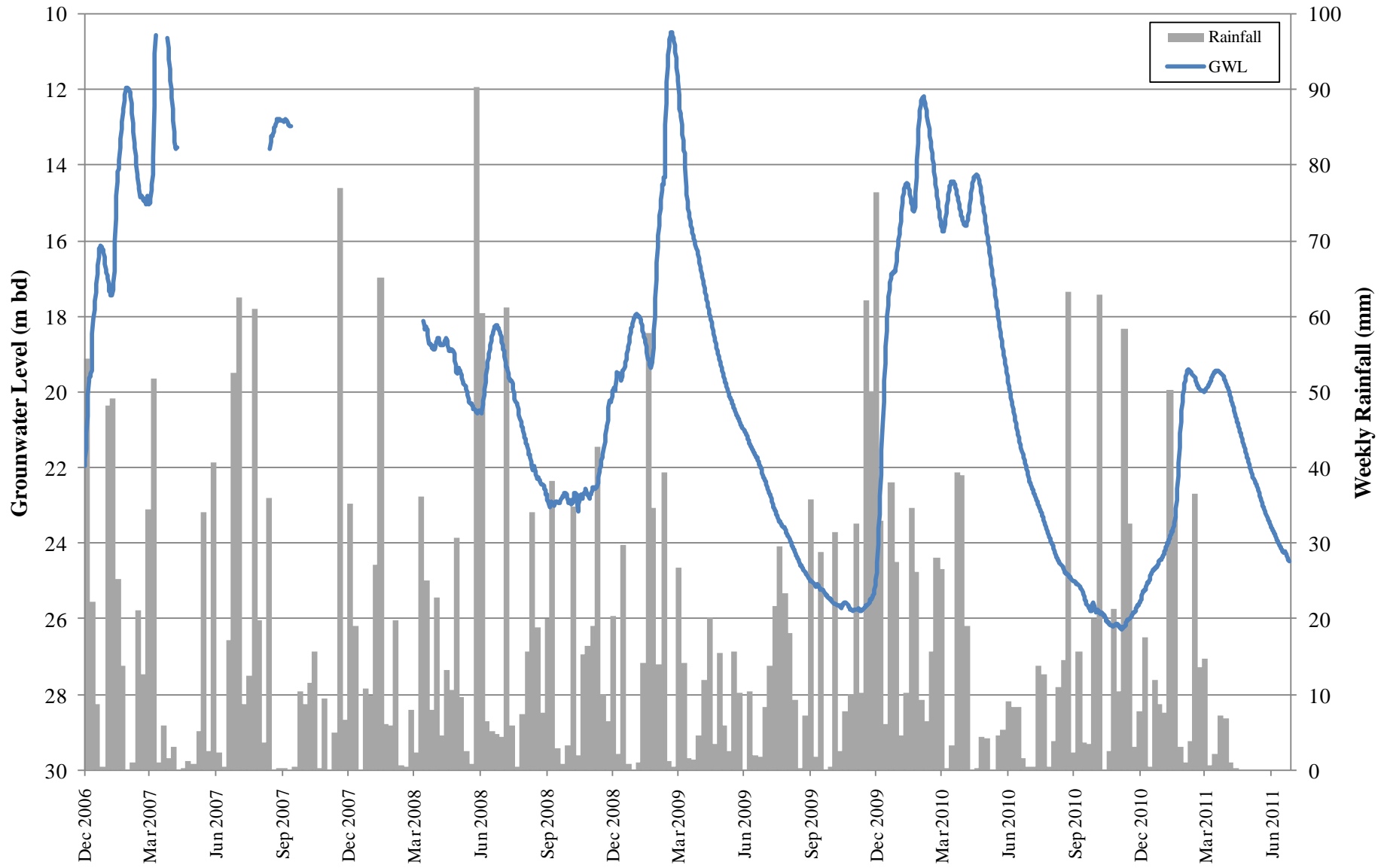


Figure 4.1 Daily groundwater hydrograph with rainfall from Otterbourne Water Works BADC station (rainfall data only until 30th April 2011).

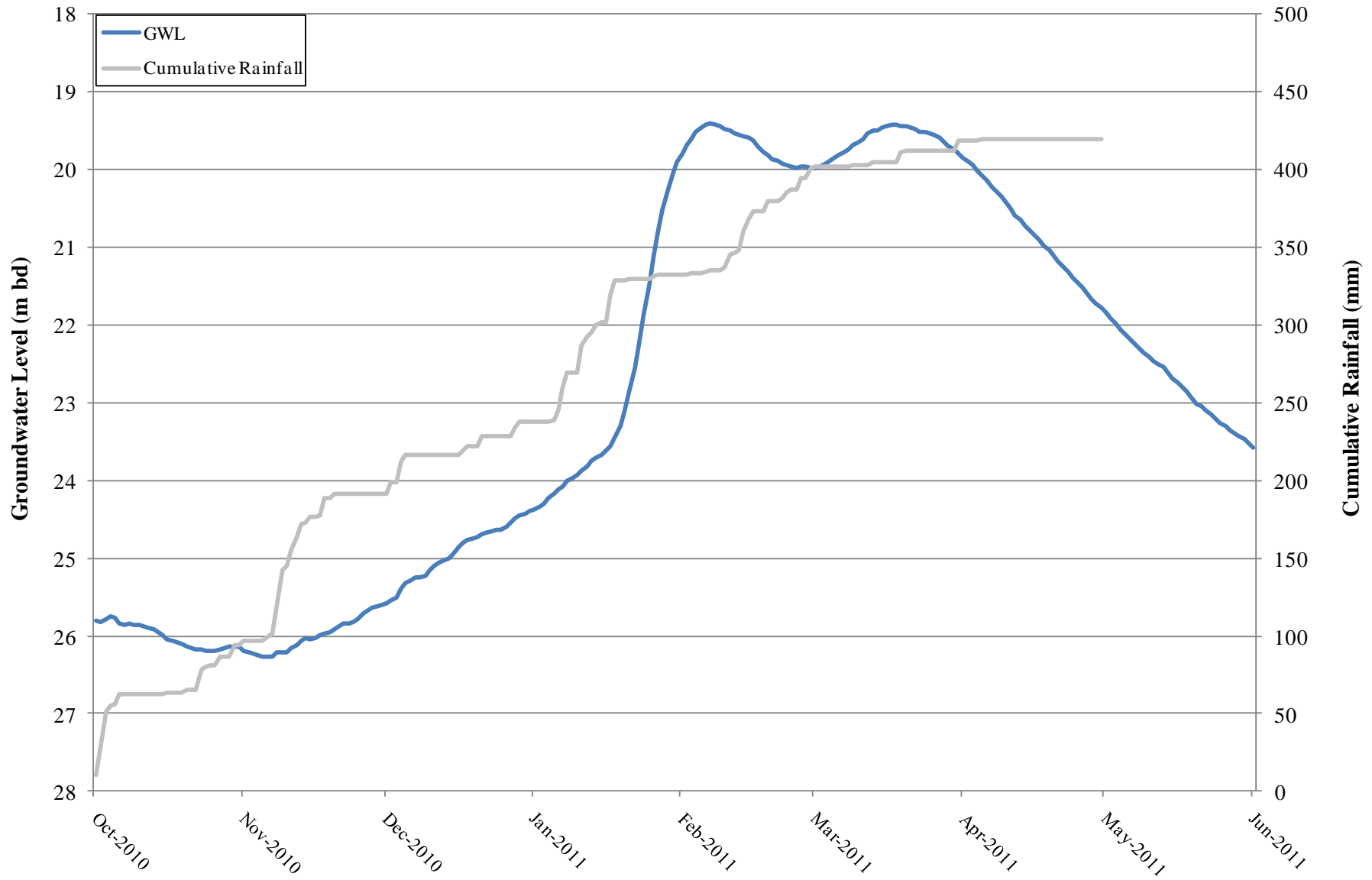


Figure 4.2 Comparison of groundwater level and cumulative rainfall between 1st October 2010 and 1st June 2011.

4.2 WATER SAMPLING

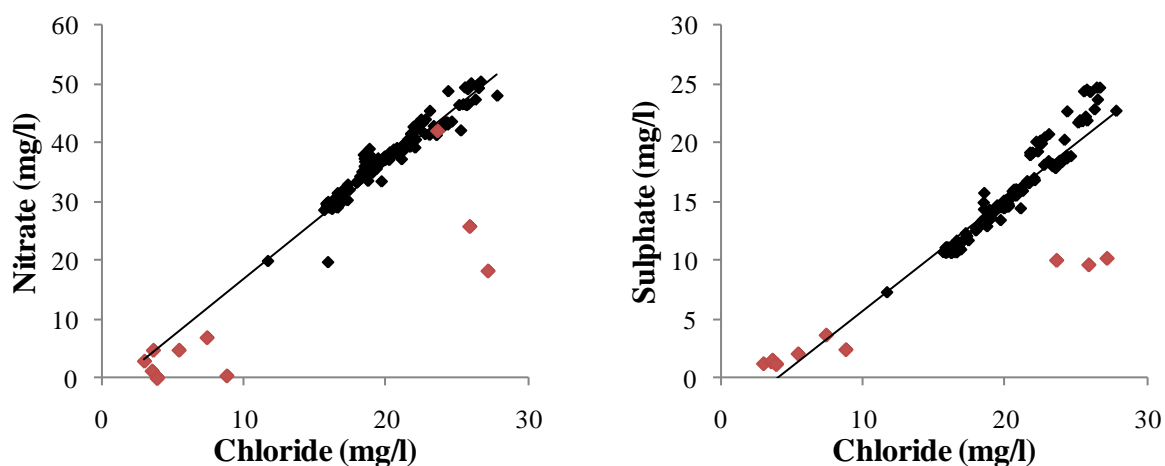
4.2.1 Site observations

During sample collection from the multi-level sampler a number of observations were recorded:

- A total of 11 samples were collected in units which had not been submerged on 7th December 2010, 22nd December 2010, 7th January 2011, 20th January 2011 and 22nd February 2011. On some occasions these contained brown organic material.
- On 20th January 2011 units from intervals 0.15 and 0.25 m on the sampler were lost down the borehole.
- Macrofauna (Collembola) were noted in many units, with up to 12 individuals recorded in one sample.

4.2.2 Variation in water sample chemistry

Water quality data are presented as Appendix A. Concentrations of chloride, sulphate and nitrate (as NO₃) range between 11.6 and 27.8 mg/l, 7.3 and 24.8 mg/l, and 19.7 and 50.4 mg/l, respectively. These concentrations exclude samples collected from above the water table which are generally much more dilute in chemistry (Figure 4.3). Moreover many of these samples are so dilute that they tend towards expected rainfall composition. It is possible rainfall may enter the borehole through the small aperture in the lid or down the outside of the casing because of poor borehole completion, although both seem unlikely. Samples which do contain typical groundwater concentrations of chloride are depleted in sulphate and usually nitrate. This could be indicative of these waters been reduced at some point or possibly of an alternative contaminant source which is relatively enriched in chloride such as road salt. Interestingly, out of a total of 14 samples where bromide concentration is less than 0.04 mg/l, 10 were collected from above the water table.



Note: black samples are from the water table and red are from above it

Figure 4.3 Concentrations of nitrate and sulphate relative to chloride

Only one sample from above the water table contained elevated concentrations of some anions. This was '270' on 7th December 2010 and contained 23.6 mg/l of chloride and 42.1 mg/l of nitrate in comparison with water table samples retrieved on the same date containing 15.9-16.5 mg/l of chloride and 19.7-30.4 mg/l of nitrate. Sulphate concentrations were comparable to those detected in the groundwater. Previously, samples above the water table with anomalously high concentrations of chloride, sulphate and nitrate were reported on 27th

January 2009 (Sorensen *et al.* 2010a) and 25th November 2009 (Sorensen *et al.* 2010b). The later sample also contained 68.4 mg/l of phosphate, indicating the sample was likely to be derived from the near surface. Only one other sample last year had measurable concentrations of phosphate last year and all concentrations were below the limits of detection (0.01 or 0.02 mg/l) this year

There were no anomalously low nitrate readings (<10 mg/l) collected from the water table which had previously been recorded in the 2008/9 recharge season (Sorensen *et al.* 2010a).

Bailed samples are generally of a very similar composition to samples collected in the sampler, as was noted in Sorensen *et al.* (2010a)

4.2.3 Trends with depth

General trends

The data suggest generally increasing concentrations of all determinands as the water level rises from 26 to 19.4 m bd (Figure 4.5 and Figure 4.6). Within the rising trend there are four noticeable peaks in concentration, which subsequently recede, at 24.2, 21.6, 20.7, 20.1 m bd. The most significant increase is at 20.1 m bd where chloride, sulphate and nitrate concentration increase from 22.7 to 26.6 mg/l, 18.2 to 24.8 mg/l and 41.5 to 50.4 mg/l, respectively. The relative order and relative range in concentrations of the species also change at this depth (Figure 4.6), with a proportionally larger increase in sulphate.

Figure 4.6 also suggests there is no correlation between the observed trend and site visits, with the exception of the single anomalous sample collected 20.9 m bd.

Repeated samples at similar depths show lower concentrations after the initial rise.

Correlation with geophysical logs

Geophysical borehole optical televiewer (OPTV) undertaken in 2009 (Sorensen *et al.* 2010b) identified several open fractures which appear to correlate with features in the depth profiles (Table 4.2). This indicates that fractures could be delivering relatively high concentrations of nitrate to the borehole. Although these fractures were noted in the OPTV log, there is no indication that these were active in the fluid and flow logs, with the exception of 25.3 m bd (Woods 2010).

Table 4.2 Relating nitrate depth profile to open fractures observed in the borehole OPTV log

Fracture depth (m bd)	Features in nitrate depth profile
20.1	Sudden increase in nitrate of 8.9 mg/l
20.7	Small sudden increase in nitrate, followed by rising concentrations subsequently
25.3	Nothing significant

Comparison with previous recharge seasons

The trend with depth is very similar to the 2009/10 season with similar concentrations and concurrent peaks at around 24.2, 20.7 and 20.1 m bd, although there is no peak at 21.6 m bd (Figure 4.5). The peak at 20.1 m bd in 2009/10 was consistent with a site visit and resulted in concerns about the field techniques. However the peak at this depth was not coincidental with a site visit this year and suggests there may be no issues with the current sampling procedure.

Comparison with the 2008/09 season is more challenging due to the data resolution and limited number of samples. Nevertheless there also appears to be a sudden increase in nitrate concentration of 9.3 mg/l at around 20.1 m bd.

4.2.4 Nitrate time series

Previously it had been suggested there was a tentative relationship between the rate of groundwater rise and nitrate concentration: as the rising limb of a recharge event begins to slow towards the peak, then the rate of rise in nitrate concentration also begins to level off (Sorensen *et al.* 2010b). This behaviour is not evident in the current dataset and there is no obvious relationship between water level and nitrate concentration over time.

4.2.5 Comparison of groundwater and porewater chemistry

Porewater samples were not collected during the construction of Borehole B, but data are available from the neighbouring Borehole A. These were collected during 2006 and the profile is likely to have been modified slightly by subsequent recharge through the matrix. Therefore an estimated current porewater profile is displayed assuming a vertical nitrate movement of 0.8 m per annum (Figure 4.8), a figure previously determined by Gale *et al.* (1994) in borehole core profiles from the Wiltshire Chalk.

The general increasing trend with elevation is prevalent in both the groundwater and estimated current porewater. It is more challenging to relate actual features within the two datasets, with the exception of the concomitant peak at around 20 m bd.

There is also an offset between the two datasets with groundwater concentrations always lower than porewaters. This was also observed in previous years where it was postulated this could be a result of (Sorensen *et al.*, 2010a; 2010b):

- Evaporation of water from the core prior to porewater analysis.
- Groundwater nitrate concentrations falling over time as a result of reduced nitrate applications to the surface – particularly as the site has been set-a-side.
- Mixing of higher and lower nitrate groundwaters – perhaps reflecting the degree of recharge through the matrix and bypass flow through the fractures.

4.2.6 Constant depth samples from Borehole A

Overall concentrations of chloride, sulphate and nitrate increase from 15.8 to 18.5 mg/l, 10.8 to 15.8 mg/l and 29.7 to 36.8 mg/l, respectively. The initial concentrations are very similar to the samples taken from Borehole B between 25 and 26 m bd. The final concentrations are in the order of 20 % lower than those taken from Borehole B on 16th March 2011.

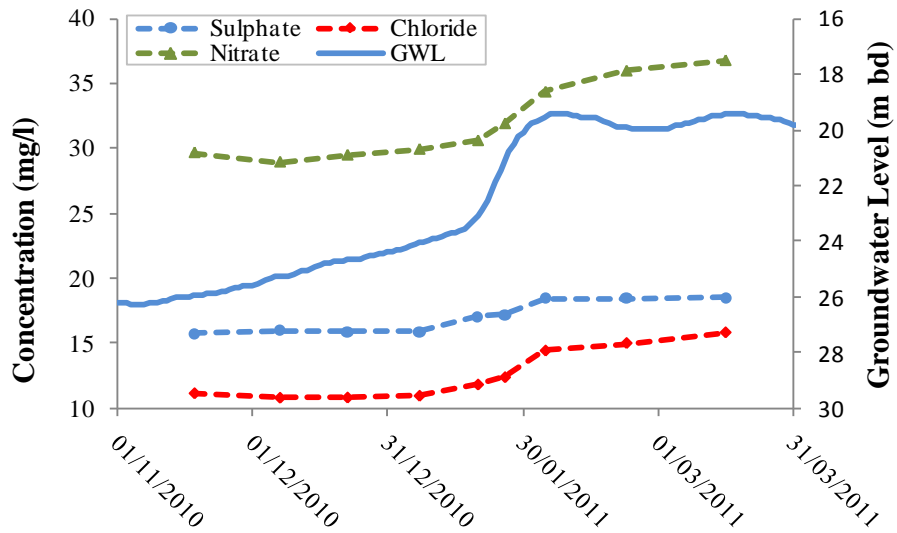
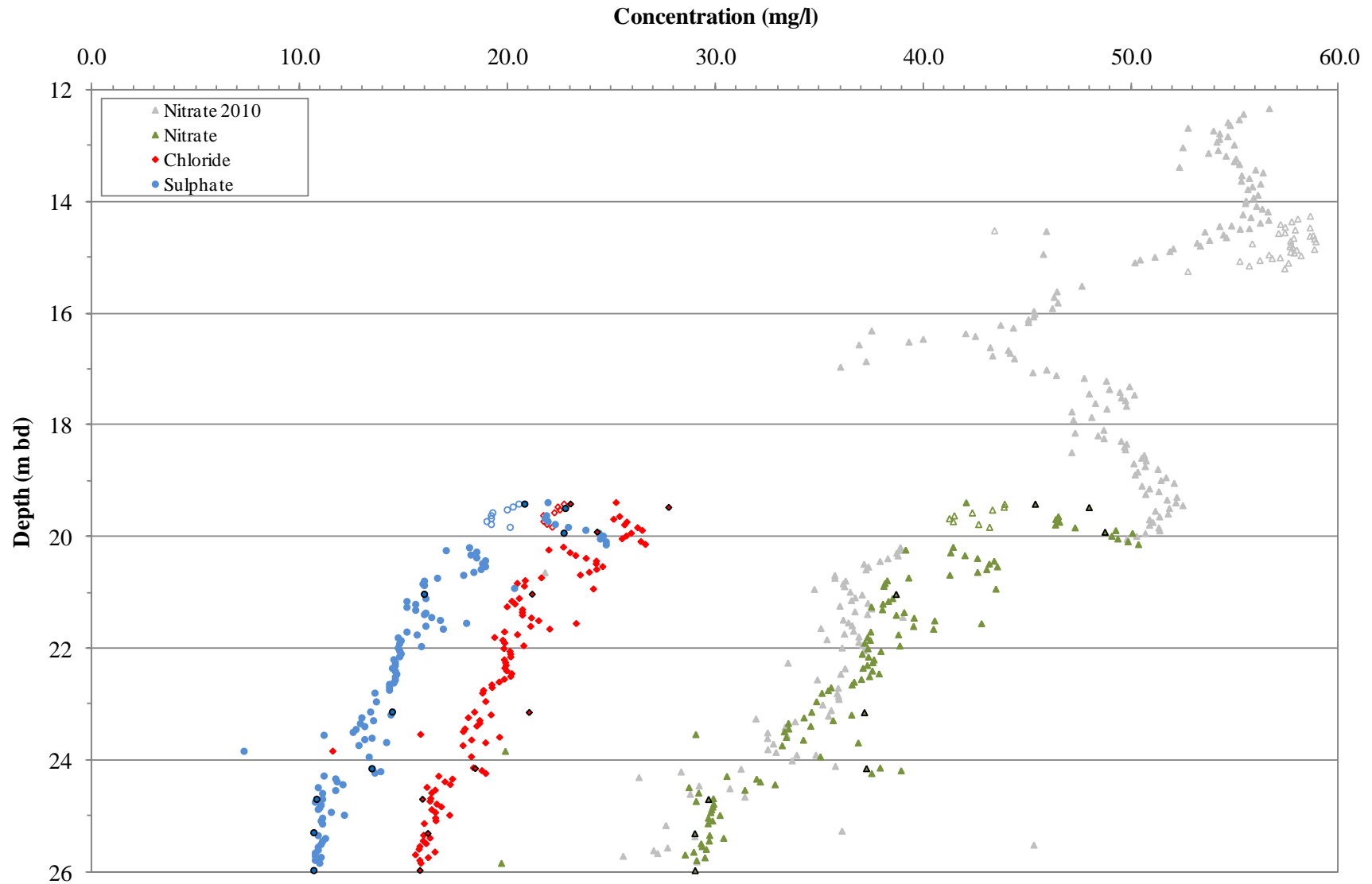


Figure 4.4 Changes in chloride, sulphate and nitrate concentration at 29.8 m bd in Borehole A

Samples show very little concentration variation between 18th November 2010 and 7th January 2011 as the water table rises steadily (Figure 4.4). Subsequently concentrations of all determinands start to increase as the water table rise becomes more rapid and this rising trend continues despite the decline in water level in February 2011. This presumably indicates continued mixing of the waters at depth with more elevated, higher nitrate waters. Borehole A is generally upgradient of Borehole B, therefore mixing is more likely to be through the fracture network rather than a result of downward flow in the adjacent open borehole.



Note: Unfilled data points relate to repeated samples at similar depths after the initial water level rise; black outlined points are bailed samples.

Figure 4.5 Depth profiles of chloride, sulphate and nitrate concentrations in Borehole B for 2010/11

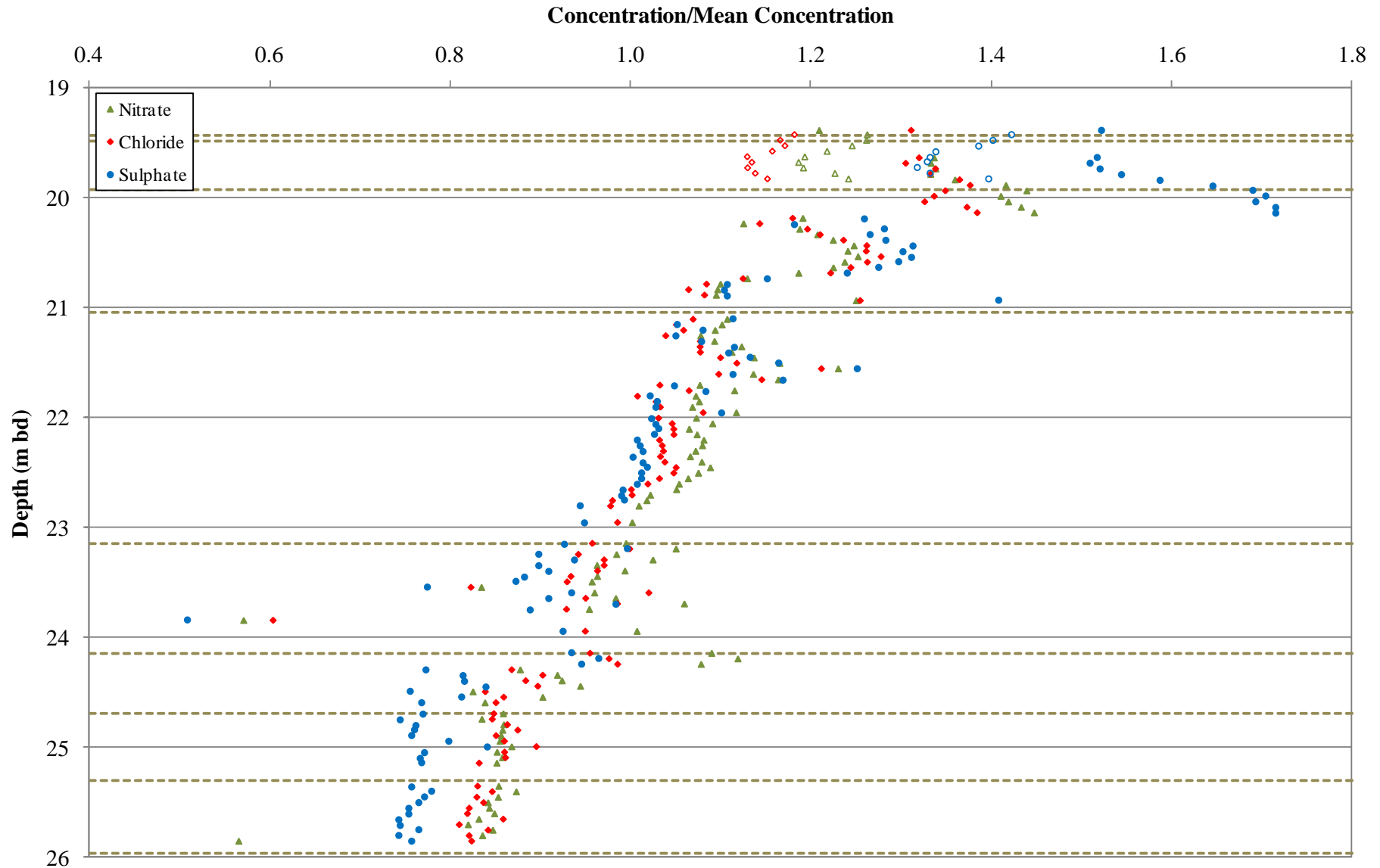
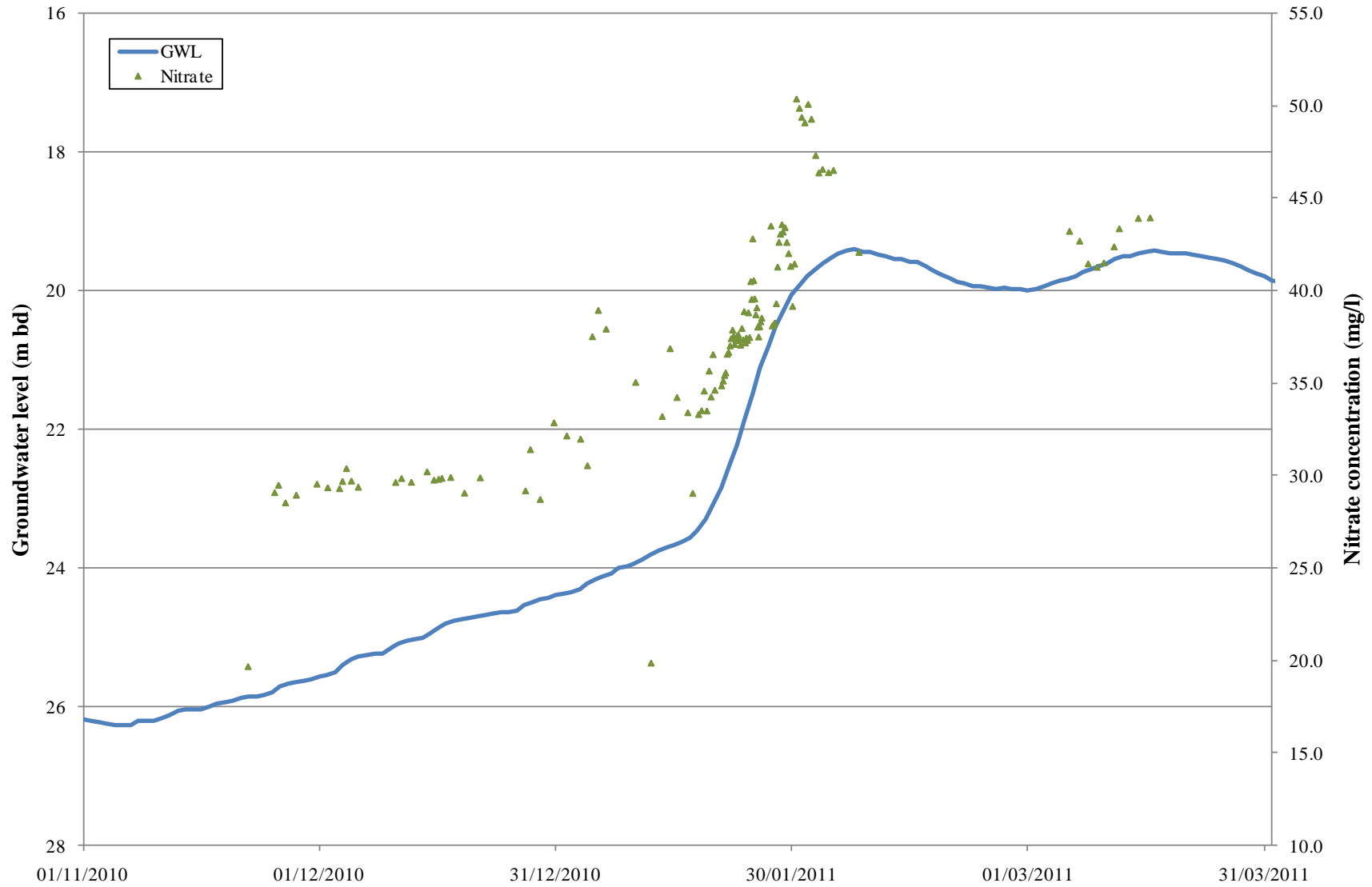
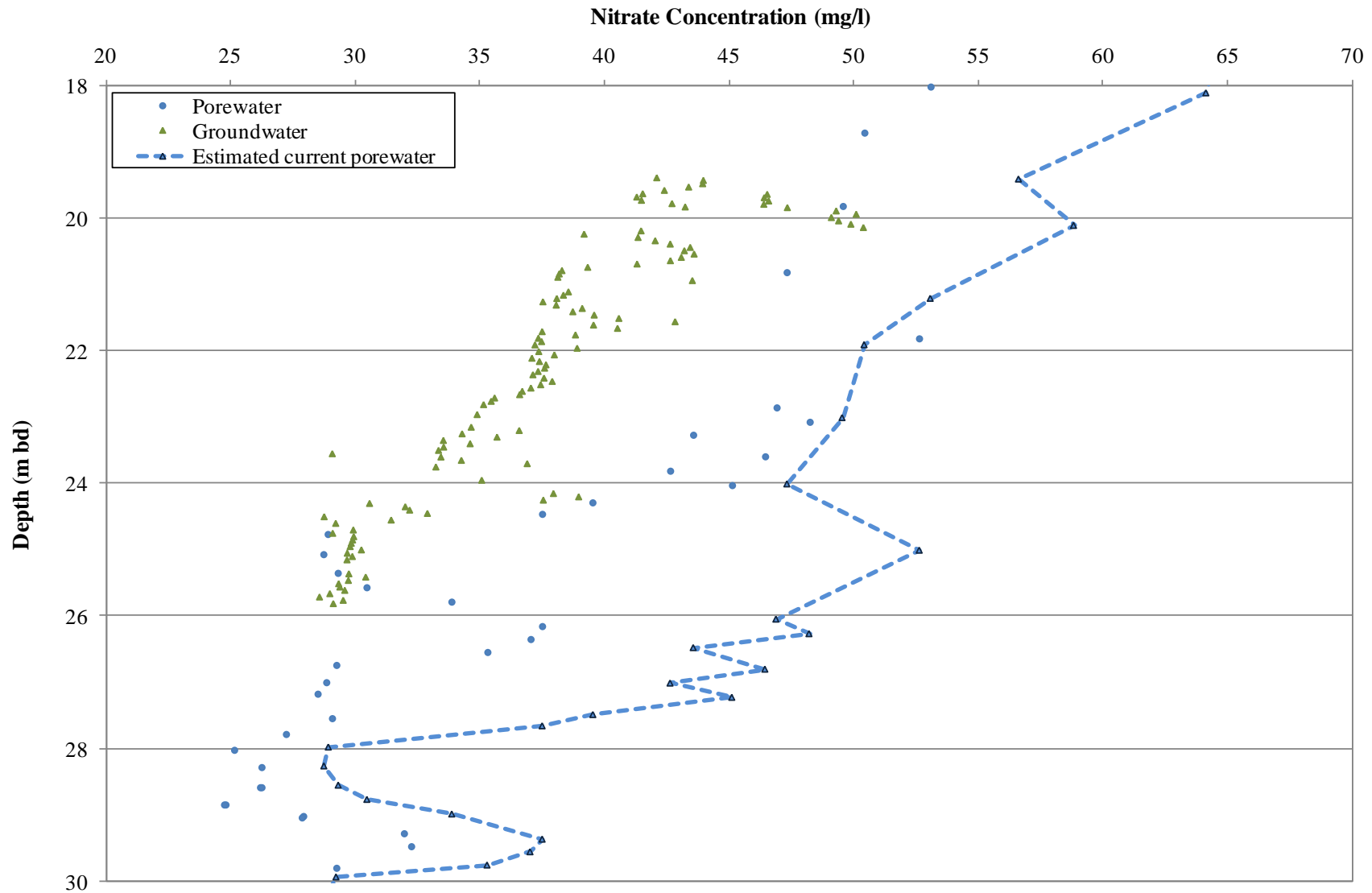


Figure 4.6 Normalised depth profiles of chloride, sulphate and nitrate with sampling dates shown as dotted horizontal lines.



Note: Date of sample capture is estimated from water levels recorded in Borehole B.

Figure 4.7 Relating nitrate concentrations in Borehole B to groundwater level over the sampling period.



Note: Porewater data are from Borehole A and groundwater data from Borehole B; estimated current porewaters assume a vertical movement of 0.8 m yr^{-1} .

Figure 4.8 Depth profiles of groundwater nitrate concentrations from 2008-9 (Borehole B) and porewater nitrate concentrations from 2006 (Borehole A).

5 Conclusions and future programme

5.1 CONCLUSIONS

A total of 140 samples were collected from Borehole B between 25.9 and 19.4 m bd at a typical depth resolution of 0.05 m between December 2010 and March 2011. These indicated concentrations of chloride, sulphate and nitrate (as NO₃) range between 11.6 and 27.8 mg/l, 7.3 and 24.8 mg/l, and 19.7 and 50.4 mg/l. Additionally 11 samples were retrieved in the multi-level sampler above the water table. Many of these samples were so dilute that they tend towards expected rainfall composition. Other samples which contained typical groundwater concentrations of chloride are depleted in sulphate and usually nitrate. This could be indicative of these waters been reduced at some point or possibly of an alternative contaminant source which is relatively enriched in chloride such as road salt. One sample collected above the water table contained elevated concentrations of nitrate and this has occurred in both previous recharge seasons.

Analysis of the groundwater samples indicated:

- A general rising trend in nitrate groundwater concentration with water levels between 26 and 19.4 m bd, although falls in concentration do often follow peaks.
- Sudden increases in concentration at 24.2, 21.6, 20.7, and 20.1 m bd which sometimes correspond with open fractures. This trend is similar to the 2009/10 recharge season.
- Concentrations always below the porewater concentration at the estimated same depth.
- No correlation between the observed trends and site visits indicating there are no issues with the current sampling procedure.

Nine samples were also collected at a consistent depth (29.8 m bd) in Borehole A. These suggested initial concentrations of chloride, sulphate and nitrate were similar to those recorded 26-25 m bd in Borehole B but final concentrations were lower. This is indicative of some, but not complete, mixing between shallower and deeper groundwaters.

5.2 FUTURE PROGRAMME

During the forthcoming year the sampling procedure will be repeated and also address the following points:

- The sampler will not be removed at 15.5 or 20.0 m bd to further confirm the sudden increases in concentration identified in 2009/10 were not associated with the sampling procedure.
- Potential contamination will be investigated by processing blank samples through the current sampling procedure.

Additionally the following activities will be undertaken:

- Further geophysical logging, when stressing the borehole to a greater degree, and/or dilution tests will be employed to infer the borehole regime at the end of the upcoming recharge year, assuming a 'normal' recharge year. The water quality sonde will also be re-calibrated and re-run to produce a nitrate depth profile at this time.
- Soil samples will be collected to investigate current nitrogen concentrations at the surface.

- Water samples will be regularly bailed from Borehole B during the summer/autumn recession to examine nitrate fluctuations during potentially low groundwater levels.

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

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Appendix A – Water quality samples and results

LIMS Code	Sample Code	Collection Date	Estimated sample capture time	Sample depth (m bd)	Cl ⁻ (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	Br ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	HPO ₄ ²⁻ (mg/l)	F ⁻ (mg/l)
12584-0005	10	07/12/2010	21/11/2010 21:00	25.86	15.9	10.9	19.7	0.053	0.037	<0.200	0.128
12584-0006	15	07/12/2010	25/11/2010 06:00	25.81	15.8	10.7	29.1	0.058	0.044	<0.200	0.118
12584-0007	20	07/12/2010	25/11/2010 18:00	25.76	16.2	11.0	29.5	0.049	<0.020	<0.200	0.117
12584-0008	25	07/12/2010	26/11/2010 15:00	25.71	15.6	10.8	28.6	0.050	0.034	<0.200	0.114
12584-0009	30	07/12/2010	28/11/2010 00:00	25.66	16.5	10.7	29.0	0.062	<0.020	<0.200	0.062
12584-0010	35	07/12/2010	30/11/2010 15:00	25.61	15.8	10.9	29.6	0.065	<0.020	<0.200	0.113
12584-0011	40	07/12/2010	02/12/2010 00:00	25.56	15.8	10.9	29.4	0.058	0.028	<0.200	0.112
12584-0012	45	07/12/2010	03/12/2010 12:00	25.51	16.1	11.0	29.3	0.054	<0.020	<0.200	0.109
12584-0013	50	07/12/2010	03/12/2010 21:00	25.46	16.0	11.1	29.7	0.053	0.060	<0.200	0.110
12584-0014	55	07/12/2010	04/12/2010 09:00	25.41	16.3	11.2	30.4	0.054	<0.020	<0.200	0.119
12584-0015	60	07/12/2010	05/12/2010 00:00	25.36	16.0	10.9	29.7	0.055	<0.020	<0.200	0.110
12584-0016	65	07/12/2010	05/12/2010 21:00	25.31	16.0	10.9	29.4	0.052	<0.020	<0.200	0.114
12584-0017	230	07/12/2010		23.66	3.59	1.61	4.82	<0.040	0.063	<0.200	0.034
12584-0018	240	07/12/2010		23.56	2.96	1.31	2.97	<0.040	0.060	<0.200	0.048
12584-0019	250	07/12/2010		23.46	5.41	2.14	4.84	<0.040	0.076	<0.200	0.107
12584-0020	270	07/12/2010		23.26	23.6	10.1	42.1	<0.040	0.220	<0.200	0.083
12584-0023	10	22/12/2010	10/12/2010 15:00	25.15	16.0	11.1	29.7	0.052	0.029	<0.200	0.110
12584-0024	15	22/12/2010	11/12/2010 09:00	25.10	16.6	11.1	29.9	0.052	<0.020	<0.200	0.108
12584-0025	20	22/12/2010	12/12/2010 15:00	25.05	16.6	11.1	29.7	0.055	<0.020	<0.200	0.106
12584-0026	25	22/12/2010	14/12/2010 15:00	25.00	17.2	12.2	30.2	0.054	<0.020	<0.200	0.107
12584-0027	30	22/12/2010	15/12/2010 12:00	24.95	16.6	11.5	29.8	0.052	<0.020	<0.200	0.107
12584-0028	35	22/12/2010	16/12/2010 02:00	24.90	16.4	10.9	29.8	0.051	<0.020	<0.200	0.114
12584-0029	40	22/12/2010	16/12/2010 12:00	24.85	16.8	11.0	29.9	0.048	<0.020	<0.200	0.107
12584-0030	45	22/12/2010	17/12/2010 15:00	24.80	16.6	11.0	29.9	0.054	<0.020	<0.200	0.108
12584-0031	50	22/12/2010	19/12/2010 09:00	24.75	16.3	10.7	29.1	0.060	<0.020	<0.200	0.106

LIMS Code	Sample Code	Collection Date	Estimated sample capture time	Sample depth (m bd)	Cl ⁻ (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	Br ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	HPO ₄ ²⁻ (mg/l)	F ⁻ (mg/l)
12584-0032	55	22/12/2010	21/12/2010 09:00	24.70	16.3	11.1	29.9	0.053	0.025	<0.200	0.066
12584-0033	260	22/12/2010		22.65	25.9	9.70	25.8	<0.040	0.457	<0.200	0.060
12584-0036	10	07/01/2011	27/12/2010 03:00	24.60	16.4	11.1	29.2	0.064	0.067	<0.200	0.106
12584-0037	15	07/01/2011	27/12/2010 18:00	24.55	16.5	11.7	31.4	0.056	<0.020	<0.200	0.086
12584-0038	20	07/01/2011	29/12/2010 00:00	24.50	16.2	10.9	28.7	0.055	0.067	<0.200	0.112
12584-0039	25	07/01/2011	30/12/2010 18:00	24.45	17.3	12.1	32.9	0.055	0.029	<0.200	0.060
12584-0040	30	07/01/2011	01/01/2011 09:00	24.40	17.0	11.8	32.2	0.051	<0.020	<0.200	0.109
12584-0041	35	07/01/2011	03/01/2011 03:00	24.35	17.4	11.8	32.0	0.056	<0.020	<0.200	0.112
12584-0042	40	07/01/2011	04/01/2011 00:00	24.30	16.7	11.2	30.6	0.058	<0.020	<0.200	0.110
12584-0043	45	07/01/2011	04/01/2011 15:00	24.25	19.0	13.6	37.5	0.056	<0.020	<0.200	0.097
12584-0044	50	07/01/2011	05/01/2011 09:00	24.20	18.8	13.9	39.0	0.059	<0.020	<0.200	0.102
12584-0045	55	07/01/2011	06/01/2011 09:00	24.15	18.4	13.5	37.9	0.083	<0.020	<0.200	0.107
12584-0046	230	07/01/2011		22.40	3.51	1.45	1.30	<0.040	<0.020	<0.200	0.078
12584-0047	260	07/01/2011		22.10	7.38	3.73	6.96	<0.040	0.061	<0.200	0.069
12584-0048	270	07/01/2011		22.00	27.2	10.3	18.3	0.044	0.392	<0.200	0.052
12605-0001	10	20/01/2011	10/01/2011 03:00	23.95	18.3	13.4	35.1	0.056	0.062	<0.100	0.081
12605-0002	20	20/01/2011	12/01/2011 02:00	23.85	11.6	7.34	19.9	0.038	<0.010	<0.100	0.037
12605-0003	30	20/01/2011	13/01/2011 12:00	23.75	17.9	12.8	33.2	0.058	0.024	<0.100	0.046
12605-0004	35	20/01/2011	14/01/2011 12:00	23.70	19.0	14.2	36.9	0.053	<0.010	<0.100	0.082
12605-0005	40	20/01/2011	15/01/2011 09:00	23.65	18.3	13.1	34.2	0.049	<0.010	<0.100	0.080
12605-0006	45	20/01/2011	16/01/2011 18:00	23.60	19.6	13.5	33.4	0.058	0.011	<0.100	0.080
12605-0007	50	20/01/2011	17/01/2011 09:00	23.55	15.8	11.2	29.1	0.035	<0.010	<0.100	0.042
12605-0008	55	20/01/2011	18/01/2011 03:00	23.50	17.9	12.6	33.3	0.043	<0.010	<0.100	0.080
12605-0009	60	20/01/2011	18/01/2011 12:00	23.45	18.0	12.8	33.5	0.052	<0.010	<0.100	0.080
12605-0010	65	20/01/2011	18/01/2011 20:00	23.40	18.5	13.1	34.6	0.053	<0.010	<0.100	0.039
12605-0011	70	20/01/2011	19/01/2011 04:00	23.35	18.7	13.0	33.5	0.068	<0.010	<0.100	0.095
12605-0012	75	20/01/2011	19/01/2011 11:00	23.30	18.7	13.5	35.7	0.029	<0.010	<0.100	0.043

LIMS Code	Sample Code	Collection Date	Estimated sample capture time	Sample depth (m bd)	Cl ⁻ (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	Br ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	HPO ₄ ²⁻ (mg/l)	F ⁻ (mg/l)
12605-0013	80	20/01/2011	19/01/2011 17:00	23.25	18.1	13.0	34.3	0.106	<0.010	<0.100	0.080
12605-0014	85	20/01/2011	19/01/2011 23:00	23.20	19.2	14.4	36.6	0.052	<0.010	<0.100	0.083
12605-0015	90	20/01/2011	20/01/2011 04:30	23.15	18.4	13.4	34.6	0.052	0.021	<0.100	0.076
12605-0016	350	20/01/2011		20.55	8.78	2.50	0.470	0.027	0.019	<0.100	0.047
12605-0019	10	26/01/2011	21/01/2011 01:00	22.96	19.0	13.7	34.9	0.058	<0.010	<0.100	0.038
12605-0020	15	26/01/2011	21/01/2011 06:00	22.81	18.8	13.6	35.1	0.057	<0.010	<0.100	0.080
12605-0021	20	26/01/2011	21/01/2011 10:00	22.76	18.9	14.4	35.4	0.050	<0.010	<0.100	0.039
12605-0022	25	26/01/2011	21/01/2011 13:30	22.71	19.3	14.3	35.6	0.055	<0.010	<0.100	0.083
12605-0023	30	26/01/2011	21/01/2011 18:30	22.66	19.3	14.3	36.6	0.059	0.010	<0.100	0.036
12605-0024	35	26/01/2011	21/01/2011 22:30	22.61	19.6	14.6	36.7	0.058	<0.010	<0.100	0.048
12605-0025	40	26/01/2011	22/01/2011 03:00	22.56	19.9	14.6	37.0	0.055	<0.010	<0.100	0.044
12605-0026	45	26/01/2011	22/01/2011 06:30	22.51	20.2	14.6	37.4	0.055	<0.010	<0.100	0.045
12605-0027	50	26/01/2011	22/01/2011 10:30	22.46	20.2	14.7	37.9	0.054	<0.010	<0.100	0.051
12605-0028	55	26/01/2011	22/01/2011 13:30	22.41	20.0	14.6	37.6	0.055	<0.010	<0.100	0.045
12605-0029	60	26/01/2011	22/01/2011 17:00	22.36	19.9	14.5	37.1	0.056	<0.010	<0.100	0.038
12605-0030	65	26/01/2011	22/01/2011 21:00	22.31	20.0	14.6	37.3	0.053	<0.010	<0.100	0.047
12605-0031	70	26/01/2011	23/01/2011 00:30	22.26	19.9	14.6	37.6	0.053	<0.010	<0.100	0.046
12605-0032	75	26/01/2011	23/01/2011 04:00	22.21	19.9	14.5	37.6	0.042	<0.010	<0.100	0.079
12605-0033	80	26/01/2011	23/01/2011 07:30	22.16	20.2	14.8	37.4	0.055	<0.010	<0.100	0.049
12605-0034	85	26/01/2011	23/01/2011 11:00	22.11	20.2	14.9	37.1	0.057	<0.010	<0.100	0.080
12605-0035	90	26/01/2011	23/01/2011 15:00	22.06	20.1	14.8	38.0	0.055	<0.010	<0.100	0.036
12605-0036	95	26/01/2011	23/01/2011 18:30	22.01	19.9	14.8	37.4	0.049	<0.010	<0.100	0.078
12605-0037	100	26/01/2011	23/01/2011 22:00	21.96	20.8	15.9	38.9	0.052	<0.010	<0.100	0.082
12605-0038	105	26/01/2011	24/01/2011 01:30	21.91	19.9	14.9	37.2	0.053	<0.010	<0.100	0.087
12605-0039	110	26/01/2011	24/01/2011 04:30	21.86	19.8	14.9	37.5	0.064	<0.010	<0.100	0.043
12605-0040	115	26/01/2011	24/01/2011 08:00	21.81	19.4	14.7	37.3	0.054	<0.010	<0.100	0.079
12605-0041	120	26/01/2011	24/01/2011 11:00	21.76	20.5	15.6	38.8	0.053	<0.010	<0.100	0.056

LIMS Code	Sample Code	Collection Date	Estimated sample capture time	Sample depth (m bd)	Cl ⁻ (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	Br ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	HPO ₄ ²⁻ (mg/l)	F ⁻ (mg/l)
12605-0042	125	26/01/2011	24/01/2011 14:30	21.71	19.9	15.1	37.5	0.057	<0.010	<0.100	0.083
12605-0043	130	26/01/2011	24/01/2011 18:00	21.66	22.1	16.9	40.5	0.058	<0.010	<0.100	0.080
12605-0044	135	26/01/2011	24/01/2011 21:00	21.61	21.1	16.1	39.6	0.060	<0.010	<0.100	0.079
12605-0045	140	26/01/2011	25/01/2011 00:00	21.56	23.3	18.1	42.8	0.057	<0.010	<0.100	0.025
12605-0046	145	26/01/2011	25/01/2011 03:00	21.51	21.5	16.8	40.6	0.053	<0.010	<0.100	0.036
12605-0047	150	26/01/2011	25/01/2011 06:00	21.46	21.2	16.4	39.6	0.055	<0.010	<0.100	0.041
12605-0048	155	26/01/2011	25/01/2011 09:30	21.41	20.7	16.0	38.7	0.056	<0.010	<0.100	0.043
12605-0049	160	26/01/2011	25/01/2011 12:30	21.36	20.7	16.1	39.1	0.064	<0.010	<0.100	0.079
12605-0050	165	26/01/2011	25/01/2011 15:30	21.31	20.7	15.6	38.1	0.068	0.013	<0.100	0.042
12605-0051	170	26/01/2011	25/01/2011 18:00	21.26	20.0	15.2	37.5	0.055	<0.010	<0.100	0.078
12605-0052	175	26/01/2011	25/01/2011 21:00	21.21	20.4	15.6	38.1	0.061	<0.010	<0.100	0.078
12605-0053	180	26/01/2011	26/01/2011 00:30	21.16	20.2	15.2	38.3	0.053	<0.010	<0.100	0.042
12605-0054	185	26/01/2011	26/01/2011 03:30	21.11	20.6	16.1	38.5	0.064	<0.010	<0.100	0.078
12624-0001	10 04/02/2011	04/02/2011	27/01/2011 07:30	20.94	24.2	20.3	43.5	0.060	<0.010	<0.100	0.080
12624-0002	15 04/02/2011	04/02/2011	27/01/2011 11:30	20.89	20.8	16.0	38.1	0.058	<0.010	<0.100	0.082
12624-0003	20 04/02/2011	04/02/2011	27/01/2011 15:30	20.84	20.5	15.9	38.2	0.056	<0.010	<0.100	0.084
12624-0004	25 04/02/2011	04/02/2011	27/01/2011 19:30	20.79	20.9	16.0	38.3	0.055	<0.010	<0.100	0.081
12624-0005	30 04/02/2011	04/02/2011	28/01/2011 00:00	20.74	21.7	16.6	39.3	0.064	0.012	<0.100	0.097
12624-0006	35 04/02/2011	04/02/2011	28/01/2011 04:00	20.69	23.5	17.9	41.3	0.063	0.020	<0.100	0.083
12624-0007	40 04/02/2011	04/02/2011	28/01/2011 08:00	20.64	24.0	18.4	42.6	0.056	0.011	<0.100	0.081
12624-0008	45 04/02/2011	04/02/2011	28/01/2011 12:30	20.59	24.3	18.7	43.1	0.061	<0.010	<0.100	0.080
12624-0009	50 04/02/2011	04/02/2011	28/01/2011 17:00	20.54	24.6	18.9	43.6	0.058	0.016	<0.100	0.077
12624-0010	55 04/02/2011	04/02/2011	28/01/2011 20:30	20.49	24.3	18.8	43.2	0.062	<0.010	<0.100	0.080
12624-0011	60 04/02/2011	04/02/2011	29/01/2011 02:30	20.44	24.3	19.0	43.4	0.059	<0.010	<0.100	0.082
12624-0012	65 04/02/2011	04/02/2011	29/01/2011 08:00	20.39	23.8	18.5	42.6	0.061	<0.010	<0.100	0.082
12624-0013	70 04/02/2011	04/02/2011	29/01/2011 13:30	20.34	23.3	18.3	42.0	0.060	<0.010	<0.100	0.086
12624-0014	75 04/02/2011	04/02/2011	29/01/2011 19:30	20.29	23.0	18.5	41.3	0.058	<0.010	<0.100	0.094

LIMS Code	Sample Code	Collection Date	Estimated sample capture time	Sample depth (m bd)	Cl ⁻ (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	Br ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	HPO ₄ ²⁻ (mg/l)	F ⁻ (mg/l)
12624-0015	80 04/02/2011	04/02/2011	30/01/2011 01:30	20.24	22.0	17.1	39.2	0.056	<0.010	<0.100	0.083
12624-0016	85 04/02/2011	04/02/2011	30/01/2011 07:30	20.19	22.7	18.2	41.5	0.057	<0.010	<0.100	0.082
12624-0017	90 04/02/2011	04/02/2011	30/01/2011 13:30	20.14	26.6	24.8	50.4	0.064	<0.010	<0.100	0.073
12624-0018	95 04/02/2011	04/02/2011	30/01/2011 22:30	20.09	26.4	24.8	49.9	0.063	<0.010	<0.100	0.075
12624-0019	100 04/02/2011	04/02/2011	31/01/2011 05:30	20.04	25.5	24.5	49.4	0.063	<0.010	<0.100	0.074
12624-0020	105 04/02/2011	04/02/2011	31/01/2011 15:00	19.99	25.7	24.6	49.1	0.063	<0.010	<0.100	0.073
12624-0021	110 04/02/2011	04/02/2011	01/02/2011 01:00	19.94	26.0	24.4	50.1	0.061	<0.010	<0.100	0.028
12624-0022	115 04/02/2011	04/02/2011	01/02/2011 11:00	19.89	26.5	23.8	49.3	0.064	<0.010	<0.100	0.074
12624-0023	120 04/02/2011	04/02/2011	02/02/2011 00:00	19.84	26.3	22.9	47.3	0.063	<0.010	<0.100	0.082
12624-0024	125 04/02/2011	04/02/2011	02/02/2011 09:30	19.79	25.6	22.3	46.4	0.062	<0.010	<0.100	0.076
12624-0025	130 04/02/2011	04/02/2011	02/02/2011 21:00	19.74	25.8	22.0	46.6	0.060	<0.010	<0.100	0.075
12624-0026	135 04/02/2011	04/02/2011	03/02/2011 15:00	19.69	25.1	21.8	46.4	0.061	<0.010	<0.100	0.076
12624-0027	140 04/02/2011	04/02/2011	04/02/2011 06:00	19.64	25.4	21.9	46.5	0.060	<0.010	<0.100	0.073
12661-0001	10	22/02/2011	07/02/2011 12:00	19.39	25.2	22.0	42.1	0.065	0.057	<0.100	0.078
12661-0002	260	22/02/2011		16.89	3.86	1.23	0.276	<0.020	<0.010	<0.100	0.058
12661-0003	270	22/02/2011		16.79	3.86	1.30	0.030	<0.020	<0.010	<0.100	0.061
12661-0006	10	16/03/2011	06/03/2011 06:00	19.83	22.2	20.2	43.2	0.056	0.503	<0.100	0.080
12661-0007	15	16/03/2011	07/03/2011 13:00	19.78	21.9	19.2	42.7	0.056	<0.010	<0.100	0.046
12661-0008	20	16/03/2011	08/03/2011 15:00	19.73	21.7	19.0	41.5	0.058	<0.010	<0.100	0.080
12661-0009	25	16/03/2011	09/03/2011 18:00	19.68	21.8	19.2	41.3	0.059	0.016	<0.100	0.083
12661-0010	30	16/03/2011	10/03/2011 15:00	19.63	21.7	19.2	41.5	0.056	0.098	<0.100	0.081
12661-0011	35	16/03/2011	11/03/2011 22:00	19.58	22.3	19.3	42.4	0.060	<0.010	<0.100	0.077
12661-0012	40	16/03/2011	12/03/2011 14:00	19.53	22.5	20.0	43.4	0.059	<0.010	<0.100	0.080
12661-0013	45	16/03/2011	15/03/2011 00:00	19.48	22.4	20.3	43.9	0.059	0.019	<0.100	0.076
12661-0014	50	16/03/2011	16/03/2011 12:00	19.43	22.8	20.5	44.0	0.067	0.032	<0.100	0.079
12584-0001	BHA 29.8 m bd	18/11/2010		29.80	15.8	11.1	29.7	0.050	<0.020	<0.200	0.120
12584-0003	BHA 29.8 m bd	07/12/2010		29.80	16.0	10.8	28.9	0.059	0.028	<0.200	0.120

LIMS Code	Sample Code	Collection Date	Estimated sample capture time	Sample depth (m bd)	Cl ⁻ (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	Br ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	HPO ₄ ²⁻ (mg/l)	F ⁻ (mg/l)
12584-0021	BHA 29.8 m bd	22/12/2010		29.80	15.9	10.8	29.5	0.053	<0.020	<0.200	0.112
12584-0034	BHA 29.8 m bd	07/01/2011		29.80	15.9	10.9	29.9	0.057	<0.020	<0.200	0.115
12605-0017	BHA 29.8 m bd	20/01/2011		29.80	17.1	11.8	30.6	0.044	<0.010	<0.100	0.058
12605-0055	BHA 29.8 m bd	26/01/2011		29.80	17.2	12.4	31.9	0.051	<0.010	<0.100	0.048
12624-0028	BHA 29.8 m bd	04/02/2011		29.80	18.5	14.4	34.4	0.109	<0.010	<0.100	0.098
12661-0004	BHA 29.8 m bd	22/02/2011		29.80	18.4	15.0	36.0	0.053	0.054	<0.100	0.091
12661-0015	BHA 29.8 m bd	16/03/2011		29.80	18.5	15.8	36.8	0.055	0.112	<0.100	0.088
12584-0002	BH B bailed	18/11/2010		25.97	15.8	10.7	29.1	0.061	<0.020	<0.200	0.119
12584-0004	BH B bailed	07/12/2010		25.31	16.2	10.7	29.1	0.042	0.024	<0.200	0.090
12584-0022	BH B bailed	22/12/2010		24.70	15.9	10.8	29.7	0.046	<0.020	<0.200	0.108
12584-0035	BH B bailed	07/01/2011		24.15	18.5	13.5	37.3	<0.040	<0.020	<0.200	0.044
12605-0018	BH B bailed	20/01/2011		23.15	21.1	14.5	37.2	0.042	<0.010	<0.100	0.020
12605-0056	BH B bailed	26/01/2011		21.04	21.2	16.0	38.7	0.056	0.011	<0.100	0.026
12624-0029	BH B bailed	04/02/2011		19.49	27.8	22.8	48.0	0.066	<0.010	<0.100	0.344
12661-0005	BH B bailed	22/04/2011		19.93	24.3	22.8	48.8	0.062	<0.010	<0.100	0.063
12661-0016	BH B bailed	16/03/2011		19.43	23.1	20.8	45.4	0.060	<0.010	<0.100	0.081

