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Hydrogeological investigations at Morestead, Twyford, 2008-2009

Groundwater Resources Programme

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Hydrogeological investigations at Morestead, Twyford, 2008-2009

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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 at Morestead, Twyford, Hampshire. It forms the second output from the BGS project “Nitrate fluctuations in groundwater” and describes the installation of the second research borehole at the site, and observations from the recharge period following completion.

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Summary

This report describes work undertaken at Morestead, Twyford as part of a BGS research project “Nitrate Fluctuations in Groundwater”. The project uses the same site as that described in Stuart et al. (2008a) for the project “Nitrate Mass Balance in the Saturated Zone”.

A new borehole (Borehole B) was drilled in October 2008, located 10 m to the west of the existing one (Borehole A) to complement the existing infrastructure. During drilling the cuttings were inspected but no systematic recording of lithology was undertaken, as this information was already available in detail from the adjacent borehole. Borehole B was completed to a depth of 70 m and was cased to a depth of 12.7 mbgl; remaining unsupported below this. It should be stated that the casing protruded approximately 0.16 m above ground level. Initial geophysical characterisation was undertaken to evaluate the hole and its suitability for further testing.

A multi-level sampler was installed in Borehole B during autumn 2008 when the groundwater level was low. The aim was to capture samples as the water table rose towards the anticipated spring 2009 high. The sampler worked well for most of the period, but there were issues with bottles not filling consistently, and the sampler length was insufficient to cope with rapid water level rise following heavy rainfall or snow melt. Samples retrieved were analysed for chloride, sulphate and nitrate (as NO_3), which ranged between 16.9 and 68.8 mg/l, 11.7 and 29.9 mg/l, and <0.6 and 60.1 mg/l, respectively. Concentrations of nitrate appeared to increase as the water table rose above 20.5 mbgl; below this depth there is significant noise. Concentrations of sulphate and chloride both increased as the water table rose.

Gamma and resistivity logs identified marl horizons which correlated with the Borehole A core as reported in Stuart et al. (2008a). Fluid and flow logs also indicate hydraulic layering within the Chalk. Temperature and conductivity logs suggested vertical flow below c. 25 m below casing top, which is was also supported by heat pulse flow meter (HPFM) and impeller flow logs. This flow regime was unaltered by pumping from a depth of 21.5 m indicating reasonable permeability in the Chalk above this depth. A nitrate sonde was also run before and during pumping. The results are currently awaiting calibration and are not available at the time of reporting.

Groundwater levels were monitored in Borehole A and fluctuated over a range of 13.5 m, from around 10 to 23.5 mbgl, between December 2006 and the beginning of March 2009. However, numerous gaps in the data remain due to water levels exceeding the range of the pressure transducer initially installed in the borehole. Water levels were notably responsive to rainfall between December and February, for example between 25th January 2009 and 23rd February 2009 the water table rose by 8.7 m. The aquifer appears less responsive during summer and autumn when there is likely to be a greater soil moisture deficit.

1 Introduction

1.1 BACKGROUND AND OBJECTIVES

Concentrations of groundwater nitrate concentrations 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 more or less 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 site infrastructure and data collected thus far.

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 has 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) in the unsaturated zone and declining concentrations in the saturated zone (up to 39 mg), except in a 15 m thick zone of the Lewes Nodular Chalk about 25 m below the water table. 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 present landuse and agricultural regime. Moreover, much of the cultivated land is located in the upper part of the catchment and the nitrate is likely to be still present in the unsaturated 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. It was hoped that vertical mixing through the water column would also be minimal.
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.

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 completed 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.

2 Installation of Borehole B

2.1 EXISTING INFRASTRUCTURE

The location of the existing borehole (Borehole A - SU 5073 2528) is illustrated in Figure 2.1 It lies 1.5 km east of the public supply borehole at Twyford, Hampshire on the Chalk of the South Downs. The borehole was completed as two piezometers (Figure 2.2); however, these were unsuitable for continuous nitrate monitoring being too narrow and slightly twisted.

Further details of the location, hydrogeological setting and borehole design are outlined in Stuart et al. (2008a).

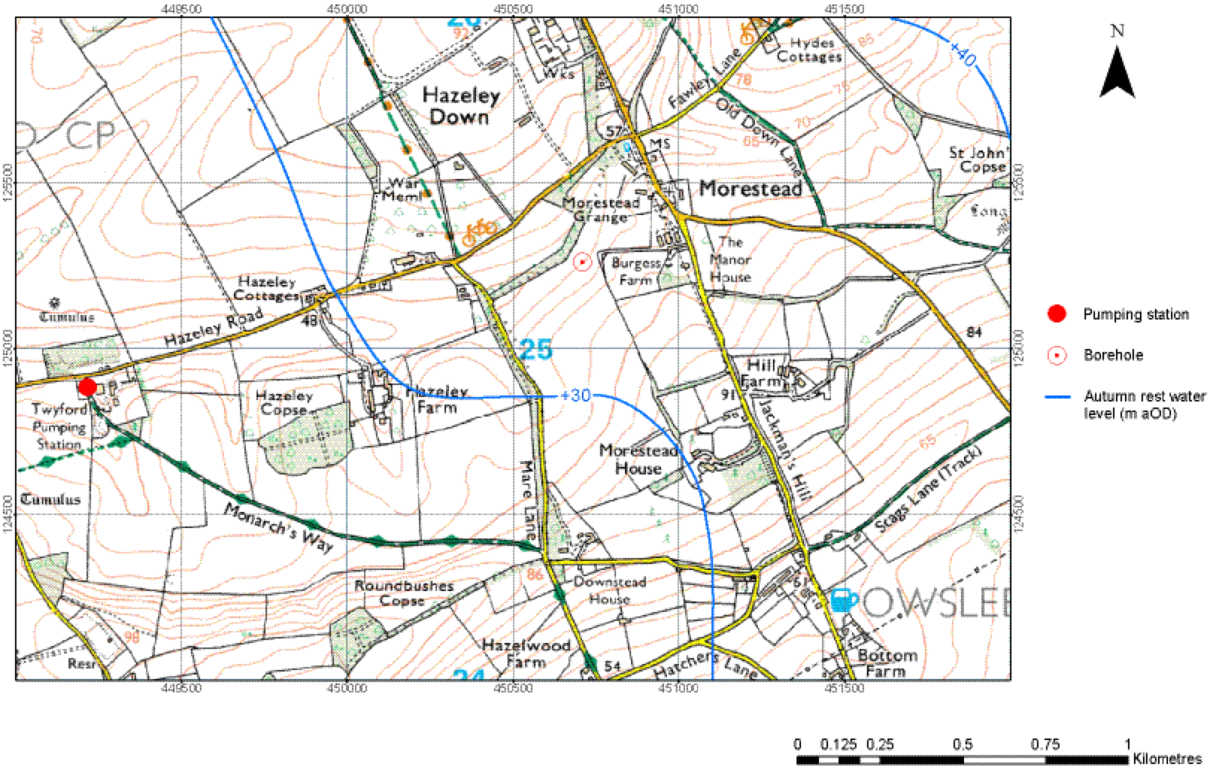
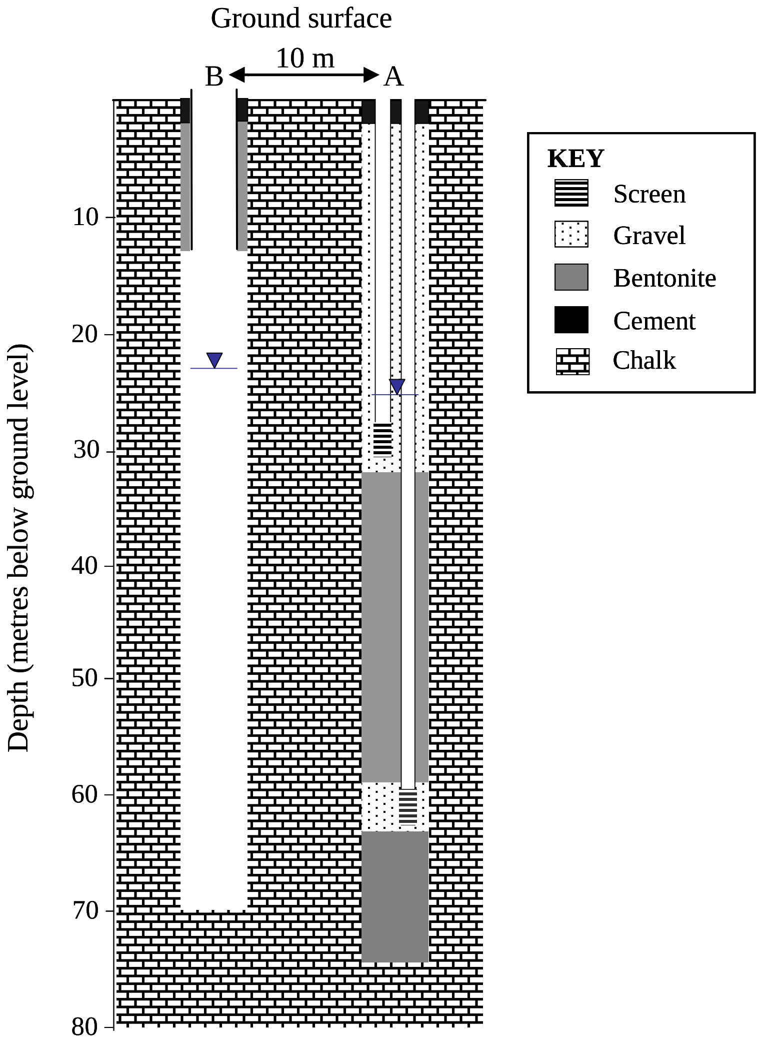


Figure 2.1 Site location and contours of autumn rest water levels (1973) from the Hampshire and Isle of Wight hydrogeological map (IGS, 1979)

2.2 DRILLING AND LOGGING

Drilling of the new Morestead borehole (Borehole B) commenced on 13th October 2008 around 10 m west of the existing piezometers. A 200 mm rotary tri-cone bit drilling with air-flush was utilised. Drilling continued to a total depth of 47 m below the water table and the hole was completed at 70 m on 15th October 2008. Permanent steel casing was installed to the base of the weathered Chalk at 12.7 metres below ground level (mbgl), with the hole remaining unsupported below this depth. The casing was fixed using a bentonite grout. The upper 1 m of casing was left protruding by 0.16 above the ground surface so that it could be removed at the end of the project. The drilling cuttings were inspected during drilling but no systematic recording was undertaken, as Borehole A had been cored and logged.



Note: water levels are shown from time of drilling; ground level at Borehole A is elevated above Borehole B by approximately 0.3 m; Borehole A datum is ground level; Borehole B datum is top of the casing, which protrudes 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

Rainfall data were retrieved from the Meteorological Office Database – MIDAS for selected currently operational stations near Morestead (UK Meteorological Office, 1853-current). These are shown in Table 3.1.

Otterbourne Water Works was the nearest MIDAS station to the field site and recorded two separate rainfall datasets: from an ordinary climatological station and also a rainfall station. 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 November 2009 total precipitation differed by around 5% (over 100 mm) between the two time series.

Table 3.1 Nearby MIDAS stations with rainfall data

Station Name	National Grid Reference (NGR)	Elevation (m aOD)	Data start date
Lake End: Longwood View	SU 557257	128	01/10/2000
Merdon Manor	SU 411266	118	01/01/1938
Otterbourne Water Works	SU 467234	34	01/01/1892
Sparsholt: Woodman Close	SU 437309	102	01/11/2000

Note: metres above Ordnance Datum (m aOD)

3.2 WATER LEVEL RECORDING

A 5-m range pressure transducer 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 diver was deployed, instead, at the base of the piezometer (30 metres below ground level) on 11th April 2008.

On each site visit the diver data were downloaded, and the borehole was dipped manually to allow the later conversion of the diver pressure readings to actual groundwater level. Borehole B was also dipped manually.

3.3 GEOPHYSICAL LOGGING

3.3.1 Initial characterisation

On completion of Borehole B, geophysical logging was carried out on 16th and 17th October 2008 to evaluate the suitability of the hole for further testing. This involved running the following tools:

- Temperature and conductivity multiple electrode sonde (TCME).
- Natural gamma ray sonde (NGRS).
- Borehole optical televiewer (OPTV).
- Caliper.

3.3.2 Subsequent investigations

Additional investigations were undertaken on 12th March, 30th April, 8th September and 9th September 2009 when the water level was 14.05, 19.55, 25.34 and 25.39 m below casing top (bct), respectively. These included:

- Initial profiling with a TCME sonde to identify potential flowing fracture horizons during ambient and low rate pumped conditions (12th March). Water samples were obtained before and during pumping for ICP-OES and nitrate analysis by ion chromatography.
- Logging the unstressed borehole flow regime with a heat pulse flow meter sonde (HPFM) (12th March) (Figure 3.1).
- Running a nitrate sonde (Figure 3.2) to investigate changes in concentration through the water column (12th March, 30th April, 9th September).
- Impeller flow meter logging during ambient and pumped conditions at high water level (30th April) and low water level (9th September). This included multiple static measurements around 25 m bct to investigate a potentially significant inflow (30th April).
- Caliper, gamma and resistivity profiling for stratigraphic purposes (8th September).
- A further improved OPTV run (8th September).

Figure 3.1 Running the nitrate sonde in stack with the HPFM (12th March 2009)

Figure 3.2 Running the nitrate sonde whilst pumping at a low rate (12th March 2009)

3.4 WATER SAMPLING

3.4.1 Completion water

On completion of the borehole on 15th October 2008 a sample was pumped from Borehole B. This was scheduled for nitrate, chloride and sulphate analysis by ion chromatography, and ICP-OES analysis (Appendix A).

3.4.2 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 3.3). The sampler originally had 18 bottles fixed at regular intervals along two 1-m adjoined sections of slotted plastic tracking (Figure 3.4). Two additional bottles were later added to increase the total to 20 sample bottles; the distance between sampling units was thus around 0.1 m.

The sampler was suspended just above the water table at 22.8 mbgl on 3rd November 2008 when the groundwater level was low, with the aid of borehole CCTV. The aim was to capture groundwater samples from known depths as the water table rose towards the bottom of the borehole casing; anticipated to be in spring 2009. The site was periodically visited following rainfall events and individual units containing groundwater were removed from the sampler. Subsequently the device was re-suspended at the new water level with fresh sample bottles in place. It should be noted that heavy snowfall prevented any site visit between 11th and 20th February 2009. Samples were retrieved on 26th November 2008, 9th December 2008, 22nd December 2008, 9th January 2009, 27th January 2009, 11th and 20th February 2009.

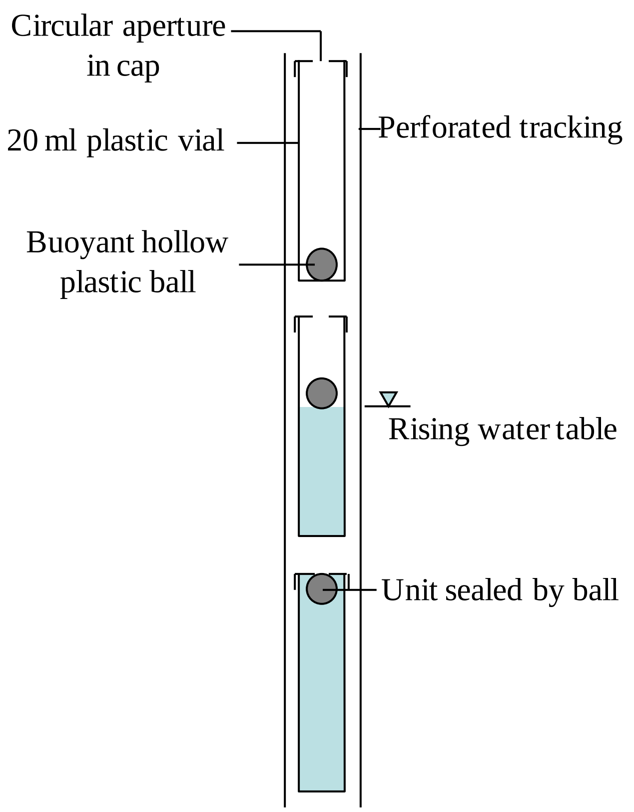


Figure 3.3 Schematic diagram of multi-level sampler bottle

The vast majority of collected samples were scheduled for nitrate, chloride and sulphate analysis by ion chromatography. A full list of samples collected and those selected for nitrate analysis is presented in Appendix A. The sampler was removed on 20th February 2009 when the water table was recorded in the casing and subsequently re-installed on 12th March 2009 after the water level had receded back below the casing.

3.4.3 Bailer

Periodically a bailer was used to sample groundwater from the water table in Borehole B. The bailer was lowered into the water column gently, with the assistance of the borehole CCTV camera, to avoid excessive mixing. The samples were subsequently scheduled for nitrate ion chromatography and ICP-OES analyses (Appendix A).

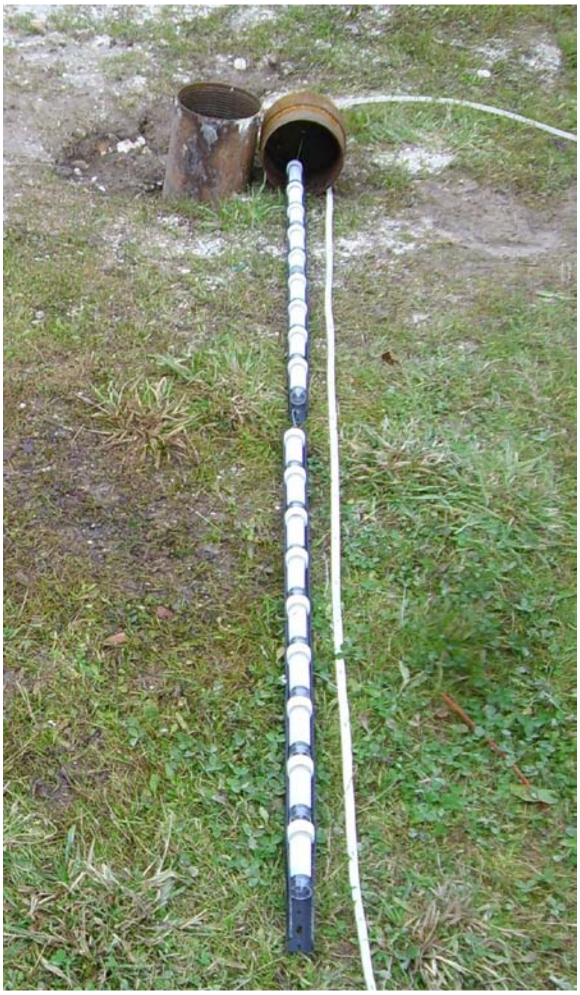


Figure 3.4 The multilevel sampler hanging via a cable from the cap of Borehole B prior to lowering down the hole.

4 Results and interpretation

4.1 WATER LEVEL RECORDING

Water level data were processed to remove spurious readings and combined with rainfall data from Otterbourne Water Works (Figure 4.1). Monthly totals of the rainfall data are shown for 2007 and 2008 in Table 4.1.

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

Between December 2007 and March 2009, available water levels ranged between 23.5 and around 10 mbgl, although a manual dip undertaken in October 2006 recorded a level of 27.6 mbgl.

Figure 4.2 compares the relationship between groundwater level and cumulative rainfall over the period when samples were actively collected. This shows that the response to rainfall appears to differ throughout the year. For example around 25 mm of precipitation fell on 13th December 2008, which resulted in a water level rise of around 1.5 m over a period of 22 days. On 10th February 2009, 26 mm of precipitation resulted in a rise of around 3.9 m over 10 days.

The groundwater hydrograph also shows natural recessions following the cessation of a rainfall event; this can be rapid, e.g. water levels fell only 6 days after the termination of the significant February recharge event. 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
					2009						
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
107.6	55.0	41 #	-	-	-	-	-	-	-	-	-

Notes: # March 2009 rainfall only up to and including 13th.

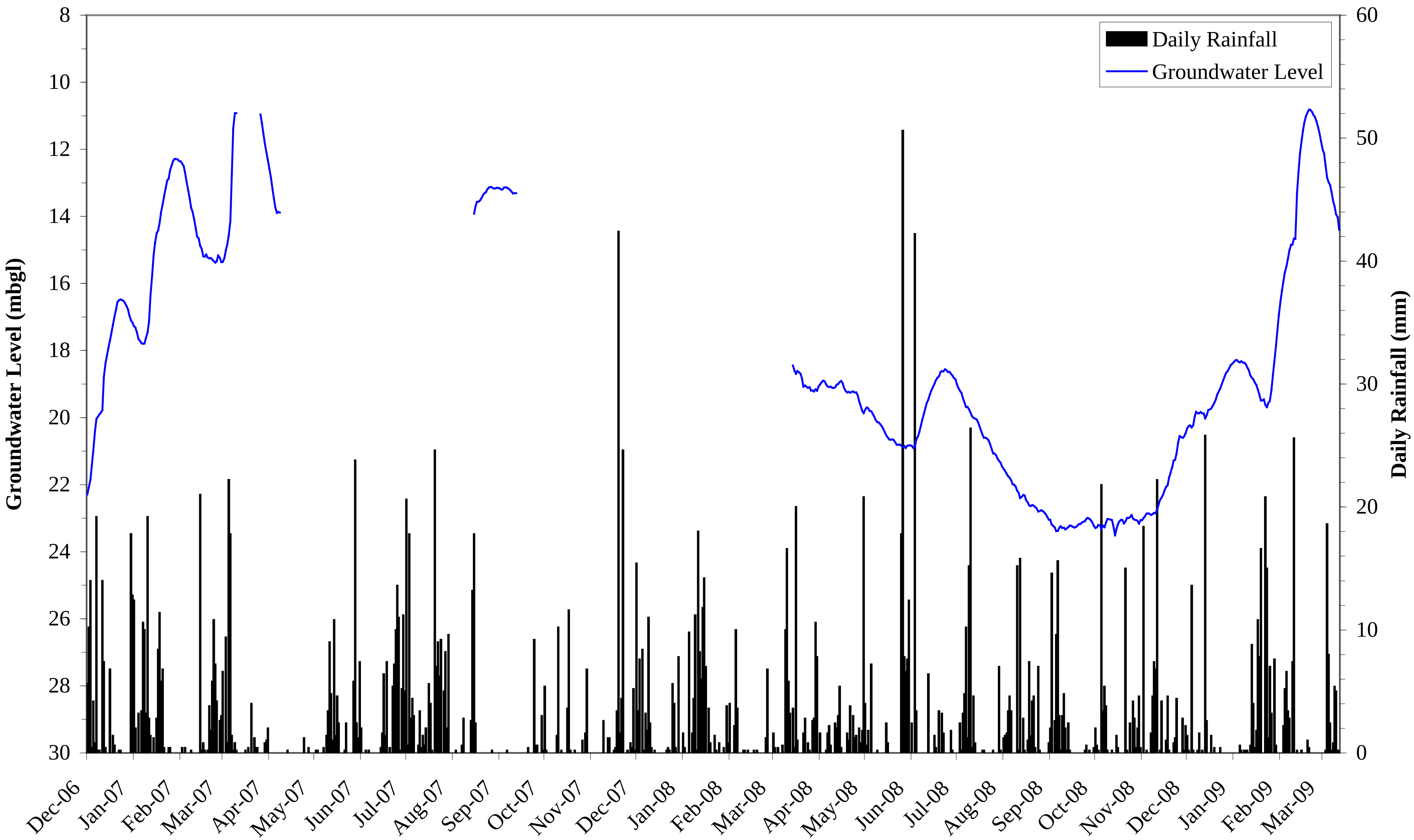


Figure 4.1 Daily groundwater hydrograph for Borehole A and rainfall from Otterbourne Water Works

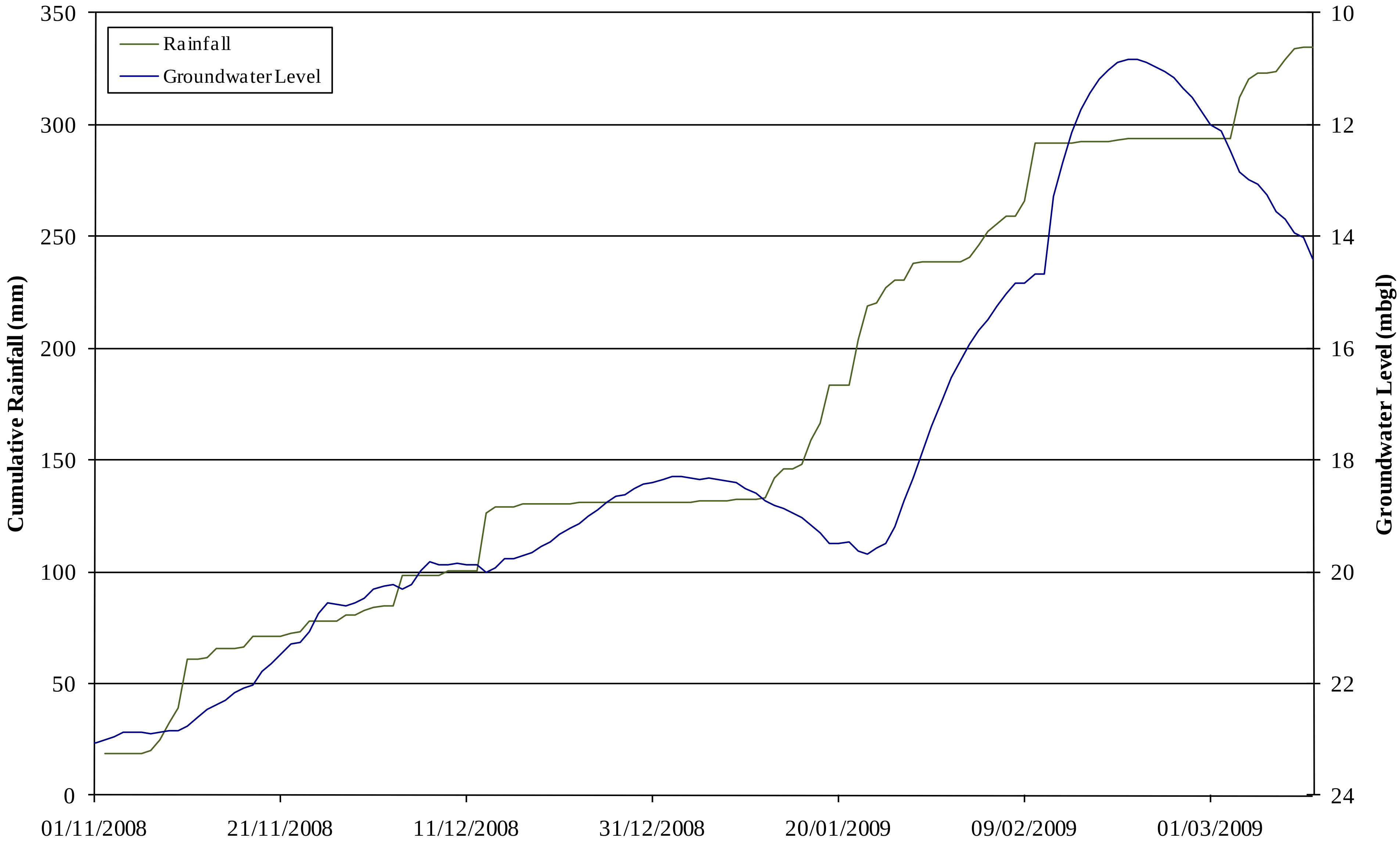


Figure 4.2 Comparison of daily groundwater level and cumulative rainfall between November 2008 and March 2009

4.2 GEOPHYSICAL LOGGING

The Borehole B OPTV imagery (September 2009) is presented as Appendix B. This confirmed the depth of the hole, the casing position and the following significant features above the summer rest water level:

- Significant flint bands – indicating potentially weaker Chalk- at 13.7, 14.1, 18.8 m bct.
- Open fractures 16.8, 19.2, 20.1 and 20.7 m bct.
- A solution enlarged fracture at 25.3 m bct which appeared to be flowing approximately 0.05 m above the water table.

Preliminary geophysical logs from October 2008 and March 2009 are presented in Appendix C. Many of the gamma-highs and resistivity-lows recorded correlate with marl horizons identified in the core obtained from Borehole A (see Stuart et al. 2008a).

Inspection of the fluid and flow logs suggests potential inflows to the borehole at 18.8, 22.0 and 25.4 m bct. Furthermore, the logs indicate hydraulic layering within the Chalk at the site. Below 36 m bct the unpumped fluid temperature and fluid conductivity logs are relatively featureless. Between 26 m bct and approximately 58 m bct the temperature profile, in particular, is quite flat suggesting that there is vertical flow below 26 m bct to the base of the borehole during ambient conditions. The HPFM and impeller flow logs also denote downflow below approximately 25 m bct. This downflow persists during pumping, thus indicating that there is sufficient permeability above 25 m bct in the Chalk to satisfy the abstraction rate of 2.1 l/s over 110 seconds.

All nitrate sonde data still requires further calibration work prior to reporting.

More detailed discussion and interpretation, including features below the summer rest water level, are reported in Woods (2010).

4.3 WATER SAMPLING

4.3.1 Site observations

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

- Frequently bottles were only partially full, despite having been completely submerged.
- On one occasion a unit (K5) was partially filled despite no rise in groundwater level.
- Samples were often opaque, but occasionally brown (K1).

4.3.2 Variation in water sample chemistry

Water quality data are presented as Appendix D. Concentrations of chloride, sulphate and nitrate (as NO_3) range between 16.9 and 68.8 mg/l, 11.7 and 29.9 mg/l, and <0.6 and 60.1 mg/l, respectively. The greatest concentrations of nitrate and sulphate were recorded in a bailed sample from 13.85 mbgl on 12th March 2009. A chloride ion concentration of 68.8 mg/l, over twice that present in any other sample, was collected at a depth of 19.04 mbgl on January 27th 2009. This bottle (K5) not been submerged and hence the chemistry is not truly representative of groundwater at that depth. The sample also contained elevated concentrations of sulphate and nitrate. Therefore, K5 is unlikely to be a result of condensation forming under the borehole cap. It is more likely to be derived from water either entering the borehole down the outside of the casing or being delivered from a fracture(s) above the water table.

There are also three anomalously low nitrate readings recorded between 20.9 and 22.2 mbgl (samples B1, K1 and N1). Additionally, B1 appears to have an elevated concentration of sulphate. Note K1 sample was brown, whereas all other collected samples were clear or opaque. All three anomalous samples were all retrieved during the first sampling round on 26th November 2008.

4.3.3 Depth profiles

Depth profiles of the data suggest concentrations of all determinands may increase with elevation above approximately 20 mbgl (Figure 4.3). Below this depth the data points are more scattered; the sulphate and chloride possibly showing a slight increase between around 22.6 and 20.5 mbgl, but nitrate generally showing a decline in concentration.

There are also more subtle features within the profiles. For example there appear to be small peaks in concentration of all three analytes around 17.1, 18.4 and 19.8 mbgl. These peaks are most evident in the chloride and sulphate profiles, with more scatter in the nitrate data. Above 14 mbgl, all profiles are relatively consistent at around 26-27 mg/l of sulphate, 29-31 mg/l of chloride and 56-58 mg/l of nitrate. Note that the bottom of the casing is at 12.7 mbgl.

It is also evident that the range in concentration is greatest in the nitrate profile, around 30 mg/l, compared with only about 10 mg/l in chloride and sulphate.

Generally, bailed and pumped samples fit consistently with samples collected from the multi-level sampler.

4.3.4 Nitrate time series

There appears to be a reasonable correlation between groundwater nitrate concentration and level over time during periods of the recharge season (Figure 4.4); although there is not a not a good correspondence during the early data in November where there is a large amount of scatter in the data.

Throughout late January there are sudden spikes in the nitrate data as the groundwater level rises significantly. Closer examination of the data reveals that these spikes can be up to 10 mg/l associated with only a 0.1 m rise in level (Figure 4.5). Following the spikes, there is a rapid recession in concentration to a ‘baseline’ level which increases at a similar rate to the water level rise. This behaviour is indicative of pulses of higher nitrate concentration being delivered to the borehole. It is also observed that the nitrate concentration of sample K5 is similar to that of the samples collected during February at a depth of around 13.0-13.5 mbgl.

Interestingly spikes in the early February data are much smaller than in January, before the water table reaches the casing, even though the rate of water level rise is more rapid.

4.3.5 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.

A comparison of the two datasets indicates similar overall trends within the general range of water level fluctuation (12-26 mbgl), with a decrease in nitrate concentration and subsequent rise – both at similar rates (Figure 4.6). However, there is an offset in the order of 10 mg/l (or

10-20 %) between groundwater concentration and the greater porewater concentration at equivalent depths. It is postulated that this could be a result of one or more of the following :

- 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.

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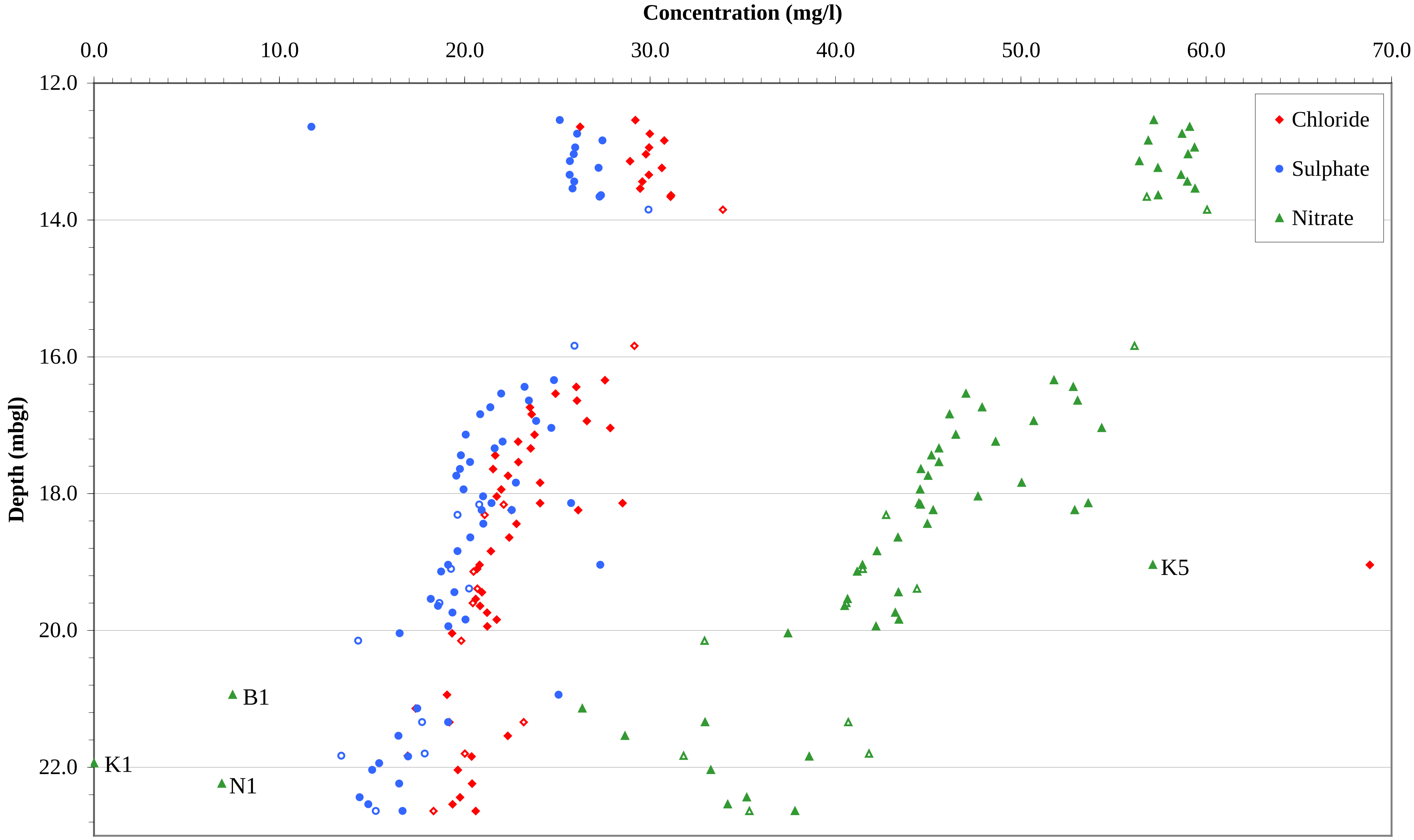
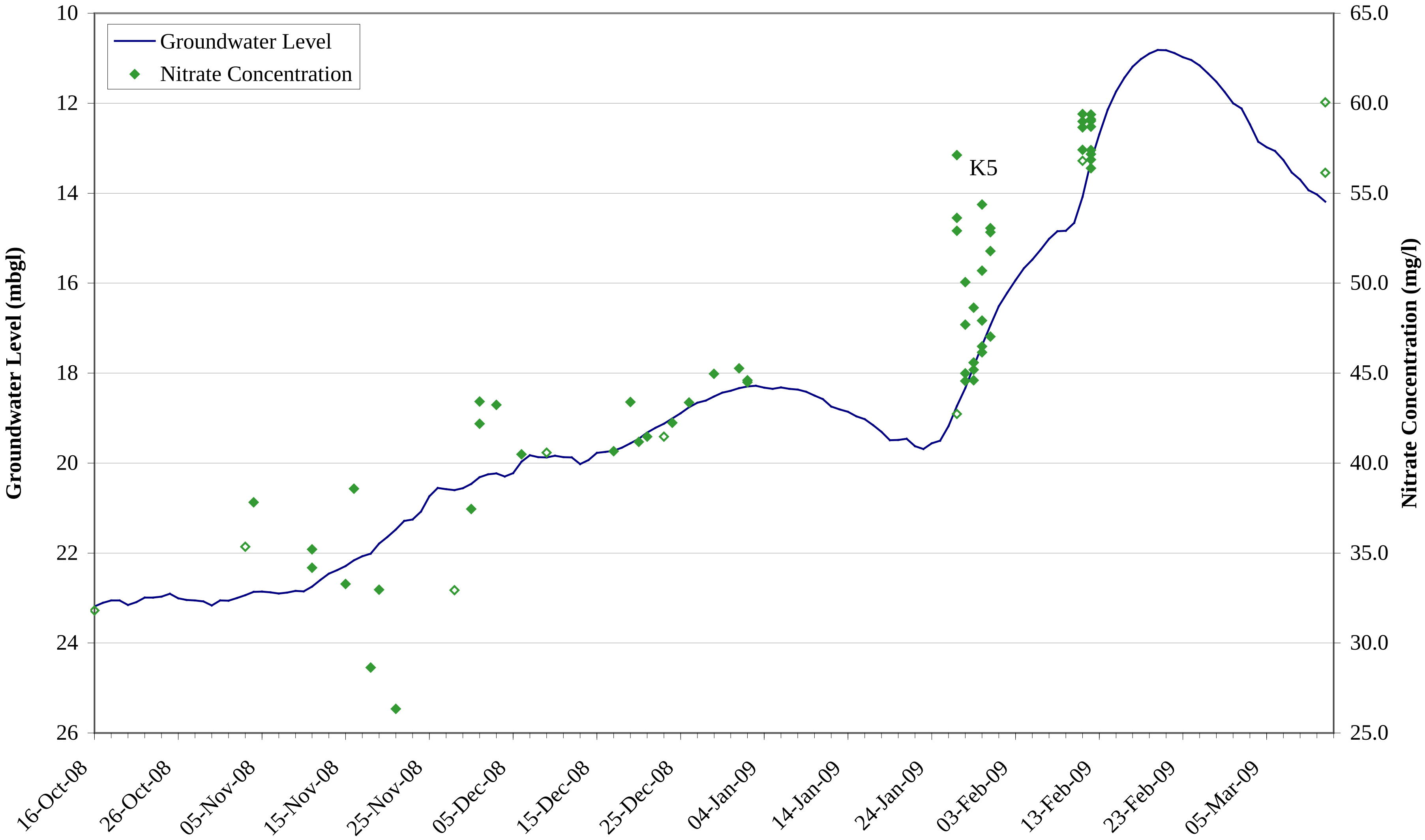


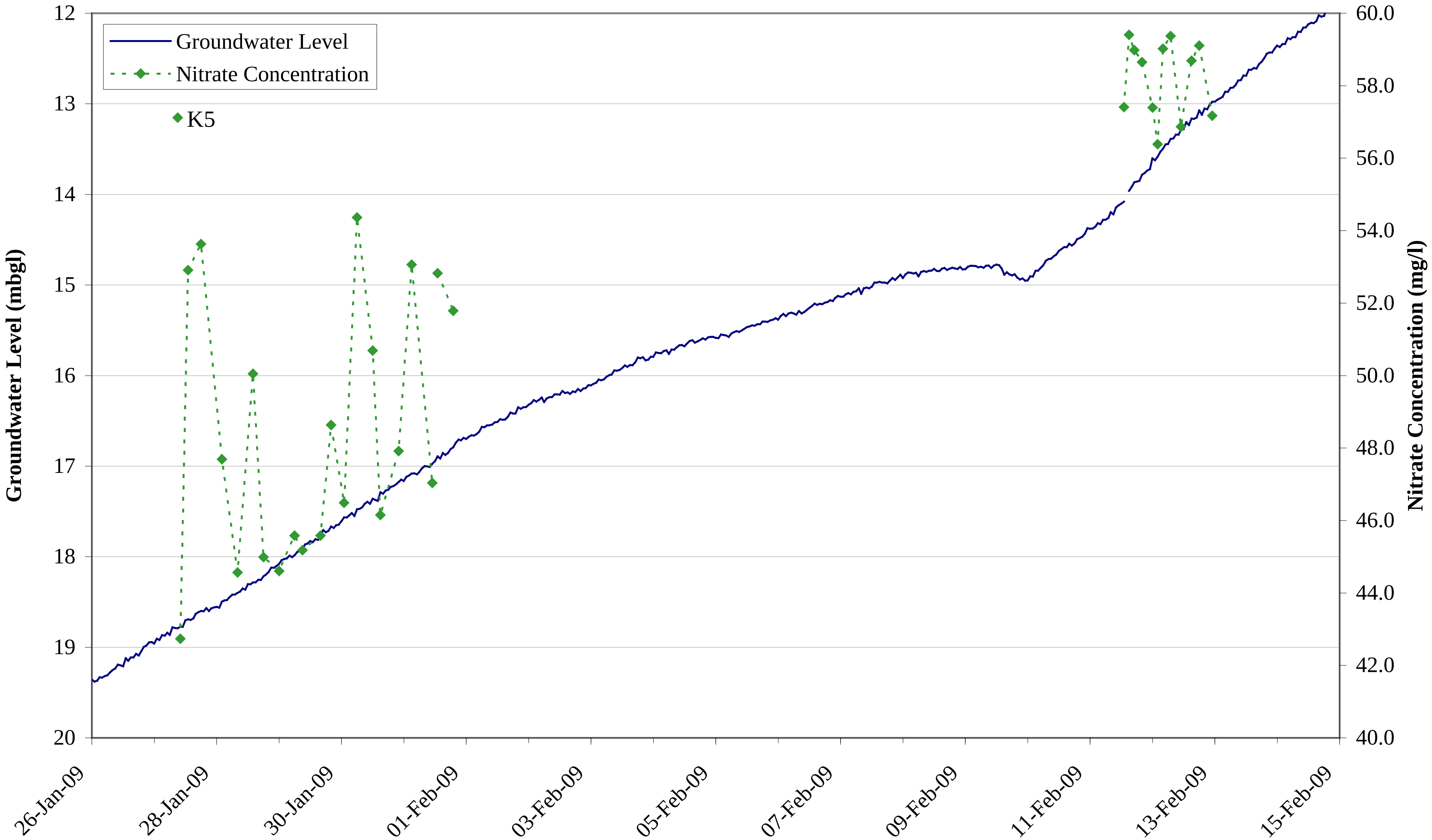
Note: Unfilled data points relate to bailed or pumped sample; pumped samples from 15.84 mbgl, 21.34 mbgl and completion water at 21.83 mbgl

Figure 4.3 Depth profiles of chloride, sulphate and nitrate concentrations in Borehole B



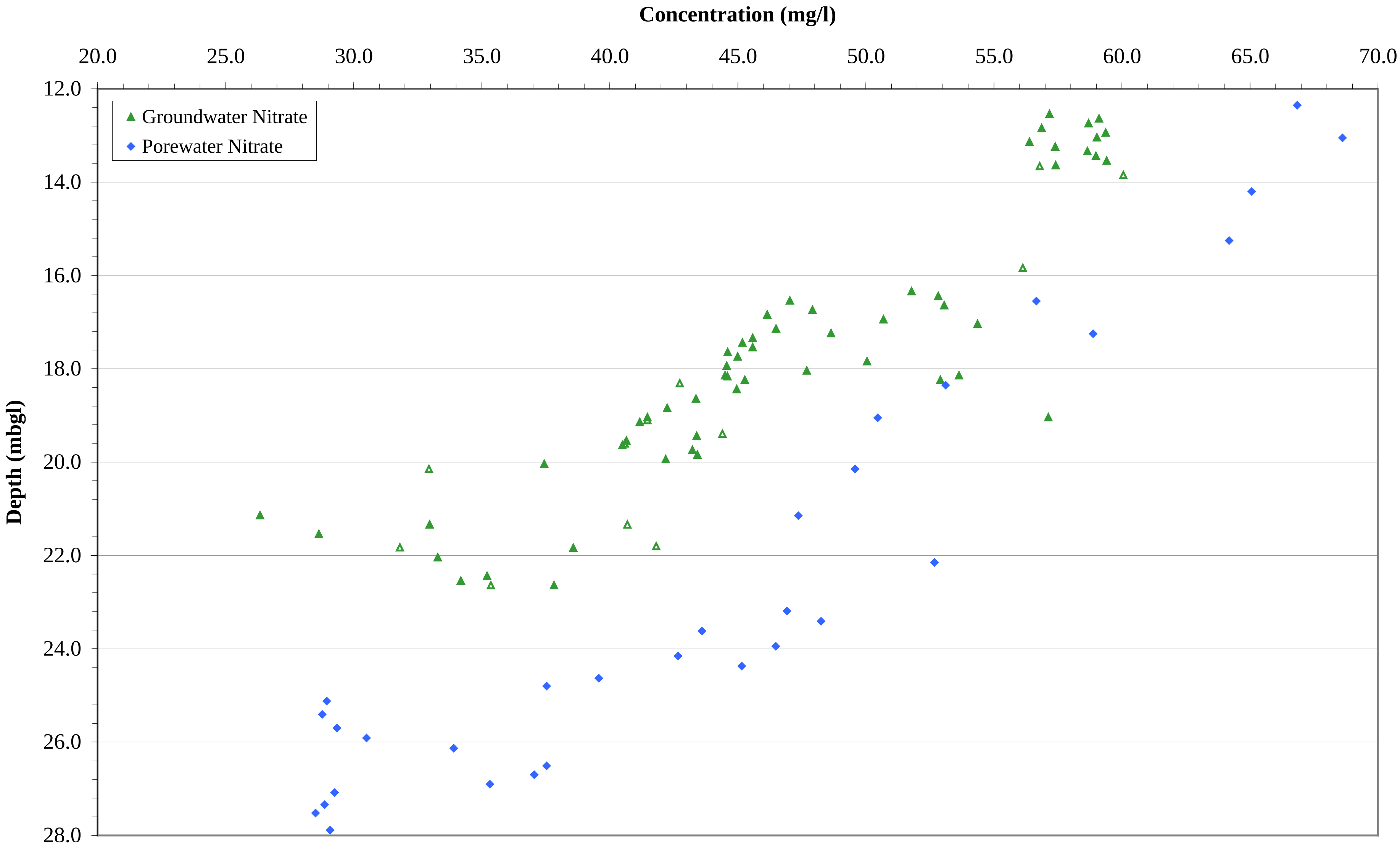
Note: Date of sample capture is estimated from water levels recorded in Borehole A; unfilled data points mainly relate to bailed samples, with completion water on 15th October 200 and pumped sample on 12th March 2010 (56 mg/l NO_3); anomalously low data points excluded.

Figure 4.4 Relating nitrate concentrations in Borehole B to groundwater level over the sampling period. The vertical scales have been adjusted to demonstrate similar changes



Note: K5 not collected from the water table and therefore the exact time of sample capture is unclear. It is likely to have been between 25 and 27th January.

Figure 4.5 Enlarged section of Figure 4.3 showing nitrate concentrations in Borehole B during rapid rises in groundwater level



Note: both datasets our plotted as mbgl at different boreholes. Borehole A ground level is approximately elevated above Borehole B by 0.15 m.

Figure 4.6 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 hanging sampler was successfully deployed in Borehole B at Morestead, Twyford. Groundwater levels were monitored in the existing Borehole A. A total of 72 groundwater samples were analysed from depths of between 12.54 and 22.64 m bgl. These indicated concentrations of chloride, sulphate and nitrate (as NO_3) ranged between 16.9 and 68.8 mg/l, 11.7 and 29.9 mg/l, and <0.6 and 60.1 mg/l, respectively. Depth profiles of the data suggest concentrations of all determinands may increase with elevation above around approximately 20 m bgl. Moreover there appear to be more subtle features with small peaks in concentration of all three analytes around 17.1, 18.4 and 19.8 mbgl.

There appears to be a reasonable correlation between groundwater nitrate concentration and level over time during periods of the recharge season, although there is not a not a good correspondence during the early data in November 2008. During the rapid water level rise in January 2009 there are also sudden spikes in the nitrate data, which can be up to 10 mg/l from a 0.1 m water level rise.

Porewater concentrations of nitrate from Borehole A and the analysed samples show a generally good correlation with depth. However, there is an offset in the order of 10 mg/l (or 10-20 %) between groundwater concentration and the greater porewater concentration at equivalent depths.

The sampler requires modifying to reduce the number of bottles which fail to fill correctly and to operate during periods of rapid and large water level rise where site access is not possible due to adverse weather conditions, such as the heavy snowfall in early February 2009.

Gamma and resistivity logs identified marl horizons which correlated with the Borehole A core as reported in Stuart et al. (2008a). Fluid and flow logs also indicate hydraulic layering within the Chalk. Temperature and conductivity logs suggested vertical flow below 26 m bct, which is was also supported by HPFM and impeller flow logs. This flow regime was unaltered by pumping from a depth of 21.5 m indicating reasonable permeability in the Chalk above this depth. A nitrate sonde was also run before and during pumping. The results are currently awaiting calibration and will be reported separately.

5.2 FUTURE PROGRAMME

During the forthcoming year it is planned that the following activities will be undertaken:

- Water levels will be continually monitored in Borehole A.
- The multi-level hanging sampler will be increased to 4 m in length to accommodate more samples. Additionally, samples will be collected at a 0.05 m resolution.
- A telemetry system will be installed to enable targeted sample collection and site visits. The system will also enable water levels to be monitored in Borehole B.
- The sampler will be re-positioned during the summer of 2009 to remain just above the water table in Borehole B, with the aim of capturing groundwater samples following any intense summer/autumn storms. Subsequently the sampler will be used to obtain samples as the water table rises towards the anticipated spring 2010 water levels.

- It may be possible to conduct a tracer test between Borehole A and Borehole B to identify interconnecting fractures at a depth of around 30 mbgl. This may be undertaken at high and low groundwater levels to assess how the flow regime between the boreholes varies.

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.

INSTITUTE OF GEOLOGICAL SCIENCES. 1979. Hydrogeological map of Hampshire and the Isle of Wight. Institute of Geological Sciences and Southern Water Authority.

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WOODS, I.S. 2010. Flow-logging of Borehole B at Morestead. BGS Internal Report IR/10/038

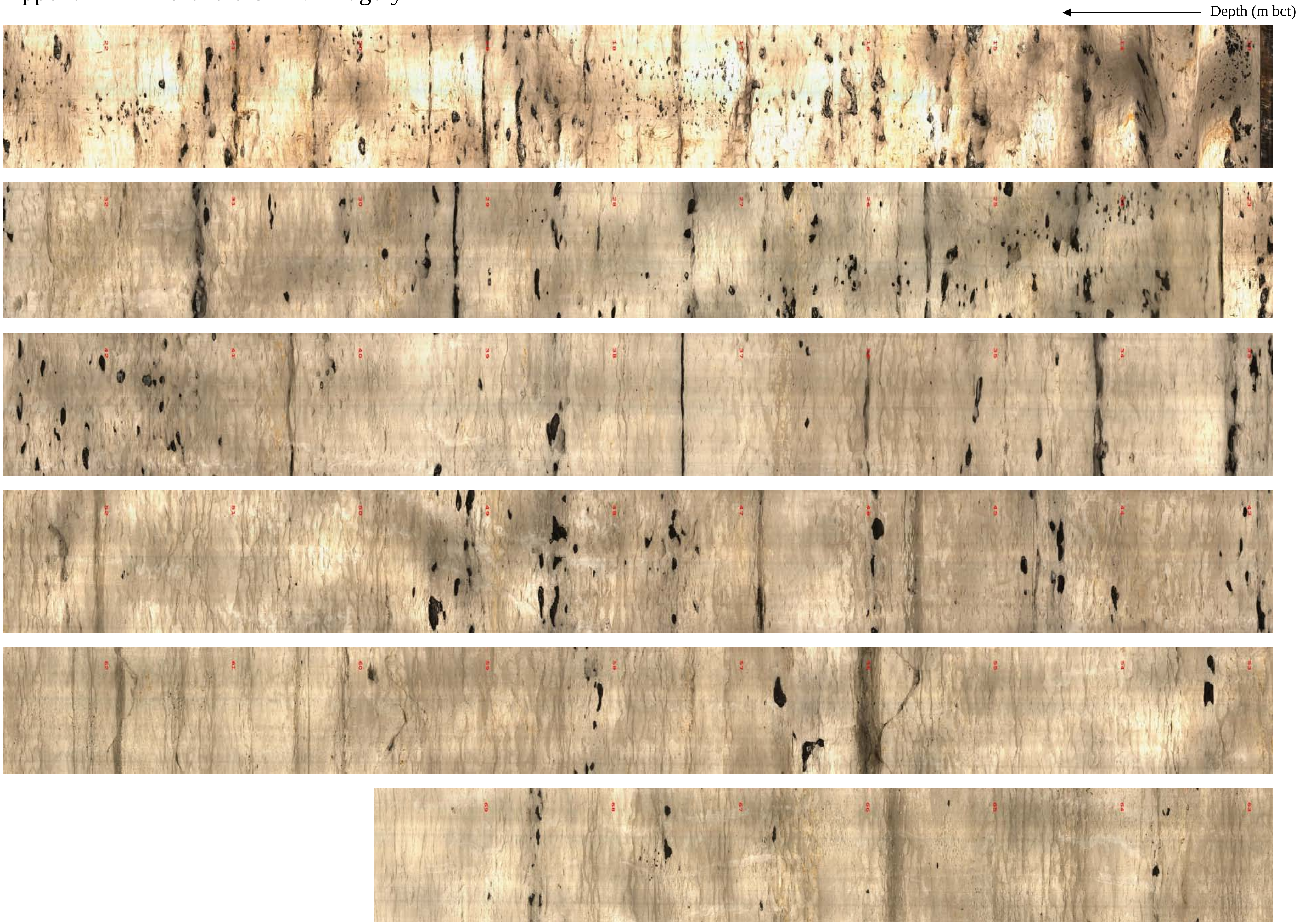
Appendix A – Samples collected and scheduled analysis

Sample ID	Site ID	Sample Type	Sample Depth (m bgl)	Collection Date	Sent for analysis
S08-01453		BH pumped clearout bulk sample	21.83	16-Oct-08	✓
S08-01454	BULKWT	bail sample @wt pre ML sampler	22.64	03-Nov-08	✓
S08-01455	R1	ML Sampler	22.64	26-Nov-08	✓
S08-01456	Q1	ML Sampler	22.54	26-Nov-08	✓
S08-01457	P1	ML Sampler	22.44	26-Nov-08	✓
S08-01458	O1	ML Sampler	22.34	26-Nov-08	
S08-01459	N1	ML Sampler	22.24	26-Nov-08	✓
S08-01460	no M			26-Nov-08	
S08-01461	L1	ML Sampler	22.04	26-Nov-08	✓
S08-01462	K1	ML Sampler	21.94	26-Nov-08	✓
S08-01463	J1	ML Sampler	21.84	26-Nov-08	✓
S08-01464	I1	ML Sampler	21.64	26-Nov-08	
S08-01465	H1	ML Sampler	21.54	26-Nov-08	✓
S08-01466	no G			26-Nov-08	
S08-01467	F1	ML Sampler	21.34	26-Nov-08	✓
S08-01468	no E		21.24	26-Nov-08	
S08-01469	D1	ML Sampler		26-Nov-08	✓
S08-01470	no C		21.04	26-Nov-08	
S08-01471	B1	ML Sampler	20.94	26-Nov-08	✓
S08-01472	A1	ML Sampler	20.84	26-Nov-08	
S08-01473	BULKWT	grab bulk sample@ WL	20.15	28-Nov-08	✓
S08-01474	T2	ML Sampler	20.04	09-Dec-08	✓
S08-01475	S2	ML Sampler	19.94	09-Dec-08	✓
S08-01476	R2	ML Sampler	19.84	09-Dec-08	✓
S08-01477	Q2	ML Sampler	19.74	09-Dec-08	✓
S08-01478	P2	ML Sampler	19.64	09-Dec-08	✓
S08-01479	BULKWT	Bail sample at water table	19.6	09-Dec-08	✓
S08-01480	T3	ML Sampler	19.54	22-Dec-08	✓
S08-01481	S3	ML Sampler	19.44	22-Dec-08	✓
S08-01482	P3	ML Sampler	19.14	22-Dec-08	✓
S08-01483	BULKWT	Bail sample at water table	19.1	22-Dec-08	✓
S08-01484	T4	ML Sampler	19.04	09-Jan-09	✓
S08-01485	S4	ML Sampler	18.94	09-Jan-09	
S08-01486	R4	ML Sampler	18.84	09-Jan-09	✓

Sample ID	Site ID	Sample Type	Sample Depth (m bgl)	Collection Date	Sent for analysis
S08-01487	Q4	ML Sampler	18.74	09-Jan-09	
S08-01488	P4	ML Sampler	18.64	09-Jan-09	✓
S08-01489	O4	ML Sampler	18.54	09-Jan-09	
S08-01490	N4	ML Sampler	18.44	09-Jan-09	✓
S08-01491	M4	ML Sampler	18.34	09-Jan-09	
S08-01492	L4	ML Sampler	18.24	09-Jan-09	✓
S08-01493	K4	ML Sampler	18.14	09-Jan-09	✓
S08-01494	BULKWT	Bail sample at water table	18.16	09-Jan-09	✓
S08-01495	K5	ML Sampler (MID!)	19.04	27-Jan-09	✓
S08-01496	BULKWT	Bail sample at water table	18.31	27-Jan-09	✓
S08-1244	T5	ML Sampler	18.24	11-Feb-09	✓
S08-1245	S5	ML Sampler	18.14	11-Feb-09	✓
	R5	ML Sampler	18.04	11-Feb-09	✓
	Q5	ML Sampler	17.94	11-Feb-09	✓
	P5	ML Sampler	17.84	11-Feb-09	✓
S08-1246	O5	ML Sampler	17.74	11-Feb-09	✓
	N5	ML Sampler	17.64	11-Feb-09	✓
	M5	ML Sampler	17.54	11-Feb-09	✓
	L5	ML Sampler	17.44	11-Feb-09	✓
S08-1247	K6	ML Sampler	17.34	11-Feb-09	✓
	J2	ML Sampler	17.24	11-Feb-09	✓
	I3	ML Sampler	17.14	11-Feb-09	✓
	H2	ML Sampler	17.04	11-Feb-09	✓
S08-1248	G2	ML Sampler	16.94	11-Feb-09	✓
	F2	ML Sampler	16.84	11-Feb-09	✓
	E2	ML Sampler	16.74	11-Feb-09	✓
	D2	ML Sampler	16.64	11-Feb-09	✓
S08-1249	C2	ML Sampler	16.54	11-Feb-09	✓
	B2	ML Sampler	16.44	11-Feb-09	✓
S08-1250	A2	ML Sampler	16.34	11-Feb-09	✓
S08-1257	BULKWT	Bail sample at water table	13.66	11-Feb-09	✓
S08-1251	T6	ML Sampler	13.64	20-Feb-09	✓
	S6	ML Sampler	13.54	20-Feb-09	✓
	R6	ML Sampler	13.44	20-Feb-09	✓
	Q6	ML Sampler	13.34	20-Feb-09	✓
S08-1252	P6	ML Sampler	13.24	20-Feb-09	✓
	O6	ML Sampler	13.14	20-Feb-09	✓

Sample ID	Site ID	Sample Type	Sample Depth (m bgl)	Collection Date	Sent for analysis
	N6	ML Sampler	13.04	20-Feb-09	✓
	M6	ML Sampler	12.94	20-Feb-09	✓
S08-1253	L6	ML Sampler	12.84	20-Feb-09	✓
	K7	ML Sampler	12.74	20-Feb-09	✓
	J3	ML Sampler	12.64	20-Feb-09	✓
S08-1254	I3	ML Sampler	12.54	20-Feb-09	✓
	H3	ML Sampler	12.44	20-Feb-09	
	G3	ML Sampler	12.34	20-Feb-09	
	F3	ML Sampler	12.24	20-Feb-09	
	E3	ML Sampler	12.14	20-Feb-09	
	D3	ML Sampler	12.04	20-Feb-09	
	C3	ML Sampler	11.94	20-Feb-09	
	B3	ML Sampler	11.84	20-Feb-09	
	A3	ML Sampler	11.74	20-Feb-09	
S08-1258	BULKWT	Bail sample at water table	10.6	20-Feb-09	
S08-1259	BULKWT	Bail sample at water table	13.85	12-Mar-09	✓
S08-1260	BULKWT	Pumped from 16 m after 1 min	15.84	12-Mar-09	✓
S08-1261	BULKWT	Pumped from 16 m after 10 min	15.84	12-Mar-09	
S08-1262	BULKWT	Pumped from 16 m after 2.5hr	15.84	12-Mar-09	

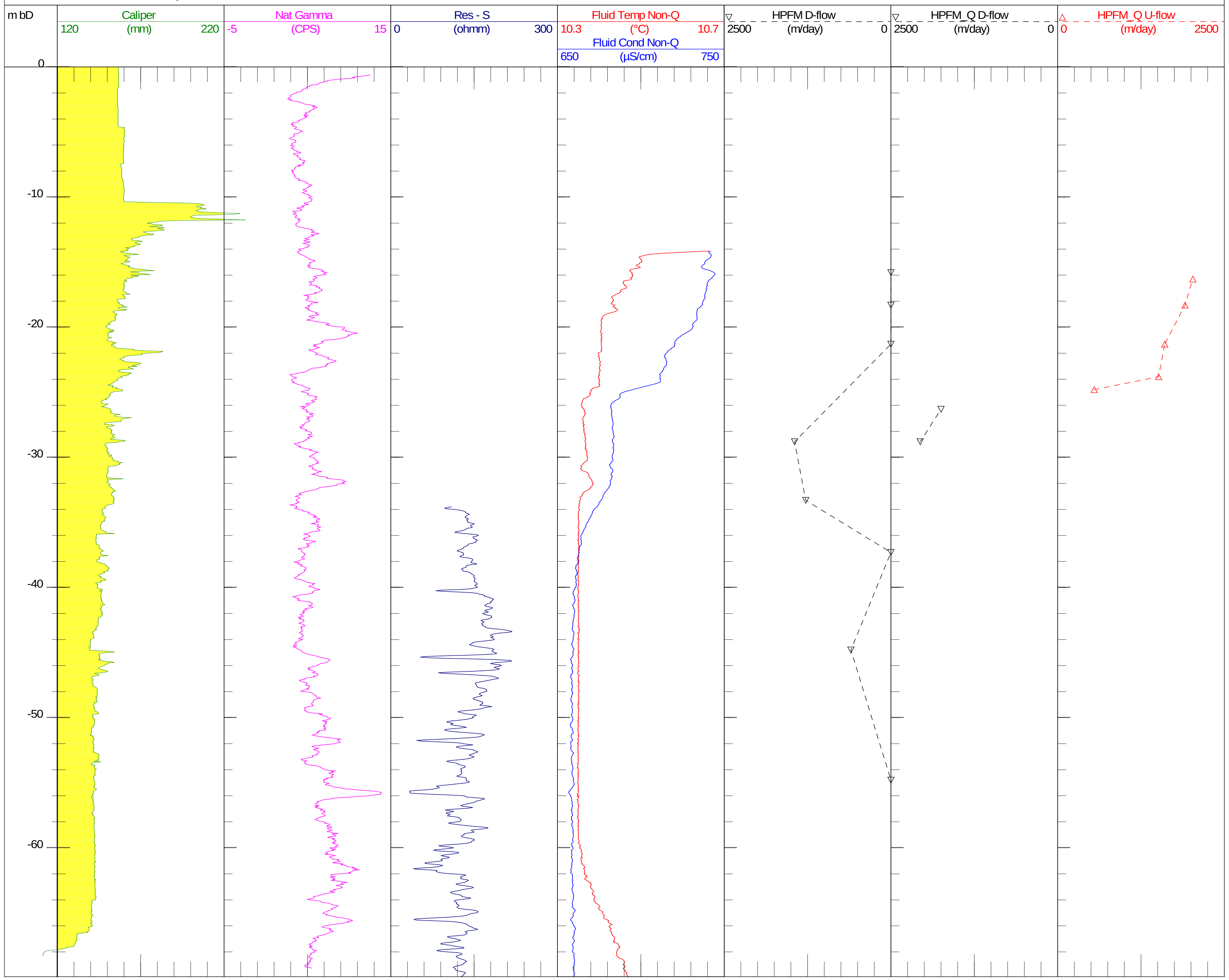
Appendix B – Borehole OPTV imagery



Appendix C – Geophysical logs

Well Name: Morestead BH2
Location: 450722 125285

Formation and fluid logs recorded by the BGS on the 17/10/08 and 12/03/09 respectively.
Datum = Casing Top = 0.2 m aGL.
SWL on 17/10/08 = 22.99 m bD, SWL on 12/03/09 = 14.05 m bGL, PWL = 14.10, Q = 0.5 l/s.
Flow-meter logs record linear velocity, i.e. are not area corrected.
Optical image of borehole also recorded.
BGS UV-Nitrate sonde used but requires recalibration.



Appendix D –Water quality results

Sample ID	Site ID	Depth (mbgl)	Collection Date	Cl (mg/l)	SO_4 (mg/l)	NO_3 (mg/l)
S08-01453		21.83	16-Oct-08	16.9	13.3	31.8
S08-01454	BULKWT	22.64	03-Nov-08	18.3	15.2	35.4
S08-01455	R1	22.64	26-Nov-08	20.6	16.7	37.8
S08-01456	Q1	22.54	26-Nov-08	19.3	14.8	34.2
S08-01457	P1	22.44	26-Nov-08	19.7	14.3	35.2
S08-01459	N1	22.24	26-Nov-08	20.4	16.5	6.9
S08-01461	L1	22.04	26-Nov-08	19.6	15.0	33.3
S08-01462	K1	21.94	26-Nov-08	n.d.	15.4	<0.6
S08-01463	J1	21.84	26-Nov-08	20.4	16.9	38.6
S08-01465	H1	21.54	26-Nov-08	22.3	16.4	28.6
S08-01467	F1	21.34	26-Nov-08	23.2	17.7	33.0
S08-01469	D1	21.14	26-Nov-08	17.4	17.4	26.3
S08-01471	B1	20.94	26-Nov-08	19.0	25.1	7.5
S08-01473	BULKWT	20.15	28-Nov-08	19.8	14.3	32.9
S08-01474	T2	20.04	09-Dec-08	19.3	16.5	37.4
S08-01475	S2	19.94	09-Dec-08	21.2	19.1	42.2
S08-01476	R2	19.84	09-Dec-08	21.7	20.0	43.4
S08-01477	Q2	19.74	09-Dec-08	21.2	19.3	43.2
S08-01478	P2	19.64	09-Dec-08	20.8	18.6	40.5
S08-01479	BULKWT	19.6	09-Dec-08	20.4	18.6	40.6
S08-01480	T3	19.54	22-Dec-08	20.6	18.2	40.7
S08-01481	S3	19.44	22-Dec-08	20.9	19.4	43.4
S08-01482	P3	19.14	22-Dec-08	20.5	18.7	41.2
S08-01483	BULKWT	19.1	22-Dec-08	20.7	19.3	41.5
S08-01484	T4	19.04	09-Jan-09	20.8	19.1	41.5
S08-01486	R4	18.84	09-Jan-09	21.4	19.6	42.2
S08-01488	P4	18.64	09-Jan-09	22.4	20.3	43.4
S08-01490	N4	18.44	09-Jan-09	22.8	21.0	45.0
S08-01492	L4	18.24	09-Jan-09	22.5	20.9	45.3
S08-01493	K4	18.14	09-Jan-09	24.1	21.5	44.5
S08-01494	BULKWT	18.16	09-Jan-09	22.1	20.8	44.6
S08-01495	K5	19.04	27-Jan-09	68.8	27.3	57.1
S08-01496	BULKWT	18.31	27-Jan-09	21.1	19.6	42.7
S08-1244	T5	18.24	11-Feb-09	26.1	22.5	52.9
S08-1245	S5	18.14	11-Feb-09	28.5	25.7	53.6
R5	R5	18.04	11-Feb-09	21.7	21.0	47.7
Q5	Q5	17.94	11-Feb-09	22.0	19.9	44.6
P5	P5	17.84	11-Feb-09	24.1	22.8	50.1
S08-1246	O5	17.74	11-Feb-09	22.3	19.6	45.0
N5	N5	17.64	11-Feb-09	21.5	19.7	44.6
M5	M5	17.54	11-Feb-09	22.9	20.3	45.6
L5	L5	17.44	11-Feb-09	21.6	19.8	45.2
S08-1247	K6	17.34	11-Feb-09	23.6	21.6	45.6
J2	J2	17.24	11-Feb-09	22.9	22.1	48.6
I3	I3	17.14	11-Feb-09	23.8	20.1	46.5
H2	H2	17.04	11-Feb-09	27.9	24.7	54.4
S08-1248	G2	16.94	11-Feb-09	26.6	23.9	50.7
F2	F2	16.84	11-Feb-09	23.6	20.8	46.2
E2	E2	16.74	11-Feb-09	23.5	21.4	47.9
D2	D2	16.64	11-Feb-09	26.1	23.5	53.1

Sample ID	Site ID	Depth (mbgl)	Collection Date	Cl (mg/l)	SO_4 (mg/l)	NO_3 (mg/l)
S08-1249	C2	16.54	11-Feb-09	24.9	22.0	47.0
B2	B2	16.44	11-Feb-09	26.0	23.2	52.8
S08-1250	A2	16.34	11-Feb-09	27.6	24.8	51.8
S08-1257	BULKWT	13.66	11-Feb-09	31.1	27.3	56.8
S08-1251	T6	13.64	20-Feb-09	31.1	27.4	57.4
S6	S6	13.54	20-Feb-09	29.5	25.8	59.4
R6	R6	13.44	20-Feb-09	29.6	25.9	59.0
Q6	Q6	13.34	20-Feb-09	29.9	25.7	58.6
S08-1252	P6	13.24	20-Feb-09	30.6	27.2	57.4
O6	O6	13.14	20-Feb-09	28.9	25.7	56.4
N6	N6	13.04	20-Feb-09	29.8	25.9	59.0
M6	M6	12.94	20-Feb-09	29.9	26.0	59.4
S08-1253	L6	12.84	20-Feb-09	30.8	27.4	56.9
K7	K7	12.74	20-Feb-09	30.0	26.1	58.7
J3	J3	12.64	20-Feb-09	26.2	11.7	59.1
S08-1254	I3	12.54	20-Feb-09	29.2	25.1	57.2
B3	B3	11.84	20-Feb-09	27.5	25.5	59.5
S08-1259	BULKWT	13.85	12-Mar-09	33.9	29.9	60.1
S08-1260	BULKWT	15.84	12-Mar-09	29.1	25.9	56.1
BULKWT	BULKWT	19.39	05-Jun-09	20.7	20.2	44.4
BULKWT	BULKWT	21.8	05-Jun-09	20.0	17.8	41.8
BULKWT	BULkWT	21.34	05-Jun-09	19.2	19.1	40.7

Note: n.d. is not determined