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Assessing the impact of sewage effluent disposal on groundwater (phase 2): final report

Science Report: SC010070/SR1

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SCHO0707BNAD-E-P

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Steve Killeen

Head of Science

Executive Summary

This report provides a written record of the site investigation undertaken at The Goodens, Cheriton, as part of Environment Agency Project SC010070 (P2-229/2): Assessing the impact of sewage effluent disposal on groundwater. The project aims to characterise and quantify the impacts on groundwater from a small septic tank sewage treatment system discharge sited on a vulnerable Chalk aquifer.

In this report a brief background to the site and project is provided, but a comprehensive desk study and geophysical survey is presented in British Geological Survey (BGS) Commissioned Report CR/02/306. Comprehensive details of the borehole installation and details of all site works undertaken are presented in the project interim report (BGS Commissioned Report CR/05/083).

The septic tank at The Goodens, Cheriton, serves a small development of eight dwellings. Raw sewage passes into the septic tank to enable the settlement and flotation of solids. The liquid effluent passes into a second chamber and is then pumped 200 m upslope to a discharge field. The discharge installation comprises three parallel perforated clay pipes perpendicular to the slope of the field and approximately 35 m in length. Five boreholes were drilled to a total depth of 15 m around the effluent discharge point. Core material was collected every 0.m for lithological logging and high-speed centrifugation to remove pore water for chemical analysis. During the 18-month project groundwater samples were collected four times from all the borehole installations, the septic tank, and an Environment Agency monitoring well up gradient of the discharge point.

Boreholes 1 and 4 (BH1 and BH4), positioned between the second and third discharge pipes, show a changing chemistry with depth, particularly BH4. Between 5.3 and 7.5 m depth, BH 4 pore waters change from dominantly calcium carbonate to dominantly sodium chloride; sodium chloride peaks between 6.5 and 7.0 m (rest water level was measured at 7.99 m when the cores were collected). Sulphate and boron also peak at this depth.

The majority of trace metals were below the analytical limit of detection in all the boreholes, with the exception of zinc, titanium, lead, cobalt, barium, strontium, antimony, boron, nickel, and aluminium. Many of these analytes were only detected using the more sensitive inductively coupled plasma–atomic emission spectrometer (ICP-MS) technique. Those trace metals detected were of comparable concentrations in the site borehole groundwaters and the tennis court (background) borehole. With the exception of one sampling round in which mineral oil was detected in all samples, no organic compounds in List I and List II analytical schedules were detected in the groundwater samples. Organochlorine pesticides, phenols, and diethyl phthalate were detected periodically in the effluent samples.

Microbiological examination at each sampling round revealed that the effluent from the septic tank and a nearby package treatment plant (PTP) at Droxford contained the critical bacterial load indicative of a sewage treatment system (that is, high coliforms, thermotolerant coliforms, and *Escherichia coli*). There was no obvious difference between the coliform loading within both Droxford and Cheriton (PTP versus septic tank). BH1, BH4, and BH5 carried similar coliform concentrations, but these indicated low-level contamination. At a distance of 10-30 m, insignificant coliform concentrations were detected, which signified a low microbiological impact on the groundwater by the septic tank effluent.

Overall, there is very little chemical or biological evidence that the septic tank effluent impacts the chalk aquifer. Hydraulic tests show hydraulic conductivity values for the site to be in the upper range of literature values and indicate relatively high flow rates in the chalk. These results suggest that beneath the outflow pipes there is a fast vertical flow because of the fissuring, which allows rapid transport to the water table. Contaminants move preferentially thorough the fissures and are likely to disperse rapidly and thus reduce the impact on the aquifer, as appears to be the case at Cheriton.

Contents

1. Introduction

The Environment Agency requires scientific research to aid our understanding of the impacts of discharge from septic tanks on groundwater and to help operational teams determine applications required for septic tank discharges to the ground, especially on aquifers used for public water supply. The aims of the project are to gain an understanding of the physical and chemical processes that inhibit the migration of contaminants in effluent released into a Chalk aquifer, and to determine what influence the microbial populations of the aquifer have on attenuation processes.

The Environment Agency R&D Technical Report P2-229/TR/3 identified two sites suitable for further study. These comprise The Goodens, Cheriton, and The Park, Droxford, both located near Winchester, Hampshire. This study aims to characterise and quantify impacts on groundwater from effluent discharged from a septic tank and to compare and contrast effluent arising from a septic tank with that from a package treatment plant (PTP).

The British Geological Survey Commissioned Report CR/02/306 details a geophysical survey of the Cheriton site that identifies the most likely locations for boreholes to intercept a contaminant plume. An interim report (British Geological Survey Commissioned Report CR/05/083) provides a written record of the borehole installations undertaken at the Cheriton site and this final report presents an interpretation of the chemical, physical, and biological processes that contribute to contaminant distribution at the site.

Four monitoring rounds were undertaken over 18 months in which samples from six boreholes (including a background borehole), a septic tank, and a PTP were collected for organic, inorganic, microbiological, and isotopic analysis. Results from all four sampling rounds are presented and a conceptual model of the site is proposed.

Brief details of the non-invasive and invasive site investigations are given, but the reports detailed above provide much greater detail.

1.1 Regional Geology

1.1.1 Stratigraphy

The Cheriton site is located on the Newhaven Member of the Upper Chalk (Santonian to Campanian). The Newhaven Chalk comprises 40-70 m of soft to medium-hard, smooth, white chalks with numerous marl seams and flint bands (Hopson 1998). Typically, the marls vary between 20 and 70 mm thick, but are thought to become much thinner or die out over syn-sedimentary positive features (Hopson 1998). Channels with hardgrounds and phosphatic chalks have been recorded elsewhere within the formation, but none have been identified in the survey area (Hopson 1998). There are abundant solution hollows in the area, primarily located on hilltops.

The dry valley bottom at Cheriton is filled with head and can be identified by a break in slope. Head is a heterogeneous group of superficial deposits that have accumulated by solifluction, hillwash, and hillcreep. The term includes chalky, flinty materials, but in general comprises pale yellow–brown, silty, sandy clays with variable proportions of coarser granular material (all with earthy texture; Hopson 1998). There are likely to be local bedrock pebbles (that is, chalk).

1.1.2 Structure

The structures discernible at the surface within the Chalk are a reflection of a complex sequence of compressional and extensional tectonics reactivated in the Cretaceous and Tertiary. There are occasional east–west orientated normal faults, downthrown generally to the south. An exposure of Newhaven Chalk (NGR: 45782 12892) shows it to have sub-vertical fractures, orientated primarily northwest to southeast (312°-132°). The Newhaven Chalk locally has a shallow dip to the north–northwest.

1.2 Site description

The locations of the septic tank at Cheriton and the PTP at Droxford, both near Winchester in Hampshire, are shown in *Figure 1.1*.

Figure 1.1 Site location map.

1.2.1 Cheriton

Cheriton is located in a valley bottom at the source of the River Itchen, Hampshire (*Figure 1.1*).

The Goodens is a small development of eight dwellings on a minor road close to the centre of the village. The septic tank that serves these eight houses is positioned adjacent to the houses, although the discharge from the tank is approximately 200 m upslope to the north at an elevation of approximately 75 m above ordnance datum (AOD). The topography slopes away to the southeast to a valley base at 65-70 m AOD. The effluent from the septic tank outflows into a pasture field (*Figure 1.2*), which occasionally serves a herd of cattle and there are abundant nettles around the outflow area. To the north of the site is a road cutting (Hill House Lane) approximately 6 m deep (69 m AOD), to the west of the site is an arable field and to the southwest is a cricket pitch.

Raw sewage passes into the septic tank at The Goodens to allow settlement and flotation of solids. The liquid effluent passes into a second chamber and is then pumped 200 m upslope to a discharge field approximately every 1.5 hours. The discharge installation comprises three parallel, perforated clay pipes perpendicular to the slope of the field, each approximately 35 m in length.

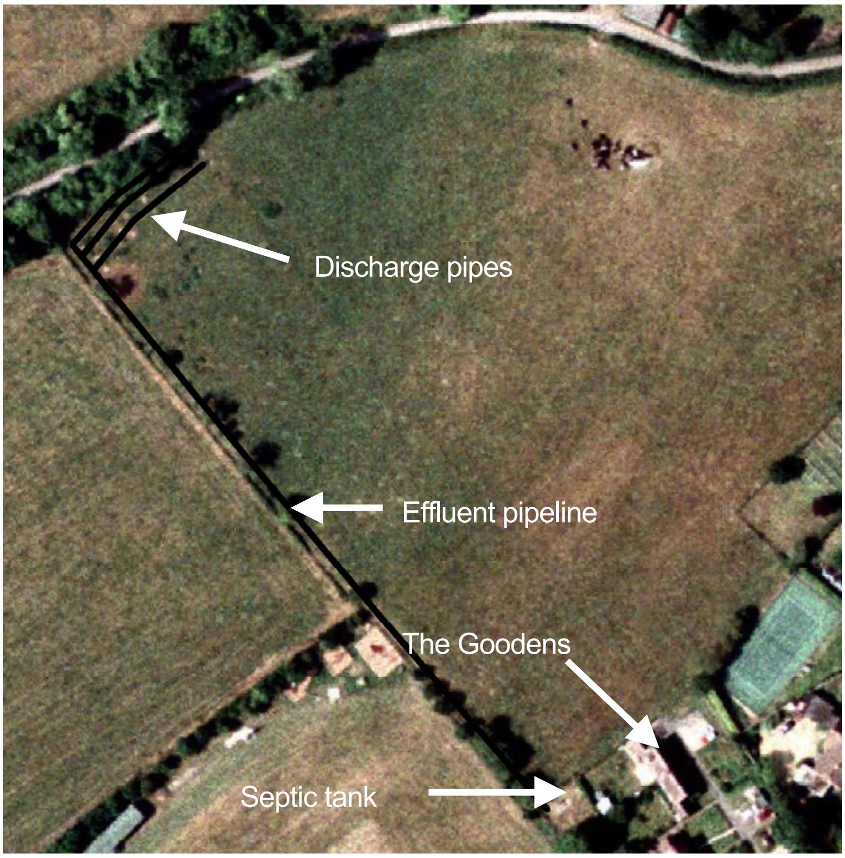


Figure 1.2 Septic tank installation at The Goodens, Cheriton.

1.2.2 Droxford

Droxford is located in the valley of the River Meon, Hampshire (*Figure 1.1*). The PTP at The Park, Droxford, was constructed to serve 35 dwellings and allows flotation and settlement of raw sewage followed by bacterially mediated oxidation of the effluent. The PTP is located adjacent to the junction of Police Station Lane and Park Lane in Droxford (NGR 460540 118293) and to a small tree-lined field, which used to serve as the drainage field for septic tank effluent. With the installation of the PTP, effluent is pumped upslope to a large drainage field, adjacent to a school and play area. The site is at an elevation of approximately 57 m AOD (water level is approximately 48 m AOD) on the west of the River Meon valley.

1.2.3 Householder survey

A questionnaire was distributed to householders at the Goodens, Cheriton, and The Park, Droxford, to establish an understanding of the volume and composition of water being discharged to the septic tank. The questionnaire aimed to establish the population demographic of the people living in each house, the water-related appliances installed (for example, toilets, washing machine, dishwasher, bath, shower, etc.), the average weekly use of these appliances, total water consumption, drainage arrangements, and any water-saving devices installed. The results suggested that water use was below the current average consumption of 150 litres per person per day (source: Environment Agency), but the number of respondents was too low to be statistically significant or to provide any further relevant information. Most respondents also chose to remain anonymous, which made it difficult to draw any conclusions regarding differences between the two sites.

2 Non-Invasive Survey

A 3D electrical resistivity tomography (ERT) geophysical survey was employed to obtain the drainage pattern and location of any potential effluent plume within groundwater at The Goodens, Cheriton (British Geological Survey Commissioned Report CR/02/306). The survey gives a detailed 3D tomographic image of the resistivity distribution in the unsaturated and saturated zones around the drainage field, based on the assumption that effluent has good electrical conductivity (EC) contrast in relation to background Chalk. The survey identified two potential plumes of low resistivity effluent in the drainage field running downslope perpendicular to the irrigation pipes, along with a possible leak along the rising main (*Figure 3.1*).

3 Invasive studies

The findings of the desk study in association with the results and interpretation of the ERT geophysical survey were used to identify appropriate locations for a total of five boreholes for the intrusive investigation (*Figure 3.1*). Boreholes were positioned to intercept the apparent effluent plume at around 9 m depth and provide down gradient samples to delineate the extent of the plume migration.

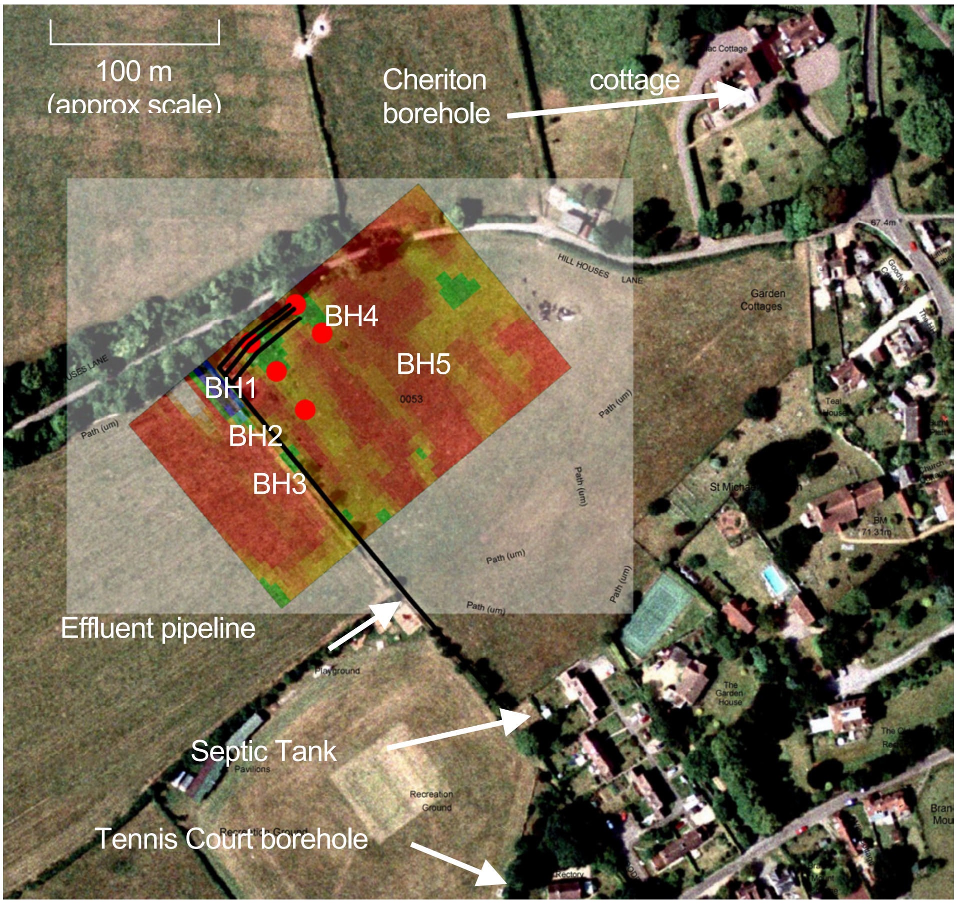


Figure 3.1 Aerial photograph of Cheriton site with ERT survey data and borehole locations.

The spatial distribution of the boreholes combined with already existing boreholes at Cheriton Tennis Courts and Cheriton Cottage were used to determine the groundwater elevation and the local groundwater flow direction. Grid references of the investigative boreholes are summarised in *Table 3.1*.

3.1 Percussive drilling

Five boreholes were drilled at the locations shown in *Figure 3.1* using a cable percussive drill rig to a total depth of 15 m below ground level (bgl). Continuous U100 core samples were taken every 0.5 m throughout the full depth of the borehole. To avoid contaminating the cores and aquifer during drilling, no fluids were introduced into the borehole. To minimise the potential for cross-contamination between boreholes, the casing, drill bits, and sliding hammers were disinfected with a solution of Virkon® and cleaned with a pressure washer between each location. Material collected in the cutting shoe after each core run was used to give a preliminary field lithological log of each borehole. (Borehole logs are given in Appendix 1).

3.2 Core collection preservation

The chalk cores were collected in rigid plastic core liners, and between 80-100% core recovery was achieved on each core run. The cores were sealed with wax and transported to the British Geological Survey (BGS, Keyworth) for cold storage.

3.3 Core logging

Preparation of the cores for logging was carried out using the procedure detailed in the Project Management Statement. The borehole cores were logged according to BS5930:1999 and CIRIA Chalk Description and Classification Scheme. (Completed borehole logs comprising on-site observations and core logging are given in Appendix 1.

3.4 Pore-water centrifugation

Selected core samples from Boreholes 1-4 (BH1 to BH4) were prepared for high-speed centrifugation to extract the enclosed pore water for subsequent inorganic chemical analysis at the BGS laboratories. Results are discussed in Section 8.

3.5 Borehole completion

All boreholes were completed from 15 to 1 m bgl with 125 mm slotted PVC casing covered with a Geowrap™ membrane. The final 1 m to ground level was completed with plain PVC casing to support a bentonite seal. After installing the casing, the borehole was backfilled with clean 1-2 mm gravel to 1 m bgl and above that by a bentonite cement to prevent surface inflow. The borehole was completed at ground level with a lockable manhole cover. An array of electrodes for down-hole ERT was installed in each borehole at 0.5 m intervals to monitor any near-hole hydrogeological effects, such as changes in saturation, leachate movement, or hydrochemistry. All five boreholes were permanently instrumented in this way, but funds were not available to utilise the installations at this time. A diagram of the completion is shown in *Figure 3.2*.

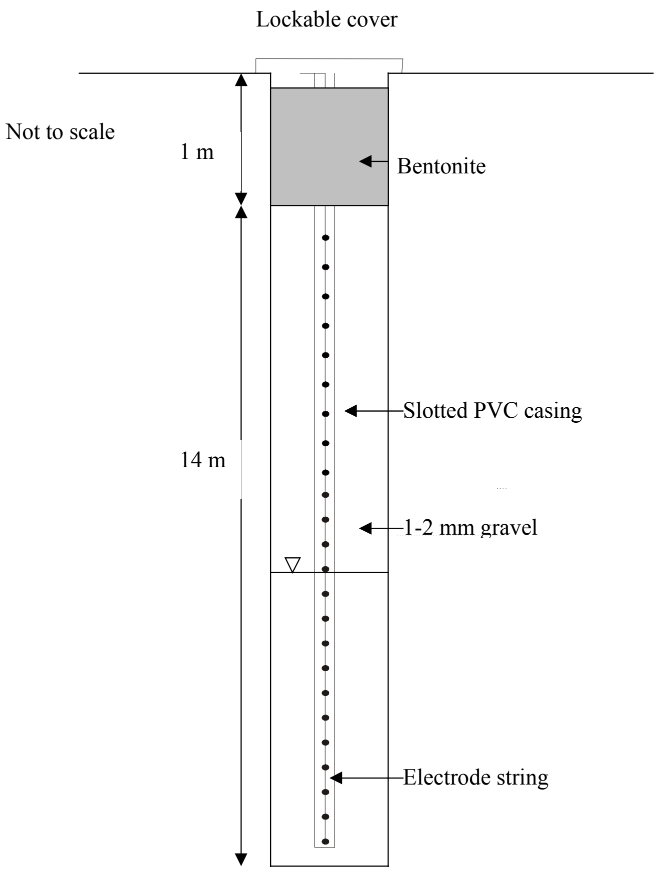


Figure 3.2 Borehole completions.

3.6 Borehole surveying

The location and elevation (x, y, and z) of all boreholes (BH1, BH2, BH3, BH4, and BH5), effluent drainage pipe manhole covers (nine in total) and a general topographic survey of the site, including the road cutting to the north of the site, were measured on the 5 October 2004. The survey was conducted using a dual frequency differential global positioning system (dGPS) used in real-time kinematic (RTK) mode. RTK mode allowed positional corrections to be made in real time via a radio link to a permanent receiver-independent exchange (RINEX) format station maintained by the Ordnance Survey.

The dGPS measurements are between 0.01 and 0.03 m accurate cumulatively in the x and y coordinates, with elevation accurate to within 0.01 m.

A summary of the borehole elevations is given in *Table 3.1*.

Table 3.1 Borehole (BH) coordinates and casing top elevations measured using dGPS.

Location ID	Easting	Northing	Casing top elevation (m AOD)
BH1	457949.9	128549.1	75.729
BH2	457956.6	128542.2	75.022
BH3	457970.0	128526.2	73.741
BH4	457969.1	128566.6	74.586
BH5	457976.1	128558.8	73.718

4 Site monitoring

4.1 Groundwater sample collection

Upon completion of the drilling, all boreholes were purged of at least three borehole volumes of water to remove sediment and colloidal material mobilised during the drilling. A total of four monitoring rounds were undertaken at intervals of approximately three months from July 2004 to April 2005. Samples were collected from the five boreholes installed in the discharge field, from an Environment Agency borehole located near to the tennis courts (as a measure of the baseline aquifer chemistry) and from each of the effluent discharge tanks at both the Cheriton and Droxford sites. Additional samples were collected in January 2005 from a small tributary to the River Itchen that runs through Cheriton village and also from the storage tanks connecting the discharge pipes in the drainage field.

Samples were collected from the septic tanks at both Cheriton and Droxford using dedicated bailers and from the boreholes using a Grundfos™ MP1 submersible pump, which was cleaned between each borehole. A minimum of three borehole volumes was purged from each borehole prior to sample collection.

Samples were collected and preserved on-site for List I and List II analysis, a full suite of inorganic analysis, microbiological analysis, and isotopic analysis.

Analytical results are discussed in Sections 8-10.

4.2 Field measurements

Temperature, pH, EC, redox potential (Eh), and dissolved oxygen concentration (DO_2) were determined on unfiltered bulk samples using calibrated electrodes. Alkalinity was measured with a Hach Titrator using 1.6N sulphuric acid and Bromocresol Green indicator (titration end point of pH 4.5). Field measurements of ammonium and detergents were also undertaken on unfiltered colourless samples using standard colorimetric techniques. Faecal coliforms were also determined on the bulk groundwater and septic tank samples.

4.3 Continuous water-quality measurements

Two Multiparameter (MP) Troll 9000 water-quality measurement units were installed in the septic tank and PTP to measure pH, temperature, oxidation–reduction potential (ORP), dissolved oxygen, EC, ammonium, and water level continuously.

4.4 Groundwater level monitoring

Water level loggers were installed in four boreholes (BH1, BH2, BH3, and BH4) and set to record pressure and temperature measurements twice a day at 09:00 and 21:00. An automatic barometric compensation logger was installed in BH5. These data are used to measure the aquifer response to rainfall, to determine an accurate groundwater flow direction and its seasonal variability. Results are presented in Sections 5.7 and 5.8.

5 Results of invasive studies

To understand the potential for contaminants to be diluted in the aquifer below the effluent outflow pipes, it is important to understand not only the direction of groundwater flow, but also the amount of water that flows and the speed at which it is travelling.

The hydraulic conductivity (K) is defined as the normal rate of transmission of water through the matrix at a certain state of wetness (Jones 1997), and is usually calculated using Darcy's Law and quoted in metres per day ($\mathrm{m\ d^{-1}}$).

The transmissivity (T) is the rate of flow per unit width of aquifer under unit hydraulic gradient for the whole width of the aquifer (Jones 1997), $T = Kb$, where b is the thickness of the aquifer. However, transmissivity can be highly variable, even within a specific rock stratum, and is often difficult to generalise.

5.1 Site geological summary

The underlying geology at the septic tank effluent outflow pipes was identified during drilling of BH1 to BH5. The typical sequence identified:

- *Topsoil*, soft, dark brown, slightly silty clay with some small chalk clasts, up to 0.7 m thick in BH4.
- *Weathered chalk*, comprising weak, white, structureless angular gravel-sized chalk clasts with varying proportions of soft brown clay matrix. This weathered horizon ranged in thickness from 1.2 m in BH4 and BH5 to 2.93 m in BH1, with the thickest weathered horizon corresponding to the location (at depth) of the effluent discharge pipes. The boundary between the weathered chalk and underlying chalk is gradual, but it has been classed as where the chalk becomes structured and there is an absence of brown clay in fractures.
- *Chalk*, comprising weak, white, structured chalk with variable fracture spacing (close to extremely close) and orientation (vertical to horizontal). Fracture sets were not discernible, but there were occasional groups of long sub-vertical fractures. Orange staining was often seen on faces of longer fractures. Around the water table many of the fracture walls comprised soft, white putty chalk, possibly because of weathering from groundwater movement. Fracture density and length generally decreased with depth, although the fracture aperture size (that is, if the fractures were open or closed) could not be assessed because of movement during removal of the core (unfortunately, project constraints meant that down-hole geophysical logging was not undertaken during drilling).
- *Flint horizon(s)*, comprising strong, black, conchoidal flint. The flint band was identified in all boreholes between 62.05 to 63.38 m AOD (approximately 11 to 14 m bgl). However the range in elevations and the presence of a white rind on some flint may indicate that the horizon comprises chalk with abundant flint clasts rather than a continuous flint bed. The density of flints may locally create a confining layer in the chalk or disrupt groundwater flow.
- *Chalk*, comprising weak, white, structured chalk with some close to very close spaced, short, vertical to horizontal fractures.

5.2 Infiltrometer tests

The infiltration of rainfall into the soil can be determined by infiltrometer tests (Wu *et al*. 1997), which in turn gives a saturated vertical hydraulic conductivity of the soil. Two steel rings of different diameters (0.53 m and 0.28 m) and 0.20 m depth are pushed a short way into the soil, the smaller diameter ring inside the larger. Known volumes of water are poured into each ring and the level maintained by topping up over a period of time. The infiltration rate (head drop) in the inner ring is measured until the infiltration rate into the soil equilibrates.

Table 5.1 Saturated vertical hydraulic conductivity values for the Cheriton site.

Test #	BH1	BH2	BH3	BH4	BH5
K_v (m d^{-1})	2.1	3.4	N/A	0.6	2.0
Soil and vegetation cover	Long grass with brown, silty clay and occasional chalk clasts	Long grass with brown, silty clay and occasional chalk clasts	N/A	Long grass with brown, silty clay and occasional chalk clasts	Long grass with brown, silty clay and occasional chalk clasts

The saturated vertical hydraulic conductivity values range from 0.6 to 3.4 m d^{-1} with an average value of approximately 2 m d^{-1} (*Table 5.1*). The variation in saturated vertical hydraulic conductivity values is likely to be the result of heterogeneities within the soil and of bypass flow via macropores and microfissures (that is, crack, root, or worm holes). The heterogeneities associated with soils mean that many infiltrometer tests are required to characterise an area, and consequently the few measurements made should be taken only as estimates for saturated K_v. Time constraints did not allow the testing of soil around BH3.

5.3 Hydraulic testing

Determination of the hydraulic properties of the Chalk aquifer that underlies the septic tank effluent outlet pipes is important in order to understand groundwater flow and the likely impacts on contaminant concentration.

A total of 15 slug tests (three per borehole) were performed to determine the hydraulic conductivity of the material that surrounds the saturated screened portion of the borehole installation. The rising head test method was used (Hvorslev 1951), whereby a volume of water is removed from a well and the return in water level to equilibrium monitored using a pressure transducer. The falling head method could not be used as the screened interval of each borehole extends above the water table (borehole installation details are shown on the borehole logs in Appendix 1). Initial testing identified that insufficient displacement of groundwater could be achieved using a displacement slug test method; therefore, it was decided to pump groundwater using a 4 inch submersible pump until equilibrium was achieved (that is, the maximum drawdown for the prescribed abstraction rate). Drawdown using this method ranged between 0.97 m (BH1) and 2.96 m (BH4). Once maximum drawdown was achieved the pump was turned off and the recovery of the water level monitored using a mini-troll datalogger that measured at one-second time intervals. Recovery times ranged from 22 seconds (BH2) to 45 seconds (BH5). Pump tests were not conducted because of cost and time constraints, and the pump used for slug tests was not able to abstract at a sufficient rate to induce the required drawdown in the observation boreholes.

5.4 Hydraulic testing analysis

Slug test data were analysed using the Aquifer^{Win32} (Professional; ESI 1999) software package. Hydraulic conductivity values were calculated using the widely used Hvorslev linear regression method (Hvorslev 1951), which assumes that the aquifer is homogeneous, isotropic, and an infinite medium in which soil and water are incompressible (that is, the aquifer storativity is zero). Analysis of slug tests also assumes an instantaneous change in head. This assumption could not be resolved during the testing, as it was necessary to pump for a period of time until drawdown equilibrated. This was, however, relatively rapid and in the order of 30-60 seconds. An additional problem with using a pump method is that of leakage from the rising main interfering with the natural recovery of the water table. This is often shown as a steady initial natural recovery followed by a slight increase in recovery rates as leakage occurs. Leakage volumes are believed to be small as the pump was fitted with a non-return valve and the rising main sections were connected securely. To remove this effect, hydraulic conductivity values were estimated from the early recovery data.

Calculated mean hydraulic conductivity values are given in *Table 5.2*. The repeatability between tests is good with standard deviations ranging from 0.0 (BH4) to 1.1 (BH2), with repeatability generally poorest where hydraulic conductivities are high (rapid recovery times).

Table 5.2 Mean bulk hydraulic conductivity determined from hydraulic testing.

Borehole	**Mean bulk hydraulic conductivity K (m d^{-1})**	**Standard deviation**
BH1	2.1	0.1
BH2	6.8	1.1
BH3	3.2	0.1
BH4	1.4	0.0
BH5	1.7	0.3

Calculated hydraulic conductivity values are all within the same order of magnitude, however the highest value (that is, quickest recovery and lowest initial drawdown) occurs at BH2 and may result from the occurrence of more, or larger aperture, fractures. However, there is considerable uncertainty associated with the calculated hydraulic conductivity values because of the rapid recovery of the water table (that is, few data points to match) and possible interference because of leakage of water from the pump rising main. Consequently, values should be used as estimates only.

Hydraulic conductivity values for the chalk matrix alone have been estimated as approximately 6.3×10^{-4} m d^{-1} (Allen *et al*. 1997), which is considerably lower than the values measured by hydraulic testing. This indicates that groundwater flow is likely to be dominated by fracture flow.

Bulk hydraulic conductivity values are estimated as ranging from 4×10^{-3} to 362 m d^{-1}, assuming a thickness range of 80-150 m for the Upper Chalk (Allen *et al*. 1997). This gives an indication of the groundwater flow velocity in the Hampshire Basin. In comparison, the hydraulic conductivity values calculated from slug tests at the Cheriton site are towards the upper middle end of this range, most likely because the site is located in the River Itchen valley, where a higher incidence of fractures is expected.

5.5 Conclusions of hydraulic testing

Groundwater flow velocities in chalk aquifers vary over a wide range, depending on the contribution from fracture flow. Hydraulic conductivity values from the boreholes at Cheriton show that large volumes of water are flowing relatively quickly in the aquifer below the site. This is probably due to significant fractures in the chalk and its position in a river valley.

5.6 Geological modelling

Geological information from borehole logs was used to construct a fence diagram for the study area. The model was constructed using the GSI3D software package in which cross-sections are hand correlated between boreholes. The model indicates that the geology is very consistent between boreholes (*Figure 5.1*). There is a slight thinning of the weathered chalk horizon to the northeast. The most significant variation is with the flint bands identified. The flint bands occur at similar elevations between boreholes, but the variability in the number and thickness of bands indicates that the flints may not form a continuous horizon. Therefore, they have only a minimal impact on groundwater movement, particularly as local flow is likely to be dominated by fractures.

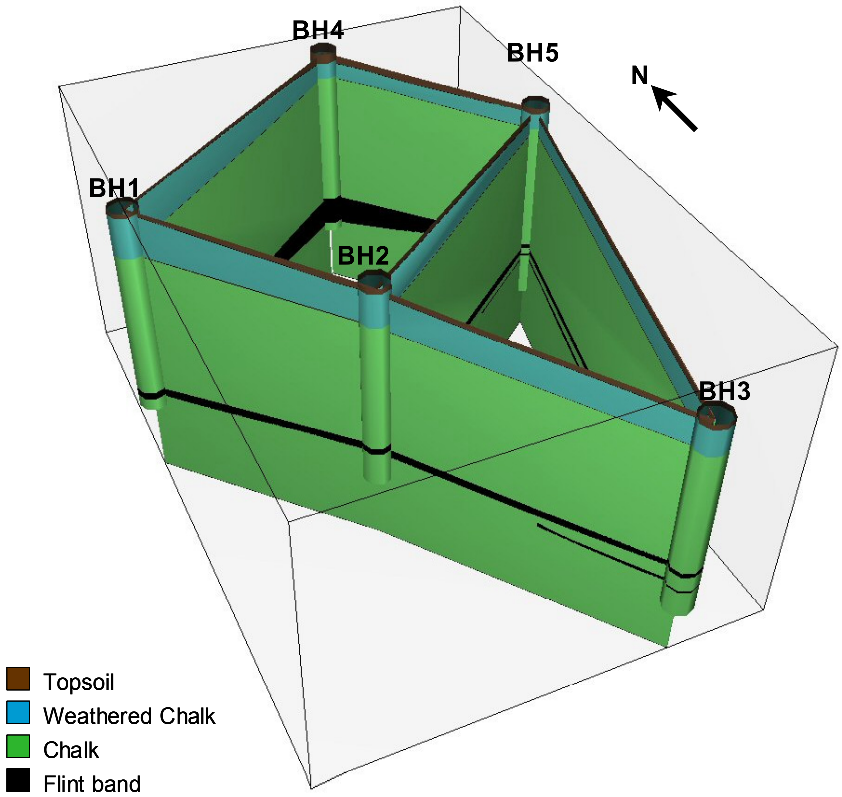


Figure 5.1 Fence diagram showing the geological variability between boreholes.

5.7 Groundwater elevation

Groundwater elevation was measured twice daily (9 am and 9 pm) using Mini-Troll pressure transducers in BH1, BH2, BH3, and BH4 over a period of approximately nine months between August 2004 and April 2005. Groundwater elevation (9 am only) data were plotted against rainfall data measured at a monitoring station in Bishops Sutton, approximately 4 km to the northeast of the site (*Figure 5.2*). The fluctuation in groundwater level broadly correlates with the cycle expected over the relative seasons, with lows in the summer, an increase through autumn, highs in the winter period, and a steady decline from January to April.

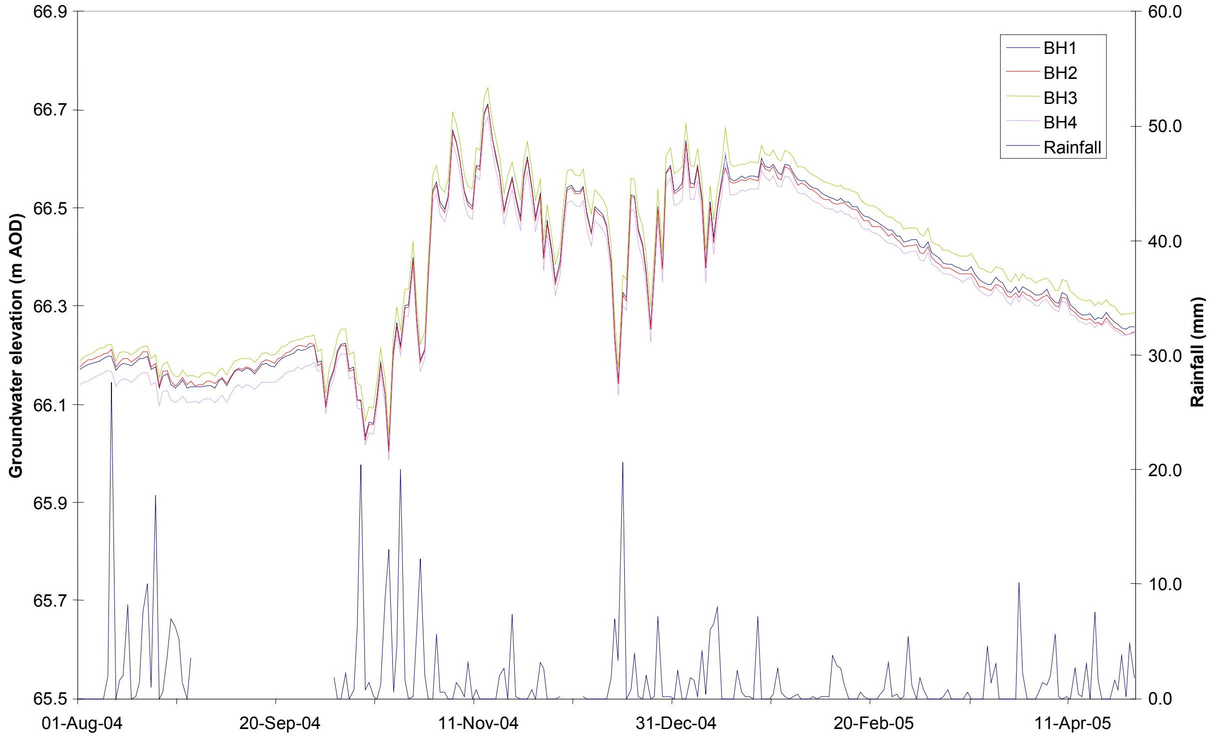
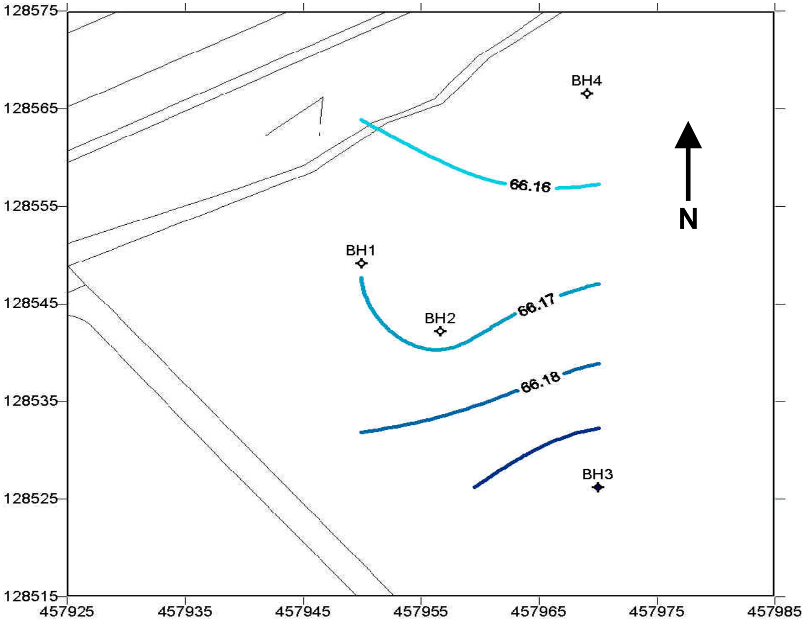


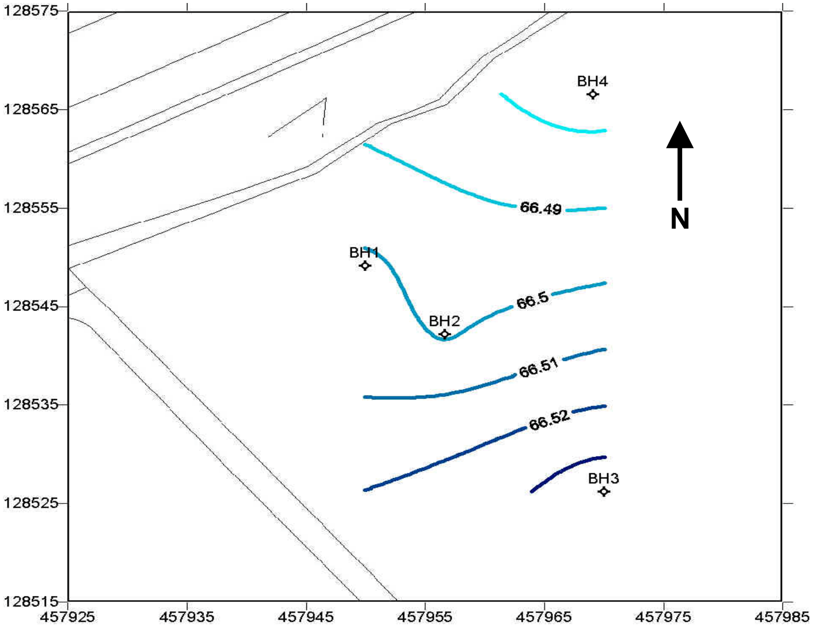
Figure 5.2 Groundwater elevation data for BH1, BH2, BH3, and BH4.

5.8 Groundwater flow direction

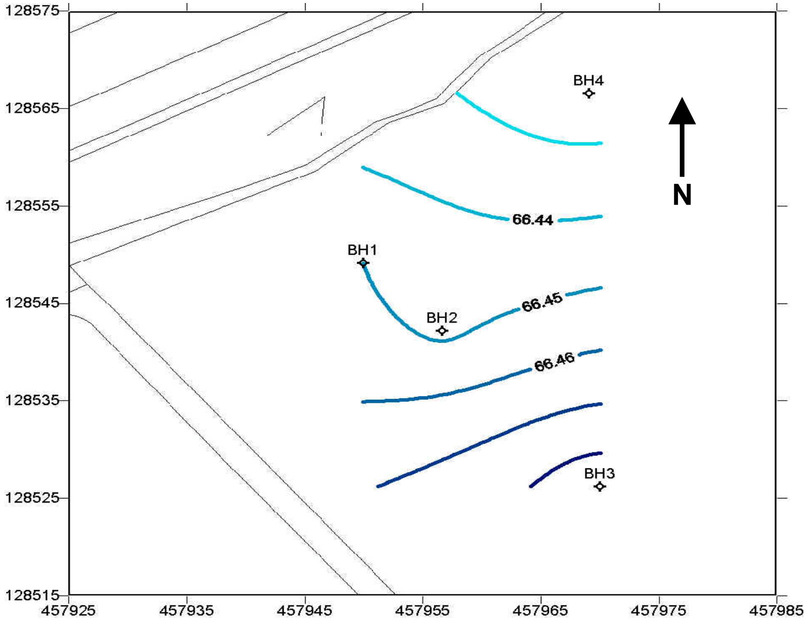
Groundwater flow directions were calculated using Surfer® 7.0 (Golden Software 2001) for measurements of groundwater elevation at BH1, BH2, BH3, and BH4. Contour plots to demonstrate the variation in groundwater flow direction between October 2004 and April 2005 are shown in *Figure 5.3*. Groundwater flow is consistently orientated approximately north, with a slight north–northwest element between BH3 and BH2 and a north–northeast element between BH2 and BH4. BH2 often has a higher groundwater level than BH1, which may locally distort the groundwater flow direction (groundwater level in the boreholes may be locally elevated because of an increased recharge from the effluent pipes). The groundwater hydraulic gradient is approximately 0.0015, but it is greatest in the south (approximately 0.0024 between BH3 and BH2) and lowest in the north (approximately 0.0012 between BH2 and BH4).



10 – Oct 04



10 – Nov 04



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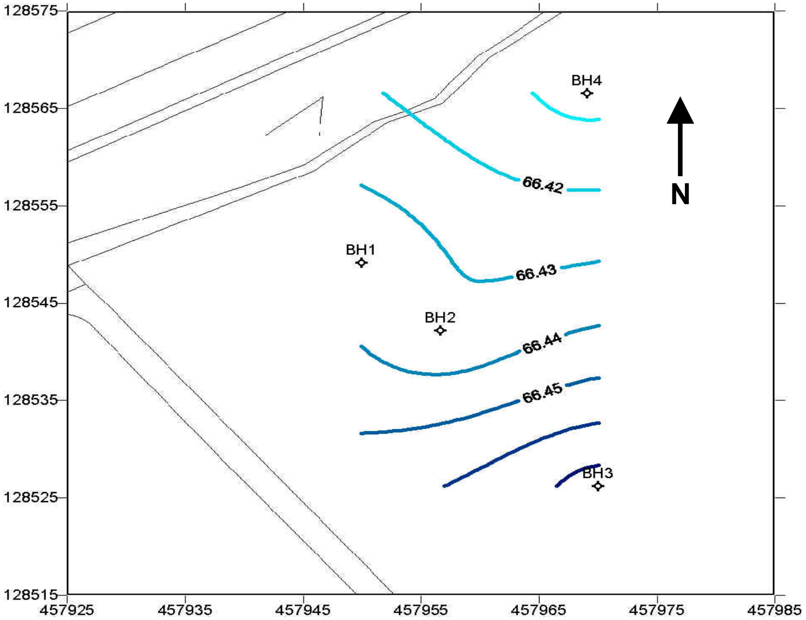

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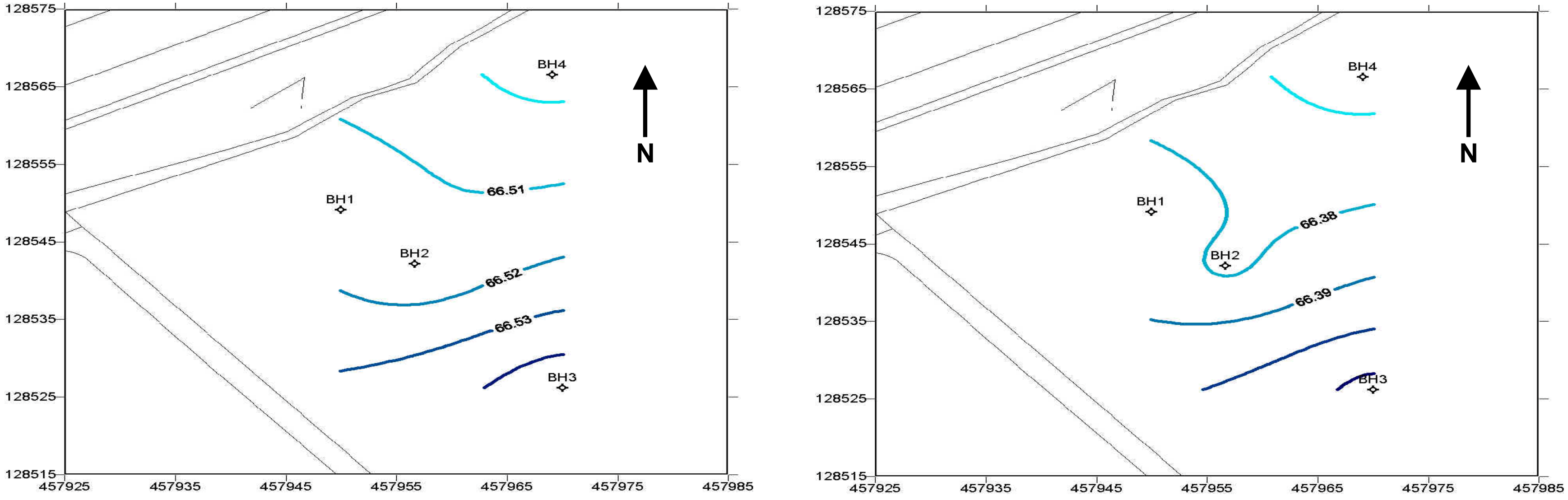


10 – Feb 05

10 – Mar 05

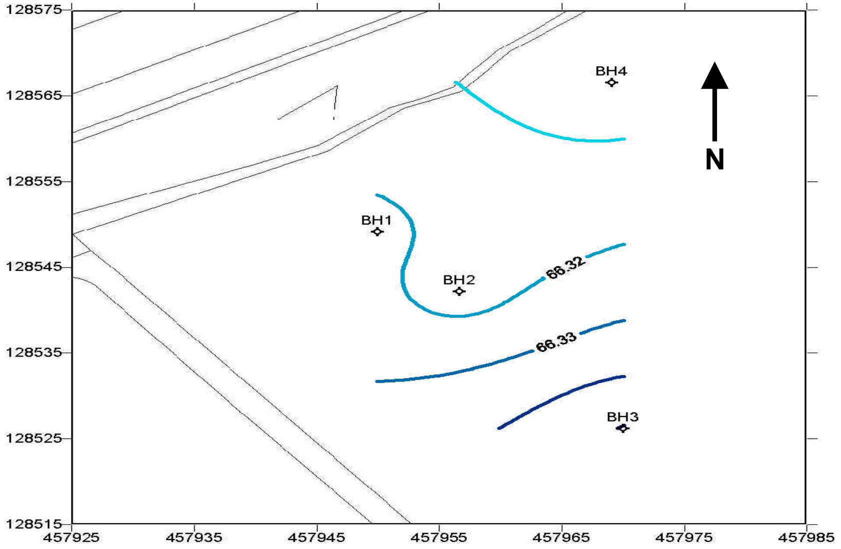
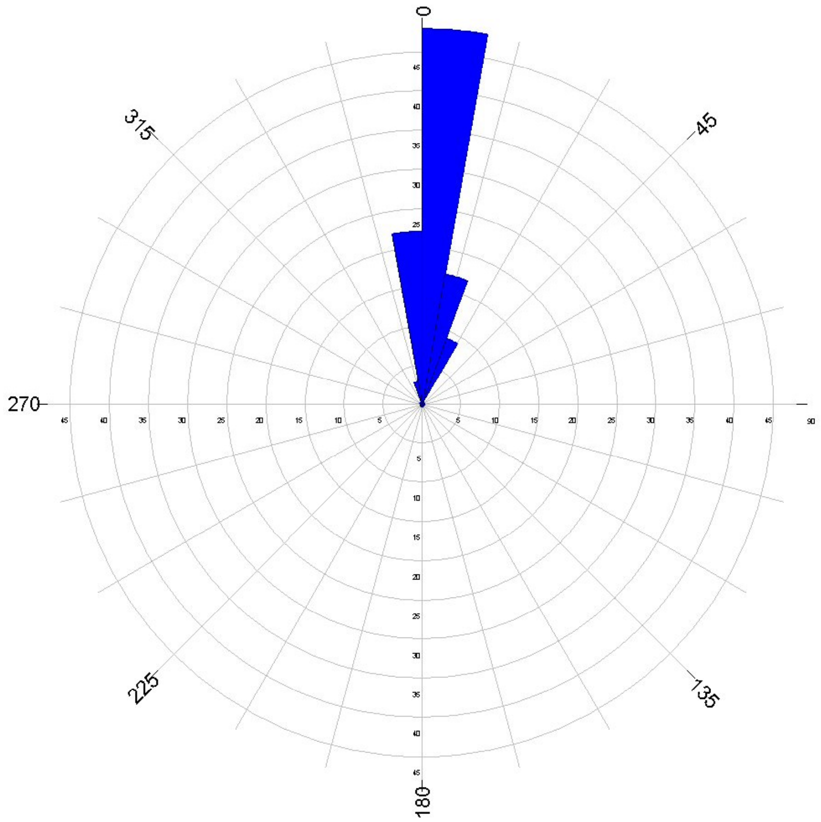


Figure 5.3 Groundwater contour plots from 10 October 2004 to 10 April –2005.



Mean groundwater flow direction: 5.15 °

Standard deviation: 17.43%

Population: 267

Class interval: 10 °

Figure 5.4 Rose diagram showing groundwater flow direction between September 2004 and April 2005 for BH1, BH3, and BH4.

The groundwater flow direction between September 2004 and April 2005, as calculated from BH1, BH3, and BH4, is approximately north (average 5.15º), ranging from 350º to 030º (*Figure 5.4*). This indicates little variability in groundwater flow direction over this time period.

5.9 Moisture content

The moisture content was determined for samples taken from BH1, BH2, BH3, and BH4 for pore-water analysis (core from BH5 was not centrifuged because of budget constraints and so there are no moisture content values for this borehole). Moisture content ranges from 18.76% (BH3 0.5-0.95 m bgl) to 25.89% (BH1 4.9-5.35 m bgl), with an average of 23.19% (*Figure 5.5*).

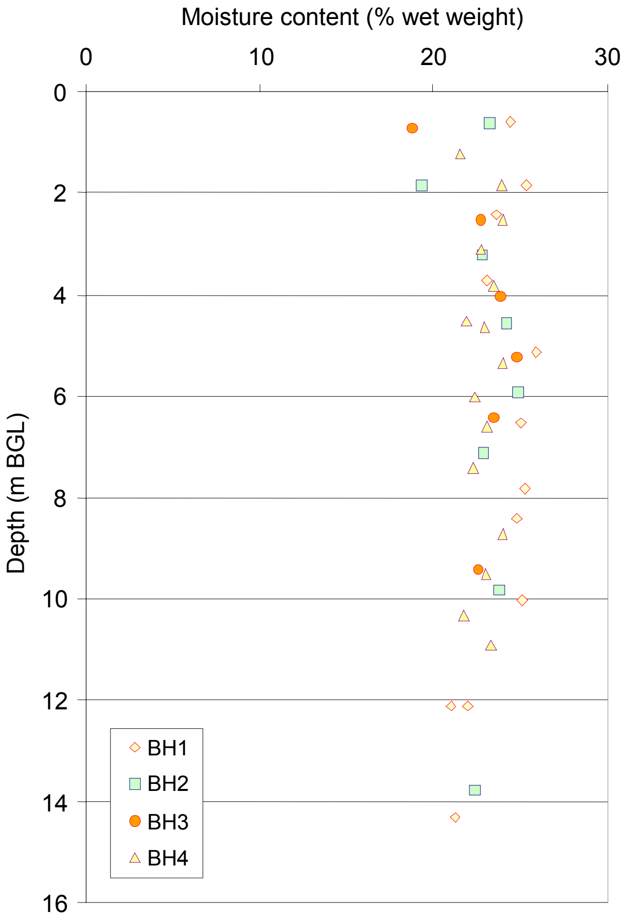


Figure 5.5 Moisture content with depth for BH1, BH2, BH3, and BH4.

Moisture content is generally relatively consistent with depth, with no marked increase at the water table, above in the capillary fringe (*Figure 5.6*) or associated with changes in lithostratigraphy. This may suggest that the chalk matrix is fully saturated, which is possible because of the small pore throats commonly associated with the Chalk that result in low specific yields (that is, the Chalk matrix does not drain freely). If the Chalk is fully saturated, then the moisture content is approximate to the total porosity, indicating the porosity of the Chalk at the site to be an average of 23.19 %. This is lower than the average regional porosity value of 38.8% determined using 724 samples from the Upper Chalk (Allen *et al*. 1997), but porosity values from these samples range from 5.6 to 48.9%.

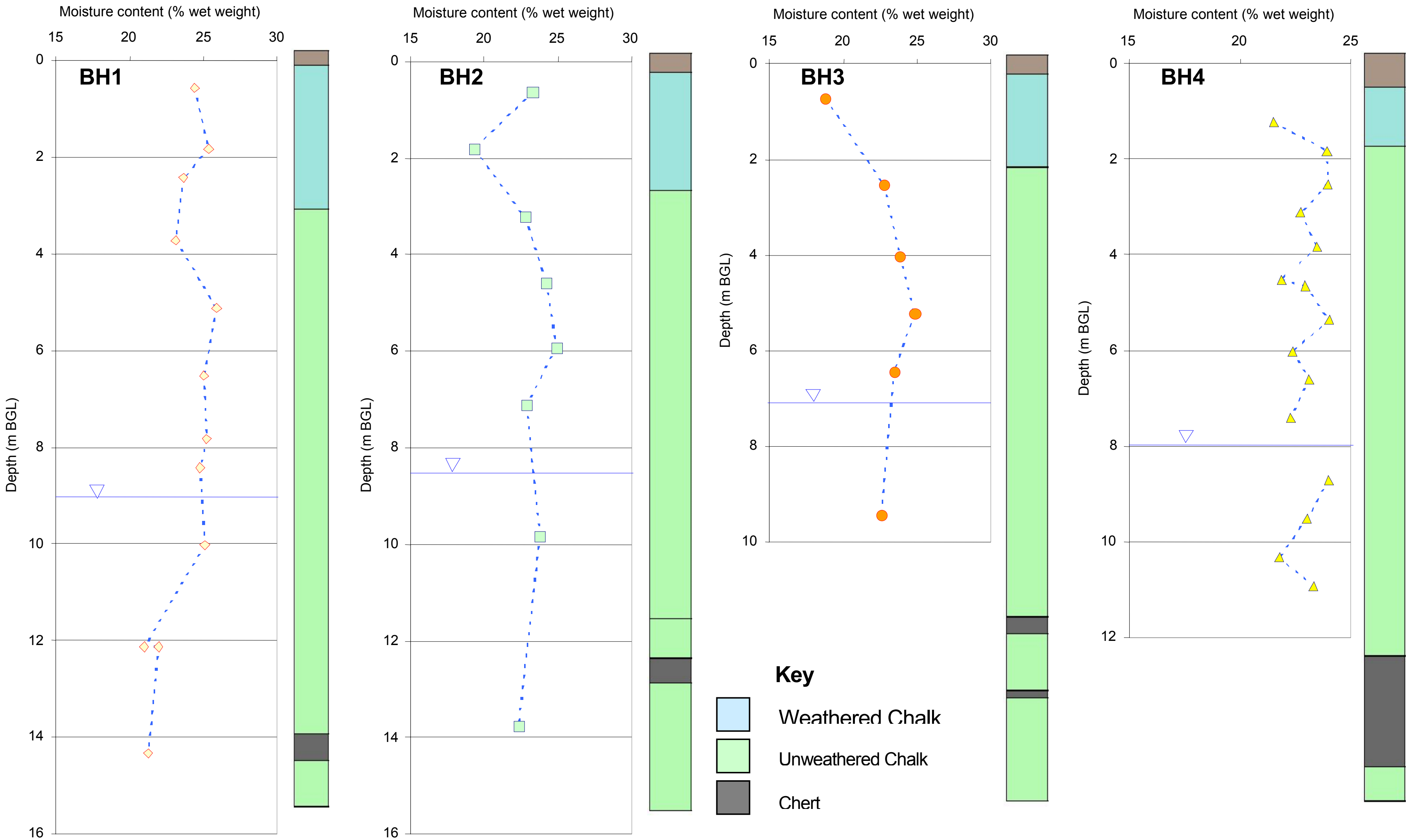


Figure 5.2 Moisture content variation with depth compared to lithostratigraphy for BH1, BH2, BH3, and BH4.

6 Inorganic chemistry of pore water

Selected core samples from BH1, BH2, BH3, and BH4 were prepared for high-speed centrifugation to extract the enclosed pore water for subsequent inorganic chemical analysis. Chemical depth profiles can then be plotted to show contaminant migration through the unsaturated zone.

Figures 6.1 to *6.4* show Piper diagrams of major ion data (in milli-equivalents) of the pore waters from BH1, BH2, BH3, and BH4 against borehole lithology and depth along with depth profiles of the major ions. BH1 and BH4, positioned between the second and third discharge pipes, show a changing chemistry with depth, particularly BH4. Between 5.3 and 7.5 m depth, BH4 pore waters change from being dominated by calcium carbonate to being dominated by sodium chloride, which peaks between 6.5 and 7.0 m (rest water level was measured at 7.99 m when the cores were collected). Sulphate and boron also peak at this depth. In unsaturated conditions contaminants move slowly by molecular diffusion through the intergranular pores of the chalk matrix. Moisture contents of the core at the time of drilling were approaching full saturation.

BH2 and BH3 exhibit less variation with depth, with the majority of samples exhibiting similar chemistry to the groundwater samples (*Figures 6.3* and *6.4*).

There are apparent peaks of ion concentrations in several of the boreholes, commonly just above the water table, the exact mechanism for which remains unclear. Further work is required to establish specifically the processes that produce these peaks.

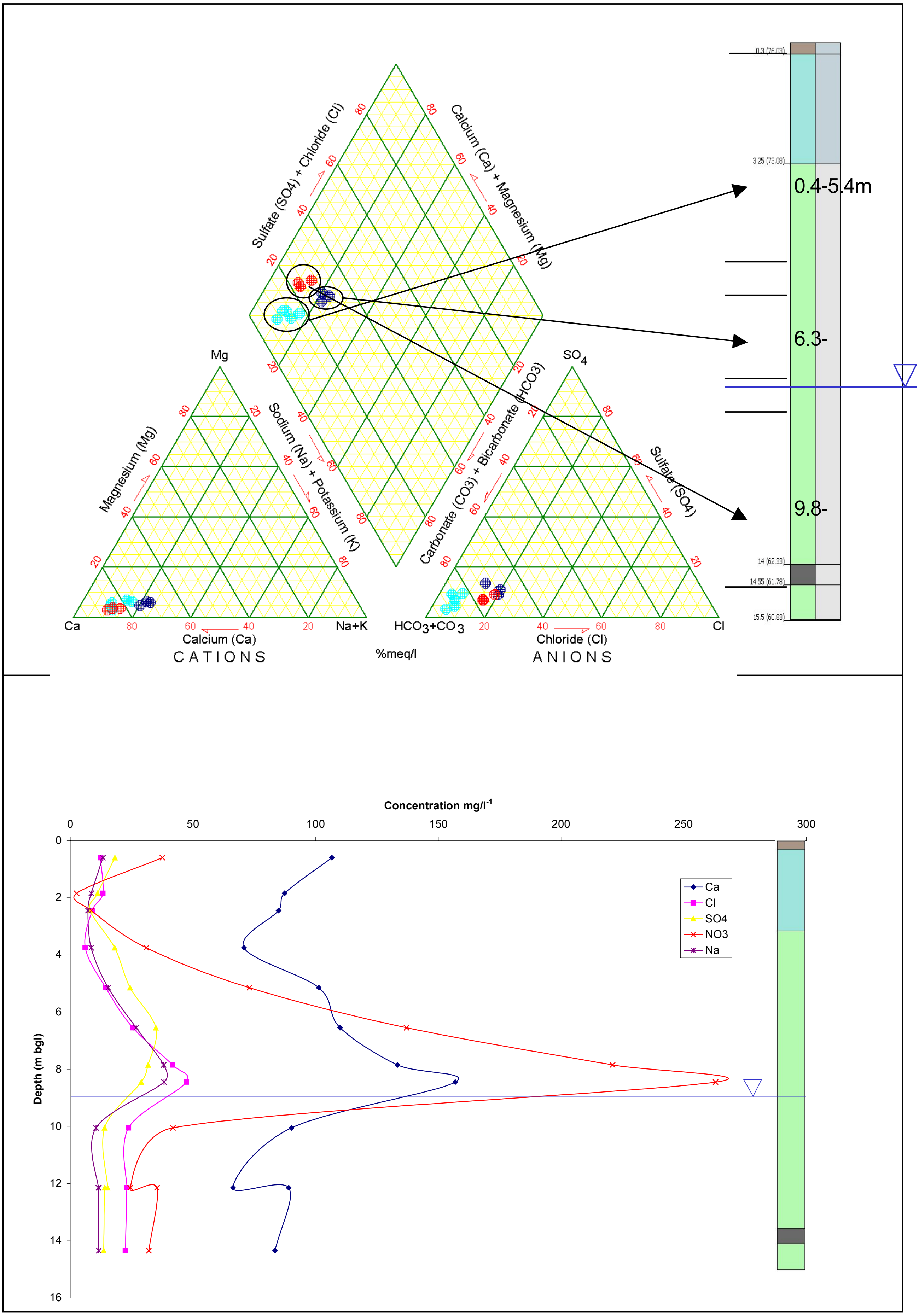


Figure 6.1 BH 1 pore-water major ion data.

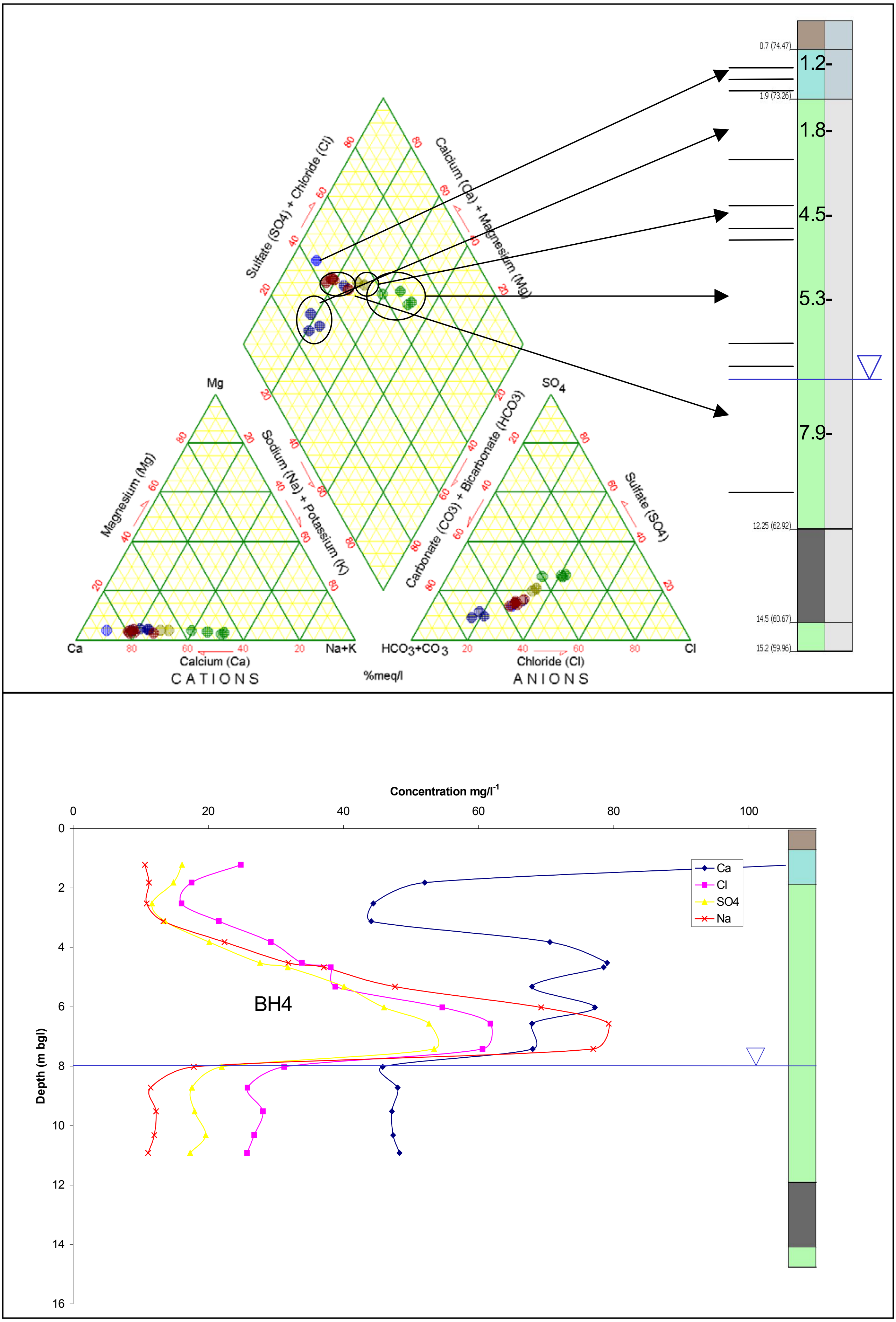


Figure 6.2 BH4 pore-water major ion data.

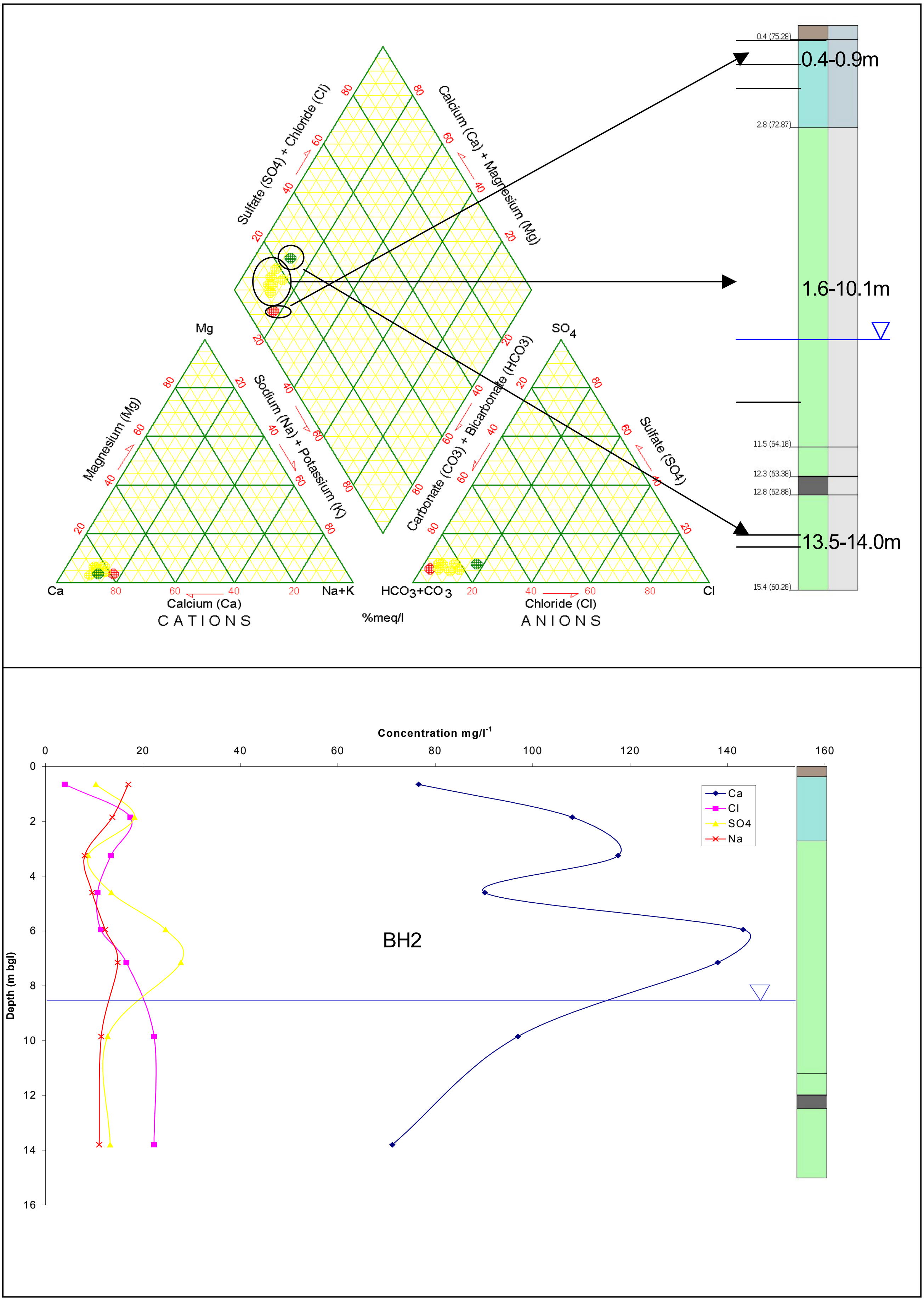


Figure 6.3 BH2 pore-water major ion data.

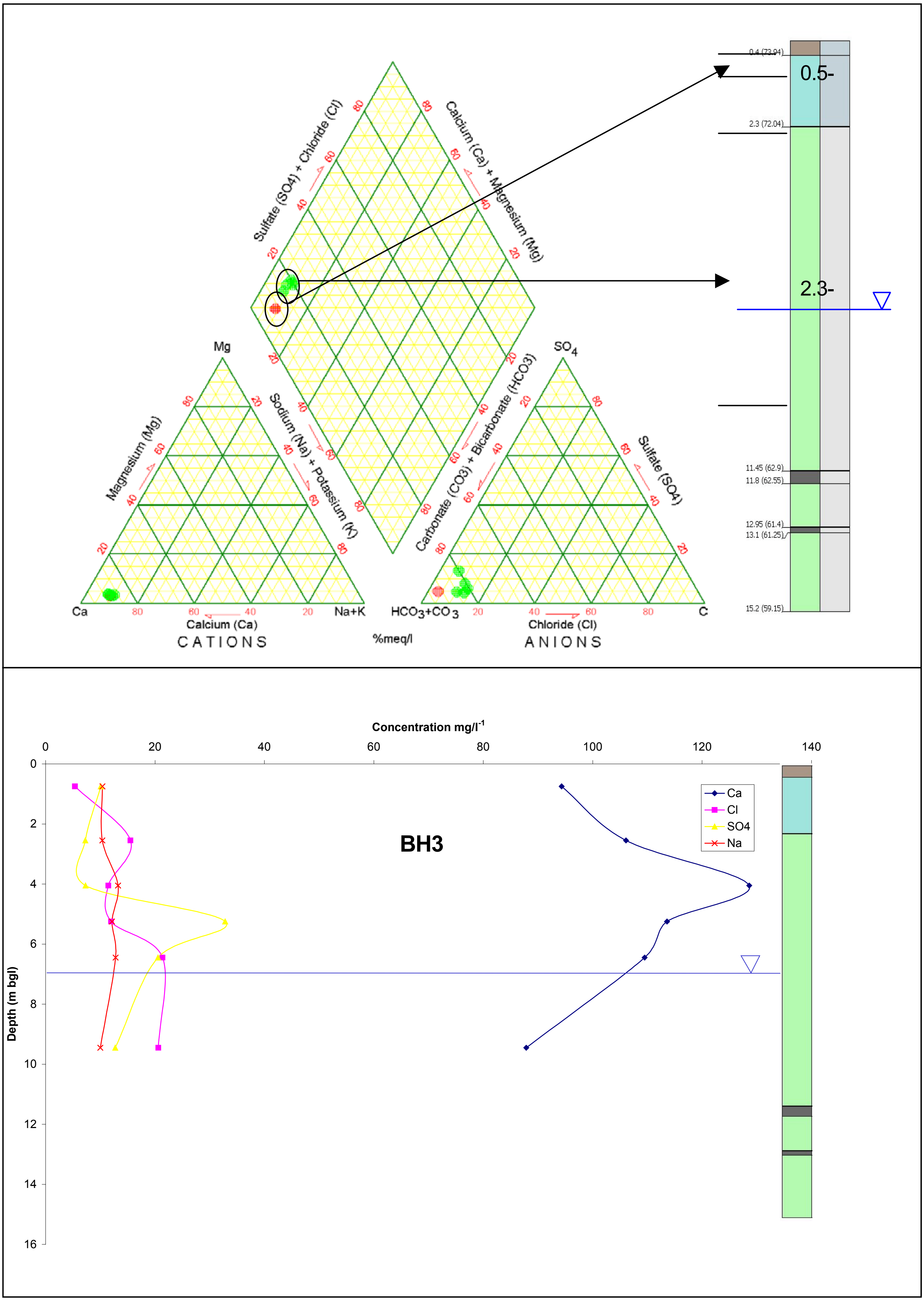


Figure 6.4 BH3 pore-water major ion data.

7 Inorganic chemistry of effluent and groundwater

Groundwater from the five boreholes and from an Environment Agency borehole (tennis court) up gradient of the tank outflow was collected four times from June 2004 to April. The borehole major and trace ion chemistry showed little variation (<5% relative standard deviation), both individually and collectively, over this period. *Figure 7.1* shows a Piper diagram of the averaged major ion data (in milli-equivalents) for this period, which indicates waters dominated by calcium carbonate with low total dissolved solids (TDSs), commensurate with a Chalk aquifer. It can be seen that the boreholes and background sample plot directly on top of each other and a comparison of the borehole data with that from the Environment Agency monitoring well also shows little or no variation.

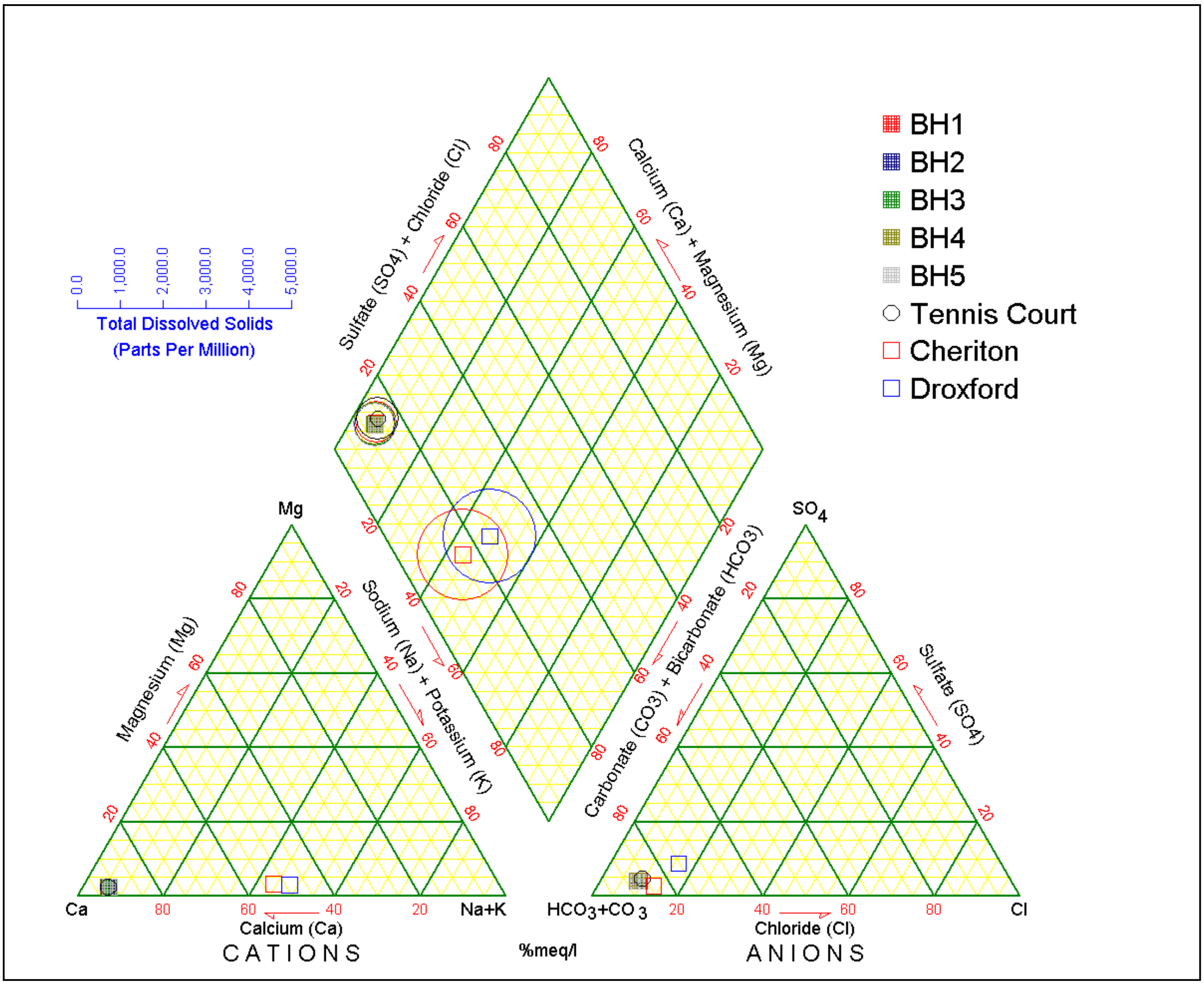


Figure 7.1 Piper diagram of average major ion data for all boreholes and septic tank samples.

Trace metals were analysed both by the BGS laboratories using inductively coupled plasma – atomic emission spectroscopy (ICP-AES), and by the AlControl laboratory using ICP-mass spectroscopy (ICP-MS) to achieve lower detection limits. Data from both laboratories compared well. In addition, bailed samples were collected to compare with purged samples, and analysed by the Environment Agency laboratory. The majority of trace metals were below the analytical limit of detection with the exception of zinc, titanium, lead, cobalt, barium, strontium, antimony, boron, nickel, and aluminium. Many of these analytes were only detected using the more sensitive ICP–MS technique. Those trace metals detected were of comparable concentrations in the groundwater samples taken from the site boreholes and the tennis court (background) borehole.

Table 7.1 Comparison of average borehole, septic tank, PTP, and tennis court samples with Water Supply Regulations (2000) maximum concentrations and permissible detection limits (DL).

Sample Code	Conductivity	pH	Na^+	Cl^-	SO_4^{2-}	NO_3^-	NO_2^-	F^-	NH_4^+	Mn	Total Fe	Al	Ni	Cu	Cr	Cd	B	As	Se	Sb	Pb	Hg
	μS cm^{-1}		mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	μg l^{-1}	mg l^{-1}	mg l^{-1}	μg l^{-1}	mg l^{-1}	μg l^{-1}	μg l^{-1}	μg l^{-1}	μg l^{-1}	μg l^{-1}
BH1 to BH5	580	7.81	9.42	20.2	12.1	30.9	0.01	0.05	0.15	<0.01	<0.01	<0.01	2.00	<0.002	<0.002	<0.4	<0.025	<1.00	<1.00	<5.00	<1.00	<0.050
Tennis court	690	7.56	7.62	21.1	14.3	33.9	0.00	0.04	0.56	0.02	0.25	<0.01	6.75	<0.002	<0.002	0.90	<0.025	1.00	4.50	32.0	4.33	<0.050
Cheriton tank	1630	7.59	86.5	68.6	19.1	0.03	0.07	0.01	104	0.03	0.13	0.04	3.25	0.015	0.006	<0.4	0.84	2.00	9.67	<5.00	3.50	<0.050
Droxford tank	1870	7.84	103	88.1	65.5	0.08	0.17	0.02	89.0	0.02	0.04	0.04	2.00	0.007	0.005	<0.4	0.37	<1.00	10.00	177	6.50	0.06
Water Regs	2500	6.5-10	200	250	250	50.0	0.50	1.500	0.50	0.050	0.20	0.200	20.0	2.000	0.050	5.00	1.000	10.0	10.0	5.00	25.0	1.00
DL			20.0	25.0	25.0	5.0	0.05	0.150	0.05	0.005	0.02	0.020	2.00	0.200	0.005	0.50	0.100	1.00	1.00	1.25	2.5	0.20

Table 7.1 gives a comparison of average concentrations (averaged for all sampling rounds) of chemicals for BH1 to BH5, the tennis court borehole, septic tank, and PTP, and the UK Water Supply (Water Quality) Regulations 2000 maximum permissible concentrations (highlighted in blue). The only chemicals to exceed the water quality guidelines in the borehole samples are NH_4^+, total iron, and antimony (highlighted in red). All three are present at elevated levels in the tennis court sample, while the septic tank at Cheriton exceeds the NH_4^+ concentration, and the PTP at Droxford exceeds the NH_4^+ and antimony concentrations.

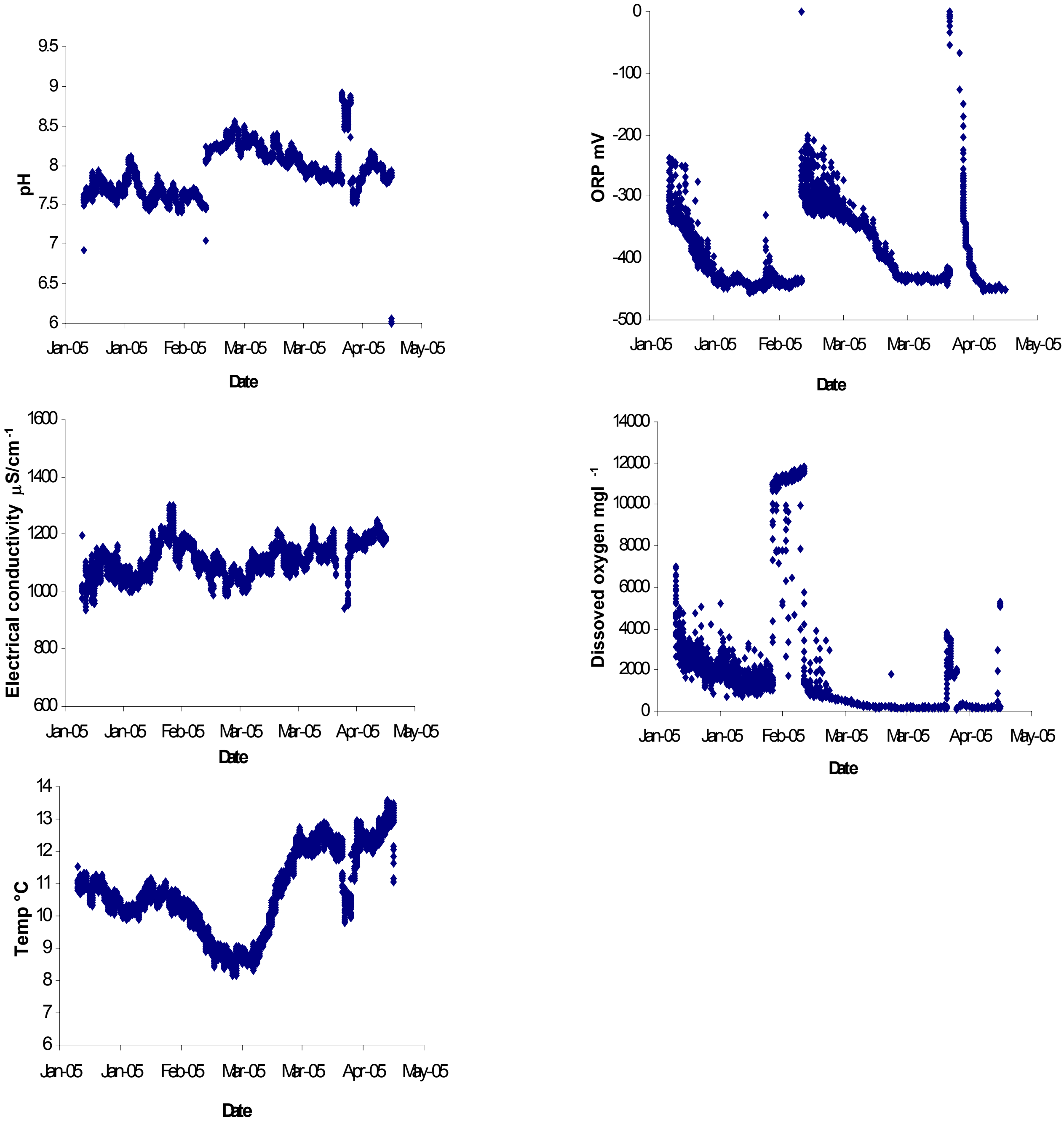


Figure 7.2 Effluent quality data collected every 30 minutes for the Cheriton septic tank.

Samples of effluent from the Cheriton septic tank and the Droxford PTP were also collected during these monitoring rounds and are also plotted on the Piper diagram in *Figure 7.1*. These samples differ in their major ion chemistry from that of the groundwaters, predominantly because of elevated concentrations of sodium, potassium, and chloride, and greater TDSs. Also apparent (*Table 7.1*) are elevated concentrations of organic and inorganic carbon, orthophosphate, total phosphorous, total sulphur, and ammonium. Biological and chemical oxygen demand (BOD and COD) is also increased in the effluent. The retention of comparatively high concentrations of ammonia in the septic tank and very low nitrate concentrations indicates the ammonia is not being extensively oxidised because of the reducing environment of the tank.

Multi-parameter probes were installed in the tanks at both Cheriton and Droxford to measure pH, temperature, EC, ORP, and pressure every 30 minutes. Plots of the data for the period January 2005 to April 2005 for Cheriton are presented in *Figure 7.2*.

Detailed interpretation of these data is difficult without knowledge of the inputs to the tank, but the effluent is in general of neutral to slightly alkaline pH, and anoxic with relatively low TDSs. Comparable data were collected for both the septic tank and the PTP.

Concentrations of the majority of trace metals detected in the effluent are comparable with those detected in the groundwater samples, with the exception of boron, which was not detected in the groundwater, but is present in the effluent at between 0.4-1.5 mg l^{-1}. A comparison of groundwater and effluent chemistry is given in *Table 7.2*.

The PTP at The Park, Droxford, clarifies the effluent in three stages, including two settlement stages and a final biological filter before discharge. In comparison, the septic tank at Cheriton only utilises primary settlement with limited biological activity before discharge. The reduced treatment at Cheriton is apparent in the effluent quality, with significantly greater BOD and COD and total organic carbon (TOC), although TDS loadings are similar. This suggests that little or no microbiological oxidation occurs in the primary treatment prior to discharge from the Cheriton septic tank. The onset of microbially mediated oxidation in the PTP at Droxford is apparent in the increased sulphate concentrations and some evidence that the sequence has started to move through to ammonium oxidation in the increased concentrations of nitrite present.

Samples were also collected from the holding tanks that connected the discharge pipes at the Cheriton site (*Figures 7.3* and *7.4*). Although further settlement appears to occur in these tanks, samples were found to be chemically indistinguishable from the effluent collected from the main discharge tank.

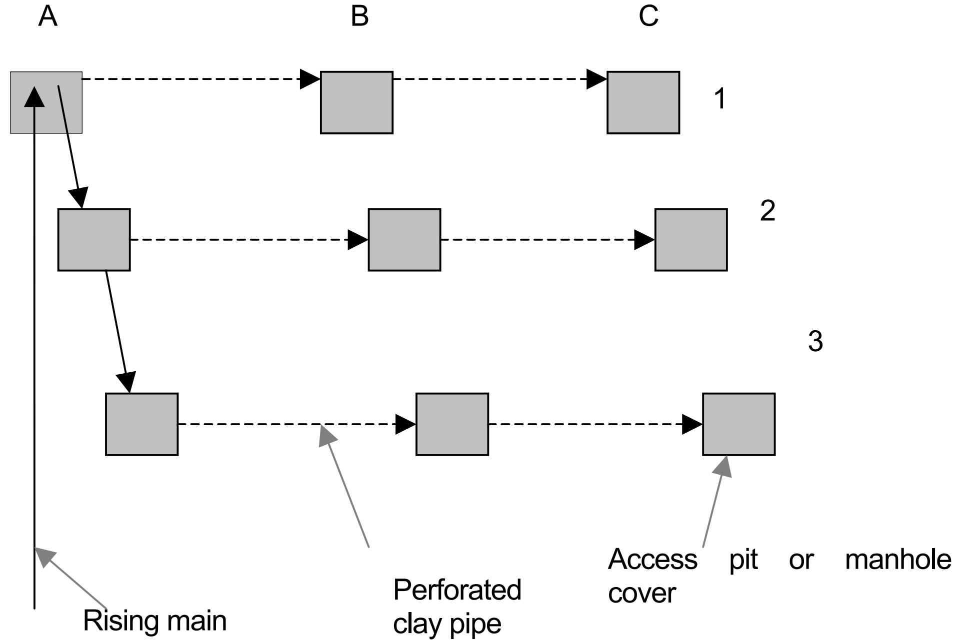


Figure 7.3 Effluent outflow pipe and access pit arrangement at The Goodens, Cheriton.

Figure 7.4 Holding tank C3.

In general, the septic tank at Cheriton and the PTP at Droxford produce effluent with fairly low pollutant loadings. Only ammonium and antimony in the tank effluent exceed the maximum permissible concentrations for drinking water (Water Quality Regulations 2000) – see *Table 7.1*. Elevated concentrations of these chemicals are not found in the borehole samples and there is no apparent chemical evidence of effluent discharge that impacts the aquifer at the points where the boreholes were installed.

Contaminant concentrations that are high in the effluent are not found in the groundwater, which may be due to:

- borehole positions not picking up contaminant plume
- rapid dilution of effluent discharge by the chalk aquifer fracture flow
- biodegradation in the unsaturated zone

Table 7.2 Comparison of groundwater and effluent major and trace ions (average mg l^{-1}).

Sample	TDS	BOD	COD	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	NO_3^{-}	Br^{-}	NO_2^{-}	HPO_4^{2-}	F^{-}	TOC	TIC	Total P	Total S	Red S	B	NH_4^{+}
BH1	524	<1	<10	125	2.06	8.63	1.47	322	20.3	12.1	32.5	0.05	<0.05	<0.1	0.05	<3.0	64.9	0.03	4.25	0.03	<0.03	0.12
BH2	525	<1	<10	126	2.05	8.85	1.53	324	19.3	12.0	31.7	0.06	<0.05	<0.1	0.05	<3.0	67.4	0.07	4.14	0.04	<0.03	0.06
BH3	541	<1	<10	131	2.10	8.90	1.68	334	20.1	12.0	31.2	0.05	<0.05	<0.1	0.05	<3.0	70.1	0.04	4.21	0.14	<0.03	0.10
BH4	532	<1	<10	128	2.08	8.54	1.42	328	19.3	12.0	32.7	0.05	<0.05	<0.1	0.07	<3.0	67.5	0.05	4.19	0.03	<0.03	0.04
BH5	543	<1	<10	131	2.13	9.54	1.59	336	20.1	11.7	30.7	0.05	<0.05	<0.1	0.05	<3.0	70.9	0.05	4.14	0.11	<0.03	0.03
Tennis court	535	<1	<10	127	2.05	7.62	3.09	326	21.1	14.3	33.9	0.05	<0.05	<0.1	0.04	<3.0	68.1	0.17	5.14	0.11	<0.03	0.56
Cheriton	1062	368	677	103	3.85	86.5	22.0	759	68.6	19.1	0.0	0.05	0.07	41.8	0.01	64.9	151	15.8	24.3	0.32	0.84	104
Droxford	1100	55	210	103	3.85	103	21.6	715	88.1	65.5	0.1	0.09	0.17	31.9	0.02	27.2	1389	10.5	23.6	1.29	0.37	89.0

Sample	Si	Ba	Sr	Mn	Total Fe	Red Fe	Al	Co	Ni	Cu	Zn	Cr	Mo	Cd	Pb	V	Li	B	As	Se
BH1	4.07	0.018	0.19	<0.002	0.00	<0.04	0.004	<0.002	<0.001	<0.002	0.02	<0.002	<0.015	<0.002	<0.005	<0.010	<0.025	<0.03	<0.015	<0.015
BH2	4.15	0.017	0.19	<0.002	0.00	<0.04	0.002	<0.002	<0.001	0.003	0.02	<0.002	<0.015	<0.002	<0.005	<0.010	<0.025	<0.03	<0.015	<0.015
BH3	4.32	0.017	0.20	<0.002	0.00	<0.04	0.007	<0.002	0.002	0.010	0.05	<0.002	<0.015	<0.002	<0.005	<0.010	<0.025	<0.03	<0.015	<0.015
BH4	4.21	0.017	0.20	<0.002	0.01	<0.04	0.001	<0.002	<0.001	<0.002	0.01	<0.002	<0.015	<0.002	<0.005	<0.010	<0.025	<0.03	<0.015	<0.015
BH5	4.34	0.017	0.20	<0.002	0.00	<0.04	<0.001	<0.002	0.002	0.001	0.02	<0.002	<0.015	<0.002	<0.005	<0.010	<0.025	<0.03	<0.015	<0.015
Tennis court	3.96	0.016	0.20	0.016	0.25	0.16	<0.005	<0.002	0.002	<0.002	0.00	<0.002	<0.015	<0.002	<0.005	<0.010	<0.025	<0.03	<0.015	<0.015
Cheriton	8.26	0.010	0.22	0.028	0.13	0.00	0.043	<0.002	0.002	0.015	0.03	0.01	<0.015	<0.002	<0.005	<0.010	<0.025	0.84	<0.015	<0.015
Droxford	8.31	0.005	0.24	0.019	0.04	0.04	0.044	<0.002	0.002	0.007	0.01	<0.002	<0.015	<0.002	<0.005	<0.010	<0.025	0.37	<0.015	<0.015

8 Trace organic chemistry of effluent and groundwater

Groundwater and effluent samples were submitted to AlControl laboratories for List I and List II analysis at each sampling round.

The majority of compounds were below the analytical limit of detection. *Table 8.1* summarises the positive compound detection for all samples over the four sampling rounds (July 2004, October 2004, January 2005 and April 2005).

The only organic compound detected in the boreholes was mineral oil during the October 2004 sampling round and in BH4 during the July 2004 sampling round only. Although there could be a correlation between the Cheriton tank and BH4 samples on 7 July 2004, the results for the October sampling round should be viewed with caution as the tennis court borehole also recorded a positive result (this is up gradient of the tank and outflow pipe) and there is no other evidence to suggest that effluent is contaminating BH3 and BH5.

Phenol and 4-methylphenol were detected in the Cheriton effluent on three occasions and at Droxford once. These compounds are used in antiseptic lotions and disinfectants and are likely to come from cleaning products used within the dwellings.

Toluene is used in detergents and was also detected in both effluent samples, but not the groundwater samples, as was diethyl phthalate, which is predominantly used as a plasticiser, but is also found in insecticidal sprays, dyes, and perfume.

Organochlorine pesticides were detected in effluent samples from both tanks during October 2004, but not in the borehole samples.

The presence of List I substances is of concern and their origin is not known. It is possible that a resident disposed of a priority chemical, but it is also possible that the aquifer was contaminated elsewhere.

Table 8.1 Trace organic chemistry of effluent and groundwater (μg l^{-1})

Sampling round	Sample Identity	EPH (mineral oil)	Quintozene (PCNB)	o,p´-Methoxychlor	Permethrin	Total OCP	Phenol	4-Methyl-phenol	Toluene	Diethyl phthalate	Bis (2-ethyl-hexyl) phthalate
July 2004	BH4	320									
July 2004	Cheriton tank	2059					395	1496	26	55	45
Oct 2004	BH1	551									
Oct 2004	BH2	99									
Oct 2004	BH3	255									
Oct 2004	BH4	152									
Oct 2004	BH5	1032									
Oct 2004	Cheriton tank	620	239	66	264	569	17	235	110		
Oct 2004	Droxford tank	40	373			373					
Oct 2004	Tennis court	222									
Jan 2005	Droxford tank							17		8	
Jan 2005	Cheriton tank	16								27	36
April 2005	Cheriton tank						26	82			
April 2005	Droxford tank								28		

PCNB, pentachloronitrobenzene.

9 Microbiological chemistry of effluent and groundwater

9.1 Specific microbial targets for analysis

The aim of the microbiology study was to estimate, by using modern molecular biological techniques, the dimensions and nature of important subsurface populations, including nitrifiers, denitrifiers, and enteric pathogens. Water samples from each borehole, the septic tank, PTP, and the tennis court borehole were collected for microbiological analysis at each of the four scheduled sampling rounds, at approximately 1 m intervals during drilling through the saturated zone and from the centrifuged cores. Analysis of faecal indicators and molecular analysis of microbial communities in samples taken from the septic tank, PTP, boreholes, and core samples was carried out as specified in *Table 9.1*.

Table 9.1 Specific microbial targets for analysis.

Organism	Detection method	Gene target	Rationale
Coliforms	MPN	–	Standardised test to generate baseline data
E. coli	MPN	–	Standardised test to generate baseline data
Bacteroides	PCR	16S rrn	Significant component of gut microflora (anaerobic)
Mycobacterium paratuberculosis (MAP)	PCR	IS900	Present in the milk, faeces, and meat of infected cattle. Indicates contamination from cattle grazing on discharge site
Staphylococcus aureus	PCR	16S rrn or enterotoxins A-D	Human pathogen
Salmonella enterica	PCR	iroB	Human pathogen
Campylobacter jejuni	PCR	Hippuricase gene (hip)	Human pathogen
Giardia lamblia	PCR	b-giardin	Protozoan parasite (size: upper range)/
Cryptosporidium parvum	PCR	COWP	Protozoan parasite (size: upper range)/
Total eubacteria	PCR	16S rrn	General marker for environmental and/or sample comparison

MPN, most probable number; PCR, polymerase chain reaction.

9.1.1 Faecal indicators

The potential for water-borne disease arises when water is polluted with faecal matter. Polluted water may contain pathogenic (disease-causing) faecal bacteria, viruses, or other micro-organisms. It is too complex to try and detect all of these on a routine basis, and many of the pathogens may be present in very small numbers only or not at all. It is therefore normal practice to look for ‘indicator bacteria’. These species are always excreted in large numbers in the faeces of warm-blooded animals. Their presence indicates faecal contamination, but it does not prove that water-borne disease is occurring.

The convention is to use faecal coliform bacteria for this purpose. Faecal coliforms, mainly comprising *E. coli*, are a subgroup of the total coliform group and they occur almost entirely in faeces. By contrast, other members of the coliform group can be free-living in nature and therefore their presence in water is not necessarily evidence of faecal contamination. *E. coli* are always present in faeces; the majority are not pathogenic, although some strains can cause diarrhoea. Differentiation can be made between faecal and total coliforms by the temperature of the test. All coliforms are detected at 37°C, but only faecal coliforms at 44°C (Cairncross and Feachem 1993).

The presence of faecal indicator bacteria (coliforms, thermotolerant coliforms, and *E. coli*) would confirm an impact of the effluent discharge on the Chalk aquifer.

9.1.2 Nitrifying and denitrifying bacteria

Nitrification is the biological or biochemical process in which ammonia is oxidised to nitrite, and nitrite oxidised to nitrate. It requires low BOD/COD levels in high dissolved oxygen concentrations (see Section 7 for chemical data).

Nitrifying bacteria are classified as obligate chemolithotrophs. This simply means that they must use inorganic salts as an energy source and generally cannot utilise organic materials. They must oxidise ammonia and nitrites for their energy needs and fix inorganic carbon dioxide (CO_2) to fulfil their carbon requirements. They are largely non-mobile and must colonise a surface (gravel, sand, synthetic biomedia, etc.) for optimum growth.

Species of *Nitrosomonas* and *Nitrobacter* are obligate aerobes and cannot multiply or convert ammonia or nitrites in the absence of oxygen.

Denitrification and dissimilation are parts of another natural process that converts nitrate into atmospheric nitrogen gas. This process only occurs in the absence of oxygen. The first stage is dissimilatory nitrate reduction, which reverses the nitrification process and converts nitrate (NO_3^-) back into nitrite (NO_2^-). The second stage of denitrification converts nitrite into nitric oxide, nitrous oxide, and finally nitrogen gas.

Confirmation of nitrifiying and denitrifiying populations in the effluent or groundwater gives an insight into the biological processes that occur in the septic tank and the saturated and unsaturated zones.

9.1.3 Enteric pathogens

A number of enteric pathogens were also targeted in addition to the pathogenic indicators. Many are present in the human gut and are excreted daily, in fact up to 50% of most faecal matter is actually *Bacteroides fragilis* cells. One person can excrete millions of *Giardia lamblia* cysts each day, and most infections probably result from ingestion of water or food contaminated with human sewage. *Bacteroides* organisms are a significant component of gut microflora and are the anaerobic counterpart of *E. coli*. *Mycobacterium paratuberculosis*, present in the milk, faeces, and meat of infected cattle, and *Salmonella enterica*, found in contaminated meat products and unpasteurised milk, are the main source of food-borne infection.

The rationale for the choice of pathogens is based on assessing the spread of pathogens over a diverse range (bacteria and protozoa) and size (for example, *S. enterica*, 1-2 µm in length; *Cryptosporidium*, >5 µm). Although the source of these organisms is not exclusively human, each is a pathogen of interest in human health and their distribution within the plume compared with that in the control allows the impact of the discharges to be assessed.

9.2 Analytical techniques

9.2.1 Standard microbiological analysis

Standardised tests (specified HMSO *The Bacteriological Examination of Drinking Water Supplies*, 1982) for coliforms, thermotolerant coliforms, and *E. coli* were used to provide background baseline measurements of faecal contamination of groundwater.

9.2.2 Molecular analyses

Molecular analyses allow the up-gradient and down-gradient samples to be compared, from which we may be able to assess the influence of the discharges on the microbial community of the aquifer. Targeting specific organisms allows us (a) to assess the transport, distribution, and survival of pathogens, and (b) to assess the influence of the plume (chemical and nutrient effects) on the general microbial community.

9.2.3 Bacterial pathogens

For each sample, DNA extraction followed by polymerase chain reaction (PCR) amplification of DNA was employed to detect a wide range of faecal and human-related bacterial pathogens (see *Table 9.6*) that lie outside standardised testing procedures and may miss detection by standard methods due to culturability status and/or low numbers. Importantly, low numbers of certain pathogens does not particularly reduce the potential impact on human health as they can cause chronic infections through long-term low-level exposure.

9.2.4 General bacterial community and population comparison

The impact of the discharges on the general bacterial community was assessed using the same DNA extracts used to assess the presence of specific organisms. These were subjected to temperature gradient gel electrophoresis (TGGE) analysis via 16S rDNA PCR using general eubacterial primers and GC clamps to provide an identifying ‘bar code’ for each sample. These bar codes can be compared between samples from the same site over the sampling period to indicate the dynamics of the microbial population and the impact of the discharge; they may also indicate possible future lines of research. In addition, primers specific to nitrifying and denitrifying bacteria were used to assess their presence in each of the samples. Nitrification and denitrification are two important processes within the nitrogen cycle – the former is sensitive to pollution events. Sample comparisons allow the impact (suppression or enhancement) of the discharges on two functional groups of bacteria to be assessed.

9.3 Faecal coliform indicator results

9.3.1 Faecal indicators by culture

Overall, 91 samples were analysed, with the distribution of counts shown in *Table 9.2.*

Table 9.2 Distribution of coliform counts in all samples

Coliform count by MPN (cfu/100 ml)	Number of samples	Sample type
<2	42	Pore waters BH1 to BH5 groundwater
2-10	21	BH1 and BH3 pore water BH1 to BH5 groundwater
11-100	14	BH1 and BH3 pore water
101-1000	5	Septic tank, PTP, and BH1
>1800	9	Septic tank and PTP

All samples in the 101 to >1800 colony-forming units (cfu) per 100 ml group were taken from the septic tank and PTP. The majority of the pore waters from BH1 to BH3 had a coliform loading of <2 cfu/100 ml. Groundwater samples were generally in the 2-14 cfu/100 ml range.

9.3.2 Pore water

Pore water from core samples from BH1, BH2, and BH3 (see Section 6) were analysed for faecal coliform indicator bacteria. No significant numbers of coliforms were detected in any samples (range from <2 to –22, with the majority with undetectable numbers for the three indicators – World Health Organisation Drinking Water Guidelines (World Health Organisation 1993) state >50 cfu/100 ml as being contaminated water). *Table 9.3* provides a summary of the positive results for pore waters.

Table 9.3 Summary of positive pore-water total coliform indicator results (pore water was only collected from BH1, BH2, and BH3).

Borehole	Depth (m bgl)	cfu/100 ml
BH1	6.55	13
	12.15	5
BH2	13.18	11
BH3	5.25	22
	9.45	5

9.3.3 Groundwater samples during drilling

Groundwater samples were collected during drilling at approximately 1 m intervals throughout the saturated zone and after the wells had been purged immediately after well completion. *Table 9.4* provides a summary of the positive results for boreholes during drilling.

Table 9.4 Summary of positive total coliform indicator results for groundwater samples collected during drilling.

Borehole	Depth (m bgl)	cfu/100 ml
BH1	10.3	170
	14.6	5
Final purge	12.0	8
BH3	8.5	6
	10.3	4
Final purge	15.0	2
BH4	9.6	22
	11.0	13
	13.0	2
	14.0	21
Final purge	15.0	2
BH5	10.8	19
	12.3	48
	13.6	14
Final purge	15.6	11

9.3.3.1 Borehole 1 drilling samples

BH1 is positioned directly below the outflow pipes and samples from this borehole should indicate the source term. The majority of sample depths returned a low coliform count (<2-11 cfu/100 ml) with no *E. coli* or thermotolerant coliforms detected. However, the first sample taken at the water strike during drilling returned a mean of 170 cfu/100 ml with detectable thermotolerant coliforms and *E. coli*. Although the drilling apparatus was disinfected and steam cleaned between each borehole, it was impractical to clean it between each sample run. Therefore surface contamination from the field may be a source of the unusually high numbers of faecal coliforms in comparison to the subsequent samples collected during drilling. The purged borehole sample showed similar indicator numbers to those of the pore water at the corresponding depth.

9.3.3.2 Borehole 2 drilling samples

BH2 is 10 m down gradient and all samples returned insignificant levels (<2 cfu/100 ml) of all three indicator organisms (coliforms, thermotolerant coliforms, and *E. coli*).

9.3.3.3 Borehole 3 drilling samples

BH3 is 30 m down gradient and all samples showed insignificant levels of all three indicator organisms (range of 2-6 cfu/100 ml). The purged borehole sample showed similar indicator numbers to those of the pore-water at the corresponding depth.

9.3.3.4 Borehole 4 drilling samples

BH4 also positioned directly below the outflow pipes, provided source term samples and showed slightly higher levels of total coliforms than Borehole 1 (range <2-22 cfu/100 ml). Corresponding pore-water samples were not available for analysis.

9.3.3.5 Borehole 5 drilling samples

BH5 is 10m down gradient of BH4 and showed similar levels of indicator organisms (<2-48 cfu/100 ml). Corresponding pore-water samples were not available for analysis.

9.3.4 Groundwater and effluent samples during routine monitoring

Samples were collected for faecal indicator analysis during each sampling round from all the boreholes, the septic tank, and the PTP. Additional samples were collected from the holding tanks at the discharge point (see *Figure 7.4*). *Table 9.5* provides a summary of the positive results for the boreholes during routine monitoring.

Table 9.5 Summary of positive total coliform indicator results for groundwater samples collected during routine monitoring.

Borehole	cfu/100 ml
BH1	2
	11
	14
BH2	7
	12
BH3	2
	5
BH4	6
	8
	11
BH5	2
	5
	2
	5
Septic tank	<1800
	<1800
	<1800
	<1800
PTP	<1800
	<1800
	<1800
	<1800

9.3.4.1 Boreholes 1 to 5 routine monitoring

All routine monitoring data fall in the range <2 to 14 cfu/100 ml, which again is well below the 50 cfu/100 ml classified as contaminated under WHO Guidelines. Only BH3 and BH4 had positive thermotolerant (faecal) coliform results. All of the tennis court samples and half of the samples from BH2 and BH3 were <2 cfu/100 ml. Groundwater coliform indicator numbers in BH1 to BH3 correspond to the values seen in the pore waters at depth and during borehole drilling.

9.3.4.2 Septic tank and PTP effluent

Effluent from the septic tank at Cheriton, the PTP at Droxford, and the holding tanks (A1 and C3) consistently showed high levels >1800 cfu/100 ml of all three indicator organisms (coliforms, thermotolerant coliforms, and *E. coli*).

9.4 Molecular analysis results

9.4.1 Polymerase chain reaction (PCR) amplification of DNA

DNA extractions were completed on all samples, each from 300 ml of sample:

- PCR for the individual indicator bacteria, detailed in *Table 9.*6, have been carried out on all samples
- PCR detected only *Bacteroides*
- *Bacteroides* were detected only in the septic tank and PTP effluent samples
- PCR for *Staphylococcus aureus* was considered to be too non-specific and required further development that was outside the scope of this project.

Table 9.6 PCR detection of bacterial indicators of contamination

Organism	Detection method	Gene target	Positive samples
Bacteroides	PCR	16S rDNA (Bernhard and Field 2000)	Droxford PTP Cheriton septic tank Cheriton A1 All pore-water samples were negative
Mycobacterium paratuberculosis (MAP)	PCR	IS900 (Pickup *et al*. 2005)	All samples were negative
Staphylococcus aureus	PCR	16S rrn or enterotoxins A-D (Klotz *et al*. 2003)	The PCR method was unsuitable to detect this bacterium
Salmonella enterica	PCR	invA (Baumler *et al.* 1997)	All samples were negative
Campylobacter jejuni	PCR	Hippuricase gene (hip) (Linton *et al*. 1997)	All samples were negative

9.4.2 Temperature gradient gel electrophoresis (TGGE)

DNA extraction was carried out on all the samples received in addition to the 16S *rrn* PCR and temperature gradient gel electrophoresis (TGGE) analyses carried out on the septic tank samples. Profiles of the microbial communities in both systems reveal very little difference between the two. The total eubacteria (total bacterial count) was very low in the groundwater samples (that is, very few bacteria are present). Consequently, some samples recovered very little DNA, which made it very difficult to generate a TGGE profile that relates to the nitrogen-cycle bacteria (denitrifiers and nitrifiers) and thus there are no data relating to these organisms.

9.5 Microbiology summary

- The septic tank at Cheriton and the PTP at Droxford contain the typical bacterial load that indicates a sewage treatment system (that is, high coliforms, thermotolerant coliforms, and *E. coli*). There was no obvious difference between the coliform loadings within Droxford and Cheriton (PTP versus septic tank).
- Low numbers of total coliforms were detected in the deeper pore waters of BH1, BH2, and BH3. Thermotolerant (faecal) coliforms and *E. coli* were not detected.
- Water sampled during the drilling of the boreholes showed that BH1, BH3, BH4, and BH5 carried similar coliform concentrations, but indicated of low-level contamination. BH2 samples were all <2 cfu/100 ml.
- Routine monitoring samples from all boreholes indicated low-level coliform contamination of all boreholes with the exception of the tennis court borehole. BH2 had only one positive result and only half of the BH3 samples were positive, although BH3 and BH4 showed evidence of low faecal coliform contamination.
- The PCR detection method only detected one type of indicator bacteria (*Bacteroides*) in the tank samples. It was not found in other samples. This potentially confirms the low impact of tanks on the underlying groundwater.
- Where MPN counts show most contamination, the samples were amenable to PCR. That 16S rrn PCR has failed on some BH samples indicates a low bacterial load (not confirmed

by microscopy because the chalky deposits affected the staining and counting) and hence low impact. Samples that returned no PCR product were not concentrated, as it would give a skewed idea of the degree of contamination.

It is apparent from this study, and others that have been undertaken, that DNA extraction from chalk aquifer material (core or pore water with chalk suspension) generates a low yield of DNA. This can be for a number of reasons, the most obvious of which is that few bacteria are present. Direct-count procedures (staining bacteria and visualisation with microscopy) are not possible because of interference by the chalk that remains in suspension. Past experience has demonstrated that it is possible to culture bacteria, but a precise count is complicated by the varying amount of chalk in suspension. Therefore, under the conditions present (sample size and method), the chalk in the suspension tends to interfere with the DNA extraction process and reduces the yield of DNA, which prevents further analysis and gives poor PCR and ill-defined TGGE profiles. The difficulty in processing such samples may be symptomatic of the lack of microbial community studies in chalk aquifer material presented in the international microbial research literature. However, there has been some success in generating TGGE profiles from sandstone aquifer material.

9.6 Microbiology conclusions

Overall, the information gained from the microbiology study has shown some low-level impact on the aquifer from the effluent discharge. The septic tank and the PTP systems have very similar microbial populations dominated by high numbers of faecal bacteria, particularly coliforms and bacteroides, as would be expected in a sewage system. Other microbial populations were more difficult to identify because of the difficulties with low yields of DNA. This is partly the result of chalk suspensions interfering with the extraction process, but it is compounded here by the low numbers of bacteria present. The absence of nitrifiying and denitrifiying bacteria in the effluent and groundwater samples is further supported by the chemical composition of the samples (see Section 7), high NH_4^+ and no NO_3^- or NO_2^- in the effluent and the opposite in the groundwater. These bacteria also favour low BOD/COD levels, which is not the case in either of the effluent samples. Isotopic analysis also provides evidence that biochemical transformations do not occur in either the effluent or the groundwater (see Section 10). It seems likely that the low bacteria numbers, the chemical and physical conditions within the treatment systems (tank is emptied every 1.5 to 2 h), and the rapid dilution in the aquifer all contribute to the low or insignificant impact on the aquifer.

10 A multi-isotope evaluation of geochemical processes within the septic tank effluent plume

By measuring the $^{15}N/^{14}N$ ratios in the effluent and the groundwater we can determine whether any nitrogen species in the groundwater came from the effluent.

10.1 Basis of the isotope study

Stable isotope data are used to provide information on reaction processes. The method is of particular benefit in environments in which chemical data alone cannot distinguish between compositional changes that may be caused by reactions and those that may result from simple physical dilution of the effluent by mixing with groundwater.

10.1.1 Isotope fractionation by bacteria

Most reactions that involve nitrogen compounds in the hydrosphere are unidirectional processes, mediated by specific bacteria, in which molecules of the substrate are converted irreversibly into molecules of the product. A bond that involves the light isotope of an element (^{14}N) is weaker than the chemically identical bond that involves its heavy isotope (^{15}N). As a consequence, the energy required to break bonds in a molecule (that is, to affect a reaction) is less for molecules that contain ^{14}N than for molecules that contain ^{15}N.

For unidirectional reactions this kinetic favouring of the reaction of ^{14}N molecules results in the $^{15}N/^{14}N$ ratio of the *instantaneously formed product* being lower than the $^{15}N/^{14}N$ ratio of the *remaining, unreacted substrate*. This 'kinetic isotope fractionation' is defined in terms of the enrichment factor, $\varepsilon_{\text{product-substrate}}$ ($\varepsilon_{\text{p-s}}$):

$$\varepsilon_{\text{p-s}}\ (\text{in ‰}) = \left(\frac{^{15}\text{N}/^{14}\text{N}_{\text{product}}}{^{15}\text{N}/^{14}\text{N}_{\text{substrate}}} - 1 \right) * 1000$$

(10.1)

Using the delta notation, Equation (10.1) very closely approximates to Equation (10.2):

$$\varepsilon_{\text{p-s}} \approx \delta^{15}\text{N}_{\text{product}} - \delta^{15}\text{N}_{\text{substrate}}$$

(10.2)

and since bacterial reactions have $\delta^{15}N_{\text{product}} < \delta^{15}N_{\text{substrate}}$, $\varepsilon_{\text{p-s}}$ is negative.

10.1.2 Effect of bacterial isotope fractionation – the 'Rayleigh' equations

The effect of kinetic isotope fractionation on the δ^{15}N values of substrate and product during the course of a bacterial transformation can be calculated using 'Rayleigh' equations. For the substrate:

$$\delta_{s,t} = \delta_{s,0} + \varepsilon_{p\text{-}s} \times \ln(f) \qquad (10.3)$$

and for the total accumulated product:

$$\delta_{p,t} = \delta_{s,0} - \varepsilon_{p\text{-}s}.\ln(f) \times [f/(1 - f)] \qquad (10.4)$$

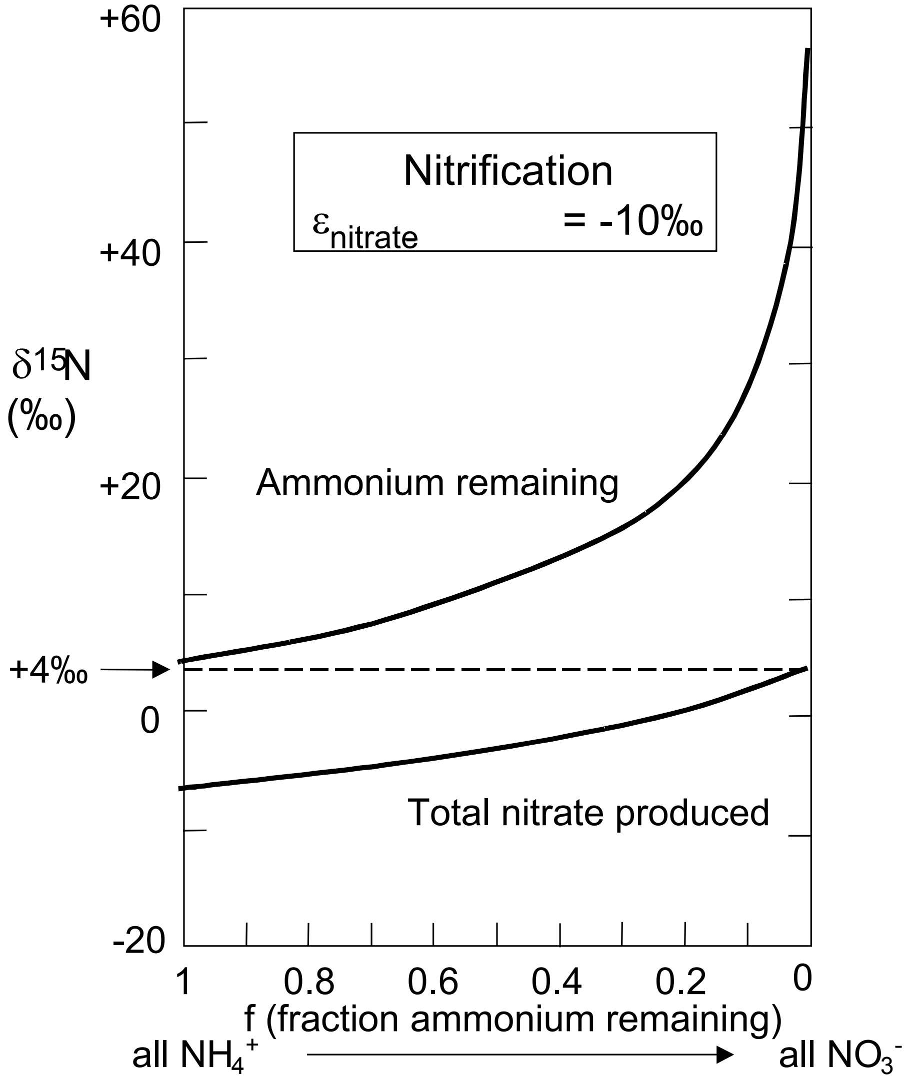
where $\delta_{s,t}$ and $\delta_{p,t}$ are the δ^{15}N values of the remaining substrate and accumulated product at time *t*, $\delta_{s,0}$ is the initial δ^{15}N value of the substrate, *f* is the fraction of substrate remaining, and $\varepsilon_{p\text{-}s}$ is the isotope enrichment factor for the process.

As an example, *Figure 10.1* shows the changes in the δ^{15}N values of ammonium (substrate) and nitrate (product) that might be expected during a process of nitrification. Although nitrification involves two separate bacterial steps,

$$NH_4^+ \xrightarrow{Nitrosomonas} NO_2^- \xrightarrow{Nitrobacter} NO_3^- \qquad (10.5)$$

the overall reaction rate is limited by the first step, and the process can be approximated as a first-order reaction described by Equations (10.3) and (10.4). *Figure 10.1* assumes an isotope enrichment factor $\varepsilon_{p\text{-}s}$ = –10‰ (values for bacterial nitrification and denitrification being typically in the range -30 to -5‰; Handley *et al.* 1999), and an initial δ^{15}N value for the substrate, $\delta_{s,0}$ = +4‰ (being the initial value for ammonium in the leachate; see section below). *Figure 10.1* illustrates three important principles that apply irrespective of the process or the values chosen for $\varepsilon_{p\text{-}s}$ (assumed negative) and $\delta_{s,0}$:

(i) the δ value of the substrate increases logarithmically with decreasing concentration
(ii) the δ value of the accumulated product is always lower than that of the remaining substrate
(iii) when the process has completed, the final δ value for the accumulated product is the same as the initial δ value for the substrate.



10.1 Rayleigh equation curves showing the theoretical changes in the $\delta^{15}N$ values of residual ammonium (upper line) and product nitrate (lower line) during bacterial nitrification. Substrate ammonium, with an initial $\delta^{15}N$ value of +4‰, is progressively converted into product nitrate by a unidirectional process with an isotopic enrichment factor, $\varepsilon_{product\text{-}substrate}$ of –10‰.

10.2 Sampling

Water samples were collected from:

(i) the Cheriton septic tank (and the PTP at Droxford for comparison)
(ii) two discharge points from the Cheriton holding tanks (outflows A1 and C3; *Figure 7.3*)
(iii) boreholes tapping chalk groundwater below the discharge area (BH1 to BH5)
(iv) chalk groundwater from a borehole distant from the septic discharge (tennis court)
(v) stream water from the River Itchen.

The samples were analysed for $^{15}N/^{14}N$ ratios of ammonium or nitrate (September 2004, January 2005, and August 2005) and dissolved gas concentrations (September 2004 only). Results are shown in the *Tables 10.1* and *10.2* and *Figure 10.2*.

Table 10.1 Concentrations (qualitative HACH test) and $^{15}N/^{14}N$ ratios ($\delta^{15}N$ in ‰ versus atmospheric N_2) of ammonium and nitrate.

	NH_4 (HACH) (mgN l^{-1})			$\delta^{15}N$ of NH_4			NO_3 (HACH) (mgN l^{-1})			$\delta^{15}N$ of NO_3		
	Sept 04	Jan 05	Apr 05	Sept 04	Jan 05	Apr 05	Sept 04	Jan 05	Apr 05	Sept 04	Jan 05	Apr 05
BH1	0.01	0.01	0.01				7.4	7.7	5.6	+4.3	+5.3	+4.2
BH2	0.00	0.05	0.00				7.6	6.1	5.9			
BH3	0.00	0.01	0.01				6.6	7.8	7.4	+5.3	+5.1	+4.8
BH4	0.01	0.00	0.01				6.2	5.9	3.2			
BH5	0.01	0.00	0.02				3.2	6.2	5.7	+5.8	+5.3	+5.2
Tennis Court	0.04	0.00					7.2	8.8	–	+4.5	+4.9	+4.0
Cheriton tank	c. 100	c. 60	c. 70	+5.5	+5.4	+4.7	0.00		0			
Outflow A1	c. 100			+5.7			0.00					
Outflow C3	c. 100			+5.7			0.00					
Droxford tank	c. 50	c. 60	c. 60	-	+6.5	+6.4			0			
River Itchen		0.04						6.7			+5.2	

Table 10.2 Concentrations of dissolved gases.

	N_2 (ml kg^{-1})	O_2 (ml kg^{-1})	Ar (ml kg^{-1})	CH_4 (ml kg^{-1})
28-29 September 2004				
BH1	15.65	6.42	0.395	
BH2*	(33.87)	(11.43)	(0.624)	
BH3	15.84	5.62	0.405	
BH4	15.78	6.33	0.413	
BH5	16.37	5.19	0.407	
Tennis court				
Cheriton tank	11.44	0.16	0.304	2.95
Outflow A1	12.10	0.12	0.319	6.04
Outflow C3	10.00	0.04	0.332	23.07

*BH2 gas sample leaked.

10.3 Chemistry

Qualitative colorimetric analyses (HACH tests) revealed ammonium with no significant nitrate in the septic samples, and nitrate with no significant ammonium in the groundwater samples.

10.3.1 $^{15}N/^{14}N$ ratios

The $\delta^{15}N$ values of nitrate in the chalk groundwater sampled in the area of septic discharge (BH1, BH3, BH5 = +4.2 to +5.8‰) are very similar to those in water not affected by the discharge (tennis court and River Itchen = +4.0 to +5.2‰), and within the +4 to +6‰ range of values commonly found for nitrate in chalk groundwaters throughout the UK (data from the BGS–NIGL BASELINE project). That the ammonium in the septic samples has a similar range of values (outflow and tank samples = +4.7 to +6.5‰) is probably a coincidence.

10.4 Dissolved gas concentrations

Chalk groundwater in the area of septic discharge had nitrogen and argon concentrations close to the values expected for ‘air saturated water’ (ASW) at a mean temperature of 10°C, with a small component of ‘excess air’ (*Figure 10.2*). There is therefore no evidence for N_2 formation via denitrification in these waters. The effluent samples contained high methane and low oxygen concentrations, consistent with their reducing nature. Outgassing of the methane probably stripped out some nitrogen and argon, leading to low concentrations relative to the expected values for ASW (*Figure 10.2*). The data for these samples therefore cannot be used to identify or discount denitrification.

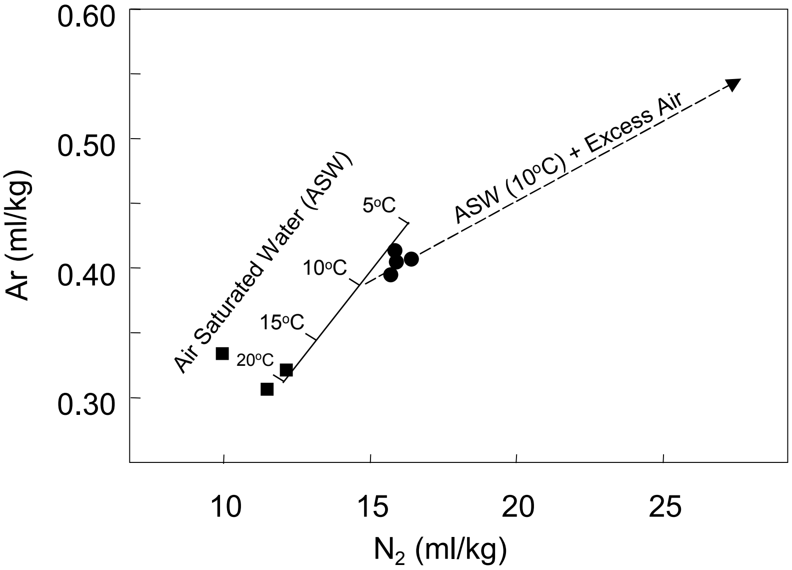


Figure 10.2 Concentrations of dissolved dinitrogen and argon in BH1 to BH5 (circles) and the Cheriton septic tank and discharges (squares).

10.5 Conclusions

The chemistry, $^{15}N/^{14}N$ composition, and dissolved gas concentrations of the chalk groundwater in the area of septic discharge show no evidence for nitrogen additions and/or transformations associated with the septic discharge. Low numbers of nitrifying and denitrifying bacteria in the effluent samples (see Section 9) seem to indicate that these processes do not occur in the septic tank at Cheriton. This is borne out in the inorganic chemical data that shows high concentrations of NH_4^+ and low NO_3^- in the effluent samples and low NH_4^+ and high NO_3^- in the groundwater samples (see Section 7). Due to the rapid emptying of the Cheriton septic tank (approximately every 1.5-2 hours) it is likely that there is insufficient time for bacterial transformation of NH_4^+ to NO_3^-. The PTP at Droxford has in the order of 20% less NH_4^+, which may be caused by the additional biological filter before discharge, although NO_3^- concentrations remain at the analytical limit of detection.

11 Discussion and conceptual model

The separate findings of the site investigation have been integrated to produce a conceptual model of the Cheriton site. The ERT geophysical survey identified two potential plumes of low resistivity effluent in the drainage field running down slope perpendicular to the irrigation pipes. The locations for a total of five boreholes for the intrusive investigation were based on these findings. The plumes identified were against the regional groundwater flow and it was assumed that local flow variations were responsible for the plume moving in this direction. Subsequent analysis of the groundwater levels showed the flow direction to be consistently orientated approximately north, with a slight north–northwest element between BH3 and BH2 and a north–northeast element between BH2 and BH4. It is possible, therefore, that BH2, BH3, and BH5 are not in the ideal location to intercept any plume development. However, numerical modelling using the small hydraulic gradient observed at the site shows a plume developing equally in both directions. This occurs because the small recharge mound formed under the effluent injection site is sufficient to overwhelm the regional gradient locally.

In addition, the following pertain to the conceptual model: -

(i) based on the tank discharging 0.18 m^3 of effluent approximately every 1.5 to 2 hours, 790 m^3 per year of effluent is injected into the chalk
(ii) average rainfall for the site is about 288 m^3 per year (British Atmospheric Data Centre)
(iii) outflow of effluent may not be uniform across the outflow pipes if the perforations are being blocked by silt or a build up of biomatter
(iv) measured hydraulic conductivity values are higher than literature values, which suggests groundwater flow is likely to be dominated by fracture flow
(v) pore-water chemistry indicates effluent impact only in BH1 and BH4
(vi) rainfall recharge is masked by recharge from the effluent outflow pipes
(vii) the groundwater hydraulic gradient is relatively flat.

11.1 The conceptual model

The percentage of the rock that is made up of spaces is known as the rock's porosity. Chalk has two principal kinds of porosity, the matrix (material) and fracture. The fine-grained nature of the chalk means that the pores and pore necks are correspondingly small and therefore flow through the matrix is very slow. The small pore sizes and corresponding high specific retention mean that the unsaturated zone is almost fully saturated – only fissures and a few large pores drain under gravity (Price, 1996). So, when the water content of the unsaturated zone reaches a certain threshold, it will tend to flow through the fractures, with an increased velocity. Fracture flow will only occur once all the pore spaces of the matrix are fully saturated, and then any additional ingress will flow via the fractures (matrix flow will still occur).

The downward velocity of a solute depends on the recharge mechanism. If matrix flow dominates, water and its solute load will move slowly and uniformly downward. Velocities are much higher if flow occurs predominantly via fissures.
Moisture content determinations on core samples (see Section 5.9) at the site suggest that the chalk acts typically with the matrix close to full saturation. In the absence of fracture flow the effluent recharge would overwhelm the storage capacity of the chalk matrix and result in raised groundwater levels. Groundwater level monitoring has demonstrated little perturbation in the water table (Section 5.8). It is most likely, therefore, that the majority of the effluent migrates through the unsaturated zone via fractures, although flow through the matrix will occur when fractures are not fully saturated.

The primary physical processes that control the movement of contaminants in the fissures are assumed to be advection and dispersion. Where matrix flow predominates, solutes will be transported through the unsaturated zone by molecular diffusion. Tracer tests on chalk aquifers in Hampshire imply a transit time for unsaturated zone infiltration (piston flow) of anything up to 50 years depending on the depth to the water table (Darling 1996). Infiltration time at the Cheriton site is likely to be significantly less, calculated as approximately 450 days assuming a matrix *K* (not including fractures) of 0.005 m d^{-1}, a hydraulic gradient of 1, a porosity of 30% and depth to water table of 9 m. This significantly shorter local travel time is mainly caused by the relative shallow depth of the unsaturated zone at this location. However, if fractures are included there is an increased potential for rapid transport to the water table, dependent on fracture aperture and orientation.

Upon reaching the aquifer the effluent will be carried in the predominant groundwater flow direction, where attenuation by sorption to the surfaces of mineral particles as well as diffusion and dispersion is expected to occur (*Figure 11.1*). We would normally expect to find biodegradation of organic material by indigenous bacterial populations, although the evidence at this site suggests this does not occur to any significant degree.

11.2 Uncertainties in the conceptual model

The conceptual model represents the outcome of several phases of site investigation, but areas of uncertainty still exist. A major source of uncertainty lies in the understanding of the fracture network, and the borehole locations may be up gradient of any plume development. Additional boreholes to intercept the north–northeast groundwater flow would provide a greater understanding of plume development, but without a detailed knowledge of the fracture system there is no guarantee that new boreholes would intercept the plume.

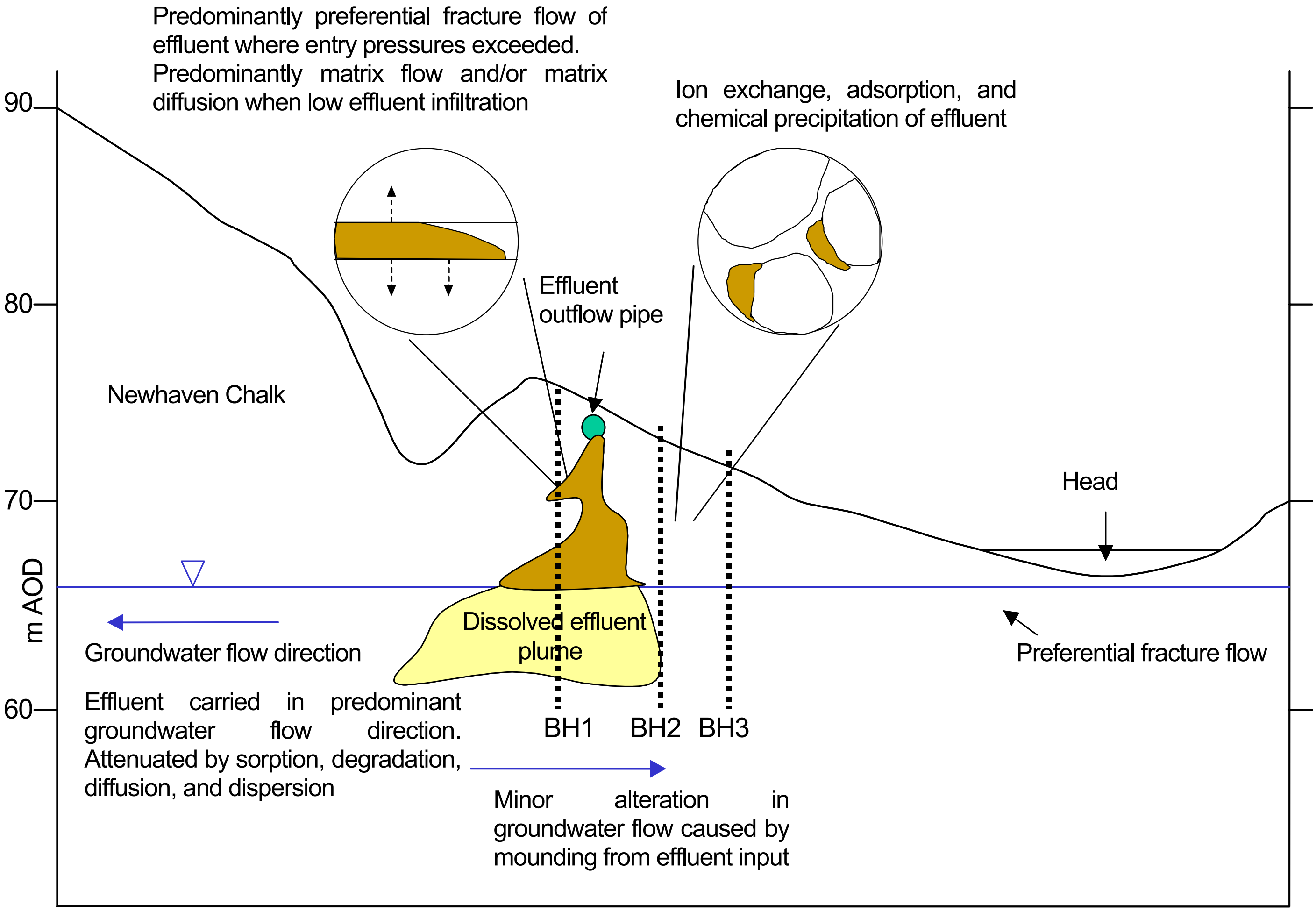


Figure 11.1 Conceptual model of The Goodens, Cheriton.

12 Modelling the effects of transient regional flow on plume development

Modelling dual permeability rocks such as the chalk is complex and beyond the scope of this project. We have used a simplified model to explore the concept that if the chalk underlying the effluent outflow pipes is able to accept the increased inflow of water without raising the water table, then much of the flow must be through fractures rather than through the chalk matrix itself. Flow through fractures is much faster than that through the matrix (although both processes occur in conjunction) and means that the effluent is very quickly dispersed in the aquifer. The site lies in the River Itchen valley and so groundwater flow is quite high – we had difficulty creating much drawdown in the boreholes using a 200 mm submersible pump, pumping approximately 100 l min^{-1}. This also indicates the probability of a significant fracture flow component and the potential for a large dilution of the effluent.

12.1 Flow model

The site lies on chalk with the water table about 9 m below the surface. The regional gradient in the water table is very small and qualitative evidence suggests that the hydraulic conductivity of the saturated formation is high. Rainfall at the site is 960 mm year^{-1} on average.

Chalk is a fractured medium with relatively conductive fractures and highly porous, but less conductive, matrix blocks. When saturated, the hydraulic conductivity of such rocks is dominated by the fracture network, but in the unsaturated zone the fractures rapidly dry and flow takes place primarily through the matrix blocks that remain very close to saturation (Wang and Narasimhan 1985).

The sewage effluent disposal system injects 0.18 m^3 (180 l) every 2 hours through a system of three parallel pipes that are about 20 m in length and 5 m apart. This equates to an injection of effluent of nearly 788 m^3 per year. In comparison, the rainfall over an area of 20 m by 15 m is about 288 m^3 per year. Since the infiltration rate may be expected to be only a fraction of the annual rainfall, through processes such as evapotranspiration and runoff, it can be seen that the effluent injection significantly exceeds the local infiltration, perhaps by an order of magnitude.

To help assess whether the chalk could be expected to accept this enhanced rate of fluid injection and remain unsaturated a highly simplified scoping model has been constructed using the FEMWATER code (Yeh and Ward 1980). This code has no facilities to handle dual permeability rocks, so the model was split into two layers. The top 9 m given a ‘matrix’-like value for hydraulic conductivity to represent the unsaturated zone, while the deeper layer was given a much higher ‘fracture’-like value. A 70 m section perpendicular to the waste injection pipes has been modelled with an infiltration rate of 250 mm per year (average rainfall – small loss for evaporation) applied to the top boundary and fixed heads applied to the ends of the lower layer to simulate a small regional gradient. The effluent was injected into three matrix-layer elements 1 m below the surface and 5 m apart.

In the unsaturated zone, saturation and relative permeability are functions of pressure and in this model the equations of van Genuchten (1980) were used to represent these dependencies. Thus, saturation is given by Equation (12.1):

$$S = (1 - S_r)\left[\frac{1}{1 + |ah|^b}\right]^{\lambda} \tag{12.1}$$

S = saturation
S_r = residual saturation
a, b = scaling factors
h = head
K_r = relative permeability

and the relative permeability by Equation (12.2):

$$k_r = \left[1 + |ah|^b\right]^{-\lambda/2}\left\{1 - \left[\frac{|ah|^b}{1 + |ah|^b}\right]^{\lambda}\right\}^2 \tag{12.2}$$

where $\lambda = 1 - 1/b$. The values used for these parameters in this model were $a = 0.5\ \mathrm{m}^{-1}$, $b = 2.0$, and $S_r = 0.33$. These choices are somewhat arbitrary in the absence of specific data, but the current models do not appear to be too sensitive to the values used. A porosity of 30% was used, which is a typical value for chalk matrix.

The saturated hydraulic conductivity of the matrix is the key parameter that determines how this system responds to the injection of the sewage effluent. *Figure 12.1* shows contour plots of water content for two steady-state flow models that differ only in the value used for the saturated hydraulic conductivity of the matrix. It can be seen that with a matrix only, conductivity of $0.005\ \mathrm{m\ d}^{-1}$ the effluent injection rate is sufficient to fully saturate the chalk around and beneath the pipes, raising the water table to the ground surface. This is not observed at the site. In contrast, if the matrix conductivity is raised to $0.01\ \mathrm{m\ d}^{-1}$ the water content in the rock around the pipes remains just below saturation and there is a relatively minor perturbation of the water table.

The mechanism for recharge to the Chalk aquifer depends on the relative magnitude of infiltration rate and the hydraulic conductivity of the material that forms the unsaturated zone (Price, 1996). If the matrix hydraulic conductivity is less than the average rate of infiltration the matrix will tend towards saturation, the water table will rise, and the local hydraulic gradient will steepen. If the hydraulic gradient exceeds unity the pore water pressure will be greater than the atmospheric pressure and the water table will rise to ground surface (*Figure 12.1(a)*). However, in a fissured aquifer, such as the Chalk, before this happens the pore-water pressures exceed the air-entry pressure for fissures, which then fill with water at less than atmospheric pressure (in effect, the capillary fringe rises to ground surface). This acts to increase the overall bulk hydraulic conductivity and allows increased transport through the fissures. In this case, the fracture flow results in a rapid transmission of the increased infiltration and relatively minor perturbation of the water table (*Figure 12.1(b)*).

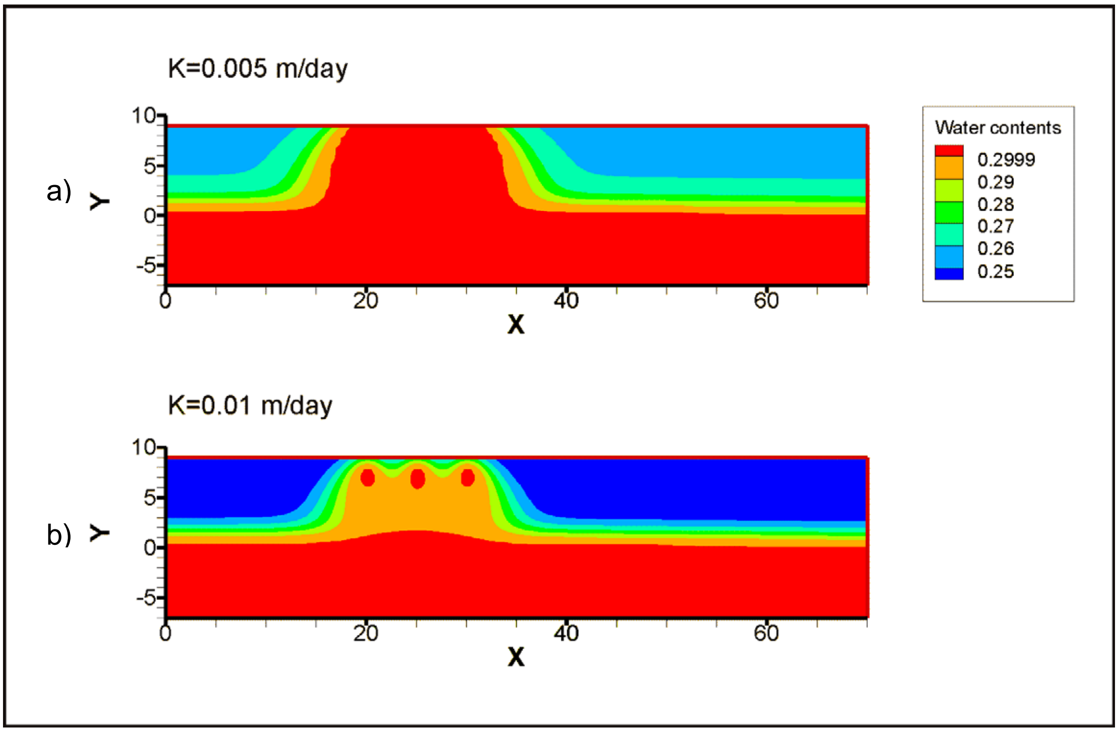


Figure 12.1(a, b) Contour plots of water content for two variations of the simplified groundwater flow model.

According to Price (1996), for a matrix hydraulic conductivity of between 0.003 and 0.005 m d^{-1}, infiltration would need to exceed 3–5 mm d^{-1} (maintained over several days) for the fissure system to become saturated and conduct water.

Average rainfall in the Winchester area is approximately 2.6 mm d^{-1}. This indicates that rainfall recharge is likely to be dominated by matrix flow (except where there are small fissures with very low air entry pressures), and that rainfall alone is therefore insufficient to saturate the matrix system. In the septic tank discharge area, effluent discharge is estimated as 790 m^3 per year. Assuming discharge over the whole 20 × 15 m area, then infiltration is equivalent to 7.2 mm d^{-1}. This infiltration greatly exceeds the expected limit for matrix-only transport, and suggests that fissures contribute to transport with an increased overall bulk conductivity (*Figure 12.1(b)*).

12.2 Solute transport model

To explore whether BH2, BH3, and BH5 are actually up gradient of the effluent outflow and not down –gradient, as the geophysical survey suggested, the model was run to see whether the increased input could actually create a plume going against the groundwater flow direction.

The FEMWATER model (Yeh and Ward 1981) described in Section 12.1 has been used to explore the potential development of the plume. The geophysical survey indicated that the plume might have migrated up gradient from the injection site, (compared to the local groundwater flow direction), so the models were run to try to see under what circumstances this might occur.

The flow model was run with a matrix hydraulic conductivity in the upper layer (unsaturated zone) of 0.01 m d^{-1}, based on the interpretation of contour plots of the groundwater flow model (*Figure 12.1(b)*).

In the lower layer the flow model was run with two regional gradients, one with a gradient of 0.005 and one of 0.001 (hydraulic gradient at Cheriton is 0.0015, Section 5.8), and a value of 2 m d^{-1} for bulk hydraulic conductivity (matrix and fracture flow). This represents a median value for hydraulic conductivity at the site, which ranges from 1.4 to 6.8 m d^{-1}. The solute transport model was then run with each of the flow fields in turn, setting the solute concentration at the locations of the pipes to C/C_0 = 1 (where C is the theoretical solute concentration and C_o is the theoretical source-term concentration). The results are shown in *Figure 12.2(a,b)* after the solute transport model has been allowed to develop the plume for 1.5 years.

It can be seen (*Figure 12.2(a)*) that the higher of the two gradients is sufficient to carry the developing plume down gradient with little or no up-gradient movement. The smaller gradient model (*Figure 12.2(b)*), however, shows the plume developing equally in both directions. This occurs because the small recharge mound that is formed under the effluent injection site is sufficient to overwhelm the regional gradient locally. The development of the plume should be considered as a general illustration because of the inherent limitations of the modelling code. However, *Figure 12.2(b)* is probably a reasonable representation of the plume development based on measured hydraulic parameters for the site. This was not originally observed during the geophysical survey because of the truncation of the geophysical field, which was restricted by local topography.

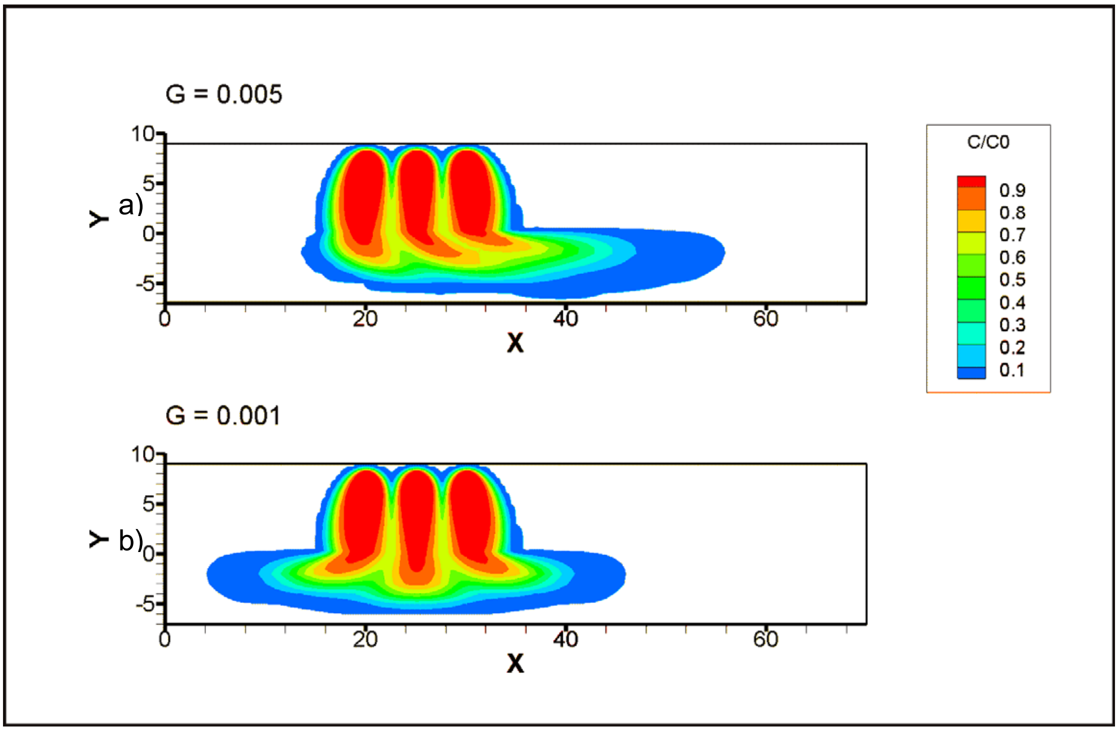


Figure 12.2(a, b) Relative solute concentration contours after 1.5 years of plume development for flow models with two values of regional gradient imposed. (Colour fill is cut off at C/C_0 = 0.001.)

12.3 Model conclusions

The simple model shows the chalk that underlies the outflow pipes is able to accept the increased input without raising the water table. This reflects what is seen at the site and suggests that much of the effluent discharge is rapidly transported via fractures to the aquifer, where it is rapidly dispersed by the high flow rates measured in all of the boreholes. In addition, it shows that, with the increased input to the system, it is possible for a plume to develop against the groundwater flow direction as indicated by the geophysical survey. These models are simplifications of the actual ground conditions, but do reflect field observations at the site.

13 Conclusions

13.1 Summary of key findings – Cheriton

- The septic tank at the Goodens, Cheriton, is a small two-stage system that serves eight dwellings.
- The system discharges every 1.5 to 2 hours.
- The effluent produced by the septic tank has elevated sodium, potassium, chloride ammonium, organic and inorganic carbon, orthophosphate, total phosphorous, total sulphur, and BOD/COD levels when compared to background and groundwater samples.
- Trace metals detected in the effluent were of comparable concentrations to those found in the groundwater and background samples.
- Some organochlorine pesticides and organic cleaning agents were detected in the effluent.
- With the exception of one sampling round in which mineral oil was detected in all samples, no organic compounds in List I and List II analytical schedules were detected in the groundwater samples.
- Groundwater samples from all the boreholes, including the background (tennis court) borehole, were virtually indistinguishable in both their major ion and trace metal chemistry and did not vary over the 12-month monitoring period.
- High numbers of faecal coliforms were detected in the effluent.
- Very few other bacteria were detected in the effluent.
- Low levels of total coliforms were detected in the pore water and the groundwater samples.
- Isotopic analysis shows that the ammonium in the effluent is not the source of nitrate in the groundwater.
- There is a very flat hydraulic gradient at the site.
- Preferential fracture flow allows rapid transport of the effluent to the aquifer.
- High flow rates in the aquifer allow rapid dilution and dispersion of contaminants.
- The impact of effluent disposal appears to be minimal at this site.

While the septic tank at Cheriton produces effluent with raised concentrations of expected contaminants (for example, ammonia), and with high BOD/COD levels, there is very little apparent impact on the aquifer. This is essentially because of the rapid transport of effluent to groundwater through a fairly shallow unsaturated zone and a substantial dilution effect in the saturated zone.

13.2 Summary of key findings – Droxford

- The PTP at Droxford is a three-stage treatment plant that services 35 dwellings.
- The system produces effluent of similar chemical and biological composition to that from the Cheriton septic tank.
- The PTP effluent has lower BOD and COD and slightly lower ammonium concentrations than does the septic tank system at Cheriton.

13.3 Overall conclusions

The study of a septic tank effluent disposal at the Goodens, Cheriton, was limited by the size of the system (it only serves eight dwellings – approximately 20 people), and because the effluent discharges over a large area to a rapidly flowing fractured aquifer. The study conclusions are therefore limited to systems of a similar size on similar geological settings.

Overall, there is very little chemical or biological evidence that the septic tank effluent impacts the chalk aquifer once it reaches the saturated zone. Pore-water profiles through the unsaturated zone show some elevated ion concentrations, particularly around the water table depth in BH1 and BH4 (which are directly below the discharge pipes), and are probably associated with the effluent discharge. These concentrations are not seen in the groundwater samples, the chemistry of which remained consistent throughout the study. Biologically, these boreholes show evidence of low-level contamination, but do not exceed WHO drinking water guidelines, and again the source is likely to be the effluent discharge, although the discharge field is used for grazing cattle, which introduce another source of faecal bacteria. It is possible that BH2, BH3, and BH5 are up gradient of the outflow and miss any contaminant plume. However, groundwater modelling suggests that the flat hydraulic gradient (a feature of chalk aquifers) and a slightly increased recharge mound formed under the effluent injection site are sufficient to overwhelm the regional gradient locally and to develop a plume equally in both directions, reaching at least BH2 and BH5. There is no evidence of chemical contamination in these boreholes. BH1 and BH4, however, are between the second and third outflow pipes and should be good indicators of any contamination present.

It appears as though much of the effluent is rapidly transported to the aquifer via fractures in the chalk matrix, then diluted by the relatively high groundwater flows. Although the fracture characteristics are poorly understood at the site, the 8 m of unsaturated chalk and the high flow rates within the aquifer seem to afford a reasonably high level of protection against contamination from a relatively small septic tank system. As it is situated in a river valley, the groundwater flows are at the upper range expected in the chalk, so a discharge site at a greater elevation may have a slower flow in the aquifer and may not cope as well with the effluent discharge. However, if the geological setting had not been so highly fractured we would have also expected to see a greater impact on the aquifer. A less fractured, slower flowing system would be less likely to cope with the additional inflow and a rising water table would be expected, particularly if there were a greater effluent discharge than from the septic tank at Cheriton. The study also demonstrates the ability of the PTP to reduce the BOD and COD levels in the outflowing effluent, and therefore suggests this treatment would be more effective in reducing the BOD/COD load to the receiving aquifer. This study did not investigate the transport of effluent contaminants from the PTP to the receiving aquifer, so we can draw no other conclusions regarding attenuation, loadings, or dispersion in such cases.

Biologically, the septic tank and PTP systems contain large numbers of faecal bacteria, which is to be expected in sewage treatment systems of this type. Low total bacteria counts meant that we were unable to detect other microbial communities within the effluent. The biological impact on the aquifer appears to be low to insignificant, although coliform indicator bacteria were detected in all of the boreholes at some time during the routine monitoring. The absence of nitrifiying and denitrifiying bacteria in the effluent and groundwater samples provides evidence that biochemical nitrogen transformations of ammonia do not occur in either the effluent or the groundwater. This is supported by the chemical and isotopic analysis of the samples, which indicates that nitrate concentrations in the groundwater are not a product of the ammonium in the effluent. Low numbers of bacteria coupled with rapid flow to a large-volume, fast-flowing aquifer suggests the bacteria are either being rapidly diluted and dispersed at this site or that there is an insufficient food source to support the development and maintenance of larger microbial communities.

Although the septic tank monitored in this study appears to have little impact on the Chalk aquifer, it is important to remember that this is a small system discharging to a large, fast-flowing aquifer. To obtain a good understanding of the flow regime and fracture network was outside the scope of this study, but it is important when assessing the impact of these types of effluent disposal systems to a Chalk aquifer to have a comprehensive understanding of the geological and hydrogeological conditions of individual sites. The flow regime in Chalk aquifers varies across the country and a wide range of flow rates and transport times will be encountered. The ability of the aquifer to cope with the effluent discharge will also depend on the size of the treatment system, the number of people served, the volume of discharge, effluent quality and the area over which discharge takes place. It is therefore recommended that site-specific risk assessments be undertaken when considering the installation of septic tank effluent disposal systems.

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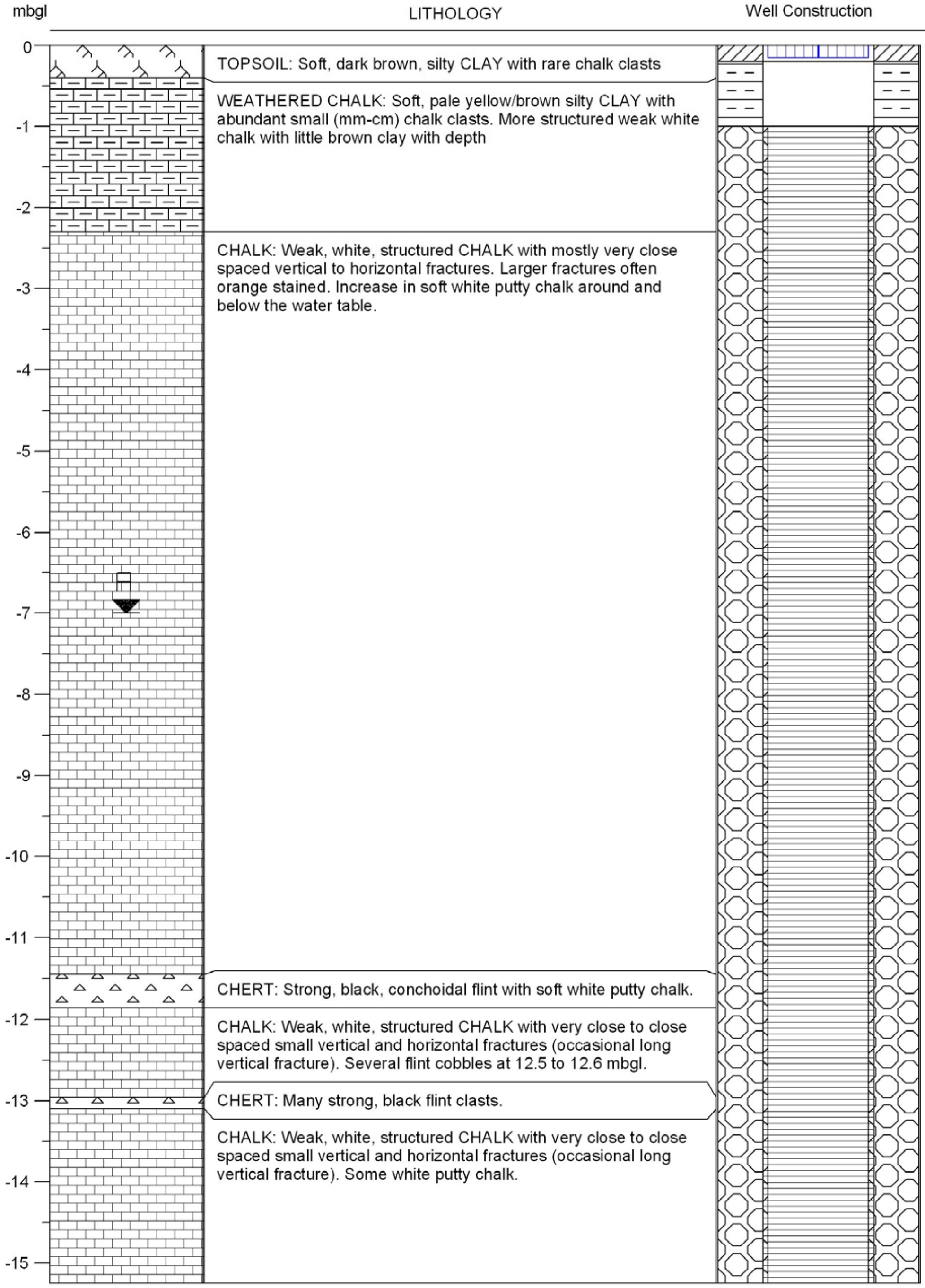
Appendix 1 Borehole logs

P-229 Cheriton

BH3

Borehole Diameter:	6"	Location:	Cheriton, Hampshire
Drilling Method:	Cable Percussion	Date Drilled:	19/04/04
Easting:	457947.23	Elevation (m)	74.35
Northing:	128555.30	Total Depth	15.45



TOPSOIL: Soft, dark brown, silty CLAY with rare chalk clasts

WEATHERED CHALK: Soft, pale yellow/brown silty CLAY with abundant small (mm-cm) chalk clasts. More structured weak white chalk with little brown clay with depth

CHALK: Weak, white, structured CHALK with mostly very close spaced vertical to horizontal fractures. Larger fractures often orange stained. Increase in soft white putty chalk around and below the water table.

CHERT: Strong, black, conchoidal flint with soft white putty chalk.

CHALK: Weak, white, structured CHALK with very close to close spaced small vertical and horizontal fractures (occasional long vertical fracture). Several flint cobbles at 12.5 to 12.6 mbgl.

CHERT: Many strong, black flint clasts.

CHALK: Weak, white, structured CHALK with very close to close spaced small vertical and horizontal fractures (occasional long vertical fracture). Some white putty chalk.

Log Compiled by J Trick

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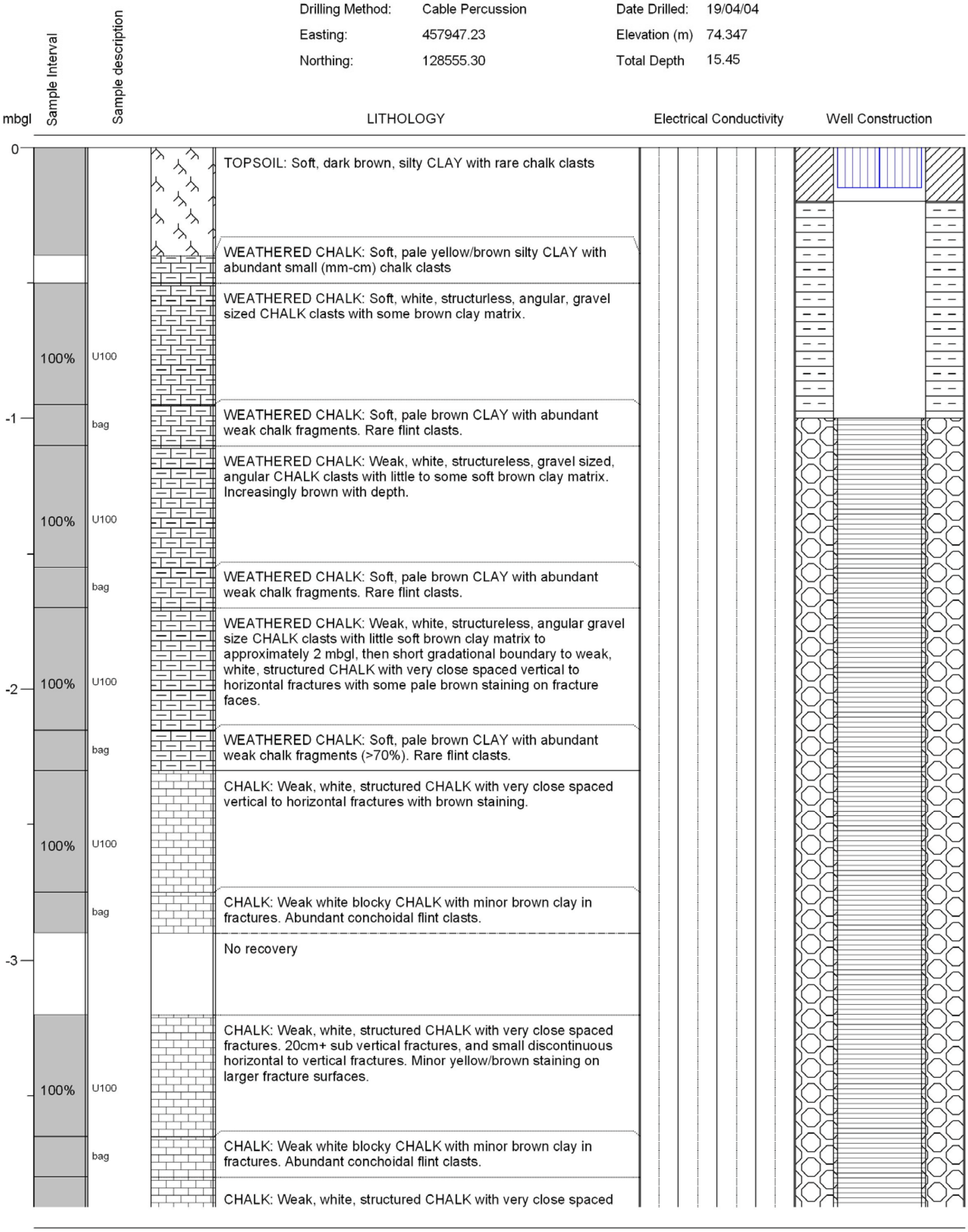
P-229 Cheriton

BH3

Borehole Diameter:	6"	Location:	Cheriton, Hampshire
Drilling Method:	Cable Percussion	Date Drilled:	19/04/04
Easting:	457947.23	Elevation (m)	74.347
Northing:	128555.30	Total Depth	15.45



TOPSOIL: Soft, dark brown, silty CLAY with rare chalk clasts

WEATHERED CHALK: Soft, pale yellow/brown silty CLAY with abundant small (mm-cm) chalk clasts

WEATHERED CHALK: Soft, white, structurless, angular, gravel sized CHALK clasts with some brown clay matrix.

WEATHERED CHALK: Soft, pale brown CLAY with abundant weak chalk fragments. Rare flint clasts.

WEATHERED CHALK: Weak, white, structereless, gravel sized, angular CHALK clasts with little to some soft brown clay matrix. Increasingly brown with depth.

WEATHERED CHALK: Soft, pale brown CLAY with abundant weak chalk fragments. Rare flint clasts.

WEATHERED CHALK: Weak, white, structureless, angular gravel size CHALK clasts with little soft brown clay matrix to approximately 2 mbgl, then short gradational boundary to weak, white, structured CHALK with very close spaced vertical to horizontal fractures with some pale brown staining on fracture faces.

WEATHERED CHALK: Soft, pale brown CLAY with abundant weak chalk fragments (>70%). Rare flint clasts.

CHALK: Weak, white, structured CHALK with very close spaced vertical to horizontal fractures with brown staining.

CHALK: Weak white blocky CHALK with minor brown clay in fractures. Abundant conchoidal flint clasts.

No recovery

CHALK: Weak, white, structured CHALK with very close spaced fractures. 20cm+ sub vertical fractures, and small discontinuous horizontal to vertical fractures. Minor yellow/brown staining on larger fracture surfaces.

CHALK: Weak white blocky CHALK with minor brown clay in fractures. Abundant conchoidal flint clasts.

CHALK: Weak, white, structured CHALK with very close spaced

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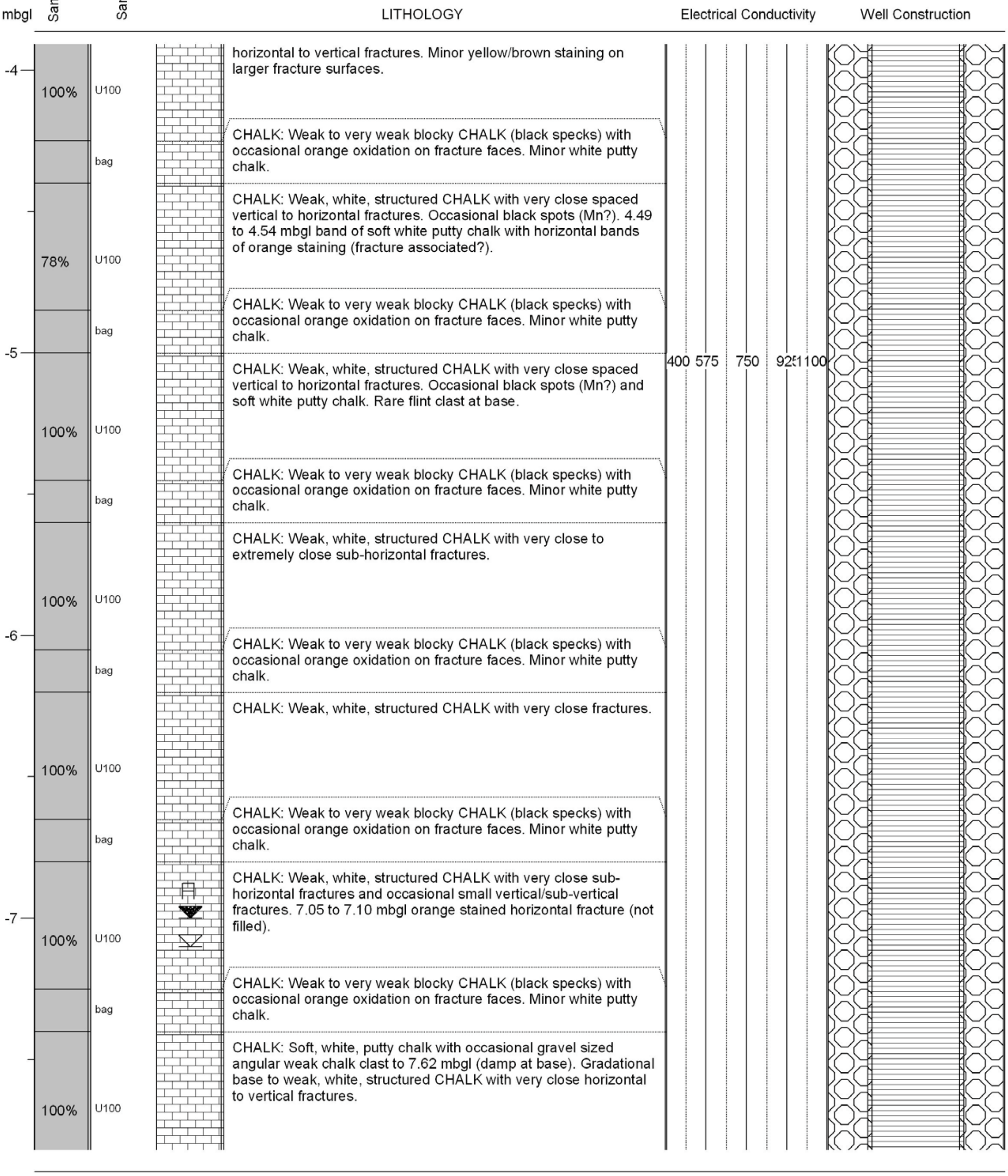
P-229 Cheriton BH3

Borehole Diameter:	6"	Location:	Cheriton, Hampshire
Drilling Method:	Cable Percussion	Date Drilled:	19/04/04
Easting:	457947.23	Elevation (m)	74.347
Northing:	128555.30	Total Depth	15.45



horizontal to vertical fractures. Minor yellow/brown staining on larger fracture surfaces.

CHALK: Weak to very weak blocky CHALK (black specks) with occasional orange oxidation on fracture faces. Minor white putty chalk.

CHALK: Weak, white, structured CHALK with very close spaced vertical to horizontal fractures. Occasional black spots (Mn?). 4.49 to 4.54 mbgl band of soft white putty chalk with horizontal bands of orange staining (fracture associated?).

CHALK: Weak to very weak blocky CHALK (black specks) with occasional orange oxidation on fracture faces. Minor white putty chalk.

CHALK: Weak, white, structured CHALK with very close spaced vertical to horizontal fractures. Occasional black spots (Mn?) and soft white putty chalk. Rare flint clast at base.

CHALK: Weak to very weak blocky CHALK (black specks) with occasional orange oxidation on fracture faces. Minor white putty chalk.

CHALK: Weak, white, structured CHALK with very close to extremely close sub-horizontal fractures.

CHALK: Weak to very weak blocky CHALK (black specks) with occasional orange oxidation on fracture faces. Minor white putty chalk.

CHALK: Weak, white, structured CHALK with very close fractures.

CHALK: Weak to very weak blocky CHALK (black specks) with occasional orange oxidation on fracture faces. Minor white putty chalk.

CHALK: Weak, white, structured CHALK with very close sub-horizontal fractures and occasional small vertical/sub-vertical fractures. 7.05 to 7.10 mbgl orange stained horizontal fracture (not filled).

CHALK: Weak to very weak blocky CHALK (black specks) with occasional orange oxidation on fracture faces. Minor white putty chalk.

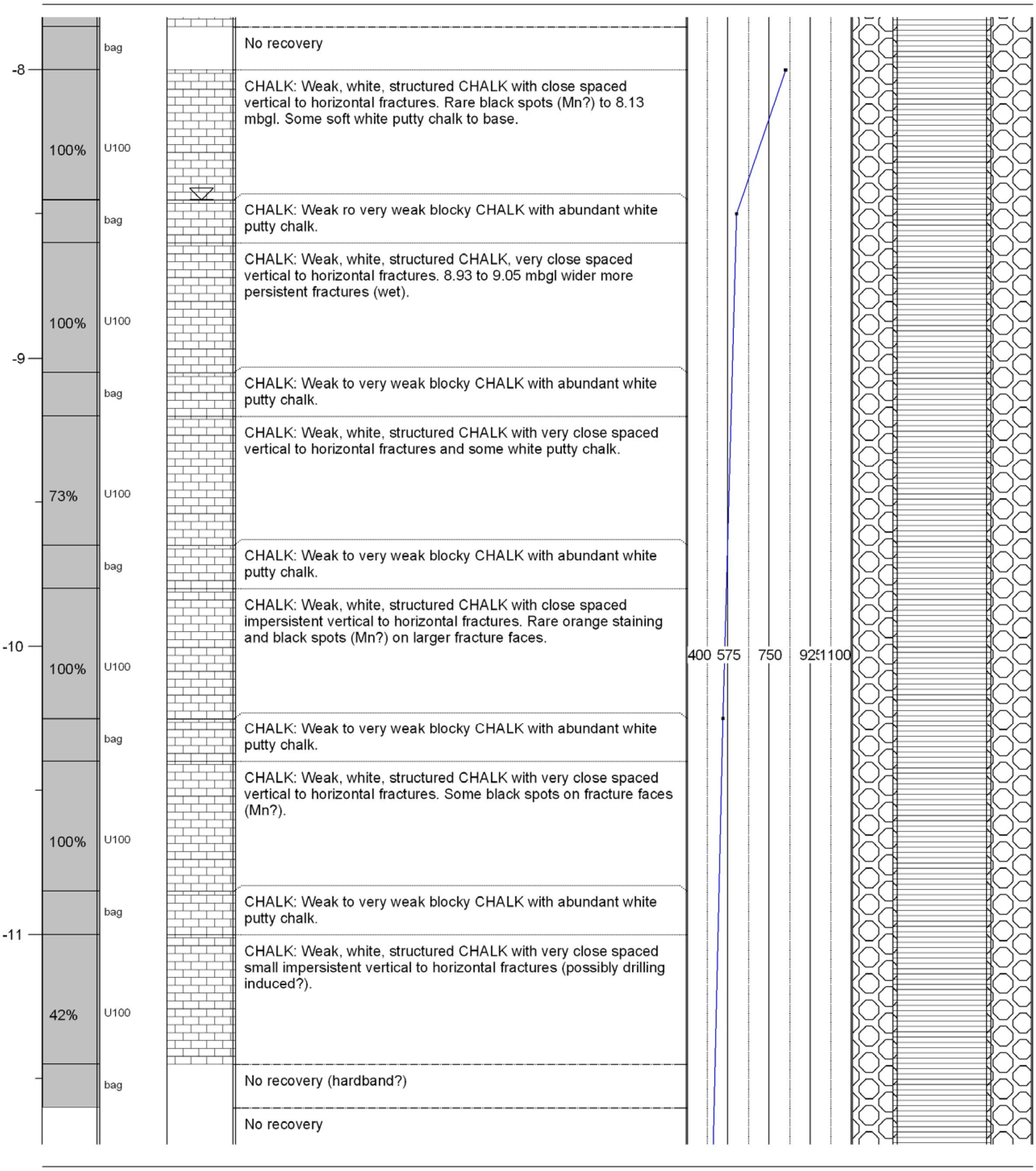
CHALK: Soft, white, putty chalk with occasional gravel sized angular weak chalk clast to 7.62 mbgl (damp at base). Gradational base to weak, white, structured CHALK with very close horizontal to vertical fractures.

Log Compiled by J Trick

P-229 Cheriton

BH3

Borehole Diameter:	6"	Location:	Cheriton, Hampshire
Drilling Method:	Cable Percussion	Date Drilled:	19/04/04
Easting:	457947.23	Elevation (m)	74.347
Northing:	128555.30	Total Depth	15.45



Sample Interval	Sample description	LITHOLOGY
	bag	No recovery
100%	U100	CHALK: Weak, white, structured CHALK with close spaced vertical to horizontal fractures. Rare black spots (Mn?) to 8.13 mbgl. Some soft white putty chalk to base.
	bag	CHALK: Weak ro very weak blocky CHALK with abundant white putty chalk.
100%	U100	CHALK: Weak, white, structured CHALK, very close spaced vertical to horizontal fractures. 8.93 to 9.05 mbgl wider more persistent fractures (wet).
	bag	CHALK: Weak to very weak blocky CHALK with abundant white putty chalk.
73%	U100	CHALK: Weak, white, structured CHALK with very close spaced vertical to horizontal fractures and some white putty chalk.
	bag	CHALK: Weak to very weak blocky CHALK with abundant white putty chalk.
100%	U100	CHALK: Weak, white, structured CHALK with close spaced impersistent vertical to horizontal fractures. Rare orange staining and black spots (Mn?) on larger fracture faces.
	bag	CHALK: Weak to very weak blocky CHALK with abundant white putty chalk.
100%	U100	CHALK: Weak, white, structured CHALK with very close spaced vertical to horizontal fractures. Some black spots on fracture faces (Mn?).
	bag	CHALK: Weak to very weak blocky CHALK with abundant white putty chalk.
42%	U100	CHALK: Weak, white, structured CHALK with very close spaced small impersistent vertical to horizontal fractures (possibly drilling induced?).
	bag	No recovery (hardband?)
		No recovery

Log Compiled by J Trick

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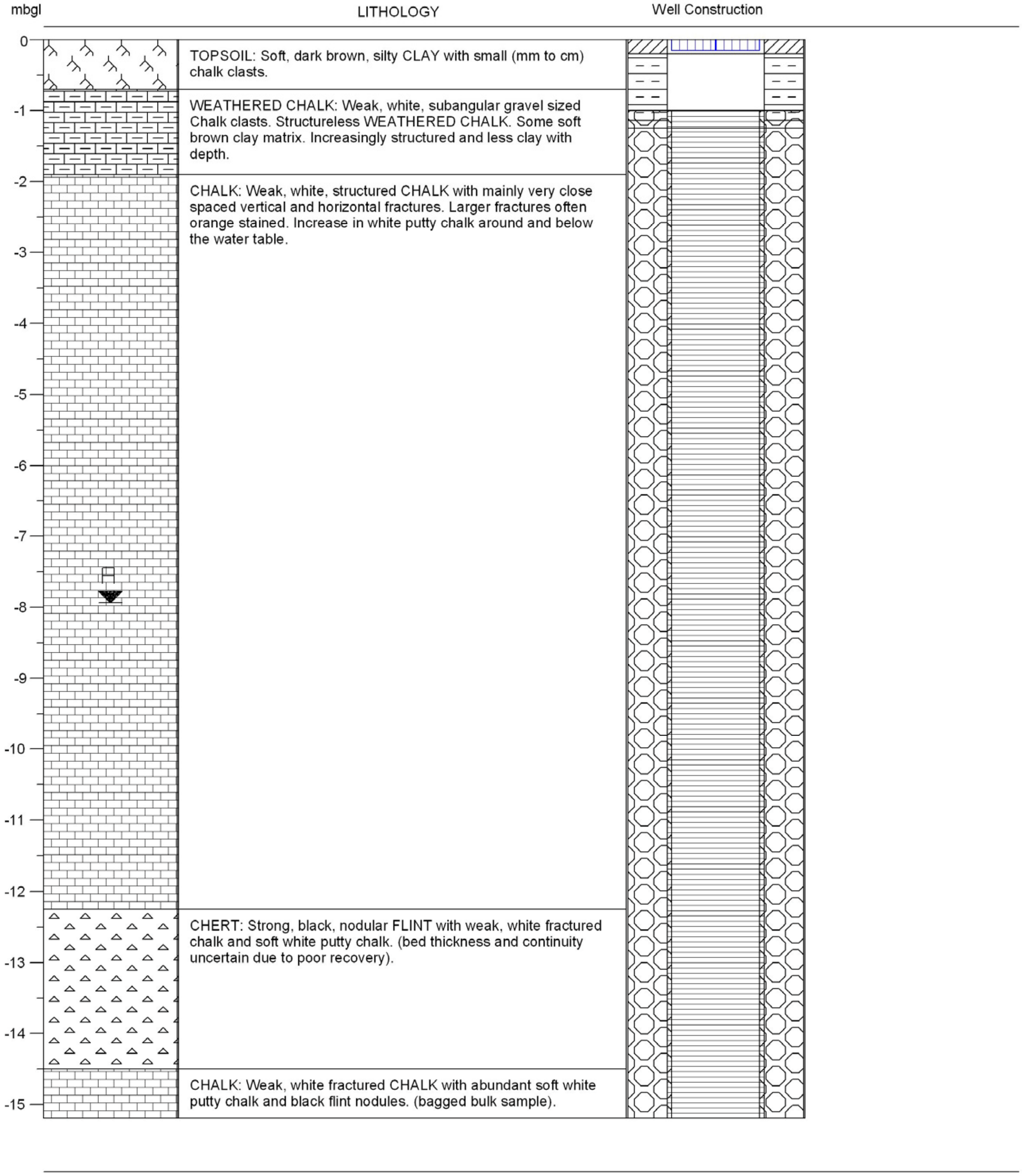
P-229 Cheriton

BH4

Borehole Diameter: 6"
Drilling Method: Cable Percussion
Easting: 457966.46
Northing: 128571.28

Location: Cheriton, Hampshire
Date Drilled: 28/04/04
Elevation (m) 75.17
Total Depth 15.2



TOPSOIL: Soft, dark brown, silty CLAY with small (mm to cm) chalk clasts.

WEATHERED CHALK: Weak, white, subangular gravel sized Chalk clasts. Structureless WEATHERED CHALK. Some soft brown clay matrix. Increasingly structured and less clay with depth.

CHALK: Weak, white, structured CHALK with mainly very close spaced vertical and horizontal fractures. Larger fractures often orange stained. Increase in white putty chalk around and below the water table.

CHERT: Strong, black, nodular FLINT with weak, white fractured chalk and soft white putty chalk. (bed thickness and continuity uncertain due to poor recovery).

CHALK: Weak, white fractured CHALK with abundant soft white putty chalk and black flint nodules. (bagged bulk sample).

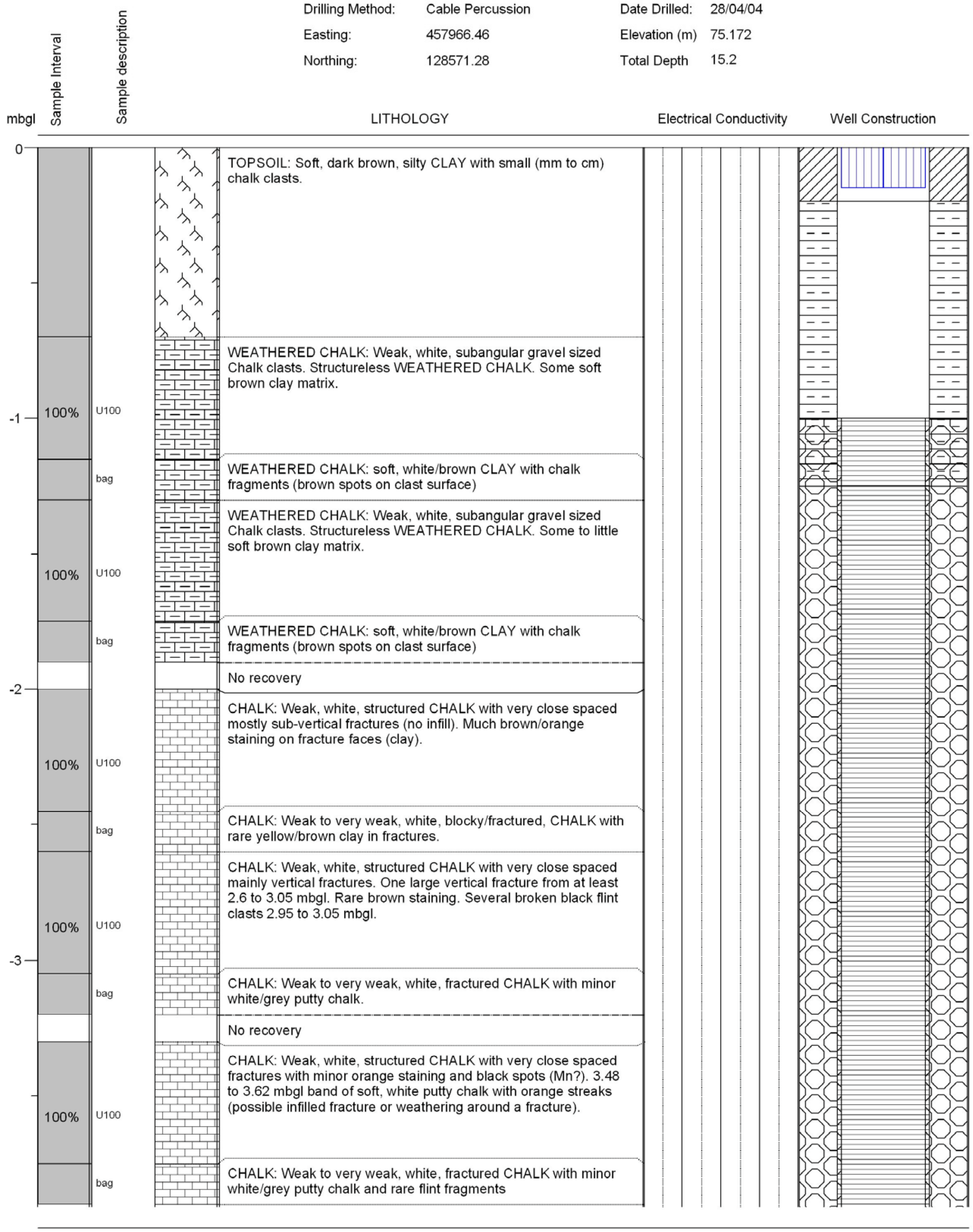
Log Compiled by J Trick

P-229 Cheriton

BH4

Borehole Diameter: 6"
Drilling Method: Cable Percussion
Easting: 457966.46
Northing: 128571.28

Location: Cheriton, Hampshire
Date Drilled: 28/04/04
Elevation (m) 75.172
Total Depth 15.2



TOPSOIL: Soft, dark brown, silty CLAY with small (mm to cm) chalk clasts.

WEATHERED CHALK: Weak, white, subangular gravel sized Chalk clasts. Structureless WEATHERED CHALK. Some soft brown clay matrix.

WEATHERED CHALK: soft, white/brown CLAY with chalk fragments (brown spots on clast surface)

WEATHERED CHALK: Weak, white, subangular gravel sized Chalk clasts. Structureless WEATHERED CHALK. Some to little soft brown clay matrix.

WEATHERED CHALK: soft, white/brown CLAY with chalk fragments (brown spots on clast surface)

No recovery

CHALK: Weak, white, structured CHALK with very close spaced mostly sub-vertical fractures (no infill). Much brown/orange staining on fracture faces (clay).

CHALK: Weak to very weak, white, blocky/fractured, CHALK with rare yellow/brown clay in fractures.

CHALK: Weak, white, structured CHALK with very close spaced mainly vertical fractures. One large vertical fracture from at least 2.6 to 3.05 mbgl. Rare brown staining. Several broken black flint clasts 2.95 to 3.05 mbgl.

CHALK: Weak to very weak, white, fractured CHALK with minor white/grey putty chalk.

No recovery

CHALK: Weak, white, structured CHALK with very close spaced fractures with minor orange staining and black spots (Mn?). 3.48 to 3.62 mbgl band of soft, white putty chalk with orange streaks (possible infilled fracture or weathering around a fracture).

CHALK: Weak to very weak, white, fractured CHALK with minor white/grey putty chalk and rare flint fragments

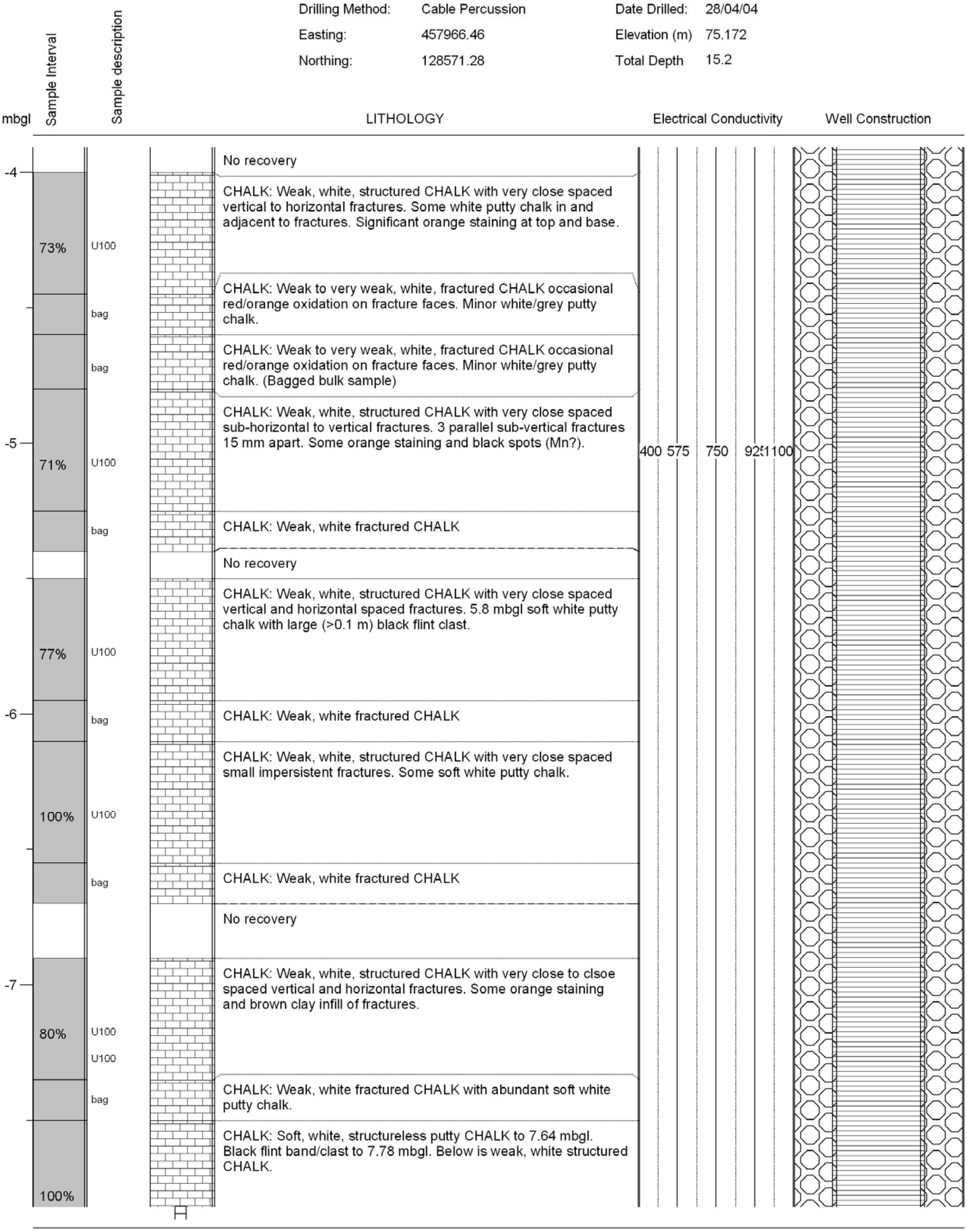
Log Compiled by J Trick

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

P-229 Cheriton

BH4

Borehole Diameter:	6"	Location:	Cheriton, Hampshire
Drilling Method:	Cable Percussion	Date Drilled:	28/04/04
Easting:	457966.46	Elevation (m)	75.172
Northing:	128571.28	Total Depth	15.2



Sample Interval	Sample description	LITHOLOGY
		No recovery
73%	U100	CHALK: Weak, white, structured CHALK with very close spaced vertical to horizontal fractures. Some white putty chalk in and adjacent to fractures. Significant orange staining at top and base.
	bag	CHALK: Weak to very weak, white, fractured CHALK occasional red/orange oxidation on fracture faces. Minor white/grey putty chalk.
	bag	CHALK: Weak to very weak, white, fractured CHALK occasional red/orange oxidation on fracture faces. Minor white/grey putty chalk. (Bagged bulk sample)
71%	U100	CHALK: Weak, white, structured CHALK with very close spaced sub-horizontal to vertical fractures. 3 parallel sub-vertical fractures 15 mm apart. Some orange staining and black spots (Mn?).
	bag	CHALK: Weak, white fractured CHALK
		No recovery
77%	U100	CHALK: Weak, white, structured CHALK with very close spaced vertical and horizontal spaced fractures. 5.8 mbgl soft white putty chalk with large (>0.1 m) black flint clast.
	bag	CHALK: Weak, white fractured CHALK
100%	U100	CHALK: Weak, white, structured CHALK with very close spaced small impersistent fractures. Some soft white putty chalk.
	bag	CHALK: Weak, white fractured CHALK
		No recovery
80%	U100 U100	CHALK: Weak, white, structured CHALK with very close to clsoe spaced vertical and horizontal fractures. Some orange staining and brown clay infill of fractures.
	bag	CHALK: Weak, white fractured CHALK with abundant soft white putty chalk.
100%		CHALK: Soft, white, structureless putty CHALK to 7.64 mbgl. Black flint band/clast to 7.78 mbgl. Below is weak, white structured CHALK.

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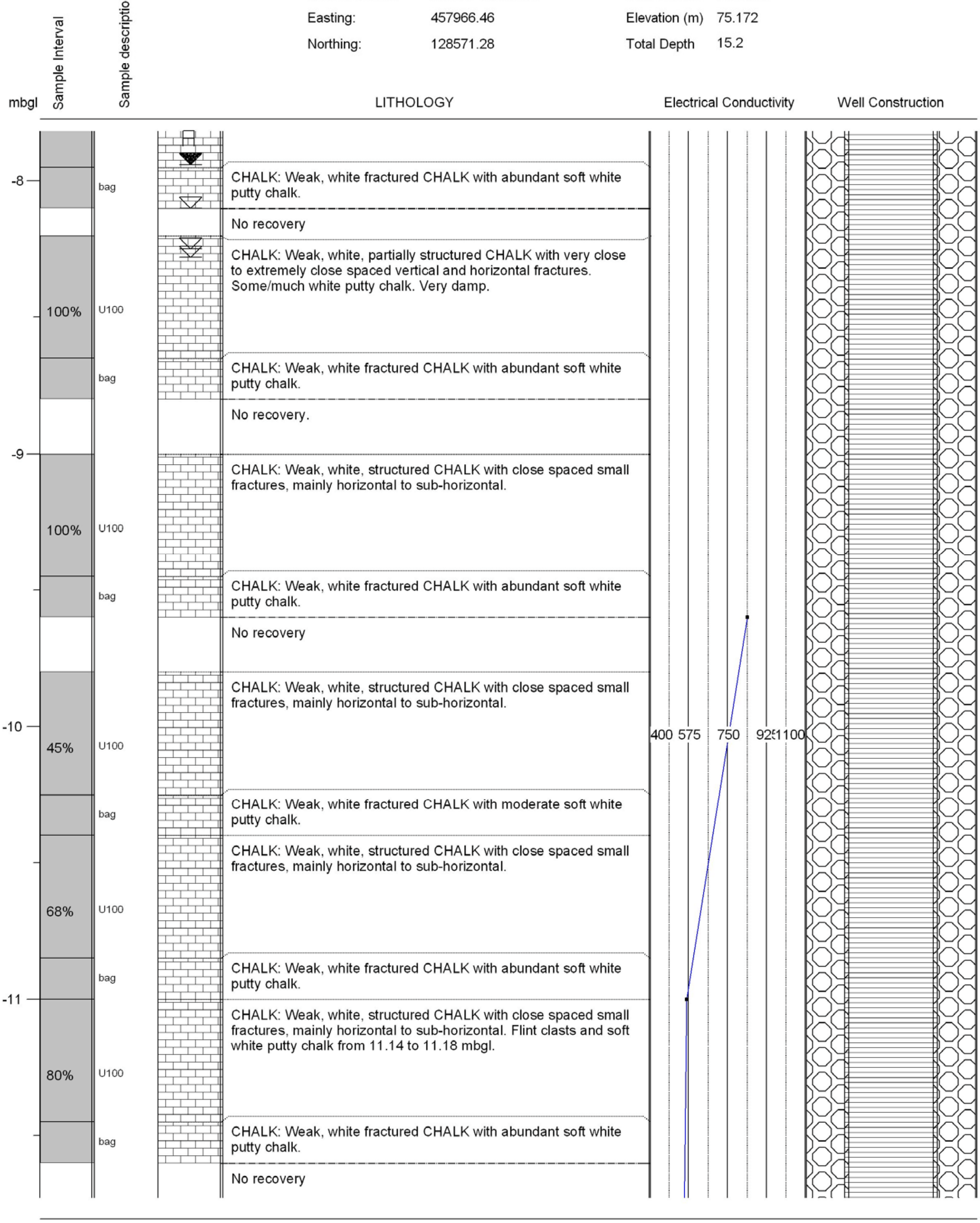
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

P-229 Cheriton BH4

Borehole Diameter:	6"	Location:	Cheriton, Hampshire
Drilling Method:	Cable Percussion	Date Drilled:	28/04/04
Easting:	457966.46	Elevation (m)	75.172
Northing:	128571.28	Total Depth	15.2



CHALK: Weak, white fractured CHALK with abundant soft white putty chalk.

No recovery

CHALK: Weak, white, partially structured CHALK with very close to extremely close spaced vertical and horizontal fractures. Some/much white putty chalk. Very damp.

CHALK: Weak, white fractured CHALK with abundant soft white putty chalk.

No recovery.

CHALK: Weak, white, structured CHALK with close spaced small fractures, mainly horizontal to sub-horizontal.

CHALK: Weak, white fractured CHALK with abundant soft white putty chalk.

No recovery

CHALK: Weak, white, structured CHALK with close spaced small fractures, mainly horizontal to sub-horizontal.

CHALK: Weak, white fractured CHALK with moderate soft white putty chalk.

CHALK: Weak, white, structured CHALK with close spaced small fractures, mainly horizontal to sub-horizontal.

CHALK: Weak, white fractured CHALK with abundant soft white putty chalk.

CHALK: Weak, white, structured CHALK with close spaced small fractures, mainly horizontal to sub-horizontal. Flint clasts and soft white putty chalk from 11.14 to 11.18 mbgl.

CHALK: Weak, white fractured CHALK with abundant soft white putty chalk.

No recovery

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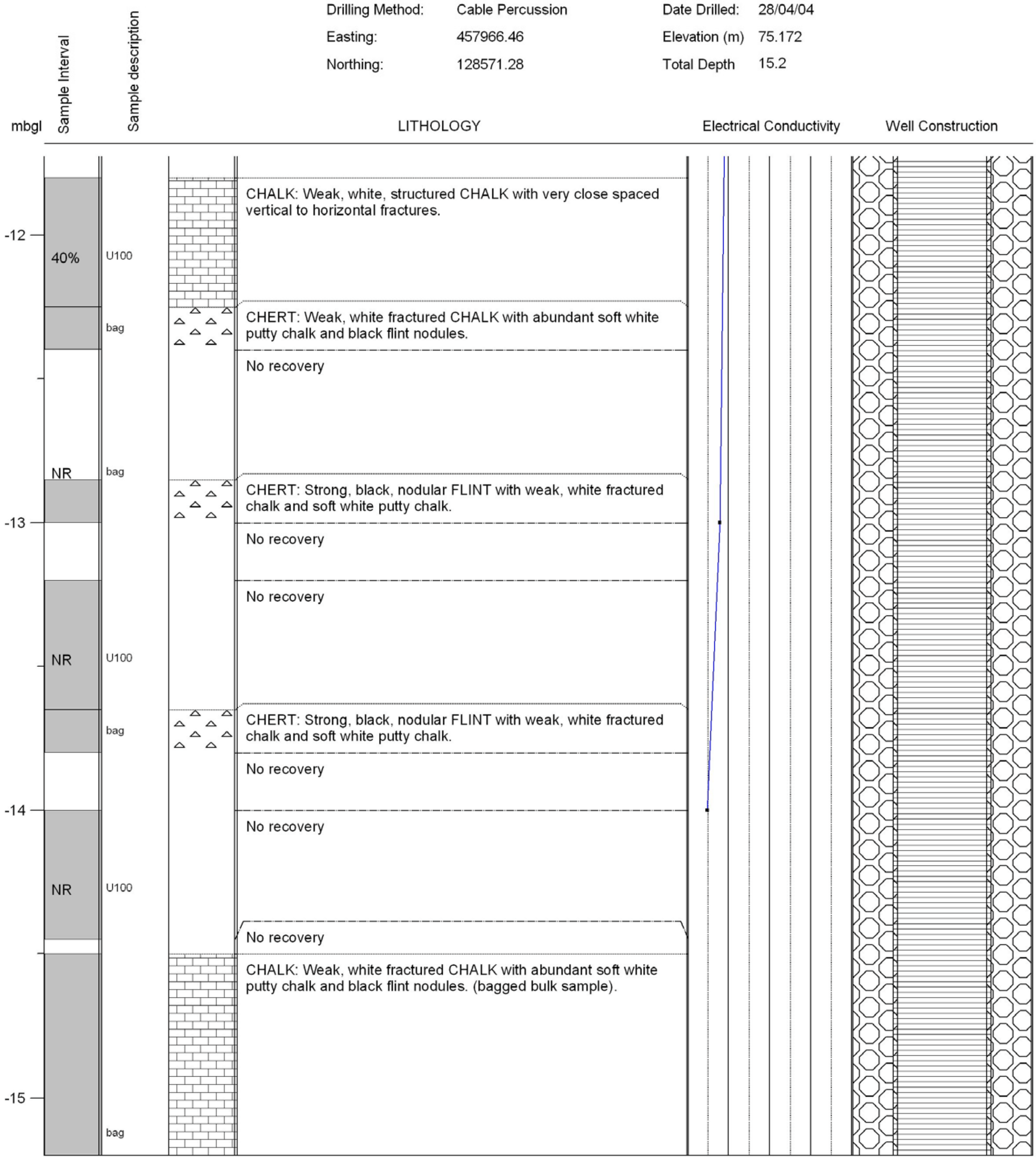
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

P-229 Cheriton BH4

Borehole Diameter:	6"	Location:	Cheriton, Hampshire
Drilling Method:	Cable Percussion	Date Drilled:	28/04/04
Easting:	457966.46	Elevation (m)	75.172
Northing:	128571.28	Total Depth	15.2



CHALK: Weak, white, structured CHALK with very close spaced vertical to horizontal fractures.

CHERT: Weak, white fractured CHALK with abundant soft white putty chalk and black flint nodules.

No recovery

CHERT: Strong, black, nodular FLINT with weak, white fractured chalk and soft white putty chalk.

No recovery

No recovery

CHERT: Strong, black, nodular FLINT with weak, white fractured chalk and soft white putty chalk.

No recovery

No recovery

No recovery

CHALK: Weak, white fractured CHALK with abundant soft white putty chalk and black flint nodules. (bagged bulk sample).

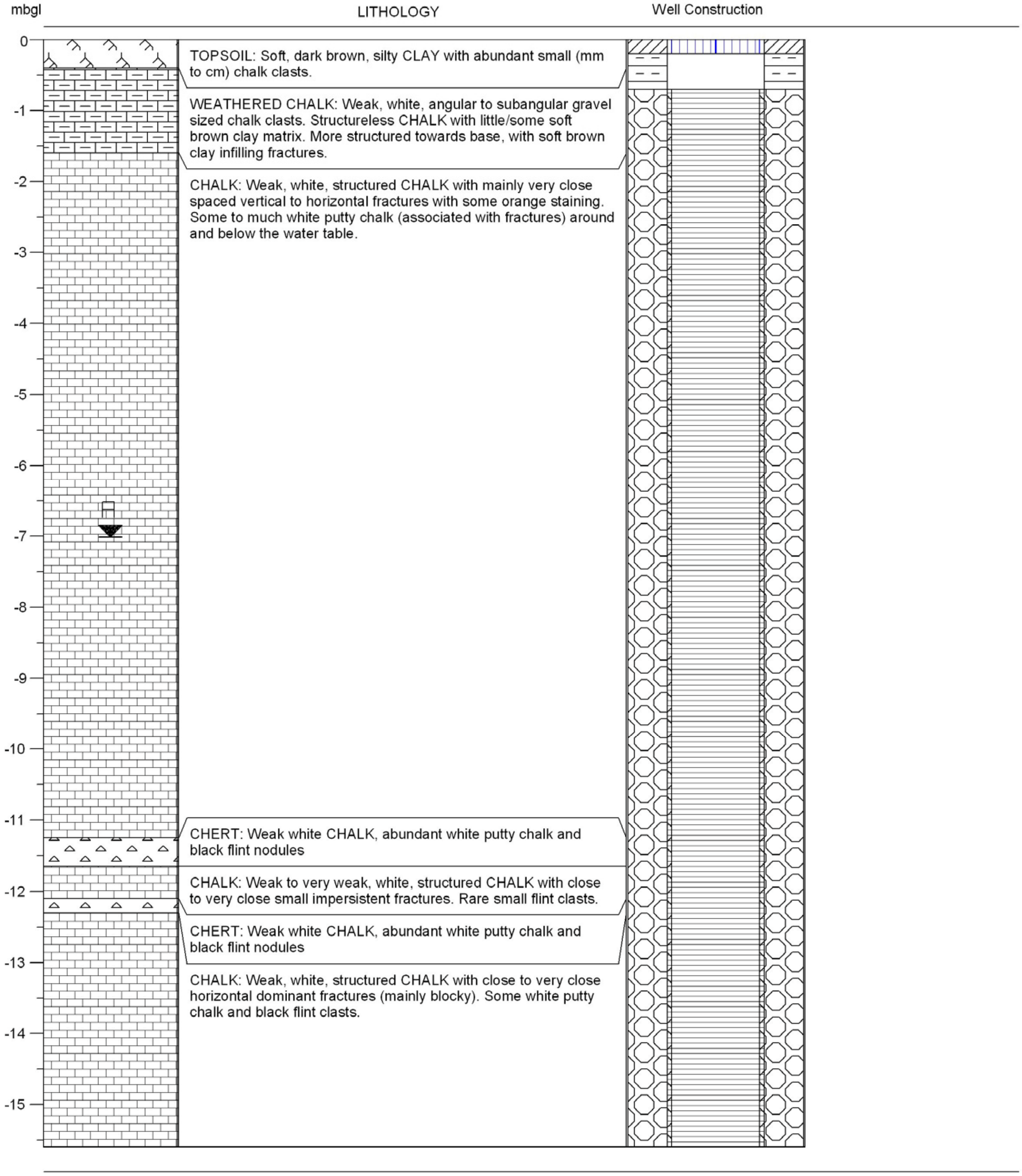
Log Compiled by J Trick

P-229 Cheriton

BH5

Borehole Diameter: 6"
Drilling Method: Cable Percussion
Easting: 457976.84
Northing: 128558.79

Location: Cheriton, Hampshire
Date Drilled: 26/04/04
Elevation (m) 74.35
Total Depth 15.6



TOPSOIL: Soft, dark brown, silty CLAY with abundant small (mm to cm) chalk clasts.

WEATHERED CHALK: Weak, white, angular to subangular gravel sized chalk clasts. Structureless CHALK with little/some soft brown clay matrix. More structured towards base, with soft brown clay infilling fractures.

CHALK: Weak, white, structured CHALK with mainly very close spaced vertical to horizontal fractures with some orange staining. Some to much white putty chalk (associated with fractures) around and below the water table.

CHERT: Weak white CHALK, abundant white putty chalk and black flint nodules

CHALK: Weak to very weak, white, structured CHALK with close to very close small impersistent fractures. Rare small flint clasts.

CHERT: Weak white CHALK, abundant white putty chalk and black flint nodules

CHALK: Weak, white, structured CHALK with close to very close horizontal dominant fractures (mainly blocky). Some white putty chalk and black flint clasts.

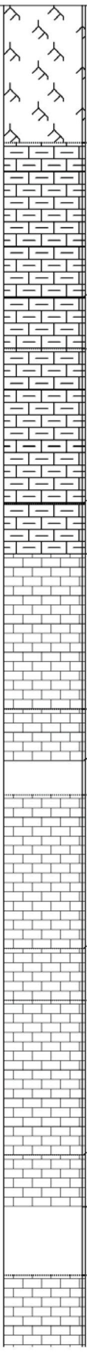
Log Compiled by J Trick

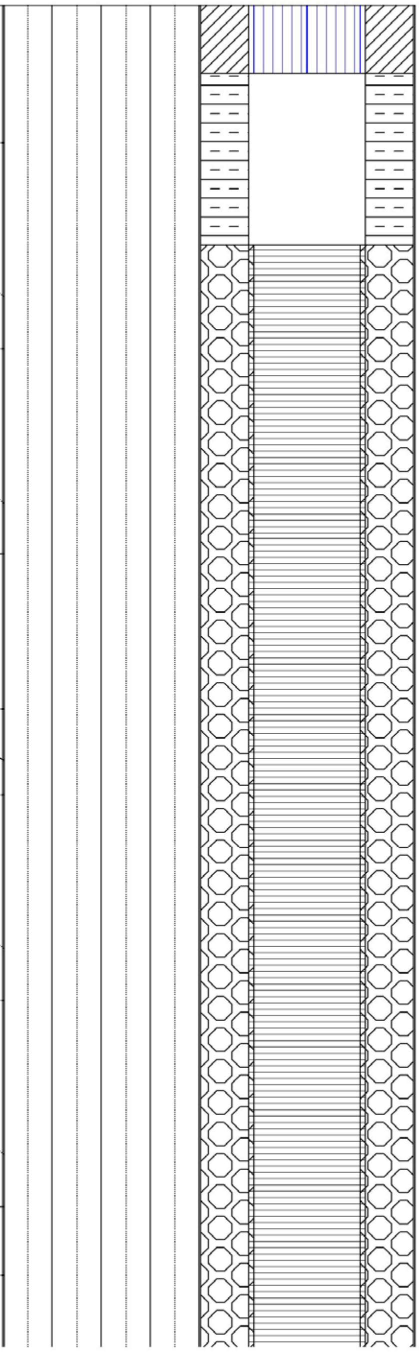
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

P-229 Cheriton BH5

Borehole Diameter:	6"	Location:	Cheriton, Hampshire
Drilling Method:	Cable Percussion	Date Drilled:	26/04/04
Easting:	457976.84	Elevation (m)	74.352
Northing:	128558.79	Total Depth	15.6

mbgl	Sample Interval	Sample description	LITHOLOGY
0			TOPSOIL: Soft, dark brown, silty CLAY with abundant samll (mm to cm) chalk clasts.
	70%	U100	WEATHERED CHALK: Weak, white, angular to subangular gravel sized chalk clasts. Structureless CHALK with little/some soft brown clay matrix.
		bag	WEATHERED CHALK: Soft, brown/yellow CLAY with weak white chalk clasts.
-1	75%	U100	WEATHERED CHALK: Weak, white, structured CHALK with very close vertical to horizontal fractures infilled largely with soft brown clay.
		bag	WEATHERED CHALK: Soft, brown/yellow CLAY with weak white chalk clasts.
	80%	U100	CHALK: Weak, white, structured CHALK with very close horizontal dominant fractures. Orange staining on fracture surfaces from 1.66 to 1.74 mbgl.
-2		bag	CHALK: Soft, brown/yellow CLAY with weak white chalk clasts.
			No recovery
	80%	U100	CHALK: Weak, white structured CHALK with very close spaced vertical to horizontal fractures with minor orange staining.
		bag	CHALK: Soft, brown/yellow CLAY with weak white chalk clasts, rare flint nodule.
-3	100%	U100	CHALK: Weak, white structured CHALK with very close spaced vertical to horizontal fractures with minor orange staining.
		bag	CHALK: Weak to very weak, white, fractured CHALK, minor yellow/brown clay in fractures.
			No recovery
			CHALK: Weak, white, structured CHALK with very close spaced vertical dominant fractures. Some/little orange staining and black spots (Mn?).





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P-229 Cheriton

BH5

Borehole Diameter:	6"	Location:	Cheriton, Hampshire
Drilling Method:	Cable Percussion	Date Drilled:	26/04/04
Easting:	457976.84	Elevation (m)	74.352
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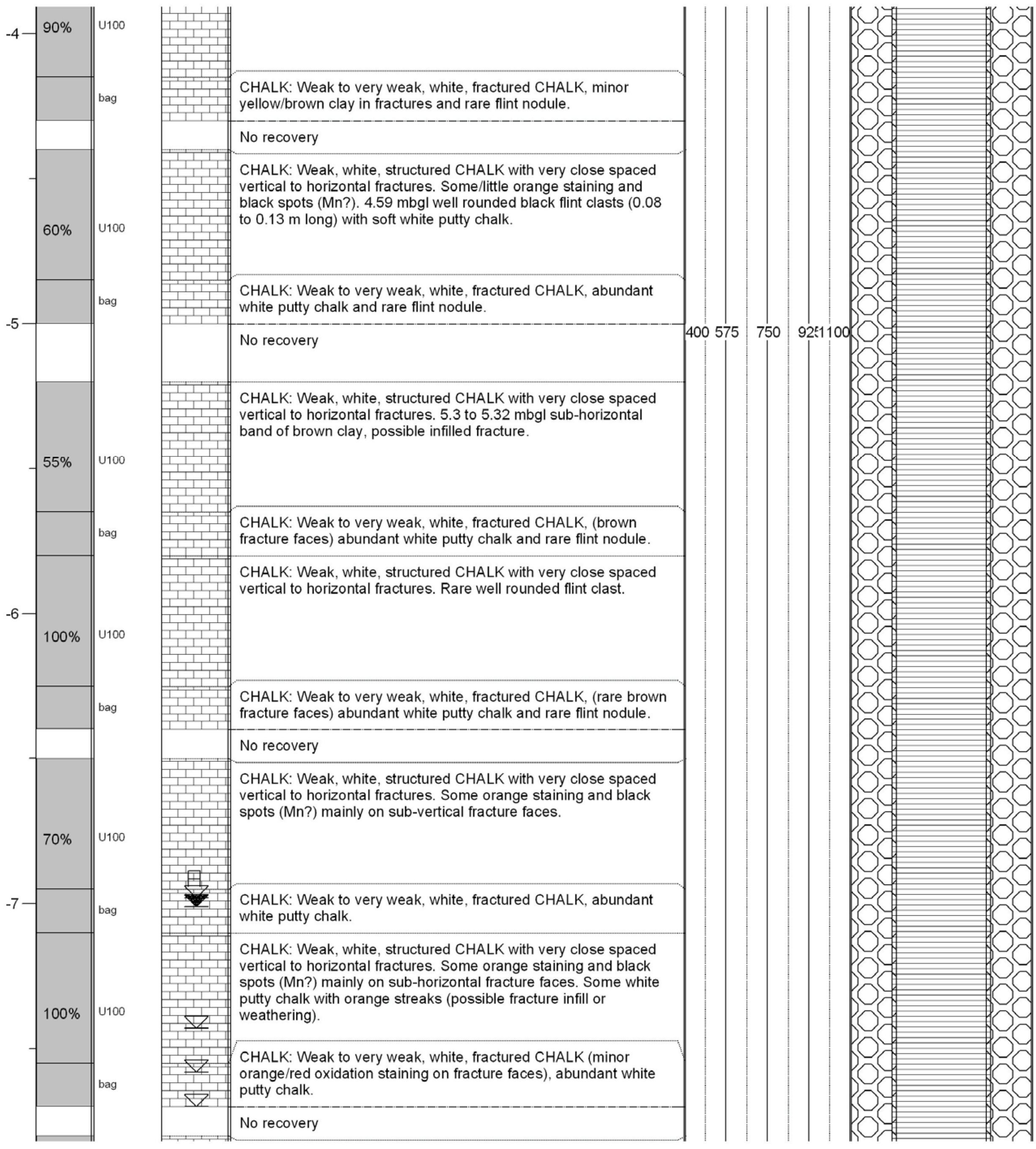

Sample Interval	Sample description	LITHOLOGY
90%	U100	
	bag	CHALK: Weak to very weak, white, fractured CHALK, minor yellow/brown clay in fractures and rare flint nodule.
		No recovery
60%	U100	CHALK: Weak, white, structured CHALK with very close spaced vertical to horizontal fractures. Some/little orange staining and black spots (Mn?). 4.59 mbgl well rounded black flint clasts (0.08 to 0.13 m long) with soft white putty chalk.
	bag	CHALK: Weak to very weak, white, fractured CHALK, abundant white putty chalk and rare flint nodule.
		No recovery
55%	U100	CHALK: Weak, white, structured CHALK with very close spaced vertical to horizontal fractures. 5.3 to 5.32 mbgl sub-horizontal band of brown clay, possible infilled fracture.
	bag	CHALK: Weak to very weak, white, fractured CHALK, (brown fracture faces) abundant white putty chalk and rare flint nodule.
100%	U100	CHALK: Weak, white, structured CHALK with very close spaced vertical to horizontal fractures. Rare well rounded flint clast.
	bag	CHALK: Weak to very weak, white, fractured CHALK, (rare brown fracture faces) abundant white putty chalk and rare flint nodule.
		No recovery
70%	U100	CHALK: Weak, white, structured CHALK with very close spaced vertical to horizontal fractures. Some orange staining and black spots (Mn?) mainly on sub-vertical fracture faces.
	bag	CHALK: Weak to very weak, white, fractured CHALK, abundant white putty chalk.
100%	U100	CHALK: Weak, white, structured CHALK with very close spaced vertical to horizontal fractures. Some orange staining and black spots (Mn?) mainly on sub-horizontal fracture faces. Some white putty chalk with orange streaks (possible fracture infill or weathering).
	bag	CHALK: Weak to very weak, white, fractured CHALK (minor orange/red oxidation staining on fracture faces), abundant white putty chalk.
		No recovery

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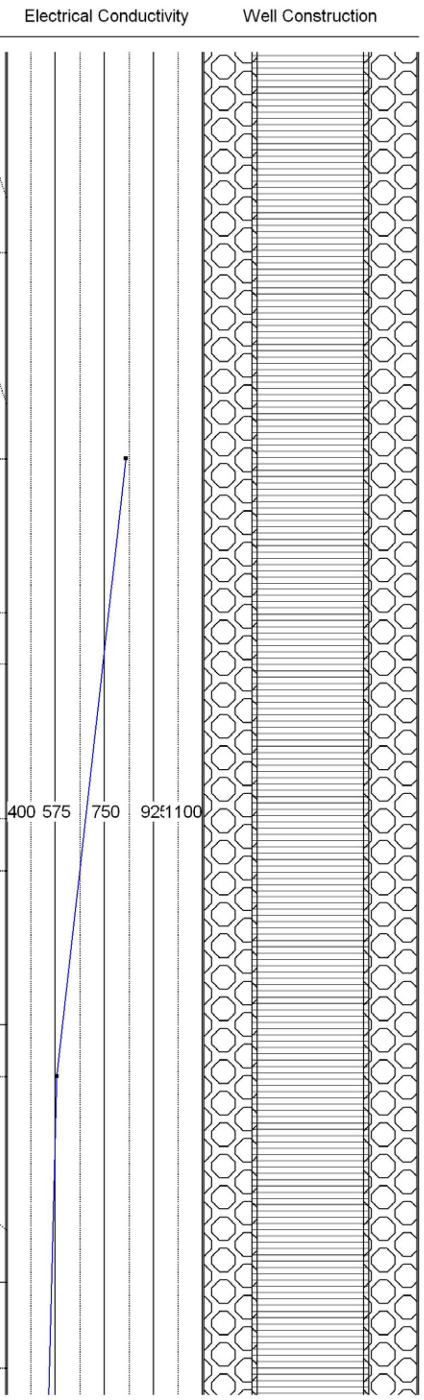
P-229 Cheriton BH5

Borehole Diameter: 6"
Drilling Method: Cable Percussion
Easting: 457976.84
Northing: 128558.79

Location: Cheriton, Hampshire
Date Drilled: 26/04/04
Elevation (m) 74.352
Total Depth 15.6

mbgl	Sample Interval	Sample description	LITHOLOGY
-8	60%	U100	CHALK: Soft white putty chalk with occasional flint clast and orange patches to 7.96 mbgl. Below is weak, white, structured CHALK with very close spaced vertical to horizontal spaced fractures.
		bag	CHALK: Weak to very weak, white, fractured CHALK (minor orange/red oxidation staining on fracture faces), abundant white putty chalk.
	73%	U100	CHALK: Weak, white, structured CHALK with close to very close spaced vertical to horizontal fractures (mainly sub-horizontal). Some orange staining.
		bag	CHALK: Weak to very weak, white, fractured CHALK (minor orange/red and brown staining on fracture faces), abundant white putty chalk.
-9	62%	U100	CHALK: Weak, white, structured CHALK with very close spaced vertical to horizontal fractures (mainly sub-horizontal). Some orange staining.
		bag	CHALK: Weak white CHALK, abundant white putty chalk (>50%)
-10	71%	U100	CHALK: Weak to very weak, white, structured CHALK with close to very close small impersistent fractures.
		bag	CHALK: Weak white CHALK, abundant white putty chalk (>50%)
	100%	U100	CHALK: Weak to very weak, white, structured CHALK with close to very close small impersistent fractures.
		bag	No recovery
-11	45%	U100	CHALK: Weak to very weak, white, structured CHALK with close to very close small impersistent fractures.
		bag	CHERT: Weak white CHALK, abundant white putty chalk and black flint nodules
			No recovery
			CHALK: Weak to very weak, white, structured CHALK with close



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P-229 Cheriton

BH5

Borehole Diameter:	6"	Location:	Cheriton, Hampshire
Drilling Method:	Cable Percussion	Date Drilled:	26/04/04
Easting:	457976.84	Elevation (m)	74.352
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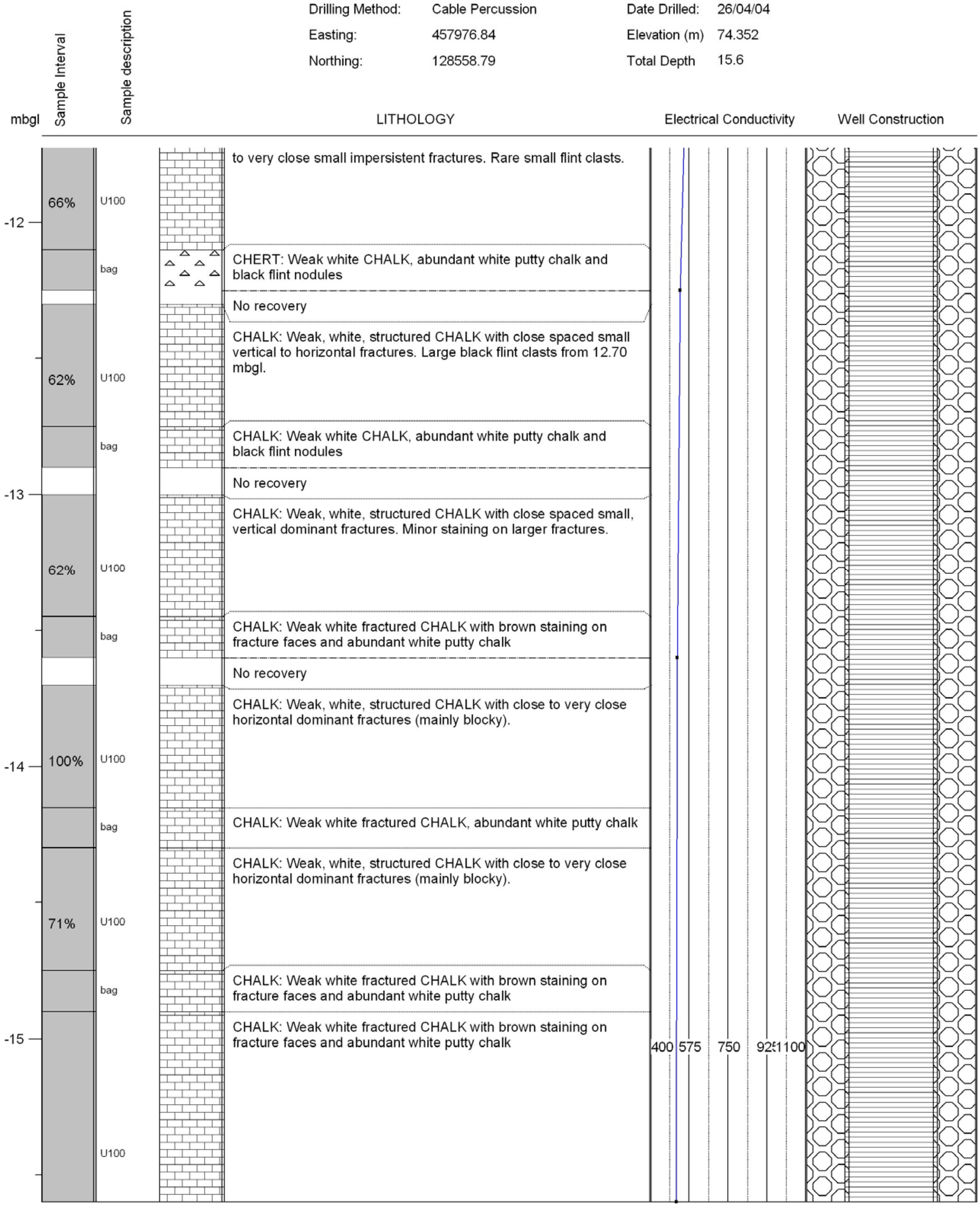

to very close small impersistent fractures. Rare small flint clasts.

CHERT: Weak white CHALK, abundant white putty chalk and black flint nodules

No recovery

CHALK: Weak, white, structured CHALK with close spaced small vertical to horizontal fractures. Large black flint clasts from 12.70 mbgl.

CHALK: Weak white CHALK, abundant white putty chalk and black flint nodules

No recovery

CHALK: Weak, white, structured CHALK with close spaced small, vertical dominant fractures. Minor staining on larger fractures.

CHALK: Weak white fractured CHALK with brown staining on fracture faces and abundant white putty chalk

No recovery

CHALK: Weak, white, structured CHALK with close to very close horizontal dominant fractures (mainly blocky).

CHALK: Weak white fractured CHALK, abundant white putty chalk

CHALK: Weak, white, structured CHALK with close to very close horizontal dominant fractures (mainly blocky).

CHALK: Weak white fractured CHALK with brown staining on fracture faces and abundant white putty chalk

CHALK: Weak white fractured CHALK with brown staining on fracture faces and abundant white putty chalk

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We are The Environment Agency. It's our job to look after your environment and make it **a better place** – for you, and for future generations.

Your environment is the air you breathe, the water you drink and the ground you walk on. Working with business, Government and society as a whole, we are making your environment cleaner and healthier.

The Environment Agency. Out there, making your environment a better place.

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