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Drilling and testing of trial groundwater abstraction boreholes at Chapeltonmoss

Groundwater Management Programme
Commissioned Report CR/05/216CN

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Drilling and testing of trial groundwater abstraction boreholes at Chapeltonmoss

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Three trial groundwater abstraction boreholes were drilled at the edge of the Chapeltonmoss area, in Forres, Morayshire, in September 2005, and a programme of hydrogeological testing carried out, in order to assess the resource potential and groundwater chemistry of the superficial deposits aquifer. The specific aims of the investigation were to assess the potential for obtaining a groundwater supply of similar magnitude and chemical character to the nearby Chapeltonmoss Spring.

Of the trial boreholes, Borehole 1 and Borehole 3 proved to be too low yielding to support a test yield. This is likely to be largely due to the limited thickness of saturated aquifer at each of these boreholes.

A step test, a 24 hour constant rate pumping test and a 3 day constant rate pumping test were carried out on Borehole 2. The results of the test pumping indicate that the borehole is likely to have a long term sustainable yield of 1.0 to 1.5 litres/second (l/s), equivalent to between approximately 86 and 130 m^3/day.

The chemistry of groundwater from Borehole 2 is distinctive and is generally similar to the chemistry of groundwater flowing from the Chapeltonmoss Spring outlet pipe. The chemistry data indicate that the two groundwaters share a source.

1 Introduction

This report describes the drilling and hydrogeological testing of three trial boreholes at the edge of the Chapeltonmoss area, in Forres, Morayshire. The drilling and testing programme was commissioned by Moray Flood Alleviation. Drilling and test pumping were carried out by Raeburn Drilling and Geotechnical Ltd. Hydrogeological supervision of the programme was carried out by the British Geological Survey (BGS).

The Chapeltonmoss area is part of a proposed flood alleviation scheme on the outskirts of Forres, in Morayshire, which would see a large part of the area covered by stored flood water during high flow times. Within the proposed area for flood water storage is the outlet pipe and at least part of the catchment area of the Chapeltonmoss Spring, which currently supplies Benromach Distillery in Forres.

The three trial boreholes were designed to investigate the resource potential and groundwater chemistry of the shallow superficial deposits aquifer in this area. The specific aim of the work was to assess the potential for obtaining a groundwater supply of similar magnitude and chemical character to the nearby Chapeltonmoss Spring. With this is mind, the work aimed:

- To assess whether groundwater in the area around the trial boreholes is chemically similar to groundwater issuing from Chapeltonmoss Spring; and
- To assess whether the superficial aquifer in the area around the trial boreholes is productive enough to support a groundwater abstraction of the same magnitude as currently flowing from Chapeltonmoss Spring.

This report presents data collected during the drilling and testing programme and an assessment of the potential for obtaining a sustainable groundwater supply of the required volume and chemistry from a borehole in the trial area.

2 Background

2.1 PREVIOUS WORK

A previous study by the British Geological Survey (BGS), commissioned by Moray Flood Alleviation, investigated the hydrogeology of the Chapeltonmoss Spring and surrounding area, including groundwater chemistry, estimates of the spring catchment area and recharge rate to the aquifer, and an assessment of the impact that stored flood water would have on the spring system (Ó Dochartaigh 2005). The results of the hydrogeological assessment are summarised in Section 2.3, below. The report concluded that the storage of flood water is likely to impact on both the quality and quantity of water discharging at the Chapeltonmoss Spring outlet, by increasing the available quantity of water by an unknown, but probably relatively small, amount, and by changing the chemistry of the water, probably over the short term, but possibly significantly.

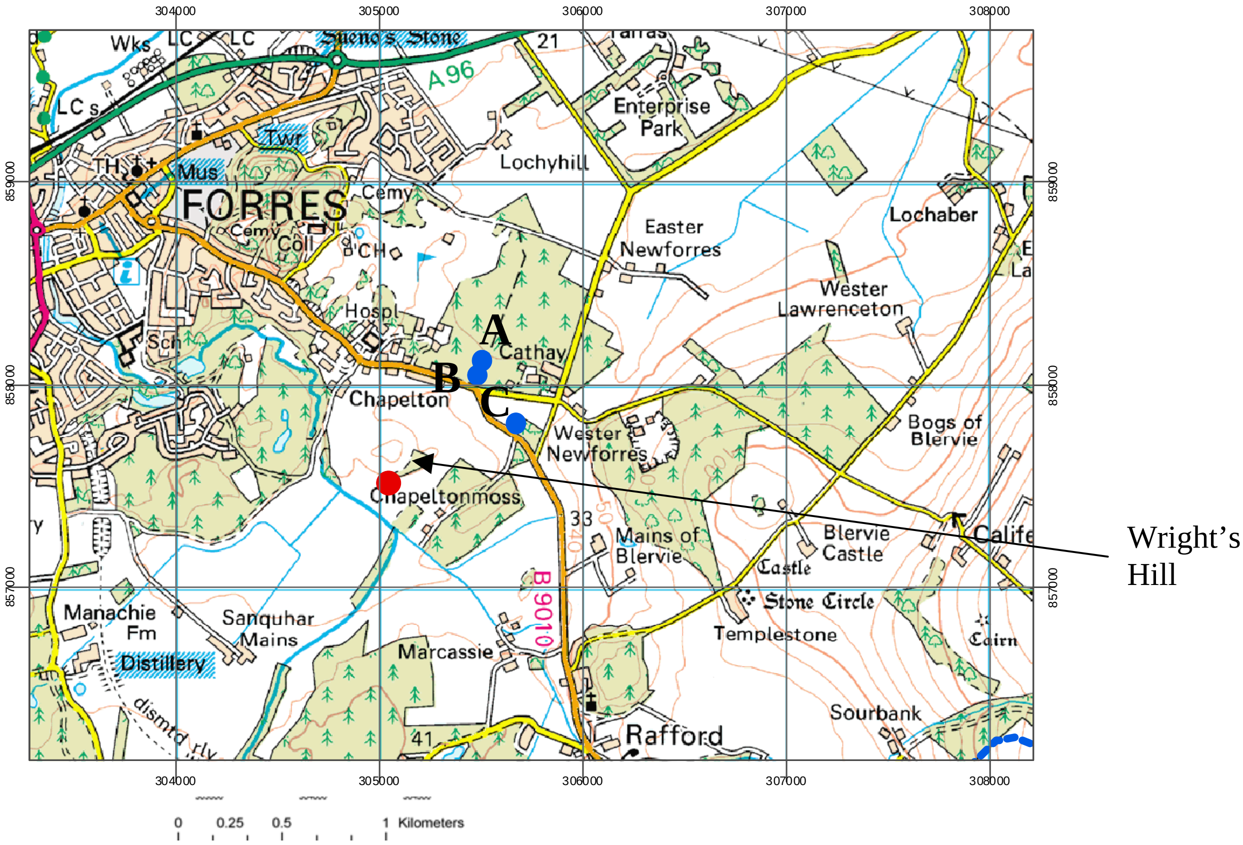
Further to this, additional investigations into water flows and chemistry in the Chapeltonmoss and surrounding areas were carried out by Moray Flood Alleviation and Gordon & MacPhail, owners of Benromach Distillery. Moray Flood Alleviation consequently commissioned BGS to prepare a further report considering a number of issues surrounding the presence and viability for abstraction of groundwater in various areas around Chapeltonmoss (British Geological Survey 2005 Ref 86344/MHHG/05/12).

2.2 DESCRIPTION OF AREA

The area of Chapeltonmoss comprises largely gently undulating land, mainly between 25 and 40 m above Ordnance Datum (OD) (Figure 1). Wright's Hill forms a distinct area of higher ground immediately to the north of the Chapeltonmoss Spring outlet. This outlet, at National Grid Reference NJ 05048 57507, takes the form of a pipe discharging to the ground surface into a drainage ditch flowing to the Burn of Mosset. The outlet does not form a spring in the true sense, but is thought to be fed from various shallow groundwater sources through a mixed system of buried pipes and surface water flows.

The flow at the outlet pipe has been measured by Moray Flood Alleviation at approximately 4 litres/second (l/s), although measurements by Gordon & MacPhail are significantly higher than this. The characteristics of the pipe outlet make it difficult to accurately measure the flow. Gordon and MacPhail report that the flow from the spring outlet does not appear to change significantly throughout the year.

Landuse in the area is largely arable agriculture, with some undrained areas left as rough ground. Forest covers the higher ground.



● Location of Chapeltonmoss Spring outlet

● Location of trial boreholes A, B and C

Figure 1 Location of Chapeltonmoss Spring outlet to the southwest of Forres

2.3 SUMMARY OF GEOLOGY, HYDROGEOLOGY AND HYDROCHEMISTRY

A detailed description of the superficial and bedrock geology and the hydrogeology of the area is provided in Ó Dochartaigh 2005. A summary is presented below.

Most of the Chapeltonmoss area is underlain by glaciofluvial ice contact deposits, largely comprising sand and gravel with varying proportions of larger cobbles, and occasionally with finer silt and clay beds. There are outcrops of alluvium, along the main stream channels, which are likely to be very similar to the glaciofluvial deposits. Geological information from boreholes indicates that the glaciofluvial and alluvial deposits vary considerably in thickness, from 6 to 30 m thick. The superficial geology is illustrated in Figure 2.

Bedrock in this area consists of the Forres Sandstone Group and the Alves Beds, of Middle to Upper Devonian age, which comprises sandstones with some siltstones and pebbly beds. The Alves Beds are a subsidiary part of the Forres Sandstone Group, and the abrupt change from one to the other (apparent in Figure 3) occurs at a geological sheet boundary. Although they have different names, the rocks are essentially similar. The Forres Sandstone Group and Alves Beds are likely to be at least 100 m deep in this area. To the east, at Wester Newforres and Mains of Blervie, the Devonian sandstones overlie metamorphic rocks of Precambrian age. The bedrock geology is illustrated in Figure 3.

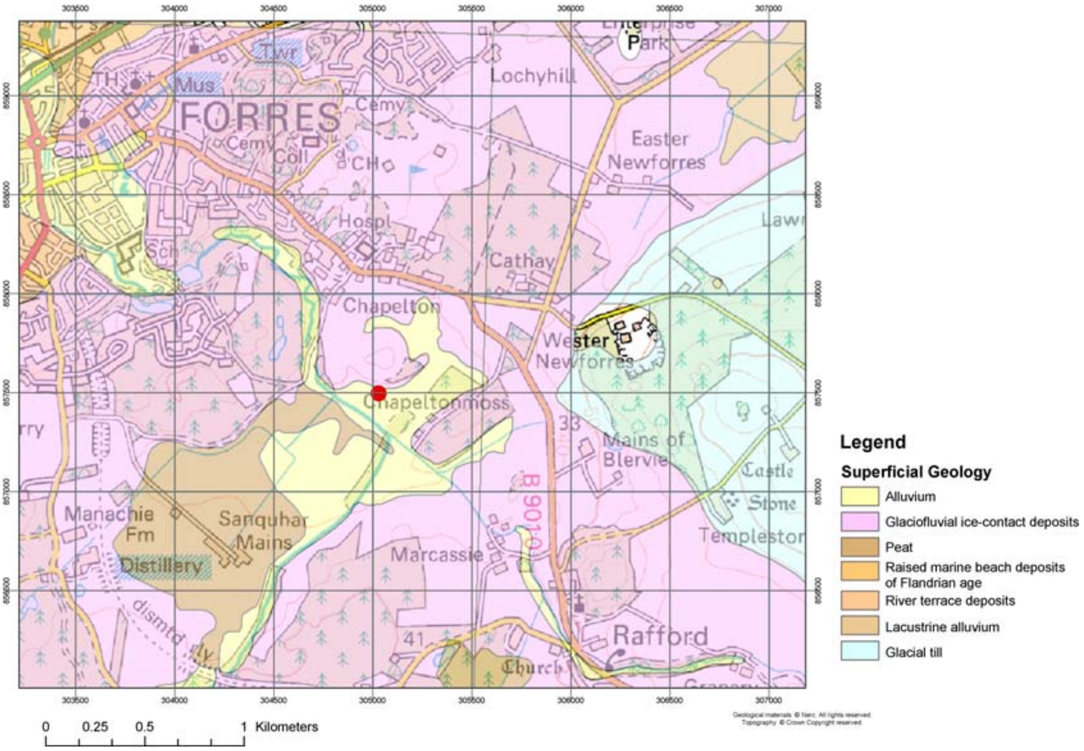


Figure 2 Superficial deposits in the Chapeltonmoss area

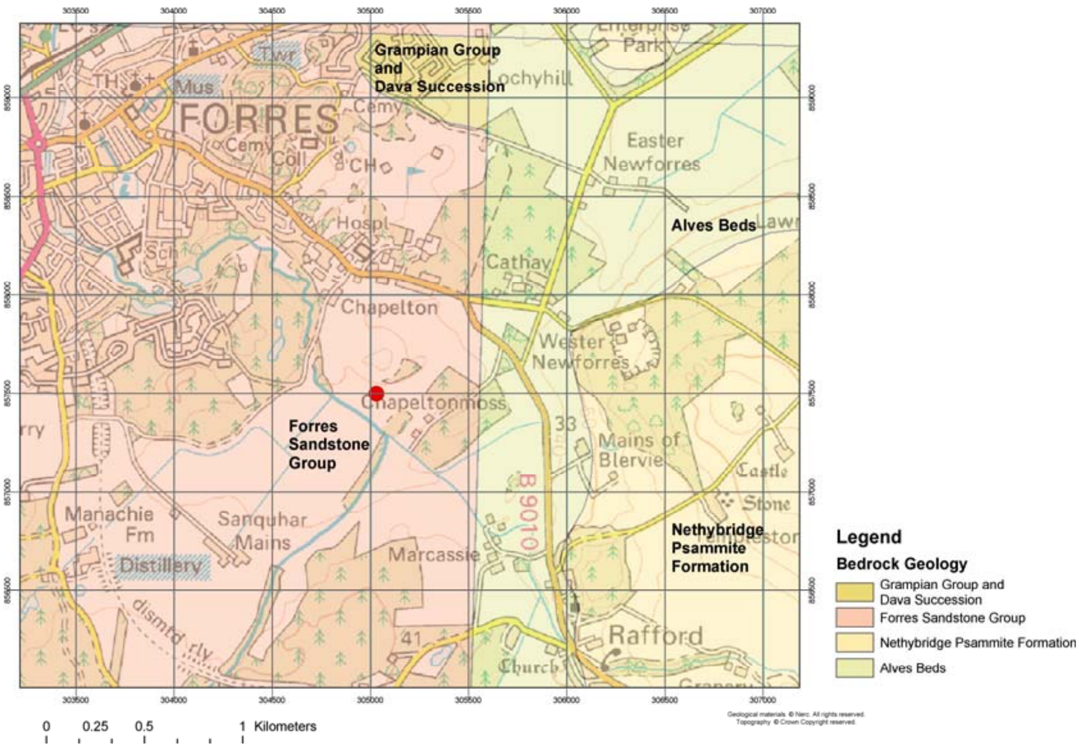


Figure 3 Bedrock geology in the Chapeltonmoss area. The abrupt change from Forres Sandstone Group to Alves Beds occurs at a geological sheet boundary, and does not represent an abrupt change in geology.

There is likely to be a dual hydrogeological system in the Chapeltonmoss area: an upper superficial deposits aquifer, comprising alluvium and glaciofluvial deposits, and a lower bedrock aquifer, comprising Devonian sandstones. The superficial deposits are generally moderately to highly permeable, allowing rapid groundwater flow and a large volume of groundwater storage, where saturated. The underlying unweathered sandstone is likely to have significantly lower permeability. Drilling evidence has shown that the uppermost part of the sandstone is significantly weathered, which will locally increase the permeability of the sandstone. The two aquifer systems may be in hydraulic contact, particularly where the upper part of the sandstone is weathered.

The evidence indicates that under natural, pre-development conditions there would be a number of diffuse springs or seepages across the Chapeltonmoss area, deriving largely from the superficial deposits aquifer, although there is likely to be a minor proportion from upflow from the bedrock aquifer. These springs have been tapped and diverted to a network of pipes, which lead to the Chapeltonmoss Spring outlet pipe.

Measurements show that water levels in the superficial deposits aquifer vary: in the area around Wright's Hill (immediately north of the Chapeltonmoss Spring outlet: see Figure 1), water levels are typically between 1 and 3 m below ground level; but further to the northeast, in the area of the three new trial boreholes, the water level is more than 5 m below ground level, reflecting the rise in land surface elevation towards the northeast.

Most of the available data on the chemistry of groundwater from the Chapeltonmoss Spring outlet is confidential to Gordon & MacPhail, but average values for major ions and other indicator parameters are given in Table 1. The average values are calculated from a series of nine samples taken between July 2004 and February 2005. A suite of wellhead chemistry measurements, taken on 10 March 2005, is also presented, in Table 2, including temperature, specific electrical conductance (SEC), pH, Eh (redox potential) and alkalinity.

Groundwater flowing from the outlet pipe is typically of sodium chloride to chloride type (Figure 4). This contrasts with the known chemistry of other groundwaters in this area, from superficial aquifers, Devonian bedrock and Precambrian bedrock aquifers, which are typically calcium or calcium-bicarbonate type. In general, groundwater from the spring shows concentrations of chloride and sodium that are high compared to other known groundwaters in this part of Moray (Robins 1989). Iron concentrations are also elevated, but this is not uncommon in groundwater from sandstone and superficial aquifers in Scotland (Robins 2002). The water is typically highly coloured and becomes increasingly discoloured after heavy rainfall.

A sample of the water from the spring was also analysed for two chlorofluorocarbon fractions, with the results indicating that the water contains between 60 and 80 % modern water (recharged since the mid 1990s).

The known hydrogeology and hydrochemistry of the area indicate that the bulk of groundwater discharging at the spring outlet is derived from recent rainfall recharge to the superficial aquifer. The dominance of chloride and sodium ions in the groundwater indicates a dominantly maritime influence on the groundwater chemistry. There could be several reasons for this: (i) the chemical alteration of the superficial deposits during seawater invasion at times of post-glacial high sea level stands, and the subsequent chemical interaction of recently recharged groundwater with these deposits causing the groundwater to be enriched in ions such as chloride and sodium; (ii) (less likely), mixing with older waters left when the superficial deposits were invaded by seawater in post-glacial times; or (iii), (least likely), concentration of chloride and sodium ions in rainfall by high levels of evapotranspiration.

The probable catchment area of the Chapeltonmoss Spring is shown in Figure 5. This encompasses the area in which the groundwater chemistry is thought to be similar to the chemistry of the water discharging at the spring outlet. This catchment includes an area of the higher ground to the east of Chapeltonmoss that is underlain by glacial till, not by the glaciofluvial/alluvial aquifer. A small amount of groundwater recharge through the glacial till may occur in this area if its composition is dominated by high permeability sand and gravel rather than by finer grained material. It is anticipated that groundwater recharge in this area would flow westwards into the main superficial deposits aquifer. However, any such input is likely to be small.

Table 1 Average concentrations of selected chemical parameters in groundwater from Chapeltonmoss Spring outlet over the period July 2004 to February 2005. All values are expressed in mg/l.

Parameter		Mean value	Standard deviation
Calcium	Ca	67.3	3.0
Magnesium	Mg	7.1	0.5
Potassium	K	4.6	0.6
Sodium	Na	86.2	6.1
Chloride	Cl	155.9	16.4
Sulphate	SO_4	25.9	1.7
Nitrate as N	NO_3-N	6.2	0.9
Iron	Fe	0.55	0.18
Manganese	Mn	0.019	0.009

Table 2 Wellhead measurements at Chapeltonmoss Spring outlet (10 March 2005)

Parameter	**Value**
Temperature (°C)	6.8
SEC (μS/cm)	799
pH (-)	8.1
Bicarbonate (mg/l HCO_3)	66

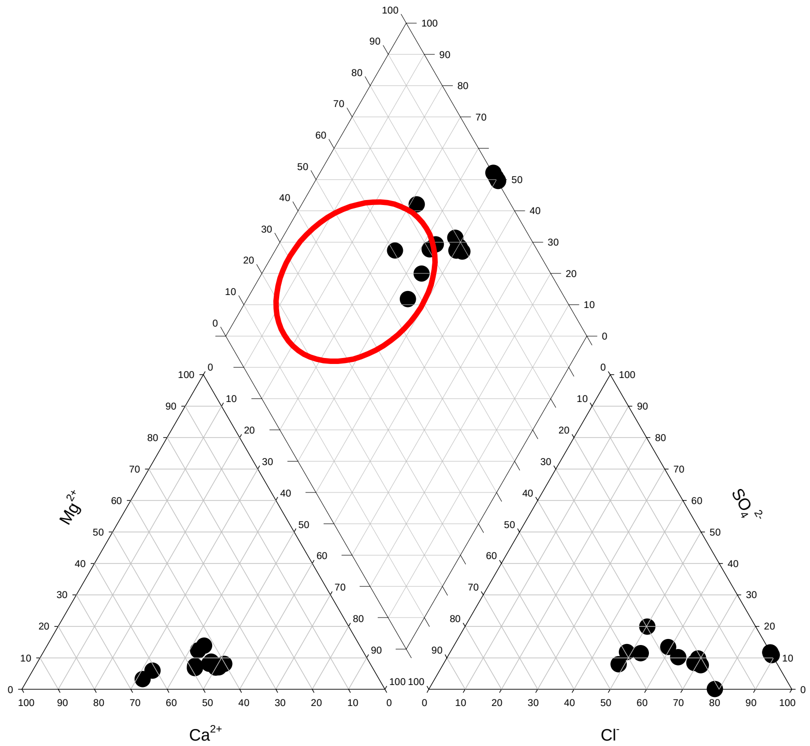
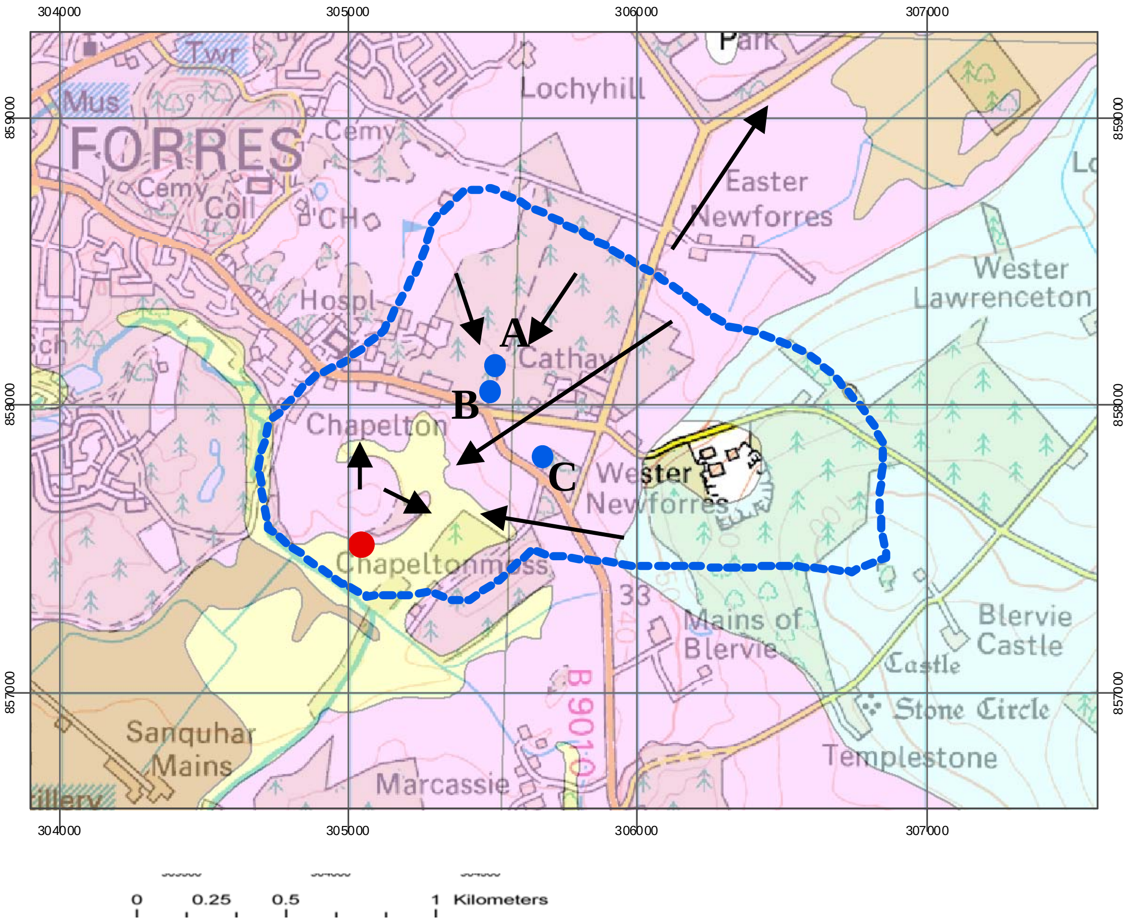


Figure 4 Piper plot showing the major ion distribution of waters from Chapeltonmoss Spring outlet (black points) and the general major ion chemistry of other groundwaters (from bedrock and from mixed bedrock and superficial aquifers) in the Moray area (red area)



Estimated catchment area of groundwater flowing to Chapeltonmoss Spring

Estimated direction of groundwater flow

Chapeltonmoss Spring outlet

Location of trial boreholes A, B and C

Figure 5 Probable catchment area for groundwater in the superficial deposits area flowing into the Chapeltonmoss area, with estimated groundwater flow directions

3 Trial boreholes

3.1 SUMMARY

Three trial boreholes were drilled, using air flush rotary down the hole hammer, in September 2005. Geological logs for the boreholes are presented in Appendix 1. Summary details for the boreholes are presented in Table 3, whilst the borehole locations are indicated on Figure 5.

Table 3 Summary details for trial boreholes

Borehole	Easting	Northing	Depth (m)	Diameter (mm)	Base of superficial deposits (mbgl)	Main water strike (mbgl)	Rest water level (mbgl)
A	305470	858020	14.5	150	13	13	5.0
B	305490	858060	10.3	150	9	5	6.4
C	305670	857780	7.5	150	-	5	4.7

3.2 BOREHOLE CONSTRUCTION

3.2.1 Borehole 1

Total depth: 14.5 m

Casing: 150 mm diameter uPVC casing; from 0 to 7.5 mbgl; sealed with bentonite

150 mm diameter uPVC casing; from 13.5 to 14.5 mbgl

Screen: 150 mm diameter uPVC screen; slot size 1 mm; from 7.5 to 13.5 mbgl

Gravel pack: Gravel of 1.9 to 2.6 mm diameter; from 7.5 to 14.5 mbgl

3.2.2 Borehole 2

Total depth: 10.3 m

Casing: 150 mm diameter uPVC casing; from 0 to 5.8

150 mm diameter uPVC casing; from 9.3 to 10.3 mbgl

Screen: 150 mm diameter uPVC screen; slot size 1 mm; from 5.8 to 10.3 mbgl

Gravel pack: Gravel of 1.9 to 2.6 mm diameter; from 5.8 to 10.3 mbgl

3.2.3 Borehole 3

Total depth: 7.5 m

Casing: 150 mm diameter uPVC casing; from 0 to 4

150 mm diameter uPVC casing; from 6.5 to 7.5 mbgl

Screen: 150 mm diameter uPVC screen; slot size 1 mm; from 4 to 6.5 mbgl

Gravel pack: Gravel of 1.9 to 2.6 mm diameter; from 4 to 7.5 mbgl

4 Test pumping, aquifer properties and sustainable yield

4.1 INTRODUCTION

Boreholes 1 and 3 proved too low yielding to support test pumping.

A series of pumping tests were carried out on Borehole 2 between 18 and 23 September 2005, the details of which are summarised in Table 4. A datalogger (pressure transducer) was used to collect borehole water level data during the tests. Manual water level readings were also made throughout the tests.

Table 4 Summary of test pumping on Borehole 2

Test	Date start	Duration (days)	Discharge (l/s)	Discharge (m^3/day)	Rest water level (mbgl)	Maximum drawdown (m)
Step test	18/9/2005	1	0.5 – 3.1	43 - 268	6.27	0.69
24 hour constant rate test	19/9/2005	1	2.6	225	6.43	0.92
3 day constant rate test	20/9/2005	3	2.5	216	n/a*	1.54

* The 3 day constant rate test was started before the borehole water level had fully recovered after the 24 hour constant rate test. The rest water level used to calculate the maximum drawdown for the purposes of this summary was taken as being equal to that at the start of the 24 hour test.

4.2 STEP TEST

A step test was carried out to assess borehole efficiency. There were five steps of 60 minutes each, with the discharge rate increasing at each step, from 0.5 to 3.1 l/s. A plot showing drawdown in the borehole during the step test is presented in Figure 6. The water level in the borehole had not stabilised at the end of each step, but was still falling when the discharge rate was increased. The drawdown measured in the borehole at the end of each step is therefore an underestimate of the drawdown that would be seen once the borehole reached an equilibrium at each of the pumping rates.

The step test results were analysed using the Hantush-Biershenk method (Kruseman and de Ridder 1994). The results indicate that non-linear (turbulent) well losses (e.g. friction losses within or close to the borehole screen) are negligible. Most of the drawdown during pumping is due to linear aquifer losses.

The aquifer losses are related, in particular, to a decrease in saturated thickness of the unconfined aquifer and therefore in transmissivity, as the pumping rate increases and water levels in the borehole and the surrounding aquifer fall. For a thick aquifer (tens of metres thick), this would not be significant. However, because the initial saturated thickness of the shallow aquifer penetrated by Borehole 2 was only 4 m, the maximum drawdown in rest water level of 0.7 m during the step test represents a decline of almost 20 % in the aquifer saturated thickness. Calculations of transmissivity for each of the steps during the test indicate the aquifer losses as the pumping water level falls: transmissivity values range from

150 m^2/day during the first step, at a pumping rate of 0.5 l/s and a drawdown of approximately 0.1 m, to 50 m^2/day during the final step, which was at a pumping rate of 3.1 l/s with a drawdown of 0.7 m.

4.3 24 HOUR CONSTANT RATE TEST

Drawdown and initial recovery data from the 24 hour constant rate test provided data to calculate the transmissivity of the aquifer and indicate the likely sustainable yield of the borehole. The water level in the borehole had not stabilised at the end of the test, but was still falling. Full water level recovery was not measured at the end of this test: this was due to both time constraints on the testing and because the main aim of this phase of the testing was to identify whether the chemistry of the groundwater was sufficiently similar to that of the water from Chapeltonmoss Spring. A plot showing drawdown and recovery in the borehole during the 24 hour test is presented in Figure 7.

The results of the test confirm the decrease in transmissivity with falling water levels which was seen in the step test. A calculation of transmissivity was made using the Jacob drawdown approximation (Kruseman and de Ridder 1994), at 59 m^2/day. This agrees closely with the minimum transmissivity calculated from the step test data.

During the 24 hour test the maximum drawdown was 0.92 m, representing a decline of 23 % in the saturated thickness of the aquifer.

4.4 3 DAY CONSTANT RATE TEST

Following the end of recovery measurements for the 24 hour test, a 3 day constant rate test was started immediately. This period of pumping was largely designed to allow for sampling for groundwater chemistry analysis, but was monitored as a test to provide more information on the likely longer-term sustainable yield of the borehole, showing how the pumping water levels responded to pumping over a period of longer than 24 hours. Recovery data from the test also allowed a further calculation of transmissivity, for comparison with that calculated from the 24 hour test.

As the 3 day test was run immediately following the 24 hour test, the borehole water level had not recovered fully at the start of the test. The water level at the start of the 3 day test was 0.3 m below the original (pre-testing) rest water level. The effect of this is that drawdown at the start of the 3 day test differed from what it would have been under unstressed initial conditions, and that at the end of the recovery, residual drawdown is negative, because the borehole recovered to the original rest water level. However, the late time drawdown data and the overall recovery response are not affected. The discharge rate during the 3 day test varied from 1.9 to 3.1 l/s, with a mean and median of 2.5 l/). The water level in the borehole had not stabilised at the end of the test, but was still falling. A plot showing drawdown and recovery in the borehole during the test is presented in Figure 8.

The results of the test confirm the decrease in transmissivity with falling water levels which was seen in the step and the 24 hour test. Transmissivity calculations were made using the Theis recovery method and the Jacob drawdown approximation (Kruseman and de Ridder 1994), at 49 and 51 m^2/day. These agree closely with both the minimum transmissivity calculated from the step test data, and the transmissivity calculated from the 24 hour test.

During the 3 day test the maximum drawdown was 1.5 m: this represents a significant decline of 38 % in the saturated thickness of the aquifer. It is not surprising; therefore, that the transmissivity decreases at higher pumping rates.

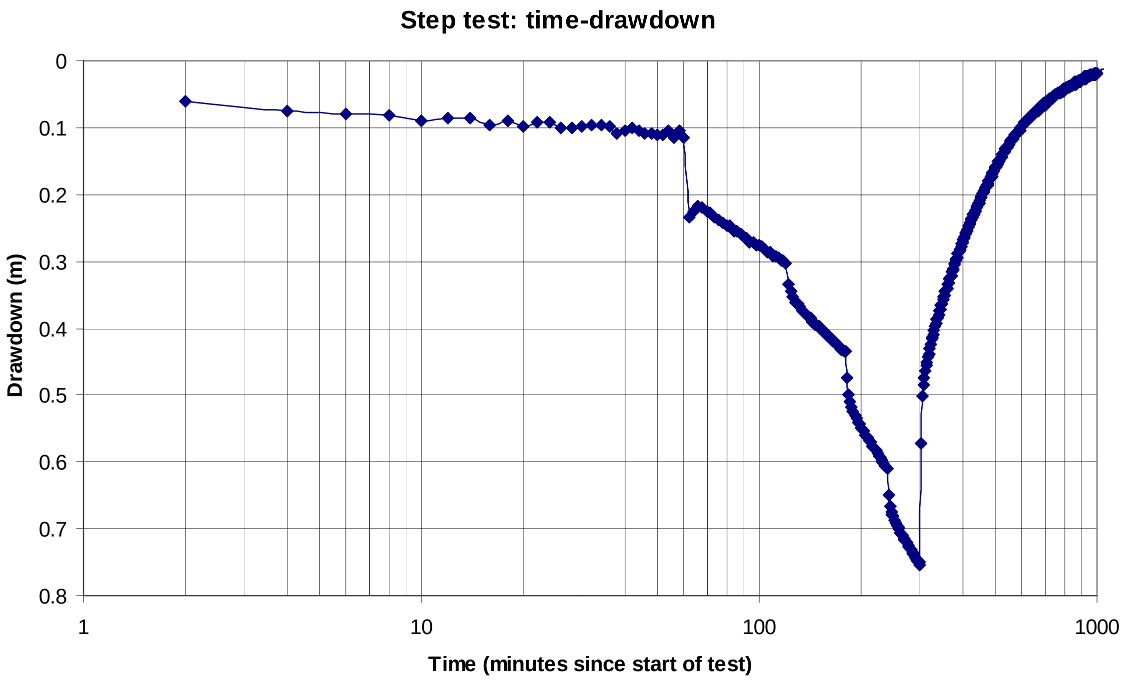


Figure 6 Time-drawdown plot for the step test

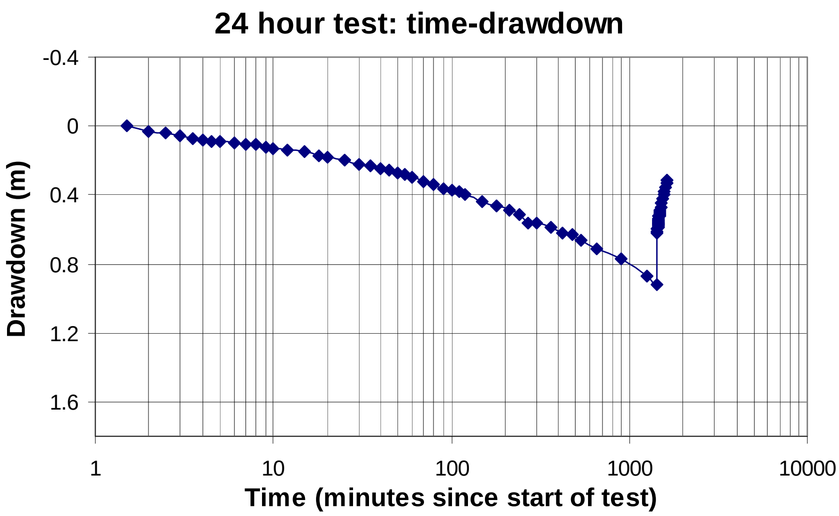


Figure 7 Time-drawdown plot for the 24 hour constant rate test

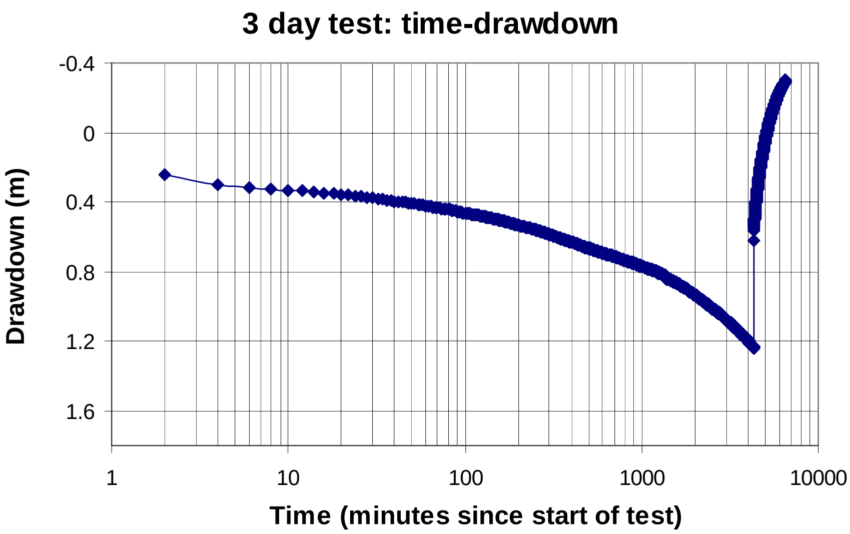


Figure 8 Time-drawdown plots for the 3 day constant rate test

4.5 SUMMARY

The calculated transmissivity values, ranging from 49 to 59 m^2/day, are low to moderate values, reflecting the often fine-grained (and therefore less permeable) nature of the sandy aquifer. By comparison, the transmissivity of very low productivity Precambrian bedrock aquifers in Scotland is typically less than 5 m^2/day; the average transmissivity of Upper Devonian sandstone, which forms one of the most productive aquifers in Scotland, is 350 m^2/day; and the transmissivity of very coarse grained gravel aquifers, such as the alluvial/glaciofluvial aquifer along the River Spey at Fochabers, can exceed 1000 m^2/day.

The long term sustainable yield of the borehole is likely to be in the range 1.0 to 1.5 l/s, although this can only be accurately assessed by longer term pumping. The saturated thickness of the aquifer in the area of Borehole 2 is relatively small, due largely to its position near the edge of the likely catchment area for the Chapeltonmoss superficial deposits aquifer (see Figure 5). The borehole should therefore be closely monitored during any pumping regime to ensure that the aquifer is not dewatered. Figure 9 illustrates the relatively small saturated thickness of the superficial aquifer at Borehole 2, and shows how both the total and the saturated thickness of the superficial aquifer vary across the area of Boreholes 1 and 2.

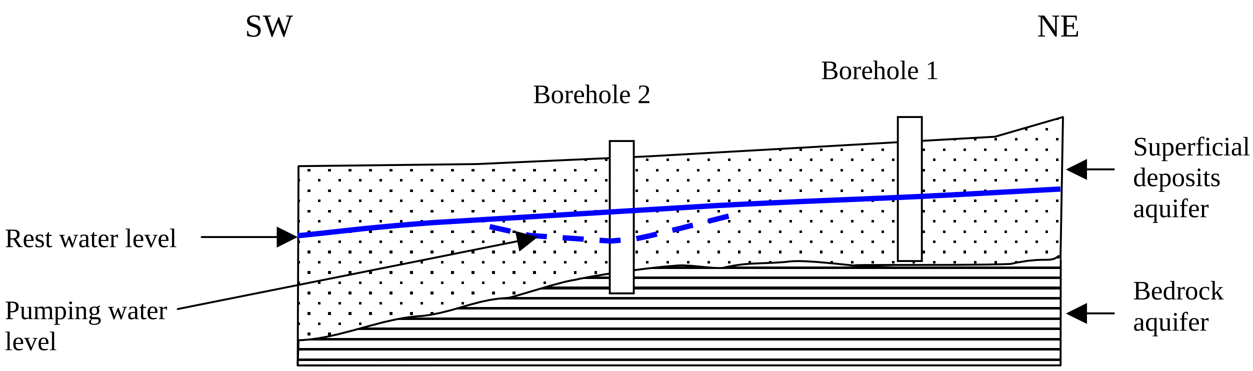


Figure 9 Schematic cross section showing how the thickness of the total and the saturated superficial deposits aquifer varies from northeast to southwest in the area of Boreholes 1 and 2

5 Groundwater chemistry

Four water samples were taken from Borehole 2 during test pumping. All of the samples were taken after the borehole had been purged for at least 28 hours.

Three samples were taken by Gordon & MacPhail. The results of analysis of these samples were not available at the time of writing.

One suite of samples was taken by BGS on 20 September 2005 for analysis at BGS laboratories. The samples were collected in polyethylene bottles and filtered through a 0.45 µm membrane filter. The aliquot used for cation and trace element analyses was acidified with 1% v/v HNO3 to minimise adsorption onto container walls. At the time of sampling, a suite of wellhead chemistry measurements was made, including temperature, specific electrical conductance (SEC), pH and dissolved oxygen (DO). The wellhead measurements are shown in Table 5. Selected details of the major and minor ion analysis are presented in Table 6.

Table 5 Wellhead measurements at Borehole 2 (20 September 2005)

Parameter	**Value**
Temperature (°C)	10.1
SEC (µS/cm)	780
pH (-)	7.88
Dissolved oxygen (mg/l)	0.9

Table 6 Selected chemical parameters in groundwater from Borehole 2 and the Chapeltonmoss Spring outlet. All values are expressed in mg/l unless otherwise specified.

Parameter		Borehole 2	Chapeltonmoss Spring (mean value)	Chapeltonmoss Spring (standard deviation)
Calcium	Ca	54	67.3	3.0
Magnesium	Mg	2.69	7.1	0.5
Potassium	K	2.58	4.6	0.6
Sodium	Na	105	86.2	6.1
Chloride	Cl	153	155.9	16.4
Sulphate	SO_4	26.5	25.9	1.7
Nitrate as N	NO_3-N	0.121	6.2	0.9
Iron	Fe	0.703	0.55	0.18
Manganese	Mn	0.377	0.019	0.009
Bicarbonate	HCO_3	156	66	-
pH (lab value) (-)	pH-lab	7.75	8.1	-
Specific Electrical Conductance (lab value) (uS/cm)	SEC-lab	741	799	-

Groundwater from Borehole 2 is of sodium-chloride type (Figure 9). Chloride and sodium concentrations are high compared to other known groundwaters, from both bedrock and superficial aquifers, in Moray (Ó Dochartaigh 2003, Robins 1989).

The chemistry of the groundwater is broadly similar to that of the water flowing from Chapeltonmoss Spring outlet. The Piper plot in Figure 9 shows how similar the two waters are, especially when compared to other known groundwaters in the Moray area. The average values for selected chemical parameters in groundwater flowing from the Chapeltonmoss Spring outlet, and values for the same parameter in groundwater from Borehole 2, are shown together in Table 6. Chloride, sulphate and iron concentrations from Borehole 2 are almost identical to those in the spring water; calcium, magnesium and potassium concentrations are slightly lower, whilst sodium concentrations are slightly higher. Nitrate concentrations are significantly lower in the borehole water sample, whilst bicarbonate and manganese concentrations are significantly higher.

The relatively high concentrations of chloride and sodium in both the waters indicate that they share a source. The catchment area shown in Figure 5 is likely to be broadly correct. The main differences between the two waters can largely be explained by the different locations of Borehole 2 and the various sources of water flowing to the Chapeltonmoss Spring outlet.

The nitrate concentration in groundwater from Borehole 2 is what would be expected from an area where the dominant land use is forestry, rather than agricultural. The higher nitrate concentrations in groundwater at the spring outlet are likely to be due to fertiliser application on the fields in the vicinity of the spring sources are located. The higher manganese concentration in groundwater from Borehole 2 is likely to be related to local redox conditions: the water had very low dissolved oxygen, which is a key control on the presence of dissolved manganese in groundwater. In contrast, the redox conditions of water at the spring outlet indicated oxygenated water, which would be expected because of the large amount of contact this water has with the air before it discharges at the spring outlet and because the water at the spring outlet is likely to contain at least some proportion of rain water. The difference in bicarbonate concentrations between the two waters may also be due to the presence of a proportion of rain water (which will have low bicarbonate concentrations) in discharge from the spring outlet.

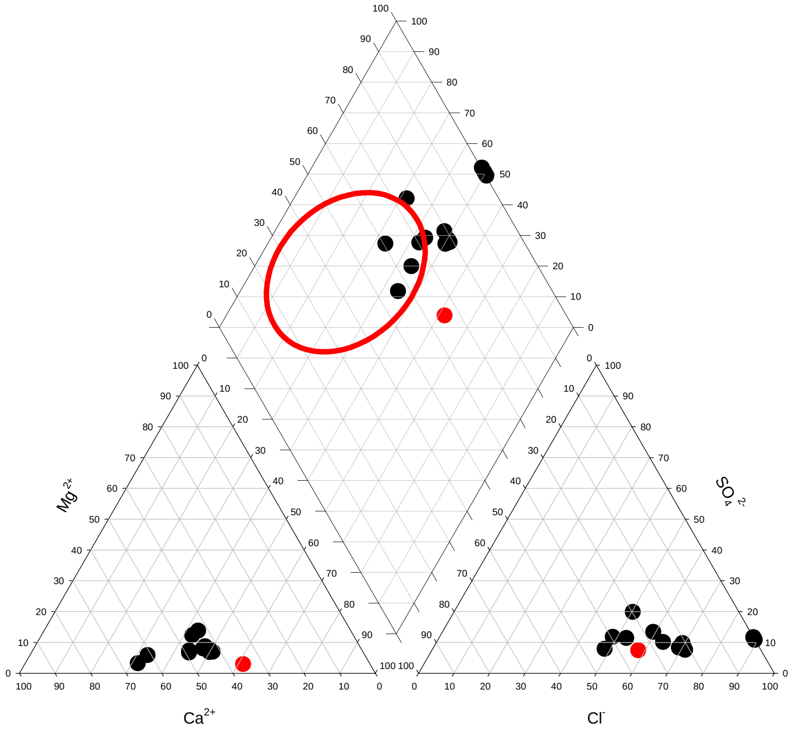


Figure 10 Piper plot showing the major ion distribution of waters from Chapeltonmoss Spring outlet (black points) and water from trial Borehole 2 (red points), and the general major ion chemistry of other groundwaters from this area (red circle)

6 Summary of trial boreholes

Of the trial boreholes, Borehole 1 and Borehole 3 proved to be too low yielding to support a test yield. This is likely to be largely due to the limited thickness of saturated aquifer at each of these boreholes.

Borehole 2 is likely to have a long term sustainable yield of 1.0 to 1.5 litres/second (l/s), equivalent to between approximately 86 and 130 m^3/day. This is lower than the estimated flow from the Chapeltonmoss Spring outlet, which is approximately 4 l/s. However, the actual long term sustainable yield can only be accurately assessed by longer term testing, ideally over the whole of a dry summer (i.e., when groundwater storage in the aquifer will be at a minimum). Because of the relatively small saturated aquifer thickness in the area of Borehole 2, the borehole should be carefully monitored during any longer term borehole testing and/or pumping.

The chemistry of groundwater from Borehole 2 is distinctive and is generally similar to the chemistry of groundwater flowing from the Chapeltonmoss Spring outlet pipe. The chemistry data indicate that the two groundwaters originate from the same source.

Appendix 1 Geological Logs

GEOLOGISTS' LOGS

Borehole 1

0 – 5 m	Fine to coarse grained, well-rounded sand with well rounded pebbles (dry)
5 – 9 m	Clayey fine grained sand with some well-rounded pebbles (damp)
9 – 13 m	Fine grained sand with some well-rounded black pebbles (damp)
13 – 14.5 m	Weathered sandstone

Borehole 2

0 – 3 m	Fine to medium grained sand with pebbles (dry)
3 – 5 m	Fine to medium grained sand with numerous pebbles (damp)
5 – 6 m	Fine to medium grained silty-clayey sand with pebbles (damp)
6 – 9 m	Fine grained sand with pebbles (wet)
9 – 10.3 m	Weathered sandstone

Borehole 3

0 – 1 m	Coarse grained, sub-angular sand (dry)
1 – 3 m	Medium grained sand with pebbles (dry)
3 – 4 m	Coarse grained sand with pebbles (damp)
4 – 6 m	Fine to medium grained sand with pebbles (wet)
6 – 7.5 m	Fine to medium grained sand with pebbles (wet), possibly with some weathered rock

DRILLERS' LOGS

RAEBURN DRILLING AND GEOTECHNICAL LTD

Site: FORRES

Client: Morrison Construction Limited

Engineer:

Contract No: 18678

Borehole No: BH1

Inspection Pit to 1.20
Cable Percussion to 14.50

Location:

Orientation: Vertical

Equipment: Unimog Dando Multitec 10

Progress	Sample Depth	Type	Result	Casing Depth	Level (mOD)	Depth	Description of Strata	Water Depth	Installation/Backfill Description	Depth
7/9 2005							SAND AND GRAVEL		Casing Bentonite	
						1.20	SAND			
						5.00	SANDY CLAY			7.50
									Screen,1.9-2.6mm sand filter	
						9.00	SAND WITH BANDS OF CLAY			
						13.00	SANDSTONE			13.50
									Casing,1.9-2.6mm Sand Filler	
7/9				14.50		14.50		-		14.50
							END OF BOREHOLE			

Remarks:
1.Borehole drileed using N273 drill and case system in conjunction with an air brush.
2. 165x150mm upvc wellscreen and casing installed from ground level to 14.0m

Diam	To Depth Boring	To Depth Casing
340	14.50	14.50

Driller	Originator	Ground-water Struck	Rose To	Time(mins)	Cut Off	Water Added From	To	Chiselling From	To	Time(hr)	Flush Returns	Type	To Depth
JH		13.00											
Chk & App	Status **Prelim**												

Fig No: B

Sheet 1 of 1

Scale 1:200

RAEBURN DRILLING AND GEOTECHNICAL LTD

Site: FORRES

Contract No: 18678

Client: Morrison Construction Limited

Borehole No: BH2

Engineer:

Inspection Pit to 1.20
Cable Percussion to 10.30

Location:

Orientation: Vertical

Equipment: Unimog Dando Multitec 10

Progress	Sample Depth	Type	Result	Casing Depth		Level (mOD)	Depth	Description of Strata	Legend	Water Depth	Installation/Backfill Description	Symbol	Depth
9/9 2005							0.50	SAND AND GRAVEL			Casing,Bentonite		
							1.50	SAND					
							5.00	SAND AND GRAVEL					
							8.00	SANDY CLAY					5.80
							9.30	BROKEN SANDSTONE			Screen,1.9-2.6mm sand filter		9.30
9/9				10.30			10.30	SANDSTONE		-	Casing1.9-2.6mm sand filter		10.30

END OF BOREHOLE

Remarks:
1.Borehole drilled using a N273 drill and case system in conjunction with an air flush.
2. 165x150mm upvc wellscreen and casing installed from ground level to 10.30m.

Diam	To Depth Boring	To Depth Casing
340	10.30	10.30

Driller	Originator	Ground-water Struck	Rose To	Time(mins)	Cut Off	Water Added From	To	Chiselling From	To	Time(hr)	Flush Returns	Type	To Depth
JH													
Chk & App	Status **Prelim**												

RAEBURN

Fig No: B

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Scale 1:200

RAEBURN DRILLING AND GEOTECHNICAL LTD

Site:	FORRES
Client:	Morrison Construction Limited
Engineer:	
Contract No:	18678
Borehole No:	BH3
Inspection Pit to	1.20
Cable Percussion to	7.50
Location:	
Orientation:	Vertical
Equipment:	Unimog Dando Multitec 10

Progress	Sample Depth	Type	Result	Casing Depth		Level (mOD)	Depth	Description of Strata	Legend	Water Depth	Installation/Backfill Description	Symbol	Depth
15/9 2005							0.20	# SOIL			Casing Bentonite		4.00
							6.00	# SAND AND GRAVEL			Screen,1.9-2.6mm sand filter		6.50
15/9				7.50			7.50	# SANDSTONE		-	Casing,1.9-2.6mm sand filter		7.50
								END OF BOREHOLE					

Remarks:
1.Borehole drilled using an N273 drill and case system in conjunction with an air flush.
2.165x150mm upvc wellscreen installed from ground level to 7.5m

Diam	To Depth Boring	To Depth Casing
340	7.50	7.50

Driller	Originator	Ground-water Struck	Rose To	Time(mins)	Cut Off	Water Added From	To	Chiselling From	To	Time(hr)	Flush Returns	Type	To Depth
JH													
Chk & App	Status: **Prelim**												

RAEBURN

Fig No: B

Sheet 1 of 1

Scale 1:200

References

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

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