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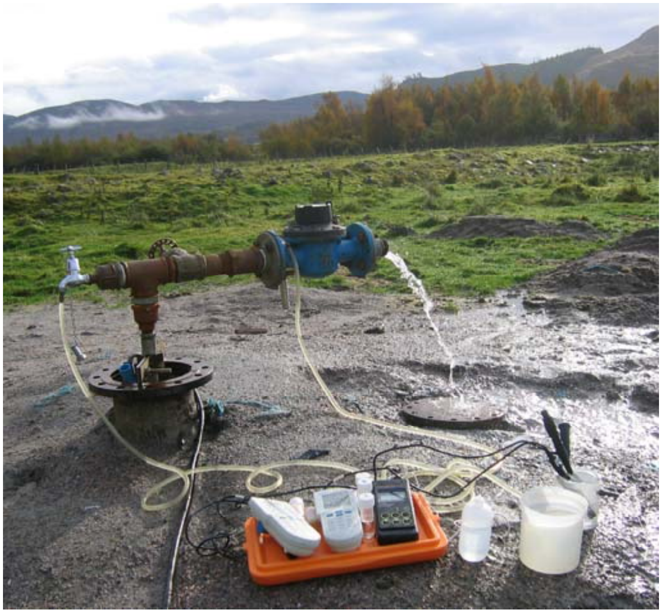
Laggan: Borehole Drilling and Testing

Groundwater Systems and Water Quality Programme

Internal Report CR/05/010N



BRITISH GEOLOGICAL SURVEY

GROUNDWATER SYSTEMS AND WATER QUALITY PROGRAMME
INTERNAL REPORT CR/05/010N

Laggan: Borehole Drilling and Testing

B É Ó Dochartaigh

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1 Introduction

A borehole for potential public water supply was drilled at Laggan Bridge in August 2004. The borehole was commissioned by Scottish Water. The project was managed by Mott MacDonald. Advice on borehole siting, construction and testing was provided by the British Geological Survey (BGS). The borehole was drilled by Raeburn Drilling and Geotechnical. Hydrofracturing and test pumping were carried out by Drilcorp in October 2004.

This report presents geological and hydrogeological data collected during borehole drilling and testing and assesses the hydrogeological characteristics of the borehole and the surrounding aquifer with reference to the suitability of the borehole to provide a public water supply.

2 Borehole location

Laggan is a small settlement in the central Highlands, located on the northern side of the valley of the River Spey (Figure 1). The broad, almost flat floodplain of the River Spey is almost 1 km wide at Laggan. Steep rocky slopes border the village immediately to the north. Amongst the Spey floodplain, large areas of poorly drained ground are present, with some areas improved for pasture.

The new borehole at Laggan (NN 6109 9435) is in a field adjacent to the village school (Figure 2).

There are four other boreholes in the field, which were drilled in 1998 by Grampian Soil Surveys to investigate the potential for abstracting groundwater from the superficial deposits. The boreholes were drilled to between 8 and 9 m depth in superficial deposits (Grampian Soil Surveys, 1998).

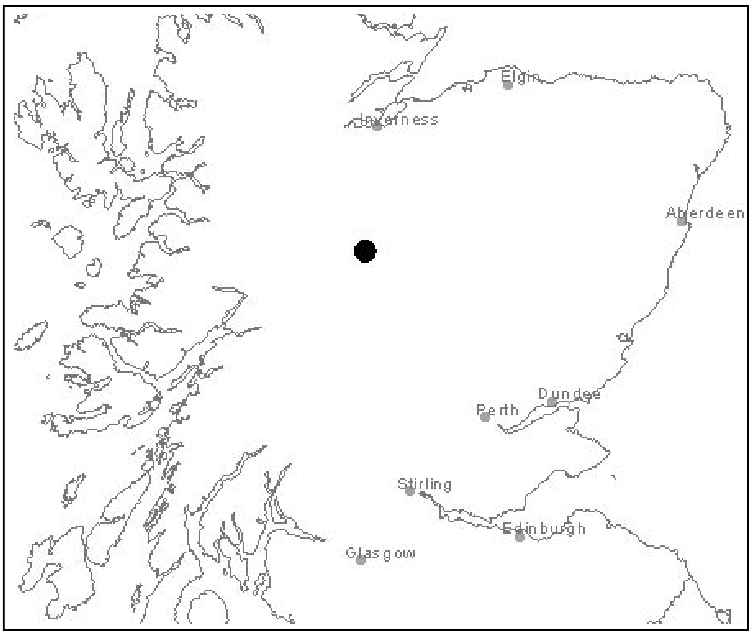


Figure 1 Location of Laggan in the central Highlands

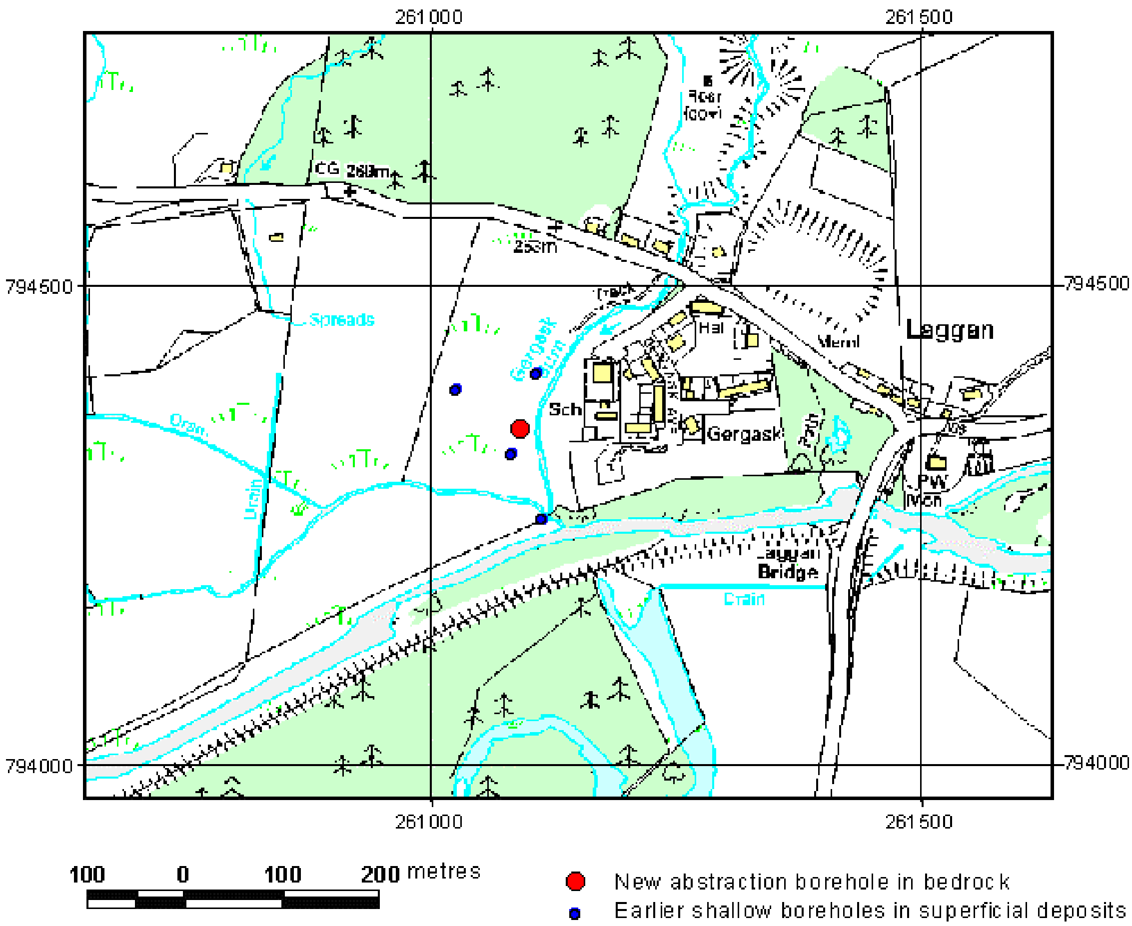


Figure 2 Location of new and existing boreholes in Laggan

3 Geology

Trial boreholes drilled in 1998 penetrated a complex interbedded sequence of superficial sand and gravel or gravelly sand, often with well-rounded cobbles and boulders, to a depth of between 5 and 7.5 m. Lenses of peaty material occur within the otherwise dominantly gravelly sequence (Grampian Soil Surveys, 1998). This is underlain by a layer of silty sand and sand, which in the new borehole extends to 26 m depth.

Bedrock in this area comprises gneissose psammites and semipelites (metamorphic rocks) of the Glen Banchor Succession, part of the Grampian Group. These are ancient, very hard rocks that are partly fractured (Figure 4).

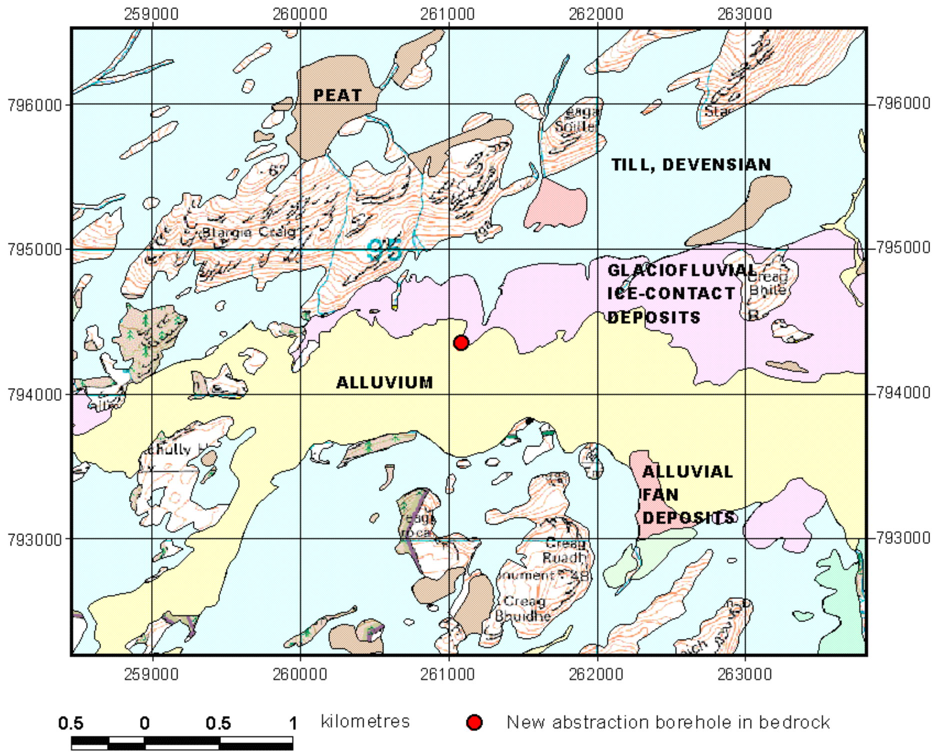


Figure 3 Superficial deposits in the Laggan area

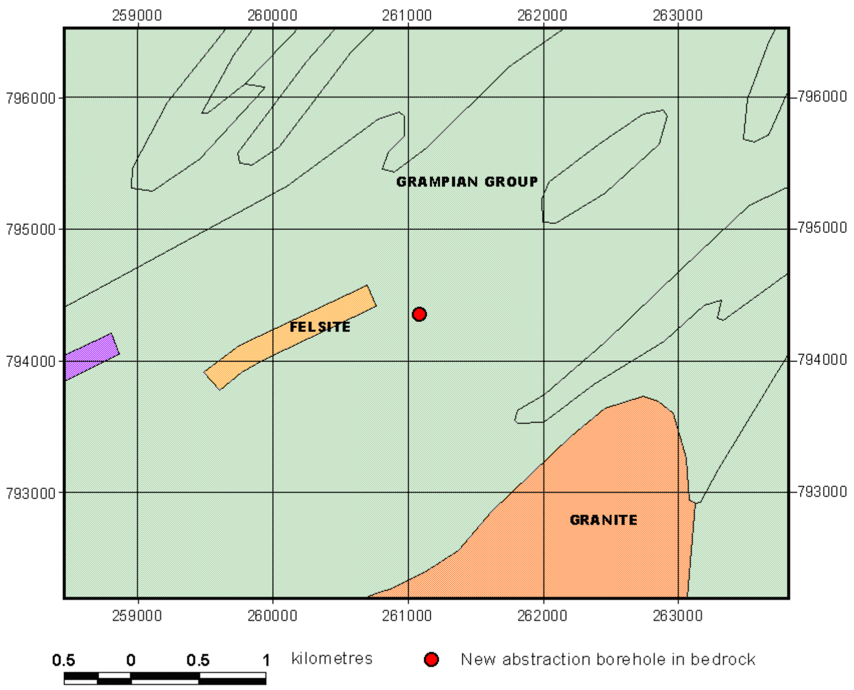


Figure 4 Bedrock geology in the Laggan area

4 Borehole drilling

The borehole was drilled between in August 2004, by Raeburn Drilling and Geotechnical.

A geological log of the new borehole is based on information collected during drilling (Table 1).

Table 1 Geological log of new borehole

Depth (m)	**Geology**
0 – 5.5	Sand and gravel
5.5 – 26	Sand
26 – 34	Basalt *
34 – 100	Schist

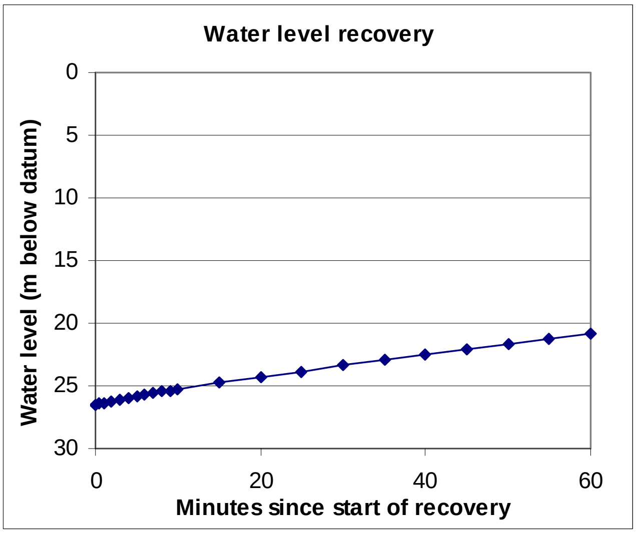
* reported by driller; likely to be schist

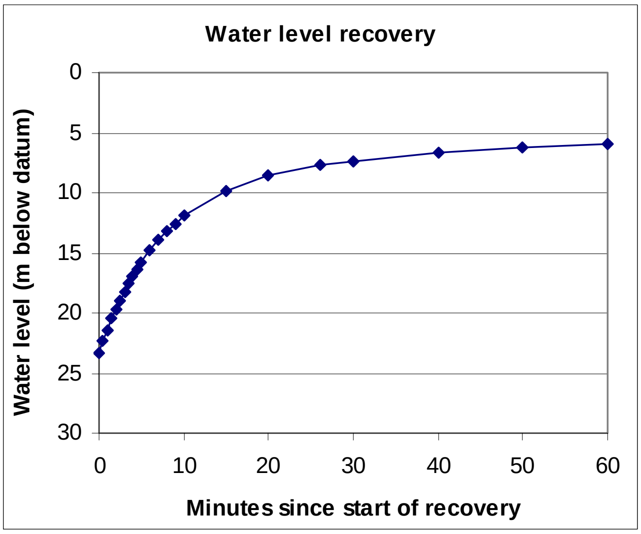
5 Hydrofracturing

The borehole was hydrofractured between 30 September and 1 October 2004, by Drilcorp. Four hydrofracture runs were carried out, with a single packer set successively at 40 m, 55 m, 70 m and 85 m below ground level.

Before hydrofracturing, a short recovery test was carried out on 29 September 2004. The borehole was pumped for 7 minutes at approximately 0.4 l/s until the pumping water level fell to 26.50 m below datum, a drawdown of 23.63 m. The specific capacity of the borehole during the 7 minute pumping period was approximately 1.5 m^3/day/m. Water level recovery was measured for 60 minutes, during which time the water level in the borehole rose very slowly to 20.81 m below datum, a recovery of only 5.69 m (Figure 5 (i)). The estimated rate of groundwater inflow to the borehole over the recovery period was 0.05 l/s.

After hydrofracturing, the inflow rate to the borehole had increased. A second short recovery test was carried out on 11 November 2004. Although the borehole was pumped for longer (12 hours) and at a lower rate (approximately 0.36 l/s) than the first recovery test, the results can be compared to indicate relative change before and after hydrofracturing. The maximum pumping water level during the test was 23.36 m below datum, a drawdown of approximately 20.4 m. The specific capacity of the borehole during the 12 hour pumping period was approximately 1.5 m^3/day/m. Water level recovery was measured for 60 minutes, during which time the water level in the borehole rose to 5.92 m below datum, a recovery of 17.44 m (Figure 5 (ii)). The estimated rate of groundwater inflow to the borehole over the recovery period was 0.15 l/s.





(i) Pre-hydrofracturing **(ii) Post-hydrofracturing**

Figure 5 Recovery of water levels following rising head tests pre- (i) and post- (ii) hydrofracturing

6 Borehole construction

Location:	NN 6109 943
Total depth:	100.0 m below ground level (mbgl)
Surface casing:	340 mm diameter steel (0 to 2 mbgl)
	200 mm diameter mild steel (0 to 34 mbgl), grouted in place
Screen/casing:	113 mm diameter plain uPVC casing (0 to approximately 30 mbgl)
	113 mm diameter uPVC well screen; slot size 1 mm (approximately 30 mbgl to 100 mbgl)
	End cap installed
Gravel pack:	Installed (approximately 26 mbgl to 100 mbgl). Details unknown.
Wellhead:	340 mm diameter from approximately 0.2 m above ground level to 2 mbgl; heavy duty flange and blank plate

7 Test pumping

The borehole was test pumped for 2 weeks from 5 to 19 October 2004. The pump was installed at 60 m depth. The borehole was pumped at an average rate of 0.3 l/s throughout the test. The pumping rate varied slightly, with a maximum recorded rate of 0.6 l/s. Pumping was also stopped temporarily a number of times during the 2 week test, due to malfunctioning equipment.

An automatic recorder (a Diver compensated pressure transducer) was used to collect borehole water level data during the pumping and recovery phases of the test (Figure 6). Manual water level measurements were also made at the start of the pumping period and during the recovery period. The rest water level in the borehole was 2.95 m below datum (mbd). The maximum pumped water level was 24 m below datum, which is a drawdown of approximately 21 m.

Data from the recovery period are shown in Figure 7. These are manually measured for the majority of the recovery, with automatically measured data integrated to provide data during later stages.

Transmissivity was estimated from the test pumping data using Jacob's method. The drawdown data indicate a transmissivity at 0.6 m^2/day. Estimates using recovery data, which are typically more accurate, put transmissivity at between 1.5 and 3 m^2/day.

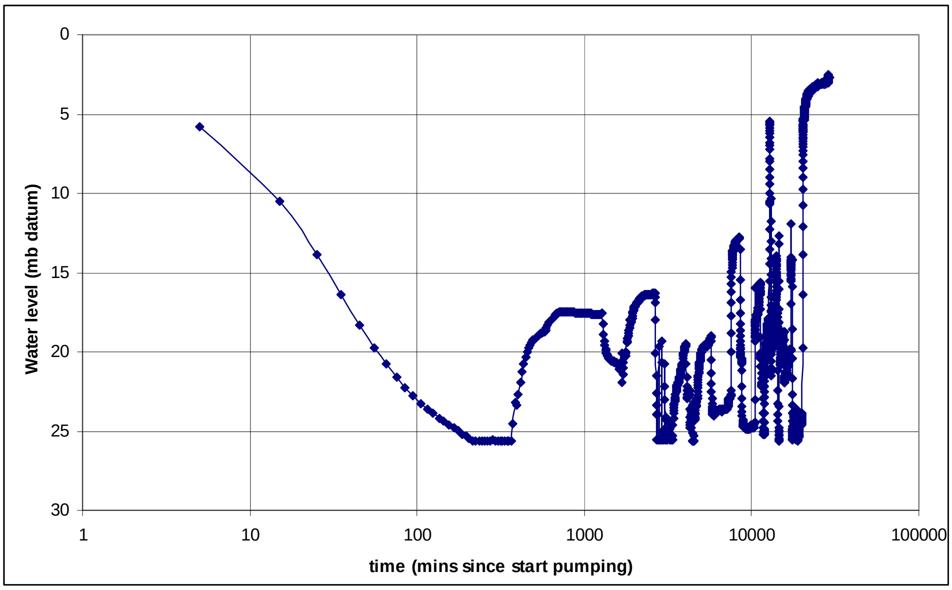


Figure 6 Water level measurements in the pumping borehole during the 2 week pumping test (drawdown and recovery phases)

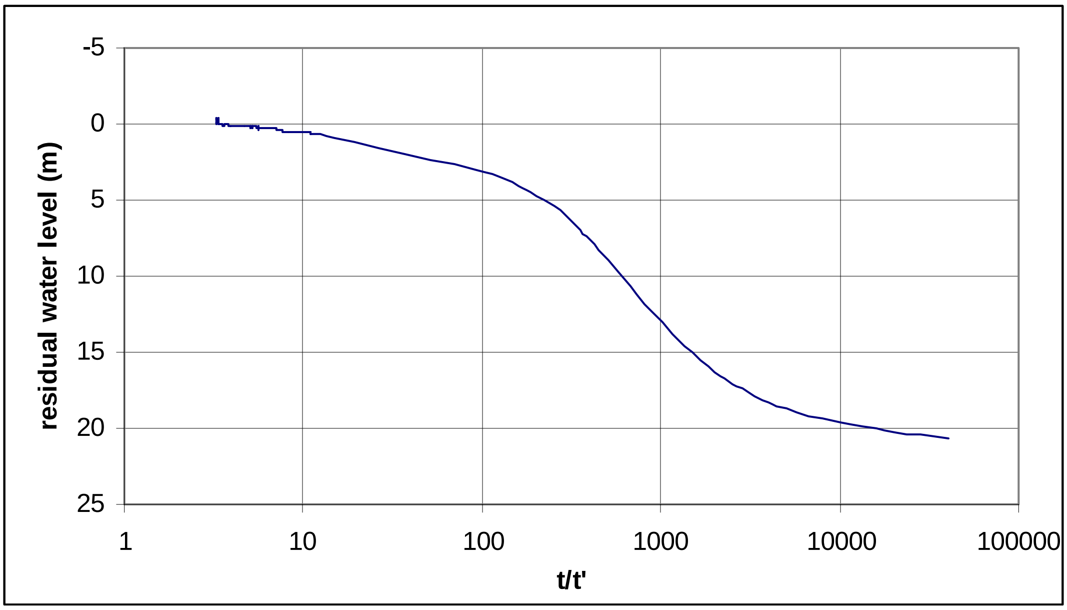


Figure 7 Recovery data from test pumping

8 Groundwater chemistry testing

8.1 GROUNDWATER CHEMISTRY SAMPLING

On site measurement of temperature, conductivity, alkalinity and occasionally pH was undertaken on 5 October at the start of the pumping test; 19 October at the end of the test; and 26 October (Table 2)

Three water samples were taken at intervals during the pumping test, on 11, 15 and 18 October. A further three samples were taken after the end of the pumping test: two on 26 October and one on 27 October. All these samples were analysed at a Scottish Water laboratory for a limited range of determinands (Table 3).

Two water samples were taken on 26 October for analysis at the BGS laboratory: one for full major, minor and trace ion analysis and one for CFC analysis. The chemical analyses are summarised in Table 4 and CFC results are summarised in Table 5.

Before each of these samples was taken, the borehole was pumped continuously for at least 18 hours, generally longer.

A sample of water for gas analysis was taken on 11 November and sent to the BGS laboratory for analysis. Before this sample was taken, the borehole was pumped for 12 hours. The results of gas analysis are summarised in Table 6.

8.2 GROUNDWATER CHEMISTRY

The water is of sodium/potassium-sulphate type, with high pH and low alkalinity. The water contains notably high concentrations of sulphate and moderately high concentrations of sodium and calcium. Zinc concentrations are variable, and are high in some samples. In contrast to groundwater abstracted from boreholes in the superficial aquifer in the same field as the current borehole, which had very high iron and manganese concentrations, iron concentrations are low in all but one sample, and manganese concentrations are very low in all samples.

Analyses of six groundwater samples over seven weeks in October and November showed relatively little variation in groundwater chemistry apart from zinc and iron concentrations. There may be longer term variations (e.g. seasonal) in other determinands.

CFC analysis indicates that most of the groundwater has been recharged in the period since 1980, and that the groundwater contains at least 40 to 60 % modern water (recharged since 1990).

During on-site testing on 26 October, the water was observed to be degassing significantly when pumped to the ground surface. A sample for gas analysis was taken on 11 November, at which time the water was not observed to be outgassing significantly. Gas analysis shows low O_2 and very low CO_2 concentrations, but the other dissolved gases analysed for are within or close to the expected range. Expected N_2 gas concentrations in groundwater are between 17 and 20 mg/l. Higher N_2 concentrations can occur naturally by overpressurisation of recharging water in the unsaturated zone by excess air.

The groundwater chemistry indicates that most of the water abstracted from the borehole is derived from the bedrock aquifer, not from leakage through the overlying superficial aquifer. Groundwater in the overlying superficial aquifer was analysed in the earlier study and shown to contain high concentrations of iron, manganese and aluminium. None of these determinands is noticeably elevated in the groundwater samples taken from the new borehole.

Water abstracted at the new borehole is likely to have been recharged on hillslopes above the valley. The low O_2 and CO_2, but normal CH_4 concentration, indicate recharge through a slightly reducing environment, such as peat. This agrees with the observed recharge environment in the area. The bedrock in this area is known to contain bands of calcareous rock, and in places is also enriched in sulphate and sulphide minerals. The chemistry of groundwater abstracted at the borehole may have been influenced by calcareous and other minerals as groundwater flows through the rock, which may have caused the high pH and relatively high concentrations of sulphate, calcium and sodium.

Table 2 Wellhead measurements of groundwater chemistry

Date	**Temperature (°C)**	**SEC (μS/cm)**	**pH**	**Alkalinity (mg/l as HCO_3)**	**Comments**
5/10/2004	11.2	333	-	67	Measured in bucket
19/10/2004	11.1	324	7.4	40	Measured in bucket
26/10/2004	13.5	330	9.34	55	Measured in flow through cell

Table 3 Groundwater chemistry analysed by Scottish Water laboratory

Sample date	**11/10/2004**	**15/10/2004**	**18/10/2004**	**26/10/2004**	**26/10/2004**	**27/10/2004**
SEC (mS/cm)	299	280	278	292	286	290
pH	-	9.0	8.6	9.2	9.0	8.9
Alkalinity (mg/l as HCO_3)	61	56	27	64.7	59.8	36.6
Calcium (mg/l)	22.1	21.9	21.1	20.4	20	21.1
Magnesium (mg/l)	0.7	0.7	0.7	0.6	0.7	0.7
Sodium (mg/l)	42.3	41.6	41.4	40.3	40	40.6
Potassium (mg/l)	2.7	2		2.8	2.1	2
Iron (μg/l)	49	35	114	78	78	51
Manganese (μg/l)	1.8	1.8	2.6	2.2	3	2.6
Nitrate (mg/l as NO_3)	0.5	< 0.3	0.4	0.6.	0.6	0.6
Nitrite (mg/l)	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.026
Total Organic Nitrogen (mg/l)	0.47	< 0.3	0.43	0.58	0.57	0.6
Chloride (mg/l)	-	-	22.4	-	-	-
Phosphorus (μg/l)	< 10	<10	<10	<10	<10	<10
Soluble reactive phosphate (mg/l)	0.05	0.08	0.06	0.07	0.06	0.1
Sulphate (mg/l)	62	67.4	66.6	87.5	93.2	76.2
Ammonium (mg/l as NO_4)	0.06	0.03	< 0.02	0.03	< 0.02	0.05
Aluminium (μg/l)	16	< 10	< 10	30	34	16
Lead (μg/l)	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	0.4
Copper (μg/l)	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Zinc (μg/l)	52	61	168	469	384	112

Table 4 Groundwater chemistry analysed by BGS. Sample taken 26 October 2004. All units are in mg/l unless specified.

Constituent	Concentration	Constituent	Concentration
Al	< 0.01	Mo	0.0155
As	< 0.05	Na	38.9
B	0.13	Ni	< 0.005
Ba	0.036	NO_2-N	0.0045
Be	< 0.002	P	< 0.1
Ca	20.9	Pb	< 0.01
Cd	< 0.001	pH (pH units)	8.56
Cl	19.5	Sc	< 0.0004
Co	< 0.003	SEC (µS/cm)	330
Cr	< 0.002	Si	4.3
Cu	< 0.008	SO_4	59.6
Fe	0.0109	Sr	0.337
HCO_3-lab	63	T	13.5
K	2.89	TON	< 0.2
La	< 0.002	V	< 0.002
Li	< 0.004	Y	< 0.0003
Mg	0.681	Zn	0.116
Mn	0.0025		

Table 5 CFC results. Sample taken 26 October 2004. A recharge temperature of 5°C is assumed.

	Recharge year	% modern water
CFC-11	1980	59
CFC-12	1973	36

Table 6 Gas analysis results. Sample taken 11 November 2004.

Gas	Concentration (mg/l)
N_2	21.8
O_2	1.3
Ar	0.8
CO_2	0.48
CH_4	0.0014

9 Assessment of the groundwater resource

The new borehole at Laggan abstracts from a low productivity bedrock aquifer beneath a thick superficial sequence. Groundwater storage in and flow through the bedrock aquifer occurs entirely within fractures in the rock.

Test pumping the borehole indicates that the long term sustainable pumping rate for the borehole is likely to be between 0.2 and 0.3 l/s. Sustainable pumping rate refers to that abstraction rate that is expected to be sustainable throughout the design life of the borehole. In other words, recharge will replenish the aquifer at the same rate, allowing abstraction to take place for an infinite time. At these pumping rates, the pumping water level is likely to stabilise at between 15 and 25 m below ground level.

The bulk of the groundwater abstracted at the borehole is likely to be recently recharged to the bedrock aquifer on the hill slopes above the valley to the north and south.

Peat cover on the hill slopes is likely to create a slightly reducing recharge environment. There appears to be very little leakage of groundwater to the bedrock aquifer from the overlying shallow superficial aquifer.

The volume of recharge to the aquifer cannot be accurately quantified based on current data.

Although the groundwater has relatively high pH, high concentrations of sulphate and relatively high concentrations of sodium and calcium, these determinands do not exceed drinking water guidelines. Zinc and iron concentrations in the abstracted water are variable, and are high in some samples.

10 Risks to groundwater abstraction

The following is a summary of the risks to groundwater abstraction from the Laggan borehole. It does not constitute a comprehensive risk assessment.

- Insufficient recharge: the main sources of recharge to the local aquifer are direct infiltration from rainfall and indirect recharge from surface water runoff. Recharge to the aquifer cannot be accurately estimated based on available data. Recharge in this area is not unlikely to be limited by rainfall, but may be limited by the low permeability of the aquifer rocks.
- Point source contamination: there is a septic tank soakaway approximately 150 to 200 m to the north-northeast of the borehole. There is likely to be a very low risk of contamination of groundwater abstracted from the borehole from the soakaway, due to the thickness of the superficial deposits and the expected limited leakage of shallow water from the superficial deposits to the bedrock aquifer, as well as the horizontal distance between the soakaway and the borehole. No other known point sources of contamination directly pose a risk to the borehole. Potential point sources include septic and fuel tanks.
- Diffuse contamination: cattle graze the field in which the borehole is sited, and the surrounding field. The presence of cattle increases the risk of cryptosporidium contamination. The stocking density is such that there is unlikely to be a risk of elevated nitrate concentrations in groundwater.

- Other groundwater abstractions: there are no known other groundwater abstractions in the area.

11 Conclusions and recommendations

- The new borehole at Laggan is likely to be capable of a sustainable yield of between 0.2 and 0.3 l/s (17 to 26 m^3/day) over the long term. However, this will need to be confirmed by long term testing.
- Groundwater abstracted from the borehole shows higher than expected concentrations of some ions, including calcium, sodium and sulphate, but not to levels that exceed drinking water quality standards. Concentrations of certain metals, including zinc and iron, are slightly variable and are sometimes elevated. Long term monitoring of groundwater chemistry should be carried out.
- Dissolved O_2 and CO_2 gas concentrations in abstracted groundwater are low, indicating reducing recharge conditions. Other dissolved gases are within or close to the expected range.

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GRAMPIAN SOIL SURVEYS (ABERDEEN) LIMITED. 1998. Water well boreholes, Laggan Bridge, Invernessshire. *For NOSWA.*