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Shieldaig: Borehole Drilling and Testing

Groundwater Systems and Water Quality Programme

Internal Report IR/05/012

BRITISH GEOLOGICAL SURVEY

GROUNDWATER SYSTEMS AND WATER QUALITY PROGRAMME

INTERNAL REPORT IR/05/012

Shieldaig: Borehole Drilling and Testing

B É Ó Dochartaigh

Keywords

Shieldaig, borehole drilling and testing.

Front cover

View north to Loch Shieldaig and Shieldaig village. Boreholes 2 and 3 are in mid-ground beside trees.

Bibliographical reference

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1 Introduction

Three trial boreholes for potential public water supply were drilled near Shieldaig, in September-October 2004. The target aquifer was Torridonian sandstone. The boreholes were commissioned by Scottish Water. The project was managed by Galliford Morgan Joint Venture. Advice on borehole siting, construction and testing was provided by the British Geological Survey (BGS). The boreholes were drilled and pumping tests carried out by Drilcorp.

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

2 Borehole location

Shieldaig is a small settlement in the northern Highlands, located on Loch Shieldaig to the west of Torridon (Figure 1). The boreholes are sited approximately 1 km to the south of Shieldaig. Borehole 1 (NG 81775 52430) lies to the east of the other two boreholes and was abandoned on drilling when Lewisian gneiss was encountered below Torridonian sandstone at less than 25 m below ground level. Boreholes 2 (NG 81645 52285) and 3 (NG 81623 52282) are sited by an electricity sub station. Borehole 2 is at an elevation of approximately 15 m above Ordnance Datum (OD) and borehole 1 is at an elevation of approximately 12 m OD. The boreholes are sited between approximately 160 and 170 m distant from the high water mark at its closest point.

Figure 1 Location of Shieldaig in the northern Highlands

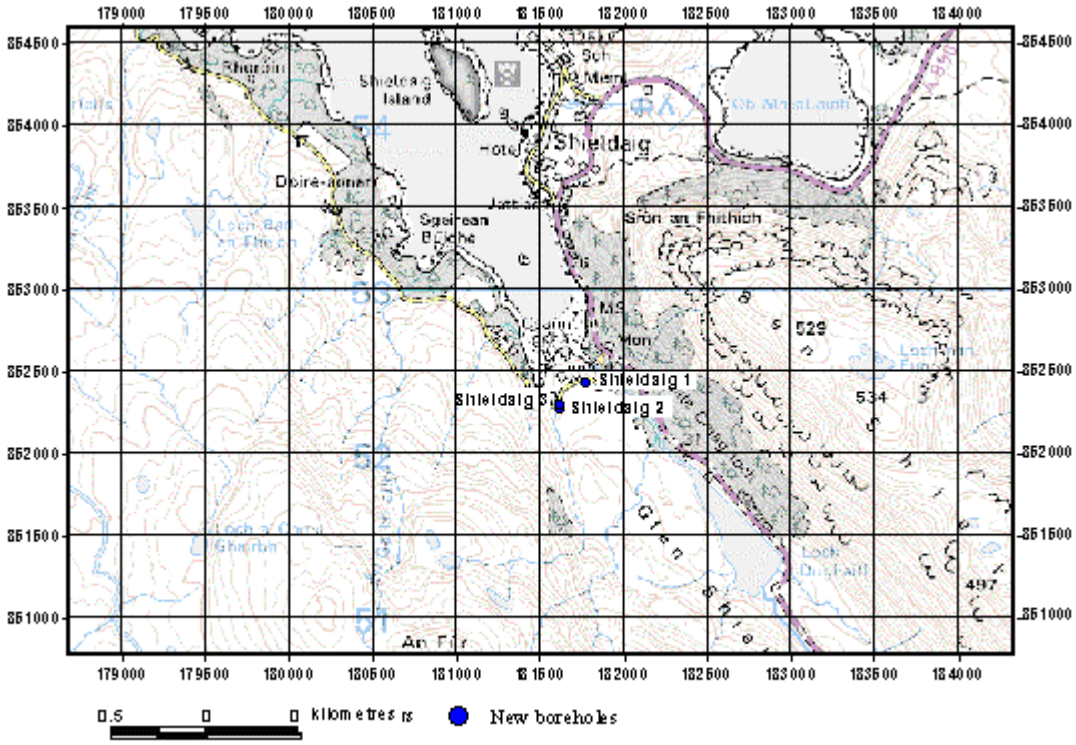


Figure 2 Location of new boreholes at Shieldaig

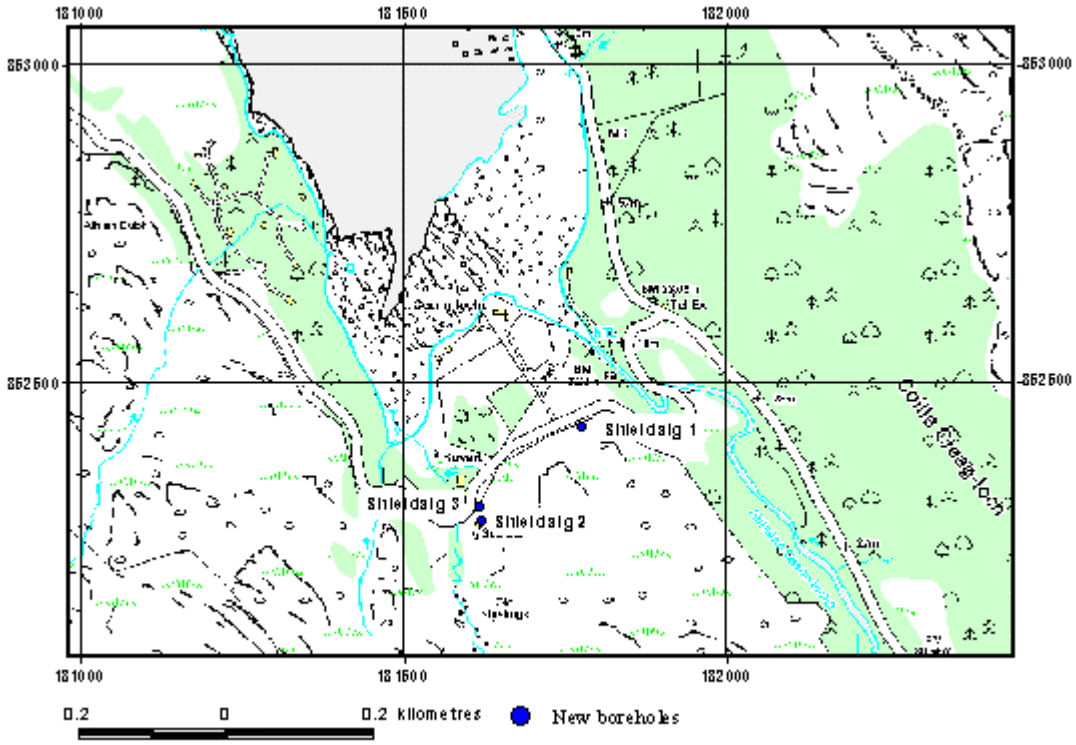


Figure 2 Site plan of new boreholes at Shieldaig

3 Geology

Thin raised beach and other marine superficial deposits are present adjacent to Loch Shieldaig in the area of the new boreholes (Figure 4). Information from drilling indicates that the superficial deposits are typically less than 3.5 m thick, and dominated by gravels, with some peat (Appendix 1).

Bedrock in this area comprises ancient pebbly sandstones of the Applecross Formation (Torridonian Sandstone), underlain by gneiss of the Lewisian Complex (Figure 5). Borehole 1 encountered gneiss at approximately 22.5 m below ground level beneath sandstones of the Applecross Formation. Boreholes 2 and 3, at 58 to 60 m depth, did not encounter gneiss.

Geological logs of the boreholes based on information collected during drilling are presented in Appendix 1.

4 Borehole drilling

Borehole 1 was drilled between 9 and 13 September 2004, to a depth of 25.7 m. No water was struck, although the borehole was damp on drilling. The borehole was terminated because it encountered only approximately 15 m of Torridonian sandstone over Lewisian gneiss, and was backfilled with cement.

Borehole 2 was drilled between 1 and 3 September 2004, to a depth of 58.0 m. Water was struck at 9.4 m, 16.5 m, between 41.7 and 45.1 m and 57.5 m below ground level (Table 2). The sandstone encountered on drilling was fractured (Appendix 1), but despite this the borehole was drilled quickly and without problem.

Borehole 3 was drilled between 5 and 7 October 2004, to a depth of 60.0 m. It is sited approximately 20 m north of borehole 2. Only one water strike was recorded, at 5.7 m below ground level. The Torridonian Sandstone was noticeably harder in this borehole than in borehole 2.

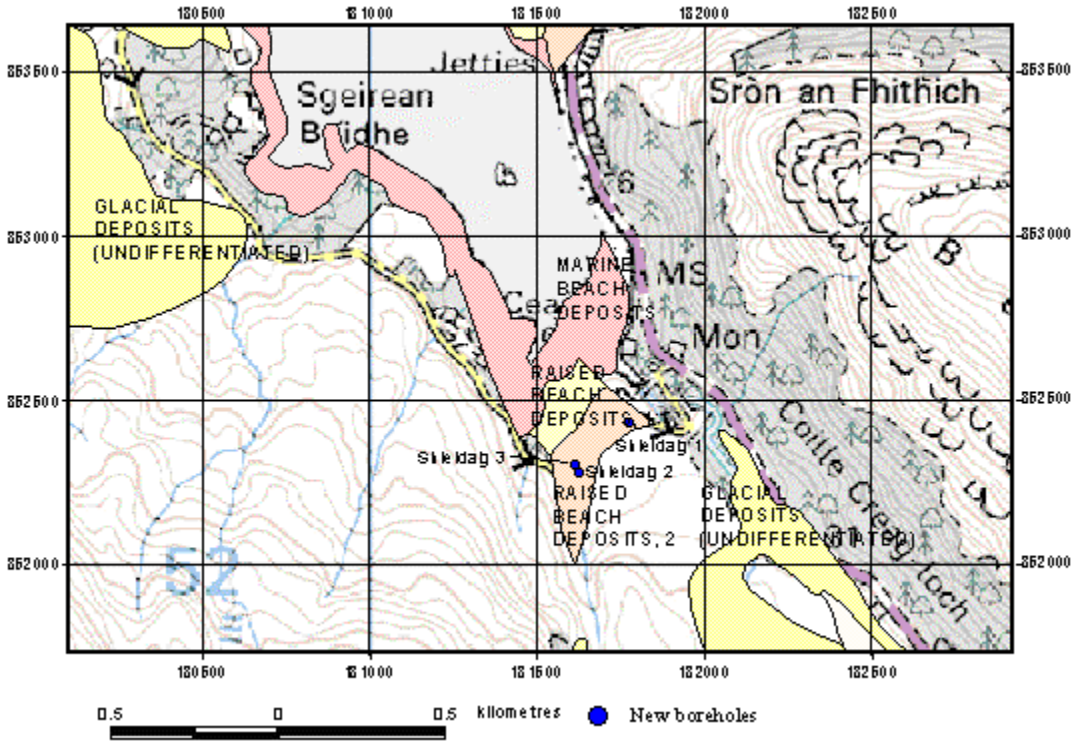


Figure 3 Superficial geology of the area around the new Shieldaig boreholes

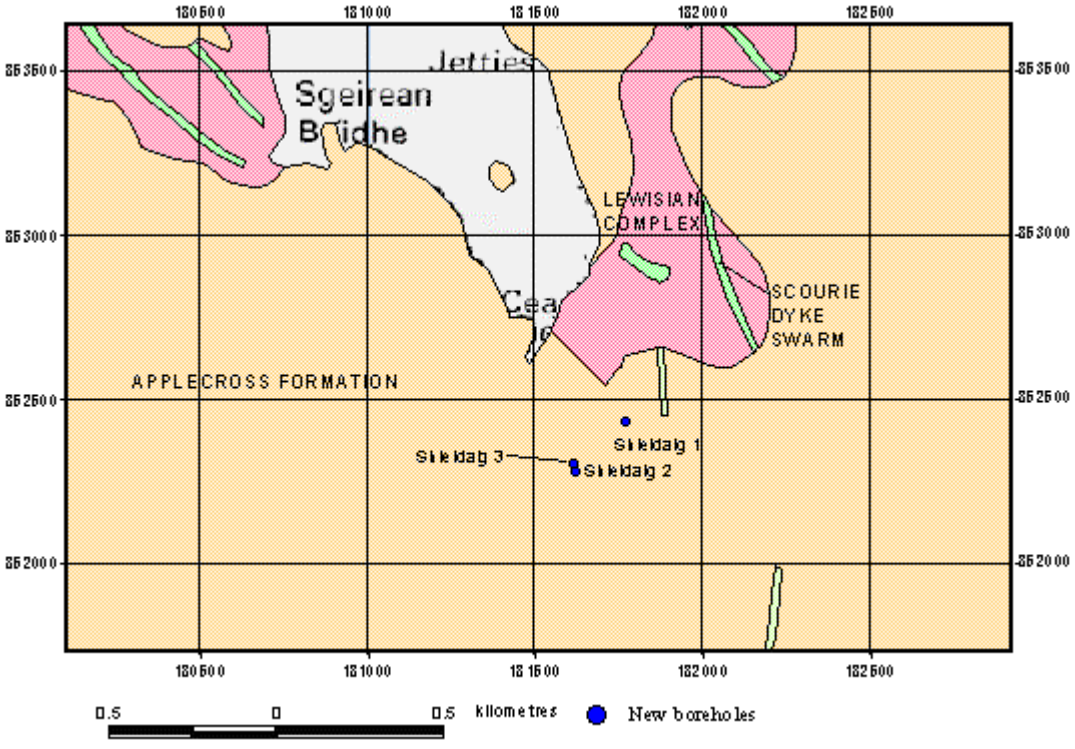


Figure 4 Bedrock geology of the area around the new Shieldaig boreholes

5 Borehole construction

Borehole construction details for boreholes 2 and 3 are presented below, based on information supplied by Drilcorp.

5.1 BOREHOLE 2

Total depth:	58.0 m below ground level (mbgl)
Surface casing:	200 mm diameter mild steel grouted in (0 to 12 mbgl) and drilled through
Screen/casing:	113 mm diameter plain uPVC casing (0 to 6 mbgl)
	113 mm diameter uPVC well screen (6 to 60 mbgl)
Gravel pack:	None
Wellhead:	300 mm heavy duty flange and blank plate set to 0.5 m above ground level, 0.9 m below ground in 600 x 600 mm concrete base
Development:	Airlift: 2 – 3 hours on 3 September 2004

5.2 BOREHOLE 3

Total depth:	60 m below ground level (mbgl)
Surface casing:	00 mm diameter mild steel grouted in (0 to 10.5 mbgl) and drilled through
Surface casing:	200 mm diameter mild steel grouted in (0 to 12 mbgl) and drilled through
Screen/casing:	113 mm diameter plain uPVC casing (0 to 6 mbgl)
	113 mm diameter uPVC well screen (6 to 60 mbgl)
Gravel pack:	None
Wellhead:	300 mm heavy duty flange and blank plate set to 0.5 m above ground level, 0.9 m below ground in 600 x 600 mm concrete base
Development:	Air lift: 1 hour on 7 October; 2 hours on 8 October 2004

6 Test pumping

6.1 BOREHOLE 2

The borehole was pumped for two weeks from 14 to 29 September 2004. Water level measurements were made during the pumping period but not during recovery. The datum for the test was the top of the surface casing. The rest water level in the borehole is approximately 7.1 m below datum (Table 1).

At the start of pumping on 14 September the borehole was pumped at 1.7 l/s (100 l/min) for the first 35 minutes (based on flow meter readings). This pumping rate was gradually reduced to an average of 0.78 l/s (47 l/min) on 18 September, and maintained from them until the end of pumping on 29 September (Figures 4 and 5). The changes in pumping rate were made to prevent water levels from drawing down below sea level.

An automatic recorder (a Diver compensated pressure transducer) was used to collect borehole water level data at 15 minute intervals between 9 and 27 September 2004. There are no data from the automatic recorder for the final 2 days of pumping, or for the recovery phase (Figure 5).

Detailed manual water level measurements were made during the first 6 hours of the pumping test and then at twice daily intervals throughout the test (Figure 6). No manual water level measurements were made during the recovery phase. The measurements are presented in Appendix 2. The readings from the recorder show the same pattern as the manual readings.

The pumping water level in the borehole fluctuated during the test as a result of pump switch off (for example, due to temporary generator failure) and of changes in pumping rate. The maximum water level drawdown in the borehole during the test was 23.5 m, after 3.5 hours of pumping, when the pumping rate was 1.25 l/s. The water level recovered slightly between then and 17 September, during which time the average pumping rate was approximately 1 l/s. The water level recovered more noticeably on 18 September when the pumping rate was reduced to an average of 0.78 l/s. However, even at this constant pumping rate, the water level in the borehole did not stabilise but continued to fall gradually for the last 11 days of the test.

It has not been possible to estimate transmissivity, because of the variations in pumping rate and the lack of recovery data. The calculated specific capacity of the borehole is 5.7 m^3/day/m, based on the average pumping rate over the last 11 days of pumping of 0.78 l/s during the test and the final drawdown of 11.75 m.

Table 1 Summary of pumping tests on new Shieldaig boreholes

	Borehole 2	**Borehole 3**
Date pumping started	14/09/2004	18/10/2004
Date pumping finished	29/09/2004	01/11/2004
Datum for test	Top of surface casing	Top of dip tube c. 0.2 m above top of surface casing
Rest water level (m below datum)	7.1	3.0
Range in pumping rates (l/s)	0.6 - 1.7	0.7 – 1.3
Final pumping rate	0.78 (average over last 11 days of test)	0.7
Maximum pumping water level (m below datum)	29.49 (at pumping rate of 1.3 l/s)	15.23 (at pumping rate of 0.9)
Final pumping water level (m below datum)	19.2 m	10.34
Specific capacity (m^3/day/m) at end of test	5.7	8.3
Transmissivity (m^2/day)	-	16

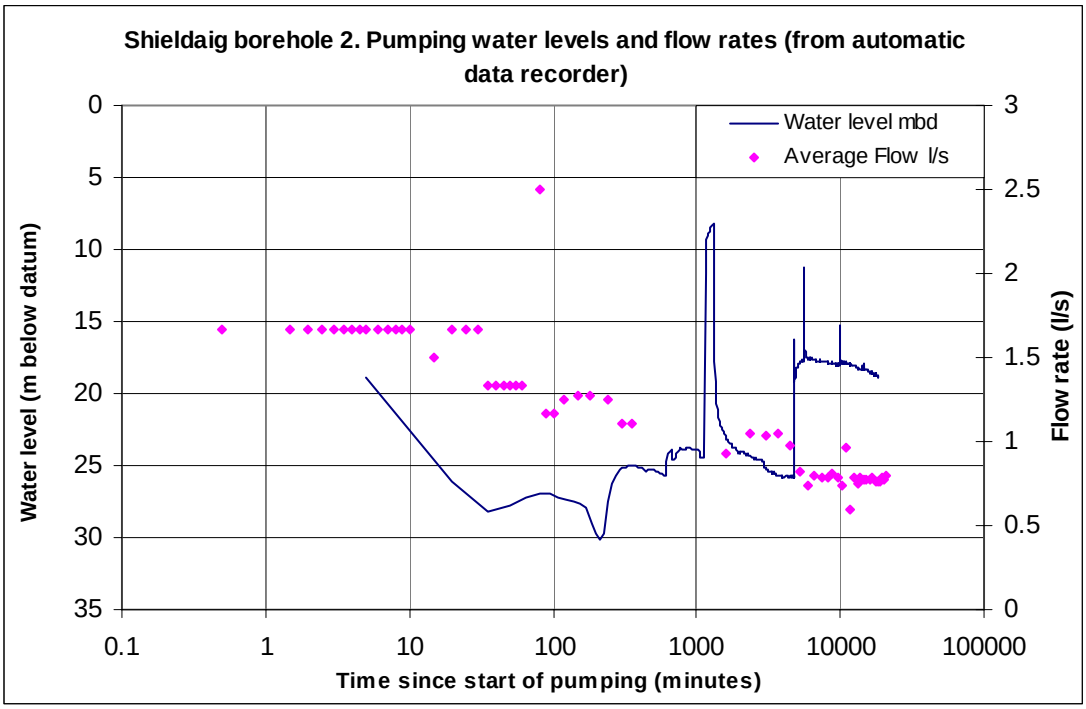


Figure 5 Water levels in borehole 2 during the pumping test on borehole 2. From the automatic data recorder

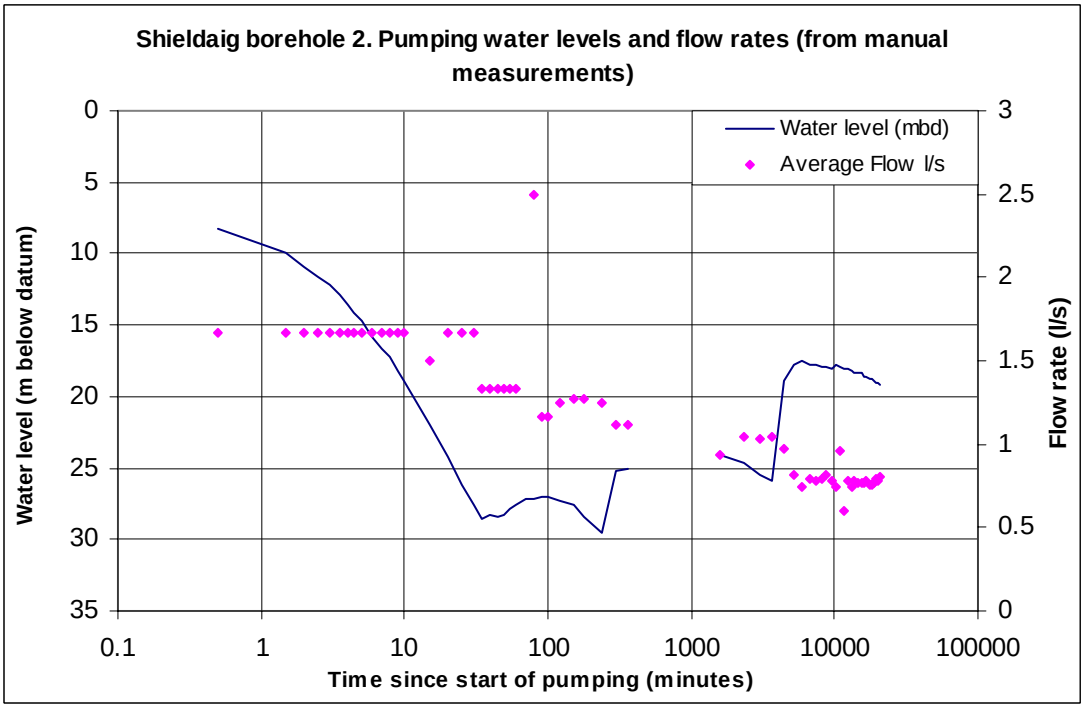


Figure 6 Water levels and pumping rates in borehole 2 during the pumping test on borehole 2. From manually measured data

6.2 BOREHOLE 3

A two week pumping test was started on borehole 3 on 18 October and run until 1 November 2004. The datum for the test was the top of the dip tube at approximately 0.2 m above the top of the surface casing. The rest water level in the borehole is approximately 3.0 m below datum.

The borehole was pumped at an average rate of 0.8 l/s (48 l/min) from 18 to 26 October. This was reduced to an average rate of 0.7 l/s (41 l/min) from 26 October to the end of the test on 1 November (Figures 6 and 7). The changes in pumping rate were made to prevent water levels from drawing down below sea level.

During the test, manual water level measurements were made at twice daily intervals (Figure 7). Detailed water level measurements were also made during the recovery period (Figure 8). These data are presented in Appendix 3. An automatic water level recorder (a Diver compensated pressure transducer) was also used to collect water level data at 10 minute intervals between 11 October and 8 November 2004 (Figure 9). The readings from the recorder show the same pattern as the manual readings.

The pumping water level in the borehole fluctuated during the test as a result of changes in pumping rate. The maximum water level drawdown in the borehole during the test was 12.2 m, on 25 October after 7 days of pumping, when the pumping rate was 0.86 l/s. The water level recovered noticeably on 26 October when the pumping rate was reduced to an average of 0.7 l/s. However, even at this constant pumping rate, the water level in the borehole did not stabilise but continued to fall gradually for the last 6 days of the test.

Water levels in borehole 2 were also recorded during the test (Figure 6). During the pumping test on borehole 3, the drawdown in borehole 2, at a distance of approximately 20 m, was 1.8 m.

The data from the pumping period of the test are difficult to analyse because of the variations in pumping rate. The transmissivity of the aquifer in the area of borehole 3 has been calculated from recovery data using Jacob's method, at 16 m^2/day. The calculated specific capacity of the borehole is 8.3 m^3/day/m, based on the average pumping rate over the last 6 days of pumping of 0.7 l/s during the test and the final drawdown of 7.3 m.

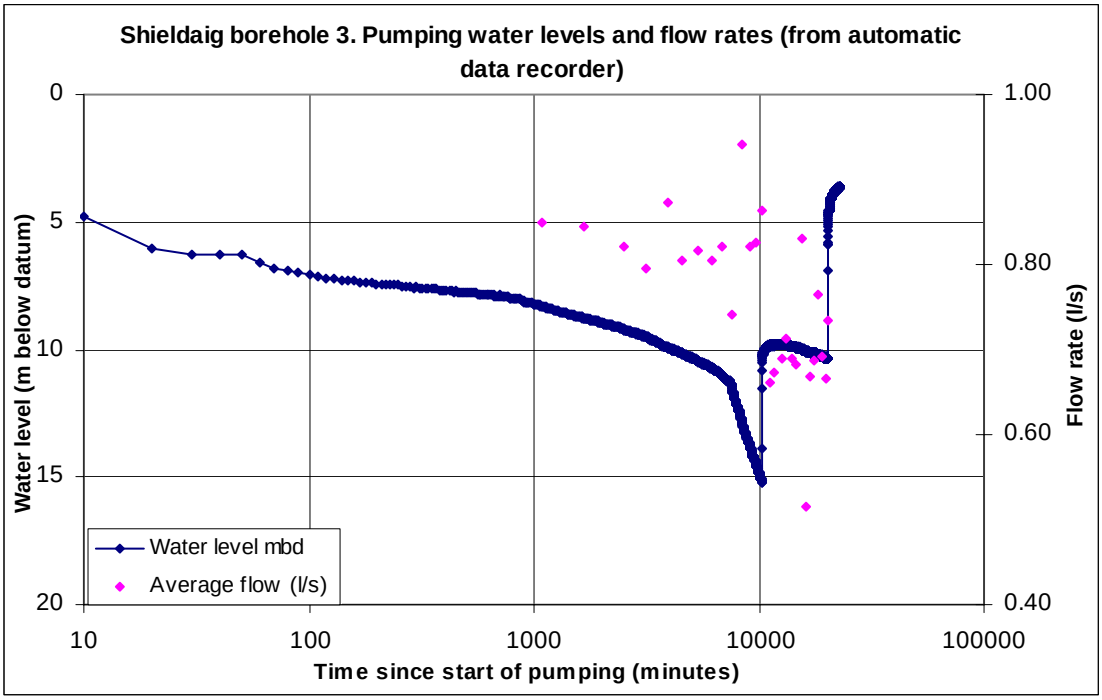


Figure 7 Water levels in borehole 3 during the pumping test on borehole 3. From the automatic data recorder. Recovery starts at 20280 minutes (1 November 2004 at 16:00)

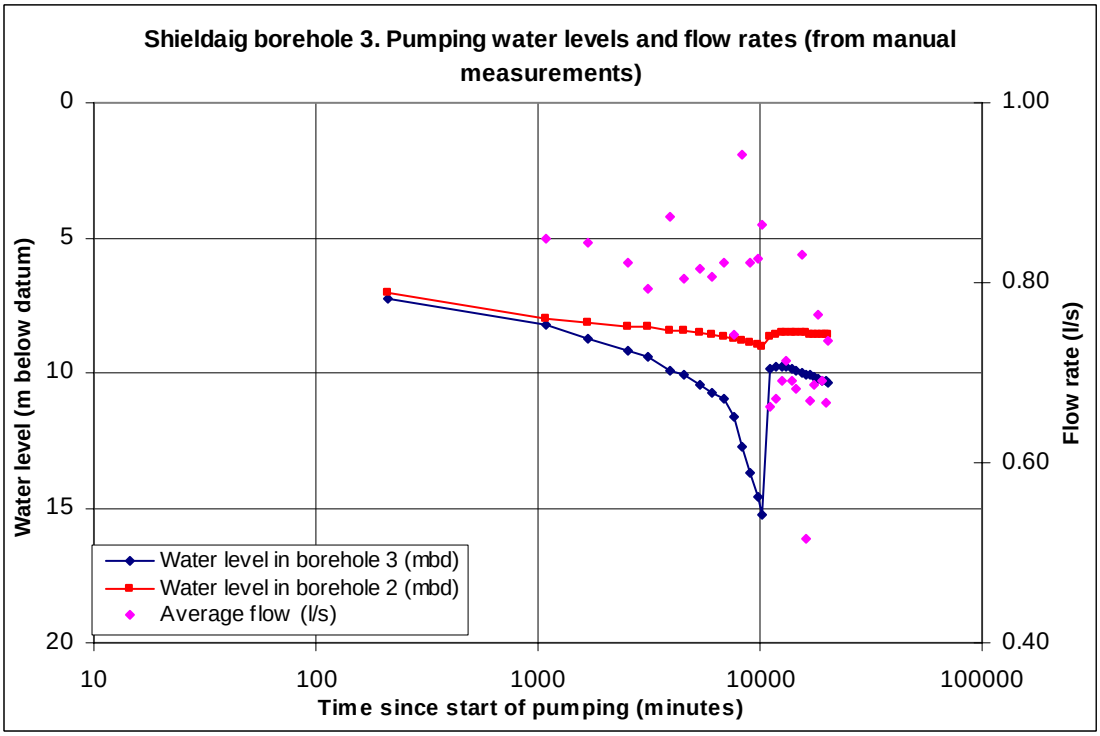


Figure 8 Water levels and flow rate in borehole 3, and water levels in borehole 2, during the pumping test on borehole 3. From manual measurements

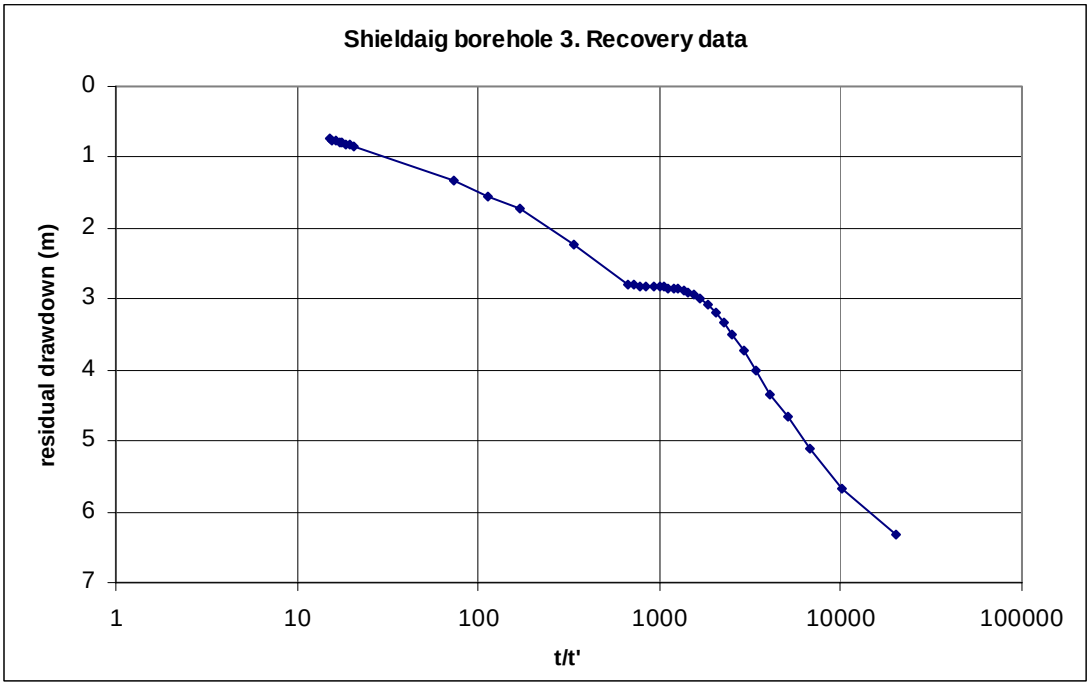


Figure 9 Recovery data from the pumping test on borehole 3

7 Groundwater quality testing

7.1 BOREHOLE 2

A number of water samples were taken from borehole 2 at intervals specified by the client, during the period of pumping in October 2004. The samples were taken as specified by Scottish Water. Before each of the samples was taken, the borehole had been pumped continuously for long enough to purge the borehole effectively. The samples were analysed at a Scottish Water laboratory for a limited range of constituents. No analyses are, as yet, available.

7.2 BOREHOLE 3

A number of water samples were taken from borehole 3 during the pumping test at intervals specified by the client. The samples were taken as specified by Scottish Water. Before each of the samples was taken, the borehole had been pumped continuously for long enough to purge the borehole effectively. The samples were analysed at a Scottish Water laboratory for a limited range of constituents. No analyses are, as yet, available.

Field chemical measurements were made during the pumping test on 20 October 2004 (Table 1).

Table 2 Field measurements of groundwater chemistry at borehole 3

Date	Temperature (°C)	SEC (μS/cm)	pH	Alkalinity (mg/l as HCO_3)	Comments
20/10/2004	10.1	174	6.08	55	Measured in flow through cell

8 Assessment of the groundwater resource

8.1 BOREHOLE 2

The specific capacity of borehole 2, from test pumping data, is 5.7 m^3/day/m. The sustained fall in pumping water level throughout the latter part of test pumping, despite the relatively constant pumping rate of 0.8 l/s, indicates that the long-term sustainable pumping rate for the borehole is lower than 0.8 l/s (67 m^3/day). 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. If the borehole pumped at too high a yield, the pumping water level may be drawn down below sea level (i.e., below approximately 15 m below ground level). If this occurs, the proximity of the borehole to the coast means that there is a risk that fractures in the rock may allow a rapid pathway for sea water to intrude into the aquifer and flow to the borehole (saline intrusion).

Further testing at lower pumping rates is needed to confirm the sustainable yield.

In the absence of groundwater chemical analysis data, no assessment of groundwater chemistry can be made.

8.2 BOREHOLE 3

The calculated transmissivity of the aquifer surrounding borehole 3, from test pumping data, is 16 m^2/day. The calculated specific capacity of the borehole is 8.3 m^3/day/m. The sustained fall in pumping water level over the test, despite the relatively constant pumping rate of 0.7 l/s, suggests that the long-term sustainable pumping rate for the borehole is less than 0.7 l/s (60 m^3/day). As with borehole 2, the proximity of the borehole to the coast means that there is a risk of saline intrusion to the borehole if the borehole is pumped at too high a yield and the pumping water level is consequently drawn down below sea level (i.e., below approximately 12 m below ground level).

Further testing at lower pumping rates is needed to confirm the sustainable yield.

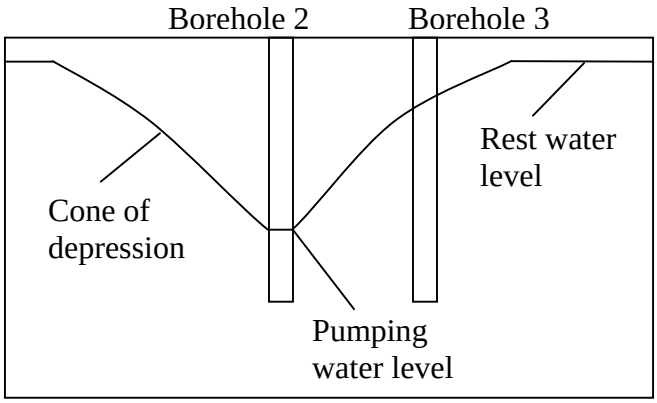
In the absence of groundwater chemical analysis data, no assessment of groundwater chemistry can be made.

8.3 OVERALL ASSESSMENT

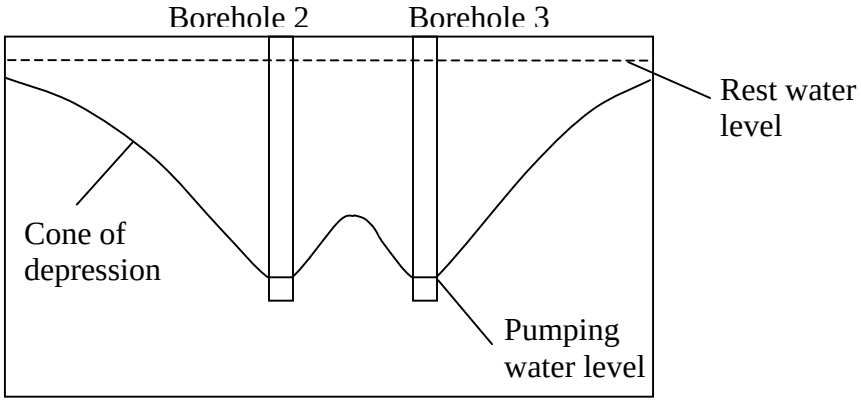
The aquifer in this area comprises Torridonian Sandstone, which is at least 60 m thick in the area around the boreholes. There is a thin overlying superficial cover. The Torridonian Sandstone has low intergranular permeability, and groundwater storage and flow occurs dominantly through fractures in the rock. These fractures may be concentrated along sub-horizontal bedding planes. In this area, the sandstone forms a low productivity aquifer.

Based on test pumping data, borehole 3 appears to be slightly higher yielding and more efficient than borehole 2.

If both boreholes were pumped simultaneously, interference between them is likely to cause some reduction in borehole efficiency and potential yield in both boreholes. This was evidenced during the pumping test on borehole 3, when the water level in borehole 2, at a distance of approximately 20 m, was drawn down by 1.8 m. Interference is likely to cause an increase in pumping water level drawdown in each borehole for any given pumping rate (Figure 10). In practise, this may cause pumping water levels to be drawn down to sea level at lower pumping rates, increasing the risk of saline intrusion.



(i) Illustration of cone of depression in borehole 2 when pumping alone (not to scale)



(ii) Illustration of combined cone of depression when two boreholes are pumped simultaneously (not to scale)

Figure 10 Illustration of the effects on water level drawdown when pumping two boreholes simultaneously

A proportion of recharge to the bedrock aquifer comes directly from rainfall, the rest being derived from surface water runoff flowing down from the mountains to the south. The volume and pathways of recharge to the aquifer are likely to be variable, as peaty layers at the ground surface will act as barriers to infiltrating rainfall. The volume of recharge cannot be accurately quantified based on current data.

Longer term testing is required to assess the long-term impacts of abstraction from the boreholes on the surrounding aquifer.

9 Risks to groundwater abstraction

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

- Saline intrusion: the boreholes lie less than 200 m from the high water mark and at elevations of approximately 12 to 15 m OD. If the pumping water level in the boreholes is drawn down below sea level (i.e. more than 12 to 15 m below ground level), there is a risk of drawing saline water into the local aquifer. This may occur if both boreholes are pumped together and abstract more than 50 m^3/day.
- 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 to the aquifer is unlikely to be limited by rainfall, but may be limited by the low permeability of the aquifer rocks.
- Point source contamination: no known point sources of contamination directly pose a risk to the boreholes. The nearest house is down-gradient of the boreholes. Potential point sources include septic and fuel tanks and landfill.
- Diffuse contamination: local land use is not such that there is likely to be a risk from diffuse contamination.
- Other groundwater abstractions: there are no known other groundwater abstractions in the area.

10 Conclusions and recommendations

- Drilling at Shieldaig has proved the presence of a bedrock aquifer, the Torridonian sandstone.
- The two new boreholes are unlikely to be capable of sustainable yields of 0.7 to 0.8 l/s (60 to 67 m^3/day), but are likely to be capable of lower sustainable yields. Further test pumping of the boreholes necessary to confirm the limits to long-term abstraction at the site.

Appendix 1 Borehole geological logs

Table 3 Geological log of Shieldaig borehole 1 (NG 81775 52430)

Depth (m)	Geology	Lithostratigraphy
0 – 1.3	Stone, peat and gravels	Superficial deposits
1.3 – 2.5	Weathered red sandstone	Applecross Formation (Torridonian Sandstone)
2.5 – 4.9	Broken, coarse-grained red sandstone	
4.9 – 6.2	Moderately hard, red-brown sandstone	
6.2 – 7.5	Broken coarse-grained sandstone	
7.5 – 8.0	Hard, red-brown sandstone	
8.0 – 10.0	Hard, red-brown, very coarse –grained sandstone	
10.0 – 11.4	Fine- to medium-grained purple sandstone	
11.4 – 12.0	Moderately hard, very coarse-grained, red-brown sandstone	
12.0 – 13.2	Moderately hard, red-brown sandstone	
13.2-16.8	Moderately hard to hard, red-brown sandstone	
16.8 – 25.7	Gneiss	Lewisian Complex (gneiss)

Table 4 Geological log of Shieldaig borehole 2 (NG 81645 52285)

Depth (m)	Geology	Notes	Lithostratigraphy
0 – 0.4	Top soil/peat		Superficial deposits
0.4 – 3.5	Gravels/boulders/broken sandstone		Applecross Formation (Torridonian Sandstone)
3.5 – 6.9	Red-brown, coarse-grained sandstone		
6.9 – 9.4	Very broken, red-brown, coarse-grained sandstone		
9.4 – 10.2	Very broken, purple, coarse-grained sandstone	Water strike	
10.2 – 12.0	Hard, red-brown sandstone		
12.0 – 16.4	Hard, red-brown coarse-grained sandstone		
16.4 – 16.7	Very broken, coarse-grained, red sandstone	Water strike	
16.7 – 18.8	Hard, red, coarse-grained sandstone		
18.8 – 19.0	Broken sandstone		
19.0 – 20.9	Hard red coarse grained sandstone		
20.9 – 37.4	Soft, medium- to coarse-grained, purple-brown sandstone		
37.4 – 37.6	Broken, red-brown, coarse-grained sandstone		
37.6 – 41.7	Soft, coarse-grained, red-brown sandstone		
41.7 – 45.1	Very broken, coarse-grained sandstone	Water strike	
45.1 – 46.6	Moderately hard, coarse-grained, red-brown sandstone		
46.6 – 48.1	Very broken, coarse-grained sandstone		
48.1 – 51.0	Moderately hard, red-brown sandstone		
51.0 – 57.4	Hard, red-brown sandstone	Water strike	
57.4 – 58.0	Very broken, coarse-grained sandstone		

Table 5 Geological log of Shieldaig borehole 3 (NG 81623 52282)

Depth (m)	Geology	Notes	Lithostratigraphy
0 – 1.1	Fine- to coarse-grained sand and gravel		Superficial deposits
1.1 – 5.7	Very soft, red and brown sandstone		Applecross Formation (Torridonian Sandstone)
5.7 – 7.0	Hard, coarse-grained, broken sandstone	Water strike	
7.0 – 10.5	Hard, coarse-grained, red-brown sandstone		
10.5 – 13.1	Moderately hard, coarse-grained, red-brown sandstone with occasional broke bands		
13.1 – 14	Soft to moderately hard, coarse-grained, purple sandstone		
14.0 – 16.8	Moderately hard, coarse-grained, red-brown sandstone		
16.8 – 19.3	Hard, broken, red-brown sandstone		
19.3 – 24.4	Soft, purple sandstone		
24.4 – 29.5	Moderately hard, red-brown, coarse-grained sandstone		
29.5 – 29.9	Soft, red-brown, coarse-grained sandstone		
29.9 – 31.7	Moderately hard, red-brown, coarse-grained sandstone		
31.7 – 36.0	Soft, red, brown and purple, coarse-grained sandstone		
36.0 – 46.0	Moderately hard, red-brown, coarse-grained sandstone with occasional soft sandstone bands		
46.0 – 46.8	Broken, red-brown sandstone		
46.8 – 53.1	Moderately hard, red-brown, coarse-grained sandstone		
53.1 – 53.5	Broken, red-brown sandstone		
53.5 – 60.0	Moderately hard, red-brown, coarse-grained sandstone		

Appendix 2 Manual water level measurements during test pumping

BOREHOLE 2

Date	Time	Minutes since start pumping	Water level (m below datum)	Pumping rate (l/s) reported by driller	Flow meter (m3)	Average pumping rate (l/s) calculated from flowmeter	Comments
14/09/2004	11:10		6.95		3.2		
		0.5	8.3	1.67			
		1.5	10	1.67			
		2	10.88	1.67			
		2.5	11.6	1.67			
		3	12.22	1.67			
		3.5	12.92	1.67			
		4	13.55	1.67			
		4.5	14.15	1.67			
		5	14.7	1.67	3.7	1.67	
		6	15.84	1.67			
		7	16.65	1.67			
		8	17.27	1.67			
		9	18.21	1.67			
		10	18.95	1.67			
		15	22.01	1.50	4.6	1.50	
		20	24.27	1.67	5.1	1.67	
		25	26.14	1.67	5.6	1.67	
		30	27.6	1.67	6.1	1.67	Pump rate reduced
		35	28.52	1.33	6.5	1.33	Pump rate reduced
		40	28.29	1.33	6.9	1.33	
		45	28.35	1.33	7.3	1.33	
		50	28.3	1.33	7.7	1.33	
		55	27.87	1.33	8.1	1.33	
	12:10	60	27.52	1.33	8.5	1.33	
		70	27.2				
		80	27.11	2.50	10	2.50	
		90	27	1.17	10.7	1.17	
		100	27.04	1.17	11.4	1.17	
	13:10	120	27.27	1.25	12.9	1.25	
		150	27.6	1.28	15.2	1.28	
	14:10	180	28.48	1.28	17.5	1.28	
	15:10	240	29.49	1.25	22	1.25	
	16:10	300	25.26	1.11	26	1.11	Pump rate reduced
	17:10	360	25.07	1.11	30	1.11	
15/09/2004	08:00	890			78.6		Generator off on morning 15/9
	20:00	1610	24.1	0.93	118.8	0.93	

Borehole 2, continued

Date	Time	Minutes since start pumping	Water level (m below datum)	Pumping rate (l/s) reported by driller	Flow meter (m3)	Average pumping rate (l/s) calculated from flowmeter	Comments
16/09/2004	08:00	2330	24.6	1.05	164	1.05	
	19:00	2990	25.52	1.04	205.1	1.04	
17/09/2004	07:00	3710	25.84	1.05	250.2	1.04	
	19:30	4460	18.91	0.97	293.9	0.97	Generator off when arrived for dip
18/09/2004	08:30	5240	17.73	0.82	332.1	0.82	
	20:00	5930	17.54	0.74	362.8	0.74	
19/09/2004	08:00	6650	17.75	0.79	397.1	0.79	
	19:45	7355	17.78	0.78	430.2	0.78	
20/09/2004	08:00	8090	17.9	0.79	464.9	0.79	
	19:15	8765	17.94	0.81	497.8	0.81	
21/09/2004	08:00	9530	18.02	0.78	533.6	0.78	Pump off after dip for 10 mins to service generator
	19:00	10190	17.82	0.74	563	0.74	
22/09/2004	08:00	10970	17.95	0.96	608.1	0.96	
	19:30	11660	18.01	0.59	632.7	0.59	
23/09/2004	08:00	12410	18.1	0.78	668	0.78	
	19:00	13070	18.18	0.74	697.5	0.74	
24/09/2004	08:00	13850	18.35	0.78	734	0.78	
	19:45	14555	18.39	0.77	766.6	0.77	
25/09/2004	08:15	15305	18.32	0.77	801.2	0.77	
	20:00	16010	18.6	0.77	833.7	0.77	
26/09/2004	08:00	16730	18.58	0.78	867.5	0.78	
	20:00	17450	18.7	0.76	900.3	0.76	
27/09/2004	08:00	18170	18.82	0.76	933	0.76	
	19:00	18830	18.92	0.77	963.4	0.77	
28/09/2004	08:00	19610	19.01	0.79	1000.4	0.79	
	20:00	20330	19.08	0.78	1033.9	0.78	
29/09/2004	08:00	21050	19.19	0.80	1068.4	0.80	Pump off 08:30

BOREHOLE 3

Drawdown data

Date	Time	Minutes since start pumping	Water level in borehole 3 (m below datum)	Flow meter (m3)	Average pumping rate (l/s) calculated from flowmeter	Water level in borehole 2 (m below datum)	Water level in borehole 1 (m below datum)	Comments
18/10/2004	14:00		3.04	110		6.82	2.52	50 l/min
	17:30	210	7.24			7.02	2.52	
19/10/2004	08:00	1080	8.23	165	0.85	8.02	2.52	50 l/min
	18:00	1680	8.75	195.4	0.84	8.13	2.52	
20/10/2004	08:00	2520	9.22	236.8	0.82	8.27	2.52	
	18:00	3120	9.44	265.4	0.79	8.32	2.52	
21/10/2004	08:00	3960	9.94	309.4	0.87	8.42	2.5	
	18:00	4560	10.11	338.4	0.81	8.47	2.5	
22/10/2004	08:00	5400	10.48	379.5	0.82	8.51	2.5	50 l/min
	20:00	6120	10.71	414.3	0.81	8.6	2.5	
23/10/2004	08:30	6870	10.98	451.3	0.82	8.64	2.5	
	21:00	7620	11.6	484.7	0.74	8.72	2.5	
24/10/2004	09:00	8340	12.75	525.4	0.94	8.81	2.5	
	20:30	9030	13.71	559.4	0.82	8.87	2.5	
25/10/2004	09:00	9780	14.59	596.6	0.83	8.94	2.48	
	17:00	10260	15.23	621.5	0.86	9.01	2.48	50 l/min
26/10/2004	08:00	11160	9.82	657.2	0.66	8.64	2.48	40 l/min
	18:00	11760	9.78	681.4	0.67	8.62	2.48	40 l/min
27/10/2004	08:00	12600	9.8	716.2	0.69	8.55	2.48	
	18:00	13200	9.8	741.9	0.71	8.55	2.48	
28/10/2004	08:00	14040	9.87	776.7	0.69	8.55	2.48	40 l/min
	18:00	14640	9.9	801.3	0.68	8.55	2.48	
29/10/2004	08:00	15480	9.99	843.2	0.83	8.55	2.48	
	20:00	16200	10.07	865.5	0.52	8.55	2.48	
30/10/2004	07:30	16890	10.04	893.2	0.67	8.57	2.48	
	20:00	17640	10.15	924.1	0.69	8.59	2.48	
31/10/2004	08:30	18390	10.2	958.5	0.76	8.58	2.48	
	20:30	19110	10.26	988.4	0.69	8.59	2.48	
01/11/2004	08:30	19830	10.3	1017.2	0.67	8.6	2.48	
	15:00	20220	10.34	1034.4	0.74	8.61	2.48	pump off 15:00

Recovery data

Date	Time	t (minutes since start pumping)	t' (mins since stop pumping)	t/t'	Residual drawdown s' (m)	Water level in borehole 3 (m below datum	WL in borehole 2 (m below datum)
01/11/2004	15:00	20220	0			10.34	8.61
		20221	1	20221	6.32	9.36	
		20222	2	10111	5.67	8.71	
		20223	3	6741	5.1	8.14	
		20224	4	5056	4.65	7.69	
		20225	5	4045	4.36	7.4	
		20226	6	3371	4	7.04	
		20227	7	2889.6	3.73	6.77	
		20228	8	2528.5	3.49	6.53	
		20229	9	2247.7	3.34	6.38	
		20230	10	2023	3.19	6.23	
		20231	11	1839.2	3.09	6.13	
		20232	12	1686	3	6.04	
		20233	13	1556.4	2.93	5.97	
		20234	14	1445.3	2.9	5.94	
		20235	15	1349	2.87	5.91	
		20236	16	1264.8	2.86	5.9	8.5
		20237	17	1190.4	2.85	5.89	
		20238	18	1124.3	2.84	5.88	
		20239	19	1065.2	2.83	5.87	
		20240	20	1012	2.83	5.87	
		20242	22	920.09	2.82	5.86	
		20244	24	843.5	2.81	5.85	
		20246	26	778.69	2.81	5.85	
		20248	28	723.14	2.8	5.84	8.4
		20250	30	675	2.79	5.83	
	16:00	20280	60	338	2.23	5.27	8.3
	17:00	20340	120	169.5	1.71	4.75	
	18:00	20400	180	113.33	1.54	4.58	
	19:40	20500	280	73.214	1.34	4.38	
02/11/2004	08:00	21250	1030	20.631	0.85	3.89	7.41
	09:00	21300	1080	19.722	0.83	3.87	
	10:00	21360	1140	18.737	0.81	3.85	
	11:00	21420	1200	17.85	0.8	3.84	
	12:00	21480	1260	17.048	0.79	3.83	
	13:00	21540	1320	16.318	0.77	3.81	
	14:00	21600	1380	15.652	0.75	3.79	
	15:00	21660	1440	15.042	0.74	3.78	