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Improvements to the SEPA groundwater monitoring network in the Stranraer area

Groundwater Management Programme

Commissioned Report CR/06/004N

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GROUNDWATER MANAGEMENT PROGRAMME

COMMISSIONED REPORT CR/06/004N

Improvements to the SEPA groundwater monitoring network in the Stranraer area

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Summary

- Three boreholes have been successfully drilled into superficial deposits at Culgrange Farm, Mark Farm and Whitecrook Farm, near Stranraer to depths of 10 m, 12 m and 12 m respectively.
- All three sites are considered suitable for groundwater monitoring purposes. They are all located on pasture land typical of much of the Stranraer basin. The new site at Whitecrook is away from the pollution source that is thought to have caused high nitrate concentrations in the original well.
- The boreholes have been constructed with a gravel filter pack of approximately 80 mm thickness which is designed to minimise sand and silt intrusion.
- All three boreholes are intended for use as a water supply source by local farmers. Regular use will help to keep the boreholes flushed out and the water 'fresh'. It will also create a small source catchment around each borehole, so making them more representative of local groundwater quality for monitoring purposes.
- Initial chemistry results show that nitrate concentrations are low at both Whitecrook and Mark Farm boreholes. The Culgrange Farm borehole has yet to be sampled.

1 Introduction

In September 2005, the Water Environment Division of the Scottish Executive commissioned the British Geological Survey (BGS) to improve the coverage, in the Stranraer area, of the groundwater monitoring network operated by the Scottish Environment Protection Agency (SEPA).

This report describes the work carried out to construct three new water abstraction boreholes at farms located to the south and east of Stranraer (Figure 1). The existing network coverage was limited to three sites at Whitecrook farm, the Caledonian Cheese factory in Stranraer and Kildonan Farm (Figure 2), only one of which (Whitecrook Farm) was within the area of the highly productive superficial aquifer (BGS, 2004) (red area in Figure 2) that covers most of the basin. A further site at East Galdenoch farm in the centre of the Stranraer basin was also under consideration by SEPA for inclusion in the network.

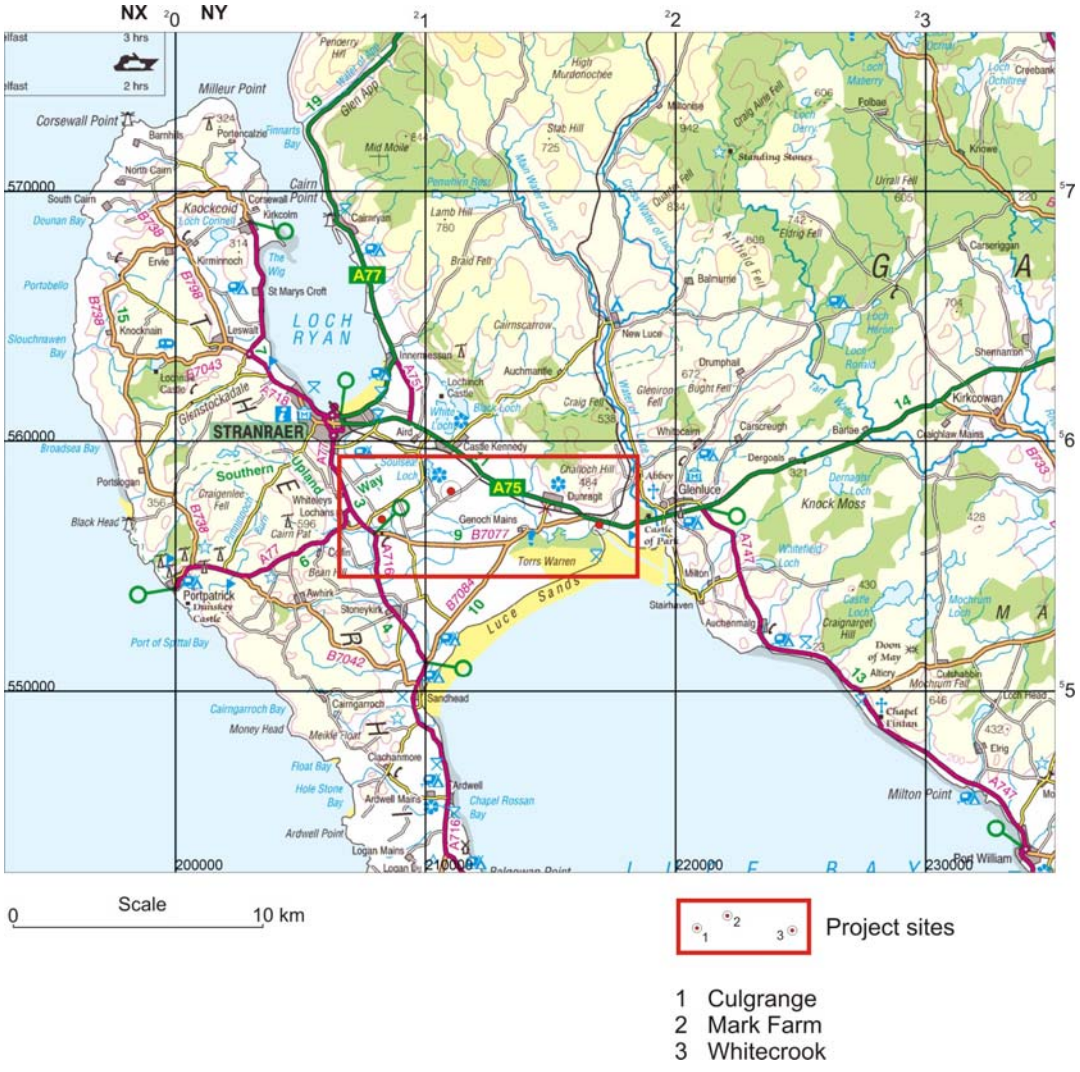


Figure 1 Map of Stranraer area

Apart from these sites, there were no other existing boreholes present in the area that were suitable for monitoring purposes by SEPA. However, nitrate concentrations were consistently in excess of 15 mg/l as N (drinking water limit 11.3 mg/l) at Whitecrook and, on inspection, this source was shown to be located in an area of the farm where surface contamination was likely to be affecting results. A replacement site for monitoring shallow groundwater was, therefore, required at Whitecrook to assess the true range of nitrate concentrations in the local superficial aquifer.

An assessment was made of the monitoring situation near Stranraer by SEPA and BGS during a field visit to the area. It was concluded that a further three sites were required in the Stranraer basin in order to monitor adequately the superficial aquifer. It was also agreed between SEPA and BGS that dormant observation boreholes, pumped only when SEPA took samples every 3 months, would not be as desirable as regularly pumped sources. Therefore, locations were chosen where local farmers could connect services and use the boreholes for supply purposes on a regular basis.

Owing to the great thickness of the glacial superficial cover, the underlying Permian bedrock aquifer was considered to be inaccessible for monitoring. All impacts on groundwater from local land use pressures were assumed to be restricted to the superficial aquifers.

1.1 OBJECTIVES

The objectives of the project were:

- To provide monitoring points within the superficial aquifer near Stranraer.
- To locate suitable sites for the drilling of three abstraction boreholes in the area to the south and east of Stranraer for the expansion of the SEPA groundwater monitoring network.
- To replace the original monitoring point at Whitecrook Farm.
- To site the boreholes within typical pasture farmland to gain further knowledge of the normal range of nitrate concentrations in shallow groundwater.
- The borehole sites were to be selected at farms where the farmers were likely to use the sources on a regular basis in order to keep them ‘flushed out’. This will also create a small source catchment area at each site that will be more representative of the water quality of the aquifer compared to a dormant site.

1.2 GEOLOGY AND HYDROGEOLOGY

Figure 2 shows areas, marked in red, which are predominantly highly productive fluvioglacial and alluvial sand and gravel aquifers. Areas on the coastal margins that are coloured brown are moderately productive raised marine aquifers comprising sand, gravel and silt. These superficial deposits are unusually thick in the Stranraer area with typical thicknesses in the centre of the basin exceeding 30 m. They were proved in one borehole near Castle Kennedy (NX 115 605) to be 76 m thick and to comprise a complex sequence of sand and gravel with lacustrine laminated clay and silt.

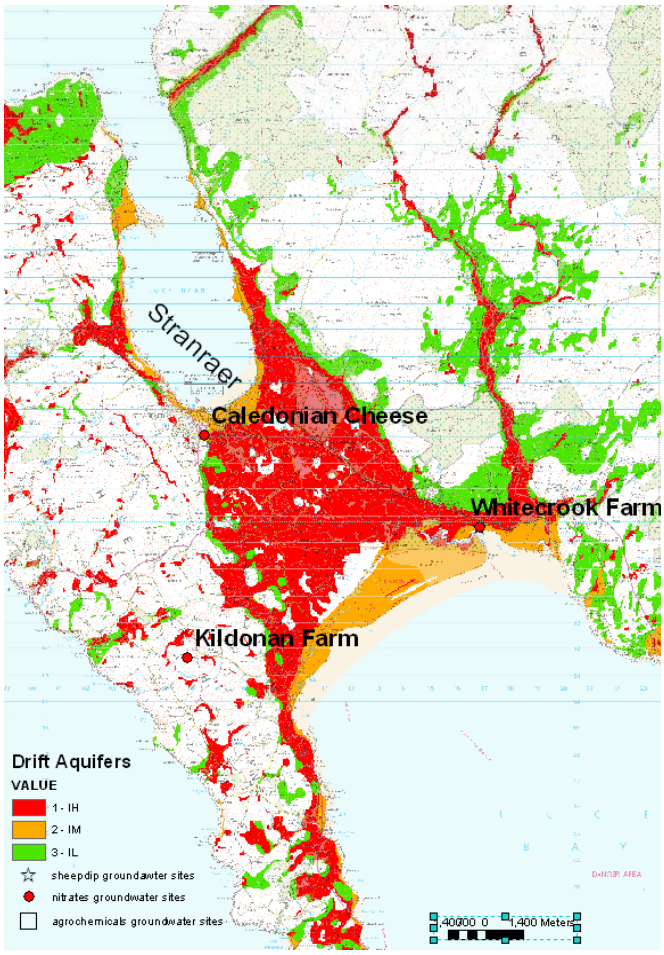


Figure 2 The Stranraer basin and existing SEPA monitoring boreholes (colours refer to high, moderate and low productivity superficial aquifers).

The moundy topography around Castle Kennedy in the north-west gives way, to the south, to generally flatter land underlain by glacial outwash deposits. A series of drainage channels and river terraces have been formed within the latter by meltwater streams and, more recently, watercourses in the Piltanton Burn catchment.

There are no exposures of bedrock in the low-lying parts of the basin. The white areas in Figure 2 show shallow bedrock to be restricted to higher ground bordering the basin.

Groundwater is present within the superficial deposits at various depths in a complex sequence of localised shallow, perched, aquifers. Clay layers within the predominantly sandy sequence underlie perched aquifers and partly determine the location of springs, surface water bodies and wetlands that are present in various localities across the area. It is thought that groundwater, in general, discharges at the coasts and to the main surface water catchment in the basin, the Piltanton Burn, before it flows to the sea in the east, near Torrs Warren (Figure 1).

The thickness of the unsaturated zone above the water table varies according to the presence of impermeable clay layers and the topography. In general terms, the water table is shallower beneath river floodplains and low-lying ground, with the higher parts of the basin having greater unsaturated zone thicknesses.

The presence of discontinuous beds of higher permeability gravel interspersed with broad spreads of sand across much of the basin has led to localised areas of higher permeability and complex groundwater flow patterns.

1.3 THE DRILLING PROGRAMME

The drilling programme for the project was designed and let by BGS to IPR Drilling of Kilmarnock. In order to avoid drilling expensive abstraction boreholes in areas of unsuitable ground, pilot boreholes were drilled at all three sites to confirm the presence of useable groundwater. Where successful, permanent abstraction boreholes were then drilled at the same location. This system proved its worth at Culgrange Farm, where the first pilot borehole encountered clayey sand overlying clay, with very little water present. It was only at the second site, 120 m to the north, where a gravel aquifer was proved.

Details of the drilling specification are given in Appendix 1. The abstraction boreholes were all drilled using 350 mm diameter percussion drilling equipment. A 125 mm od diameter plastic slotted well screen (Figure 3) was installed in each borehole and a 1.9 – 2.6 mm diameter washed gravel filter pack installed adjacent to the screened section (Figure 4).

Figure 3 125 mm diameter plastic well screen was used in the boreholes

Two bags of bentonite pellets were emplaced directly above the gravel pack, with cement grout added above the bentonite to approximately 4 m bgl. Figure 5 shows the construction details of the boreholes.

Figure 4 A 1.9-2.6 mm diameter gravel filter pack was used in all boreholes

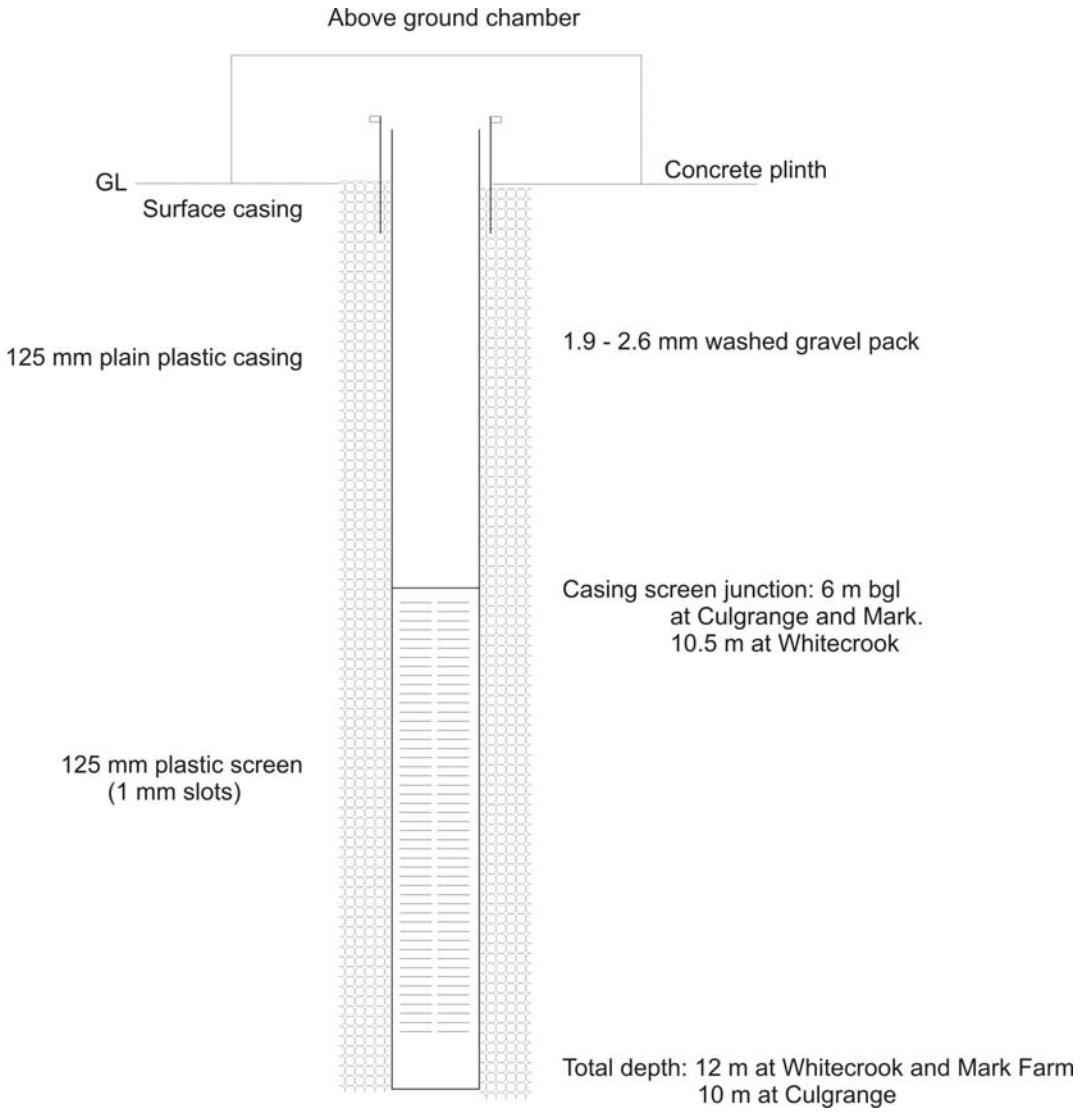


Figure 5 Typical borehole construction

The filter pack is approximately 80 mm thick and is designed to restrict the ingress of fine-grained sand to the boreholes. All three boreholes, upon completion, were air-lifted for a minimum of 3 hours. Each borehole was completed at ground level with a concrete chamber within which there is sufficient space to install a water pressure vessel for supply purposes (the borehole at Mark farm was fitted with such a tank during the site work). Each borehole was equipped with an electrical submersible pump, complete with cabling to the chamber. Ducting to enable water pipes and surface cables were also installed in the surface concrete plinth.

A short pumping test was carried out on each borehole, during which the water level variation in the boreholes was measured, along with the flow rate of the pumped water. The results of the testing are given in the following section.

2 The boreholes

2.1 CULGRANGE FARM

Culgrange Farm is located 4 km south of Stranraer. The borehole site is 400 m north of the Piltanton Burn (Figure 6).

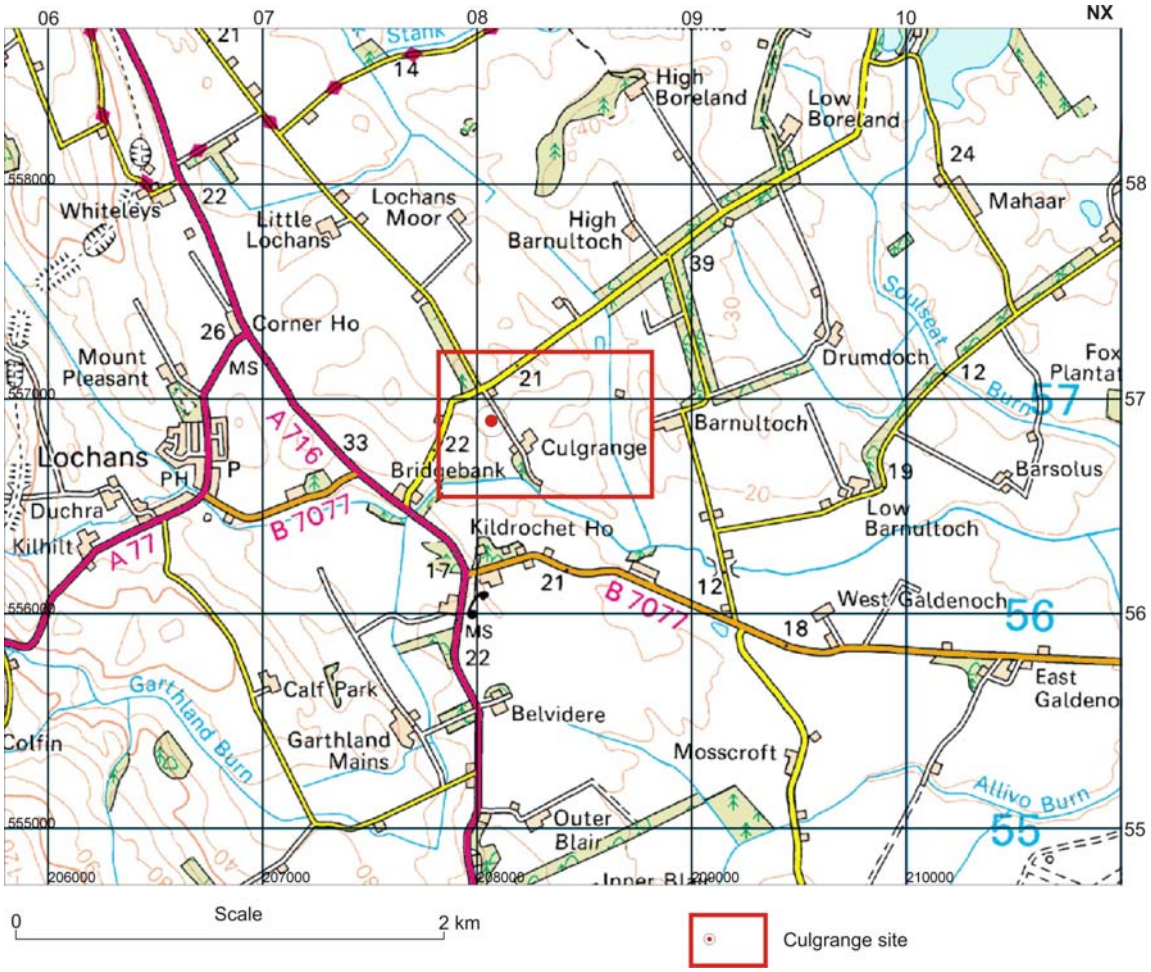


Figure 6 Culgrange Farm location, immediately to the north of the Piltanton Burn that flows eastwards

2.1.1 Setting

The borehole site is located on sloping ground approximately 120 m north of the farmhouse. There are no obvious sources of nitrate within 100 m of the site (Figures 7 and 8). A spring is present immediately adjacent to the borehole (Figure 8) and was flowing in November 2005 at an approximate rate of 2 litres/second (l/s).

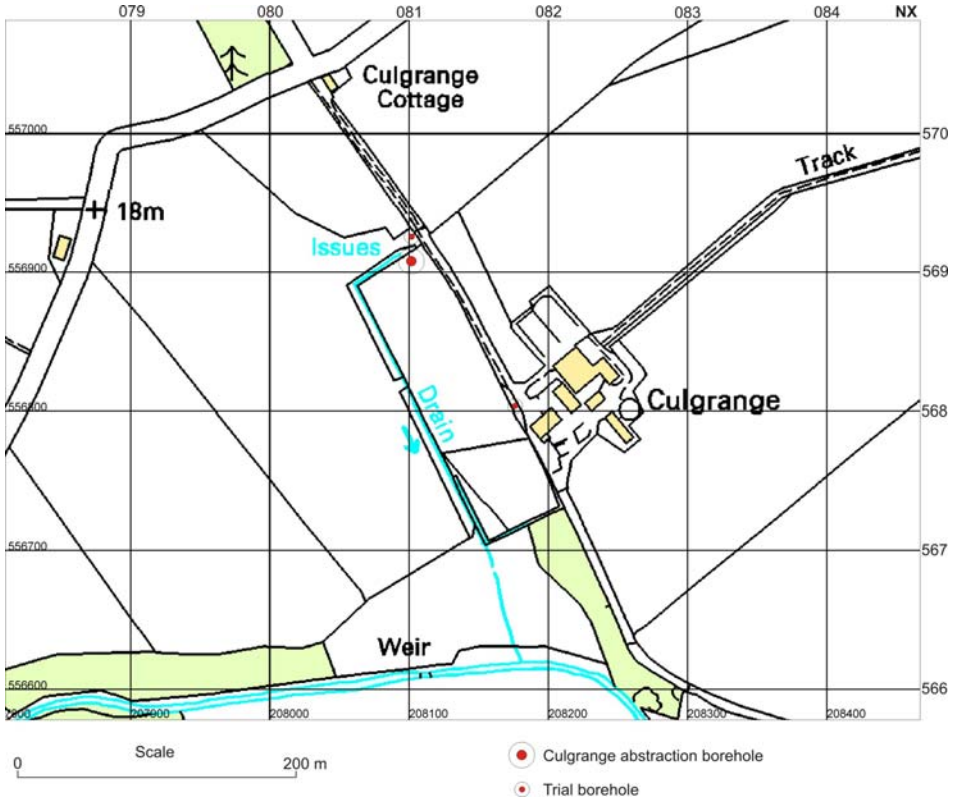


Figure 7 Culgrange Farm

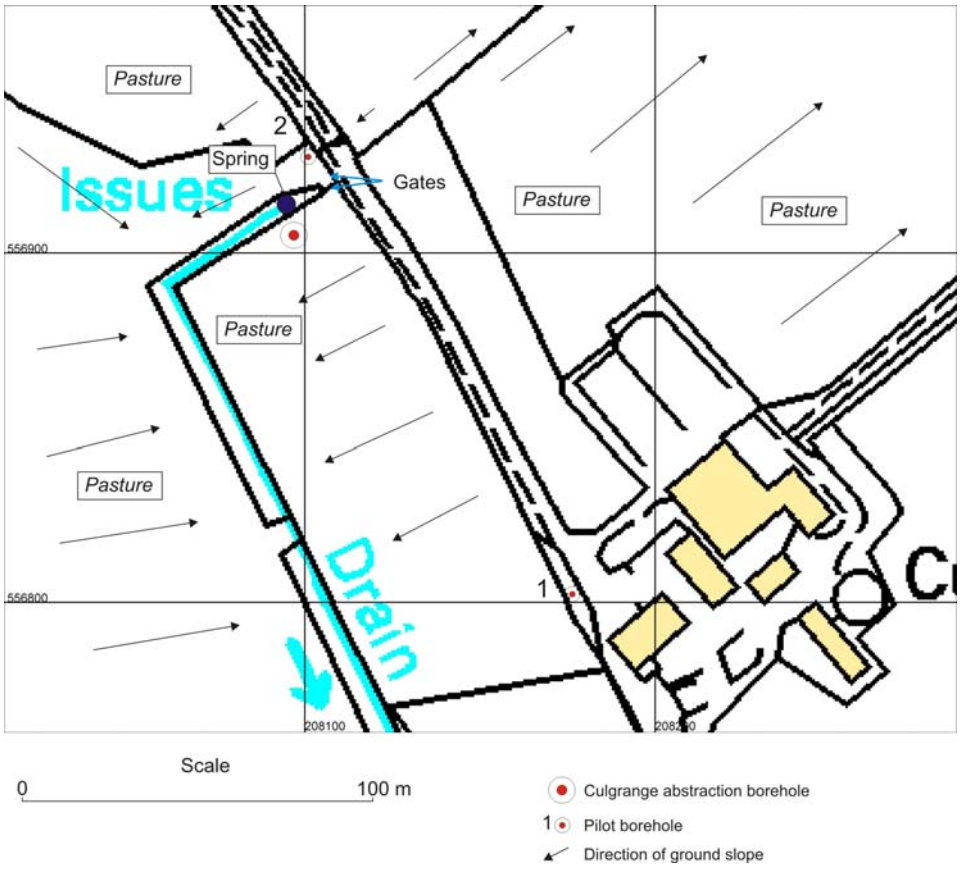


Figure 8 Culgrange Farm site map

Figure 9 shows the site, with the borehole near the middle of the scene. The spring is to the left of the hedge. The farm buildings are to the right of the photo.

Figure 9 Culgrange borehole

Access to the borehole is via a farm track and two gates. The borehole is approximately 25 m from the track.

Figure 10 shows the distribution of superficial deposits in the farm area.

2.1.2 Drilling

The first pilot borehole (1 in Figure 8) proved 10 m thickness of silty sand and clay. There was very little water in this borehole. Consequently, the site, in the farmyard, was deemed unsuitable for an abstraction borehole and a second pilot hole was drilled by the spring (Figure 8). This proved sandy gravel to 10 m depth and contained a significant amount of groundwater within 5 m of ground level. The abstraction borehole was, therefore, sited close to this location.

The borehole was drilled to 10 m depth. Plain casing was inserted to 6 m bgl and well screen from 6 m to 10 m bgl. The well head chamber is located close to the hedge.

The geological log was as follows:

Depth (m)	Description
0 – 2.5	Medium- to coarse-grained sand and well rounded gravel.
2.5 – 8.0	Mainly coarse-grained sand and gravel
8.0 – 9.0	Sand and gravel, becoming finer-grained with less gravel.
9.0 – 9.20	Clay, red/brown, stiff.
9.20 – 10.0	Sand, medium-grained, with occasional gravel clasts.

Upon completion, the rest water level was 3.00 m bgl. Images of the drilling operation and final completion are shown in Figures 11 to 16.

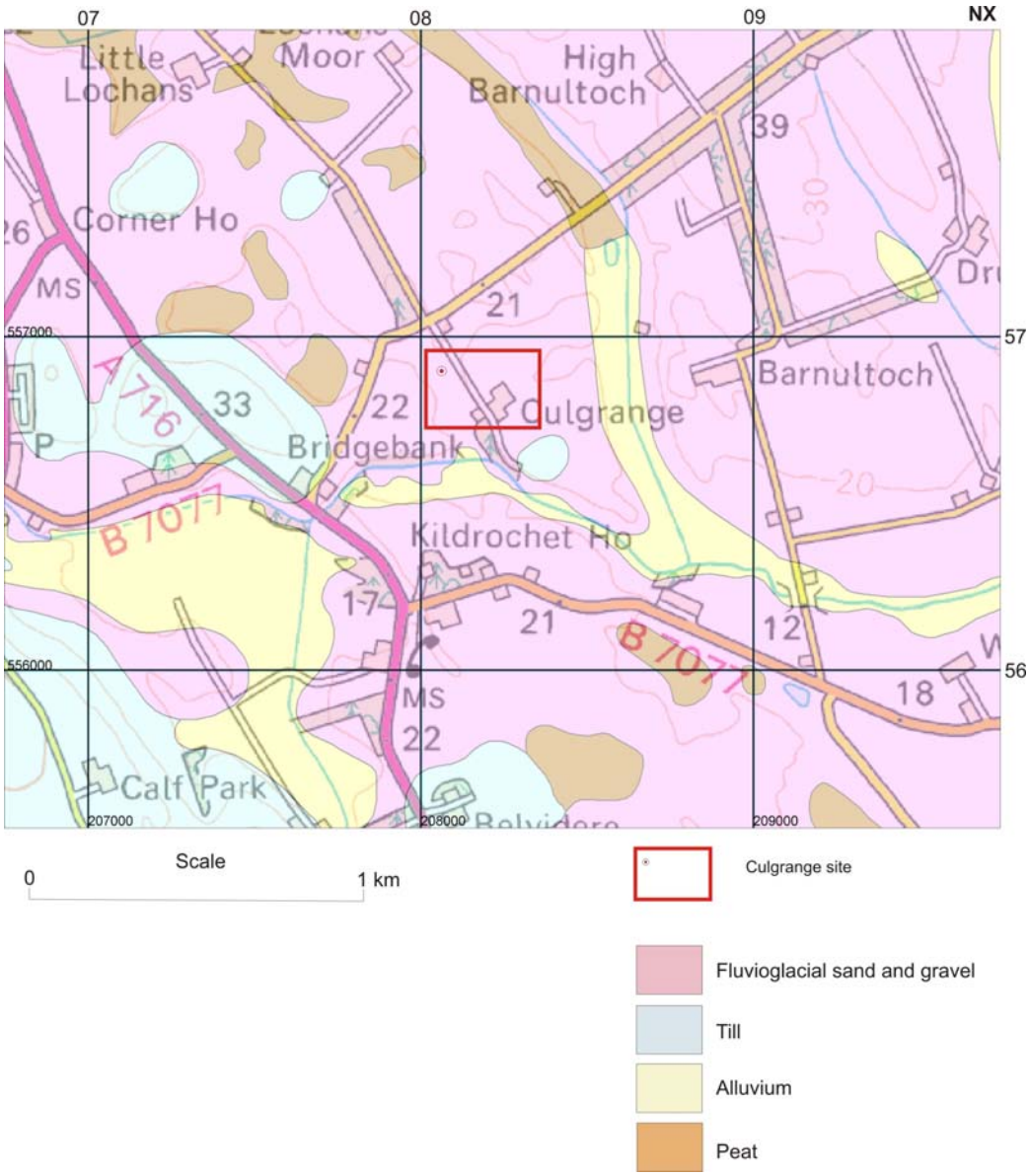


Figure 10 Culgrange superficial geology

Figure 11 The Culgrange drilling site

Figure 12 Emptying sand and gravel from the drill tool

Figure 13 Adding water to aid the drilling process

Figure 14 A sample of the aquifer material

Figure 15 Culgrange sand from 9.5 m bgl

Figure 16 The completed surface chamber with the borehole in the bottom right cormer

2.2 MARK FARM

Mark Farm is located 1 km to the south-east of Soulseat Loch (Figure 16).

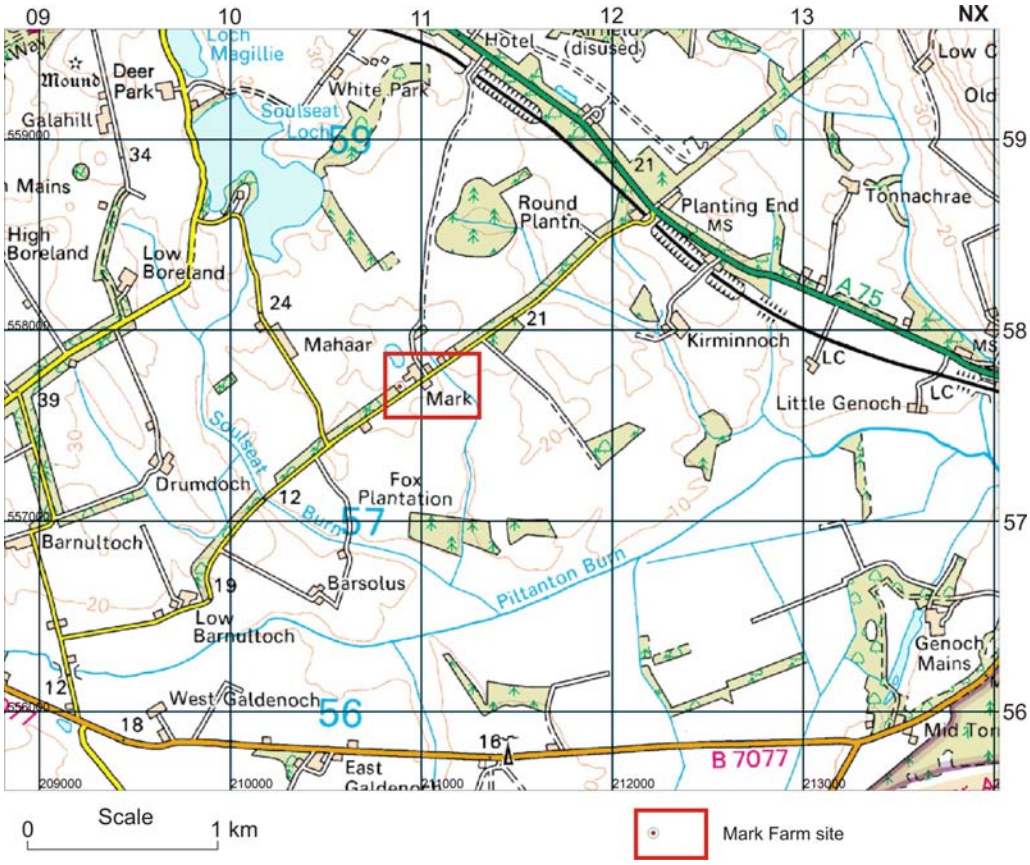


Figure 17 Location of Mark Farm

2.2.1 Setting

The borehole is located at the edge of a small, flat, pasture field immediately to the west of the farm buildings. There are no obvious sources of nitrate within 150 m of the borehole. A wooded area lies immediately west of the borehole, with a wetland area to the north. Access for future sampling is straightforward (Figures 18 and 19).

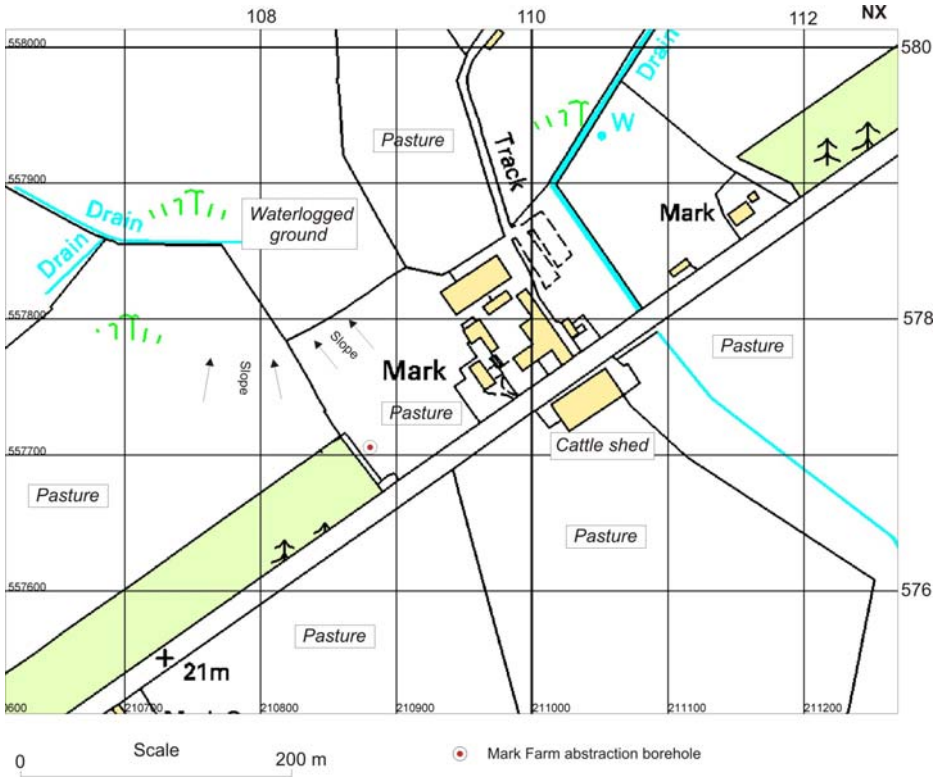


Figure 18 Mark Farm location

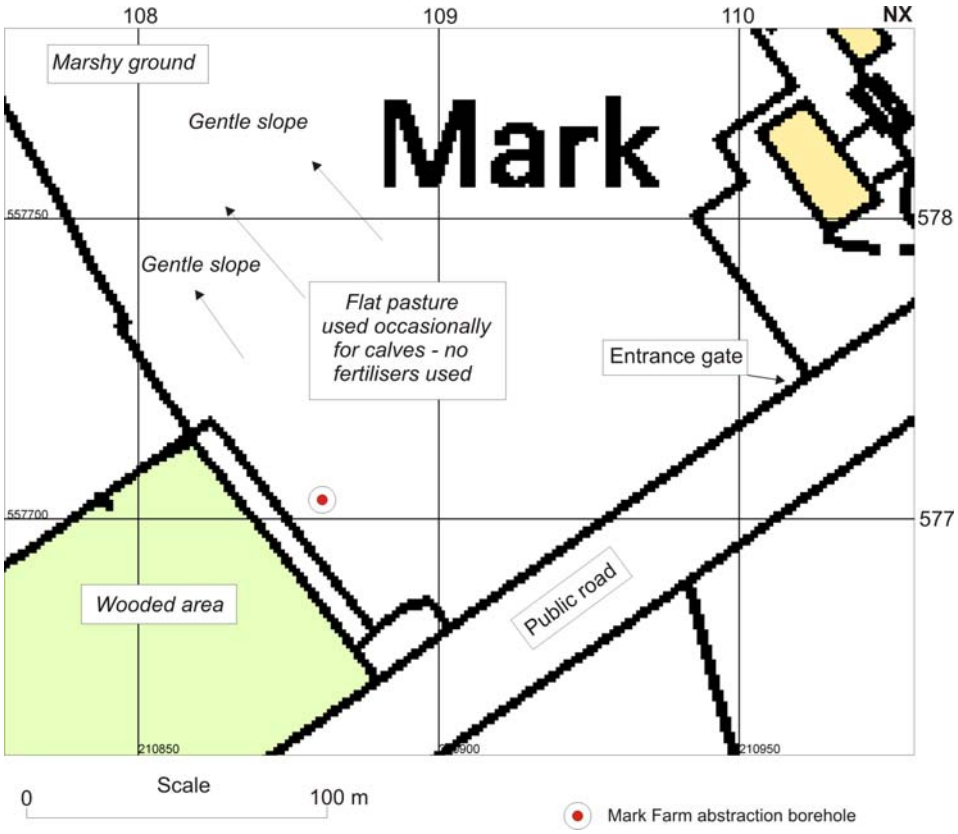


Figure 19 Mark Farm site

Figure 20 shows the distribution of superficial deposits around Mark Farm.

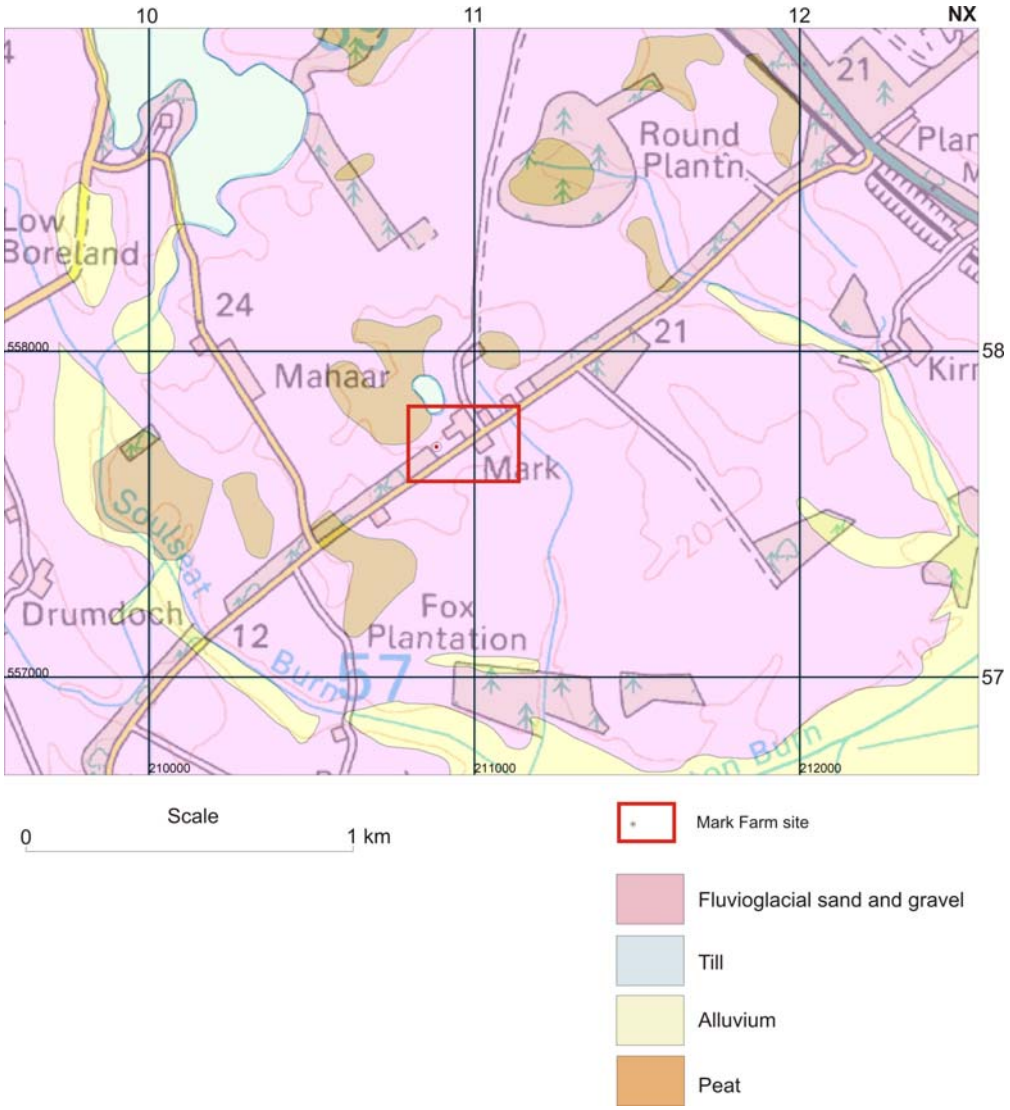


Figure 20 Mark Farm superficial geology

2.2.2 Drilling

The pilot borehole was drilled on 3 November 2005 and proved 15 m thickness of sand and pebbly sand. This site was considered suitable for a permanent abstraction borehole because of land use, the acceptable distance from the cattle sheds at the farm, but close enough for the farmer to be able to lay cables and pipes to it from the farmhouse.

The abstraction borehole was drilled to 12 m depth, with 6 m plain casing and 6 m screen below.

The geological log was as follows:

Depth (m)	Description
0 – 2.0	Medium-grained brown sand with some fine to coarse gravel clasts
2.0 – 7.5	Fine-grained brown sand with occasional fine to coarse gravel clasts
7.5 – 8.0	Fine-to coarse-grained brown sand
8.0 – 10.0	Fine- to coarse-grained with occasional pebbles
10.0 – 10.5	Fine- to coarse gravel
10.5 – 11.0	Soft to moderately stiff dark brown clay
11.0 – 12.0	fine- to coarse-grained brown sand with some gravel

Upon completion, the rest water level was 5.20 m bgl. Figure 21 shows the surface chamber.

Figure 21 Mark Farm well head completion

Figures 22 and 23 show the detail inside the chamber, with the farmer's pressure vessel already installed.

Figure 22 Mark Farm chamber detail, with pressure vessel

Figure 23 Mark Farm well head

2.3 WHITECROOK FARM

Whitecrook Farm is located 2.5 km west of Glenluce, adjacent to the main A75 road from Dumfries to Stranraer (Figure 24).

2.3.1 Setting

The borehole is located to the south of the A75, away from the farm building area. The site is near the edge of a short, but quite steep, slope leading down to a raised beach feature (Figures 25 and 26).

The new borehole is approximately 55 m north-east of the original SEPA monitoring well at Whitecrook which has consistently returned very high nitrate concentrations, thought to be due to polluted surface water flowing overland from a cattle trough (Figure 26). Cattle slurry was regularly deposited on the field in which both water sources are situated, but it is not known whether the very high nitrate concentrations found in the well will be present in the new borehole which is not affected by trough run-off.

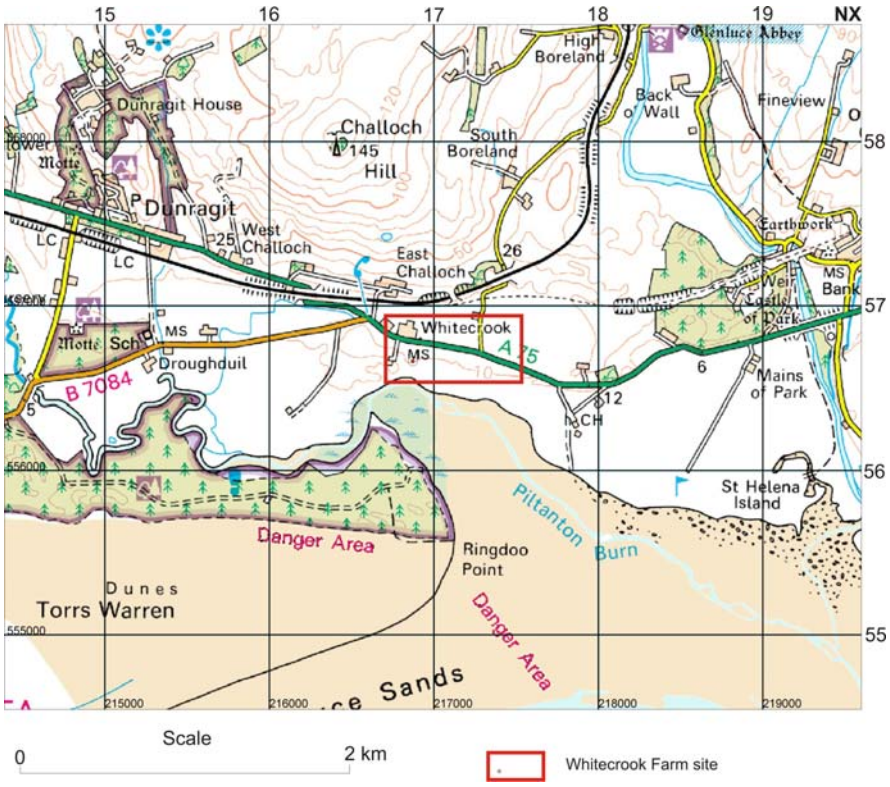


Figure 24 Whitecrook Farm location

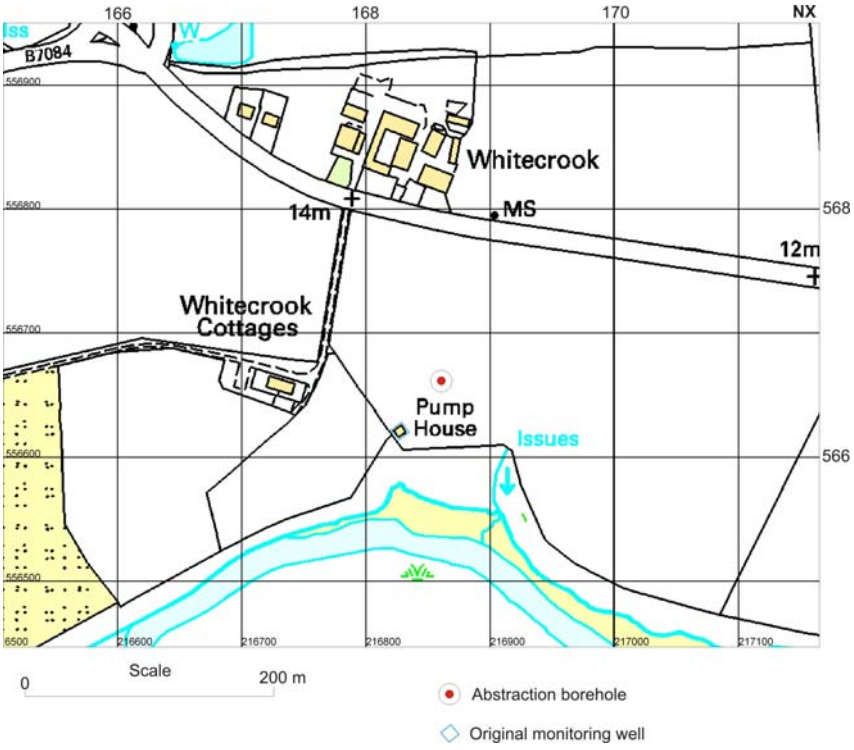


Figure 25 Whitecrook Farm location

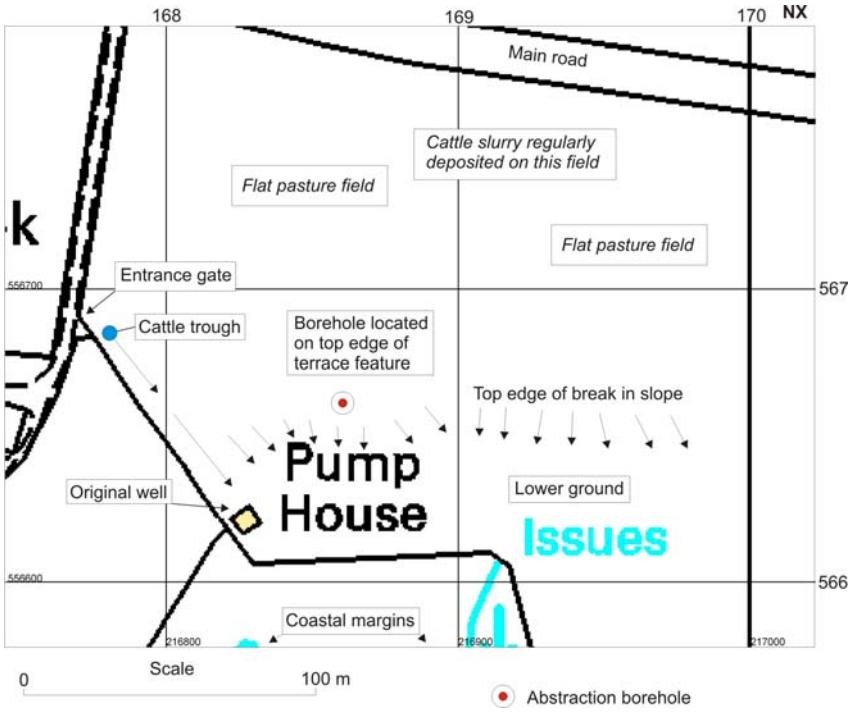


Figure 26 Whitecrook Farm site

Figure 27 shows the distribution of superficial deposits around Whitecrook Farm.

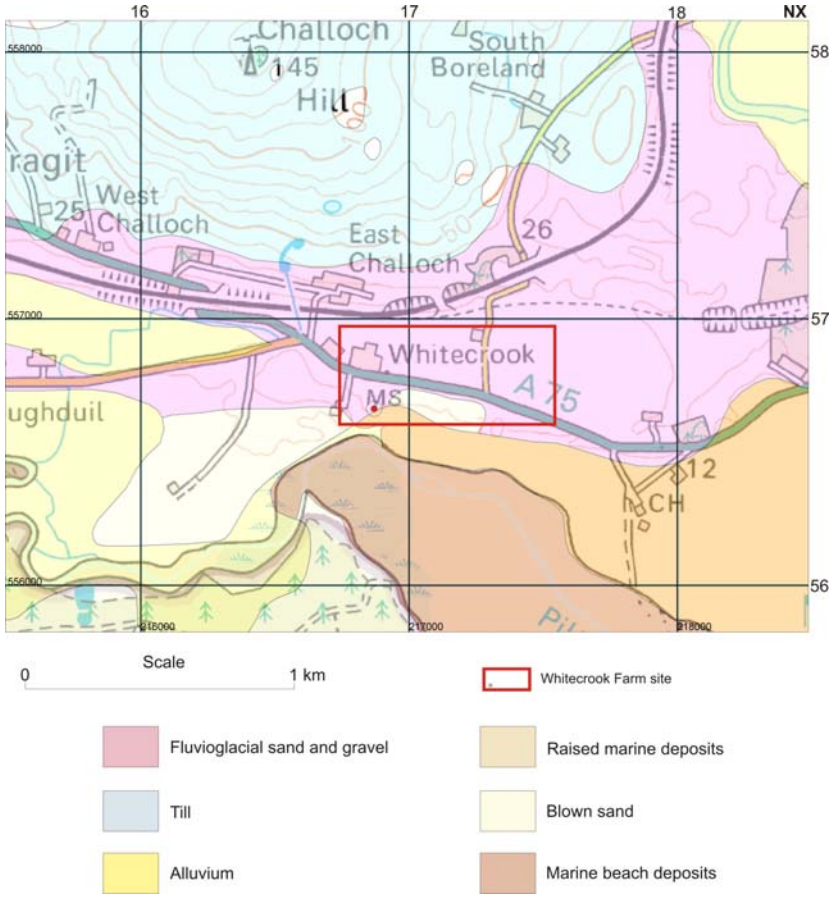


Figure 27 Superficial deposits around Whitecrook Farm

The new borehole is located very close to the tidal estuary of the Piltanton Burn and the rest water level in the borehole is clearly affected by the tide.

2.3.2 Drilling

The pilot borehole was drilled on 3 November 2005, with favourable results achieved. As a consequence, the permanent abstraction borehole was also drilled at this site.

The geological log was as follows:

Depth (m)	Description
0.0 – 6.0	Fine-grained reddish-brown sand with rare medium pebbles
6.0 – 7.5	Fine-grained grey sand with gravel up to boulder size
7.5 – 9.25	Stiff grey, slightly silty clay with a high proportion of dark organic material.
9.25 – 9.35	Thin bed of fissile woody material and other plant matter. Organic smell.
9.35 – 10.5	Stiff grey clay with occasional inclusions of organic material. Some rounded cobbles.
10.5 – 11.5	Rounded beach cobbles with fine- medium-grained grained grey sand
11.5 – 12.0	Silty fine-grained grey sand with rounded cobbles

Plastic 125 mm casing was installed to 10.5 m bgl. 125 mm diameter screen is present from 10.5 m to 12.0 m bgl. Figure 27 shows the air-lifting arrangements at Whitecrook Farm, whereby sand and silt is flushed out of the borehole using an air compressor.

Figure 28 Whitecrook Farm borehole air-flush arrangement

Figure 29 shows the trough area near the old well which has returned consistently high nitrate concentrations. Figures 29-33 show general scenes at Whitecrook and the new well head.

Figure 29 The waterlogged trough area at Whitecrook Farm

Figure 30 The slurry field at Whitecrook Farm

Figure 31 The trough and old well (by windmill) at Whitecrook Farm

Figure 32 Whitecrook Farm borehole showing the borehole in the top corner

Figure 33 Whitecrook Farm borehole chamber and the Piltanton estuary

Figure 34 Whitecrook Farm well head with sampling tube ready for SEPA

2.4 PUMPING TESTS

A constant rate test was carried out for 6-7 hours on each of the boreholes during November 2005. Details of the tests are given in Table 1 and Appendix 1. Values for transmissivity are calculated from the pumping test results and, although this characteristic is not required for assessing the long-term use of the boreholes, it is included for reference as it is a standard aquifer property.

Table 1 Pumping test details

Site	Rest water level (mbgl)	Pumping water level (mbgl)	Drawdown (m)	Duration of test (hours)	Discharge rate (l/s)	Transmissivity (m^2/day)
Culgrange	3.00	3.59	0.59	6	0.5	194
Mark farm	5.50	6.97	1.47	7	0.26	14
Whitecrook	6.80	8.19	1.39	6	0.21	35

Of the three pumping tests carried out, the test at Culgrange shows the highest value of transmissivity (T), at 194 m^2/d. The dominant lithology here is sand and gravel, with a small band of clay (0.2 m) at around 9 m below the surface. The borehole depth of 10 m gives a likely hydraulic conductivity of close to 19 m/d, which appears reasonable for deposits of this type. The drawdown curve fails to reach a steady state over the period of the test (6 hours), thereby preventing the specific capacity of the borehole from being determined. The final drawdown recorded during the test constrains it to a maximum value of around 73 m^2/d, with an abstraction rate of 43.2 m^3/d.

Mark Farm shows a much lower value of T (14 m^2/d). The Mark Farm borehole passes through 12 m of sands and gravels, with a higher proportion of sand than was encountered at Culgrange. The overall hydraulic conductivity of the deposits reflects this, with a likely value of around 1 m/d. The test appears to show a steady state drawdown of around 1.6 m at later times, giving a specific capacity of 14.1 m^2/d (with an abstraction rate of 22.5 m^3/d).

The test at Whitecrook Farm appears to have suffered from significant well storage, which has affected the early time data. Nevertheless, it was possible to determine a T of 35 m^2/d from the rest of the curve. The borehole was drilled to 12 m depth, passing through dominantly fine sands, with some gravels and lesser amounts of clay and peat. These deposits have an overall hydraulic conductivity of close to 3 m/d.

The drawdown appears to equilibrate more rapidly than the other boreholes tested, although the possible influence of tides makes interpretation of late-time data more difficult. This borehole is particularly close to the sea, leading to significant oscillations in the time-drawdown curve. Faster equilibration may be due to an increasing proportion of gravel with depth - a pattern shown by the borehole log - which may lead to a more ready supply of water at later times. Assuming a final drawdown of 1.6 m, a specific capacity of 11.3 m^2/d is obtained (with an abstraction rate of 18.1 m^3/d).

2.5 LONG-TERM YIELD

Table 2 shows details of the pumps installed and the flow rates. These rates are considered to be suitable for long-term use of the boreholes for regular abstraction, assuming intermittent daily usage using a pressure vessel. All pumps are single phase. The rising main is 32 mm alkathene. Each borehole is fitted with a restrictor valve at the well head.

Table 2 Pump installation details

Site	Pump type	Power use (Kw)	Depth (m bgl)	Flow rate (l/s)
Culgrange	Lowara 2GS07M	0.75	10 m	0.5
Mark Farm	Lowara GSL02FM	0.37	10 m	0.21
Whitecrook	Lowara GSL02FM	0.37	10 m	0.20

3 Chemistry

The results from initial water sampling in the three boreholes are presented below. The Culgrange borehole has yet to be sampled because of access difficulties at the site. The sampling was carried out by members of staff from the SEPA Dumfries office.

Table 3 Whitecrook Farm Borehole chemistry

Suspended Solids	**pH**	**ElecCond-25**	**Alkalinity**	**Hardness**	**TOC**	**Ammonia**	**TON**	**Nitrite**	**Nitrate as N**
mg/L	pH units	µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
130	7.78	486	120	457	4.14	0.04	1.22	0.026	1.19
o-Phosphate	**Chloride**	**Silicate**	**Na**	**K**	**Ca**	**Mg**	**Fe**	**Mn**	
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
0.003	140	13	25.4	10.2	37.3	28.2	6.61	0.268	

Table 4 Mark Farm Borehole chemistry

Suspended Solids	**pH**	**ElecCond-25**	**Alkalinity**	**Hardness**	**TOC**	**Ammonia**	**TON**	**Nitrite**	**Nitrate as N**
mg/L	pH units	µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
2	7.56	538	219	170	4.2	0.04	1.9	0.051	1.85
o-Phosphate	**Chloride**	**Silicate**	**Na**	**K**	**Ca**	**Mg**	**Fe**	**Mn**	
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
0.003	43.9	12.4	37.1	26.1	24.1	9.27	0.14	0.0564	

Table 5 Mark Farm well chemistry

Suspended Solids	**pH**	**ElecCond-25**	**Alkalinity**	**Hardness**	**TOC**	**Ammonia**	**TON**	**Nitrite**	**Nitrate as N**
mg/L	pH units	µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
2	7.58	449	99.8	297	2.31	0.04	5.36	0.03	5.33
o-Phosphate	**Chloride**	**Silicate**	**Na**	**K**	**Ca**	**Mg**	**Fe**	**Mn**	
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
0.003	37.1	15	14.8	0.781	33.6	14.4	0.04	0.0707	

The results for the new boreholes Mark Farm and Whitecrook Farm show the presence of low concentrations of nitrate in the superficial aquifer. Electrical conductivity values are within the range normally present in superficial aquifers. Iron and manganese are very high in the Whitecrook borehole. More detailed analyses are required in order to carry out a more thorough assessment of the groundwater chemistry.

4 Conclusions

- Three boreholes have been successfully drilled into superficial deposits at Culgrange Farm, Mark Farm and Whitecrook Farm, near Stranraer to depths of 10 m, 12 m and 12 m respectively.
- All three sites are considered by BGS to be suitable for groundwater monitoring purposes. They are all located on pasture that is typical of much of the Stranraer basin. The new site at Whitecrook is located further from the pollution source thought to have caused high nitrate concentrations in the original well and draws water from a greater depth.
- The boreholes have been constructed with a gravel filter pack of approximately 80 mm thickness which is designed to minimise sand and silt intrusion. A small amount of fine sand has been observed whilst pumping water from the Whitecrook borehole, but this is not significant and is expected to minimise with use.
- All three boreholes are intended for use as a water supply source by local farmers. Regular use will help to keep the boreholes flushed out and the water 'fresh'. It will also create a small source catchment around each borehole, so making them more representative of local groundwater quality for monitoring purposes.
- The initial chemistry results reveal that low concentrations of nitrate are present in both Mark and Whitecrook Farm boreholes. The Culgrange Farm borehole has yet to be sampled.

Appendix 1

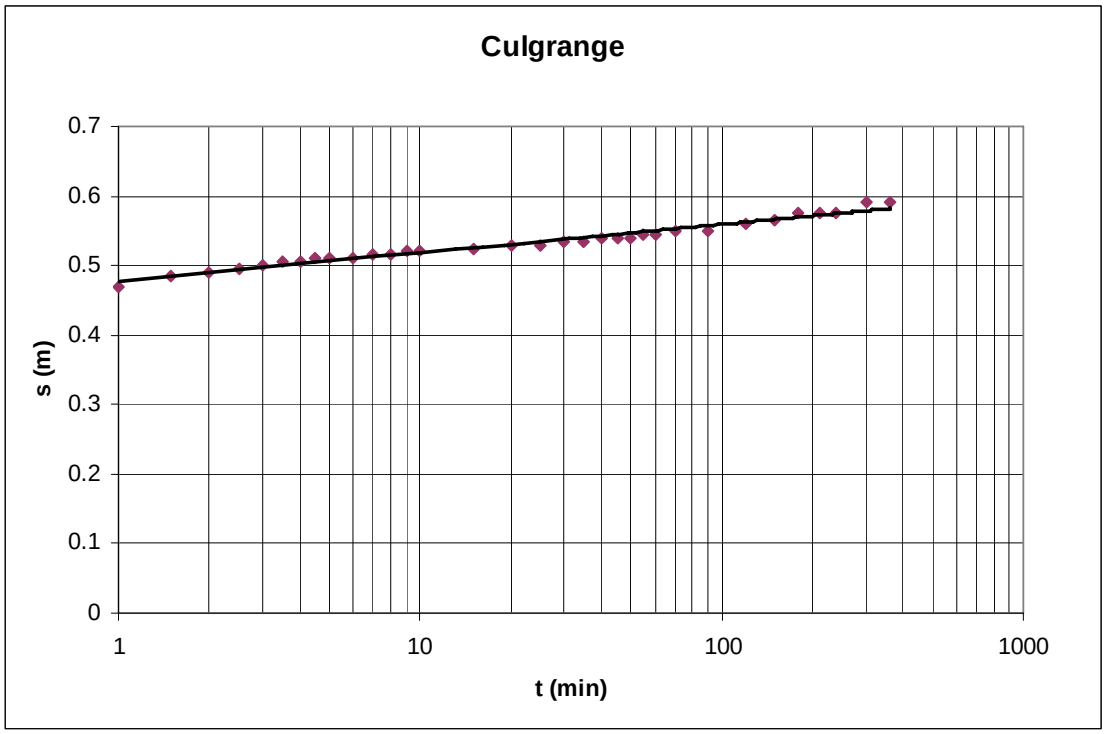
Pumping test results

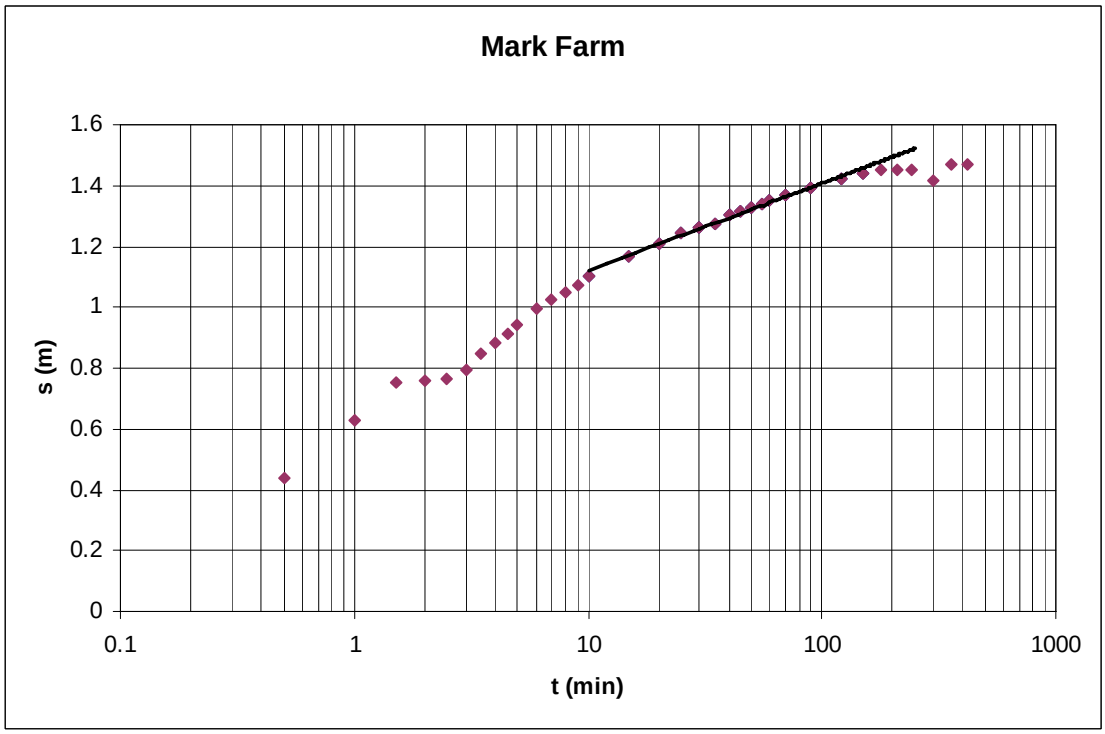
Test flow rates: Culgrange - 0.5 l/s

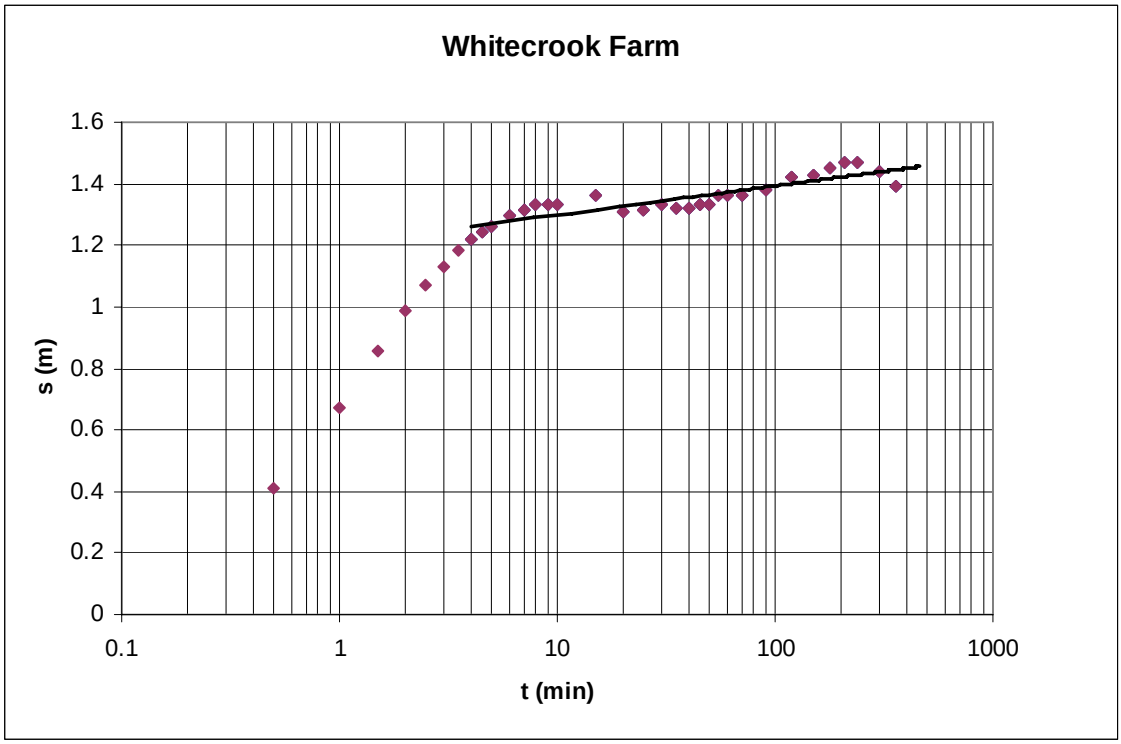
Mark Farm – 0.26 l/s

Whitecrook – 0.21 l/s

Time (min)	s (Culgrange)	s (Mark Farm)	s (Whitecrook Farm)
0	0	0	0
0.5	0.34	0.44	0.41
1	0.47	0.63	0.67
1.5	0.485	0.75	0.855
2	0.49	0.76	0.985
2.5	0.495	0.765	1.07
3	0.5	0.795	1.13
3.5	0.505	0.85	1.185
4	0.505	0.885	1.22
4.5	0.51	0.915	1.245
5	0.51	0.945	1.26
6	0.51	0.995	1.295
7	0.515	1.025	1.315
8	0.515	1.05	1.33
9	0.52	1.075	1.33
10	0.52	1.1	1.33
15	0.525	1.17	1.365
20	0.53	1.21	1.31
25	0.53	1.245	1.315
30	0.535	1.26	1.33
35	0.535	1.275	1.32
40	0.54	1.305	1.32
45	0.54	1.315	1.33
50	0.54	1.33	1.335
55	0.545	1.34	1.36
60	0.545	1.35	1.36
70	0.55	1.37	1.36
90	0.55	1.395	1.38
120	0.56	1.42	1.42
150	0.565	1.44	1.43
180	0.575	1.45	1.45
210	0.575	1.45	1.47
240	0.575	1.45	1.47
300	0.59	1.415	1.44
360	0.59	1.47	1.39
420		1.47	


Culgrange
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
s (m)
1
10
100
1000
t (min)


Mark Farm
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
s (m)
0.1
1
10
100
1000
t (min)


Whitecrook Farm
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
s (m)
0.1
1
10
100
1000
t (min)