Clones Public Water Supply

Scotshouse Boreholes

Groundwater Source Protection Zones

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1 Introduction

The two boreholes at Scotshouse are used to supply the Clones Public Water Supply.

The objectives of the report are as follows:

- To delineate source protection zones for Scotshouse boreholes.
- To outline the principal hydrogeological characteristics of the Scotshouse area.
- To assist Monaghan County Council in protecting the water supply from contamination.

2 Location, Site Description and Well Head Protection

The two boreholes are located near Scotshouse, approximately 0.4 km and 0.8 km respectively, north west of Scotshouse village and represent the groundwater portion of the source that supplies the people of Scotshouse and Clones.

The two boreholes were drilled in 1998. Both wells are 70 m deep and are lined with steel casing to bedrock, after which they are unlined to the bottom of the hole. The boreholes are situated in lay-bys, off a minor road leading out of Scotshouse. Observation wells are located within 5 m of each borehole. With the exception of one observation well, the boreholes have been welded closed with a metal plate, as they are not yet in production. The County Council expects to install the pumps in the summer of 2000.

3 Summary of Well Details

Grid ref. (1:50,000)	:	24881E; 31982N	
Townland	:	Cavanreagh	
Well type, name	:	Borehole, PW1	
Owner	:	Monaghan County Council	
Elevation (ground level)	:	50 m OD	
Depth of borehole	:	70 m below ground level	
Diameter of borehole	:	300 mm	
Depth to rock	:	9.5 m	
Static water level	:	0.9 m (16 April 1998)	
Pumping water level	:	Not yet established	
Planned abstraction rate	:	360 m/d^3	
Pumping Test Summary:		(i) Abstraction rate:	1221 m/d^3
		(ii) Drawdown:	27 m (at end of test)
		(iii) Transmissivity:	80 m^2/d

Grid ref. (1:50,000)	:	24850E; 32047N	
Townland	:	Cavanreagh	
Well type, name	:	Borehole, PW2	
Owner	:	Monaghan County Council	
Elevation (ground level)	:	50 m OD	
Depth of borehole	:	70 m below ground level	
Diameter of borehole	:	300 mm	
Depth to rock	:	5 m bgl	
Static water level	:	1.1 m bgl (16 April 1998)	
Pumping water level	:	Not yet established.	
Planned abstraction rate	:	540 m/d^3	
Pumping Test Summary:		(i) Abstraction rate:	917 m/d^3
		(ii) Drawdown	:16 m (at end of test)
		(iii) Transmissivity	: 400-500 m^2/d

The pumping test data analysed are from 4-week pumping tests carried out by K.T. Cullen and Company (KTC) in June 1998. Both boreholes were pumped simultaneously and water levels were monitored in six wells during the course of the test.

4 Methodology

4.1 Desk Study

Details about the boreholes such as elevation and abstraction figures were obtained from GSI records and County Council personnel; geological and hydrogeological information was provided by the GSI and the various hydrogeologic reports by KTC. Additional information regarding the hydrogeology of the area was gained through a meeting with Kieran O'Dwyer of KTC in August 2000.

4.2 Site visits and fieldwork

This included carrying out depth to rock drilling, subsoil sampling and vulnerability mapping. Field walkovers were also carried out to investigate the subsoil geology, the hydrogeology and vulnerability to contamination.

4.3 Assessment

Data analyses incorporated field studies and previously collected data to delineate protection zones around the sources.

5 Topography, Surface Hydrology and Land Use

The boreholes are located to the north west of Scotshouse, on the edge of Hilton Park. The boreholes are located in a small river valley that drains Killyfargy Lough and Hilton Lough towards the Finn River. The Finn River is the primary surface water feature in the area, flowing southwest. The overall topography in the area is hilly due to the large number of drumlins in the region.

Agriculture and the village are the main activities in the area. There are a few farmyards within 500 m of the boreholes, and it is known that organic wastes are applied to the fields adjacent to PW1.

6 Geology

6.1 Introduction

This section briefly describes the relevant characteristics of the geological materials that underlie the Scotshouse area. This provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections.

Bedrock information was taken from a variety of sources including:

- GSI publication on the bedrock geology of the region (Geraghty *et al*, 1997)
- Hydrogeological reports and borehole logs from KTC
- A geophysical investigation performed by KTC.

Subsoils information was gathered from Quaternary geology maps from the 1950's, and from vulnerability mapping by GSI field personnel in 2000.

6.2 Bedrock Geology

The area around the Scotshouse boreholes is underlain by Lower Palaeozoic 'dirty' sandstones and Carboniferous limestones, sandstones and siltstones. The limestones that the boreholes are drilled into are commonly known as the 'Lower Limestones'. The Lower Limestones overlie the Lower Palaeozoic bedrock, and are found in a northeast-southwest band from Monaghan to Killeshandra in

County Cavan. Along this band, the contact between the Lower Limestones and the Lower Palaeozoic rocks is offset by a series of northwest-southeast trending faults. Two such faults are thought to be located to the east and west of the boreholes. Thus, the boreholes lie within an area of faulted limestones, sandstones and siltstones that are surrounded on the south, east and west by Lower Palaeozoic mudstones, shales and 'dirty' sandstones. Specifically, the boreholes lie within the Cooldaragh Formation. A summary of the different bedrock types found in the area is provided below in Table 1.

Table 1: Bedrock Geology of the Scotshouse area.

Age	Geological Name			Geological Description	Thickness (m)
CARBONIFEROUS	*Lower Limestones*		**Ballyshannon Limestones (BS)**	Limestones and silty shales at base of unit with pale grainstones at top of unit	560
			Drumgesh Shales (DH)	Fossiliferous shales with minor limestones to poorly fossiliferous, muddy limestones with minor shale beds	400-1200
			Ballysteen Limestones (BA)	Clean sandy or silty limestones at base of unit grading into a muddy fine grained limestone	N/A
			Ulster Canal Limestones (UC)	Silty and sandy limestones, some fine grained limestones	60
		Basal Clastics	**Cooldaragh Limestones (CH)**	Pale brown-grey siltstones and mudstones; algal, evaporitic and fine grained limestones; muddy siltstones	125
			Fearnaght Sandstones (FT)	Pale conglomerate and red sandstone	~20
ORDOVICIAN (LOWER PALAEOZOIC)			**Coronea Sandstones (CA)**	Muddy sandstone, red shale, minor volcanic	1,600 - 2,300

Descriptions of rock units and details of the overall relationship between the Lower Palaeozoic and Carboniferous rocks are largely derived from a GSI report on the area (Geraghty *et al.*, 1997). Borehole logs and geophysical information provided by the KTC reports indicated that the original boundaries shown on the GSI's bedrock geology map are incorrect. Therefore, we redrew the boundaries using the borehole logs, geophysical results and consultations with the GSI's bedrock section. Specifically, the eastern fault is based on the original geology map and the geophysical investigation. While the geophysical information indicates where the fault is, the exact location has not been confirmed by boreholes. The location of the different limestone units, and the boundary between the Fearnaght Sandstones and the Coronea Limestones is based primarily on the borehole logs from KTC reports. A map showing the geology of the area is provided as Figure 1.

6.3 Subsoil Geology

The subsoils in Monaghan were mapped in the 1950's by Mike O'Meara of the GSI. A drilling programme (4 holes) and permeability mapping carried out by the GSI provided additional information on the subsoils. The subsoils comprise a mixture of coarse and fine-grained materials, namely alluvium, peat, tills, and tills with gravel. The distribution of subsoils and depth to rock data are shown in Figure 2. Logs from the boreholes drilled by the GSI are given in Appendix 1. The characteristics of each category are described briefly in the following sections.

6.3.1 Alluvium

This material is found in the lowlying area between Hilton Lough and Production Well 2. Borehole logs from the installation of the well and from the GSI drilling program indicate that the alluvium near PW2 is just under 5 m thick and is a fine-grained, blue-black, smooth CLAY.

6.3.2 Peat

Deposition of peat occurred in post-glacial times with the onset of warmer and wetter climatic conditions. Peat is an unconsolidated brown to black organic material comprising a mixture of decomposed and undecomposed plant matter which has accumulated in a water logged environment. It has an extremely high water content averaging over 90% by volume. In the source area, peat is found in the lowlying areas across the road from PW1, and along the small stream between PW1 and PW2.

6.3.3 Till (Boulder Clay)

'Till' is an unsorted mixture of coarse and fine materials lain down by ice. Tills are the dominant subsoil type in the locality and comprise most of the drumlins (elongated hills) around the borehole. These tills are generally dark brown to dark grey sandy CLAY with frequent to abundant gravels. The gravel sized fragments are usually striated, angular to subangular, dark blue limestone fragments ranging from 1 cm to 3 cm.

6.3.4 Tills with Gravel

Tills with Gravel is a term used to indicate areas where subsoils are a mix of gravels and tills. Depending on the depositional environment, these deposits may be stratified, or comprised predominantly of one material with lenses of the other. Tills with Gravels are located to the north and east of PW1. A GSI borehole drilled in the field adjacent to PW1 indicates the subsoils are silty GRAVEL (TILL), with the gravel fragments being subangular to subrounded, dark blue limestone fragments ranging from 1-5 cm. In one borehole, a thin (~20 cm thick) layer of till may have been encountered; however, sample material was not recovered from the borehole.

While PW1 is located in this unit, the borehole log indicates that the subsoils are quite different. A GSI borehole drilled adjacent to PW1 shows approximately 6 m of grey-brown, silty fine SAND with few to no gravels. Because so little gravel is present, it is difficult to tell if this sample is glaciofluvial or till. The sand is underlain by approximately 4.5 m of grey, very dense sandy CLAY (TILL).

6.3.5 Depth to Bedrock

The drilling programme (4 holes) was carried out to ascertain the depth, thickness and permeability of the subsoils. Using this information and knowledge of sites that have rock cropping out, the depth to rock is estimated across the area. The borehole locations and spot depth to rock locations are shown in Figure 2. The depth to bedrock varies between 3 and 10 m, with the thicker deposits corresponding with the drumlins.

7 Hydrogeology

7.1 Introduction

This section presents our current understanding of groundwater flow around the Clones boreholes. These interpretations and conceptualisations of flow are used to delineate source protection zones around the source.

Hydrogeological and hydrochemical information for the study was obtained from the following sources:

- Four-week pumping test performed by K.T. Cullen & Co. in April-May 1998.
- A local, one-day hydrogeological mapping survey carried out by the GSI.
- A drilling programme and permeability mapping carried out by GSI to ascertain depth to bedrock and subsoil permeability.
- GSI files and archival Monaghan County Council data.
- Discussions with KTC in August 2000.
- Water quality test results from samples collected during the pumping tests.

7.2 Meteorology and Recharge

The term 'recharge' refers to the amount of water replenishing the groundwater flow system. The recharge rate is generally estimated on an annual basis, and generally assumed to consist of the input (i.e. annual rainfall) less water losses prior to entry into the groundwater system (i.e. annual evapotranspiration and runoff). The estimation of a realistic recharge rate is critical in source protection delineation, as it dictates the size of the zone of contribution to the source.

In areas where point recharge from sinking streams and other karst features do not play a role, the main parameters involved in recharge rate estimation are annual rainfall, annual evapotranspiration, and annual runoff and are listed as follows:

- **Average Annual Rainfall:** Calculated to be 948mm yr^{-1}. Rainfall data are from Met Eireann average annual rainfall values for 1961-1990 at the Redhills station (Met Eireann, 1996).
- **Annual Evapotranspiration:** Estimated at 416mm yr^{-1}. Potential evaporation (P.E.) is estimated to be 438mm yr^{-1}. P.E. data are from a synoptic weather station located in Clones, and are averaged over the years 1961-1990. Actual evapotranspiration (A.E.) is then estimated as 95% of P.E.
- **Potential Recharge:** Calculated at 532 mm yr^{-1}. Potential Recharge is calculated by subtracting the estimated evapotranspiration from the average annual rainfall. It represents an estimation of the excess soil moisture available for either vertical downward flow to groundwater, or lateral flow through soil and overland flow to surface water.
- **Estimated Actual Recharge:** Estimated Actual Recharge represents the amount of water that will infiltrate to groundwater. This is an estimation of recharge which allows for surface water outflow, particularly during periods of heavy rainfall. It roughly estimates the amount of groundwater available to each well.

  An infiltration rate of 70% was assumed for the tills with gravel, since it is a stratified unit with the gravels being of moderate permeability (10% silt and clay). The NERDO report provides an infiltration rate of 26% for tills in the Clones area (An Foras Forbartha and GSI, 1981). We have applied this figure to the tills, which are assumed to have a low permeability. This infiltration rate may be slightly high in view of the low permeability nature of the subsoils; on the other hand, it is possible that additional recharge may be induced from the streams and lakes in the area. However, this is unlikely since the alluvium is a CLAY, and the hydraulic connection between the ground and surface waters is expected to be poor. Zero infiltration was assumed for the peat and alluvium.

7.3 Groundwater Levels, Flow Directions and Gradients

Besides the supply boreholes and the associated observation wells, there are two other wells located within 200 m of the supply boreholes. One well is the existing group scheme well; the second is a domestic well. Recent water level data are not available for the boreholes; therefore water levels recorded at the start of the 4-week pumping test were compared with stream water levels measured in June 2000.

The water table is generally assumed to be a subdued reflection of topography. The topography in the Scotshouse area is hilly, due to the number of drumlins in the area. The River Finn lies to the northwest of Scotshouse, with small tributaries that drain Killyfargy and Hilton Loughs running near the boreholes. A comparison of stream and borehole water levels shows a difference of 1 m between the two. It is possible that groundwater discharges to these smaller streams, however, it is most likely that the Finn River is the primary groundwater discharge area. Thus, flow are expected to be towards the northwest and in general, perpendicular to contour lines, but will not be influenced by drumlins.

The groundwater gradient during pumping, and over a distance of 250 m, is estimated from a MODFLOW model to be 0.03 around PW1 and 0.01 around PW2.

7.4 Aquifer Characteristics

The data used in this section are based on test pumping undertaken by K.T. Cullen and Company in June 1998. Four-week constant discharge tests were run in June 1998, simultaneously testing both boreholes. The discharge in PW1 averaged 1221 m/d^3 for the first four days of the test, after which it dropped to 1172 m/d^3. The average discharge in PW2 for the duration of the test was 917 m/d^3. Information gained from the pumping tests, such as drawdown, specific capacity and transmissivities are summarised in Table 2. Drawdown vs. time graphs for each borehole are provided as Figure 1.

Table 2: Summary of Pumping Test Calculations

Well	Average Discharge (m^3/d)	Drawdown (m)	Specific Capacity ($m^3/d/m$)	Transmissivity (m^2/d)
PW1	1221	27	45	80
PW2	917	16	57	420
Notes: Pumping test data were analysed using the Jacob straight-line method.				

The Scotshouse boreholes are located in the Cooldaragh Limestones, which are predominantly limestones but contain some silt and mudstones. The borehole log shows that PW1 intersects one discreet fracture, while PW2 intersects a number of fractures and layer of fine-grained sandstone. In this area, the limestones are bound to the west and east by faults, which juxtaposes them against Lower Palaeozoic 'dirty' sandstones. These Lower Palaeozoic rocks have a low permeability do not generally provide substantial supplies of water.

Figure 1 shows a graph of the drawdown vs. time for PW1 and the associated observation well during the 4-week pumping test. An increase in the rate of drawdown is seen at 1,000 minutes (0.7 days), potentially indicating a 'barrier condition'. An alternative possibility for this change in rate of drawdown may be due to dewatering of the till with gravel subsoils, which 'leak' water into the aquifer. However, the former is the more likely reason. Since the data after 1,000 minutes is indicative of the effect the barrier has on the well, this data is not representative of the aquifer. Transmissivity calculations for PW1 are based on the pumping test results between 10 and 1,000 minutes; and give a result of 80 m^2/d. Aquifer permeability is estimated as 2.4 m/d.

A plot of drawdown vs. time for PW2 and the associated observation well from the 4-week pumping test is also included in Figure 1. Towards the end of the test, at approximately 20,000 minutes (14 days), the rate of drawdown in the pumping well appears to increase even while the rate of drawdown in the observation borehole decreases. Rainfall records provided by Met Eireann from the Clones station show a rainfall event did occur at approximately this time, which explains the decrease in rate of drawdown in the observation borehole. However, this rainfall event is only slightly reflected in PW2. The increase in the rate of drawdown at the end of the pumping test is not understood. Long term pumping data are needed to indicate whether this change in rate of drawdown is significant. Therefore, transmissivity and permeability calculations for PW2 are based on pumping test results from between 10 and 20,000 minutes, and give values of 420 m^2/d and 7.5 m/d respectively.

While these figures cannot be taken as definitive values for the aquifer itself, they do indicate that the transmissivity and permeability of the aquifer in the immediate vicinity of the boreholes, especially PW2, is relatively high.

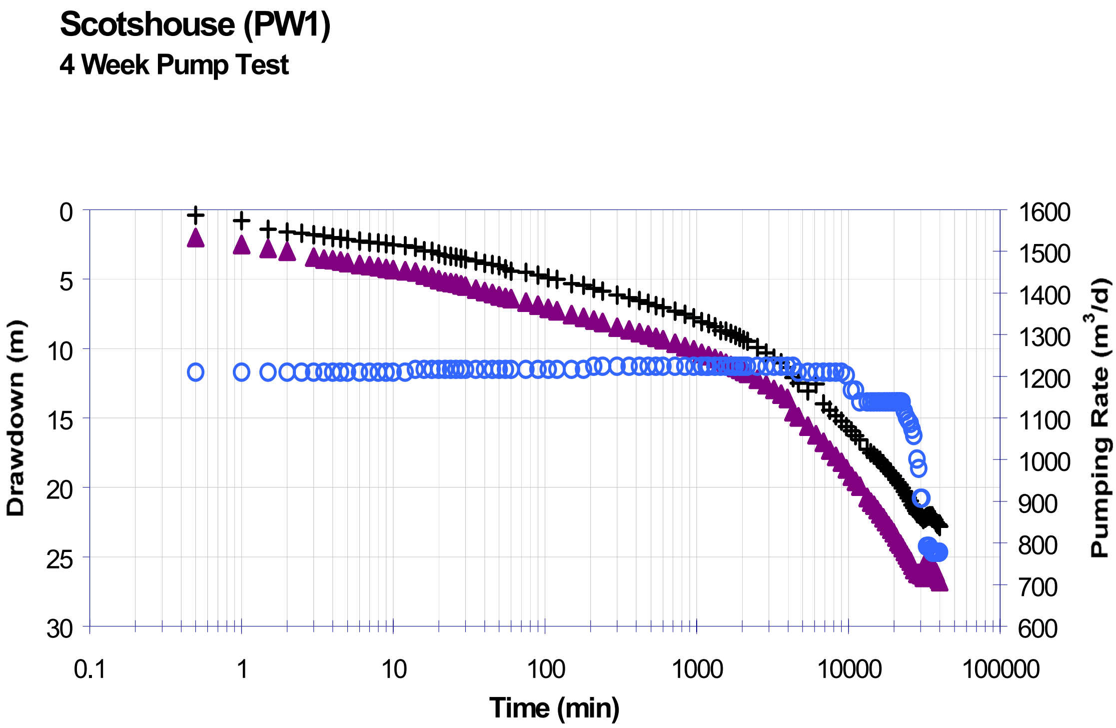

Figure 1 Drawdown vs. Time graphs for the 4-week pumping tests conducted by KTC. Pumping well data are shown as closed triangles, observation well data are shown as crosses, and discharge data are shown as open circles.

7.5 Aquifer Category

Available hydrogeological information was compiled for the different bedrock types found in the Clones/Scotshouse area to analyse the potential productivity of each unit. Information on the specific well information available in each unit is summarised in Swartz and Daly (2000). A summary of each bedrock unit is provided in the section below, and the aquifer map of the area is shown in Figure 1.

7.5.1 Coronea Formation

The Lower Palaeozoic rocks in the Clones/Scotshouse area contain few wells with yields above 40 m/d^3. Based on the available well details, the lithology and information from other counties, the Coronea Formation is provisionally classed as a **poor aquifer that is generally unproductive except for local zones (Pl)**.

7.5.2 Fearnaght Sandstones

The Fearnaght unit is the sandstone and conglomerate rocks that forms the basal member of the 'Lower Limestones'. Little well information is available for the Fearnaght Formation; however, one trial well drilled by KTC in 1996 provided a yield greater than 400 m/d^3, and a specific capacity of 56. Based on the borehole log for this trial well and the information available, the Fearnaght Formation is provisionally classified as a **moderately productive aquifer (Lm)**.

7.5.3 Cooldaragh Limestones

The two public supply boreholes and the group scheme borehole are located in this unit, and have high yields (>350 m/d^3). Two other wells located in the Cooldaragh Limestones provide yields of between 100-400 m/d^3. Based on these yields and level of fracturing indicated in the borehole logs, this unit is provisionally classified as a **regionally important fissured aquifer** (**Rf**). It is worth mentioning that evaporite lenses are associated with the Cooldaragh Limestones, which may result in high levels of sulphate in the groundwater.

7.5.4 Ulster Canal Limestones

No well information is currently available for the Ulster Canal Limestones; however, considering that it has a similar lithology to the Cooldaragh Limestones, this unit is provisionally classified as a **moderately productive aquifer (Lm)**.

7.5.5 Ballysteen Limestones

Compiled well information indicates that well yields in the Ballysteen Limestones in the Clones area generally fall between 100-400m^3/d. Analysis of well information from the Ballysteen around Monaghan show similar yields. Based on the existing data and lithologic descriptions, the Ballysteen Limestones are provisionally classed as a **regionally important fissured aquifer (Rf)**.

7.6 Hydrochemistry and Water Quality

Samples for water quality analysis were collected by KTC during the 4-week pumping test in 1998. Each well was sampled four times during the pumping test, although every parameter was not necessarily analysed for each time. These data are tabulated in Table 3, and are summarised below.

Table 3: Summary of Hydrochemistry Data for Pumping Wells 1 and 2

Parameter	Units	MAC Value	PW1				PW2			
			20 Apr 98	27 Apr 98	5 May 98	14 May 98	20 Apr 98	27 Apr 98	5 May 98	14 May 98
Colour	Hazen	20	6	9	6	11	6	9	6	11
Turbidity	N.T.U	10	3	1	0	0	10	6	0	7
pH		6-9	7.27	7.21	7.17	7.34	7.08	7.01	6.95	7.16
Conductivity	µS/cm	1500	680	692	710	710	848	893	911	889
Hardness	$CaCO_3$ mg/L		315	347.5	340	365	390	487.5	520	475
Alkalinity	$CaCO_3$ mg/L		168.1	146	151.7	151.7	202.6	190.3	200.1	182.1
Sulphate	SO_4 mg/L	250	36	50	60		57	64	90	
Chloride	Cl mg/L	250	16	16	16	16	18	17	18	18
Nitrate	NO_3 mg/L	50	0.04	0.09	0.04	0.04	0.09	0.05	0.04	0.04
Nitrite	NO_2 mg/L	0.1	0.003	0.003	0.01	0.003	0.01	0.007	0.016	0.003
Ammonia	NH_4 mg/L	0.3	0.03	0.03	0.01	0.01	**0.58**	**0.57**	**0.5**	**0.46**
Copper	Cu µg/L	500	<10				<10			
Iron	Fe µg/L	200	**319**	**220**	**225**		**978**	**970**	**856**	
Manganese	Mn µg/L	50	**120**	**140**	**180**		**80**	**90**	**88**	
Aluminium	Al mg/L	0.2	<0.02				<0.02			
Phosphorous	P205 µg/L	5000	16	60	23	23	16	60	46	23
Fluoride	F µg/L	1000	290	98			290	111		
Suspended Solids	mg/L	No Visible	**9**	**1**	**4**		**3**	**3**	**6**	
Lead	Pb µg/L	50	1.7				<0.8			
Odour	Dilution No.	2/12 DegC								Sulphide
Total Coliforms	no./100 mL	<1	Nil	Nil	Nil	Nil	Nil	Nil	**1**	Nil
Faecal Coliforms	no./100 mL	<1	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

- The groundwater samples indicate that the groundwater is hard to very hard with total hardness values of 680-710 mg/L $CaCO_3$ for PW1 and 390-520 mg/L $CaCO_3$ for PW2. This indicates that the groundwater has a hydrochemical signature of a calcium bicarbonate type water. These values are typical of groundwater from a limestone source.
- The levels of iron and manganese are above the EU MAC value in both boreholes. These are most likely derived from the bedrock, and indicate reducing conditions.
- Electrical conductivity values are indicative of limestone bedrock, and are higher in PW2. This may indicate that PW2 is drawing water from either the adjacent fault or a different rock unit.
- The levels of ammonium (NH_4) are above the EU MAC value in PW2. New wells sometimes have high ammonium levels, although they typically drop during pumping. These high levels of ammonia indicate reducing conditions, which may be due to the rock type. However, high ammonium levels can also indicate organic waste pollution.
- Chloride concentrations range from 16-18 mg/L. Chloride is a constituent of organic wastes and levels higher than 25 mg/L may indicate significant contamination. Concentrations higher than 30 mg/L usually indicate significant contamination has occurred. Thus, the chloride levels give no rise for concern at the Scotshouse boreholes.
- The suspended solids are above the EU MAC value in both wells, which is not suprising since the wells are new. If the water samples were not filtered prior to analysis, these suspended solids may explain the high concentrations of iron and manganese.
- A sulphide smell was reported in the last sample from PW2. Both wells are located in the Cooldaragh Formation, which is known to have evaporitic lenses that give rise to high sulphate concentrations. Sulphate levels were below the EU MAC value for all samples.
- One count of total coliforms was detected in PW2 in the third week of pumping. No faecal coliforms were detected in the samples from either well. Total coliforms may result from naturally occurring bacteria.

7.7 Conceptual Model

- The planned abstraction rates for supply wells PW1 and PW2 are 360 and 540 m^3/d respectively.
- The groundwater regime in the area is complex due to the structural history of the rocks and the available hydrogeological information does not allow a definitive understanding of the hydrogeology.
- The boreholes lie in a faulted wedge of limestone that is bounded on the east and west by faults, and is juxtaposed against much less permeable rocks.
- Groundwater flow is primarily controlled by faults and fractures in the bedrock. The overall direction of groundwater flow is towards the streams and rivers.
- Borehole logs and pumping test data from trial wells in the area indicate that the majority of groundwater supplying the wells comes from the Cooldaragh and Fearnaght units. Very little groundwater is expected to come from the Coronea Formation.
- The pumping test results from PW1 suggest that groundwater abstraction in the immediate area is reduced by the low permeability rocks west of the boundary fault. An increase in the rate of drawdown occurred near the end of the pumping test at PW2. Without long term pumping data, it is not known whether this change in rate of drawndown is significant.
- An infiltration rate of 70% was assumed for the Tills with Gravel, while an infiltration rate of 26% was assumed for the tills, and zero infiltration was assumed for alluvium and peat. Additional recharge from the streams and lakes may be induced by pumping, but is unlikely due to the low permeability subsoils.

8 Delineation of Source Protection Areas

This section delineates the areas around the borehole that are believed to contribute groundwater to the borehole, and that therefore require protection. The areas are delineated based on the conceptualisation of the groundwater flow pattern, as described in Section 7.7, and are presented on Map 3.

Two source protection areas are delineated:
- *Inner Protection Area (SI)*, designed to give protection from microbial pollution;
- *Outer Protection Area (SO)*, encompassing the remainder of the zone of contribution (ZOC) of the well.

8.1 Outer Protection Area

The Outer Protection Area (SO) is bounded by the complete catchment area to the source, i.e. the zone of contribution (ZOC), which is defined as the area required to support an abstraction from long-term recharge. The ZOC is controlled primarily by a) the total discharge, b) the groundwater flow direction and gradient, c) the rock permeability and d) the recharge in the area. In general when delineating a ZOC, the maximum abstraction rate is increased by 50% to allow for possible future increases in abstraction and for expansion of the ZOC in dry periods (DoELG, EPA and GSI, 1999). The planned combined abstraction rate for the Scotshouse boreholes is 900 m/d^3. However, there is a slight possibility that a higher rate might not be sustainable over the long term due to the assumed relatively low recharge rate through the tills and alluvium, and the presence of poor aquifers nearby. Therefore, we have not increased the discharge by 50% when drawing the ZOC.

The ZOC for the Scotshouse source is delineated as follows:
1) An estimate of the area size is obtained by using the average recharge and the abstraction rate.
2) The shape of the area is then derived by both numerical modelling (using MODFLOW) and hydrogeological mapping techniques.

Estimated recharge values and discharge estimates are used to carry out a water balance. A water balance estimates the areal extent of the catchment providing the water to the source. The area constrained by hydrogeological mapping and the numerical model is 2.3 km^2.

Overall, the shape and boundaries of the ZOC were determined using hydrogeological mapping and numerical modelling. These boundaries delineate the physical extents within which the ZOC is likely to occur. In this case, the majority of groundwater is expected to come from the limestones. The ZOC catchment boundaries and the uncertainties associated with them are as follows:

An additional buffer zone of 100 m is added to the limestone boundary to the west of the catchment (overlying the Namurian rocks) to allow for groundwater movement through the sandstones and shales at the boundary area into the limestones.

- The Eastern Boundary is defined by the fault between the Limestones and the Coronea Formation. to allow for groundwater and surface water flowing into the ZOC from the low permeability Coronea Formation.

- The Southern Boundary is defined by the contact between the Limestones and the Coronea Formation. An additional buffer zone of 30 m was added south of the contact.

- The Western Boundary is defined by the fault between the Limestones and the Coronea Formation. As the wells are close to this fault, an arbitrary 100m buffer is placed on the west side of the fault to account for any groundwater that may come from the Coronea Formation. Where the fault enters the limestones, the geological boundary between the Limestones and the Coronea Formation forms the boundary.

- The Northern Boundary is largely derived from the numerical modelling, and is located at the edge of the alluvial plain for the Finn River. With extended pumping from the wells, this boundary may shift north, towards the Finn River.

The Western and Northern Boundaries are somewhat arbitrary; while they are refined by the numerical modeling, they are based largely on the calculated area required to supply the proposed abstraction rate. In addition, we assume that water will be drawn from whatever distance is necessary to supply the pumping wells.

8.2 Inner Protection Area

The Inner Protection Area (SI) is the area defined by a 100-day time of travel (ToT) to the source. It is delineated to protect against the effects of potentially contaminating activities that may have an immediate influence on water quality at the source, in particular microbial contamination. Estimations of the extent of this area cannot be made by hydrogeological mapping and conceptualisation methods alone. By using the aquifer parameters for permeability and hydraulic gradient, 100-day ToT estimations are made. In this case, the 100-day ToT was derived from the MODFLOW model.

Numerical modeling gives an average permeability of 4 m d^{-1}, which we have used to calculate the Inner Protection Area (SI) boundary, as shown on Map 3.

9 Vulnerability

The distribution of interpreted groundwater vulnerability in the ZOC is presented on Map 2. The subsoils in the ZOC range from low to moderate permeability, and are generally 3 m to 10 m thick, as described in Section 6.3.4. Vulnerability categories in the ZOC are predominantly High and Low. The Low Vulnerability materials tend to occur on the drumlin hills, with small areas of Moderate Vulnerability around the base of the hills. The predominantly flat area where the production wells are located, and in the area of Scotshouse itself, are High Vulnerability. There are no areas delineated as Extreme Vulnerability within the ZOC.

9.1 Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the two elements of land surface zoning (source protection areas and vulnerability categories) – there are eight possible source protection zones. In practice, the source protection zones are obtained by superimposing the vulnerability map on the source protection area map. Each zone is represented by a code e.g. **SI/H**, which represents an Inner Protection area where the groundwater is highly vulnerable to contamination. These are presented Map 3. There are six groundwater protection zones present around the Scotshouse boreholes as shown below in Table 4. The final groundwater protection map is presented as Map 3.

Table 4: Matrix of Source Protection Zones at Scotshouse

VULNERABILITY RATING	SOURCE PROTECTION	
	Inner (SI)	*Outer (SO)*
Extreme (E)	Absent	Absent
High (H)	SI/H	SO/H
Moderate (M)	SI/M	SO/M
Low (L)	SI/L	SO/L

9.2 Potential Pollution Sources

The land in the vicinity of the source is largely grassland-dominated and is primarily used for grazing. Agricultural activities and the few houses in the ZOC are the principal hazards to the boreholes. The main potential sources of pollution within the ZOC are landspreading of organic fertilisers, farmyards, septic tank systems and runoff from roads. The main potential pollutants are faecal bacteria, viruses, cryptosporidium, and nitrogen.

10 Conclusions and Recommendations

The boreholes at Scotshouse are high yielding wells, which are located in a fissured limestone aquifer. However, the geometry of these limestones is such that they are surrounded by low permeability rock. Also, for much of the area the bedrock aquifer is overlain by low permeability sediments which reduce recharge. Both of these factors may restrict the amount of water available to the wells.

Vulnerability in the ZOC is predominantly High and Low, with small areas of Moderate. There are no areas of Extreme Vulnerability delineated within the ZOC.

The runoff from the roads, houses, farmyards and landspreading pose a threat to the water quality in the two boreholes.

The protection zones delineated in the report are based on our current understanding of groundwater conditions and on the available data. Due to the hydrogeological complexity of the area, there is uncertainty regarding some of the boundaries.

Overall, our recommendations are as follows:

1. Regular monitoring of water levels in the pumping and observation wells.
2. Chemical and bacteriological analyses of raw water rather than treated water should be carried out on a regular basis at both boreholes.
3. Particular care should be taken when assessing the location of any activities or developments that might cause contamination at the borehole.
4. The potential hazards in the ZOC should be located and assessed.

11 References

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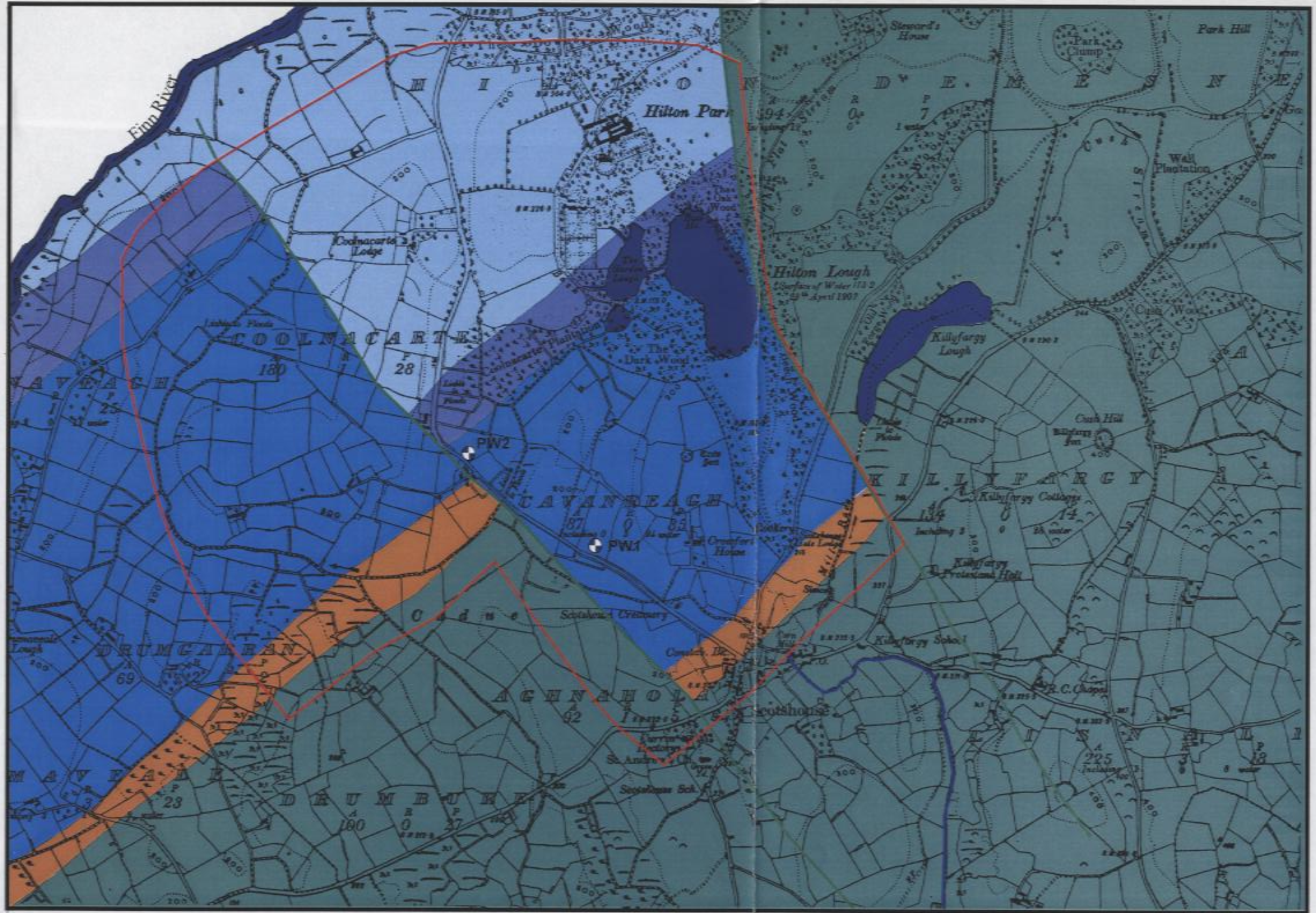
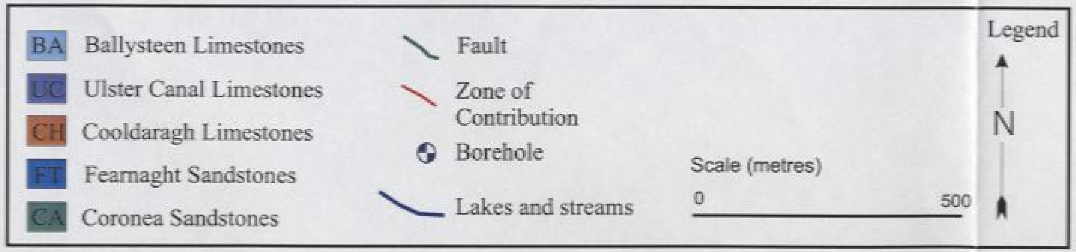


Map 1: Geology of the Clones District



Scotshouse Water Supply Scheme

Fig.2. Groundwater Vulnerability

- Extreme (E)
- Outcrop/Shallow rock (E)
- High (H)
- Moderate (M)
- Low (L)

Zone of Contribution of Wells (SO)

Inner protection area (SI)

Public Supply Source

Vulnerability is a term used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities.

The map shows the vulnerability of the first groundwater encountered (in either sand/gravel aquifers or in bedrock) to contaminants released at depths of 1-2 m below the ground surface. Where contaminants are released at significantly different depths, there will be a need to determine groundwater vulnerability using site-specific data. The characteristics of individual contaminants have not been taken into account.

This vulnerability map is designed for general information and strategic planning usage. The boundaries are based on the available evidence and local details have been generalised to fit the map scale. Evaluation of specific sites and circumstances will normally require further and more detailed assessments and will frequently require site investigations to determine the risk to groundwater.

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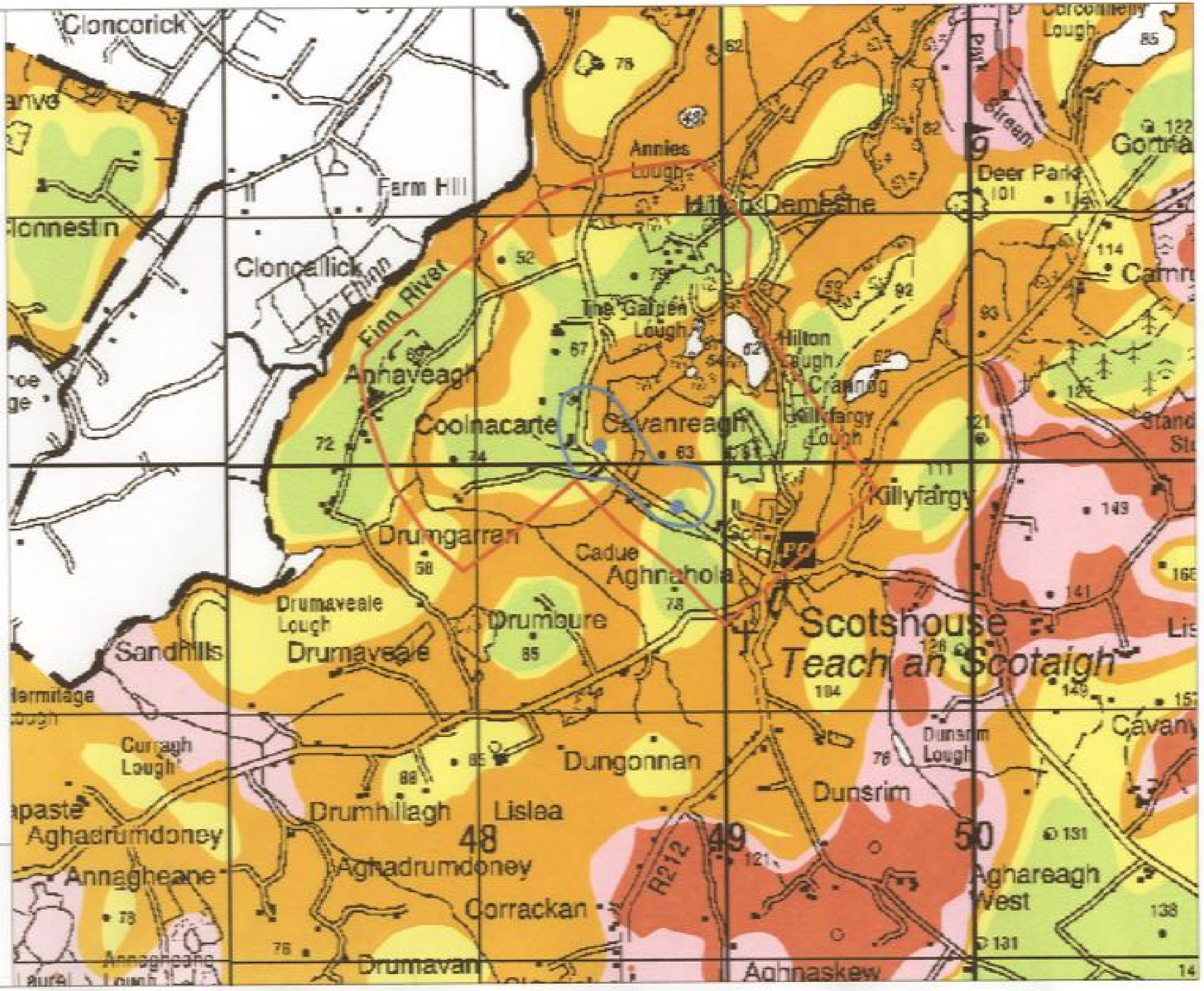
SCALE

0 1Km



Scotshouse Water Supply Scheme

Fig. 3. Source Protection Zones

VULNERABILITY RATING	SOURCE PROTECTION ZONES			
	Inner (SI)		Outer (SO)	
Extreme (E)	not present	SI/E	not present	SO/E
High (H)		SI/H		SO/H
Moderate (M)		SI/M		SO/M
Low (L)		SI/L		SO/L

Public Supply Well

Zone of Contribution of Wells (SO)

Inner protection area (SI)

his Source Protection Zone map is designed for general information nd strategic planning usage. The boundaries are based on the available vidence and local details have been generalised to fit the map scale. valuation of specific sites and circumstances will normally require further nd more detailed assessments and will frequently require site vestigations to determine the risk to groundwater.

he map is intended for use in conjunction with groundwater protection sponses for potentially polluting activities, which lists the degree of cceptability of these activities in each zone and describes the control easures necessary to prevent pollution.

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SCALE

0 1Km