



Louth County Council

Establishment of Groundwater Source Protection Zones

Ardee Water Supply Scheme

Curraghbeg Borehole

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Revision 4

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PROJECT DESCRIPTION

Since the 1980's, the Geological Survey of Ireland (GSI) has undertaken a considerable amount of work developing Groundwater Protection Schemes throughout the country. Groundwater Source Protection Zones are the surface and subsurface areas surrounding a groundwater source, i.e. a well, wellfield or spring, in which water and contaminants may enter groundwater and move towards the source. Knowledge of where the water is coming from is critical when trying to interpret water quality data at the groundwater source. The Source Protection Zone also provides an area in which to focus further investigation and is an area where protective measures can be introduced to maintain or improve the quality of groundwater.

Louth County Council contracted the GSI to delineate source protection zones for nine groundwater public water supply sources in Co. Louth. The sources comprised Ardee, Cooley (Carlingford and Ardtully Beg), Collon, Termonfeckin, Omeath (Lislea Cross and Esmore Bridge), Drybridge and Killineer.

This report documents the delineation of the Ardee source protection zones.

A suite of maps and digital GIS layers accompany this report and the reports and maps are hosted on the GSI websites (www.gsi.ie).

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1 INTRODUCTION

The Curraghbeg Borehole, which contributes water to the Ardee Water Supply Scheme, is located west of Ardee, adjacent to the River Dee. Water is also abstracted from the River Dee for the Supply Scheme.

Louth County Council requested Source Protection Zone delineation for the Curraghbeg Borehole from the Geological Survey of Ireland (GSI), in order to develop Source Protection Zones for the entire zone of contribution to the groundwater component of the Ardee Water Supply.

The objectives of the report are as follows:

- To delineate source protection zones for the Ardee public supply well.
- To outline the principal hydrogeological characteristics of the Ardee area.
- To assist Louth County Council in protecting the water supply from contamination.
- To assist Louth County Council in estimating groundwater resources.

The protection zones are delineated to help prioritise certain areas around the source in terms of pollution risk to the borehole. This prioritisation is intended to provide a guide in the planning and regulation of development and human activities. The implications of these protection zones are further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

The report forms part of the groundwater protection and source protection map/report suite for the county. The maps produced for the scheme are based largely on the readily available information in the area, a field walkover and on mapping techniques which use inferences and judgements based on experience at other sites. As such, the maps and conceptual model cannot claim to be definitively accurate across the whole area covered, and should not be used as the sole basis for site-specific decisions, which will usually require the collection of additional site-specific data.

2 METHODOLOGY

Details on trial wells, production wells and observation boreholes such as depth, depth to bedrock, construction, and abstraction figures, along with geological and hydrogeological information were obtained from GSI records, County Council personnel and hydrogeological reports.

The fieldwork undertaken for this project included depth-to-rock auguring, subsoil sampling and vulnerability mapping. Basic surface water physico-chemical data were collected when site visits were made. Field walkovers were also carried out to investigate the subsoil geology, the hydrogeology and vulnerability to contamination.

To delineate protection zones around the public supply well, previous studies were assessed, and data from current field studies and those collected previously were analysed. Information on the current abstraction regime at the source was supplied by the local authority. The assessment of the source protection areas to the well uses all the information to develop a conceptual model for the area.

3 LOCATION, SITE DESCRIPTION AND WELL HEAD PROTECTION

There is one borehole currently in use at the Ardee Public Water Supply source (Ardee WSS). The borehole is located in Curraghbeg townland, on Hickey's farm (Figure 1). Another borehole was previously in use which is located in the Townpark townland. However, this well no longer contributes to the supply. The Curraghbeg (Hickey's) borehole was drilled as part of a water supply development programme in the area in 1980.

The borehole supplies around between 380 and 1,700 m³/d (Figure 2), and the borehole abstraction comprises part of the water provided by the Ardee Public Water Supply Scheme, which also abstracts directly from the River Dee. Water from the borehole is pumped to the pumping station where river water is abstracted and treated, and mixed with the surface water. Pumping rate data are recorded continuously, and transmitted to the Local Authority offices.

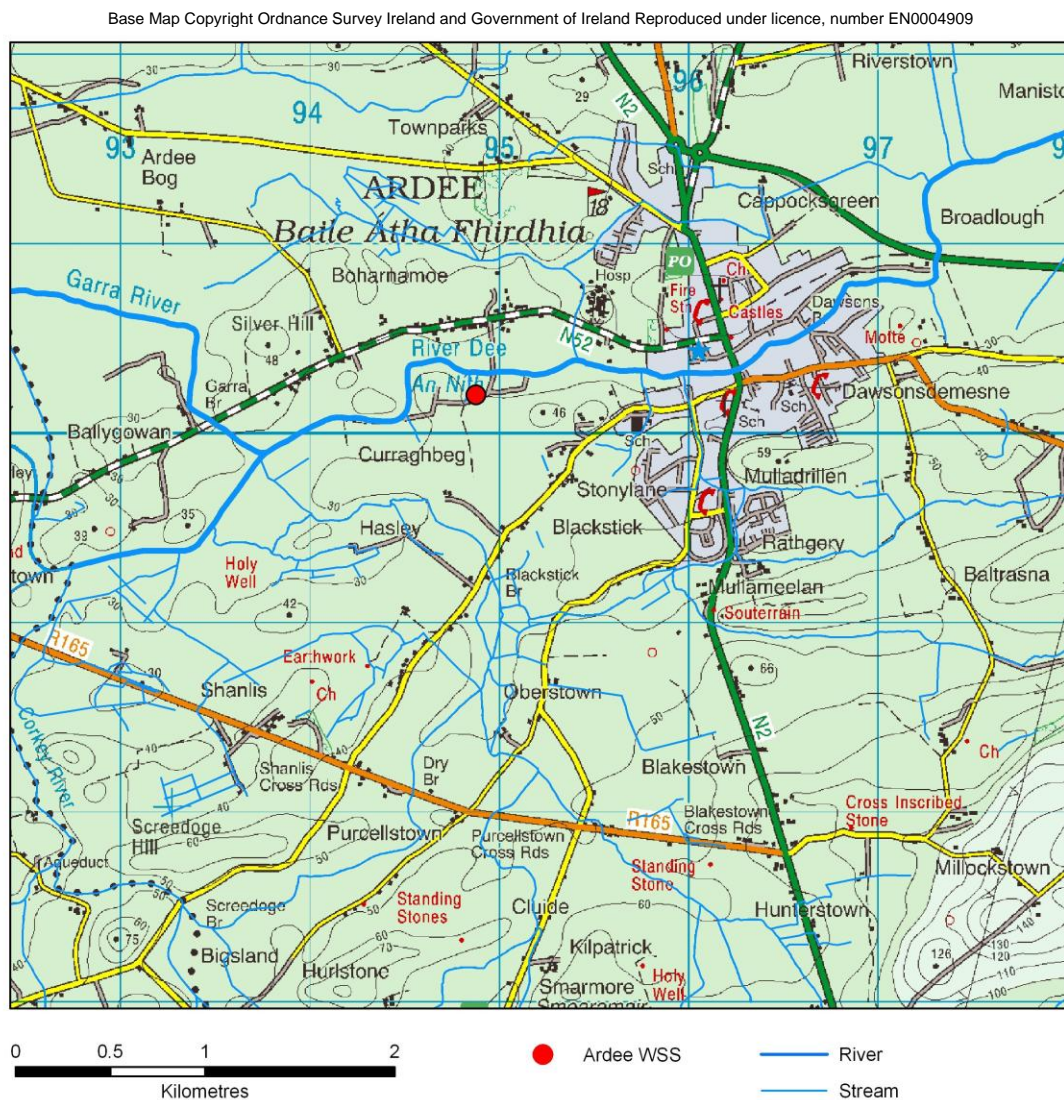


Figure 1 Location map of the Curraghbeg (Hickey's) borehole

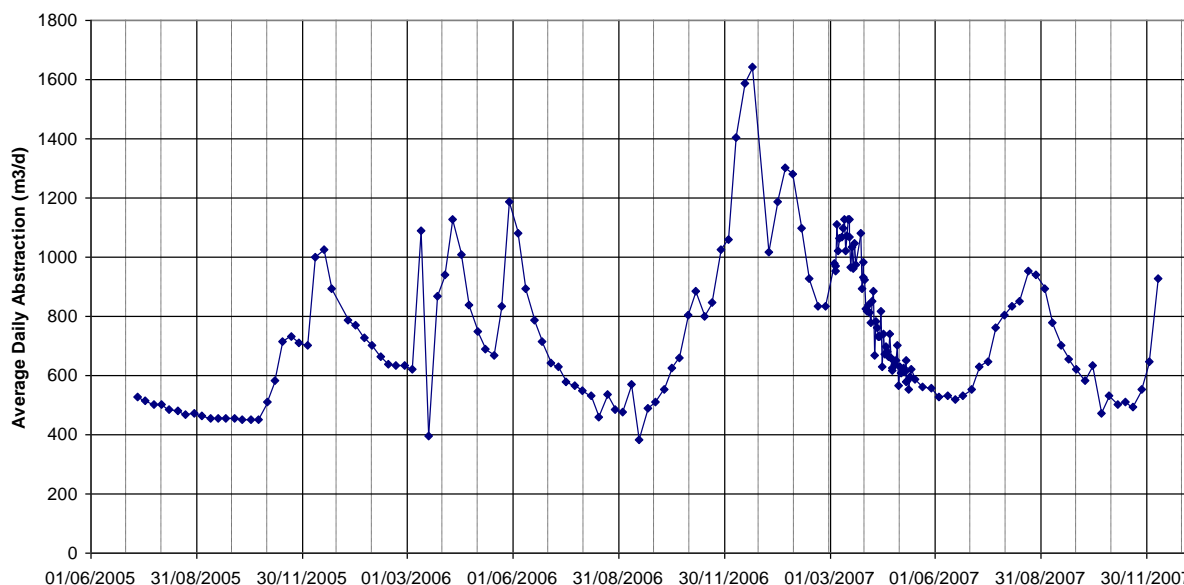


Figure 2 Average daily abstraction, Ardee WSS

The sanitary protection of the Hickey borehole appears to be good. The borehole is located on a concrete platform approximately 1.5 m x 1.5 m that is elevated 5 cm above the surrounding ground, and enclosed within a cabin (Figure 3). The top of the casing is approximately 30 cm above the floor of the pump-house, and the riser and pipe work to the pumping station are fully sealed.



Figure 3 Well-head protection cabin at the abstraction borehole

4 SUMMARY OF BOREHOLE DETAILS

Table 1, below, provides summary details of the wells drilled during the original 1980 investigation in the area and the borehole currently used for abstraction (Hickey's well). The locations of the boreholes are shown on Figure 4.



Figure 4 Wells drilled in the 1980's during the exploration phase for Ardee WSS. See Table 1 for details.

Table 1 Summary of well details at Curraghbeg

Original Name	Hickey's Well #3	Well #1	Well #2	Well #4	Well #5	Well #6	Well #7	Well #8
GSI Code	2929SWW183	2929SWW181	2929SWW182	2929SWW184	2929SWW185	2929SWW186	2929SWW187	2929SWW188
Well Type	Borehole	Borehole	Borehole	Borehole	Borehole	Borehole	Borehole	Borehole
Drill Date	15-Oct-80	16-Jul-80	23-Aug-80	15-Oct-80	15-Oct-80	01-Nov-80	03-Nov-80	07-Nov-80
Easting	294890	294690	294880	294990	294510	294670	294970	295130
Northing	290200	290270	290200	290280	290070	290110	290380	290240
Depth (meters)	16.8	85	31	10.4	15	12.5	15.2	10.8
Depth to rock (m)	16.8	16	13.7	6	10.3	11.5	7	9.4
Yield (m³/d)	1414	100		100	500	100	200	200
Casing diameter (mm)	250	250	200	150	150	150	150	150
Water Strike (mbgl)	9.5	6	10	5.5	11.5	11.5		10
Static Water Level (mbtc) (29/08/1981)	2.07	10.52	2.29	3.79			4.3	
Pumped Water Level (mbtc) (04/09/1981)	7.08	11.9	7.25	4.47			4.94	
Transmissivity (m²/d)			224					

NB aquifer tests in 2005 indicate a transmissivity of 114 m²/d.

5 TOPOGRAPHY, SURFACE WATER HYDROLOGY AND LAND USE

The topography and surface water features in the area around the Ardee WSS borehole are shown on Figure 5. The location of the pumping well is shown on all maps.

Hickey's borehole is situated on a flat-lying area about 110 m south of the River Dee. The well-head is at approximately 30 mAOD. The River Dee flows in a roughly easterly direction, and the ground slopes gently towards the river valley from both the north and the south. Ground surface gradients are low, generally on the order of 0.01 (1:85), although there are steeper areas in more hilly ground to the east (1:6 or 0.16). Within a 2 km radius of the borehole, ground elevations rise no higher than around 60 mAOD, with the highest elevations found in the south east.

The topographic 'grain' in the vicinity of the borehole doesn't appear to have been influenced by the bedrock geology to any large extent, although the higher ground 4 km to the south follows the WSW-ENE trend of the interbedded sandstones and mudstones of the Salterstown Formation, which are more resistant to erosion than the other, limestone, bedrock units in the area.

The east-flowing River Dee is the major water body in the study area. Smaller streams drain into the river from the south and north. The Garra River joins the Dee upstream of the supply source, approximately 1.2 km to the west. Drainage density is variable in the area: south-southeast and north of the borehole, drainage density is relatively low. However, in the shallow valleys and dips across the area, drainage density is high, with significant artificial drainage observed and shown on the 1:10,560 maps. Around 1 km to the northwest, there is a large bog area, which drains into the Dee.

Land use in the area is primarily agricultural. Around and south of the source, it is predominantly tillage, with potatoes and wheat observed growing. The field between the borehole and the river is grazed by cattle. North of the River Dee, tillage crops were observed, but cattle pasturage appears to be more prevalent south of the river.

6 HYDRO-METEOROLOGY

Establishing groundwater source protection zones requires an understanding of general meteorological patterns across the area of interest. The data source is Met Éireann.

Average Annual rainfall: 819 mm. The average annual rainfall for the period 1961–1990 is 819 mm/yr at the Ardee (Boharnamoe) rain gauge (Fitzgerald and Forrestal 1996). Monthly rainfall data for this station was obtained from Met Éireann for 2006 and 2007. Total rainfall in these years was 838 mm and 800 mm respectively (Chart A1.1 in Appendix 1).

Average Annual evapotranspiration losses: 513 mm. Evapotranspiration is not recorded at the Ardee station so data from the Casement Aerodrome Station in Dublin has been used. The average annual potential evapotranspiration (P.E.) for 1981–2000 is approximately 540 mm/yr at Casement., Actual Evapotranspiration (A.E.) is taken as 95% of the Potential Evapotranspiration, i.e. 513 mm/yr. The monthly estimated actual evapotranspiration for 2006–2007 is presented Chart A1.2, Appendix 1. The total actual evapotranspiration in these years was 543.5mm and 516.9mm respectively.

Average Annual Effective Rainfall: 306 mm. The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is, therefore, 306 mm/year. See also Section 10.3 on Recharge which estimates the proportion of effective rainfall that enters the groundwater system.

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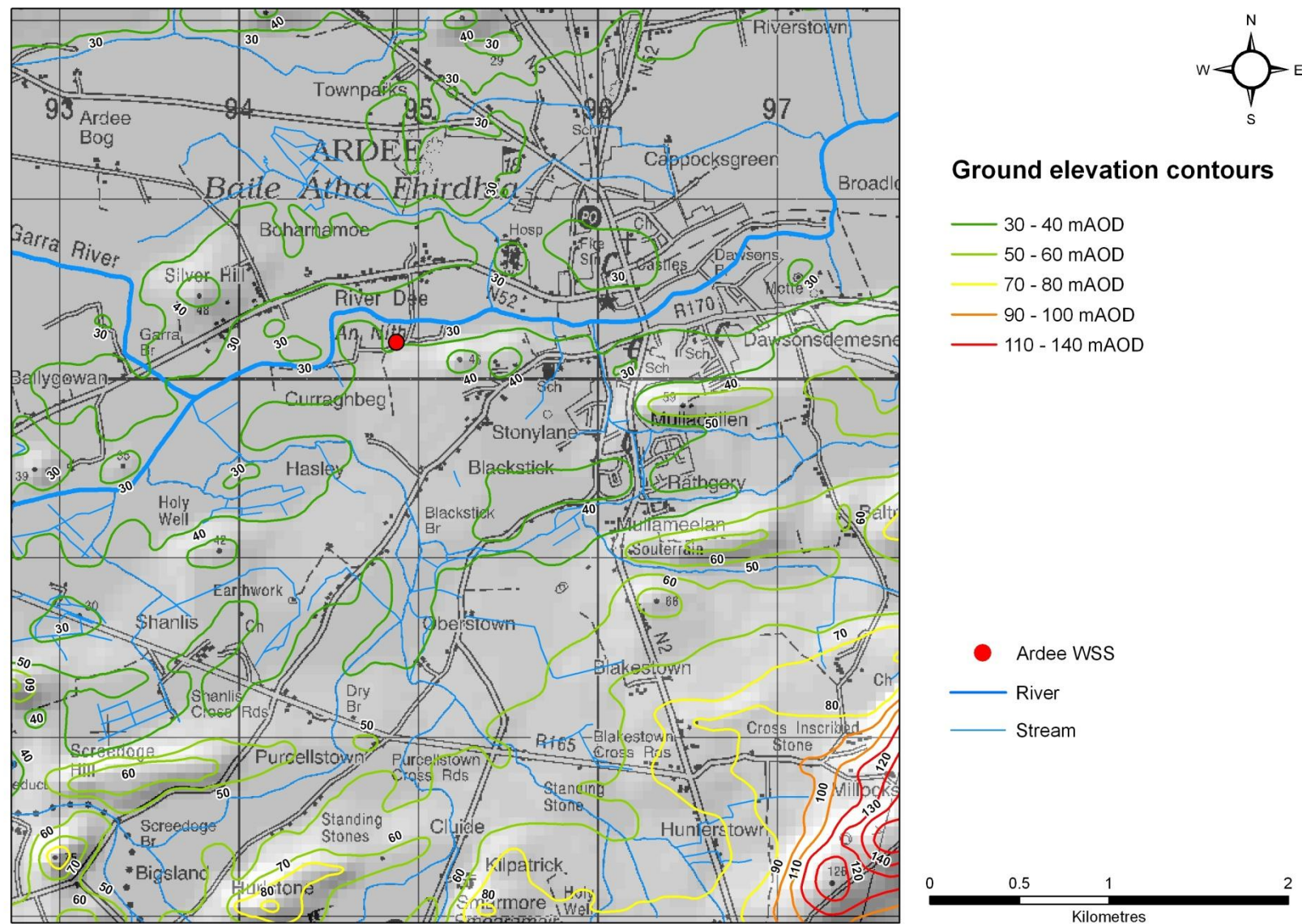


Figure 5 Topography and surface water drainage in the area around the Ardee Public Water Supply Source

7 GEOLOGY

This section briefly describes the relevant characteristics of the geological materials that underlie the area surrounding the Ardee Public Water Supply boreholes. 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 (McConnell *et al.*, 2001)
- Hydrogeological reports and borehole logs from KTC (1980, 1981, 1996).

Subsoils information derives from

- Quaternary mapping undertaken by the GSI;
- Teagasc subsoils mapping (Meehan, 2004);
- Permeability mapping by GSI field personnel in May 2007 including geotechnical descriptions and tests (e.g., particle size analyses).

7.1 BEDROCK GEOLOGY

Descriptions of rock units, and details of the relationship between the older Lower Palaeozoic and younger Carboniferous rocks, are derived from a GSI report on the area (McConnell *et al.*, 2001) and are summarised in Table 2. A bedrock map of the area is presented on Figure 6. Cross-sections are shown in Figure 7.

Table 2 Bedrock geology of the area around Ardee Public Water Supply

Age	Geological Name	Geological Description	Maximum thickness (m)
CARBONIFEROUS	Cruicetown Group (undifferentiated) (CRT)	Argillaceous Bioclastic Limestone and unbedded pure limestones	~270
	Navan Beds (NAV)	Dark limestone, mudstone, sandstone	~200
	Rockfield Sandstone Member in undifferentiated Navan (NAVsd)	Sandstone	70
SILURIAN (LOWER PALAEOZOIC)	Clontail Formation (CL)	Green-grey medium- to thickly-bedded coarse and very fine-grained calcareous red-mica greywackes.	>500
	Salterstown Formation (SA)	Calcareous greywacke comprising dark, blue-grey siltstones with interbedded sandstones; banded mudstones.	>500
	Black shale and chert in the Salterstown Formation (SABs)	Black shale and chert	

The Ardee water supply wells are located in an area underlain by the Cruicetown Group (undifferentiated limestones), which comprise shaly (impure) limestones. These shaly limestones are commonly known as 'Argillaceous Bioclastic Limestones' (ABL), and elsewhere in Ireland are also

known as 'Ballysteen Limestone'. For the purpose of aquifer classification, all such rocks of an equivalent composition and age are grouped together as Dinantian Upper Impure Limestones.

In this part of Co. Louth, the rock units are folded into a syncline ("U"-shaped fold), whose axis trends roughly NE-SW. The Cruicetown Group limestones, which are the youngest rocks in this area, occupy the centre of the fold. They underlie a zone approximately 1.5 km wide. Surrounding the Cruicetown Group in narrow (~500 m) 'bands' are progressively older Carboniferous-age rocks. These are the Navan Beds (dark limestone, sandstone and mudstone) and the Rockfield Sandstone Member

The Carboniferous-age limestones, shales, mudstones and sandstones overlie significantly older rocks (the Lower Palaeozoic Clontail Formation). The Clontail Formation is juxtaposed next to the Lower Palaeozoic Salterstown Formation by a major fault. NE-SW trending faults cutting through rocks of all ages are dominant in the area, although a WSW-ENE fault cuts across the syncline about 1 km south of the supply borehole.

7.2 SOILS AND SUBSOILS

The subsoils in Co. Louth were originally mapped by the Quaternary Section of the GSI. This information was subsequently incorporated in the Teagasc subsoil mapping (Meehan, 2004), on which the following categories and descriptions are based. Drilling and permeability mapping carried out for this project by the GSI provided additional information on the subsoils. The subsoil map is shown on Figure 8.

The subsoils around the source comprise a mixture of materials, specifically, Tills (TLs, TLPSsS), Alluvium (A), and small areas of Lacustrine deposits (L) and Limestone gravel (GLs). A significant built-up area (Made) occurs to the east of the source. There are extensive cut peat (Cut) areas to the northwest. Soils in the area are, in the main, well-drained. Wet soils primarily coincide with occurrences of peat and alluvium, with small pockets of wet soil occurring in very low-lying areas and on the margins of the peat.

Till is a poorly sorted sediment comprising a wide range of particle sizes. Tills are often over-consolidated, or tightly packed, unsorted, unbedded, possessing many different particle and clast (stone) sizes, and commonly have sharp, angular clasts (Meehan, 2004). Tills are often termed 'boulder clays' by engineers. There are two main till types in the area.

The limestone till dominates the majority of area surrounding the Ardee WSS. Thirteen exploration boreholes were drilled by GSI in May 2007 in this unit. Six of these samples were analysed for Particle Size Distribution (PSD). The results of the analyses are presented in Appendix 2. The results indicate that five of the samples are very similar in composition and are typical of till. The field description of the samples is SILT/CLAY. The limestone tills are mapped as **moderate permeability**.

The 'clayey' Lower Palaeozoic Sandstone and Shale till unit (TLPSsS) is predominantly deposited to the south-east, over 2.5 km from the production well. The Sandstone and Shale Till (TLPSsS) is not deposited over the Cruicetown Group in this area. In the area nearer to Ardee town, it is mapped as **moderate permeability**, grading southeastwards to **low permeability**.

Alluvium is found along the River Dee, and in topographic hollows along small tributaries to the Dee in the gently undulating landscape. One of the samples collected by the GSI in the area was collected adjacent to a stream from an area mapped by Teagasc as undifferentiated Alluvium deposits. This sample has a different characteristic to the other samples, which are from till deposits. The field description of the sample is SILT which is confirmed by the laboratory analysis which shows silt comprises 64% of the sample; it is mapped as **moderate permeability**.

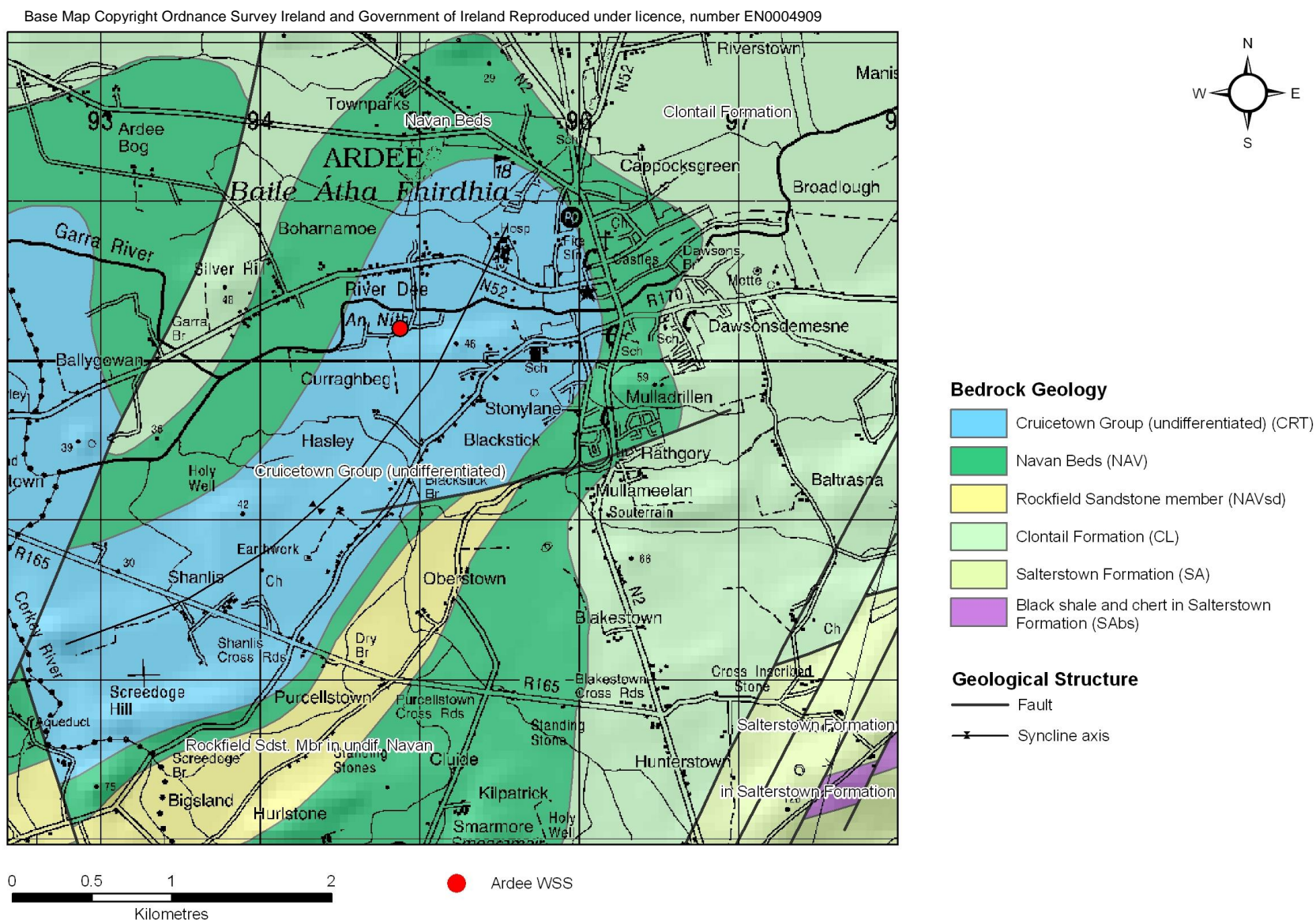


Figure 6 Bedrock geology in vicinity of Ardee

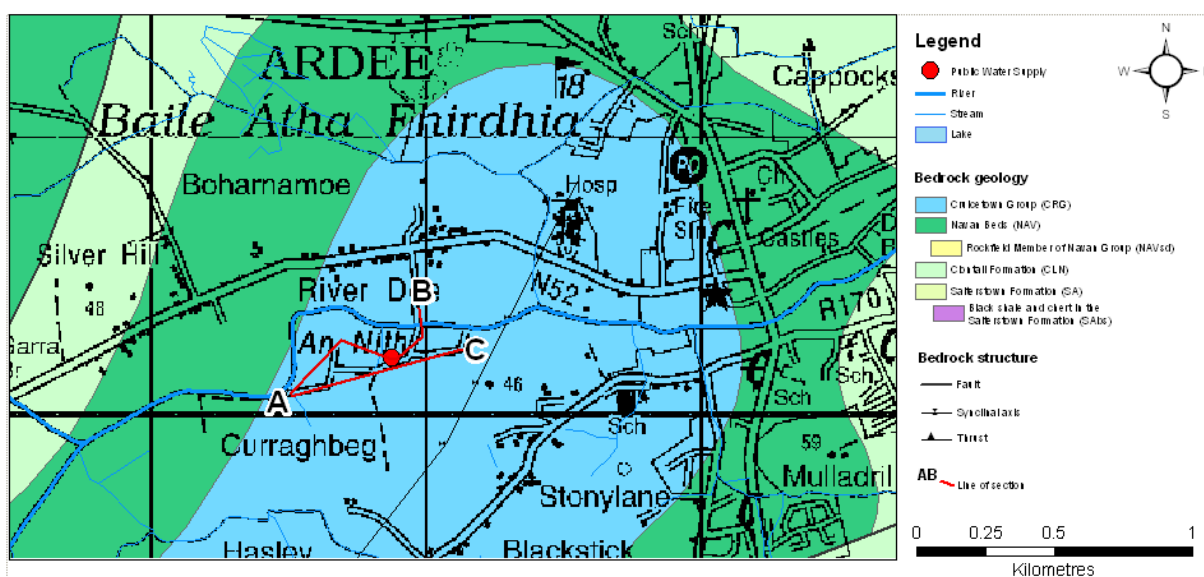
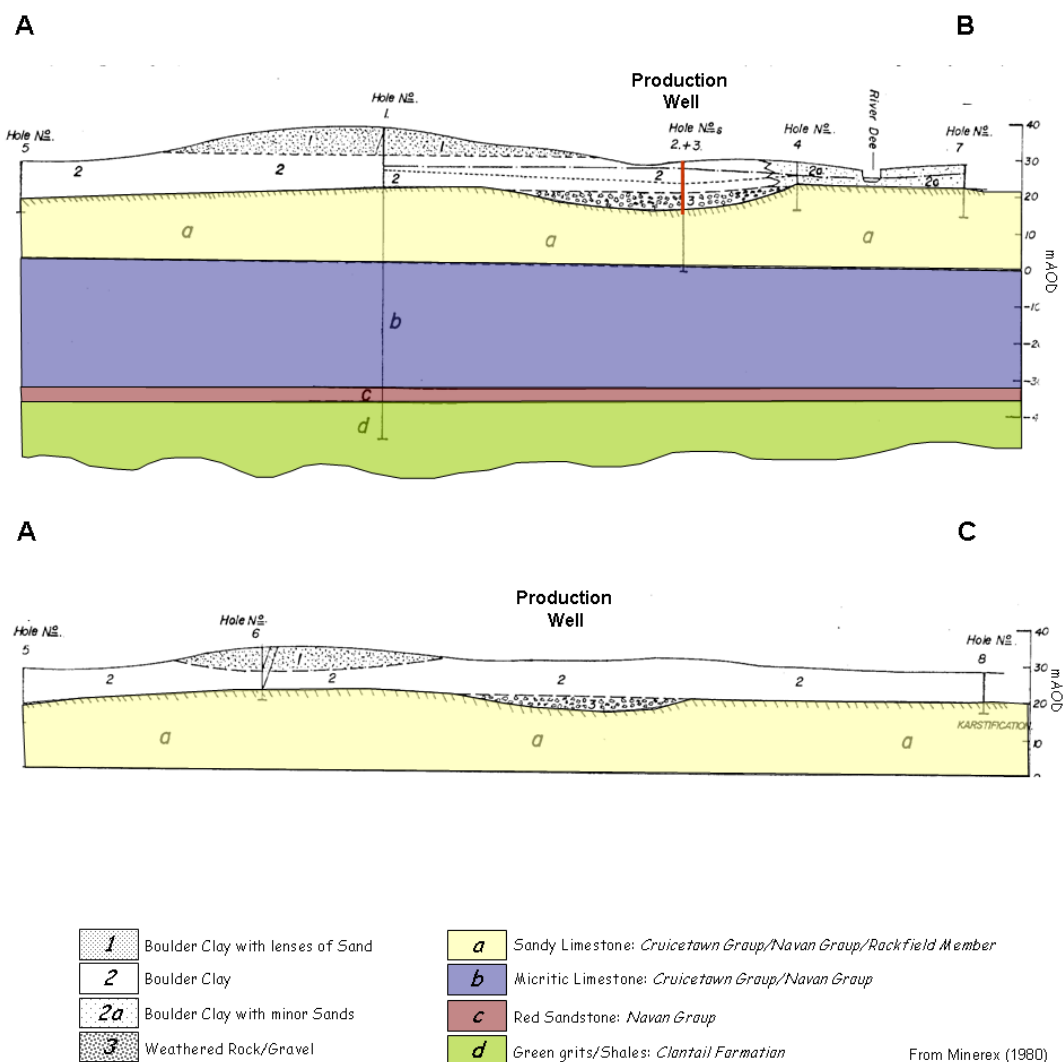


Figure 7 Cross-section from A – B and A – C, with map showing lines of section

Subsoils mapped by Teagasc

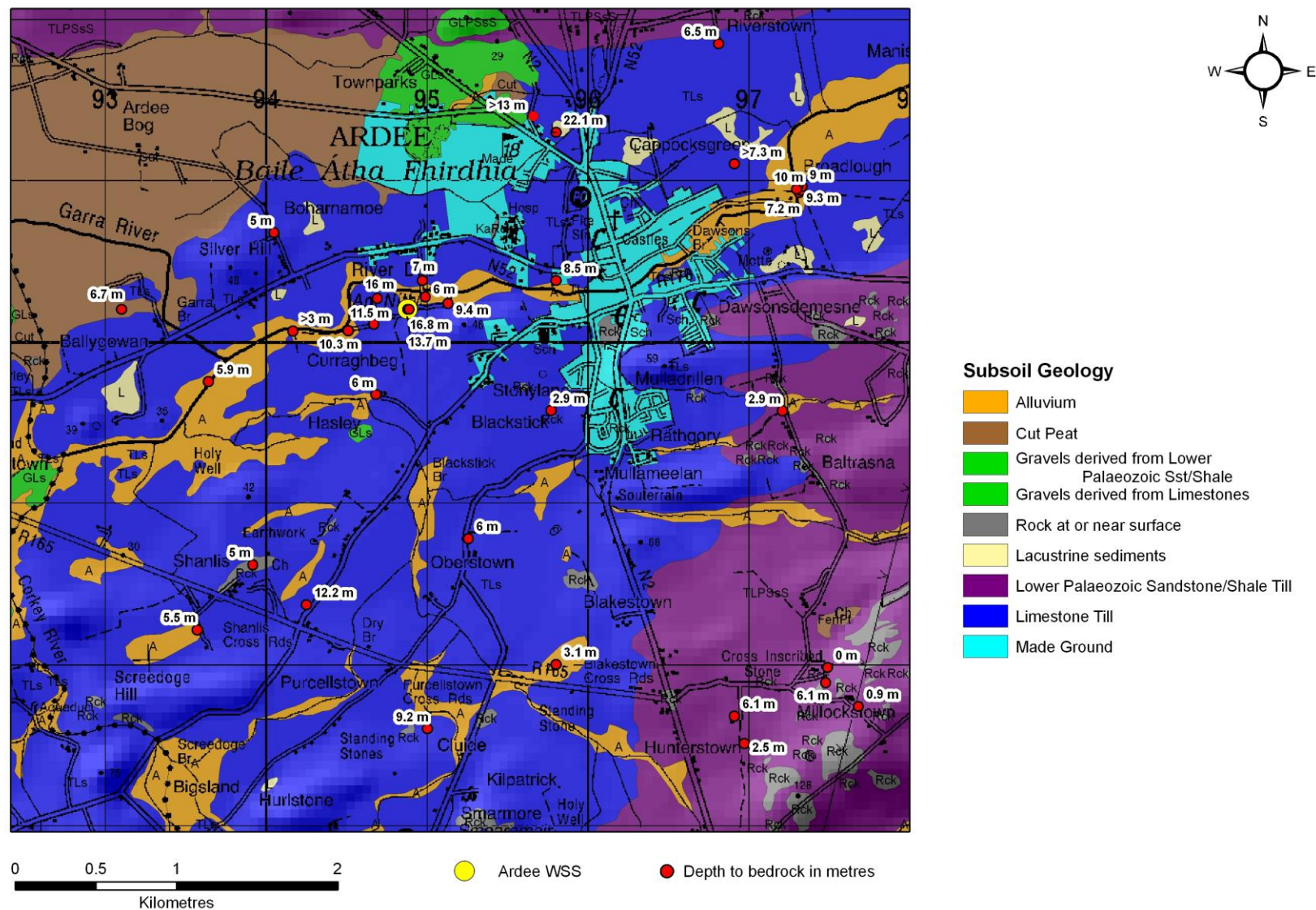


Figure 8 Subsoils and subsoil thicknesses in the vicinity of Ardee

Glaciofluvial sands and gravels are different from tills in that they are deposited by running water only. Gravel deposits are mapped as occurring in very small areas (about 1 ha) to the south of the source, near to tributaries to the River Dee. About 1 km north of the source, there are more extensive Limestone gravels. There is a known gravel pit located about 210 m west of the production well in the vicinity of Well #4 drilled in the 1980's. The extent of the gravel is considered to be limited as it was not encountered in Well #4. Gravels have **high permeability**.

Cut Peat deposits are organic soils deposited after the last Ice Age. There is large area to the northwest of the source at Ardee Bog. The peat has a high moisture content but **low permeability**.

7.3 DEPTH TO BEDROCK

Depth to rock data are shown on the subsoils map in Figure 8. In the immediate vicinity of the source, and at other locations along the River Dee, depth to rock is typically on the order of 10 m or greater, with the deepest rock head at 16.8 m. Moving upslope away from the river, subsoil thicknesses are on the order of 5 to 7 m, until they thin out adjacent to rock outcrops/subcrops.

Depth to rock data are available from a variety of sources, including the initial drilling program undertaken between 1980 to 1981. Louth County Council commissioned the drilling of a further six trial wells to the west of the original drilling site in 2005. No factual report on the drilling and testing of the wells was provided, but raw data in the form of drillers' logs, mapped locations and pumping test results were provided by Louth Co. Co. In 2007, GSI drilled a further ten auger holes in the vicinity of the source.

8 GROUNDWATER VULNERABILITY

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target'. This means that vulnerability relates to the thickness of the unsaturated zone in the sand/gravel aquifer, and the permeability and thickness of the subsoil in areas where the sand/gravel aquifer is absent. A detailed description of the vulnerability categories can be found in the Groundwater Protection Schemes document (DELG/EPA/GSI, 1999) and in the draft GSI Guidelines for Assessment and Mapping of Groundwater Vulnerability to Contamination (Fitzsimons *et al.*, 2003).

The groundwater supply source is the bedrock aquifer beneath the ground surface. For the purposes of vulnerability mapping, the "**top of the rock**" is the target¹.

The groundwater vulnerability map presented in Figure 9 shows that, in the immediate vicinity of the source, vulnerability is **moderate**, since the moderate permeability subsoils are greater than 10 m thick.

In the wider moderate subsoil permeability area to the south (upgradient) of the source, depth to rock is shallower (5-10 m), and groundwater vulnerability is **high**. Areas of **high** groundwater vulnerability also occur north of the River Dee, where there are relatively sizeable glaciofluvial sand and gravel deposits.

¹ In areas where the water table is below the top of the bedrock, the thickness of the unsaturated zone within the bedrock is not taken into consideration in vulnerability mapping, as little attenuation of contaminants would occur owing to a lack of filtration by granular materials.

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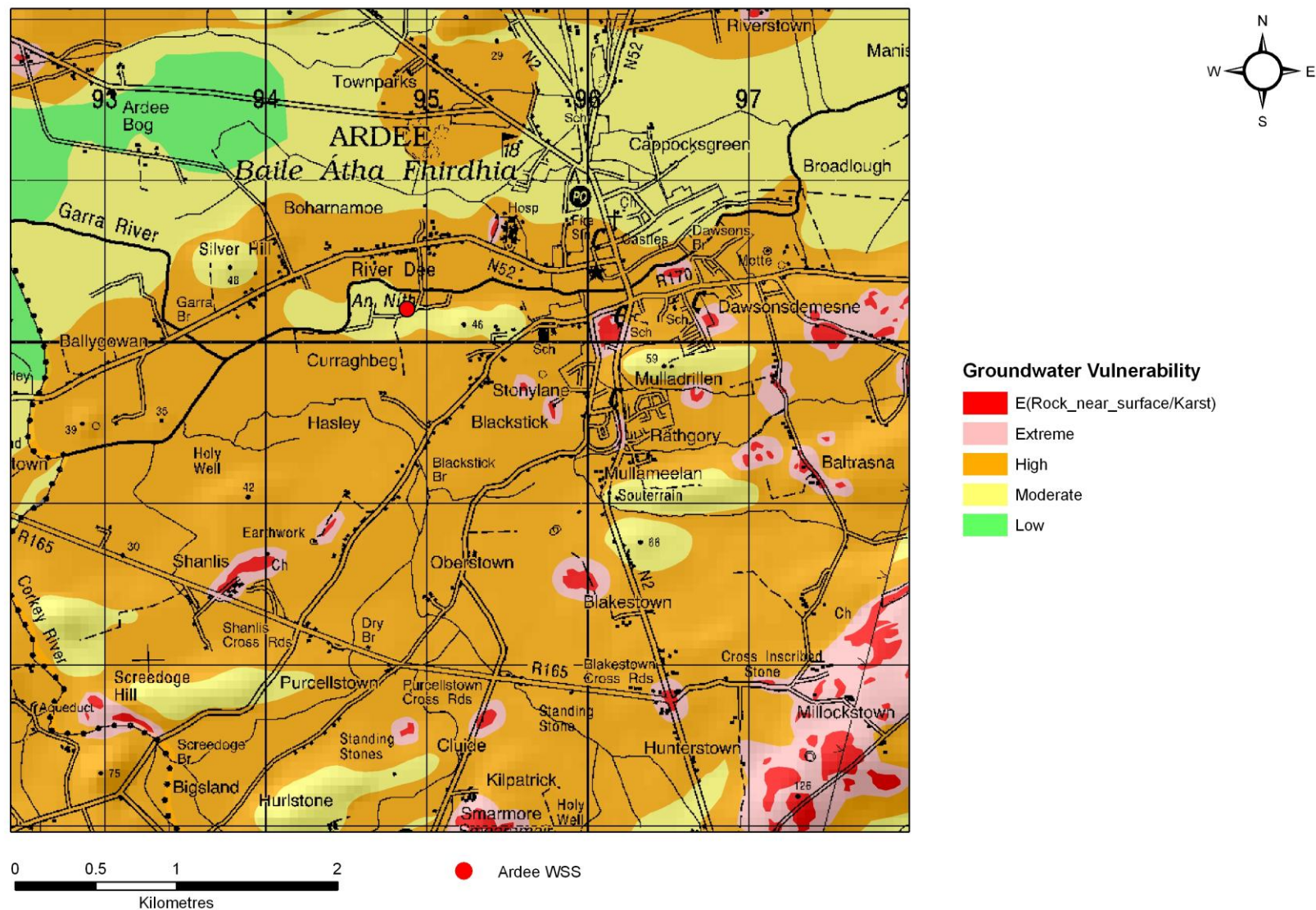


Figure 9 Groundwater vulnerability in the vicinity of Ardee

There are small areas of **extreme** vulnerability approximately 1.4 km to the southwest, 800 m southeast, and 700 m northeast of the abstraction borehole, where subsoils are less than 3 m in thickness, or rock is at the surface.

Low vulnerability areas only occur outside the zone of contribution to the abstraction borehole, under Ardee Bog.

Depth to rock interpretations are based on the available data cited here. However, depth to rock can vary significantly over short distances. As such, the vulnerability mapping provided will not be able to reflect all the natural variation that occurs in an area. The mapping is intended as a guide to land use planning and hazard surveys, and is not a substitute for site investigation for specific developments. Classifications may change as a result of investigations such as trial hole assessments for on-site domestic wastewater treatment systems. The potential for discrepancies between large scale vulnerability mapping and site-specific data has been anticipated and addressed in the development of groundwater protection responses (site suitability guidelines) for specific hazards. More detail can be found in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

9 HYDROGEOLOGY

This section presents our current understanding of groundwater flow around the Ardee borehole. These interpretations and conceptualisations of flow are used to delineate the source protection zones around the wells. Hydrogeological and hydrochemical information for this study were obtained from the following sources:

- GSI Databases.
- EPA Groundwater chemistry data.
- Subsoil permeability and groundwater vulnerability mapping carried out as part of the Louth GWPS study.
- *Report on the Hydrogeology of the Mental Hospital Farm Ardee, Co. Louth* – Includes reporting on drilling of Wells at Curraghbeg (Wells #1-9), 72 hour pumping test conducted on PW3 from 17/11/1980 with monitoring of observation wells (K.T. Cullen, 1980).
- *Report on the Test Pumping of the Production Well on the Mental Hospital Farm* – Includes information on 6 day pumping test and recovery conducted on PW3 from 29/08/1981 (K.T. Cullen, 1981).
- Ardee Geophysical Survey – Letter report by KT Cullen & Co. Ltd to Louth Co. Co. on results of Geophysics of the Survey conducted in the area (1996).
- Bohernamoe, Ardee, Co. Louth – Public Water Supply Well, Source Protection Zone Report prepared by Komex (2003). Interim source protection scheme developed using Fixed Radii method.
- GSI drilling and subsoil permeability assessments (2007 and 2009).
- Raw data including trial well driller's logs and 72 hr pumping test data for new Trial Wells at Hickey's Farm from 05/04/2005 (No report – data provided by Louth Co. Co.).
- A drilling programme carried out by the GSI to ascertain depth to bedrock and subsoil permeability in May 2007.

9.1 GROUNDWATER BODY AND STATUS

The source and the surrounding area are located within the Ardee groundwater body (GWB) (GSI, 2005), that is classified as “at Good Status”. The groundwater body descriptions are available from the GSI website: www.gsi.ie and the status is obtained from the WFD website: www.wfdireland.ie.

9.2 GROUNDWATER LEVELS, FLOW DIRECTIONS AND GRADIENTS

Groundwater levels in the immediate vicinity of the production well are available from measurements taken during the 1981 pumping test and are converted to elevation using the topographic map provided in the KTC report (1980). The information in Table 3 shows that groundwater levels are significantly above the base of the subsoils. The production well is reportedly artesian sometimes.

Table 3 Groundwater levels during 1981 pumping test

See Figure 4 for locations of the boreholes.

Well	Ground Elevation (maOD)	Static Water Level (mbtc)	Static Water Level (maOD)	Pumped Water Level (mbtc)	Pumped Water Level (maOD)	Drawdown (mbswl)	Distance from Pumping Well (m)
Hickey's Well	29.3	2.07	27.2	7.1	22.2	5.01	-
Well #2	29.3	2.29	27.0	7.3	22.0	4.96	4.4
Well #4	28.5	3.79	24.7	4.5	24.0	0.68	75.8
Well #7	28.5	4.3	24.2	4.9	23.6	0.64	196.0
Well #1	37.5	10.52	27.0	11.9	25.6	1.38	204.0

Based on the information available it is considered that the groundwater flow direction follows topography – i.e. flows from south to north. The groundwater gradient uphill (south of) the Hickey borehole is on the order of 0.025, based on subsoil groundwater levels in an auger hole at Curraghbeg House and the 1981 groundwater level data given in Table 3. The hydraulic gradient between the production well and Well #4, based on static water levels given in Table 3, is estimated to be 0.033.

In general, groundwater will discharge to the River Dee from both the south and the north of the river. However, results from the 1980/1981 pumping tests and the seasonally varying production well yields (Section 9.4) indicate that groundwater connectivity with the River Dee is limited in the vicinity of the borehole on Hickey's Farm.

9.3 HYDROCHEMISTRY AND WATER QUALITY

Water quality data are available from the following sources outlined below, and are compiled in Appendix 3. (No recent raw water quality data are available because the rising main is sealed and no sampling point exists prior to mixing with the river water source at the treatment plant.)

- Sampling of the Production Well and River Dee during the 1980 pumping test (KTC, 1980).
- Sampling of the Production Well and River Dee during the 1981 pumping test (KTC, 1981).
- EPA Sampling of the raw water supply from 1995 to 2002.

The water quality data from the first pumping test in 1980 show the hydrochemistry of the production well to have a calcium bicarbonate signature. The data are presented graphically on a Piper diagram in Appendix 3. The results for the River Dee are also presented on the chart and show that the river

water chemistry is not dissimilar to the groundwater. The average Total Alkalinity for the production well is 306 mg/l, and the average Total Hardness is 395 mg/l CaCO₃, which is very hard.

Samples were collected at the start and end of both the pumping tests in 1980 and 1981. The results show no significant change in the parameters which may indicate a contribution from the river over the course of the tests (conductivity, alkalinity and hardness).

Water quality data assessed by the EPA show a high level of variability in certain parameters, including nitrate, conductivity, calcium and magnesium. Results for these parameters are shown on Figure 10. Parameter values appear to be higher in the December to March sampling round, in comparison to those sampled in August to September. Nitrate concentrations measured in August/September average 14.8 mg/l, while those sampled in December to March average 30.9 mg/l.

The variability in results may be linked to the variability in the well yield, suggesting a reduction in water quality with increasing yield. This may be due, in part, to the borehole abstracting more shallow groundwaters (that are more susceptible to contamination) during high recharge and high water table periods (usually the winter months). Higher nitrate concentrations during the winter months may also be related to higher leaching of existing soil nitrate, or different nitrate application rates during these months. Other water quality parameters, such as sulphate, calcium, hardness and alkalinity, show variability but with less clear-cut seasonality.

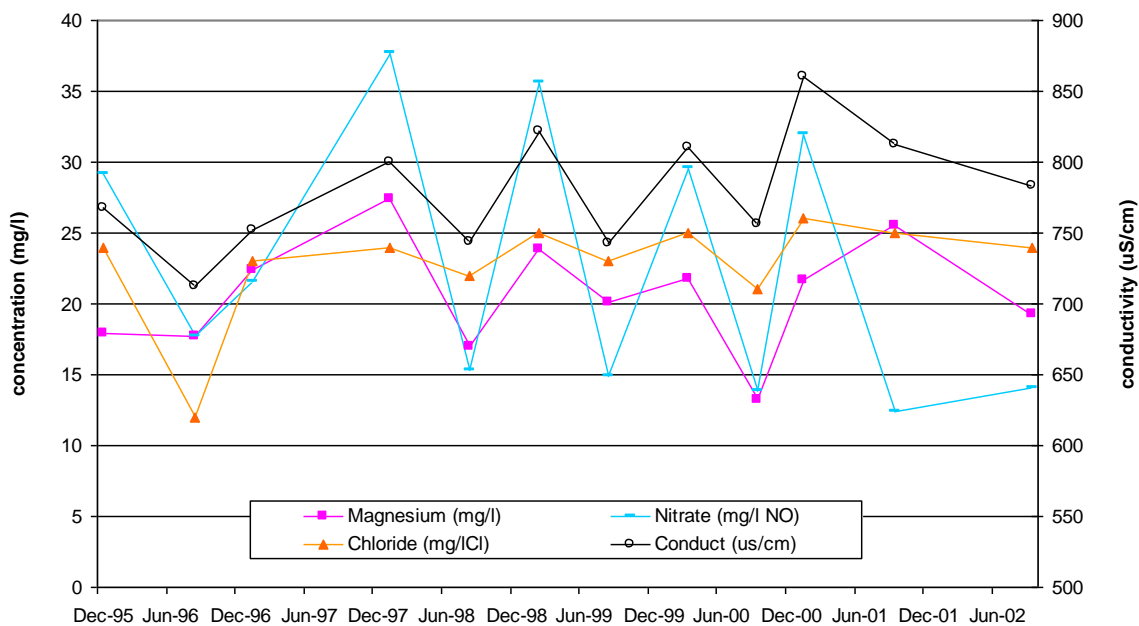


Figure 10 Selected EPA water quality data

Indicators of organic contamination, such as Iron and Manganese, ammonium, and the potassium:sodium ratio are all below their respective parametric values. However, total coliforms have been detected intermittently at low counts (1 to 4 per 100 ml) in both the winter and summer sampling rounds. Faecal coliforms are reported for September sampling rounds in 2001 and 2002 (5 and >200 per 100 ml respectively), but zero total coliforms are reported at the same time, so the reliability of these data is not known.

9.4 AQUIFER CHARACTERISTICS

Hickey's borehole is drilled into the Cruicetown Group, which is classified as a Locally important bedrock aquifer that is moderately productive only in local zones (LI). The Navan Beds rock unit is also classified as an LI aquifer. The Rockfield Sandstone is considered to be more productive, and is classified as a Locally important bedrock aquifer that is generally moderately productive (Lm). The Lower Palaeozoic rocks are Poor (PI). Figure 11 shows the distribution of bedrock aquifer classifications in the vicinity of Ardee WSS.

Two main stages of drilling have been undertaken in the vicinity: in 1980-1981 (K.T. Cullen) and in 2005. Geophysical Surveys were completed in the area in 1987 and in 1996 (K.T. Cullen). Results from these investigations indicate that the very high well yield at Hickey's Well is the result of a localised layer of weathered/broken rock and gravel. The results of the drilling and pumping tests indicate that the bulk of the Cruicetown rock unit is a reasonably productive aquifer in the vicinity of the abstraction borehole.

“Water bearing unit”: The main water bearing unit in the production well (Hickey's Well, Well #3) is a 4 m thick layer described as Broken Rock/Gravel. This layer is encountered beneath 9.5m of boulder clay. The layer is shown on Figure 7 as Unit 3 (Weathered Rock/Gravel). The layer is described as containing coarse blocks which yielded large volumes of water. The layer consists of fist-sized blocks of weathered sandy limestones. This may represent a zone of weathering or possibly may be a gravel-filled buried river channel. The latter was considered to be more likely as it exists in a depression in the bedrock surface that is very limited in lateral extent.

Geophysical Surveys were completed in the area in 1987 and in 1996. The survey completed in 1987 used a resistivity survey with a Schlumberger array with a single current electrode separation of 10 m. This survey did identify an area of low apparent resistivity at the location of the production well. The low resistivity zone is quite restricted but does extend some distance to the west including the location of Well #1. The layer of broken rock was not encountered in Well #1. The borehole log for Well#1 shows a 6 m thick Sand and Gravel layer in the top section of the well. These are the same gravels exposed and exploited at the gravel pit in this area. This layer of gravels may account for the lower resistivity but are not the same unit as the productive section in Hickey's Well. The 1996 survey was completed with a WADI instrument which uses Very Low Frequency Radio Waves to infer anomalies in the subsurface. The results show an anomalous area coinciding with the production well. The anomalous area is much smaller than that mapped in the previous study. The area is elongated in a north-south direction and which appears to pass beneath the Dee River.

There have been a number of wells drilled in the area of Hickey's farm. Only Wells #2 and #3 intercept the broken rock layer. Although the real extent of this feature cannot be defined it is accepted that the feature is restricted in aerial extent.

Majority of aquifer: Trial well drilling was completed in 2005 to the west of the Hickey's Well site in this aquifer where no broken rock or gravels were intersected. Abstraction rates achieved during the drilling range from 33 to 463 m³/d (see Appendix 4). The highest yielding well, TW2, was tested for 72 hours. The test incorporated a step test during the first day, with the well being pumped at the highest step for the remainder of the 72 hour test. Drawdowns in TW1, TW3 and TW4 were also measured during the test. The results of the pumping section of the test are shown on Chart A4.1 in Appendix 4. The pumping tests show the well was pumped at a rate of 620 m³/d for the period of the test. However, the water levels did not stabilise and continued to drop until the end of the test. This indicates that this abstraction rate is not sustainable in the long term. The results for the recovery of the test are shown on Chart A4.2. This shows a rapid initial phase of recovery followed by a slower recovery.

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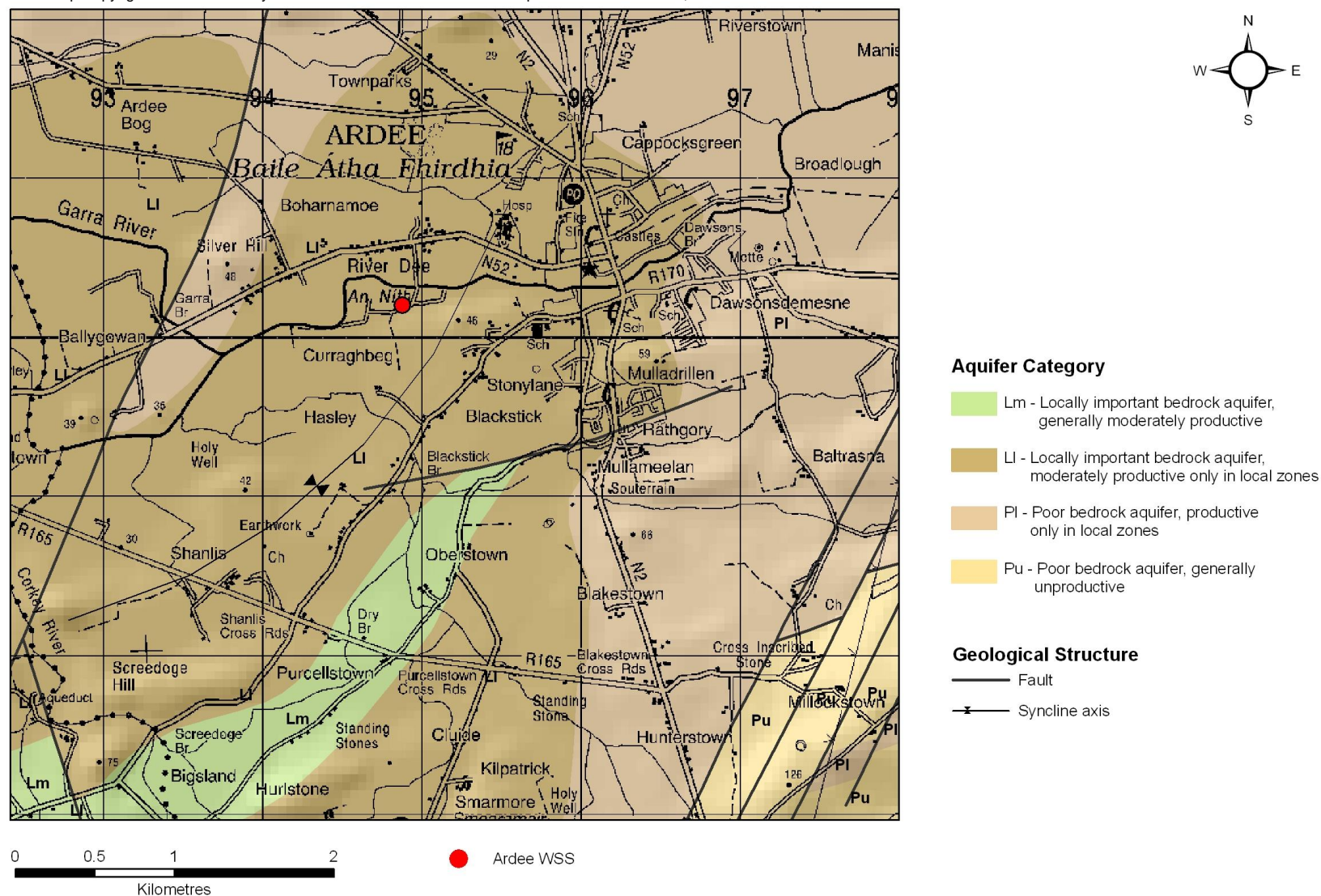


Figure 11 Bedrock aquifer classification in the vicinity of Ardee WSS

Aquifer properties: The results of the 1980 pumping test on the production well were analysed in the original report. The aquifer properties reported for the first section of the test were that at Well #2 the transmissivity was $224 \text{ m}^2/\text{d}$ and the storage coefficient was 8.0×10^{-3} . The storage coefficient is indicative of semiconfined aquifer.

Aquifer properties cannot readily be established from the 2005 pumping test results; because the test began with a step test, it is not possible to use standard pumping test analysis methodologies as these require a constant pumping rate. However, the specific capacity at the end of the pumping test is a good measure of the productivity of the well. At the end of the 72 hours test, the specific capacity of the well was $117 \text{ m}^3/\text{d}/\text{m}$. The Logan Approximation (Misstear, 2007) gives an estimated transmissivity of $140 \text{ m}^2/\text{d}$. Analysis of the recovery test shows that the recovery rate changes during course of the monitoring period. There is a much more rapid period of recovery in the first four minutes, which then slows for the remainder of the test. Each section was analysed, and the estimates of transmissivity for the early section are $284 \text{ m}^2/\text{d}$, and the transmissivity estimate for the later section is $114 \text{ m}^2/\text{d}$.

The results of short pumping tests on the boreholes drilled in 1980/1981 and 2005 indicate that, away from the weathered “water bearing unit”, abstraction rates supported by the aquifer are modest, typically on the order of $100\text{-}200 \text{ m}^3/\text{d}$ (see Table A4.1 in Appendix 4), and in line with the LI aquifer classification. Transmissivities for these boreholes and the aquifer around them would be expected to be lower than the transmissivities cited above for the more productive zones.

Aquifer anisotropy: During the six day pumping test in 1980, the water levels in the production well and the nearest observation well (Well #2, 4.4 away) were very similar, with a maximum difference of 13 cm. Observations at Well #1, 204 m northwest of Hickey’s well show that the drawdown is greater (by 0.7 m) than at Well #4, 76 m to the northeast. Well #4, and Well #7 on the opposite river bank, show indications of recharge during the six-day test.

Groundwater-surface water interaction: The production well is located within 115 m of the River Dee. Results from the pumping tests conducted in 1980 showed that drawdown occurred in an observation well located in the bedrock aquifer on the opposite bank of the River Dee. Drawdown would not be expected on the opposite bank of the river if the river was providing water to the aquifer in significant quantities. The subsoil thickness measured in the wells in this area is between six and nine metres. The river may cut through a certain portion of this but there appears to be sufficient subsoil thickness remaining below the river bed to prevent a direct link with the fissured parts of the aquifer.

The available yield from the well appears to fluctuate with river levels, with more yield available during higher river flows. River flow data are available from the OPW stream gauge at Charleville Weir (No 06013) located 8.7 km down-stream of the production well. The flow data measured at the gauge is presented on Figure 12 with the abstraction data for the production well. The chart clearly shows there is a correlation between the abstraction rates and the river flow magnitude. However, on closer inspection there is a distinct lag between the river flood peak and the abstraction rate peak. The lag period appears to be nine days in most cases². In situations where groundwater supplies receive a significant proportion of recharge from adjacent river water bodies, the link between the two is more direct.

Together with results from the 1980 pumping test at Hickey’s well that shows a response to abstraction in observation Well #7 on the opposite side of the River Dee, this indicates that the

² The abstraction data are mainly provided in 7-day averages, so a more accurate analysis of the lag time is not possible, but the trend is clear.

interaction between the groundwater and river is limited in the immediate area. It is possible that the aquifer may receive some water from the river, but this does not appear to be significant or drawdown would not have been observed on the opposite bank of the river during the pumping test, and there would also be a considerably shorter lag period between river flow peak and the available yield from the well.

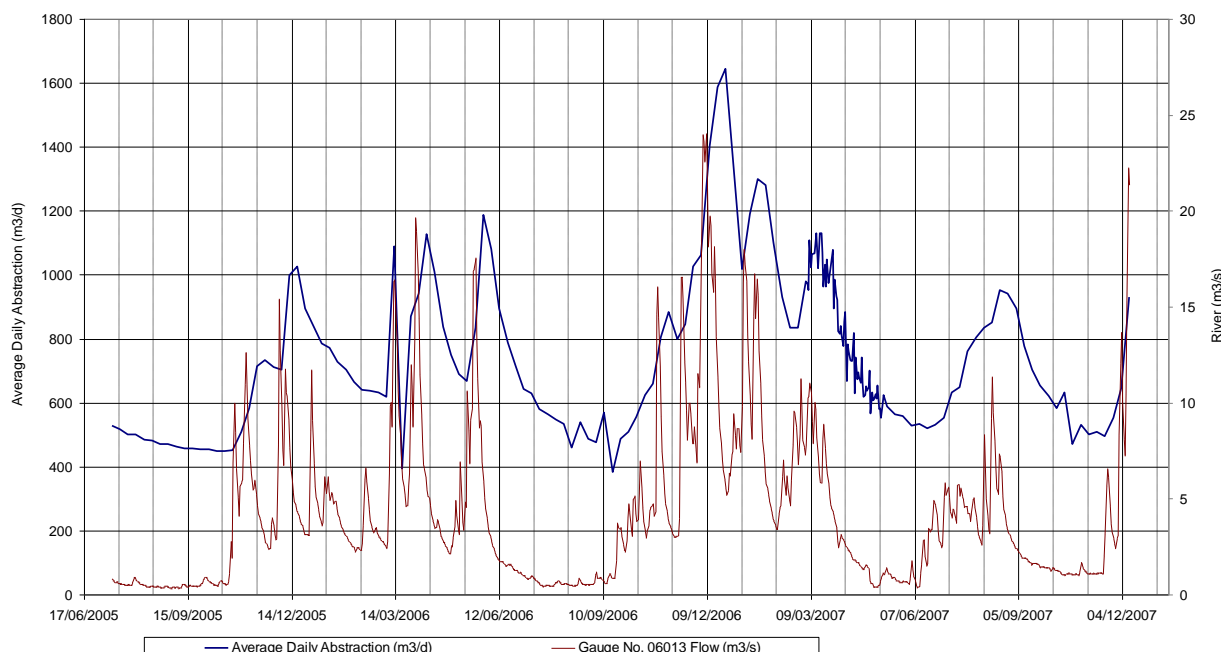


Figure 12 Groundwater abstraction at Ardee WSS and river flow (Gauge No 06013)

Groundwater yield sustainability and recharge: The similarity of variations in both river flows and available aquifer yields indicate that both are linked to rainfall events. The lag period between rainfall events and the borehole yield suggests that time is required for the recharge to percolate through the subsoil and into the aquifer, and replenish aquifer storage before being available to be abstracted from the well.

The pumping tests on the wells were all conducted over short periods. The water levels did not stabilise during any of the pumping tests which limits the conclusions that may be drawn from these tests about the sustainability of the supply. An assessment of the operational data from the well provides additional information. It is clear from the data provided that the yield from the well varies over a wide range and, as has already been discussed, this appears to be linked to temporal variations in aquifer recharge.

The lower end of the range for Hickey's well yields (c. 400 m³/d) is closer to the better yields realised from the trial wells drilled directly into bedrock aquifer. The much higher yields (i.e. 1,700 m³/d) are only available when recharge has occurred. Once a dry spell occurs, the yield from the well reduces steadily over time.

In examining the reduction in yield over time, the rate of decline is quite uniform throughout the period for which data are provided. The trend from peak yield to trough is shown on Figure 13 which is a composite of two recession periods. A trend line can be fitted to the recessions and it is seen that a power law relationship between yield reduction and time provides a very good fit ($R^2 = 0.94$). This suggests the well is draining a store of water once the peak yield has been achieved. As this store is

emptied, the yield reduces until it approaches something similar to the yields from other wells drilled in the bedrock aquifer. This filling and draining of a store also suggests a relatively constrained or small groundwater-bearing zone such that the zone of contribution can not expand to capture significantly more flow when recharge reduces during drier periods.

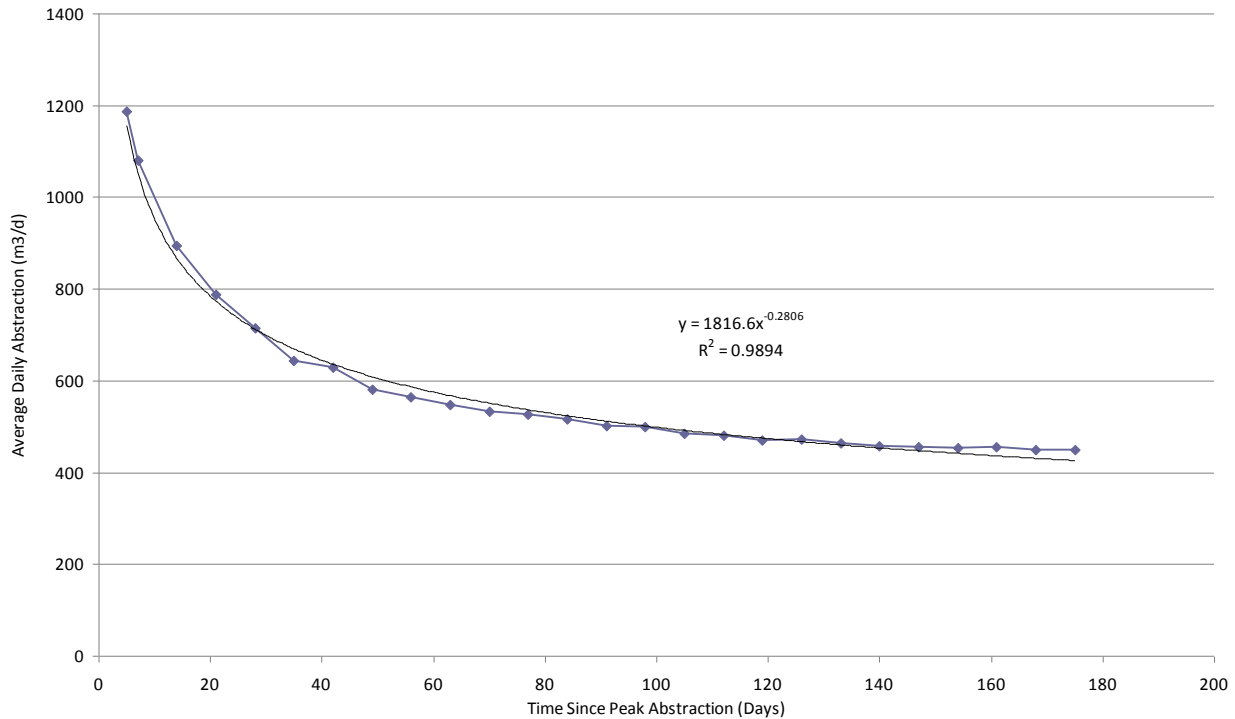


Figure 13 Recession analysis of abstraction rates (recession periods 11/07/05 to 17/10/05 and 29/05/06 to 07/08/06)

10 ZONE OF CONTRIBUTION

10.1 CONCEPTUAL MODEL

The conceptual model is based on the mapped geology and on hydrogeological data such as water levels, pumping tests, subsoil thicknesses and permeabilities, surface water features, topography, etc.

- Groundwater is replenished by recharging waters percolating diffusely through the overlying subsoils.
- Pumping test and abstraction data indicate that groundwater connectivity with the River Dee is limited in the vicinity of the production borehole (Hickey's well), and that surface water contribution to the abstracted groundwater is negligible.
- The subsoil layers overlying the bedrock aquifer comprise limestone tills and limited gravelly layers. Subsoil thicknesses are generally more than 10 m thick in the vicinity of Hickey's well, decreasing to around 5-7 m over much of the area up-gradient. Limestone till permeabilities are mapped as moderate, and groundwater vulnerability in the immediate vicinity of the boreholes is moderate, and uphill (south) of the abstraction point is high, with limited areas of extreme vulnerability.
- The Hickey's well abstracts groundwater from impure bedded limestones and 'sandy limestones' that are classified as a **Locally important bedrock aquifer that is Moderately Productive only**

in **Local Zones (LI)**. In the southeastern part of the zone of contribution, groundwater flows through a **Locally important bedrock aquifer that is generally Moderately Productive (Lm)**.

- Hickey's well intersects a 4 m thick buried layer of weathered bedrock/gravel, the 'water bearing unit'. Significant inflows (up to 1,700 m³/d) were recorded directly from this layer during drilling.
- Only two boreholes encountered this 'water bearing unit'. It has not been encountered in any of the other wells drilled in the area. Geophysical surveys have found a low resistivity anomaly in the vicinity of the production well which is considered to represent the water bearing unit. The low resistivity zone is quite limited and is oriented in a N-S direction.
- Other wells drilled in the bedrock have a wide variety of yields, ranging from 33 m³/d to 500 m³/d, typically on the order of 100-200 m³/d.
- The production well yield shows considerable seasonal variability, ranging from 383 m³/d to 1,700 m³/d. The yield increases following rainfall recharge events and reduces during periods where no recharge occurs. The lower yields in the production borehole are similar to the upper range of yields in other wells abstracting from the bedrock aquifer away from the 'water bearing unit'.
- The close relationship between yield and recharge suggests minimal amount of storage in the bedrock aquifer. The storage coefficient for the production well suggests the aquifer is semi-confined. Since the porosity of a layer of broken rocks/gravel would be high, it appears therefore that the 'water bearing unit' acts mainly as a sump and provides only very limited storage.
- It is conceptualised that the layer of broken rock/gravel at the production well acts as a conduit for groundwater flow connecting up otherwise more isolated productive fissures within the bedrock aquifer. When recharge occurs in the bedrock aquifer the groundwater levels in the bedrock aquifer will rise and groundwater will flow towards the cone of depression generated by the production well. The capture zone of the borehole therefore extends into the main body of the Cruicetown Formation.
- The zone of contribution to the well is considered to be limited as the yield available reduces in periods without recharge. Because the higher flows at Ardee WSS rely on the sump effect of the water bearing unit, the zone of contribution cannot increase during dry periods to capture more flow to satisfy the abstraction at the well. The yield of the well therefore decreases.

The conceptual model described above represents the current understanding of groundwater flow in the area. The groundwater regime in the area is complex due to the structural and glacial history of the area. The available hydrogeological information does not allow a definitive understanding of the hydrogeology.

10.2 BOUNDARIES OF THE ZOC

This section describes the delineation of the areas around the well that are believed to contribute groundwater to the source, and that therefore require protection. The areas are delineated based on the conceptualisation of the groundwater flow pattern as described in section 10.1.

The shape and boundaries of the ZOC were determined using hydrogeological mapping and a conceptual understanding of groundwater flow water balance estimations, supported by water balance calculations (section 10.3 below). The abstraction rate at Hickey's Well fluctuates from 380m³/d to 1,700m³/d. The yield available is considered to be directly related to seasonally varying recharge to the source. It is therefore not considered accurate to define the ZOC by only considering an average abstraction rate. The resulting boundaries and the uncertainties associated with them are described as follows:

The **Northern Boundary** is based on the calculated down-gradient extent of the ZOC. This is calculated using the following equation:

$$X_L = \frac{Q}{2\pi kbi}$$

Where X_L is distance in metres to the down-gradient null point, Q is the abstraction rate (m^3/d), k is permeability (m/d), b is effective aquifer thickness, and i is hydraulic gradient. The hydraulic gradient value is 0.033 (Section 9.2). The product of k and b is transmissivity. The transmissivity value used is that calculated from the 1980 pumping test ($224 \text{ m}^2/\text{d}$). The down-gradient null point is calculated using the maximum abstraction rate ($1,700 \text{ m}^3/\text{d}$)³. The resulting distance to the down-gradient extent of the ZOC is 37 m. This has been extended to 50 m to allow for uncertainty in the calculations⁴.

The **Northeastern Boundary** is delineated using topography and tracing back the conceptual groundwater flow path from the down-gradient extent of the ZOC.

The **Western Boundary** location is estimated using the equation given in Todd (1980):

$$Y_L = \frac{Q}{2kbi},$$

where Y_L is the half-width of the ZOC, and the other parameters are as described for the Northern Boundary, above. Parameter values used are different from those used to estimate the Northern Boundary, however, since the bulk of the aquifer is less transmissive than for the north-south oriented 'water bearing unit' from which the borehole directly abstracts. Thus, a groundwater gradient, i , of 0.025 is used. The abstraction rate, Q , is the sustainable rate, $600 \text{ m}^3/\text{d}$ ⁵. A transmissivity of $60 \text{ m}^2/\text{d}$ is used as it is considered to be more representative of the bulk of the aquifer than the higher values estimated from pumping tests. The calculated half-width of the ZOC is 200 m. This distance is used to guide hydrogeological mapping of the Western Boundary.

The **Southeastern Boundary** extends across the east-west fault, and tracks the contact between the Rockfield Sandstone (the Lm aquifer) and the Navan Beds (the LI aquifer to the southeast of the sandstones). The boundary extends 100 m into the Navan Beds to allow for flow from this aquifer into the sandstones. Parts of this boundary cut across a topographic 'saddle' between where streams appear to emerge.

The **Southern Boundary** uses local topographic features, presumed minor groundwater divides between streams, and the location of the more productive Lm aquifer. The boundary is less certain than, for example, the Northeastern Boundary, as the ground elevation (and the hydraulic head) continue to rise southwards uphill of the ZOC boundary. This area is also a groundwater discharge zone, as evidenced by the high stream density. Parts of this boundary cut across streams. The lesser degree of certainty associated with the location of this boundary is indicated by hatching on the map, which indicates the area in which the southern boundary may fall.

The zone delineated encompasses 1.4 km^2 . The area with uncertainty is 0.35 km^2 . The ZOC is shown in Figure 14.

³ Using the highest measured values for the transmissivity and abstraction rate is considered to be appropriate, since the borehole is located in a high permeability zone.

⁴ The boundary does not extend across the opposite bank of the River Dee. Although drawdown was observed in the Well #7 during the pumping test in 1980, while this implies the cone of depression extends to the opposite bank, the null point calculations indicate that the zone of contribution does not extend this far.

⁵ The highest yields are not supported by the majority of the aquifer, only the areally restricted high permeability zone.

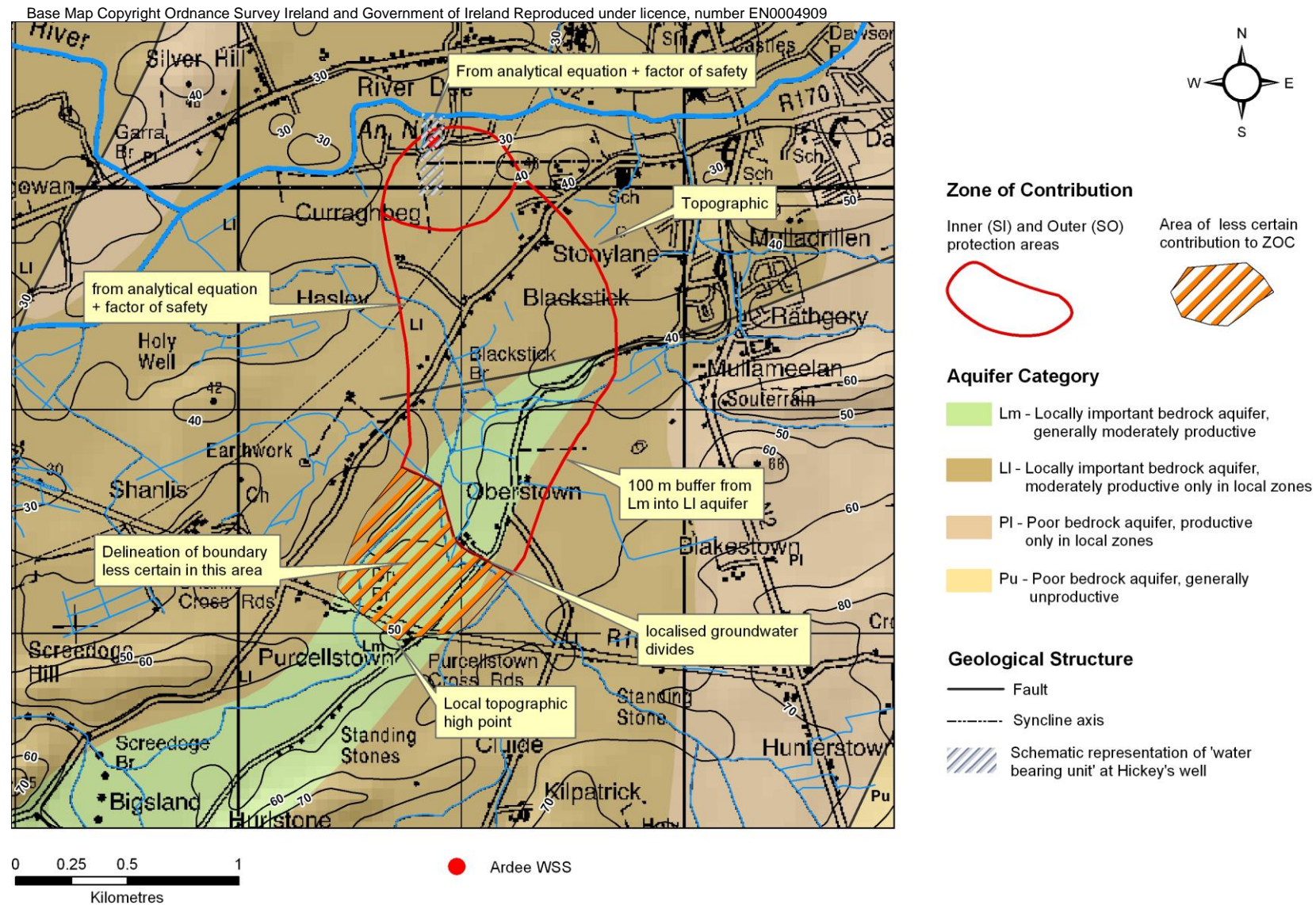


Figure 14 Zone of Contribution to Ardee WSS

10.3 RECHARGE & WATER BALANCE

The term 'recharge' refers to the amount of water replenishing the groundwater flow system. The estimation of a realistic recharge rate is critical in source protection zone delineation, as it dictates the size of the zone of contribution to the source.

The recharge rate is typically estimated on an annual basis, and is 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 main parameters involved in recharge rate estimation are annual rainfall, annual evapotranspiration, the recharge coefficient for the area, and annual runoff. Actual Recharge represents the amount of water that will infiltrate to become part of the groundwater resource. Recharge will vary spatially, and depend on subsoil permeability and subsoil thickness. For example, recharge is likely to be greater in areas dominated by higher permeability subsoils and shallower depths to bedrock. Recharge coefficients from the WFD Guidance Document GW8 (Irish Working Group on Groundwater, 2004) and the 30 year average meteorological data (section 6) are considered.

As outlined below, an average actual recharge estimate is made, together with detailed recharge estimates over 2006 and 2007. The calculations are summarised as follows:

	30 year annual average	2006	2007	Approx area for recharge coef- ficients
annual rainfall [mm] (R)	819	838	800	
estimated P.E. [mm]	540			
estimated A.E. [mm] (95% of P.E.)	513		516.9	
effective rainfall [mm] (R – A.E.)	306	295 (annual)	283 (annual)	
		446 (monthly)	371 (monthly)	
potential recharge [mm]	306	295	283	
recharge coefficient for high vulnerability areas, moderate perm subsoil, well drained soil		70%		75%
recharge coefficient for high vulnerability areas, moderate perm subsoil, poorly drained soil		25%		15%
recharge coefficient for moderate vulnerability areas, moderate perm subsoil, well drained soil		35%		10%
bulk recharge coefficient		60%		
runoff losses		40%		
Average annual recharge mm	183	176 (annual)	169 (annual)	
		268 (monthly)	223 (monthly)	
Recharge capacity for LI aquifers [mm]			200	

For 2006 and 2007, potential recharge has also been calculated on a monthly basis and the results are shown on Chart A1.3, Appendix 1. The graph shows that in some months there is no potential recharge.

The *bulk recharge coefficient* for the area is estimated to be 60%. The average annual recharge to the aquifer is therefore considered to be 183 mm/yr. Runoff losses are assumed to be 40% of potential

recharge (i.e. 147 mm/yr). This implies that just over half of potential recharge enters the aquifer, and that the remainder will run off to the streams and rivers in the area. This assessment is supported by the relatively high drainage density in parts of the area.

A more nuanced approach to estimating groundwater recharge in the area of Ardee WSS is derived from a detailed consideration of the variability in abstraction pattern across 2½ years (from July 2005 to December 2007) and the rainfall pattern over that period. The details are summarised in Appendix 5, and show that there are periods during the year where recharge is greater or lesser. These periods correspond strongly with the ability of the water supply source to provide greater or lesser volumes of groundwater.

Water balance: The area within the ZOC boundaries described in section 10.2 is about 1.4 km². Taking the total abstraction for 2006 and 2007 of 281,780 and 263,165 m³ respectively, an area of between 1.44 and 1.54 km² would be required for an average recharge rate of 183 mm/yr.

An area of 1.4 km² is considered to be an upper limit, since detailed calculations for 2006 and 2007 (Appendix 5) indicate that an area of between 1 and 1.3 km² is required to supply the boreholes, with peak abstraction rates only possible after sustained recharge.

11 GROUNDWATER SOURCE PROTECTION ZONES

The groundwater source protection zones are obtained by integrating the two elements of land surface zoning (source protection areas and vulnerability categories) – a possible total of eight source protection zones (see **Error! Reference source not found.**). In practice, this is achieved 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. Not all of the hydrogeological settings represented by the zones may not be present around any given source.

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 ZOC of the well.

11.1 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 abstraction from long-term recharge (Figure 14). The ZOC is controlled primarily by a) the total discharge, b) groundwater flow directions and gradients, c) bedrock aquifer permeabilities and d) the recharge in the area.

11.2 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. By using the aquifer parameters for permeability and hydraulic gradient, 100-day ToT estimations are made. Estimations of the extent of this area are done by using Darcy's Law, which can be used to estimate groundwater velocities.

$$\text{Velocity} = (\text{gradient} \times \text{permeability}) \div \text{porosity}$$

Groundwater velocities are calculated for the 'water bearing unit' comprising gravel or fist-sized broken rock and for the bulk of the aquifer in the ZOC. The calculations are summarised in Table 4.

Table 4 Groundwater velocity calculations

	Transmissivity (m ² /d)	Thickness (m)	Permeability (m/d)	Gradient	Porosity (%)	Groundwater velocity (m/d)
'water bearing unit'	224	7 ⁶	32	0.033	20	5.3
bulk of aquifer	60	20	3	0.02	1.5	4.0

The groundwater velocity is calculated as between 4 and 5.3 m/d. The resulting 100 day time of travel distance is 400-530 metres, the lesser of which is taken to estimate the extent of the Inner Protection Area (SI), since the upper estimates relate to the restricted extent of the 'water bearing unit'.

Four groundwater protection zones are present around the source as illustrated in Table 5. The final groundwater protection zones are shown in Figure 15.

Table 5 Matrix of Source Protection Zones for Ardee WSS

VULNERABILITY RATING	SOURCE PROTECTION	
	<i>Inner</i>	<i>Outer</i>
<i>Extreme (E)</i>	Not present	Not present
<i>High (H)</i>	SI/H	SO/H
<i>Moderate (M)</i>	SI/M	SO/M
<i>Low (L)</i>	Not present	Not present

12 POTENTIAL POLLUTION SOURCES

The lands around the wells are primarily used for crop growing, grazing and tillage. Agricultural activities and the houses in the ZOC are the principal hazards to the supply wells. Overall, the main potential sources of pollution within the ZOC are fertilisers, pesticides, livestock, septic tank systems and runoff from roads. The main potential pollutants are nitrogen, faecal bacteria, viruses, and Cryptosporidium. Planning permission has been granted for a Pharmaceutical Plant to the south-east of the abstraction well. The development of the site should be considered in the context of the source protection zones delineated here.

Detailed assessments of hazards have not been carried out as part of this study.

⁶ Thickness is 4 m thick broken rock layer and the 3 m of bedrock into which the borehole extends

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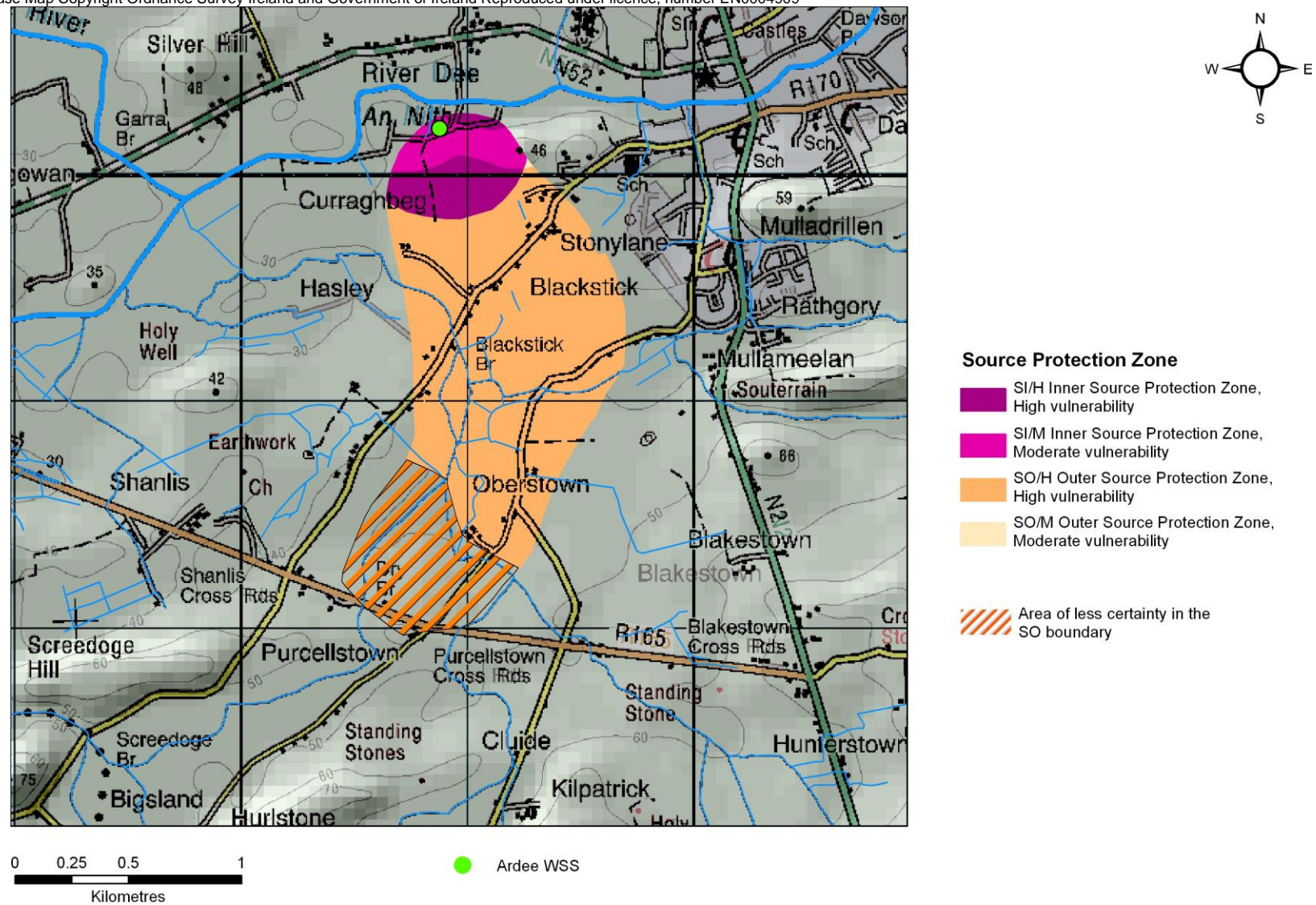


Figure 15 Source Protection Zones (SPZ) for Ardee WSS

13 CONCLUSIONS

- The production well at the Ardee WSS is an excellent yielding well, which is located in a weathered/broken rock zone in a **locally important aquifer which is moderately productive in local zones (LI)**.
- The high yields observed at the production well are due to the presence of a restricted zone of broken rock with high transmissivity. The water table rises above the top of the aquifer, in to the subsoil layer when the well is not pumped. The well can also be artesian when not in use.
- The yield is highly variable ranging from 400m³/d to 1,700m³/d. The variability is directly linked to recharge. The trend in the variability of the well yield suggests the well is abstracting from an aquifer of limited extent with little storage. The highly fractured 'water bearing unit' fills up during recharge and high yields are available, but these yields reduce in a systematic manner after recharge ceases, bottoming out to a sustainable 400-600 m³/d.
- The area around the source is generally classified as “**high**” and “**moderate**” vulnerability.
- Overall, water quality samples from the trial and production wells do not indicate significant contamination or pollution of these wells. The seasonal fluctuations of nitrate indicate that the shallow groundwater tapped by the abstraction well is vulnerable to agricultural contamination.
- The ZOC is delineated for the current abstraction regime.
- The protection zones delineated in this report are based on our current understanding of groundwater conditions and on the available data. Due to the general complexity of Ireland's hydrogeology and limitations in data availability, uncertainty is an inherent element in drawing boundaries (see Section 3.5 in DoELG/EPA/GSI, 1999). The hydrogeology of the Ardee area is very complex. Therefore, drawing boundaries is difficult and some uncertainty is inevitable.

14 RECOMMENDATIONS

Overall, it is recommended that:

1. Chemical and bacteriological analyses of the untreated, unmixed water should be carried out at a minimum frequency of twice a year – during low abstraction after dry periods, and during high abstraction after a wet period.
2. Any open trial boreholes should be secured such that they do not create a pathway for contaminants to access the aquifer.
3. Pumping rates and the water level variations in the production well would enable the performance of the well to be assessed more accurately.
4. Wells previously drilled in the area and that remain accessible should be identified and surveyed. These remaining observation wells could be monitored for water levels to allow a better groundwater level map to be established.
5. Particular care should be taken when assessing the location of any activities or developments within the inner protection area (SI) that might cause microbial contamination at the boreholes, and potential hazards in the ZOC should be identified.

15 ACKNOWLEDGEMENTS

We wish to acknowledge the contributions to the study made by the following people: Keith Hanratty & John Duff – Louth Co. Co.

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APPENDIX 1 – 2006-2007 METEOROLOGICAL DATA

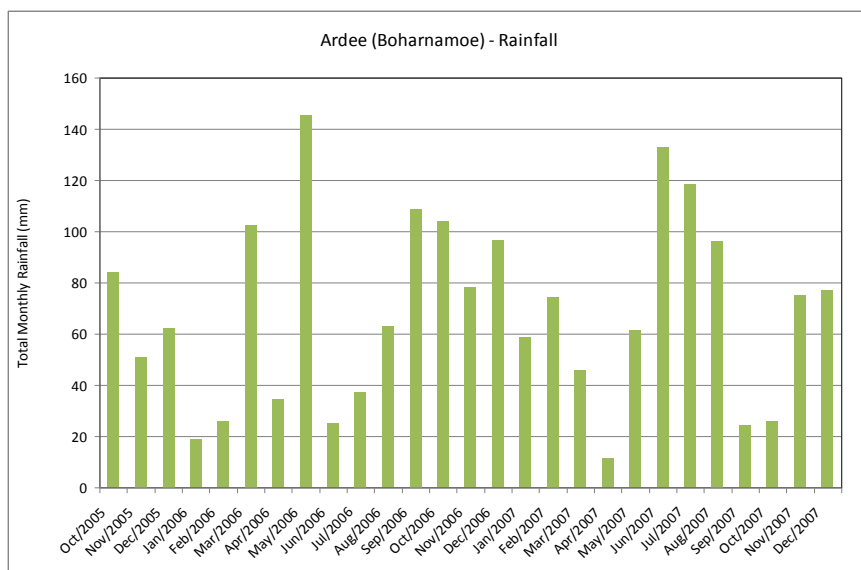


Chart A1.1 Ardee (Boharnamoe) – Rainfall

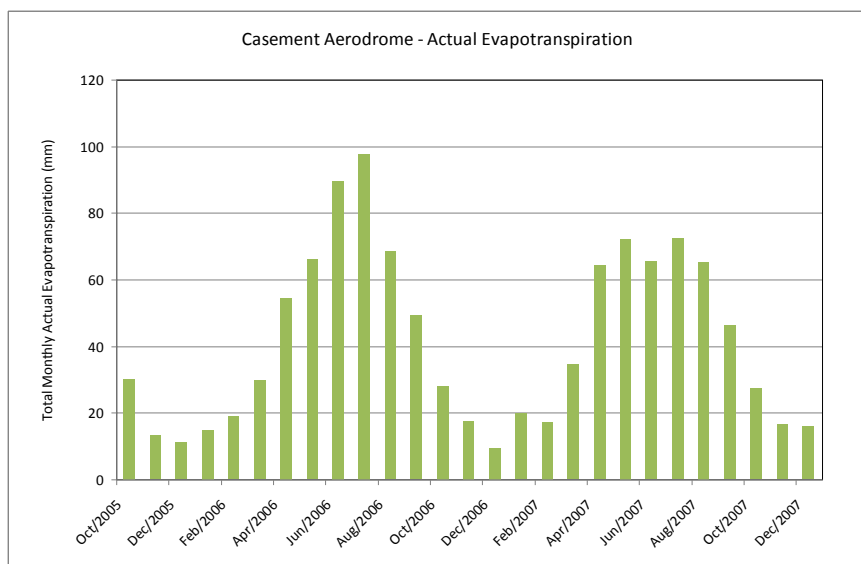


Chart A1.2 Casement Aerodrome – estimated Actual Evapotranspiration

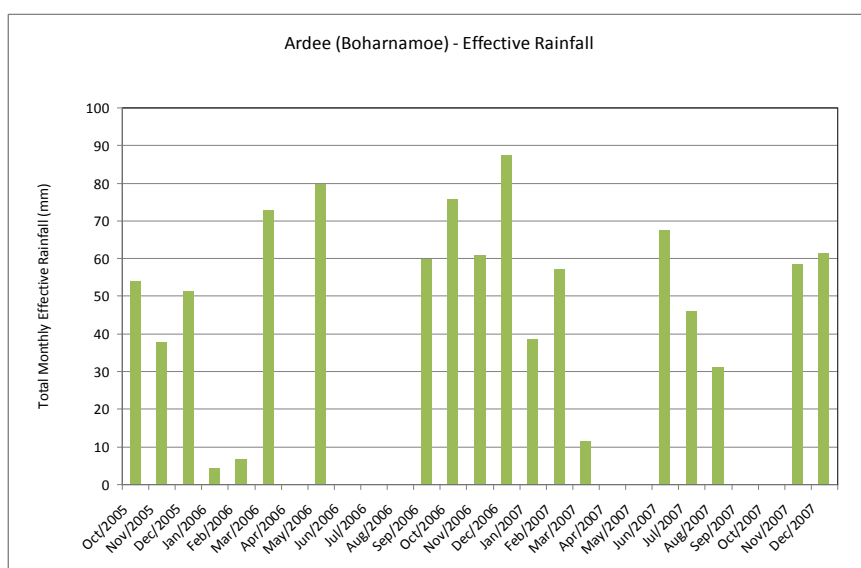


Chart A1.3 Ardee (Boharnamoe) – Effective Rainfall (Potential Recharge)

APPENDIX 2 – PARTICLE SIZE DISTRIBUTIONS

Chart A2.1 Particle size distribution curves, Ardee, Co. Louth

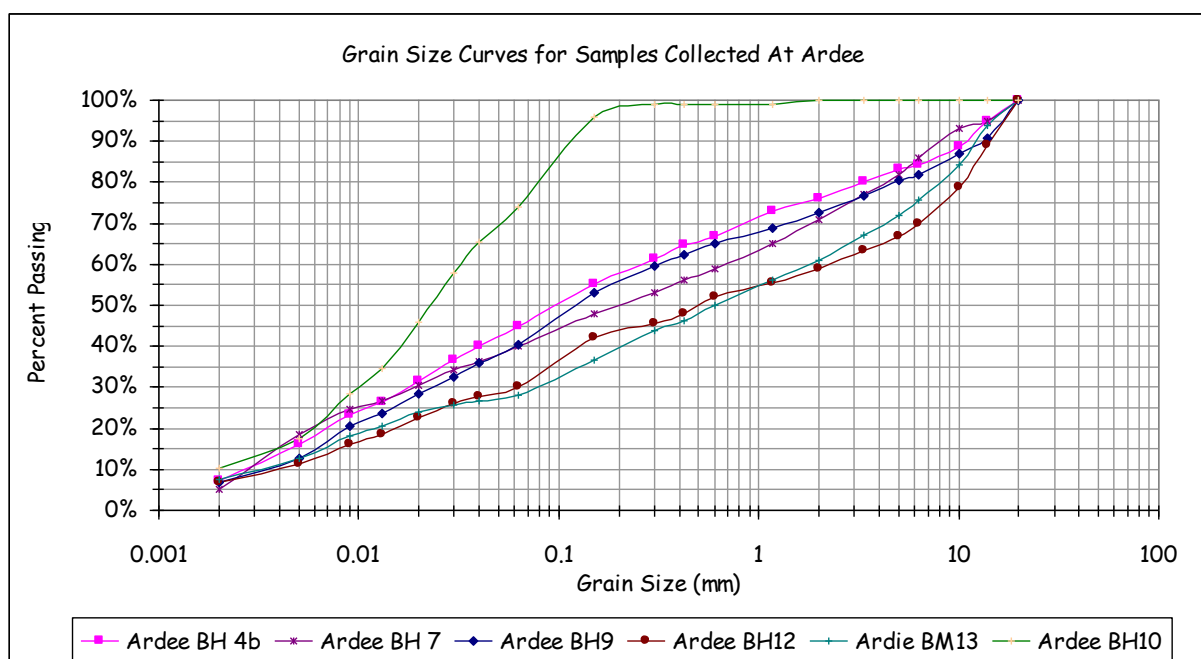


Table A2.1 - Summary of particle size distribution (PSD) tests

Sample No	%Gravel	%Sand	% Silt	%Clay	Summary description		Field Description
					% Coarse	%Fines	
ARD4b	0.24	0.31	0.37	0.07	0.55	0.45	SILT/CLAY
ARD7	0.29	0.31	0.35	0.05	0.60	0.40	SILT/CLAY
ARD9	0.27	0.32	0.33	0.07	0.60	0.40	SILT/CLAY
ARD10	0.00	0.26	0.64	0.10	0.26	0.74	SILT
ARD12	0.41	0.29	0.23	0.07	0.70	0.30	SILT/CLAY
ARD13	0.39	0.33	0.20	0.08	0.72	0.28	SILT/CLAY

APPENDIX 3 – WATER QUALITY DATA

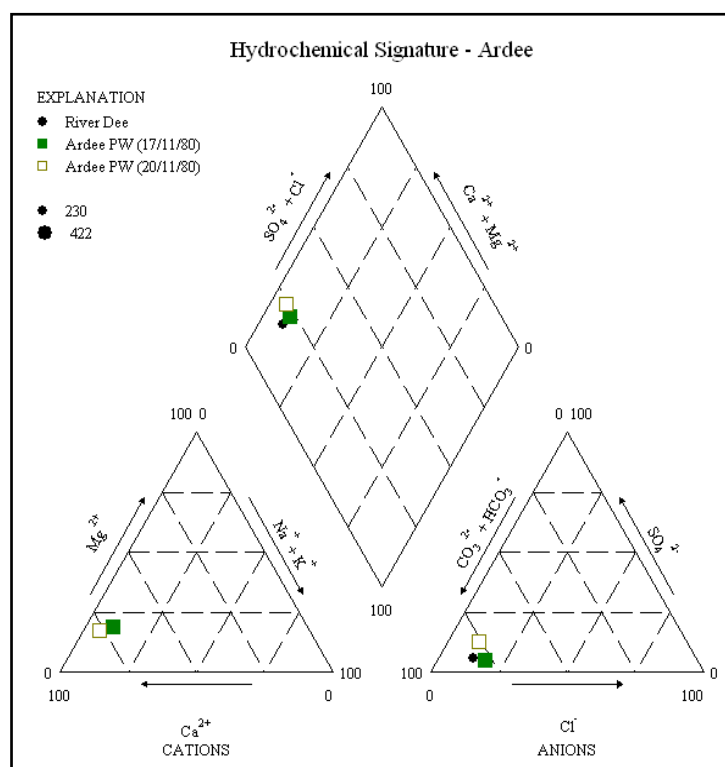


Chart A3.1 Piper diagram showing hydrochemical data sampled at Ardee in 1980

Table A3.1 - Summary of water quality data

Sample Date	Units	20/11/1980	26/08/1981	04/09/1981	17/11/1980	20/11/1980	26/08/1981	04/09/1981	18/12/1995	21/08/1996	15/01/1997	27/01/1998	19/08/1998	02/02/1999	19/08/1999	02/03/2000	20/09/2000	17/01/2001	26/09/2001	18/09/2002
Site	-	River Dee	River	River	PW	PW	PW	PW	PW	PW	PW	PW	PW	PW	PW	PW	PW	PW	PW	PW
Faecal Coliforms	No./100ml				ND				0	1	0	0	0	0	0	0	0	0	0	0
Total Coliforms	No./100ml				ND				0	4	0	1	0	0	1	0	2	0	5	> 200
Total Calcium	mg/l Ca	71.3	99	100	143.2	139.2	134.6	131.4	161.6	116	140.4	136.8	106	162.2		125.35	113.58	137.76	141.4	120.28
Total Magnesium	mg/l Mg	10.2	17	16.7	22.4	19	15.5	20.9	17.9	17.71	22.44	27.37	17	23.84	20.09	21.75	13.26	21.64	25.54	19.24
Sodium	mg/l Na	8.2	9	8	23	12	10	10	10.5	11.67	12.41	31.14	10.8	12.05	12.64	12.31	14.13	18.5	17.54	12.35
Potassium	mg/l K	3.8	3.8	1.3	1.1	1.3	1.2	0.5	2.43	3.34	3.45	8.5	3.6	3.55	4.31	3.75	4.18	5.37	4.44	3.78
Ammonium	mg/l N	0.5			0.24	0.24			0.01	0.01	0.01	0.01	0.01	0.01	< 0.01	< 0.01	< 0.03	< 0.03	< 0.03	< 0.03
Iron	ug/l Fe	0.5			<0.1	<0.1			< 50	< 50	< 50	< 50	< 50	< 50	< 10	< 20	< 50	< 50	< 50	< 50
Copper	ug/l Cu	<0.02			<0.02	<0.02			< 10	< 10					20	4.5	22.9	17.6	14.7	9.8
Chloride	mg/l Cl	20	24	25	56	36	34	35	24	12	23	24	22	25	23	25	21	26	25	24
Sulphate	mg/l SO ₄	12.6	36	41	20	52	40	48	80	35	80	46	44	76	78	69	53	78	67	
Nitrite as NO ₂	mg/l	0.012			<0.001	<0.001			0.001	0.001	0.001	0.001	0.001	< 0.005	< 0.005		< 0.002	< 0.002	< 0.002	< 0.002
Nitrate as NO ₃	mg/l	16.4	2.13	2.7	47.60	25.50	8.30	27.50	29.18	17.67	21.61	37.73	15.28	35.65	14.88	29.62	13.86	32.01	12.36	14.04
Total Hardness	mg/l CaCO ₃	220	318	324	450	426	400	414	364	391	430	392	304	410	374	428	396	396	412	336
Alkalinity	mg/l CaCO ₃	180	258	262	339	337	320	328	304	308	300	272	268	292	272	304	280	332	336	316
pH_Laboratory	pH	7.3	8.1	7.8	7.4	7.1	7.2	7.4	7.3	7.41	7.34	7.27	7.29	7.33	7.2	7.4	7.2	7.2	7.1	7.2
Conductivity	uS/cm (at 25oC)	360	500	510	660	660	680	700	788	713	752	800	744	822	743	810	758	880	812	783
Colour	Hazen	40	10	<5	<5	<5	<5	<5							0	7	3	2	6	13
Temperature_field	°C	10.4	nd	nd	10	10	10	10								9.9		10	12	12.4
Turbidity	NTU		1.7	nil			0.3	Nil							0		0	0	0	0
Molybdate Reactive Phosphate	mg/l P		258						0.01	0.01	0.01	0.01	0.01	< 0.01	0.01	0.01	< 0.02	< 0.02	< 0.02	< 0.02
Total Organic Carbon	mg/l C										3.1	3.3	0.6	1.6	6.7		2.3	2.2	2.1	
Fluoride	mg/l F								0.087	0.096	0.104	0.1	0.051	0.117	< 0.300		< 0.300	0.57	< 0.300	
Manganese	ug/l Mn								<20	<20	<20	<20	<20	<20	5.5	0.9	2.3	2	1.6	3.8
Boron	ug/l B															33.6	< 50	61.9	< 50	< 50
Aluminium	ug/l Al																< 50	< 50		
Chromium	ug/l Cr															< 0.5	< 1	< 1	2.9	7.7
Nickel	ug/l Ni															1.3	< 1	< 1	< 1	< 1
Zinc	ug/l Zn								20	< 10						6.7	10.5	22	13.4	10.8
Arsenic	ug/l As																< 0.5	< 1	< 1	< 1
Cadmium	ug/l Cd								0.2	0.2	0.2	0.2	< 0.2	< 0.2	< 0.1	< 0.05	< 0.1	< 0.1	< 0.10	< 0.10
Antimony	ug/l Sb																< 1	< 1		
Barium	ug/l Ba															122.9	110.5	122.1	141.6	121.4
Lead	ug/l Pb										< 0.8	< 0.8				< 0.5	3.5	4.4	2.7	2.3
Uranium	ug/l U																1.87		1.54	2.43
Mercury	ug/l Hg																	< 1	< 1	
Cobalt	ug/l Co																< 1	< 1		
Molybdenum	ug/l Mo																< 5	< 5		
Silver	ug/l Ag																< 1	< 1		
Berillium	ug/l Be																< 1	< 1		
Suspended Solids	mg/l								1	0	1.2	7	1	2						
Total Oxidised Nitrogen	mg/l N														3.36	6.69	3.13	7.23	2.79	3.17
Selenium	ug/l Se																< 1	< 1		
Thallium	ug/l Tl																< 1	< 1		
Thorium	ug/l Th																< 1	< 1		
Tin	ug/l Sn																< 5	< 5		
Vanadium	ug/l V																< 1	< 1		

APPENDIX 4 – AQUIFER TEST ASSESSMENTS

Table A4.1 - Summary details of wells in the vicinity of Ardee WSS

Borehole name	Depth (mbgl)	Depth to bedrock (m)	Predominant subsoil	Pumping test rates (m³/d)
Well #1	85	16	6m sand & gravel underlain by boulder clay	100
Well #2	31	14	9m boulder clay underlain by broken rock	1,400
Well #3	16	14	9m boulder clay underlain by broken rock	1,440
Well #4	10	6	Boulder clay with sand lenses	100
Well #5	27	10	Boulder clay	500
Well #6	12	11	6m sand/gravel underlain by boulder clay	100
Well #7	15	7.5	Boulder clay with sand lenses	200
Well #8	11	10	Boulder clay	200
Well#9	20	7.5	Boulder clay	100
Wells #10 A & B	30	7.5	Boulder clay	100
Well x11	30	10	Boulder clay	<100
TW1	61	11	Gravelly boulder clay	327
TW2	61	12	Brown stony clay	436
TW3	30	12	Gravels & silt/clay	55
TW4	46	11	Brown gravelly clay & silt	131
TW5	91	5	Brown clay	273
TW6	91	3	Clay	33

Chart A4.1 Time-drawdown data during 2005 Pumping Test

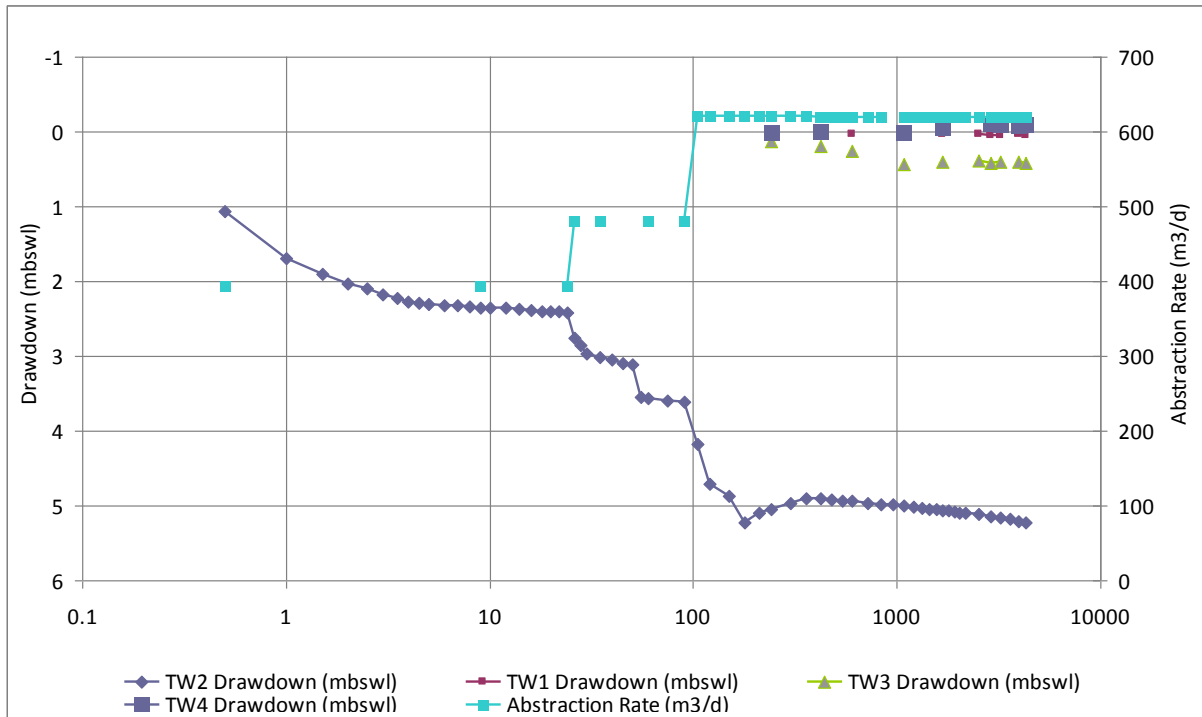
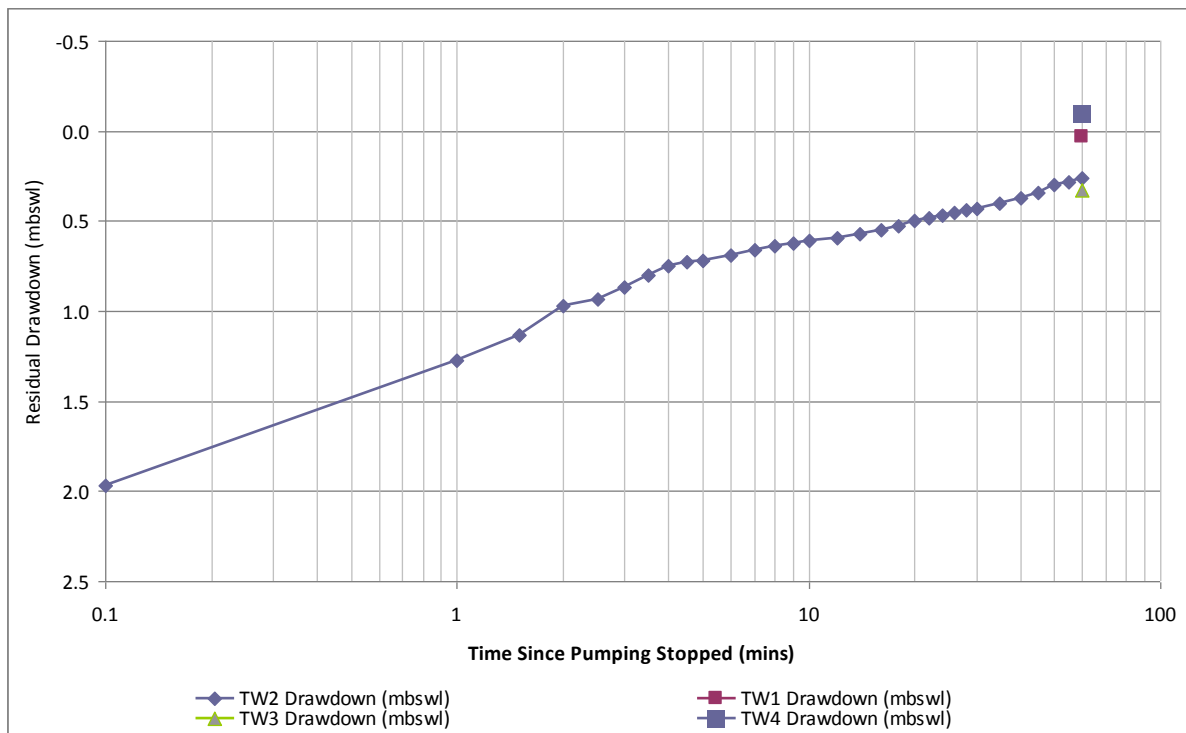


Chart A4.2 Groundwater level recovery following 2005 pumping test



The pumping test data from the tests on Hickey's Well was also made available for the purposes of this assessment. The results of these tests are presented on Charts A4.3 to A4.5. The results from the 1980 test show the well being pumped at 1767 m³/d for the first 90 minutes and then 1414 m³/d for the

remainder of the test. The drawdown in the pumping well increases to 3.07 m during the first 90 minutes.

After the pumping rate was reduced, there was a temporary recovery of the water levels for 45 minutes, but groundwater levels resumed their drop after that. The water levels do not stabilise during the test, indicating that the yield may not be sustainable. It is clear with the information on the daily usage at the production wells that the yield ranges from 400 m³/d to 1,700 m³/d and that the yield of 1700 m³/d is not sustainable.

The test also shows the water level in Well #2, which is 4.4 m from the abstraction point, is very closely linked to the production well with the drawdown only 0.2m less than that in the production well. The test shows there is clearly observable drawdown in Well #1 and Well #4. The drawdown at the end of the test is greater in Well #1 (1.05 m) in Well 4 (0.44 m). Well #1 is located further from the production well but Well #4 is located downgradient which may be why there is less drawdown.

The results of the test were analysed in the original report and the aquifer properties reported for the first section of the test were that at Well #2 the transmissivity was 224 m²/d and the storage coefficient was 8.0×10^{-3} . The storage coefficient is indicative of semiconfined aquifer which implies the aquifer is confined at the well, but at some point within the reach of the cone of depression it becomes unconfined.

The test in 1980 was conducted in November and, as such, the results are not indicative of the aquifer during low groundwater levels. Another test was planned for the wellfield for the end of August of 1981. The static water level in the production well at the start of the 1981 test was 2.07 mbtoc in comparison to 1.57 mbtoc before the start of the 1980 test in November. Although the static water table is lower in August 1981 than in November 1980, it is not significantly lower.

During the 1981 test, the well was pumped at 883 m³/d for the first 240 minutes. The drawdown in the production well was 1.58 m during this period. The pumping rate was then increased to 1,963 m³/d for 15 hours. During this time, the drawdown increased to 4 m. The pumping rate was reduced to 1,472 m³/d at this point and was reduced to 1,040 m³/d towards the end of the test. There was a brief recovery of the water levels with the reduced pumping rate but they soon started to drop again reaching a final drawdown of 4.91m at the end of the test.

The results of the summer 1981 test are similar to the autumn 1980 test, with the water level in Well #2 closely tracking the production well, and drawdown in Well #1 exceeding the drawdown in Wells #4 and #7. Additional observation boreholes were, however, drilled for the purposes of the test in 1981. These included Well #9, Well #10A and Well #10B. All three wells were drilled around 150 m to the northwest of the production well, on the southern bank of the River Dee. The purpose of the additional observation wells was to determine the extent of the cone of depression and also the interaction of the groundwater with the river. Wells #9 and #10B were drilled into the bedrock, but Well#10A was screened in the boulder clay at that location. The results show that drawdown occurs in Wells #9 and #10B but that no drawdown occurs in Well #10A. This indicates that, during the course of the six day test, the drawdown did not influence the groundwater in the subsoil layer.

The water level in Well #2 and the other observation wells was monitored for 91 hours following the test. The results of the recovery test are shown on Chart A4.5. The results show that there was still 1.37 m of residual drawdown at the well after 91 hours. The results show that water levels measured in the other observation wells had also still not fully recovered in the 91 hour period, with 0.75 m of recovery remaining in Well #1. The trend suggests it would take another 13 days for Well #2 to fully recover. Due to the shape of the recovery graph it is not possible to analyse the data using standard pumping test analyses techniques.

Chart A4.3 November 1980 72 hour pumping test results

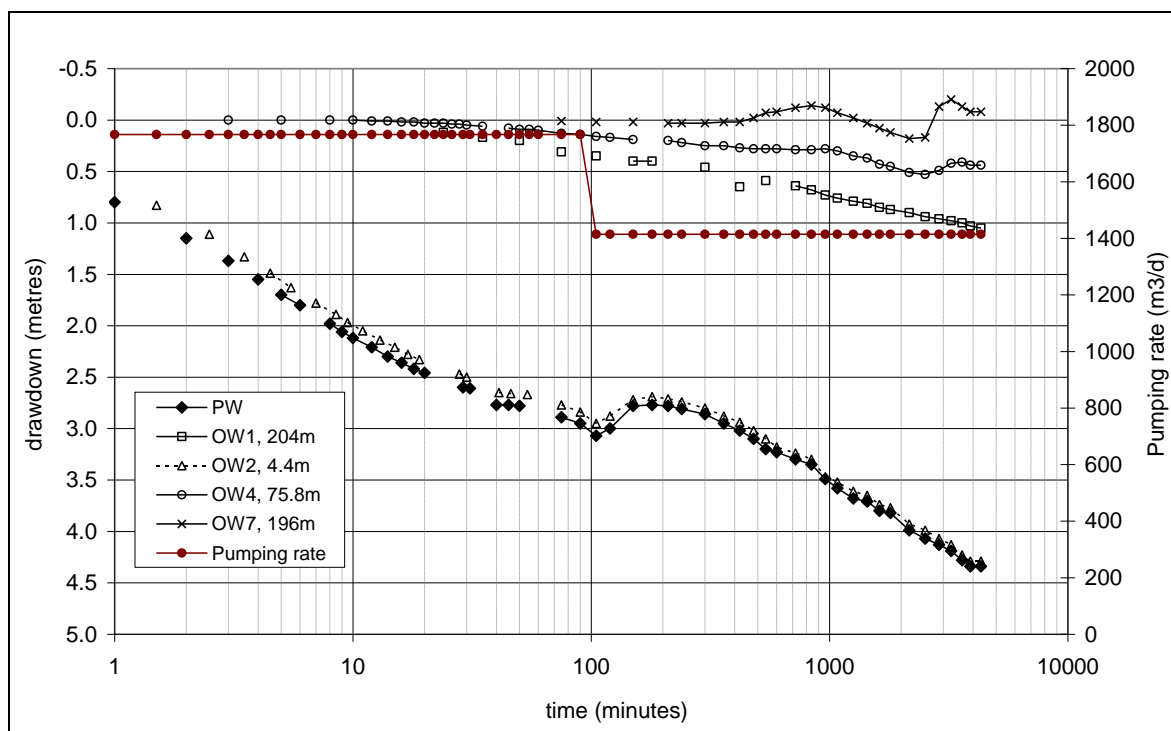


Chart A4.4 August 1981 six day pumping test results

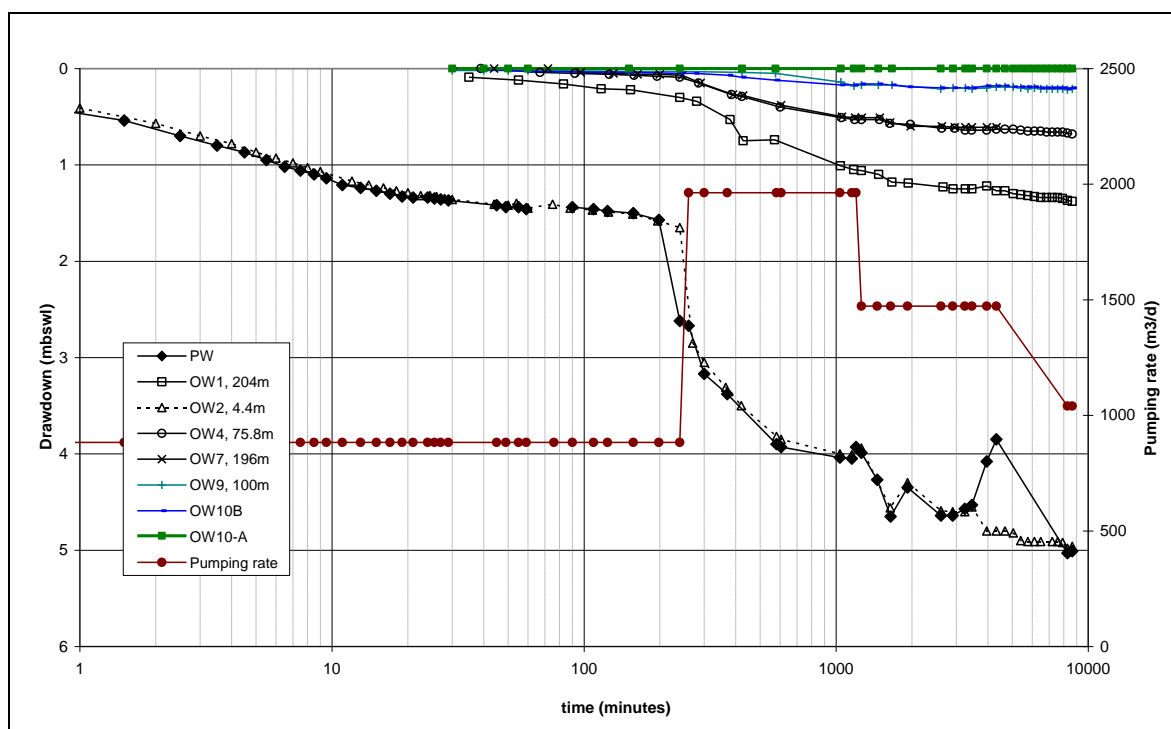
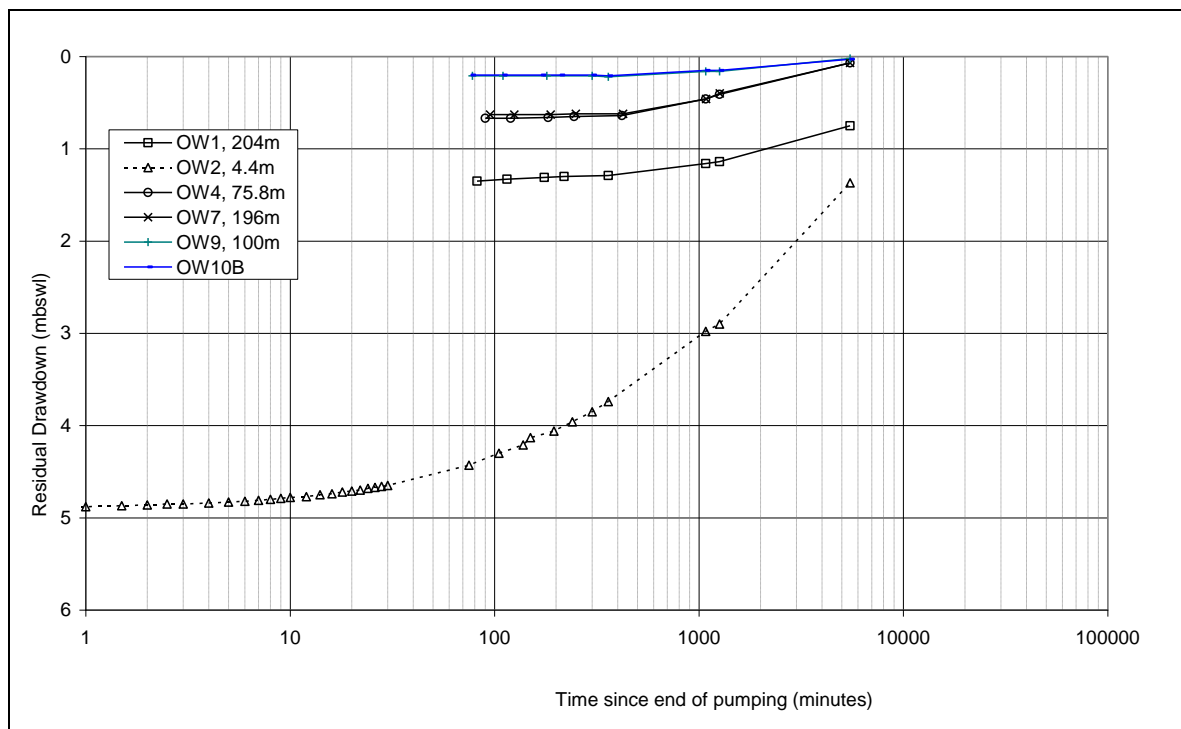


Chart A4.5 August 1981 recovery following pumping test



APPENDIX 5 – RECHARGE ASSESSMENTS

Table A5.1 Recharge coefficient table (WGW, 2005)

Vulnerability category		Hydrogeological setting	Recharge coefficient (rc)		
			Min (%)	Inner Range	Max (%)
Extreme	1.i	Areas where rock is at ground surface	60	80-90	100
	1.ii	Sand/gravel overlain by 'well drained' soil	60	80-90	100
		Sand/gravel overlain by 'poorly drained' (gley) soil			
	1.iii	Till overlain by 'well drained' soil	45	50-70	80
	1.iv	Till overlain by 'poorly drained' (gley) soil	15	25-40	50
	1.v	Sand/ gravel aquifer where the water table is ≤ 3 m below surface	70	80-90	100
	1.vi	Peat	15	25-40	50
High	2.i	Sand/gravel aquifer, overlain by 'well drained' soil	60	80-90	100
	2.ii	High permeability subsoil (sand/gravel) overlain by 'well drained' soil	60	80-90	100
	2.iii	High permeability subsoil (sand/gravel) overlain by 'poorly drained' soil			
	2.iv	Moderate permeability subsoil overlain by 'well drained' soil	35	50-70	80
	2.v	Moderate permeability subsoil overlain by 'poorly drained' (gley) soil	15	25-40	50
	2.vi	Low permeability subsoil	10	23-30	40
	2.vii	Peat	0	5-15	20
Moderate	3.i	Moderate permeability subsoil and overlain by 'well drained' soil	25	30-40	60
	3.ii	Moderate permeability subsoil and overlain by 'poorly drained' (gley) soil	10	20-40	50
	3.iii	Low permeability subsoil	5	10-20	30
	3. iv	Basin peat	0	3-5	10
Low	4.i	Low permeability subsoil	2	5-15	20
	4.ii	Basin peat	0	3-5	10

Note: Unless other information exists to suggest otherwise, recharge caps of 200 mm/yr are applied to LI aquifers, and 100 mm/yr to PI and Pu aquifers.

DETAILED RECHARGE ESTIMATES OVER THE ZOC FOR 2005-2007

Information on the abstractions at Hickeys well has shown that the yield ranges between 400-1,700 m³/d throughout the year. The variability in the yield appears to have a seasonal trend with higher yields in the winter and lower yields in the summer. Louth Co. Co. provided average daily abstraction rates for the supply from 4th July 2005 to 10th December 2007. These data are presented in Chart A5.1.

Due to the variability in the yield, the size of the ZOC has been calculated for a number of periods. These calculations are shown below in Table A5.2.

For each calculation period the total abstraction is calculated from the average daily abstraction data provided by Louth Co. Co. This is divided by the number of days in the period to determine the average daily abstraction over that period. The total potential recharge is calculated for each period from the monthly meteorological data. The actual recharge for each period a proportion of the potential recharge as defined by the recharge coefficient (0.6). The Zone of Contribution is calculated as the area required to provide sufficient recharge to equal the abstraction rate. The results of the calculations indicate that the ZOC is between 1 km² and 1.3 km².

The calculation periods range includes the entire data for 2006 and 2007. The other intervals are taken from periods beginning and ending with low abstraction rates and no potential recharge. These periods are selected to ensure there is no net surplus or deficit of storage in the aquifer over the period. The length of the periods range from 147 days to 420 days. The average abstraction rate over these periods ranges from 712 m³/d to 898 m³/d.

Table A5.2 ZOC Calculation Periods

Date	2006	2007	October 2005 - August 2006	September 2006 - October 2007	June 2007 - October 2007	September 2006 - May 2007
Total Abstraction (m ³)	281,780	263,165	241,454	343,477	104,707	238,770
No Days	365	365	329	420	147	266
Average Daily Abstraction (m ³ /d)	772	721	734	818	712	898
Total Potential Recharge (mm)	446	371	305	535	145	390
Total Recharge (mm)	268	223	183	321	87	234
Recharge Rate (mm/yr)	268	223	203	279	216	321
ZOC Area (km ²)	1.1	1.2	1.3	1.1	1.2	1.0

There is a strong positive correlation ($R^2 = 0.93$) between the total recharge and the total abstraction over the period, which is shown in Chart A5.1. The ZOC area is calculated as a function of abstraction and total recharge over the periods given in Table A5.2. The strong positive correlation between the two suggests there is limited variability expected in the ZOC area. This matches the conceptual model for the area which suggests the high permeability zone which Hickey's well taps into is very limited in extent, and sits within a lower transmissivity aquifer. Maximum abstraction rates are only possible when the high permeability zone is 'full up'; lower abstraction rates pertain during non-recharge periods and reflect the rate at which the bulk of the aquifer can transmit water to the high permeability zone and the abstraction borehole.

Note that the estimated recharge rate exceeds the 200 mm/yr recharge capacity for LI aquifers suggested by the Groundwater Working Group (2005) for the recharge-recession calculation periods. This is not surprising given that the high permeability zone can periodically accept and transmit groundwater that is not part of the 'background' aquifer resource.

The relationship between annual recharge rate and abstraction is far less strong than that calculated for specific recharge-recession periods, again highlighting the temporary nature of the additional groundwater store and transmission provided by the high permeability water bearing unit at the abstraction borehole.

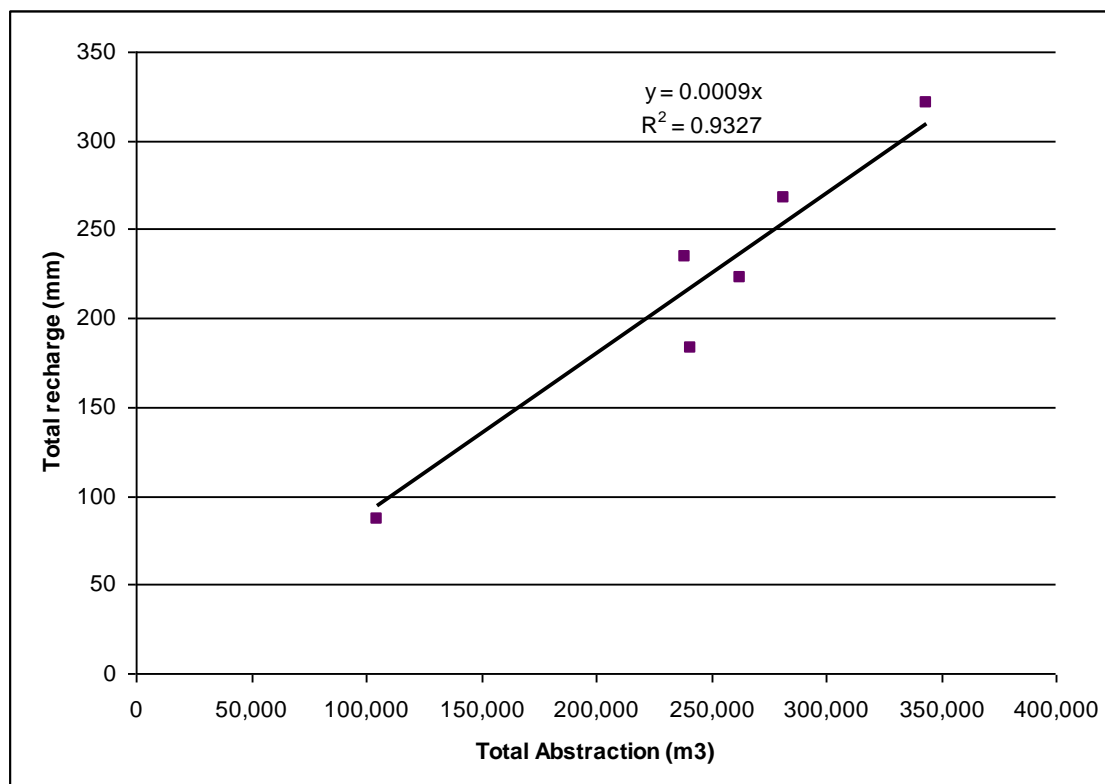


Chart A5.1 Relationship between Total Recharge over a recharge-recession period and Abstraction at Ardee PWS

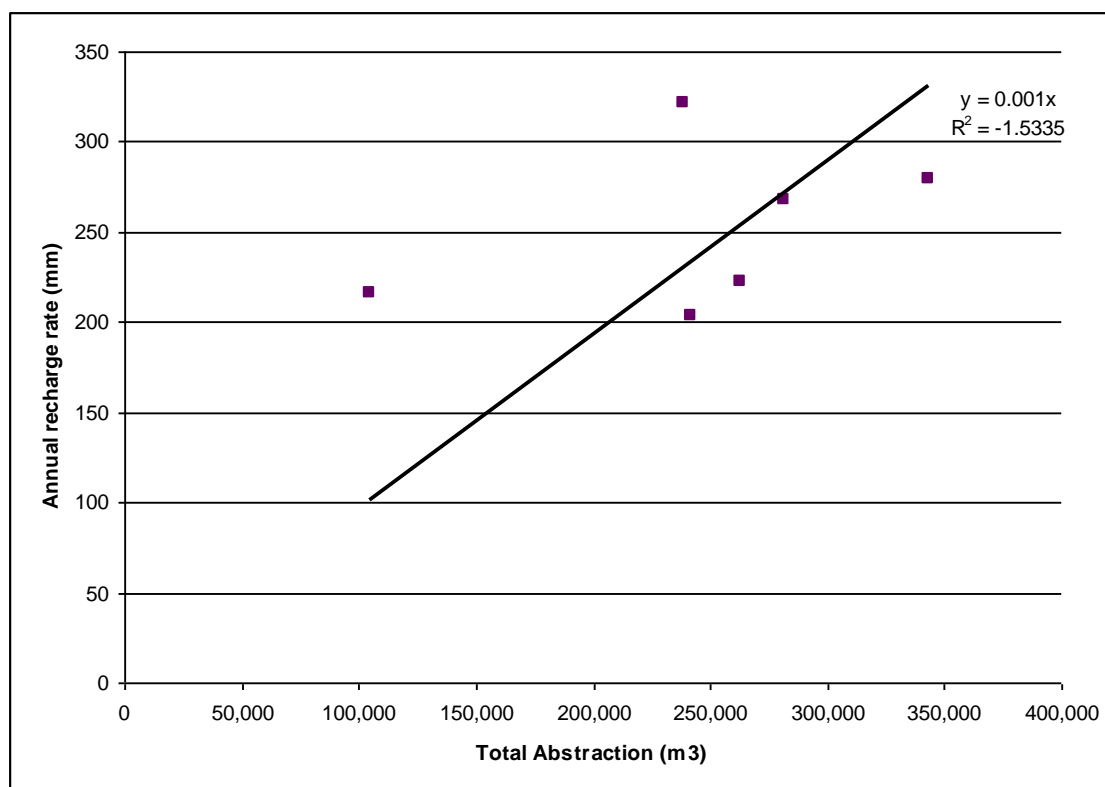


Chart A5.2 Relationship between Annual Recharge Rate and Abstraction at Ardee PWS