Environmental Protection Agency

Establishment of Groundwater Source Protection Zones

Fethard (Coalbrook) Regional Water Supply Scheme

December 2011

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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.

The project "Establishment of Groundwater Source Protection Zones", led by the Environmental Protection Agency (EPA), represents a continuation of the GSI's work. A CDM/TOBIN/OCM project team has been retained by the EPA to establish Groundwater Source Protection Zones at monitoring points in the EPA's National Groundwater Quality Network.

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

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1 Introduction

Groundwater Source Protection Zones (SPZ) have been delineated for the Fethard Regional Water Supply (RWS) at Coalbrook according to the principles and methodologies set out in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999) and in the GSI/EPA/IGI Training course on Groundwater SPZ Delineation.

The Fethard RWS Water Supply is provided by five boreholes BH-1 (IE_SE_G_126_23_003), BH-2 (no code), BH-3 (no code), BH-4 (no code) and BH-5 (no code), which were installed between 1937 and 2006.

The objectives of the study were:

- To outline the principal hydrogeological characteristics of the Curraheenduff area where the supply is located.
- To delineate source protection zones for the well field.
- To assist the Environmental Protection Agency and South Tipperary County Council in protecting the water supply from contamination.

The protection zones are intended to provide a guide in the planning and regulation of development and human activities to ensure groundwater quality is protected. More details on protection zones are presented in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

2 Methodology

The methodology applied to delineate the SPZ consisted of data collection, desk study including review of previous pumping tests in BH-1 and BH-2, site visits and field mapping and subsequent data analysis and interpretation.

The site visit and interview with the caretaker took place on 28/06/2010. Field mapping of the study area (including measuring the electrical conductivity and temperature of the source and streams in the area) took place on 14 and 19th of July, 2010. It was not possible to undertake pumping tests as part of the site assessment as the wells are being pumped continuously 24 hours per day seven days per week. Data from the previous pumping tests was therefore used to assess the aquifer characteristics as part of the assessment programme.

While specific fieldwork was carried out in the development of this report, the maps produced are based largely on the readily available information and mapping techniques using inferences and judgements from experience at other sites. As such, the maps may not 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.

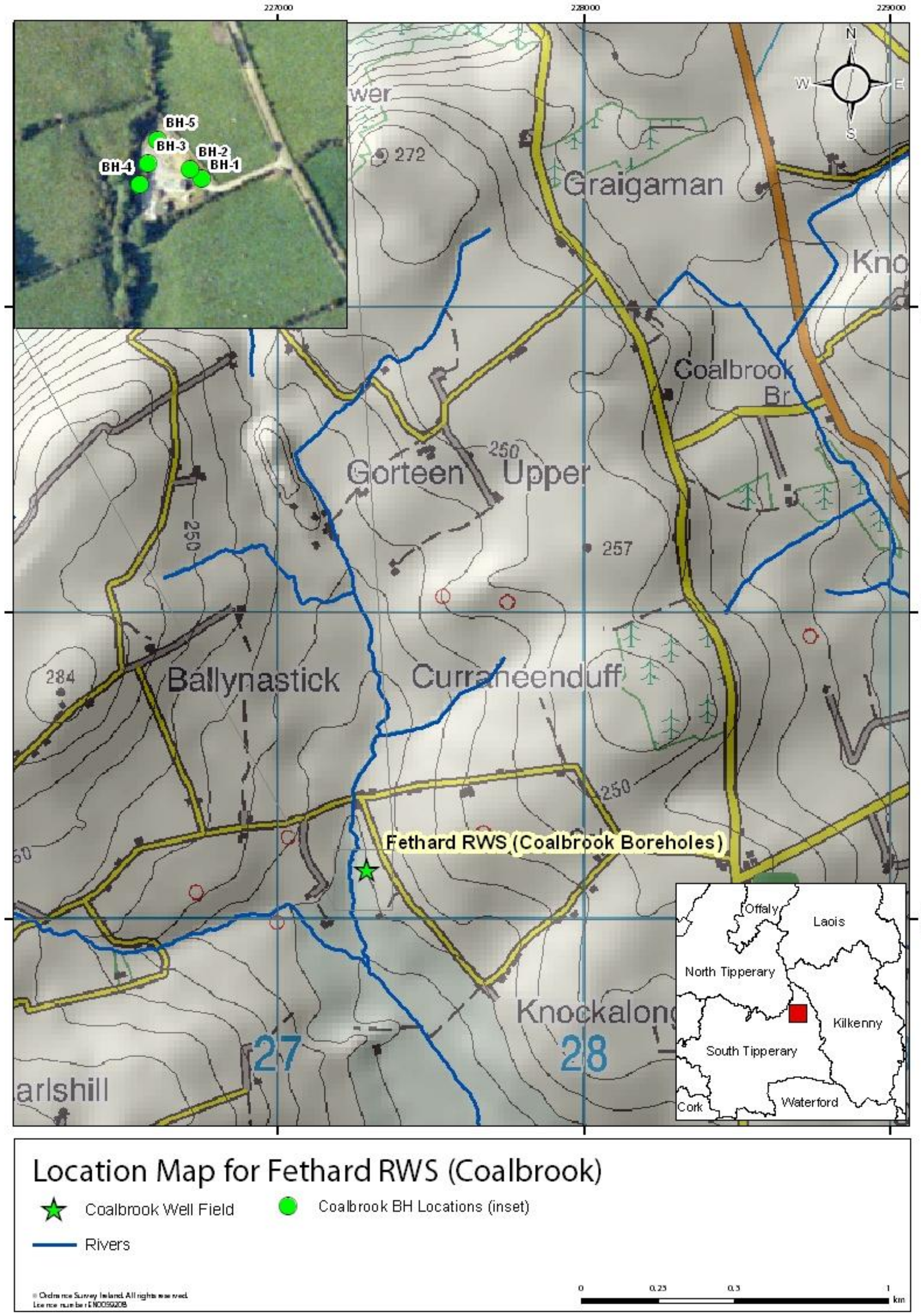

Figure 1: Location Map

3 Location, Site Description and Well Head Protection

The wells and associated water treatment works are in a compound approximately 1 km west of Coalbrook village in the townland of Curraheenduff, as shown in Figure 1. Access is via a local public road that links the villages of New Birmingham and Coalbrook. The site slopes from the road to an unnamed stream that rises approximately 2 km north of the site and forms part of the head waters of the Kings River. The compound is surfaced with gravel hard core and is protected by a fence. The stream forms the western site boundary.

The well field comprises five wells, all situated within the compound, with the wells being no more than 15 m apart over a distance of approximately 100 m (Figure 1 (inset) and Photo 1). Wells BH-1, 2 and 5 are roughly in a line running east to west from the road toward the stream, while BH-3 and BH4 are approximately 4 m from the stream. With the exception of BH- 4, each well head is fitted with a lockable, steel, rectangular box sitting on a concrete base (Photo 2). BH-4 is surrounded by an above ground concrete block walled chamber.

Photo 1: Well Field

Photo 2: Well Head Construction (BH-1)

Photo 3 and 4: BH-4 Well Head Construction

The only construction details known about BH-1 or BH-2 are that a steel liner was installed to prevent the soil, subsoil and top of weathered rock falling into the borehole. It is likely that some shallow groundwater i.e. top of weathered bedrock can make its way down the well casing into the boreholes. There are no construction details for BH-3 and BH-4 as the drilling contractor did not prepare drilling logs. Some anecdotal information regarding well depths has been obtained about these wells from South Tipperary County Council Water Services Section and from phone discussions with the drilling contractor who installed BH-4 and BH-5. A log of BH-5 was also provided by the well driller and is included in Appendix 2.

4 Summary of Well Details

The available details are based primarily on information contained in two reports: a GSI Pumping Test Report from 1980 undertaken by Eugene Daly; and a K.T. Cullen & Co. Ltd (KTC) Report on the Coalbrook Water Supply Scheme 1991. The full GSI report was not available, but the relevant sections obtained from GSI are included in Appendix 1. The KTC Report is also included in Appendix 1.

BH-1 was originally drilled as an exploration well for coal deposits in the area in 1937. Sometime in the 1980s a pump broke off and lodged in the well at c 55 m bgl. In 1990, attempts were made to recover the pump but failed. Instead the pump was pushed further down the hole, leaving the well with an effective depth of 72 m bgl. A geological log for BH-1 was compiled by KTC and is shown in Figure 2 and in Appendix 1. Because of the depth of drilling, the log is considered to be reasonably representative of the formation beneath the site.

Due to increased demand, borehole BH-2 was installed in 1990, 50 m west of BH-1. This well was installed to a depth of 48 m. It had been proposed to drill to a greater depth but collapses in a weathered, water bearing sandstone unit prevented this. BH-2 is a 200 mm diameter open borehole from surface to base with a steel liner in the top 7 m bgl. A well construction and geological log is included in the KTC Report in Appendix 1.

At the time BH-2 was installed, some remedial works were undertaken in BH-1 because the yield from the well had reduced over time due to the oxidisation of iron and manganese on the side walls of the well bore with the large drawdowns. Bacteria in the well, which feed off the iron and manganese, formed a slime on the walls of the well further reducing the well efficiency. To mitigate this problem, the side walls were cleaned using compressed air to remove deposits of iron and manganese and bacterial slime, and then chlorine was added to the well. This resulted in improved water inflow to the well.

In 1991 it was estimated that BH-1 was producing 25 m^3/hr, while BH-2 was producing 12 m^3/hr. In 2010, BH-1 is only producing 1.5 m^3/hour, while BH-2 is producing 2.2 m^3/hr. The dramatic reduction in output appears to be due to the gradual reoccurrence of iron and manganese precipitation and bacterial growth.

Information on BH-3, 4 and 5 is limited. It appears from discussions with the Council that BH-3 was installed in 2003, BH-4 in 2006 and BH-5 in 2007 to depths ranging from 100 m (BH-3 and BH-5) to 160 m (BH-4).

A geological log for BH-5 provided to the Council by the well driller (Appendix 2) shows that BH-5 encountered similar layers of shale, fireclays and sandstone as in BH-1 and BH-2). It is unclear from the log where the water inflow occurs, but it appears to primarily be in the final 8 m (92–100 m bgl), where the log indicates alternating layers of sandstone and shale with water yields. The Council understands that BH-3 and BH-4 are of similar construction to BH-5 but that BH-4 is much deeper.

Groundwater is abstracted at variable rates from each of the five wells, twenty four hours per day and seven days per week. All five wells are not pumped continuously, but are fitted with a float activated switch mechanism. The pumping rates for the wells at the time of the site inspection in June 2010 were as follows;

Well No	**BH-1**	**BH-2**	**BH-3**	**BH-4**	**BH 5**
m^3/hour	1.5	2.2	9.3	19	16.2
m^3/day	36	53	223	456	389

The combined pumping rate is 48 $m^{3/}$hr. During the winter, the pumping rate is higher at approximately 56 m^3/hr and most of the demand is met by BH-4 and BH-5. By August 2010, the yield had reduced to 35 m^3/hr. The Council considers that this is the result of a significant leakage problem in the distribution pipework at the site. It is possible that some of the fall off, is due to declining water table levels in the spring and summer period of 2010, which was drier than normal. The declining pumping rates in the older boreholes indicate that pumping in those wells is becoming unsustainable. Before chlorination, the water is treated to reduce iron and manganese levels. Water is pumped from each of the wells to a holding tank in the southeast of the site, where it is aerated by cascading over a series of concrete steps. From here it is goes for filtration and chlorination. Iron and manganese deposition is visible on the cascade steps and also at the outlet from the holding tank.

Table 3-1 provides a summary of the well details as currently known.

Table 4-1: Well Details

	BH-1	BH-2	BH-3	BH-4	BH-5
EU Reporting Code	**IE_SE_G_126_23_003**	**No Code**			
Grid ref. (GPS)	227289 151182	227281 151188	227253 151192	227247 151178	227259 151208
Townland	Curraheenduff	Curraheenduff	Curraheenduff	Curraheenduff	Curraheenduff
Source type	Borehole	Borehole	Borehole	Borehole	Borehole
Drilled	~1937	~1990	unknown	unknown	~2006
Owner	South Tipperary CC				
Elevation (Ground Level)	~200 m OD	~ 200 m OD	~ 195 m OD	~ 195 m OD	~ 195 m OD
Depth (m)	221.21	48	100	160	100
Depth of casing	4.5m-	7 m-		4.5	8
Diameter	229 - 178 mm	200 mm			250 -168 mm
Depth to rock	2.21 m	3 m	c.1.5 m	c.1.5 m	1.5 m
Static water level	Artesian (Feb 1991)	c.1 m bgl 31/1/91[1]	unknown	unknown	unknown
Pumping water level	-	40 m bgl	28 m bgl	-	12 m bgl
Consumption (Co. Co. records)	36 m^3/d	53 m^3/d	223 m^3/d	456 m^3/d	389 m^3/d
Pumping test summary: (i) abstraction rate m^3/d	1991: 42 m^3/h 1980: 56 m^3/h Safe yield of 900 m^3/d recommended by E. Daly,1980	1991: 29 m^3/h	unknown	unknown	unknown
(ii) specific capacity	1991: ~0.90 m^3/h/m or ~ 22 m^3/d/m 1980: ~1.95 m^3/h/m or ~46 m^3/d/m	1991: ~1.4 m^3/h/m or ~ 34 m^3/d/m	unknown	unknown	unknown
(iii) transmissivity	101 m^2/d	64 m^2/d	unknown	unknown	unknown

1 During the visit on the 14/06/2010

Depth below ground level (m)	Description	Formation	Hole Diameter
0.00 - 2.21	Clay		
2.21 - 6.5	Shale		
6.5 - 7.62	Coal	Main Coal	0.0 to 10.7 m @ 229 mm (201 mm steel casing to 4.5 m)
7.62 - 23.93	Shales		
23.93 - 30.28	Sandstone with quartz strings		
30.28 - 41.22	Shales		
41.22 - 49.38	Green and brown sandstone		
49.38 - 103.45	Shales and fireclay		
103.45 - 107.75	Sandstone with quartz strings		10.7 to 173.9 m @ 203 mm
107.75 - 159.11	Shales		
159.11 - 165.12	Grey sandstone with quartz strings	Main Rock Sandstone	
165.12 - 169.01	Sandy shale		
169.01 - 169.62	Coal	Upper Glengoole Seam	
169.62 - 175.72	Shales		
175.72 - 192.10	Quartzose sandstone	Glengoole Sandstone	
192.10 - 217.25	Shales		
217.25 - 217.52	Coal	Lower Glengoole Seam	173.9 to 221.2 m @178 mm
217.52 - 219.05	Sandy shale		
219.05 - 221.21	Sandstone		

Figure 2: Geological log of BH-1

5 Topography, Surface Hydrology and Landuse

The well field is located in the Slieve Ardagh Hills at approximately 200 m OD. The land slopes from local high points at Curraneenduff to the northeast and Ballynastuck to the northwest toward the well field. A stream to the west of the wells rises approximately 2 km north of the site and is one of two streams that form part of the head waters of the Kings River. The lands to the north, east and west drain into the stream. The topographical gradient is approximately 0.06 between the high points to the northeast and the stream. The stream flows to the south joining the Kings River approximately 5 km to the south of the well field (Figure 1).

The land use in the local area is dominated by agriculture, primarily grazing pasture with dairy, beef and horses being the main enterprises. There are three farm holdings and two residential dwellings within 250 m of the well field. The lands appear to be well draining.

6 Hydrometeorology

Establishing groundwater source protection zones requires an understanding of general meteorological patterns across the area of interest. Meteorological information was obtained for this study from Met Eireann.

Annual rainfall: 1100 mm. The contoured data map of rainfall in Ireland (Met Éireann website, data averaged from 1961–1990) shows that the source is located between two 1200 mm average annual rainfall isohyets.

Annual evapotranspiration losses: 458 mm. Potential evapotranspiration (P.E.) is estimated to be 482 mm/yr based on the contoured data map of potential evapotranspiration in Ireland (Met Éireann website, data averaged from 1971–2000) which shows that the source is located between the 490 mm and 480 mm average annual evapotranspiration isohyets. Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., to allow for seasonal soil moisture deficits.

Annual Effective Rainfall: 642 mm. The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore equivalent to this, or 642 mm/year.

7 Geology

7.1 Introduction

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

Geological information was taken from a desk-based survey of available data, which comprised the following:

- Groundwater Investigations Slieve Ardagh Hill (E.P. Daly, GSI, 1980)
- Report on Groundwater Development at Curraheenduff, Coalbrook, (K.T. Cullen & Co, 1991).
- Geology of Tipperary. Bedrock Geology 1 : 100,000 Map series, Sheet 18, Geological Survey of Ireland (J.B. Archer, A.G. Sleeman and D. C. Smith, 1996)

- Forest Inventory and planning system – Integrated Forestry Information System (FIPS-IFS) Soils Parent Material Map, Teagasc (Meehan, 2002).

7.2 Bedrock Geology

The bedrock geology is illustrated on Figure 3. The Geology of Tipperary Sheet 18 indicates the area is underlain by the Lickfinn Coal Formation. This is classified as part of the Wesphalian Sandstone Rock Unit Group. The Lickfinn Coal Formation consists of shale and sandstone with seat earths. Within the formation are several coal seams including the Upper Glengoole Seam and the Lower Glengoole Seam. The geological log for BH-1, which was drilled in 1937, indicates that the bedrock comprises multiple layers of shale, coal and sandstone of variable thickness and frequency of occurrence.

Daly 1980 indicates that the Westphalian Succession in the Slieve Ardagh Hills is approximately 330 m thick. The well field is located on the southeast limb of a syncline in the Earlshill Basin, with BH-1 penetrating the full Westphalian sequence. This sequence comprises sandstone, shales, fireclay and the Upper and Lower Glengoole Coal Seams that dip 10 -30 degrees to the northwest in the southern part of the basin and to the southeast in the northern part of the basin. There are four, large, north to south trending faults mapped between 1 and 5 kilometres to the east of the well field.

7.3 Soil and Subsoil Geology

The soil and subsoils are illustrated in Figures 4 and 5, respectively. The EPA and GSI Mapping websites classify the soils as Acid Mineral Shallow Well Drained (AminSW) in the vicinity of the well field. In the middle portion of the catchment, the soils are a mix of AminSW soils and Acid Deep Poorly drained mineral soils (AminPD), while in the upper reaches, the soils are generally AminSW.

The subsoils are classified as Namurian sandstone and shale tills (TNSs) where present. Close to the well field, the subsoil map indicates the presence of rock close to the surface or outcrop.

The field observations generally support the mapped soil and subsoil classifications. In the vicinity of the well field, the tills are very thin to absent, with rock outcrop present along the stream. Higher up in the catchment, the bedrock is overlain by thin, Namurian sandstone and shale till (TNSs) subsoil derived from the underlying Namurian bedrock. The tills are no more than 1–2 thick and preferential flow paths were observed in cuttings close to the top of the catchment (Photo 7 and Figure 5). Where the subsoil is present, the permeability appears to be moderate.

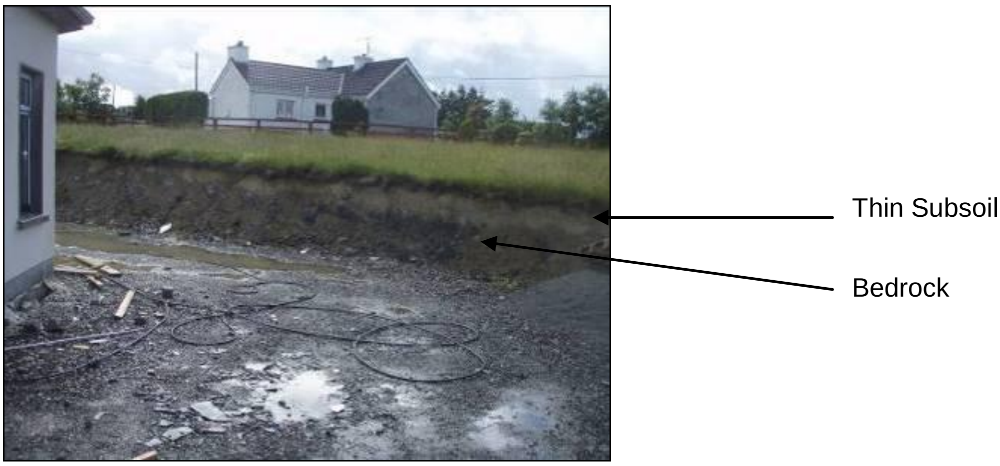

Photo 7: Tills overlying the bedrock

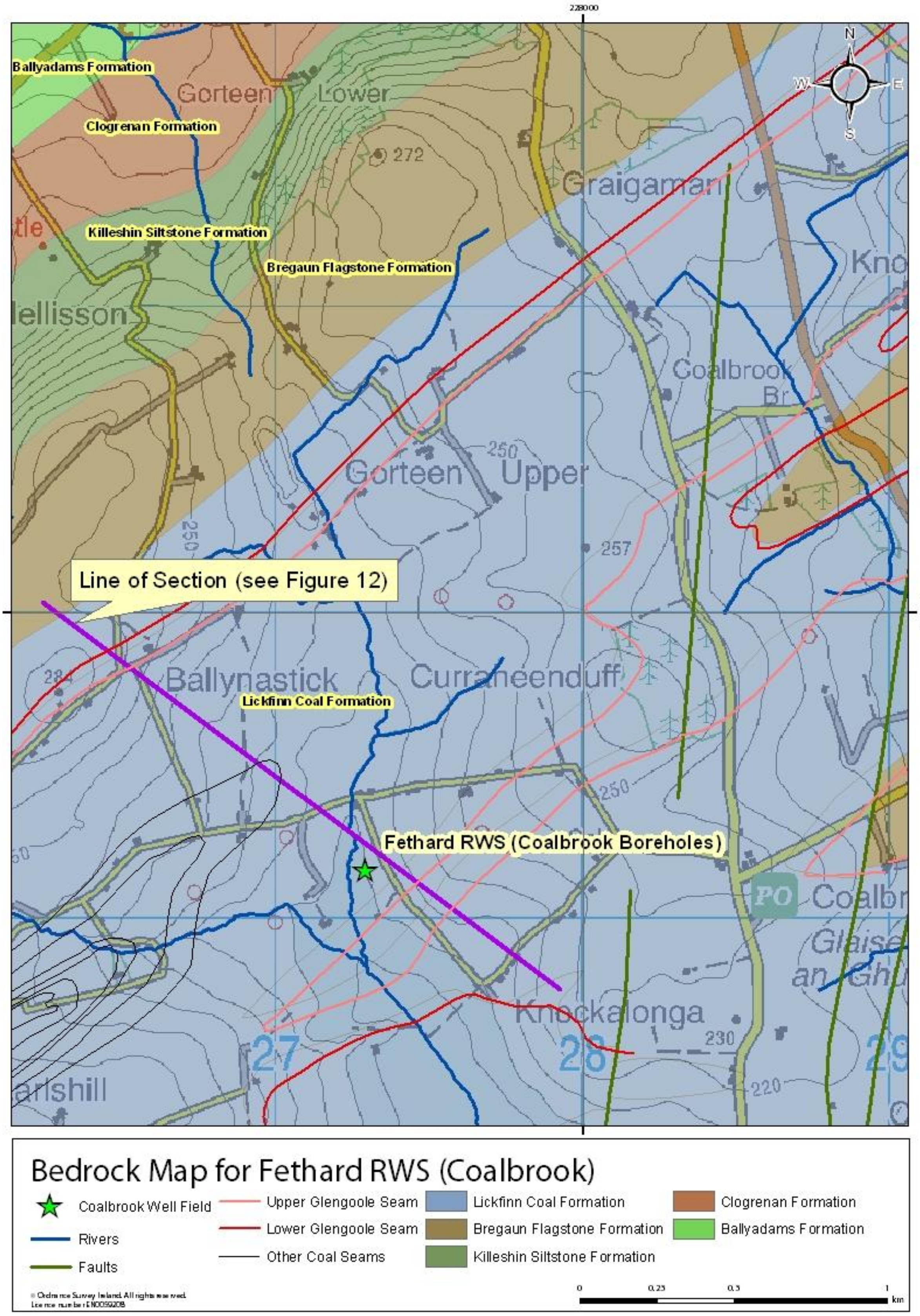

Figure 3: Bedrock Map

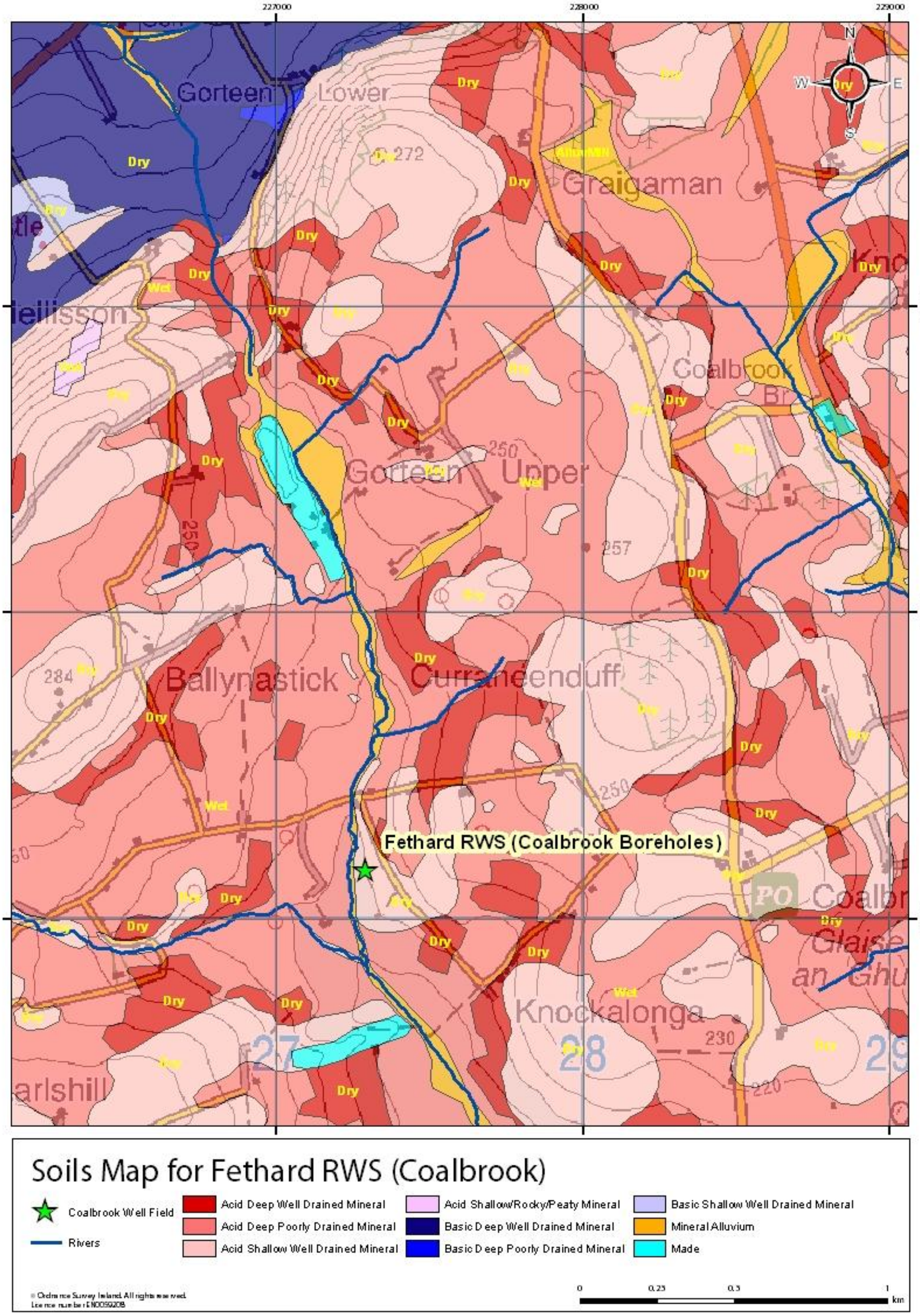

Figure 4: Soils Map

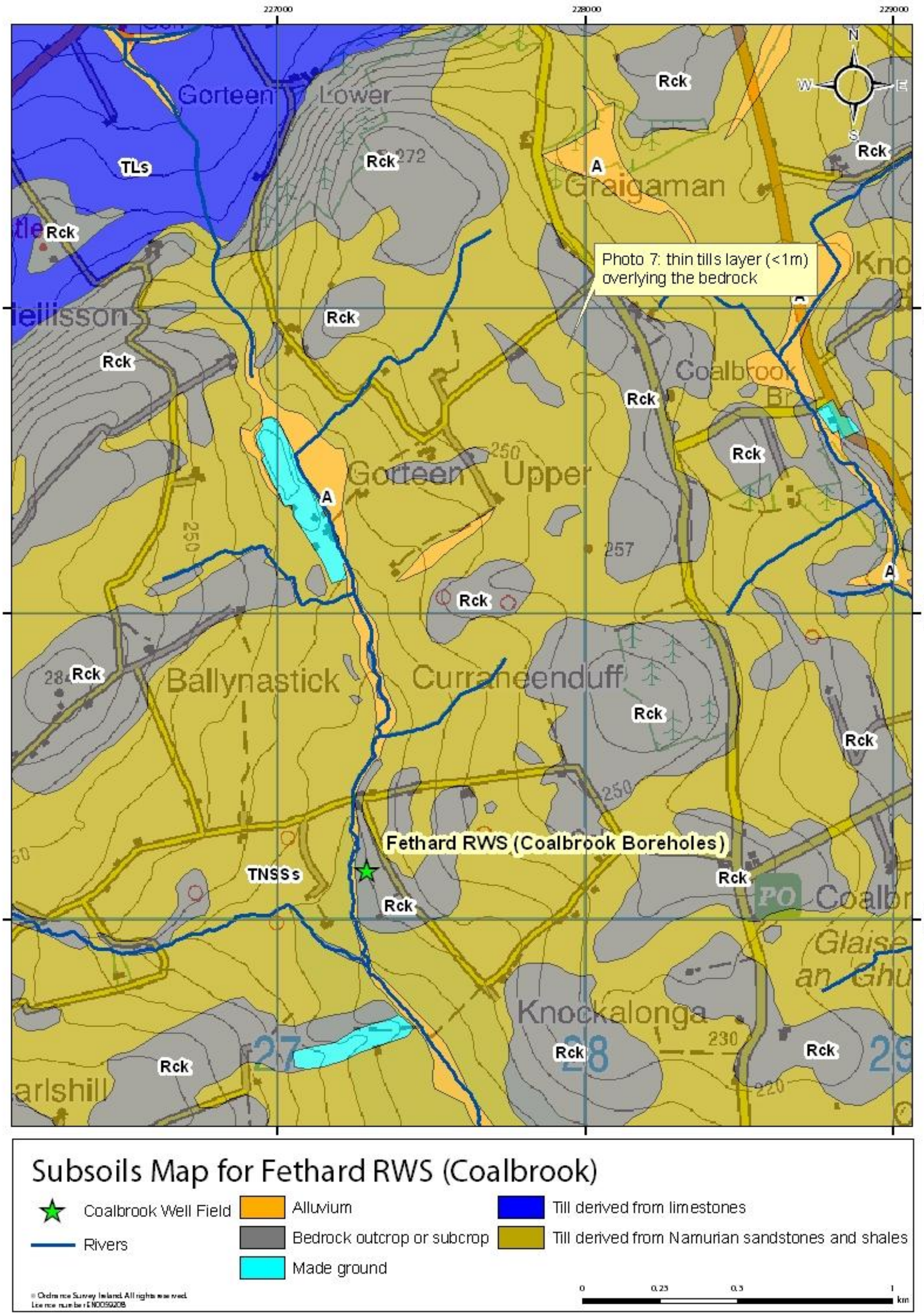

Figure 5: Subsoils Map

7.4 Depth to Bedrock

The GSI vulnerability classification for this area indicates that within the catchment, the bedrock either outcrops or is close to the surface (less than 3 m). The borehole logs for BH-1, BH-2 and BH-5 indicate a depth to bedrock of between 1.3 and 3 m bgl in the vicinity of the wells.

8 Groundwater Vulnerability

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target'. This means that in this area the vulnerability relates to the permeability and thickness of the subsoil, as the target is the bedrock aquifer. 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 vulnerability map is shown in Figure 6 and, in terms of subsoil coverage within the catchment, the area can be divided into three zones:

- Within 200 m of the well, the bedrock is less than 1 m bgl. Rock outcrops in the stream bed located less than 5 m to the west of the well field.
- Rock is also close to the surface in the high ground at the top of the local catchment.
- The depth to rock in between these areas is generally less than 3 m.

9 Hydrogeology

This section describes the current understanding of the hydrogeology in the vicinity of the source. Hydrogeological and hydrochemical information was obtained from the following sources:

- GSI Website and Database including Pumping Tests for BH-1 and BH-2 undertaken in 1978 and 1980 (E.Daly)
- Report on Groundwater Development at Curaheenduff, Coalbrook (K.T. Cullen & Co, 1991)
- County Council Staff
- EPA website and Groundwater Monitoring database
- Local Authority Drinking Water returns

9.1 Groundwater Body and Status

The Fethard Water Supply boreholes are located in the Slieve Ardagh Hills Groundwater Body (IE_SE_G_126) which has been classified as being of Good Status. The groundwater body descriptions are available from the GSI website: www.gsi.ie and the 'status' is obtained from the Water Framework Directive website: www.wfdireland.ie/maps.html.

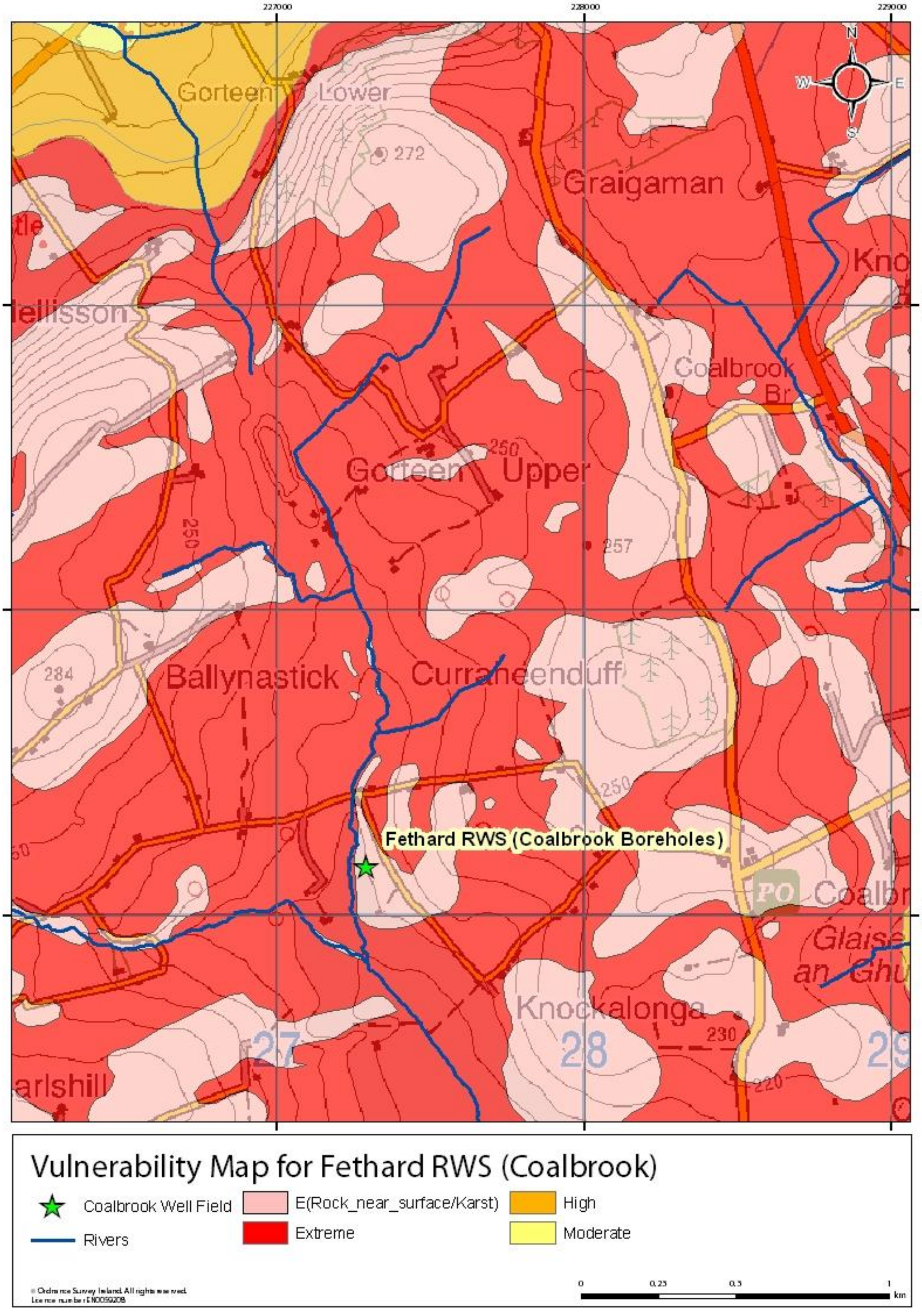

Figure 6: Vulnerability Map

9.2 Groundwater Levels, Flow Directions and Gradients

Daly (1980) observed that the sandstone outcrops at higher elevations in the northwest than in the southeast, resulting in groundwater flow from northwest to southeast. Given the topography in the vicinity of the site, some shallow groundwater flow is expected from the high ground immediately to the northeast of the site, toward the well field, discharging to the river along the western site boundary.

The groundwater gradient is likely to reflect the topography, which is approximately 0.05 from the top of the catchment to the vicinity of the boreholes but it increases significantly in the vicinity of the well field due to the large drawdowns with pumping. At the well field, there is a strong upward hydraulic gradient due to the presence of confining coal and shale layers above the water bearing sandstone units.

BH-1 is known historically to exhibit artesian conditions when not being pumped. Based on down hole geophysical logging of BH-1 by Daly in 1980, under static/unpumped conditions, most of the artesian water originates from the sandstone units at 23 m and 41 m depth. The larger amount comes from the sandstone at 41–49 m, with little contribution coming from deeper levels in the borehole. However, under pumping conditions the upper sandstone units at 23 m are largely dewatered and most of the flow is from the sandstone units between 41 and 49 m with more flow also coming from the deeper in the borehole than under non-pumped conditions. These conditions most likely apply to the more recent boreholes also but in the case of BH-1 it is likely that the upper sandstones are now primarily dewatered and much of the flow is from shallow groundwater inflow closer to the surface.

9.3 Hydrochemistry and Water Quality

The well field has been included in the EPA operational chemical network since 1993. The raw water is sampled from the aeration storage tank, which comprises a mix of all five wells. The laboratory results have been compared to the EU Drinking Water Council Directive 98/83/EC Maximum Admissible Concentrations (MAC) and the where relevant, mean values have been compared to the European Communities Environmental Objectives (Groundwater) Regulations 2010 recently adopted in Ireland under (S.I. No. 9/2010) as part of the implementation of the Water Framework Directive 2000. The data are summarized graphically in Figures 7 to 10 and summarised below.

- The water has a moderately hard calcium/magnesium bicarbonate hydrochemical signature (average 190 mg/l $CaCO_3$) indicative of siliceous bedrock. The average conductivity is 426 µS/cm and pH is around 7. In 1980 hydrochemical analysis of the BH-1 by Daly indicated that the groundwater chemistry changes with depth. Under non-pumped conditions the groundwater at depth was stagnant and allows ion exchange to occur between calcium/magnesium and sodium/potassium conditions. The stagnant conditions allowed the build up of iron precipitates in the well in the groundwater. Under pumping conditions iron levels decline.

- There are two reported incidents of faecal coliforms (September 2000: 1 No/100ml; and October 2003: 16 No/100ml). Ammonium values greater than the Threshold Level (0.175 mg/l) were recorded on two occasions.

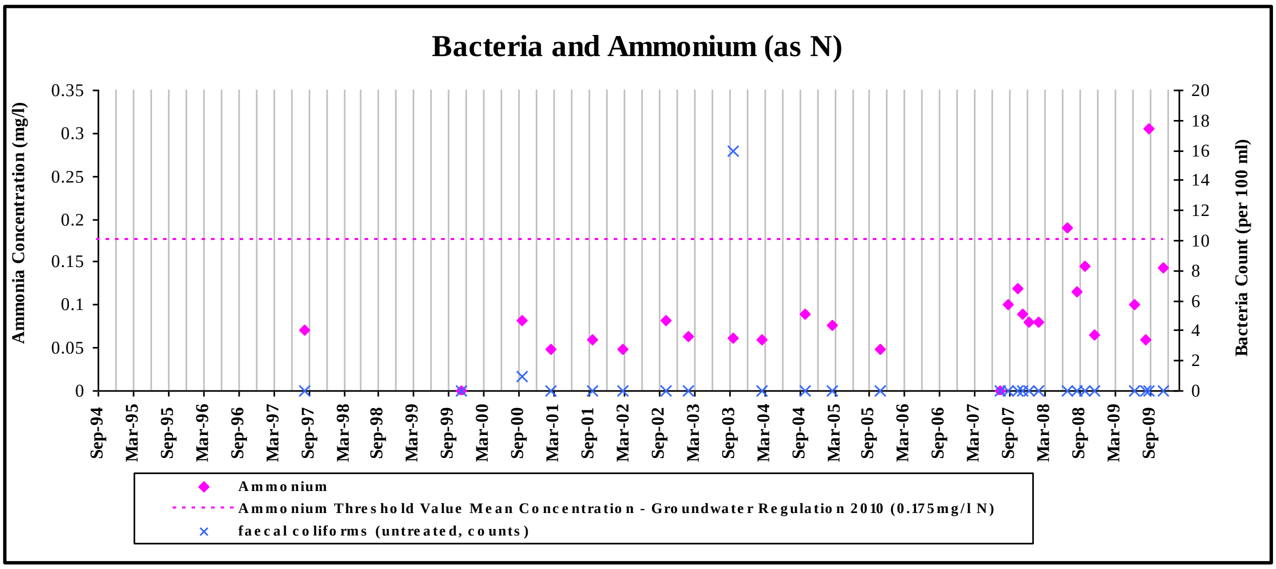

Figure 7: Key Indicators of Agricultural and Domestic Contamination: Bacteria and Ammonium Graph

- The nitrate concentration ranges from 0.3 mg/l to <10.3 mg/l with a mean of 1.8 mg/l (as NO_3). Neither the Threshold Value (37.5 mg/l) nor EU Drinking Water Directive maximum admissible concentration (MAC; 50 mg/l), has been exceeded.

- Chloride is a constituent of organic wastes, sewage discharge and artificial fertilisers, and concentrations higher than 24 mg/l (Groundwater Threshold Value) may indicate contamination, with levels higher than 30 mg/l usually indicating significant contamination (Daly, 1996). Chloride concentrations range from 8 mg/l to18 mg/l, with a mean of 13.1 mg/l, which is indicative of good water quality.

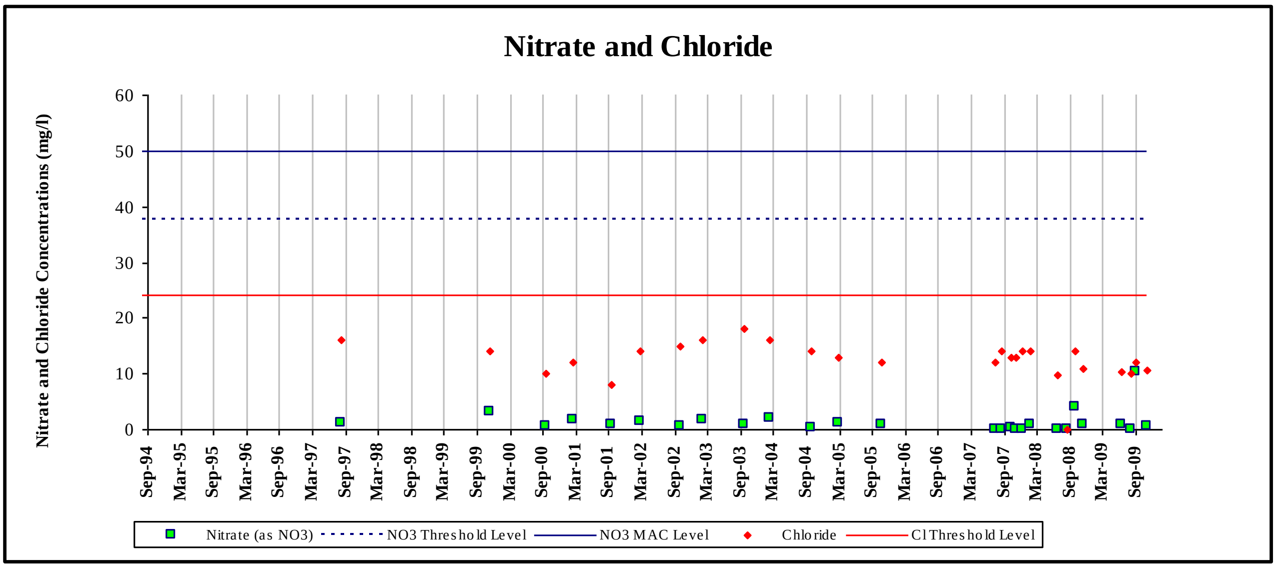

Figure 8: Key Indicators of Agricultural and Domestic Contamination: Nitrate and Chloride Graph

- Turbidity exceeded the drinking water standard limit of 1 NTU on 10 occasions, most likely due to the presence of iron or manganese particles which precipitate out when the water becomes aerated at the ground surface.

- The sulphate, potassium, sodium, magnesium and calcium levels are within normal ranges. The potassium/sodium ratio exceeded the threshold of 0.35, in twenty one of the twenty eight tests. The exceedances are probably related to the natural geological conditions rather than to contamination incidents.

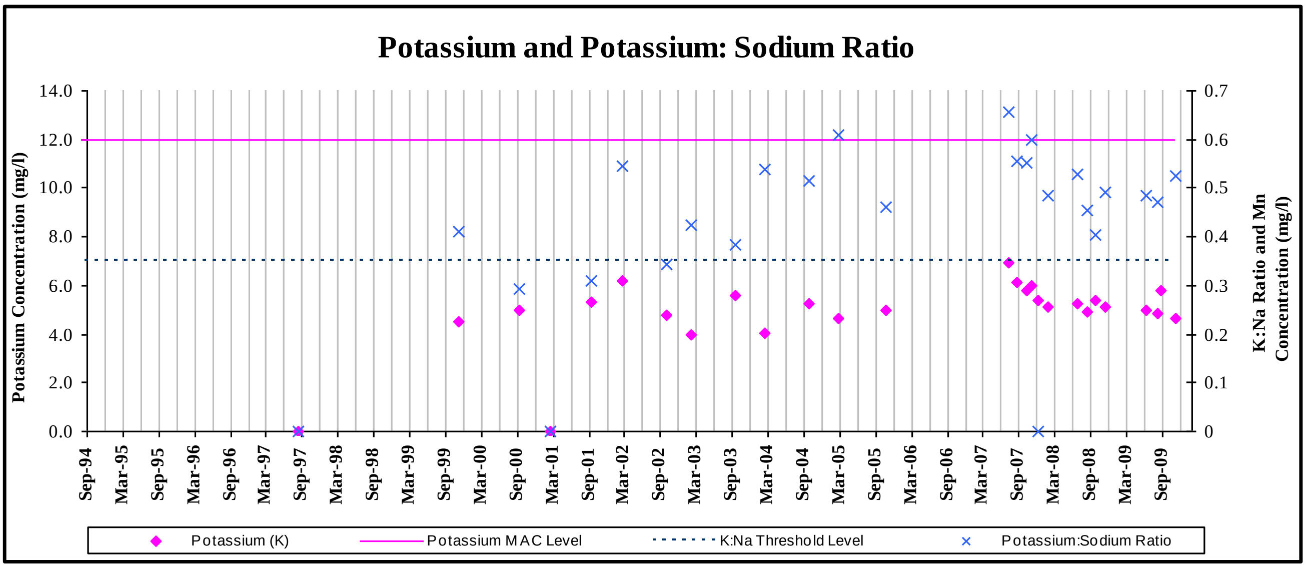

Figure 9: Key Indicators of Agricultural and Domestic Contamination: Manganese, Potassium and K/Na ratio

- The level of manganese has been always above normal ranges. The level of iron was above the MAC limit (200 µg/l) until 2005 and since then the level has stabilized around 50 µg/l. The reduction in iron levels may corresponds to the abstraction of water from the lower sandstone unit i.e. the deeper boreholes (BH-4 and 5) around 41–49 m, where iron levels may be lower than in the upper sandstone units, and in part due to the fact that the shallower sandstone unit providing flow in BH1 is virtually dewatered with oxidation resulting in high levels of iron precipitation at this level in the borehole.

- Trace metals were either within the normal range for good quality drinking water or were not detected. Similarly, organic compounds and herbicides have not been detected.

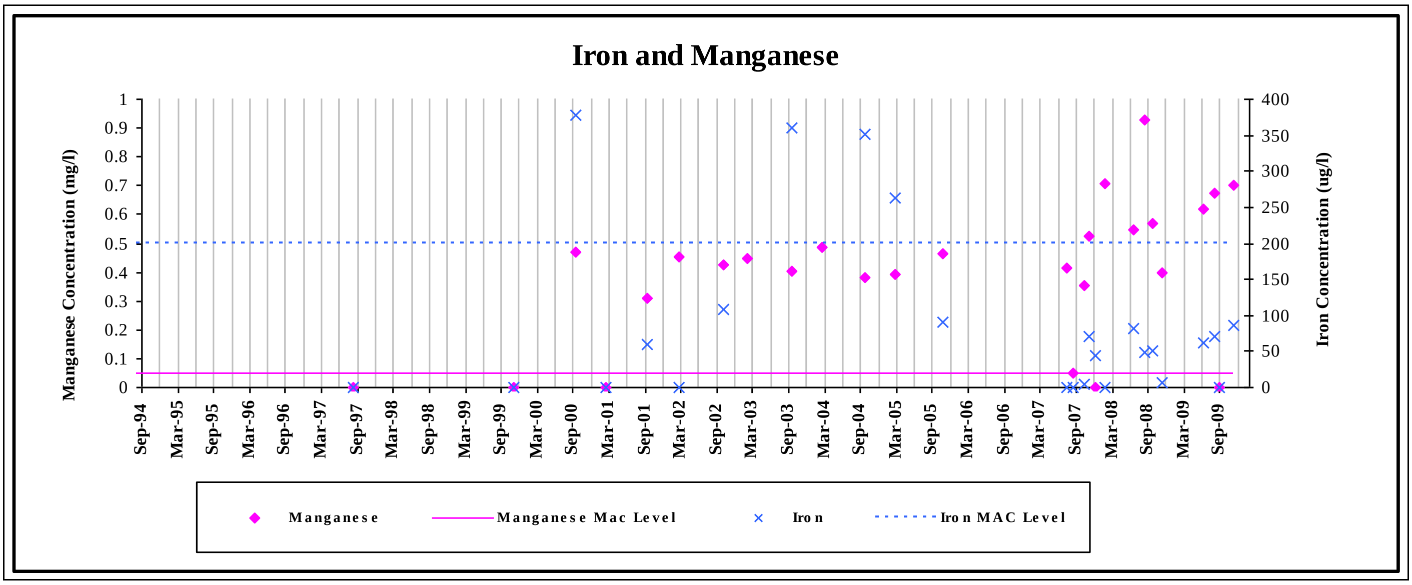

Figure 10: Manganese and Iron Graph

In summary, the high levels of iron and manganese are the main water quality issues for this water supply. The gradual precipitation of these metals in the boreholes has caused clogging of the wells and the pump screens in the past, as documented in the KT Cullen Report, and therefore reduced well efficiency and pump performance. The K/Na ratio is greater than 0.35 for many of the records, primarily because of high Potassium levels. While this could indicate contamination by plant organic matter, because other associated contaminate indicators are low i.e. Faecal Coliforms, chloride and ammonium, it is more likely that the potassium levels are naturally occurring associated with the local geology.

The EPA monitoring records at the five boreholes and field data at the unnamed stream indicate that the groundwater and surface water have similar, pH and electrical conductivity (Table 9-1). The stream is not in hydraulic continuity with the boreholes, as the sandstone aquifers are confined beneath the coal, fire clays and shale beds. However, substantial leakage of groundwater from the pipework beneath the ground is reported to be occurring which most likely discharges into the stream and possibly accounts for the similar readings between the surface and groundwater. It is possible that baseflow derived from shallow groundwater flow into the stream channel also accounts for some of the similarity in pH and electrical conductivity.

Table 9-1: Groundwater and Surface Water Quality pH and Electrical Conductivity

	BH-1 to BH-5 (from EPA analyses)	Unnamed Stream
Location	On site	On site (was almost dry)
pH	Ave 7 Range: 6.3-8.1	8.05
Conductivity (µS/cm)	Ave 251 Range: 335-707	350

9.4 Aquifer Characteristics

The Westphalian sandstone aquifer is characterised by the GSI as *a Locally Important Aquifer that is Moderately Productive (Lm),* as indicated in Figure 11. Daly (1980), states that for the purposes of groundwater development, the Westphalian sandstones can be divided into two principal sandstone units. Group I are the Glengoole and Main Rock Sandstones. These units are stratigraphically lower in the succession and occur throughout the coalfields of the Slieve Ardagh Hills. The Group II sandstones are thinner and are present at shallower depths c.100 m i.e., closer to the top of the succession.

The older boreholes (BH-1 and 2) most likely abstract most of their water from the Group I sandstones. Given its depth BH-1 originally abstracted water from both the Group I and II sandstones but clogging of the well by iron precipitation has most likely closed off much of the shallower inflow. Based on the borehole log for BH-1, the hydrogeologically significant/water bearing units in the aquifer in terms of the well field are located at approximately 23–30 m bgl, 41–50 m bgl and 103–107 m bgl. With the current abstraction regime in BH-1 it is not considered to be abstracting from its full depth. Given their depths (100 m) the newer wells (BH-3 and 5) appear to abstract groundwater from the upper Group II sandstone units. BH-4 however may abstract water from the Group I main sandstone rock unit and Group II sandstone units given its greater depth (160 m and higher yield). The groundwater in the sandstone units is confined by overlying coal and shale bands. Artesian conditions were reported at BH-1 before it was commissioned and prior to a pumping test in 1990 when the pump was switched off.

Daly (1980) states that the synclinal structure of the basin and the topography in the vicinity of the well field i.e. the river valley being located perpendicular to the axis of the syncline makes the installation of well fields feasible in this area which is why multiple wells operating close together at this site have to date been sustainable. However, Daly did recommend that individual wells should be 500 – 750 m apart. It is likely that the wells pumping from the shallower Group II sandstone units are competing with each other, i.e. that the drawdown cones are overlapping and that the better yields are now coming from the newer wells, primarily BH-4 installed in the Group I sandstone units at depth where the aquifer is isolated from, and unaffected by, pumping in the upper sandstone units.

In 2009/10, the yield from the well field ranged from 1100 m^3/d in the summer to 1300 m^3/d during the winter period. However, in the summer of 2010, the yield fell to 840 m^3/d. This may in part be due to lower recharge as a result of much lower rainfall levels than normal over the April to August period. However significant leakage in the pipelines is also thought to be affecting the pumping rates in the wells due to pressure losses. (Pers Comm Joe Burke, South Tipperary CC).

Pumping tests undertaken by the GSI in 1980 on BH-1 indicated that a pumping rate of 1,357 m^3/d resulted in a drawdown of 28.9 m after 120 minutes during the third step of a step test. At this point the sandstone unit between 23.9 and 30.3 m bgl was largely dewatered and the pumping rate was considered to be too high to be coming from the next unit down alone which was located between 41 and 49 m bgl. It was concluded that a significant portion of the inflow at this pumping rate was coming from the lower (Group I) sandstone unit (Glengoole Sandstone). During the main pumping tests, unpredictable and unstable variations in response to pumping in each of the sandstone units were observed. The transmissivity at BH-1 provided in the 1980 GSI pump test report is 101 m^2/day, mostly attributable to the deeper sandstone units. Given that BH-1 is not effective for its entire depth a lower T vale was used based on the effective aquifer thickness for the deepest borehole currently in use (BH-4 at 160 m). The revised T value is calculated to be 80 m^2/day. Overall, this is considered to be a leaky aquifer with inflow to the wells from shallow and deep aquifer units. Given that the deeper wells in particular (BH-1, 3, 4 and 5) intersect a series of mostly confined aquifers on top of each other there is likely to be a general upward gradient. It is possible however that with leaky conditions resulting from fractures in the rock units and where the drawdown is high that the hydraulic gradient can potentially reverse in these confined units within the ZOC to the wells.

The safe yield for BH-1 proposed by Daly in 1980 was 900 m^3/day based on the presumption that a significant portion of the groundwater flow was from the deeper sandstone units (Glengoole Sandstone) that was only penetrated by BH-1. The newer wells (BH-4 and 5) are 160 m and 100 m deep respectively. They now provide the largest volume of water in the well field and at least BH-4 appears to penetrate both the Group I and Group II sandstone units.

The pumping test by KTC on BH-2 indicated a transmissivity of 64 m^2/d. This was based on a higher abstraction than the well is presently capable of. Based on the drawdown now occurring in this well and saturated thickness of the borehole a T value of 10 m^2/d was calculated.

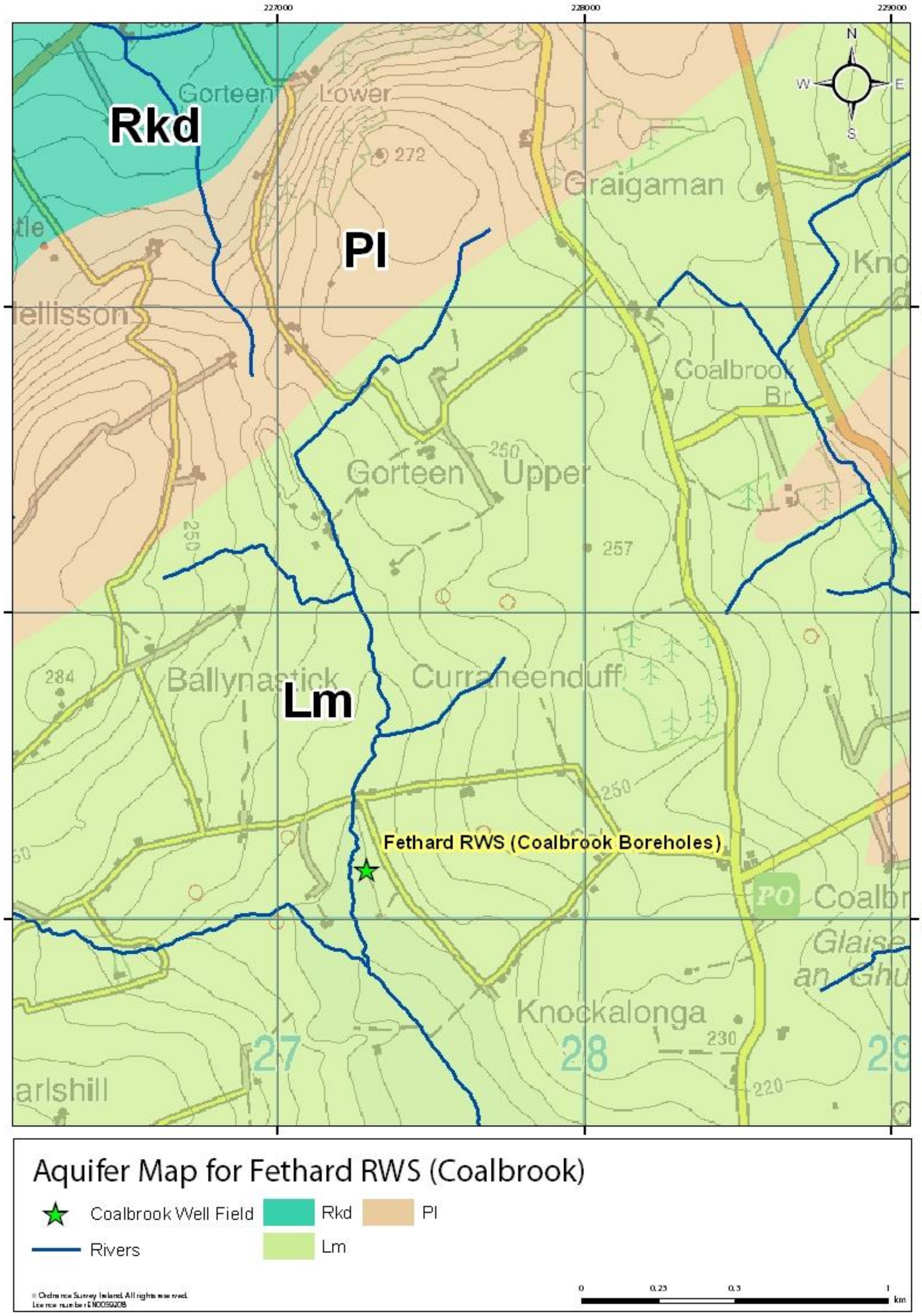

Figure 11: Aquifer Map

Bedrock permeability for an Lm aquifer is expected to be moderate. The permeability is high in the upper few metres where weathering results in enhanced permeability zones, but generally decreases with depth. However, the confined sandstone aquifer units are high yielding resulting from high fracture permeability and it is likely that within these confined aquifers, the permeability is also high. The permeability can be calculated by dividing the transmissivity by the saturated thickness of the aquifer.

Given the lack of information on the newer wells (e.g. a borehole or well construction log for BH-3 and 4) the saturated thickness of the aquifer for the area is estimated as the depth of the deepest fully operational borehole (160 m for BH-4) for BH-1, 3, 4 and 5 and the depth of BH-2 (48 m), assuming recharge is coming to the wells from both the Group I and II sandstone units. The bulk permeability (K) is estimated as follows:

Table 9-2: Permeability Range

	BH-1, 3, 4 and 5	BH-2
Transmissivity (m^2/d)	80	10
Permeability (m/d)	0.36	1.33

The permeability for the aquifer is estimated at 0.36 m/d for the confined boreholes and 1.33 m/d for BH-2.

The velocity of water moving through this aquifer to the borehole has been estimated from Darcy's Law:

Velocity (V) = (K x Groundwater Gradient (i)) / porosity

The natural gradient is estimated at 0.05 (described in section 9.2). The effective porosity (n) range for the formation is estimated at 2% based on GSI derived assessments of porosity for this aquifer type elsewhere.

Table 9-3: Velocity Range

	BH-1, 3, 4 and 5	BH-2
Permeability (m/d)	0.36	1.33
Gradient	0.05	0.05
Porosity	0.02	0.02
Velocity (m/d)	0.90	0.52

The velocity is estimated at 1.1 m/d.

The aquifer parameters are summarized in Table 9–4.

Table 9-4: Indicative Parameters for the Westphalian Sandstones Formation Aquifer in Fethard

Parameters	Source of Data	BH-1, 3, 4 and 5	BH-2
Transmissivity (m^2/d)	From drawdown and saturated thickness	80	10
Permeability (m/d)	Assumed (estimated from T value)	0.36	1.33
Effective Porosity	Based on values applied elsewhere by GSI for this aquifer type	2%	2%
Groundwater gradient	Assumed based on topography	0.05	0.05
Velocity (m/d)	calculated based on above	0.90	0.52

10 Zone of contribution

The Zone of Contribution (ZOC) is usually considered to be the complete hydrologic catchment area to the source, or the area required to support an abstraction from long-term recharge. The size and shape of the ZOC is controlled primarily by (a) the total discharge, (b) the groundwater flow direction and gradient, (c) the subsoil and rock permeability and (d) the recharge in the area. This section describes the conceptual model of how groundwater flows to the source, including uncertainties and limitations in the boundaries, and the recharge and water balance calculations which support the hydrogeological mapping techniques used to delineate the ZOC.

10.1 Conceptual Model

The well field is located high up in the catchment and water is being extracted from the shallower and thinner Group II sandstones, and from the deeper and thicker Group I Main Rock Sandstone. BH-1 was the only borehole that penetrated the Group I Glengoole Sandstone but it not considered to be extracting water from this depth. The deepest effective borehole is BH-4 at 160 m bgl which terminates at the Upper Glengoole Coal Seam which separates the Main Rock Sandstone from the Glengoole Sandstone. The older boreholes (BH-1 and BH-2) appear to abstract water from both Group I and II sandstones but most of the flow is most likely coming from the deeper Group I units. The newer wells, (BH-3, BH-4 and BH-5) abstract water from both the upper and lower sandstone units. The aquifers supplying BH-1, 3, 4 and 5 are considered to be confined, while BH-2 is considered to be unconfined.

Given the level of drawdown in BH-2, it is likely that much of the flow to this well comes from shallow, unconfined groundwater flow to the well in the upper weathered portions of the bedrock primarily to the east of the well. Some flow may also reach this well from the high ground to the west of the well field where the excessive drawdown in the shallower sandstone units may result in a reversal of the artesian conditions at the well head and consequently flow into the shallower well (BH-2). However, much of the unconfined shallow flow from the west is expected to discharge to the stream just west of the well field. Because of the very high pumping rates across all boreholes, it is likely that much of the upper Group II sandstone units are being dewatered, particularly in the summer months, and that most of the flow now comes from the deeper Group I sandstone units.

Direct recharge occurs where the sandstone units are exposed, or are close to the surface along synclinal ridges, particularly in the high ground to the north, east and west of the well field. Daly indicates that the Group I Sandstone comes close to the surface not only along the margins but also in the centre of the coalfields. The hydraulic gradient is steep and an upward gradient is present at the well field.

Groundwater recharge to the well field is controlled primarily by the nature and structure of the bedrock geology where the stratigraphy is the predominant control with the sandstone layers being the main water bearing units. Recharge occurs where these units outcrop or come close to the surface to the northeast and west of the well field. The siltstone and coal bands have limited or no recharge potential. The geological structure is a syncline that is slightly boat-shaped, which funnels in groundwater along the sandstone strata from the north, east and small amounts from the south in a mainly confined groundwater system.

In the core of the syncline and close to the well field it is likely that recharge to the deeper sandstone aquifer units is inhibited by the overlying coal and shales. However, some limited recharge may occur through fractures in these rocks also.

Higher recharge is available in the winter time. When the effective rainfall levels decline in the summer period, the flow to the wells from the confined aquifer units reduces because of the limited available storage in these units.

Large seasonal fluctuations in water level (potentiometric surface) occur because of reduced rainfall amounts in the summer. Variations between winter and summer water levels under pumping can be as much as 22 m. The aquifer is confined by the coal and shale beds in the river basin and while shale is exposed in the base of the stream, it is unlikely that surface water is hydraulically linked to the groundwater system. However, there may be some leakage occurring between the units in the vicinity of the well due to the large drawdowns. The water quality results supports the assumption that the aquifers are confined, with the very low nitrate, moderately high ammonium, and iron and manganese all suggesting reducing conditions which are often associated with confined aquifer units. The isolated faecal coliform results may have been due to a small contribution of groundwater from the shallow weathered zone at the top of the bedrock as the vulnerability in those areas is Extreme.

A schematic representation of the conceptual model is shown in Figure 12.

10.2 Boundaries of the ZOCs

Two separate ZOCs have been delineated for the well field, one for the wells abstracting water from the confined aquifer units (BH-1, 3, 4 and 5) and one for the unconfined abstraction at BH-2. The boundaries of the areas contributing to the source are illustrated on (Figure 13):

The majority of the flow reaching the well field is from the confined sandstone units which are recharged where these outcrop or come close to the surface on the northern and southern flanks of the boat shaped syncline. This results in two separated areas to the confined ZOC. The width of the northern sandstone unit recharge area is estimated at 250 m along the north-western flank of the syncline, while the width of eastern sandstone unit along the southern flank of the syncline is estimated at 180 m. The width of these recharge areas was calculated using the borehole log for BH-1, the cross section constructed in Figure 12, which in turn is based on dip and strike data for the various geological units and the mapped area of the confining coal seams in the catchment. The northern and southern boundaries are assumed to be marked by the Upper Glengoole Coal Seam. A buffer of 30 m beyond the seam was incorporated to be conservative to allow for some flow from beyond the boundary. The centre of the boat shape is not considered to be contributing to the source as the aquifer is confined in that area.

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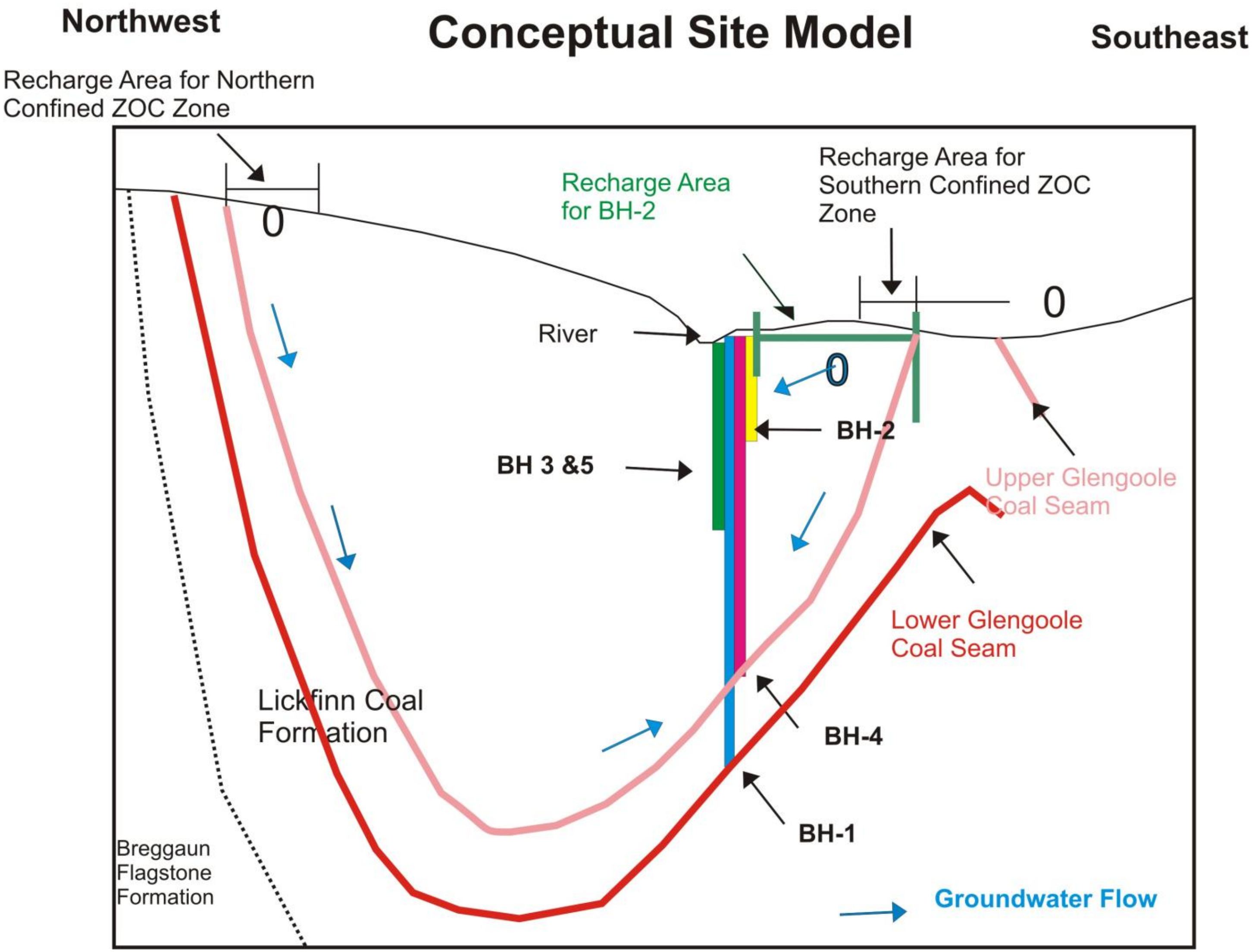

Figure 12: Conceptual Model

The northern and north-eastern confined recharge zones both extend in a north easterly direction until they reach a fault boundary. These units also extend to the southwest. The extent of the ZOC areas to the southwest is controlled by topography, and for the northern ZOC unit, by the calculated up hydraulic gradient no flow boundary. For the north-eastern ZOC area, the south-western boundary is defined by the abstraction rate from the Deep Boreholes (BH1, 3, 4 and 5) and the down gradient no flow boundary. Both no flow boundaries are based on using the uniform flow equation (Todd, 1980).

$$x_L = Q / (2\pi * T * i)$$

where: Q is the daily pumping rate +/- X%, T is Transmissivity (taken from aquifer characteristics), i is gradient.

The ZOC for unconfined flow in BH-2, which accounts for very shallow groundwater flow above the confining coal and fireclays reaching the well field, is based on the topography, and conceptualised shallow groundwater flow-lines, which flow primarily from the high ground to the northeast to the southwest in the direction of the unnamed stream. It is possible, though less likely, that some shallow flow also occurs to this well from the high ground to the northwest and may reach the borehole when the upper sandstone units are dewatered, allowing a reversal of the upward hydraulic gradient and shallow groundwater flow to BH-2.

Given the pumping rate is 1104 m^3/d for BH-1, 3, 4 and 5, the transmissivity is 80 m^2/d and the hydraulic gradient is 0.05, the approximate downgradient distance from the well field is calculated at 44 m. For BH-2, the downgradient distance is 17 m.

10.3 Recharge and Water Balance

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 assumed to consist of input (*i.e*. annual rainfall) less water loss 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 will dictate the size of the zone of contribution to the source (*i.e*. the outer Source Protection Area).

At Curraheenduff therefore, the main parameters involved in recharge rate estimation are: annual rainfall; annual evapotranspiration and a recharge coefficient. There are two ZOCs to calculate recharge for, the confined ZOC for BHs 1, 3, 4 and 5 and the unconfined ZOC. The recharge is estimated as follows.

Potential recharge is equivalent to 642 mm/year i.e. (Annual Effective Rainfall as outlined in Section 6). The Westphalian sandstone is classified as a Locally Important Aquifer that is Moderately Productive (Lm). The Guidance Document GW-5 suggests a range of recharge coefficients for types of soil and subsoil encountered in the catchment. Where a poorly drained soil overlies till, a recharge coefficient of 0.35 was assumed. For a well drained soil over till, a recharge coefficient of 0.6 was assumed. Where the rock is close to the surface a recharge coefficient of 0.85 was used. The assumptions made are summarised in Table 10.1 below (IWWG 2005).

Table 10 - 1 Recharge Coefficient Assumptions

Soil	Subsoil	Recharge Coefficient
AminPD	**TNSSs**	**0.35**
AlluvMin	A	0.35
AminSW	RckNa	0.85
AminDW	TNSSs	0.6
Made	Made	0.35

10.3.1 Confined ZOC

Recharge: *353 mm/*yr. The shallow bedrock comprises shales and sandstones that are fractured and weathered. The recharge for the ZOC occurs to the deeper sandstone units of the Lickfinn Coal Formation. These are to the north and northeast of the well field. The coal and shale layers create a confining or partially confining layer in the vicinity of the well field. Using the assumption in Table 10.1, the bulk ***recharge coefficient*** for the contributing area is therefore estimated to be 55%.

Runoff losses: *289* mm. Runoff losses are assumed to be 45% of potential recharge.

These calculations are summarised as follows:

Average annual rainfall (R)	1100 mm
Estimated P.E.	482 mm
Estimated A.E. (95% of P.E.)	458 mm
Effective rainfall	642 mm
Potential recharge	642 mm
Run off losses	289 mm
Runoff losses	45%
Bulk recharge coefficient	55%
Assumed Recharge	**353 mm**

The water balance calculation states that the recharge over the area contributing to the source should equal the discharge at the source. At a recharge of 353 mm/yr, an average discharge of 1104 m^3/day (based on maximum winter abstraction rates for BH-1, 3, 4 and 5) would require a recharge area of 1.14 km^2. The delineated ZOC is slightly larger at 1.18 km^2.

10.3.2 Unconfined ZOC

Recharge: *371 mm/*yr. The shallow bedrock comprises shales and sandstones that are fractured and weathered. Shallow groundwater recharge within the topographic catchment can reach BH-2. Using the assumptions in Table 10.1, the bulk ***recharge coefficient*** for the unconfined contributing area is therefore estimated to be 58%.

These calculations are summarised as follows:

Average annual rainfall (R)	1100 mm
Estimated P.E.	482 mm
Estimated A.E. (95% of P.E.)	458 mm
Effective rainfall	642 mm
Potential recharge	642 mm
Run off losses	271 mm
Runoff losses	42%
Bulk recharge coefficient	58%
Assumed Recharge	**371 mm**

The water balance calculation states that the recharge over the area contributing to the source should equal the discharge at the source. At a recharge of 371 mm/yr, an average discharge of 53 m^3/day (based on maximum winter abstraction rates for BH-2) would require a recharge area of 0.052 km^2. The ZOC, which is delineated based on hydrogeological mapping techniques, is larger than that required at 0.127 km^2 but provides for a conservative ZOC.

The total area of the two ZOCs is 1.307 km2. Although the two ZOC's overlap and when combined give a surface area of 1.23 km^2. Increasing the size of the ZOC in this case would be unrealistic in terms of the hydrogeological limitations of the boreholes and the topography of the catchment. It is possible that the recharge is higher than that assumed in this assessment. However, the installation of five boreholes in close proximity on the site, with significant drawdown does indicate that the well field is pumping at a potentially unsustainable level. Daly (1980) recommended that individual boreholes should ideally be up to 750 m apart and that the sustainable yield of individual wells at that separation distance was around 900 m^3/day.

The boundaries of the ZOCs are shown in Figure 13.

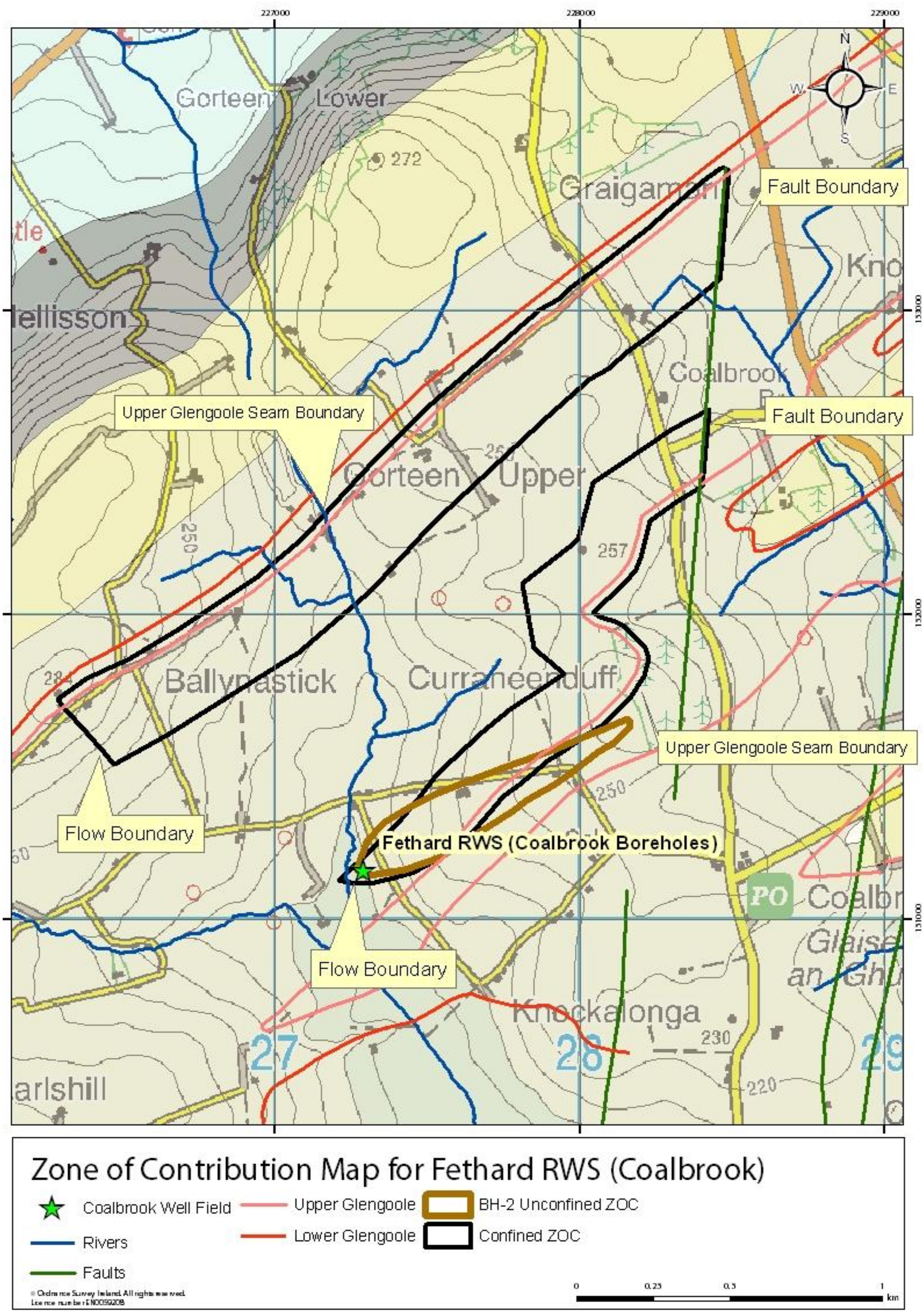

Figure 13: Zone of Contribution

11 Source Protection Zones

The Source Protection Zones are a landuse planning tool which enables an objective, geoscientific assessment of the risk to groundwater to be made. The zones are based on an overlay of the source protection areas and the aquifer vulnerability. The source protection areas represent the horizontal groundwater pathway to the source, while the vulnerability reflects the vertical pathway. Two source protection areas have been delineated, the Inner Protection Area and the Outer Protection Area.

The Inner Protection Area (SI) is designed to protect the source from microbial and viral contamination and it is based on the 100-day time of travel to the supply (DELG/EPA/GSI 1999). Based on the indicative aquifer parameters outline in section 9.4, the groundwater velocity is 1.1 m/d. Hence, the 100-day time of travel is 110 m. The Inner Source Protection Zone has not been extended across the stream to the west, as this is likely to act as a barrier to shallow groundwater flow from the west of the stream toward the well field. The Inner Protection Zone is illustrated on Figure 14.

Groundwater protection zones are shown in Figure 15 and listed in Table 11-1 and are based on an overlay of the source protection areas on the groundwater vulnerability. Therefore the groundwater protection zones are SI/X, SI/E, SO/X and SO/E. The majority of the area is designated SO/E.

Table 11-1 Source Protection Zones (%area, km^2)

Source Protection Zone		% of total area (km^2)
SI/X	Inner Source Protection area / ≤1 m subsoil	0.57% (0.007 km^2)
SI/E	Inner Source Protection area / <3 m subsoil	0.03% (0.0003 km^2)
SO/X	Outer Source Protection area / ≤1 m subsoil	36.23% (0.446 km^2)
SO/E	Outer Source Protection area / <3 m subsoil	63.17% (0.777 km^2)

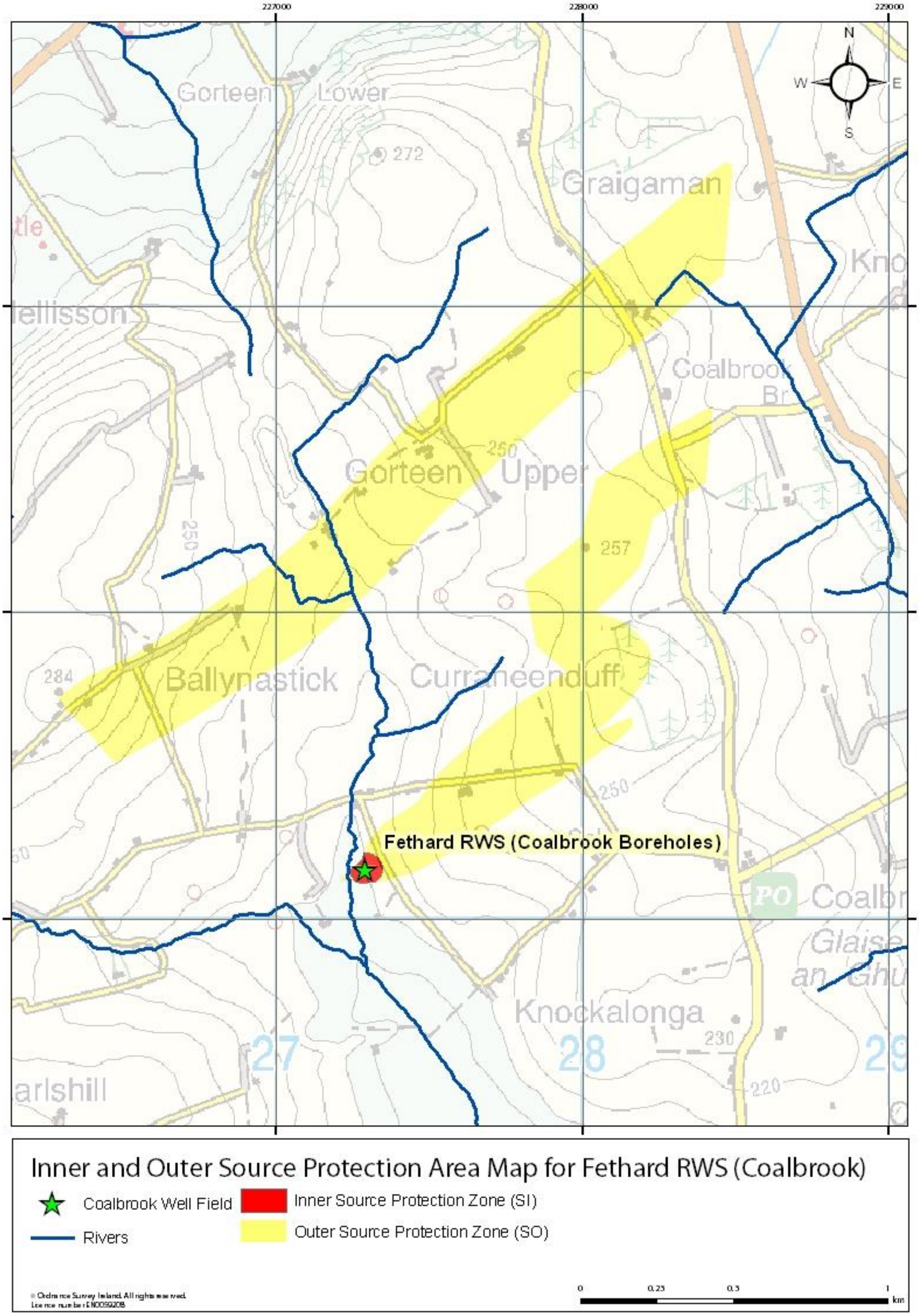

Figure 14: Inner and Outer Source Protection Areas

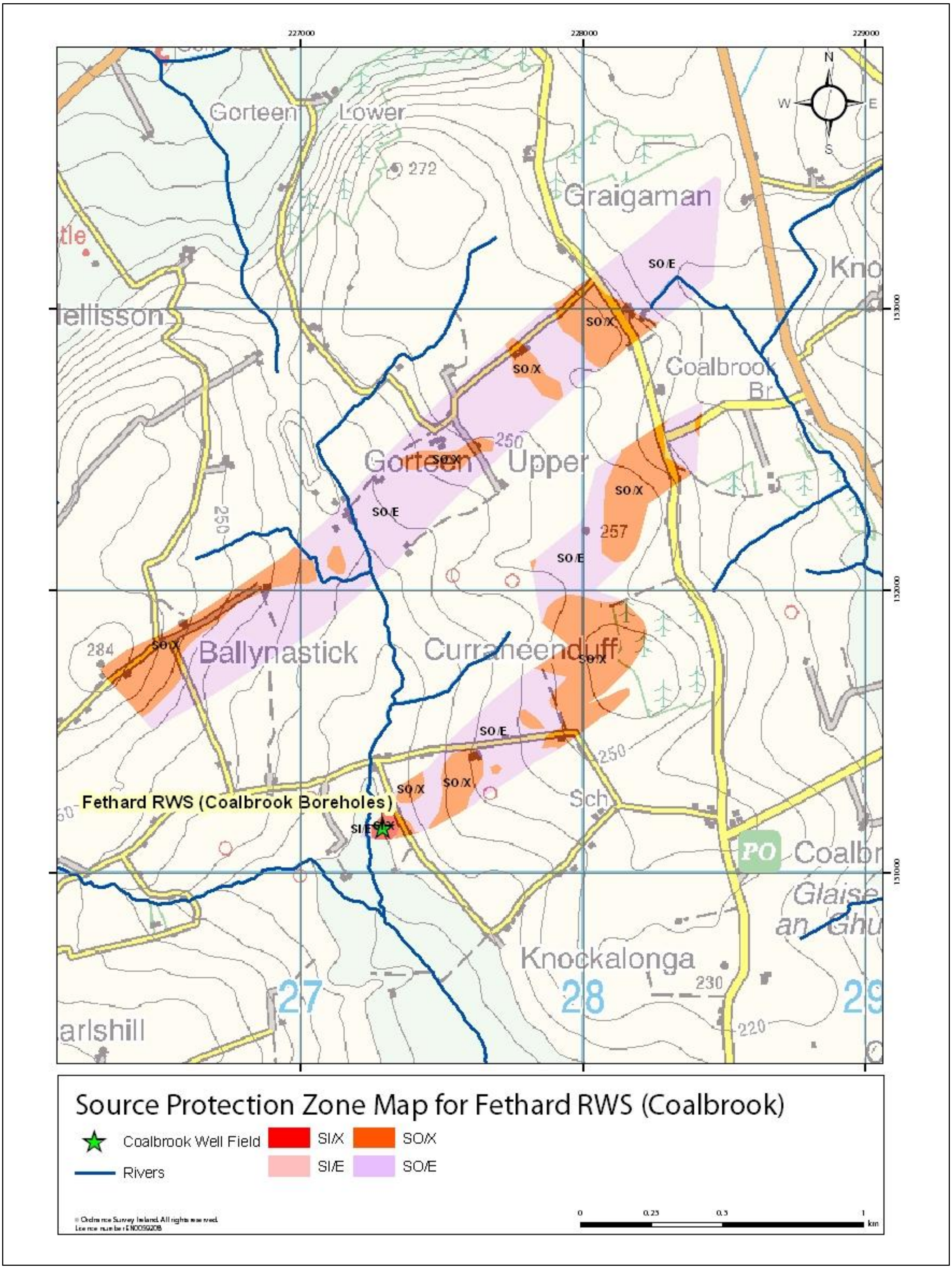

Figure 15: Source Protection Zones

12 Potential Pollution Sources

This Section has been compiled based on site observations and a "Source Risk Investigation Report" compiled by South Tipperary County Council, Environment Section in 2009. A copy of the report is included in Appendix 3.

The well field is located in a fenced and locked compound and the ground surface comprises granular fill with some areas of grass. With the exception of BH-4, each well is located in lockable, steel, rectangular container placed on a concrete base. Well No 4 is located in a concrete block walled chamber. Based on the site inspection it appears that none of the boreholes are grout sealed but a steel casing has been driven to the top of bedrock. Given the protection of the boreholes and their location, the potential risk for contamination as a result of surface spills in the vicinity of the well heads is moderate.

The land use in the Inner Source Protection Area is primarily pastureland for grazing animals. The main potential microbial pollution sources are considered to be the presence of cattle grazing in the field surrounding the compound. The compound fence is not in good condition and it is possible for cattle on adjacent lands to enter the site. Cow dung was observed on the ground within the site during an OCM site inspection in June and previously by STCC Environment Section. Faecal coliforms have only been detected in the untreated water twice at low levels. While the primary aquifer is considered to be confined at the source, there is the potential for pollution close to the wells heads from animal manures. Given the predominantly Extreme vulnerability within the Inner Source Protection Area and possible dewatering of the upper sandstone units in the summer time, the potential risk from cryptosporidium and viruses is moderate.

The majority of land within the rest of the ZOC is agricultural grassland and the dominant farm activity is dairy farming. There are two farmyards within the source protection zone. The closest farmyard is 165 m to the north, and contains a slatted shed for wintering suckler cows and cattle. The farmer also out-winters cattle in the field adjoining the Coalbrook site. The Council indicates that there have been issues with run-off from this yard polluting the river in the past though there is no reported impact on the groundwater. The other farmyard is 380 m to the north north-east but has not been used for wintering cattle for the past 15 years. The possible impacts to the water quality of the public supply associated with these activities within its Outer Source Protection Area are elevated levels of ammonia, nitrate, phosphate, chloride, potassium, BOD, COD, TOC and pesticides. However the groundwater quality monitoring conducted to date has not identified significant impacts.

There are two, third class road in the north and the east. The main potential contaminants from these are surface water runoff contaminated with hydrocarbons and metals. However, the low traffic density locally indicates that the risk of such contamination is low.

There are 15 individual private dwellings located in the ZOC which are served by individual wastewater treatment systems. The Council has been in contact with all householders within 250 m of the well field regarding the location of the drinking water source and the importance of protecting it from pollution.

In summary, given the nature of the activities within the outer zone and the generally good water quality, the potential risk of contamination is low.

13 Conclusions

The Fethard RWS Water Supply (Coalbrook) is provided by five boreholes (BH1 to BH-5) located in a fenced compound which also houses the water treatment works. The boreholes abstract water from two units (Upper Group II and Lower Group I) within the Westphalian sandstone aquifer, which is characterised by the GSI as *a Locally Important Aquifer that is Moderately Productive (Lm)*. The bulk of the water is obtained from BH-4 and BH-5, which were installed in 2006/7 and appear to obtain water primarily from the Lower Group I rocks. Pumping in BH-1, 2 and 3 has resulted in the gradual dewatering of the upper Group II unit and may not be sustainable. Dewatering may also be resulting in oxidation and consequently clogging of the fractures in the shallow Group II sandstones with iron.

The overall yield from the well field declined in 2010 as a result of leakage in the water pipe network at the site and the reduced rainfall recharge over the spring and summer of 2010. The groundwater vulnerability with the ZOC is Extreme. With the exception of naturally occurring iron and manganese, the water quality is generally good.

Groundwater flow to BH-1, 3, 4 and 5 is considered to result from recharge to the confined sandstone aquifer units where these outcrop or come close to the surface to the north and east of the well field. A ZOC area for the confined well field encompasses an area of 1.18 km^2. Groundwater flow to BH-2 is considered to derive from unconfined shallow groundwater flow primarily from the topographic catchment to the northeast of the well. A ZOC area for BH-2 encompasses an area of 0.127 km^2 .The Source Protection Zones are based on the current understanding of the groundwater conditions and the available data. Additional data obtained in the future may require amendments to the protection zone boundaries

14 Recommendations

The following actions are recommended:

- The leaks in the on-site system water delivery network should be identified and repaired as soon as possible to ensure sustainability of supply and unnecessary waste of the resource.
- The wells should be more frequently chlorinated and the well screens pressure cleaned to remove bacterial slime build up and where possible iron or manganese precipitation. This type of treatment will improve well efficiency and increase yields provided it is regularly undertaken (i.e. every six months).
- The compound fencing should be repaired to prevent access by animals grazing in adjacent lands.
- A cryptosporidium filter should be fitted to the treatment system.

15 References

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APPENDIX 1

Groundwater Investigations Slieve Ardagh Hill (E.P. Daly, GSI, 1980)

Report on Groundwater Development at Curraheenduff, Coalbrook, (K.T. Cullen & Co, 1991).

Eugene Daly
19. 3. 1980.

II. GROUNDWATER INVESTIGATIONS

II.1 Criterion used for the selection of a drilling site

The north and northwestern side of the hills are more elevated (Figure 4), hence the sandstones will outcrop at higher elevations on this side than on the south and southeast side. As a result the general direction of groundwater movement in the sandstones will be from northwest to southeast. Hence only sites on the southeastern sides of the synclines were considered for possible locations.

Other criterion used to select a location for the boreholes were:

(1) The Earlshill basin was not considered, as a borehole TY 49/34 which is located in this syncline penetrated the full Westphalian succession below the Earlshill Main Coal and produced a good quantity of water.

(2) It was not considered wise to locate the boreholes in areas where there had been recent coal mining, as it might impair the quality of the water.

(3) It was only intended to drill the Upper sandstone (Main Rock Sandstone), as drilling the lower sandstone would probably have doubled the cost and not provided much additional information.

(4) It was intended to tap the sandstone where it would be confined and where the nearest outcrop of the sandstone was at least 250m away, to avoid boundary conditions occurring during a short pumping test.

(5) It was decided not to drill on a fault as anonymously high yields could be expected in this type of location.

/...

(6) It was not intended to drill more than 90m.

The best fit to these conditions occurs in the Knockabritta-Ballingary Syncline. Hence a site was chosen in the townland of Springfield northeast of the Ballincurry Post Office (Figure 1). This site is about 300m from the nearest outcrop and 130m from the position of a mapped fault. Normally the site would have been chosen in the bottom of the river valley, where the sandstones could be expected to be artesian. However it was known from previous coal exploration boreholes that there is over 20m of superficial deposits in the valley bottom at Springfield. Hence it was decided to move up the side of the valley to a site about 15m above stream level where it was anticipated the overburden thickness would not be as great.

II.2 Well drilling and construction

The two boreholes at Springfield were drilled with a Bucyrus-Erie 22 cable tool drilling rig operated by the Irish Land Commission. Samples of the drill chippings were taken every two to three metres. The boreholes were bailed continuously for one to two hours at various depths to assess the yield and clean out the borehole. The production well (TY 55/65) was cased with 203mm steel casing and the observation well (TY 55/66) with 178mm p.v.c. casing. In both boreholes the casing was grouted in, and a small concrete pad one metre square, laid at the surface. In August 1978, an Ott R16 automatic recorder was fitted to borehole TY 55/65.

Borehole TY 49/34 was one of eight boreholes drilled in the Slieveardagh Coalfield as part of an exploration programme for coal (Johnstone 1937) in the mid-1930's. The borehole was drilled with a diamond core drilling rig by Andrew Coyle Limited of the United Kingdom.

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The borehole was supposed to have been plugged when completed. However this was obviously unsuccessful as there has been an artesian discharge of at least 30 cubic metres per day ever since. The borehole is now blocked at a depth of 109.3 metres. Steel casing was used in the borehole and it is not badly rusted. This borehole is probably in poor condition and may become unstable in the future particularly under pumping conditions.

For further details of the construction of these boreholes see Tables XII, XIII and XIV in Appendix A.

II.3 Borehole Geology

The boreholes at Springfield (TY 55/65 and TY 55/66) encountered a succession of interbedded sandstones, shales and siltstones (Table XII and XIII Appendix A). The sandstone met at 41.2m (TY 55/65) and 45.1m (TY 55/66) is considered to be the Main Rock Sandstone. It consists of fine grey and green sandstones which are friable and also micaceous in places.

The sandstone in these boreholes is considerably thicker than was anticipated. In a section of the Ballincurry Colliery, Hardman (1881) shows the Main Rock Sandstone to be 11.6m. The log of borehole D (Table XV, Appendix A) located 1.8 kilometres from the drilling site (Figure 1) shows the Main Rock Sandstone underlain by 1.7m of sandy shale and then by 3.7m of sandstone. The geophysical well logs of this borehole show that the borehole strata is not as sandy at about 53m. Hence what I have called the Main Rock Sandstone may infact be two sandstones with a sandy shale in between (see Section II.4.2). The Main Rock Sandstone is also at a greater depth than anticipated and hence the Upper Glengoole coal seam.

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This may indicate that the faulting on the east side of the drill site is more complicated than appears on the geological maps.

Bit penetration was fast although the steel drilling bits did wear quite rapidly. When the boreholes penetrated the Main Rock Sandstone the standing water level dropped from 2.7m to 8.3m (TY 55/65) and from 3.4m to 6.4m (TY 55/66). Recharge occurred while the observation well (TY 55/66) was being drilled. This accounts for the higher water level in this borehole. The water in both the upper and lower sandstones in these boreholes is confined.

Borehole TY 49/34 encountered a succession of sandstones, shales, coal seams and fireclays. A copy of the detailed lithological log as described by Johnstone is given in Table XVI (Appendix A). The Main Rock Sandstone (159.11 - 165.12m) is described as a grey sandstone with quartz strings, whereas the Glengoole Sandstone (175.72 - 192.10m) is described as a quartose sandstone. Other significant sandstone units were met at 23.9m, 41.2m and 103.5m.

II.4 Geophysical Well Logs

II.4.1 Introduction:

Geophysical well logs were run in boreholes TY 55/65 and TY 49/34 with the Geological Survey logging unit. A short note on well logging is attached as Appendix B.

II.4.2 Borehole TY 55/65

The single point resistance and natural gamma log accurately give the thickness of the main units (Figure 5). Between 52.4m and 54.3m there is a reduction in the resistance values, which is not due to the presence of the fissure as is the case with the two sections immediately above and below this zone, and a corresponding increase

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occurs on the natural gamma log. This could indicate the presence of a less sandy unit between two sandstone units as explained previously in Section II.3. From the caliper and fluid velocity logs (Figures 5 and 6) it can be seen that this lower sandstone unit (54.3m - 57.6m) is fissured and does contribute flow, hence it is considered to be part of the aquifer.

The caliper log (Figure 5) shows that fissuring is confined to the sandstone units i.e. 12-19m and 41-57m with the exception of the fissure in the shale at 28m.

The fluid temperature log (Figure 6) shows that the water moving down the borehole to the pump comes from the strata (fissure) at 28m and that the majority of the water moving up the borehole comes from a zone between 43 and 52m. There is a difference in water temperatures of .4°C between the water from the two zones.

The fluid velocity logs (Figure 6) shows water moving towards the pump with the exception of water in the upper sandstone which is moving up the borehole at this stage of pumping. When these logs were run the pump had only just been turned on and the conditions would almost certainly reverse as the pumping time increases.

II.4.3 Borehole TY 49/34

The main sandstone units are clearly shown on resistance and natural gamma logs (Figure 7). Both electrical logs detect the coal, fireclays and carbonaceous shales.

The caliper log (Figure 7) shows the poor condition of this borehole. Some sections have caved in e.g. around 97m (coal seam) and in other places strata has been squeezed out into the borehole as a result of pressure from the overlying strata e.g. at 46.9m and at 79.0m. A fissure was detected in the sandstone at 47m. The temperature log (Figure 7) shows that the water discharging from the borehole under

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artesian conditions is derived from the sandstone above 48m i.e. there is almost no gradient down to this depth. Water in the zone below 70m has a normal temperature gradient and hence water is not moving in this zone. Between 48m and 68m there is a small gradient and this may indicate that water from the sandstone (41.2 - 49.4m) is moving down the borehole. It is difficult to analyse the fluid velocity logs (Figure 7) as they appear to contradict the interpretation derived from the temperature log. The high line speed of 12 metres/minute relative to low artesian discharge may account for this. Nonetheless from these two types of logs it can be said that the sandstone (41.2 - 49.4m) is producing water and that the obstruction blocking the hole at 109.3m is unlikely to prevent the movement of water up the borehole from the principal sandstone units under pumping conditions.

II.5 Pumping Tests

II.5.1 Pumping Operations:

Pumping tests were run on both boreholes. The Geological Survey pumping unit, which consists of a trailer mounted generator and Grundfos submersible pump, was used for the test on borehole TY 55/65, whereas a mains operated submersible pump was used for the test on borehole TY 49/34. In both cases discharge was to small streams close to the boreholes which were known to be unconnected hydraulically to the aquifers. Water level measurements were made with an Ott electrical contact gauge and also with an Ott R16 automatic recorder which was installed on the observation well TY 55/66 at Springfield. Discharge rates were measured with a water meter, controlled by a gate valve and checked with a large barrel and stop watch.

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The testing procedure included a step test followed by overnight recovery, on the first day and followed by a continuous test and recovery. It was not possible to do more than three steps on TY 49/34 because of a shortage of time and on borehole TY 55/65 to avoid damaging the pumps. The data collected during these tests is given in Appendix C.

II.5.2 Analysis and Interpretation (TY 55/65)

The observation well (TY 55/66) is located 30m from the production well (TY 55/65). Both boreholes fully penetrate the Main Rock Sandstone and also a thin sandstone close to the top of both boreholes. Both sandstone units are confined and unsteady state condition exist during pumping. The water levels in the observation and production wells at the start of pumping operations were 9.1m and 7.8m respectively.

A short bailer test was run on the production well on completion of drilling in September 1977. After 60 minutes with a discharge rate of 81.8 cubic metres per day there was a drawdown of 1.28m. Measurements were taken of the recovery (Figure 19, Appendix C).

The drawdown data for the first step of the step test is plotted on Figure 20 (Appendix C). The semi log plot of the observation well data gives values of 16.2m^2 per day and 3.7 x 10^{-4} for transmissivity and storage coefficient. The lower limit U of the exponetial integral does not become less than or equal to 0.01 until "t" (time) is greater than or equal to 0.5 days. Hence, this data is not used in getting average values for the aquifer parameters.

The latter stages of the continuous pumping test gives a good fit to the theis curve (Figure 8). The poor fit of the data during the early part of the test is probably due to the effect of the upper sandstone which becomes dewatered during the test. The semi log plots are similarly affected (Figure 21, Appendix C). The values obtained

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for the aquifer parameters by these two methods are shown on Table III. On the semi log plots it should be noted that the slope and shape of both the observation and production well curves is the same. The difference between the two curves of 1.7m is primarily due to the d drawdown resulting from well losses in the production borehole.

The water level in the observation well had recovered to within .45m of the original water level after 7480 minutes. The middle section of the residual drawdown curve (Figure 9) is taken for transmissivity calculations as it is considered to be a more accurate reflection on the aquifers recovery. It should be noted that the residual drawdown curve does not pass through the origin. This probably results from the change in storage during the pumping test.

To use the Jacob Recovery Method (Johnstone 1966) the drawdown and recovery data for the continuous test are plotted on arithmetic paper (Figure 22, Appendix C). Values for calculated recovery are obtained by subtracting the extended drawdown from the residual drawdown for various time intervals. Calculated recovery is then plotted against time since pumping stopped (Figure 23, Appendix C) to obtain the aquifer parameters.

A summary of the details of the tests carried out, and the results obtained are given on Table III. Average values of 9.7m^2 per day and 4.6×10^{-4} are taken for transmissivity and storage coefficient.

II.5.3 Analysis and Interpretation (TY 49/34)

This borehole fully penetrates four significant sandstone units (Table XVI, Appendix A). An obstruction at 109.3m blocks the borehole to scientific instruments (15-50 mms in diameter), and seperates the two major aquifers from the three minor ones. Without this obstruction these aquifers would behave as a multiaquifer system, however the addition of the blockage further complicates the analysis.

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The yield of 1,357m^3/day achieved with a drawdown of 28.9m (after 120 minutes) during the third step of the step test (when the sandstone at 23.9 - 30.3m was largely dewatered) is considered too large for the sandstone between 41.2 and 49.4m to produce. Hence, it is concluded that the two principal sandstone units are supplying a significant quantity of the water pumped at this discharge rate, and that the obstruction does not prevent the flow under pumping conditions. This is confirmed by the analysis of depth samples taken from the upper part of the borehole (see Section II.7).

The sandstone units are confined and had a small artesian discharge prior to pumping. Unsteady state conditions existed during pumping.

The early part (up to 10 minutes) of the log log drawdown curve for the continuous test fits a leaky artesian type curve (Figure 10). The middle portion (20 - 500 minutes) approximates the mid-section of a Boulton type curve (although delayed yield cannot be a factor here). However the last three points on the drawdown curve at 1585, 1748 and 2891 minutes seem to indicate the influence of a recharging boundary (i.e. the development of unconfined storage in the sandstone at 23.9m).

The semi log drawdown plots of the first step of the step test and that of the continuous test (Figures 24, and 25 Appendix C) show the complicated nature of the response of the various sandstone units to pumping. It is clear from these plots that as the discharge and drawdown are increased the proportion of total discharge supplied by any one sandstone unit changes. It is probably that the contribution of the sandstones below the obstruction increases with time and higher discharge rates.

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In the light of the above discussion only the transmissivity value of 101.8m^2/day, derived from the residual drawdown plot (Figure 11) is considered to be valid. The large zero drawdown intercept of this curve is evidence of the recharge which resulted from the rainfall which fell (15.5 mms measured at Drangan rainfall station, 8-11 January 1978) before and during the test which began on the 11 January.

The differing thicknesses of sandstones present in the two boreholes (22.6m in TY 55/65, and 41.2m in TY 49/34) does not explain the difference, by a factor often between the transmissivity values. It is considered that relatively high transmissivity in the Glengoole Sandstone is primarily responsible for this difference.

II.5.4 Step Drawdown Tests

As stated previously (Section II.5.1) it was only possible to carry out three steps on each well, hence the results obtained in the subsequent analysis can only be considered approximate. This is particularly true in the case of borehole TY 49/34 where the initial water level is unknown due to a small artesian flow.

The plots of the data obtained during the step drawdown tests of boreholes TY 55/65 and TY 49/34 are shown on Figures 12 and 26 (Appendix C) respectively. The data derived from these plots for subsequent use in the analysis are shown in tabular form on these figures. The values for specific drawdown (S_W/Q) and discharge (Q) are then plotted (Figures13, Appendix C) to obtain the two components of drawdown for the equation;

$$S_W = BQ + CQ^2 \quad \text{(Jacob 1946)}$$

where
- BQ = aquifer loss
- CQ^2 = well loss
- Q = discharge
- S_W = drawdown in the production well for a pumping period (t), equal to the length of the steps in the test.

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Two values for the well loss factor (C) can also be obtained using the equation developed by Jacob (1946);

$$C = \frac{(S_W^{i}/Q^{i}) - (S_W^{i-1}/Q^{i-1})}{(Q^{i-1} + Q^{i})}$$

where S_W = drawdown increment
Q = discharge rate increment.

and the data tabulated on Figure 26 (Appendix C) for borehole TY 49/34. This latter type of analysis cannot be applied to the borehole at Springfield (TY 55/65) as the initial two discharge rates of the test were less than 193m^3/day (Walton 1970).

The results of both types of analysis are shown on Table V. The value of C for steps 1 and 2 is greater than that for steps 2 and 3. This suggests that the well is unstable (Walton 1970) and in fact may indicate that more water is getting through the obstruction as the pumping rate is increased.

With the above drawdown equation a plot is drawn to show the theoretical drawdown (after 120 minutes), for various pumping rates, for each borehole (Figures 14 and 28, Appendix C). The drawdown thus obtained are in reasonable agreement (± 10%), with those actual drawdowns (120 minututes) recorded during the continuous tests. It should be noted that the aquifer loss factor (B) for TY 55/65 is an order of magnitude greater than that for TY 49/34 (Table V) whereas the reverse is true for transmissivity.

Well efficiency is defined as the ratio of the theoretical drawdown computed by assuming that no turbulence is present (i.e. BQ) to the drawdown in the well (Rorabaugh, 1953). Well efficiency curves for the two wells are shown on Figure 14. It is not possible to make a direct comparison between these two wells because of the

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the difference in transmissivity, well depths (frictional losses) and the number of aquifers penetrated. However it is readily apparent from these curves and the known condition of borehole TY 49/34 that there is scope for the reduction of the well loss factor (C) and hence the well losses.

II.5.5 Safe Yield

Although the tests above indicate that both wells can produce certain discharge rates over the period of the test they do not show that these rates can be sustained or increased over an extended period, nor whether the drawdown at the end of this period can meet a number of conditions which are necessary to prevent large well losses, damage to the borehole and pumping installation and an uneconomic pumping regime. The pumping tests do however provide the necessary information to predict the safe yield over an extended period.

In this part of Ireland the non-recharge period is normally less than 150 days (216,000 minutes). Although the amount of water produced will be small in relation to the overall resource (see Section III.4) it is necessary to ensure that the abstraction rate, over the non-recharge period from each borehole, does not result in excessive drawdown.

The details of the safe yield calculations and the conditions necessary to meet the requirements discussed above, for both boreholes, are given in Appendix D. The boreholes at Springfield and Curraheenduff have safe yields of 360m^3/day and 900m^3/day, respectively.

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II.6 Well Hydrographs

Since August 1978 the Geological Survey has maintained an Ott R16 automatic water level recorder on borehole TY 55/65. A number of manual measurements were made during the period between the completion of drilling and the installation of the recorder. Measurements are also taken in the observation well (TY 55/66).

The well hydrograph since the completion of drilling is shown on Figure 16 and a detailed hydrograph with daily rainfall totals (at Drongan rainfall station) for the 1979 Hydrometric year are shown on Figure 17. During this period (September '78 to March '80) the piezometric surface has varied from a maximum of 167.3m O.D. to a minimum of 161.73m O.D. (i.e. 3.05m to 8.33m below the recorder zero which is .3m above the well head). By exptrapolating the groundwater recession for 1979 over a non-recharge period of 150 days it is estimated that the piezometric surface would drop to 160.5m O.D. (9.5m below the well head).

Analysis of the recorder charts has shown that when the soil is at field capacity the piezometric surface responds to recharge within 36 hours and that the response ceases within 48 hours of the cessation of the recharge event (Figure 17). This confirms observations made by O'Brien (1951) in which he notes an increase in flow 12-48 hours after heavy rain, in workings 76m below ground. In areas where mining has been extensive both rapid recharge and discharge of water is facilitated by shafts, drainage addits etc.

The specific yield for the Main Rock Sandstone is estimated from the rainfall, evapotranspiration and change in the hydrograph associated with a number of recharge events using the following equation;

$$\text{Specific Yield} = \frac{\text{Rainfall - Evapotranspiration (estimated)}}{\text{Rise in the Hydrograph + an estimate of the fall due to drainage}}$$

The results are shown in Table VI, and give an average value of 1.3×10^{-2} for the specific yield.

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II.7 Hydrochemistry

The chemical analysis of the waters from the two boreholes (TY 55/65 and TY 49/34), the Gloune Drainage Level at Commons and a borehole drilled into a flooded mine shaft at Copper, are shown on Table VII. The waters are calcium and magnesium bicarbonate waters although those at Springfield and Curraheenduff also contain a small quantity of sodium bicarbonate. The magnesium content in these waters is higher than that in Castlecomer. The levels of manganese are high in all four waters whereas iron is only present in the mine waters.

Water samples were taken at four depths in borehole TY 49/34, under artesian conditions and the analyses are shown on Table VIII. These analyses show that under normal conditions most of the flow is coming from the sandstone between 41.2 and 49.4m and that the water in the borehole below this unit is stagnant and allows ion exchange between calcium/magnesium and sodium/potassium to take place. The depth samples picked up quantities of iron slime and iron precipitate which explains the high iron values in the analyses. These iron bacteria would have built up over the long period during which the borehole was relatively inactive. The shales and ironstones in the borehole wall would provide a readily available source of iron. However under pumping conditions the quantity of iron is negligible (Table VII). The differences between the water at 45m and that obtained during pumping are significant and confirm the view that water from below the blockage at 109m is contributing water under discharging conditions.

The saturation indices suggest that the water from borehole TY 55/65 is likely to be slightly incrusting with respect to $CaCO_3$, whilst the Gloune Drainage Level (Ballingary Water Supply) water will be quite corrosive.

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The waters from the boreholes at Springfield and Curraheenduff and hence the two principal sandstone units are moderately hard with high manganese. They are considered to be potable and probably would be considered to be superior to the present Ballingary Water Supply. However the two other waters indicate that boreholes drilled close to the areas with recent mining activity are likely to be less suitable. As most of the mining in this coalfield has been in the Upper Glengoole seam, problems with water quality are most likely to arise in the Glengoole Sandstone which underlies this coal seam.

Samples for carbon 14 analysis were taken from the boreholes at Springfield and Curraheenduff. The analyses (Table IX) show that both waters are modern in age and indicates that water rapidly moves through the system, as suggested by the transmissivity, chemical data and the structure.

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APPENDIX D

Calculation of the safe yield for boreholes TY 55/65 and TY 49/34.

Calculation of safe yield for boreholes TY 55/65 and TY 49/34

In borehole TY 55/65 the Main Rock Sandstone is encountered at a depth of 41.2m. Hence, the pumping level should be kept above 41m at all times to maintain the aquifer in a confined state close to the borehole. From the well hydrograph (Figure 17) it is estimated that the piezometric surface under normal conditions at the end of a 150 day non-recharge period would be approximately be 9.5m below the well head (150.5m O.D.). Hence the available drawdown for this period is 31.5m. The drawdown at time (t) equal to 216,000 minutes (150 days) for the discharge rate of 253.8m^3/day can be obtained from the formula;

(216,000 minutes) = (216 minutes) + 3 s

where (216 minutes) = drawdown after 226 minutes on the time drawdown curve

s = slope of the time-drawdown curve per log cycle

3 = number of log cycles

and the time drawdown curve (Figure 21, Appendix C) for the production well and is equal to 21.38m. Hence the discharge rate can be increased to utilise this unused available drawdown of over 10m.

To estimate the discharge rate associated with a drawdown of 31.5m (after 216,000 minutes) an analysis similar to the above is carried out using the formulas:

$$_{sy} = Q_{sy} + 3.2553 \quad Q_{sy}$$

$$Q_{sy} = \frac{2.3 \quad Q_{sy}}{4 \quad T}$$

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and where

sy	=	the drawdown produced after 216,000 minutes, when the discharge rate is equal to the safe yield (Q_{sy})
Q_{sy}	=	the drawdown after 120 minutes discharge at the safe yield and taken from the drawdown yield curve (Figure 14)
Q_{sy}	=	the slope of the time drawdown curve when the discharge rate is equal to the safe yield
T	=	transmissivity (the value of $9.55m^2$/day is being used here, as it is considered to be more applicable).

and substituting various values of Q_{sy} into these formulae until a value for is found which is close to the available drawdown of 31.5m. This method gives a discharge rate of $365m^3$/day for a drawdown of 31.4m.

This result can be verified by using the Jacob modification of Theis equation i.e.

$$= \frac{2.3}{4\ T} \log \frac{2.25\ T\ t}{r^2\ S}$$

where		=	drawdown in the observation well at a distance r from the production well at time t.
	T	=	transmissivity ($9.55m^2$/day)
	t	=	150 days
	r	=	distance between observation and production wells (30m)
	S	=	storage coefficient (3.3×10^{-4})

and the relationship between the drawdown in the production and observation wells to predict the safe yield. By estimating the drawdown in the observation well (TY 55/66) it is possible to solve the above equation for Q. The difference in the drawdowns in the

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two wells at the same yield is equal to the well loss in the production well at that discharge rate plus the difference in the aquifer loss. The value for well loss can be read from Figure 13. The difference due to aquifer loss has to be estimated from a comparison of the values obtained from the two time drawdown plots (Figures 20 and 21, Appendix C) and those predicted by the theoretical drawdown us discharge plot (Figure 13). In this case it is taken to be .4 times the well loss. Hence it is estimated that a drawdown of 27.6m in the observation well corresponds to the available drawdown of 31.5m in the production well after a period of 216,000 minutes. Substituting this value for s in the above equation gives a safe yield of 357m^3/day.

Furthermore by rearranging the modified Theis equation to

$$2 \log r = \frac{\log 2.25\, Tt}{s} - \frac{4\ \ T}{2.3\ \ Q}$$

and letting s approach zero it is possible to calculate the approximate radius of the cone of depression after a non-recharge period of 150 days. At a constant discharge of 360m^3/day and assuming no boundary conditions. This gives a value of approximately 2,300m for r. However before the cone of depression reaches this size a recharge boundary (the development of unconfined storage in the outcrop area) will be encountered first in the south and then in the north. This will reduce the rate of expansion of the cone. As the cone expands beyond the outcrop of the sandstone (particularly to the south) the cone of depression will expand at a faster rate. It is likely that these two effects will cancel each other out and not effect the drawdown or discharge significantly.

It has been mentioned previously that borehole TY 49/34 is considered to be unstable. Hence as the water level decreases under pumping conditions, turbulance will increase and the borehole walls will loose the support of the column of water. As a result the borehole will become more unstable and caving will become more likely.

Due to the frequent change in the slope of the time-drawdown curve (Figure 25, Appendix C) of this borehole, it is not possible to calculate the drawdown after 150 days with a discharge of $1113 m^3$/day. It is estimated that the drawdown would be between 32 and 38m. While this borehole remains in its present condition it is recommended that the pumping level be kept above the level of the highest sandstone i.e. 24m. This condition could be achieved with a discharge rate of $900 m^3$/day.

The state of this borehole could be improved by seeming it out to its original diameter and by treating it with chlorine to remove the iron and slime forming bacteria which have built up on the borehole walls (see Section II.7). This should result in higher output and a reduction in well losses and pumping costs. It is also recommended tnat the well be cased down to the level of the pump to protect the installation. The casing should be slotted opposite the sandstone units. Any of the modern type of plastic well casing will be adequate for this purpose. The performance of this borehole over time should be monitored at intervals by conducting step tests

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III. GROUNDWATER DEVELOPMENT, RESOURCES AND CONCLUSIONS

III.1 Factors pertinent to development

(a) For the purposes of groundwater development the Westphalian sandstones can be divided into two groups i.e. the two principal sandstone units (Glengoole and Main Rock Sandstones) which occur almost throughout the coalfield (Group I), and those thinner sandstones (Group II) which occur frequently in that part of the succession which extends from just beneath Pat Maher's vein to the top of the sequence (see Tables I and XVI). It is only in the centre and southwestern part of the Earlshill Syncline that the outcrop area of the Group II sandstones is extensive enough for them to be a significant resource.

(b) With the exception of the Glengoole Sandstone in the southwestern part of the coalfield, the sandstones within the two groups are seldomly seperated by more than 40m. Hence, in general the boreholes should penetrate all the sandstones in the group to minimise drilling costs and obtain a reasonable yield (500-1,000m^3/day) without excessive drawdown (less than 30m). This procedure will make aquifer management difficult, especially in the case of the Group I sandstones. However, these problems can be circumvented by adequate well testing prior to production, continuous monitoring during production and by the construction of observation wells in which the piezometric surface in both sandstones in the group can be measured.

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(c) As a result of the synclinal structure, the topography and in particular the steep dip of the strata in the Earlshill syncline and the southwest portion of the coalfield it is possible to develop both groups and yet site the boreholes within a reasonable distance (500-750m) of each other (Figure 18). Furthermore as the river valleys in this area are normally perpendicular to the axis of the synclines, boreholes can be connected by pipelines following these valleys. Hence, the boreholes can be developed as a wellfield with centralised surface installations.

(d) Large scale mining operations, in the last forty years, have been mainly confined to the Upper Glengoole Seam and have been concentrated in the north and eastern part of the coalfield. These operations are likely to have a deleterious effect on the groundwater in these areas. On the northwestern side of the Earlshill syncline, around Gorteen (Figure 1) where mining has been extensive, the Upper Glengoole Seam lies just above the Glengoole sandstone. Hence the water in this sandstone, in this area will probably not be potable.

(e) In this country most boreholes are less than 90m deep and 250mms in diameter. Hence it is recommended that boreholes do not exceed 150m as the plant and drilling expertise are generally not available.

(f) Boreholes tapping the same group of sandstones should be located about 1500m apart, where practical, to avoid significant interference.

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III.2 Well Construction

Boreholes tapping these aquifers should be drilled at 250mms in diameter 3m into bedrock and continued at 200mms to the pump setting and then reducing to 150mms for that portion below the pump. Steel casing, 200mms in diameter should be used and grouted into the bedrock.

In an area such as this where there has been considerable small scale mining, it is always a possibility that boreholes will encounter old mine workings particularly near the surface. If the workings are not too deep (less than 20m) it should be possible to seal them off with casing and concrete grout. In areas where this is a possibility the boreholes should be drilled to a depth of 30m with a diameter of 300mms.

As mentioned previously (Section III.1(b)) the observation wells should be constructed so that changes in the piezometric surface, in both sandstones penetrated by the production borehole can be monitored during pumping. This can be done simply by plugging the borehole between the two sandstones and running a narrow diameter pipe through the plug. The observation wells should be drilled through bedrock with a diameter of 150mms. Significant savings in the cost of the observation wells could be made by siting them updip and several hundred metres from the production wells.

If it is considered to be more economic to develop both sandstone groups at the one location then it would be necessary to drill two production boreholes and seal off the upper group in the deeper borehole. This could be achieved by drilling a

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wide diameter borehole (300mms) through the upper sandstones and sealing them off with casing which has been grouted in with concrete.

III.3 Suggested locations for Groundwater Development

In each of the synclinal groups the sandstone units can be developed subject to the specific constraints mentioned in Sections III.1 and the more general criterion stated in Section II.1. The details of the various areas selected for development are given in Table X and their locations are shown on Figures 1 and 3.

Boreholes drilled close to faults should have higher yields than normal, whilst the yields of boreholes in the Group II sandstones will be lower than those in the sandstones of Group I.

In the Coolquill area (Figure 1) which is mainly upland the Main Rock Sandstone is close to the surface and hence would not be suitable for large scale development. However it should be possible to get a small supply (up to $200m^3$/day) from the sandstones equivalent to the Glengoole Sandstone. There are also a few areas where similar supplies could be obtained by tapping one sandstone unit e.g. the Main Rock Sandstone around Ballingemy Lower, and the Glengoole Sandstone at Newpark (Figure 1).

Domestic and farm supplies should be obtained at most reasonable locations although boreholes may have to be up to 90m deep in some places.

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III.4 Groundwater Resources

The sandstone units in the Westphalian of the Slieveardagh Hills are relatively thin hence the areas over which the outcrop has to be estimated from the dip and structure of the strata. This introduces a considerable source of error into the calculations of effective rainfall.

In a recent report (Wright et al 1979) the author calculated the recharge to be 1.68Mm^3/yr (4600m^3/day). This only took account of the recharge area for the Group I sandstones on the perimeter of the coalfield. However it is now known (Section I.3) that these sandstones came to the surface in the centre of the coalfield. Effective rainfall (resources) of 2.63Mm^3/yr (7200m^3/day) and .34Mm^3/yr (930m^3/day) for the Group I and II sandstones are now considered to be as accurate an estimate of groundwater resources that can be obtained with the information available at present.

By extrapolating the low flows measured by O'Brien (1951) and Ball (1972) for the Gorteen and Ballingarry Collieries, values of 6.8Mm^3/yr (19076m^3/day) and 4.77Mm^3/yr (13045m^3/day) are obtained for the groundwater resources. Hence the value given above of 2.97Mm^3/yr (8130m^3/day) for the two sandstone groups may slightly underestimate the resources.

If development proceeds, the estimate of the resources can be improved by continuous monitoring of the discharge and water levels throughout the year.

If the resource of .34Mm^3/yr (930m^3/day) for the Group II sandstones is correct it will be necessary to reduce the number of boreholes tapping this group by one (i.e. the borehole at site 4).

/...

The cost of adequately drilling, testing and supervising the work necessary to bring this resource into production would be of the order of £140,000.

III.5 Conclusions

The two principal sandstone units, the Glengoold Sandstone and the Main Rock Sandstone which are correlated with the Clay Gall Sandstone and the Swan Sandstone of the Castlecomer Plateau, are also the two most important aquifers in the Slieveardagh Hills.

O'Brien pers comm suggests that the Castlecomer Plateau may have been subjected to more intense pressure than the Slieveardagh Hills, whereas the opposite is true in the case of folding. This probably accounts for the higher transmissivities of the sandstones in the Slieveardagh Hills.

The resource of 2.97Mm^3/yr (8130m^3/day) is relatively small in national terms, however it assumes greater importance when one considers that there is no readily available surface source in the area. Two further advantages are the elevation (160-240m, O.D.) of the suggested development locations which should be of considerable benefit to the distribution system and the fact that the resource can be developed in stages as demand increases.

IV. ACKNOWLEDGEMENTS

The author would like to acknowledge the assistance of H. McEvoy of the Irish Land Commission and S. O Breasail of Tipperary County Council.

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TABLE I

WESTPHALIAN SUCCESSION IN THE SLIEVEARDAGH HILLS AT EARLSHILL COLLIERY (HARDMAN 1881)

FORMATION	ROCK TYPES	Thickness (m)
Parkenaclea Coal	Shales and Sandstones	11.9
	coal	1.2
	shales, fireclays and coal	11.1
	sandstone	14.6
Clashacona Coal	coal	.4
	shales and fireclay	9.1
Hanleys Vein	coal	.4
	shales and fireclay	20.1
	sandstone	6.9
Earlshill Crow Coal	coal	.5
	shales, sandstones and fireclay	38.4
Earlshill Main Coal	coal	.6
	shales, sandstones and fireclay	72.2
Pat Maher's Vein	coal	.2
	shales, sandstones and fireclays	73.5
Main Rock Sandstone	sandstone	6.9
	shale	8.2
Upper Glengoole Coal	coal	.5
	fireclay	1.5
Glengoole Sandstone	sandstone	32.0
	shale	18.3
Lower Glengoole Coal	coal	.3
	TOTAL:	328.9

TABLE VII

CHEMICAL ANALYSES OF FOUR WATERS FROM THE WESTPHALIAN STRATA IN THE SLIEVEARDAGH HILLS

BOREHOLE NUMBER AND LOCATION	TY 55/65 GALLINCURRY	TY 49/34 CURRAHEENDUFF	GLOONE DRAINAGE LEVEL, COMMONS	BOREHOLE INTO SHAFT AT COPPER BALLINGORY
pH	7.1	7.3	6.4	6.9
Total dissolved solids(mg/l)	283	222	143	340
Total hardness(as $CaCO_3$) "	225	168	92	288
Total alkalinity " "	237	[illegible]	76	216
Calcium " "[mg/l]	170 [3.4]	98 [1.921]	54 [1.08]	168
Magnesium " " "	55 1.1	70 1.40	38 0.76	120
Sodium " "	18.8 0.82	12.5 0.544	6.3 0.27	
Potassium " "	1.3 0.03	5.5 0.141	1.6 0.04	
Manganese " "	0.2 0.01	0.35 0.025	0.3 0.02	.5
Bicarbonate " "	289 4.74	214.72 3.52	92.7 1.52	
Chloride " "	17 0.48	15 0.423	12 0.34	27
Nitrate (as N) " "	1.4 0.10	0.67 0.048	0.7 0.05	1.5
Sulphate " "	2.0 0.04	-	13 0.27	
Iron " "	NIL	NIL	.6	4.0
Free and Saline ammonia (as N) "	0.04	-	0.084	
Electrical Conductivity (Ec) at 25° C (mhos)	394.3			
Redox Potential (Eh) mu	400			
Calcium carbonate saturation Index	.15	.035	- 1.31	- 0.075
Date Sampled	8/7/'78	12/1/'78	[illegible]	8/8/'72
Laboratory	State Lab.	State Lab.	State Lab.	Mahon & McPhillips

TABLE VIII

CHEMICAL ANALYSES OF DEPTH SAMPLES FROM BOREHOLE TY 49/34 AT CURRAHEENDUFF, COUNTY TIPPERARY

Date of Sampling	18/7/'77	18/7/'77	18/7/'77	18/7/'77	18/7/'77
Depth at which sample was taken	Surface	26m	45m	70m	106m
pH	7.4	7.4	7.45	7.3	7.3
Total dissolved solids (Mg/lit)	219	217	210	195	186
Total hardness (as Ca CO_3) "	169	163	162	137	129
Total alkalinity " "	171	172	170	161	164
Total iron "	0.25	53.3	61.5	12.5	8.3
Manganese "	0.3	0.2 [0.015]	0.3 [0.022]	-	- [0.025]
Calcium (as Ca CO_3) (mg/lit) [Meg/lit]	109 [2.136]	106 [2.078]	107 [2.097]	97 [1.901]	82 [1.607]
Magnesium " " "	60 [1.200]	57 [1.140]	55 [1.100]	40 [0.800]	47 [0.940]
Sodium " "	12.0 [0.522]	12.0 [0.522]	12.0 [0.522]	14.5 [0.630]	19.5 [0.848]
Potassium " "	6.3 [0.161]	6.3 [0.161]	6.3 [0.162]	9.1 [0.212]	9.1 [0.233]
Bicarbonate " "	208.62 [3.420]	209.84 [3.440]	207.4 [3.400]	196.42 [3.220]	195.2 [3.280]
Chloride " "	16 [0.451]	16 [0.451]	17 [0.479]	16 [0.451]	14 [0.395]
Sulphur " "	-	-	-	-	-
Nitrate (as N) " "	0.51 [0.036]	0.83 [0.059]	0.91 [0.065]	0.74 [0.052]	0.7 [0.050]
Sediment	Noticable brown deposit	slightly reddish	noticable dark brown	slight brown	slight dark brown deposit
Odour	NIL	NIL	NIL	NIL	NIL
Electrical Conductivity (Ec) at 25° (mhos)	426 (July '78)	389	404	345	321
Redox Potential mv	150				

TABLE V

THE RESULTS OBTAINED FROM THE STEP-DRAWDOWN TESTS ON BOREHOLES TY 55/65 AND TY 49/34 IN THE WESTPHALIAN SANDSTONES OF THE SLIEVEARDAGH HILLS.

BOREHOLE NUMBER	$sw = BQ + CQ^2$		$c = \dfrac{(sw^i/Q^i)-(sw^{i-1}/Q^{i-1})}{(Q^{i-1} + Q^i)}$		SAFE YIELD	PUMPING EFFICIENCY
	B	C	C 1 - 2	C 2 - 3	m^3/day	
TY 55/65	1.6×10^{-2}	2.0×10^{-5}	-	-	300	.92
TY 49/34	1.5×10^{-3}	1.5×10^{-5}	1.5×10^{-5}	1.1×10^{-5}	900	-

TABLE VI

CALCULATION OF SPECIFIC YIELD FOR THE MAIN ROCK SANDSTONE FROM THE HYDROGRAPH OF BOREHOLE TY 55/65.

PERIOD	RAINFALL mms.	ESTIMATE OF EVAPOTRANSPIRATION mms	EFFECTIVE RAINFALL	RISE IN HYDROGRAPH	ESTIMATE OF FALL IN HYDROGRAPH DUE TO DISCHARGE (m)	TOTAL RISE IN HYDROGRAPH	SPECIFIC YIELD
21/11/'78-27/11/'78	58.2	7	51.2	3.45	.1	3.55	.014
21/12/'78-28/12/'78	108.7	0	108.7	1.14	1.6	2.74	.04 *
17/2/'79-23/2/'79	21.4	4	17.4	.48	1.3	1.78	.01
23/3/'79-28/3/'79	27.1	7	20.1	.66	1.4	2.06	.01
9/4/'79-117/4/'79	37.7	11	26.7	.93	1.375	2.31	.012
21/11/'79-28/11/'79	29.2	1	28.2	.86	.70	1.56	.018

* Not used to calculate the average, as considerable surface runoff probably resulted from the heavy rainfall.

TABLE

DETAILED GEOLOGICAL LOG OF BOREHOLE TY 49/34 AT CURRAHEENDUFF, CO. TIPPERARY (Johnstone 1937).

BOREHOLE NUMBER*	LOCATION	DATE COMPLETED	GRID REFERENCE	SURFACE ELEVATION	STRATA DIP
TY 49/34	CURRAHEENDUFF COALBROOK, CO. TIPPERARY	Jan. '37			10°

Depth below ground level(m)			Lithology	Formation
0	-	2.21	Soil and gravelly clay	
2.21	-	5.9	Sandy shale	
5.9	-	6.5	Shale	
6.5	-	7.62	Coal and fireclay	Main Coal
7.62	-	8.23	Sandy fireclay	
8.23	-	22.10	Sandy shale	
22.10	-	22.33	Shaly sandstone	
22.33	-	23.01	Sandy shale	
23.01	-	23.32	Shaly sandstone	
23.32	-	23.93	Sandy shale	
23.93	-	30.28	Sandstone with quartz strings	
30.28	-	34.67	Sandy shale	
34.67	-	35.74	Black shale	
35.74	-	41.22	Sandy shale	
41.22	-	49.38	Green and brown sandstone	
49.38	-	50.37	Shaly sandstone	
50.37	-	53.65	Shale with sandstone bands	
53.65	-	60.06	Sandy shale	
60.05	-	78.56	Shale	
78956	-	82.75	Sandy shale	
82.75	-	96.24	Shale	
96.24	-	97.46	Fireclay	Pat Maher's Vein (?)
97.46	-	103.45	Sandy shale	
103.45	-	107.75	Sandstone with quartz strings	
107.75	-	109.42	Shale with sandstone partings	
109.42	-	115.37	Sandy shale	
115.37	-	122.53	Shale	

/...

TABLE contd.

Depth below ground level(m)	Lithology	Formation
122.53 - 138.15	Sandy shale	
138.15 - 139.37	Shaly sandstone with shale bands	
139.37 - 152.48	Sandy shale	
152.48 - 154.76	Shale with thin ironstone bands	
154.76 - 157.20	Sandy shale	
157.20 - 159.11	Shaly sandstone	
159.11 - 165.12	Grey sandstone with quartz strings	Main Rock Sandstone
165.12 - 169.01	Sandy shale	
169.01 - 169.62	Coal	Upper Glengoole Seam
169.62 - 171.53	Fireclay	
171.53 - 172.52	Sandy shale	
172.52 - 172.97	Sandstone	
172.97 - 173.89	Sandy shale	
173.89 - 175.72	Sandy shale with sandstone bands	
175.72 - 192.10	Quartose sandstone	Glengoole Sandstone
192.10 - 194.16	Sandy shale	
194.16 - 216.48	Shale	
216.48 - 217.25	Sandy shale	
217.25 - 217.52	Coal	Lower Glengoole Seam
217.52 - 217.98	Fireclay	
217.98 - 219.05	Sandy shale with sandstone	
219.05 - 221.21	Sandstone	

* This borehole is referred to as NO. 3 in the Johnstone Report.

TABLE

GEOLOGICAL LOG OF BOREHOLE D AT BALLINCURRY, CO. TIPPERARY

BOREHOLE NUMBER D. (Johnstone Report 1937)	LOCATION BALLINCURRY, Co. Tipperary	DATE COMPLETED October 1936	GRID REFERENCE	SURFACE ELEVATION 508.72 m.o.d.	STRATA DIP 22°
Depth below Ground level (m)	**Lithology**	**FORMATION**			
0 - 1.5	Boulder clay				
1.5 - 4.7	Grey sandstone				
4.7 - 19.5	Shales and sandy shales				
19.5 - 21.3	Hard grey sandstone				
21.3 - 28.0	Shales and sandy shales				
28.0 - 34.7	Hard grey sandstone				
34.7 - 37.1	Grey sandy shale	MAIN ROCK SANDSTONE			
37.1 - 38.5	Hard grey sandstone				
38.5 - 40.2	Grey sandy shale				
40.2 - 43.9	Hard grey sandstone				
43.9 - 59.0	Shales and sandy shales				
59.0 - 59.4	Coal	UPPER GLENGOOLD COAL SEAM			
59.4 - 62.5	Fireclay				
62.5 - 107.2	Shales and sandy shales				

TABLE II

THE CORRELATION OF THE WESTPHALIAN SUCCESSION IN THE SLIEVEARDAGH HILLS WITH THAT OF THE CASTLECOMER PLATEAU
(AFTER HARDMAN, 1881; NEVILL 1957 and 1958 and EAGAR 1975)

SLIEVEARDAGH HILLS (Earlshill Syncline)	CASTLECOMER PLATEAU
Strata	Strata
Crow Coal Seam	Three Foot Coal Seam
Strata	Strata
Main Coal Seam	Jarrow Coal Seam
Strata	Strata
Pat Maher's Vein	Double Fireclay (approximate correlation) (See Eagar, 1975)
Strata	Strata
Main Rock Sandstone	Swan sandstone
Strata	Strata
Upper Glengoole Coal	Wards Seam
Strata	Strata
Glengoole Sandstone	Clay Gall Sandstone
Strata	Strata
Lower Glengoole Coal	No. II Coal
Strata	Strata
Namurian	No. I Coal
	Namurian

TABLE

GEOLOGICAL LOG OF BOREHOLE B AT KILMAHONE, COUNTY TIPPERARY (JOHNSTONE 1937)

BOREHOLE NUMBER	LOCATION	DATE COMPLETED	GRID REFERENCE	SURFACE ELEVATION	STRATA DIP
B. (Johnstone Report 1937)	Kilmahone, Mordyke, County Tipperary	June 1936		526.76 m.o.d.	33°

Depth below Ground level (m) (m)	Lithology	FORMATION
0 - 1.0	Boulder clay	
1.0 - 24.23	Shale	
24.23 - 27.81	Fireclay, coal and thin sandstone	Main Coal Seam (?)
27.81 - 55.63	Shales and sandstones	
55.63 - 56.24	Sandy fireclay with coal and spar balls	Pat Maher's Vein (?)
56.24 - 59.74	Hard sandstone	
59.74 - 98.76	Shales and sandstones	
98.76 - 106.22	Hard sandstone	Main Rock Sandstone
106.22 - 151.49	Shales and sandstones	
151.49 - 152.65	Coal and fireclay	Upper Glengoole Coal Seam
152.65 - 241.55	Shale with ironstone	
241.55 - 248.50	Hard fine grained sandstone	Glengoole Sandstone (equivalent)

TABLE IX

ANALYSES OF WATERS FROM THE SLIEVEARDAGH HILLS

BOREHOLE NUMBER	LABORATORY NUMBER	13 c (%)	SAMPLE ACTIVITY (S) c.p.m.	MODERN STANDARD ACTIVITY (M) c.p.m.	UNCORRECTED AGE (YEARS)	CORRECTED AGE (YEARS)
TY 55/65	Birm - 975	- 17.32	15.381 ± 0.095	20.103	2150 ± 100	modern
TY 39/34	Birm - 1014	- 15.6	7.259 ± 0.064	10.183	2720 ± 100	modern

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3.14.0.

APPENDIX B

Geophysical Well Logging

Geophysical Well Logging

Geophysical well logs were run in all of the boreholes. The equipment used was a Gearhart-Owen Porta-Logger, model PLA-PRG, number 101. The unit is mounted in a long-wheel base Land Rover. Six geophysical methods were used in this study: spontaneous potential, single-point resistance, natural gamma, caliper, fluid velocity and fluid temperature. The uses of these methods and the conditions under which the logs can be run are summarised on Table XVII.

Spontaneous potential (s.p.) logs are continuous records of the natural electrical potentials developed between the borehole fluid and the surrounding rock materials. The measurements are made through two lead electrodes: one stationary in the ground at the surface, and the other moving in the borehole.

Single point resistance logs are continuous measurements of the resistance of the strata lying between a moving electrode in the hole, and a ground electrode. The same lead electrodes are used for both s.p. and resistance measurements.

The natural gamma log is a continuous record of the intensity of gamma radiation emitted by all naturally occuring radio isotopes in geological strata. The measurement is made by scintillation crystal (sodium iodide) used in conjunction with a photomultiplier tube.

The three methods described above mostly provide geological information. In the s.p. and natural gamma logs movement to the right generally indicates increasing clay or shale content whereas movement to the left indicates high sand content. With resistance logs the movement of the trace is opposite to the above.

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TABLE XVII

USES, LIMITATIONS AND DETAILS OF GEOPHYSICAL LOGS USED IN THIS STUDY

PROBE	USES	BOREHOLE CONDITIONS	UNITS	LINE SPEED m/min	PROBE MOVING
Spontaneous Potential	Geological correlation, determination of bed thickness and detecting permeable zones.	Open hole fluid filled	Millivolts	5-6	Up the borehole
Single-Point Resistance	Geological correlation, determination of bed boundaries and changes in lithology and identifying fractures in resistive rocks.	Open hole fluid filled	Ohm metres	5-6	"
Natural Gamma	Identification of lithology and stratigraphic correlation.	Open or cased hole, dry or fluid filled	Counts per second	5-6	"
Caliper	Measuring hole or casing diameter. Locating fissures or wall collapse.	Open or cased hole, dry or fluid filled	inches	1	"
Fluid Velocity	Determining rate and direction of fluid movement up or down the hole. Locating points of water entry or loss.	Open or cased hole, fluid filled	Counts per second	3-12	Both directions
Fluid Temperature	Provides information on water movement and points of water entry.	Open or cased hole, fluid filled	Degrees centigrade	3	Down the borehole

Eugene Daly
24.6.80

TABLE II

THE DUNCANNON GROUP SUCCESSION IN FOUR AREAS IN THE SOUTHEAST REGION

	TRAMORE	DUNCANNON	ENNISCORTHY	COURTOWN
DUNCANNON GROUP	Upper Tramore Volcanic FormationFm. 1900m - rhyol rhyolites dykes and sills.	Campile Volcanic Formation 1000m rhyolites, intrusives	Raheenahoon Volcanic Formation 950m rhyolites, minor basalts and andesites, and interrelated sediments	Gorey Rhyolite Formation 400m rhyolites
	Garraun Shale Formation 100m Shales and tuffs	Ballyhack Formation 400m siltstones and mudstones Arthurstown Formation 400m siltstones and mudstones	Docnocney Formation 1700m shales, siltstones and greywackes	
	Middle Tramore Volcanic Formation 1900m rhyolites and minor andesites	Duncannon Volcanic Formation 320m andesites and dacites	Ballybrennan Volcanic member basalts and andesites	Balleymoney Formation 100m andesites and basalts
	Tramore Limestone Formation acid tuffs, shales and limestones		siltstones, shales and greywackes Unconformity	Ballinatray Formation Shales
END	Lower Tramore Shale and Volcanic Formation 1700m	Sandstones, siltstones, slates and some minor intermediate to basic volcanics		

Eugene Daly
24.6.80

TABLE III

THE OLD RED SANDSTONE SUCCESSION IN SIX AREAS IN THE SOUTHEAST REGION

CAPEWELL 1957			COLTHURST 1978	DREW 1970	AMBASSADOR OIL CORPORATION 1964
COMERAGHS	CENTRAL COMERAGHS	NORTH COMERAGHS	SLIEVENAMON	SLIEVE PHELIM	BALLYRAGGET, CO. KILKENNY
Kiltorcan Sandstone Group 305m	Kiltorcan Sandstone Group 305m buff, white and greenish sandstone with subordinate purple beds	Kiltorcan Sandstone Group 305m subordinate purple beds	Kiltorcan Formation 228m yellow sandstones, red, yellow and green mudstones	Cappagh White Sandstone Formation approx. 300m	50m thick at 1045m below G.L. sandstones, siltstones and mudstones
Nier Sandstone Group 580m purple, fine silty sandstones	Nier Sandstone Group 2135m purple, fine silty sandstones	Nier Sandstone Group 640m purple, fine silty sandstones	Carrigmaclea Formation 460m sandstones, pebbly sandstones, conglomerates	red and white, coarse, quartzitic sandstones, fine, red, micaceous, friable sandstones	
Comeragh Conglomerate Sandstone Group 75m	Comeragh Sandstone Conglomerate Group 335m fine silty sandstones, quartz-pebble conglomerates Coumshingaun Conglomerate Group 305m Conglomerates and Sandstones, unbedded cobble-conglomerates, siltstone and silty sandstones				

[redacted]

E.P. Daly
8.7.80

TABLE I

STRATIGRAPHIC SUCCESSION IN THE CASTLECOMER PLATEAU

PERIOD	SERIES	HYDROGEOLOGICAL UNITS	DOMINANT HYDROGEOLOGICAL CHARACTERISTIC	FORMATION	ROCK TYPES	THICKNESS (Metres)
Quaternary		1	Aquifer		Gravels, Sands, Clays	0-45
					Shales	50
				Three foot seam	Coal	1
			Aquitard		Shales and Sandstones	41-50
Upper Carboniferous		2		Jarrow seam	Coal	.3
	Westphalian				Shales with Sandstones	60-72
				Double Fireclay	Fire Clay	8-14
					Shales with Sandstones	0-50
		3	Aquifer	Swan Sandstone	Sandstone	0-28
		4	Aquitard		Shales	15-45
				Wards Seam	Coal	0-5
		5	Aquifer	Clay Gall Sandstone	Sandstone	2-58
				Black Rock	Shales	0-30
				Number II Coal Seam	Coal	3-13
		6	Aquitard		Shales	1-9
				Woodview Sandstone 0-38m	Shales, Siltstones with Sandstones	30-60
				Number I Coal Seam	Coal	1-3
	Namurian	7			Sandstone	60-180
					Shales	150-300
Lower Carboniferous	Dinantian				Limestone	

E. P. Daly
8.7.80

TABLE I

STRATIGRAPHIC SUCCESSION IN THE CASTLECOMER PLATEAU

PERIOD	SERIES	HYDROGEOLOGICAL UNITS	DOMINANT HYDROGEOLOGICAL CHARACTERISTIC	FORMATION	ROCK TYPES	THICKNESS (Metres)
Quaternary		1	Aquifer		Gravels, Sands, Clays	0-45
					Shales	50
				Three foot seam	Coal	1
			Aquitard		Shales and Sandstones	41-50
Upper Carboniferous		2		Jarrow seam	Coal	.3
	Westphalian				Shales with Sandstones	60-72
				Double Fireclay	Fire Clay	8-14
					Shales with Sandstones	0-50
		3	Aquifer	Swan Sandstone	Sandstone	0-28
		4	Aquitard		Shales	15-45
				Wards Seam	Coal	0-5
		5	Aquifer	Clay Gall Sandstone	Sandstone	2-53
				Black Rock	Shales	0-30
				Number II Coal Seam	Coal	3-13
		6	Aquitard		Shales	1-9
				Woodview Sandstone 0-38m	Shales, Siltstones with Sandstones	30-60
				Number I Coal Seam	Coal	1-3

K. T. Cullen & Co. Ltd.

Hydrogeological & Environmental Consultants.

Report on the Groundwater Development

at

Curraheenduff, Coalbrook,

County Tipperary

Kieran O'Dwyer 20 February 1991

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Report on the Groundwater Development at Curraheenduff, Coalbrook.

1. Introduction.

The Coalbrook area is presently served by two water well sources located in the Slieveardagh Hills. One at Curraheenduff and the other to the south at Ballincurry. The larger of these is the Curraheenduff source. The works and studies described in this report were commissioned by Tipperary County Council (South Riding). This report will describe the situation to date, the remedial work carried out on the existing well, the drilling and testing of a new well at the Curraheenduff site and recommend proposals to supply the present and projected demands of the Coalbrook area.

2. Situation to Date

The existing well (Production Well No.1) at Curraheenduff was drilled in 1937 as an exploration borehole to assess the coal deposits of the area. The well is drilled through Westphalian shales, sandstones, coal seams and fireclays. Subsequently this well was developed as a borehole supply by Tipperary County Council in the early 1980's. It is the sandstones in this succession that constitute the aquifers. In all, five sandstone units were intercepted during the drilling of Production Well No.1. It is the lower two of these that are considered to be the principal aquifers. The construction of this well is outlined below in Table No.1. It was tested by the Geological Survey of Ireland and the safe yield was quoted as 8250 gals/hour. Until recent summers the well performed satisfactorily.

V.A.T. Reg. No 1760772 H

Depth below ground level (m)	Description	Formation	Hole Diameter
0.00 - 2.21	Clay		
2.21 - 6.5	Shale		0.0 to 10.7 m @ 229 mm (201 mm steel casing to 4.5 m)
6.5 - 7.62	Coal	Main Coal	
7.62 - 23.93	Shales		
23.93 - 30.28	Sandstone with quartz strings		
30.28 - 41.22	Shales		
41.22 - 49.38	Green and brown sandstone		
49.38 - 103.45	Shales and fireclay		10.7 to 173.9 m @ 203 mm
103.45 - 107.75	Sandstone with quartz strings		
107.75 - 159.11	Shales		
159.11 - 165.12	Grey sandstone with quartz strings	Main Rock Sandstone	
165.12 - 169.01	Sandy shale		
169.01 - 169.62	Coal	Upper Glengoole Seam	
169.62 - 175.72	Shales		
175.72 - 192.10	Quartzose sandstone	Glengoole Sandstone	
192.10 - 217.25	Shales		173.9 to 221.2 m @178 mm
217.25 - 217.52	Coal	Lower Glengoole Seam	
217.52 - 219.05	Sandy shale		
219.05 - 221.21	Sandstone		

Table No.1 Geological Log of Well No.1 at Curraheenduff, Coalbrook.

The situation at Curraheenduff prior to this study can be summarised as follows.

a) The output from the existing Coalbrook well (PW No.1) at Curraheenduff was reported to have fallen off dramatically during the summer months of 1990 to the extent that the water supplies in the area had to be cut off during the night.

b) The pump was replaced and the probes checked and there was no improvement in the yield of the well.

c) The submersible pump intake was at a level of 54.86 metres below ground. This pump cannot be lowered any further due to the presence an old pump which broke off and is lodged down the well. In addition, there is 18 metres of riser pipe still connected to the pump. The obstruction or cave-in of the well is located at a level approximately 78 metres below ground level. This corresponds to a constriction in the well diameter indicated by the calliper log.

d) The main inflows to Coalbrook PW No.1 are from the sandstone units found within the coal measures and these occur at 24, 41, 103, 159, 175 and 219 metres.

e) Water samples from Production Well No.1 have regularly shown elevated levels of manganese and iron.

In the light of the critical summer time situation two measures were adopted. Firstly another production well would be drilled on the site and secondly the depleting yield of PW No.1 would be investigated and remedial steps undertaken. Prior to this study very little was known regarding the yield of PW No.1 apart from the work carried out by the Geological Survey in 1980. This report will describe the drilling of the new well (PW No.2), the possible reasons for the decrease in the well performance of PW No.1, the remedial work carried out on PW No.1, the pumping tests carried out at the site and will quantify the yields of each well.

3. Drilling of Production Well No.2

A decision was taken to drill a second production well (PW No.2) and this was carried out by Fogarty Brothers at the start of October 1990. At this stage the water supply to the Coalbrook scheme was in such a critical state that the supply was turned off during the night. It had been intended to drill this well to a depth of 212 metres to intercept all five of the major water bearing sandstone layers. PW No.2 was drilled at a distance of 24.7 metres from PW No.1 and the completed well design is shown in Figure No.1. The well was drilled at a diameter of 200 mm and was completed to a depth of 48 metres. Drilling could not be continued after 48 metres as the water bearing sandstone layer was extremely weathered and broken at this level causing the well walls to collapse. This weathered layer coincided with a major groundwater inflow. The original production well did not encounter such broken conditions as is evidenced by the fact that the rock was drilled entirely at an open hole diameter of 200 mm and no casing was required to support the well walls. Rather than install 150 mm steel casing which would limit the size of pump that could be installed in the well and limit the output to ≈ 3000 gals/hour it was decided to test the well as it was. If a production well completed to 212 metres is required then drilling will have to start at a much greater diameter to facilitate the installation of well casing to support the well walls. The standing water level in this well was recorded to be some 27 metres below ground level when Production Well No.1 was pumping on the 9 October 1990.

4. Rehabilitation of Production Well No.1

The output from the existing well (PW No.1) at the Curraheenduff site decreased dramatically over the summer of 1990 to the extent that the water supply to the area had to switched off at night. The reason for this is a combination of a number of factors. The rainfall for the summer of 1990 was considerably less than average with the exception of the month of June. Although this was below average it was still greater than the rainfall of the previous year (1989) but the effect of two dry summers in succession can be cumulative as the winter rains never fully replenished the aquifer. The details of the rainfalls recorded at Kilkenny for 1989 and 1990 are shown in Table No.2.

Completed Well Design

Trial Well No.1

Client : Tipperary Co. Co.
Project : Fethard RWSS
Location : Coalbrook
County : Tipperary
Date : October 1990
Driller : Fogarty
Aquifer : Coal Measures
Output : 307 m3/day
Specific Capacity : m3/day/m
National Grid : East
Co - ordinates : North

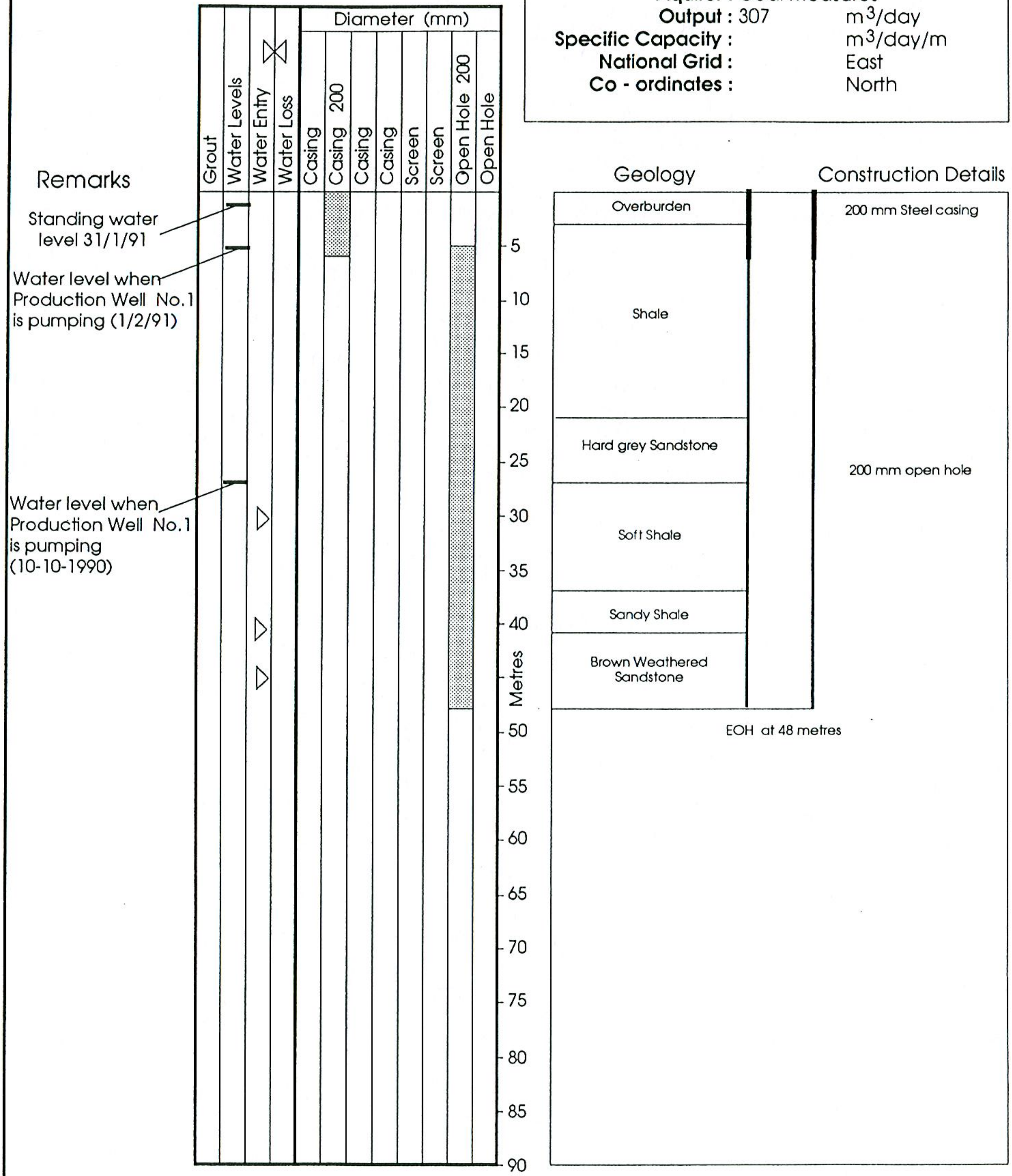

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Figure No.1

The elevation of the wells at Curraheenduff cause them to be susceptible to very rapid recharge and the seasonal fluctuation in the regional water table will be much greater than that for a well situated at a lower topographical level. The variation in the water level at Curraheenduff over 1990 was approximately 20 metres. It follows from this that the available drawdown in a pumping well will be reduced considerably.

Over the past years the water demand of the Coalbrook area will have increased as more consumers are added on to the system.

	1989		1990	
	Recorded Rainfall	% of Average	Recorded Rainfall	% of Average
January	48.7	55	97	99
February	74.6	124	156	260
March	83.3	146	14.6	26
April	57.2	110	34.8	67
May	17.3	27	26	41
June	51.6	51.6	91.1	194
July	7	12	42.4	72
August	125.6	190	53.8	82
September	36.9	45	45.8	56
October	93.6	113	134.7	162
November	50.8	66	55.7	72
December	107.8	107.8	95.7	104
Total	754.4		847.6	

Table No.2 Rainfall Recorded at Kilkenny for 1989 and 1990

There has been a history of high iron and manganese concentrations associated with Production Well No.1. It is common for wells with this problem to have a high build up of iron and manganese bacteria which will cause encrustation and form a slime on the well walls thus hampering the ability of water to flow into the well. This can be exacerbated when the water level in the well fluctuates considerably. The water cascades into the well as fissures become dewatered. The water becomes aerated which can cause the iron and manganese to precipitate and the walls of the well become coated with iron and manganese. Improvements in yield can be achieved through rapid chlorination coupled with development using compressed air which removes the wall coating.

The yield of the well was limited by an obstruction which prevented the pump from being lowered below 54 metres. This obstruction was an old pump attached to 18 metres of riser pipe. If this could be forced down the well then the extra available drawdown would allow the well to be pumped at a higher rate.

The remedial work consisted of two separate operations. Firstly efforts were made to remove the obstruction in the well and secondly the well was shock chlorinated which would result in an increase in available drawdown and an increase in transmissivity.

The pumping contractors who were installing the new pump in the well unsuccessfully attempted to extract the old pump which was lodged in the well. A drilling rig was then brought in and attempted to force the the pump to the bottom of the hole. However it only succeeded in clearing the hole to 72 metres below ground when the pump became firmly lodged and could not be forced down any further.

The well was then shock chlorinated in order to eradicate iron and manganese bacteria which are present in the well and are responsible for the undesirable slime that can hamper the flow into the well. To do this 65 litres of sodium hypochlorite (10 to 12 % chlorine) was introduced into the well, mixed thoroughly and allowed to stand for 4 hours and then blown out and pumped to waste. The blowing out with compressed air also cleared a lot of the encrustation caused by the precipitation of iron and manganese. A new pump was installed in the well with its intake at 72 metres below ground which amounts to 14 metres greater than before. The well was then pumped to waste for several days to remove any remaining chlorine. When these operations had been completed the output had visibly improved. It was not possible to quantify the improvement as the flowmeter on the well was subsquently discovered to be functioning incorrectly.

5. Pumping Tests

The only previous investigations into well yields at the Curraheenduff site was carried out in January 1978 by the Geological Survey of Ireland when Production Well No.1 was tested and its safe yield was calculated to be 8250 gals/hour .

Pumping tests were carried out as part of this investigation on two separate occasions. The first during October 1990 when the regional water table was close to its lowest level. It was discovered subsequently that the flowmeter on PW No.1 was malfunctioning and therefore the flow data had to be disregarded. A further set of tests were carried out at the end of January 1991 after the new flowmeters had been installed.

5.1 October 1990

A short duration pumping test was carried out on the recently drilled well (Production Well No.2) at urraheenduff, Co Tipperary on 9th and 10th of October 1990 when the regional ground water table is close to its lowest level. The time-drawdown is listed and shown graphically in Figure No.s 2 - 5 in the appendix. The results can be summarised as follows.

The water level in Production Well No.2 was 27.06 metres below ground when the existing borehole Production Well No.1 was pumping. The pump in the existing Production Well No.1 was reported to be at 57 metres below ground level at this time. Production Well No.2 was pumped for the first hour at a rate of 1350 gals/hour. The resulting drawdown after one hour was 2.96 metres which is equivalent to a water level of 30.02 metres below ground. Steady state conditions had almost been reached at this stage. This output was then increased to 2915 gals/hour. After a further 4 hours the drawdown was 7.64 metres (34.7 metres below ground). The water level was still dropping marginally at this stage. Throughout this period the existing well was pumping and the water level was down to the pump as evidenced by the amount of air entrained in the discharged water. Both pumps ran overnight and the following morning when the test was to be continued the pump in the existing well had cut off as the reservoir was full. Production Well No.2 was still pumping but its level had risen to 33.7 metres. PW No.1 was then restarted for a period of 1 hour in order to regain the water level in the PW No.2. The pump in PW No.1 was then turned off and the partial recovery in PW No.2 monitored for a period of 30 mins. Over the thirty minutes the well recovered by 1.25 metres. This shows that there is very little interference between the two wells.

The rate at which the existing PW No.1 was pumping is not known as it was discovered later that the flow meter was malfunctioning. The pumping level in this well was down to the pump intake at 57 metres.

The pump in Production Well No.2 cuts out when the water level is at 36.65 metres and cuts in again at 30.1 metres. The time between cut-out and cut-in was less than one minute during the test.

The conclusion to be made from this pumping test is that during the worst of the summer conditions Production Well No.2 is capable of yielding 2700 gals/hour in addition to that quantity being pumped from Production Well No.1.

5.2 January - February 1991

Another pumping test was carried out at the start of February 1991 and details are given in Figure No's 6 -17 in the appendix. The groundwater table at this stage had risen by over 20 metres. In fact Production Well No.1 was flowing under artesian conditions after both pumps had been switched off prior to conducting the test. The water level in PW No.2 when PW No.1 was pumping was 5.03 metres which clearly shows the difference from the summer situation when under the same pumping conditions the water level in PW No.2 was 27.26 metres.

The pumping tests were carried out in the following manner. Initially both pumps were turned off overnight and the wells allowed to recover. The following morning pumping commenced in Production Well No.1 (Fig No's 6 - 13). This well was then pumped for a period of 24 hours at a rate of 9360 gals/hour. It must be noted the pumping regime in operation at the Cuuraheenduff site is based on a 21 hour pumping day. The electricity is automatically switched off for three hours in the evening to avail of the cheap rate. The next day, PW No.2 was turned on and both wells pumped together for a further 24 hours. Production Well No.2 was then pumping at a rate of 5600 gals/hour and the combined output was 14300 gallons per hour. On 6 February 1991, Production Well No.2 was pumped alone for a period of 24 hours at a rate of 6360 gallons per hour (Figure No's 14 - 17).

The results of these tests are based on the winter water table conditions and can be summarised as follows;

i) Production Well No.1 pumping at a rate of 9300 gals/hour results in a drawdown of 46.6 metres and reduces the water level in Production Well No.2 by some 3.78 metres after 24 hours.
ii) Production Well No.2 pumping at a rate of 6360 gals/hour results in a drawdown of 20.14 metres in the pumping well and reduces the water level in PW No.1 by some 1.51 metres.
iii) The safe combined winter yield is estimated to be 15000 gals/hour (315000 gals per 21 hour day) based on the prevailing conditions at the time of testing.

It becomes more difficult to predict the outputs during a dry summer and this is compounded by the fact that the improvement in the the yield of Production Well No.1 was impossible to quantify. However based on the results of the February tests and the limited testing of October 1990 when it is assumed that the groundwater table was at its lowest the estimated yields are as follows;

a) Production Well No.1 will have improved since the remedial work. The seasonal water table fluctuation is of the order of 24 metres. The pump intake is now located at a level 14 metres lower than last October. An analysis of the data indicates that PW No.1 ought to be capable of yielding approximately 5500 gals per hour. Precise flow data from PW No.1 is unavailable for the critical stage of last summer. Therefore this prediction will have to be confirmed by careful monitoring of the output and water levels of PW No.1 during the coming summer months.
b) PW No.2 is capable of yielding 2600 gals per hour during the critical summer period.
c) The combined output from the Coalbrook site during drought conditions has been increased by approximately 84000 gallons per day.

6. Hydrochemistry

The groundwater abstracted from the Coalbrook site regularly shows elevated levels of iron and manganese. In order to improve the quality of the water a rudimentary iron and manganese removal system has been employed. This consists of aerating the water by cascading over a series of steps in order to promote the precipitation of iron and manganese and thus reduce the concentration prior to its distribution through the mains. The shock chlorination of Production Well No.1 was designed to kill any iron and manganese bacteria that may have been exacerbating this problem. A water sample collected after this operation was forwarded for chemical analysis (13/11/90). The results are listed in Table No.3 and show that all the parameters are below the maximum admissible concentrations (M.A.C.) as defined by the E.C. directive on water intended for human consumption. The iron and manganese concentrations in a pumped groundwater can fluctuate over a period of time. However the fact that the concentrations are below the E.C. M.A.C. would tend to suggest that the chlorination was beneficial. This improvement is often only temporary as the bacteria will repopulate over a period of time. A further sample collected on 31 January 1991 has shown that both the iron and manganese concentrations had increased considerably. The manganese concentration in this sample was over ten times the E.C. maximum. This could be due to either normal fluctuations or the repopulation of the iron and manganese bacteria. Regular monitoring of these concentrations over time will present a clearer picture.

A sample was also collected from PW No.2 (8/10/90) and showed concentrations of manganese and zinc which exceeded the M.A.C. The results of this analysis are shown in Table No.4. The manganese concentration is only marginally in excess of the maximum. The elevated level of zinc is unusual and is probably related to the galvanised piping attached to the pump which had not been pumped for some time prior to sampling. A sample collected on 1 February 1991 shows little change in these concentrations, in fact there is an overall reduction in their levels. The level of zinc is much lower as was anticipated and does not present a problem as long as the the well is pumped on a regular basis. The consistent levels of iron and manganese would seem to indicate that the the new production well does not have an iron and manganese problem to the same degree as Production

PARAMETERS	UNIT	PRODUCTION WELL No. 1		POTABLE Water M.A.C.
		13-11-90	31-1-91	
Calcium	Ca mg/l	52.4		200
Magnesium	Mg mg/l	19.2		50
Sodium	Na mg/l	-		150
Potassium	K mg/l	-		12
Bicarbonate	HCO3 mg/l	88		---
Sulphate	SO4 mg/l	-		250
Chloride	Cl mg/l	15		250
Ammonium	NH4 mg/l	0.15		0.3
Nitrate	NO3 mg/l	0.4		50
Nitrite	NO2 mg/l	< 0.01		0.1
Copper	Cu mg/l	0.03		0.5
Iron	Fe mg/l	0.04	0.17	0.2
Manganese	Mn mg/l	0.04	0.66	0.05
Zinc	Zn mg/l	0.01	0.05	1
T.O.C	C mg/l			---
pH	units	7.4		6 - 9
Hardness	CaCo3 mg/l	210		>60
Colour	mg/l Pt/Co	5		20
Turbidity	F.T.U.	-		4
Conductivity	µS/cm	459		1,500
Alkalinity	CaCo3 mg/l	72		>30
Coliforms	MPN/100 ML	0		0
E - coli	MPN/100 ML	0		0
Plate Count @ 37 C	COL/ML	No Increase		No significant increase above background level
Plate Count @ 22 C	COL/ML	No Increase		

M.A.C. = Maximum Admissable Concentration under E.C. directive (No.80/778/E.C.)

Chemical Analysis of groundwater at Production Well No.1, Coalbrook.

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NOTE : N.E. = Not Examined
N.D. = None Determined
< = Less Than

Table No.3

PARAMETERS	UNIT	PRODUCTION WELL No.2		POTABLE Water M.A.C.
		13-11-90	1-2-91	
Calcium	Ca mg/l	54.4		200
Magnesium	Mg mg/l	7.3		50
Sodium	Na mg/l	10.2		150
Potassium	K mg/l	4.1		12
Bicarbonate	HCO3 mg/l	226		---
Sulphate	SO4 mg/l	22		250
Chloride	Cl mg/l	19		250
Ammonium	NH4 mg/l	0.04		0.3
Nitrate	NO3 mg/l	1.8		50
Nitrite	NO2 mg/l	0.02		0.1
Copper	Cu mg/l	0.03		0.5
Iron	Fe mg/l	0.05	0.04	0.2
Manganese	Mn mg/l	0.09 *	0.06	0.05
Zinc	Zn mg/l	1.46 *	0.17	1
T.O.C	C mg/l	-		---
pH	units	7.5		6 - 9
Hardness	CaCo3 mg/l	166		>60
Colour	mg/l Pt/Co	10		20
Turbidity	F.T.U.	4		4
Conductivity	µS/cm	431		1,500
Alkalinity	CaCo3 mg/l	185		>30
Coliforms	MPN/100 ML	2 *		0
E - coli	MPN/100 ML	0		0
Plate Count @ 37 C	COL/ML	No Increase		No significant increase above background level
Plate Count @ 22 C	COL/ML	No Increase		

M.A.C. = Maximum Admissable Concentration under E.C. directive (No.80/778/E.C.)

Chemical Analysis of groundwater at Production Well No.2 , Coalbrook.

K.T.Cullen & Co. Ltd.
Hydrogeological & Environmental Consuhtants

NOTE : N.E. = Not Examined
N.D. = None Determined
< = Less Than

Table No.4

Well No.1. The iron manganese problem may well be related to lower sandstone layers that are tapped in PW No.1 but not in PW No.2. If this is the case a blend of the two well waters would result in a net decrease in the iron and manganese concentrations. A sampling programme should be initiated in order to monitor the fluctuation of these iron and manganese concentrations. Samples should be collected every six weeks for the next six months and every two months after that.

7. Summary and Conclusions

a) The well drilling and testing programme at Curraheenduff has been successful in providing an additional 84000 (c. 381 m3/d) gallons per day at the Curraheenduff site during the drought periods. This additional capacity was achieved in spite of the fact that PW No.2 was unable to be completed to its target depth due to the unstable sandstone formation encountered at 41 metres.

b) The combined winter yield when the groundwater table is high is over 300,000 gallons per day. (c. 1363 m3/d)

c) The remedial work carried out on the existing well PW No.1 succeeded in increasing its yield and the pump intake is now some 14 metres lower at 69 metres.

d) Another well drilled to 212 metres at the Curraheenduff site would be capable of yielding quantities in excess of those presently available from the shallow PW No.2. The unstable bedrock conditions encountered in PW No.2 would necessitate the installation of casing throughout the entire depth of the hole.

e) The information available from the chemical analyses to date would suggest that a shallower borehole (similar to PW No.2) intercepting the higher sandstones would have lower concentrations of iron and manganese.

f) Despite the two wells being only 24 metres apart there is very little interference between them. When PW No.1 is pumping its water level is some 47 metres below ground. The effect of this on PW No.2 is to lower the water level by only 4 metres. If more water is required then another well can be developed within the Coalbrook site itself. This well should be located as far from the other two production wells as is possible within the confines of the site.

g) The water levels together with the output from the individual wells at the Curraheenduff site should be monitored weekly throughout the coming year. If the coming year is also very dry the aquifer may not fully recover and the cumulative effect may result in the outputs being less than predicted.

h) The chemical quality of the two wells is generally good. The only parameters giving any cause for concern is the iron and manganeseand to a lesser extent the zinc. The iron and manganese concentrations in PW No.1 have increased considerably since last November. The manganese concentration is over ten times greater than the maximum permissible. This is due to either the effects of the chlorination wearing off or a natural fluctuation. PW No.2 however appears to have more consistant levels and this could be due to the fact that only the upper sandstone layers have been intercepted. The elevated zinc level which has decreased is probably due to the galvanised riser pipe and the lack of pumping of PW No.2 prior to sampling. This will not be a problem if the well is pumped regularly for lengthy periods.

i) In order to develop a picture of the fluctuation in iron and manganese concentrations it is recommended that samples be forwarded for analysis every 6 weeks for the next 6 months and every two months after that. The effectiveness of the shock chlorination can then be assessed.

j) The wells should be shock chlorinated at least twice a year to remove iron and manganese bacteria which cause caking on the well walls and inhibit the flow of water into the wells. Blowing out the well with compressed increases the effectiveness of this remedial operation. Following chlorination the well should be pumped to waste until the residual chlorine has reached an acceptable level.

Appendix I

Pumping Test Data.

October 1990

Note. Both Production Wells Pumping.

TIME (mins.)	WATER LEVEL below G.L. (m.)	DRAWDOWN (metres)	YIELD (m3/day)
0	27.06	0	147
0.5	28.06	1	
1	28.6	1.54	
1.5	28.95	1.89	
2	29.13	2.07	
2.5	29.24	2.18	
3	29.37	2.31	
3.5	29.45	2.39	
4	29.53	2.47	
4.5	29.58	2.52	
5	29.64	2.58	
7	29.75	2.69	
8	29.78	2.72	
9	29.81	2.75	
10	29.85	2.79	
12	29.89	2.83	
14	29.92	2.86	
16	29.93	2.87	
18	29.95	2.89	
22	29.97	2.91	
29	29.99	2.93	
30	29.99	2.93	
35	30	2.94	
40	30	2.94	
45	30.01	2.95	
50	30.02	2.96	
55	30.02	2.96	
60	30.02	2.96	318
61	31.76	4.7	
61.5	32.23	5.17	
62	32.59	5.53	
63	33.03	5.97	
65	33.48	6.42	
66	33.62	6.56	
67	33.72	6.66	
68	33.79	6.73	
69	33.87	6.81	
72	33.99	6.93	
74	34.05	6.99	
76	34.1	7.04	
78	34.14	7.08	
80	34.17	7.11	
82	34.2	7.14	
84	34.21	7.15	
88	34.25	7.19	
90	34.27	7.21	
95	34.29	7.23	

Figure No.2 Time Drawdown Data from Short Test on Production Well No.2, Coalbrook. 9/10/90

Note. Both Production Wells Pumping.

TIME (mins.)	WATER LEVEL below G.L. (m.)	DRAWDOWN (metres)	YIELD (m3/day)
100	34.3	7.24	
105	34.33	7.27	
110	34.35	7.29	
115	34.39	7.33	
120	34.42	7.36	
135	34.43	7.37	
150	34.47	7.41	
189	34.59	7.53	
210	34.62	7.56	
240	34.66	7.6	
300	34.7	7.64	

Figure No.2 Time Drawdown Data from Short Test on Production Well No.2, Coalbrook. 9/10/90

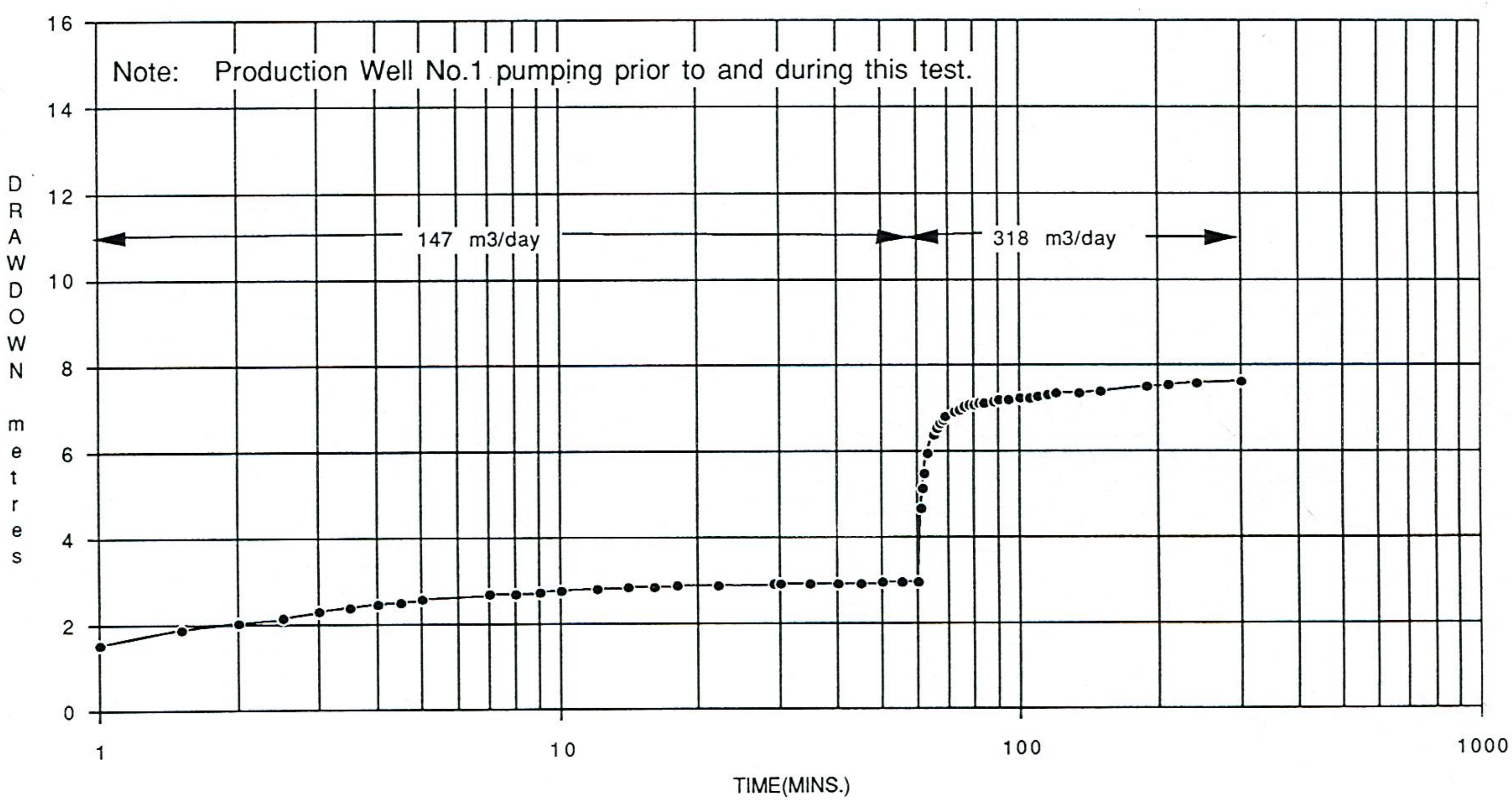


FIGURE NO.3 TIME DRAWDOWN GRAPH FROM SHORT YIELD TEST ON PRODUCTION WELL NO.2, COALBROOK. 9/10/1990

TIME (mins.)	WATER LEVEL below G.L. (m.)	DRAWDOWN (metres)	YIELD (m3/day)
0	34.83	7.77	318
1	34.81	7.75	
1.5	34.75	7.69	
2	34.66	7.6	
2.5	34.56	7.5	
3	34.47	7.41	
3.5	34.4	7.34	
4	34.31	7.25	
4.5	34.25	7.19	
5	34.18	7.12	
6	34.09	7.03	
7	34.01	6.95	
8	33.95	6.89	
9	33.89	6.83	
10	33.85	6.79	
14	33.73	6.67	
16	33.7	6.64	
20	33.65	6.59	
26	33.59	6.53	
28	33.59	6.53	
30	33.58	6.52	

NOTE: PUMP TURNED OFF IN PW NO.1 AT TIME ZERO
PW NO.2 PUMPING CONTINUOUSLY

Figure No.4 Time Drawdown Data from PW No.2 After Pumping Halted in PW No.1. 10/10/90

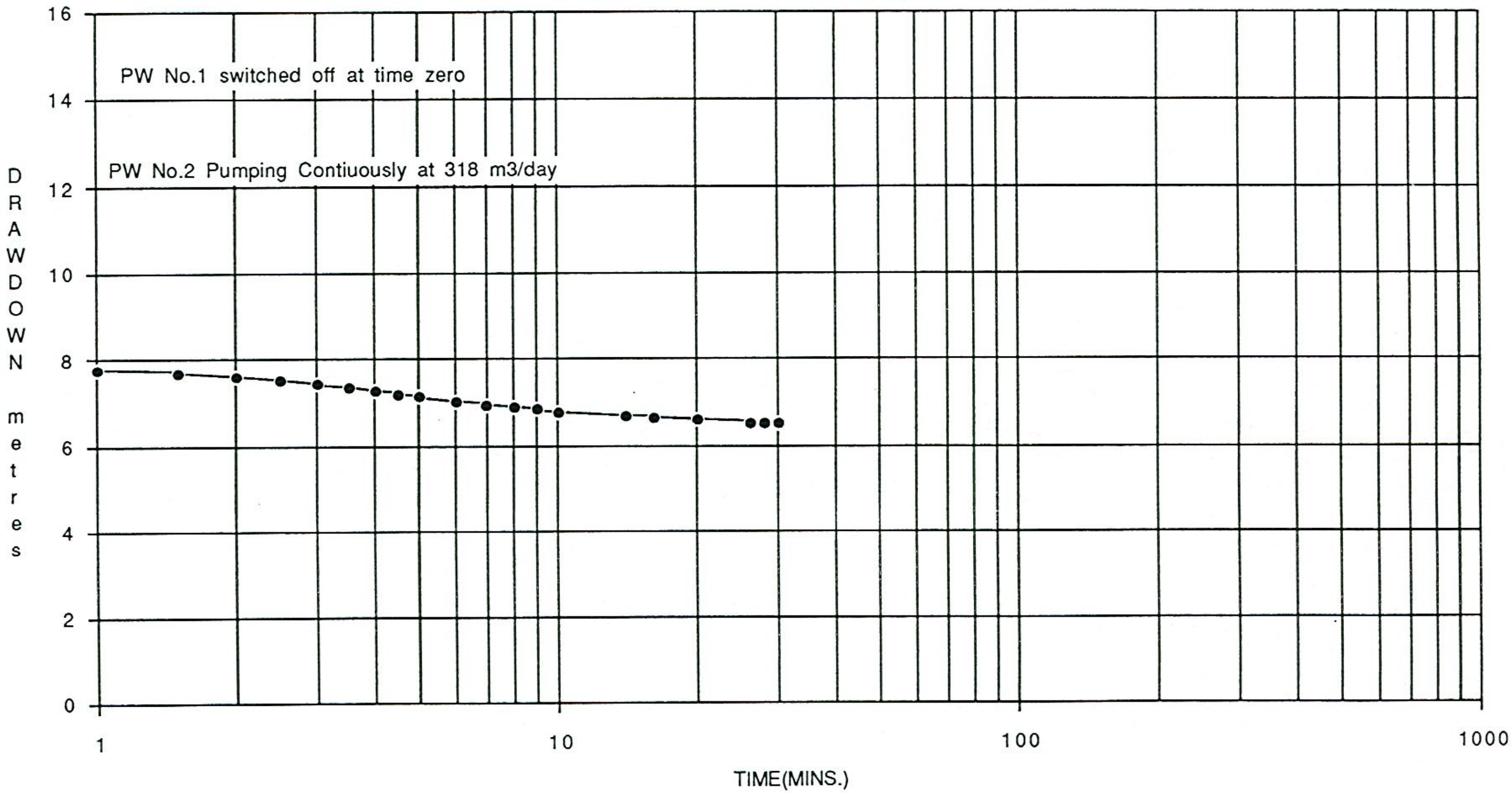


Figure No.5 Time Drawdown Graph from PW No.2 After Pumping Ceased from PW No.1. 10/10/90

Appendix II

Pumping Test Data.

January - February 1991

TIME (mins.)	WATER LEVEL below G.L. (m.)	DRAWDOWN (metres)	YIELD (m3/day)
1446	47.32	47.32	
1447	47.46	47.46	
1448	47.61	47.61	
1449	47.7	47.7	
1450	47.79	47.79	
1452	47.92	47.92	
1454	47.99	47.99	
1456	48.12	48.12	
1458	48.13	48.13	
1460	48.07	48.07	975
1462	48.06	48.06	
1464	48.09	48.09	
1466	48.1	48.1	
1468	48.12	48.12	
1470	48.19	48.19	
1475	48.49	48.49	
1480	48.44	48.44	
1485	48.44	48.44	
1490	48.34	48.34	
1495	48.29	48.29	960
1500	48.22	48.22	
1515	48.49	48.49	
1530	48.72	48.72	
1545	48.66	48.66	
1560	48.72	48.72	
1620	48.4	48.4	
1697	48.83	48.83	949
1740	48.83	48.83	
1840	49.33	49.33	

Figure No.6 Time Drawdown Data from Pw No.1, Coalbrook, starting 31/1/91.

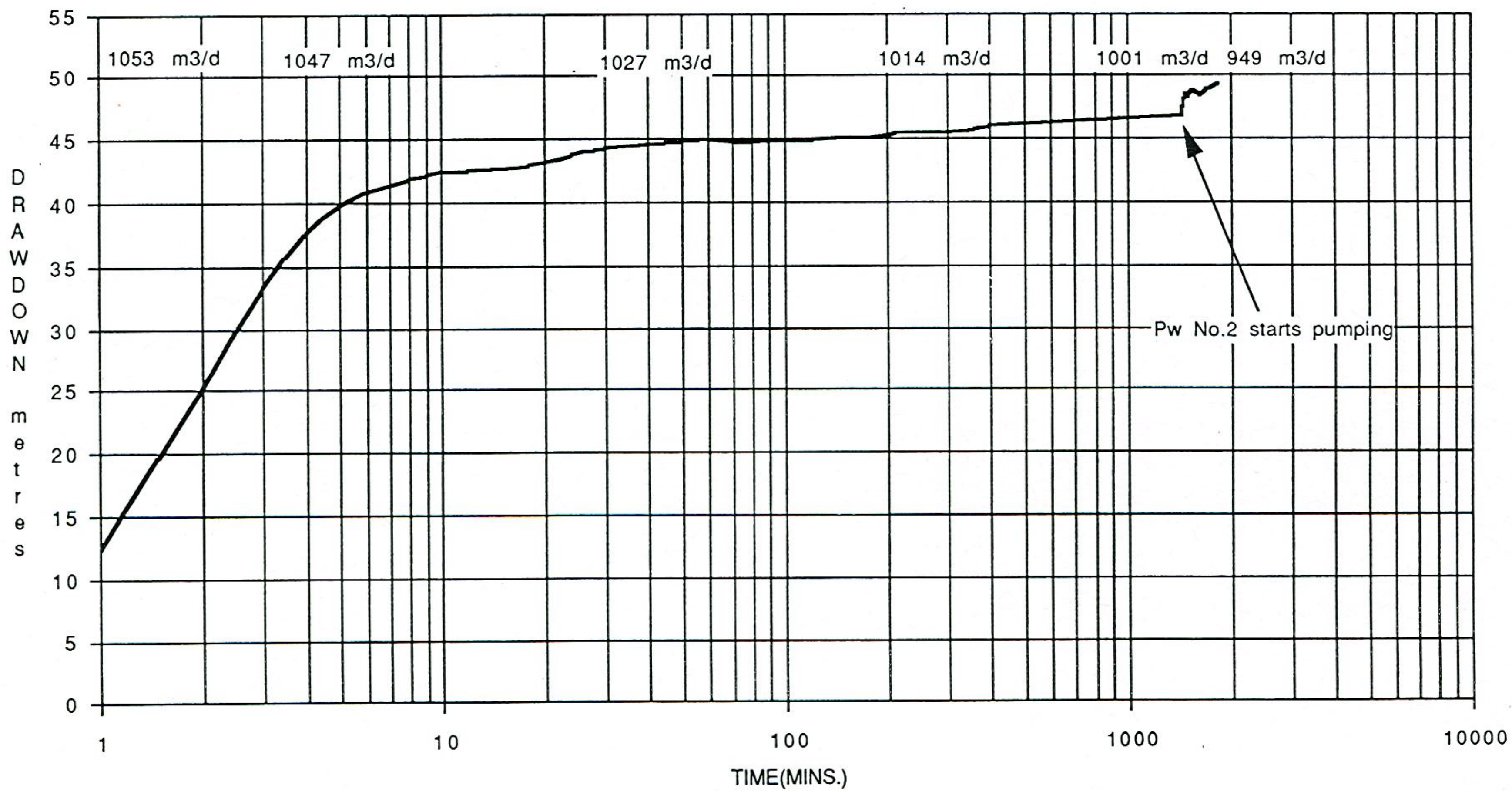


Figure No.7 Time Drawdown Graph from PW No.1, Coalbrook, starting 31/1/91

TIME (mins.)	WATER LEVEL below G.L. (m.)	DRAWDOWN (metres)	YIELD (m3/day)
0	47.03	46.8	
0.5	46.8	46.57	
1	46.75	46.52	
1.5	46.75	46.52	
3	46.84	46.61	
4	47	46.77	
5	47.12	46.89	
6	47.32	47.09	
7	47.46	47.23	
8	47.61	47.38	
9	47.7	47.47	
10	47.79	47.56	
12	47.92	47.69	
14	47.99	47.76	
16	48.12	47.89	
18	48.13	47.9	
20	48.07	47.84	
22	48.06	47.83	975
24	48.09	47.86	
26	48.1	47.87	
28	48.12	47.89	
30	48.19	47.96	969
35	48.49	48.26	
40	48.44	48.21	
45	48.44	48.21	
50	48.34	48.11	
55	48.39	48.16	
60	48.32	48.09	962
75	48.49	48.26	
90	48.72	48.49	
105	48.64	48.41	
120	48.72	48.49	
180	48.4	48.17	
257	48.83	48.6	
300	48.8	48.57	949
400	49.33	49.1	949

Note: P.W.No.1 had been pumping continuously for the previous 24 hours.
P.W.No.2 switched on at time equal to zero.

Figure No.8 Time Drawdown Data from P.W.No.1 Coalbrook, Co.Tipperary.(1/2/91)

Note: P.W.No.1 had been pumping continuously for the previous 24 hours. P.W.No.2 switched on at time equal to zero.

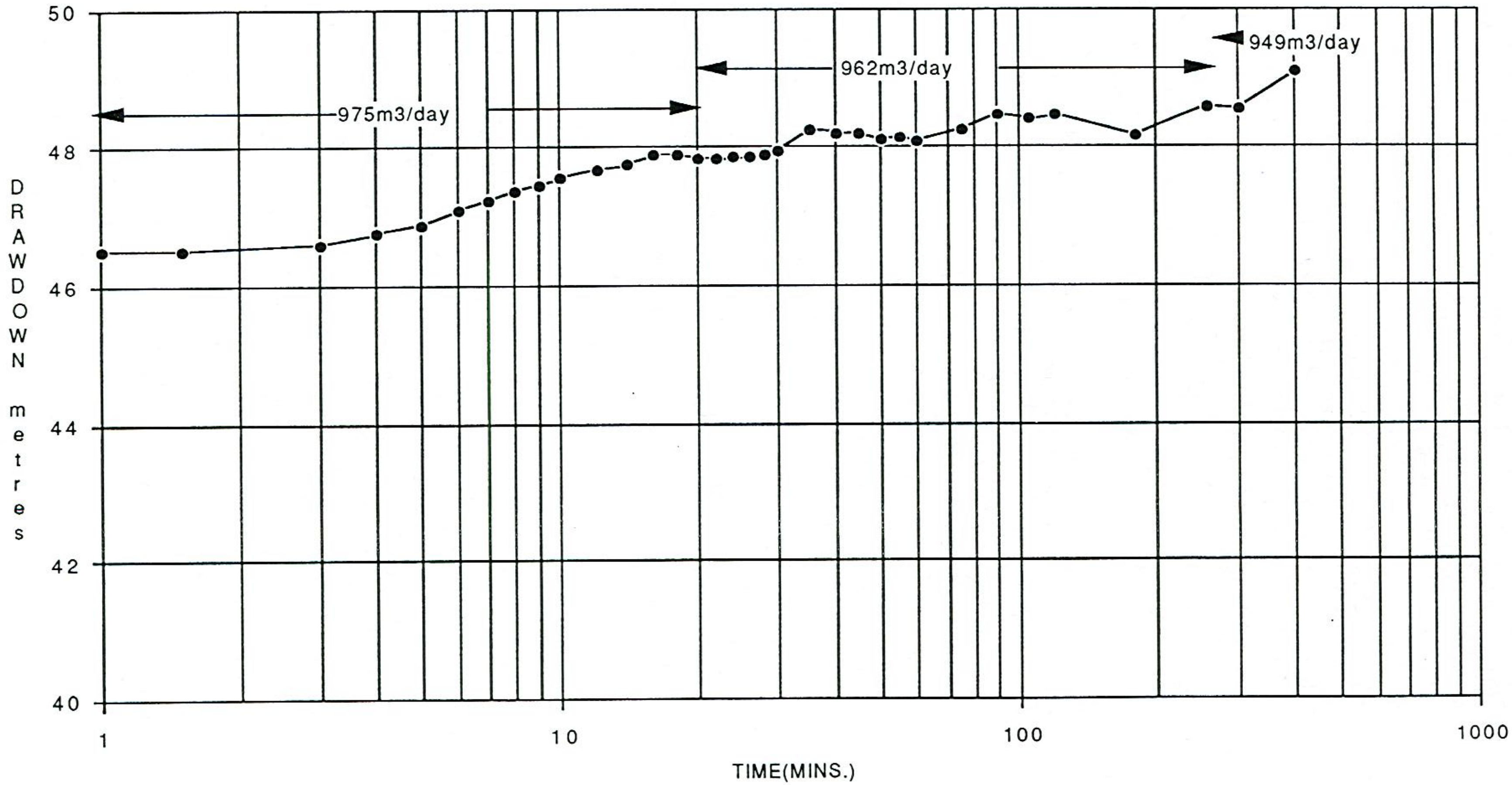


Figure No.9 Time Drawdown Graph from P.W.No.1 after P.W.NO.2 starts pumping. Coalbrook,Co.Tipperary.(1/2/91)

TIME (mins.)	WATER LEVEL below G.L. (m.)	DRAWDOWN (metres)	YIELD (m3/day)
0	1.65	0	0
0.5	1.68	0.03	
1	1.93	0.28	
1.5	2.08	0.43	
2	2.18	0.53	
2.5	2.36	0.71	
3	2.52	0.87	
3.5	2.68	1.03	
4	2.8	1.15	
4.5	2.87	1.22	
5	3.09	1.44	
6	3.37	1.72	
7	3.45	1.8	
9	3.51	1.86	
12	3.54	1.89	
14	3.68	2.03	
16	3.74	2.09	
18	3.6	1.95	
20	3.69	2.04	
22	3.73	2.08	
24	3.76	2.11	
26	3.8	2.15	
30	3.84	2.19	
35	3.91	2.26	
40	3.97	2.32	
45	4	2.35	
50	4.05	2.4	
55	4.08	2.43	
60	4.11	2.46	
75	4.2	2.55	
90	4.27	2.62	
107	4.32	2.67	
122	4.37	2.72	
152	4.46	2.81	
182	4.53	2.88	
210	4.6	2.95	
240	4.68	3.03	
303	4.77	3.12	
362	4.86	3.21	
400	5	3.35	
1440	5.43	3.78	

Figure No.10 Observation Data from Pw No.2 during Pumping Test on Pw No.1, 31/1/91

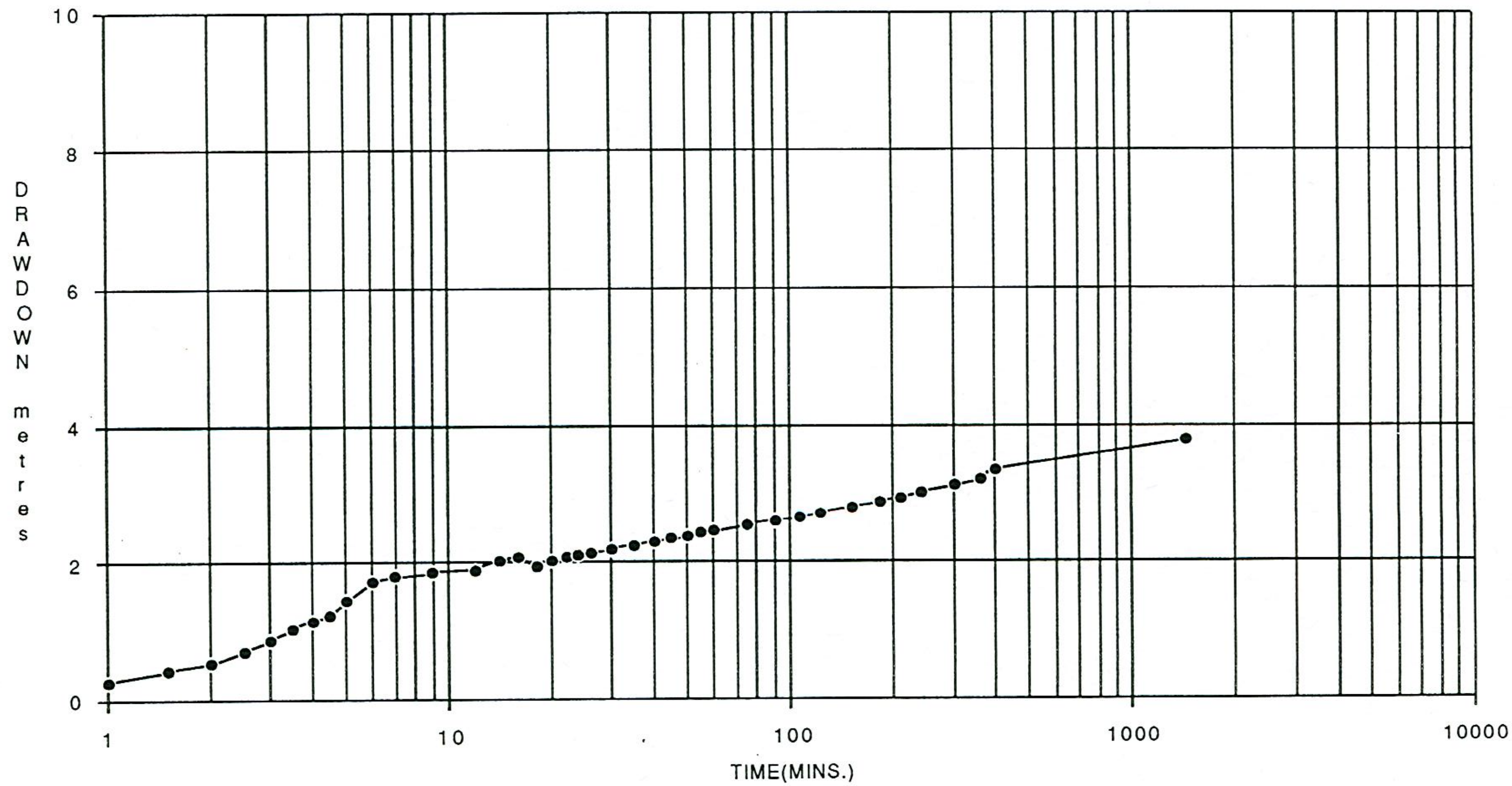


Figure No.11 Graph of Drawdown Data from Pw No.2 during Pumping Test on PW No.1 , 31/1/91

TIME (mins.)	WATER LEVEL below G.L. (m.)	DRAWDOWN (metres)	YIELD (m3/day)
0	4.63	-0.02	578
1	15.3	10.65	
1.5	18	13.35	
2	19.8	15.15	
3	22.2	17.55	
4	23.55	18.9	
5	24.23	19.58	
6	24.7	20.05	
8	25.4	20.75	
9	25.58	20.93	
10	25.72	21.07	
12	25.94	21.29	
14	26.12	21.47	
16	26.24	21.59	
18	26.33	21.68	
22	26.47	21.82	
24	26.52	21.87	
26	26.58	21.93	
28	26.63	21.98	
30	26.69	22.04	
35	26.86	22.21	
41	26.93	22.28	
45	27.03	22.38	
50	27.1	22.45	
55	27.14	22.49	
60	27.19	22.54	595
75	27.36	22.71	
90	27.52	22.87	
105	27.6	22.95	628
120	27.67	23.02	
180	27.96	23.31	
255	28.22	23.57	
300	28.38	23.73	666
400	28	23.35	

Note: PW No.2 starts pumping at time zero.
PW No.1 had been pumping for previous 24 hours.

Figure No.12 Time Drawdown Data from PW No.2 while PW No.1 pumping, 1/2/91

PW No.2 switched on at time zero. PW No.1 pumping for previous 24 hours

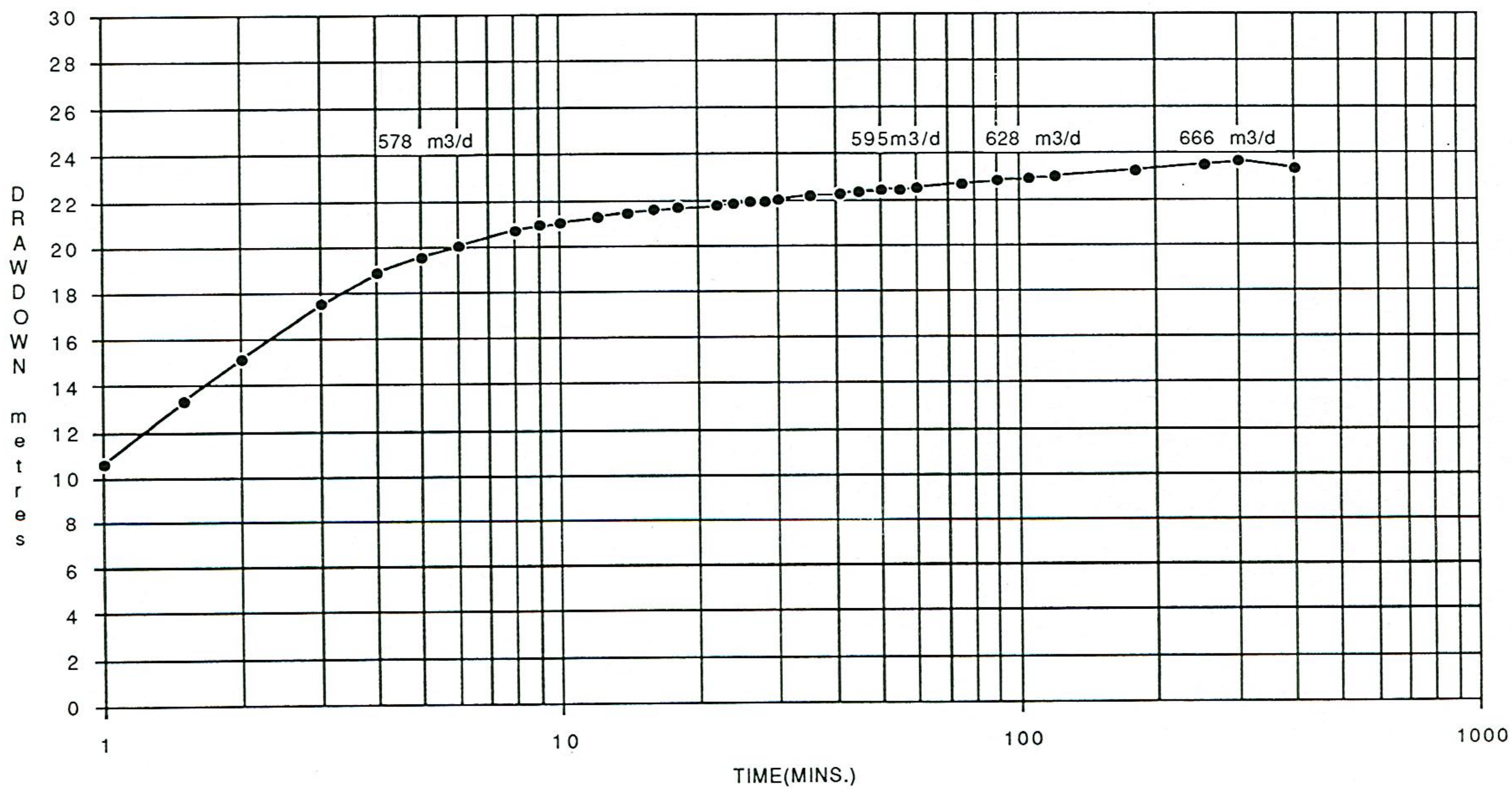


Figure No.13   Time Drawdown Graph from PW No.2 While PW No.1 is pumping, 1/2/91

TIME (mins.)	WATER LEVEL below G.L. (m.)	DRAWDOWN (metres)	YIELD (m3/day)
0	2.51	0	713
1	13	10.49	
2	16.3	13.79	
2.5	17.32	14.81	
3	17.97	15.46	
3.5	18.6	16.09	
4	18.92	16.41	
5	19.48	16.97	
6	18.83	16.32	
8	20.18	17.67	
10	20.42	17.91	
12	20.58	18.07	
14	20.69	18.18	
16	20.78	18.27	
18	20.85	18.34	
20	20.91	18.4	
22	20.98	18.47	
24	21.04	18.53	
26	21.09	18.58	
28	21.14	18.63	
30	21.15	18.64	
35	21.28	18.77	700
40	21.38	18.87	
45	21.39	18.88	
50	21.42	18.91	
60	21.56	19.05	
75	21.68	19.17	
90	21.74	19.23	
105	21.81	19.3	
120	21.81	19.3	
150	21.95	19.44	
180	22.01	19.5	
240	22.12	19.61	
290	22.18	19.67	
362	22.21	19.7	
415	22.34	19.83	
1440	22.65	20.14	654 (PW No.1 on)
1800	25.58	23.07	

Note: PW No.2 Pumping alone until 1440 minutes when Pw No.1 is switched on.

Figure No. 14 Time Drawdown Data from PW No.2, 6/2/91

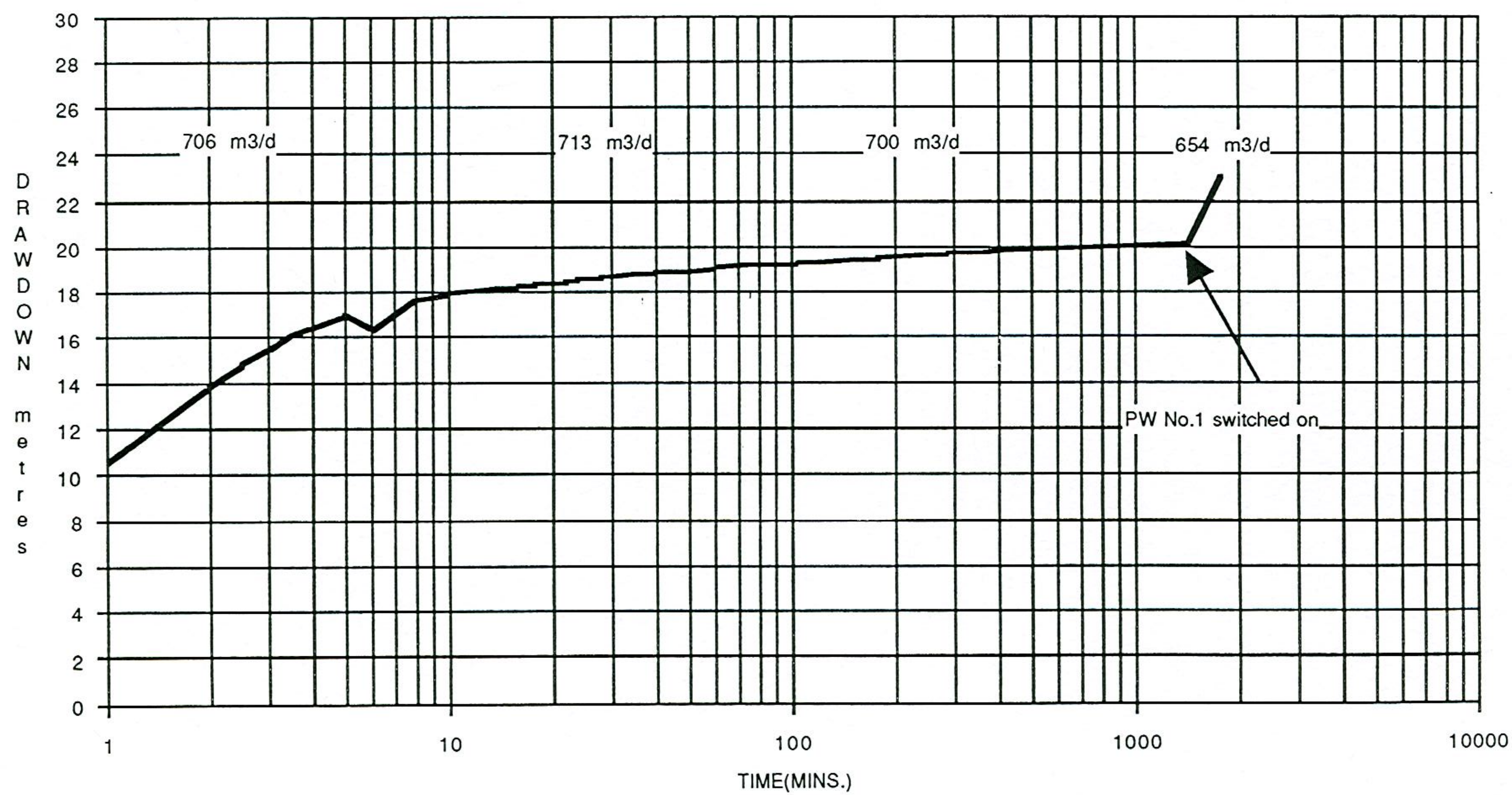


Figure No.15 Time Drawdown Graph from PW No.2, 6/2/91

TIME (mins.)	WATER LEVEL below G.L. (m.)	DRAWDOWN (metres)	YIELD (m3/day)
0	1.61	0	0
0.5	1.69	0.08	
1	1.83	0.22	
1.5	1.97	0.36	
2	2.12	0.51	
2.5	2.22	0.61	
3	2.24	0.63	
3.5	2.26	0.65	
4	2.28	0.67	
4.5	2.29	0.68	
5	2.32	0.71	
6	2.39	0.78	
7	2.42	0.81	
8	2.44	0.83	
9	2.45	0.84	
10	2.46	0.85	
12	2.52	0.91	
14	2.56	0.95	
18	2.64	1.03	
20	2.67	1.06	
22	2.67	1.06	
24	2.71	1.1	
26	2.74	1.13	
30	2.78	1.17	
35	2.8	1.19	
40	2.81	1.2	
45	2.84	1.23	
50	2.91	1.3	
60	2.95	1.34	
75	2.97	1.36	
105	3.02	1.41	
120	3.06	1.45	
150	3.09	1.48	
180	3.12	1.51	
240	3.12	1.51	
290	3.15	1.54	
368	3.16	1.55	
420	3.17	1.56	
1440	3.12	1.51	

Figure No. 16 Observation Data from Pw No.1 During Test on Pw No.2, 6/2/91

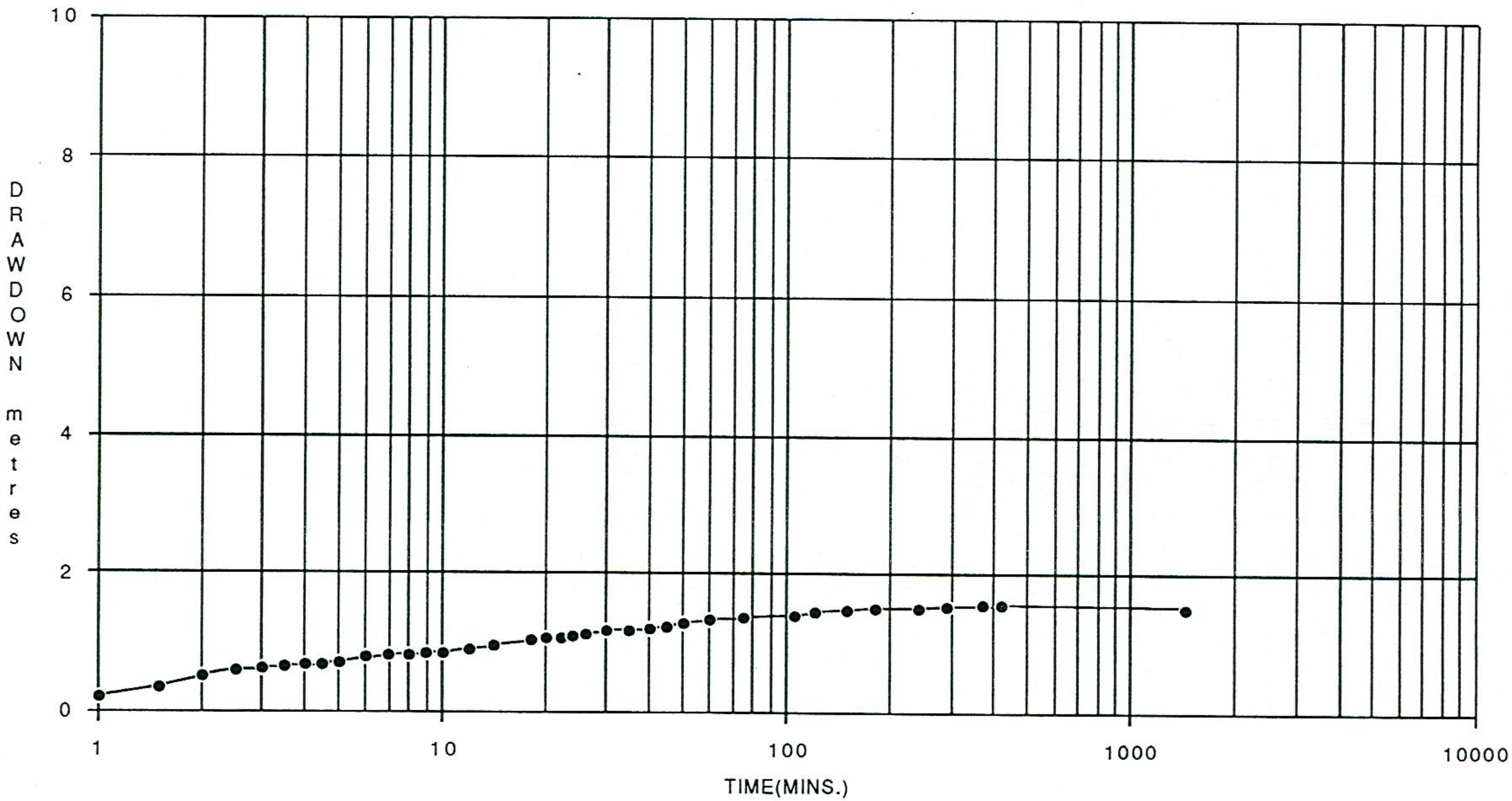


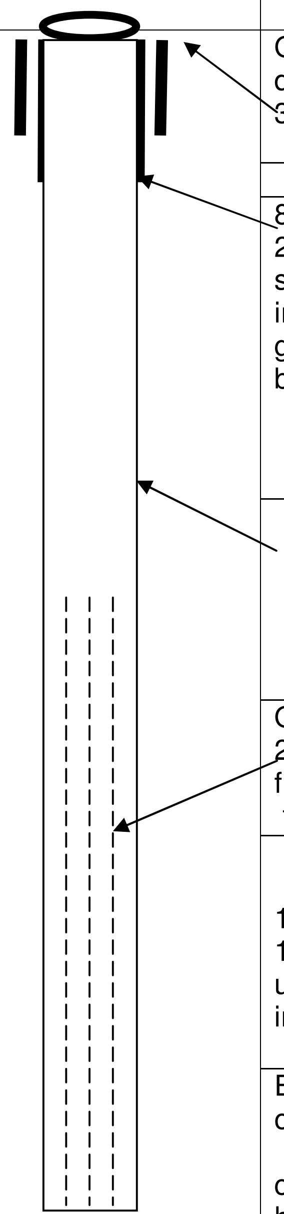
Figure No.17 Graph of Observation Data from PW No.1 During Test on PW No.2, 6/2/91

APPENDIX 2

Borehole Log BH-5

Log of Production borehole at Coalbrook , Co. TIPPERARY.

Borehole No; #10 X 7, i.e. (10" borehole with 7" screen)
Date of drilling ; Jan 2007 .

From	To	Description	Construction Diagram	Details
G.L	1.3	Dark peaty CLAYs		Overburden drilled at 300mm to 8M.
1.3	5	Brown weathered SHALEs		
5	8	Dark blue-grey Shale		
				8 Mtrs of 250mm I.D steel casing installed & grouted into bedrock
8	12	Hard dark blue-grey SHALE		
12	23	Soft black SHALE		
23	24	Hard grey SANDSTONE		
24	30	Hard weathered SHALE		
30	38	Hard black SHALE		
38	43	Hard weathered SANDSTONE		
43	50	Hard black SHALE		
50	61	Soft black SHALE		Open hole @ 250mm dia . from 8 Mtrs to 100 Mtrs
61	70	Hard dark blue-grey SHALE		
70	71	Fireclay vein		
71	91	Hard dark blue-grey SHALE		100 Mtrs of 168mm I.D uPVC screen installed
91	92	Fireclay vein		
92	100	Hard dark blue-grey SHALE		
		Alternating layers of SANDSTONE with shale yields water.		Estimated output at 100 Mtrs = 60 cubic Mtrs / hour
		Total yield = 60 M3/ Hr.		
	End of borehole @ 100 Mtrs.			

APPENDIX 3

South Tipperary County Council Report (2009) "Source Risk Investigation for Coalbrook Drinking Water Source".

South Tipperary County Council
Environment Section
Source Risk Investigation for Coalbrook Drinking Water Source

Prepared by Pat O'Dwyer, Environment Section, December2009.

Introduction

In November 2009 Source risk investigation was carried out on Coalbrook drinking water source. The purpose of this investigation was to identify and highlight any possible risks that may lead to the contamination of this source within 250metres of the source.

Source protection was carried out using arbitrary fixed radii, which comprised of both inner and outer protection zones.
The inner protection zone is the area up to 200metres from the source and the outer protection zone is the area up to 250metres from the source. This is illustrated in **fig.1.** below

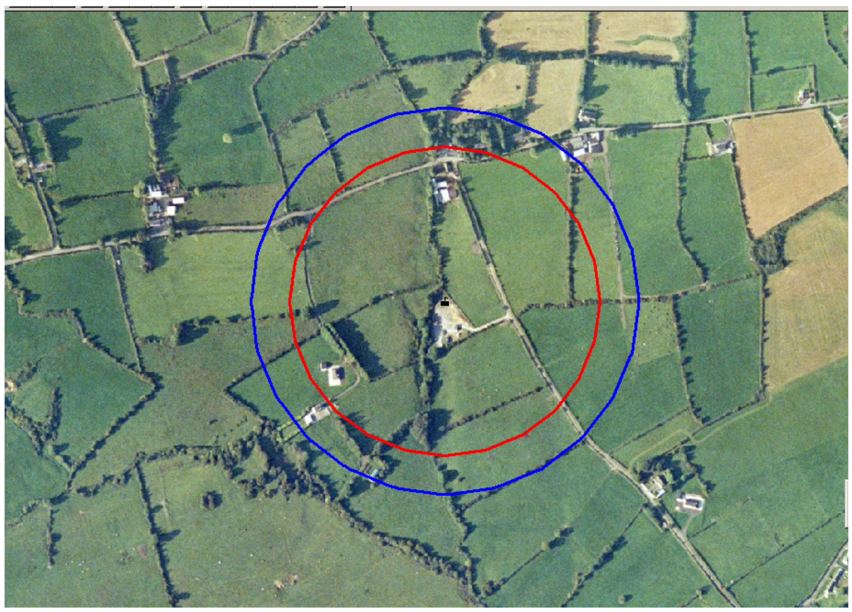


Fig.1.

These distances are specified in European Communities (Good Agricultural Practice for Protection of Waters) Regulations S.I 101 of 2009 (Part 4, Section 17).

Site & Source Description

Coalbrook public water supply *(2900 PUB 0111)* provides approx 991m^3/day of raw water. The source is a groundwater source comprised of five borehole wells located at Curraheenduff, Coalbrook.

The first well (No.1) was drilled in 1937 as an exploration borehole to assess the coal deposits of the area and in the 1980's was developed as a borehole supply by South Tipperary County Council.

The site itself is located over a locally important aquifer, which Geological Survey Ireland has classified as being extremely vulnerable to groundwater pollution. The site is positioned in a valley on the bank of a river, which is a tributary of the Kings River.

Monitoring Programme

The treated water is monitored and analysed eight times per year by South Tipperary County Council Laboratory staff. This sampling is carried out at the consumers tap and is normally taken at Pollards Shop, Copper Cross, Coalbrook and is located approx 3.2km from the source.

Raw water is pumped from all of the boreholes to an elevated chamber and cascades over a series of steps before it enters the plant for treatment. Raw water is sampled as it cascades over these steps. This sample is a composite of all the boreholes. There are facilities for raw water sampling on borehole No. 5 only.

The raw water is treated by disinfection using chlorine and also filtration to remove iron and manganese.

Source Investigation & Conclusion

Agricultural land use in the area is grazing pasture with dairy and beef being the main farm enterprises. Within the 250metre buffer zone there are two farmyards. One of these yards has not been used for wintering cattle for the past 15 years and there are no facilities for containment of slurry. This yard along with the farm, which is comprised, of thirty-five acres is leased out to a neighbouring farmer.

The other farmyard is comprised of a slatted shed for wintering suckler cows and cattle. This farmer also outwinters cattle in the fields adjoining the Coalbrook site. There have been issues with run-off from this yard to the river in the past and there are issues regarding the operation of this farm given its close proximity to the source. This farm provides the main risks to the source, which are run-off from land and cattle access due to poor fencing. During this investigation it was evident that cattle are regularly entering the site given the amount of animal waste deposits around the site. This is illustrated in **fig.2.** & **fig.3.** below.

fig.2.

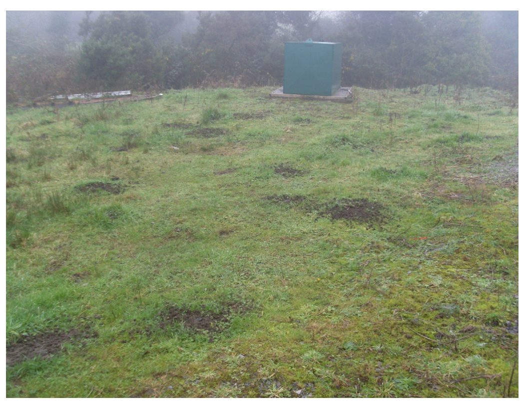


fig.3.

Within the 250metre zone there are four occupied residences all of which are served by individual septic tanks with percolation areas/soak pits. All occupants have been briefed on the location of the drinking water source and the importance of protecting the source.
An information pack was presented to each resident, landowner and farm operator. This information pack contained information regarding the following:

- Origins of the buffer zones
- Obligations under Agricultural Regulations
- Guidelines for upkeep of domestic wastewater systems.

In conclusion the main risks to the Coalbrook drinking water source originate from agricultural activity and residents in the area. The risks identified and possible control measures are detailed in a. appendix 1. Details of landowners and residents are listed in appendix 2.

Appendix 1

Risks identified:

Risk Identified	Impacts of Risk	Possible Control Measures
Cattle access to site	Damage to equipment. Animal waste deposits on site can lead to high levels of Nitrogen & pathogens such as Salmonella, E-coli & Cryptosporidium through percolation.	Repair fencing on perimeter of site
On site septic tank/bio cycle treatment plant.	Bacteria and viruses present in sanitary wastewater which may cause illness.	Put in place a programme for regular de-sludging.
Livestock waste	Elevated levels of Nitrogen & pathogens such as salmonella, E-coli & Cryptosporidium through percolation.	No out wintering of animals within buffer zone.
Agricultural chemical fertilizer spreading	High levels of nitrogen in source due to leaching High levels of nitrogen may cause blue baby syndrome.	Control application and apply only as crop requirement and at time of maximum uptake.
Pesticide application	Run-off and percolation risk to groundwater. May have health implications due to presence in drinking water over a long period of time.	Proper storage and disposal. Limit applications within buffer zone.
Hydrocarbon spills	Oil including diesel or kerosene percolating to groundwater.	Bunding of all tanks within buffer zone.

Appendix 2

Table of Residents

Name	Address	Contact No:	Comments
Richard Cleary	Curraheenduff, Coalbrook, Thurles, Co. Tipperary	052 54438	Resident, farmer & Landowner.
Martin Fitzgerald	Curraheenduff, Coalbrook, Thurles, Co. Tipperary	087 9941685	Farmer & Landowner.
Richard Butler	Curraheenduff, Coalbrook, Thurles, Co. Tipperary	087 2034608	Resident & Landowner. Farm is leased out to Michael Fitzgerald.
Mrs Dalton	Curraheenduff, Coalbrook, Thurles, Co. Tipperary.	N/A	Resident.
Ann Rigney	Curraheenduff, Coalbrook, Thurles, Co.Tipperary	052 9154702	Resident & Landowner.