Louth County Council

Establishment of Groundwater Source Protection Zones

Ardtullybeg Water Supply Scheme

May 2009

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Prepared by:

Fionnuala Collins, Geological Survey of Ireland

Assisted by:

Caoimhe Hickey, Geological Survey of Ireland,

Natalya Hunter Williams, Geological Survey of Ireland,

Dr Robert Meehan, Consultant Geologist

and in partnership with:

Louth County Council

PROJECT DESCRIPTION

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

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

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

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

Document control

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TABLE OF CONTENTS

TABLES & FIGURES

FIGURES

TABLES

APPENDICES

1 INTRODUCTION

The Ardtully Beg Boreholes, which provide drinking water to the Carlingford Water Supply Scheme, are located on the Cooley Peninsula, near Cooley Point.

Louth County Council requested Source Protection Zone delineation for the Ardtully Beg boreholes from the Geological Survey of Ireland (GSI), in order to develop Source Protection Zones for the entire zone of contribution to the boreholes.

The objectives of the report are as follows:

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

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

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

2 METHODOLOGY

Borehole details such as depth, date of commissioning and estimated abstraction figures were obtained from Louth County Council personnel. GSI mapping, field mapping and final draft vulnerability maps produced by Tobins on behalf of the GSI for the National Vulnerability Mapping Programme were assessed. In addition, information on the trial, production and observation boreholes, along with geological and hydrogeological information were obtained from GSI records, and the following hydrogeological reports:

- Groundwater Resources in the North East Regional Development Organisation (NERDO) (An Foras Forbatha and Geological Survey Office, 1982).
- Report on a Water Well Drilling Project at Ardtully Beg, Co. Louth (K.T. Cullen and Nicholas O'Dwyer, 1983).
- BMA Geoservices.

Site visits and fieldwork undertaken for this project included the following:

- Meetings with County Council personnel in August and November 2006 and April 2007, and walkover surveys in April and June 2007 and August 2008.
- Depth to bedrock drilling programme and site walkover in June 2007 to investigate the subsoil geology, the hydrogeology and vulnerability to contamination.
- Groundwater vulnerability mapping for County Louth in 2009.

Field studies were undertaken, and new and previously collected data were analysed to delineate protection zones around the public supply wells.

3 LOCATION, SITE DESCRIPTION AND WELL HEAD PROTECTION

Two boreholes are used for the Ardtully Beg Public Water Supply. The boreholes are located in the townland of Ardtully Beg, on the southern Cooley Peninsula approximately 2.7 km west-northwest of Cooley Point, Co Louth (Figure 1). Currently, the two boreholes are active and are pumped at a combined rate of 60 m^3/hr for approximately 16-17 hours out of every 24, resulting in a combined abstraction of 1,020 m^3/d. The abstracted groundwater is chlorinated, and combined with water abstracted at the Carlingford borehole and the Greenore spring prior to distribution through the piped network.

The pumping station compound is surrounded by a low fence and brick wall boundary, and is situated on a small country lane. The pump control equipment and water treatment system is housed in a separate small brick building (Figure 2). The degree of sanitary protection of the Ardtully Beg boreholes appears moderately suitable. The boreholes are located within concrete chambers (c. 1.5 m x 1 m) that are securely covered by lockable galvanised steel lids (Figure 3). The tops of the chambers are very slightly higher than ground level. However, the top of the well casing is not elevated significantly above the chamber floor, which could result in surface water ingressing the borehole if there is water leakage into the well chamber. The chambers are situated to the north (Production Well 1) and east (Production Well 2) of the pump house, in a grassed area, within the pump house compound.

Figure 1: Location map of Ardtully Beg Public Water Supply Source

The red circles show the location of the water supply boreholes

Figure 2: View of the pump house at Artully Beg, with the top of the Production Well 1 concrete chamber to the north of the pumphouse visible

Figure 3: Exterior view of PW 1 chamber (left) and view inside PW 2 chamber (right)

4 SUMMARY OF BOREHOLE DETAILS

Well Name [1]	PW1	PW2
Date Drilled	1977	1982
GSI Well Number	2929NEW040	2929NEW090
Grid Reference	319576 306265	319558 306280
Location	Ardtully Beg	Ardtully Beg
Well type	Bored	Bored
Owner	Louth Co. Co.	Louth Co. Co.
Ground elevation (mAOD)	28	28
Depth of borehole (m)	20	20.7
Diameter of hole (mm)	250	250
Diameter of casing/ screen (mm)	250 nominal	250 nominal
Screened interval (mbgl)	14.8 - 19.3	12.3 - 16.5
Screened length (m)	4.5	4.0
Depth to rock (m)	20	20.4
Lithological Unit	Sand and Gravel	Sand and Gravel
Static water level (mbgl)	Between approximately 5-6	
Static water level (mAOD)	Between approximately 23-24	
Pumping water level (mbgl) [2]	9.81 on 18/04/06	10.56 on 18/04/06
Pumping water level (mAOD)	19.2	18.40 approx
Average Current Abstraction (m^3/d)	1,020 combined yield (November-December 2008) (38 m^3/hr and 22 m^3/hr in September 2008)	
Maximum Drawdown (m) [3]	9.28	2.94
Specific Capacity (m^3/d/m) [4]	118.2	471

1. In KT Cullen report (1983) PW 1 was termed "Exploration Well 1" and PW2 was "Exploration Well 5".
2. Top of casing assumed 1m below chamber lid.
3. During pumping test in 1983, as reported in KT Cullen.
4. Specific capacity = abstraction divided by the drawdown. It is an indicator of both the efficiency of the well under varying pumping rates, and indirectly of the capacity of an aquifer to transmit water to the well.

5 TOPOGRAPHY, SURFACE HYDROLOGY AND LAND USE

The Ardtully Beg boreholes are situated in a low-lying area between the Carlingford Mountains and the sea, at an elevation of approximately 28 mAOD. Ground level contours and surface waters are shown in Figure 1.

The topography is controlled by the underlying geology, with the more resistant granites forming the higher ground to the northwest, which reaches an elevation of 300 m approximately 3.5 km north west of the source. Less resistant Carboniferous-age limestone rocks underlie the low-lying area at the foot of the mountains, extending to the coast. The geology is discussed in further detail below (Section 7).

The topographic gradient in the area around Ardtully Beg stretching to the coast is relatively flat, in the order of 1 in 100. To the northeast of the source, beyond the R175 and The Bush, the gradient steepens initially to 1 in 11 and then to 1 in 6 as a result of presence of the more resistant granites and other similar rocks which form the Carlingford Mountains.

The steep western flanks of the Carlingford Mountains are characterised by high drainage density, with the majority of the surface water draining to the south-flowing Big and Castletown Rivers, which enter the sea at Riverstown, approximately 3 km to the west of the supply source.

In contrast, the low-lying areas to the east and south of the mountains, including where the source is located, are characterised by a comparative absence of surface drainage apart from a few streams and water logged enclosed depressions, some of which have been exploited for peat (cutover bogs). This indicates that, on the whole, soils and subsoils in the source area are relatively free draining.

Agriculture is the main activity in the area, with tillage and pastures in the fertile lowlands. Tracts of forestry occupy the higher valleys flanking the Carlingford Mountains. Locally, sand and gravel deposits have been exploited through the excavation of large pits in the area to the north of The Bush, as well as at Mountbagnell (3 km to the west of the public supply source) and Ardtully More (c. 1 km to the east).

6 HYDRO-METEROLOGY

The main meteorological parameters involved in recharge rate estimation are rainfall and evapotranspiration. The main hydrogeological factors influencing recharge are subsoil permeability, groundwater vulnerability, soil drainage characteristics and the ability of the aquifer to accept recharge (either as a function of transmissivity and aquifer class, or due to the proximity of the water table to the ground surface). Recharge is likely to be greater in areas dominated by higher permeability subsoils, where subsoils are thinner, and where higher transmissivity aquifers can accept the recharge. The calculations used to estimate recharge are outlined in the following sections.

Average Annual Rainfall: The average annual rainfall for the period 1961-1990 is 1,067 mm/yr at Carlingford (rainfall data are from Met Éireann average annual rainfall values). The Carlingford station is located approximately 5 km north of the source and is at a similar low elevation. The rainfall pattern could therefore be expected to be broadly similar to that at Ardtully Beg.

Average Annual Potential Evapotranspiration: Annual potential evapotranspiration (P.E.) is approximately 440 mm/yr (Met Éireann average annual evapotranspiration data).

Average Annual Actual Evapotranspiration: Actual evapotranspiration (A.E.) is estimated as 92 % of P.E. This accounts for periods when soil moisture deficits limit evapotranspiration (i.e. when potential evapotranspiration exceeds rainfall, usually in the summer months). Average annual A.E. is estimated as 405 mm/yr.

Average Annual Effective Rainfall (Potential Recharge): Annual effective rainfall (potential recharge) is calculated by subtracting the estimated actual evapotranspiration from the average annual rainfall. This gives an estimate of 662 mm/yr.

7 GEOLOGY

This section briefly describes the relevant characteristics of the geological materials that underlie the area surrounding the Ardtully Beg Public Water Supply boreholes. This provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections.

Bedrock information was taken from a variety of sources including:

- GSI publication on the bedrock geology of the region (Geraghty, 1996 and 1997);
- Hydrogeological reports and borehole logs from KTC/Nicholas O'Dwyer (1983) and BMA Geoservices (2006).

Subsoils information derives from:

- Teagasc subsoils mapping (Meehan, 2004);
- Twelve auger holes drilled and three trial pits excavated/inspected by the GSI (April and June 2007);
- Permeability mapping by GSI contracted field personnel (Tobin Environmental Ltd) in 2008;
- Site investigation data, including geological logs and sieve analysis, by Irish Soil Laboratories Ltd, the drilling contractor, provided in KTC, 1983 and the BMA 2006 investigations.

7.1 BEDROCK GEOLOGY

The Ardtully Beg area is underlain by the Carboniferous-age undifferentiated Dinantian Limestones. These rocks occupy the low-lying ground on the east and south of the Cooley Peninsula. These rocks are poorly characterised.

The limestones have been intruded by younger Tertiary igneous rocks, which are exposed in the higher ground to the north where they have been folded and faulted to form the Carlingford Mountains. To the north of the source, these rocks are mainly fine-grained granites (microgranite).

Faults in the bedrock have a northwest-southeast orientation, and are identified by the way they offset the boundary between the limestones and the granites. The boreholes at Ardtully Beg are situated in an area that may be faulted, if the faults extend sufficiently far southeast from their mapped location.

The individual bedrock units are described in Table 1, and their distribution is shown on

Figure 4.

Table 1: Bedrock Geology of the area around Ardtully Beg Public Water Supply

Age	Geological Name	Geological Description	Occurrence
TERTIARY	**Carlingford Igneous Complex**	Layered Gabbro, Basaltic Lava, Microgranite, Vent Agglomerate and Dolerite	North West of the Source forming the Carlingford Mountains
CARBONIFEROUS	**Dinantian Limestones (undifferentiated)**	Sandstones, Shales and Limestone	Underlies the Source

7.2 SOILS AND SUBSOILS

The subsoils in Louth were mapped in the 1990's by the Quaternary Section of the GSI. This information has been incorporated in the Teagasc subsoil mapping (Meehan, 2004), on which the following categories and descriptions are based. Drilling and permeability mapping carried out by the GSI for this project, and by Tobin Environmental Ltd for the National Vulnerability Mapping Programme, provided additional information on the subsoils. Particle size analyses for the sand and gravels were obtained from earlier reports (Cullen and O'Dwyer, 1983).

The subsoils at the source comprise glaciofluvial sands and gravels derived from Lower Palaeozoic age sandstones and shales (GLPSsS). Further significant areas of glaciofluvial sands and gravels lie to the east at Ardtully More/Ballynamoney, northwest beyond 'The Bush', and westwards from Riverstown. An extensive area to the west of the source is dominated by till derived chiefly from granite (TGr). The area to the east is underlain by till chiefly derived from Lower Palaeozoic sandstones and shales (TLPSsS).

Small areas of cutover peat (Cut) occur to the west of the source, and to the southeast at Ballynamaghery and Templetown. Fen peat (Fen Pt) overlies the granite-derived till to the west, at Liscarragh Bog. The areas of peat are associated with low-lying enclosed depressions or are located adjacent to water courses (Templetown). Made ground also occupies the built up area at The Bush.

Depending on the saturated thickness, areal extent and grain size of the deposits, some of the sand and gravel subsoil units are classified as aquifers. This is discussed in more detail in Section 9. The majority of the subsoil units in this area are not classed as an aquifer, however. Thus, their main significance is in relation to the protection provided to the underlying bedrock aquifers from infiltrating contaminants (see Section 8). The characteristics of each category are described briefly in the following sections. The subsoil map is shown in

.

Figure 4: Bedrock geology in the vicinity of Ardtully Beg

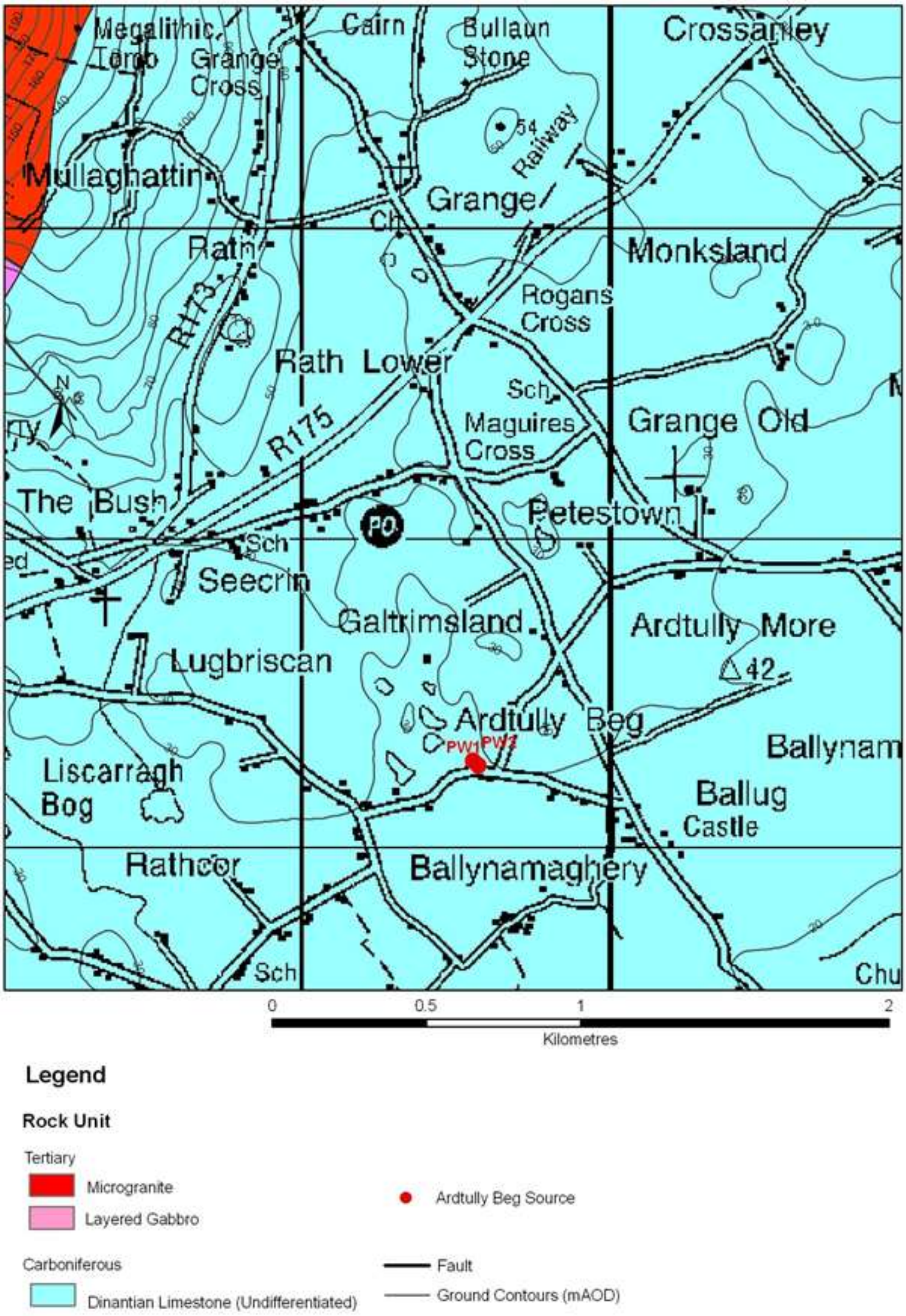
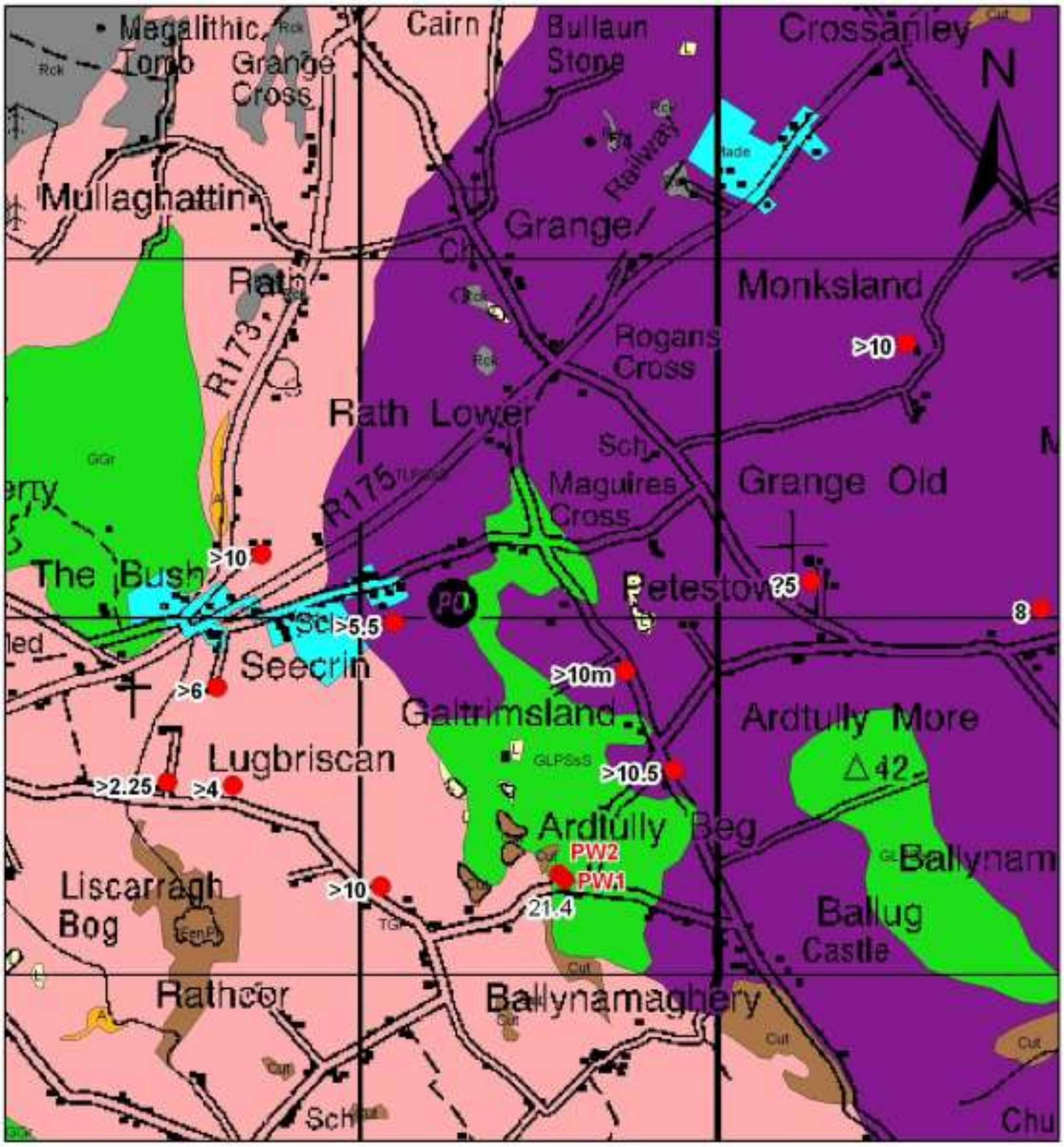


Figure 5: Subsoil geology and thickness in the vicinity of Ardtully Beg



Legend

- Borehole with Depth to Bedrock (m)
- A - Alluvium
- Fen - Fen Peat
- Cut - Cut Peat
- Rck - Rock
- Made ground
- GLPSsS - Sandstone and shale sands and gravels (Lower Palaeozoic)
- GGr - Granite Sands and Gravel
- TGr - Till derived chiefly from Granite
- TLPSsS - Sandstone and shale till (Lower Palaeozoic)

Till is a poorly sorted sediment comprising a wide range of particle sizes. Tills are often overconsolidated, or tightly packed, unsorted, unbedded, possessing many different particle and clast (stone) sizes, and commonly have sharp, angular clasts (Meehan, 2004). Tills are often termed ‘boulder clays’ by engineers. There are two main types in the area, categorised according to their dominant lithological component.

Granite till (TGr) dominates the area to the west, and extending northwards to flank the higher ground of outcropping granite bedrock, this till is predominantly ‘gravelly’. Four auger holes were drilled by the GSI into this till unit within the vicinity of the source. Using BS 5930 (1999), one sample was classified as a ‘sandy silty GRAVEL’; two as ‘sandy SILT’ and two as ‘gravelly SAND’.

The Sandstone and shale till (Lower Palaeozoic) (TLPSsS) unit predominates to the east, northeast and southeast of the source. Seven auger holes were drilled by the GSI into the sandstone and shale till (Lower Palaeozoic) till. The texture is variable, even at different depths from the same location. Two samples are classed as “gravelly SAND”, two classed as “SILT”, and one each classed as “SAND”, “GRAVEL”, “silty GRAVEL” and “SILT/CLAY”, using BS 5930. A sample from a further borehole was too wet to retrieve.

Glaciofluvial sands and gravels are different from tills in that they are deposited by running water only. The gravels usually have rounded edges, and the deposits are generally stratified (layered). As these deposits were laid by the water from melting glaciers, they represent the stagnation and decay of the ice sheets. The deposits are categorised according to dominant lithology (Meehan, 2004).

The principal category of glaciofluvial sand and gravel in the area is sandstone and shale sands and gravels (Lower Palaeozoic) (GLPSsS). Surrounding the boreholes, a gravel deposit of 42 ha is mapped as extending over 1 km northwards from Ardtully Beg to Rath Lower, and 300 m south to Ballynamaghery. At the source itself, this deposit is found to be up to 19.5m thick and is described as coarse sand and coarse gravel with cobbles and boulders. This deposit directly overlies bedrock. One auger hole was drilled in the recent drilling programme by the GSI into this sand and gravel unit. Using BS 5930 (1999), the sample taken was classified as ‘sandy GRAVEL’.

Further significant (25 ha) gravel deposits are found to the east of the source at Ardtully More, and immediately northwest of ‘The Bush’ (52 ha of deltaic gravel).

Granite sands and gravels (GGr) associated with a linear gravel moraine occur in an extensive area in the Riverstown-Castlecarragh area, approximately 2 km to the west of the source.

The deposits that have sufficient saturated thickness and areal extent are classified as sand and gravel aquifers. Based on current knowledge, all of the deposits described in this section meet thickness and areal extent criteria.

Deposition of peat occurred in post-glacial times with the onset of warmer and wetter climatic conditions. Peat is an unconsolidated brown to black organic material comprising a mixture of decomposed and undecomposed plant matter which has accumulated in a water logged environment. It has an extremely high water content averaging over 90% by volume. In the vicinity of the source, Fen Peat (FenPt) peat is found in lowlying areas, enclosed depressions and riparian zones along stream margins. At Liscarragh Bog, approximately 1 km west of the source, the peat forming in this natural basin is more alkaline than rain-fed peat as the plants receive their nutrients from mineral rich groundwater. Cut Peat (Cut) is found along the western margin of the Ardtully Beg gravel deposit; at Ballynamaghery and upgradient of a stream at Templetown.

Alluvium (A) is a post-glacial deposit that may consist of gravel, sand, silt or clay in a variety of mixes and usually includes a high percentage of organic carbon (10%-30%). Alluvium is mapped only on modern day river floodplains. The alluvial deposits are usually bedded, consisting of many complex strata of waterlain material left both by rivers flooding over their floodplains and the meandering of rivers across their valleys. Alluvial deposits in the area of the source are limited to isolated zones north of The Bush, and just southeast of Liscarragh Bog.

Isolated pockets of Lake sediments (L) occur to the north of the supply source within and along the western limits of the sand and gravel deposit. A further isolated pocket of lake sediment occurs at Petestown less than 1 km north northeast of the source. Due to inaccessibility, it was not possible to sample the lake sediments

7.3 DEPTH TO BEDROCK

Depth to bedrock, thickness and permeability of the subsoils was ascertained from trial well and production well logs, auger holes drilled by the GSI, knowledge of sites that have rock cropping out, and areas indicated by Teagasc mapping as having rock close to surface.

At the source itself, depth to bedrock reaches 20.4 m. Boreholes in the general area are drilled to a depth of between 5.5 m and 10 m and did not encounter bedrock. Rock outcrop and subcrop occur to the north, where the bedrock rises to form the Carlingford Mountains. Shallow rock (2.4 m) was also found at Rathcor approximately 1 km west-southwest of the source.

8 GROUNDWATER VULNERABILITY

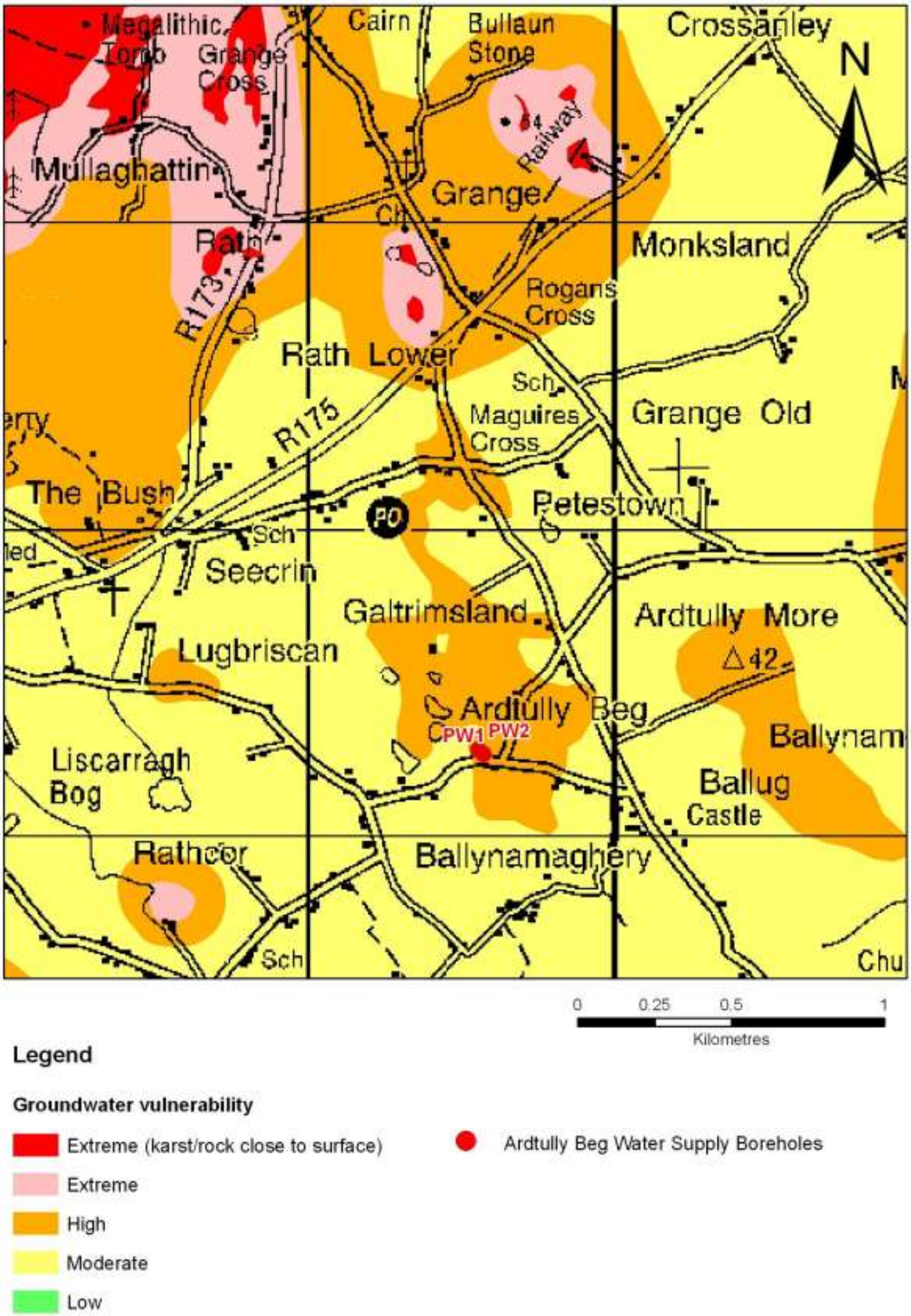
Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target'. Consequently, vulnerability relates to the thickness of the unsaturated zone in the gravel aquifer and the permeability and thickness of the subsoil in areas where the gravel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

The groundwater supply source is the bedrock aquifer beneath the ground surface. For the purposes of vulnerability mapping, the "**top of the rock**" is the target. In unconfined sand and gravel aquifers, the **water table** is the 'target'. Therefore, where the water table is less than 3 m from ground surface, vulnerability is extreme. Elsewhere in the sand and gravel aquifer, vulnerability is high.

The vulnerability of groundwater to pollution around Ardtully Beg is shown in

Figure 6.

Figure 6: Groundwater vulnerability in the vicinity of Ardtully Beg



The permeability of the sand & gravel deposits (GGr and GLPSsS) is high. Regionally, the permeability of the till deposits (TGr and TLPSsS) is classed moderate, although in the vicinity of the source these deposits are quite variable and there are places where very locally the permeability tends towards high.

The depth to bedrock across the area is variable, but predominantly greater than 10 m in the immediate area around the supply boreholes. Subsoil thicknesses decrease northwards, as the till covering the upland areas pinches out. There is also a small area of thin (<3 m) subsoils at Rathcor, WSW of the supply source.

At the source boreholes, and across most of the gravel aquifer, the vulnerability is classified as high. In the vicinity, much of the area surrounding the source has moderate groundwater vulnerability. There is a small area of extreme vulnerability about 1 km to the WSW of the source. Extreme vulnerability areas also occur on the upland areas north of the gravel pits at The Bush. There are small areas of marly deposits and cut peat, which are interpreted as areas where the water table is close to the ground surface.

9 HYDROGEOLOGY

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

- Results of Step Drawdown and Constant Yield hour pumping tests on Exploration Wells (No. 1 and No.5) performed by K.T. Cullen & Co. (KTC) in 1983;
- Local hydrogeological mapping carried out by the GSI and Tobins Environmental Ltd as part of the National Vulnerability Mapping Programme;
- Drilling and permeability mapping carried out by GSI to ascertain depth to bedrock and subsoil permeability;
- Particle size analyses from Well No 1 (E Daly in KTC 1983);
- GSI files and Louth County Council data;
- Water quality test results from samples collected during the pumping tests at the exploration wells (KTC, 1983) and Louth County Council and EPA monthly water quality monitoring results.

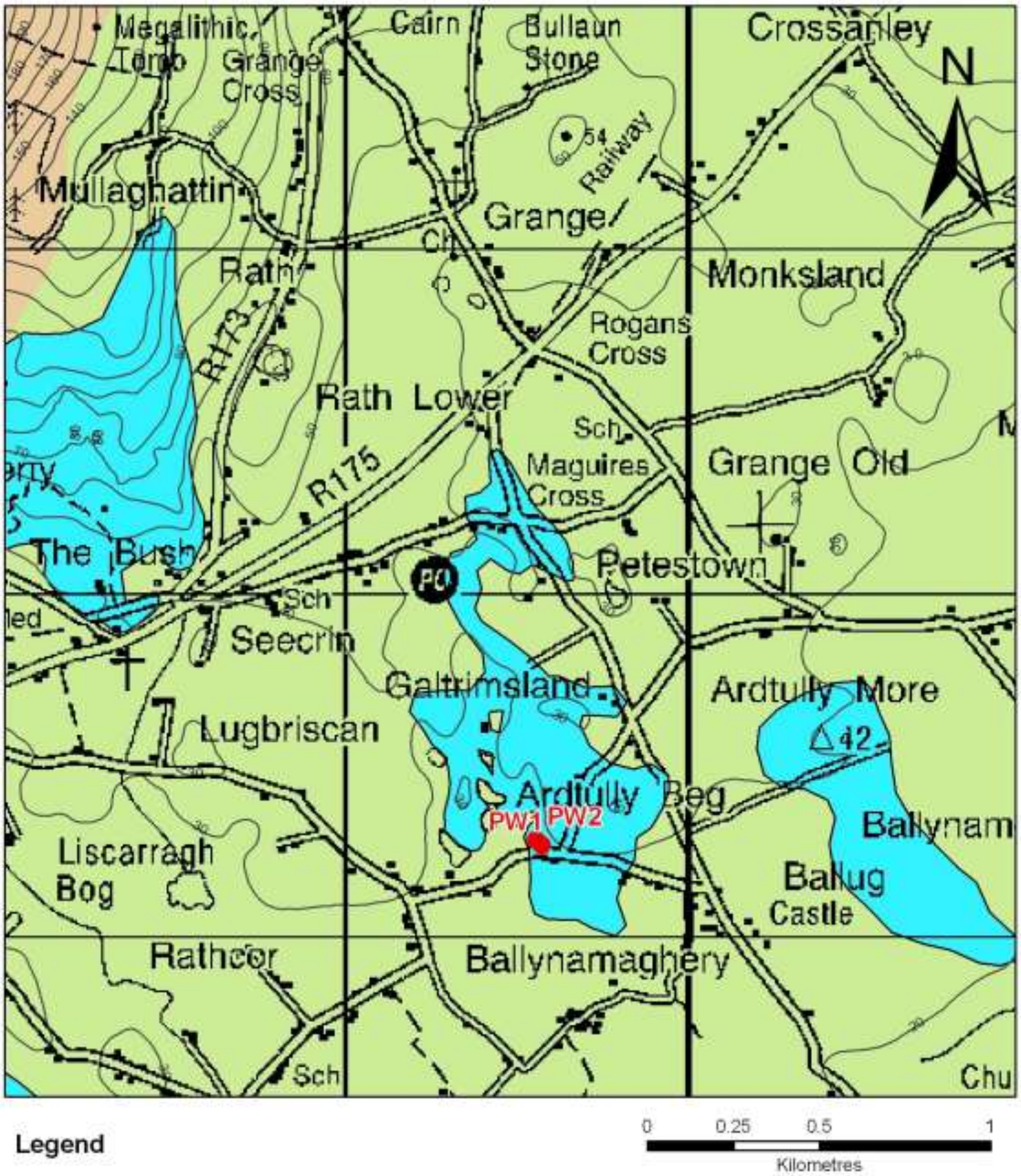
9.1 GROUNDWATER BODY AND STATUS

The Ardtully Beg source abstracts water from a **Locally Important Sand and Gravel Aquifer (Lg)**. Other sand and gravel aquifers in the vicinity include the deposits at Ardtully More, The Bush and Riverstown.

The sand and gravel aquifer at Ardtully Beg overlies limestone bedrock, which has been classified as **Locally Important Aquifer which Generally Moderately Productive (Lm)**. The granites that form the mountains to the north are classified as a **Poor Aquifer which is Generally Unproductive except for Local Zones (Pl)**.

The distribution of the aquifers in the Ardtully Beg area are shown in Figure 7.

Figure 7: Bedrock and Sand and Gravel aquifers in the vicinity of Ardtully Beg



Legend

Aquifer category

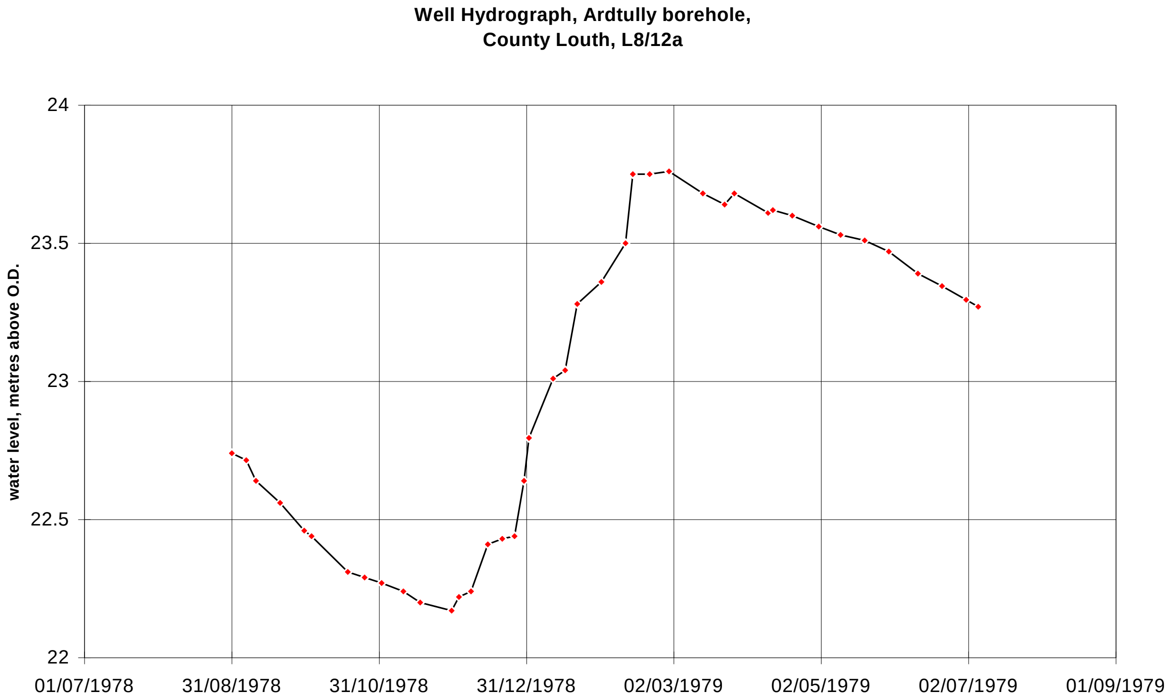
- Lg - Locally important sand and gravel aquifer
- Lm - Locally important bedrock aquifer which is generally moderately productive
- Pl - Poor bedrock aquifer which is generally unproductive except for local zones
- Ardtully Beg Public Water Supply boreholes
- Ground elevation contours (mAOD)

9.2 GROUNDWATER LEVELS, FLOW DIRECTIONS AND GRADIENT

In the sand and gravel aquifer at Ardtully Beg, the water table is within 5-6 m of the ground surface under unpumped conditions (approx. 22.5 mAOD). Pumping water levels are on the order of 9.8-10.5 mbgl (18.4-19.2 mAOD on 18/4/2006).

The water table in the sand and gravel aquifer fluctuates by about 1.5-2 m annually, as shown in Figure 8. This compares with annual groundwater level variations of between 0.65 m and 2.17 m at four other wells in the area (NERDO, 1981).

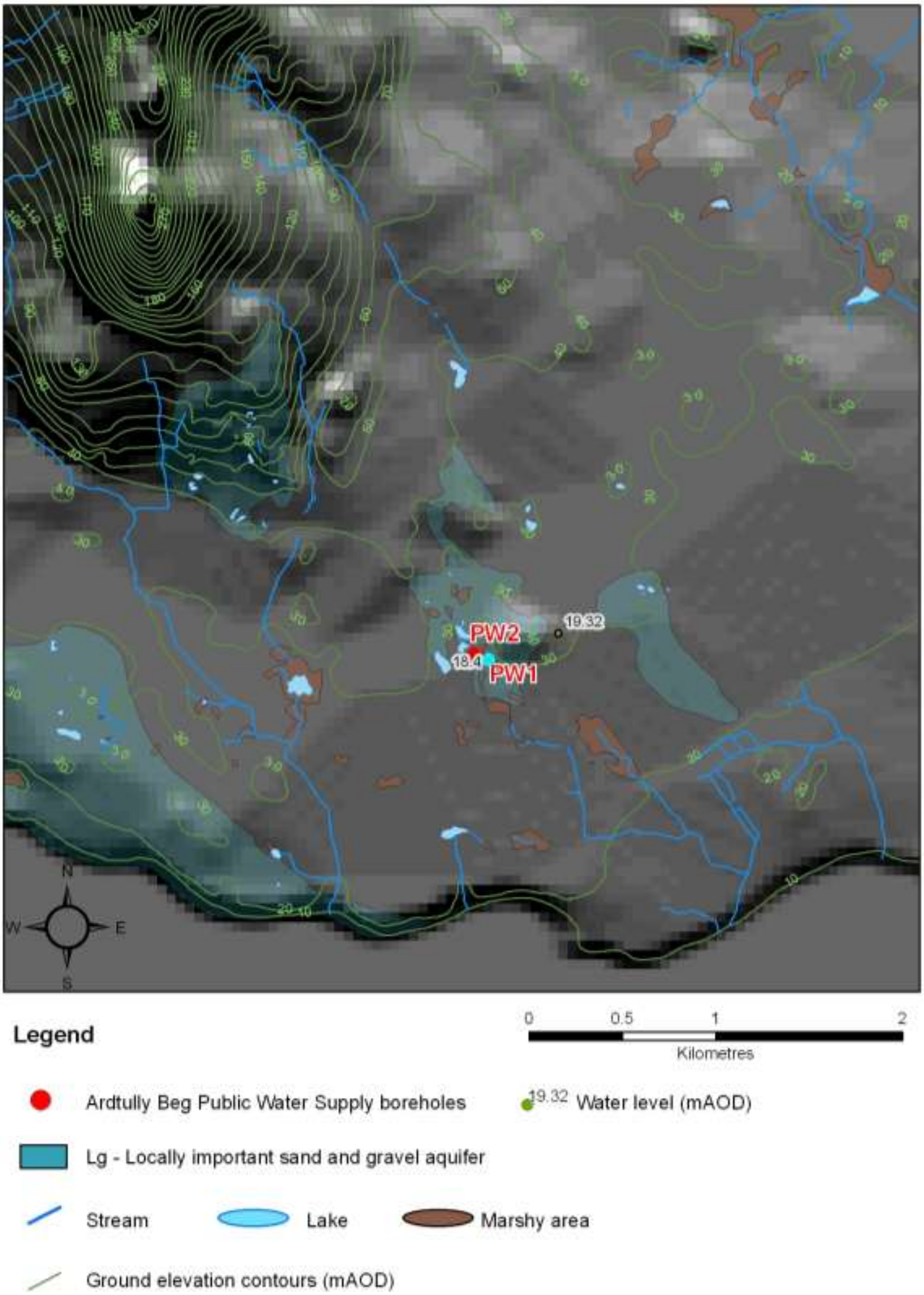
Figure 8: Variation in groundwater level at Ardtullybeg 1978-1979



There is one other known water level measurement from a nearby borehole in an area mapped as being covered by Lower Palaeozoic till. The water level in the 30 m borehole, which didn't encounter bedrock, is recorded as 11.6 mbgl. This is approximately 19.3 mAOD.

In locations where groundwater emerges at springs, or seeps to the surface causing marshy areas, the depth to the water table is effectively zero. These areas are identified from 1:10,560 (6" to 1 mile) and 1:5,000 OSi maps, and shown on Figure 9. These indicators should be used with caution, however, as it is likely that some of the features reflect shallow groundwater flow systems. For example, in parts of the sand and gravel deposits where clay interbeds prevent the downwards percolation of water, and cause perching of shallow groundwaters.

Figure 9: Topography and surface water in the vicinity of Ardtully Beg



The groundwater flow direction in both the sand and gravel aquifer and the bedrock aquifer is expected to be generally from north-northwest to south-southeast, following topography, with the groundwater ultimately discharging to the sea just over a kilometre to the south of the boreholes. The northwest-southeast orientation of the faults in the bedrock may additionally influence the groundwater flow direction.

On a local scale, the groundwater flow direction and gradient will be influenced by variations in the topography and by the depression in the water table caused by pumping in the immediate vicinity of the boreholes.

Due to limited data availability, groundwater gradients in the bedrock are difficult to calculate. Because the subsoils are high and moderate permeability, the groundwater is considered to behave as effectively unconfined, even in the parts of the bedrock aquifer where the piezometric surface (water table) is above the base of the subsoils. Thus, in this area, the water table will be a subdued reflection of topography, so will be slightly less than ground surface gradients. Where the water table intersects the ground surface, it emerges as springs, ponds or marshy areas above seeps. As noted above, however, these features should be used with caution when estimating groundwater levels, as it is likely that some of the features reflect shallow groundwater flow systems.

North of the R175, the topography steepens considerably, ranging from 0.1 to 0.17. The water table will also steepen, but not at the same rate, and depth to water from the ground surface will increase considerably in the sands and gravels (except in areas where the unsaturated part of the sand and gravel deposit have been removed by quarrying). South of the R175, the topographic gradient ranges from 0.008-0.012, becoming flatter towards the coast.

Over much of the area, the groundwater gradient is downwards – i.e. groundwater is recharged. However, in the area between the boreholes and the coast, an increase in the number of streams, ponds and marshes indicate that groundwater is discharging to the surface. In this area, the hydraulic gradient will be generally slightly upwards.

9.3 HYDROCHEMISTRY AND WATER QUALITY

EPA water quality monitoring data for the Ardtully Beg Source are available since 1995. The data are assessed against EU Drinking Water Standards and against the Interim Guideline Values (IGV's) (EPA, 2003: Towards Setting Guideline Values for the Assessment of Groundwater) as well as recommended threshold values set by the GSI. The latter and the IGVs were established to assess the degree of contamination and therefore whether appreciable impact is occurring. Guidelines values set for key parameters are outlined in Table 2.

Table 2 Water Quality Assessment Standards

Parameter	Threshold Value [1] mg/l	Drinking water limit [2] mg/l
Nitrate	25	50
Potassium	4	12
Chloride	25	250
Ammonia	0.15	0.3
K/Na ratio	0.4[3]	-
Faecal bacteria	0	0

[1] Interim Guideline Values (EPA, 2003: Towards Setting Guideline Values for the Assessment of Groundwater)

[2] S.I. 278, 2007

[3] GSI Guidance Note- Assessing groundwater quality, some useful tips.

The following key points are identified from the data for the Ardtully Beg Group Water Scheme:

- The hydrochemical analyses show that the Ardtully Beg source water is hard to very hard (total hardness in the range of 262 mg/l $CaCO_3$ to 388 mg/l $CaCO_3$ (average 320 mg/l $CaCO_3$). This compares with a value of 320 mg/l $CaCO_3$ at the time of initial pump testing in 1982. This is higher than the recommended EPA threshold value and Drinking Water Standard of 200 mg/l $CaCO_3$. These values are based on scale formation and palatability rather than on health grounds. Total hardness is normally around 200 mg/l $CaCO_3$ in this aquifer (Daly, 1980 in NERDO, 1981).
- Electrical conductivity for monitored period is in the range 632-697 µs/cm with an average of 671 µs/cm. However, the initial water quality results at the time of pump testing was significantly lower (450 µs s/cm).
- Chloride values range from 28 to 45 mg/l, and are on average 31 mg/l. In general, chloride is slightly higher than the EPA threshold value of 30 mg/l. However, in a coastal area such as the Carlingford Peninsula, background concentrations of chloride are expected to be 30-35 mg/l due to rainwater enrichment by sea spray.
- Nitrate ranges from 24.8 to 36 mg/l with an average of 31 mg/l, generally exceeding the EPA threshold of 25 mg/l, indicating some impact from organic waste has occurred. However, the drinking water standard of 50 mg/l was not exceeded.
- Potassium exceeded the threshold level of 5 mg/l in January 04 (6.8 mg/l) and March 05 (6.3 mg/l). At this time the K:Na ratio slightly exceeded the threshold of 0.4 indicating contamination impact from an organic source such as agricultural or septic tank waste. However the drinking water standard of 12 mg/l was not exceeded.
- Anomalously high iron levels were found in December 1995 (7.85 mg/l) however all of the remaining results were normal and within acceptable limits.
- The total coliform count fluctuates from 0 to greater than 200 (August 2004). However, faecal coliforms were detected only once (1 cfu in August 1996).
- Normal levels of trace metals were identified, safe for drinking.

- The water appears to be free of chlorinated hydrocarbons, solvents and pesticides, based on test results.

Overall, the samples from the source wells indicate contamination or pollution of these wells by agricultural sources. The presence during testing of occasional coliforms suggests that contamination events have occurred within the inner protection area, either due to insufficient well head protection, or pollution into the ground very close to the abstraction boreholes.

Figure 10: Variation of nitrate concentrations at Ardtully Beg Public Supply Source

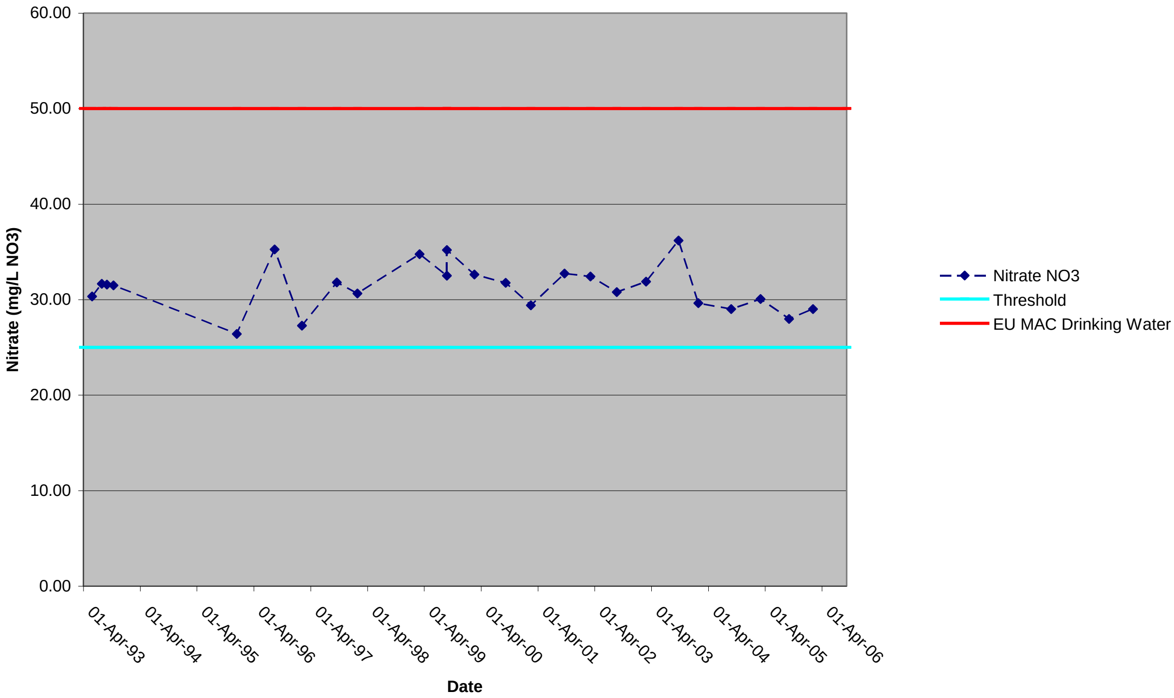


Figure 11: Variation of chloride concentrations at Ardtully Beg Public Supply Source

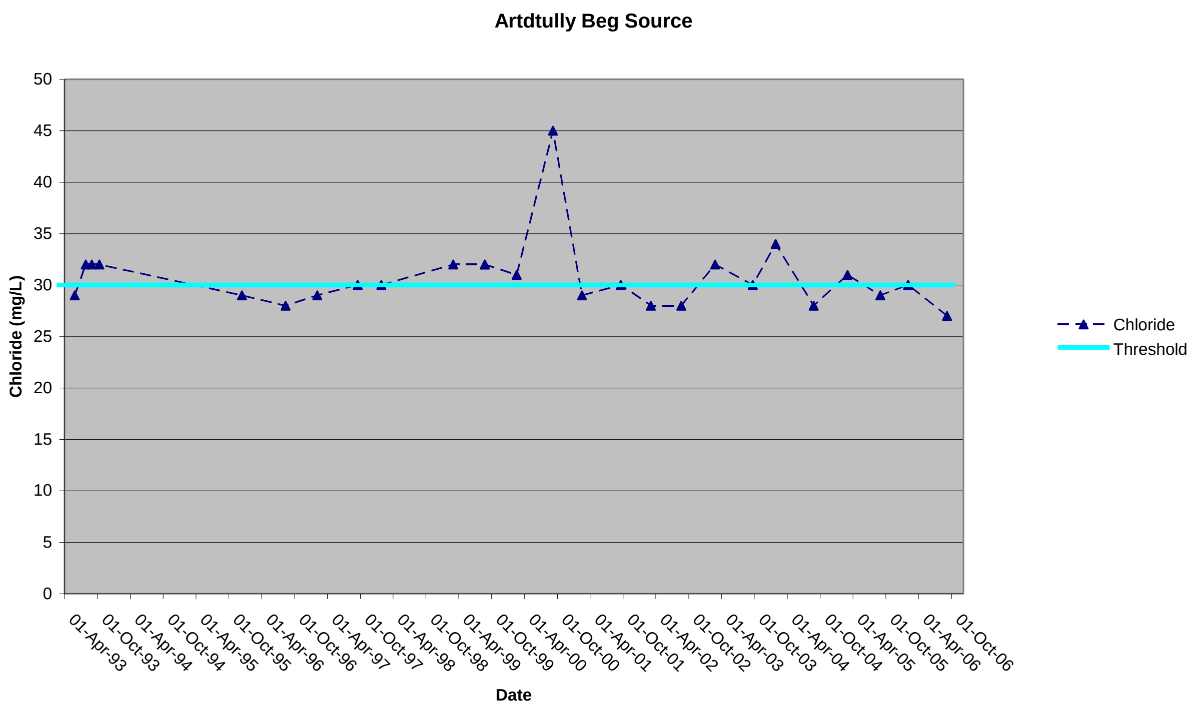
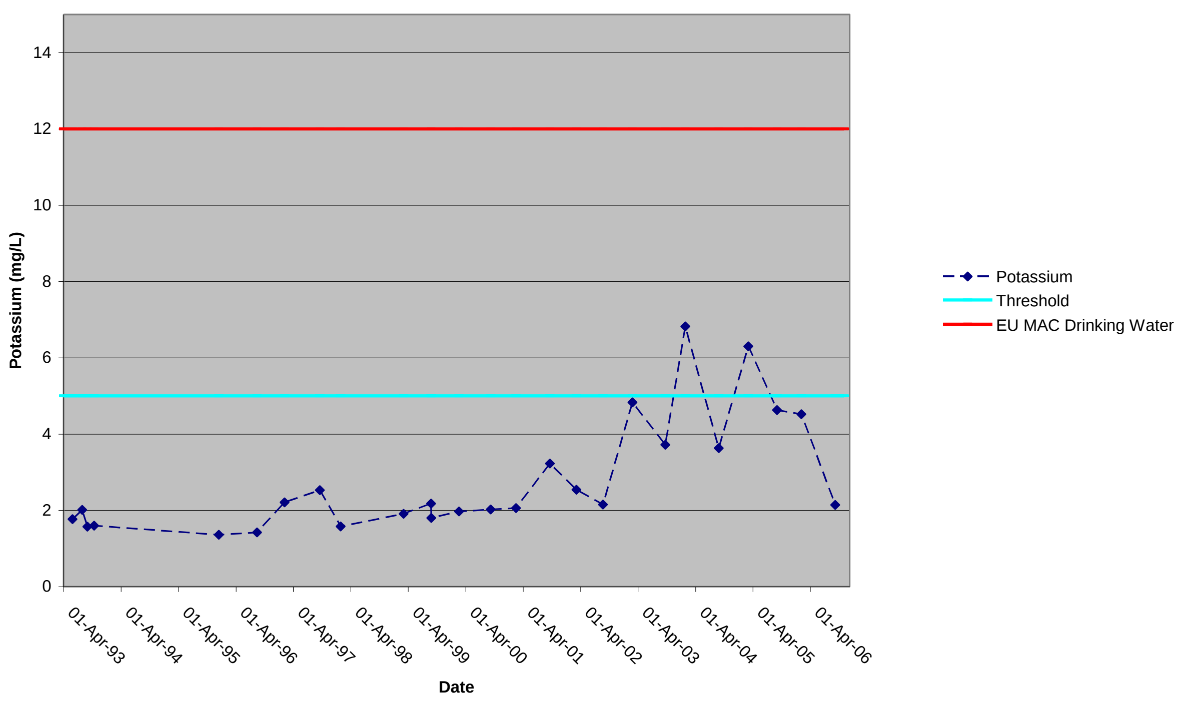


Figure 12: Variation of potassium concentrations at Ardtully Beg Public Supply Source



9.4 AQUIFER CHARACTERISTICS

The aquifer characteristics have been determined from available pumping test and abstraction data which include:

- Pumping tests (24 hour and Step) on Well No. 1 in March 1977 (Nicholas O'Dwyer data reproduced in K.T. Cullen, 1983);
- Step tests on Well No's 1 and 5 in December 1982 (K.T. Cullen & Co. 1983);
- Daily pumping volumes from Louth Co. Co. for PW 1 (Well No 1) and PW2 (Well No 5) for 2008;
- An Foras Forbatha/GSI (1982).

At Ardtully Beg, the sand and gravel aquifer is at least 19.5 m thick, with a saturated thickness of approximately 15 m. The sands and gravels are not uniform, but are shown to be layered (An Foras Forbatha/GSI, 1982).

Pumping tests on both wells indicate a transmissivity of 1,000m^2/d, and a specific yield of 0.1 (An Foras Forbatha/GSI, 1982). For a saturated thickness of approximately 15 m, this is a permeability of about 65 m/d. This is in the typical range of transmissivities for sands and gravels elsewhere, i.e. 50-100 m/d.

There are no data available from the locality for the limestone bedrock aquifer. Groundwater flow is through fissures and fractures in the bedrock, and can be very heterogeneous, depending on the distribution of fracturing in the bedrock unit. Transmissivity values from similar aquifers in other areas are on the order of 10-50 m^2/d, but can be much higher in significantly faulted areas (100-200 m^2/d). Effective porosities are typically 0.01-0.02.

10 ZONE OF CONTRIBUTION (ZOC)

This section delineates the areas around the wells that are believed to contribute groundwater to the wells, and that therefore require protection. The areas are delineated based on the conceptualisation of the groundwater flow system. Two source protection areas are delineated:

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

10.1 CONCEPTUAL MODEL

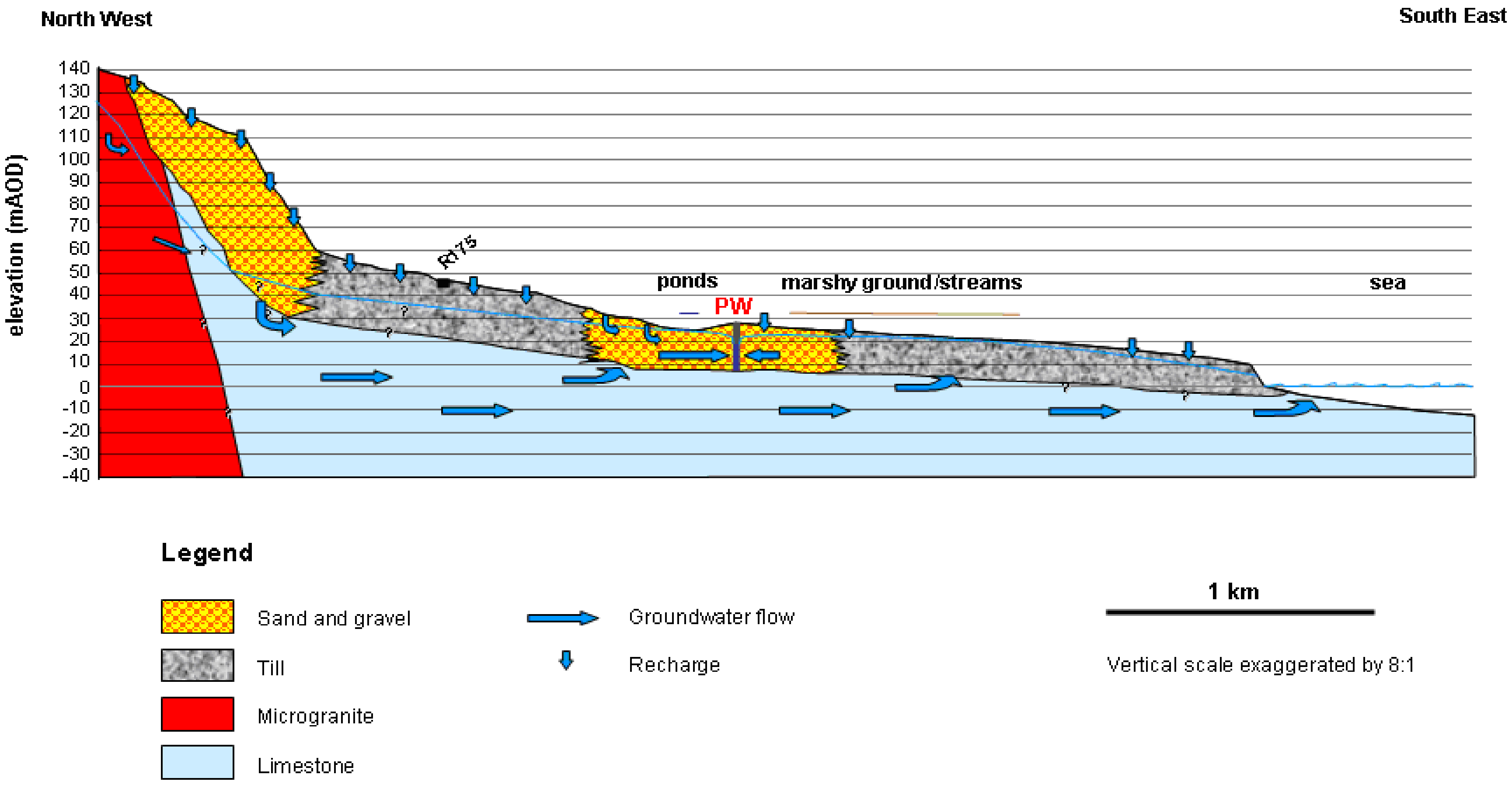
This section provides a qualitative overview of the geological framework, recharge, flow and discharge patterns across the aquifer contributing groundwater to the source. It summarises the main inferences drawn in previous sections, and provides a foundation upon which the quantitative analyses required for delineating source protection areas can be drawn.

The conceptual model is based on available data in relation to the source and in the vicinity of the source. The key points are outlined below, and summarised in Figure 13.

- The Ardtully Beg water supply source abstracts groundwater from a glacio-fluvial sand and gravel which is classified as a **locally important sand and gravel aquifer (Lg)**.

- The gravel aquifer is underlain by Dinantian Undifferentiated Limestones which are classified as a **locally important aquifer which is generally moderately productive (Lm).**
- Groundwater flow within the sand and gravel aquifer is intergranular, whereas in the bedrock it is through fractures and fissures in the limestone.
- Groundwater in the sand and gravel aquifer is thought to be unconfined and in hydraulic communication with the underlying bedrock aquifer. The saturated thickness of the sand and gravel aquifer at the source is about 15 m.
- The sand and gravel aquifer has high permeability, transmissivity and effective porosity. Transmissivities and effective porosities in the underlying limestone bedrock aquifer will be lower. NW-SE faulting at the boundary between the limestone and the granites may extend southeastwards to the area around the boreholes, potentially increasing the fracturing and permeability of the bedrock aquifer.
- The groundwater flow direction is generally north-northwest to south-southeast, from the higher ground north of the boreholes, to the sea. Faults in the bedrock have a NW-SE orientation, which may additionally influence groundwater flow direction.
- The recharge area is considered to be in the area north of the public water supply boreholes, with the higher elevation providing the driving head for groundwater flow. An increase in drainage density towards the sea indicates that groundwater is discharging in the area south of the boreholes.
- Groundwater is thought to flow upwards from the limestone bedrock aquifer into the sand and gravel aquifer at Ardtully Beg, at least over part of its extent, as indicated by the groundwater chemistry – very hard groundwaters are not typical from gravels derived from Lower Palaeozoic sandstones and shales – and the location of the boreholes between general groundwater recharge and groundwater discharge areas.
- The till subsoils in the vicinity of the boreholes are moderately permeable. The sand and gravel aquifer is high permeability. Subsoil thicknesses in the area south of the R175 are typically greater than 10 m. The groundwater vulnerability over the sand and gravel aquifer is high, and over most of the rest of the area around the public supply boreholes it is moderate.
- The high and moderate groundwater vulnerability hydrogeological setting lends itself to good groundwater recharge rates. However, this very permeability limits the effectiveness with which the subsoils protect the groundwater, and nitrates in the groundwater are elevated, with contamination from an agricultural source indicated.
- Recharge to the Ardtully Beg sand and gravel aquifer is estimated as approximately 560 mm/yr. Recharge to the limestone bedrock aquifer, where it is overlain by tills, is on the order of 265 mm/yr. Where bedrock is overlain by high permeability gravels, recharge will be higher.

Figure 13: Conceptual model shown schematically for groundwater flow in the vicinity of Ardtully Beg



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

11 DELINEATION OF SOURCE PROTECTION AREAS

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

11.1 OUTER PROTECTION AREA

The Outer Protection Area (SO) is bounded by the complete catchment area to the source, i.e. the zone of contribution (ZOC), which is defined as the area required to support abstraction from long-term recharge. The ZOC is controlled primarily by a) the total discharge, b) groundwater flow directions and gradients, c) sand/gravel and bedrock aquifer permeabilities and d) the recharge in the area. The shape and boundaries of the ZOC have been determined using hydrogeological mapping, water balance estimations, and a conceptual understanding of groundwater flow. The boundaries

The current combined abstraction rate at the Ardtully Beg boreholes is about 1,020 m^3/d (end of 2008). The ZOC is delineated for the current abstraction rate plus 50%, to allow for potential future increases in demand, and also to allow for an expansion of the ZOC during dry weather. The recharge area required to supply the source at an abstraction rate of approximately 1,500 m^3/d (abstraction + 50%) is 1.4 km^2 (see section 11.2).

In delineating the ZOC, the following have been taken into account: (i) the areal extent of the sand and gravel aquifer, (ii) regional topographic gradients and local topographic divides, (iii) probable groundwater flow into the sand and gravel aquifer from the underlying bedrock aquifer (iv) faulting directions in the bedrock aquifer. The calculations and hydrogeological reasoning employed to give the resulting boundaries are described below, together with the uncertainties associated with them.

Hydrogeological mapping and analytical equations were used to delineate the boundaries of the ZOC:

North-western boundary: The hill at Rath Lower determines the up-gradient ZOC extent, as the topographic divide is assumed to coincide with a local groundwater divide. Groundwater north of this boundary flows into the river flowing next to the R173.

South-western boundary: This boundary is the lateral boundary of the ZOC. Nearer to the borehole, it is constrained by the mapped extent of the sand and gravel aquifer. Further upgradient (north), this lateral boundary of the ZOC is in the bedrock aquifer. A local topographic divide is used to constrain its position.

North-eastern boundary: This boundary is the lateral boundary of the ZOC. It is also constrained by the mapped extent of the sand and gravel aquifer in the area near to the borehole. Further upgradient (north), this lateral boundary of the ZOC is in the bedrock aquifer. A local topographic divide is used to constrain its position.

The width of the ZOC is controlled by the lateral extent of the sand and gravel aquifer, and also the transmissivity of both the sand and gravel aquifer and the bedrock aquifer. These boundaries are drawn such that the size of the ZOC matches that determined from the water balance (see section 11.2 below) as being required to balance out a daily abstraction of 1,500 m^3/d. The topographic variations in the area underlain by the bedrock aquifer are small and are therefore relatively weak controls on the lateral boundaries of the ZOC.

The Uniform Flow Equation (Todd, 1980) was applied to check the theoretical maximum ZOC width:

$$\text{Approximate width of ZOC} = \frac{\text{Abstraction rate}}{\text{transmissivity} \times \text{hydraulic gradient}}$$

$$\text{for gravels} = 1{,}500 / (1{,}000 \text{ x } 0.01)$$
$$= 150 \text{ m}$$

$$\text{for limestone} = 1{,}500 / (100 \text{ x } 0.01)$$
$$= 1{,}500 \text{ m}$$

Overall, the ZOC has a north west-south east trend. The orientation of the ZOC is influenced by the shape and orientation of the sand and gravel aquifer. The main axis of the ZOC is determined by the groundwater flow direction. This is, in turn, controlled by topography. It is thought that the orientation of faulting in the bedrock aquifer may also influence groundwater flow directions.

South-eastern boundary: This boundary is formed the down-gradient limit of the zone of contribution. The sand and gravel aquifer is mapped as extending more than 200 m south of the pumping boreholes. This is taken to be the maximum limit on the downstream boundary. The downstream limit is further constrained by using analytical equations, using the Uniform Flow Equation (Todd, 1980):

$$\text{Approximate down-gradient extent of ZOC} = \frac{\text{Abstraction rate}}{2 \times \Pi \times \text{transmissivity} \times \text{hydraulic gradient}}$$

$$= 1{,}500 / (2 \text{ x } 3.14 \text{ x}1{,}000 \text{ x } 0.01)$$

$$= 24 \text{ m}$$

In summary, the ZOC constrained by hydrogeological mapping, with consideration of the recharge area indicated to be required using a water balance. The ZOC is shown on Figure 14 as the SO (ZOC), and has an area of 1.4 km^2. An increase in abstraction rate above the 1,500 m^3/d allowed in the above calculations would require the ZOC to expand. The current understanding of the flow system indicates that the north-western ZOC boundary would move northwest-wards, with the width of the ZOC increasing also. There would also be a small increase in the downstream extent of the ZOC.

11.2 RECHARGE AND WATER BALANCE

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

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

The area underlain by the Ardtully Beg sand and gravel aquifer is, in the main, characterised by shallow, well-drained mineral soils and high permeability subsoils. The WGGW table suggests recharge coefficient (Rc) inner ranges of 80-90% and outer ranges of 60-100%. There is a virtual absence of surface drainage channels, although there are small waterlogged marly and peaty areas in enclosed topographic depressions. Thus, an Rc of 85% is used, giving a recharge estimate of 563 mm/yr over the sand and gravel aquifer.

In the area where the bedrock aquifer is covered by moderate permeability tills, moderate vulnerability predominates (see Sections 7.2 and 8), and the mineral soils are deep and well-drained. For this hydrogeological setting, the Rc outer range is 25-60%, with an inner range of 30-40%. The area is flat-lying, with an average ground surface gradient of 0.01, and with low drainage density overall (drainage density increases in the zone between the pumphouse and the sea). Therefore, an Rc of 55% is considered to be appropriate, giving a recharge estimate of 364 mm/yr to the limestone bedrock aquifer overlain by moderate permeability till. Recharge to the poorly productive granite-type bedrock aquifer is limited by its inability to accept and transmit away the recharging waters. Therefore, the WGGW suggests a cap of 100 mm/yr is applied to recharge for these aquifers.

Estimates of runoff can be made by considering the part of the effective rainfall which does not infiltrate to groundwater. These calculations are summarised in Table 3.

Groundwater flow volumes in the sand and gravel aquifers are likely to be increased by groundwater inflowing from the underlying bedrock aquifer.

Table 3: Recharge Estimates

Average annual rainfall	1,067 mm
Estimated annual P.E.	440 mm
Estimated annual A.E. (92% of P.E.)	405 mm
Annual effective rainfall	662 mm
Recharge coefficient (sand & gravel)	85%
Annual recharge (sand & gravel)	**563 mm**
Recharge coefficient (bedrock aquifer)	55%
Annual recharge (Lm bedrock aquifer)	**364 mm**
Annual recharge (Pl bedrock aquifer)	**100 mm**
Annual runoff (range)	99-552 mm

The total estimated recharge to the groundwater supply source is discussed below. Firstly, a water balance was undertaken to assess whether all of the groundwater abstraction could be provided by the sand and gravel aquifer.

Water Balance: A basic water balance calculation is used to determine the size of the ZOC required to supply the abstracted groundwater. The average long-term recharge is about 560 mm/yr over the sand and gravels, and about 265 mm/yr over the till-covered bedrock aquifer. The daily abstraction plus 50% is about 1,500 m^3/d, thus:

Recharge area required to sustain discharge	= annual abstraction ÷ average annual recharge (gravel aquifer) = (1,500 m^3/day × 365 days) ÷ 0.56 m = 0.98 km^2.

This area is more than twice the size of the gravel aquifer (mapped areal extent 0.414 km2). Therefore, further calculations are required, based on the areal extent of the gravel aquifer:

Approximate area of sand and gravel aquifer upstream (northwest) of the Ardtully Beg boreholes (width x upstream length)	= 400 m x 500 m = 0.2 km^2
Average daily recharge over 0.2 km^2 extent of sand and gravel aquifer	= average annual depth of recharge x area of aquifer ÷ 365 = 0.56 x 200,000 ÷ 365 = 307 m^3/d

The additional area required to balance the remainder of the abstraction is calculated as follows:

Remainder of the abstraction	= daily abstraction + 50% - estimated recharge over sand and gravel aquifer = 1,500 m^3/d – 307 m^3/d $\approx$ 1,200 m^3/d
Area required to support remainder of abstraction at recharge rate for the limestone bedrock aquifer	= remainder of the abstraction ÷ average annual recharge = 1,200 x 365 ÷ 0.364 = 1.2 km^2

Therefore, the total area required to sustain a discharge of 1,500 m^3/d is approximately 1.4 km^2.

11.3 INNER PROTECTION AREA

The Inner Source Protection Area (SI) is the area defined by a 100-day time of travel (ToT) from any point below the watertable to the source (DoELG, EPA, GSI, 1999). It is delineated to protect against the effects of potentially contaminating activities that may have an immediate influence on water quality at the source, in particular microbial contamination. The 100-day horizontal time of travel to the source is calculated from the velocity of groundwater flow in the bedrock. The velocity multiplied by the 100 day time period gives the distance travelled by the groundwater during the TOT. This distance gives the lateral extent of the buffer which must be applied around the source to form the SI. By using the aquifer parameters for permeability and hydraulic gradient, 100-day ToT estimations are made. Estimations of the extent of this area are made using Darcy’s Law, which can be used to calculate average groundwater velocities. The parameters of the sand and gravel aquifer are used:

Velocity = (gradient x permeability) ÷ porosity
= 0.01 x 60 ÷ 0.1
= 6 m/d

The distance travelled in 100 days is therefore 600 m. Accordingly, the boundary of the SI is approximately 600 m north of the boreholes. The SI takes in all the area to the south of the boreholes. The remainder of the ZOC is classified as the Outer Source Protection Area (SO). The SO and SI areas are shown on Figure 14.

12 GROUNDWATER SOURCE PROTECTION ZONES

The groundwater protection zones are obtained by integrating the two elements of land surface zoning (source protection areas and vulnerability categories) – there are eight possible source protection zones. In practice, the source protection zones are obtained by superimposing the vulnerability map on the source protection area map. Each zone is represented by a code (e.g. **SI/H**, which represents an Inner Protection area where the groundwater is highly vulnerable to contamination). These are on the final source protection map, which is presented in Figure 15. Four groundwater protection zones are present around the Ardtully Beg public supply wells as shown below in Table 4.

Table 4: Matrix of Source Protection Zones for the Ardtully Beg public supply

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

Figure 14: Zone of contribution (ZOC) to the Ardtully Beg wells, showing the Inner (SI) and Outer (SO) protection zones. See text and Table 4 for explanation

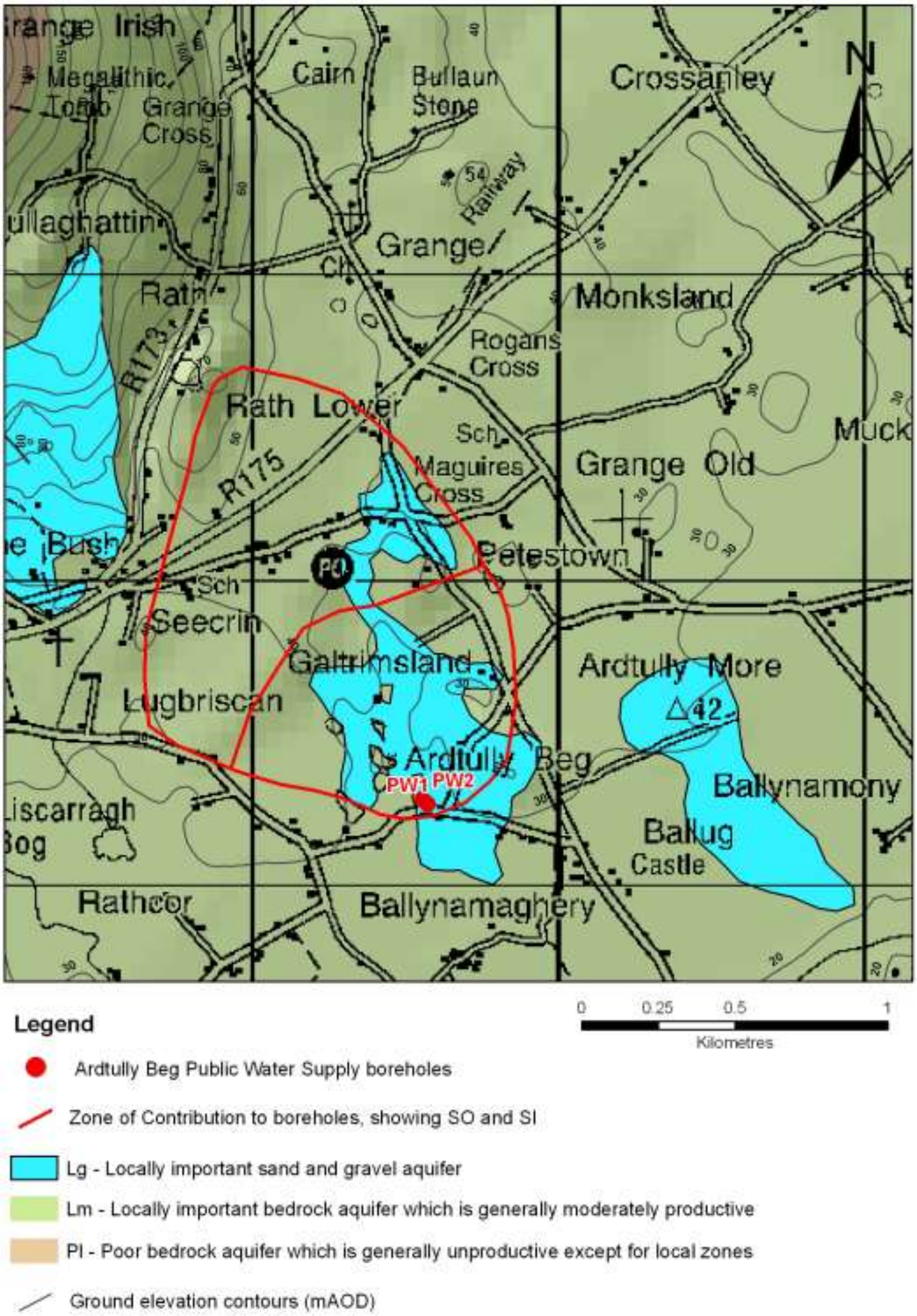
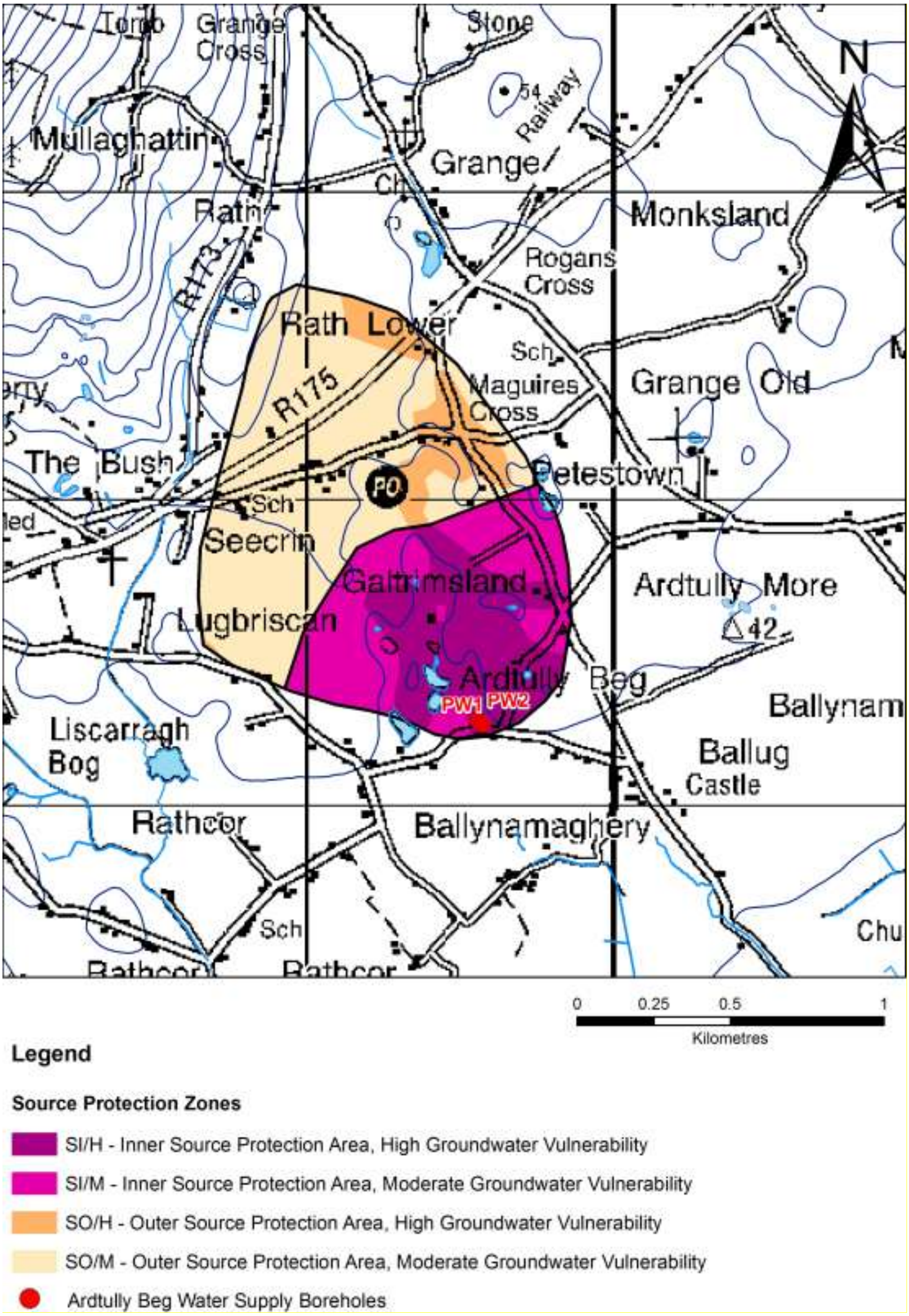


Figure 15: Source Protection Zones (SPZ) around the Ardtully Beg wells. See text and Table 4 for explanation



13 POTENTIAL POLLUTION SOURCES

The boreholes draw groundwater from the sand and gravel aquifer and the underlying fractured bedrock aquifer. In general, sands and gravels provide good filtration of particulate and microbial contaminants. However, other contaminants such as nitrates are not attenuated within sands and gravels. Groundwater and contaminants within fractured bedrock travel faster and have less attenuation than in sands and gravels. The lands around the wells are primarily used for tillage and grazing. There are also regional and local roads traversing the ZOC. The main potential sources of contamination within the ZOC are:

- Direct microbial contamination of the source from any water entering the well head chamber. The ponded water may enter via drainage along service ducts or seepage through the chamber walls. This water may be contaminated by animals and birds. The main potential contaminants from these sources are faecal bacteria, viruses and cryptosporidium.
- Agricultural landuse comprising a mix of pasture and arable uses occupies a significant part of the zone of contribution. It is likely that landspreading of organic matter from agricultural sources (*e.g*. cattle slurry) takes place within the delineated ZOC. The main potential contaminants from these sources are the same as for sewerage, plus pesticides.
- Domestic waste water systems from any unsewered houses in the ZOC could give rise to groundwater contamination if not properly constructed and maintained. The main potential contaminants from this source are ammonia, nitrates, phosphates, chloride, potassium, BOD, COD, TOC, faecal bacteria, viruses and cryptosporidium.
- Roadways are present within the ZOC. The main potential contaminants from this source are hydrocarbons and metals.

Overall, the main potential sources of pollution within the ZOC are grazing animals, applied fertilisers, pesticides and herbicides applied to crops, livestock; and septic tank systems. The main potential pollutants are faecal bacteria, viruses, Cryptosporidium, and nitrogen.

14 CONCLUSIONS

- The boreholes at Ardtully Beg are located in a **locally important sand and gravel aquifer (Lg)**.
- Groundwater abstracted by the boreholes comprises a mixture of water that has recharged the sand and gravel aquifer and groundwater that has travelled through the underlying limestone bedrock aquifer (**a locally important aquifer that is generally moderately productive, Lm**). The bulk of the groundwater comes from the fissured bedrock aquifer.
- Over most of the zone of contribution, groundwater vulnerability is high or moderate.
- Much of the area is covered by free draining soils and subsoils, which permits high recharge to the sand and gravel aquifers. These vulnerability classes generally provide good protection against bacterial contamination; chemical contamination can be an issue in this vulnerability setting, however.

- The water quality data shows that most relevant parameters are within drinking water standard limits. However, nitrate concentrations are consistently above the GSI threshold of 25 mg/l. Although faecal coliform have been detected only once, total coliforms have been detected more frequently, which indicates a rapid pathway from the contamination source to the supply boreholes.
- The Protection Zones delineated in this report are based on the current understanding of groundwater conditions and on the available data. Additional data obtained in the future might indicate that amendments need to be made to the boundaries of the ZOC and/or the sand and gravel aquifer.

15 RECOMMENDATIONS

Overall, our recommendations are as follows:

1. The headworks of the boreholes should be modified such that the borehole liner pipe is sufficiently elevated above the base of the chamber. This is to prevent ingress of surface waters that have entered the borehole chamber entering the borehole directly over the lip of the liner.
2. Nitrate concentrations show that there is an appreciable impact already occurring within the borehole catchment. A Source Protection Plan should be implemented, incorporating the code of Good Agricultural Practice.
3. The potential hazards in the ZOC should be identified, and a risk assessment of each hazard is recommended.
4. Particular care should be taken when assessing the location of any activities or developments within the inner protection area (SI) that might cause contamination at the boreholes.
5. Monitoring of water levels in the pumping wells and in nearby observation wells should be undertaken, in order to establish better control on groundwater flow directions.
6. Bacteriological analyses of raw water (rather than treated water) should be carried out approximately once a month to get baseline reference data. Following analysis of the data it may be decided to reduce the frequency to once every two or three months. Chemical analyses of the indicator parameters should be undertaken on a quarterly basis. A full suite of chemical analyses would be useful to establish baseline conditions.

16 REFERENCES

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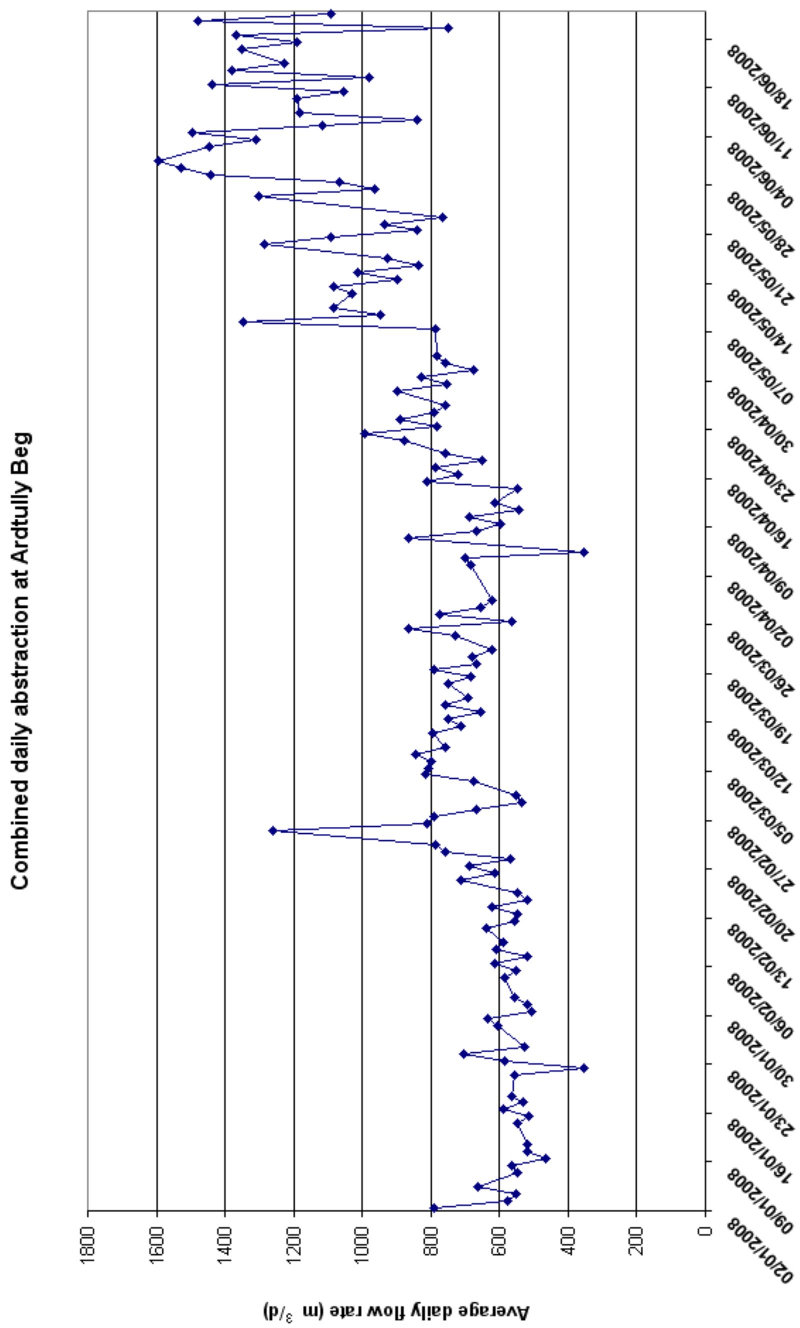
APPENDIX 1

Flow data: Combined pumping rates at Ardtully Beg in 2008


Combined daily abstraction at Ardtully Beg
Average daily flow rate (m 3/d)
1800
1600
1400
1200
1000
800
600
400
200
0
02/01/2008
09/01/2008
16/01/2008
23/01/2008
30/01/2008
06/02/2008
13/02/2008
20/02/2008
27/02/2008
05/03/2008
12/03/2008
19/03/2008
26/03/2008
02/04/2008
09/04/2008
16/04/2008
23/04/2008
30/04/2008
07/05/2008
14/05/2008
21/05/2008
28/05/2008
04/06/2008
11/06/2008
18/06/2008