Louth County Council

Establishment of Groundwater Source Protection Zones

Cooley Water Supply Scheme

Carlingford Boreholes

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PROJECT DESCRIPTION

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

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

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

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

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1 INTRODUCTION

The Carlingford Boreholes, which form part of the Cooley Water Supply Scheme, are located in the southern suburbs of the town of Carlingford, at the eastern end of the Cooley Peninsula in northeast County Louth.

Louth County Council requested Source Protection Zone delineation for both the Carlingford Boreholes and 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 Cooley Water Supply. The Ardtully Beg Boreholes are considered in a separate report.

The objectives of the report are as follows:

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

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

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

2 METHODOLOGY

Details about the borehole source such as date commissioned, historical data and outline abstraction figures were obtained from County Council personnel. As well as this, the data collection process included the following:

- Interview with the acting caretaker, 23/02/2009.
- A desk study of existing geological and hydrogeological information was completed on 18/03/2009 and 19/03/2009, procured predominantly within the relevant GSI databases and maps.
- Detailed field survey of the subsoil geology, the hydrogeology and vulnerability to contamination was carried out by walkover stream surveys, logging of outcrops and exposures, and hand augering. This was completed on 23/03 and 25/03, 2009.
- Auger drilling of 9 no. boreholes was carried out by the GSI to ascertain depth to bedrock and subsoil permeability between 28/05/2007 and 05/06/2007.
- Analysis of field study results, previously collected data and hydrogeological mapping were used in order to delineate protection zones around the source.

3 LOCATION, SITE DESCRIPTION AND WELL HEAD PROTECTION

The boreholes' pumping station and pump house compound are located on a narrow, third class road just off the Regional R173 road, approximately 0.9 km south-southeast of the centre of the town of Carlingford. The location of the site is shown in Figure 1.

The area surrounding the boreholes is situated at the junction between a coastal lowland and the northeastern flank of a high ridge to the south, and seems to be a zone of groundwater discharge. The Ordnance Survey six inch map of the 1860's depicts a stream rising at the location of the pump house, with water emerging and flowing northwards through a marshy area, and into the sea at the Harbour (Figure 1). The area around the pump house is labelled 'Springfield' on this map.

The source was mooted as being a potential water supply when the adjacent sewage treatment works were completed in the 1990's. At that time, considerable quantities of groundwater were encountered when constructing the works, 100 m to the northeast of the now-utilised boreholes. An exploration borehole was then drilled to 13 m depth in September 1998 and a pumping test carried out on the groundwater there, suggesting a minimum yield of 2,000 m^3 per day (730,000 m^3 per year)[1]. The proposal was to abstract a maximum amount of 1,200 m^3 per day.

The scheme was then commissioned in 1998, as part of the augmentation scheme for the Ardtullybeg Source, but did not begin until 2000. By then a second borehole had been drilled, two metres away from to the first[2].

The pumphouse site area is only *c*. 150 m^2. It is fenced off with good quality fencing, and is further surrounded by dry grassland to the east, a recently-built housing estate and the Carlingford Wastewater Treatment Works to the north, and the southern Carlingford suburbs to the west and south.

The sanitary protection of the Carlingford boreholes appears satisfactory. The bores are situated within sunken concrete chambers (c. 1.5 m x 1 m) that are securely covered by lockable, galvanised steel lids, and are drained via ducts in the chamber. The chambers are situated to the immediate southeast of the pump house, in a tarmacadamed area. The pump control equipment and water treatment system is housed in the pump house, a separate, small brick building.

The groundwater is chlorinated and fluoridated on-site and then pumped to a 2,000 m^3 reservoir at Rath, 3.5 km to the south-southwest, *via* a 200 mm diameter watermain, where it is combined with water abstracted from boreholes at Ardtully Beg prior to distribution through the Cooley Water Supply piped network. The chlorination tank and chemicals are stored in the pump house and there is a tap for raw water samples.

[1] The maximum yield is given as 4,500 m^3/d, as quoted in historical Local Authority documentation on the boreholes.
[2] There are no logs available for this second borehole: data on it have come from the memories of Louth County Council personnel, rather than logged records.

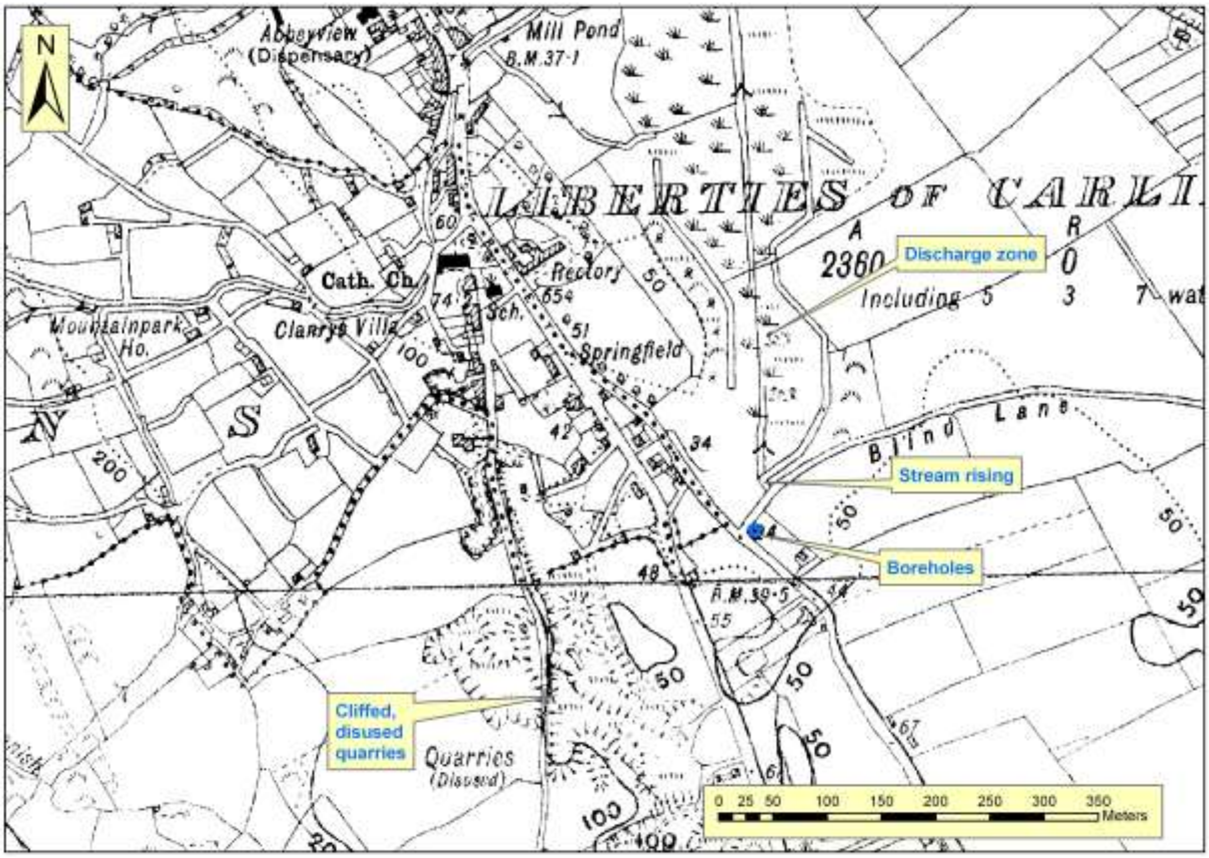

Figure 1: Location of the boreholes, as well as the rising stream and interpreted discharge zone to their immediate north. The deep, cliffed, disused quarries up-slope are also shown.

4 SUMMARY OF BOREHOLE DETAILS

Currently, the two boreholes are active and are pumped at a combined rate of 50 m^3/hr, 24 hours a day, resulting in a combined abstraction rate of 1,200 m^3/d.

Table 1: Summary of borehole details

Well Details	Well Name	
	PW1	PW2
Date Drilled	1998	1999
GSI Well Number	2929NEW123	2929NEW123
Grid Reference	319252 310894	319253 310893
Location (townland)	Liberties of Carlingford	Liberties of Carlingford
Well type	Bored	Bored
Owner	Louth Co. Co.	Louth Co. Co.
Ground elevation	7.5 mAOD	7.5 mAOD
Depth of borehole	13 m	21.3 m
Diameter of hole (mm)	250	250
Casing/screen diameter	250mm nominal	250mm nominal
Lithological Unit	Sand and Gravel	Sand and Gravel
Static water level (mbgl)	3.9 mbgl (09/02/2009)	3.9 mbgl (09/02/2009)
Static water level (mAOD)	3.6 mAOD approx (09/02/2009)	3.6 mAOD approx (09/02/2009)
Pumping water level (mbgl)	6.5 m approx. (09/02/2009)	6.5 m approx. (09/02/2009)
Pumping water level (maOD)	1.0 m approx. (09/02/2009)	1.0 m approx. (09/02/2009)
Average Current Abstraction (m^3/d)	1,200 combined yield	
Hours pumping	24 hours per day	24 hours per day
Depth of pump	~12 m	~19 m
Depth to bedrock	>13 m	>13 m (assumed)
Maximum Drawdown (m)	2.5 m	2.5 m
Estimated Potential Yield	2,000 m^3/day	
Treatment	Chlorinated and raw water tap available	
System	Submersible pump to mains *via* reservoir	

5 TOPOGRAPHY, SURFACE HYDROLOGY AND LAND USE

The boreholes are located in Hydrometric Area 6 of the Neagh-Bann River Basin District. The area's hydrology is characterised by a number of unnamed mountain streams rising high on the mount backslopes and flowing short distances into Carlingford Lough. These streams, forming a small but discrete hydrological area, occur only along the eastern flank of the Cooley Mountains between Omeath at the north, where they are flanked by the Newry River Catchment, and the Bush at the south, where they bound the Big River Catchment (Figure 2).

Figure 2: Topography and hydrology of the Carlingford peninsula. The short streams flowing from the mountains into the sea occur between The Bush and Omeath.

West of Carlingford Town the land rises steeply from the sea to the mountain summits, at an average topographic gradient of 0.33 (Figures 2 and 3). South of the town and in the vicinity of the boreholes the gradients are not as steep, at an average of 0.19, and a broad coastal plain opens up to the southeast. This area is comprised of gently undulating to rolling topography, with some small pockets of relatively hummocky terrain. The general altitude here is usually 5-25 mAOD.

The natural drainage density in the immediate vicinity of the source on its northern side is high owing to the presence of a flat, waterlogged area of alluvium/peat (Figure 1). Further west and southwest, the steep mountain slopes and associated streams also mean relatively high drainage densities where they feed surface water into the sea. A particularly long, large stream flows through the centre of Carlingford Town, 850 m north of the source. The artificial drainage density in the upland area to the southwest is low, however, as streams are relatively common and drains are not required.

To the east, south and west of the source, there are few surface drainage features, either natural or anthropogenic; only one stream is seen at Catherine's Grove, 1 km to the southeast, at the base of a deep glacial meltwater channel. It is interesting to note that, 450 m south of the source, two adjacent streams rise from a marked bedrock scarp (see section 7.2 below) but each disappears underground after a distance of 50-100 m. Cut drainage ditches are rare in this overall area.

Figure 3: Topography of the area around Carlingford Town, and the source. The high mountains to the west are clearly seen, as are the main hydrological features.

Small ponds and pools occur every now and then at the base of marked hollows to the south and southeast of the source; these seem to be no more than areas where the water table breaks the surface, and have no inflow or outflow features.

The land in the vicinity of the source is split between two land uses: agricultural and built land. South of the source, and for several kilometres south, southeast and southwest, the land is primarily agricultural, dominated by sheep grazing, with some dairying and cattle rearing (Figure 4). To the east between the source and the sea, both pasture and arable land is seen. Though the lowlying area immediately north of the source comprises wet grassland and an area of improved amenity grassland in a park, to the north and northwest of the source, built land comprising buildings and artificial surfaces dominates in and around Carlingford Town. Further to the north and northwest, as the land rises into the uplands, montane heath and scrub occurs.

The area immediately adjacent to the source includes a number of new housing estates to the north and northwest, as well many older residences to the west (Figure 4). These connect to the Carlingford mains sewer but some of the individual houses to the southwest are served by septic tanks, particularly those higher up the hillslopes. The sewage treatment works themselves are situated 85 m northeast of the source. A nursing home lies 100 m to the west-southwest of the source, and a farmyard 75 m to the east. There also occurs a cemetery 135 m to the southeast of the source, and disused quarries 250m to the southwest.

Figure 4: Land use around the source. The sewage treatment works comprise the buildings immediately northeast of the pumphouse. The dominance of well drained pasture land to the south and southwest is seen, as are the arable fields to the east and the built area of Carlingford to the north. Montane heath and scrub is also seen to the west on the high mountains slopes.

6 HYDRO-METEOROLOGY

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

Annual rainfall: taken to be 1,067 mm. The contoured data map of rainfall in Ireland (Met Éireann website, data averaged from 1961-1990) shows that the boreholes are located between the 1,000 mm and 1,200 mm average annual rainfall isohyet. The 1971-2000 data indicate an average annual rainfall of 986 to 1,032 mm/yr. The closest meteorological station to the boreholes is at Carlingford, which has average annual rainfall of 1,067 mm (Fitzgerald and Forrestal, 1996). Given that the topography and altitude at the Carlingford gauging station (1 km to the north-northwest) are similar, we can therefore interpret that annual rainfall is calculated as c. 1,067 mm for the boreholes locality.

Annual evapotranspiration losses: 416 mm. The closest synoptic weather stations to the study area are Dublin Airport, 67 km to the south, and Clones, 67 km to the west. Although the Carlingford borehole is coastal, the mountainous nature of the land in the zone of contribution is more akin to Clones than to the flat Dublin Airport area, therefore Clones data are used. Average annual potential evapotranspiration (P.E.) at Clones from 1961-1990 is 438 mm. The 1971-2000 MetÉireann data gives PE at Clones as about 492 mm/yr and at Carlingford as about 486 mm/yr. Actual evapotranspiration (A.E.) is estimated as 95% of the 1961-1990 P.E., to allow for seasonal soil moisture deficits, giving a value of 416 mm/yr.

Annual Effective Rainfall: 651 mm. The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is, therefore, 651 mm/year. See also Section 10.3 on Recharge which estimates the proportion of effective rainfall that enters the groundwater system.

7 GEOLOGY

This section briefly describes the relevant characteristics of the geological materials that underlie the Carlingford boreholes source locality. It provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections. Geological information was initially taken from a desk-based survey of available data, which comprised the following:

- Geology of Monaghan-Carlingford: A geological description of Monaghan-Carlingford, to accompany the Bedrock Geology 1:100,000 Scale Map Series, Sheet 8/9, Monaghan-Carlingford (Geraghty, 1997).
- The Subsoils Permeability Map and Groundwater Vulnerability Map of County Louth, drawn up as part of the National Groundwater Protection Scheme (GSI, 2009).
- Meath Groundwater Protection Scheme (Woods *et al*., 1995).
- Information from geological mapping in the nineteenth century (on record at the GSI).
- Information from Mineral Exploration Open Files, also held by the GSI.
- Data from Quaternary mapping of County Louth, carried out by the GSI (O'Connor, 1998).
- Data from the EPA/Teagasc Subsoils Map for County Louth (Teagasc, 2006).
- Data from the Teagasc Preliminary Reconnaissance Soil Map of County Louth.

As well as this, a detailed field survey of the geology was carried out in the area around the source by walkover stream surveys, logging of outcrops and exposures, and hand augering. This was completed in February 2009.

7.1 BEDROCK GEOLOGY

According to the 1:100,000 bedrock sheets of the region (Geraghty, 1997), the area around the boreholes is underlain by Undifferentiated Dinantian limestones (Dinantian Mixed Sandstones, Shales and Limestones). These Dinantian rocks unconformably overlie Ordovician-Silurian age greywacke and schists of the Inishkeen Formation, which are the oldest rocks in the Cooley Peninsula. The Carboniferous and Silurian rocks have been intruded by younger Tertiary igneous rocks, exposed on the higher ground to the west and northwest where they have been folded and faulted to form the Cooley Mountains.

The Undifferentiated Dinantian limestones (Dinantian Mixed Sandstones, Shales and Limestones) have not been subdivided into discrete units, as detailed mapping of the bedrock has not been carried out in the area. The limestone rock in this part of County Louth is, however, generally described as pale grey, medium to fine grained, and bedded. Some dolomite units occur in places.

Faulting has occurred in the general region around the source, with an unconformity occurring 290 m to the northeast at the boundary with the Inniskeen Formation, but no faults have currently been delineated in the immediate source locality (Figure 5).

A relatively extensive area of bedrock outcrop occurs immediately west of the boreholes, across the road from the site. The majority of this outcrop takes the form of a 25-35 m high cliff, which has been quarried at certain localities historically and which stretches for *c.* 800 m north-south. Small areas of outcrop and subcrop also occur further west and northwest, up-slope.

7.2 SUBSOIL GEOLOGY

Subsoils mapping was carried out by the author in 2001 while working at Teagasc on the EPA/ Teagasc Soil and Subsoil Mapping Project. In 2009, refined mapping of subsoils was carried out throughout County Louth and in the Carlingford locality for the county Groundwater Protection Scheme (GSI, 2011). This information forms the basis for subsoil permeability assessments of the area, also carried out for the current project. Further information was gathered from GSI boreholes drilled around the source in May and June 2007.

The subsoils around the source comprise a mixture of coarse- and fine-grained materials. Granite tills, tills derived from shales and sandstones and sand/gravel (often at depth) are the dominant subsoils in the area, with more restricted areas of sands and gravels, limestone bedrock outcrop, peat and alluvium occurring (Figure 6). In general, subsoils are relatively shallow west of the source on the hillslopes, but are considerably deeper to the east of the source on the more lowlying and gently undulating terrain.

- Till is the dominant subsoil type south, west and north of the source. ‘Till’ or ‘Boulder clay’ is an unsorted mixture of coarse and fine materials laid down by glacier ice during the last Ice Age.
- The tills are varied in their dominant lithology, being dominated by granite on the hillslopes west of the source, by limestone in pockets on the lower ground to the south and southeast and by shale to the north and east, but all of tills are classed as being of moderate permeability[3]. The tills encountered in the boreholes drilled by GSI around the source in May and June 2007 were described using BS 5930 as either silty sandy GRAVEL or silty GRAVEL.

[3] Moderate permeability subsoil materials are silty and sandy glacial tills that are generally quite free draining, except in low lying areas and/or areas of groundwater discharge. The lower permeability limit of these materials is ~0.001 m/day or ~10^{-8} m/s.

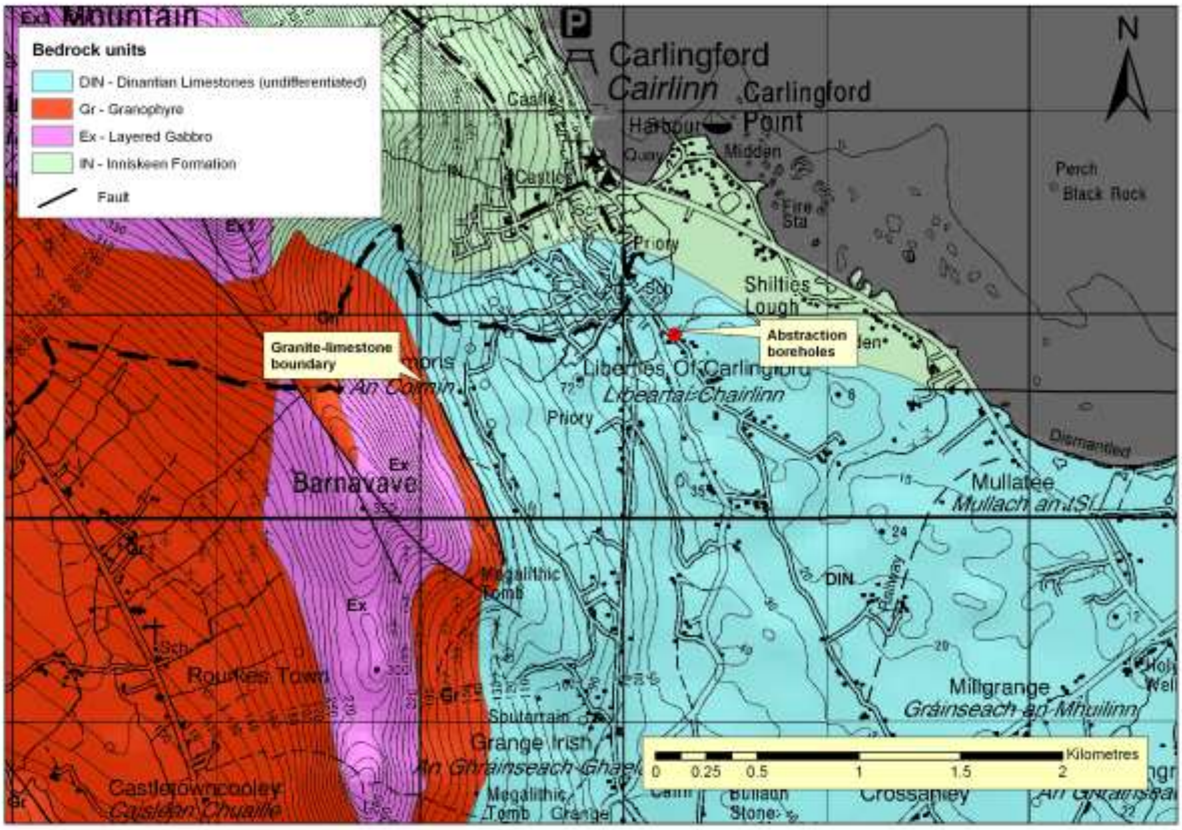

Figure 5: Bedrock geology map of the area around the Carlingford Source.

7.3 DEPTH TO BEDROCK

- The depth to bedrock in the areas where till occurs on the hillslopes west and southwest of the source is generally less than 5 m, and often less than 3 m. The till to the east of the hillslopes and the source, in the lowland area, is much deeper.
- It seems that, though the area east of and including the source itself is mapped on the Teagasc subsoil map as being underlain by till, from detailed mapping and associated augering for this Source Protection report much of this area is underlain by deep glaciofluvial sands and gravels derived from shales and sandstones. These were deposited by wide meltwater rivers during deglaciation, when the ice sheets of the last Ice Age melted. The depth to bedrock in the sands and gravels to the east of the source is generally deep at >12 m, though pockets with depths <5 m do occur.
- Immediately north of the source, for a distance of 750 m and as far as the coastline, a narrow, flat, low-lying area of postglacial deposits occurs. These have accumulated in this lowlying area since the last Ice Age, and have been mapped as 'Marine sands and gravels' on the Teagasc subsoil map. From examination during field work this was seen to be the case in the northern portion of the area, but in the south close to the source the material comprises a mixture of interbedded peat and alluvium. The alluvium material is dominated by CLAY but also hosts interbedded SAND, and seems to overlie glaciofluvial sands and gravels, as seen in the source borehole logs and from mapping around the locality.
- To the west and southwest of the source, bedrock protrudes through the deep glacial and postglacial subsoils within the cliffed outcrop area mentioned in Section 7.2.
- In and around Carlingford itself, much of the subsoils have been covered by 'Made' ground: built land, residential gardens and concreted/tarmacadamed areas. This 'Made' material is underlain by till and bedrock at or close to the surface, similar to the areas immediately adjacent to it.

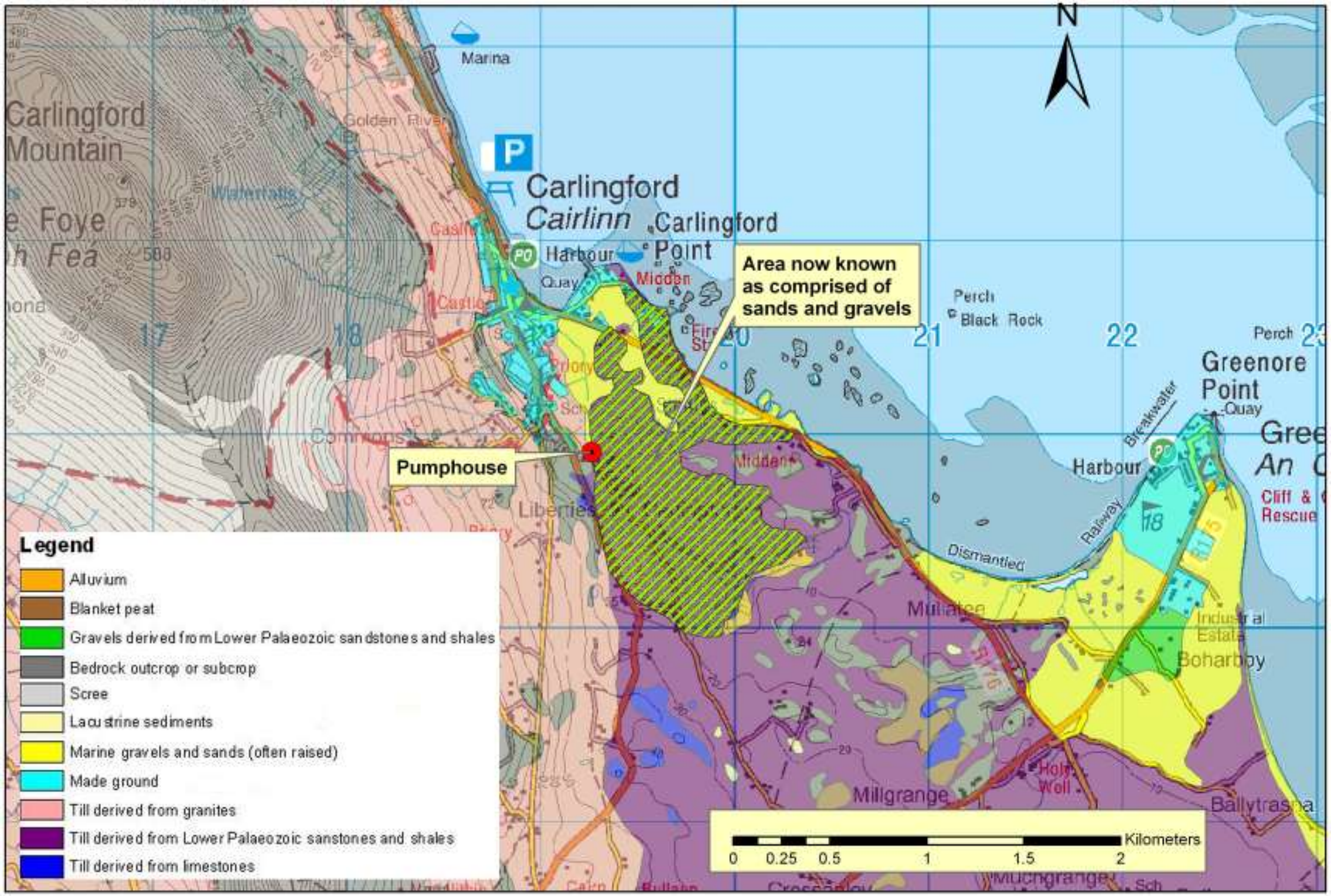

Figure 6: Subsoils geology map of the area around the Carlingford Source. The area now known to be sands and gravels, which was previously mapped as till derived from sandstones and shales (purple), is also shown.

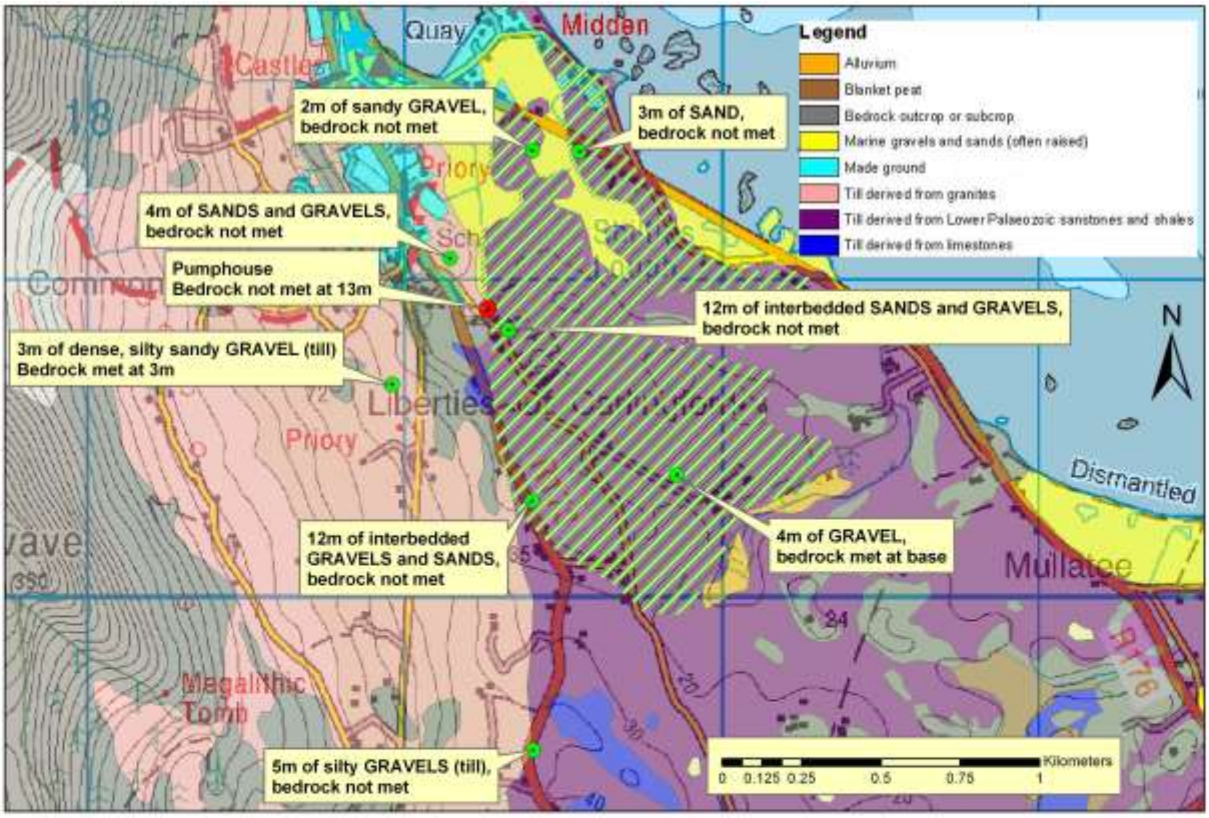

Figure 7: Details of boreholes bored by GSI in summer 2007 around the source. The logs from these, along with mapping of exposures in the locality around the source, were used to delineate the area of sands and gravels constituting the source aquifer (shown as green hatch).

8 GROUNDWATER VULNERABILITY

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

The groundwater supply source is the aquifer hosted in the sand/gravel beneath the ground surface. For the purposes of vulnerability mapping in the immediate vicinity around the boreholes, the "**water table**" is the target, as this lies above the top of the bedrock. Further west and southwest, and up-slope, where the subsoil is thin till of moderate permeability at an elevation higher than that of the water table in the boreholes, then the "**top of the rock**" is the target[4].

The spatial arrangement of groundwater vulnerability parameters around the Carlingford source is shown in Figure 8, and is as follows.

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

- Around the source, the permeability of the till subsoil is interpreted to be "**moderate**" (see Figure 6 for the pattern of subsoils in these areas). Immediately north of the source, the permeability of the alluvium/peat subsoil is also interpreted to be "**moderate**", and to the east and southeast the permeability of the sand/gravel subsoil is "**high**"**.**
- Depth to bedrock varies from being greater than 13 m around and to the east of the source to zero where the rock outcrops occur along the cliffs to the west and southwest.
- Where subsoil thickness is less than 3 m as indicated by the outcrop, subcrop and drilling data, bulk permeability becomes less relevant when mapping vulnerability across a region (as opposed to at specific sites). This is because infiltration is more likely to occur through 'bypass flow' mechanisms such as cracks in the subsoil. Based on the general depth to bedrock, a vulnerability classification of **"extreme (E)"** has been assigned in these areas of shallower subsoil with <3m cover. A separate class, that of **"extreme (X)"** applies to areas with less than 1m depth of subsoil/soil cover, where contamination by by-pass flow of bacteria is eve more likely.
- Where subsoil thickness is greater than 3 m, the vulnerability classification is **"high"**, where sands and gravels occur or where till of moderate permeability is greater than 3 m but less than 10 m thick.

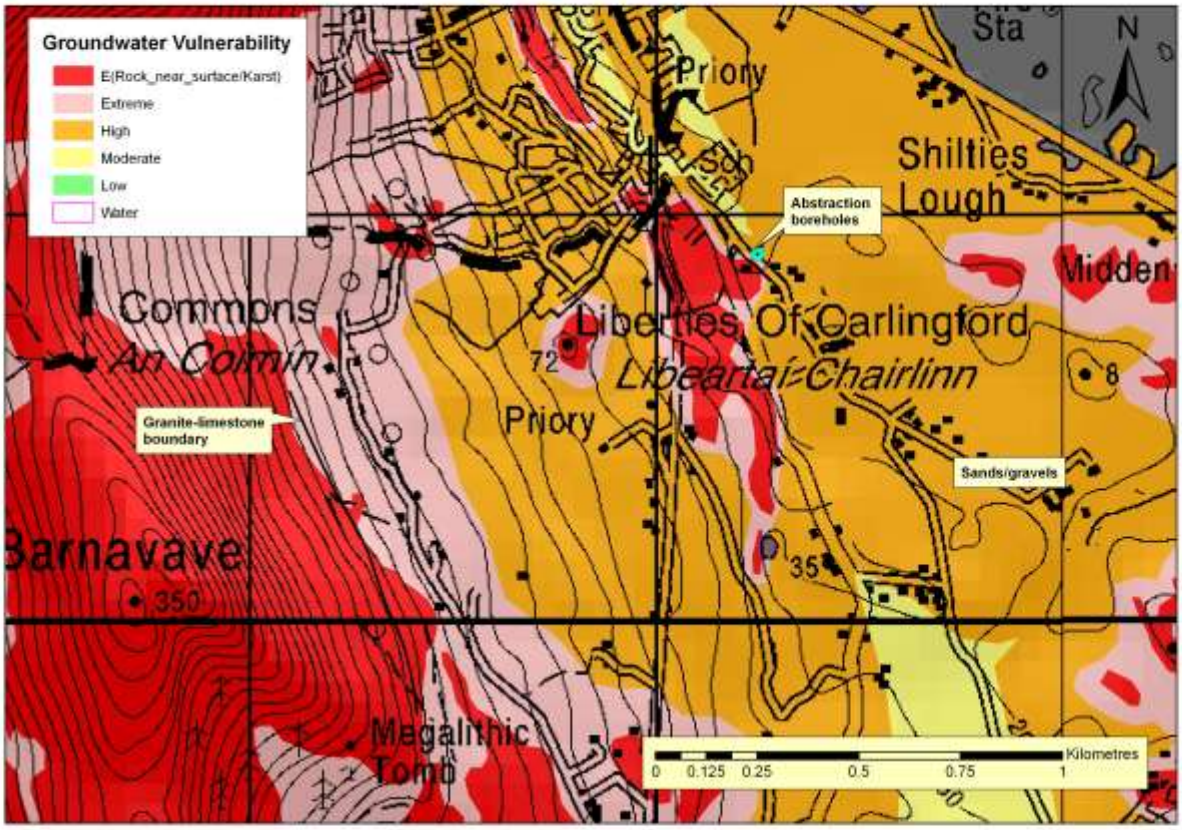

Figure 8 Groundwater vulnerability in the vicinity of Carlingford WSS

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

9 HYDROGEOLOGY

This section presents the current understanding of groundwater flow in the area of the source boreholes and their feeder catchment. The interpretations and conceptualisations of flow are used to delineate source protection zones around the boreholes.

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

- GSI Databases.
- Fitzgerald, D. and Forrestal, F. (1996) Monthly and Annual Averages of Rainfall for Ireland 1961-1990. Meteorological Service, Climatological Note No. 10, UDC 551.577.2(415).
- Historical Louth County Council hydrochemistry data.
- EPA Groundwater Monitoring Data from the Carlingford Boreholes.
- Hydrogeological and permeability mapping carried out by the lead author.
- A drilling programme carried out by the GSI to ascertain depth to bedrock and subsoil permeability in May and June 2007.

9.1 GROUNDWATER BODY AND STATUS

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

9.2 GROUNDWATER LEVELS, FLOW DIRECTIONS AND GRADIENTS

The flat, lowlying area to the north effectively has water at the land surface, being a marshy area, and groundwater seems to discharge around the edges of this, as shown on the Ordnance Survey six inch map of the 1860's, where streams rise (Figure 1). The streams rise in the footslope zone at the base of the surrounding sand/gravel hills, on which the source boreholes have been drilled, and flow northwards.

Groundwater flow to the sands and gravels feeding the source area is expected to be from the hillslopes to the southwest, moving northeast within the limestone bedrock aquifer and generally following topography. With this in mind, the GSI drilled a borehole up-gradient of the source in the topographically higher till/shallow bedrock area, 320 m southwest (NGR 318960 310670). This did not encounter the water table at 3 m depth, but the water table in this area is expected to mirror topography and flow downslope under steep head towards the sands and gravels. The fact that the water at the source is very hard (see following section 9.3) suggests that the majority of its chemical signature is derived from the limestone, with the relatively steep groundwater gradient of the hillslopes constantly feeding water northeast towards the source.

The groundwater in the sands and gravels area is expected to have a shallower water table gradient. A borehole drilled into these deposits 620 m south-southeast (NGR 319401 310303, and again 'up-gradient') did not encounter the water table at 12 m depth. The altitude of this hole at 29 mAOD suggests a groundwater gradient no steeper than 0.02 between the two boreholes in the sands and gravels. The borehole records for the source show that the groundwater is unconfined in the sands and gravels, with the water table at 3.9 m below ground level in the 13 m deep borehole. To the north, almost at the shoreline, the water table breaks the surface. The groundwater gradient between the borehole and the shoreline is estimated as 0.008. These data indicate a relatively flat groundwater table in the area of the sands and gravels and corroborates the gradient estimated by An Foras Forbartha/GSI in 1982 at Ardtully Beg (1:60, or 0.017).

9.3 HYDROCHEMISTRY AND WATER QUALITY

The majority of the available water quality data for the Carlingford boreholes source is from EPA monitoring data, which has been collected several times a year at Carlingford since 2007. As well as this, water quality results from the initial pumping test in 1998 were also included in the analysis. Key characterisation and contaminant indicator water quality parameters are summarised in Table 2.

Sample date	Conductivity ųS/cm	Ammonia mg/l N	Chloride mg/l Cl	Iron ųg/l	Total coliforms No/100ml	Faecal coliforms No/100ml	Nitrate mg/l NO_3	Sodium mg/l	Potassium mg/l	Total hardness mg/l $CaCO_3$
15/09/98	484	<0.01	17.7	<50	nm	nm	4.6	10.2	1.5	229
16/09/98	469	<0.01	18.1	<50	nm	nm	4.7	10.5	1.8	239
27/07/07	486	0.02	14	14	**10**	<1	12.6	11.5	1.7	222
30/09/07	516	0.01	16	<2	<1	<1	15.4	12	1.9	253
24/10/07	Nm	0.1	17	10	<1	<1	16.6	9.5	1.5	249
30/11/07	475	0.03	15	<2	<1	<1	16.5	11.5	1.7	261
11/01/08	414	0.02	15	<2	<1	<1	16.1	11.5	1.7	231
04/06/08	530	<0.007	16.1	<5.0	<1	<1	12.2	8.7	1.3	208
30/07/08	493	0.088	13.7	<5.0	<1	<1	14.5	10.6	1.6	218
29/10/08	504	0.059	14	<5.0	**2**	<1	14.9	13.1	1.9	280
11/12/08	526	0.021	16	12.6	<1	<1	14.6	11.5	1.9	233

Table 2: Summary water quality data for Carlingford Boreholes, 1998 and 2007-2008.

The following key points are identified from the data:

- The water is generally "very hard" with an average total hardness of *c*. 217 mg/l (as $CaCO_3$) calcium-bicarbonate hydrochemical signature. The values are typical of groundwater from limestone and therefore show that although the groundwater is sourced in gravels that are dominated by shales and sandstones, this has little or no effect on the hydrochemical signature derived from the bedrock to the west of, northwest of, and under the source. The hardness values are higher than the recommended Drinking Water Standard (DWS) of 200 mg/l $CaCO_{3,}$ which is, however, based on palatability and formation of limescale, rather than on health grounds.
- Electrical conductivity values as sampled by the EPA are between 461 and 521 µS/cm, with an average of 485 µs/cm. This is a slight increase on values found at the time of initial pump testing (469 and 484 µS/cm).
- Faecal coliforms were absent from the water on all occasions sampled. As well as this, on no occasions were ammonia values greater than the GSI threshold value (0.15 mg/l, Buckley and Fitzsimons, 2002) recorded; ammonia levels were consistently below 0.1 mg/l.

- On two occasions, total coliforms were present in the samples taken (10/100 ml on 27/07/07 and 2/100 ml on 29/10/08). However, such low values may be due to sampling or analysis error so the results are not considered noteworthy.
- Nitrate concentrations in available samples since 2007 range from 12.2 mg/l to 16.6 mg/l as NO_3 (average is 14.82 mg/l). There are no reported exceedances above the DWS of 50 mg/l, or the groundwater Threshold Value (Groundwater regulations S.I. No. 9 of 2010) value of 37.5 mg/l. The area around the source, though relatively densely populated, has a relatively low density of septic tanks owing to the presence of the sewer network to the north and west. Further from this, little tillage is practiced around the area up-gradient of the source and, excepting the cliffed outcrop localities along the scarp to the west, depths to bedrock are moderately deep. The source area itself has a CLAY cap above the >10 m thick sands and gravels of. Therefore, the relatively low nitrate levels at Carlingford are probably due to a combination of the above factors. It is noteworthy, however, that nitrate levels in 2007 and 2008 are generally three to four times what they were in 1998: the nitrate data have therefore seem to have shown an upward trend in recent years and this chemical signature should be monitored closely in the future.
- Chloride is a constituent of organic wastes and levels higher than 25 mg/l may indicate contamination, with levels higher than the 30 mg/l usually indicating significant contamination (Daly, 1996). Chloride concentrations range from 13.7 to 18.1 mg/l (average 15.7 mg/l), suggesting that contamination from organic wastes does not seem to be an issue at Carlingford. The chloride levels are also interesting in that in a coastal area such as Carlingford, background concentrations of chloride are expected to be 30-35 mg/l due to rainwater enrichment by evaporating seawater, but this does not seem to be the case at the source.
- The levels of potassium are consistently well below the GSI threshold value of 4 mg/l. Again, this shows consistent levels, averaging at 1.68 mg/l, with a maximum of 1.9 mg/l (30/09/2007, 29/10/2008, 11/12/2008). The potassium:sodium ratio of soiled water and other wastes derived from plant organic matter is considerably greater than 0.4, whereas the ratio in septic tank effluent is less than 0.2. Consequently a potassium:sodium ratio greater than 0.4 can be used, subject to some geological constraints, to indicate contamination by plant organic matter - usually from poorly managed farmyard 'dirty water', and occasionally landfill sites (from the breakdown of paper). The potassium:sodium (K/Na) ratio at Carlingford never exceeds the GSI threshold of 0.35, with the highest value at 0.165 (11/12/2008). These data suggest no organic waste sources, and the K/Na ratio again seems to rule out farmyard waste as an issue.
- The levels of iron range from <2 to 14 µg/l at Carlingford, with records showing that iron never exceeds the DWS (0.200 µg/l).
- Normal levels of trace metals were identified, safe for drinking, and no positive occurrences of chlorinated hydrocarbons, solvents or pesticides were detected.
- Overall, the samples from the source boreholes do not indicate significant contamination or pollution of these wells.

9.4 AQUIFER CHARACTERISTICS

The sands and gravels through which the boreholes are drilled, though previously unmapped at adjacent localities around the Carlingford Source, have been seen as extensive following the mapping and drilling carried out for the current project. The deposit hosting the water table that the source abstracts from is therefore classed as a **Locally Important Sand & Gravel aquifer (Lg)**. The probable extent of this aquifer is depicted in Figure 6 and Figure 7, and is also referred to in Section 7.2 above. The full aquifer thickness is unknown but it is at least 12 m thick both 80 m southeast and 630 m south of the source.

Bodies of sands and gravels with similar geometries to that outlined above have previously been mapped on the southern side of the Cooley Peninsula, at Ardtully Beg, Ballynamoney and The Bush. These materials form part of the 'Dundalk Gravels' Groundwater Body of the GSI, for which some hydrogeological data are available. At Ardtully Beg, a transmissivity of about 1000 m^2/d and a specific yield of 0.1 have been reported (An Foras Forbartha/GSI, 1982). This equates to bulk permeabilities of about 65 m/d (which is in the typical range of permeabilities for sands and gravels elsewhere, i.e. 50-100 m/d) and the porosity is assumed to be in the order of 0.13, from work carried out by GSI on other sand and gravel sources around Ireland, the closest of which is at Ardtully Beg, 4.5 km south of Carlingford. The groundwater at Carlingford is likely to be unconfined.

Though not tapped directly at this borehole source, the underlying Undifferentiated Dinantian limestones (Dinantian Mixed Sandstones, Shales and Limestones) are classified as a **Locally Important Aquifer – bedrock which is generally moderately productive (Lm)**. This aquifer rises to elevations higher than the sands and gravels to the west and southwest of the source, up-gradient.

10 ZONE OF CONTRIBUTION

10.1 CONCEPTUAL MODEL

The conceptual model is described following, and summarised in Figure 9 below.

- The Carlingford pumping wells are installed in glaciofluvial sands and gravels which are classified as a **Locally important sand and gravel aquifer (Lg)**.
- The groundwater level at the source is 3.9 m bgl and is within the sands and gravels, indicating that the aquifer is unconfined. The saturated aquifer thickness at the source is at least 10 m.
- The gravel aquifer is underlain by Undifferentiated Dinantian Limestones which are classified as a **Locally important aquifer – bedrock which is generally moderately productive (Lm).**
- Groundwater flow within the sand and gravel aquifer is intergranular, whereas in the bedrock beneath and up-gradient to the southwest, flow is through fractures and fissures in the limestone.
- The higher hillslope area to the west and southwest of the Carlingford Source is underlain by these Undifferentiated Dinantian limestones (Dinantian Mixed Sandstones, Shales and Limestones) and has few surface streams and rare drainage features. The absence of surface drainage suggests that recharge readily infiltrates into the groundwater system here.
- Diffuse recharge dominates in this area. The subsoil over 95% of the area is either highly or moderately permeable, and to the west and southwest of the source is relatively thin (<5 m), with much of the area to the immediate east and southeast being composed of thick, high permeability sands and gravels: these materials allow a very high proportion of recharge to occur through them. The total diffuse recharge amount occurring over the catchment is estimated at an annual average recharge of 501 mm per year (see section 10.3, following).
- The limestone as seen in the adjacent quarries in this area to the west has a well developed fracture system, but does not seem to have undergone significant karstification. This is also suggested by the absence of dolines, swallow holes, springs, dry valleys and other karst features in the area.
- The water table is interpreted to be deep in the bedrock in this area, as no seeps or springs occur in the cliffed bedrock area west of the source. The groundwater gradient in the sands and gravels has been calculated as no greater than 0.015; in the limestone bedrock aquifer to the southwest, it is considered that the groundwater gradient is steeper, on the order of 0.075.

- The bedrock is relatively close to the surface in the area to the immediate west and southwest of the source, but is deep at the source itself, with the water emerging through the permeable sand and gravel deposits which act as a 'window' for flow, as well as through a capping veneer of thick clay.
- At the groundwater discharge zone suggested by the Ordnance Survey six inch map of the area, springs seem to emerge close to the borehole locality, in a low hollow at the base of a regional topographic high. The hollow is surrounded by thick sands and gravels and is fed primarily by groundwater from the limestone to the southwest.
- The groundwater flow direction is expected to be from southwest to northeast, following topography. The precise pathways of groundwater flow in the limestone up-slope of the source, as well as the flow depths, are not known.
- Overall, the samples from the source boreholes do not indicate contamination or pollution of these wells.

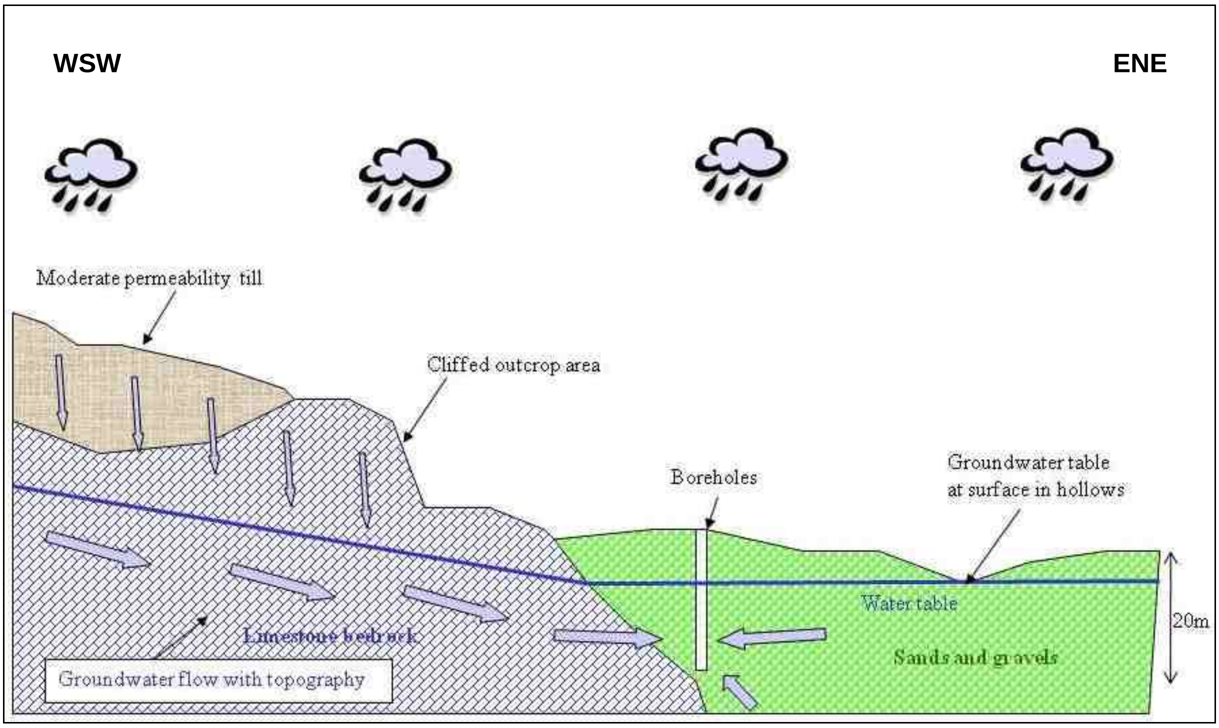

Figure 9: Two-dimensional conceptual model for the Carlingford boreholes source, with groundwater being fed into the permeable sands and gravels from the higher elevation limestone bedrock to the west and southwest.

10.2 BOUNDARIES OF THE ZOC

This section describes the delineation of the areas around the source that are believed to contribute groundwater to it, and that therefore require protection. The areas are delineated based on the conceptualisation of the groundwater flow pattern, as described in Section 10.1 and presented in Figure 9.

The shape and boundaries of the ZOC were determined using hydrogeological mapping and a conceptual understanding of groundwater flow water balance estimations, supported by water balance calculations (section 10.3 below). The current abstraction rate + 50% (1,800 m^3/d) is used to estimate the area required. This is to allow for a possible increase in abstraction and also to allow for an expansion of the ZOC during dry weather. The resulting boundaries and the uncertainties associated with them are described as follows:

The **southwestern boundary** is defined using the topographic ridge to the west/southwest at Barnavave. The ridge is a surface watershed and is assumed to be a groundwater divide. The majority of the groundwater abstracted at the source is assumed to derive from the limestone bedrock and gravels, with lesser contributions from the granites to the west of the fault. However, the ZOC boundary is considered to extend as far as the summit of Barnavave, since although flow paths are generally very short in the poor granite aquifers, the total absence of surface water features or spring points in the upland area indicates that a large proportion of effective rainfall is accepted. Therefore, even if groundwater is only flowing within the weathered zone at the top of the granite bedrock, it will flow downhill into the more permeable limestone aquifer and become part of the groundwater resource. Groundwater flow paths up to about a kilometre are therefore possible, assisted by the potentially high transmissivities of the limestone bedrock, and the topographic gradient.

The **northeastern boundary** is on the down gradient side of the borehole. The maximum downgradient distance that the borehole can pump water from can be estimated using the uniform flow equation (Todd, 1980):

$x_L = Q / (2 * \pi * T * i)$ where: Q is the daily pumping rate

T is the Aquifer Transmissivity, and

i is background non-pumping hydraulic gradient.

Using the current pumping rate + 50%, aquifer parameters from section 9.3, and a gradient of 0.01, the calculation indicates that the boreholes could draw water from up to 50 m downstream.

The **northern and southern boundaries** are based on topography. The northern boundary is defined by the surface water catchment of the tributary stream that flows north-eastwards into Carlingford. The location of the southern boundary is based on topography, consideration of surface water features, and the distribution of the sand and gravel deposit at the foot of the slope, which has the potential to act as a 'sump' that can collect groundwater flowing downhill within the bedrock aquifer.

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 Carlingford, therefore, the main parameters involved in recharge rate estimation are: annual rainfall; annual evapotranspiration; and a recharge coefficient.

The recharge coefficient is estimated using Guidance Document GW5 (Groundwater Working Group 2005). The area of recharge is assumed to be across the sands and gravels around the boreholes, plus the bedrock area elevated above the boreholes, WSW towards Barnavave. These calculations are summarised as follows:

Average annual rainfall (R)	1067 mm
estimated P.E.	438 mm
estimated A.E. (95% of P.E.)	416 mm
effective rainfall	651 mm
potential recharge	651 mm
recharge coefficient for high perm subsoil	90%
recharge coefficient for moderate perm subsoil	55%
recharge coefficient for low perm subsoil	20%
bulk recharge coefficient	77%
runoff losses	23%
Average annual recharge	**501 mm**

The bulk *recharge coefficient* for the area is estimated to be 77%. Runoff losses are assumed to be 23% of potential recharge (i.e. 245 mm/yr). This value is based on an assumption of *c*. 20% runoff for 95% of the area[5] (high or moderate permeability subsoils and soils, no drains or surface streams), and 80% runoff over 5% of the area due to thicker, less permeable subsoil or shallow subsoil with less permeable bedrock, less permeable subsoil (Irish Working Group on Groundwater, 2004).

The area contributing to the water supply source at Carlingford therefore receives annual average recharge of 501 mm, both directly through overlying soils and subsoils into the sands and gravels, as well as indirect recharge from groundwater flow within bedrock from the higher land to the west and southwest.

Water balance: The area within the zone of contribution boundaries described in section 10.2 is about **0.932 km^2**. This compares to an area required to supply the boreholes, computed using a water balance approach, of **1.31 km^2.**

Abstraction = 1,200 m^3/day + 50% = 1,800 m^3/d = 657,000 m^3/year

Recharge = 501 mm = 0.5012 m/year

ZOC area = Abstraction/Recharge = 657,000 m^3/0.501 m = 1.31 km^2

The ZOC boundaries take into consideration surface hydrological catchments. It is possible that there are deeper groundwater flowpaths taking recharge from higher ground beneath some of the surface streams that are fed by shallow groundwater, which then emerges within the gravels near the break in slope where the source is situated. Furthermore, there are uncertainties inherent in the recharge parameter values. Therefore, the difference between the water balance calculation and hydrogeologically mapped area is not considered to be significant. However, should there be a series of dry years and/or an increase in abstraction rate, groundwater levels at and around the source in the gravels should be monitored for indications of decline.

11 GROUNDWATER SOURCE PROTECTION ZONES

The groundwater source protection zones are obtained by integrating the two elements of land surface zoning (source protection areas and vulnerability categories) – a possible total of eight source protection zones (see Table 3). In practice, this is achieved by superimposing the vulnerability map on the source protection area map. Each zone is represented by a code e.g. **SI/H**, which represents an <u>Inner Protection area</u> where the groundwater is <u>highly</u> vulnerable to contamination. Not all of the hydrogeological settings represented by the zones may not be present around any given source.

[5] The 'area' here is the expected, or estimated, potential zone of contribution from preliminary assessments of the topography, soils, subsoils and bedrock geology of the area.

Two source protection areas are delineated:

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

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 an abstraction from long-term recharge (Figure 10).

11.2 INNER PROTECTION AREA

According to "Groundwater Protection Schemes" (DELG/EPA/GSI, 1999), delineation of an Inner Protection Area is required to protect the source from microbial and viral contamination and it is based on the 100-day time of travel (ToT) to the supply. Estimations of the extent of this area are made using Darcy's Law as follows:

For the bedrock west of the source at Carlingford, there are no data on permeability of the rocks. On the basis of other similar aquifers, a permeability (K) of 0.5 m/d is considered reasonable. A typical porosity (n) of 0.02 is assumed, and the gradient (i) estimated to be 0.075 (a subdued reflection of the ground gradient). Using these parameter values and Darcy's law, an average groundwater velocity (V) in the bedrock aquifer is estimated as follows:

$$V = (K.i) / n$$

$$= 0.5 \times 0.075 / 0.02 = 1.875 \text{ m/d}$$

This means that in 100 days groundwater will move approximately 190 m in the bedrock.

For glaciofluvial sands and gravels, with a permeability (K) of 60 m/d, effective porosity (n) of 0.1 and a gradient (i) of 0.015 the velocity (V) can be estimated as follows;

$$V = (K.i) / n$$

$$V = 60 \times 0.015 / 0.1 = 9 \text{ m/d}$$

This means that in 100 days groundwater will move approximately 900 m in the sands and gravels.

Groundwater from anywhere within the sand and gravel body in the ZOC, as well as up to 185 m up-gradient in the bedrock, could reach the source within 100 days. The sands and gravels themselves cover only a small portion of the area of the ZOC (approx. 10%).

Four groundwater protection zones are present around the source as illustrated in Table 3. The final groundwater protection zones are shown in Figure 11.

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

Table 3: Matrix of Source Protection Zones at Carlingford

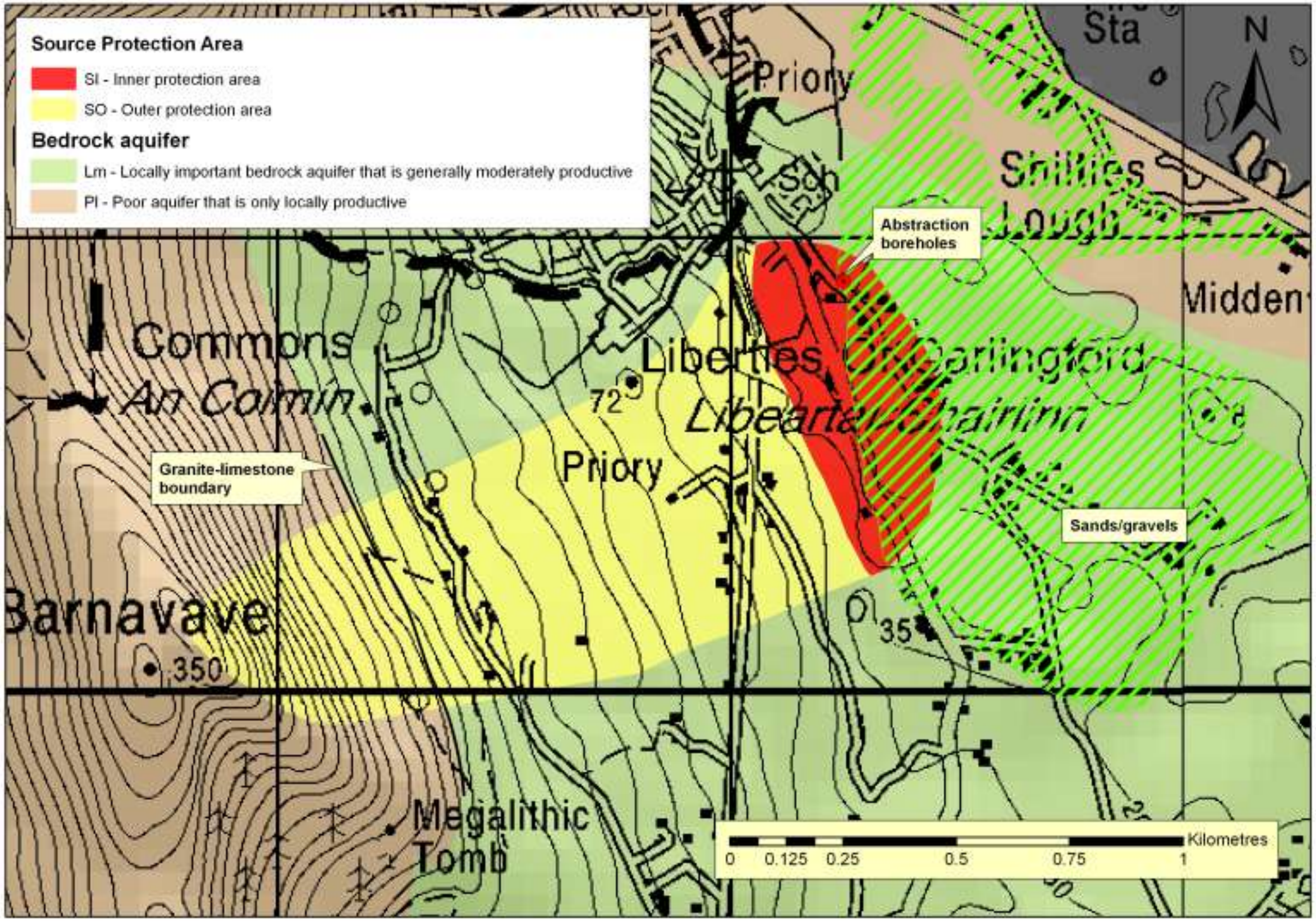

Figure 10: Source Protection Areas for the Carlingford Boreholes Source. The majority of the Zone of Contribution comprises bedrock aquifer, with about 10% situated in the sands and gravels.

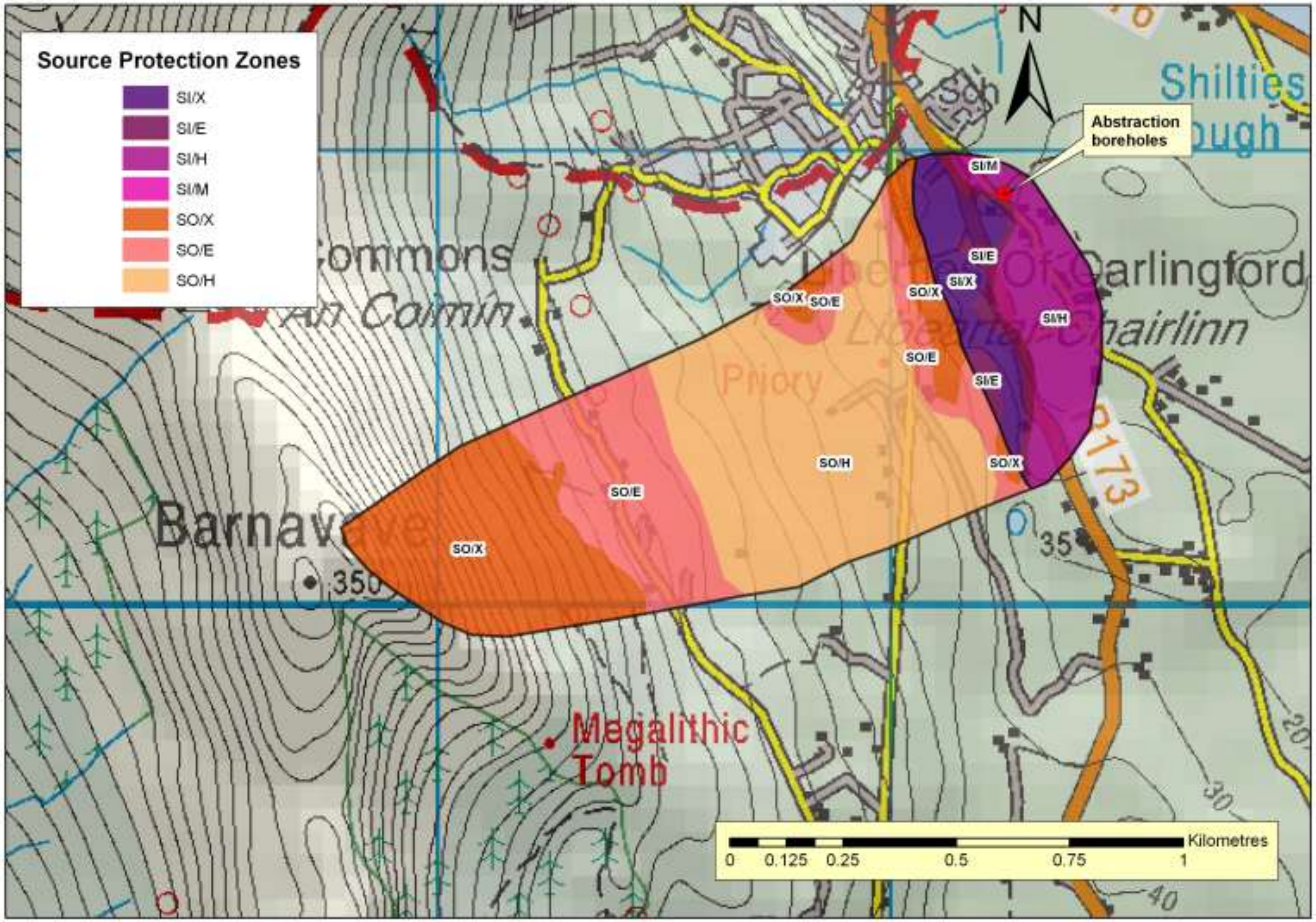

Figure 11: Source Protection Zones for Cooley WSS Carlingford Boreholes.

12 POTENTIAL POLLUTION SOURCES

There are a large number of houses and farmyards within the ZOC (Figure 4). Land use in the vicinity of the source is described in Section 5 and shown in Figure 4; within the ZOC, agriculture is the main land use. Disused quarries occur 250 m to the southwest, the sewerage works themselves are situated 85 m to the northeast, and a cemetery is situated 135 m to the southeast.

The hydrochemical data do not indicate significant contamination or pollution of the boreholes at the source. However, as nitrate levels have risen fourfold in the eight years since the source has been in operation, these levels should be monitored closely.

The main hazards associated with the ZOC are therefore considered to be agricultural (farmyards leakage, landspreading of organic and inorganic fertilisers) and oil/petrol spills. Though domestic septic tanks and treatment systems are not a major problem at present, the installation of any new systems should be monitored closely. The location of these activities in any part of the ZOC categorised as ‘extremely’ vulnerable presents a potential risk, given rapid travel time through the underlying bedrock and lack of attenuation by subsoils. These are delineated as SI/E or SO/E on Figure 11.

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

13 CONCLUSIONS

- The boreholes at Carlingford, including the water supply source, are located in, and supplied by, a previously unmapped sand and gravel aquifer of local importance.
- The boreholes are drilled adjacent to a groundwater discharge zone which was historically mapped as having a rising stream, and was labelled ‘Springfield’.
- The majority of the water pumped from the source is, however, fed by a locally important bedrock aquifer to the immediate southwest, which is topographically higher than, and has a steeper groundwater gradient than that in the lower-lying sands and gravels.
- The ZOC has been delineated for the boreholes based on the assumption that the majority of the ZOC comprises this higher bedrock area.
- Due to the rapid groundwater velocities in the sands and gravels, it is considered that groundwater in any part of the ZOC underlain by sands and gravels could potentially reach the boreholes within 100 days. However, as the sands and gravels cover only a small portion of the ZOC, and as the groundwater velocity of the bedrock aquifer up-gradient of the source is much less than in the sands and gravels, the Inner Protection Area for the Carlingford Boreholes is relatively small in relation to the overall ZOC
- The ZOC as delineated covers 0.93 km^2, with 0.096 km^2 of this within the sands and gravels.
- The water balance for current abstraction + 50% indicates that the recharge over the mapped ZOC may not match that higher abstraction rate. This indication is not necessarily a cause for concern, since there are uncertainties in the recharge parameter values and meteorological data. . However, should there be a series of dry years and/or an increase in abstraction rate, groundwater levels at and around the source in the gravels should be monitored for indications of decline.

- Available data suggest that there is little contamination at the source from organic sources at present, but as nitrate levels have increased fourfold in the eight years since the source went into production, and as the groundwater is unconfined, these levels should be monitored closely.
- The groundwater in the Source Protection Area ranges in vulnerability from Extreme to High, with a very small area of Moderate vulnerability within the Inner source protection area (SI).
- 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 to the boundaries are necessary.

14 RECOMMENDATIONS

It is recommended that:

1. The potential hazards in the ZOC should be located and assessed, especially given the high number of farmyards and houses up-gradient of the source in the ZOC.
2. A full chemical and bacteriological analysis of the **raw** water at the boreholes source should be carried out on a regular, quarterly basis by the Local Authority.
3. Particular care should be taken when assessing the location of any activities or developments which might cause contamination at the boreholes.
4. Groundwater levels at and around the source should be monitored regularly such that any declines that may arise from a series of dry years/increased abstraction rate can be determined.

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