1 CARNDONAGH PUBLIC WATER SUPPLY SCHEME

1.1 Introduction

The objectives of the report are as follows:

- To delineate source protection zones for the Carndonagh (Tirnaleague) Water Supply Scheme; namely the two infiltration galleries, and two summer augmentation boreholes.
- To outline the principal hydrogeological characteristics of the surrounding area.
- To assist Donegal 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 abstraction points. This prioritisation is intended to provide a guide in the planning and regulation of development and human activities. The protection of public water supplies is also mentioned in Circular letter SP 5-03, which was issued from the DEHLG to all County/City Managers in July 2003. The circular states that source protection zones around public water supplies should be included in all county development plans. 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 scheme for the county. The maps produced for the scheme are based largely on mapping techniques that use inferences and judgements gained from experience at other sites. As such, the maps cannot claim to be definitively accurate across the whole county 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.

1.2 Summary of Supply Details

	Infiltration Gallery 1	Infiltration Gallery 2	Borehole 1	Borehole 2
GSI Number	2343NEW051	2343NEW050	2343NEW048	2343NEW049
Grid ref. (GPS)	246252 446465	246247 446474	246475 446504	246726 446310
Townland	Churchland Quarters		Churchland Quarters	
Source type	Infiltration Gallery	Infiltration Gallery	Bored Well	Bored Well
Date Drilled	Late 1970s	Late 1980s	c. 1999	c. 1999
Owner	Donegal Co. Co.		Donegal Co. Co.	
Elevation (m OD)	c.17.0	c.17.0	c.17.5	c.20.0
Depth (m)	7.3	5.5	c. 9 – 12	c. 9 – 12
Gallery Width (m)	3	3	–	–
Gallery Length (m)	65	34	–	–
Depth to rock (m bgl[1])	> 15	> 15	> 12	> 12
Static water level (m bgl)	c. 1.5	–	–	–
Depth of pump (m)	c. 6.0	–	c. 9.0	c. 9.0
Pumping water level (m bgl)	5.2	c. 4.7	c. 4.0	c. 4.0
Consumption	Winter: 1680 m^3/d. Summer: 1440 m^3/d[2].	In the winter, Gallery 2 and Boreholes 1 and 2 supply an additional 240 m^3/d		
Pumping test summary:	–			
(i) abstraction rate (m^3/d)		800-1750	Max c.400	Max c.400
(ii) specific capacity (m^3/d/m)		460	–	–

[1] Below Ground Level.

[2] Includes gravity flow from Infiltration Gallery 2.

(iii) transmissivity (m^2/d)		410		

1.3 Methodology

1.3.1 Desk Study

Details about the source such as abstraction, depth and dates commissioned were obtained from County Council personnel and reports written by K.T. Cullen & Co. Ltd. (KTC) in 1992. Additional geological and hydrogeological information was provided by the GSI and Teagasc mapping programmes (Long and McConnell, 1997; Meehan, 2002 respectively) and by site investigation work (T.J. O'Connor & Assoc., 1989; Farrell 1989; Solmec, 1974).

1.3.2 Site Visits and Fieldwork

This part of the work included the following:

- meetings with Donegal County Council staff in October 2002 and July 2003;
- drilling of depth to bedrock/permeability holes in the general area;
- site walkovers in July and August 2003 to further investigate the subsoil geology, hydrogeology and vulnerability to contamination;
- water sampling in November 2002 and March 2003.

1.3.3 Assessment

Analysis of the data utilised field studies and previously collected data to delineate protection zones around the source.

1.4 Location and Site Description

The well field is located in the Churchland Quarters townland, close to the Tirnaleague Demesne, some 1.5 km north to northwest of Carndonagh Town (Figure 1.1).

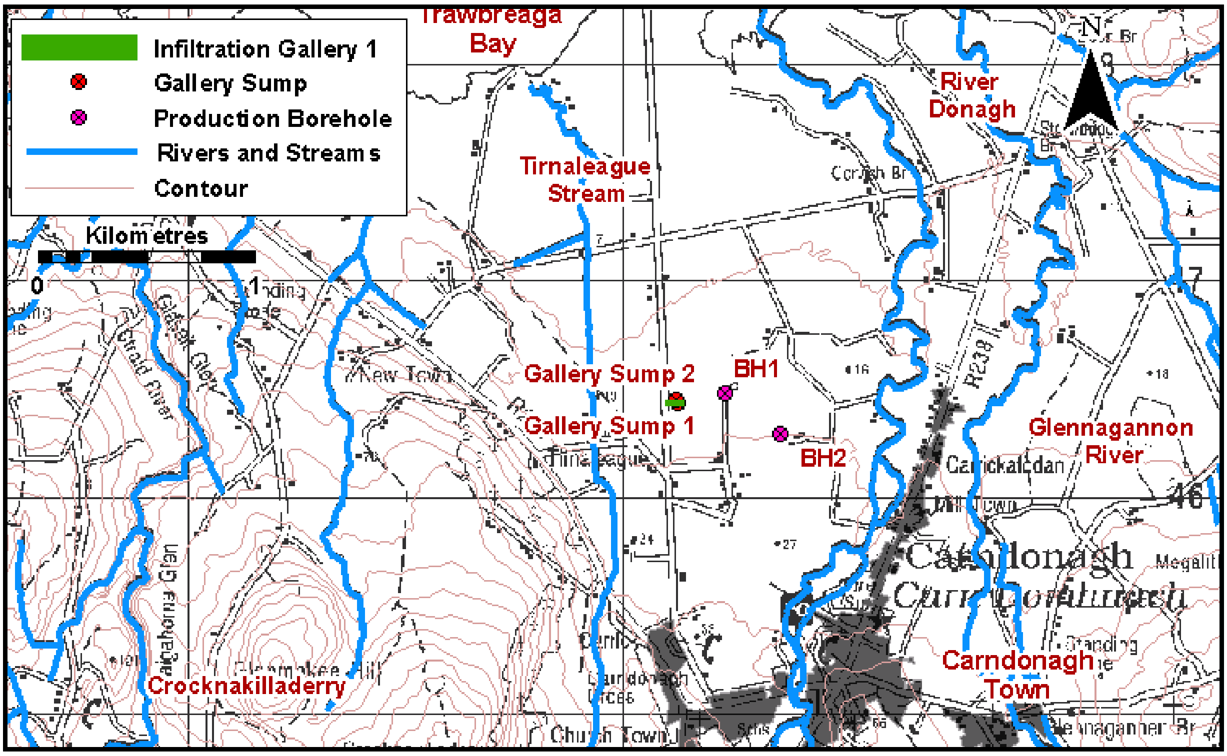

Figure 1.1. Location of Carndonagh Water Supply Scheme.

Main Well Field

The Tirnaleague Scheme comprises two infiltration galleries and two boreholes although the main well field only includes the two infiltration galleries and the pump house. This area is enclosed by a 2 m high fencing and is secured by a locked gate (Figure 1.2).

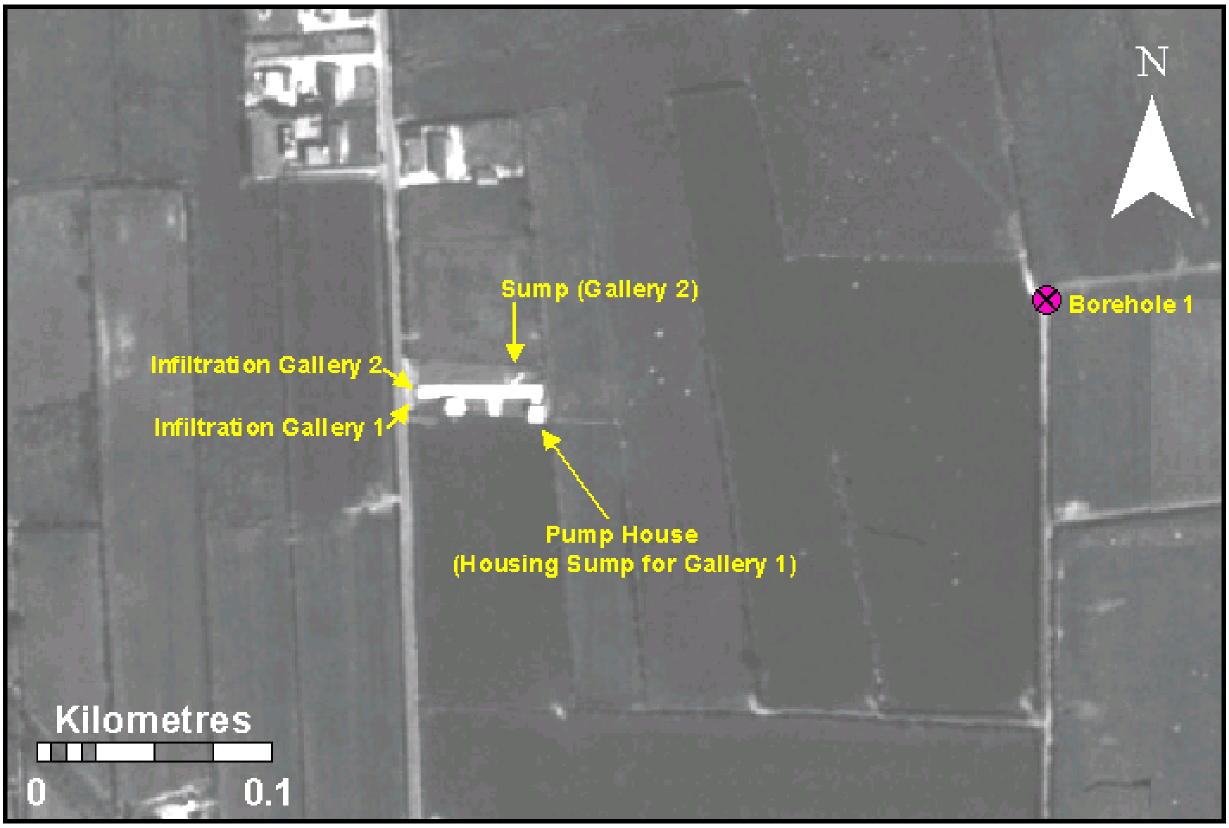

Figure 1.2. Carndonagh Water Supply Scheme Well Field.

Gallery 2, which is located just to the north of the newer Gallery 1, is approximately 3 m wide and 34 m in length with its longer side orientated east to west. The gallery invert is approximately 6 m below ground level and there is a pipe running along its length which drains the collected groundwater into a sump at its eastern end. The sump is 2 m in diameter and thought to be around 5.5 m (18 feet) deep. The sump rises to approximately 0.3 m above the ground surface and is sealed with a concrete cover.

The larger gallery – Gallery 1 – was installed with the intention of increasing the abstraction. It is located approximately 5 m on the up-gradient side (south) of Gallery 2 as its aim was to supersede the older gallery. Gallery 1 is 65 m long by 3 m wide and 6.3 m deep. There is a 450 mm pipe running along is length and also a number of smaller diameter feeder pipes set perpendicular to the main pipe. The pump house is located over Gallery 1, approximately 20 m from the western end. The sump, into which Gallery 1 drains, is located beneath the pump house. It is 5 m by 4 m in area and thought to be about 7.5 m (24 feet) deep.

During the construction of Gallery 1, a connecting pipe was installed between the two galleries in order to allow drainage from Gallery 2 into Gallery 1.

Boreholes

Approximately two to three years ago, two additional boreholes were installed in order to augment the infiltration galleries. Both of the boreholes are between 9-12 m deep, with a pump situated near the bottom. Borehole 1 is located roughly 225 m east of the main well field whilst Borehole 2 is approximately 500 m to the southeast. Both boreholes are covered by concrete plinths and are comprehensively fenced off from their surrounding fields.

Workings of Existing Scheme

At present, 1680 m^3/d (70 m^3/hr) of groundwater is pumped from the main pump house (Gallery 1 sump) to a reservoir. This water supplies Carndonagh Town, the rural area to the south, and the Malin Head area to the north.

In winter, all of the abstraction is supplied by Gallery 1, which includes the natural gravity drainage from Gallery 2. However in summer, Gallery 1 can only supply 1440 m^3/d, or 60 m^3/hr. At this maximum rate, the main sump is systematically pumped dry, causing the pump to stop for 20 minutes, up to three times in every 24 hour period. In order to meet the summer demand, the additional 240 m^3/d (10 m^3/hr) is acquired by pumping the water in Gallery 2's sump and from the two boreholes. The abstraction rates from these additional sources are not monitored individually.

1.4.1 Topography, Surface Hydrology and Land Use

The infiltration galleries are situated in a low-lying area, at an approximately elevation of 17 m O.D. The landscape is relatively flat although gentle dips northwards toward Trawbreaga Bay. Moving southwards and inland from the source, the land initially continues to rise gently but becomes more pronounced to the south and southeast of Carndonagh town. A much steeper slope is encountered approximately 500 m to the southwest of the well field as the land rises to an elevation of 200 m over a distance of 1.5 km (Crocknakilladerry townland).

The main surface water features in the area are the Rivers Donagh and Glennagannon, which are located some 1.0 km and 1.5 km east of the infiltration galleries respectively. A smaller, unnamed stream (hereafter referred to as the Tirnaleague Stream) is located just under 350 m to the west of the supply. All of the rivers/streams flow northwards across the gently sloping area, to discharge into the Trawbreaga Bay (Figure 1.1).

To the south of the main well field, the land is free draining, although the number of drainage channels increases moving northwards. Land drainage is required in the northern area because the combination of shallow water table and gently sloping landscape results in a low natural drainage capacity of the soil. One of the more prominent drainage ditches runs from north to south approximately 10 m west of the infiltration gallery. Although flow has been recorded in this channel, it was mainly dry and well vegetated during the GSI site visits.

Grazing is the main land use around Carndonagh town. Although the land drainage increases the utility of the land, it does become noticeable wetter to the north, with an increasing proportion of thin peat. Throughout this gently sloping area there are a number of individual houses, the closest of which is located immediately south of the main well field, within 50 m of Gallery 1. Further housing is also being developed within 1.0 km of the main well field. The urban development of Carndonagh town is generally focussed along the roads.

1.5 Geology

1.5.1 Introduction

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

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

- Geology of North Donegal. Bedrock Geology 1:100,000 Map Series, Geological Survey of Ireland (Long and McConnell, 1997).

- Information from geological mapping in the nineteenth century (on record at the GSI).
- Forest Inventory and Planning System – Integrated Forestry Information System (FIPS-IFS) Soils Parent Material Map, Teagasc (Meehan, 2004).
- Proposed Groundwater Protection Policy for the Carndonagh Gravel Aquifer (KTC, 1992).
- Lough Inn Regional Water Supply Scheme Carndonagh Section – Ground Investigation Report (T.J. O'Connor & Assoc., 1989).
- Site investigation information including borehole and PSA information (Farrell, 1989).
- Lough Inn Regional Water Supply Scheme Carndonagh Section – Trial Boreholes Logs and PSA (Solmec, 1974).

1.5.2 Bedrock Geology

The source area is underlain by the Lower Crana Quartzite (Figure 1.3), which is a layered, finer-grained metamorphic rock with some marble beds. This formation also extends to the north and west of the source. The Upper Crana Quartz Formation lies to the east and south of the infiltration galleries. This is a similar metamorphic rock although is dominated by more coarse-grained material. The southern area also includes Metadolerite which is a massive, coarse-grained, deformed, igneous rock. These rocks are described in more detail in Section 2, Volume 1, and their distribution is shown on.

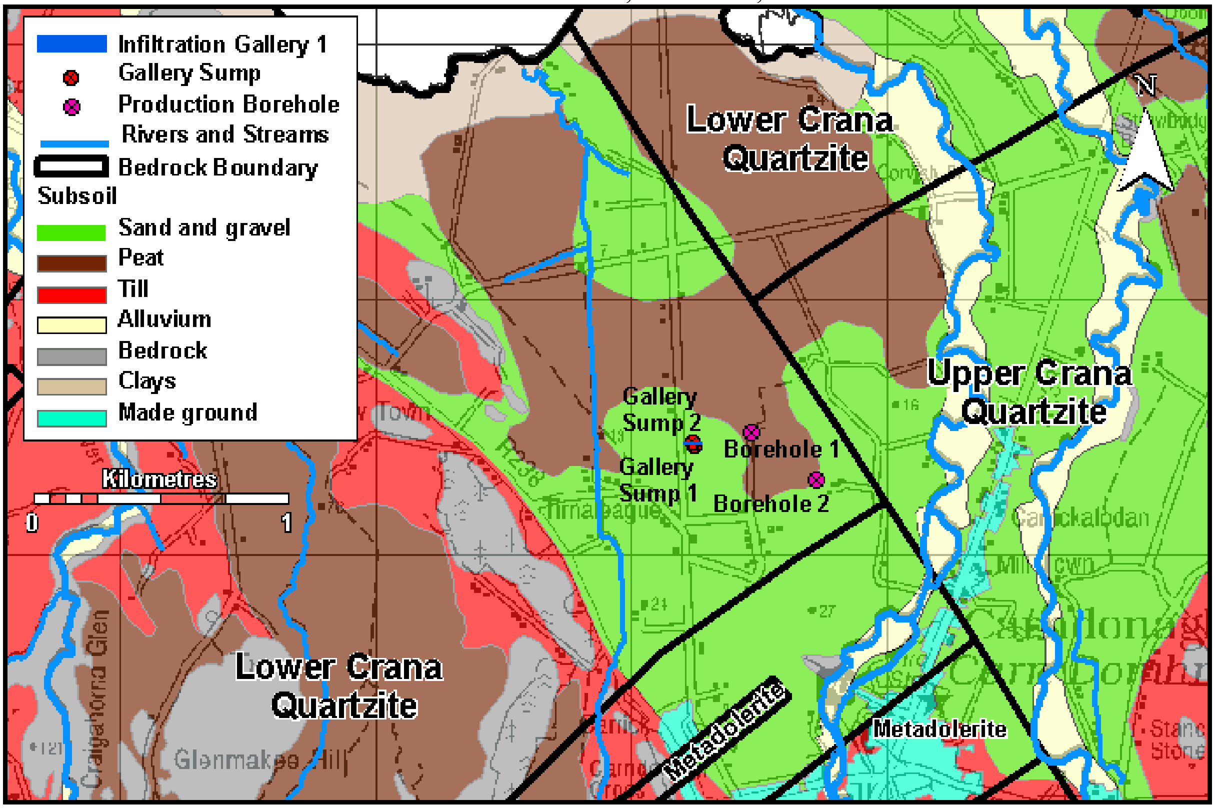

Figure 1.3. Bedrock and Subsoil Geology of the Carndonagh Area.

1.5.3 Subsoil Geology

The main subsoil categories in the vicinity of the source are sand and gravel, peat, alluvium and 'till' (or boulder clay). The distribution of these deposits is shown on Figure 1.3 and their main characteristics are described below.

Sand and Gravel. There are several extensive areas of sand and gravel in north Inishowen, one of these being the dominant subsoil around the Carndonagh/Tirnaleague area. Due to the depositional environment (possibly fluvio-glacial outwash, or deltaic), the material is likely to grade from coarser sand and gravel near Carndonagh town to finer material at the coast (McCarron, 2002).

Both the infiltration galleries and the boreholes abstract water from the sand and gravel aquifer. The invert levels of the infiltration galleries are situated at the base of the gravel layer, which is the main water-bearing layer. In the vicinity of the infiltration galleries the gravel primarily consists of 'sandy GRAVEL' (KTC, 1992). Fifteen samples with Particle Size Analyses (PSA) have been obtained from eight boreholes within the sand and gravel body, five of which are adjacent to Gallery 2 (Solmec, 1974) and Gallery 1 (Farrell, 1989). All but one of the boreholes (13 samples) have between 1-4% (averaging 2%) fines (silt+clay fraction). The remaining, most westerly located, borehole has a fines content of 2-22%, depending on the depth of the sample.

Ground investigation works presented in the KTC report (1992) show the gravel to have an average thickness of just over 5.0 m. The gravel is generally overlain by approximately 0.7-0.8 m of 'silty CLAY', which the report suggests is relatively impermeable. Only three of these nine investigation boreholes penetrate below the gravel layer. These logs record an underlying 1-2 m of 'SILT with bands of gravel' over 'sandy SILT' (up to 6.5 m). Five of the boreholes record a 'refusal', which may indicate boulders or large cobbles within the gravel as bedrock is not mentioned and has not been identified in the deeper boreholes in this area (GSI, 2002; KTC, 1992; Solmec, 1974). The final investigation borehole, BH9, records 14m of 'sandy SILT' with no specific water bearing gravel layer. This is located between BH8 and BH10 (c.50 m to the west and east respectively), which both record approximately 5 m of gravel at roughly 1 m below the surface.

Although ***peat*** is mapped to the north of the infiltration galleries, it is generally considered to be thin and is most likely underlain by the gravel (Dr. R. Meehan, *pers.comm*., 2003). Much of the peat appears to have been drained or cut, in order to utilise the land.

Alluvium occupies narrow floodplains along the Rivers Donagh and Glennagannon. Works on the river beds found the alluvium to be thin and underlain by the gravel (Anthony Porter, *pers.comm*., 2003). Furthermore, the disappearance of the River Donagh flow into the gravel during a particularly dry summer c.15 years ago, suggests a hydraulic connection between the river and the groundwater in the gravel.

Till is an unsorted mixture of coarse and fine materials laid down by ice. Till surrounds the gravel although is generally thin (<3 m in thickness). Where it is thicker, it is characterised by coarser material derived from the coarse-grained metamorphic rocks in this region. The main role of the till is as a protective layer to the underlying aquifers, rather than as an aquifer itself.

1.5.4 Depth to Bedrock

All available drilling information was previously compiled and a drilling programme undertaken by the GSI to ascertain the general changes in subsoil thickness and permeability throughout County Donegal. There are also a number of boreholes associated with the Carndonagh/ Tirnaleague source work (Solmec, 1974; Farrell, 1989; KTC, 1992), non of which actually prove bedrock. The borehole depths range from 3-17 m below ground level.

1.5.5 Groundwater Vulnerability

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target'. The target associated with the Carndonagh /Tirnaleague source is the water-table in gravel aquifer. Here, the vulnerability is based on the permeability and thickness of the unsaturated material overlying the water-table.

KTC (1992) indicate that the thickness of overlying unsaturated material (till plus gravel) is less than 1.5 m around the infiltration galleries. Shallow static water levels (less than 2 m below ground level) have also been recorded in boreholes 350 m west and 250 m north of the galleries. Consequently, the vulnerability of the groundwater in the gravel aquifer is categorised as 'extreme' in the vicinity of the boreholes, i.e. there is less than 3 m of overlying unsaturated material. Further to the south of the galleries, the land gently slopes up towards Carndonagh Town although the water-table is thought to be relatively flat (see Section 1.6.3). Therefore the thickness of overlying unsaturated material increases, which reduces the vulnerability to 'high'. The mapped vulnerability[3] for the area of interest is shown in Figure 1.4 below.

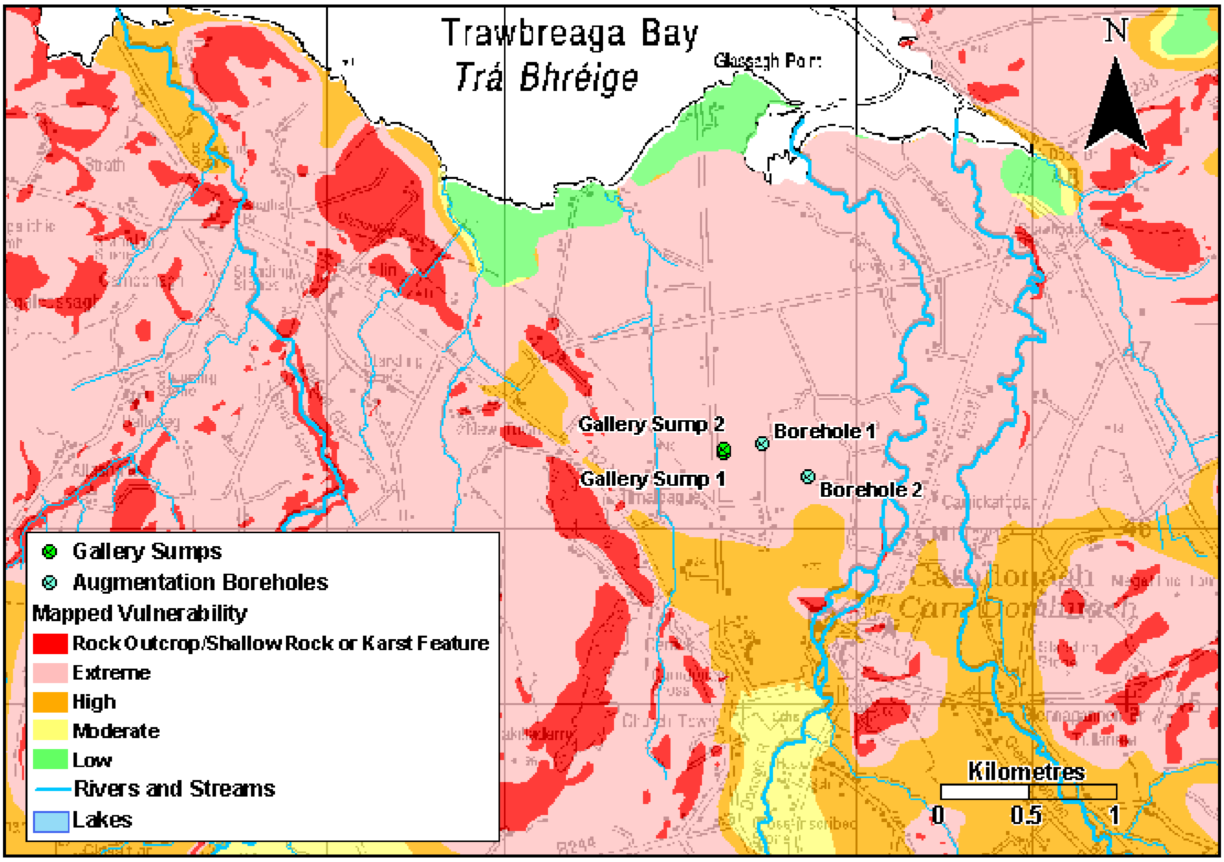

Figure 1.4. Mapped Vulnerability in the Carndonagh Area.

1.6 Hydrogeology

1.6.1 Introduction

This section presents our current understanding of groundwater flow in the area of the well field. Hydrogeological and hydrochemical information for this study was obtained from the following sources:

- GSI files and archival Donegal County Council data.
- GSI site walkovers in October 2002 and July 2003, and a levelling survey in November 2003.
- A drilling programme carried out by GSI to ascertain depth to bedrock and subsoil permeability.
- Proposed Groundwater Protection Policy for the Carndonagh Gravel Aquifer (KTC, 1992).

[3] The permeability estimations and depth to water table interpretations are based on regional-scale evaluations. The mapping is intended only 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.

- Lough Inn Regional Water Supply Scheme Carndonagh Section – Ground Investigation Report (T.J. O'Connor & Assoc., 1989).
- Lough Inn Regional Water Supply Scheme Carndonagh Section – Trial Boreholes Logs and PSA (Solmec, 1974).
- Environmental Protection Agency water quality data 1995-2003.
- Donegal County Council drinking water returns for 2001-2002.

1.6.2 Rainfall, Evaporation and Recharge

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

- *Annual rainfall:* **1190 mm**.

  There are a number of rainfall gauges located on the Inishowen Peninsula. The nearest station (Carndonagh Rocksmount, Fitzgerald and Forrestal, 1996) is situated approximately 2 km to the east of the source, at a similar elevation. Therefore the average annual rainfall will be representative of that experienced at the source. This value is also indicated by the interpreted precipitation contour maps presented in the "Agroclimatic Atlas of Ireland" (Collins and Cummins, 1996).
- *Annual evapotranspiration losses:* **530 mm**.

  Potential evapotranspiration (P.E.) is estimated to be 560 mm/yr (Collins and Cummins, 1996). Actual evapotranspiration (A.E.) is estimated as 95% of P.E., to allow for seasonal soil moisture deficits. More local measurements of evapotranspiration are not available.
- *Annual effective rainfall:* **660 mm**.

  This figure is based on subtracting estimated evapotranspiration losses from average annual rainfall. It represents an estimation of the excess soil moisture available for either vertical downward flow to groundwater or runoff.
- *Annual recharge:* ~**595 mm**.

  Over the area of gravel up-gradient (south) of the well field, the subsoil is very thin (< 1 m thick) and therefore runoff is considered to be negligible. A high infiltration rate is also reflected by the lack of artificial drainage throughout this area, and the dry, vegetated drainage channel to the west of the galleries. The recharge is estimated to be in the order of 90% across this area (GWWG, November 2004).

These calculations are summarised as follows:

Average annual rainfall (R)	1190 mm
Estimated P.E.	560 mm
Estimated A.E. (95% of P.E.)	530 mm
Effective rainfall (R – A.E.)	660 mm
Estimated Recharge (90% of effective rainfall)	**595 mm**

1.6.3 Groundwater Levels, Flow Direction and Gradient

A number of *boreholes* were installed during September 1988 (T.J. O'Connor & Assoc., 1989) as part of a ground investigation around the Gallery 2. In September/October 1991, groundwater *monitoring* *wells* were installed to investigate the hydrogeology of the same area (KTC, 1992). The borehole and monitoring well locations are shown on Figure 1.5 and Figure 1.6.

As part of the hydrogeological investigation, a six day pumping test was undertaken by KTC. The submersible pump used by the County Council was supplemented by an additional vacuum pump which increased the normal discharge of 680 m^3/d to 1750 m^3/d. Although pumping rates were generally erratic during the pumping test, the constant higher pumping rate (1750 m^3/d) over the last two days of the test illustrated the longer term response of the aquifer to this level of abstraction.

Static and pumping levels were obtained from both the boreholes and the monitoring wells. The monitoring well information gives a more detailed impression of water levels in close proximity to Gallery 2 whilst the borehole distribution gives a broader picture across the aquifer. The main points of interest from these data are outlined below:

1. Generally, the static water levels reflect the topography across the gravel aquifer.
2. Static water levels highlight a shallow water table: 1.5 m bgl in Gallery 2; within 1.0 m bgl in the monitoring wells around Gallery 2 (1991); within 1.6 m bgl in the boreholes that had available water level data i.e. the five boreholes closest to Gallery 2.
3. The similar static water levels in BHs 8, 9 and 10 in 1988 (1.0-1.4 m bgl) suggests that groundwater can move freely across this small, relatively flat area without restriction from the sandy SILT material logged in the BH9. Furthermore, the static water levels recorded in the surrounding monitoring wells in 1991 (0.52-1.33 m bgl in MWs 1, 2, 4, 7, 8, 9 and 10) suggest that the groundwater can move between the GRAVEL and the overlying silty CLAY i.e. that the groundwater is unconfined.
4. The static water level in MW2, which is adjacent to the drainage channel, are higher than the surrounding monitoring wells. During, and at the end of, the 6 day KTC pumping test the higher level of groundwater in MW2 is further exaggerated compared to the other monitored pumping water levels. The consistently higher level in MW2 is likely to be a 'recharge mound', which is due to downward leakage from the drainage channel to the water-table. This connection between the surface water (drainage channel) and groundwater also support the unconfined nature of the groundwater. Furthermore, it is inferred from these data that a proportion of the Gallery abstraction will be derived from 'induced' recharge from the surface drainage channel and probably from other nearby surface water channels.
5. The static water levels were all measured towards the end of the summer period. These levels are therefore likely to be higher during and after winter when higher rainfall is expected.
6. At lower pumping rates (610-900 m^3/d during the initial 4 days of the test) there was minimal impact on the water levels in the aquifer. The resulting drawdown ranged from 0.01 m at MW9 to 0.67 m at the pumping well (Gallery 2).
7. Water levels at the end of the pumping test reflect the *longer term* impact of abstraction, as well as the impact of a *higher* pumping rate (1750 m^3/d) during the last 2 days of the test. The larger drawdown recorded in the pumping (3.77 m) and monitoring wells (0.07-1.38 m), suggest that this pumping rate is having a more significant impact on the aquifer.

When looking at the north-south cross section of the data, static water levels are recorded in BH8 (1.4 m bgl) and BH4 (1.6 m bgl), 'nil' groundwater is recorded in BH6 and no reference is made to water in BH7. In the KTC report (1992), these water levels are not specifically mentioned although the graphical interpretation of these data suggests that the water level logged in BH8 and BH4 continue southwards at a similar gradient, consequently passing through BH6 and BH7. There are two main issues with this interpretation. Firstly, as mentioned above, water is specifically not logged in BH6 and BH7. Secondly, the hydraulic gradient between BH8 and BH4 (c.0.012) is considered to be exceptionally high for a coarse gravel aquifer in a relatively uniform environment.

On re-examination of these data, it is possible that a steeper gradient between BH8 and BH4 and no water in BH6 (i.e. a shallower gradient) may be due to a heterogeneous material where clay-rich lenses are supported a perched water-table. Although the available logs and PSAs do indicate a degree of heterogeneity in the deposit, all of the material is considered to have a relatively high permeability that would not result in perched water. However, no elevation data given with the logs and the approximate metres O.D. shown in the KTC report do not correspond with the Ordnance Survey contours, as depicted in Figure 1.1.

Approximate elevations relative to Ordnance Datum for the boreholes were estimated from the Six Inches to One Mile Scale Maps Series Sheet 11 (1903). Elevations for Gallery 2 and BHs 4, 6 and 7 were also surveyed on site although the precise locations of the boreholes were no longer identifiable. Consequently, levels were surveyed along the road adjacent to their estimated locations. By using this method, a possible ±1.5 m margin of error is assumed due to factors such as imprecise positioning, additional height of the road and uneven surface in the fields.

In order to re-assess the groundwater levels across this area, it is also assumed that the 'refusals' encountered in BH6 and BH7 do not represent the base of the gravel but are likely to be due to large cobbles or boulders, which are also part of the aquifer. Furthermore, as 'nil' water is recorded in BH6, is it is assumed that the groundwater may be just below the base of the borehole i.e. greater than 6 m below ground.

Using the above assumptions, the assessment of the recorded water levels with the re-evaluated elevations gives a more likely hydraulic gradient between BH8 and BH4 of c.0.007. However, not only is this still slightly higher than would be expected, it is also different from the gradient between BH8 and just below BH6 – c.0.005. Based on the permeable nature of the material and the potential margin of error of the elevations, the gradient between BH8 and below BH6 is thought to be more realistic.

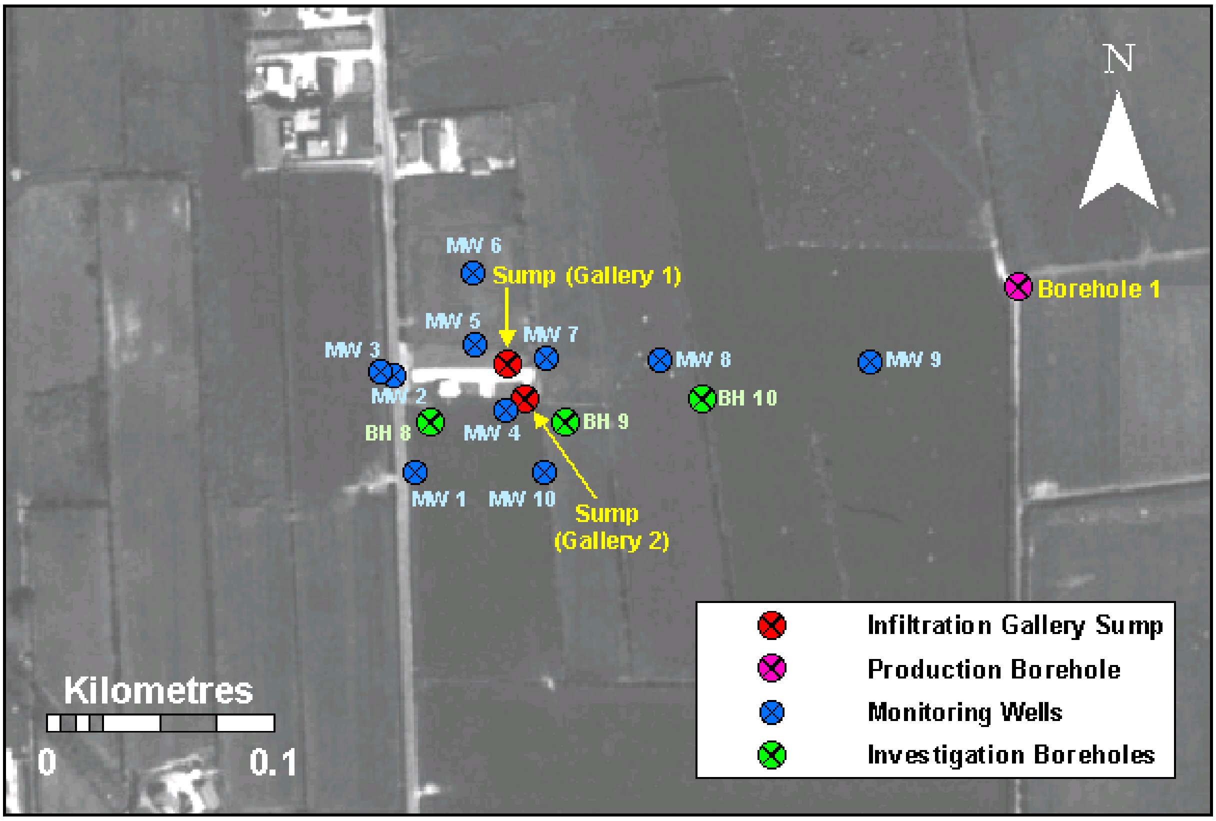

Figure 1.5. Monitoring Well Locations.

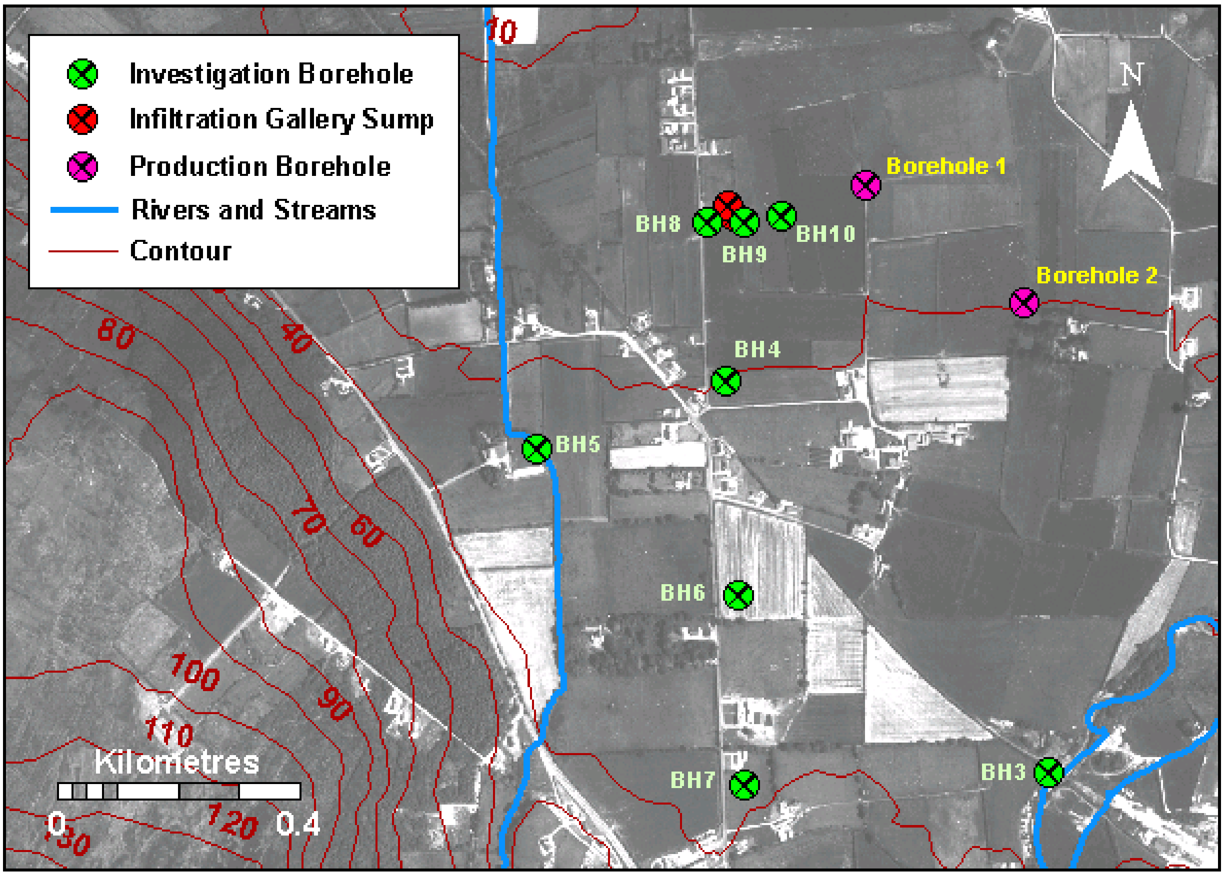

Figure 1.6. Site Investigation Borehole Locations.

Groundwater Flow Directions

As outlined above, the static water levels in the boreholes reflect the general topographic trend in the area, which indicates that the groundwater is mainly flowing from south to north.

Immediately around Gallery 2, the water levels in the monitoring wells also indicate a main south to north groundwater flow direction. However the main point of interest is the induced recharge from the surface drainage channel to the pumping well. The implied connection between nearby surface water channels and the infiltration gallery will have a direct influence on the delineation of the area contributing to the abstraction.

Groundwater Gradients

The distribution of boreholes provides a broader picture of the water levels across the aquifer. 'Nil' water was recorded in BH6, which is approximately 600 m south of the galleries. Assuming that the water-table is just beneath this borehole, the groundwater gradient is in the region of 0.005. This relatively flat gradient would be expected in a permeable sand and gravel aquifer.

1.6.4 Hydrochemistry and Water Quality

Hydrochemical data for the Carndonagh Tirnaleague Scheme have been obtained from the County Council (1994), the Environmental Protection Agency (1995-2003) and the GSI in conjunction with the County Council (2002-2003). The data for Gallery 2 are summarised in Figure 1.7 below.

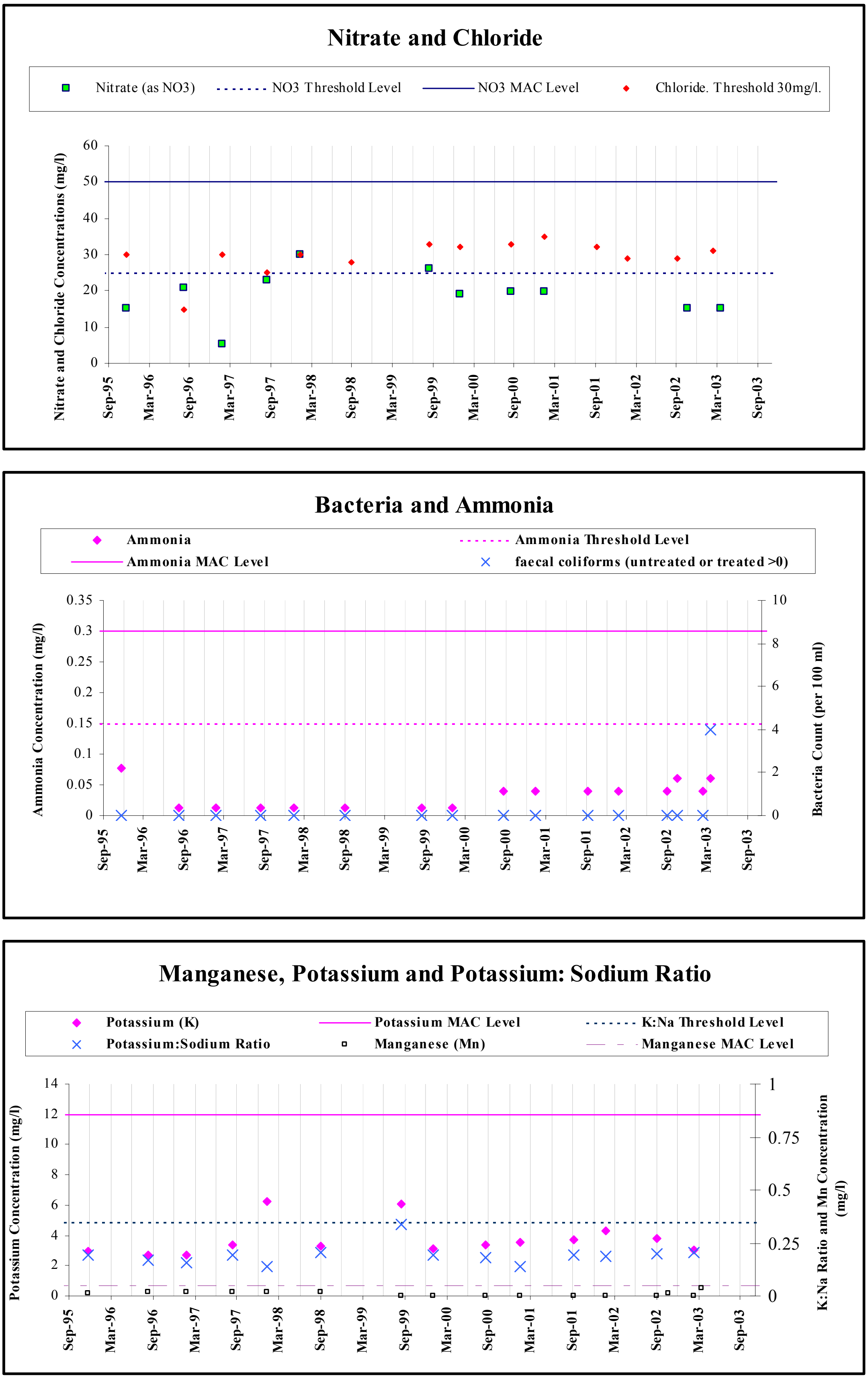

Figure 1.7. Key Indicators of Agricultural and Domestic Contamination.

From these data, the following key points have been identified.

- Analysis of hardness indicate a hard (251-350 mg/l $CaCO_3$) calcium bicarbonate hydrochemical signature. Conductivities range from 650-700 µS/cm.
- The available nitrate data range from 5-30 mg/l although mainly fall between 15-25 mg/l. On two occasions, nitrate levels exceeding the threshold (25 mg/l) ~ 30 mg/l in January 1998 and 26 mg/l in September 1999. There have also been a couple of occasions when levels of between 20-25 mg/l have been detected. Although the nitrate concentrations are mainly below the threshold value, they are considered to be above natural levels (< c.5 mg/l). The nitrates levels have remained fairly consistent over the monitoring period, averaging at around 19 mg/l (11 samples taken between December 1995 and March 2003). The last two samples have been in the order of 15 mg/l. Further data are required in order to identify any definite trends.
- The available chloride concentrations range from 15-35 mg/l, with an average of 29 mg/l. Six of the 14 samples exceed the threshold of 30 mg/l which can indicate a source of organic waste. However, the Carndonagh Scheme is located less than 2 km away from Trawbreaga Bay and hence these chloride levels may be influenced by sea spray and salty rainwater.
- All of the 16 available ammonia concentrations are beneath the threshold level (0.15 mg/l) and these data are maintaining a fairly consistent level. There is only reported incident of faecal coliforms in the analyses which occurred March 2003. There were six other occasions when total coliforms (less than 10 counts/100 ml) were detected.
- Within the monitoring period, there were three samples that exhibited potassium levels in excess of the 4 mg/l threshold; 6.2 mg/l in January 1998, 6.1 mg/l in September 1999 (which also had an elevated level of nitrate) and 4.3 mg/l in February 2002. The remaining 11 potassium concentrations were in the order of 2.5-4 mg/l, with no specific trends evident.

The main areas of concern for the Carndonagh/Tirnaleague source is the occasional presence of bacteria and the incidents of elevated nitrate and potassium concentrations. These levels do not infer gross contamination but may indicate releases from point (e.g. on-site wastewater treatment systems) and/or diffuse (spreading of organic or inorganic fertilisers) hazards, upslope of the abstraction points.

1.6.5 Aquifer Characteristics

The Carndonagh/Tirnaleague Public Water Supply Scheme comprises two infiltration galleries and two augmentation boreholes that abstract water from the Carndonagh gravel aquifer. From south the north, the *gravel* extends from Carndonagh Town to the mapped clays adjacent to Trawbreaga Bay (Figure 1.3). The gravel is considered to continue underneath the mapped peat, which is thought to be thin where it has not been drained and/or cut. The western boundary of the gravel is at the change in slope, which coincides with the R238. To the east the gravel body continues beneath the Rivers Donagh and Glennagannon.

The *aquifer* comprises the gravel that is saturated. By extrapolating the strata and water level data recorded in BH8, BH4 and BH6, the water-table is estimated to coincides with the base of the gravel approximately 700 m south of the infiltration galleries[4], which is just below 30 m O.D. Although there is essentially no saturated material at this extent, it does allow for seasonal increases in water-table.

In the vicinity of the infiltration galleries, the main water-bearing gravel layer is relatively thin – just over 5.0 m thick. However, the gravel is considered by very permeable due to the minor proportion of fines (averaging 2%) and the high percentage of gravel-sized clasts, or larger (70-90%) in these deposits. Thus this particular gravel deposit has been classified as a **locally important sand and gravel aquifer (Lg).**

[4] Due to the limited water level data, this distance is a conservative estimate to ensure that the area of aquifer is fully accounted for.

During the six day pumping test undertaken by KTC (1992), pumping rates were erratic during the first part of the test, although remained constant at 1750 m^3/d over the last two days. This later period is likely to reflect the longer term response of the aquifer at a pumping rate similar to the present rate. The aquifer parameters estimated from this period of the pumping test are described below and summarised in Table 1.1

The specific capacity (Sc) is approximately 460 m^3/d/m based on 3.77 m drawdown in the sump. The calculated transmissivity (T) from the time-drawdown data at the sump and the surrounding wells ranges from 350-600 m^2/d. For the purposes of this report, a representative transmissivity of 410 m^2/d was taken from the nearest up-gradient well (MW4). The permeability can be calculated by dividing the transmissivity by the saturated thickness of the aquifer, which is approximately 5.0 m. Therefore the permeability (K) is in the region of 80 m/d. The velocity of water moving through this aquifer can be calculated from Darcy's Law:

$$\text{Velocity (V)} = \frac{\text{(K x groundwater gradient (i))}}{\text{porosity (n)}}$$

Although no data are available to accurately estimate the effective porosity (n) for these gravel deposits, the PSA data highlight the high proportion of gravel – or larger – sized clasts and low percentage of fines. Thus the porosity is assumed to be relatively high; in the order 0.2 (20%). Using a groundwater gradient of 0.005 (Section 1.6.3), the velocity is estimated to be approximately 2.5 m/d.

Table 1.1. Estimated Parameters for Carndonagh Gravel Aquifer.

Parameter	***Source of data***	***Carndonagh Gravel Aquifer***
Transmissivity (m^2/d)	Pumping Tests	410 (350-600)
Specific Capacities (m^3/d/m)	Pumping Tests	460
Permeability (m/d)	Pumping Tests	80
Porosity	Assumed	20%
Velocity (m/d)	From Pumping Test	2.5

1.6.6 Conceptual Model

- The Carndonagh/Tirnaleague Public Water Supply Scheme comprises a main infiltration gallery (Gallery 1) which supplies 1680 m^3/d in winter and 1440 m^3/d in summer. The abstraction from Gallery 1 includes a gravity feed from Gallery 2, which is approximately 5 m down-gradient (north) of the newer Gallery 1.
- During the summer, the abstraction from Gallery 1 is augmented by and additional 240 m^3/d, which is the combined discharge from the sump in Gallery 2 and two boreholes. The total abstraction is pumped from the sump in Gallery 1 into a reservoir, before entering into the distribution system.
- Both the infiltration galleries and the boreholes are located in, and abstract water from, the Carndonagh gravel aquifer. The gravel is considered to be the main water-bearing layer due to its high permeability, as identified by the pumping test analysis and the PSA. This deposit has been categorised as a **locally important sand & gravel aquifer (Lg)**.
- In the vicinity of the infiltration galleries, the gravel is relatively thin – an average of just over 5 m thick.
- The gravel layer is overlain by less than 1 m of subsoil, described as 'silty CLAY'. Underneath the gravel are 'silts with gravel bands' (averaging less than 1.0 m in thickness) and then at least 6 m of 'sandy SILT'. Bedrock was not recorded in any of the boreholes.
- The aquifer is considered to be 'unconfined' because the static water levels in the vicinity of the infiltrations galleries appears to continue from the top of the gravel aquifer layer into the overlying subsoil layer.

- The static and pumping water levels indicate that there is 'induced' recharge from the nearest surface water channel into the aquifer. It is assumed that other surface water channels across this area also have some degree of hydraulic connection with the underlying gravel aquifer.
- A relatively flat water-table is expected in gravel, due to its permeable nature. The 'nil' water recorded in BH6 some 600 m south of the infiltration galleries meets this expectation.
- Generally, the water levels indicate that groundwater is moving from the higher ground to the south of the well field, to Trawbreaga Bay, which is directly to the north. This groundwater flow direction mirrors the surface water flow direction.
- Across the gravel area, a surface water catchment divide between the River Donagh and the Tirnaleague Stream can be depicted. The galleries and boreholes are all located within the Tirnaleague Stream catchment, although the most easterly borehole (BH2) is situated just within the catchment boundary.
- In the area to the south of the infiltration galleries, it is inferred from the vegetation and lack of artificial drainage infers that the soil and subsoil is free draining. It is assumed that recharge can occur diffusely over this area. Estimates of the amount of effective rainfall recharging the gravel aquifer are in the order of 600 mm/yr.

1.7 Delineation of Source Protection Areas

1.7.1 Introduction

This section delineates 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 around the abstraction points, and are presented in Figure 7.

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 infiltration galleries and boreholes.

1.7.2 Outer Protection Area

The Outer Protection Area (SO) is bounded by the complete catchment area to the well field, i.e. the zone of contribution (ZOC), which is defined as the area required to support an abstraction from long-term recharge. The ZOC is controlled primarily by (a) the pumping rate, (b) the groundwater flow direction and gradient, (c) the subsoil and gravel permeability and (d) the recharge in the area. The delineation of the ZOC uses:

i. hydrogeological mapping techniques and analytical modelling to determine the boundaries,

ii. a comparison of average discharge and recharge data to estimate the area required,

iii. a safety margin of 20^{o} in the estimated groundwater flow direction, and

iv. the maximum pumping rates to account for the larger ZOC required during the drier summer months.

Overview. It is assumed that the majority of the recharge to the scheme is occurring over the gravel aquifer. However, due to the very permeable nature of the gravel, its the assumed connection with surface water, and the low water table, at least during the dry weather, it is probable that the Tirnaleague Stream is 'losing' water to the underlying gravel. Once water enters the gravel, it will move northwards as groundwater and thus contribute to the reserve of water that supplies the scheme. These is one of the main considerations when delineating the ZOC boundaries.

The ***northern boundary*** takes account of the influence of the pumping down-gradient of the infiltration galleries and augmentation boreholes. The distances influenced are derived by using the aquifer parameters (transmissivity of 410 m^2/d; hydraulic gradient of 0.005) in the uniform flow equation:

$$\text{Approximate down-gradient extent} = \frac{\text{(discharge rate)}}{\text{2 x pi x (transmissivity) x (hydraulic gradient)}}$$

Using a pumping rate[5] of 1680 m^3/d at Gallery 1 and 240 m^3/d at each of the boreholes, these estimates are in the region of 120 m from Gallery 1 and 20 m from Boreholes 1 and 2. Given the limitation of the available data, a precise down-gradient boundary for the individual abstraction points cannot be delineated. Therefore these values have been used to define an 'averaged' boundary ensuring that the entire area supplying the infiltration gallery and boreholes is taken into consideration.

The ***south-western ZOC boundary*** is based on the boundary of the gravel deposit. The unsaturated gravel at the slightly higher elevation is hydraulically connected to the aquifer (the saturated material). Given the topography of this area, any recharge occurring over the unsaturated material will rapidly contribute to the groundwater reserve, thus constituting the aquifer's catchment area. The southern ZOC boundary also includes an arbitrary 50 m buffer along the extent of the gravel deposit to account for any surface runoff discharging into the gravel body.

This boundary also take into account the influence of the Tirnaleague Stream. Although it is anticipated that the majority of the Tirnaleague's flow will discharge to sea via surface flow, as outlined in the Overview, some of the surface water is likely to recharge the gravel which is supplying the scheme. Therefore a 30 m around the stream is included as part of the ZOC. This buffer width is used around locations of point recharge such as karst swallow holes.

The ***eastern boundary*** is constrained by topography. The area influenced by the abstraction is likely to be west of the topographic divide between the Tirnaleague Stream and the River Donagh. This divide therefore forms the catchment boundary to the area affected by the abstraction.

The ***northeast boundary*** is determined by the pumping regime of BH2 and the estimated response of the aquifer. BH2 is located in close proximity to the topographic divide between the Tirnaleague Stream and the River Donagh. It is therefore anticipated that groundwater can be pulled from beyond this natural divide. At an abstraction rate of 240 m^3/d, groundwater may be pulled from up to 60 m east of BH2. This distance has been incorporated into the delineation of the ZOC boundary.

ZOC Area. The available discharge data (Section 1.4) are not comprehensive enough to undertake a water balance and thus accurately estimate the catchment area required. However, the area of gravel aquifer within the ZOC (c.1 km^2) provides in the region of 1600 m^3/d recharge. This is almost equivalent to the abstraction rate and it does not take into account the induced recharge from the Tirnaleague Stream. Although these data are only approximations, it does suggest that the ZOC is realistic.

1.7.3 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 contamination and it is based on the 100-day time of travel (ToT) to the supply.

Based on the aquifer parameters in Section 1.6.5, the groundwater velocity is calculated as being in the region of 2.5 m/d. Thus over 100 days, the groundwater will travel a distance of 250 m to Gallery 1, Borehole 1 and Borehole 2.

Delineation of source protection zones is difficult in a hydrogeological situation such as that at Carndonagh without having more site investigation records than are available. Therefore, uncertainty

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[5] 1680 m^3/d is the winter pumping rate for Gallery 1. This value allows for a 15% increase in the summer rate. It is noted that the aquifer is unlikely to be able to sustain a significantly higher abstraction rate.

Although not individually monitored, 240 m^3/d is likely to represent a 50-100% increase in the abstraction rate for the individual boreholes, thus accounting for lower groundwater levels in summer.

is an inherent element is drawing these boundaries. However, these boundaries shown in Figure 1.8 represent a reasonable interpretation of the situation based on the available data.

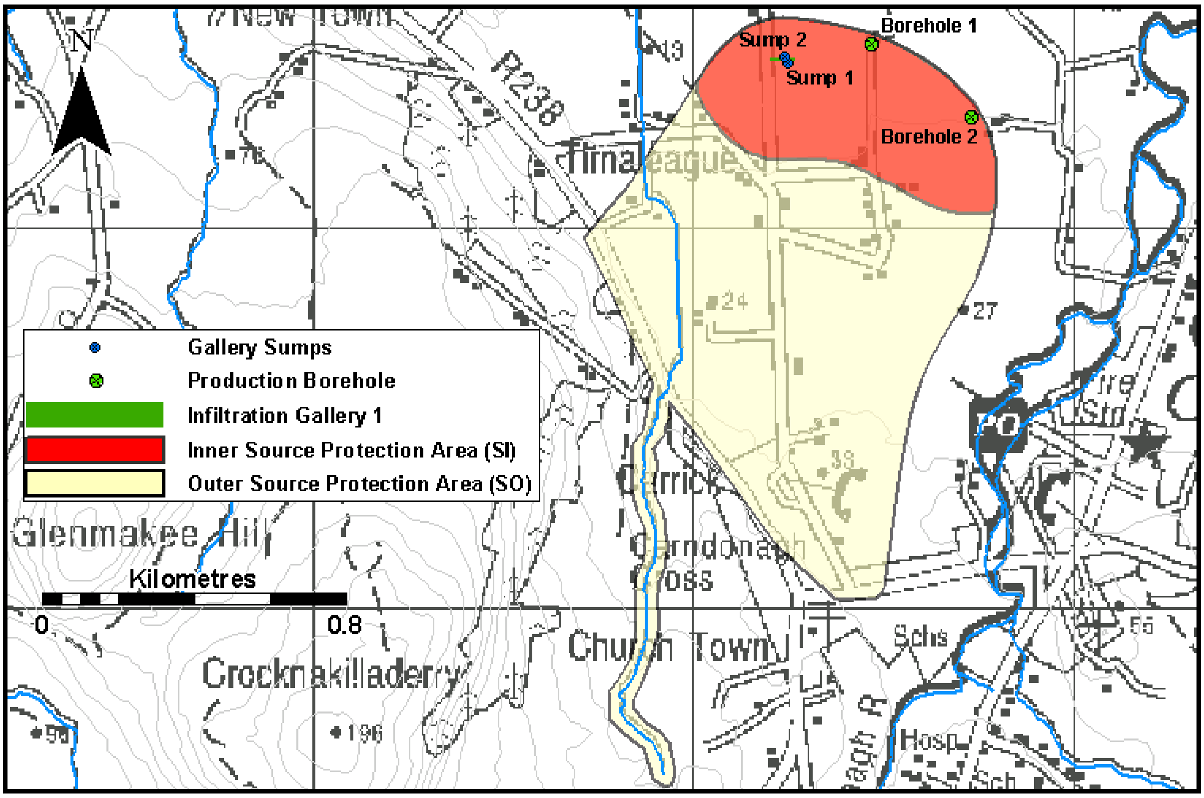

Figure 1.8. SO and SI Around the Carndonagh (Tirnaleague) Public Supply Scheme.

1.8 Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the two elements of land surface zoning (source protection areas and vulnerability categories), giving a possible total of 8 source protection zones. 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.

Five source protection zones are present around the Carndonagh Tirnaleague water supply scheme (Figure 1.9), as shown in the matrix below. Due to the shallow water table and thin covering of subsoil over the highly permeable gravel, the majority of the source protection area is considered to be extremely vulnerable to contamination.

Table 1.2 Matrix of Source Protection Zones for Carndonagh Public Water Supply Scheme.

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

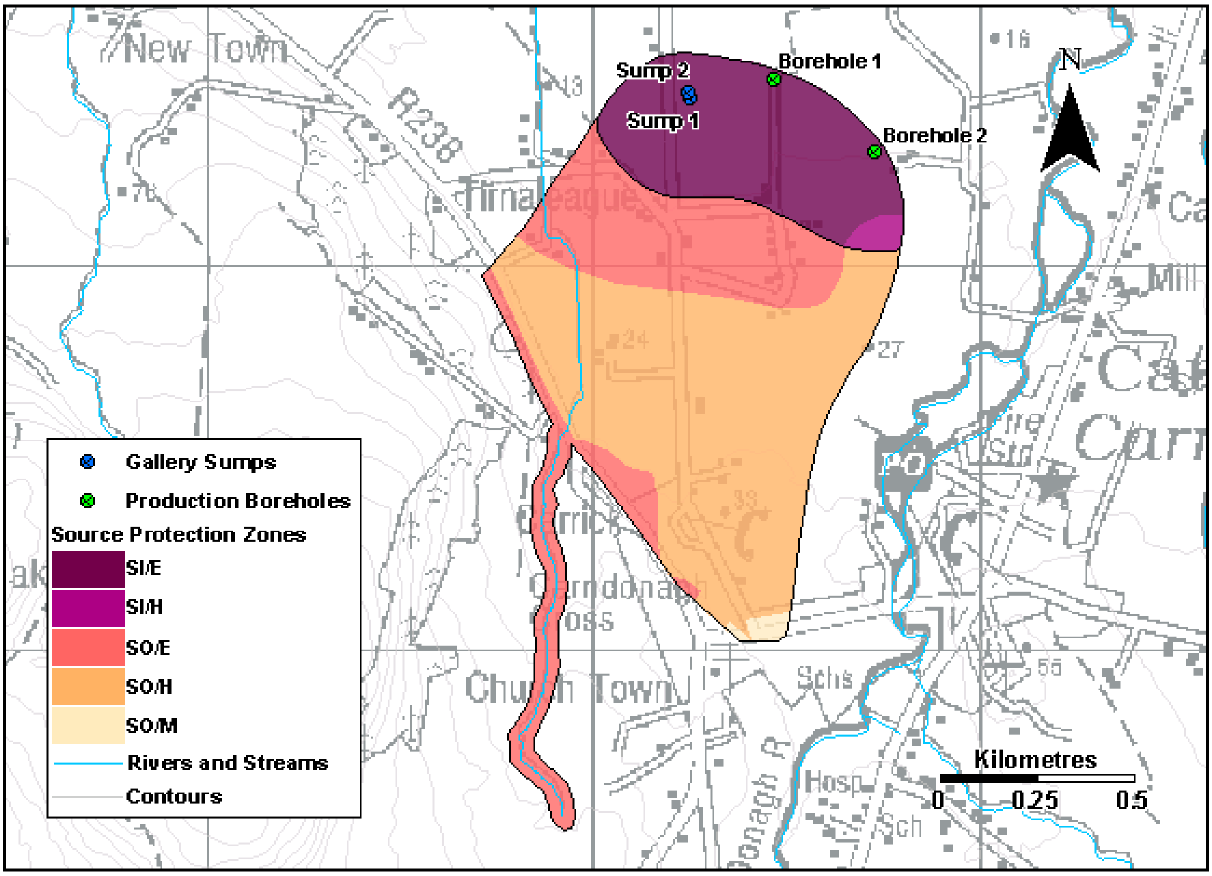

Figure 1.9. Source Protection Zones for the Carndonagh Public Supply Scheme.

1.9 Potential Pollution Sources

The majority of the land up-gradient of the infiltration galleries is used for pasture. There are a number of single houses, one of which is located only 50 m up-gradient of the infiltration galleries. Newer housing developments are also located within the ZOC as is the northwest limb of Carndonagh Town. This part of the town mainly comprises a linear development of housing along the road. Small roads cross the gravel aquifer, passing through the SI. The R238 route to Ballyliffin borders the gravel area to the east, south and west, thus passing through the ZOC.

The potential hazards from these land uses include on-site wastewater treatment systems from individual houses and leaky underground sewers from newer housing developments or houses that have switched over to the sewerage system. The application of fertilisers (organic and inorganic), herbicides and pesticides are issues to be considered especially with the anticipated high infiltration rates to the gravel aquifer. Oil and diesel spillage along the roads is also a potential hazard. The high levels of nitrate and presence of bacteria indicate that sources of organic wastes are an issue, although the contamination is not considered to be gross.

1.10 Conclusions and Recommendations

- The Carndonagh Tirnaleague Water Supply Scheme consists of a main infiltration gallery which is supplemented by gravity feed from a second, older infiltration gallery. These abstract between 1440 m^3/d in the summer and 1680 m^3/d in the winter. During the summer months, the abstraction is augmented by pumping from a) the sump in the original infiltration gallery and b) two more recently installed boreholes. The total abstraction from the additional sources is approximately 240 m^3/d.

- Both the infiltration galleries and boreholes abstract water from the **locally important sand and gravel aquifer (Lg)**.
- The ZOC mainly comprises the area of gravel aquifer influenced by the abstraction but also takes account of the potential for induced recharge from the Tirnaleague stream due to the assumed hydraulic connection between surface water and groundwater. It also includes the areas influenced by the pumping of the augmentation boreholes.
- The groundwater vulnerability is categorised as 'extreme' over much of the aquifer due to the thin layer of overlying, unsaturated material (< 3 m in thickness). Where this material is considered to be thicker, the vulnerability is categorised as 'high'.
- On-site wastewater treatment systems, leaky underground sewers, spreading of fertilisers, and diesel/oil spills pose a threat to the water quality at the well field.
- The protection zones delineated in the report are based on our current understanding of groundwater conditions and on the available data. Additional data obtained in the future may indicate that amendments to the boundaries are necessary.
- It is recommended that:
  1. a full chemical and bacteriological analysis of the **raw** water at each abstraction point is carried out on a regular basis.
  2. particular care should be taken when assessing the location of any activities or developments which might cause contamination at the well field; particularly in relation to underground sewers and waste pipes.
  3. given the elevated levels of contaminant indicators, the potential hazards in the ZOC should be located and assessed.