Environmental Protection Agency

Establishment of Groundwater Source Protection Zones

Cullahill Group Water Supply Scheme

Toberboe Spring

May 2010

Prepared by:
Dr. Robbie Meehan, Consultant Geologist

With contributions from:
John Dillon and Coran Kelly, Tobin Consulting Engineers;
Dr. David Drew and Jenny Deakin TCD

PROJECT DESCRIPTION

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

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

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

TABLE OF CONTENTS

TABLES and FIGURES

TABLES

FIGURES

1 INTRODUCTION

Groundwater Source Protection Zones are delineated for the Cullahill source according to the principles and methodologies set out in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999) and in the GSI/EPA/IGI Training course on Groundwater Source Protection Zone Delineation.

There are a number of springs located in the vicinity of the townland of Toberboe in southwest County Laois. One of the largest of these, which is known as Toberboe Spring, was developed in 1938 and is used to supply the Cullahill Group Water Supply Scheme. The other seven springs in the immediate vicinity are not used for water supply. The spring supplies approximately 140 m^3/day to the scheme.

The objectives of the report are as follows:

- To outline the principal hydrogeological characteristics of the area around Toberboe.
- To delineate source protection zones for the Toberboe Spring(s).
- To assist the Environmental Protection Agency and the Cullahill Group Water Scheme 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 source. 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).

While there was specific fieldwork carried out in the development of this report, the maps produced are based largely on the readily available information in the area and on mapping techniques which use inferences and judgements based on experience at other sites. As such, the maps cannot claim to be definitively accurate across the whole area covered, and should not be used as the sole basis for site-specific decisions, which will usually require the collection of additional site-specific data.

2 LOCATION, SITE DESCRIPTION AND WELL HEAD PROTECTION

The pumphouse and springs are located between 2 km and 3 km east-northeast Cullahill Village, which is on the N9 between Durrow, County Laois and Johnstown, County Kilkenny. The spring source is one of the the largest of eight springs in Toberboe, Graigueavoice and Newtown Townlands, all which are within 915m of each other. Their locations are shown in Figure 1.

The second largest of these eight springs forms the spring source, which has supplied Cullahill Village and its' surrounding rural area since the late 1930s. At the spring, groundwater emerges from sands and gravels along four individual subsurface conduits to collect in a circular, 0.3m thick solid concrete chamber dug into the subsoil (approximately 4m in diameter by 2.0m deep), with a solid concrete roof just above ground level. The sump and drainage channel are fenced off relatively poorly, and the overflow channel is overgrown with weeds and scrub, as recorded on a number of site visits and by the caretaker. The water is then pumped to the pumphouse which is 950m to the north-northwest.

The water is chlorinated and fluoridated at the pumphouse before flowing into a 40 m^3 capacity tank in the fenced-off area outside, before being pumped to a reservoir at Graigueavoice with a storage capacity of approximately 300 m^3 (80,000 gallons), which equates to just over 2 days storage. The chlorination tank and chemicals are stored in the pumphouse and a tap is present for untreated water samples.

The entire pumphouse site area of *c*. 0.25 acres is fenced off with good quality fencing, and is partially surrounded further by a narrow belt of young forestry.

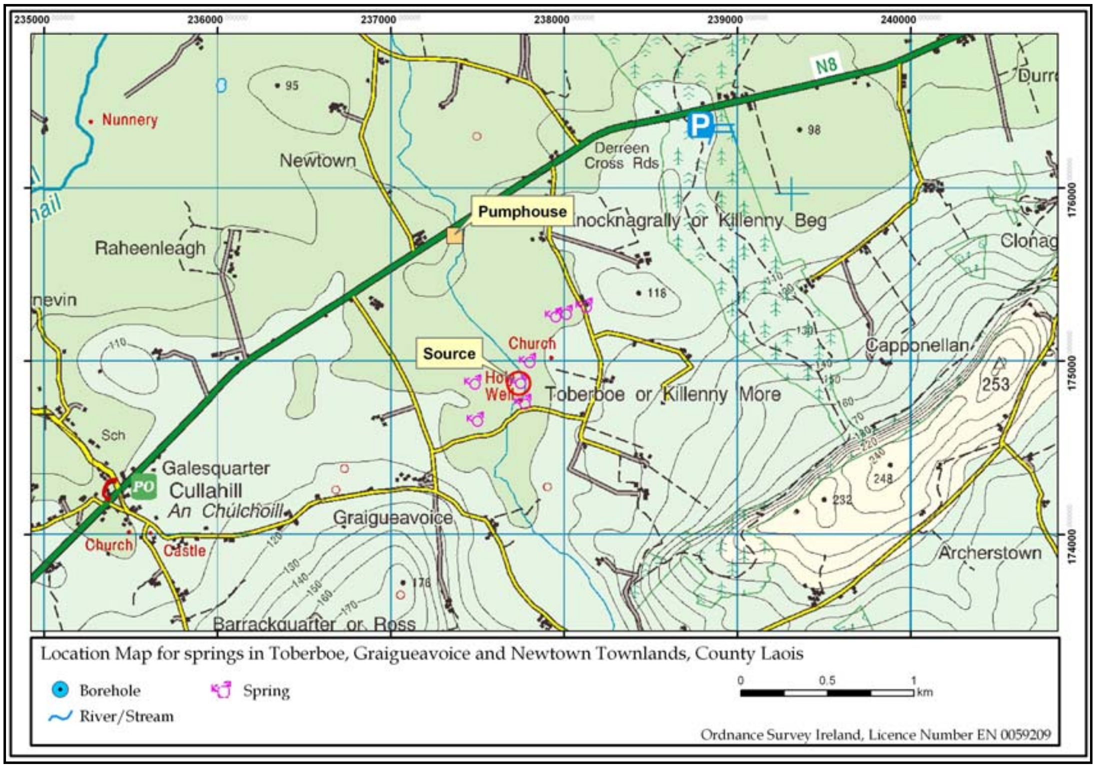

Figure 1 Location Map showing the region around Toberboe Spring(s).

3 SUMMARY OF SPRING DETAILS

Table 3.1 provides a summary of all spring details as currently known for the townlands of Toberboe, Graigueavoice and Newtown.

Table 3-1 Summary of spring details around the Toberboe Spring Source

Spring Details	Spring Name	
	Farmyard Spring	Copse Spring
EU Reporting Code	Not applicable	Not applicable
GSI No.	2317SW K004	2317SW K005
Grid reference	E238113 N175324	E237997 N175283
Townland	Toberboe	Toberboe
Source type	Spring	Spring
Owner	Private Ownership	Private Ownership
Elevation (ground level)	100.0m OD.	97.5m OD.
Static water level	At ground level (12/01/2010) but goes dry in summer	At ground level (12/01/2010) but goes dry in summer
Depth to rock	Unknown	Unknown
Transmissivity	Unknown	Unknown
Specific capacity	Unknown	Unknown
Normal abstraction	Not applicable	Not applicable
Maximum Abstraction	Not applicable	Not applicable
Estimated total discharge (see section 8.4)	2 l/s (172.8 m^3/day)	4 l/s (345.6 m^3/day)
Hours Pumping	Not applicable	Not applicable
Depth of sump	Not applicable	Not applicable

Spring Details	Spring Name	
	Pipe Spring	Church Spring
EU Reporting Code	Not applicable	Not applicable
GSI No.	2317SW K006	2317SW K007
Grid reference	E237937 N175267	E237787 N174005
Townland	Toberboe	Toberboe
Source type	Spring	Spring
Owner	Private Ownership	Private Ownership
Elevation (ground level)	97.0m OD.	99.0m OD.
Static water level	1.2m below ground level (12/01/2010, at pipe in drain)	At ground level (12/01/2010)
Depth to rock	Unknown	Unknown
Transmissivity	Unknown	Unknown
Specific capacity	Unknown	Unknown
Normal abstraction	Not applicable	Not applicable
Maximum Abstraction	Not applicable	Not applicable
Estimated total discharge (see section 8.4)	0.037 l/s (32.25 m^3/day)	3 l/s (259.2 m^3/day)
Hours Pumping	Not applicable	Not applicable
Depth of sump	Not applicable	Not applicable

Spring Details	Spring Name	
	Toberboe Spring	St. John's Well
EU Reporting Code	IE_SE_G_059_11_004	Not applicable
GSI No.	2317SW K008	2317SW K009
Grid reference	E237734 N174883	E237758 N174767
Townland	Toberboe	Toberboe
Source type	Spring	Spring
Owner	Private Ownership	Private Ownership
Elevation (ground level)	98.0m OD.	98.5m OD.
Static water level	At ground level (12/01/2010)	At ground level (12/01/2010), but goes dry in summer
Depth to rock	Unknown	Unknown
Transmissivity	Unknown	Unknown
Specific capacity	Unknown	Unknown
Normal abstraction	140 m^3/day	Not applicable
Maximum Abstraction	170 m^3/day	Not applicable
Estimated total discharge (see section 8.4)	4.6 l/s (399.2 m^3/day)	15 l/s (1,296 m^3/day)
Hours Pumping	12	Not applicable
Depth of sump	2.0m	Not applicable

Spring Details	Spring Name	
	Wetland Spring	Newtown Spring
EU Reporting Code	Not applicable	Not applicable
GSI No.	2317SW K010	2317SW K011
Grid reference	E237484 N175669	E237470 N17880
Townland	Graigueavoice	Newtown
Source type	Spring	Spring
Owner	Private Ownership	Private Ownership
Elevation (ground level)	96.5m OD.	97.5m OD.
Static water level	At ground level (12/01/2010)	0.6m below ground level (12/01/2010, in drainage pipe)
Depth to rock	Unknown	Unknown
Transmissivity	Unknown	Unknown
Specific capacity	Unknown	Unknown
Normal abstraction	Not applicable	Not applicable
Maximum Abstraction	Not applicable	Not applicable
Estimated total discharge (see section 8.4)	0.5 l/s (43.2 m^3/day)	6.8 l/s (587.5 m^3/day)
Hours Pumping	Not applicable	Not applicable
Depth of sump	Not applicable	Not applicable

Plate 1 Detail of subsurface sump chamber at Toberboe Spring Source.

Plate 2 The pumphouse adjacent to the N9 road (NGR 237375 175757), with the holding tank also visible, to the left.

Plate 3 Relatively warm groundwater emerging from frozen ground at St. John's Well (air temperature -3^{o}C) on 5th January 2010.

4 METHODOLOGY

The methodology consisted of collection of data from the Cullahill Group Water Scheme records and from GSI Archival Records, desk studies of relevant maps and reports, site visits and field mapping. Analysis of the information collected during the various stages of review were used to delineate the Groundwater Source Protection Zones.

The initial site visit and interview with the Group Scheme caretaker took place on 03/12/2009.

Site walk-overs and field mapping (including measuring the flows, electrical conductivity and temperature of springs and streams in the area) of the study area were conducted on 03/12/2009, 04/12/2009, 05/01/2010 and 12/01/2010.

5 TOPOGRAPHY, SURFACE HYDROLOGY AND LAND USE

The springs are located within a wide valley gouged into the northwesternmost flank of the Castlecomer Plateau. The springs emerge at elevations between 96m and 100m OD (see Section 3 for exact elevation details) at the boundary between higher, hummocky land to the southeast and an extensive flat-lying alluvial flat at the northwest (Figure 1). Though being generally hummocky, the land to the southeast and southwest rises gently from the valley floor, before an abrupt change in gradient at the steep backslope of the high plateau. The average topographic gradients are 1:90 to the north of the springs, 1:30 for the first kilometre to the south, and 1:7 on the high plateau backslope.

The natural and artificial drainage density in the immediate vicinity of the source area is high owing to their situation at the edge of the alluvial flat area. To the east, south and west, however, there are no surface drainage features on the hummocky terrain, but drainage ditches become common on the high plateau area. Rushes occur sporadically on these higher ridge slopes also, but are completely absent from the hummocky areas.

One stream flows through the springs' area from the south, rising at the eastern edge of Cullahill Mountain and flowing off to the northeast, before turning at Ballykealy 2 km south of the springs, where it flows northwards past them before joining the River Goul at Ballyboodin. Toberboe Spring and St. John's Well are adjacent to and flow directly into this along short channels a number of metres long, with the Farmyard, Copse and Wetland Springs conducted into it *via* a long network of surface drains, and the Pipe, Church and Newtown Springs fed into it *via* subsurface pipes.

Two small wetland waterbodies which fluctuate markedly with respect to their water levels and area between winter and summer are situated at the southwestern edge of the springs, at NGR 237460 174645 and NGR 237400 174455. The Wetland Spring rises in the northernmost of these, and it is noted that the southern wetland flows into the northern one *via* overland flow following extreme rainfall events (as seen there on 03/12/2009), with it in turn flowing *via* drains into the aforementioned stream.

Parts of the extensive alluvial flat to the north of the springs, in particular the area 500m from them adjacent to the pumphouse and the N9 road, was flooded at the start of December 2009, owing to the recent heavy rains. In contrast, the hummocky areas around the springs seem to constitute extensive areas of well drained soils upon first inspection,

Land use in the area is primarily agricultural, with the majority of the lands set to pasture for dairying (c. 80%) or used for tillage (c. 15%). Small areas of scrub, broadleaf forestry and bedrock outcrops (hosting a few small, disused quarries) also occur (5%). A number of farmyards occur in the area, with the nearest to the source spring *c.* 450 m to the east. Many of these farmyards host slatted units, milking parlours and silage pits. Grazing of areas hosting small pockets of scrub, and with bedrock at the surface, was noted to the southeast.

No major industries occur in the area. Single houses discharge to ground *via* septic tank systems and mechanical aeration systems along the base and flanks of the valley. Disused sand and gravel pits also occur to the southeast of the spring source.

6 GEOLOGY

6.1 BEDROCK GEOLOGY

This section briefly describes the relevant characteristics of the geological materials that underlie the area around Toberboe Spring(s). The geological information is based the bedrock geological map of Tipperary, Sheet 18, 1:100,000 Series (Archer *et al*., 1996) and the Geological Survey of Ireland (GSI) Karst Database.

According to the 1:100,000 bedrock sheets of the region (Archer *et al*., 1996, see Figure 2), this area is underlain principally by limestones of the Ballyadams Formation, which are also described as the Dinantian Pure Bedded Limestones for the purposes of the generalised rock unit map prepared for the WFD in characterising and describing groundwater bodies in Ireland by the GSI. These rocks are crinoidal wackestones and packstone limestones, and are the classic 'Burren' type limestone,

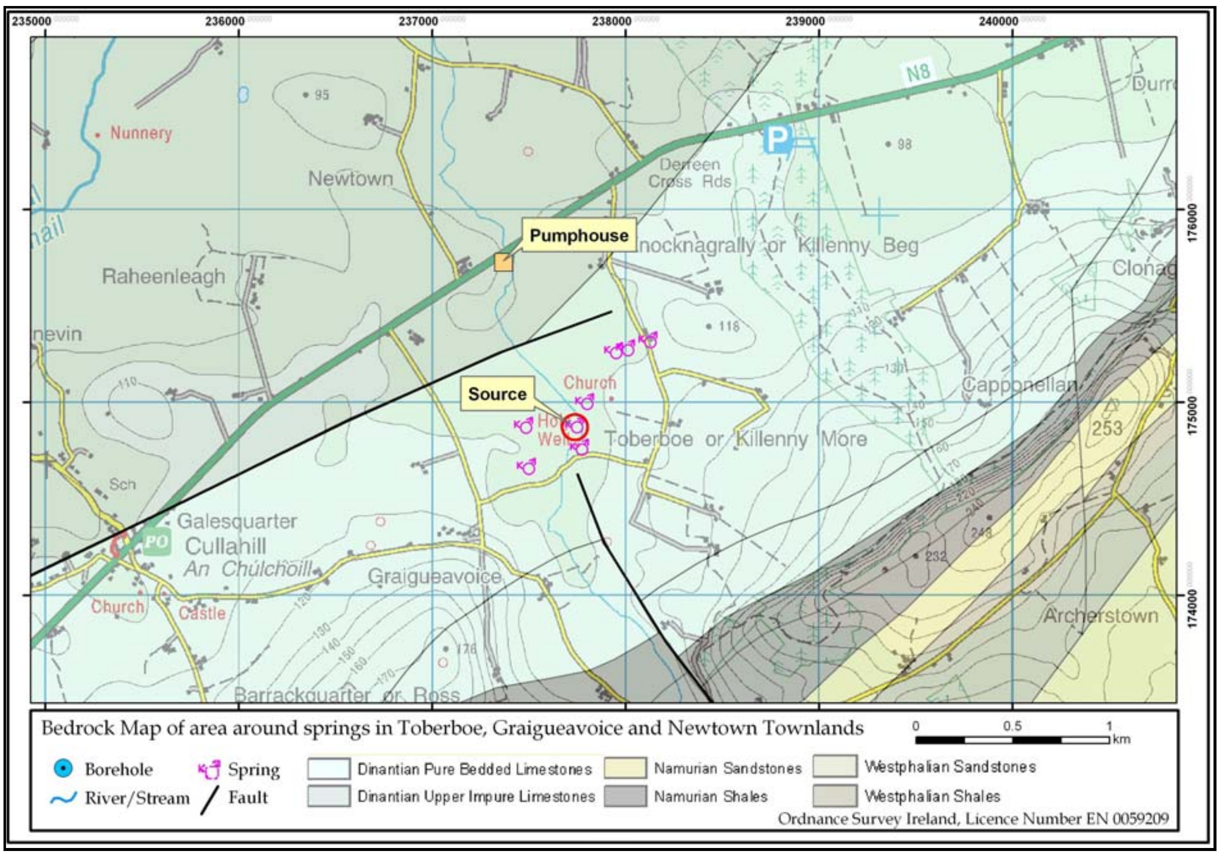

Figure 2 Bedrock geology of the area around Toberboe Spring(s).

The Dinantian Pure Bedded limestones of the Ballyadams Formation are composed of clean-bedded limestone which is generally homogenized, comminuted shelly debris, cemented by fine spar. Some oolithic and even micritic beds may occur near the base, just above the highest shales which define the top of the underlying Durrow Formation. The formation is over 200 m thick.

The Ballyadams Formation rocks outcrop rarely in the area around the springs but forms a strip between 1.5 km and 2 km wide under the subsoils, and extends along a northeast-southwest orientation by at least 4 km in each direction along the base of the high ridge. A thin strip of cherty, muddy, calcarenitic limestone of the Cloghrenan Formation then occurs at the base of the scarp to the southeast, overlying the Ballyadams Formation. This has thinner beds and more chert than the Ballyadams Formation, but is still classed as Dinantian Pure Bedded limestone.

An extensive area of Dinantian Upper Impure limestones extends off to the northwest from approximately 500 m to the northwest of the spring source. These rocks are the shaly fossiliferous and oolithic limestones of the Durrow Formation, and are partially separated from the pure limestone by a marked west-southwest to east-northeast oriented fault. Faulting has also occurred south of the springs along a north-south orientation, both within the limestones and extending into the 'Namurian' upland region further south again (Figure 2). This is only 150m - 200m from the largest of the springs, including the source itself.

A number of surface exposures of limestone were mapped during field studies conducted in December 2009. A small, disused quarries which has no current rock outcrop occurs 750 m west of the spring source. On the ridge backslope to the southeast, small outcrops occur on the farm 800m from the source, at NGR 238464 174110 and NGR 238511 174498 respectively. The bedrock units comprised thinly bedded bluish-grey, clean limestones, generally dipping less than 5^0 to the south. Adjacent to this, the landowner states (03/12/2009) that the large field at NGR 238610 174450 is known as 'The Quarry Field', having hosted old quarries and currently having bedrock within 0.3m of the surface across it's extent.

To the south and southeast of the springs by 1.25 km, and forming generally the highest ground on the steep scarp, the limestones are succeeded unconformably by Upper Carboniferous (Namurian) age shales of the Killeshin Siltstone Formation, as well as thick, flaggy sandstones of the Bregaun Flagstone Formation further west.

6.1.1 Karst Geology

Hydrogeological mapping (December 2009) included checking existing, known karst features in the district around the source and searching for possible new features. The karst features listed in Table 6-1 are those recorded in the GSI Karst Feature Database within a 5 km radius of Toberboe Spring(s). The locations of these features at Seskin, where three swallow holes occur adjacent to each other and a stream sinks into the ground having flowed off the Namurian Outlier, are shown in Figure 8.

None of the springs at or around the source were listed in this database, and all eight have been detailed in Section 3. No other new karst features were mapped in the area around the source in December 2009.

Table 6-1 Karst features within a 5 km radius of the Toberboe Spring Source (GSI Karst Database)

Number	Feature type	Feature name	Easting	Northing	Distance to source	Townland
K1	Swallow Holes	Seskin Swallow Holes	241930	173190	4.5 km southeast	Seskin

Solutionally enhanced karst was noted in the top 1 m bgl at the bedrock outcrop at NGR 238464 174110, 1 km to the southeast of the source. The enlarged fissures typically ranged from 5 mm to 10 mm wide. A decrease in karstification was noted with depth, as the widths of karstified joints generally decreased from 5 mm to 3 mm at 2 m bgl.

Plate 4 Epikarst within bedrock outcrop at NGR 238464 174110, 1 km to the southeast of the Toberboe Spring Source.

6.2 SUBSOILS GEOLOGY

The subsoils around the source comprise a mixture of coarse- and fine-grained materials. Sands and gravels and limestone tills are the dominant subsoils in the area, with more restricted areas of bedrock outcrop, lacustrine clay, alluvium and tills derived from Namurian shales and sandstones also occurring (Figure 3). In general, subsoils are relatively shallow on the high scarp south and southeast of the source, but are considerably deeper in the valley and around of the source on the more lowlying and hummocky terrain.

The area around and east of the spring source comprising the hummocky terrain is mapped on the Teagasc subsoil map as being underlain by deep glaciofluvial sands and gravels derived from limestones. These were deposited by a wide meltwater river flowing off a retreating ice margin along the valley side during deglaciation, when the ice sheets of the last Ice Age melted. From examination of gravel pit faces at NGR 237995 174565 and NGR 238160 174375, 300 m to 600m southeast of the spring source, the sands and gravels are generally deep at >5 m, with depths of over 10 m possible given the topography of the area.

A northwest to southeast-oriented esker ridge, also comprised of sands and gravels, occurs 500m to the south of the source. This extends along the lower slopes of the high ridge at Graiguavoice.

Till or 'Boulder clay' is an unsorted mixture of coarse and fine materials laid down by glacier ice during the last Ice Age. Till is the dominant subsoil type on the hummocky to gently undulating terrain west of the spring source. The till here is dominated by limestone. This gently undulating to hummocky, lowlying area of till derived from limestone extends to the southeast around Cullahill Village, as well as to the north towards the River Goul. It also occurs on the lower flanks of the ridge to the south at Graigueavoice, and extends from the sands and gravels at the northeast towards Durrow (Figure 3).

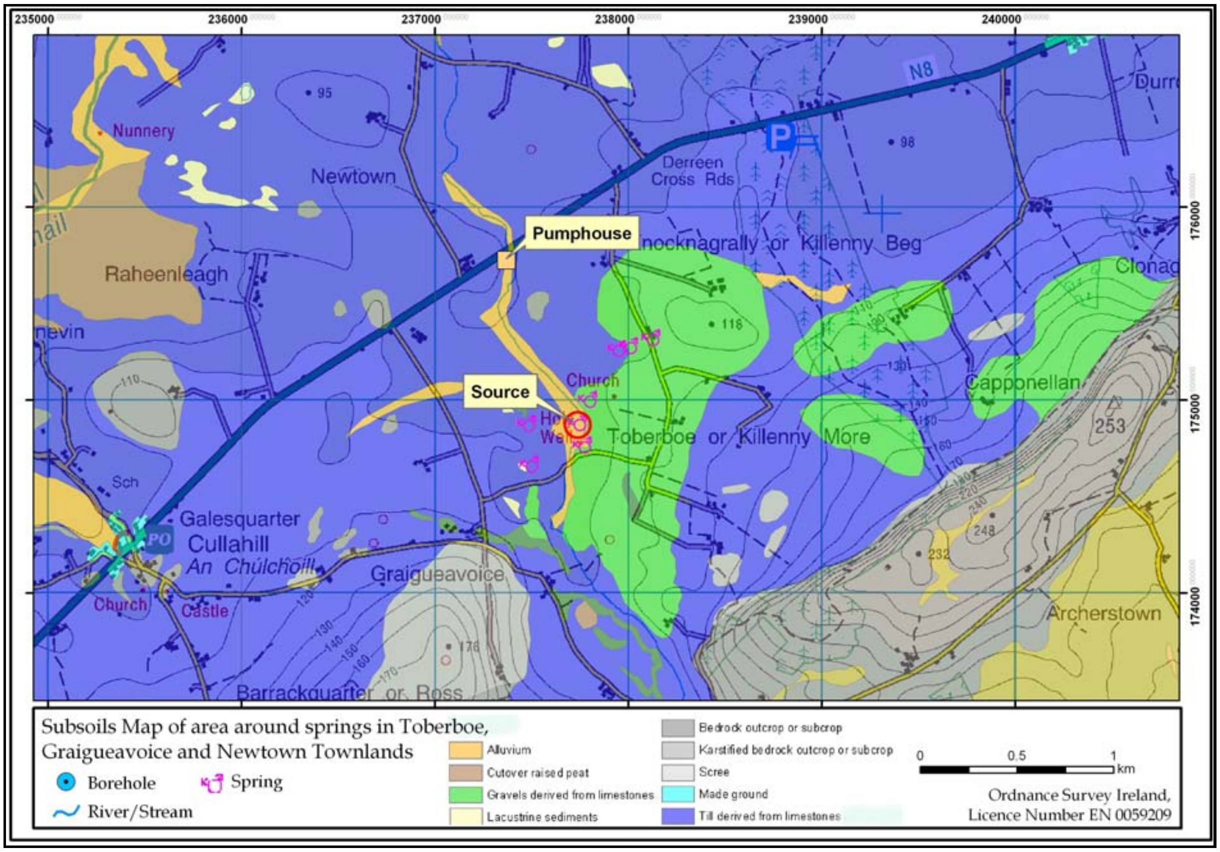

Figure 3 Subsoil Map for the area around Toberboe Spring(s).

Note: The valley is dominated by the sands and gravels (green) and till derived from limestone (blue), with a narrow strip of alluvium along the stream (orange) and much bedrock outcrop and subcrop on the flanking ridge crests (grey).

Immediately adjacent to the stream flowing south to north past the source, a long, narrow, flat, low-lying strip of postglacial alluvial deposits occur. These have accumulated from repeated flooding of the stream in this lowlying area since the last Ice Age. The alluvium material seems to be dominated by SAND but also hosts interbedded GRAVELS, and seems to overlie glaciofluvial sands and gravels, as seen in the stream sections to the north of the source.

Small areas of lacustrine CLAY flank the wetlands southwest of the spring source, at NGR 237460 174645 and NGR 237400 174455. These materials have accumulated in the hollows since deglaciation by repeated flooding there, similar to the alluvium along the stream.

To the southeast of the boreholes by 1 km, bedrock protrudes through the deep glacial and postglacial subsoils. The area north of this also forms an extensive area of bedrock subcrop (within 1 m of the surface). Bedrock outcrop and subcrop is also common on the summits of the upland ridges to the south and southeast.

In and around Cullahill Village, much of the subsoils have been covered by 'Made' ground; built land and concreted/tarmacadamed areas. This 'Made' material is underlain by shallow bedrock and till, similar to the areas immediately adjacent to it.

The soils on the sand and gravel areas are dominated by 'dry' soil types: typically well drained deep mineral soils of brown earths and grey brown podzolics, and well drained shallow brown earth soils (Conry, 1974, 1987; Gardiner and Radford, 1980). The tills derived from limestone in the region are also characterized by generally well drained grey brown podzolic soils, whereas the Namurian ridges to the south and southeast are often characterized by poorly drained gleys. Within the areas of bedrock outcrop/subcrop and alluvium, the soils are widely variable in their depths and drainage status.

Within the study area of the source, the only subsoil exposures discovered were in gravel pits within the sand and gravel areas.

6.3 DEPTH TO BEDROCK

Depth to bedrock varies greatly throughout the study area, as seen from consultation of the depth to bedrock maps produced by GSI from the Counties Kilkenny and Laois Groundwater Protection Schemes (2002).

The depth of subsoil is generally less than 3 m on the ridge scarp summits to the south and southeast of the spring source, increasing in depth towards the centre of the valley and the source area. A conceptual cross section through the subsoil/bedrock is shown in Figure 4.

Within the lowlying terrain around the springs, depths to bedrock are interpreted as highly variable as the karstified limestone has a jagged, uneven surface and has been overlain by sands and gravels of complex geometry and varying depths. Wells records for the valley area show depths to bedrock of between 5m and 19m within the sands and gravels area. In general, the sands and gravels in the area are interpreted to be >5 m thick as seen in gravel pit exposures, but are expected to be over 10m thick across much of the area based on the topography of the materials and many of the well depths.

The depth to bedrock mapping for the County Laois Groundwater Protection Scheme indicates that the depth of till in the area to the west of the spring source is between 2m and 6m deep.

7 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 water table emerging at the springs. For the purposes of vulnerability mapping in the immediate vicinity around the springs, the "**water table**" is the target, as this lies above the top of the bedrock. Further south and southeast, towards the ridge scarp, where the subsoil is either sands and gravels or till of moderate permeability with the bedrock surface at an elevation higher than the water table both here and at the springs, then the "**top of the rock**" is the target[1]

Around the source, the permeability of the till subsoil in the gently undulating area to the west and north, and on the lower flanks of the ridge to the south at Graigueavoice, is interpreted to be "**moderate**", based on the general absence of permanent surface water features or secondary indicators of low subsoil permeability (see Figure 3 for the pattern of subsoils in these areas). On the summit of the high ridge scarp to the southeast of the source, the permeability of the till subsoil is interpreted to be "**low**" owing to the opposite being the case. In the sands and gravels subsoil, the permeability is interpreted as "**high**".

Depth to bedrock varies from being greater than 10 m in some localities within the sands and gravels to zero where the bedrock outcrops occur 1 km to the southwest.

At subsoil thickness of less than 3 m, as indicated by the outcrop, subcrop and Groundwater Protection Scheme data, bulk permeability becomes less relevant in mapping vulnerability across wide areas (as opposed to 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"** has been assigned in these areas of shallower subsoil.

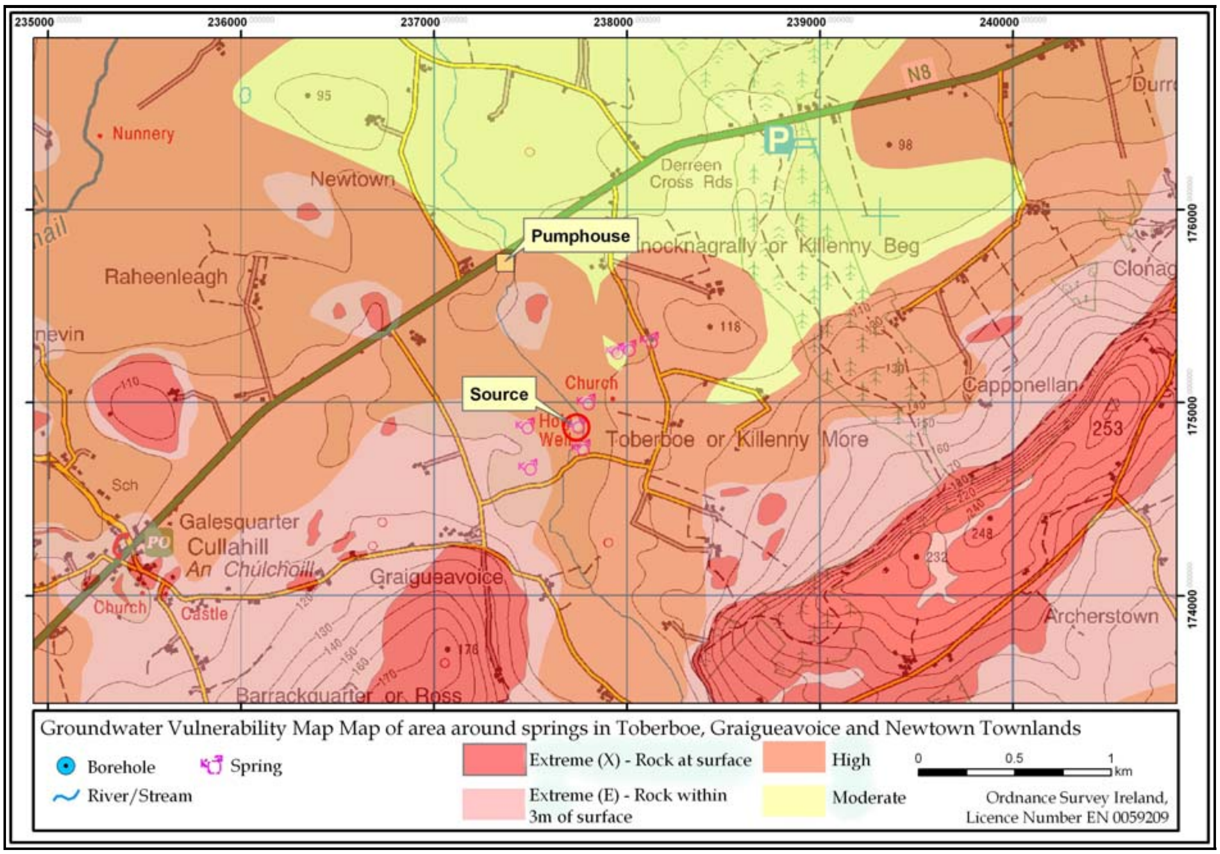

Figure 4 Groundwater Vulnerability Map for the area around Toberboe Spring(s).

[1] In areas where the water table is below the top of the bedrock, the thickness of the unsaturated zone within the bedrock is not taken into consideration in vulnerability mapping, as there is no attenuation of contaminants in fractured bedrock

As the water table at the springs exits either in a chamber with no protective sediment cover, or subaerially (at the surface), the vulnerability to contamination at the springs is also classed as "**extreme**". The extent of the extreme vulnerability is estimated to extend for 30 m around the springs, over the surface area of the flanking till/alluvium/sand and gravel.

Where subsoil thickness is greater than 3m, the vulnerability classification ranges from **"low"** to **"high"**, depending on the specific combination of permeability and subsoil thickness.

The Groundwater Vulnerability Map as mapped by the GSI for relevant Local Authorities as part of the Counties Kilkenny and Laois Groundwater Protection Schemes (2002) is consequently dominated by 'high' vulnerability in the sand and gravel area within the valley, as shown in Figure 5. On the high, flanking ridges where bedrock is at or relatively close to the surface, the vulnerability is classed as 'Extreme'. An extensive area of moderate vulnerability extends northwards from Killenny Beg Townland and across the N9.

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 anticipate 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).

8 HYDROGEOLOGY

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

- ⇨ GSI Website, Well Database and Groundwater Section in-house archives
- ⇨ Cullahill Group Water Scheme Caretaker
- ⇨ EPA website and Groundwater Monitoring Database
- ⇨ Local Authority Drinking Water returns
- ⇨ Hydrogeological mapping by the author in December 2009 and January 2010.

8.1 GROUNDWATER BODY AND STATUS

The descriptions of groundwater bodies throughout Ireland are available from the GSI website: www.gsi.ie and the 'status' is obtained from the Water Framework Directive website: www.wfdireland.ie/maps.html.

The area around Toberboe Spring(s) is included as part of the Durrow Groundwater Body (as part of a Regionally Important karstified bedrock aquifer) which is classified as being of Good Status (December 2008).

8.2 METEOROLOGY

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

Annual rainfall: 879 mm.
The contoured data map of rainfall in Ireland (Met Éireann; 1961-1990 dataset) shows that the source is located between the 900 mm and 1000 mm average annual rainfall isohyets. The closest meteorological station to the Toberboe Spring(s) is 3.5 km to the northeast at Durrow, where detailed rainfall measurements for the same period are averaged at 879 mm per annum.

Annual evapotranspiration losses: 427 mm.
Potential evapotranspiration (P.E.) is estimated to be 450 mm/yr (based on data from Met Éireann at Johnstown Castle, Wexford). Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., to allow for seasonal soil moisture deficits.

Annual Effective Rainfall: 452 mm.
The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore equivalent to this, or 452 mm/year. Section 8.7 following (Recharge) estimates the proportion of effective rainfall that enters the aquifer utilising other hydrogeological data for the area.

8.3 GROUNDWATER LEVELS, FLOW DIRECTIONS AND GRADIENTS

All eight springs emerge either in or at the edge of flat, lowlying areas: none emerge from bedrock and all pass through (interpreted) relatively deep subsoil. In the majority of the flat area around the springs a high density of artificial drainage is required in order to utilise the land, which is mainly grazed. There is also a relatively high natural drainage density in this lowlying area around Toberboe Spring(s). The land to the north of the springs is flat, covered in rushes and saturated, and was flooded following extreme rainfall on 03/12/2009. As stream sections through this zone expose sands and gravels and gravelly alluvium, it therefore seems that this area is a discharge zone.

The emergence of the springs, the high natural and artificial drainage densities and the rushes/flooded areas therefore generally indicate a shallow water table in the area around the springs (*i.e.* close to the surface).

The fact that seven out of the eight springs goes dry in summer, and given that the source diminishes to a very low flow during these times also, suggests that the springs are an overflow mechanism for the regional groundwater flow system. From this, in order to attain reliable groundwater flow data and in the absence of specific, reliable depth to bedrock or borehole data in the immediate vicinity of the springs, the measurement of groundwater levels in wells around the source was required. This was completed using GPS Total Station on 12/01/2010.

The results of the groundwater level monitoring are shown in Figure 6. Four out of the five wells dipped and positioned were within the Ballyadams Formation bedrock; the most southerly was in bedrock of the Cloghrenan Formation. No wells were pumping at the time; only two were still in use.

On the lower flanks of the ridge to the east, where depth to bedrock is relatively shallow, the water table is c. 4m from the surface. The water table deepens moving westwards into the sands and gravels, at 8.57m bgl in the northern portion of this area (and also emerging as an overflow around the springs). To the south of the springs, in the Cloghrenan Formation bedrock, the water table is at 10.02m bgl and to their west in the till the water table is at 17.32m bgl.

The sequence of water levels to a common datum and the resultant contour map, when allied with topographical data, shows that the regional-scale groundwater table demonstrates a regular groundwater gradient of approximately 0.022 from southeast to northwest. Groundwater is therefore expected to flow from southeast to northwest across the area. This flow direction therefore broadly focuses toward the River Goul discharge area, mirroring to a large degree the valleys' macro-topography.

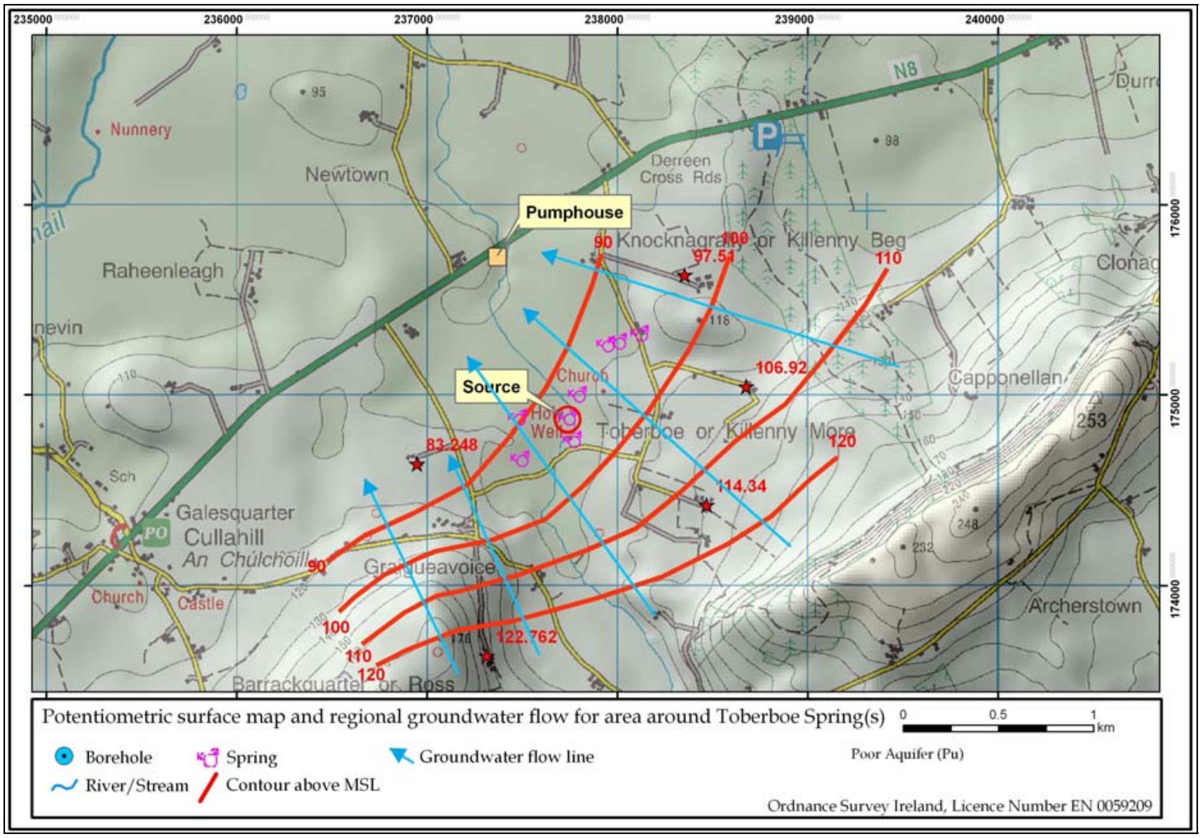

Figure 5 Potentiometric surface map of the area around Toberboe Spring(s), compiled as part of the current project.

Groundwater elevations at individual wells are shown in metres OD. The general flow gradient along flow towards the northwest is clearly seen.

The stream flowing off the high ridge to the south catches the surface water flow from the Namurian-bedrock upland, reflected in the conductivity measurement of 402 µS/cm at Ballykealy (NGR 238341 173208) on 03/12/2009. The relatively low conductivities along the stream (maximum of 574 µS/cm in the vicinity of the springs) suggest that this stream is largely fed by surface water along it's length, and therefore seems to be largely removed from the groundwater regime, excepting around the springs.

8.4 SPRING DISCHARGE

Field measurements of electrical conductivity and temperature from the eight springs on the 12/01/2010, when the air temperature was 1°C, show that they all seem groundwater-fed. Only at the pipe spring was the temperature of the water close to the air temperature, with the remainder all having much warmer water emerging (many also retaining this following piping).

There are no long-term discharge data for the springs at Toberboe, and the total spring(s) discharge (abstraction quantities and overflow volumes) was not well characterised prior to this project.

However, the EPA did measure discharge at St. John's Well on three occasions over a period of one year between February 2004 and January 2005. The average discharge per day varied between 6 l/s

(518 m³/day, 04/11/2004) and 16 l/s (1382 m³/day, 05/02/2004). Given that the measurement on 04/11/2004 followed a week of dry weather, again following a week of wet weather, this is probably most representative of 'mean' flow for the spring. The measurement taken on 05/02/2004 followed a week of very wet weather.

The flow from St. John's Well was measured as part of this project on two separate occasions in December 2009 (following an extreme rainfall event) and January 2010 (following a prolonged cold spell). The flow rates were 14.5 l/s (1,253 m³/day, 03/12/2009) and 15 l/s (1,296 m³/day, 12/01/2010).

Table 8-1 Field measurements of electrical conductivity, temperature and pH at Toberboe Spring(s)

Spring Name	Conductivity (µS/m @ 25°C)	pH	Temperature	Notes
Farmyard Spring	795	7.03	7.6°C	Measured following piping and mixing with surface water
Copse Spring	771	6.89	8.1°C	Measured at overflow
Pipe Spring	737	6.53	3.9°C	Measured following piping
Church Spring	846	6.90	8.6°C	Measured following piping
Toberboe Spring	740	7.27	9.0°C	Measured at overflow
St. John's Well	907	7.02	9.6°C	Measured at emergence
Wetland Spring	747	7.16	6.8°C	Measured at overflow into field
Newtown Spring	715	7.2	7°C	Measured following piping, at stream

According to the caretaker for the Group Scheme and Group Scheme Records, the abstraction at Toberboe Spring itself is relatively constant, approximately 140 m³/day, with a maximum abstraction rate of 170 m³/day.

The overflow volume (discharge following abstraction) at the Toberboe Spring Source is not well characterised. While no long term calibrated data are available in relation to the overflow, and as it is quite overgrown with scrub and the channel quite collapsed, the overflow was measured as part of this project on two separate occasions in December 2009 and January 2010. The maximum overflow from the spring source following the rainfall event was estimated to be 6 l/s (518 m³/day), with the flow following the cold spell much greater and estimated at 7.6 l/s (656 m³/day).

Flows from the Farmyard Spring, the Copse Spring, the Pipe Spring, the Church Spring, the Wetland Spring and the Newtown Spring were all measured on the same two occasions during this project. The estimated discharge values, as well as abstractions, are shown in Table 8.2.

The total discharge from the eight springs is therefore **36.3 l/s (3,135 m³/day)** during a cold, dry, winter period on 12/01/2010.

Utilising the value for what is considered the most representative figure for 'mean' flow from St. John's Spring, taken on 04/11/2004 and being of 6 l/s, the pro-rata 'mean' flows based on measured values (03/12/2009) for the other springs are shown on column 5 of in Table 8.2. This gives a total estimated 'mean' discharge from the eight springs of **23.6 l/s (2,029 m³/day)** on 04/11/2004 following a week of dry weather, which again followed a week of wet weather.

Table 8-2 Measured and estimated 'mean' discharges from Toberboe Spring(s)

Spring Name	Flow, l/s (m^3/day) 03/12/2009	Flow, l/s (m^3/day) 12/01/2010	Abstraction l/s (m^3/day)	Pro-rata 'mean' flow, as on 04/11/2004 l/s (m^3/day)
Farmyard Spring	5.5 (475)	2 (172.8)	n/a	2.2 (190)
Copse Spring	5 (432)	4 (345.6)	n/a	2 (172.8)
Pipe Spring	1 (86)	0.037 (32.25)	n/a	0.413 (35.6)
Church Spring	6 (518)	3 (259.2)	n/a	2.5 (216)
Toberboe Spring	6 (518)	3 (259.2)	1.6 (140)	2.5 (216)
St. John's Well	14.5 (1253)	15 (1296)	n/a	6 (518.4)
Wetland Spring	0.58 (50)	0.5 (43.2)	n/a	0.24 (20.7)
Newtown Spring	15 (1297)	6.8 (587.5)	n/a	6.2 (535.7)

The stream flowing off the high ridge to the south had a flow of 110 l/s (9,504 m^3/day) at the EPA Stream gauge adjacent to St. John's Well (03/12/2009, NGR 237395 174695) and a flow of 138 l/s (11,923 m^3/day) adjacent to the EPA Stream gauge[2] near the pumphouse (03./12/2009, NGR 237392 175739). The stream therefore seems to partially sink into the groundwater along its course past the springs, which is deduced as the difference between the measured flows to the south of the springs and to the north of them is 28 l/s (2,419 m^3/day), much less than the calculated discharge from the springs.

8.5 HYDROCHEMISTRY AND WATER QUALITY

The majority of the available water quality data for the Toberboe Spring Source is from EPA Drinking Water Returns, which are available from 2003-2008, and EPA Water Monitoring data, which has been collected several times a year at the source since 2007. As well as this, trends from water quality results from sampling completed by the Group Scheme Caretaker were consulted, but were not included in the analysis below. The data on trends in water quality across 28 no. samples are however summarised in Table 8.3, while key indicators of agricultural and domestic contamination are shown graphically in Figure 6. The following key points are identified from the data.

The water quality is hard to very hard (330 to 452.1 mg/l, as $CaCO_3$), showing a calcium-bicarbonate chemical signature and corroborating the data from the Durrow Groundwater Body description of the GSI. These values are typical of groundwater from limestone. The hardness values are higher than the recommended EPA threshold value and Drinking Water Standard of 200 mg/l $CaCO_3$, which are however, based on palatability and formation of limescale, rather than on health grounds.

The alkalinity of the groundwater ranges from 250 to 390 mg/l $CaCO_3$, and the pH ranges between 6.82 and 8.42, which is slightly alkaline. Electrical conductivity generally ranges from 589 to 750 µS/cm @ 25^{o}C, with one 'erratic' conductivity of 164 µS/cm on 30/06/2004. As this was a dry summer period, it is assumed that at this stage the water at the source is dominated by surface runoff rather than groundwater. Averaging all conductivity measurements (and including the 'erratic' value), an average of 686 µS/cm is arrived at.

Faecal coliforms were present in the untreated water on seven out of twenty five occasions sampled and on seventeen out of these twenty five occasions, total coliforms were also present in the samples

[2] The gauge itself could not be used to measure flow, as it had been damaged by livestock.

taken. However, on no occasions were ammonia values greater than the GSI threshold value recorded in the untreated water; ammonia levels were almost always below 0.1 mg/l, but have been rising recently and were slightly below the threshold (0.149 mg/l) at end 2008. The 'high' groundwater vulnerability around the source suggests a relatively low likelihood of faecal contamination occurring due to the filtration in the deep sands and gravels, but it is probably that the contamination is entering the system in areas where bedrock is at the surface.

Table 8-3 Summary hydrochemical data for Toberboe Spring Source, 2003-2008.

Sample date	Conductivity ųS/cm	Ammonia mg/l N	Chloride mg/l Cl	Iron ųg/l Fe	Total coliforms No./100ml	Faecal coliforms No./100ml	Nitrate mg/l NO_3	Sodium mg/l Na	Potassium mg/l K	Total hardness mg/l $CaCO_3$
18/03/2003	726	n/a	22	n/a	n/a	n/a	*48.7*	8.6	5.6	394
09/07/2003	760	n/a	16	n/a	n/a	n/a	*43.4*	8.7	4.8	378
18/12/2003	664	n/a	19	n/a	n/a	n/a	35	9	3.8	329
23/02/2004	670	n/a	21	n/a	n/a	n/a	*44.3*	112	0.4	n/a
18/03/2004	n/a	<0.02	18	n/a	**2**	<1	8.8	n/a	n/a	363
01/04/2004	642	n/a	n/a	n/a	n/a	n/a	**54.2**	n/a	n/a	n/a
31/05/2004	n/a	<0.02	13	n/a	**21**	**9**	9.8	n/a	n/a	379
22/06/2004	n/a	<0.02	19	n/a	<1	<1	10.8	n/a	n/a	384
30/06/2004	164	n/a	n/a	n/a	n/a	n/a	**52.2**	n/a	n/a	n/a
12/07/2004	781	n/a	n/a	n/a	n/a	n/a	**50.9**	n/a	n/a	n/a
28/07/2004	n/a	<0.02	19	n/a	<1	<1	11.1	n/a	n/a	364
12/08/2004	778	n/a	n/a	n/a	n/a	n/a	*42.4*	n/a	n/a	n/a
23/08/2004	n/a	<0.02	19	n/a	**517**	**88**	10.4	n/a	n/a	389
21/09/2004	n/a	<0.02	18	n/a	**4**	0	9.5	n/a	n/a	362
14/10/2004	n/a	<0.02	18	n/a	**5**	**1**	8.4	n/a	n/a	341
04/11/2004	n/a	<0.02	19	n/a	**16**	**2**	6.8	n/a	n/a	330
07/12/2004	n/a	<0.02	19	n/a	**9**	<1	8.3	n/a	n/a	360
31/01/2005	n/a	<0.02	21	n/a	**4**	<1	10.4	n/a	n/a	381
23/02/2005	n/a	<0.02	21	n/a	**4**	<1	11.5	n/a	n/a	367
26/04/2006	730	n/a	*31.24*	0.009	0	0	*40.92*	n/a	n/a	376
12/07/2005	699	n/a	21	n/a	n/a	n/a	*48.7*	9	n/a	383
04/01/2006	647	n/a	n/a	n/a	n/a	n/a	*41.2*	n/a	n/a	n/a
06/02/2006	687	n/a	22	n/a	n/a	n/a	**53.1**	9	n/a	337
12/06/2006	683	n/a	n/a	n/a	n/a	n/a	*41.81*	n/a	n/a	n/a
13/07/2006	703	n/a	n/a	n/a	n/a	n/a	*48.54*	n/a	n/a	n/a
29/08/2006	738	n/a	n/a	n/a	n/a	n/a	*44.53*	n/a	n/a	n/a
26/09/2006	735	n/a	n/a	n/a	n/a	n/a	*43.91*	n/a	n/a	n/a
07/11/2006	680	n/a	n/a	n/a	n/a	n/a	*38.15*	n/a	n/a	n/a
10/09/2007	664	n/a	19	n/a	n/a	n/a	*43.4*	n/a	n/a	n/a
03/08/2007	750	<0.01	16	16	**15**	<1	*46.2*	9	4.6	325
12/09/2007	747	<0.01	18	30	**6**	**3**	*46.2*	8	4.9	432
19/10/2007	589	0.06	20	<2	**2**	<1	**53.1**	9	5.2	390
13/11/2008	707	0.01	19	30	<1	<1	*47.1*	9	5.3	336
13/12/2008	671	<0.01	17	65	<1	<1	*38.4*	7.5	4.1	365
30/01/2008	737	0.01	18	<2	<1	<1	**55.3**	8	7.8	361
23/06/2008	722	0.012	18.8	10.97	**95**	**87**	**108**	8.544	4.618	375.6
25/08/2008	683	0.027	14.5	<5.0	**6**	<1	30.7	8.336	3.709	343.4
02/10/2008	743	0.029	5.09	<5.0	<1	<1	**177**	9.9	6.1	409.7
18/11/2008	705	0.149	3.48	8.498	<1	<1	<0.53	9.5	5.4	452.1

The concentration of nitrate is quite low in some of the water analyses completed in the early years of the source's available sample analyses (2003-2005), but with a mean of 39 mg/l (as NO_3) and with levels over 100 mg/l in some cases, nitrate is seen to be a major issue at the spring source. Though there are only eight reported exceedances above the EU Drinking Water Directive maximum admissible concentration of nitrate of 50 mg/l NO_3 during this time, the groundwater threshold value (Groundwater regulations S.I. No. 9 of 2010) value of 37.5 mg/l

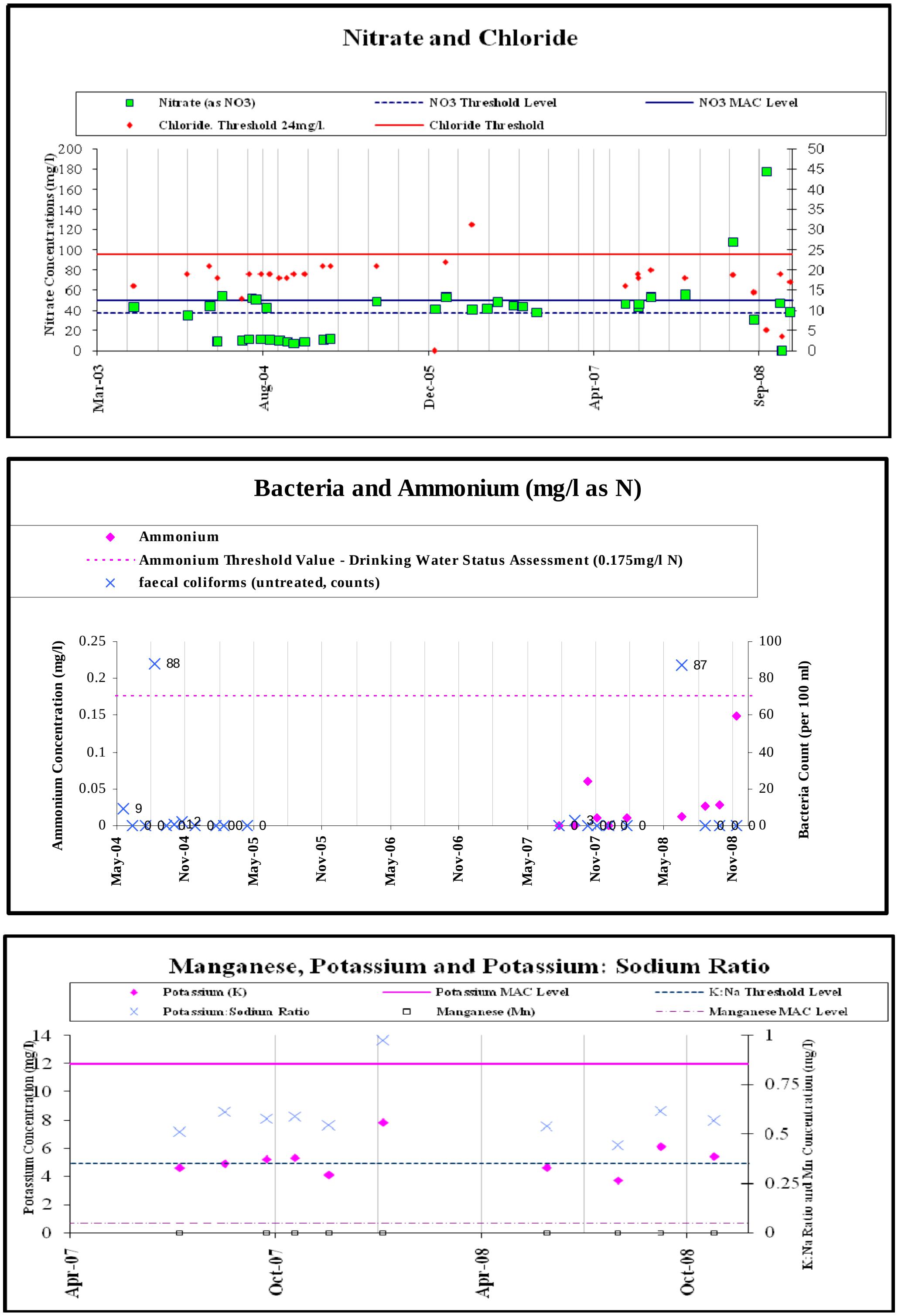

Figure 6 Key Indicators of Agricultural and Domestic Contamination at the Toberboe Spring Source.

NO_3 has been exceeded on twenty five out of thirty nine occasions. Though the area around the springs is relatively sparsely populated, and served by septic tank and mechanical aeration systems discharging to ground into deep sediment, there are many farms, often with slatted units, and some tillage is practiced in the general area. Therefore, the relatively high nitrate levels at Toberboe are probably due to the proximity of large farms and intensive agriculture practices.

Chloride is a constituent of organic wastes, sewage discharge and artificial fertilisers, and levels higher than 24 mg l^{-1} (Groundwater Threshold Value for Saline Intrusion Test, Groundwater Regulations S.I. No. 9 of 2010) may indicate contamination, with levels higher than 30 mg l^{-1} usually indicating significant contamination (Daly, 1996). Chloride concentrations range from 3.48 mg/l to 31.24 mg/l, with a mean of 18.1 mg/l which is considered to be above the mean natural background level of 18 mg/l (Baker *et al.*, 2007), but is below the threshold value. Levels of chloride above the threshold value were recorded on only one occasion, considered as significant contamination. This, and the corresponding and fluctuating and generally high nitrate levels, suggests that contamination from either organic wastes or fertilisers may be an issue at Toberboe.

The concentrations of sulphate, potassium, sodium, magnesium and calcium are within normal ranges. The potassium: sodium (K:Na) ratio is however high, consistently greater than 0.4 and only less than the GSI threshold of 0.35 on one out of fourteen occasions. A high K/Na ratio suggests that organic wastes derived from vegetable matter (*e.g*. farmyards or landspreading of agricultural wastes) are a cause for concern.

The concentration of iron is well within normal ranges, which suggests an absence of any influence of effluent from organic wastes. Manganese concentrations were also consistently low.

Normal levels of trace metals were identified in general, but Strontium levels are quite high, averaging 181 µg/l. In general levels of metals are below the detection limit of the laboratory, and the water is safe for drinking. The concentration of all organic compounds and herbicides is below the detection limit of the laboratory.

In summary, slightly elevated chloride and fluctuating but often significantly elevated nitrate at the Toberboe Spring Source, as well as a regular presence of faecal coliforms in the untreated water, suggest contamination from organic waste source. Given the potassium:sodium ratio and the farming practices in the area, the most likely source is from organic wastes, potentially from farmyards.

8.6 AQUIFER CHARACTERISTICS

The limestone of the Ballyadams Formation provides the groundwater to the eight springs at Toberboe. Two of the eight are considered to have a moderately high spring yield. Some of them may be interconnected with each other, and all are no more than 910 m from each other.

An extensively karstified bedrock probably underlies the springs, extending in all directions as far as the boundaries with other rock types to the southeast and northwest, and with flow concentrated in conduits. The karst network causes the water to concentrate in the low lying discharge area. The limestone bedrock is however deep under the surface around the springs, and is at its closest to the surface in the overall area on the flanks of the high ridge in the southeastern portion of Toberboe Townland. The evidence for the karstification includes the solutionally enlarged joints on the bedrock outcrop at NGR 238464 174110.

Karstification is an important process in Irish hydrogeology. It involves the enlargement of rock fissures when groundwater dissolves the fissure walls as it flows through them. The process can result in significantly enhanced permeability and groundwater flow rates and can mean either very productive or generally-failed wells. It usually occurs in 'cleaner' limestones.

The bedrock in the Toberboe area seems likely to be characterised by:

- groundwater flow in solutionally enlarged bedding plane partings, joints, faults and conduits;
- high groundwater velocities, several orders of magnitude greater than in granular (sand/gravel) aquifers;
- concentration of groundwater flow into zones of high permeability;
- an irregularly or poorly connected water table over short distances;
- the potential for extreme vulnerability to contamination in particular localities from point recharge *via* swallow holes which by-pass the potential attenuation capability of the subsoil;
- minimal attenuation of contaminants within the aquifer, except by dilution;
- potentially relatively short response times when pollution incidents occur in areas of extreme vulnerability.

The Ballyadams Formation bedrock under the site is therefore classified as a Regionally Important Karstic Aquifer, which is characterised by diffuse flow (**Rk**[d]), which is in agreement with the GSI classification for the area. Groundwater velocities through fissures/conduits in this aquifer may be high. Aquifer storage is frequently low, but seems to be relatively high around the source spring, potentially owing to the extensive overlying sands and gravels which should provide additional storage. Storage and permeability within the aquifer may be enhanced by the presence of dolomitised limestones in places. As well as this, flow through this aquifer may be comprised of both diffuse and conduit flow.

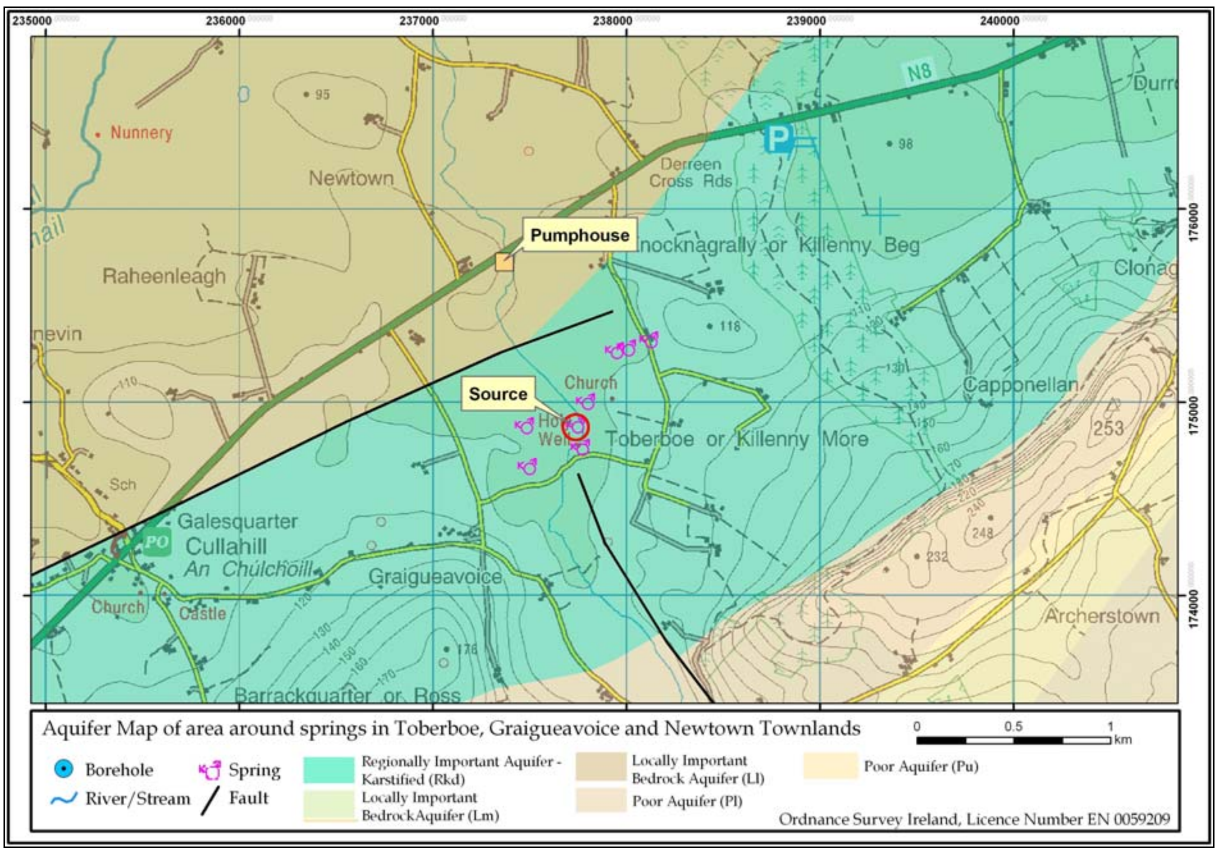

Figure 7 Aquifer Map of the area around Toberboe Spring(s).

The site overlies a Regionally Important Karstified Aquifer characterized by diffuse flow.

Table 8-4 Estimated Aquifer parameters for the Ballyadams Limestone at Toberboe Spring(s).

Parameter	*Source of data*	*Ballyadams Fm.*
Transmissivity (m^2/day)	E. Daly report on Ballyconra (Pumping test data, GSI Archives)	1,280-2,675
Permeability (m/day)	Using regional data (Nore Basin and Laois) (T / 75 m saturated thickness from E. Daly report)	15[3]
Porosity	Regional	0.025
Velocity (m/day)	Regional (Nore Basin and Laois)	6
Hydraulic Gradient	Local (Figure 6)	0.022

Karst springs generally indicate very high transmissivities, permeabilities and velocities in the vicinity of springs. However, as with most karstic systems, permeability and transmissivity data are very variable. Daly (1994) cites a range in permeability of 0.1 m/day to 100 m/day in the karst limestones within the Nore Basin as a whole, with ranges in transmissivity of 5 m^2/day to 3,000 m^2/day.

Calculations of aquifer parameters based on representative values for permeability and aquifer thickness, which are based primarily on data from the Nore Basin study (1994) and on test pumping in nearby County Laois, are shown in Table 8.2.

8.7 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 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 Toberboe, the main parameters involved in the estimation of recharge are: annual rainfall; annual evapotranspiration; and a recharge coefficient. Owing to the highly permeable nature of the bedrock type and its' capacity to accept large volumes of water, no recharge cap is applied. The recharge is estimated as follows.

Runoff losses are assumed to be 20% of potential recharge (effective rainfall). This value is based on an assumption of *c*. 15% runoff for 80% of the area (extreme vulnerability with bedrock at surface, or high vulnerability, permeable sands and gravels), and 40% runoff over 20% of the area due to high vulnerability, moderate permeability and deep subsoil (Misstear *et al*., 2009).

The bulk ***recharge coefficient*** for the area is therefore estimated to be 80%.

These calculations are summarised as follows:

Average annual rainfall (R)		879 mm
estimated P.E.		450 mm
estimated A.E. (95% of P.E.)		427 mm
effective rainfall		452 mm
potential recharge		452 mm
recharge coefficient for Extreme Vul rock at surface	85%	384 mm
recharge coefficient for High Vul Sands/Gravels	85%	384 mm

[3] 15 m/day was taken as a conservative estimate for the permeability at Ballyconra.

recharge coefficient for High Vul Till/Well dr. soil	60%	271 mm
Averaged runoff losses	20%	90 mm
Bulk recharge coefficient	80%	362 mm
Recharge		**362 mm**

8.8 CONCEPTUAL MODEL

The current understanding of the geological and hydrogeological setting around the Toberboe Spring(s) is as follows:

- The Toberboe Spring(s) issue from the limestone bedrock of the Ballyadams Formation, which is classified as a **Regionally Important Karstic Aquifer, which is characterised by diffuse flow (Rk^d).** The aquifer is overlain at this locality by glaciofluvial sands and gravels**.**

- The limestone as seen in the exposure to the southeast has a well developed fracture system, which has undergone karstification in places. The presence of swallow holes at Seskin to the southeast and the 'hit and miss' nature of well drilling in the area also supports this view[4]. However, a water table contour map has been drawn for the area which suggests groundwater flow is more regular than might be expected in a highly karstified aquifer.

- It is unclear as to whether adjacent faults mapped on the bedrock map of the area influence the springs location or groundwater flow in the locality. Groundwater flow within the sand and gravel aquifer around the source is intergranular, whereas in the bedrock beneath this it is through enlarged conduits and smaller fractures and fissures in the limestone. The two aquifers are hydraulically interconnected with the gravels providing additional storage to the limestone aquifer.

- Groundwater flow within the sand and gravel aquifer is intergranular, whereas in the bedrock beneath this it is through enlarged conduits and smaller fractures and fissures in the limestone. The two aquifers are hydraulically interconnected with the gravels providing additional storage to the limestone aquifer.

- The around the Toberboe Spring(s), with the exception of the flay-lying areas, has few surface streams and rare drainage features. The subsoil over the majority of the area is highly permeable, and to the southeast and south of the source is relatively thin (<3m), with much of the area around the boreholes being of (interpreted) thick, high permeability sands and gravels. These characteristics suggest that recharge is diffuse and relatively high at 362 mm/year.

- The saturated aquifer thickness at the source is unknown.

- Groundwater flow to the source area through the gravels and bedrock seems to be from the higher ground to the southeast, towards the River Goul discharge zone, and broadly following topography. The precise pathways of groundwater flow in the limestone up-slope of the source, as well as the flow depths, are however not known. The natural hydraulic gradients in the aquifer are likely to be approximately 0.022, reflecting the generally high transmissivities which have been calculated in the adjacent area of Ballyconra at 1,280-2,675 (E. Daly's GSI Archival notes and report). Permeability is conservatively estimated at 15 m/d based on the measured transmissivity values there and a regional aquifer thickness of 75 m.

- The groundwater vulnerability is 'extreme' around the springs as the water table emerges either in a chamber with no protective sediment cover (at the source), or subaerially (at the surface). The

[4] One of the wells sampled to calculate gradients, to the southeast at the base of the 'Namurian' ridge, was a failed well.

vulnerability to contamination is 'high' in the surrounding area, owing to the presence of high permeability sands and gravels.

- The groundwater is of calcium bicarbonate signature and hard. Chloride has been elevated once and nitrate has consistently been elevated since 2006, allied with frequent bacteriological issues. The groundwater appears to be impacted by either an organic or inorganic waste source. Given the levels of nitrate and the potassium: sodium ratio, and the farming practices in the area, the most likely source is from organic wastes, potentially from farmyards..

Limitations to the conceptual model mainly lie with a lack of information on depth to bedrock and depth to water table within the general area, and particularly close to the springs themselves, as well as on detailed aquifer properties such as transmissivity and porosity.

9 DELINEATION OF SOURCE PROTECTION AREAS

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 to the source, as described in Section 8.8 Conceptual Model.

Two source areas are delineated:

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

9.1 OUTER PROTECTION AREA

The Outer Protection Area (SO) is bounded by the complete catchment area to the source, or **the zone of contribution (ZOC).** This is defined as the area required to sustain abstraction from the springs considering long-term recharge. Given that the abstraction from Toberboe Spring itself is less than half the considered 'mean' discharge from the spring (see Table 8.2), it is felt that the delineated ZOC also covers a potential increase in abstraction from the spring source by more than 50%.

The ZOC is controlled primarily by (a) the total discharge, (b) the groundwater flow direction and gradient, (c) the subsoil and rock permeability and (d) the recharge in the area. The shape and boundaries of the ZOC were determined using hydrogeological mapping, water balance estimations, and conceptual understanding of groundwater flow. The ZOC is shown in Figure 9 and its' boundaries are described below along with associated uncertainties and limitations.

The southeastern boundary is based on the topographic divide along the topographical high on the 'Namurian' ridge in Ballykealy and Aharney Townlands, that is assumed to coincide with the groundwater divide.

The northeastern and southwestern boundaries are based on the assertion that the springs are 'overflows' to the regional groundwater flow as they go dry in summer, and the assumption that groundwater cannot flow to the source from the majority of the area to the east and south them, as the contours drawn from water level and topography data mean that flow from this area is directed alongside the springs. This means that recharge through the Graigueavoice ridge will flow towards the north and northwest, west of all the springs.

For the **northwestern boundary** it is assumed that the water down-gradient of the springs will not flow back to contribute to their discharge. Therefore the boundary delineates the groundwater flow down-gradient of the springs, which will be outside the ZOC. It is based on the direction of flow suggested by the water level and contouring data, and the general trend of surface water drainage patterns. A buffer of 30m downgradient of the springs is incorporated into this boundary.

Based on a an estimated 'mean' discharge of 23.6 l/s (2,029 m^3/day) and the estimated recharge of 362 mm/year, a zone of contribution of 2.04 km^2 in area is calculated. This is shown in Figure 8 and is delineated as the ZOC.

If we take into account the topography of the area south and southeast of the source, and using the topographic catchment as a 'potential' ZOC, the area covers 4.18 km^2. Taking into account the area within this which is directly 'up-gradient' using the regional groundwater flow data, means an area of only 2.25 km^2 is delineated. This has then been further refined by taking off the sharp corners of the area on the Namurian bedrock topographic high at the southwest and southeastern extremes of the area.

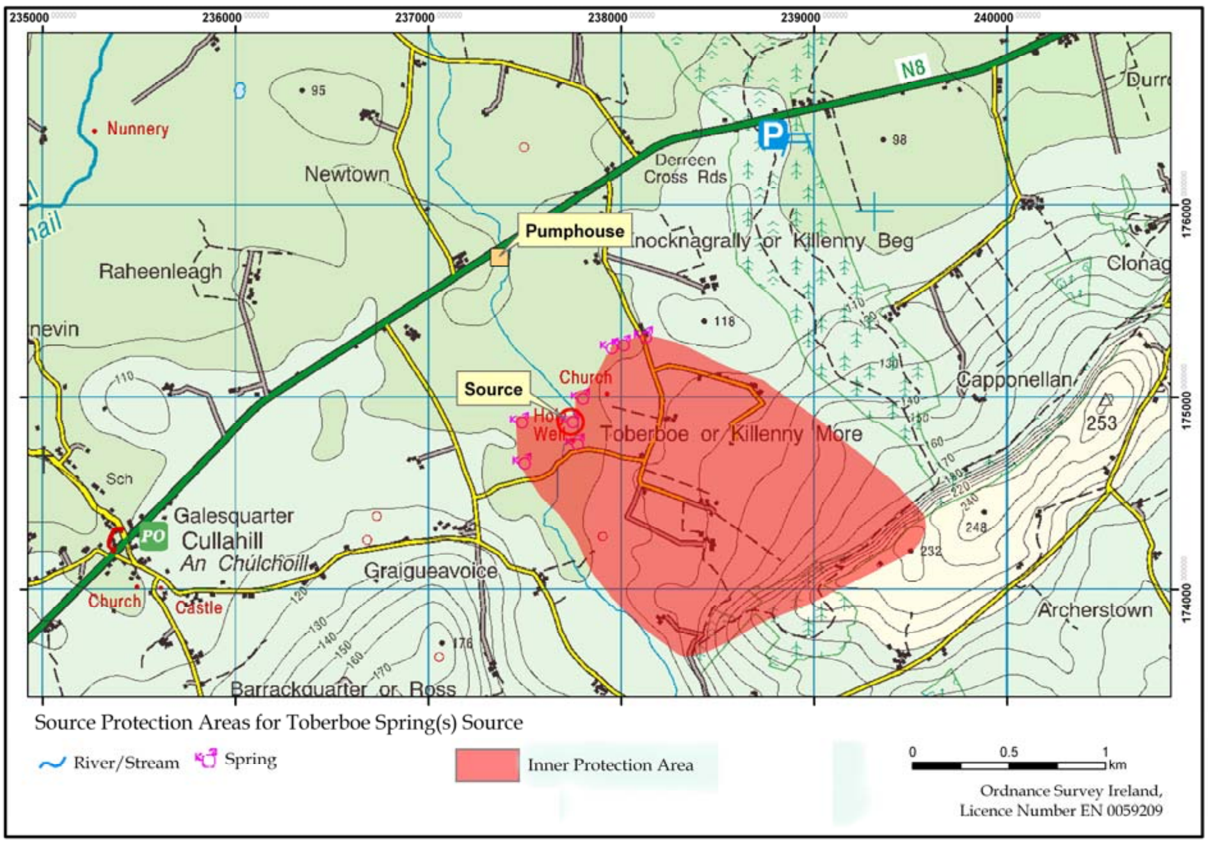

Figure 8 Source Protection Areas for the Toberboe Spring(s) Source.

9.2 INNER PROTECTION AREA

The Inner Source Protection Area is the area defined by the horizontal 100-day time of travel from any point below the watertable to the source (DoELG, EPA, GSI, 1999). The 100-day horizontal time of travel to the source is delineated to protect against the effects of potentially contaminating activities which may have an immediate influence on water quality at the source, in particular from microbial contamination.

The 100-day time of travel is calculated from the velocity of groundwater flow in the bedrock. The velocities are normally based on the results of the hydraulic test programme, however, in this instance, the aquifer category of Rk^d, suggests that very rapid groundwater velocities are likely in this area due to karstification of the limestones. Groundwater flow can be focused and travel very fast. Results from tracing programmes in similar rock types indicate velocities in the order of hundreds of metres/day. On this basis, all of the ZOC is designated as part of the Inner Protection Area to the source.

From this, it is therefore likely that any of the groundwater within the delineated catchment could reach the source in less than 100 days.

10 GROUNDWATER PROTECTION ZONES

The groundwater protection zones are obtained by integrating the two elements of land surface zoning (source protection areas and vulnerability categories) – a possible total of 8 source protection zones (see Table 10.2). In practice, this is achieved by superimposing the vulnerability map (Figure 5) 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. All of the hydrogeological settings represented by the zones may not be present around any given source.

Three groundwater protection zones are present around the source as illustrated in Table 10.1. The final groundwater protection zones are shown in Figure 9.

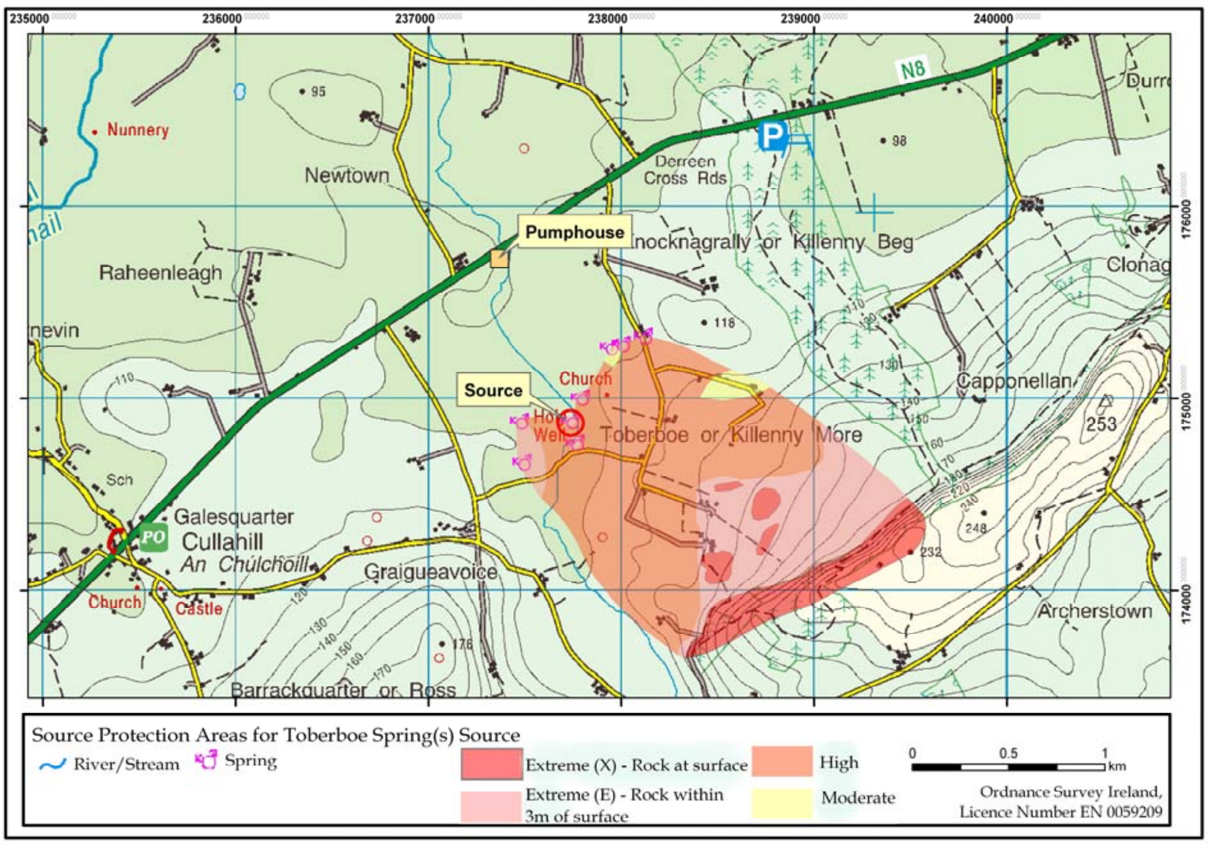

Figure 9 Source Protection Zones for the Toberboe Spring(s) Source.

Table 10-1 Matrix of Source Protection Zones at Toberboe Spring(s)

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

11 POTENTIAL POLLUTION SOURCES

Though detailed assessments of hazards have not been carried out as part of this study, it is noted that there are many houses and farmyards within the ZOC. Land use in the vicinity of the source is described in Section 5; within the ZOC, agriculture is the main land use.

The hydrochemical data indicate significant contamination or pollution of the spring source by nitrate, with chloride also relatively high. Coliforms, many of these faecal, are often present in the untreated water. These levels should be monitored closely.

The main hazards associated with the ZOC are considered to be agricultural (farmyard leakage, landspreading of organic and inorganic fertilisers) and potential oil/petrol spills. Though domestic septic tank and other treatment systems are not a major problem as is, the installation of any new systems should be monitored closely. The location of any 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 red zones on Figures 5 and 8, and the main potential contaminants from this source are ammonia, nitrates, phosphates, chloride, potassium, BOD, COD, TOC, faecal bacteria, viruses and Cryptosporidium.

As well as this, there are some private home heating fuel tanks located within the catchment area. The main potential contaminants from this source are hydrocarbons. There is currently no evidence of any contamination from hydrocarbons at the source.

Roadways are present within the ZOC. The main potential contaminants from this source are hydrocarbons and metals.

12 CONCLUSIONS

- The eight springs at Toberboe are located in the Dinantian Pure Bedded limestones of the Ballyadams Formation which is a Regionally Important Karstified Aquifer. The aquifer is overlain by sands and gravels.

- The ZOC has been delineated for the eight springs together. This approach is necessary due to the close proximity of the springs and the potential interconnected zones of contribution of some of them. The ZOC has been delineated using hydrogeological mapping techniques and is larger than the area required to sustain the source. The ZOC is therefore considered to be conservative and takes into consideration the unpredictability of groundwater flow in karst areas.

- Due to the rapid groundwater velocities, it is considered that groundwater in any part of the ZOC could potentially reach the source within 100 days. Therefore the entire ZOC should be classified as the Inner Protection Area.

- The groundwater in the Source Protection Area ranges in vulnerability from Extreme to Moderate.

- Available data shows generally elevated nitrate and relatively high chloride at the source, often allied with the presence of faecal coliforms. This suggests contamination from an organic waste source, the most likely source is from farmyard waste.

- 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, and the conclusions should not be used as the sole basis for site-specific decisions.

13 RECOMMENDATIONS

The ZOC as delineated has been compiled from available data, and further information gathering as detailed following would help refine the delineated area. Notwithstanding this, given the deduced groundwater flow gradient around the springs and the initial flow data, it is felt that as the maximum area topographically that the ZOC could cover is just over 4 km^2, and as that delineated is just over 2 km^2, the area delineated is relatively reliable.

1. Karst mapping should be carried out both within the ZOC and the wider area around Ballyconra to locate any further potential point recharge localities.

2. The depth to bedrock should be investigated surrounding the source to provide greater certainty to the conceptual model.

3. Continued monitoring of water levels and flow data during the operation of the scheme should be carried out to develop a real-time database of hydrogeological information.

4. A full chemical and bacteriological analysis of the **untreated** water should be carried out on a regular basis.

5. The ZOC of the source includes a relatively extensive area of Extreme Vulnerability with a not insignificant proportion of it comprising shallow rock. It is recommended therefore that an adequate barrier to Cryptosporidium must be installed as part of the water treatment system for the supply.

6. The potential hazards in the ZOC should be located and assessed, especially given the number of farmyards and houses up-gradient of the source in the ZOC.

7. Particular care should be taken when assessing the location of any activities or developments which might cause contamination at the springs or adversely affect the springs (for example groundworks or excavations).

14 REFERENCES

Archer, J.B., Sleeman, A.G. and Smith, D.C., 1996. A geological description of Tipperary and adjoining parts of Laois, Kilkenny, Offaly, Clare and Limerick, to accompany the Bedrock geology 1:100,000 Scale Map Series, Sheet 18, Tipperary, with contributions by K. Claringbold, G. Stanley (Mineral Resources) and G. Wright (Groundwater Resources). Geological Survey of Ireland, 76pp.

Baker, G., Crean, D. and Moran, S. (2007) Establishing Natural Background Levels for Groundwater Quality in Ireland. GSI Groundwater Newsletter No. 46.

British Standards Institution (1999) Code of practice for site investigations. British Standards Institution, London.

Collins, J.F. and Cummins, T. (1996) Agroclimatic Atlas of Ireland. AGMET – Joint working group on Applied Agricultural Meteorology, Dublin.

Conry, M., 1974. Kilkenny's Golden Vein; its soils, land use and agriculture. Irish Geography, 7: 19-28.

Conry, M., 1987. Soils of County Laois. Soil Survey Bulletin Number 41, National Soil Survey of Ireland (An Foras Taluintais). 260pp.

Daly, E.P. (1994). Groundwater Resources of the Nore River Basin. Geological Survey of Ireland, Report Series RS 94/1 (Groundwater). Unpublished internal GSI report.

Daly, D. (1996) Groundwater in Ireland. Course notes for Higher Diploma in Environmental Engineering, UCC.

DELG/EPA/GSI (1999) Groundwater Protection Schemes. Department of the Environment and Local Government, Environmental Protection Agency and Geological Survey of Ireland.

Drinking Water Regulations (SI 439 2000) . Irish Government Supplies Agency. 25pp.

Environmental Protection Agency (2009). Code of Practice: Wastewater Treatment and Disposal Systems serving Single Houses (p.e. <10). 100pp.

Environmental Protection Agency (2002) Water Quality in Ireland 1998-2000.

Ford, D. And Williams, P., 1989. Karst geomorphology and hydrology. Chapman and Hall, 1989.

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).

Fitzsimons, V., Daly, D. and Deakin, J. (2003) GSI Guidelines for Assessment and Mapping of Groundwater Vulnerability to Contamination. Geological Survey of Ireland.

Gardiner, M.J. and Radford, T., 1980. Soils Association of Ireland and their land use potential. An Foras Talúintais, Dublin,142pp.

Geological Survey of Ireland (2005). Freshford Groundwater Body: Summary of Initial Characterisation, 2pp.

Geological Survey of Ireland (2005). Durrow Groundwater Body: Summary of Initial Characterisation, 6pp.

Geological Survey of Ireland Karst Working Group (2000). The Karst of Ireland. 38pp.

Misstear, B.D.R., Brown, L. And Daly, D., 2009. A methodology for making initial estimates of groundwater recharge from groundwater vulnerability mapping. Hydrogeology Journal, Vol. 17, No.2, 275-287.

Teagasc/EPA, 2006a. Digital soil map of County Kilkenny. Prepared as part of the EPA Soil and Subsoil Mapping Project, Teagasc, Kinsealy, Dublin.

Teagasc/EPA, 2006b. Digital soil map of County Laois. Prepared as part of the EPA Soil and Subsoil Mapping Project, Teagasc, Kinsealy, Dublin.

Teagasc/EPA, 2006c. Digital subsoil map of County Kilkenny. Prepared as part of the EPA Soil and Subsoil Mapping Project, Teagasc, Kinsealy, Dublin.

Teagasc/EPA, 2006c. Digital subsoil map of County Laois. Prepared as part of the EPA Soil and Subsoil Mapping Project, Teagasc, Kinsealy, Dublin.