Establishment of Groundwater Zones of Contribution

Update Report 2016

Toberfin Springs at Newtown
Killeigh, Killurin and Cloneygowan
Group Water Scheme
and
Meelaghans Group Water Scheme, Co. Offaly

March 2017

and

Killeigh and Meelaghans Group Water Schemes
Toberfin Springs

Groundwater Source Protection Zones

April 2001

'Note:
Since the Toberfin Springs report was published (2001), the Source Protection Area and, possibly, other component maps have been updated based on improved geoscientific evidence and hydrogeological knowledge.
The most up-to-date version of the Source Protection areas (SPAs) and other maps can be found on the Geological Survey Ireland website (https://www.gsi.ie/en-ie/data-and-maps/Pages/default.aspx).'

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Project description

Since the 1980s, 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 'Zone of Contribution' (ZOC) 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.

This report has been prepared for Toberfin Springs Source of the Killeigh, Killurin and Cloneygowan Group Water Scheme and the Meelaghans Group Water Scheme as part of the Rural Water Programme funding initiative of grants towards specific source protection works on Group Water Schemes (DECLG Circular L5/13 and Explanatory Memorandum). The GSI previously delineated Groundwater Source Protection Zones for the Toberfin Springs in 2001. However since this time the available scientific understanding and knowledge has evolved and this current report has revisited the original 2001 report and updated it to include new data.

The report has been prepared in the format developed during an earlier pilot project "Establishment of Zones of Contribution" which was undertaken by the Geological Survey of Ireland (GSI), in collaboration with the National Federation of Group Water Schemes (NFGWS), and with support from the National Rural Water Services Committee (NRWSC).

The methodology undertaken by the GSI included: liaising with the GWS and NFGWS to facilitate data collection, a desk study, a site visit to inspect the supply, the local area, and to record groundwater level(s). The data was then analysed and interpreted in order to delineate the ZOC.

The maps produced are based largely on the readily available information in the area, a field walkover survey, 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.

The report and maps are hosted on the GSI website (www.gsi.ie).

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1 Overview: Groundwater, groundwater protection and groundwater supplies

Groundwater is an important natural resource in Ireland. It originates from rainfall that soaks into the ground. If the ground is permeable, the rainfall will filter down until it reaches the main body of groundwater, which is usually within either the bedrock, or a sand/gravel deposit. If the bedrock or sand/gravel deposit can hold enough groundwater and allow enough flow to supply a useful abstraction, it is referred to as an aquifer.

In Irish bedrock aquifers, groundwater predominantly flows through interconnected fractures, fissures, joints and bedding planes, which can be envisaged as a 'pipe network', of various sizes, with varying degrees of interconnectivity. The speed of flow through this network is relatively fast, delivering groundwater, and a large proportion of any contaminants present in the groundwater, to its destination *e.g.* borehole, spring, river and sea.

In sand/gravel aquifers, the groundwater flows in the interconnected pore spaces between the sand/gravel grains. Generally, this is equivalent to a filter system that may physically filter out contaminants to varying degrees, depending on the nature of the spaces and grains. It also slows down the speed of flow giving more time for pathogens to die off before they reach their destination *e.g.* borehole, spring, river and sea.

Further filtration of contaminants may occur where overlying soil and subsoil protects the aquifers; thick, impermeable clay soil and subsoil provide good protection while thin, very permeable gravel will provide limited protection. Therefore, variations in subsoil type and thickness are important when characterising the 'vulnerability' of groundwater to contamination.

The karst limestone aquifers provide significant and important groundwater supplies in Ireland. Karst landscapes develop in rocks that are readily dissolved by water *e.g.* limestone (composed of calcium carbonate). Consequently, conduit, fissure and cave systems develop underground[1]. Groundwater typically travels very fast in karst aquifers, which has a significant impact on the water quality; neither filtration nor pathogen die-off are associated with these aquifers.

The interaction between abstraction and geology is shown in **Diagram 1**. In this scenario, a borehole is pumping groundwater from the bedrock aquifer. As the water is abstracted through the well, the original water table (a), is drawn down to level (b), where it induces a drawdown curve of the natural water table (c). The shape of this curve depends on the properties of the aquifer, for example, if the borehole is intersecting an aquifer with few fractures that are poorly interconnected, the groundwater from that system will soon be exhausted, and therefore the pumping will have to pull from deeper depths to maintain supply, which results in the steep, deep drawdown curve. Alternatively, if the borehole is intersecting an aquifer with a large number of well-connected groundwater-filled fractures, the abstraction will be met by pulling water from farther away, at a shallower depth, resulting in a shallow, wide drawdown curve.

By knowing the rate of abstraction (output), how much rainfall there is (input), and by assessing the geological elements outlined above (nature of the bedrock fractures or sand/gravel deposit; how permeable the soil and subsoil are) to determine what happens in between input and output, the catchment area, or 'Zone of Contribution' (ZOC), to any groundwater water supply can be determined.

The Killeigh, Killurin and Cloneygowan Group Water Scheme is supplied by four individual sources; one of which is Toberfin Springs at Newtown, which also supplies the Meelaghans Group Water Scheme. The springs emerge from fractured shaley limestone bedrock classified as a Locally Important Aquifer that is generally moderately productive only in local zones (LI). 976 m^3/d are taken from the springs.

[1] Geological Survey of Ireland, 2000.

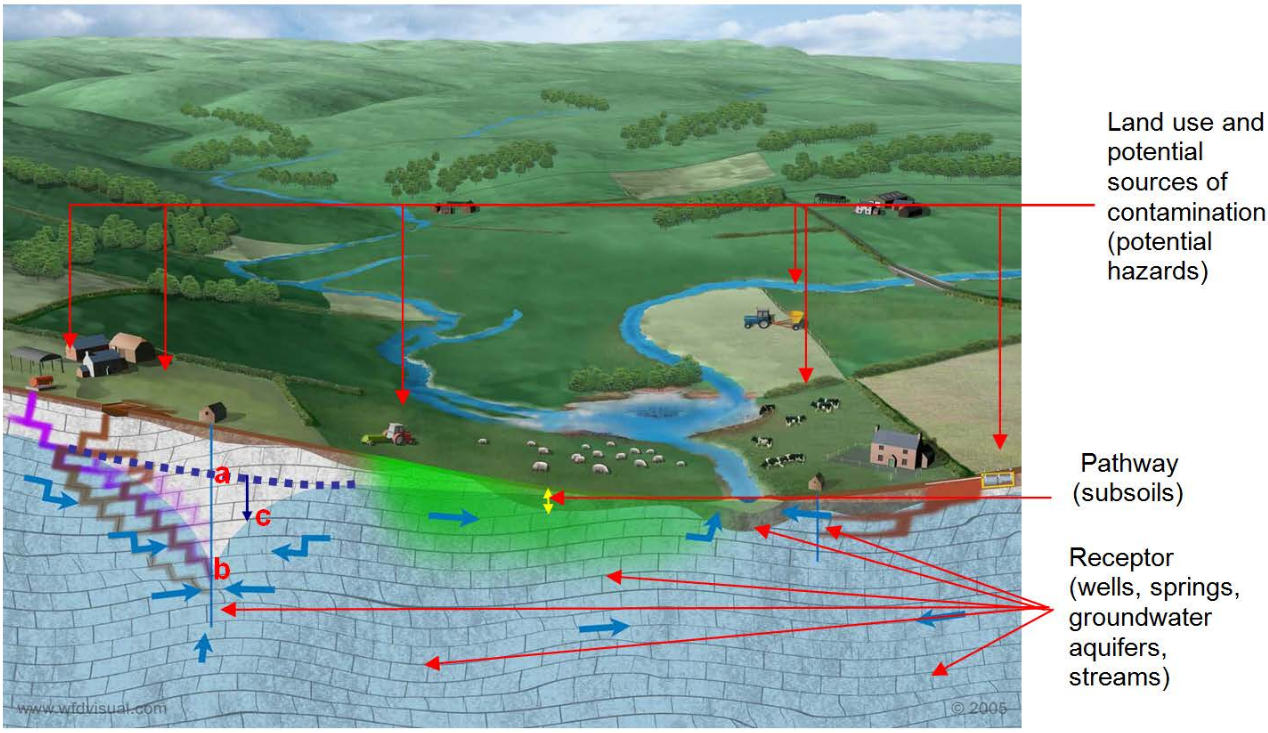

Diagram 1. Rural Landscape Highlighting Interaction between Surface Water, Groundwater and Potential Land Use Hazards.

2 Location, Site Description, Well Head Protection and Summary of Borehole Details

The Killeigh, Killurin and Cloneygowan Group Water Scheme (GWS) is currently supplied by four separate sources:

- Toberfin Springs at Newtown;
- Danganbeg Spring (sometimes known as Tobernanoge Spring);
- Two wells at Clonyquin;
- 'Moat Well' Spring at Killurin.

The Meelaghans GWS is also supplied by the Toberfin Springs at Newtown.

A previous 'Groundwater Source Protection Zone' report has been prepared by the Geological Survey of Ireland for Toberfin Springs (April 2001). This current report updates the existing 2001 report, as the hydrogeological data and understanding has evolved since that time. The three other sources used by the Killeigh, Killurin and Cloneygowan GWS are assessed in separate reports, as follows: the Zone of Contribution (ZOC) of the 'Moat Well' Spring was delineated as part of the 2013 phase of this project (Meehan 2013); a ZOC report for the two wells at Clonyquin and for the Danganbeg Spring are being produced as part of this current 2016 project.

Toberfin Springs are approximately 6.5 km from the centre of Tullamore town and 6 km north of Killeigh village in Co. Offaly (**Figure 1**). The springs are located on the southern side of the R420 Tullamore to Geashill road and to the south of the main Dublin – Galway railway line. The site is accessed via a track through fields. The site is surrounded by agricultural land with some houses and farm yards dotted around the area.

The Killeigh, Killurin and Cloneygowan GWS (KKC GWS) was started in 1962. It is unclear when the Meelaghans GWS (MGWS) was founded.

The KKC GWS currently supplies 1,300 domestic connections and around 250 farm connections, making it a very large scheme and has an overall usage of around 1,766 m^3/d currently. The springs at Toberfin contribute approximately 976 m^3/d towards this overall figure (**Appendix 1**). The MGWS has just 39 connections and an average daily abstraction of 30 m^3/d.

The water abstracted from Toberfin Springs for the KKC GWS is pumped to the scheme's treatment unit (consisting of chlorination and ultra-violet treatment) and two storage reservoirs at Finter. The water abstracted from Toberfin for MGWS is treated (chlorination) in their pump house adjacent to the springs.

There are four individual springs at the site, collectively known as Toberfin Springs. The site is enclosed within a secure fence which houses two individual pump houses (**Photo 1**). The KKC GWS abstracts groundwater from three of the springs, which are all located in close proximity to each other within the fenced area. The three springs are covered by a long narrow steel shed (**Photo 2**) and there are a number of large concrete sumps into which the groundwater feeds. The MGWS abstracts groundwater from the fourth spring, which is located in a small wooded area about 35 m away. The groundwater from this spring is piped back up to the fenced compound via a 2" hydrodare pipe and into a large concrete sump. This Meelaghans GWS Spring is referred to as Spring No. 4 in this report.

Photo 1 – Toberfin Springs – Killeigh, Killurin and Cloneygowan GWS Pump House on the left of the image; Meelaghans GWS Pump House on the right of the image

Photo 2 – Toberfin Springs – Killeigh, Killurin and Cloneygowan GWS long metal shed covering the springs

The KKC GWS have two pumps at Toberfin Springs, which alternate every 48 hours. They pump for a period of about 14 hours in every 24. Meelaghans has one pump at the site. Its pumping regime is unknown.

The yield of the springs is not fully known. It was anecdotally reported that an informal measurement of the yield was undertaken about 20 years ago. At that time, the yield of Toberfin Springs was estimated to be around 1,818 m^3/d (or 400,000 gallons per day). No information is known about how this measurement was made or the time of year it was undertaken so it is unclear how much confidence should be placed in it. The 2001 GSI report (Kelly)[2] reports several estimates of the total yield as follows:

Table 1. Estimates of discharge from Toberfin Springs – GSI 2001 Report

Date	Source	Discharge m^3/d	Detail
June 1999	GWS	1,269 m^3/d	KKCGWS 1,182 m^3/d and MGWS 87 m^3/d; measurement did not take account of overflow
July 1999	GSI & GWS	1,443 m^3/d	KKCGWS 1,360 m^3/d and MGWS 83 m^3/; includes estimate of overflow; both schemes pumping at the time
Nov 1999	GSI	1,037 m^3/d	KKCGWS not pumping at time of measurement and MGWS 87 m^3/d; includes estimate of overflow 950 m^3/d
Dec 1999	GWS	1,335 m^3/d	No pumping at time of measurement; overflow from main springs 981 m^3/d; overflow from Meelaghans Spring 353 m^3/d

The 2001 GSI report stated the abstraction from the spring at that time was between 1,182 – 1,245 m^3/d. The flow meter records from October 2015 to mid-April 2016 were obtained from the caretaker (**Appendix 1**). These records confirm that over a 235 day period a total of 229,375 m^3 was abstracted, equivalent to a daily average total of 976 m^3/d. This indicates a decrease in abstraction from the spring in the 15 year period since the previous GSI report was published. This is most likely because the two wells at Clonyquin and the 'Moat Well' Spring have both come into operation since that time, perhaps taking some of the pressure off the Toberfin Springs.

Kelly (GSI 2001)[2] reported that the three main springs are not hydraulically connected to Spring No. 4 (the Meelaghans Spring). Evidence for this lack of hydraulic connection is as follows:

- the elevation of the main three springs is higher (by 1.5 m) than the elevation of Spring No. 4;
- a tracer test carried out by Offaly County Council [2] links a swallow hole in the catchment (**Figure 1**) directly to the main three springs but not to Spring No. 4;
- a number of overflow measurements indicate that the overflow from th emain springs is consistently higher than the overflow from Spring No. 4. The overflow in July 1999 was measured at 52 m^3/d from the main springs and 31 m^3/d from Spring No. 4; in November 1999 the overflow was measured at 605 m^3/d from the main springs and at 345 m^3/d from Spring No. 4; in December 1999 the overflow from the main springs was meausred at 981 m^3/d and from Spring No. 4 at 354 m^3/d. If the springs were hydraulically linked then the lower elevation of Spring No. 4 would mean that it had the greater overflow.

The caretaker of the KKC GWS referred to a pollution incident a number of years ago during which a large quantity of milk was accidently spilt into a drainage ditch (**Figure 1**). The milk discharged via the spring sometime later. The reported location of this milk spill (as shown on **Figure 1**) is very close to the location of a swallow hole. Kelly 2001 reports that Offaly County undertook a tracer test that proved the link between this swallow hole and the main three springs at Toberfin. It is likely that the milk travelled to the springs from this swallow hole via an underground conduit. In May 2016 the overflow from the main three springs was

[2] Kelly, C. (2001). Killeigh and Meelaghans Group Water Schemes; Toberfin Springs – Groundwater Source Protection Zones. April 2001. Geological Survey of Ireland.

visually estimated at around 5 litres/second. It was reported that this overflow runs dry at certain times of the year.

Although the Toberfin Springs consists of three main springs and a separate (not hydraulically connected) fourth spring, all the springs emerge within close proximity to each other. Therefore they are considered together in this report and one Zone of Contribution (ZOC) is delineated.

Table 2 provides a summary of all known information about the springs, including estimates of hydraulic parameters.

Table 2. Supply Details

	Toberfin Springs
Grid reference	ING E: 239533 N: 221371
Townland	Newtown
Source type	Springs
Constructed	1962
Constructed By	Unknown
Owners	Killeigh, Killurin and Cloneygowan GWS and Meelaghans GWS
Elevation (m aOD)	71 maOD
Total depth (m)	4.8 m
Construction details	Three KCC GWS springs are housed with long steel shed. Spring No.4 piped into concrete sump via 2" hydrodare pipe
Depth to rock (metres below ground level), m bgl	8 m approx. (GSI 2001).
Static water level (m bgl)	Water level above the floor of the shed/sump was measured at 0.57 m above the floor level on 09/05/2016. The Winter water level was estimated as 0.67 m above the floor level and the Summer water level as 0.47 m above the floor.
Pump intake depth	Unknown
Current abstraction rate (GWS)	976 m^3/d – KCC GWS 30 m^3/d – MGWS
Reported spring yield (m^3/d)	Unknown. Various estimates (**Table 1** above) – KCC GWS 981 – 1,360 m^3/d and MGWS 83 – 353 m^3/d
Number of connections	KCC GWS – 1,300 domestic, 250 farm connections approx. *Note: GWS also abstracts from three other sources, Toberfin Springs at Newtown, the 'Moat Well' Spring at Killurin and two wells at Clonyquin, all of which are the subject of separate reports* MGWS – 39 connections
Estimated transmissivity (m^2/d)	Unknown. Kelly (2001) estimates permeability as 10 m/d and porosity as 1.5%.

3 Physical Characteristics and Hydrogeological Considerations

3.1 Physical characteristics of the area

A summary of the relevant information on rainfall, land use, topography, hydrology and geology for the area is provided in **Table 3**.

Table 3. Physical Characteristics of the Area of Interest

	Toberfin Springs	Description/Comments
Annual Rainfall (mm)	948	Met Éireann average annual rainfall data 2013 - 2016
Annual Evapotranspiration Losses (mm)	516	Met Éireann (www.met.ie)
Annual Effective Rainfall (mm)	432	National Groundwater Recharge Data (www.gsi.ie)
Topography	Toberfin Springs emerge from the ground at an elevation of between 69 - 71 m aOD. The land around the springs is relatively flat. An east-west trending ridge (with maximum elevation 143 m aOD) lies about 1.5 km to the south. The land slopes from this ridge towards the north.	
Land use	Agricultural land surrounds the site with grazing and grassland the predominant activities. A number of houses and farm yards are dotted around the area.	
Surface Hydrology	The land surrounding the springs is boggy in places. An ephemeral stream sinks into the ground at a swallow hole (**Figure 1**) 900 m south west of the springs. The stream rises again as the Toberfin River which then flows northwards where it forms a tributary of the Tullamore River. The area around the springs drains northwards via a number of small streams and ditches towards the Toberfin River and ultimately the Tullamore River.	
Topsoil	Basin Peats (Teagasc 2006). Large areas of Till to the south.	
Subsoil (**Figure 2**)	Peat (Teagasc 2006). Large areas of Till and some glaciofluvial sands and gravels to the south. The GSI 2001 site investigations (Kelly 2001) included six augers to establish soil type and depth to bedrock around the springs. The soil types encountered varied from clay to sand and gravel (**Appendix 2**).	
Groundwater Vulnerability (**Figure 3**)	High (See **Appendix 3**) around the springs. Large area of Moderate (M) to the south with areas of High (H) and Extreme (E) on the higher ground to the south.	
Geology (**Figure 4**)	The bedrock type underlying this area is classified as the Lucan Formation, commonly known as 'the Calp'. This limestone is part of the Dinantian Upper impure Limestones rock unit group. It is a fine grained, dark muddy limestone interbedded with layers of shale. Bedrock layers dip north-westwards at a low angle. Two major bedrock fault zone orientations are present: NE-SW and SE-NW. The joint pattern is likely to have similar orientations. There are faults mapped in the region and it is likely that others are present but have not been identified due to lack of bedrock outcrop. Given the presence of a significant spring system at this location it is highly likely that there is a large fracture network present in the bedrock here. The limestone in this area has undergone karstification. This is evidenced in the presence of karst features such as the swallow hole about 900 m southwest of the spring system (**Figure 4**). The presence of karst features indicates that the limestoneis relatively purer (or less muddy) here than elsewhere.	
Aquifer (**Figure 5**)	**Locally Important Aquifer that is generally moderately productive only in local zones (LI).** Flow occurs along fractures, joints and major faults. Generally, this limestone has poor potential for water storage and abstraction but localised zones of higher permeability do exist. It is likely that the Calp in this area is purer and less shaley than normal, so is more fractured and karstified and more permeable.	
Groundwater Body	Geashill GWB. Categorised as 'possibly at risk of not achieving good status' (www.epa.ie)	
Recharge Coefficient (**Appendix 4**)	4 % - 60 %	Hydrogeological setting 3.iv (see **Appendix 4**). Low permeability Peat overlying LI Aquifer. Maximum recharge capacity 200 mm/yr. Area of higher recharge capacity to south feeding the springs, recharge coefficient 60 %, average recharge 200 mm/yr.
Average Recharge (mm/yr)	17 - 200	

3.2 Hydrochemistry and water quality

During the site visit to Newtown on 09/05/2016 measurements were taken of pH, electrical conductivity and temperature. The results are presented in **Table 4** below.

Table 4. Summary of field measurements of physico-chemical parameters

Parameter	Toberfin Spring
pH (pH units)	7.16
Conductivity @ 20C (µS/cm)	759
Temperature (deg C)	9.9

There are no recent data available for the raw water quality at the spring. Offaly County Council carry out check and audit monitoring around the supply network. The check and audit monitoring data for 2014 and 2015 were made available for this report but as the samples were collected from around the supply network it represents a blend of the water from several of the schemes individual supplies rather than the water from one single source. Therefore it is not considered in this report.

The 2001 report analysed available data. There were a number of parameters that exceeded the EU Drinking Water Directive maximum admissible concentrations (MAC), which was the accepted water quality standard at that time. The section of the report is reproduced in **Appendix 5**.

- Colour, turbidity, ammonia, total coliform, faecal coliforms, E.Coli counts and oxidisability were all in excess of the acceptable limits at various times.

- The caretaker reported that a number of pollution incidents which resulted in a green colouration in the water at the main three springs did not appear to have any visible effect on Spring No. 4.

- Prior to 2001, concentrations of chloride, sodium and nitrate were all elevated at various times.

- Average nitrate concentrations rose from 20 mg/l to 30 mg/l during 1979 - 1999 (see graph reproduced in **Appendix 5**).

- There was a potassium:sodium ratio of 0.79 recorded on one occasion (July, 1998), which indicated contamination by farmyard wastes.

As part of this current project, the NFGWS collected a raw (untreated) water sample from the spring in June 2016. The analytical data are presented in **Appendix 5** with summary information below in **Table 5**. The analytical results have been compared to drinking water limits from the Drinking Water Regulations (SI No. 122 of 2014) and/or the Threshold Values from the European Communities Environmental Objectives (Groundwater) Regulations 2010 (S.I. No. 9 of 2010), whichever is the lower.

The water is very hard, indicating that much of the groundwater has sufficient contact with the fractured limestone to dissolve the lime into it. All chemical parameters analysed for are within acceptable limits, including nitrates, chloride and iron. The nitrate concentration (18.3 mgl/l) was lower than during the late 1990s. The potassium:sodium ratio is 0.3.

The bacteriological data indicate that organic contamination is reaching the spring, with positive counts of both total coliforms and E. Coli. Counts of 23.8 of total coliforms and 6.4 E. Coli were recorded, which is above the drinking water limit of zero for both parameters.

Hydrochemical information in the 2001 GSI report on Toberfin Springs concluded that the water emerging at the springs is largely derived from the underlying limestone but that some of the water does not have a typical limestone chemical “signature”. Part of the spring flow is reaching the springs via a shorter pathway i.e. via a conduit from the swallow hole. Groundwater travels between those two points quickly and so does not have enough time to dissolve the limestone into it.

Table 5. Summary Raw Water Quality Data

Parameter	Toberfin Spring	Units	Drinking Water Limit (DWL) or Threshold Value (TV)
Conductivity @ 20C	698	µS/cm	800 (TV)
Sodium	8.09	mg/l	150 (TV)
Chloride	12.48	mg/l	24
Ammonium NH_4	0.03	mg/l NH_4	0.3 (DWL)
Nitrate as NO_3	18.3	mg/l	37.5 (TV)
Nitrite as NO_2	<0.03	mg/l	0.5 (TV)
Total Hardness (Kone)	403	mg/l $CaCO_3$	
Iron	<20	µg/l	200 (DWL)
Manganese, dissolved	<5	µg/l	<50 (DWL)
Potassium	2.47	mg/l	
E Coli	**6.4**	cfu/100ml	0
Total Coliforms	**23.8**	cfu/100ml	0
Potassium:Sodium	0.3		>0.4 indicates contamination from plant organic matter

4 Zone of Contribution

4.1 Conceptual model

The current understanding of the geological and hydrogeological setting is given as follows (see vertical cross section **Diagram 2)**.

Groundwater is mainly replenished by rainfall percolating diffusely through the soils and subsoils down to the water table in the bedrock. Generally in this area the subsoils consist of low permeability peat which restricts groundwater recharge. There is an area of higher permeability localised sand and gravel unit in the immediate area of the springs. Gravelly subsoils permit more water to percolate to the water table.

Groundwater emerging from the KKC GWS springs is also replenished by water (and any contamination) flowing directly into the sinkhole approximately 1 km to the southwest of the springs. This is known as 'point' recharge. Focussed (or 'point') groundwater recharge also seems to be getting into the groundwater in other areas to the southwest of the spring, as highlighted by the pollution incident. These may be localised collapse features (known as 'dolines', see Glossary) that are currently not mapped.

The portion of rainfall that percolates down to the water table in the fractured muddy limestone bedrock (rather than running off to surface water) will flow as groundwater through its upper weathered zone which is likely to have a well-developed network of fractures and fissures. The deeper limestone will have fewer fractures and fissures and less groundwater flow.

The groundwater flow follows the topographic gradient (or slope) from the higher ground in the south towards the north. It is likely that the NE-SW bedrock faulting in the area also influences the direction of groundwater flow.

The Toberfin Springs, consisting of four individual springs, emerge from the ground over a small area (50 m x 20 m size site). The springs emerge where a well-developed system of fractures and fissures is feeding groundwater through a localized zone of higher permeability subsoils, thus allowing the groundwater to emerge at the surface. The limestone in the area has undergone some degree of karstification, as demonstrated by the presence of the sinking stream and swallow hole and indeed the springs themselves. The hydrogeological environment is clearly complex; while three of the springs are hydraulically connected to each other the fourth spring, known as Spring No. 4, is isolated from them and appears to be supplied by a separate network of fissures and fractures that are not connected to the system supplying the other three springs. The swallow hole is directly linked to the main three springs, but not to the separate Spring No. 4. Although the exact underground pathway between the swallow hole and the springs in unknown it is likely to be roughly a line between these two points; this line being parallel to the regional fault strike (see **Table 3**). The connection between the swallow hole and the springs has been demonstrated through the tracer testing carried out by Offaly County Council but also by the historical hydrochemical information available.

The limestone in the area of the Toberfin springs is thought to be more permeable than it is elsewhere; the groundwater velocity has been estimated (Kelly 2001) as 6.7 m/d (using a permeability of 10 m/d, porosity of 1.5 % and hydraulic gradient of 0.01).

The discharge from the main three springs is large; between 981 – 1,360 m^3/d. The discharge from Spring No. 4 is estimated between 83 – 353 m^3/d. The overflow from the springs is reported to fluctuate although there is no history of the springs running dry.

The groundwater in the immediate area of the spring is considered to have a High (H) vulnerability to contamination. The area surrounding the spring is primarily classified with a Moderate (M) vulnerability rating while some of the higher ground has an Extreme (E) vulnerability rating. The area around the swallow hole is Extremely vulnerable to contamination as the swallow hole represents a direct pathway into the aquifer and to the (main three) springs.

There are very few surface water features in the catchment, except for the Toberfin River and a network of small drains around the springs themselves. This also supports the theory that the Calp limestone in this area probably has a higher permeability to that elsewhere in the same rock unit.

The vulnerability of the spring and the complexity of the subsurface is highlighted with the raw water data which confirms that organic contamination is present in the spring. Given the proven connection between the swallow hole and the spring it is possible that the contamination is originating some distance from the spring but accessing the spring via the direct pathway between the two features.

The Zone of Contribution (ZOC) will extend upgradient (upslope) from the wells in a southerly direction.

The delineation of the zone of contribution boundaries includes a safety margin for some variability in groundwater flow direction and for seasonal variability in abstraction rates and water levels.

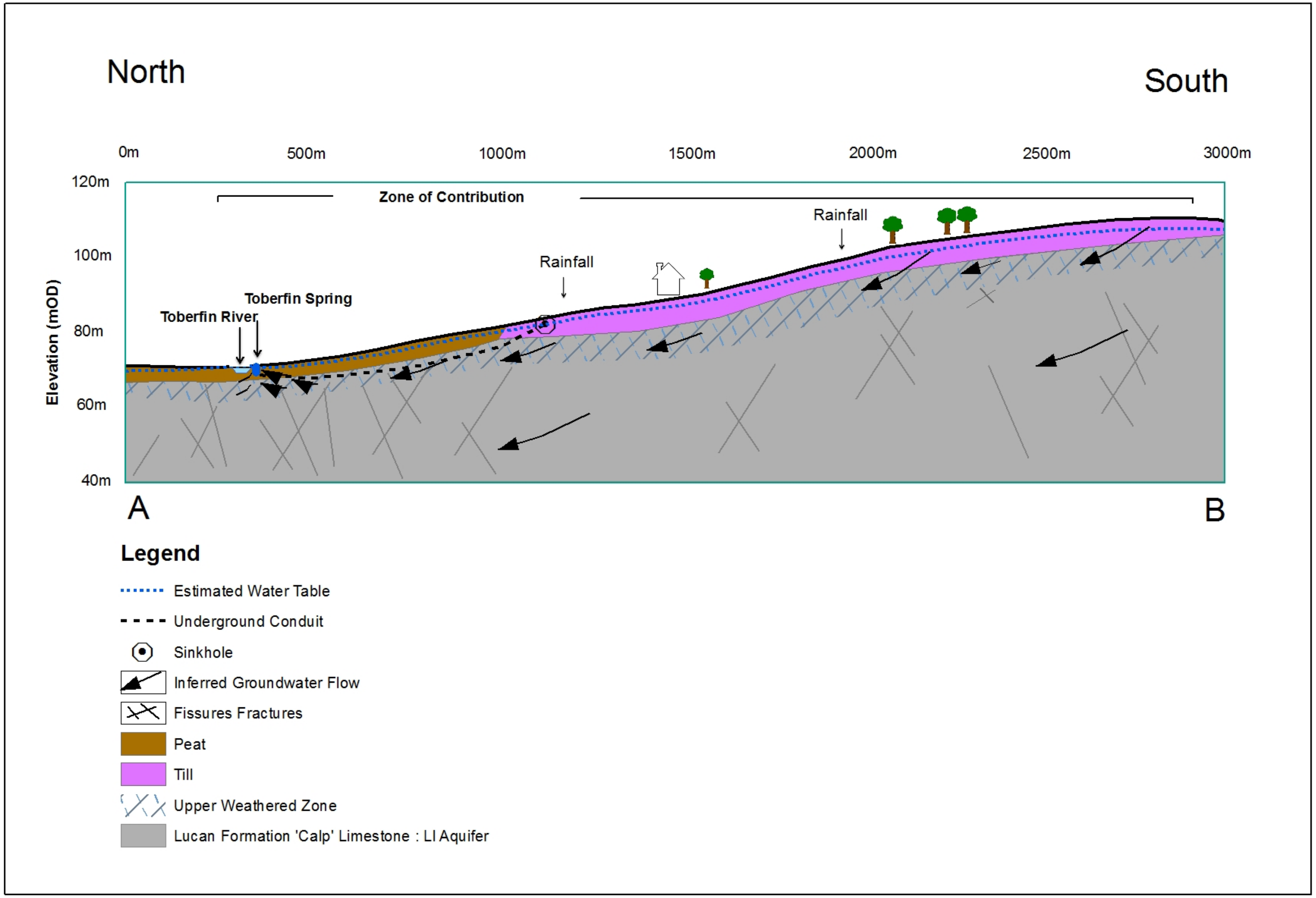

Diagram 2: Schematic Cross Section and Conceptual Model

4.2 Boundaries

The boundaries of the area contributing to the source are considered to be as follows (**Figure 6**). These boundaries were delineated in the Kelly 2001 report.

All of the boundaries are based on a combination of hydrogeological mapping and topography (**Appendix 6**).

The **Northern boundary**, is the 'downgradient' limit', beyond which groundwater will not be drawn back upgradient under the influence of the pump. It is constrained by the location of the springs themselves in relation to the Toberfin River which flows past the springs to the north. An arbitrary buffer of 30 m is used to delineate the downgradient boundary.

The **Southern Boundary**, represents the upgradient boundary of the zone of contribution. This is based on the water balance for the site and on the local topography. The boundary is defined by the topographic ridge in the townland of Finter. However the changes in slope in this area are subtle and so it is hard to delineate an exact position for the catchment divide. The boundary has been delineated with a conservatove approach.

The **Eastern Boundary** is defined by the topographic ridge which runs northwest to southeast before swinging northeast to southwest on the eastern side of the springs, creating a surfacewater divide and a probable groundwater divide between water flowing northeastwards and water flowing towards the springs and the Toberfin River. The point at which this divide changes its orientation is on the roadside at Newtown House.

The **Western Boundary** is topographically constrained and in addition water tracing has been used to prove this boundary (Kelly 2001). A catchment divide exists along the western boundary with water flowing northwest towards Kileenmore and water flowing northeast towards the springs. Water tracing has confirmed a positive link between the swallow hole and the springs.

These boundaries delineate the physical limits within which the ZOC is likely to occur. The delineation of the boundaries includes a safety margin for some variability in groundwater flow direction and for seasonal variability in abstraction rates and water levels.

Figure 6 presents the ZOC boundary with the inner and outer protection zones, as delineated in Kelly 2001, also displayed.

4.3 Recharge and water balance

Recharge and water balance calculations are used to support the hydrogeological mapping and to confirm that the ZOC delineated is big enough to supply the quantity of water abstracted by the source.

The abstraction rate from the Toberfin Springs is 1,006 m^3/d. In order to account for seasonal fluctuations in abstraction volumes plus uncertainties in the groundwater flow direction, a conservative approach is adopted and therefore the water balanace has been calculated based on a daily abstraction rate of 1,509 m^3/d i.e. 150% of the current abstraction rate.

The available recharge in the immediate area surrounding the springs is estimated at 17 mm/yr (see Table 2). However the majority of the area to the south (i.e. the area feeding the springs) has a maximum available recharge of 200 mm/yr; this figure is considered more applicable and so is used here in the calculations. The minimum geographical area required to sustain an abstraction of 1,509 m^3/d (or 550,785 m^3/yr) based on the minimum available recharge of 200 mm/yr (or 0.2 m/yr) is 2.75 $km^{2.}$ (or 2,753,925 m^2). The delineated ZOC measures 2.76 km^2.

5 Conclusions

The Toberfin Springs are used by two group water schemes; the Killeigh, Killurin and Cloneygowan GWS (KCC GWS) and the Meelaghans GWS (MGWS). The KCC GWS also use three other sources (Danganbeg Spring, the 'Moat Well' Spring and two boreholes at Clonyquin). KCC GWS has 1300 connections and MGWS has 39. The KCC GWS is a very large scheme, currently using approximately 976 m^3/d. Meelaghans are a very small scheme, using just 30 m^3/d. The merging of the schemes has been agreed in principle and wil progress when funding is available.

The Toberfin Springs consist of four springs; three of which are hydraulically connected and a fourth (Spring No. 4) which is isolated and not connected to the other three despite being in close proximity. The hydrogeological environment in this area is complex due to the karstified nature of the limestone. The springs are being fed groundwater from the underlying limestone bedrock. The main three springs are also directly connected to a swallow hole 900 m to the south west and are receiving recharge (and potentially anything that is discharged to the surface at this location such as organic wastes being landspread) from this swallow hole. The presence of the springs suggests that the limestone in the area has a well developed network of fractures and fissures through which the groundwater flows. This limestone is considered to be a Locally Important Aquifer that is generally moderately productive (Ll). The vulnerability of the groundwater in the area around the springs is considered High (H) although there are areas of Moderate (M), High (H) and Extreme (E) vulnerability elsewhere in the area. The swallow hole represents a point of Extreme (E) vulnerability, highlighting its significance to the springs in terms of groundwater quality and protection.

The ZOC was delineated as part of the 2001 Source Protection Zone report compiled by the GSI (Kelly 2001). This ZOC is presented on Figure 6 along with the inner and outer protection zone boundaries, again delineated in Kelly 2001.

Recharge to the groundwater will be predominately diffuse recharge, although point recharge will occur at the swallow hole. This emphasizes the significance of the swallow hole and the risk it poses to the quality of water emerging at the springs.

The ZOC is occupied by agricultural land and houses. Potential sources of contamination to the springs include septic tanks (in particular old or inefficient tanks that have not been emptied in many years) and agricultural activities e.g. grazing, landspreading, slurry pits or slatted units. The swallow hole, 900 m away, is a proven direct pathway to the springs and so any activities on the land around the swallow hole will directly impact the groundwater quality at the springs.

Recent raw water analysis has highlighted the vulnerability of the spring to contamination, particularly bacteriological contamination from human or animal effluents. The presence of the underground pathway between the swallow hole and the spring is significant as it means activities on the area of the swallow hole will directly impact on the water quality at the spring.

Any landuse changes or planning permissions within the ZOC, and particular in the area around the swallow hole, should be carefully monitored and assessed for likely impacts on the springs.

6 Recommendations

The recommendations below have been subdivided into higher and lower priority; ideally the higher priority recommendations should be addressed immediately.

Essential:

- Routine untreated groundwater monitoring should be undertaken for the source for a specified period of time (e.g. monthly/quarterly for a year, to include sampling immediately after at least one rainfall event). The need for future monitoring can be determined on the basis of these results, and in discussion with a hydrogeologist.

- The yield of the main three springs should be established; particularly with a view to the two schemes merging.

- The presence of the swallow hole, with its proven direct link to the springs is a cause of concern, particularly given the bacteriological contamination that is present in the spring. It is recommended that the committee, with support from the NFGWS, engage with the landowner on whose land the swallow hole is located, to discuss the water quality concerns and perhaps agree to implement a 30 m buffer zone around the swallow hole. This could be implemented by erecting a stock proof fence around the swallow hole and prohibiting any activities such as the application of organic wastes or chemicals within this buffer zone.

- Any future planning applications made within the ZOC and in particular around the swallow hole should be assessed for their potential impact on the quality of groundwater (refer to the local authority's county development plan and Groundwater Protection Schemes Document, 1999). Similarly any significant changes in land use should be monitored.

- Licensed landspreading must only take place within the context of the guidelines as specified in the document entitled "Groundwater Protection Schemes" published by the Department of the Environment and Local Government, Environmental Protection Agency and Geological Survey of Ireland in 1999 and 'Landspreading of Organic Wastes' Guidance on Groundwater Vulnerability Assessment of Land, Environmental Protection Agency 2004.

Desirable:

- Comprehensive hazard mapping (e.g. septic tanks, slatted units and slurry pits) within the delineated ZOC should be undertaken. This should ideally include septic tank inspections to clarify their condition.

- The ZOC should be assessed to establish the level of risk, if any, posed by cryptosporidium.

Other:

- The following EPA guidelines may serve as future useful reference documents for the Killeigh, Killurin and Cloneygowan GWS and the Meelaghans GWS:
    - EPA Drinking Water Advice Note No. 7: Source Protection and Catchment Management to Protect Groundwater Sources. Of particular interest would be Section 4.1 – Step 2 – Hazard Mapping[3].
    - EPA Drinking Water Advice Note No. 8: Developing Drinking Water Safety Plans. This document contains checklists for hazards which would assist in hazard mapping within the ZOC[4].
    - EPA Drinking Water Advice Note No. 14. Borehole Construction and Wellhead Protection

7 References

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[3] http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvicenote-advicenoteno7.html#.UpNP_eJ9KEp

[4] http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvicenote-advicenoteno8.html#.UpNQf-J9KEo

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EPA Drinking Water Advice Note No. 14. Borehole Construction and Wellhead Protection

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FIGURES

Figure 1. Location Map

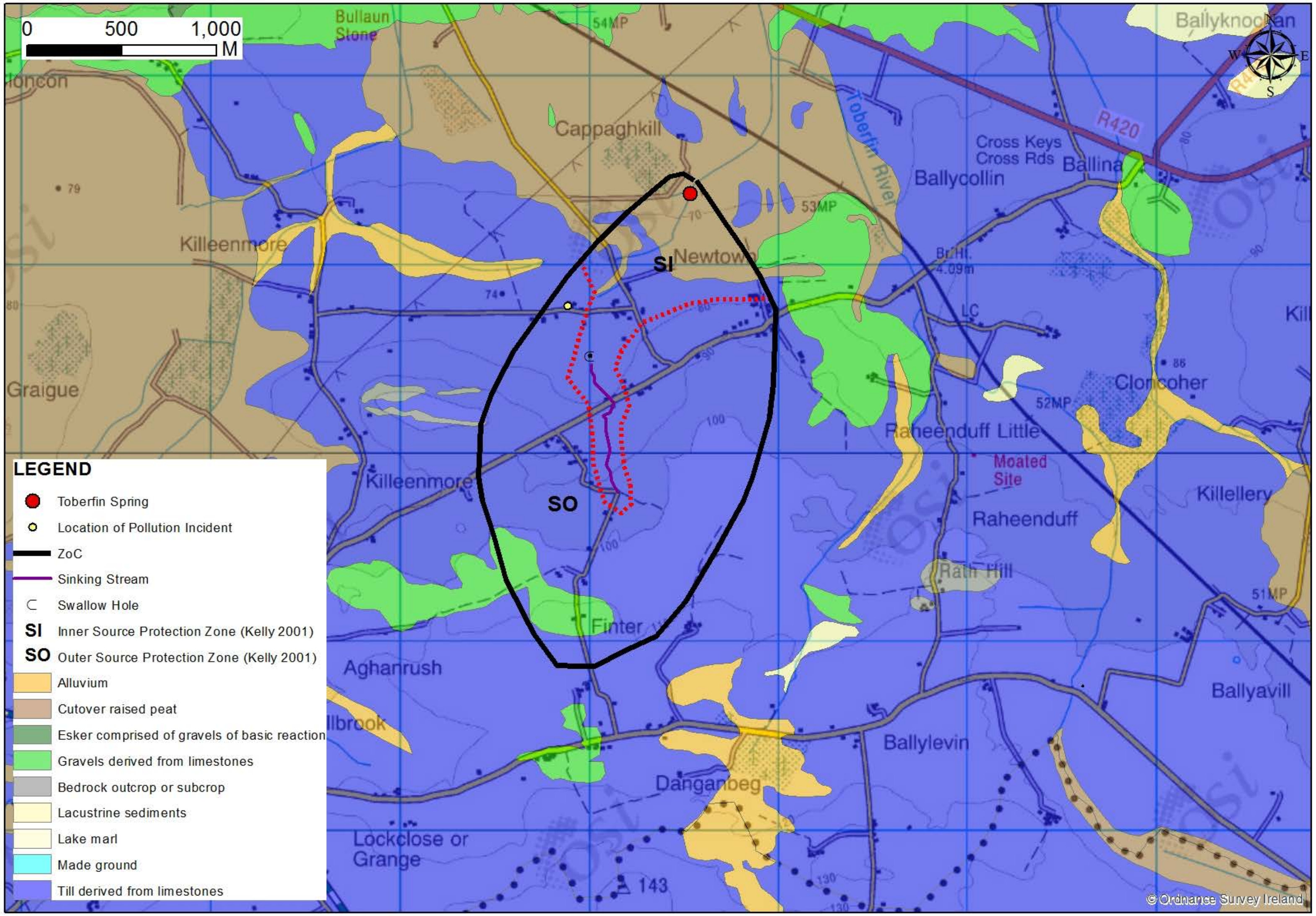


Figure 2. Subsoils Map

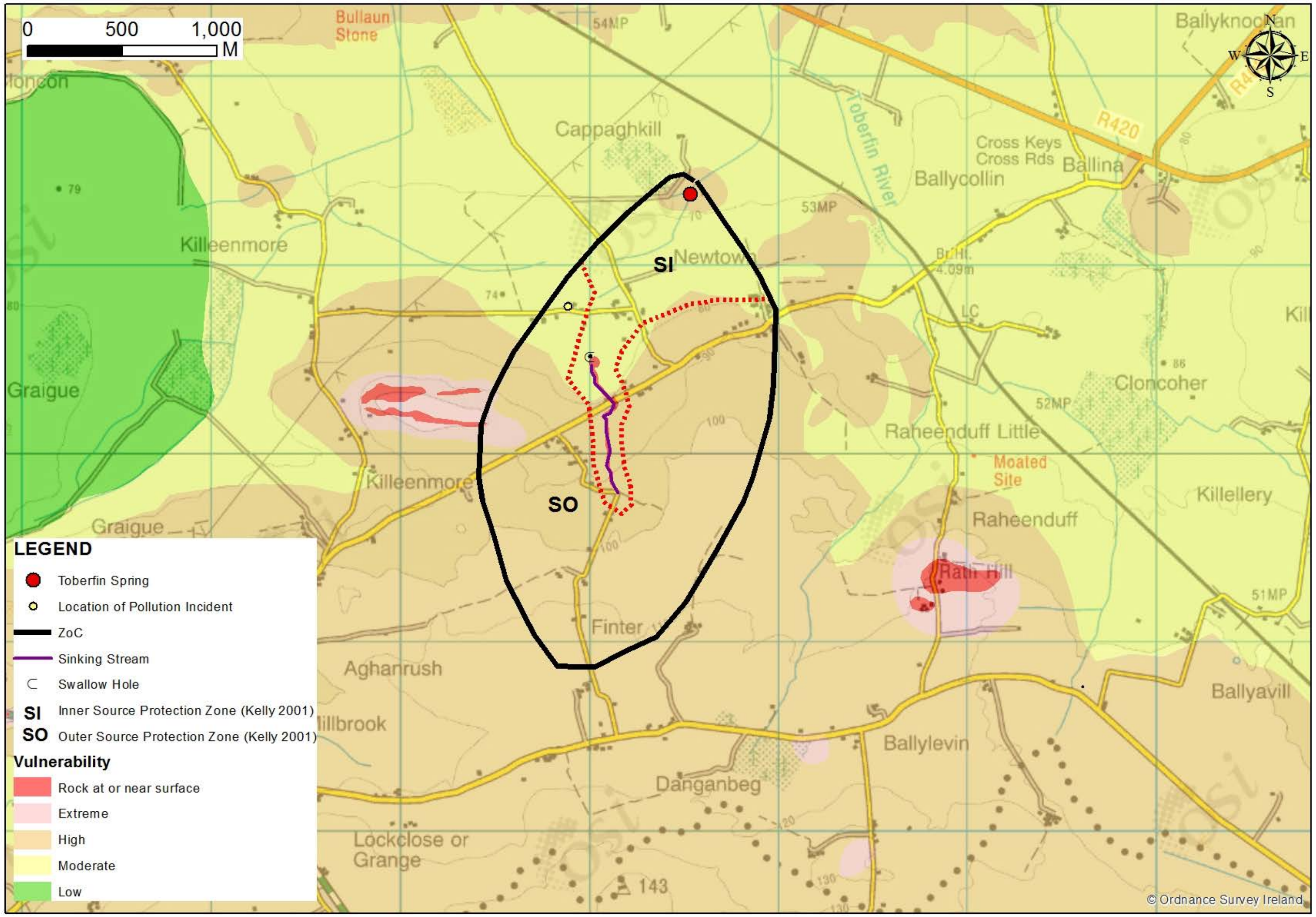


Figure 3. Groundwater Vulnerability Map

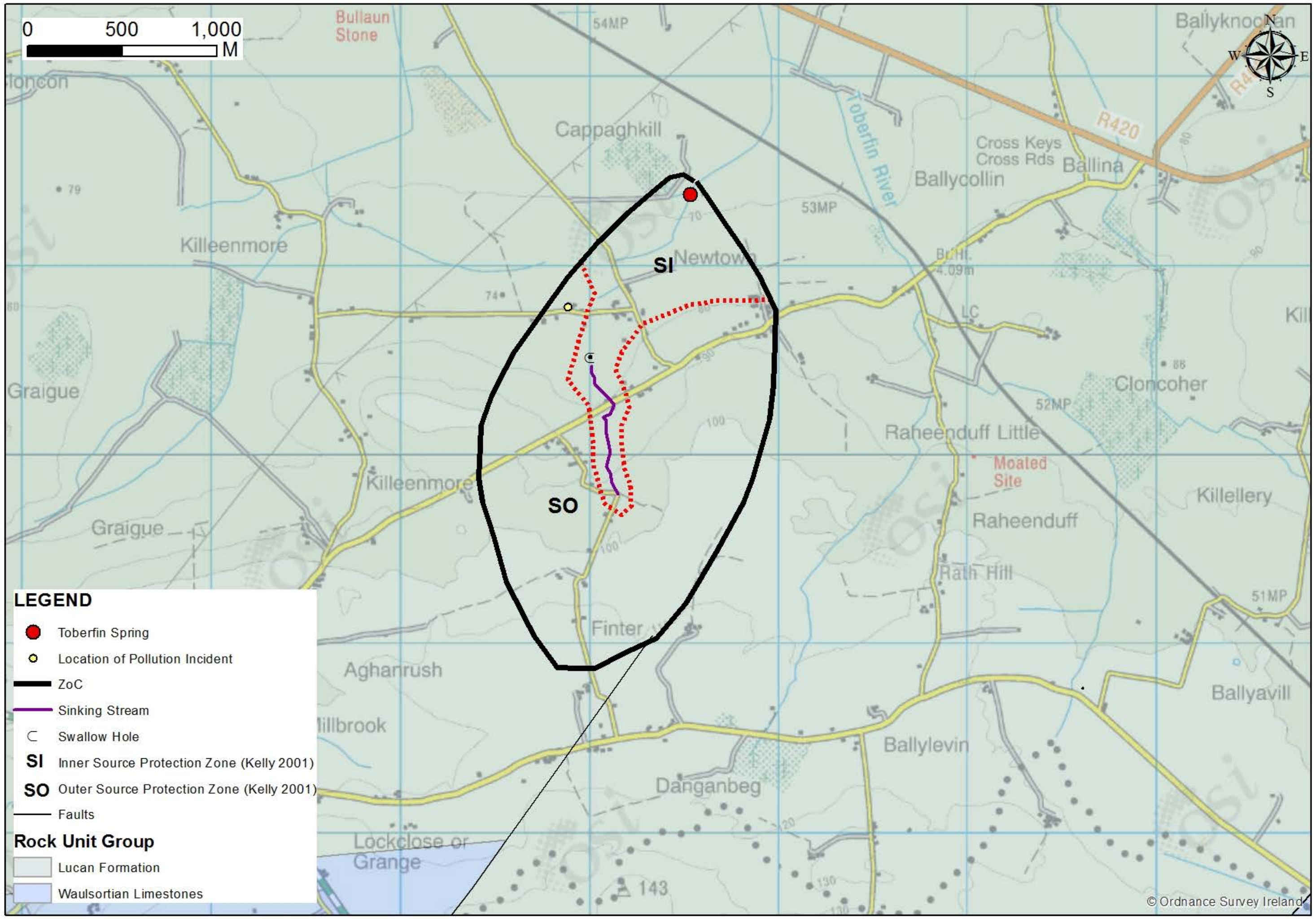


Figure 4. Rock Unit Group Map

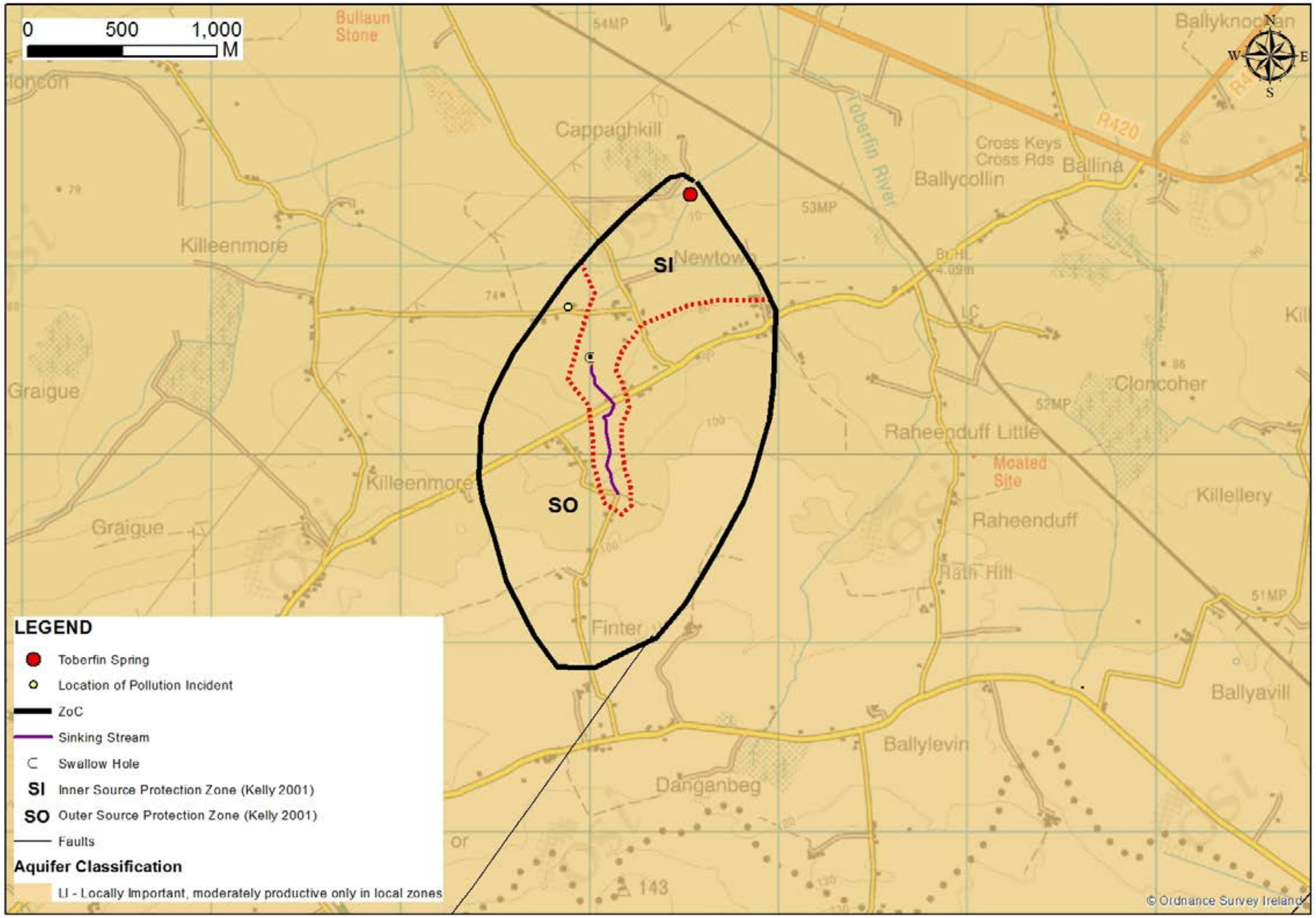


Figure 5. Aquifer Map

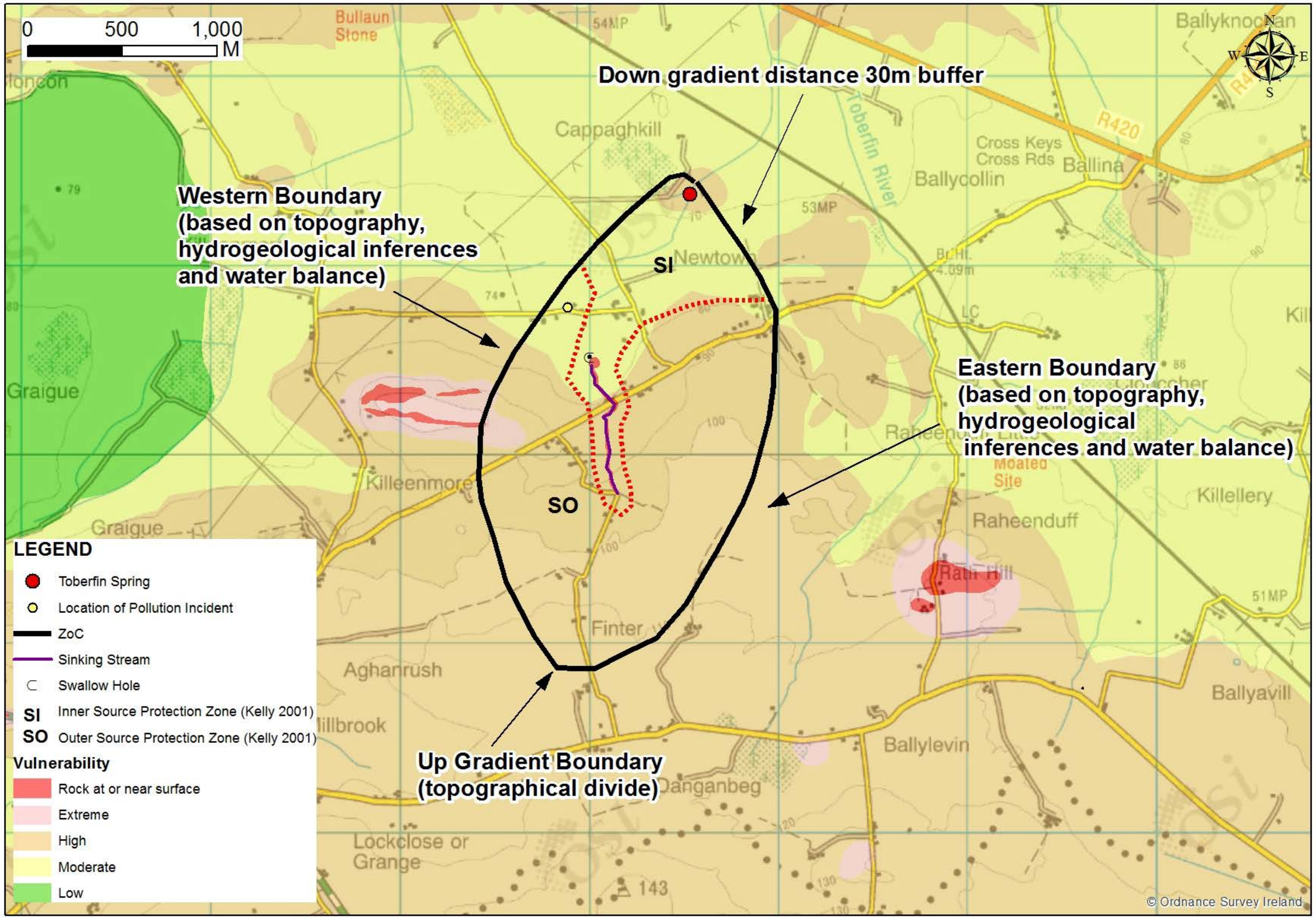


Figure 6. ZOC Boundary Map

Acronyms and Glossary of Terms

BGL	Below Ground Level
EPA	Environmental Protection Agency
DEHLG	Department of Environment Heritage and Local Government
EQS	Environmental Quality Standard
EU	European Union
GPZ	Groundwater Protection Zone
GSI	Geological Survey of Ireland
GWB	Groundwater Body
GWD	Groundwater Directive (European Union)
GWS	Group Water Scheme
IGI	Institute of Geologist of Ireland
MOD	Metres Ordnance Datum
MRP	Molybdate-Reactive Phosphorus
NRG	National Grid Reference
NRWMC	National Rural Water Monitoring Committee
PVC	Polyvinyl Chloride
SPZ	Source Protection Zones
TOT	Time of Travel
TVs	Threshold Values
UV	Ultra-Violet
ZOC	Zone of Contribution
WFD	Water Framework Directive (European Union)

Glossary of Terms

Aquifer

A subsurface layer or layers of rock, or other geological strata, of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater (Groundwater Regulations, 2010).

Attenuation

A decrease in pollutant concentrations, flux, or toxicity as a function of physical, chemical and/or biological processes, individually or in combination, in the subsurface environment.

Borehole

A particular type of well - a narrow hole in the ground constructed by a drilling machine in order to gain access to the groundwater system.

Conceptual Hydrogeological Model

A simplified representation or working description of how a real hydrogeological system is believed to behave on the basis of qualitative analysis of desk study information, field observations and field data.

Confined Aquifer

A confined aquifer occurs where the aquifer is overlain by low permeability “confining” material. Once all the void space in the aquifer is full of water up to the confining layer, the addition of more water to the aquifer causes the stored water to become pressurised and, the additional water is stored by compression, sealed in by the overlying confining layer (the water is added upgradient where the confining layer is absent). Where a borehole punctures the confining layer, the water will rise up into the borehole to equalise the confining pressure.

Diffuse Sources

Diffuse sources of pollution are spread over wider geographical areas rather than at individual point locations. Diffuse sources include general land use activities and landspreading of industrial, municipal wastes and agricultural organic and inorganic fertilisers.

Direct Input

An input to groundwater that bypasses the unsaturated zone (e.g. direct injection through a borehole) or is directly in contact with the groundwater table in an aquifer either year round or seasonally.

Doline

Or enclosed depressions are relatively shallow bowl or funnel shaped depressions that form in karst landscapes, and serve to funnel or concentrate recharge underground. Their presence indicates that subterranean drainage is in operation.

Dolomitisation

Is a process, whereby the calcite crystals in limestone is replaced by magnesium. This results in an increase in the porosity and permeability of the rock. Dolomitised rocks are a highly weathered, yellow/orange/brown colour and are usually evident in boreholes as loose yellow-brown sand with significant void space and poor core recovery. Dolomitisation often occurs preferentially in both fault zones and purer limestones.

Down-gradient

The direction of decreasing groundwater levels, i.e. flow direction. Opposite of upgradient.

Dry Weather Flow (Receiving Water)

The minimum flow likely to occur in a surface water course during a prolonged drought.

Environmental Quality Standard (EQS)

The concentration of a particular pollutant or group of pollutants in a receiving water which should not be exceeded in order to protect human health and the environment.

Enclosed Depression

See doline

Fissure

A natural crack in rock which allows rapid water movement.

Good Groundwater Status

Achieved when both the quantitative and chemical status of a groundwater body are good and meet all the conditions for good status set out in Groundwater Regulations 2010, regulations 39 to 43.

Groundwater

All water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil (Groundwater Regulations, 2010).

Groundwater Body (GWB)

A volume of groundwater defined as a groundwater management unit for the purposes of reporting to the European Commission under the Water Framework Directive. Groundwater bodies are defined by aquifers capable of providing more than 10 m3/d, on average, or serving more than 50 persons.

Groundwater Protection Scheme (GWPS)

A scheme comprising two principal components: a land surface zoning map which encompasses the hydrogeological elements of risk (of pollution); and a groundwater protection response matrix for different potentially polluting activities (DELG/EPA/GSI, 1999).

Groundwater Protection Responses (GWPR)

Control measures, conditions or precautions recommended as a response to the acceptability of an activity within a groundwater protection zone.

Groundwater Protection Zone (GPZ)

A zone delineated by integrating aquifer categories or source protection areas and associated vulnerability ratings. The zones are shown on a map, each zone being identified by a code, e.g. SO/H (outer source area with a high vulnerability) or Rk/E (regionally important karstified aquifer with an extreme vulnerability). Groundwater protection responses are assigned to these zones for different potentially polluting activities.

Groundwater Recharge

Two definitions: a) the process of rainwater or surface water infiltrating to the groundwater table; b) the volume (amount) of water added to a groundwater system.

Groundwater Resource

An aquifer capable of providing a groundwater supply of more than 10 m3/d as an average or serving more than 50 persons.

Hydraulic Conductivity

The rate at which water can move through a unit volume of geological medium under a potential unit hydraulic gradient. The hydraulic conductivity can be influenced by the properties of the fluid, including its density, viscosity and temperature, as well as by the properties of the soil or rock.

Hydraulic Gradient

The change in total head of water with distance; the slope of the groundwater table or the piezometric surface.

Igneous

Igneous rock is formed through the cooling and solidification of magma or lava.

Indirect Input

An input to groundwater where the pollutants infiltrate through soil, subsoil and/or bedrock to the groundwater table.

Input

The direct or indirect introduction of pollutants into groundwater as a result of human activity.

Karst

A distinctive landform characterised by features such as surface collapses, sinking streams, swallow holes, caves, turloughs and dry valleys, and a distinctive groundwater flow regime where drainage is largely underground in solutionally enlarged fissures and conduits.

Karstification

Karstification is the process whereby limestones are slowly dissolved by acidic waters moving through them. This results in the development of an uneven distribution of permeability with the enlargement of certain fissures at the expense of others and the concentration of water flow into these high permeability zones. Karstification results in the progressive development of distinctive karst landforms such as caves, swallow holes, sinking streams, turloughs and dry valleys, and a distinctive groundwater flow regime. It is an important feature of Irish hydrogeology.

Pathway

The route which a particle of water and/or chemical or biological substance takes through the environment from a source to a receptor location. Pathways are determined by natural hydrogeological characteristics and the nature of the contaminant, but can also be influenced by the presence of features resulting from human activities (e.g., abandoned ungrouted boreholes which can direct surface water and associated pollutants preferentially to groundwater).

Permeability

A measure of a soil or rock's ability or capacity to transmit water under a potential hydraulic gradient (synonymous with hydraulic conductivity).

Point Source

Any discernible, confined or discrete conveyance from which pollutants are or may be discharged. These may exist in the form of pipes, ditches, channels, tunnels, conduits, containers, and sheds, or may exist as distinct percolation areas, integrated constructed wetlands, or other surface application of pollutants at individual locations. Examples are discharges from waste water works and effluent discharges from industry.

Pollution

The direct or indirect introduction, as a result of human activity, of substances or heat into the air, water or land which may be harmful to human health or the quality of aquatic ecosystems or terrestrial ecosystems directly depending on aquatic ecosystems which result in damage to material property, or which impair or interfere with amenities and other legitimate uses of the environment (Groundwater Regulations, 2010).

Poorly Productive Aquifers (PPAs)

Low-yielding bedrock aquifers that are generally not regarded as important sources of water for public water supply but that nonetheless may be important in terms of providing domestic and small community water supplies and of delivering water and associated pollutants to rivers and lakes via shallow groundwater pathways.

Preferential Flow

A generic term used to describe water movement along favoured pathways through a geological medium, bypassing other parts of the medium. Examples include pores formed by soil fauna, plant root channels, weathering cracks, fissures and/or fractures.

Saturated Zone
The zone below the water table in an aquifer in which all pores and fissures and fractures are filled with water at a pressure that is greater than atmospheric.

Soil (topsoil)
The uppermost layer of soil in which plants grow.

Source Protection Area
The catchment area around a groundwater source which contributes water to that source (Zone of Contribution), divided into two areas; the Inner Protection Area (SI) and the Outer Protection Area (SO). The SI is designed to protect the source against the effects of human activities that may have an immediate effect on the source, particularly in relation to microbiological pollution. It is defined by a 100-day time of travel (TOT) from any point below the water table to the source. The SO covers the remainder of the zone of contribution of the groundwater source.

Specific Yield
The specific yield is the volume of water that an unconfined aquifer releases from storage per unit surface area of aquifer per unit decline of the water table.

Spring
A spring is a natural feature where groundwater emerges at the surface. Springs usually occur where the rate of flow of groundwater is too great to remain underground. The position of a springs usually reflects a change in soil or rocktype or a change in slope.

Subsoil
Unlithified (uncemented) geological strata or materials beneath the topsoil and above bedrock.

Surface Water
An element of water on the land‘s surface such as a lake, reservoir, stream, river or canal. Can also be part of transitional or coastal waters. (Surface Waters Regulations, 2009.).

Swallow Hole
The point where concentrated inflows of water sink underground. They are found in karst environments.

Threshold Values (TVs)
Chemical concentration values for substances listed in Schedule 5 of the Groundwater Regulations (2010), which are used for the purpose of chemical status classification of groundwater bodies.

Till
Unsorted glacial Sediment deposited directly by the glacier. It is the most common Quaternary deposit in Ireland. Its components may vary from gravel, sands and clays.

Transmissivity
Transmissivity is the product of the average hydraulic conductivity of the aquifer and the saturated thickness of the aquifer.

Unsaturated Zone
The zone between the land surface and the water table, in which pores, fractures and fissures are only partially filled with water. Also known as the vadose zone.

Vulnerability
The intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities (Fitzsimmons et al, 2003).

Water Table

The uppermost level of saturation in an aquifer at which the pressure is atmospheric.

Weathering
The breakdown of rocks and minerals at the earth's surface by chemical and physical processes.

Zone of Contribution (ZOC)

The area surrounding a pumped well or spring that encompasses all areas or features that supply groundwater to the well or spring. It is defined as the area required to support an abstraction and/or overflow (in the case of springs) from long-term groundwater recharge.

APPENDIX 1

Flow meter records from KCC GWS Caretaker Notebook

October 2015 – April 2016

Meter reading notes from KCC GWS caretakers notebook, October 2015 – April 2016

Date	Meter reading m^3	Equivalent discharge – m^3/d
01/10/15	68446	1256.60
06/10/16	74729	1441.00
09/10/15	79052	1136.00
12/10/15	82460	1391.25
16/10/15	88025	1327.71
23/10/16	97319	1253.14
30/10/15	106091	1189.38
07/11/15	115606	630.00
14/12/15	164116	1406.25
18/12/15	169741	1326.00
23/12/15	176371	1378.10
02/01/16	190152	1259.17
08/01/16	197707	1115.33
11/01/16	201053	1104.50
15/01/16	205471	975.67
18/01/16	208398	1006.00
22/01/16	212422	1096.40
27/01/16	217904	533.00
29/01/16	219503	1007.80
03/02/16	224542	1332.75
07/02/16	229873	755.00
12/02/16	233648	993.83
18/02/16	239611	1171.25
22/02/16	244296	1068.22
02/03/16	253910	1084.50
04/03/16	256079	1111.67
07/03/16	259414	1015.75
11/03/16	263477	1137.40
16/03/16	269164	1033.67
22/03/16	275366	1160.00
25/03/16	278846	1074.50
29/03/16	283144	1112.00
31/03/16	285368	1031.83
06/04/16	291559	1101.50
08/04/16	293762	996.33
11/04/16	296751	1070.00
12/04/16	297821	1256.60
	Total discharge over 235 days	**229,375 m^3**
	Average discharge per day	**976.06 m^3/d**

APPENDIX 2

Geological Logs of Auger Boreholes from GSI 2001 Report

Geological Logs of Auger Boreholes – sourced from 2001 GSI Report.

All borehole depths are maximum depths drilled by the auger. The depths are the depth at which the auger would not go any further. It was assumed that the auger had reached bedrock, the evidence being that in most cases floured bedrock is recovered on the teeth of the auger.

Auger I.D	Subsoil Type	BS 5930 Description	Permeability Category
Killeigh No. 1			
0 – 3.5 m	Peat	Silty CLAY	Low
3.5 – 6.5 m	Alluvium	CLAY	Low
6.5 – 8.2 m	Till	Clayey SILT	Moderate
Killeigh No. 2			
0 – 1.0 m	Peat	Silty CLAY	Low
1.0 – 3.7 m	Alluvium	CLAY	Low
3.7 – 10.5 m	No returns	CLAY?	Low
Killeigh No. 3			
0 – 0.5 m	Topsoil	SILT	MODERATE
0.5 – 2.0 m	Till	Sandy SILT with clay	MODERATE
2.0 – 3.0 m	Till	Silty SAND	HIGH
3.0 – 4.0 m	Till	Silty GRAVEL	HIGH
4.0 – 6.3 m	Till	Clayey SILT with gravel	MODERATE
Killeigh No. 4			
0 – 0.5 m	Topsoil	SILT	MODERATE
0.5 – 1.5 m	Till	Silty GRAVEL	HIGH
1.5 – 2.5 m	Till	Silty SAND	HIGH
2.5 – 3.0 m	Till	Silty GRAVEL	HIGH
3.0 – 4.0 m	Till	Clayey SILT with gravel	MODERATE
Killeigh No. 5			
0 – 0.5 m	Topsoil	SILT	MODERATE
0.5 – 2.0 m	Till	Silty SAND and gravel	HIGH
2.0 – 3.0 m	Till	Silty SAND with gravel	HIGH
3.0 – 4.0 m	Till	Clayey SILT and gravel	MODERATE
Killeigh No. 6			
0.0 – 0.3 m	Topsoil	SILT	MODERATE
0.3 – 1.5 m	Till	Sandy SILT with gravel	HIGH
1.5 – 2.7 m	Till	Sandy GRAVEL	HIGH

APPENDIX 3

Groundwater Vulnerability

Introduction

The term ‘vulnerability’ is used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities (DELG *et al.,* 1999). The vulnerability of groundwater depends on:

- the time of travel of infiltrating water (and contaminants)
- the relative quantity of contaminants that can reach the groundwater
- the contaminant attenuation capacity of the geological materials through which the water and contaminants infiltrate.

All groundwater is hydrologically connected to the land surface; the effectiveness of this connection determines the relative vulnerability to contamination. Groundwater that readily and quickly receives water (and contaminants) from the land surface is more vulnerable than groundwater that receives water (and contaminants) more slowly and in lower quantities. The travel time, attenuation capacity and quantity of contaminants are a function of the following natural geological and hydrogeological attributes of any area:

- the type and permeability of the subsoils that overlie the groundwater
- the thickness of the unsaturated zone through which the contaminant moves
- the recharge type – whether point or diffuse.

In other words, vulnerability is based on evaluating the relevant hydrogeological characteristics of the protecting geological layers along the pathway, and the possibility of bypassing these layers. In summary, the entire land surface is divided into four vulnerability categories: **E**xtreme, **H**igh, **M**oderate and **L**ow, based on the geological and hydrogeological characteristics. Further details of the hydrogeological basis for vulnerability assessment can be found in ‘Groundwater Protection Schemes’ (DELG et al., 1999).

The Groundwater Vulnerability Map shows the vulnerability of the first groundwater encountered, in either sand/gravel or bedrock aquifers, by contaminants released at depths of 1-2 m below the ground surface. Where the water-table in bedrock aquifers is below the top of the bedrock, the target needing protection is the water-table. However, where the aquifer is fully saturated, the target is the top of the bedrock. The vulnerability map aims to be a guide to the likelihood of groundwater contamination, if a pollution event were to occur. It does not replace the need for site investigation. Note also that the characteristics of individual contaminants are not considered.

Except where point recharge occurs (*e.g*. at swallow holes), the groundwater vulnerability depends on the type, permeability and thickness of the subsoil.

The groundwater vulnerability map is derived by combining the permeability and depth to bedrock maps, using the three subsoil permeability categories: high, moderate and low; and four depths to rock categories: <3m, 3–5m, 5–10m and >10m. The resulting vulnerability classifications are shown in Table 1.

Table 1 Vulnerability mapping guidelines (adapted from DELG et al, 1999)

Thickness of Overlying Subsoils	Hydrogeological Requirements for Vulnerability Categories				
	Diffuse Recharge			**Point Recharge**	**Unsaturated Zone**
	Subsoil permeability and type				
	High permeability (*sand/gravel*)	moderate permeability (*sandy subsoil*)	low permeability (*clayey subsoil, clay, peat*)	*(swallow holes, losing streams)*	(*sand & gravel aquifers only*)
0–3 m	**Extreme**	**Extreme**	**Extreme**	**Extreme (30 m radius)**	**Extreme**
3–5 m	**High**	**High**	**High**	**N/A**	**High**
5–10 m	**High**	**High**	**Moderate**	**N/A**	**High**
>10 m	**High**	**Moderate**	**Low**	**N/A**	**High**

Notes: (i) N/A = not applicable.
(ii) Release point of contaminants is assumed to be 1–2 m below ground surface.
(iii) Permeability classifications relate to the engineering behaviour as described by BS5930.
(iv) Outcrop and shallow subsoil (i.e. generally <1.0 m) areas are shown as a sub-category of extreme vulnerability
(amended from Deakin and Daly (1999) and DELG/EPA/GSIa (1999))

Sources of Vulnerability Data

Specific vulnerability field mapping and assessment of previously collected data were carried out as part of this project. Fieldwork focused on assessing the permeability of the different subsoil deposit types (Figure 3), so that they could be subdivided into the three permeability categories. This involved:

- Describing selected exposures/sections according to the British Standard Institute *Code of Practice for Site Investigations* (BS 5930:1999).
- Collection of subsoil samples for laboratory particle size analyses
- Assessing the recharge characteristics of selected sites using natural and artificial drainage, vegetation and other recharge indicators.

The following additional sources of data were used to assess the vulnerability and produce the map:

- Subsoils Map (EPA/Teagasc Subsoil Map, 2006), which is the basis for the main permeability boundaries. 'Clean' sands and gravels are usually high permeability. Alluvium deposits are either moderate or low permeability.
- Depth to bedrock map, compiled by the mapping team for the current project in the Geological Survey of Ireland, using data compiled from GSI, consultant and county council reports, along with purpose-drilled auger holes
- Geological Survey of Ireland Bedrock Geology Map
- Geological Survey of Ireland well and karst database, which supplied information on well yields and depth to bedrock, as well as locations of point recharge.
- General Soils Map of Ireland (Gardiner and Radford, 1980). This gives additional, indirect information on subsoil permeability in the areas mapped by Teagasc as 'till'.

Thickness of the Unsaturated Zone

The thickness of the unsaturated zone, or the depth of ground free of intermittent or permanent saturation, is only relevant in vulnerability mapping over unconfined sand and gravel aquifers. As described in Table 6.1, the critical unsaturated zone thickness is 3m; unconfined gravels with unsaturated zones thicker than 3m are classed as having a 'high' vulnerability, while those with unsaturated zones thinner than 3m are classed as having an 'extreme' vulnerability.

APPENDIX 4

Groundwater Recharge

Introduction

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 is assumed to consist of the rainfall input (i.e. annual rainfall) minus 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 this dictates the size of the zone of contribution to the source (i.e. the outer Source Protection Area).

The main parameters involved in the estimation of recharge are: annual rainfall; annual evapotranspiration; and a recharge coefficient (Table 1). The recharge coefficient is estimated using Hunter Williams et al (2013) (see also Guidance Document GW5 Groundwater Working Group 2005; Hunter Williams et al 2011).

Groundwater vulnerability category	Hydrogeological setting		Recharge coefficient (RC)		
			Min (%)	*Inner Range*	*Max (%)*
Extreme (X or E)	1.i	Areas where rock is at ground surface	30	80-90	100
	1.ii	Sand/gravel overlain by 'well drained' soil	50	80-90	100
	1.iii	Sand/gravel overlain by 'poorly drained' (gley) soil	15	35-50	70
	1.iv	Till overlain by 'well drained' soil	45	50-70	80
	1.v	Till overlain by 'poorly drained' (gley) soil	5	15-30	50
	1.vi	Sand/ gravel aquifer where the water table is ≤ 3 m below surface	50	80-90	100
	1.vii	Peat	1	15-30	50
High (H)	2.i	Sand/gravel aquifer, overlain by 'well drained' soil	50	80-90	100
	2.ii	High permeability subsoil (sand/gravel) overlain by 'well drained' soil	50	80-90	100
	2.iii	High permeability subsoil (sand/gravel) overlain by 'poorly drained' soil	15	35-50	70
	2.iv	Sand/gravel aquifer, overlain by 'poorly drained' soil	15	35-50	70
	2.v	Moderate permeability subsoil overlain by 'well drained' soil	35	50-70	80
	2.vi	Moderate permeability subsoil overlain by 'poorly drained' (gley) soil	10	15-30	50
	2.vii	Low permeability subsoil	1	20-30	40
	2.viii	Peat	1	5-15	20
Moderate (M)	3.i	Moderate permeability subsoil and overlain by 'well drained' soil	35	50-70	80
	3.ii	Moderate permeability subsoil and overlain by 'poorly drained' (gley) soil	10	15-30	50
	3.iii	Low permeability subsoil	1	10-20	30
	3.iv	Peat	1	3-5	10
Low (L)	4.i	Low permeability subsoil	1	5-10	20
	4.ii	Basin peat	1	3-5	10

Note: Areas of 'made ground' are assigned a recharge coefficient of 20%.

APPENDIX 5

Hydrochemistry and Water Quality of Raw Water

(including excerpt from GSI report on Toberfin by Kelly, 2001)

Raw Water Data, Toberfin Springs, June 2016

Parameter	Toberfin Spring	Units	Drinking Water Limit (DWL) or Threshold Value (TV)
BOD	<1	mg/l	
Turbidity	0.02	N.T.U.	No abnormal change
pH	6.9	pH units	6.5 – 9.5
Conductivity @ 20C	698	µS/cm	800 (TV)
Alkalinity	375.06	mg/l $CaCO_3$	
Sodium	8.09	mg/l	150 (TV)
Chloride	12.48	mg/l	24
Ammonium NH_4	0.03	mg/l NH_4	0.3 (DWL)
Nitrate as NO_3	18.30	mg/l	37.5 (TV)
Nitrite as NO_2	<0.03	mg/l	0.5 (TV)
Dissolved Oxygen (%)	4.85	%Sat	
Total Hardness (Kone)	403	mg/l $CaCO_3$	
Magnesium, total	10.9	mg/l	50 (DWL)
Colour, apparent	<1.0	mg/l Pt Co	No abnormal change
Silica as SiO_2	5.96	mg/l	
Sulphate	16.84	mg/l	187.5 (TV)
Orthophosphate as PO4-P	0.01	mg/l	
Calcium, total	143.4	mg/l	
Aluminium, dissolved	26	µg/l	150 (TV)
Iron	<20	µg/l	200 (DWL)
Potassium	2.47	mg/l	
Manganese, dissolved	<5	µg/l	<50 (DWL)
Copper, dissolved	<10	µg/l	1500 (TV)
Lead, dissolved	<1	µg/l	10 (DWL)
Chromium, dissolved	<5	µg/l	37.5 (TV)
Nickel, dissolved	<2	µg/l	15 (TV)
Cadmium, dissolved	<0.5	µg/l	3.75 (TV)
Arsenic, dissolved	<10	µg/l	7.5 (TV)
Zinc, dissolved	13	µg/l	
Barium, dissolved	65	µg/l	
Total Organic Carbon	1.3	mg/l	No abnormal change
Clostridium Perfringens	0	cfu/100ml	0
Strontium, dissolved	438	µg/l	
E Coli	**6.4**	cfu/100ml	0
Total Coliforms	**23.8**	cfu/100ml	0
Fluoride	0.12	mg/l	0.8 (DWL)
UV Transmittance	94.4	µg/l	

From Killeigh and Meelaghans Group Water Schemes: Toberfin Springs Groundwater Source Protection Zones (Kelly, 2001), Geological Survey of Ireland/Offaly Co Co.

7.6 Hydrochemistry and Water Quality

The hydrochemical analyses show that the Toberfin spring water is a hard to a very hard water with alkalinity values of 292-344 mg l^{-1}, total hardness values of 288-457 mg l^{-1} (equivalent $CaCO_3$) and electrical conductivity values of 579-820 µS cm^{-1}, indicating that the groundwater has a hydrochemical signature of calcium bicarbonate type water. These values are typical of groundwaters from limestone rocks. Table 1 shows summary statistics of electrical conductivity (EC). Electrical Conductivity values are high and the current data set shows a unimodal tendency. The coefficient of variation of conductivity is 7.7% which indicates that diffuse recharge is the dominant type of recharge (Doak, 1995), but also, that there is an element of point recharge picked up by the springs, and this is likely to be recharge from the swallow hole.

Table 1 Summary Statistics for Electrical Conductivity (EC).

Parameter	*Value (µS cm^{-1})*
Average	696
Max.	820
Min.	579
Standard Deviation	54
Coefficient of variation of Standard Deviation. of Electrical Conductivity	7.7%
Sample Number	26

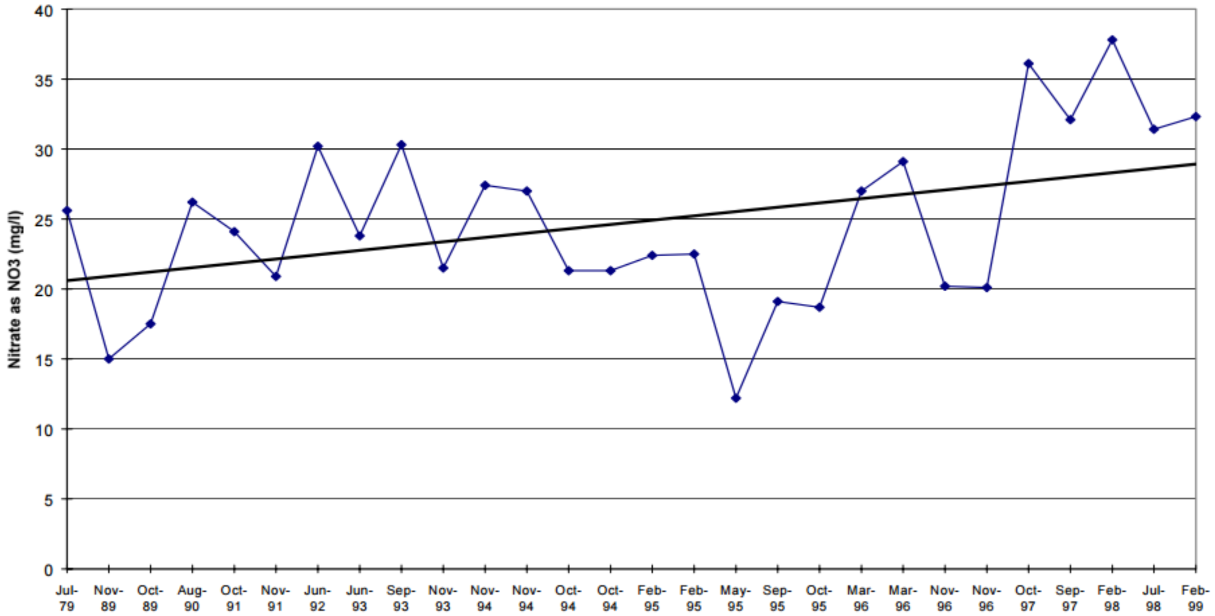
The pH of the groundwater is generally slightly alkaline (a mean of 7.2) and on three occasions has been recorded as being slightly acidic (Oct. 1994-6.8; Mar. 1996-6.9; Aug. 1981-6.8). The underlying bedrock is a muddy limestone, which sometimes results in higher levels of iron in groundwaters in other parts of Offaly, for example in Ferbane and Gallen (Cronin *et al*, 1999). However, levels of iron in Toberfin springs are generally low (< 0.02 mg l^{-1}) with occasional peaks (1989, 0.11 mg l^{-1}), which seem to be coincident with pollution events and which may signify temporary oxygen deficient conditions allowing iron to be brought into solution. The hydrochemical analyses do not distinguish between the different springs.

The water quality analyses show that a number of parameters have exceeded the EU Drinking Water Directive maximum admissible concentrations (MAC). Colour, turbidity, ammonia, total coliforms, faecal coliforms, *E. Coli* counts and oxidisibility have all exceeded the EC Drinking Water Directive MAC. Anecdotal evidence from the caretaker's observations indicate that whenever the main springs have been polluted to the degree that the water is green that Spring No. 4 never goes green. *E. Coli* counts regularly exceed the EU MAC.

Nitrate concentrations to date have not exceeded the EU MAC; values range between 12.2 to 37.8 mg l^{-1} with a mean of 25 mg l^{-1}. Nitrate levels were consistently between 15 and 30 mg l^{-1} throughout the data set until November 1996. Since October 1997 the levels of nitrate are higher, varying from 32.1-37.8 mg l^{-1}. It is possible that a change in landuse practise in 1997 has caused this general increase in nitrate levels. A plot of nitrate levels is given in Appendix 2.

Chloride levels range from 19 to 33 mg l^{-1}, with a mean of 24 mg l^{-1}, which are higher than typical background levels (12-15 mg l^{-1}).

Sodium levels are inside the normal range of 5-15 mg l^{-1}. Potassium levels generally lie in the range of 2.5 to 3.0 mg l^{-1}, except on one occasion (July'98) when it was 7.5 mg l^{-1}. The ratio of potassium to sodium (K:Na), may indicate contamination if the ratio is >0.4. Generally the ratio lies in the range of 0.28 to 0.30. However, in July'98 the ratio was 0.79 (due to the high potassium level) and on that date chlorides and nitrates are 24 mg l^{-1} and 34 mg l^{-1} respectively. The high level of potassium causing this high ratio suggests contamination from farmyard wastes.



APPENDIX 2 GRAPH OF NITRATES AT TOBERFIN SPRINGS, KILLEIGH.

The graph above shows historical nitrate concentrations recorded at Toberfin springs (Kelly, 2001). The most recent sample, taken in June 2016, showed a significant reduction, at 18.3 mg/l.

Killeigh and Meelaghans Group Water Schemes

Toberfin Springs

Groundwater Source Protection Zones

(April 2001)

Prepared by:
Coran Kelly
Geological Survey of Ireland

In collaboration with:

Offaly County Council

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1. Introduction

The Groundwater Section, Geological Survey of Ireland, have prepared this report at the request of Offaly County Council.

Toberfin springs provides most of the water for the Killeigh Group Water Scheme and all of the water for the Meelaghans Group Water Scheme.

The objectives of the report are as follows:

- To delineate source protection zones for Toberfin spring.
- To outline the principle hydrogeological characteristics of the Killeigh area.
- To assist Offaly County Council in protecting the water supply from contamination.

2. Location, Site Description and Well Head Protection

Toberfin springs are located four kilometres north east of Killeigh village just south of the main Tullamore-Portarlington road (R420).

Toberfin springs comprise a number of springs and there are four large diameter, sixteen foot deep sumps installed to allow collection of the water. An important feature of the springs is that one of the springs is at a lower elevation (1.5m lower) than the main springs. This spring will be referred to as Spring No. 4.

The site area is closed off with a fence. The four sumps are covered. Surrounding the sumps is a narrow band of gravel fill. The rest of the site is grassed over. The pipes from the sumps leading to the pumphouses are galvanised and lagged.

3. Summary of Well / Spring Details

GSI no.	:	2321NWW006
Grid ref. (1:25,000)	:	N 23959 22131
Townland	:	Newtown
Well type	:	Spring
Owner	:	Killeigh (KGWS) and Meelaghans Group Water Schemes (MGWS)
Elevation (ground level)	:	71 m OD (233 feet OD)
Depth & Diameter of sumps	:	4.8 m x 1m (16 feet x 3.3 feet)
Depth to rock	:	~ 8 m (26 feet)
Potentiometric surface	:	At or more likely to be above ground level
Normal Abstraction	:	KGWS: 1182-1245 $m^3 d^{-1}$ (~260,000-274,000 gal d^{-1})
	:	MGWS: 87-117 $m^3 d^{-1}$ (~19,000-26,000 gal d^{-1})
Estimated Total Discharge	:	1445 $m^3 d^{-1}$ (~318,000 gal d^{-1})

4. Methodology

The assessment involved three stages: (a) a desk study; (b) site visits and fieldwork; and (c) analysis of the data.

The desk study was conducted in the Geological Survey: details about the group schemes and springs such as elevation, and abstraction figures were obtained from GSI records and County Council personnel; geological and hydrogeological information was provided by the Groundwater Protection Scheme (Daly et al, 1998).

The second stage comprised site visits and fieldwork in the Killeigh area. This included carrying out spring overflow measurements, depth to rock drilling and subsoil sampling. Field walkovers were also carried out to investigate the subsoil geology, the hydrogeology and vulnerability to contamination.

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

5. Topography, Surface Hydrology and Land Use

Toberfin springs emerge at about 71m OD (233 ft). The topography surrounding the springs is generally flat with an east-west trending ridge (116m OD) occurring about one and half kilometres to the south. The land slopes steeply around the hill itself, then gently toward the spring and then on down towards the Tullamore river.

Toberfin springs occur in the Toberfin river catchment which is a subcatchment of the Tullamore river. The Toberfin river flows in northerly direction until it meets the Tullamore river. In general, all the area around the springs drains to the north in a series of streams that meet the Tullamore river. The land is generally well drained except around the spring itself where it is boggy.

Agricultural activity dominates the area with most of the land used for grassland. A number of houses and farmyards are present in the vicinity of the springs.

6. Geology

6.1 Introduction

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

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

- County Offaly Groundwater Protection Scheme (Daly *et al*, 1998)
- Information from geological mapping in the nineteenth century (on record at the GSI).

Subsoils information was taken from the Offaly Groundwater Protection Scheme (Daly *et al*, 1998) and gathered from a drilling programme that was undertaken by GSI personnel to investigate the subsoils of the area.

6.2 Bedrock Geology

The area is underlain by Calp Limestone; a dark grey bedded, fine grained, muddy limestone.

Movements in the earth's crust have caused the rocks to be folded, faulted and jointed. The rock unit has a NE-SW trend or strike and dips either north-westwards at a low angle. Two major fault sets are present — NE-SW and SE-NW. The joint pattern is likely to have similar orientations. There are two mapped faults in the region and there are probably other faults that haven’t been noted because of the lack of outcrop in the area.

The location and size of the springs in an area of flat topography also indicates the probable presence of a large fracture network in the locality (see section 0) and so, the structure is an important element of geology as it most likely to influence the emergence of the springs at this locality.

6.3 Subsoil (Quaternary) Geology

6.3.1 Introduction

The subsoils comprise a mixture of coarse and fine grained materials, namely; alluvium, peat, tills and gravels and are influenced by the underlying bedrock, which in the area is primarily the Calp limestone. The muddy, dark nature of this rock type in this part of Offaly could mean that the subsoils will have proportionally higher percentages of fine grained material than subsoils produced over bedrock of a 'cleaner' nature. The gravel sized component (2-60 mm) are dominated by limestone fragments, mostly angular to subangular. The logs of the auger holes drilled are given in Appendix 1.

The characteristics of each category are described briefly below:

6.3.2 Peat

This material occurs in the low-lying area around the springs themselves. The borehole records indicate that the peat is quite a substantial layer. The peat can be seen in stream cuttings next to the springs.

6.3.3 River Alluvium

This material occupies the vicinity of the springs themselves. The alluvium is a fine grained, grey blue deposit (BS5930: CLAY). The borehole records indicate that the alluvium is up to 3m thick in the vicinity of the springs. The alluvium can be seen in stream cuttings next to the springs.

6.3.4 Tills

This is the dominant subsoil type in the area. 'Till' is an unsorted mixture of coarse and fine materials laid down by ice. Angular limestone fragments are abundant in the tills. The matrix is composed primarily of silty SANDS, silty GRAVELS and clayey SILT with gravels. See Appendix 1 for further details.

6.3.5 Depth to Bedrock

A drilling programme was carried out to ascertain the depth, thickness and permeability of the subsoils. Using this information and knowledge of sites that have rock cropping out, the depth to rock is estimated across the area. The borehole locations are given in Figure 1. The depth to bedrock is variable (0-10m), with the lower lying areas around the springs having the thickest subsoil cover (8-10m) and the higher ground of the catchment to the south and south west has rock close to the surface, having thinner subsoil cover (0-3m).

7. Hydrogeology

7.1 Introduction

This section presents our current understanding of groundwater flow in the vicinity of the Toberfin source. The interpretations and conceptualisations of flow are used to delineate source protection zones around the spring.

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

- Offaly Groundwater Protection Scheme (Daly *et al* 1998).
- An Assessment of the Quality of Public and Group Scheme Groundwater Supplies in County Offaly, (Cronin *et al*, 1999).
- GSI files. Archival Offaly County Council data for the years 1977, 1989, 1991. C1–C2 type

parameters.
- Offaly County Council annual drinking water returns 1992–1999 inclusive (C1, C2, C3 and C4 type parameters). Some raw water analyses were also carried out.
- Limited additional fieldwork.

7.2 Meteorology 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 generally assumed to consist of an input (i.e. annual rainfall) less water losses 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 (i.e. the outer source protection area).

In areas where point recharge from sinking streams, etc., is discounted, the main parameters involved in recharge rate estimation are annual rainfall, annual evapotranspiration, and annual runoff and are listed as follows:

- Annual rainfall: 825 mm. Rainfall data for the area are taken from a contoured rainfall map of Co. Offaly, which is based on data from Met Éireann.
- Annual evapotranspiration losses: 431 mm. Potential evaporation (P.E.) is estimated to be 454 mm $yr.^{-1}$ (from Met Éireann data). Actual evapotranspiration (A.E.) is then estimated as 95 % of P.E.
- Potential recharge: 394 mm $yr.^{-1}$. This figure is a calculation 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 lateral soil quickflow and overland flow direct to surface water.
- Annual runoff losses: 99 mm. This estimation is based on the assumption that 25% of the potential recharge will be lost to overland flow and shallow soil quickflow prior to reaching the main groundwater system (Flow in the Toberfin stream needs to be measured to determine the accuracy of this estimate).

These calculations are summarised below:

Average annual rainfall (R)	825 mm
Estimated A.E.	431 mm
Potential Recharge (R – A.E.)	394 mm
Runoff losses	99 mm
Estimated Actual Recharge	295 mm

This is an estimation of recharge which allows for surface water outflow, particularly during periods of heavy rainfall.

7.3 Groundwater Levels, Flow Directions and Gradients

- There is no water level data for the area south of the springs.
- At the springs the water level (the potentiometric surface[1]) is at or more likely to be above the ground level.
- There is a swallow hole in the catchment (which has been traced to the springs) where an ephemeral stream sinks, a short distance away this stream rises again (Toberfin river) where it flows past the springs. This sinking/rising stream may also indicate shallow groundwater levels in the catchment.
- An important feature of the springs is the lower elevation of Spring No. 4. This suggests that this spring which is 35m distant from the main springs is not hydraulically connected.

[1]An imaginary surface that represents the head of groundwater in a confined aquifer that is defined by the level to which water will rise in a well.

- The water table in the area is generally assumed to be a subdued reflection of topography; as the topography slopes northwards, the water table slopes northwards toward the springs. The dominant driving head are the hills east of Killeigh village. The flow directions will be perpendicular to the contour lines. In simple terms, rainfall reaching the water table anywhere in the catchment of the springs will flow in a northerly and north-easterly direction toward the springs.
- The groundwater gradient is assumed to somewhat less than the topographic gradient, i.e. is estimated as 0.01.

7.4 Aquifer Characteristics

The Calp unit provides the groundwater to the Toberfin source. The muddy nature of the unit suggests generally poor potential for water storage and abstraction, however, the Toberfin springs are a high yielding source of water - the discharge being an order of magnitude higher than any other source located in the Calp in Offaly (Offaly Groundwater Protection Scheme, Daly *et al*, 1998).

A large fracture network probably underlies the source and causes the water to concentrate in this area.

It is possible that the Calp in this locality is cleaner and more permeable than normal. The evidence of this is discussed as follows:

1. 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. It generally occurs in 'cleaner' limestones. Evidence of some karstification has been found in the Calp Limestone in the Killeigh area in the form of a small swallow hole, shown in Figure 1. At higher stream flows the swallow hole cannot take all the flow. This karst conduit may be present at shallow depth in the epikarst (uppermost part of the karst aquifer).

2. Apart from the Toberfin stream and the drains in immediate vicinity of the springs there is a paucity of surface streams in the catchment, suggesting the Calp has higher a permeability in this locality. To the south of Finter House (outside the catchment to the springs), there are streams and boggy ground even though this area is at a much higher elevation than the area in the catchment to the springs. This would suggest that the Calp to the south of Finter House is of lower permeability than the Calp between Finter House and the springs.

General aquifer parameters, such as permeability and porosity for the Calp in this locality are based on evaluation of data for the Calp in other areas and of rocks that are generally more permeable than the Calp. Estimates for these parameters are as follows:

Permeability ~ 10 m d^{-1};
Porosity ~ 1.5 %.

These values give velocities of 6.7 m d^{-1}, and so it is assumed that for a 100 day time of travel, groundwater would travel 670 m, using a hydraulic gradient of 0.01.

7.5 Aquifer Category

The Calp limestone has a wide variation in hydrogeological characteristics across the country. The Calp limestone is described in County Offaly as a Locally Important aquifer which is moderately productive only in local zones **(Ll)** (Daly et al, 1998).

7.6 Hydrochemistry and Water Quality

The hydrochemical analyses show that the Toberfin spring water is a hard to a very hard water with alkalinity values of 292-344 mg l^{-1}, total hardness values of 288-457 mg l^{-1} (equivalent $CaCO_3$) and electrical conductivity values of 579-820 µS cm^{-1}, indicating that the groundwater has a hydrochemical signature of calcium bicarbonate type water. These values are typical of groundwaters from limestone rocks. Table 1 shows summary statistics of electrical conductivity (EC). Electrical Conductivity values are high and the current data set shows a unimodal tendency. The coefficient of variation of conductivity is 7.7% which indicates that diffuse recharge is the dominant type of recharge (Doak, 1995), but also, that there is an element of point recharge picked up by the springs, and this is likely to be recharge from the swallow hole.

Table 1 Summary Statistics for Electrical Conductivity (EC).

Parameter	*Value ($\mu S\ cm^{-1}$)*
Average	696
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Min.	579
Standard Deviation	54
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Sample Number	26

The pH of the groundwater is generally slightly alkaline (a mean of 7.2) and on three occasions has been recorded as being slightly acidic (Oct. 1994-6.8; Mar. 1996-6.9; Aug. 1981-6.8). The underlying bedrock is a muddy limestone, which sometimes results in higher levels of iron in groundwaters in other parts of Offaly, for example in Ferbane and Gallen (Cronin *et al*, 1999). However, levels of iron in Toberfin springs are generally low (< 0.02 mg l^{-1}) with occasional peaks (1989, 0.11 mg l^{-1}), which seem to be coincident with pollution events and which may signify temporary oxygen deficient conditions allowing iron to be brought into solution. The hydrochemical analyses do not distinguish between the different springs.

The water quality analyses show that a number of parameters have exceeded the EU Drinking Water Directive maximum admissible concentrations (MAC). Colour, turbidity, ammonia, total coliforms, faecal coliforms, *E. Coli* counts and oxidisibility have all exceeded the EC Drinking Water Directive MAC. Anecdotal evidence from the caretaker's observations indicate that whenever the main springs have been polluted to the degree that the water is green that Spring No. 4 never goes green. *E. Coli* counts regularly exceed the EU MAC.

Nitrate concentrations to date have not exceeded the EU MAC; values range between 12.2 to 37.8 mg l^{-1} with a mean of 25 mg l^{-1}. Nitrate levels were consistently between 15 and 30 mg l^{-1} throughout the data set until November 1996. Since October 1997 the levels of nitrate are higher, varying from 32.1-37.8 mg l^{-1}. It is possible that a change in landuse practise in 1997 has caused this general increase in nitrate levels. A plot of nitrate levels is given in Appendix 2.

Chloride levels range from 19 to 33 mg l^{-1}, with a mean of 24 mg l^{-1}, which are higher than typical background levels (12-15 mg l^{-1}).

Sodium levels are inside the normal range of 5-15 mg l^{-1}. Potassium levels generally lie in the range of 2.5 to 3.0 mg l^{-1}, except on one occasion (July'98) when it was 7.5 mg l^{-1}. The ratio of potassium to sodium (K:Na), may indicate contamination if the ratio is >0.4. Generally the ratio lies in the range of 0.28 to 0.30. However, in July'98 the ratio was 0.79 (due to the high potassium level) and on that date chlorides and nitrates are 24 mg l^{-1} and 34 mg l^{-1} respectively. The high level of potassium causing this high ratio suggests contamination from farmyard wastes.

7.7 Spring Discharge

The total discharge at the springs is difficult to measure accurately. There have been several estimates of the total yield and these are summarised in Table 2.

Table 2 Estimates of Spring Discharge at Toberfin, Killeigh.

Date	*Source*	*Estimate type (m^3 d^{-1})*	*Discharge*
June 1999	GWS	Abstraction (MGWS 87 + KGWS 1182)	1269 m^3 d^{-1}
July 1999	GSI & GWS	Overflow + abstraction (83+1360)	1443 m^3 d^{-1}
November 1999	GSI	Overflow + abstraction (950 *(overflow figure)* + 87) Killeigh pumps off at time of measurement.	1037 m^3 d^{-1}
December 1999	GWS	Overflow (all pumps off) Main spring: 981, Spring 4: 354	1335 m^3 d^{-1}

The differences in these estimates is that in the first estimate does not take account of the overflow; the second estimate of discharge took account of the overflow and both pumps were pumping at the time of measurement; and the third estimate took account of overflow but only one set of pumps was operating at the time of measurement. The last estimate is an underestimate as when the pumps switched off there is a lag time before the overflow discharge reaches its natural rate and in this instance the water level in the sump was rising slowly and so the overflow measurement taken is an underestimate.

There is evidence given earlier to suggest that Spring No. 4 isn't hydraulically connected to the main spring system. Table 3 shows overflow figures from the springs, and shows that the overflow is greater in the main spring system, which is at a higher elevation than Spring No. 4. If the springs were connected hydraulically then the overflow would be greater at Spring No. 4 because of its' lower elevation.

Table 3 Overflows from the Toberfin Springs, Killeigh.

Date	Main Springs (m^3 d^{-1})	Spring No. 4 (m^3 d^{-1})
July 99	52	31
November 99	605	345
December 99	981	354

7.8 Conceptual Model

- Groundwater discharges at Toberfin Springs at up to 1445 m^3 d^{-1}. The source of groundwater is the Calp Limestone. The groundwater regime in the area is complex and the available hydrogeological information does not allow a definitive understanding of the hydrogeology.
- The spring system emerges over a small area (50m X 20m) yet one of the springs (No. 4) does not appear to be hydraulically connected to the main spring system. The evidence for this is as follows:
    1) the elevation of the main spring system is higher (1.5 m) than the elevation of Spring No. 4 and this is a significant head difference over such a short distance (35m);
    2) the tracer test carried out by the County Council links the swallow hole directly to the main system but not to Spring No. 4;
    3) overflow measurements are consistently higher for the main spring system than for spring No. 4; and
    4) according to the caretaker, after a pollution incident the water often goes green in the main springs but the colour of the springs in Spring No. 4 remains the same.
- The groundwater system in the vicinity of the springs is confined by thick fine grained subsoils.
- It is possible that a fracture system associated with a fault is causing the groundwater to focus in this area. A "window" in the subsoils, perhaps due to the presence of a localised sand/gravel unit, may have allowed the spring water to emerge from the underground system at the springs.
- The hydrochemistry shows that the groundwater is hosted in limestone but the variation in the

electrical conductivity shows some groundwater has reached the springs via a shorter pathway, and so does not reside in the limestones for long enough time to acquire the same chemical signature as the main bulk of the groundwater emerging at the springs.

- The limestone in the catchment has undergone some degree of karstification, indicated by the swallow hole. Groundwater entering this swallow hole has been traced to the springs, which would have higher velocities than the main bulk of groundwater reaching the springs. However, karstification is not well developed.
- There are very few surface streams in the catchment except for the Toberfin river and a network of surface drains around the springs. This indicates that the Calp Limestone in this area probably has a higher permeability than the Calp outside the catchment.
- Groundwater flow is likely to flow through interconnected, possibly solutionally enlarged fracture zones and along fractures and joints outside the main fracture systems. The trace from the swallow hole to the spring probably highlights one of the large fractures. The precise path between the swallow hole and the spring is not known. However, if a line is drawn from the swallow hole to the spring (parallel to the regional fault strike) then it is likely that the pathway will be close to that line.
- Recharge to the groundwater system is predominantly diffuse recharge. Point recharge occurs at the swallow hole. The recharge via this pathway is picked up by the variation of electrical conductivity.

8. Delineation Of Source Protection Areas

8.1 Introduction

This section delineates the areas around the well that are believed to contribute groundwater to the well, and that therefore require protection. The areas are delineated on the basis of the conceptualisation of the groundwater flow pattern, and are presented in Figures 1 and 2.

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) of the well.

8.2 Outer Protection Area

The Outer Protection Area (SO) is bounded by the complete catchment area to the source, i.e. the zone of contribution (ZOC), and is defined as the area required to support an abstraction from long-term recharge. The ZOC is controlled primarily by a) the total discharge, b) the groundwater flow direction and gradient, c) the rock permeability and d) the recharge in the area. There are three effective methods for delineating catchment areas of springs (USEPA, 1996):

- ♦ tracer testing;
- ♦ hydrogeological mapping and
- ♦ water balance estimations.

A tracer test was carried out by the council which links the swallow hole in the western part of the catchment directly to the spring.

The shape and boundaries of the ZOC were determined using hydrogeological mapping and the conceptual model. The ZOC catchment boundaries are as follows:

1. The **Northern Boundary** is constrained by the location of the springs themselves in relation to the Toberfin river which flows past the springs on the northern side. Groundwater to the north of the springs cannot flow to the springs as the groundwater is downgradient on the northern side of the

springs. An arbitrary buffer of 30 m is placed on the downgradient side of the lower spring (Spring No. 4).

2. The **Eastern Boundary** is defined by a topographic ridge which runs north west to south east before swinging north east to south west on the east side of the springs creating a surface watershed and a probable groundwater divide between water flowing north-east to an unnamed stream[2] (a tributary of the Toberfin, rising in the townland of Danganbeg) and water flowing toward the springs and the Toberfin river. The point at which this divide changes its orientation is on the roadside at Newtown House.

3. The **Southern Boundary** is constrained by a watershed divide to south, created by the high ground which lies in the townland of Finter. The aspects of the slopes in this area change subtly and frequently thus proving difficult to pinpoint precisely the divide even with the use of aerial photographs. The area just to the north of Finter House may be within the ZOC but it is unclear where the surface outlet is and so may provide additional water to the springs.

4. The **Western Boundary** is topographically constrained and in addition water tracing has helped to prove this boundary. A catchment divide exists along the western boundary with water flowing north-west towards toward Kileenmore and water flowing north-east toward the springs. Water tracing has proved a positive link between the swallow hole and the springs. Slopes are subtle in this area and are gently lying with difficult breaks in slope to map.

These boundaries delineate the physical limits within which the ZOC is likely to occur. The area constrained by the hydrogeological mapping is 2.0 km^2.

A water balance is then carried out to estimate the areal extent of the catchment providing the water to the springs and the resulting area is compared to that delineated by mapping. Table 4 shows the results of the water balance and the various estimates of the ZOC according to the discharge. A water balance is carried out by using an estimated recharge value and the discharge estimates.

Table 4 Water balance calculations at Toberfin Springs.

Discharge (m^3 d^{-1})	Recharge (mm yr.$^{-1}$)	Area (ZOC) (km^2)
1443	295	1.8
1037	295	1.3
1269	295	1.6
1335	295	1.7

The water balance indicates that the largest estimated discharge requires an area of 1.8 km^2. The results suggest that the boundaries as defined by the hydrogeological mapping and the conceptualisation processes are slightly conservative, however, the largest discharge is a summer time record and an accurate corresponding winter would be higher and would probably correspond to the area delineated by the mapping.

8.3 Inner Protection Area

The Inner Protection Area (SI) is the area defined by a 100 day time of travel (ToT) to the source and it 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 microbial contamination. Estimations of the extent of this area cannot be made by hydrogeological mapping and conceptualisation methods

[2]There is a difference in the naming of the two streams on either side of the springs. The 6” maps indicate the stream rising and flowing past the springs on the north side as being the Toberfin. The Discovery maps indicate the stream flowing on the east side of the springs as being the Toberfin river. The report refers to the streams in accordance to the 6” maps.

alone. Analytical modelling is also used and by using the aquifer parameters for permeability and hydraulic gradient 100 day ToT estimations are made.

The swallow hole and the associated pathway to the springs complicates the delineation of the inner protection area. It is known that water getting into the swallow hole can reach the springs in a number of hours, i.e. far less than the 100 day ToT. Although there is no direct evidence, it is assumed that this highly permeable pathway can draw water in from the surrounding bedrock and then transmit it rapidly to the springs. The precise location of this pathway between the swallow hole and spring is not known; however it may not be direct as shown in Figure 1. In order to allow for variations in the direction of the pathway, an arbitrary buffer with a width of 100m each side of the shortest possible pathway is taken to include the pathway.

It is likely that a pollutant gaining access to the surface water course upstream of the swallow hole could reach the springs within 100 days and therefore it is included in the Inner Protection Area. A 30 m buffer zone is added to the water channel boundary as a precautionary measure.

9. Vulnerability

The distribution of interpreted groundwater vulnerability in the ZOC is presented in Figure 1. The distribution of the extremely vulnerable zones are those areas to the south of the catchment where depth to rock is less than 3m. It also includes the area around the swallow hole. The highly vulnerable areas occur in the middle of the catchment where the depth to rock is between 3 and 10 m and the permeability is in the moderate range. The moderately vulnerable area is the area around the spring where there are low permeable materials but the depth to rock is still less than 10m. The southern boundary of this zone is marked close to the final change in slope before the springs where there is a thinning of subsoil cover and a change in subsoil type from peat/alluvium/till to till.

As some surface water flowing into the swallow hole is connected to the springs via, an area of 'Extreme' vulnerability is delineated along the surface water channel throughout the catchment as a means of indicating the threat to the source from surface runoff of contaminants into streams. This area also comprises an arbitrary 10 m buffer zone added to the normal water channel boundary.

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 the matrix in the table below). In practice, the source protection zones are obtained by superimposing the vulnerability map on the source protection area map. Each zone is represented by a code e.g. **SI/H**, which represents an Inner Protection area where the groundwater is highly vulnerable to contamination. There are 5 groundwater protection zones present around the Toberfin Source as shown in Table 5. The final groundwater protection map is presented in Figure 2.

Table 5 Matrix of Source Protection Zones for Toberfin Springs, Killeigh.

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

It is not within the scope of this report to delineate the resource protection zones in the surrounding area and this is dealt with at the regional resource protection scale. For further details refer to Groundwater Protection Scheme for County Offaly (Daly et al, 1998).

11. Potential Pollution Sources

The land in the vicinity of the source is largely grassland-dominated and is primarily used for grazing. Agriculture is the principal activity in the Killeigh area. The main potential sources of pollution within the ZOC are farmyards, septic tank systems and landspreading of organic fertilisers. There is also a creamery in the zone of contribution to the springs. The main potential pollutants are faecal bacteria, viruses and cryptosporidium.

12. Conclusions and Recommendations

- The source at Killeigh is an excellent yielding spring supply, which is located in the Calp Limestone, classified a Locally Important aquifer **(Ll)**.

- Parts of the area around the supply are extremely vulnerable to contamination, most of the area is highly vulnerable and the area around the springs is classed as moderately vulnerable.

- The sinking stream poses a major threat to the springs, consequently, great care is recommended when considering potentially polluting activities in the vicinity of this stream, in particular housing, landspreading and road runoff.

- It is recommended that:

1) a full chemical and bacteriological analysis of the **raw** water should be carried out on a regular basis at all the springs.
2) particular care should be taken when assessing the location of any activities or developments which might cause contamination at the GWS.
3) the potential hazards in the ZOC should be located and assessed.

- The protection zone delineated in the report is based on our current understanding of groundwater conditions and on the available data. Due to the hydrogeological complexity of the area, there is relatively high level uncertainty regarding some of the boundaries. Additional data obtained in the future may indicate that amendments to the boundaries are necessary.

- A more definitive understanding of the hydrogeology would require a site investigation that would include drilling and geophysics.

13. References

Cronin, C. and Daly, D., 1999. *An Assessment of the Quality of Public and Group Scheme Groundwater Supplies in County Offaly*. Geological Survey Report, 30 pp.

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Doak, M., 1995. *The Vulnerability to pollution and hydrochemical variation of eleven springs (catchments) in the karst lowlands of the west of Ireland*. M Sc. Thesis, Sligo RTC, 52 pp.

Thorn, R., 1994. STRIDE project report, DoE.

US Environmental Protection Agency. (1996) *Guidelines for Wellhead and Springhead Protection Area Delineation in Carbonate Rocks*. Prepared for the agency by Eckenfelder Inc., Tennessee.

APPENDIX 1 LOGS OF THE AUGER BOREHOLES

All borehole depths are maximum depths drilled by the auger. The depths are the depth at which the auger would not go any further. It assumed that the auger has reached bedrock, the evidence being that in most cases floured bedrock is recovered on the teeth of the auger.

Killeigh No. 1

Depth (m)	Subsoil	BS 5930	Permeability
0-3.5	Peat	silty CLAY	LOW
3.5-6.5	Alluvium	CLAY	LOW
6.5-8.2	Till	clayey SILT	MODERATE

Killeigh No. 2

Depth (m)	Subsoil	BS 5930	Permeability
0-1.0	Peat	silty CLAY	LOW
1.0-3.7	Alluvium	CLAY	LOW
3.7-10.5	no returns,	CLAY?	LOW

Killeigh No. 3

Depth (m)	Subsoil	BS 5930	Permeability
0-0.5	Top Soil	SILT	MODERATE
0.5-2.0	Till	sandy SILT with clay	MODERATE
2.0-3.0	Till	silty SAND	HIGH
3.0-4.0	Till	silty GRAVEL	HIGH
4.0-6.3	Till	clayey SILT with gravel	MODERATE

Killeigh No. 4

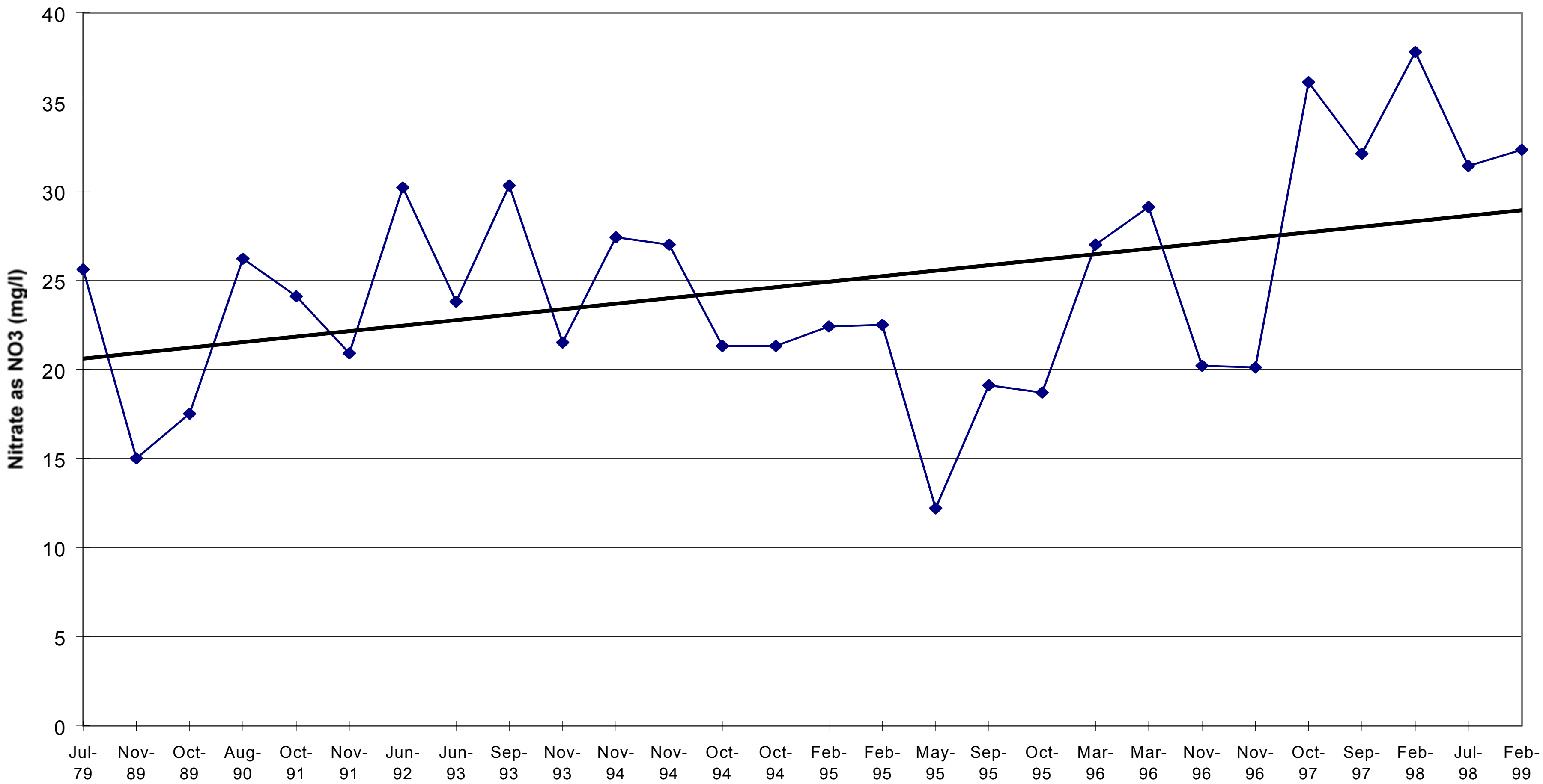
Depth (m)	Subsoil	BS 5930	Permeability
0-0.5	Top Soil	SILT	MODERATE
0.5-1.5	Till	silty GRAVEL	HIGH
1.5-2.5	Till	silty SAND	HIGH
2.5-3.0	Till	silty GRAVEL	HIGH
3.0-4.0	Till	clayey SILT with gravel	MODERATE

Killeigh No. 5

Depth (m)	Subsoil	BS 5930	Permeability
0-0.5	Top Soil	SILT	MODERATE
0.5-2.0	Till	silty SAND with Gravel	HIGH
2.0-3.0	Till	silty SAND with gravel	HIGH
3.0-4.0	Till	clayey SILT with gravel	MODERATE

Killeigh No. 6

Depth (m)	Subsoil	BS 5930	Permeability
0-0.3	Top Soil	SILT	MODERATE
0.3-1.5	Till	sandy SILT with gravel	HIGH
1.5-2.7	Till	sandy GRAVEL	HIGH



APPENDIX 2 GRAPH OF NITRATES AT TOBERFIN SPRINGS, KILLEIGH.

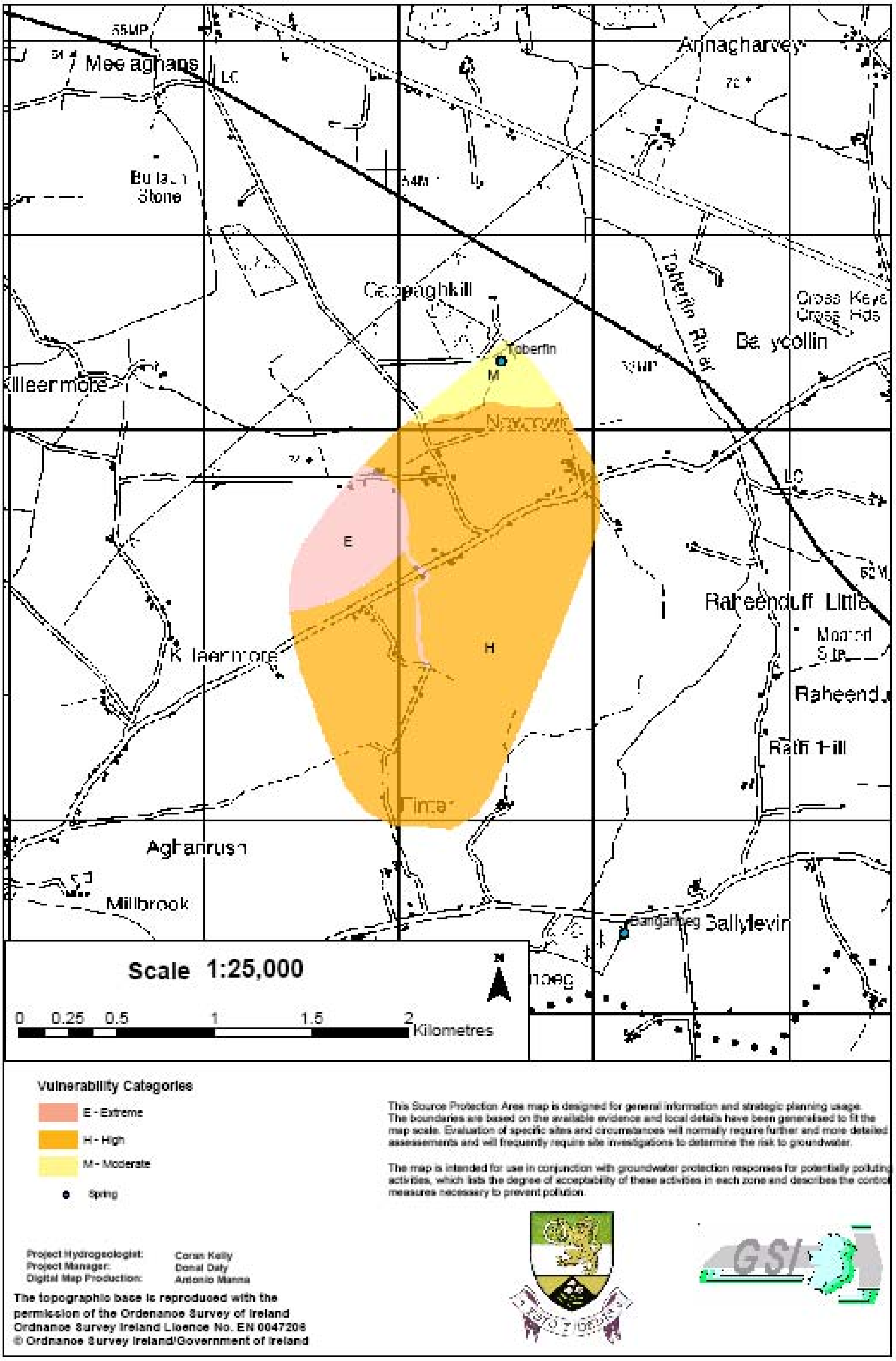


Figure 1 **Groundwater Vulnerability around Toberfin**

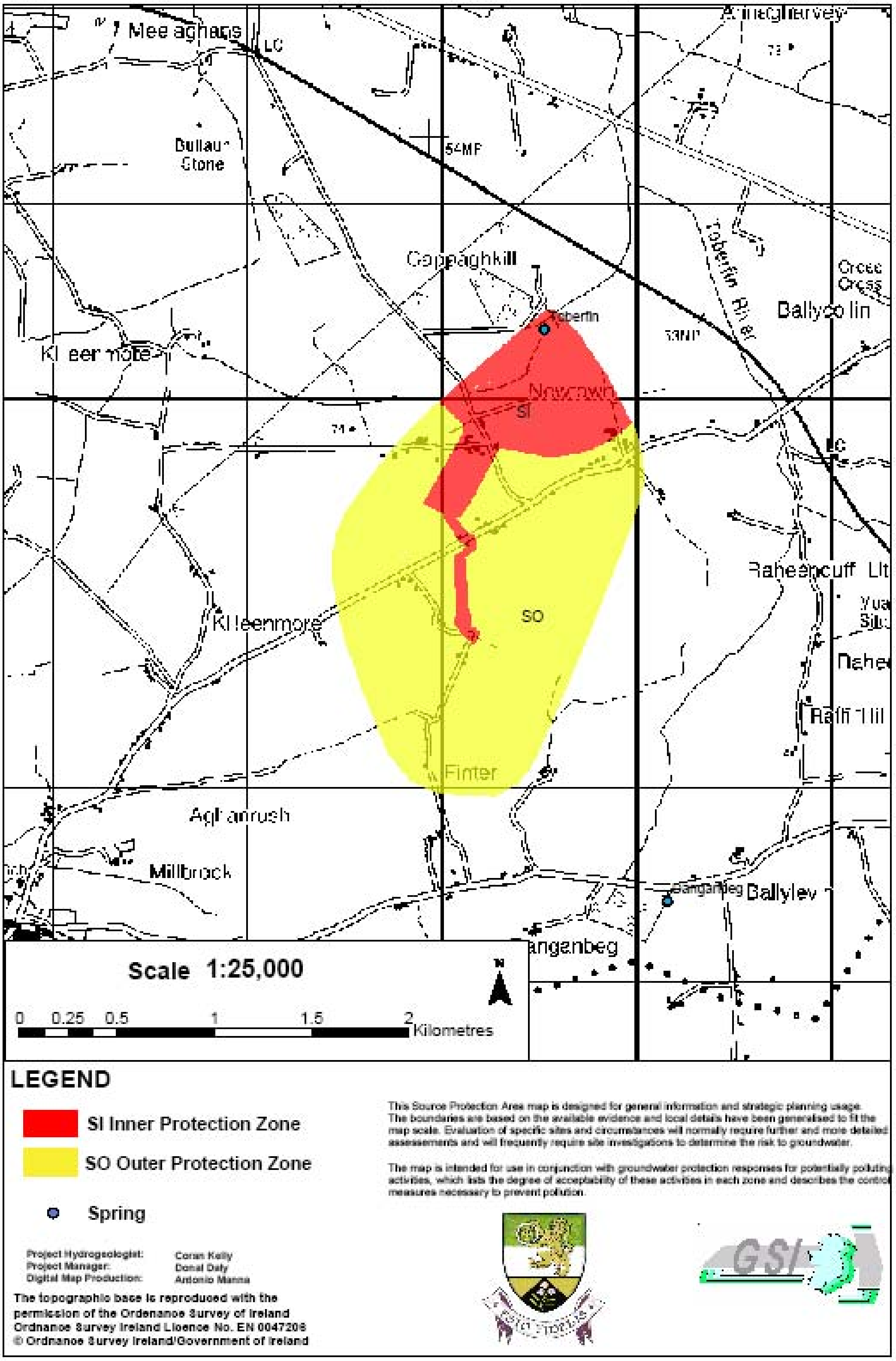


Figure 2 **Groundwater Source Protection Areas for Toberfin**

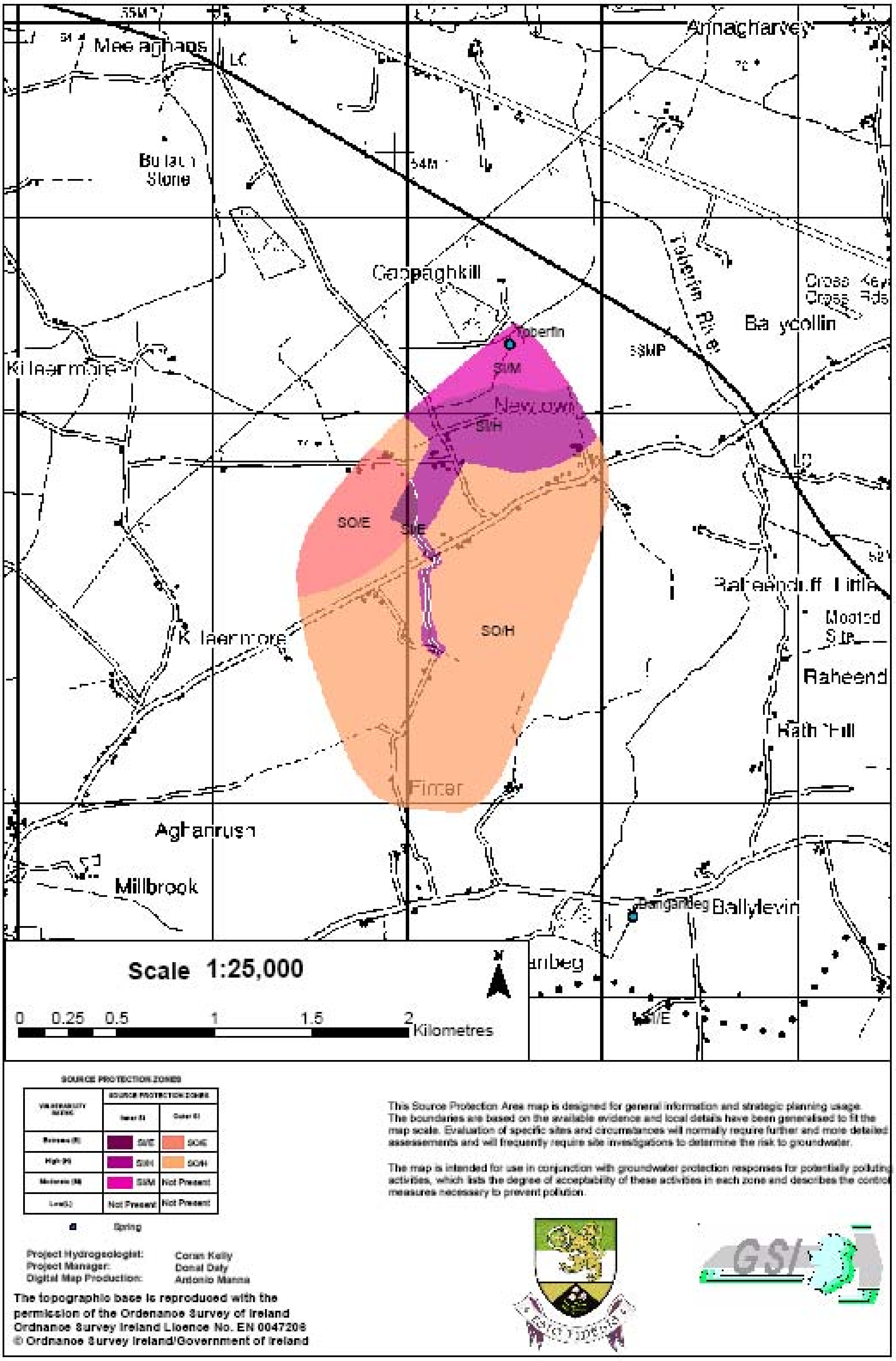


Figure 3 **Groundwater Source Protection Zones for Toberfin**