

# **Killeigh and Meelaghans Group Water Schemes**

**Toberfin Springs**

## **Groundwater Source Protection Zones**

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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-Portarlinton 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 <sup>3</sup> d <sup>-1</sup> (~260,000-274,000 gal d <sup>-1</sup> )
	: MGWS: 87-117 m <sup>3</sup> d <sup>-1</sup> (~19,000-26,000 gal d <sup>-1</sup> )
Estimated Total Discharge	: 1445 m <sup>3</sup> d <sup>-1</sup> (~318,000 gal d <sup>-1</sup> )

## 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.<sup>-1</sup> (from Met Éireann data). Actual evapotranspiration (A.E.) is then estimated as 95 % of P.E.
- Potential recharge: 394 mm yr.<sup>-1</sup>. 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<sup>1</sup>) 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.

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<sup>1</sup>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 be 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 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  $\sim 10 \text{ m d}^{-1}$ ;

Porosity  $\sim 1.5 \%$ .

These values give velocities of  $6.7 \text{ m d}^{-1}$ , 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 (LI) (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  $292\text{-}344 \text{ mg l}^{-1}$ , total hardness values of  $288\text{-}457 \text{ mg l}^{-1}$  (equivalent  $\text{CaCO}_3$ ) and electrical conductivity values of  $579\text{-}820 \text{ }\mu\text{S cm}^{-1}$ , 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).

<i>Parameter</i>	<i>Value (<math>\mu\text{S cm}^{-1}</math>)</i>
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 ( $< 0.02 \text{ mg l}^{-1}$ ) with occasional peaks (1989,  $0.11 \text{ mg l}^{-1}$ ), 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  $\text{mg l}^{-1}$  with a mean of 25  $\text{mg l}^{-1}$ . Nitrate levels were consistently between 15 and 30  $\text{mg l}^{-1}$  throughout the data set until November 1996. Since October 1997 the levels of nitrate are higher, varying from 32.1-37.8  $\text{mg l}^{-1}$ . 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  $\text{mg l}^{-1}$ , with a mean of 24  $\text{mg l}^{-1}$ , which are higher than typical background levels (12-15  $\text{mg l}^{-1}$ ).

Sodium levels are inside the normal range of 5-15  $\text{mg l}^{-1}$ . Potassium levels generally lie in the range of 2.5 to 3.0  $\text{mg l}^{-1}$ , except on one occasion (July'98) when it was 7.5  $\text{mg l}^{-1}$ . 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  $\text{mg l}^{-1}$  and 34  $\text{mg l}^{-1}$  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.

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

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.

<i>Date</i>	<i>Main Springs (m<sup>3</sup> d<sup>-1</sup>)</i>	<i>Spring No. 4 (m<sup>3</sup> d<sup>-1</sup>)</i>
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<sup>3</sup> d<sup>-1</sup>. 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<sup>2</sup> (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<sup>2</sup>.

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 <sup>3</sup> d <sup>-1</sup> )	Recharge (mm yr. <sup>-1</sup> )	Area (ZOC) (km <sup>2</sup> )
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<sup>2</sup>. 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

<sup>2</sup>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	
	<i>Inner</i>	<i>Outer</i>
<i>Extreme (E)</i>	SI/E	SO/E
<i>High (H)</i>	SI/H	SO/H
<i>Moderate (M)</i>	SI/M	_____
<i>Low (L)</i>	_____	_____

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 (LI).
- ◆ 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.

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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

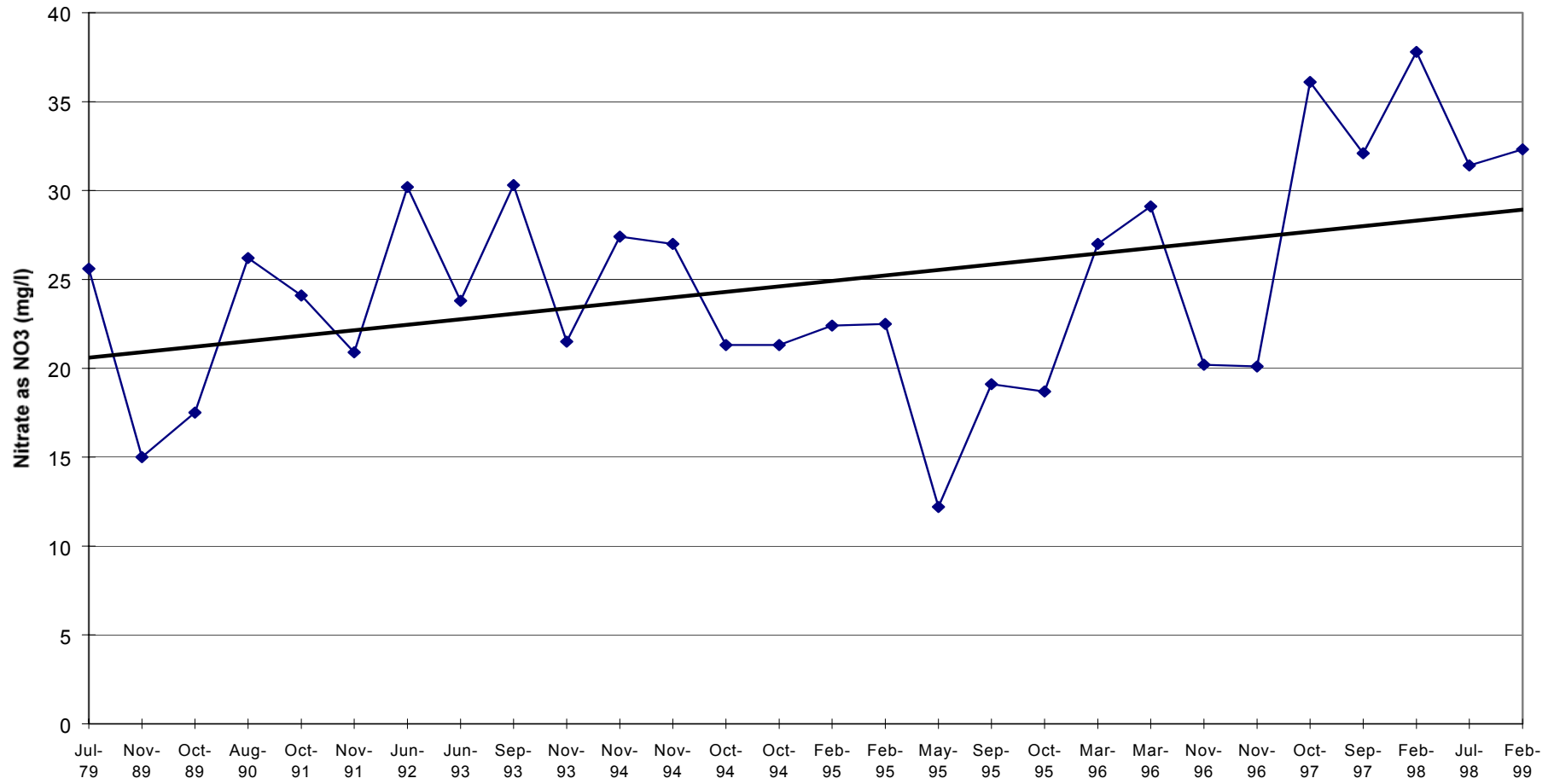
Depth (m)	Subsoil	BS 5930	Permeability
0-0.5	Top Soil	SILT	MODERATE
0.5-1.5	Till	silty GRAVEL	HIGH
1.5-2.5	Till	silty SAND	HIGH
2.5-3.0	Till	silty GRAVEL	HIGH
3.0-4.0	Till	clayey SILT with gravel	MODERATE

### 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.**

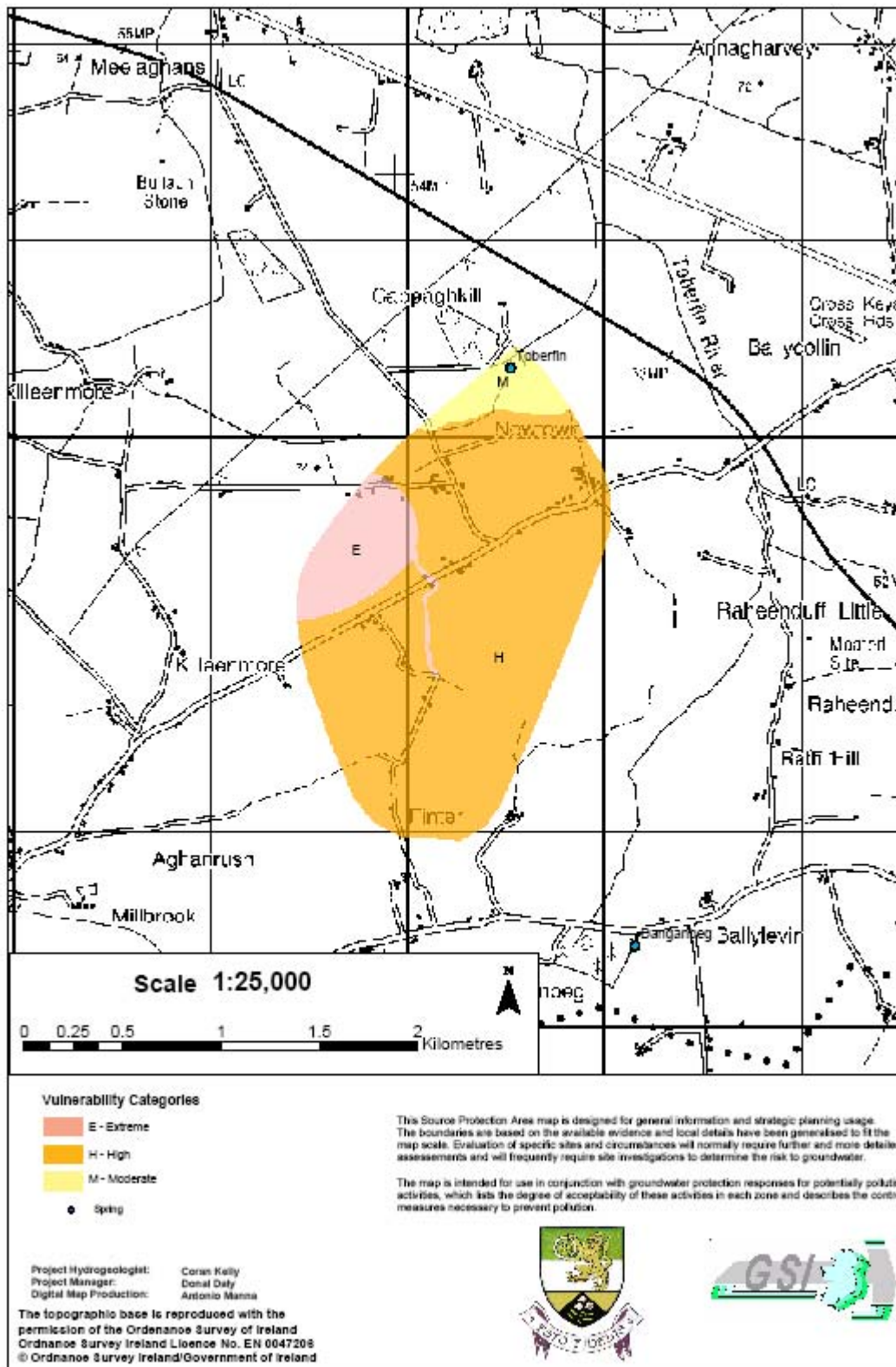


Figure 1 Groundwater Vulnerability around Toberfin

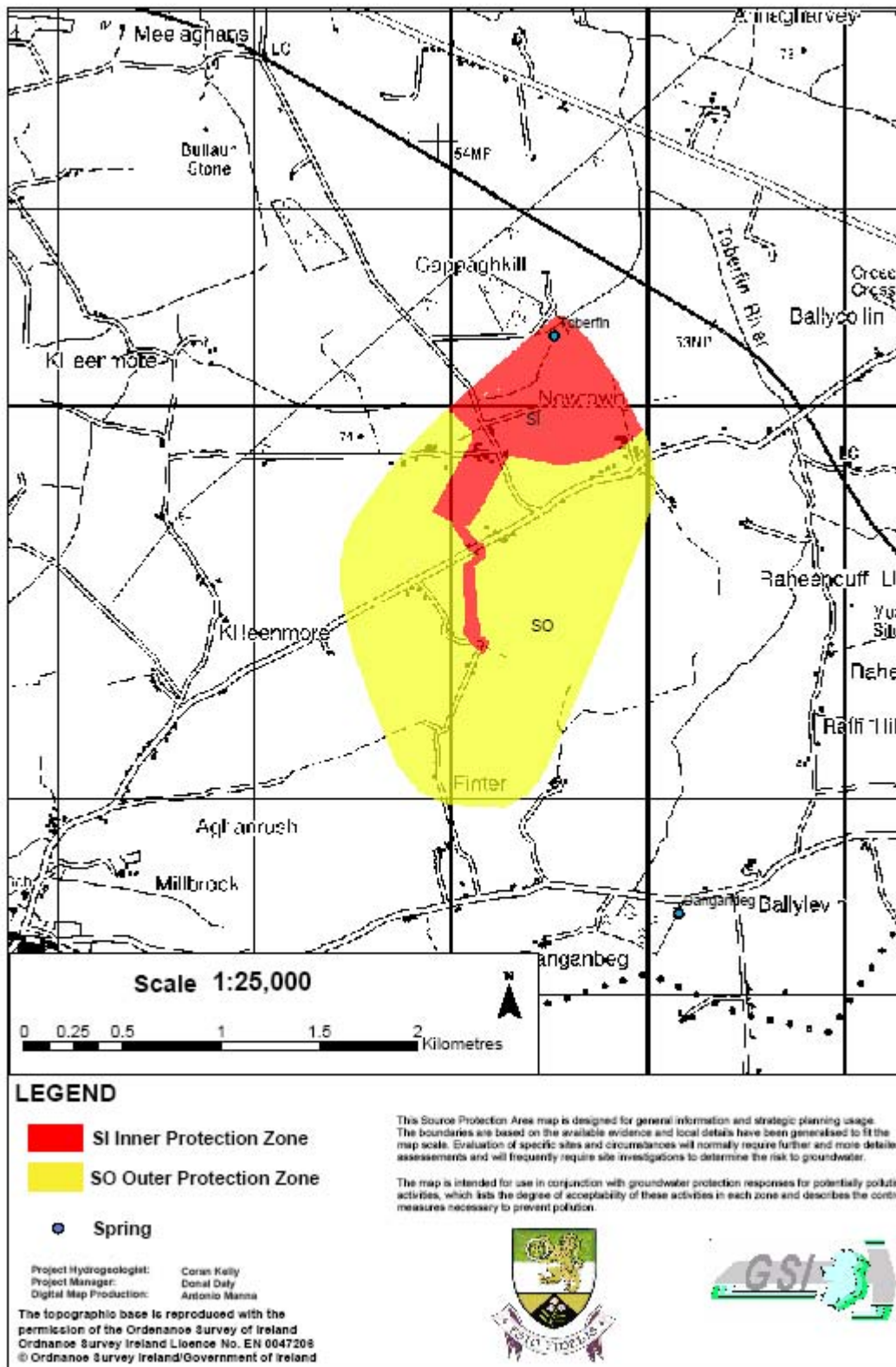


Figure 2 Groundwater Source Protection Areas for Toberfin

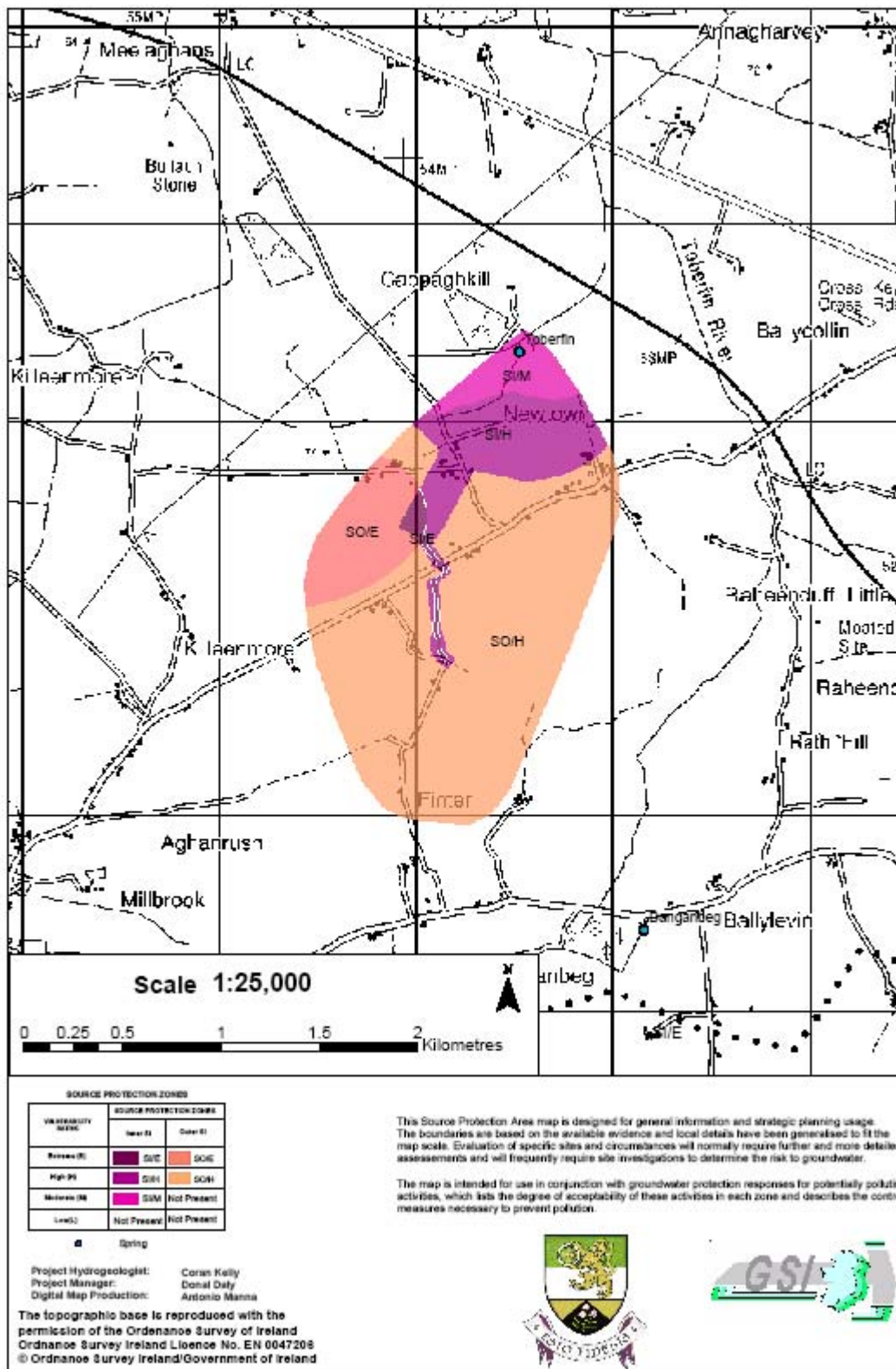


Figure 3 Groundwater Source Protection Zones for Toberfin