



Environmental Protection Agency

Establishment of Groundwater Source Protection Zones

Mountnorth Regional Water Supply Scheme

Mountnorth Spring and Borehole

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Prepared by:

Coran Kelly TOBIN

With contributions from:

Donal Crean (OCM), Michal Smietanka (CDM), Dr. Robert Meehan, Consultant Geologist; Jenny Deakin (TCD); Dr. David Drew, Consultant Geologist; Dr. Caoimhe Hickey and Ramón Aznar (GSI)

And with assistance from:

Cork County Council and local farmers



PROJECT DESCRIPTION

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

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

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



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1 Introduction

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

The objectives of the report are as follows:

- To outline the principal hydrogeological characteristics of the area surrounding the source.
- To delineate source protection zones for the Mountnorth Regional Water Supply Scheme.
- To assist the Environmental Protection Agency and Cork County Council in protecting the water supply from contamination.

Groundwater protection zones are delineated to help prioritise the area around the source in terms of pollution risk to groundwater. This prioritisation is intended as a guide in evaluating the likely suitability of an area for a proposed activity prior to site investigations. The delineation and use of groundwater protection zones is further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

The maps produced are based largely on the readily available information in the area, extensive field walkovers, water tracing, water level measuring, flow measurements and on mapping techniques which use inferences and judgements based on experience at other sites. As such, the maps cannot claim to be definitively accurate across the whole area covered, and should not be used as the sole basis for site-specific decisions, which will usually require the collection of additional site-specific data.

2 Methodology

It is acknowledged that the technical standard to be achieved within Source Protection Zone (SPZ) delineation is that of the Geological Survey of Ireland, both in terms of implementation and reporting. The primary guidance documents are:

- Groundwater Protection Scheme Guidelines (DELG/EPA/GSI, 1999); and
- GSI Guidelines for the Assessment and Mapping of Groundwater Vulnerability to Contamination (GSI, draft 2003).

As such the methodology consisted of a desk study, site visits, walk over surveys, investigative field work, data analysis, interpretation and reporting.

The initial site visit was conducted on 31st August 2011 which included an interview with the caretaker. Subsequent site walk-overs and investigative field mapping were conducted on:

31st August, 14th September, 6th and 9th October, 2nd November (2011),

14th and 15th February, 5th and 6th March, and 9th July (2012).

The field work included a field by field karst feature survey, a water well survey, hydrogeological mapping, mapping of drainage indicators and logging of bedrock outcrops and subsoil exposures of the study area.

In addition, a multi-dye tracing programme was conducted in conjunction with the GSI during March, April and May 2012, which commenced with input of dyes on 17th March. Subsequent laboratory analysis for tracer dye was conducted in the GSI of the collected water samples and cotton wool bags.

3 Location, site description and well head protection

The Mountnorth source is located approximately 6 km northwest of Mallow and approximately 1.4 km east of Ballyclough as shown in Figure 1. The source comprises a spring (Tobershivaun) and an adjacent borehole which is used when the spring flow is insufficient to support the daily abstraction. Figure 2 shows the location of the spring and borehole on an aerial photograph, along with topographic contours, the Finnow stream and the access gate.

The spring emerges at the foot of a rock scarp, approximately 50 m south of the Finnow river. The spring is contained within a large concrete chamber, shown in Figure 3, and overflows to the Finnow. The concrete chamber consists of a series of heavy rectangular slabs. There are narrow gaps between the slabs which are vegetated in part, mostly by moss. The abstraction intake is in an adjacent gravity fed sump, shown in Figure 4 and the site is fenced off. There is an overflow channel from the large concrete chamber to the site boundary, and from there the overflow channel parallels the main channel of the Finnow for several hundred metres before joining the Finnow. There is currently no flow monitoring hardware in place for the overflow. Conifer trees positioned on the scarp shade the entire site.

The borehole, shown in Figure 5 is located approximately 30 m west of the spring alongside the access track and is housed in a rectangular concrete chamber. The borehole, whilst capped and contained inside a concrete block plinth, is not grouted. The untreated water is chlorinated at the pumphouse on site and pumped to a reservoir in Mountnorth. A spring in Ballyclough, some 1.5 km west, is also pumped to the reservoir at a rate of approximately 600 to 700 m³/day.

The sample tap used for collecting samples for the EPA Groundwater Monitoring Programme is inside the pumphouse shown in Figure 6 and is supplied by the main spring and/or the adjacent borehole if the demand is not being met by the spring.

4 Summary of spring & borehole details

The spring is the main source of water and the borehole only pumps when the probes located in the gravity fed chamber indicate that there is insufficient water coming from the spring sump.

The abstraction rate is currently 1300 to 1400 m³/day (12,000–13,000 gallons per hour). Available local authority data indicates that the abstraction rate was approximately 455 m³/day from 2000-2006 and since 2007 is approximately 1300 to 1400 m³/day and the borehole was put into service in the early 2000's to mitigate against low spring flows and to meet an increasing demand. The spring struggled to meet the demand of 455 m³/day during drier periods. Apart from the driest weather periods it is difficult to know when the borehole pump kicks in and for how long. Due to the lack of spring discharge data it is difficult to assess the mean spring flow. From September 2010 to June 2012 it seems that the borehole has not had to pump at all due to sufficient flow available from the spring.

It is estimated that an upper range of 35-45 l/s (3000-3900 m³/day) is the total spring discharge during wetter periods. During dry weather periods the flow is greatly reduced, insufficient for the demand, and the gravity pipe from the main chamber dries up, such as August 2010, when the overflow channel was clearly still

gaining some flow. Based on these data it is estimated that a lower total flow is in the order of 5l/s (400 m³/day) for the spring.

Table 4-1 Summary of Mountnorth Source Details

	Spring (Tobershivaun)	Supplementary Borehole
EU Reporting Code	IE_SE_G_082_04_023	IE_SE_G_082_04_023
Drinking water code	0500PUB1316	0500PUB1316
Grid reference	E150670 N102720	E150686 N102763
Townland	Mountnorth	
Source type	Spring	Borehole
Drilled		2005 Declan Barry No log
Owner	Cork County Council	
Elevation (Ground Level)	81.2 mOD	81.3 mOD
Depth		30 - 35 m (some uncertainty)
Depth of casing		13 m (reported details)
Casing Diameter		6 inch (150 mm)
Depth to rock	Spring issues from base of rock scarp	Unknown but reported to be 13-15m
Static water level	80.4 mOD (Sept 2011) to 77mOD (nov 2005)	80.2 mOD (1.17mbgl)
Pumping water level		Not pumping late 2011 through to 2012, reported to have small drawdown
Average abstraction rate (Co Co records)	1300 to 1400 m ³ /day (2007 to present) 455 m ³ /day (2000 to 2006)	
Overflow (no long term flow data available)	None to 30 litres/second (2590 m ³ /day) (February 2012)	No overflow, not artesian
Specific Capacity		Unknown, but drawdown reported to be very little

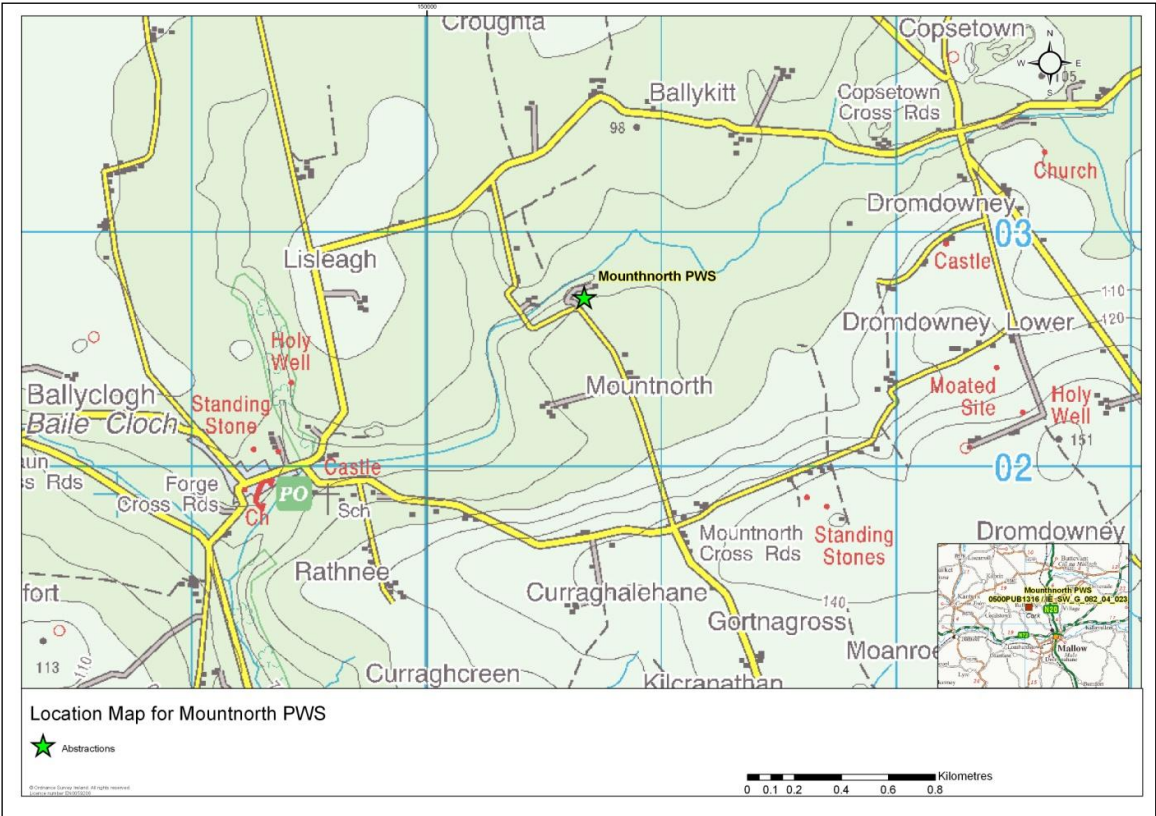


Figure 1 Location of Mountnorth PWS

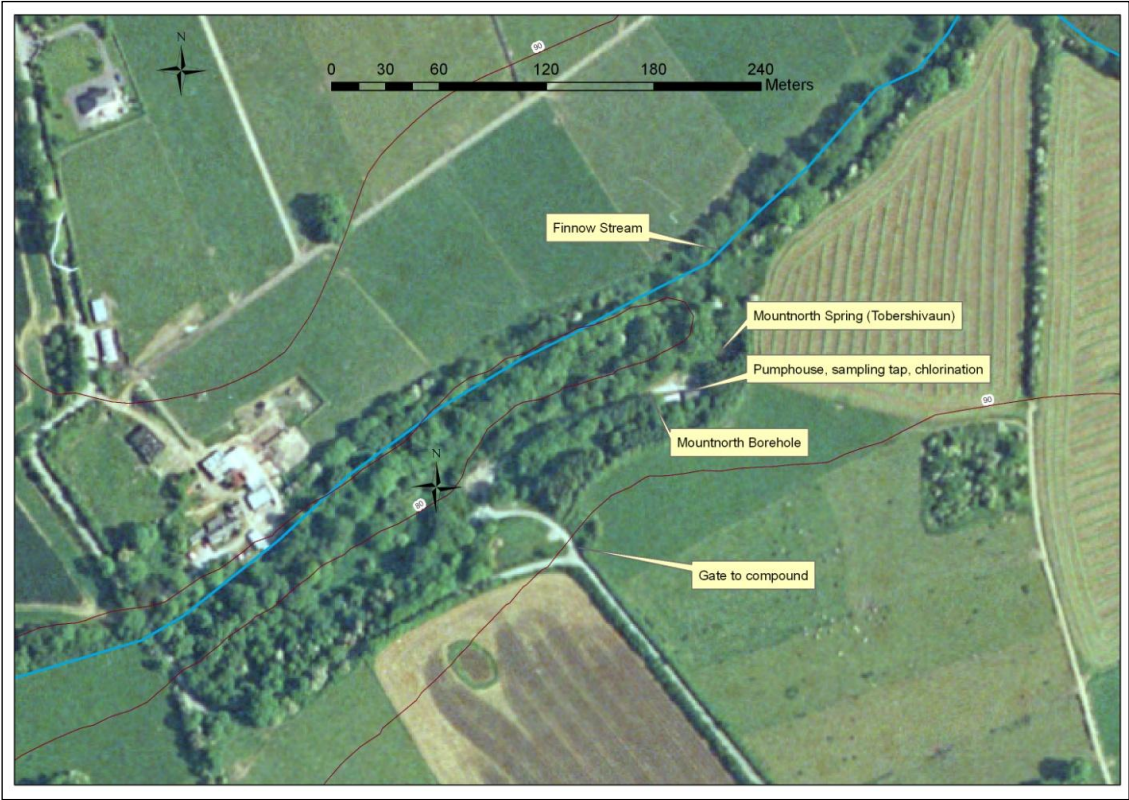


Figure 2 Location of Mountnorth spring, borehole, Finnow & pumphouse on aerial photograph



Figure 3 Main Chamber at Mountnorth Spring, concreted over (Donal Crean (OCM))



Figure 4 Gravity fed sump from main chamber (above) and pumphouse (Donal Crean, OCM)



Figure 5 Mountnorth borehole; there is now a concrete block housing over it (Donal Crean, OCM)

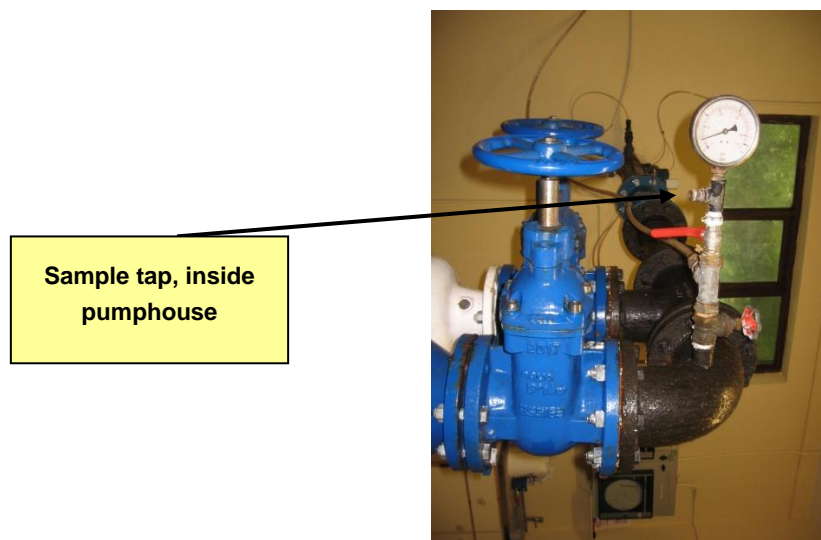


Figure 6 Mountnorth sampling tap (EPA (WYG))

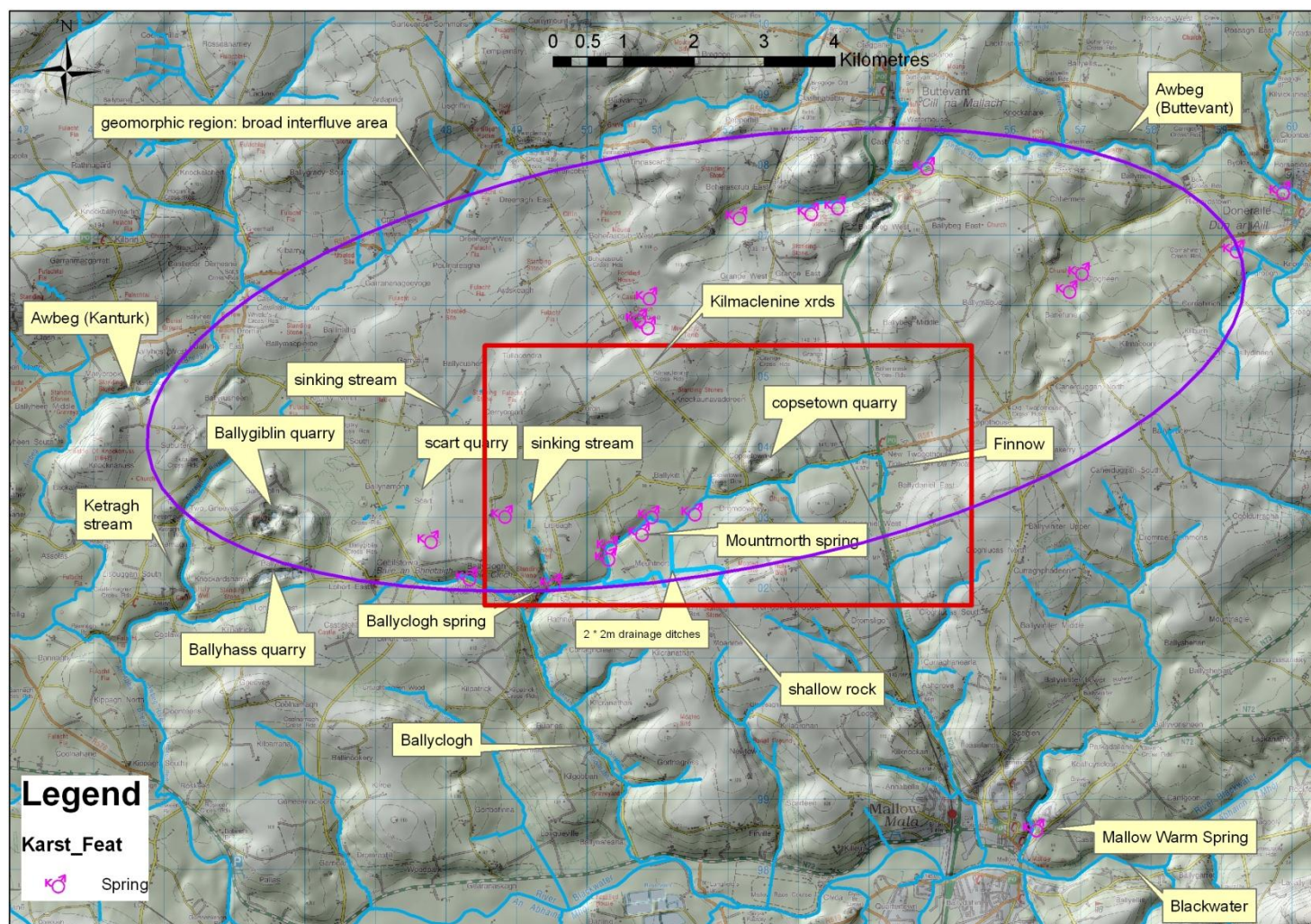


Figure 7 Broad study area indicating main geomorphic area, topography, surface water hydrology, springs, and internal study area (red rectangle) that underwent detailed investigation. The “interfluve” is encircled by the purple line.

5 Topography, surface hydrology and landuse

Due to the known hydrogeological complexity, a wide areal extent formed the initial study area as shown in Figure 7, which illustrates the broad regional topography, hydrology and location of the main springs. In addition, the focus of the main study is shown in the red box – in which the detailed investigative field work took place.

The landscape in the region comprises a mixture of distinct regions. A marked feature is the relatively low lying plateau characterised by an absence of surface water. This broad interfluvium is circled in purple in Figure 7, and extends east between the Awbeg and Funshion rivers and is the subject of previous Source Protection Zone reports on Shanballymore and Castletownroche (EPA, 2010; GSI, 2000).

- The broad interfluvium generally undulates between 60-110 mOD, with the exception of a prominent ridge that divides this interfluvium, centred on Kilmaclenine Cross roads (146 mOD), orientated NE-SW, which is at the centre of Figure 7.
- South of the ridge at Kilmaclenine Cross roads, the local area forms a shallow northeast-southwest trending valley, drained by the Finnow which flows southwest to Ballyclogh, at which point turns south of the source towards the Blackwater. Mountnorth spring (Tobershivaun) and adjacent borehole are located in this valley. South of the Finnow, the topography sharply inclines from 110 mOD to 150 mOD.
- Across the flanks of the interfluvium area there are small rounded knolls, for example at Mountnorth, Dromdowney and Copsetown.

The main upland areas have several streams flowing across them. In contrast, the broad interfluvium area is largely devoid of streams and rivers with the exception the Awbeg rivers (Kanturk and Buttevant branches) that run around the northern perimeter, and the Ketragh and Finnow streams flow around the southern perimeter.

The Finnow is the principal stream of the main study area. There are a number of springs, including Mountnorth spring (Tobershivaun) discharging to the Finnow along its course, marked in Figure 7. Mountnorth Spring and borehole are located on the south side of the Finnow. During prolonged dry periods, the springs significantly reduce in flow, with some drying up completely and the Finnow appears to dry up, as observed on the field visit 31st August 2011. There are EPA gauging stations at Ballyclogh [18023] on the Finnow, and on the Ketragh [18014] and the recorded dry weather flow is 0.2 m³/s and 0.18 m³/s respectively.

Landuse in the vicinity of the source is mainly a mixture of dry grassland and tillage. The area is intensively farmed, with the upper slopes south of the Finnow being poorly drained, particularly south of Mountnorth. There are large deep drains indicated on Figure 7. There is a relatively low housing density in the area, with the nearest farmhouse 400 m south, and 200 m north (on the north side of the Finnow) and several other farms and houses over 500 m distant on both sides of the Finnow. Despite the presence of the public water supply scheme quite a number of properties, particularly farms, are served by private boreholes. There is no sewerage network.

There are number quarries, some recently closed, all located to the north of the Finnow; at Copsetown Cross Roads, Ballyhass, Ballygiblin and Ballybeg. There is one additional quarry of note at Scart, just northeast of Ballyclogh, which post dates the 50k discovery series mapping shown in Figure 7. In summary, land use pressures are moderate, principally due to the intensive farming.

6 Hydro-meteorology

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

Annual rainfall: taken to be 1000 mm. Nearby historical rain gauges at Kanturk, Mallow (Sugar factory) and Mallow (Hazelwood) record amounts of approximately 1000 mm/year. The contoured data map of rainfall in Ireland (Met Éireann; 1961-1990 dataset) shows that the source and potential zone of contribution is located between the 1000 – 1200 mm average annual rainfall isohyets. Given the potential size of the zone of contribution the rainfall amounts are likely to vary.

Annual evapotranspiration losses: taken to be 428 mm. Potential evapotranspiration (P.E.) is estimated to be 450 mm/yr (based on data from Met Éireann). Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., to allow for seasonal soil moisture deficits.

Annual Effective Rainfall: 572 mm. The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore equivalent to this, or 572 mm/year. See section on Recharge which estimates the proportion of effective rainfall that enters the aquifer.

7 Geology

This section briefly describes the relevant geological characteristics which provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections. The geological information is based on the bedrock geological map of Kerry—Cork, Sheet 21, 1:100,000 Series (Geological Survey of Ireland (GSI), 1997) and accompanying memoir (Pracht *et al.*, 1997), the GSI Well, Borehole and Karst Databases and on bedrock outcrop and subsoil exposures encountered during site visits, an MSc thesis by Williams (2010), and site investigation data for the M20 Cork – Limerick Motorway Scheme (Arup, IGSL, 2010, 2011) and discussions with Dr. Mike Philcox (consultant geologist, who has mapped the geology of this area).

7.1 Bedrock geology

The regional bedrock map as shown in Figure 8 indicates that the interfluvial area is underlain principally by limestone units whilst the upland areas bounding the limestones are underlain to south by interbedded siltstones and shales and to the north by sandstones and mudstones. Of note is that the central portion of the interfluvial area is occupied by a relatively small area of sandstones. The geological sequence is shown in Table 7-1. In Figures 9 and 10 the individual bedrock formations and the generalized Rock Units are displayed for the main area investigated. In Figure 10, an unused council borehole is indicated as, whilst, there is no log readily available, it appears from the reported high yield that this intercepts pure limestones at depth.

The published mapping indicates considerable structural deformation with intense folding and faulting. A noted feature is the “Kilmaclenine anticline”, the axis (the line of a major fold) of which is coincident with the ridge centred on Kilmaclenine cross roads. The area in which the spring is located is on the southern limb of the Kilmaclenine Anticline. The rocks on the southern limb dip south at approximately 35 to 50 degrees in the immediate vicinity of Mounthnorth Spring. There are two major fault sets that are widespread across the region; east-west trending and north-south trending.

Outcrops of rocks are exposed in Copsetown Quarry. This is the Copstown¹ Formation which occupies the lowermost central part of the valley through which the Finnow flows, are shown in Figures 11 and 12. The exposures along the eastern, southern and western walls are hard to access, but there are indications along portions of the southern wall of broken weathered limestone up to 1m thick.

At Mountnorth, Dromdowney and Copsetown there small rounded hills standing proud of the general slopes, which appear to comprise Waulsortian limestone knolls. Borehole logs and geophysical surveys of the area at Scart, 2.5km northeast of Mountnorth indicate that the Waulsortian is dolomitised with frequent cavities present, and cavities are also reported in the Ballysteen which is also reported to be impure (argillaceous) (Williams, 2010).

Table 7-1 Geological sequence of the study area

National Generalised Bedrock Map Name	Formation / member	GSI Code	Geological Description (Pracht, 1997)
Namurian Undifferentiated	Cloone Flagstone	CF	Greywackes and shales
Namurian Sandstones	Annabella	AN	Interbedded siltstone and shale
Dinantian Pure Bedded Limestones	Caherduggan	CD	Crinoidal limestone with nodular chert
Dinantian Pure Unbedded Limestones	Hazelwood	HZ	Massive, pale grey
Dinantian Upper Impure Limestones	Copstown	CT	Well bedded, dark Grey
Dinantian Pure Unbedded Limestones	Waulsortian	WA	Massive Unbedded
Dinantian Lower Impure Limestones	Ballysteen Limestone	BA	Dark, muddy limestones and shale
Dinantian Early Sandstones, Shales and Limestones	Lower Limestone Shale	LLS	Sandstone, mudstone and thin limestone
Devonian Old Red Sandstones		CW	Pale and red sandstone

¹ OSI mapping spells the townland as Copsetown; whilst published GSI work spells the formation name which is based on the type location at Copsetown as the Copstown Formation. This report maintains the spelling as per context.

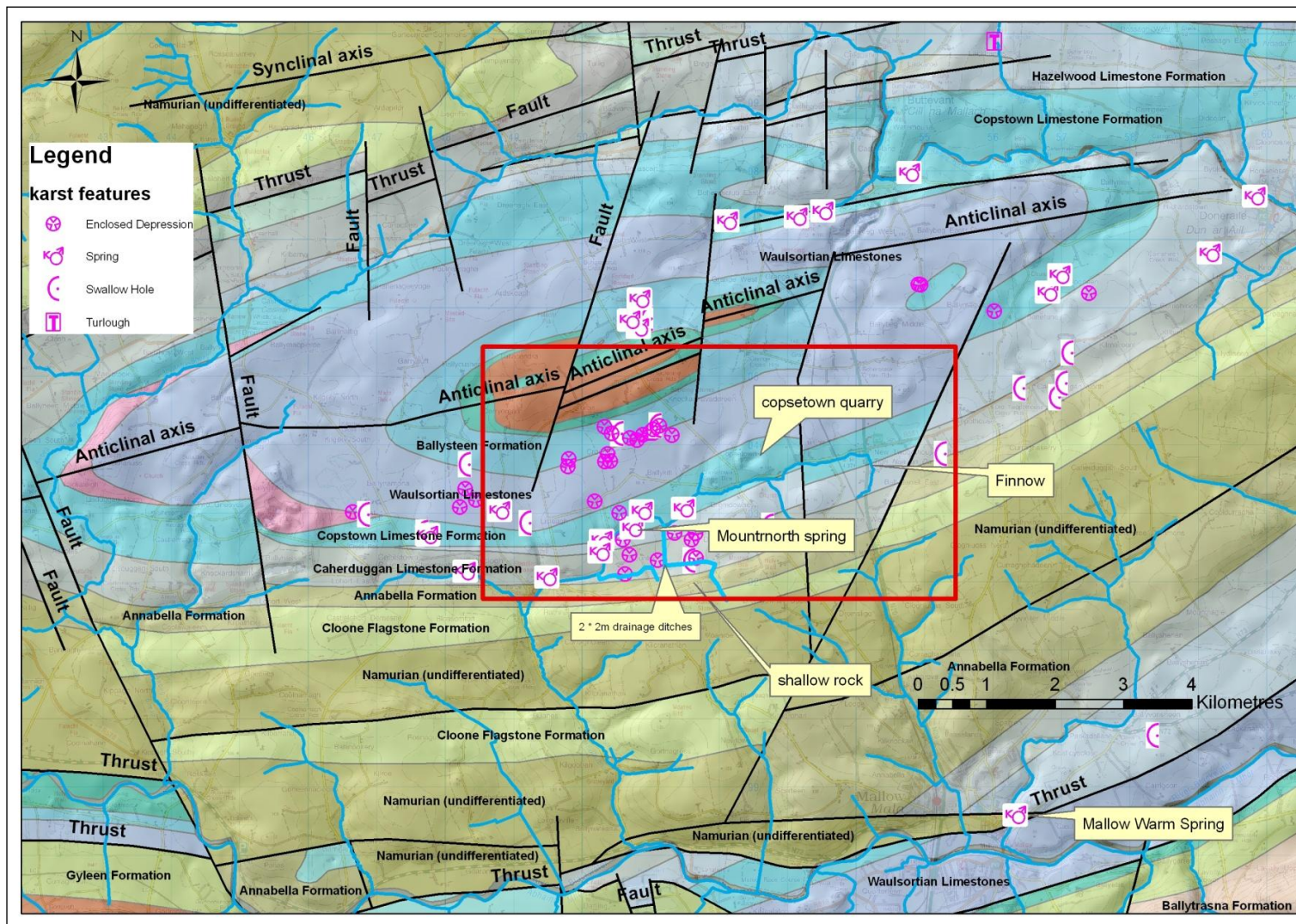


Figure 8 Geological Map of the region of interest; a separate map of the red-line study area is shown in Figure 9



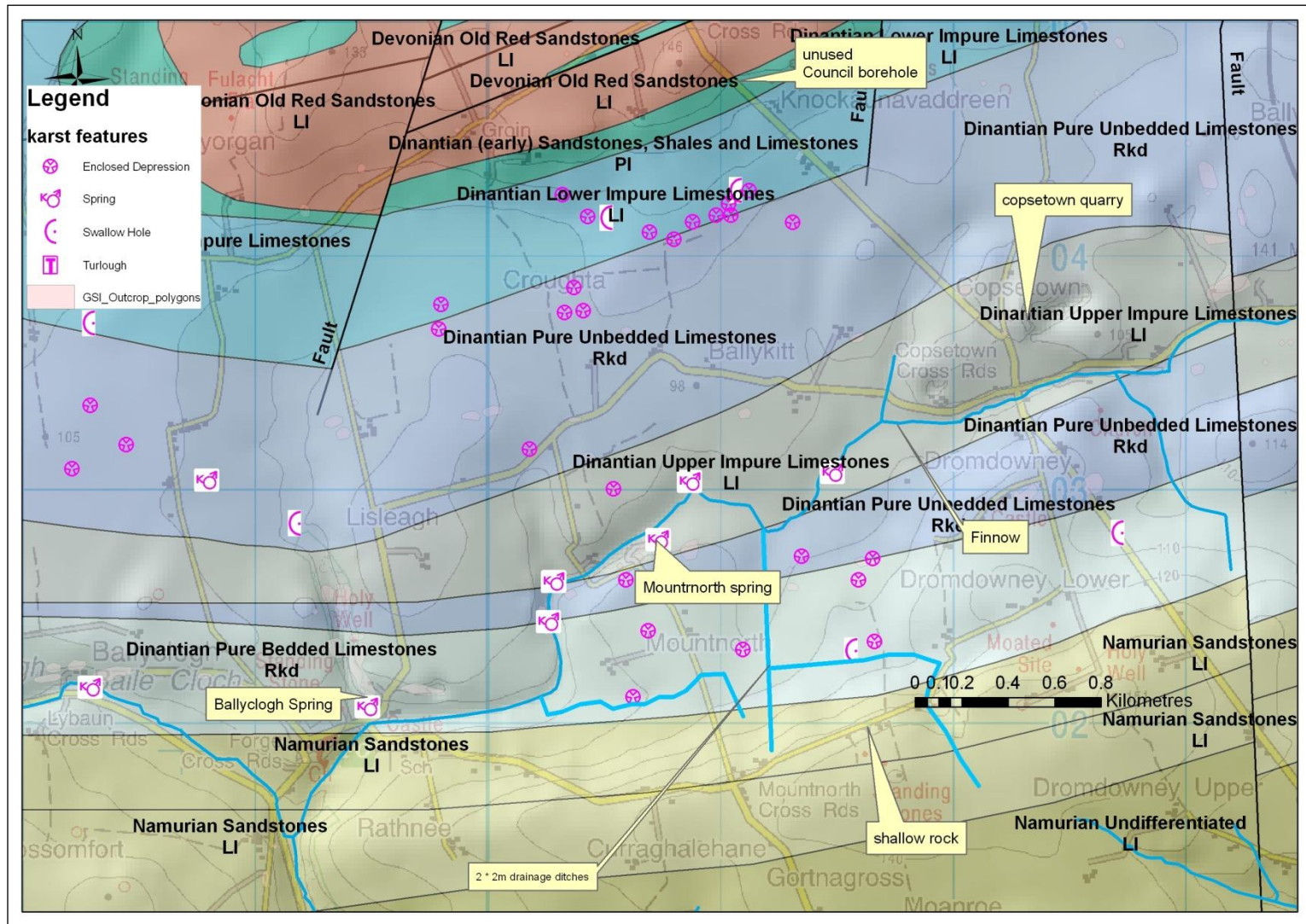


Figure 10 Generalised Rock Unit / karst feature map of the main field area, also indicated unused council borehole

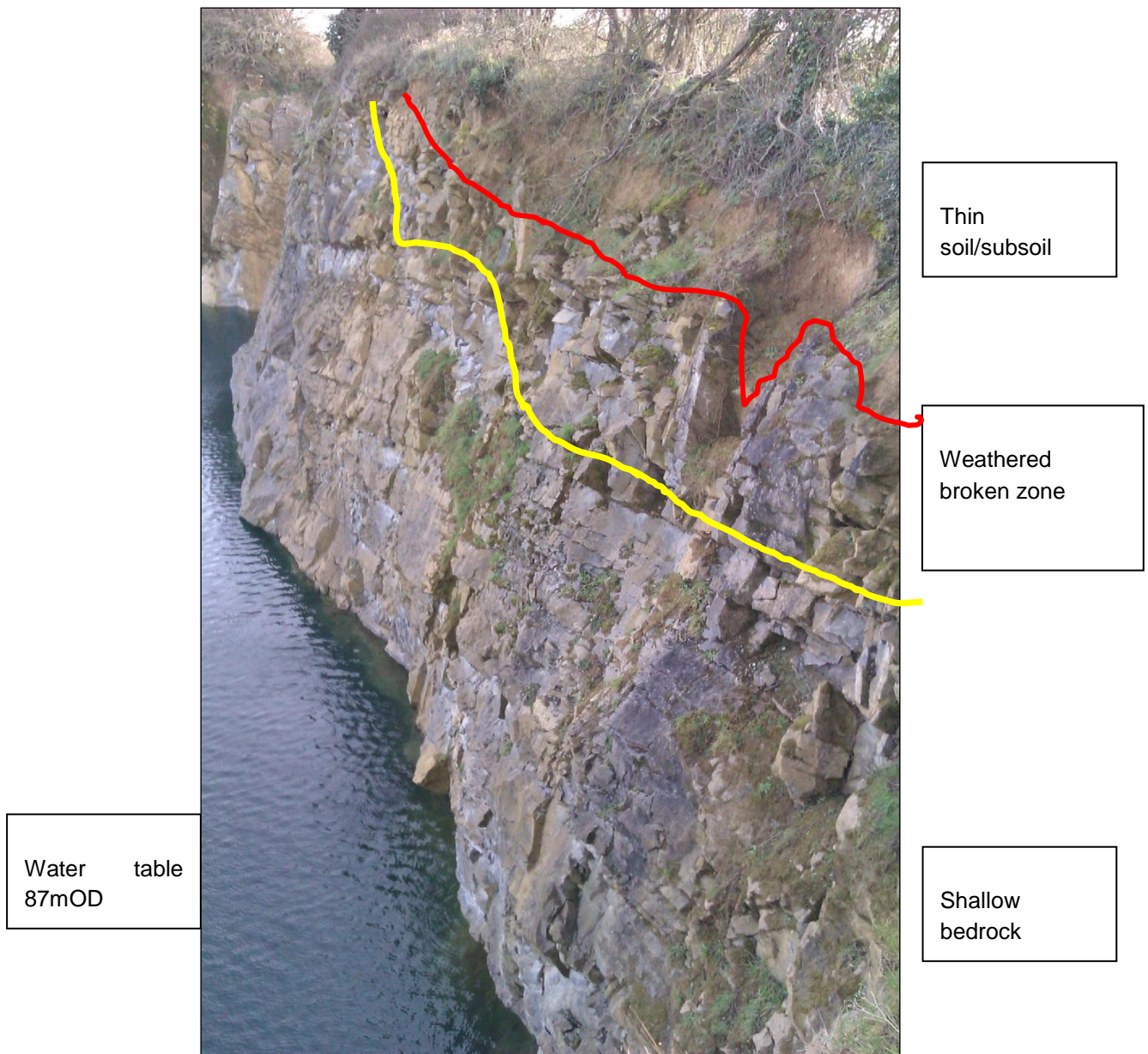


Figure 11 Southern wall of Copsetown Quarry, exposing southerly dipping layers of limestones of what is mapped as the Copstown Formation. (Coran Kelly)



Figure 12 Northern wall of Copsetown Quarry, exposing southerly dipping layers of limestones of what is mapped as the Copstown Formation. (Coran Kelly)

7.2 Karst Features

As shown in Figures 8, 9 and 10, karst features are present within the study area. However, relative to other karstified areas in the country they are not particularly numerous. This is somewhat similar to the terrain in Shanballymore and Castletownroche (EPA, 2010), where there is an apparent lack of obvious karst features. The features indicated on Figure 8 and 9 were surveyed and recorded as part of this study, and as part of a recent study for the M20 Cork – Limerick Motorway scheme (Arup, 2010) and as part of an MSc study on Scart Quarry (Williams, 2010). Mapping of karst features was conducted during walkover surveys to identify potential recharge areas and injection points for the purpose of dye tracer testing. It is noticeable that the karst features are distributed across all the limestone units, including those that are generally regarded as impure, such as the Ballysteen and Copstown Formations. A ‘sluggera’ was identified during the course of this study in July 2012, that was not there at the start of the project, shown in Figure 13. In Scart, ‘sluggeras’ (enclosed depressions and swallow holes, normally formed suddenly and often subsequently infilled by local farmers) were mapped (Williams, 2010), which are also common in Shanballymore and Castletownroche (GSI, 2000; EPA, 2010). Figure 14 shows a swallow hole in the townland of Crougtha, north of the Finnow.



Figure 13 Typical 'slugger', which can appear suddenly, normally circular with straight walls, generally infilled subsequently by farmers (Donal Crean)



Figure 14 Swallow hole at E150507 N104164; this feature takes water at the bottom, and a field drain conveys water into it (R.Aznár)

7.3 Soils and subsoils and depth to bedrock

The mapped soils and subsoils are given in Figure 15 and Figure 16. Poorly drained soils (AminPD) occupy both the lowermost portions of the landscape and the elevated areas occupied by Namurian rocks to the south of the Finnow. Deep well drained soils (AminDW) occupy most of the remainder of the landscape.

The subsoils are dominated by Till, in particular till derived from Namurian rocks (TNSSs). In general the subsoil cuttings, particle size data and GSI auger drill holes indicate moderately permeable subsoils over the majority of the area, becoming dominated by low permeability subsoils on the flanks of the ridge south of Mountnorth Spring.

The depth of subsoil is highly variable. Outcrops of rock occur on the major ridges, and the depth of subsoil is shallow across the limestone knolls, for instance at Mountnorth, Dromdowney and Copsetown. Along the Finnow stream, the springs are discharging where rock is exposed or close to the ground surface. However, the majority of the river bed is composed of sediments, which is deep in places - for instance the reported details for the Mountnorth borehole suggest over 10 m of sediment present.

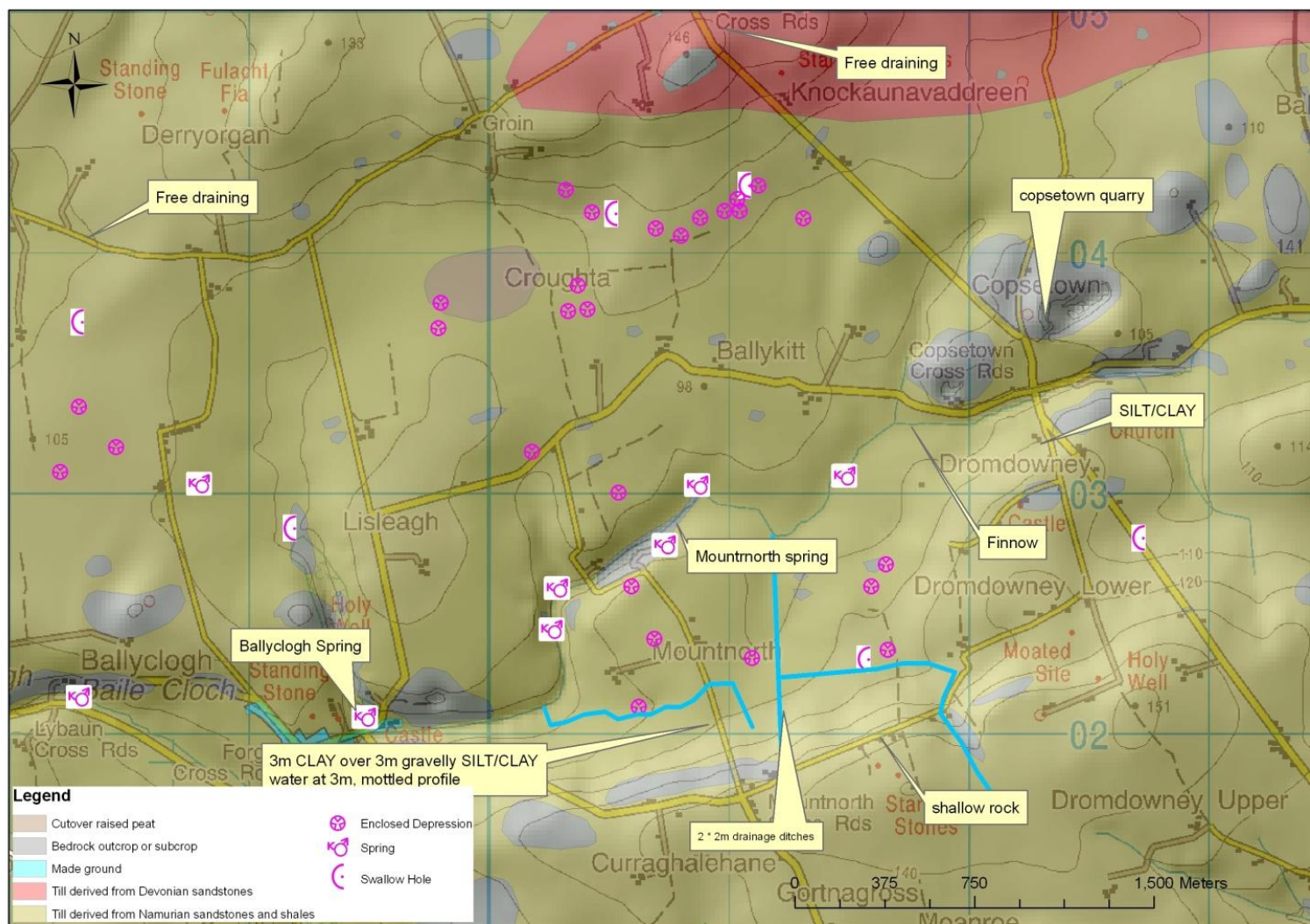


Figure 16 Subsoils Map

8 Groundwater vulnerability

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target'. A detailed description of the vulnerability categories can be found in the Groundwater Protection Schemes document (DELG/EPA/GSI, 1999) and in the draft GSI Guidelines for Assessment and Mapping of Groundwater Vulnerability to Contamination (Fitzsimons *et al.*, 2003).

A groundwater vulnerability map has been developed for County Cork by the GSI and ranges from extremely vulnerable to moderately vulnerable, and a portion of the map of north Cork which encompasses the study area is given in Figure 17.

The '**High**' vulnerability is based on the presence of '**moderate**' permeability tills in the vicinity of the source that are 5-10m thick or on '**low**' permeability tills that are 3-5m thick. Moderate permeability tills dominate the area north of the Finnow and immediately to the south of the Finnow. However, where slopes steepen dramatically south of the Finnow, low permeability tills dominate the uppermost slopes.

The '**Moderate**' vulnerability is based on the presence of '**moderate**' permeability tills that are greater than 10m thick.

Areas mapped as having as rock at / or close to surface, are denoted as '**X**' on the map.

The remaining portion, classified as '**Extreme**' is assessed to comprise subsoils and soils with a depth of between 1 m and 3 m.

9 Hydrogeology

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

- GSI Website and Databases.
- County Council Staff.
- EPA website and Groundwater Monitoring database.
- Local Authority Drinking Water returns.
- GSI report Castletownroche SPZ (2000).
- EPA report Shanballymore SPZ (2010).
- EIS, M20 Cork-Limerick Motorway Scheme (Arup, 2010, 2011)
- IGSL, M20 Cork – Limerick Motorway scheme. Factual Ground Investigation reports for preliminary investigation and detailed investigations Phase 1 & 2. Report on behalf of Cork County Council and Arup.
- MSc Thesis Williams, I., (2009). Investigation of Potential groundwater pathways for surface water infiltration and run off from Scart Quarry, Ballyclogh, Co. Cork. Unpublished MSc thesis, Cardiff University.
- O'Brien, M. 1987. The development of geothermal resources in the Mallow Area for Heating Purposes. Unpub. ME thesis, National University of Ireland, Cork. 219pp.
- Brück, P.M., Cooper, C.E., Cooper, M.A., Duggan, K., Goold, L. & Wright, D.J. 1983. The Geology and Geochemistry of the Warm Springs of Munster. ECE – European Geothermal Update, Munich.
- Field mapping and tracer testing for this study.

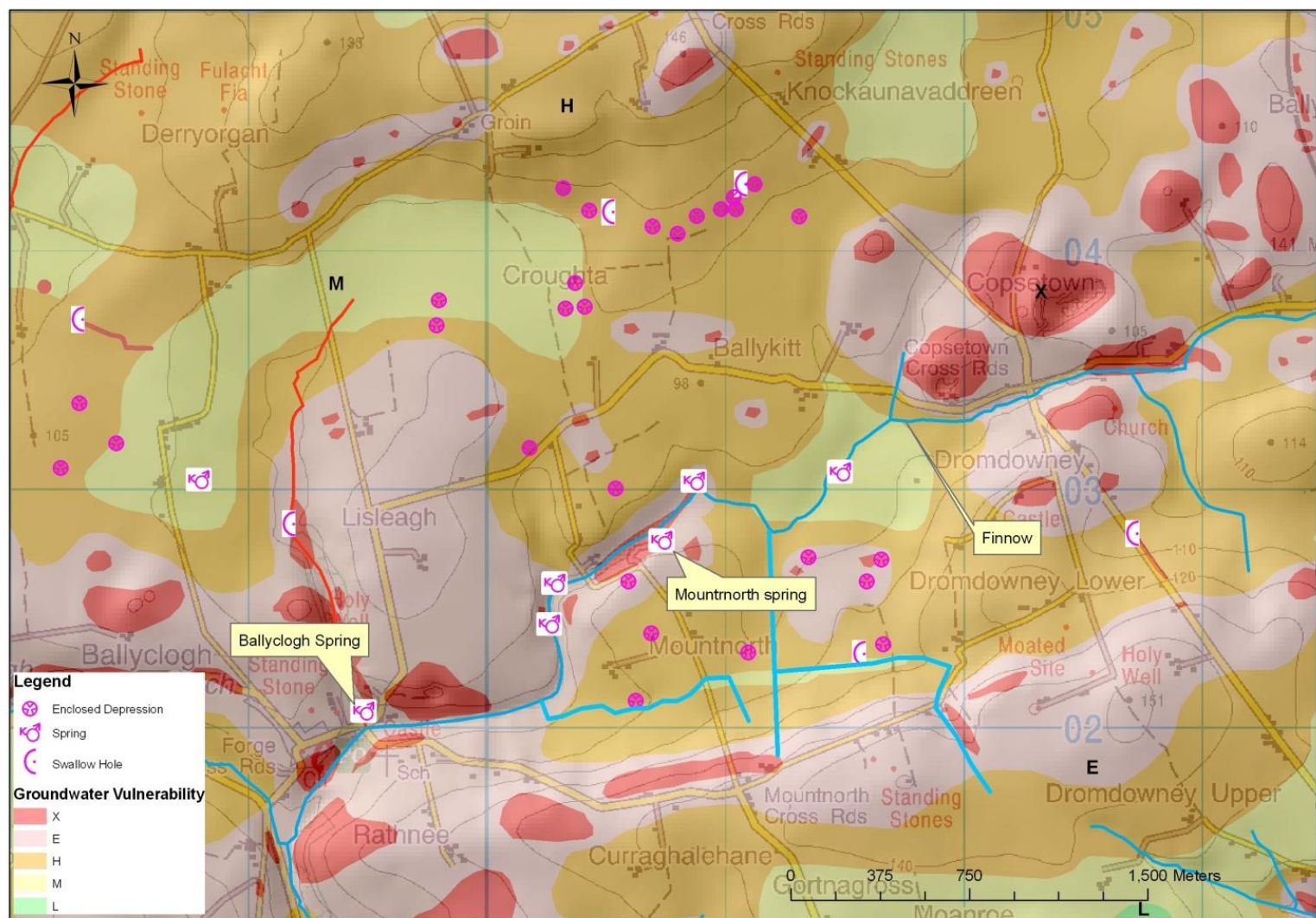


Figure 17 Groundwater Vulnerability Map

9.1 Groundwater body and status

The source and the surrounding areas are located within the Mitchelstown, Kilmaclenine, Rathmore groundwater bodies (GSI, 2004). All of the groundwater bodies are classified as “at Good Status”. The groundwater body descriptions are available from the GSI website: www.gsi.ie and the ‘status’ is obtained from the WFD website: www.wfdireland.ie. The Mitchelstown Groundwater body coincides with the low karst interfluvium; the Kilmaclenine Groundwater body comprises the sandstone ridge in the centre of the karst interfluvium; and the Rathmore Groundwater body coincides with the upland Namurian ridge between the source and Mallow.

9.2 Groundwater levels, flow directions and gradients

The limestone bedrock is karstified as evidenced from the karst features mapped, and as such, fissures and conduits are expected to influence flow patterns, directions and rates. However there is evidence that conduit flow is not the dominant flow mechanism. For instance relative to other karstified areas in the country karst landforms are not as numerous and recent work by D. Drew on Flow Duration curves for a number of karst springs suggests that hydrogeological regime in the vicinity of Shanballymore is less karstic than other major karst springs (D. Drew, *pers comm*). The flow characteristics are expected to vary spatially. The most active groundwater flow pathways to the spring and borehole at any given time are also expected to vary depending on groundwater levels in line with different hydrometeorological conditions.

To establish flow directions, travel times, and zones of contribution(s) and to understand the flow regimes, a water well audit, hydrogeological mapping, flow measurements of the streams and springs and dye tracer test was undertaken. Each of these is discussed in turn:

Groundwater levels were obtained from private boreholes, quarries, the supplementary borehole at Mountnorth and springs across the study area during October 2011, and February and July 2012 (including the limestone areas outside the main field area), and from available groundwater monitoring for the M20 EIS. Relevant boreholes, springs, water levels in quarries and the Finnow stream were levelled in by TOBIN Consulting Engineers (February 2012).

The water level data indicate the following:

- (1) There is a complicated and variable groundwater flow pattern both at regional and local scale that is dependent on weather conditions and geology. Within the main central limestone domain of the study area there appear to be divergent flow patterns that are difficult to differentiate. In addition, the numerous springs and their location, the main stream patterns and their hydrology and the borehole data add to the complexity. Figure 18 shows the regional groundwater levels and groundwater directions and Figure 19 shows the groundwater levels and groundwater directions at a local scale around Mountnorth.
- (2) Water levels in the limestones in the vicinity of Copsetown and Ballykitt range from 85 to 87 mOD. In the vicinity of Mountnorth, levels range from 75 to 80 mOD. Further west in the vicinity of Scart the water levels range from 75 to 85 mOD and to the east of Kilmaclenine the levels range from 83 to 90 mOD and further northeast, range from 75 to 85 mOD. The boreholes in the non limestone rocks indicate levels expected with these rocks and are generally quite high, coincident with the elevated areas.
- (3) Water levels in the Namurian rocks to the south are generally quite high and similarly in the Old Red Sandstones at Kilmaclenine. There is one notable exception, that of Mallow Hospital. Based on

information at the GSI, this borehole penetrated beyond the Namurian rocks into the limestone beneath and information indicates very high yields, warm water and a relatively low water table. According to Cork County Council this borehole is no longer in use. Along the limestones to the south of the Namurian tract the evidence from Olivers Cross (Kelly, 2000) and other boreholes is that the water levels in the limestone are very low and indicate a groundwater direction to the River Blackwater.

- (4) Groundwater divides coincide with surface water divides in areas underlain by the Namurian rocks of the ridge to the south of Mountnorth, and by Old Red sandstones of the Kilmaclenine anticline. Whilst the groundwater divides coincident with topographic highs underlain by the non limestone rocks to the north and south appear to be reasonably certain, the divides east and west are less certain and very difficult to locate accurately.
- (5) To attempt to assess the groundwater data, the analysis concentrates on the borehole data only. Examination by successive triangulation using different borehole configurations and analysis of the dipped water levels recorded in October 2011, and February and July 2012 in the limestones indicate a strong southerly groundwater flow component as shown in Figure 19. The static water level in the supply well has been measured up to 4m bgl which is significantly lower than the level of the spring and below the level of the Finnow. Additionally a groundwater well, south of Mountnorth spring in the townland of Mountnorth (see Figure 19) also has a level that is significantly lower than the spring. The levels in October 2011 are lower than the other two datasets: it was considerably drier during this period and it is easier to pick out the southerly groundwater flow component. It is likely that, during wetter weather that the water levels reflect a combination of a shallow and deep flow components. The limestone strata dip 40 to 50 degrees to the south as shown in Figure 9 and Figure 12, and it is probable that the flow is influenced by the orientation of the bedding planes. The springs are located along the banks of the Finnow and it is during wet weather that the Finnow and springs activate.
- (6) Water level fluctuations in the limestones in the vicinity of Mountnorth and Scart vary between 5-10m. Further northeast (northeast of the eastern groundwater divide) data from boreholes close to the Awbeg indicate fluctuations of up to 20m.
- (7) Groundwater gradients are approximately 0.0014 to 0.005 in the limestone, on the lower slopes in the vicinity of Copsetown and Ballykitt in the limestone; gradients steep to 0.02 close the ridge at Kilmaclenine and the ridge at Mountnorth.

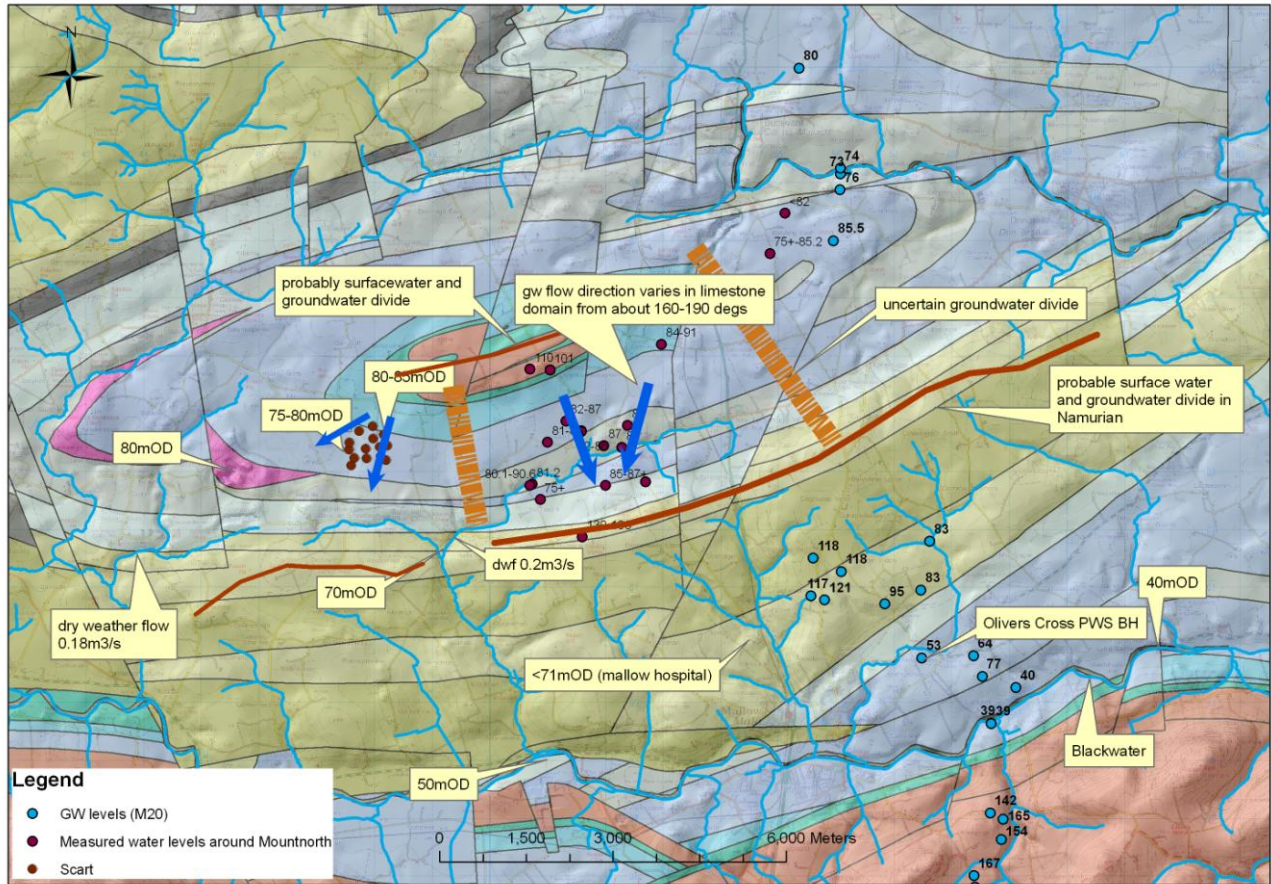


Figure 18 Regional Groundwater levels, streams, geology

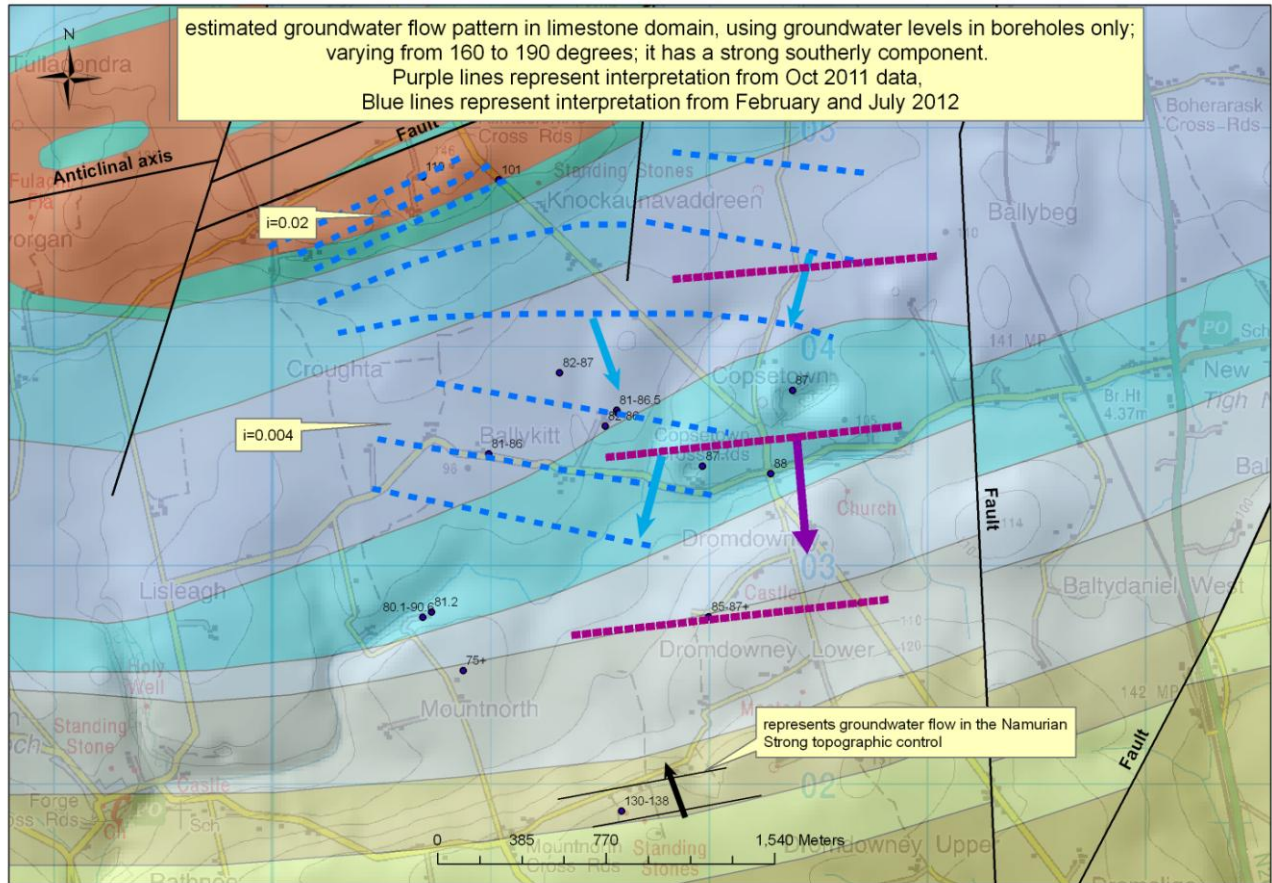


Figure 19 Groundwater levels and directions for area proximal to Mountnorth

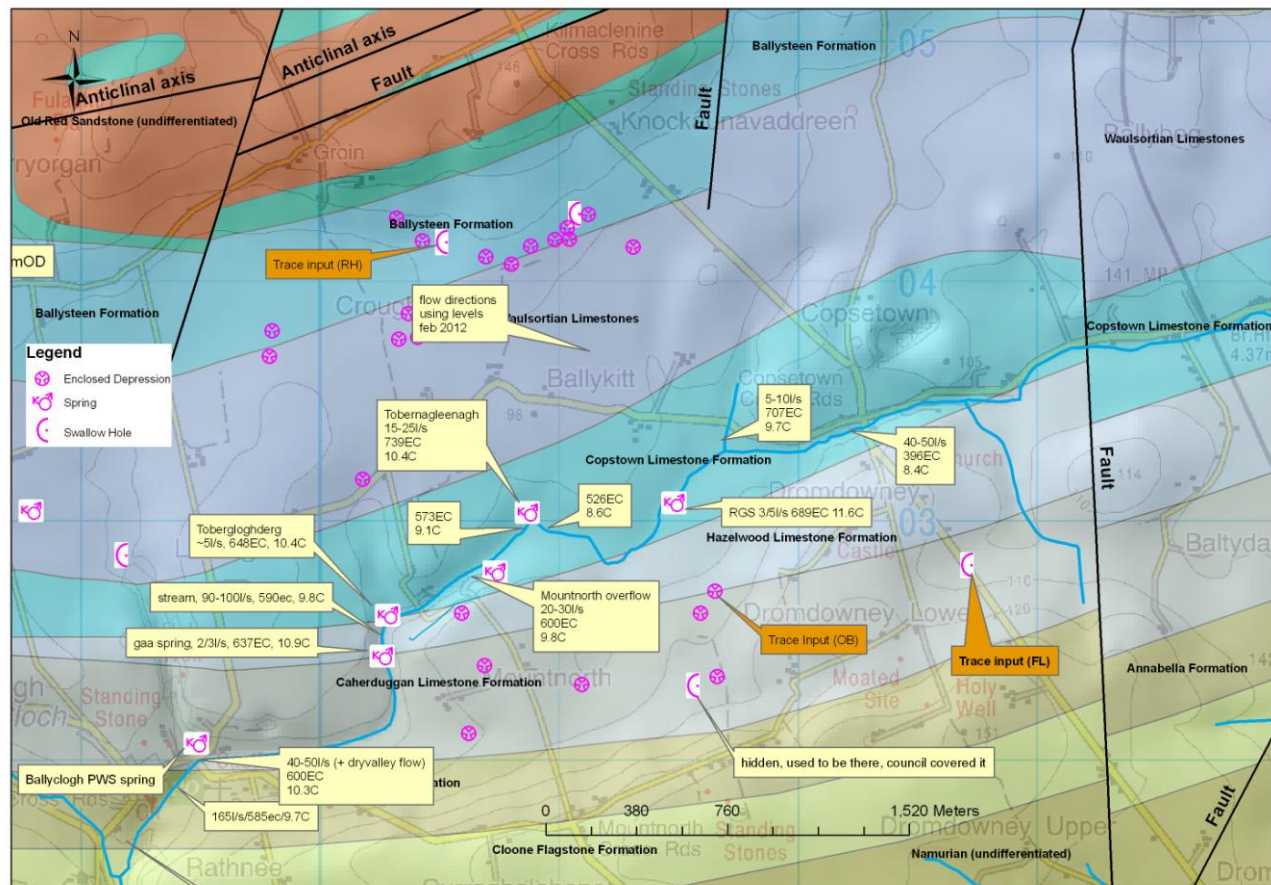


Figure 20 Hydrogeological mapping measurements, karst features and tracer input points

Hydrogeological mapping and flow measurement of the springs, and the Finnow in several locations, was carried out. This was to compare spring flows to stream flow in to test if the Finnow was a gaining stream and predominantly spring fed. Electrical conductivity and temperature was measured also to see if there were changes that may correspond to groundwater inputs. The locations and the measurements are shown in Figure 20. Dry weather flow data for the Finnow were also obtained, and the topographic catchments to the measuring points was used to back-calculate the potential groundwater contributions.

It is known from field visits that the Finnow Stream ceases to flow upstream of the main set of springs during prolonged dry weather. It is reported that the springs reduce greatly in flow, though anecdotal evidence suggests that the springs do not fully dry up with possibly the exception of 'GAA spring', as there is no indication of it on the six inch OSI mapping and local farmers were unaware of it. The spring at Ballyclogh is not reported to dry up.

Electrical conductivity and temperature values of the Finnow at Copsetown cross roads suggests that, at that point, it is dominated by overland flow and / or by groundwater from the Namurian rocks on the ridge to the south of the stream. Further, taking into account the topographic catchment to that point and estimating the likely dry weather flow, the field flow measurement, albeit one data point, suggests not all the potential available groundwater is discharging to the river.

Over the course of its journey from Copsetown cross roads, the electrical conductivity in the Finnow (October 2011) increased from 396 $\mu\text{S}/\text{cm}$ to 585 $\mu\text{S}/\text{cm}$ and the temperature increased from 8.4°C to 9.7°C. This suggests the Finnow is dominated by groundwater and appears to be a gaining stream from the point that the springs are located. It is considered that the springs contribute a significant component of flow to the Finnow. The springs are relatively small, tending to occur along but above the river bank at the base of rock scarp. In the case of Toberchloigdearg, the spring emerges from bedding planes a metre or so above the Finnow stream level as shown in Figure 21. It is considered that the borehole is intercepting deeper groundwater flowing toward the Finnow, as one reported static water level was 4m below the base of the spring which is also significantly below the base of the Finnow. As indicated earlier, it is likely that groundwater flow is influenced by the dip of the bedding planes, and the springs and Finnow are likely to be predominantly fed by up-dip flow.

Further downstream, from the main area of spring contributions, the temperature and electrical conductivity signals of the Finnow reflect the inputs from the springs. Flow data are shown in Figure 20, and also graphed in Figure 22, which compares accumulative spring flows and streams flows. The data broadly indicate an increase in stream flow corresponding to successive spring inputs, though the total flow in the Finnow appears to be greater than the sum of the spring flows, with the difference probably from overland flow and diffuse groundwater discharge to the river. The data do not suggest any significant spring that may have been missed during field mapping or any significant discrete point input *via* the river bed. The spring contributions are estimated to account for between 55% to 78% of the total stream flow. It is likely that diffuse groundwater flow makes up the majority of the remainder.

The Dry Weather Flow of the Finnow stream and Ketragh stream as indicated in Section 5 is 0.2 m^3/s and 0.18 m^3/s respectively based on EPA data. These data represent base flow from the limestone bedrock as both gauges are located just onto the Namurian rocks, south of the Namurian / Limestone boundary. Both these streams occur south of the Kilmaclenine Anticline. The topographic area that contributes to the Ballyclough location is approximately 22 km^2 – which is estimated would generate more than 0.2 m^3/s . As at Copsetown cross roads, the dry weather flow is estimated to be less than the potential available groundwater flow to that point. However, it is known that the volumes of water abstracted from Copsetown Quarry were very large up to 7000 m^3/d which was discharged to the Finnow and may have influenced dwf estimates. Despite this it would be expected that the Finnow at this point would be stronger and groundwater fed. It also indicates highly transmissive limestones with large available yields.



Figure 21 Toberchloigdearg [E150281, N102606], on northern bank of Finnow issuing from a bedding plane; there are red and brown gravels gathered as a 'mini-delta' where the spring water spills into the stream

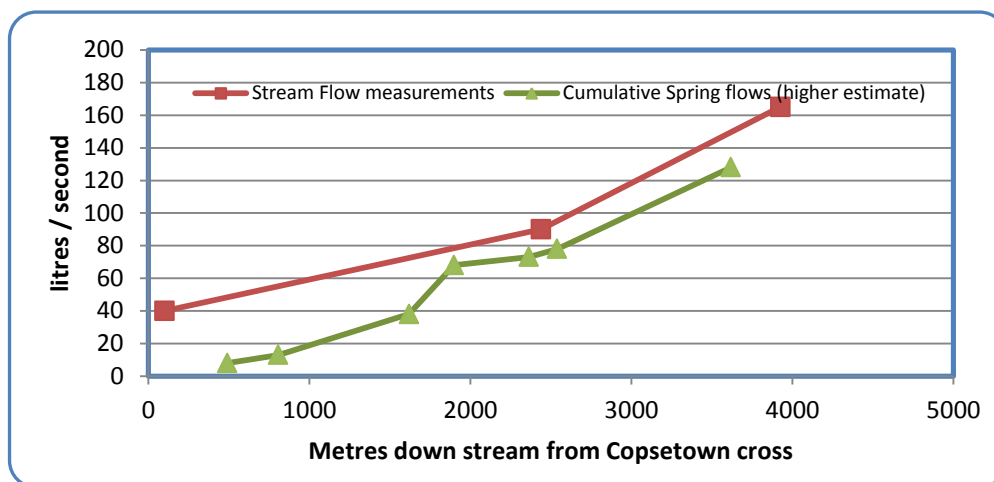


Figure 22 Graph illustrating gain in stream flow corresponding to successive cumulative spring flows

Tracer Tests were conducted from 3 dye injection locations on March 17th 2012, shown in Figure 20 and Figure 23. In addition, the warm spring in Mallow was included in the sampling. None of the traces came through as distinct and clear positives to any of the springs sampled, with the possible exception of a slight result of Optical Brightener to Mountnorth and to a river sampling point just upstream of the spring labelled 'RGS'. It is considered that the dye types and volumes and sampling strategy were appropriate for this type of study. The negative results are similar to those at nearby Shanballymore (EPA, 2010 SPZ report) and also for a study undertaken for the M20 EIS Cork Limerick Motorway scheme (Arup, 2010).

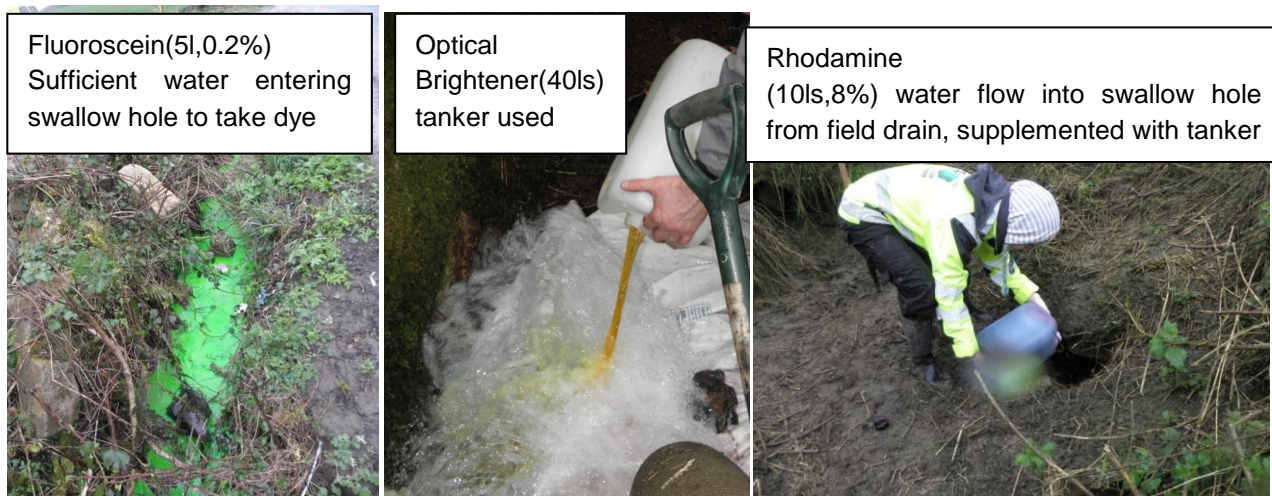


Figure 23 Tracer inputs March 2012 (R.Aznár)

9.3 Hydrochemistry and water quality

Hydrochemical analyses for Mountnorth (20 untreated samples from 2007 to 2011 (EPA data), and data for a few parameters (nitrate, conductivity, chloride) from Local Authority returns from 2000 to 2007) were examined. The water is hard to very hard, with total hardness values of 251–386 mg/l (equivalent CaCO_3) and electrical conductivity (EC) values of 443–749 $\mu\text{S}/\text{cm}$, (average 591 $\mu\text{S}/\text{cm}$). The coefficient of variance of electrical conductivity is 11%, indicating a mixture of diffuse and conduit flow (Doak, 1995). The groundwater has a calcium bicarbonate hydrochemical signature. Alkalinity ranges from 251–386 mg/l

CaCO₃. Samples are within acceptable levels for colour and turbidity, and it is known from the caretaker that the spring water is never discoloured. It cannot be distinguished which samples are likely be from the spring or from the borehole or a mixture.

Figure 24 shows the data for the key indicators of contamination and the main points are as follows:

- Nitrate concentrations range from 14.3–37.1 mg/l with a mean of 25.6 mg/l. The mean is less than the groundwater Threshold Value (Groundwater regulations S.I. No. 9 of 2010) of 37.5 mg/l and less than standard (50 mg/l) set in the Drinking Water Regulations (S.I. No. 278 of 2007). Across the dataset from 2000 to 2011 there is no discernible trend but there are considerable fluctuations: 37 mg/l in January 2008 to 14 mg/l in June 2009. Whilst there is no clear seasonal pattern present in the data, the majority of the peaks are in winter or autumn months, and the 2007 and 2008 data do indicate a concentration rise across the summer to winter. Ammonium concentrations are below the Groundwater Threshold Values.
- Chloride is a constituent of organic wastes, sewage discharge and artificial fertilisers, and concentrations higher than 24 mg/l (Groundwater Threshold Value for Saline Intrusion Test, Groundwater Regulations S.I. No. 9 of 2010) may indicate contamination, with levels higher than 30 mg/l usually indicating significant contamination (Daly, 1996). Chloride concentrations range from 19–25 mg/l with a mean of 22 mg/l.
- The average concentration of Molybdate Reactive Phosphorous (MRP) is 0.01 mg/L P, which is below the Groundwater Threshold Value (Groundwater Regulations S.I. No 9 of 2010) of 0.035 mg/L P.
- The ratio of potassium to sodium (K:Na) is used to help indicate if water has been contaminated, along with other parameters, and may indicate contamination if the ratio is greater than 0.4. The ratio exceeded 0.4 on one occasion (8/12/2009) due to a lower than normal sodium concentration of 4.6 mg/l – which may be anomalous (on the same data the only other parameter that appears to be anomalous is sulphate, for which a concentration of <1mg/l is reported). An interesting aspect to the data is a seasonal cycle in the potassium: sodium ratio, which appears to be due to low potassium concentration in the summer that rise in the autumn and winter months.
- The concentrations of trace metals are low and / or below laboratory detection limits or within normal ranges expected from limestone bedrock, with the exception of Barium whose concentrations are occasionally elevated, possibly due to undissolved sediment load.
- Faecal coliform counts exceeded 0 counts per 100ml fourteen times out of nineteen samples (73%) and exceeded 100 counts per 100ml once in December 5/8/2008, which is indicative of gross contamination. Total coliform counts were exceeded on every occasion.
- There has been one confirmed detection in 2007 of MCPA and mecoprop (active ingredients in herbicides) but concentrations were both below drinking water standards. The concentrations of all organic compounds to date are also below respective laboratory limits of detection.

In summary, faecal and total coliforms are the only parameters to exceed the EU MAC, and do so on a regular basis. However, gross contamination has only occurred once in the collected samples. The contamination may indicate contamination from organic wastes or relatively poor protection at the spring and well head. The concentrations of nitrates and chlorides are those expected from groundwater in an intensively farmed land.

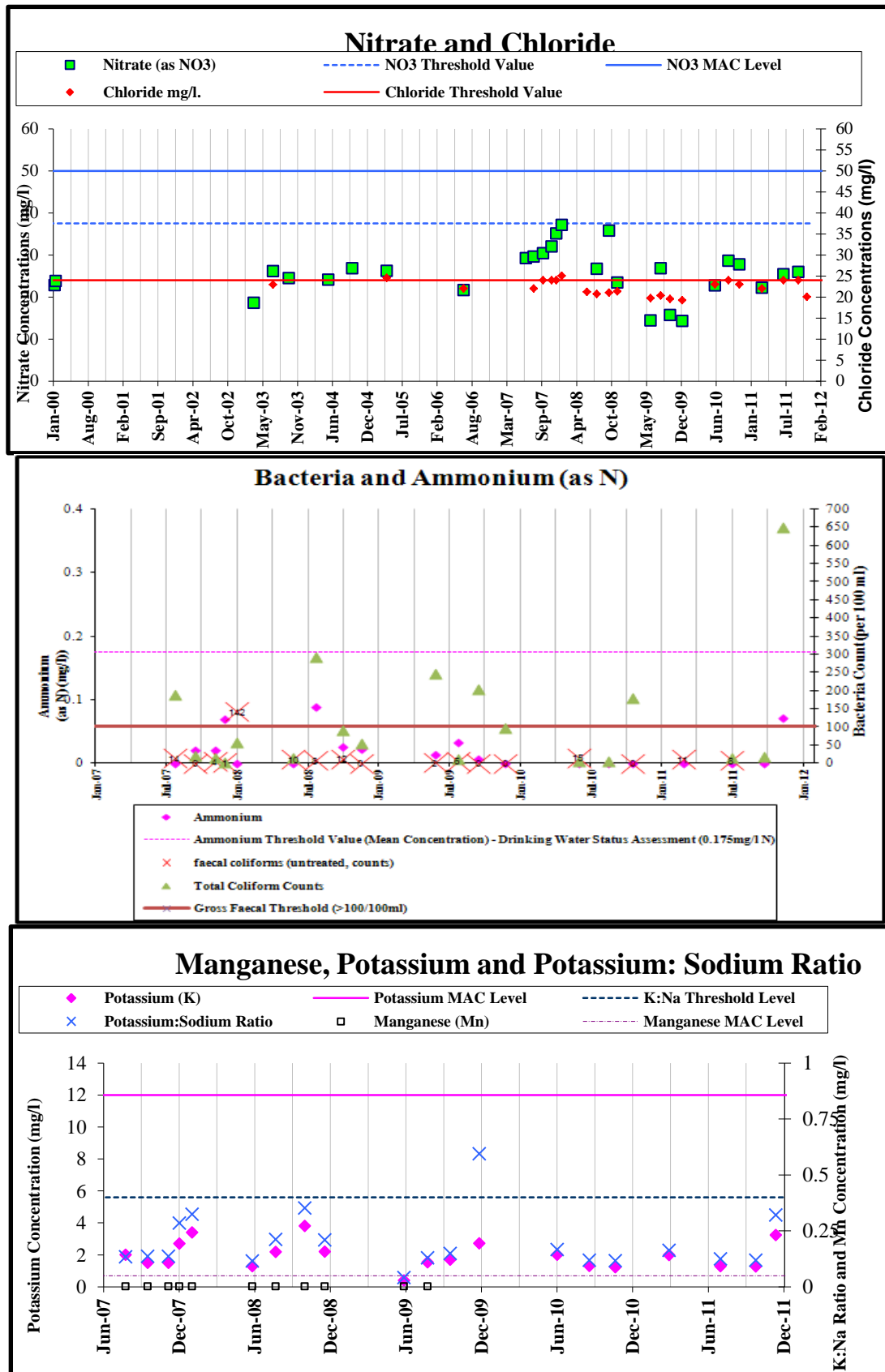


Figure 24 Key indicators of contamination at Mounthnort Spring & Borehole

9.4 Aquifer characteristics

The current published bedrock aquifer map is given in Figure 25. The limestone aquifers comprising the Waulsortian, Hazelwood (Dinantian Pure Unbedded Limestones) and the Caherduggan Formations (Dinantian Pure Bedded Limestones) have been classified by the GSI as Regionally Important Karst aquifers (Rkd), dominated by diffuse flow. The Copstown Limestone Formation (Dinantian Upper Impure Limestone) and the Ballysteen Formation (Dinantian Lower Impure Limestones) have been classified as Locally Important Aquifers that are moderately productive in only local zones (LI). The Namurian Sandstones and the Dinantian Old Red Sandstones are classified as Locally Important Aquifers that are moderately productive in only local zones (LI). The Lower Limestone Shales (Dinantian (early) Sandstones, Shales and Limestones are classified as a Poor Aquifer that is moderately productive only in local zones (PI).

Site investigations, mainly into the Waulsortian, at Scart (Williams, 2010) indicate cavities (infilled and open), dolomitised and fractured bedrock that is variable over short distances and also report hydraulic conductivities of 0.8 to 5 m/d. There are no pump test data available for the borehole at Mountnorth which is located in the Copstown Formation, but it is a high yielding borehole, and suggests high transmissivity in the vicinity of the borehole and spring. Given the shallow depth of the borehole; that the majority of samples indicate faecal contamination (though that it cannot be determined which are from the spring or from the borehole); that deeper water levels are reported during dry weather; and, that the borehole was drilled to draw from deeper groundwater indicates that both shallow and deeper groundwater contribute to the borehole.

The presence of karst features (enclosed depressions, dolines, swallow holes) within the study area provides evidence for karstification of the limestone bedrock aquifer, including the Ballysteen and Copstown Formations. The 'sluggera', shown in Figure 13, indicates that karstification is a dynamic process. The stretch of river along which the springs discharge is underlain by the Copstown Formation. Water levels in the boreholes indicate hydraulic continuity across the Ballysteen, the Copstown and the Waulsortian formations. Further, there are no seepages or springs along the boundary between the Copstown and Waulsortian Formation – the springs occur in the middle mapped part of the Copstown Formation. The dip of bedrock layers may promote groundwater movement southwards. Outcrops into the Copstown Formation are fractured and jointed, suggesting that water can percolate freely through the rock. In addition, the sump water level remains low within the quarry at Copsetown Quarry suggesting that it is transmissive. It is known that the volumes of water abstracted from Copsetown Quarry were very large up to, at up to 7000 m³/d. An assessment of the flow regime of several karst springs across the country, including Shanballymore spring by D.Drew, on behalf of EPA, suggests that the groundwater flow regime in the North Cork area, may not be as karstic as other karst terranes. This is supported by the coefficient of variance of electrical conductivity, which at 6% for Shanballymore, and 11% for Mountnorth, suggests a mix of conduit and diffuse flow; and, the outcrops in the quarries do not appear to show epikarst; and the karst features are not as numerous – though this may be related to a dominance of acidic subsoils across the area. Whilst there is evidence for karstification, it appears that the area is not as karstified as other renowned karst areas.

A borehole drilled by Cork County Council close to Kilmaclenine cross roads is reported to have a very high yield; it is located on the boundary of the Old Red Sandstone and the Lower Limestone shales, and it is likely that it penetrates into the Ballysteen Formation. There are no data specific to the Namurian rocks in the vicinity of Mountnorth and it is assumed that transmissivity is in the order of 0.5-10 m²/d.

For the purposes of estimating velocities to delineate the inner protection zone, the limestones are assumed to have velocities such that groundwater in the limestones in the zone of contribution will reach the source within 100 days.

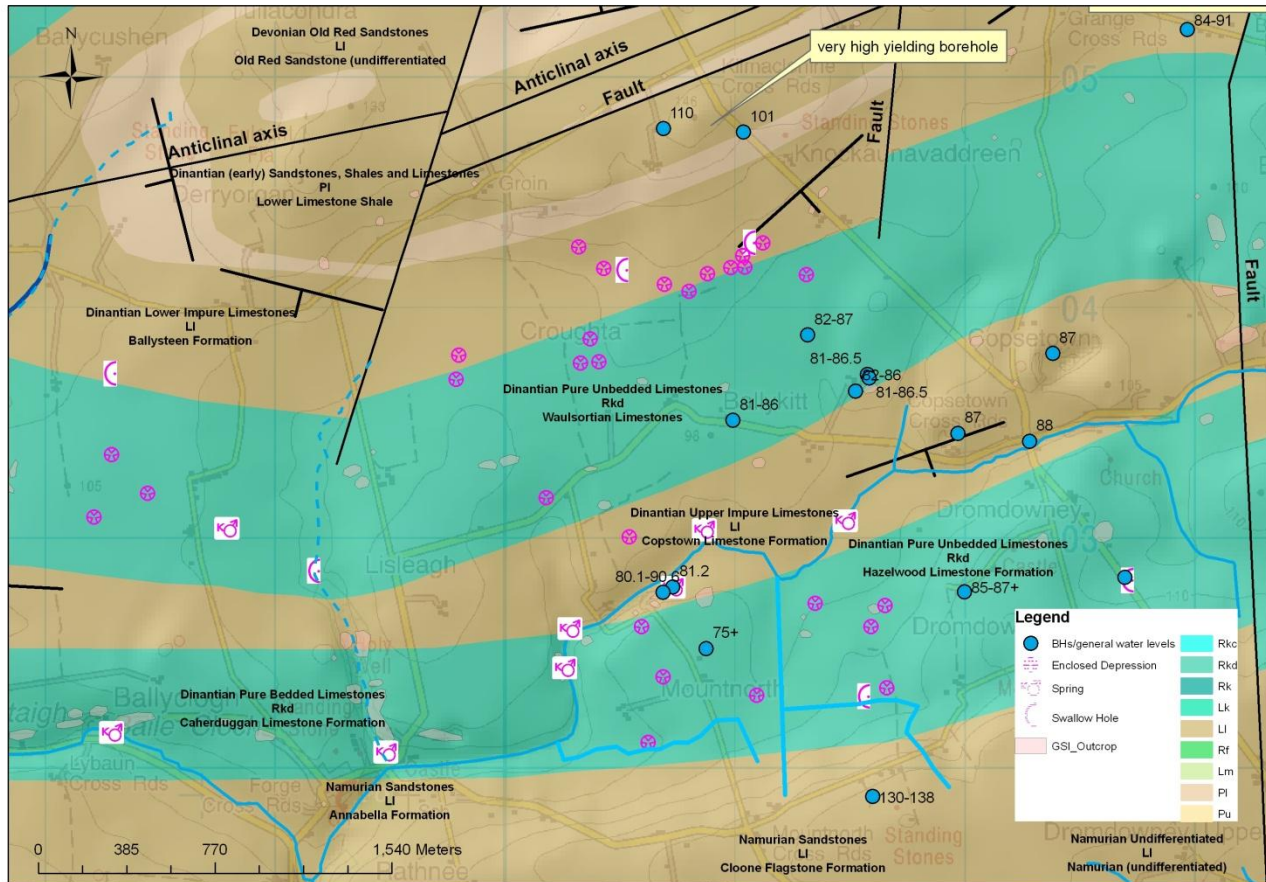


Figure 25 Bedrock Aquifer Map

10 Zone of contribution

10.1 Conceptual model

The current understanding of the geological and hydrogeological situation is given as follows:

- The region comprises a fluvio-karst system – a karstic interfluvium (plateau) with a fluvial system in the river valleys comprising principally the Awbeg Rivers, the Finnow and Ketragh streams draining the interfluvium, which are flowing to the River Blackwater. Numerous small streams flow off the back of the non limestone ridges to the Blackwater.
- The geology although dominated by karstified limestones indicates that there may be a significant structural/geological control on groundwater behaviour particularly where folding and/or faulting is present.
- The karst system comprises solutionally enlarged channels and other karst features at the surface but it appears to comprise a more distributed, less hierarchically organised/focussed system and on

the whole does not appear to be as dominated by conduit flow as other karst areas. The nature of the karst is largely unknown.

- The analysis of the water level data, dry weather flow data, the dye tracing, the hydrogeological mapping and the surface water flow measurements indicate a complicated groundwater flow regime. Based on the groundwater level data there is a significant component of flow to the south across the limestone domain. The negative tracing results support the concept that there is a significant flow component that does not arise at any of the springs.
- The springs, dominated by single outflows, occur along the banks (and along bedding planes) of the Finnow at the base of the karst plateau, appear to be overflows for shallow groundwater heading to the Finnow. The springs may occur where there is a local focus of groundwater flow – possibly related to geological structure. Measurements of the spring flows and the Finnow suggest that the springs are a significant component of the total flow along the Finnow. The Finnow appears to be a gaining stream from where the main springs issue, but its uppermost section, above the springs, dries up in prolonged dry weather periods; as do the springs for the most part. The Finnow and springs appear to collect shallow groundwater whilst the main groundwater flow occurs beneath this shallow flow regime. Further, the dry weather flow of the Finnow, appears to be less than what the estimated topographic catchment could contribute.
- Due to the calculated and interpreted groundwater flow directions, interpreted hydrological and hydrogeological flow regime it is considered that the groundwater flow patterns comprises diffuse and conduit flow; with the springs representative of shallow, possibly conduit driven groundwater and that there is a significant component of deeper groundwater flowing south. It is possible that this component of groundwater ultimately discharges to the River Blackwater. Given the groundwater level data that is evident in the limestones along the Blackwater in the vicinity of Mallow and Oliver's cross there is a gradient that would allow for this to occur.
- Therefore it is considered that Mountnorth source is fed by predominantly shallow groundwater flow from the east and north east. The presence of faecal and total coliforms supports the view that the source is largely fed by shallow groundwater.
- Principally due to the lack of surface drainage on the karst plateau it is considered that there is very little runoff, with the exception of the uppermost slopes south of Mountnorth, and the majority of effective rainfall descends to the water table diffusely. There appears to be few sites of concentrated recharge and none of these indicated a definitive positive trace to any of the springs.
- Limitations to the conceptual model mainly lie with a lack of information on the following:
 - ⇒ Detailed groundwater flow directions between the main springs. The tracing programme attempted to define and distinguish the zones of contribution to the main springs with a particular focus on Mountnorth Spring. However, as no tracer was positive at Mountnorth there is still a great deal of uncertainty associated with the most likely zone of contribution.
 - ⇒ Long term discharge data from the springs, particularly the overflow at Mountnorth. Information on this is required to be confident on the size of the area required to provide the water to the spring. Further, the groundwater regime is unknown for the other springs in the area.

- ⇒ Water level data in the boreholes in the vicinity of Mountnorth and to a wider extent across the limestone domain and as far south as Mallow, particularly during prolonged dry weather periods which would give more information on the overall groundwater flow regime.

10.2 Boundaries

The boundaries of the area contributing to the source are based on the considerations and limitations described above. It is difficult to distinguish the zone of contribution with any degree of certainty to Mountnorth from the other springs and to differentiate the shallow and deep groundwater flow systems. This means that quite a large area could be contributing to the springs but the zones of contribution to all the springs and boreholes need to be considered together. The boundaries are very difficult to define due to the uncertainties of groundwater flow.

Taking all of the evidence, it is the water level data and the negative tracing on which the boundaries are based. It is likely that the spring and borehole are predominantly fed by groundwater from the north, northeast and east and to a lesser degree to the south. This is depicted as the most likely Zone of Contribution in Figure 26.

The **southern** boundary is based on the water level data and is considered to be coincident with a topographic divide present south of the spring and borehole. It allows for shallow groundwater flow from the south and also takes account of the distance that the borehole could abstract water from; which based on the uniform flow equation is between 100 and 300m. The borehole data at Mountnorth farm suggests that the gradient is southerly. There is a significant topographic depression that is present at the base of the hill where Mountnorth townland is marked. It is considered that on the upper slopes beyond Mountnorth up to Mountnorth cross roads that groundwater within the Namurian will flow into the limestones and join the regional groundwater flow to the south. There are also drainage ditches running down the uppermost slopes that are likely to take much of the water away directly to the Finnow. The negative traces at Dromdowney Lower and Dromdowney supports this boundary.

The **western, northern, northeastern and eastern** boundaries are based on the water level data, groundwater flow directions and on topography. They are delineated subdued topographic highs toward the Kilmaclenine ridge. The negative traces at Groin in the north and Dromdowney also support this boundary.

As indicated there is a great deal of uncertainty regarding the boundaries and further work is recommended outlined in Section 14, which would help to improve the conceptual model and delineated boundaries.

10.3 Recharge and water balance

The term 'recharge' refers to the amount of water replenishing the groundwater flow system. The recharge rate is generally estimated on an annual basis, and 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. The recharge coefficient is estimated using Guidance Document GW5 (Groundwater Working Group 2005).

The recharge calculations are summarised as follows:

Average annual rainfall (R)	1000 mm
Estimated P.E.	450 mm
Estimated A.E. (95% of P.E.)	428 mm
Effective rainfall	572 mm

At Mountnorth, there is a general lack of a surface drainage system apart from the Finnow and a couple of deep drainage ditches to the south of the spring running of the steep southern flanks covered by low permeability till with shallow rock toward the top. The bulk recharge coefficient is based on:

14% of the area gets a 0.35 rc [area occupied by Moderate Vulnerability (moderate permeability subsoils)]

60% of the area gets a 0.80 rc [High vul (mod permeability subsoils, well drained soils)]

26% of the area gets a 0.9 rc [Extreme, X, no surface water features]

Bulk Recharge coefficient	76%
Recharge	435 mm

Water balance: The area described above and shown in Figure 26 is 5.5 km², and is sufficient for over 300% of the current abstraction rate and estimated overflow. It is a conservative area allowing for varying groundwater flow directions and associated uncertainties.

11 Delineation of source protection zones

The Source Protection Zones are a landuse planning tool which enables an objective, geoscientific assessment of the risk to groundwater to be made. The zones are based on an amalgamation of the source protection areas (also the Zone of Contribution) and the aquifer vulnerability. The source protection areas represent the horizontal groundwater pathway to the source, while the vulnerability reflects the vertical pathway. The Source Protection Areas are subdivided into an Inner Protection Area and the Outer Protection Area.

The **Inner Protection Area (SI)** is designed to protect the source from microbial and viral contamination and it is based on the 100-day time of travel to the supply (DELG/EPA/GSI 1999). This is based on the velocities given in the Aquifer Characteristics. All the limestone area in the Zone of Contribution is within the 100 day time of travel. The **Outer Protection Area (SO)** encompasses the entire zone of contribution to the source, described in the previous section. It is based on hydrogeological mapping and is larger than the area required to supply 150% of the yield and as the entire ZoC is within the 100 day time of travel, the SO is the same as the SI, thus the entire ZoC is termed SI.

The **Source Protection Zones** are shown in Figure 26 Source Protection Zones to Mountnorth, and are listed in Table 11-1.

Table 11-1 Source Protection Zones

Source Protection Zone	m ²	% of total area (5.5 km ²)
SI/X	325119	6%
SI/E	1141676	20.9%
SI/H	3193097	58.5%
SI/M	799672	14.6%

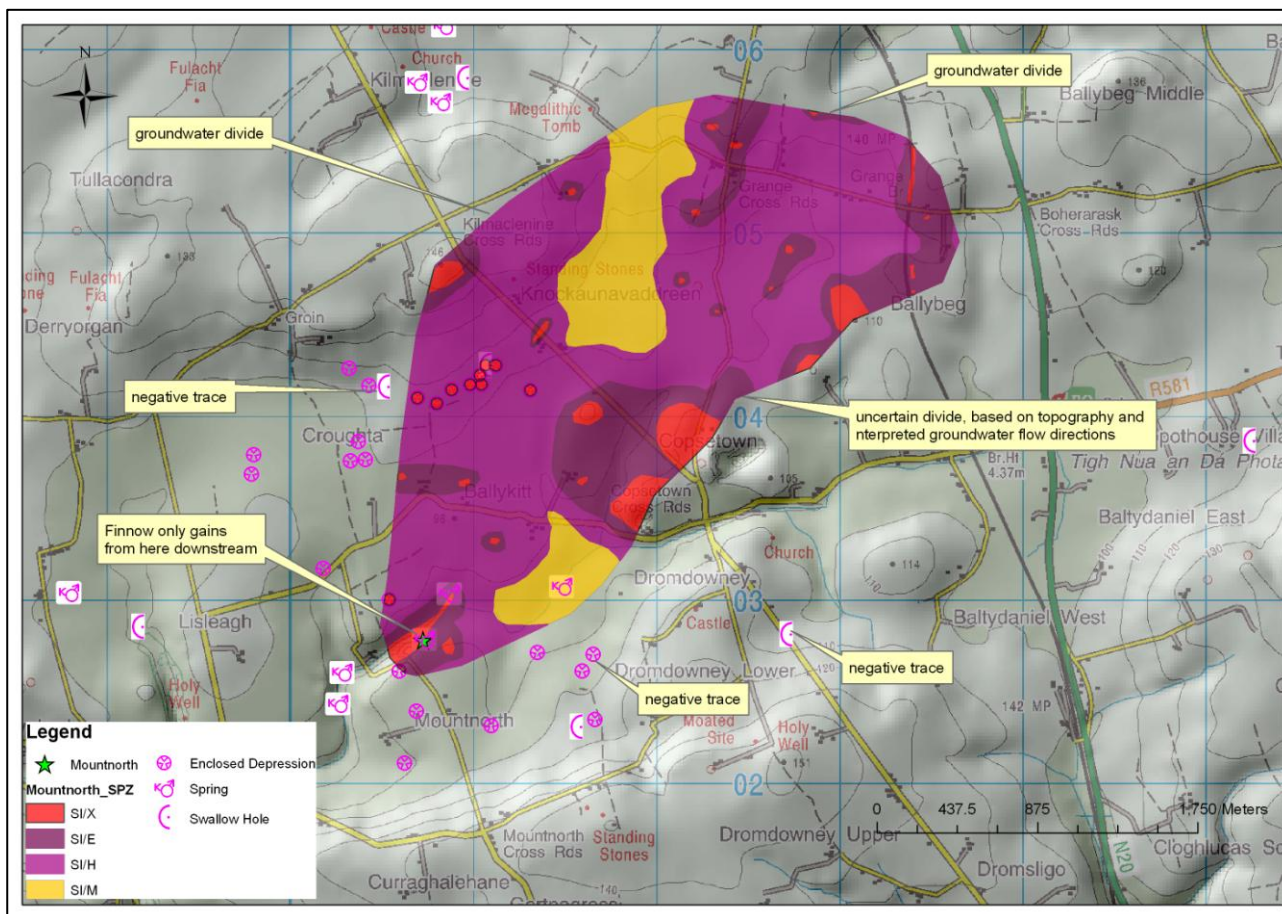


Figure 26 Source Protection Zones to Mountnorth

12 Potential pollution sources

The spring, despite being covered is vulnerable due to the gaps in the concrete slabs and from the very shallow rock and scarp to the south side of the chamber. The borehole is not grouted. The water quality reflects the vulnerability and susceptibility of the source due to the persistent faecal and total coliform counts.

The Inner Protection Area (SI) encompasses the entire ZoC which ranges from **'extreme'** to **'high'** vulnerability to contamination. Land use in this area is mainly a mixture of grazing cattle and tillage. To the immediate south of the source, the first 200 m of the land surface is predominantly **'extreme'** (both **'E'** and **'X'**) with a steep scarp occupying the final 60m to the source.

There are number of houses and farms upgradient of the boreholes which pose a risk to the source.

Finally, there is only a small length of road present in the ZOC and the traffic density is low, so the risk of contamination is low from this source.

13 Conclusions

- The Mountnorth Spring and Borehole are drawing water from a karstified limestone bedrock. There are considerable uncertainties regarding the nature of karstification and the nature of the groundwater regime. The data indicate a strong southerly groundwater flow component and it is on the basis of this data that the zones are delineated.
- The water quality indicates persistent contamination - generally at a low level but occasionally gross contamination occurs.
- The groundwater vulnerability is mainly '**extreme**' to **high**' and borehole is not grouted and the spring chamber is susceptible to contamination.
- Land use pressures are relatively '**moderate**'.
- The ZOC encompasses an area of 2.7 km². The Source Protection Zones are based on the current understanding of the groundwater conditions and the available data. Additional data obtained in the future may require amendments to the protection zone boundaries.
- Whilst the tracing results are negative they do indicate that the karst regime differs in behaviour to other karst regimes such as those in Mayo, Galway and Roscommon, for which dye tracing has been a significantly more successful technique. Recent work in mapping Radon activity in locating groundwater discharges has been successful (Wilson et al, 2011) and may offer an additional tool to assist in locating groundwater discharges to rivers other than the observable springs along river banks.

14 Recommendations

- Improve well head protection to the spring and borehole (grouting).
- Further investigations might usefully include.
 - Obtain long term discharge data from springs and Finnow in the vicinity of Mountnorth and long term water level data from Scart, Copsetown and private boreholes south and north of Finnow.
 - Tracer testing to be redone on - intensify sampling regime and extend sampling sites.
 - Investigate rivers – Finnow, Awbeg, Ketragh with new radon mapping techniques.
 - Record at the time of sampling whether it is the spring or borehole being used.

The recommendations above, particularly long term water level monitoring and flow monitoring will assist in improving the conceptual model and the boundaries of the zone of contribution.

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