Environmental Protection Agency

Establishment of Groundwater Source Protection Zones

Lismore, Cappaquin, Ballyduff Water Supply Scheme

Ballyhane Borehole

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

The Ballyhane borehole source contributes to the Cappaquin part of the greater Lismore-Cappaquin-Ballyduff Water Supply Scheme.

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 Ballyhane borehole.
- To assist the Environmental Protection Agency and Waterford 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, a field walkover and on mapping techniques which use inferences and judgements based on experience at other sites. As such, the maps cannot claim to be definitively accurate across the whole area covered, and should not be used as the sole basis for site-specific decisions, which will usually require the collection of additional site-specific data.

2 LOCATION, SITE DESCRIPTION AND WELL HEAD PROTECTION

The Ballyhane borehole (henceforth referred to as "the source") is located 8 km east southeast of Cappaquin in the townland of Ballyhane, as shown in Figure 1. The source is located in a 10 m by 10 m gated compound with concrete post and rail fencing, adjacent to the N72 from Cappaquin to Dungarvan / Waterford. The compound contains the source pumping house, which also houses the treatment system. The borehole is located inside the pumping house and in this report is labeled borehole PWSBH01.

The top of the borehole casing is slightly raised above the floor level of the pumping house. The floor level is at the same elevation as the surrounding ground level outside.

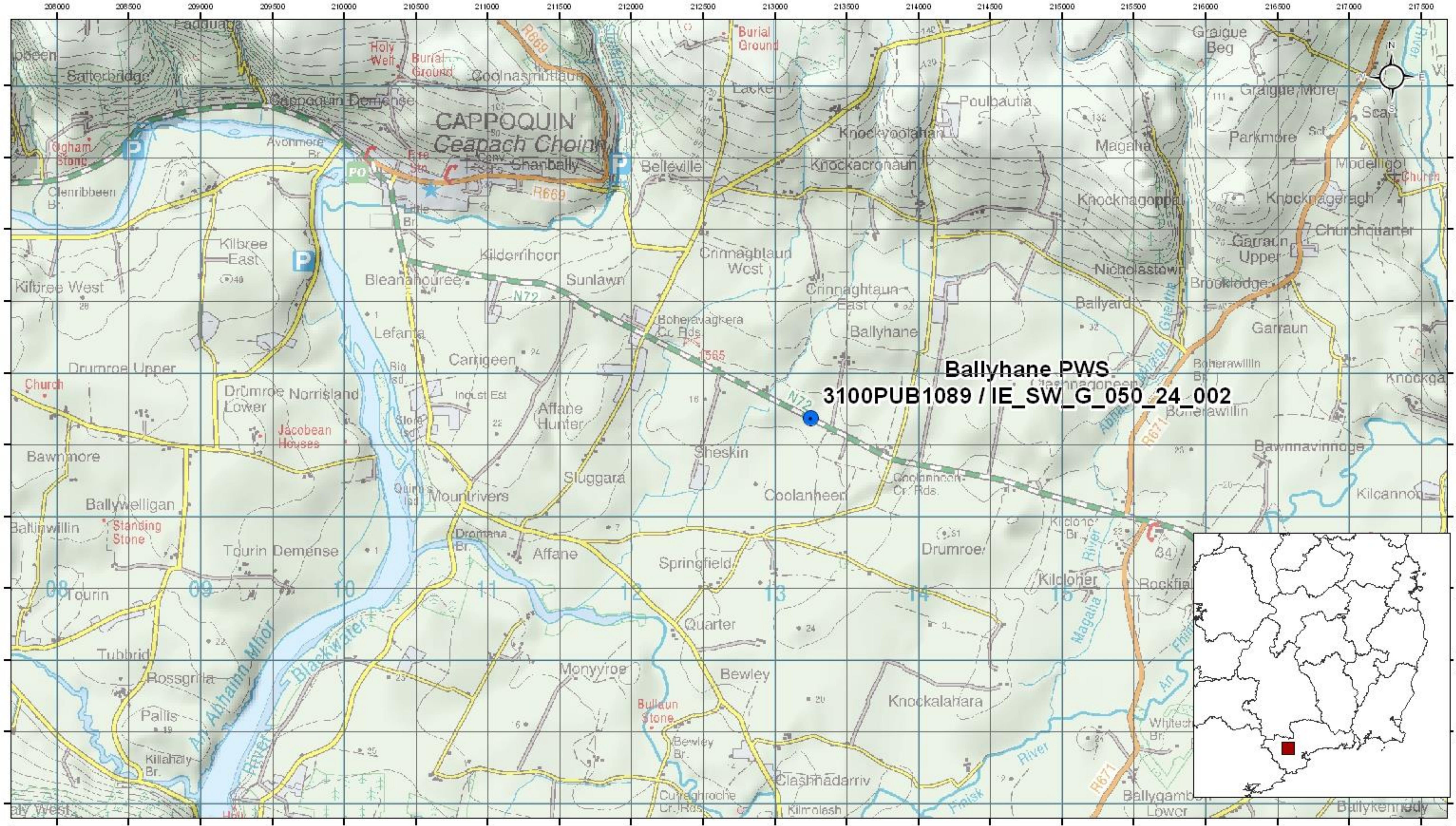

Figure 1 Ballyhane PWS Site Location Map

● PWS Abstraction

—— River

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0 0.25 0.5 1
km

3 SUMMARY OF WELL / SPRING DETAILS

No original borehole records were available for borehole PWSBH01, however various historical Waterford County Council records relating to the source make reference to the borehole and data from these sources have been used in the compilation of Table 3-1.

The borehole was drilled before 1976, probably in autumn 1975, when a 72 hour yield test was carried out on it. The borehole diameter is 200 mm (8 inches) and the depth quoted in 1976 water quality sampling records was 25 m (82 feet). The borehole was dipped to a total depth of 26.7 m in October 2009.

The average abstraction from the source is 345 m^3/day, based on Waterford County Council data. Data from the year 2000 indicate that in that year the average abstraction was 334 m^3/d with a minimum monthly rate of 271 m^3/d in December and a maximum of 477 m^3/d in July (MCOS, 2001).

Table 3-1 Summary of Source Details

EU Reporting Code	IE_SW_G_050_24_002
Borehole Name	PWSBH01
Grid reference	E213257 N97706
Townland	Ballyhane
Source type	Borehole
Drilled	unknown
Owner	Waterford County Council
Elevation (Ground Level)	approx. 15 m AOD[1]
Depth	26.7 m
Depth of casing	unknown
Diameter	200 mm
Depth to rock	unknown
Static water level[2]	approx 10.66 mbtc[3]
Pumping water level[4]	10.66 mbtc
Average abstraction rate (Co Co records)	345 m^3/day

Note 1: mAOD = metres above ordnance datum; Note 2: water level measured on 03/11/2009 while borehole was pumping. This level is approximately the static level because a yield test in 1992 at three times the current yield generated only 0.02m of drawdown; Note 3: 'mbtc' = metres below top of casing & tc = top of 8-inch steel casing; Note 4: Water level measured on 03/11/2009.

Photograph 1 Borehole PWSBH01 Pumping House

Photograph 2 Borehole PWSBH01

4 METHODOLOGY

Site visits, site walk-overs and field mapping (including a well survey, groundwater level survey, mapping of drainage indicators and logging of bedrock outcrops and subsoil exposures) of the study area were conducted between 19/10/2009 and 03/11/2009. An interview with the source Caretaker was carried out on 19/10/2009.

Due to the fact that previous large scale pumping tests did not generate significant drawdown in the pumping well, it was decided not to carry out a pumping test during this study.

The locations of all of the features investigated during the site visits and identified during the desk study are shown in Figure 2. A summary table of the location data collected during the site visits and field mapping is provided in Appendix No. 1.

5 TOPOGRAPHY, SURFACE HYDROLOGY AND LANDUSE

The borehole is located in a broad valley which runs roughly east-west between Lismore and Dungarvan. Ground elevation at the site is approximately 15 m AOD. The area surrounding the borehole is gently undulating. From the site, the ground slopes gently to the south southwest toward the bottom of the valley, which drops to 0 mAOD at the River Blackwater estuary 3 km to the west. The ground rises gently to the north and northeast to approximately 60 mAOD at the foot of the Knockmealdown Mountains. The ground rises steeply to the north of this, reaching 207 m AOD at Coolnacreena 5 km north of the borehole.

The broad valley is drained by the River Finisk in the study area (Fig 1). The river meanders west along the valley floor and has a west northwest trend where it passes 1.7 km to the south of the source. The Finisk drains into the Blackwater estuary which runs north-south to the west of the source. The Magaha River runs north-south into the Finisk approximately 2.2 km east of the source. Two streams are mapped running north northeast to south southwest through the study area at distances of 300 m and 1 km west northwest of the source. The level of the base of the stream closest to the source is 14.9 mAOD where is crosses the N72 road (at surface water monitoring location SW02) (MCOS, 2001). These are the only two streams crossing the study area in a 5 km wide zone between Cappaquin and the R671 road to the west of the source. The drainage density of the area is considered to be low at less than 1 km/km^2. The two streams converge 1.7 km southwest of the source and join the River Finisk a further 800 m to the south southwest. A further stream runs west to east through the townland of Ballyard to the northeast of the source.

The stream closest to the source was found to sink underground at karst feature KF02. The stream to the west of this flows through a GSI mapped sink hole feature (KF10), but at the time of the site visit the sink hole site was flooded and the stream continued overland downstream of the feature, such that it was not possible to confirm that the stream was losing water at that location.

Areas with plant indicators of poor drainage conditions and with artificial drainage were mapped to the north of the source in low lying parts of Crinnaughtaun East and West and Ballyard and immediately south and southwest of the source in Coolaneen and Sheskin. In the Crinnaughtaun East and Ballyard areas this area coincides with the west to east running stream draining the topographic low.

Land use in the area is primarily agricultural, with lands used for livestock and bloodstock pasture and for arable cereal crops. There is a large apple orchard on the Crinnaughtaun Estate in the townland of Crinnaughtaun East to the north of the borehole. The nearest farmyards to the source are located approximately 475 m to the east northeast and southeast of the borehole. There are numerous abandoned private boreholes and private boreholes with poor well head protection located in and near farmyards or on agricultural land within the study area.

The population density of the study area is moderate, with roughly 50 domestic residences and related farmyards located within a 1.5 km radius of the source.

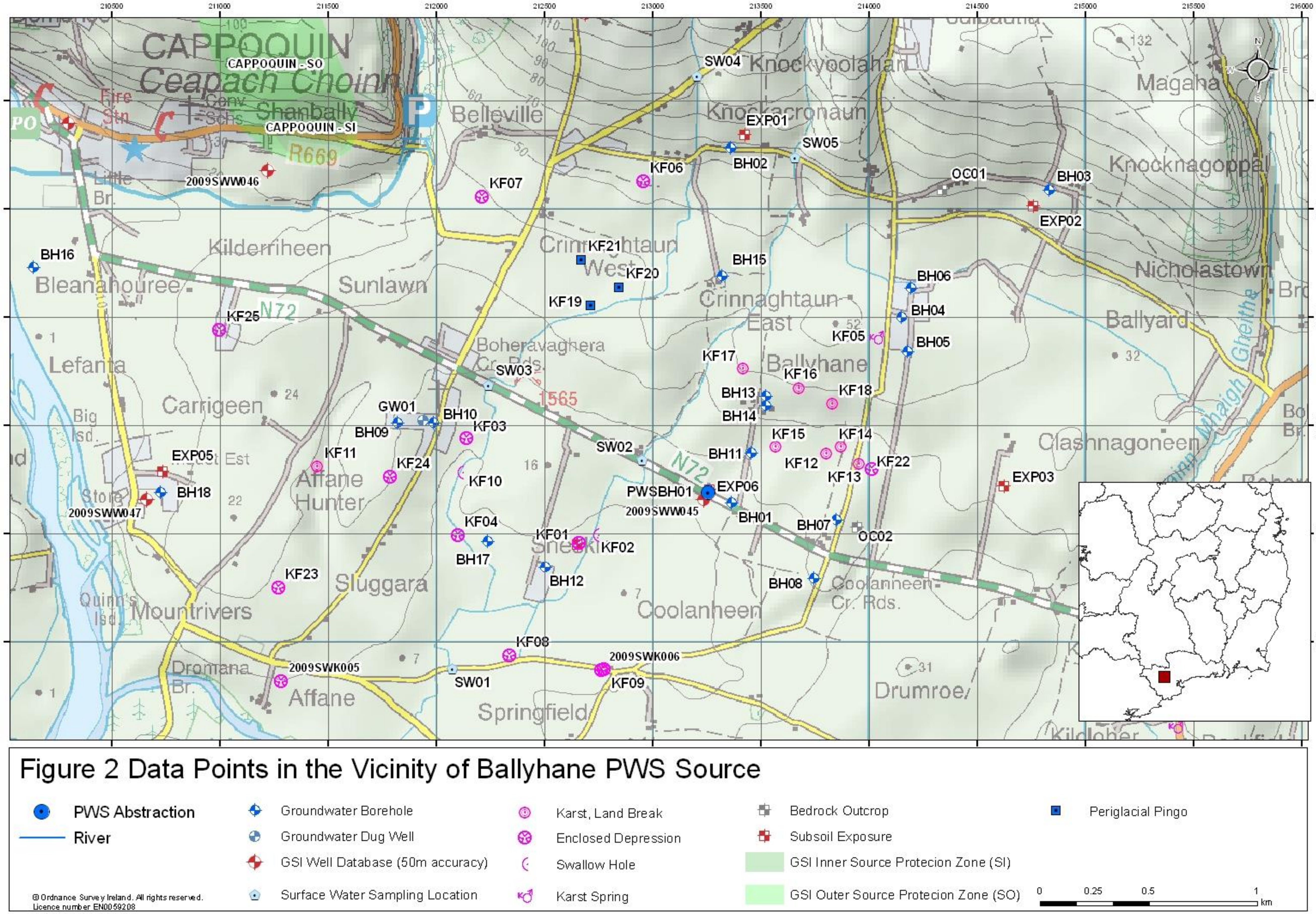


Figure 2 Data Points in the Vicinity of Ballyhane PWS Source

6 GEOLOGY

6.1 INTRODUCTION

This section briefly describes the relevant characteristics of the geological materials that underlie the Ballyhane source. It 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 East Cork - Waterford, Sheet 22, 1:100,000 Series (Geological Survey of Ireland (GSI), 2005) and accompanying memoir (Sleeman *et al*, 2005), the GSI Well, Borehole and Karst Databases and on bedrock outcrop and subsoil exposures encountered during site visits.

6.2 BEDROCK GEOLOGY

The geological formations occurring in the study area are detailed in Table 6.1. The bedrock geology of the area is shown in Figure 3.

Table 6.1 Bedrock Geology of the Study Area

Formation	**GSI Code**	**National Generalised Bedrock Map Name**	**Geological Description**
Waulsortian Limestones	WA	Dinantian Pure Unbedded Limestones	Pale to medium grey, massive limestones of mudmound origin. Often contain cavities filled with internal sediments and sparry cement
Ballysteen Limestone	BA	Dinantian Lower Impure Limestones	Dark, muddy limestones and shale
Ballymartin Limestone	BT	Dinantian Lower Impure Limestones	Limestone and dark-grey calcareous shale
Lower Limestone Shale	LLS	Dinantian (early) Sandstones, Shales and Limestones	Sandstone, mudstone and thin limestone
Kiltorcan Sandstone	KT	Devonian Kiltorcan-type Sandstones	Yellow and red sandstone and green mudstone
Knockmealdown Sandstone	KM	Devonian Old Red Sandstones	Medium-grained, pink-purple Sandstone

Outcrops in the area showed dips in the Waulsortian (WA) of 60^0 to the northwest 600 m to the north of the source and 70^0 to the south 1.5 km south of the source (MCOS, 2001). Further outcrops to the south of the source at KF01 and KF08 showed the rock is heavily jointed and fractured with orthogonal vertical fracture sets trending east/west, northeast/southwest and north/south. Fracture spacing was generally 0.1 to 0.3 m with solution enlarged apertures varying between 0.001 and 0.01 m and occasionally 0.1 m. A further sub-horizontal set was encountered dipping 30^0 to the northeast. Large pore spaces in places in the outcrop at KF01 indicate potential dolomitisation of the limestone. Further evidence of dolomitisation occurs in Cappagh Quarry 5 km south east of the source (M^{c}Daid, 1994).

A major regional synclinal axis is mapped running west northwest to east southeast along the valley floor, with the source located on the northern limb of the fold. Bedrock dips to the north and south of the source may indicate that the source is located on the anticlinal axis of a smaller fold (MCOS, 2001). Further north at the boundary between the limestone formations and the Kiltorcan sandstones (KT) a number of north-south trending faults are mapped cutting across and transversely displacing the formation boundaries in the Knockacronaun and Crinnaughtaun areas. The WA in the area has been subjected to intense faulting with resulting jointing steeply inclined and predominantly trending north-south (McDaid, 1994).

6.2.1 Karst Geology

Hydrogeological mapping (November 2009) included searching for karst features in the vicinity of the source. The geomorphology of the area is complex with many humps and hollows of interpreted complex and varying genetic origin. In total 25 potential karst features have been identified in the study area within a 1.5 km radius of the source. Many of the features make up two high density karst clusters in Ballyhane to the northeast of the source and in the Affane Hunter – Sluggara area. All of the features identified are shown on Figure 2. The various features are discussed in Table 6.2 and details of each site are provided in Table A1.1 in Appendix 1. Only six of the 25 features identified were previously known in the GSI database (2 No.) and in the Nitrate Vulnerable Zones study of the area (4 No.) (MCOS, 2001). Further karst features are known in the area immediately outside the study area from GSI databases and from historical maps of the area.

Highly fissured karstified bedrock is considered to occur throughout the upper 15 m of the limestone bedrock (M^{c}Daid, 1994). The majority of the karst features occur in the area underlain by the clean WA limestones. The muddy Ballysteen Limestone (BA) is less prone to karstification. Nonetheless, the solutional karst feature KF06 (and possible KF07) is mapped as underlain by BA limestones, while the feature KF05 is located on the boundary between the WA and BA (see Figure 3). These features may be a result of enhanced solution potential of acidic runoff from the KT sandstone bedrock areas impacting on the generally resistant muddy BA limestones. Such conditions are known to occur at other places in the country where sandstone and muddy limestone lithologies are juxtaposed, such as in the Trim Groundwater Body (GSI, 2004a).

In addition to the “point” karst feature locations a number of other more extensive features were recognised. Both streams to the west of the source intersect and sink into swallow holes, such that the streams themselves from part of the karst environment. Two dry valleys are also visible on the 1:50,000 scale topographical map of the area in the townlands of Affane Hunter – Sluggara and in Coolaneen. Furthermore the townland name Sluggara derives from the Gaelic word for sink-holes. Landowners in the area reported that land breaks (see Table 6.2, KF11 – KF18) are extremely common in the townlands of Affane Hunter and Sluggara, especially along the route of the N72 between Affane Cross and the townland of Bleanahouree. The land breaks have been interpreted to be the surface expression of karst collapse features at depth. The land break locations are expected to have subsoil material overlying the bedrock and to act as a preferential pathway through the subsoil rather than as a direct connection from the ground surface to the underlying bedrock.

The karst geology is also known from logging of the limestone bedrock in outcrop and boreholes. Solution enlarged joints and fractures were observed in bedrock outcrop at KF01 and KF08. The owner of borehole BH13 reported that during drilling of the borehole a large cavity was encountered approximately 24 m bgl in which the drill rods got stuck.

Overall the karst geology is considered to extend across the parts of the study area underlain by limestone. The main trend of the solution features is expected to be north-south in line with the predominant trend of faulting. Evidence of both north-south and east-west trending solution enlarged joints and fractures has been seen in outcrops in the study area. In the north of the study area, the genesis of the karst features present may be linked to runoff from the sandstone bedrock to the north. Zones with a very high intensity of karst features were identified in the Affane Hunter – Sluggara area and in the Ballyhane area northeast of the source.

Table 6.2 Discussion of Potential Karst Features

Feature ID	Discussion	Feature Type Conclusion
KF01, KF04, KF06, KF08 – KF09	Enclosed Depressions confirmed during site visits	Karst – enclosed depression
KF02 & KF10	Sink holes – KF02 confirmed during site visit, KF10 detailed on GSI Karst database	Karst – sink hole
KF05	Enclosed feature marked on the historical 25” to 1 mile topographical map. Presence confirmed during site visit. Site recently drained but appears to be a small spring, which may be related to the underlying limestone bedrock	Possible karst spring but may be related to perched watertables in the subsoil
KF03 & KF07	Large, shallow, flooded circular depressions. Marked on the historical 25” to 1 mile topographical map. Presence confirmed during site visit but not clear cut karst collapse features	Possible karst enclosed depression / possible periglacial pingo
KF11 – KF18	Land breaks reported by landowners. “Land break” or “ground break” is a local term for a sudden/overnight collapse of the ground surface. Due to the bedrock geology these collapses are likely to be karst related. The largest reported collapse was KF11 which formed a trough 9 m long and 2.5 m deep. KF18 formed a circular depression approximately 4 to 6 m deep. These features have all been backfilled with stone and covered with soil.	Likely to be related to collapse of karst features below the subsoil – karst enclosed depressions
KF19 – KF21	Flooded circular depression reported by landowner. Landowner does not know if the depressions are backfilled land breaks.	Possible periglacial pingos
KF22 – KF24	These features are marked as karst features in maps produced for development of Nitrate Vulnerable Zones in the study area (MCOS, 2001). KF22 may be the same feature as KF13.	Karst

6.3 SOILS

The soils across the study area are generally comprised of brown-earth and grey-brown podzolics of the Dungarvan Series (MCOS, 2001). These are classified as deep, well-drained mineral soils (AminDW) across the majority of the area (EPA website and An Foras Talúntais, 1980). A large area of deep, poorly drained mineral soil (AminPD) is mapped in a topographic low running east to west at the base of the Knockmealdown mountains through the townlands of Ballyard, the northern part of Ballyhane and Crinnaughtaun East and West. A further poorly drained area is mapped immediately southwest of the source between the townlands of Sheskin and Coolanheen in the low areas of the undulating topography. These areas were mapped by An Foras Taluintais as being area of 'slow permeability', which suggests that the subsoils are of low permeability status (R. Meehan 2009, pers. comm.). The areas of poorly drained soils coincide with the areas of plant indicators of poor drainage and sites of artificial drainage noted in Section 5. Alluvial soil is mapped along the north-south running stream closest to the source and along the stream running west to east through Ballyard and along the major rivers.

6.4 SUBSOILS GEOLOGY

The majority of the study area is underlain by till derived from Devonian sandstone bedrock material (TDSs) (Meehan, 2002). Alluvial subsoils are mapped along the north-south running stream closest to the source and along the stream running west to east through Ballyard as well as along the major rivers. Small areas of bedrock outcrop are mapped at several locations in the area to the south of the source. The subsoil map of the area is shown in Figure 4.

Subsoil Permeability

The subsoils across County Waterford are currently being classified into one of three GSI permeability categories in the preparation of a Groundwater Vulnerability map for Waterford County Council, by TOBIN on behalf of the Geological Survey of Ireland. The underlying data were made available for the preparation of this report. Under the TOBIN/GSI investigations the subsoil permeability of the till units in the study area has been classed as '***Moderate Permeability'***, based on two subsoil exposures in the townlands between 2 km and 3 km from the source. Two further trial pits in the area, both underlain by WA limestones, one adjacent to the source and another 2.6 km to the west in the Lefanta industrial estate encountered material described as "moderate to high permeability, sandy silty material with sandstone cobbles and boulders" in the NVZ report for the area (MCOS, 2001). In the case of these two trial pits the silt component of the subsoil description might suggest till, and therefore moderate permeability, rather than high permeability, sorted, washed sand and gravel material (R. Meehan 2009, pers. comm.).

Further exposures at EXP01 (which overlies the KT/LLS boundary) and EXP03 and EXP04 (both overlying WA limestone) encountered moderately permeable SILT and SILT/CLAY. Exposure EXP02 (overlying KT sandstone approx 100m north of the KT / LLS boundary) in the Ballyard – Knockacronaun area was logged as '***low permeability***' gravelly CLAY, although GRAVEL lenses in the greater deposits were present and acting as high permeability preferential pathways through the deposit. This exposure was located in a poorly drained area in Ballyard.

Data from Frank Seery, a local water well Drilling contractor based at Ballyhane, Cappaquin, Co. Waterford, indicate that at boreholes BH09 and BH10 in Affane Hunter and at BH17 in Sheskin, saturated, '***high permeability***' SAND and GRAVEL deposits greater than 20 m in thickness were encountered overlying the limestone bedrock. The deposits appear to be confined to the area between Affane Hunter and Sheskin. Based on their morphology the deposits may derive from a sandur or outwash plain, which clogged the stream valley in that location (R. Meehan 2009, pers. comm.).

Depth to bedrock

Depth to bedrock (DTB) has been interpreted across the study area based on bedrock outcrops mapped by the GSI, outcrops mapped during site visits, areas mapped as extreme groundwater vulnerability under the GSI Groundwater Protection Scheme (GWPS) (i.e. zones where DTB < 1 m bgl and where

DTB is between 1 m and 3 m bgl) and logged and anecdotal evidence from drilling of boreholes across the study area.

From the GWPS mapping, DTB is mapped as less than 3 m across the steep sided flank of the Knockmealdown Mountains in the townland of Knockacronaun and the northern parts of Crinnaughtaun east and Ballyard. Further areas of extreme vulnerability are mapped in the townlands of Sluggara, Springfield, Coolaneen and Drumroe approximately 800 m to the southeast, south and southwest of the source, as well as a small area 1 km to the west of the source in Affane Hunter. A further previously unmapped outcrop was encountered at KF01 in the Sheskin area.

Away from the areas mapped as < 3 m DTB, local drilling experience indicates that DTB is greater than 10 m across the majority of the study area in the areas underlain by WA and BA limestones. Data from Frank Seery indicate that at BH07, BH08 and BH12 east and south of the source, DTB was in excess of 10 m. The owner of boreholes BH11 and BH13 to the north of the source reported that DTB at these locations was approximately 18 m. To the west of the source at borehole BH09, Frank Seery reported DTB of approximately 20 m, while at boreholes BH10 and BH17, which were drilled to 25 and 20 m respectively, bedrock was not encountered. Further west at borehole BH16, the report for the trial well indicates the DTB was 12 m (Connor, 2005). Overall DTB in excess of 10 m is expected across the study area, with a zone of DTB in excess of 20 m present in the Affane Hunter – Sheskin area which coincides with the area of saturated sand and gravel deposits reported by Frank Seery.

7 GROUNDWATER VULNERABILITY

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target'. In this area this means that vulnerability relates to the permeability and thickness of the subsoil. 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).

An interim groundwater vulnerability map for the area has been developed for the area by the GSI. This regional scale map has been amended to take account of the local scale data collected during the desk study, site visits and field mapping stages of this project and data from the ongoing development of the regional scale Waterford County vulnerability map under the National Groundwater Protection Scheme.

The resulting local scale map reveals areas of extreme vulnerability on the steep slopes of the Knockmealdown mountains and around bedrock outcrop locations to the south of the source. Extreme vulnerability buffers are also mapped in the vicinity of mapped karst features (except "land breaks") and along sinking streams in their losing reaches and upstream of losing reaches. High vulnerability is also mapped around "land break" karst features. Concentric areas of high and in places moderate vulnerability are encountered around outcrop areas as the DTB increases moving away from the outcrop. Moderate vulnerability pertains across the majority of the study area where moderate permeability subsoils combine with DTB in excess of 10 m. Low vulnerability conditions occur at the base of the Knockmealdown Mountains and in the Sheskin – Coolanheen areas where subsoils interpreted as low permeability combine with DTB greater than 10 m.

The local scale groundwater vulnerability map, incorporating the data from desk study sources and site visits is shown in Figure 5. Maps of the various components of the groundwater vulnerability, DTB, Subsoil Permeability and buffered karst features can be seen in Figures A1.1, A1.2 and A1.3 respectively in Appendix 1.

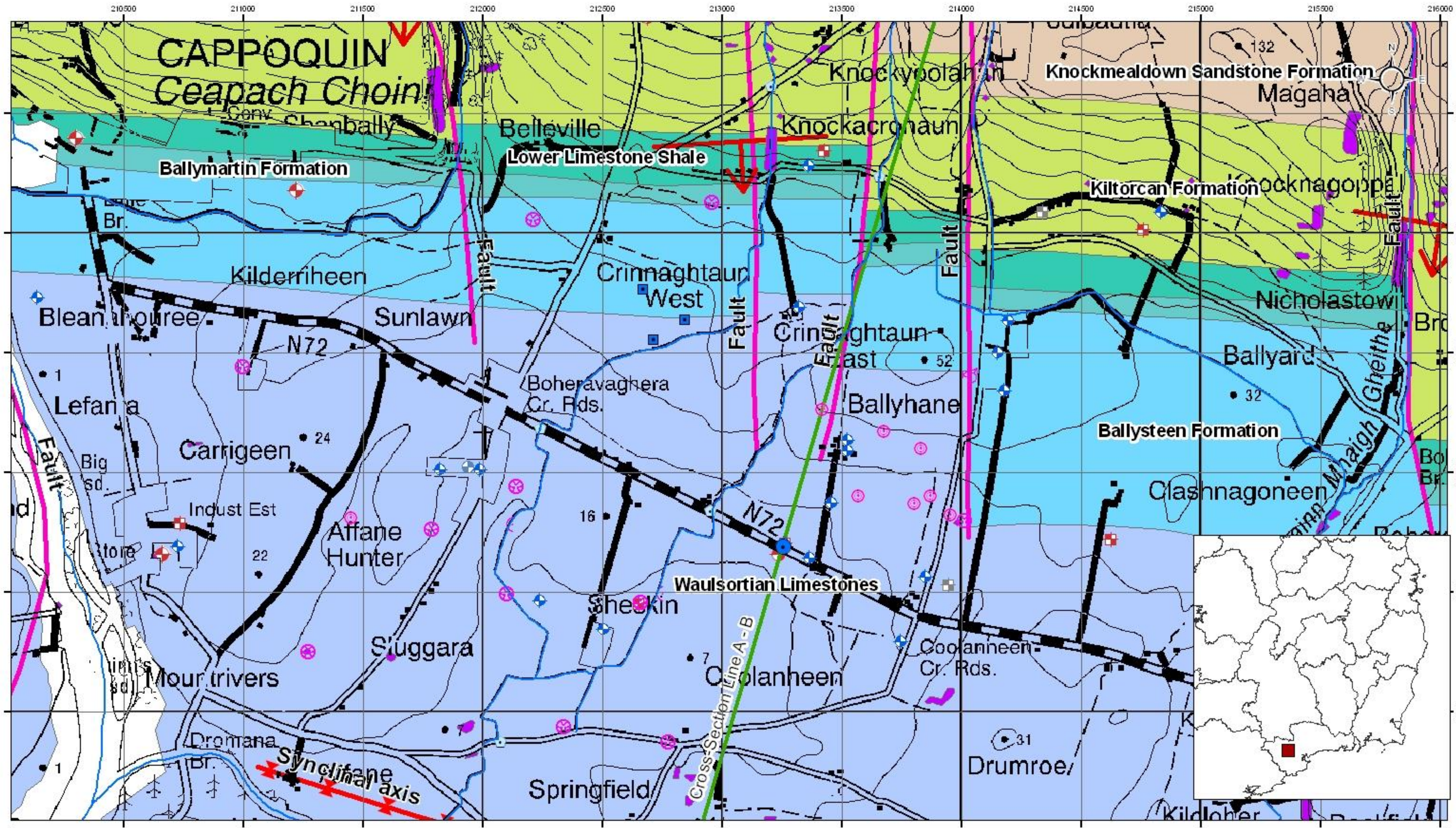


Figure 3 Bedrock Geology of Study Area

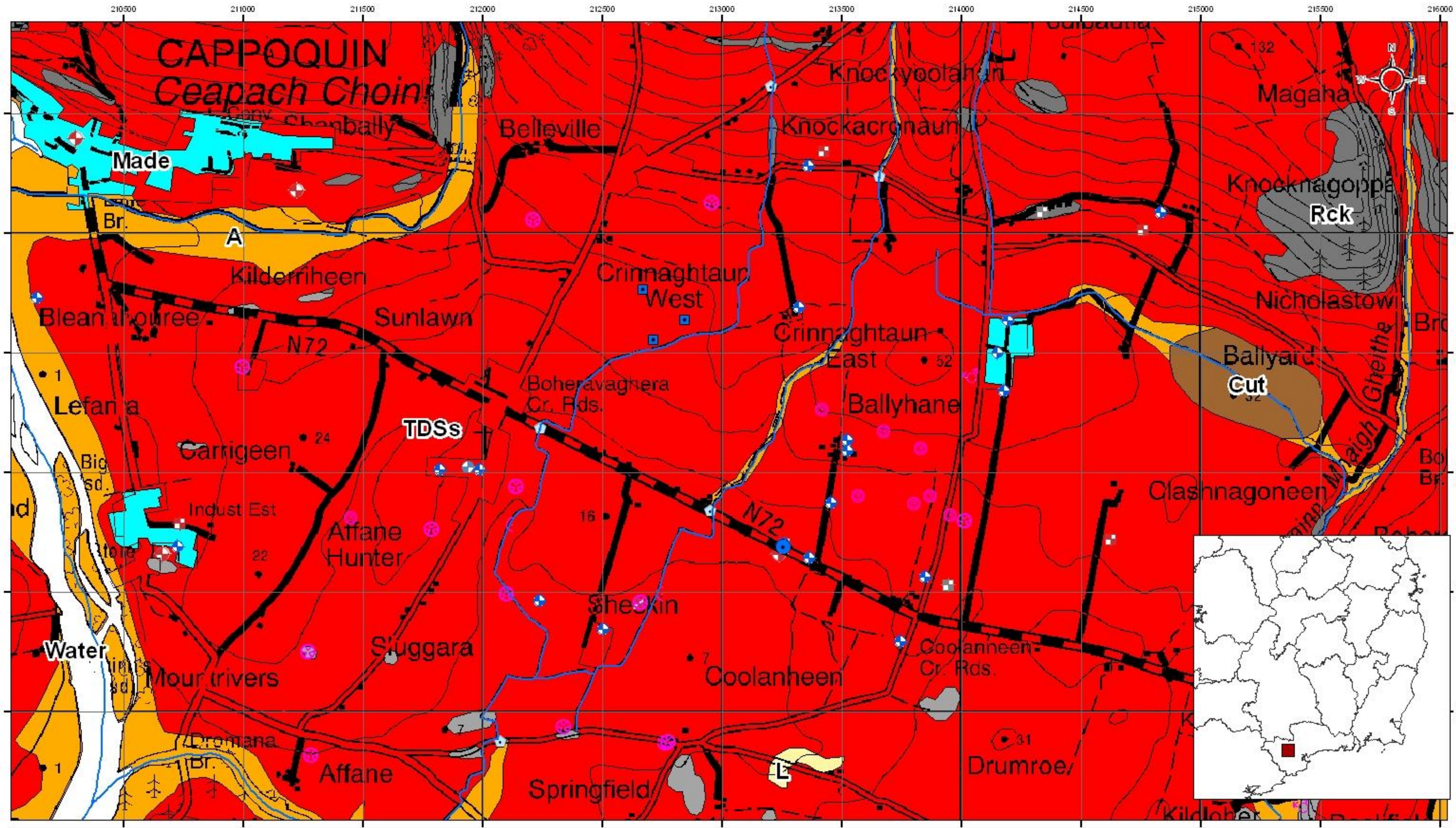


Figure 4 Subsoil Geology of Study Area

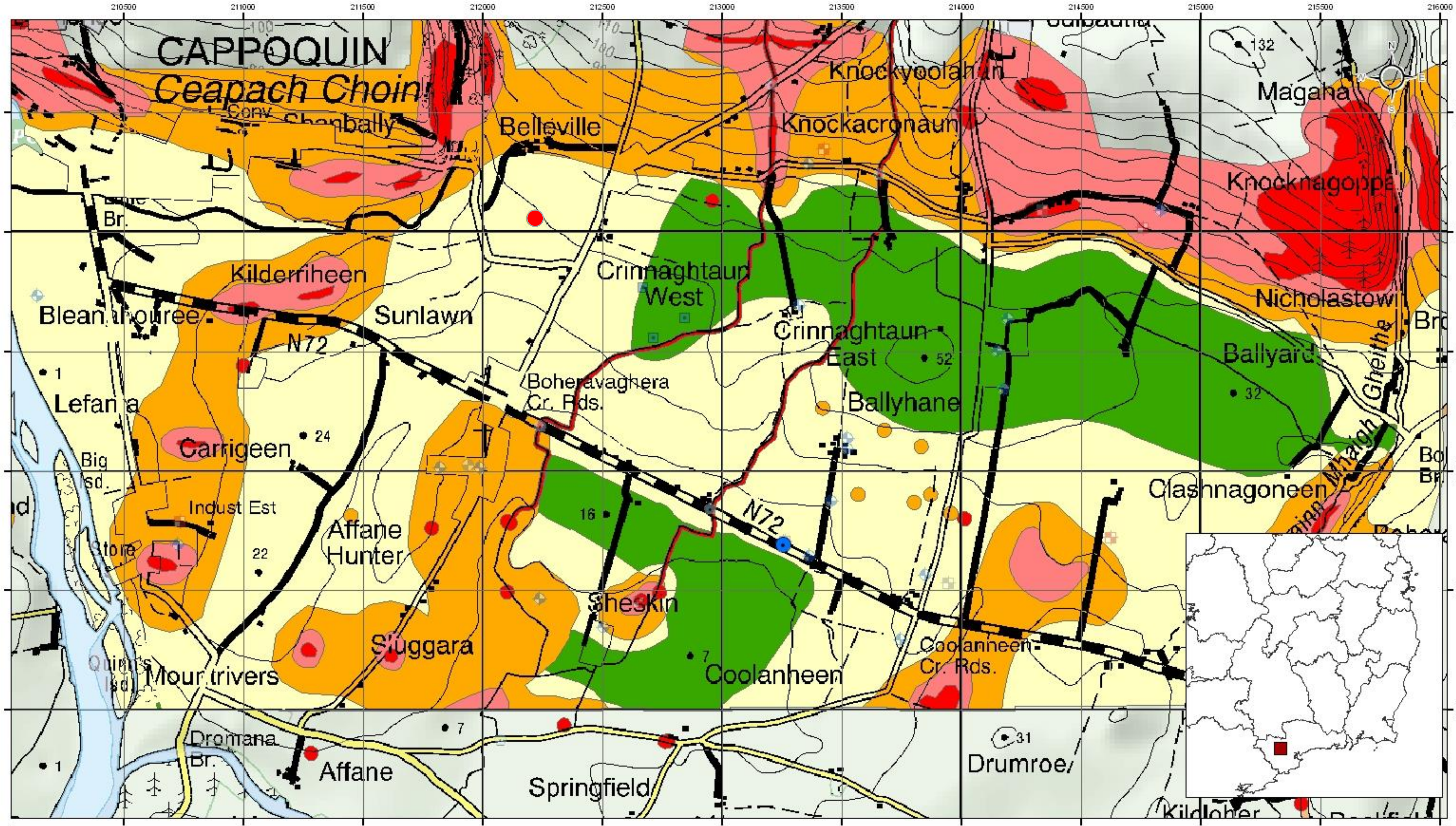


Figure 5 Local Scale Groundwater Vulnerability Map

8 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
- Waterford Groundwater Protection Scheme (Hudson *et al*, 1997)
- Groundwater Modeling for Resource Management (of the Dungarvan Limestone Aquifer) (M^{c}Daid, 1994)
- Nitrate Vulnerable Zones Study for Groundwaters at Ballyhane, Lefanta and Monument, Cappaquin Co. Waterford – Hydrogeological Investigations (MCOS, 2001)
- West Waterford Water Supply Scheme Stage 1 Area, Preliminary Report – Appendix I Hydrogeology (RPS, 2008)
- IPPC Application and Enforcement Data for License Numbers PO388-01 (O'Connor Poultry Farm), PO834-01 (Cappaquin Chickens) and PO447-01 (M^{c}Grath Piggery)
- John A. Wood Cappagh Quarry, Environmental Impact Statement (TOBIN, 2006)
- Hydrogeological mapping by TOBIN Consulting Engineers and Robert Meehan October and November 2009.

8.1 GROUNDWATER BODY AND STATUS

The source and the surrounding area are located within the Lismore groundwater body (GWB), close to the southwestern boundary of the body (GSI, 2004b). The Lismore GWB is classified as "at risk of not achieving 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 .

8.2 METEOROLOGY

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

Annual rainfall: 1108 mm. The contoured data map of rainfall in Ireland (Met Éireann; 1961–1990 dataset) shows that the source is located between the 1,000 mm and 1,200 mm average annual rainfall isohyets. The closest meteorological station to the Ballyhane Source is at Cappaquin House (closed in 1990), 3.9 km to the northwest where the average rainfall between 1961 and 1990 was 1108 mm/yr (Fitzgerald and Forrestal, 1996).

Annual evapotranspiration losses: 488 mm. The closest representative (coastal) synoptic weather stations to the study area are Cork Airport and Rosslare at 57 km southwest and 100 km east respectively. Average potential evapotranspiration (P.E.) at each site between 1961 and 1990 was 513.2 mm and 577.5 mm respectively, based on Met Eireann data. The contoured mean annual potential evapotranspiration for Ireland shows that Cappaquin lies close to the 500 mm/yr contour (France & Thornley, 1984). Due to the greater proximity to Cork Airport the PE for Cork Airport is assumed to be the most representative value for the source. As such, PE for Ballyhane is taken as 513 mm/yr based on the Cork Airport data. Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., to allow for seasonal soil moisture deficits giving an Actual Evapotranspiration of 488 mm.

Annual Effective Rainfall: 620 mm. The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore equivalent to this, or 620 mm/year. See also Section 8.6 on Recharge which estimates the proportion of effective rainfall that enters the aquifer.

8.3 GROUNDWATER LEVELS, FLOW DIRECTIONS AND GRADIENTS

Groundwater levels were measured at the PWS borehole and in private boreholes across the study area in November 2009. Full details of the water level data collected are provided in Table A1.1 in Appendix 1.

Depth to groundwater in the private boreholes across the area varied between 0.47 m and 16.05 m below ground level (bgl). In the public supply borehole, the pumping water level was measured at 11.31 mbgl (11.35 m below the top of the well casing) on 19/10/09, rising to 10.66 mbgl on 03/11/09. Rest water levels are expected to be within 0.02 m of the pumping water levels based on drawdown records for the well in the GSI well database. The November site visits were carried out after a wet summer and during an exceptionally wet November, such that ground water levels are likely to have been close to maximum. Large volumes of diffuse spring discharge were observed emanating from KT sandstone bedrock in the vicinity of exposure EXP02 between Knockacronaun and Ballyard.

Approximate groundwater contours based on the available, measured groundwater level data and ground elevations estimated from the 1:50,000 scale topographical map are shown in Figure 6. Data from 2001 showed that the groundwater elevation in the limestone bedrock aquifer is lower than the base of the surface water courses crossing the study area, e.g. at surface water monitoring location SW02. This indicates a hydraulic gradient from the surface water to the bedrock groundwater such that the streams are likely to lose water to the bedrock aquifer as they cross the study area, especially where karst features are intersected.

Numerical modeling of regional scale groundwater flow in the Dungarvan Aquifer indicated that groundwater flow in the vicinity of Ballyhane is generally in an east to west direction (M^{c}Daid, 1994). This model assumed a no-flow boundary between the KT sandstone of the Knockmealdown Mountains and the karstified limestone, even distribution of recharge across the model domain and placed discharge boundaries along the north-south oriented Blackwater Estuary. These assumptions, together with the modelled aquifer geometry, automatically imposed a generally east-west groundwater flow direction on the model in the Ballyhane area. These assumptions do not accurately represent the local scale hydrogeology of the Ballyhane area. During site visits surface runoff across the area and groundwater discharge from the sandstone aquifer at EXP02 were observed to runoff onto the adjacent limestone aquifer. This phenomenon is also described in the GWB summary (GSI, 2004b). This runoff provides an additional source of recharge to the karstified bedrock aquifer in the area north of the source. This additional recharge can be readily accepted by the aquifer via losing stream and karst features such as enclosed depressions and swallow holes. This process contributes to the head of the groundwater system to the north and northeast of the source, and imparts a significant south to southwesterly trend to the groundwater flow direction which is not expressed in the numerical model. In the Crinnaughtaun East and Ballyard area the west to east running stream is likely to intercept some of this runoff before it can infiltrate and remove it from the bedrock aquifer water balance.

The southwesterly hydraulic gradient and groundwater flow direction can be seen in the groundwater contours for the study area shown in Figure 6. This groundwater flow direction is different to the southeast to northwest flow direction interpreted in the immediate vicinity of the source in 2001, which depended on a local groundwater elevation high at borehole BH12 (MCOS, 2001). This local high point in the watertable was not encountered in the 2009 data.

At the scale of individual fractures and conduits within the karst system, flow direction is likely to be determined by the orientation of individual fractures and conduits. Nonetheless, the overall trend of flow through the highly karstified system will be in the direction of the hydraulic gradient.

The hydraulic gradient in the north of the study area across the LLS and BA bedrock and the boundary with the WA limestone is approximately 0.05. The gradient decreases to approximately 0.038 as flow enters the WA limestone bedrock and drops further to approximately 0.009 in the vicinity of the source and further downgradient.

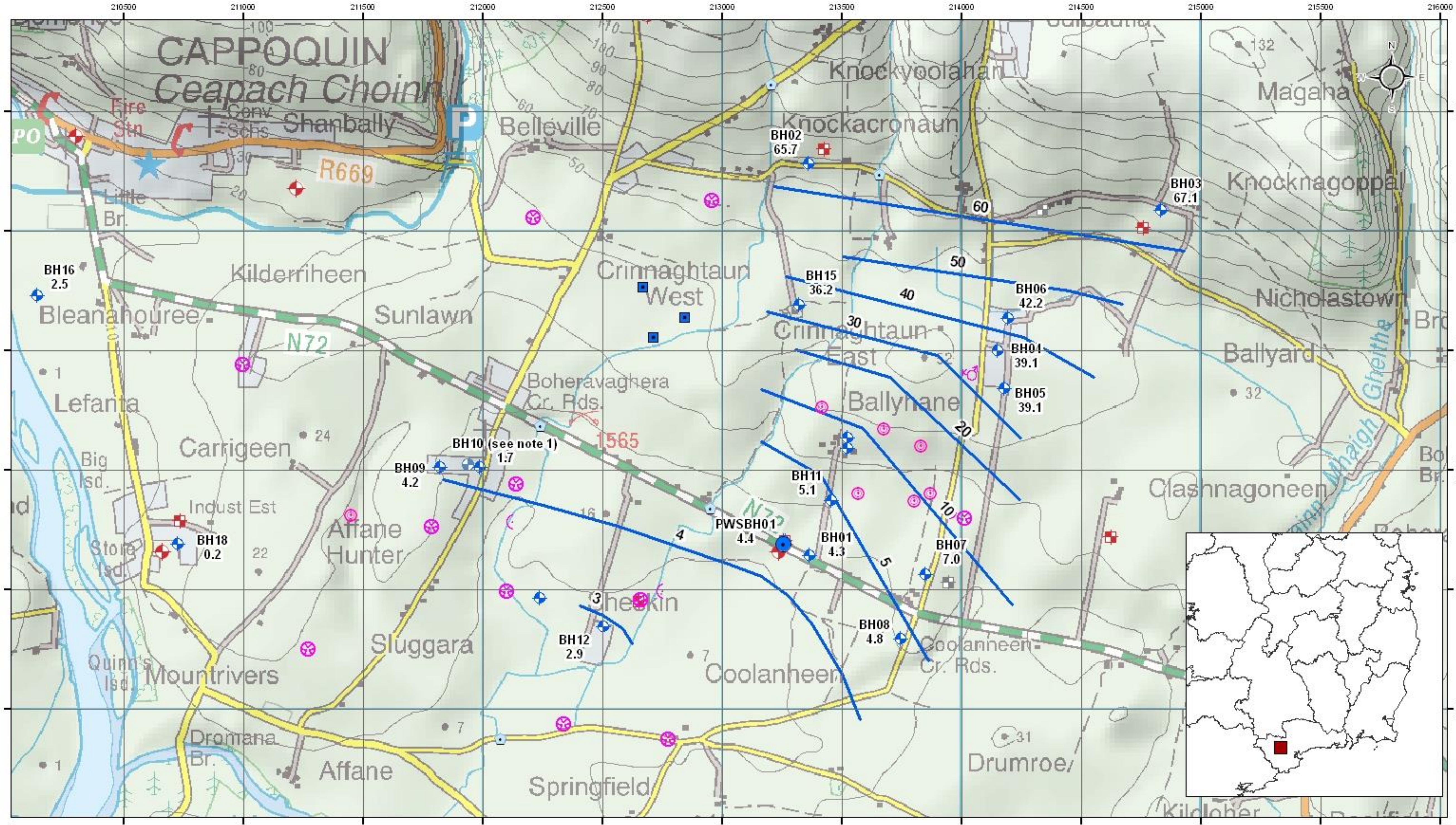


Figure 6 Groundwater Contour Map

● PWS Abstraction

River

4 Approximate Bedrock Groundwater Elevation Contours based on measured borehole groundwater levels(mAOD)

BH12 2.9 Approximate Bedrock Groundwater Elevation in Borehole (mAOD)(Levels measured on 02 & 03/11/2009)

Note 1: Borehole BH10 is drilled into Sand & Gravel deposits and does not penetrate the bedrock aquifer. The groundwater level reflects the water level in the saturated Sand & Gravel Deposits

Note 2: Borehole BH18 (Lefanta) and borehole BH15 water levels measured in September 2001; Borehole BH16 water level measured on 09/12/2005.

0 0.25 0.5 1 km

8.4 HYDROCHEMISTRY AND WATER QUALITY

Samples of untreated groundwater are collected from the untreated water tap in the source pump house. Twenty eight samples were collected and analysed by the EPA between June 1993 and November 2008. Samples were collected on an *ad hoc* basis until 2001, when biannual sampling commenced. Five samples per year were collected in 2007 and 2008. The resulting data are presented in Table A1.2 in Appendix 1. Field water quality data (pH, conductivity and temperature) were collected from surface water sampling locations SW01 to SW05 on 03/11/2009. The field data are presented in Table A1.3 in Appendix 1.

Overall, the source has a high level of mineralization as indicated by the high average electrical conductivity (650 µS/cm) and alkalinity (272 mg/l as $CaCO_3$) and high hardness (327 mg/l as $CaCO_3$). The groundwater is of calcium-bicarbonate type, i.e. the ions present in greatest concentrations are calcium and bicarbonate, which is typical for limestone groundwater. The anions chloride and nitrate and the cations magnesium, sodium, potassium are also present as minor components. The pH of the groundwater is slightly alkaline with a field measured average of 7.51. The groundwater hydrochemistry is distinct from the surface water which had a pH range of 5.5 to 5.7 and an electrical conductivity range of 162 to 202 µS/cm. Trace but detectable levels of various heavy metals have been encountered occasionally over the monitoring period including arsenic, mercury, and cadmium and are likely to be naturally occurring.

The water quality of the source has failed to meet the prescribed drinking water standards for four separate parameters on various occasions and has occasionally been in excess of the groundwater threshold values (Groundwater Regulations S.I. 9 of 2010) for various other parameters.

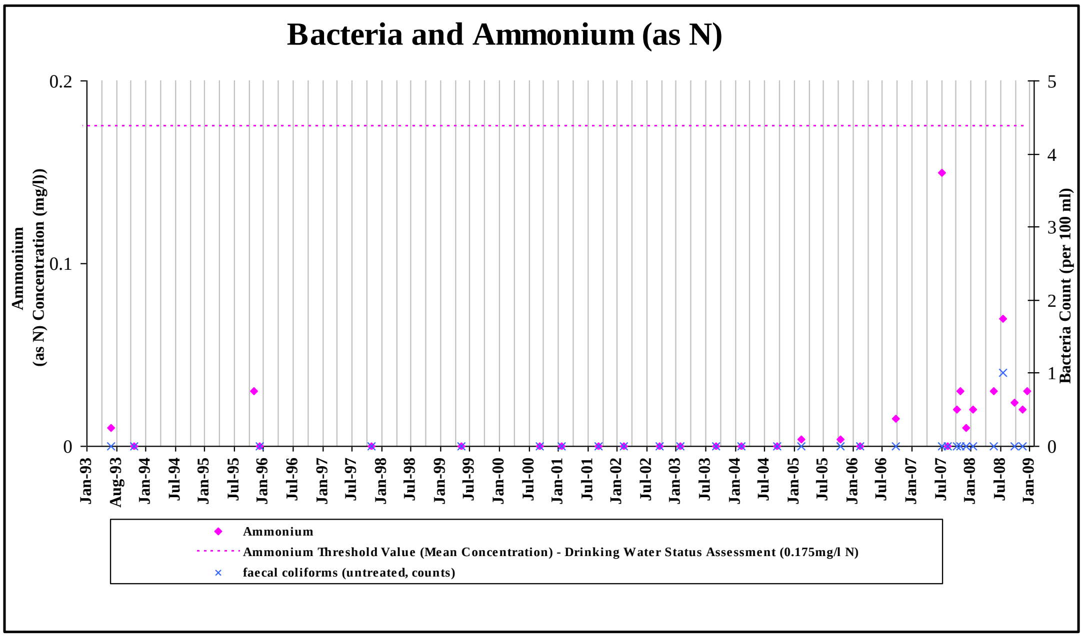


Figure 7a Graph of Bacteria and Ammonia Concentrations at Borehole PWSBH01

Figure 7a shows the EPA measured concentrations of faecal and total coliforms and ammonia at the source. Faecal coliform concentrations in the untreated groundwater were above the drinking water limit of zero counts per 100 ml on one occasion in July 2008 (1 count / 100ml). Total coliforms exceeded the same limit on three occasions, one of which coincided with the faecal event. Ammonia (as mg/l NH_3) has been detected regularly at the source but has always been below the groundwater threshold values (Groundwater Regulations S.I. 9 of 2010) of 0.175 mg/l, with a peak of 0.15 mg/l in July 2007.

The faecal coliforms detection correlated with total coliform and ammonia detections. Ammonia and total coliforms both occurred independently of the other parameters on other sampling dates.

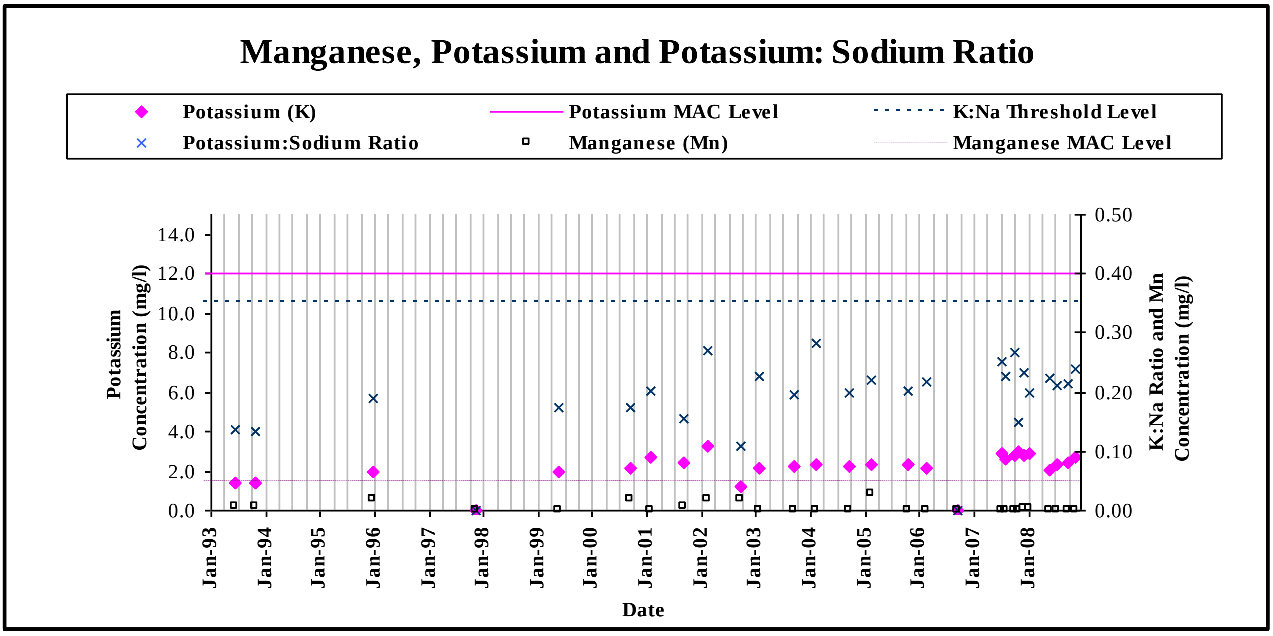


Figure 7b Graph of Manganese, Potassium and Potassium:Sodium Ratio at Borehole PWSBH01

Figure 7b shows that manganese and potassium concentrations and the potassium: sodium ratio at borehole PWSBH01 are below their respective groundwater threshold values (Groundwater Regulations S.I. 9 of 2010).

Figure 7c shows the EPA measured concentrations of nitrate (mg/l as NO_3) and chloride at the source. The concentration of nitrate at the source has been above the groundwater threshold value (Groundwater Regulations S.I. 9 of 2010) of 37.5 mg/l since November 1997, with the exception of a two events in June and July of 2008. Average nitrate concentration between June 1993 and November 2008 is 48.4 mg/l which is above the groundwater threshold value. Fourteen out of the twenty eight samples over the monitoring period exceeded the drinking water standard of 50 mg/l with a maximum concentration of 85.5 mg/l recorded in August of 2007. Nitrate concentrations at the source followed a rising trend at the source between 1993 and 2007, however 2008 saw the beginning of a possible reversal of the trend with only a single exceedence of the drinking water standard and an average concentration in 2008 of 35.2 mg/l.

Chloride concentrations at the well fluctuate and may generally follow a subdued reflection of the nitrate concentrations but the correlation has not been statistically tested. Chloride concentrations exceeded the groundwater threshold value for saline intrusion test (Groundwater Regulations S.I. 9 of 2010) of 24 mg/l on 21 No. occasions. The average chloride concentration of 24.9 mg/l is just greater than the threshold value. The chloride concentrations are all above the typical background level for Irish aquifers of 18 mg/l (Baker et al, 2007). This may indicate that the nitrate and chloride concentrations are linked to pollution of groundwater by organic matter. Alternatively the chloride concentrations may reflect the proximity of the source to the sea and the higher concentrations of chloride in precipitation close to the coast.

The concentration of orthophosphate exceeded the groundwater threshold value (Groundwater Regulations S.I. 9 of 2010) of 0.035 mg/l as P on four occasions between November 2007 and June of 2008, however the average concentration over the monitoring period is 0.02 mg/l as P. Three of the phosphate exceedences coincide with nitrate exceedences however nitrate was decreasing in 2008 and the final phosphate exceedence coincided with the lowest nitrate concentration recorded for the source.

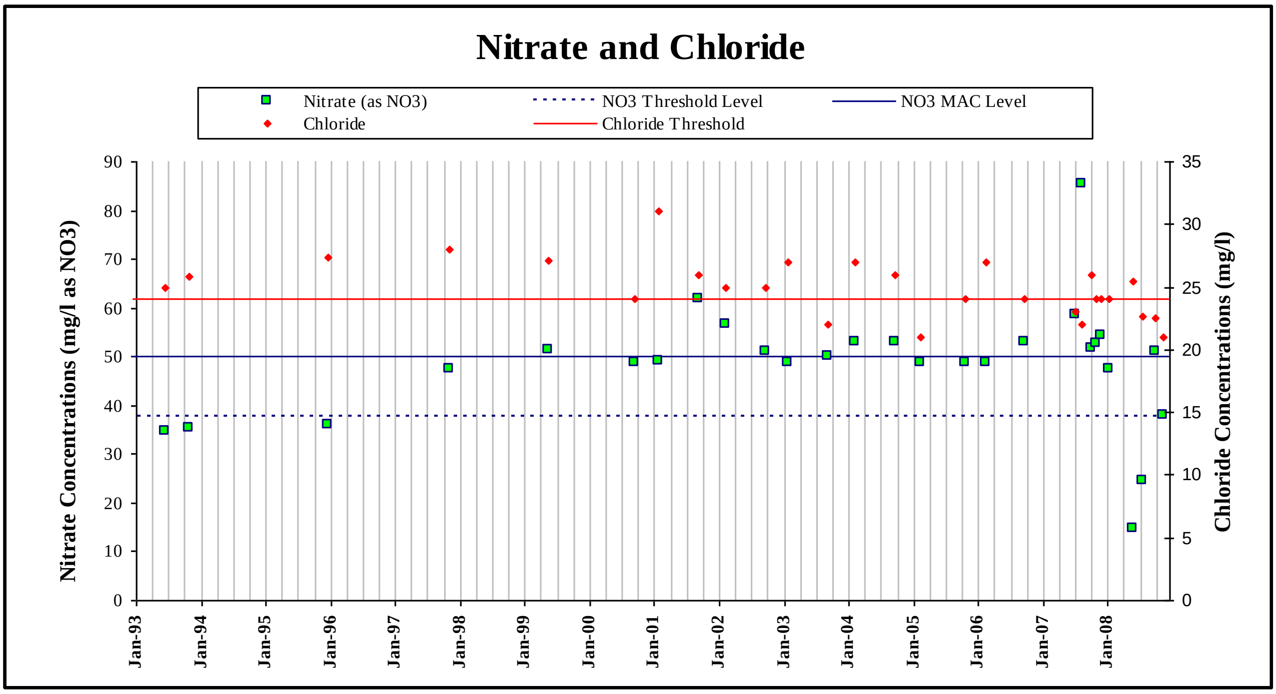


Figure 7c Graph of Nitrate and Chloride Concentrations at Borehole PWSBH01

The heavy metals chromium and nickel each exceeded their respective groundwater threshold values (Groundwater Regulations S.I. 9 of 2010) once, while zinc did so on three sporadic occasions. Aluminum exceeded its drinking water standard on one occasion. The events are likely to be due to naturally occurring metals in the aquifer matrix or sediments in the karst system. Organic pollution can bring these metals out of the geological materials into the water, such that high metal concentrations are often an indicator of organic contamination.

The remainder of the parameters measured do not exceed their respective drinking water standard and have average concentrations less than their respective groundwater threshold values.

In summary, nitrate and chloride exceedences together with occasional orthophosphate and heavy metal exceedences and ammonia detections suggest contamination from an organic waste source. Given the land use in the area, the most likely sources are grazing animals, farmyard wastes and onsite waste water treatment systems upgradient of the source. There are also some registered pig slurry spread-lands under IPPC License No. P0447-01 and an IPPC licensed poultry farm (IPPC License No. P0388-01) in the townlands north of the source.

8.5 AQUIFER CHARACTERISTICS

The groundwater source is located in the Lismore Groundwater Body. The GSI bedrock aquifer map of the area indicates that the WA limestones in which the borehole is located, are classified as a *Regionally Important Aquifer which is diffusively karstified (Rk$_d$)*. This implies that the bedrock is generally highly productive. The BA and BT Limestones and KM Sandstones are mapped as *Locally Important Aquifer (Ll)* while the LLS strata are mapped as a *Poor Aquifer which is productive only in Local Zones (Pl)*. The KT Sandstone is mapped as a *Regionally Important Aquifer – Fissured Bedrock (Rf)*. The bedrock aquifer map of the area is shown in Figure 8.

Only a small amount of throughflow from the Rf to the Ll and Rk_d aquifers is expected, with most contribution from the north of the Rk_d aquifer coming via runoff augmenting recharge along the north of the Rk_d aquifer (GSI, 2004b). This is because the relatively low permeability Pl aquifer (the Lower Limestone Shales) acts as a barrier to flow. This model assumes that the north-south trending faults cutting across the aquifer boundaries in the north of the study area do not act as transmissive pathways channelling flow from the Rf aquifer into the Rk_d aquifer.

Groundwater flow in the Rk_d aquifer is largely via fractures and solution enlarged fissures, however karst conduits also occur and where they are present groundwater flow in the diffuse network is expected to be focused on the conduits. Conduits have been encountered during drilling of boreholes upgradient of the source, e.g. at borehole BH13.

Borehole yields in the Rk_d aquifer are high with a yield of 1,363 m^3/day recorded at PWSBH01 for a drawdown of 0.02 m during a GSI pumping test in 1996 (MCOS, 2001). Using the Logan Eqn (T=Q/s x 1.22), these data indicate that the transmissivity in the vicinity of the borehole is very high at approximately 83,000 m^2/d. This however may not be representative of the aquifer as a whole and so the results of the Dungarvan aquifer modeling were taken into consideration.

Transmissivity at the Lefanta borehole was estimated at 3,585 m^2/d based on analysis of tidal fluctuations in the borehole (M^cDaid, 1994). Overall, the aquifer in the study area was estimated to lie in hydraulic conductivity Zone 2 of the numerical model of the aquifer, giving a hydraulic conductivity range of 90 to 180 m/d (M^cDaid, 1994). Based on an aquifer thickness of approximately 20 m, as used in numerical modelling of the Lefanta area (M^cDaid, 1994), the transmissivity range is 1,800 to 3,600 m^2day. In the numerical modeling of the aquifer, the base of the aquifer was set at -20 mAOD (M^cDaid, 1994), such that aquifer thickness across the study area could reach up to 70 m in places.

Transmissivity is likely to be lower in the Ll aquifer. This is demonstrated by the changes in hydraulic gradient seen in the groundwater contours on Figure 6, from higher gradients in the Ll aquifer, decreasing moving down gradient into the Rk_d aquifer.

The combined porosity derived from dolomitisation and karstification of the limestone is estimated at 0.02 (M^cDaid, 1994). Based on the estimated bedrock aquifer transmissivity and the aquifer hydraulic gradients, the advective groundwater flow velocity can be estimated based on the equation:

$$v = \frac{T \cdot i}{b \cdot n_e}$$

where: v = average groundwater velocity (m/day);
T = Aquifer Transmissivity (m^2/day); ne = effective porosity (dimensionless)
i = hydraulic gradient; and, b = aquifer thickness.

The estimated groundwater velocity range in the bedrock aquifer, based on the available data is shown in Table 8-1.

Table 8-1 Estimated Groundwater Velocity Range in the Karstified Limestone

Parameter	Units	Minimum in model	Maximum	Data Source
T	m^2/d	1,800	83,000	(McDaid, 1994; and GSI pumping test 1996 (MCOS, 2001)
i	[-]	0.009	0.05	Section 8.3

b	m	20	20	(McDaid, 1994)
n_e	[-]	0.02	0.02	(McDaid, 1994)
v	m/d	40.5	10,375	

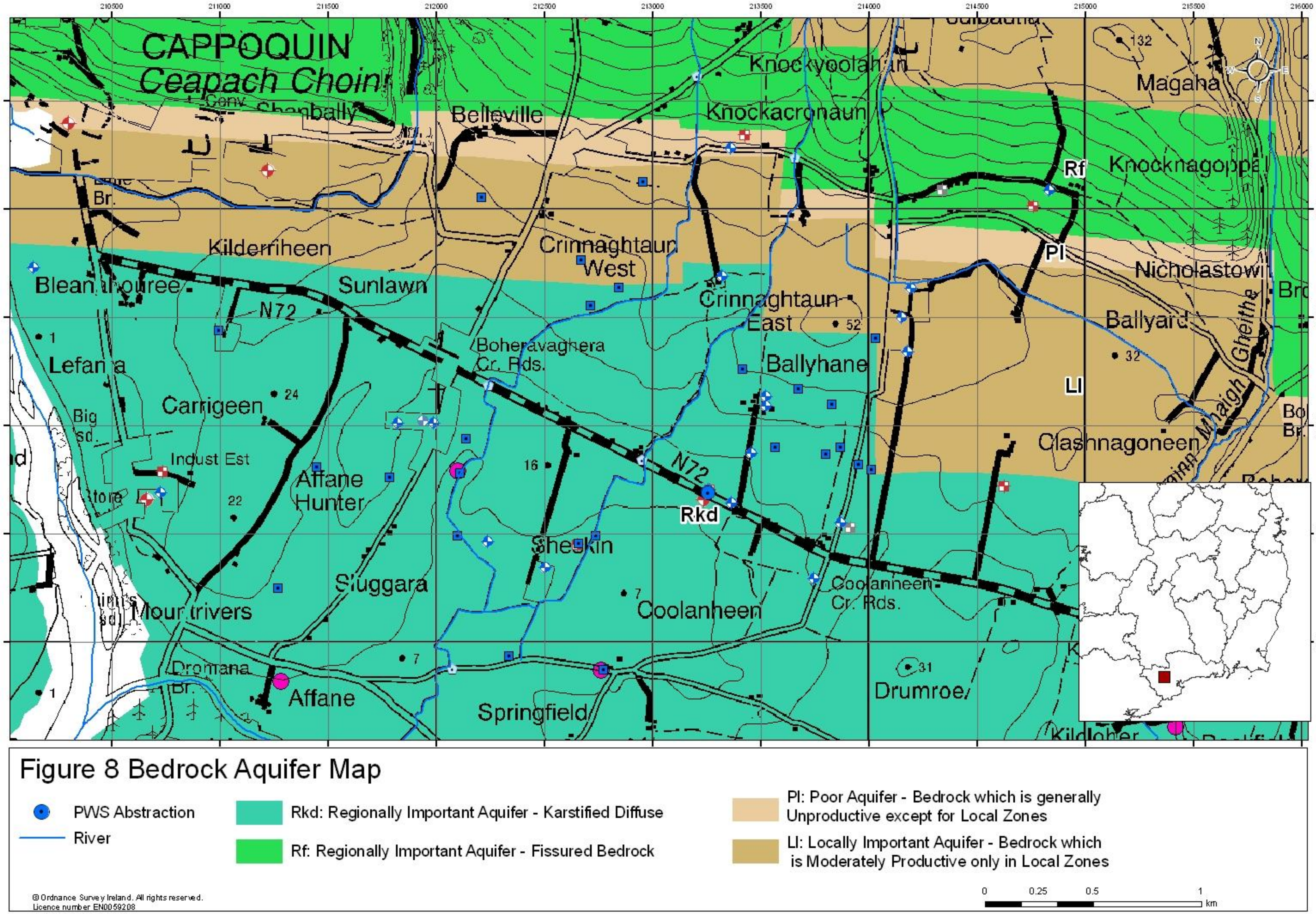


Figure 8 Bedrock Aquifer Map

8.6 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 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).

At Ballyhane, the main parameters involved in recharge rate estimation are: annual rainfall; annual evapotranspiration; and a recharge coefficient.

The majority of the area surrounding the source is mapped as moderate groundwater vulnerability with the Rf aquifer overlain by moderate permeability subsoils and well drained soils. Guidance Document GW5 recommends a maximum recharge coefficient of 0.6 for these conditions (IWWG, 2005). Based on the low drainage density of the study area it is considered that the maximum recharge coefficient of 0.60 should be used. It is expected that a significant proportion of the runoff from this area will be intercepted by downgradient karst features. This contribution to recharge has not been quantified.

A large area to the north of the source and a further area just south of the source are mapped as low vulnerability with low permeability subsoils and poorly drained soils. A maximum recharge coefficient of 0.2 is recommended for these areas (IWWG, 2005). Based on the low drainage density of the study area it is considered that the maximum recharge coefficient of 0.20 should be used. Where local topography directs runoff from this zone onto downgradient moderate vulnerability zones it is likely that a component of the excess runoff will be intercepted by karst features. This contribution to recharge has not been quantified.

Areas of high vulnerability are mapped around "land break" karst features and to the north of the source where moderate permeability subsoil combines with subsoil depths between 3 and 10 m. These zones are given a recharge coefficient of 0.85.

The extremely vulnerable areas in the north of study area are generally underlain by the Kiltorcan sandstone aquifer which is considered to have minimal hydraulic continuity with the Ll and Rk_d aquifer as the Pl aquifer in between acts a barrier to flow. As a result, groundwater recharge in these areas is not directly relevant to the Ballyhane PWS source which abstracts from the Rk_d aquifer. Groundwater discharge from this aquifer may impact on the Rk_d aquifer where it contributes to augmented recharge of the Rk_d aquifer by runoff onto its northern margins. This additional recharge component of the Rk_d aquifer has not been included in the recharge calculation for the Rk_d aquifer. This is the more conservative approach and it acknowledges that the augmented recharge, which has not been quantified, may only occur under certain flow conditions. In the Crinnaughtaun East and Ballyard area some of this runoff is likely to be intercepted and removed from the aquifer water balance by the west to east running stream through the area.

The remaining extremely vulnerable areas overlying the Rk_d aquifer are typically associated with karst features which can generally accept all available recharge. As such, a recharge co-efficient of 1.0 is applied in these areas.

Table 8-2 Recharge Calculation Summary

Parameter	**Coefficient**	**Rate**
Average rainfall (R)		1,108 mm/yr
Estimated P.E.		513mm/yr
Estimated A.E. (95% of P.E.)		488 mm/yr
effective rainfall		620 mm/yr
Potential recharge		620 mm/yr
Recharge coefficient for extreme (1) and high Vul (0.85)	0.92	527 mm/yr
Recharge coefficient for moderate Vul	0.6	372 mm/yr
Recharge coefficient for Low	0.2	124 mm/yr
Averaged runoff losses	(56%)	348 mm/yr
Bulk recharge coefficient	0.44	
Recharge		272 mm/yr

Because of the low surface water drainage density and the presence of karst features in the Ll aquifer area the Ll aquifer has been assumed to accept all recharge available to it and no recharge cap has been applied to the aquifer.

Runoff losses are therefore assumed to be 56% of potential recharge (effective rainfall). This value is based on an assumption of an average of 8% runoff for 8% of the area (extreme and high vulnerability); 80% runoff for 47% of the area (low vulnerability); and 40% runoff for 45% of the area (moderate vulnerability).

It is likely that a large part of the runoff from the areas with a low recharge coefficient augments recharge in other areas via losing streams, intersection of sink holes and runoff into enclosed depressions. This additional recharge has not been accounted for in the summary recharge calculations. As such, the bulk recharge coefficient may significantly underestimate the total recharge to the area.

The bulk ***recharge coefficient*** for the area is therefore estimated to be 0.44. The calculations are summarised in Table 8.2.

8.7 CONCEPTUAL MODEL

The current understanding of the geological and hydrogeological setting is given as follows. A schematic cross-section illustrating the conceptual model is shown in Figure 9.

- The source under consideration in this report is comprised of one borehole (PWSBH01) in the Ballyhane area of Cappaquin, located in Waulsortian Limestone bedrock, classified as a *Regionally Important Bedrock Aquifer which is diffusely karstified (Rkd)*. Abstraction rates from the source average 345 m^3/day.

- The study area is underlain by bedrock comprised of Waulsortian Formation limestones (WA), Ballysteen and Ballymartin Formation muddy limestones (BA and BT), Lower Limestone Shale

Formation sandstones, shales and thin limestones (LLS), Kiltorcan Formation sandstones (KT) and Knockmealdown Formation sandstones (KM).

- Abundant karst features including sink holes, enclosed depressions, dry valleys and losing streams were encountered across the study area. The areas of Affane Hunter, Sluggara and the north and northeastern parts of Ballyhane had particularly high densities of features.

- Depth to bedrock is considered to be less than 3 m on the steep flank of the Knockmealdown Mountains in the north of the study area and around sporadic outcrop locations to the southeast, south and west of the source. Over the remainder of the study area, DTB is greater than 10 m to the east, north and south of the source and in excess of 20 m to the west and southwest.

- The subsoils of the area are considered to have a moderate permeability based on BS5930 assessment of subsoil samples and on indicators of good drainage across the study area. Areas underlain by poorly drained subsoils are considered to have low permeability based on indicators of poor drainage and on a single subsoil exposure. These areas may at least partially confine the underlying bedrock aquifers.

- Local scale groundwater vulnerability mapping for the study area, taking into account desk study and site visit data, shows that the ridges and karst features (including losing reaches and upstream thereof of streams) are classified as extremely vulnerable. The area of high subsoil permeability in Affane Hunter is mapped as high vulnerability. Poorly drained areas across Crinnaughtaun East and West, Ballyard and parts of Sheskin and Coolaneen are mapped as low vulnerability. The remainder of the study area is classified as having moderate groundwater vulnerability.

- Depth to groundwater in the private boreholes across the area varied between 0.47 m and 16.05 m below ground level (bgl) and measured 10.66 mbgl at the source in early November 2009. Large volumes of diffuse spring discharge were observed emanating from KT sandstone bedrock in the vicinity of exposure EXP02 between Knockacronaun and Ballyard.

- The groundwater elevation in the limestone bedrock aquifer is lower than the base of the surface water courses crossing the study area, such that streams are likely to lose water to the bedrock aquifer as they cross the study area, especially where karst features are intersected. There is evidence that the stream closest to the source is a losing stream.

- There is little throughflow from the Rf aquifer to the Rk_d aquifer because the Pl aquifer acts as a barrier. However, groundwater discharge from the Rf aquifer at the boundary with the lower permeability rocks, and rejected recharge from those lower permeability rocks, are considered to runoff onto the Rk_d aquifer and result in augmentation of recharge to that aquifer. In the Crinnaughtaun East and Ballyard areas some of this runoff will be intercepted by the west to east running stream through the area.

- Groundwater discharge from the Rk_d aquifer is to the Blackwater estuary and the River Finisk to the west and south of the source.

- The hydraulic gradient in the Rk_d aquifer is directed to the southwest. In the north of the study area the gradient is approximately 0.05 in the lower permeability rocks. The gradient decreases to approximately 0.038 as flow enters the WA limestone bedrock and drops further to approximately 0.009 in the vicinity of the source and further downgradient. This reflects the high permeability and transmissivity in the Rk_d karst aquifer.

- The groundwater has a high level of mineralisation and is of calcium-bicarbonate type. The pH is slightly alkaline and has a high electrical conductivity, which is in sharp contrast to the more acidic, low conductivity surface water in streams crossing the study area.

- The untreated water quality has had consistently elevated nitrate concentrations above the drinking water standard since 1993, with an average concentration 48.4 mg/l (as NO_3) in 2007. Data from 2008 were significantly lower than average and lower than the 2007 data and showed an average concentration of 35.2 mg/l (as NO_3). The average chloride concentration, in addition to frequent individual chloride concentrations, is above the EPA threshold of 24 mg/l. Occasional exceedences of the DWS for total and faecal coliforms and of the EPA threshold for phosphate and various metal parameters have occurred. It is likely that the nitrate and chloride contamination together with the other elevated parameters are due to pollution by organic matter.

- Analysis of tidal fluctuations at Lefanta borehole 3 km west of the source carried out by M^{c}Daid (1994) indicates aquifer transmissivity in the region of 3,363 m^2/day. Regional scale numerical modeling of the Rk_d aquifer indicates hydraulic conductivity in the area ranges from 90 to 180 m/d in an aquifer approximately 20 to 40 m thick (M^{c}Daid, 1994).

- Recharge is assumed to be an average of 92% of potential in areas where bedrock is mapped as close to the ground surface, in the vicinity of karst features and in areas mapped as high vulnerability. In areas of moderate and low permeability, recharge is estimated to be 60% and 20% of potential recharge respectively. This gives an averaged percentage of 44% for the whole source catchment and an annual actual recharge of 273 mm/yr. This value does not account for augmented recharge resulting from discharge and runoff from the Rf and Pl aquifers upslope of the Ll and Rk_d aquifers.

- The limitations of the conceptual model are mainly related to a lack of information with respect to the following:

    - ⇨ Subsoil Permeability – subsoils are considered to be in excess of 10 m across large parts of the study area. The permeability of the subsoils present at depth is unknown. Greater certainty on this parameter could lead to changes in the groundwater vulnerability map.

    - ⇨ Throughflow from the Rf to the Rk_d aquifer is assumed to be negligible because of the presence of the lower permeability Ll and Pl rocks in between. If significant throughflow occurs along the north-south fault zones, this would allow the Rf aquifer to contribute groundwater directly to the source and would require the Rf aquifer to be included in any source protection considerations.

    - ⇨ The interpreted hydraulic gradient and groundwater flow direction are based on estimated ground levels. Errors in these levels could impact on the estimates of the key aquifer properties in ways that might require reconsideration of elements of the conceptual model.

9 DELINEATION OF SOURCE PROTECTION AREAS

This section describes the delineation of the areas around the source that are believed to contribute groundwater to it, and that therefore require protection. The areas are delineated based on the hydrogeological conceptual model, as described in Section 8.7 and are shown in Figure 10.

Two source areas are delineated:

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

9.1 OUTER PROTECTION AREA

The Outer Protection Area (SO) is bounded by the complete catchment area to the source, i.e. **the zone of contribution (ZOC)**, which is defined as the area required supporting 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 subsoil and rock permeability and (d) the recharge in the area. The shape and boundaries of the ZOC were determined using hydrogeological mapping, water balance estimations, and conceptual understanding of groundwater flow. The boundaries are described below along with associated uncertainties and limitations.

In Rk_d aquifers, the volume of groundwater flow through fissures / conduits intersected by boreholes may greatly exceed the demand of the borehole. This is demonstrated by the negligible impact of pumping at 1,363 m^3/d (approximately 4 times the average demand) on water levels at borehole PWSBH01.

It is not possible to separate the ZOC of the abstracted component from the overall ZOC of the total discharge through the karst fissures / conduits intersected by the borehole. In order to protect the abstracted component it is necessary to protect the entire catchment contributing to the total discharge through the borehole – fissure / conduit intersection, i.e. PWS abstraction plus groundwater through-flow which is not captured by the PWS. As a result the ZOC for the source has been delineated on the basis of the maximum recorded abstraction of 1,363 m^3/d plus a factor of safety of 50%, i.e. 2,044 m^3/d. The water balance calculation indicates that an area of approximately 2.7 km^2 should be delineated for the ZOC. Taking the conceptual understanding of the source and augmented recharge from runoff intercepted by karst features into consideration means that in reality a smaller area can be delineated.

The northern boundary is the geological boundary between the BT Ll aquifer and the LLS Pl aquifer. This is assumed to be a no flow boundary with respect to groundwater flow. Due to the potential for runoff from the Pl aquifer and spring discharge from the Rf aquifer to augment recharge on the Ll / Rk_d aquifer side of the boundary, the ZOC has been extended 100 m upgradient of the boundary to protect the quality of this runoff before it recharges the Rk_d aquifer via karst features and losing streams. This buffer has not been applied in areas upslope of the west to east running stream in the East Crinnaughtaun area because the stream will intercept and remove the majority of recharge prior to infiltration into the Rk_d aquifer.

The western and eastern boundaries are taken as flow lines which capture a roughly symmetrical footprint upgradient of the source, reflecting the predominantly diffuse nature of flow in the Rk_d aquifer. The delineation of the boundaries also takes into account the potential for local topography to focus runoff on karst features.

Due to the minimal drawdown induced by pumping at a rate of 1,363 m^3/d, it is not expected that the abstraction will draw significant volumes of water from the downgradient side of the borehole. As a result the **southern boundary** has been delineated by joining the western and eastern boundaries at an arbitrary distance of 30 m downgradient of the source. This is to ensure adequate sanitary protection for the source.

The boundaries are shown in Figure 10 overlain on the geology boundaries as background.

Overall the delineated boundaries describe a ZOC for a well yield of 1363 m^3/d which has an area of 1.71 km^2. This is less than the area calculated from the water balance approach. Given the conceptual understanding of the source and the potential for recharge augmentation by runoff intercepted by karst features, the delineated area is expected to account for the total discharge through the karst fissures / conduits intersected by the borehole.

9.2 INNER PROTECTION AREA

The Inner Source Protection Area is the area defined by the horizontal 100 day time of travel from any point below the watertable to the source (DoELG, EPA, GSI, 1999). The 100-day horizontal time of travel to the source is calculated from the velocity of groundwater flow in the bedrock. The velocities are normally calculated based on the average aquifer hydraulic properties of the ZOC. In this instance however, the very rapid groundwater velocities expected in individual karst conduits through the aquifer render such calculations almost irrelevant with respect to protection of the source from pollution by micro-organisms. Results from tracing programmes in similar rock types indicate velocities of many metres / day. On this basis, it is considered appropriate to designate all of the ZOC as part of the inner protection area to the source (SI).

There is therefore no separately delineated Outer Source Protection Area (SO).

10 GROUNDWATER PROTECTION ZONES

Groundwater protection zones are shown in Figure 11, and are based on an overlay of the source protection areas on the groundwater vulnerability. Therefore the groundwater protection zones are SI/E, SI/H, SI/M and SI/L.

An anomaly has arisen between the source protection zones (this report) and the resource protection zones (Regional Groundwater Protection Zone map) which has lead to a difference in vulnerability classification in the buffered zone around the stream flowing through the ZOC. On the regional maps the buffered stream is classified as extremely vulnerable because the stream is known to sink into the karstified bedrock down gradient of this source. The sinking stream, however, does not pose a specific threat to this source and so ordinarily it would simply be given the vulnerability classification of the surrounding subsoils. In the interests of consistency and of not causing confusion between the regional and source maps, this stream zone is therefore also given an Extreme vulnerability classification in this source report.

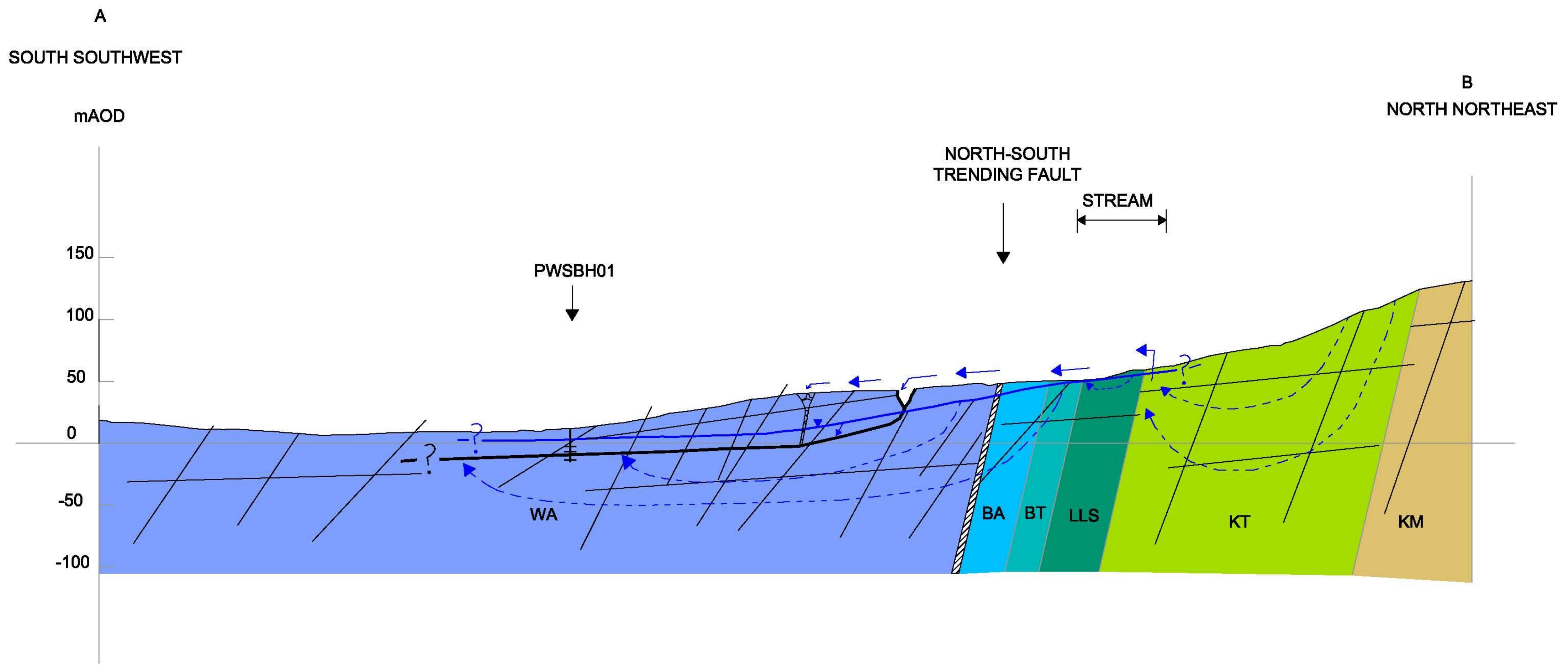
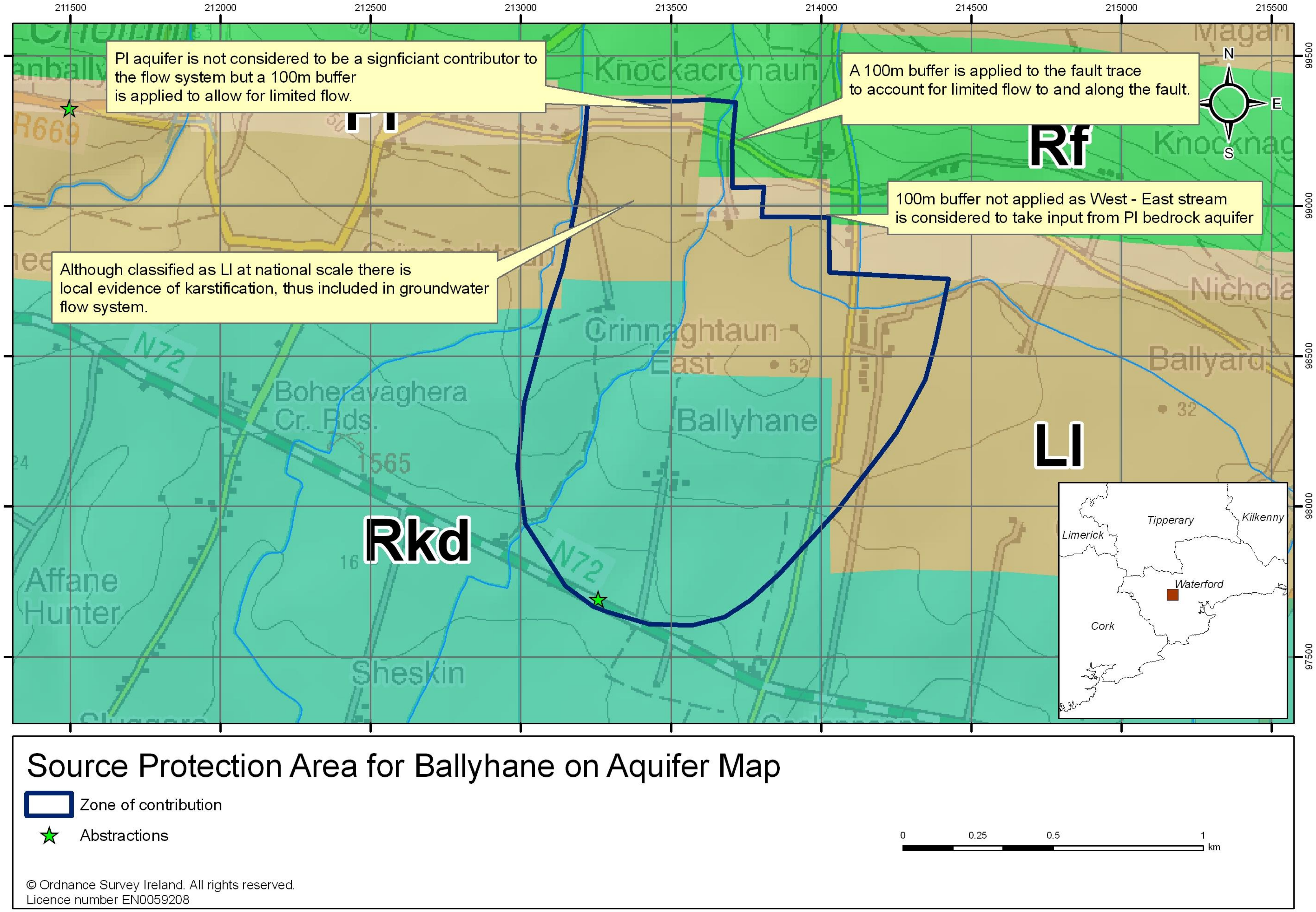


FIGURE 9 SCHEMATIC CONCEPTUAL MODEL

LEGEND

- 🟦 WAULSORTIAN LIMESTONE (WA)
- 🟦 BALLYSTEEN LIMESTONE (BA)
- 🟦 BALLYMARTIN LIMESTONE (BT)
- 🟩 LOWER LIMESTONE SHALE (LLS)
- 🟩 KILTORCAN SANDSTONE (KT)
- 🟫 KNOCKMEALDOWN SANDSTONE (KM)
- ▨ BEDROCK FAULT ZONE
- ‡ PUBLIC WATER SUPPLY BOREHOLE
- ∼ BEDROCK GROUNDWATER ELEVATION
- "LAND BREAK" KARST FEATURE BACKFILLED WITH STONE
- KARST SINKHOLE FEEDING INTO KARST CONDUIT
- ↰ SPRING DISCHARGE AT BOUNDARY OF KT/LLS
- ← RUNOFF/SPRING DISCHARGE INTERCEPTED BY KARST FEATURES
- ⇠ GROUNDWATER FLOW LINES (IN Rkd AQUIFER THESE LINES INDICATE DIFFUSE FLOW IN FRACTUE NETWORK BEFORE INTERCEPTION BY A CONDUIT FEATURE)
- / BEDROCK FEATURES



Pl aquifer is not considered to be a signficiant contributor to the flow system but a 100m buffer is applied to allow for limited flow.

A 100m buffer is applied to the fault trace to account for limited flow to and along the fault.

100m buffer not applied as West - East stream is considered to take input from Pl bedrock aquifer

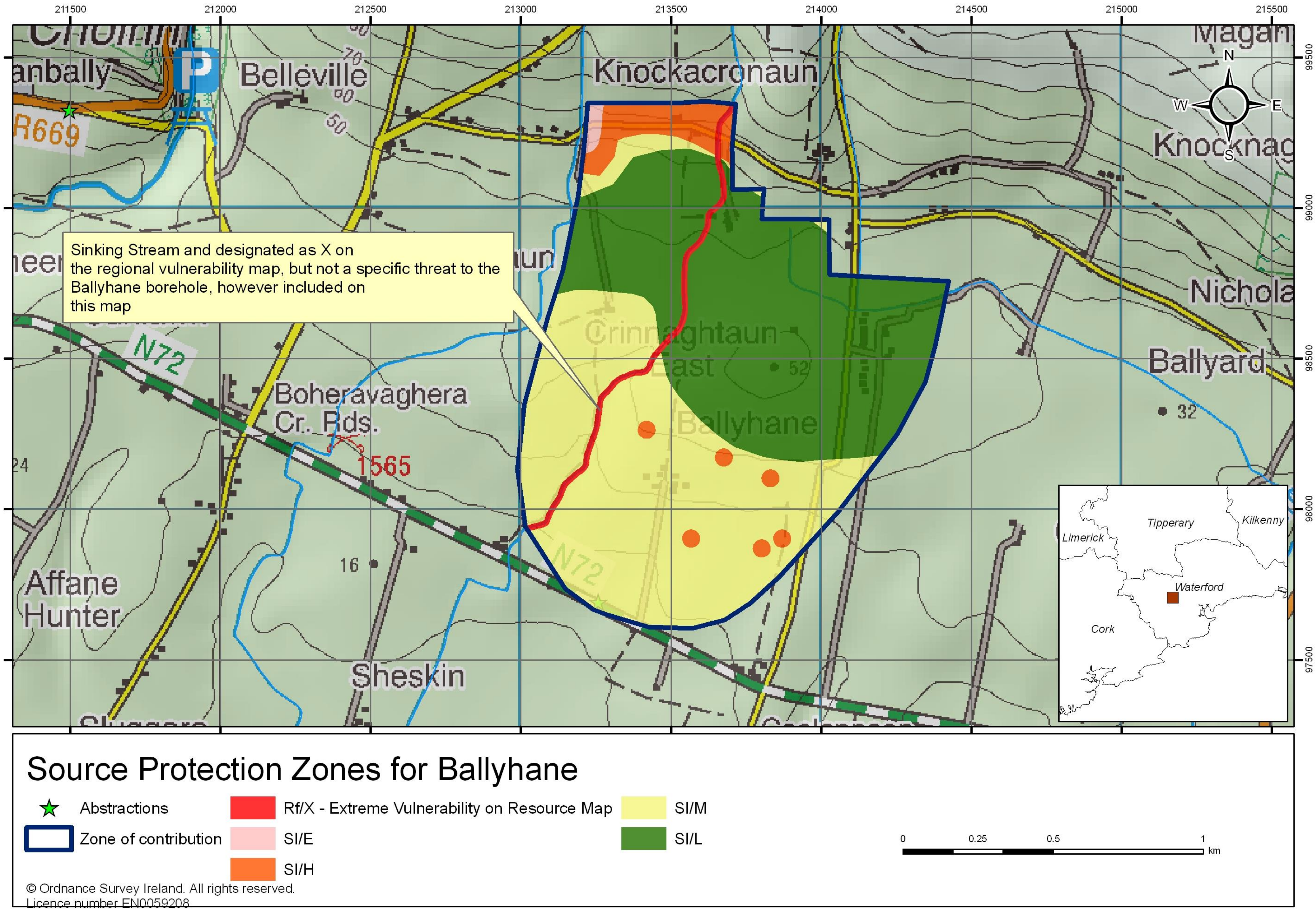
Although classified as Ll at national scale there is local evidence of karstification, thus included in groundwater flow system.

Source Protection Area for Ballyhane on Aquifer Map

Zone of contribution

★ Abstractions

Figure 10 Source Protection Areas (SI) for Ballyhane



Sinking Stream and designated as X on the regional vulnerability map, but not a specific threat to the Ballyhane borehole, however included on this map

Figure 11 Source Protection Zones for Ballyhane

11 POTENTIAL POLLUTION SOURCES

The main potential sources of contamination within the ZOC are:

- All private residences within the ZOC are serviced by septic tanks or similar wastewater treatment discharging percolation areas. The main potential contaminants from this source are ammonia, nitrates, phosphates, chloride, potassium, BOD, COD, TOC, faecal bacteria, viruses and cryptosporidium. The nitrate vulnerable zones (NVZ) study of the area counted 159 onsite waste water treatment systems within the NVZ area (MCOS, 2001).
- The majority of land within the zone of contribution is agricultural land, primarily arable and pasture with some apple orchard. An intensive poultry farm (IPPC License No. P0388-01) is also present within the ZOC upgradient of the source. In addition several of the farm holdings in the ZOC are registered as spread lands for a piggery located in the Cappagh area to the east (IPPC License No. P0447-01. Several livestock farming operations are active within the ZOC. The main potential contaminants from these sources are ammonia, nitrates, phosphates, chloride, potassium, BOD, COD, TOC, pesticides, faecal bacteria, viruses and cryptosporidium.
- Abandoned private boreholes and private boreholes with poor wellhead protection within the ZOC do not act as sources in their own right but may provide a pathway which exacerbates the impact of potential pollution sources nearby.
- Private home heating fuel tanks are likely to be located within the catchment area. The main potential contaminants from this source are hydrocarbons.
- Roadways are present within the ZOC. The main potential contaminants from this source are hydrocarbons and metals.

12 CONCLUSIONS

The untreated groundwater is currently impacted by contamination which is likely to be of organic or inorganic origin. While the subsoils within the ZOC are of moderate permeability and reasonably thick resulting in a moderate vulnerability classification, there are a number of karst features present which provide direct access to the aquifer for contaminants.

Due to the potentially high groundwater velocity within the study area it is possible that groundwater recharging anywhere within the ZOC could reach the source in less than 100 days. For this reason the entire ZOC has been classified as the Inner Protection Area (SI). The protection zones delineated in this report are SI/E , SI/H, SI/M and SI/L.

The conclusions and recommendations of the report are based on current understanding of groundwater conditions and bedrock geology as inferred from the available data. The report should not be used as the sole basis for site-specific decisions.

Particular care should be taken when assessing the location of any activities or developments that might cause contamination of the Ballyhane Source, particularly within the inner source protection zone (SI). Reference should be made to the guidelines contained within the DELG/EPA/GSI “Groundwater Protection Scheme” publication regarding the siting of certain activities, such as septic tanks and landspreading of organic wastes, within source protection areas.

13 RECOMMENDATIONS

Further investigations might usefully include.

- Two to three intrusive subsoil investigations across the study area to better assess the subsoil permeability of the full subsoil profile and the depth to bedrock; in particular across the 'landbreaks' as they are not fully understood or characterised.

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APPENDIX 1

POINT DATA, WATER QUALITY DATA, COMPONENTS OF GROUNDWATER VULNERABILITY

- Table A1.1 – Point Data from hydrogeological Mapping
- Table A1.2 – EPA Water Quality Data For Ballyhane PWS Source
- Table A1.3 – Surface water Field Water Quality Data
- Figure A1.1 – Depth to bedrock map
- Figure A1.2 – Subsoil permeability map
- Figure A1.3 – Map of Karst Features in the Study Area

Table A1.1 - Point Data from Hydrogeological Mapping - Ballyhane Public Water Supply

Name	Type	Sub-type	X	Y	Description	GWL mbtc	GWL mbtc	GWL mbtc	GWL mbtc	Total Depth (m)	tc magl	GL mAOD	GWL mAOD	DTB	Exp Interval	Subsoil K
						09/12/2005	19/10/2009	02/11/2009	03/11/2009							
OC01	Bedrock	Outcrop	214337	99091	Outcrop of Kiltorcan Formation. Yellowish, green-grey, fine grained Sandstone. Weathered & broken exposure, SST is quite weak. Bedding (Cleavage?) seems to run E-W, vertical, orange & black (Fe & Mn) staining on fracs & joint faces. Fratures: Set trending North - South, frac plane dips at 80 to 90 degrees, spacing 0.1 to 0.4m, aperture approx 0.001m;											
OC02	Bedrock	Outcrop	213913	97530	RPS NVZ Report (2001) - Bedrock outcrop identified on Report Figure 4.											
BH01	Groundwater	Borehole	213366	97643	Waterford CoCo trial well. In field approx 100m ESE of PWS borehole, at field boundary adjacent to N72 main road. Welded shut with a steel plate, with a 2 cm diameter hole for dipper access. The ground has collapsed to a depth of about 0.5m immediately aorund the steel casing. TC = top of 8-inch steel casing.		13.67	12.955	.	25.5	1.24	16	4.285			
BH02	Groundwater	Borehole	213360	99285	Private borehole adjacent to small pump house at gate into field, adjacent to the local road. TC = top of 6-inch steel casing.			2.5		45.72	0.175	68	65.675			
BH03	Groundwater	Borehole	214835	99089	Private borehole adjacent to small pumphouse in rough ground adjacent to new house. TC = top of 6-inch steel casing.			0.42			0.05	67.5	67.13			
BH04	Groundwater	Borehole	214152	98502	O'Connor Chicken Farm. Owner said this BH has good WQ - no Fe or Mn issues, but water needs to be softened. TC = top of 8-inch steel casing.			8.075			0.125	47.1	39.15			
BH05	Groundwater	Borehole	214181	98345	O'Connor Chicken Farm. Owner said this BH has high Fe & Mn issues, but water also needs to be softened. TC = top of 6-inch steel casing. BH pump came on & off during water level measurement. Lowest level measured = 12.85mbtc after 3 mins of pumping. Pump off & water level rose to 10.19 mbtc (still rising) after 5 mins, then pump cut in again. Est RWL at 10.0mbtc. Peak use for poultry farm approx 65m3/day BH05 + BH04)			10			0.1	49	39.1			
BH06	Groundwater	Borehole	214194	98639	O'Connor Chicken Farm. Owner said this BH has high Fe & Mn issues, but not treated or softened as just used for watering the cattle. TC = top of 8-inch steel casing.			2.89			0.11	45	42.22			
BH07	Groundwater	Borehole	213869	97553	Private borehole in small pump house, beneath large conifer tree, in field at boundary adjacent to local road. Location approx 100m north of farmyard. Owner said WQ is satisfactory for milking parlour & drinking use. Drilled 1991 or 1992 by Frank Seery. TC = top of 6-inch steel casing.			16.05		60.96	0.02	23	6.97	12.192		
BH08	Groundwater	Borehole	213745	97296	Private borehole in lawn adjacent to new house. Drilled approx 2005 by Frank Seery. Collapsing bedrock below 30mbgl. TC = top of 6-inch steel casing.			15.44		30	0.2	20	4.76	>10		
BH09	Groundwater	Borehole	211822	98016	Lardenn Poultry Farm in Affane. BH located at SE corner of poultry sheds. Abstraction approx 3000 to 4000gpd peak, average = 2000gpd (9m3/d). Drilled by Frank Seery. Large yield. TC = top of 6-inch steel casing.				16.02	40	0.2	20	4.18	20		Saturated Gravels overlying bedrock
BH10	Groundwater	Borehole	211987	98013	Private borehole in lawn adjacent to new house. Drilled by Frank Seery, approx 2007. Driller est Yield approx 58m3/day. Installed in S&G deposits above bedrock. TC = top of 6-inch steel casing.				16.53	25	0.19	18	1.66	>25		Saturated Gravels overlying bedrock
BH11	Groundwater	Borehole	213455	97876	Private borehole in field adjacent to farm house access track, approx half way up the track on eastern side. TC = top of 6-inch steel casing. Pump on => water level dropped to 18.3mbtc.				17.65	36.576	0.255	22.5	5.105	18.288		
BH12	Groundwater	Borehole	212502	97348	Private borehole in boundary hedge of a bungaloe. Drilled by Frank Seery, approx 1999. Driller indicated yield was far in excess of private house needs. TC = top of 6-inch steel casing.				4.105	35	0	7	2.895	>10		
BH13	Groundwater	Borehole	213523	98136	Private borehole drilled in field immediately north of farmyard, adjacent to boundary. Borehole abandonned and backfilled. DTB = approx 60 ft; Driller hit cavity at 80 to 90 ft bgl. Drilled on but bit got stuck & had to drill casing down around the existing hole to recover, took several weeks.									18.288		

Table A1.1 - Point Data from Hydrogeological Mapping - Ballyhane Public Water Supply

Name	Type	Sub-type	X	Y	Description	GWL mbtc	GWL mbtc	GWL mbtc	GWL mbtc	Total Depth (m)	tc magl	GL mAOD	GWL mAOD	DTB	Exp Interval	Subsoil K
						09/12/2005	19/10/2009	02/11/2009	03/11/2009							
BH14	Groundwater	Borehole	213525	98092	Old private bored well in farm yard. Casing collapsed. No longer in use. TD approx 160 ft. Water strike at approx 120 ft.											
BH15	Groundwater	Borehole	213322	98694	RPS NVZ Report (2001) -Location of borehole at Crinnaughtaun Farm. Ground water elevation measured in Sept. 2001. Ground elevation and depth to groundwater not given. This location was visited on 02/11/2009 but the farm manager was unable to locate the borehole to enable the 2009 water level to be measured.								36.2			
BH16	Groundwater	Borehole	210135	98732	BP Connor Assoc. Bleanahouree BH Report (2005) - Borehole drilled by Frank Seery for housing development water supply. Location taken from report. Pump tested at 432 m3/d. No aquifer properties obtained due to tidally fluctuating water levels in borehole. Main inflow of 324 m3/d at 21 mbgl & increasing afterwards with depth. NO3 as mg/l NO3 range 13 to 22 mg/l during pump test.	2.47				71.93	0.4	4.6	2.53	12	0 - 12 m	6m CLAY overlyting 6m SAND & GRAVEL
BH17	Groundwater	Borehole	212239	97466	Disused borehole in saturated SAND and GRAVEL deposits. Drilled by Frank Seery after 2000. Yield approximately 130 m3/d. Borehole location not confirmed. A manhole cover in a concrete foundation was encountered in a field at the co-ords indicated which is assumed to correspond to the borehole, based on the driller's description of the location. The cover was sealed with concrete and could not be opened to confirm the presence of the borehole.					20				>20		SAND and GRAVEL
BH18	Groundwater	Borehole	210726	97691	RPS NVZ Report (2001) - Location of Lefanta PWS on Report Figure 4. Groundwater elevation given as 0.2 m OD for Sept. 2009. Ground elevation at borehole given as 12.3 m OD on page 33 of report. Abstraction in 1991 was 191 m3/d. Original 72hr pump test was at Q = 1362 m3/d. Report quotes GSI pump test from 13/07/1992: Q = 634m3/d. Specific capacity estimated at 1585 m3/d/m; Tidal impacts on test Data GSI Well D'base: Yield = 634m3/d. McDaid MSc Thesis (1994): Estimated T from Tidal fluctuation as 3585 m2/d. Abstraction abandoned due to elevated nitrate concentrations (>50 mg/l as NO3)							12.3	0.2			
GW01	Groundwater	Dug Well	211938	98025	Dug well at Affane Cross Poultry Farm, in the old farmyard. Marked on 25-inch map. Owner says well is 15 m deep & 1 m diameter, but dries out in the summer. Sealed over at the surface but not filled in.									>15		
PWSBH01	Groundwater	Borehole	213257	97706	PWS abstraction borehole. TC = top of 8-inch steel casing. Total depth estimated using dip meter to detect base of well. Flow on Siemans Mag 5000 = 16.64 m3/hr (399 m3/day); Flow on Kent flow meter = 10 l in 2.08 sec = 415 m3/d.		11.35		10.66	26.7	0.04	15	4.38			
KF01	Karst	Enclosed Depression	212660	97459	Circular collapse feature approx. 20m diameter & 4m deep. Bedrock exposed on north side of depression. Bedrock is generally massive, pinkish white to grey, sparry limestone. Thinly bedded in places. Fractures: Solution enlarged, up to 0.1 o 0.2m aperture; 1 set trending NE, frac plane dips @ 85 to 90 degrees. Dry on 30/10/09 (rainy day); base of depression flodded on 3/11/2009 (dry/showery day).									0		
KF02	Karst	Sink Hole	212736	97494	Sink hole with small, unnamed stream flowing in from north. Flooded on 30/10/09. Flood mostly cleared on 3/11/2009, sink hole located in stream channel adjacent to hedgerow at approx south west corner of field. Sink hole located in a shallow natural topographic bowl.											
KF03	Karst	Enclosed Depression	212138	97943	Shallow enclosed depression approx 10m diameter; Flooded on 30/10/2009. Est total depth (incl flood) at approx 2m.											

Name	Type	Sub-type	X	Y	Description	GWL mbtc	GWL mbtc	GWL mbtc	GWL mbtc	Total Depth (m)	tc magl	GL mAOD	GWL mAOD	DTB	Exp Interval	Subsoil K
						09/12/2005	19/10/2009	02/11/2009	03/11/2009							
KF04	Karst	Enclosed Depression	212099	97495	Large, flooded depression, roughly oval shaped in stream channel. Looks like a flooded collapse feature with stream running in from NW and out to SE due to heavy rains and high water table. Approx 20m long and 8m wide. Looks several metres deep gauging from semi-submerged trees.											
KF05	Karst	Possible Spring	214031	98406	Possible spring clsoe to top of small hill. Feature is shallow, marshy depression approx 1.5m deep and drainin into an artificial drain. Location is over a mapped fault close to boundary of WA & BA formations											
KF06	Karst	Enclosed Depression	212957	99131	Circular collapse feature approx 15m diameter. Flooded on 30/10/09. Semi submerged trees in centre. Likely to be a sink hole. Located on a gentle southerly slope and intercepts upslope runoff.											
KF07	Karst	Enclosed Depression	212211	99059	Shallow enclosed depression approx 25m diameter, est approx 1.5m deep. Flooded on 30/11/09.											
KF08	Karst	Enclosed Depression	212337	96938	Enclosed depression approx 10 m wide & 40 m long, 5 to 7 m deep. Rock is exposed in south face of the feature: Pale, pink-white limestone, slightly sparry, thinly laminated, large pores indicating dolomitisation. Beds dip at 85 degrees to south south west (195 deg east of north). Fractures: Orthogonal vertical sets - (1) trending south & 85 deg from horizontal, (2) trending east (100degrees) & 78 degress from horizontal. Frac spacing 0.1 - 0.3 m, aperture 0.001 to 0.01 m with occasional 0.1 m apertures; Subhorizontal frac set - trending northeast and dipping 30 degrees from horizontal. Frac Spacing approx. 0.3 to 0.5 m, aperture <0.001 to 0.01 m. Groundwater level at base of feature - standing water in large open fissure at base of feature.											
KF09	Karst	Enclosed Depression	212773	96873	GSI Karst Feature - Enclosed Depression - FNUM:2009SWK006. Approx. 3 m wide and 10 m long. Location was flooded on 30/11/09. Landowner said it doesn't tend to overflow, just fills up & drains. Surface drainage from adjacent road floods into it in heavy rainfall, as on day of site visit.											
KF11	Karst	Enclosed Depression	211446	97813	Infilled land break. Location identified by landowner on 2004 orthophoto. Landowner reported largest land break in his memory at this location - break was 0.5 acre in area. Land breaks common in this field and fields to north and 1 field to east, but not further east. Breaks typically elongated cracks about 30 ft long and 8 ft deep. Breaks were more common during heavy machinary use of the beet harvesting era.											
KF12	Karst	Enclosed Depression	213870	97903	Infilled land break. Location identified by landowner on 2004 orthophoto. Break occurred in 2009.											
KF13	Karst	Enclosed Depression	213955	97824	Infilled land break. Location identified by landowner on 2004 orthophoto. Local landowner indicated that location floods regularly and has no outward drain, i.e. drains to ground.											
KF14	Karst	Enclosed Depression	213802	97870	Infilled land break. Location identified by landowner on 2004 orthophoto. Area of field with multiple historical land breaks. Low points flood in wet weather.											
KF15	Karst	Enclosed Depression	213567	97903	Infilled land break. Location identified by landowner on 2004 orthophoto.											
KF16	Karst	Enclosed Depression	213676	98172	Infilled land break. Location identified by landowner on 2004 orthophoto.											
KF17	Karst	Enclosed Depression	213419	98264	Infilled land break. Location identified by landowner on 2004 orthophoto.											
KF18	Karst	Enclosed Depression	213831	98103	Infilled land break. Location identified by landowner on 2004 orthophoto. Occurred in 2005. Break was 15 to 20 ft deep (4.5 to 6 m)											
KF19	Karst	Enclosed Depression	212714	98559	Infilled land break. Location identified by landowner on 2004 orthophoto. Landowner indicated that depression has not dried out throughout 2009.											

Name	Type	Sub-type	X	Y	Description	GWL mbtc	GWL mbtc	GWL mbtc	GWL mbtc	Total Depth (m)	tc magl	GL mAOD	GWL mAOD	DTB	Exp Interval	Subsoil K
						09/12/2005	19/10/2009	02/11/2009	03/11/2009							
KF20	Karst	Enclosed Depression	212845	98643	Infilled land break. Location identified by landowner on 2004 orthophoto. Landowner indicated that depression has not dried out throughout 2009.											
KF21	Karst	Enclosed Depression	212671	98769	Infilled land break. Location identified by landowner on 2004 orthophoto.											
KF22	Karst	Enclosed Depression	214012	97801	RPS NVZ Report (2001) - Karst feature identified on Report Figure 4. Assume that its an enclosed depression.											
KF23	Karst	Enclosed Depression	211267	97252	RPS NVZ Report (2001) - Karst feature identified on Report Figure 4. Assume that its an enclosed depression.											
KF24	Karst	Enclosed Depression	211784	97763	RPS NVZ Report (2001) - Karst feature identified on Report Figure 4. Assume that its an enclosed depression.											
KF25	Karst	Enclosed Depression	210996	98442	RPS NVZ Report (2001) - Karst feature identified on Report Figure 4. Assume that its an enclosed depression.											
KF10	Karst	Sink Hole	212112	97782	GSI Karst Feature - Sink Hole - FNUM:2009SWK008. Location was flooded on 30/11/09 & feature could not be distinguished in flooded stream - stream was overflowing the feature and continuing to south over land.											
EXP01	Subsoil	Exposure	213426	99346	Exposure in cutting behind new house in Knockacronaun townland, on lower part of a southerly trending slope. Surrounding land use is pasture & arable. Subsoil is Stiff, mottled grey-pink to pink-brown to orange, slightly sandy, very gravelly SILT/CLAY									> 2m	0 to 2 m	SILT/CLAY
EXP02	Subsoil	Exposure	214759	99015	Exposure in cutting behind new house in eastern part of Knockacronaun townland. Exposure is approx 50 m long & 3 m high at highest point. Base is on sandstone bedrock. Located at foot of southerly trending slope. Surrounding land use is pasture. Frequent seepage from gravel lenses in subsoil. Up to 1 l/s in places. Spring discharge across the footprint of the house site due to intense heavy rainfall (owner says only occurs after heavy rain). Subsoil is Stiff to very stiff, mottled white-grey & orange, gravelly to very gravelly with cobbles, CLAY. Almost clast supported in places. Frequent preferential pathways of GRAVEL.									< 3 m to 3 m	0 to 3 m	CLAY
EXP03	Subsoil	Trial Hole	214626	97719	SSA open trial hole in field in townland of clashnagoneen. Surrounding vegetation is pasture. Subsoil is soft, mottled grey-brown to pink-brown & orange, slightly sandy, gravelly SILT/CLAY									>1.4	0 to 1.4 m	SILT/CLAY
EXP04	Subsoil	Exposure	212650	97449	Subsoil exposure in field. Exposure is in wall of KF01. Setting is an inward sloping bowl with in a generally gently, southerly sloping area. Land use is pasture. Bedrock outcrop in north wall of KF01 & groundwater at base of feature on 3/11/09. Subsoil is soft, brown, gravelly SILT.									0 to >3 m	0 to 3 m	SILT
EXP05	Subsoil	Trial Hole	210733	97788	RPS NVZ Report (2001) - Trial hole excavated 100 m to the noreth of the Lefanta borehole. TD = 3.5 m. No log available. Material encountered summarised as "Sandy silty material with sandstone cobbles and boulders"									>3.5 m	0 - 3.5 m	Sandy Silty material with Cobble & Boulders of moderate to high permeability
EXP06	Subsoil	Trial Hole	213262	97704	RPS NVZ Report (2001) - Trial hole excavated adjacent to the Ballyhane borehole. TD = 3.5 m. No log available. Material encountered summarised as "Sandy silty material with sandstone cobbles and boulders"									>3.8	0 - 3.8	Sandy Silty material with Cobble & Boulders of moderate to high permeability
SW01	Surface Water	Stream	212073	96880	Stream water quality measurment point. EC, pH & T measured on 02/11/09											
SW02	Surface Water	Stream	212951	97844	Stream water quality measurment point. EC, pH & T measured on 02/11/09											
SW03	Surface Water	Stream	212241	98189	Stream water quality measurment point. EC, pH & T measured on 02/11/09											
SW04	Surface Water	Stream	213205	99618	Stream water quality measurment point. EC, pH & T measured on 02/11/09											
SW05	Surface Water	Stream	213659	99240	Stream water quality measurment point. EC, pH & T measured on 02/11/09											

Table A1.2 - EPA Water Quality Data for Ballyhane PWS Source

			mg/l	mg/l Ca	mg/l Mg	mg/l K	mg/l Na	mg/l Cl	mg/l	mg/l SO_4	mg/l $CaCO_3$	mg/l $CaCO_3$	uS/cm	ug/l Al	ug/l Fe
EPA Name	**Date**	**Body**	**NO3**	**Ca**	**Mg**	**K**	**Na**	**Cl**	**NO2**	**SO4**	**Alk**	**Hard**	**Cond**	**Al**	**Fe**
mg/l	**Jan-82**	**Threshold**	**37.5**	**200**	**50**	**5**	**150**	**24**	**0.1**	**200**			**1000**	**200**	**200**
mg/l	**Jan-82**	**EU MAC**	**50**	**200**	**50**	**12**	**150**	**250**	**0.1**	**250**			**1500**	**200**	**200**
Ballyhane PWS	29/06/1993		34.5	-	19.7	1.4	10	25	0.001	-	275	342	-	-	55
Ballyhane PWS	17/11/1993		35.4	-	17.7	1.4	11	26	-	-	293	325	-	-	11
Ballyhane PWS	04/01/1996		35.9	-	17.1	2.0	11	27	0.003	-	290	363	-	-	60
Ballyhane PWS	24/11/1997		47.4	-	-	-	-	28	0.004	20	-	-	-	-	-
Ballyhane PWS	02/06/1999		51.4	-	-	2.0	12	27	0.030	16	274	-	-	-	-
Ballyhane PWS	25/09/2000		48.7	-	13.0	2.1	12	24	0.001	18	-	318	-	-	60
Ballyhane PWS	13/02/2001		49.2	124	16.2	2.7	13	31	0.001	15	252	-	-	-	50
Ballyhane PWS	24/09/2001		62.0	117	15.9	2.4	16	26	0.001	15	272	358	-	208	154
Ballyhane PWS	26/02/2002		56.7	121	16.2	3.3	12	25	0.001	15	276	369	-	-	60
Ballyhane PWS	07/10/2002		50.9	112	14.7	1.2	11	25	0.001	14	266	340	-	-	60
Ballyhane PWS	10/02/2003		48.7	94	12.9	2.1	9	27	0.001	-	266	288	-	50	110
Ballyhane PWS	23/09/2003		50.0	108	13.7	2.2	11	22	0.001	15	-	326	-	50	58
Ballyhane PWS	23/02/2004		53.1	99	11.0	2.3	8	27	0.001	15	276	294	-	-	90
Ballyhane PWS	04/10/2004		53.1	112	14.1	2.3	11	26	0.001	14	254	338	-	50	73
Ballyhane PWS	28/02/2005		48.7	106	14.1	2.4	11	21	0.001	14	268	323	-	50	85
Ballyhane PWS	01/11/2005		48.7	109	13.8	2.3	11	24	0.001	16	246	329	-	50	94
Ballyhane PWS	28/02/2006		48.7	103	16.3	2.1	10	27	0.001	13	277	325	-	50	77
Ballyhane PWS	03/10/2006		53.1	-	-	-	-	24	0.001	15	274	-	-	-	-
Ballyhane PWS	18/07/2007		58.5	123	13.0	2.9	12	23	0.050	17	330	357	619	-	2
Ballyhane PWS	20/08/2007		85.5	116	13.0	2.6	12	22	0.050	16	330	235	731	2	20
Ballyhane PWS	16/10/2007		51.6	112	13.5	2.8	11	26	0.050	15	220	354	719	2	2
Ballyhane PWS	12/11/2007		52.6	115	13.7	3.0	20	24	0.050	16	310	306	630	2	32
Ballyhane PWS	11/12/2007		54.3	114	13.2	2.8	12	24	0.050	13	250	345	539	9	83
Ballyhane PWS	23/01/2008		47.6	116	14.2	2.9	15	24	0.050	13	280	322	601	2	2
Ballyhane PWS	04/06/2008		14.7	96	11.3	2.1	9	25	0.043	18	262	295	628	5	5
Ballyhane PWS	29/07/2008		24.7	100	11.3	2.4	11	23	0.043	17	236	309	652	5	5
Ballyhane PWS	08/10/2008		51.1	110	11.3	2.4	11	23	0.043	14	257	332	664	5	5
Ballyhane PWS	25/11/2008		38.0	113	11.3	2.7	11	21	0.08	15	266	345	722	5	5
	Average	mg/l	**48.39**	**110.47**	**14.09**	**2.34**	**11.62**	**24.89**	**0.02**	**15.34**	**272.00**	**326.59**	**650.50**	**34.07**	**50.27**
		mmol/l	0.79	2.76	0.56	0.06	0.51	0.70	0.00	0.16	2.72	mmol of CaCO3 = mmol of CO3--			
		MW	61.00	40	25.31	39.1	22.99	35.45	47	96.066	100				
		charge	1	2	2	1	1	1	1	2	2				
		meq/l	0.79	5.52	1.11	0.06	0.51	0.70	0.00	0.32	5.44	meq of CO3-- = meq of HCO3-			
		meq cations	7.20								5.44	mmol HCO3-			
		meq anions	7.25								331.84	mg/l as HCO3-			

Red colour denotes result in excess of MAC

Orange Colour denotes result in excess of EPA Threshold

Blue Colour Denotes result was less than the Detection Limit (DL), where DL is equal to the numeric value shown

Sources: GSI/County Council sampling and available EPA data.

Table A1.2 - EPA Water Quality Data for Ballyhane PWS Source

		ug/l Mn	mg/l N	No./100ml	No./100ml	ug/l Ba	ug/l B	ug/l Cd	ug/l Cr	ug/l Cu	mg/l F^-	ug/l Pb	ug/l Hg	ug/l Ni	mg/l P
EPA Name	**Date**	**Mn**	**NH4**	**Total Coli**	**Faecal Coli**	**Ba**	**B**	**Cd**	**Cr**	**Cu**	**F**	**Pb**	**Hg**	**Ni**	**PO4**
mg/l	**Jan-82**	**50**	**0.175**	**0**	**0**		**1000**	**5**	**30**	**30**	**1**	**10**	**1**	**20**	**0.035**
mg/l	**Jan-82**	**50**	**0.233**	**0**	**0**	**500**	**2000**	**5**	**50**	**500**	**1**	**50**	**1**	**50**	**5**
Ballyhane PWS	29/06/1993	5	0.010	0	0	-	-	-	-	-	-	-	-	-	0.004
Ballyhane PWS	17/11/1993	5	0.010	0	0	-	-	0.1	-	10	-	1	-	-	0.010
Ballyhane PWS	04/01/1996	20	0.010	-	-	-	-	-	-	-	-	-	-	-	0.014
Ballyhane PWS	24/11/1997	-	0.010	1	-	-	-	-	-	-	-	-	-	-	0.020
Ballyhane PWS	02/06/1999	-	<0.2	1	0	-	-	-	-	-	-	-	-	-	0.040
Ballyhane PWS	25/09/2000	20	0.003	0	0	-	-	-	-	-	-	-	-	-	0.009
Ballyhane PWS	13/02/2001	1	0.003	0	0	50	50	0.1	-	6	0.8	1	-	1	0.014
Ballyhane PWS	24/09/2001	5	0.003	0	0	50	50	0.1	48	26	0.1	1	-	21	0.012
Ballyhane PWS	26/02/2002	20	0.003	0	0	-	-	-	-	-	0.6	-	-	-	0.009
Ballyhane PWS	07/10/2002	20	0.003	0	0	-	-	-	-	-	0.8	-	-	-	0.013
Ballyhane PWS	10/02/2003	1	0.003	0	0	50	50	0.1	4	6	-	1	-	1	0.011
Ballyhane PWS	23/09/2003	1	0.003	0	0	50	50	0.1	6	10	0.8	1	-	1	0.011
Ballyhane PWS	23/02/2004	1	0.003	0	0	50	50	0.1	5	14	0.7	1	-	1	0.012
Ballyhane PWS	04/10/2004	1	0.003	0	0	50	50	0.1	13	9	1.0	1	-	1	0.008
Ballyhane PWS	28/02/2005	29	0.004	0	0	50	50	0.1	9	1	0.1	1	-	1	0.006
Ballyhane PWS	01/11/2005	1	0.004	0	0	50	50	0.1	3	6	0.1	1	-	1	0.006
Ballyhane PWS	28/02/2006	1	0.003	0	0	50	50	0.1	7	2	0.9	1	-	1	0.006
Ballyhane PWS	03/10/2006	-	0.015	0	0	-	-	-	-	-	0.1	-	-	-	0.007
Ballyhane PWS	18/07/2007	1	0.150	0	0	5	3	0.4	6	1	0.1	1	0.05	2	0.010
Ballyhane PWS	20/08/2007	1	0.010	0	0	3	3	0.4	4	1	0.1	1	0.05	5	0.010
Ballyhane PWS	16/10/2007	1	0.020	0	0	4	3	0.4	7	2	0.1	1	0.05	4	0.023
Ballyhane PWS	12/11/2007	1	0.030	0	0	5	17	0.4	3	1	0.2	1	0.05	3	0.043
Ballyhane PWS	11/12/2007	2	0.010	0	0	10	43	0.4	11	26	0.2	1	0.05	2	0.039
Ballyhane PWS	23/01/2008	2	0.020	0	0	5	58	0.4	9	2	0.2	1	0.05	4	0.043
Ballyhane PWS	04/06/2008	1	0.030	0	0	4	20	0.2	1	3	0.1	0	0.04	8	0.043
Ballyhane PWS	29/07/2008	1	0.070	6	1	3	20	0.1	1	3	0.6	0	0.02	1	0.009
Ballyhane PWS	08/10/2008	1	0.024	0	0	4	20	0.1	1	13	1.0	2	0.02	1	0.009
Ballyhane PWS	25/11/2008	1	0.020	0	0	7	20	0.1	1	5	0.5	0	0.02	1	0.009
	Average	**5.73**	**0.02**	**0.30**	**0.04**	**26.36**	**34.58**	**0.20**	**7.71**	**7.33**	**0.43**	**0.95**	**0.04**	**3.15**	**0.02**

Red colour denotes result in excess of MAC

Orange Colour denotes result in excess of EPA Threshold

Blue Colour Denotes result was less than the Detection Limit (DL), where DL is equal to the numeric value shown

Sources: GSI/County Council sampling and available EPA data.

Table A1.2 - EPA Water Quality Data for Ballyhane PWS Source

		mg/l P	µg/l Se	µg/l Ag	µg/l Sr	ug/l Zn	ug/l Sb	ug/l As			°C	pH_field	pH_Lab
EPA Name	**Date**	**P**	**Se**	**Ag**	**Sr**	**Zn**	**Ant**	**As**	**K/Na Ratio (using mg)**	**K/Na Ratio (using meq)**	Temperature	pH	pH
mg/l	**Jan-82**					**100**		**10**	**0.35**				
mg/l	**Jan-82**	**5000**	**10**	**10**	**5000**	**1000**	**10**	**50**				**6.5-9.5**	**6.5-9.5**
Ballyhane PWS	29/06/1993	-	-	-	-	63	-	-	0.14	0.08	-	-	7.4
Ballyhane PWS	17/11/1993	-	-	-	-	59	-	-	0.13	0.08	10.0	-	7.2
Ballyhane PWS	04/01/1996	-	-	-	-	20	-	-	0.19	0.11	9.0	-	7.3
Ballyhane PWS	24/11/1997	-	-	-	-	-	-	-	-	-	11.4	-	7.1
Ballyhane PWS	02/06/1999	-	-	-	-	-	-	-	0.17	0.10	13.2	-	7.1
Ballyhane PWS	25/09/2000	-	-	-	-	64	-	-	0.18	0.10	10.8	-	7.2
Ballyhane PWS	13/02/2001	-	1.6	5	-	39	1.0	1.0	0.20	0.12	10.2	-	6.6
Ballyhane PWS	24/09/2001	-	1.6	50	-	353	1.0	1.0	0.15	0.09	11.0	-	7.3
Ballyhane PWS	26/02/2002	-	-	-	-	28	-	-	0.27	0.16	10.5	-	7.3
Ballyhane PWS	07/10/2002	-	-	-	-	32	-	-	0.11	0.06	11.8	-	6.3
Ballyhane PWS	10/02/2003	-	2.1	50	-	29	1.0	1.0	0.23	0.13	10.8	-	6.7
Ballyhane PWS	23/09/2003	-	1	50	-	11	1.0	1.0	0.19	-	11.0	-	7.2
Ballyhane PWS	23/02/2004	-	1.78	50	-	16	1.0	1.0	0.28	0.17	9.0	-	7.2
Ballyhane PWS	04/10/2004	-	1.75	-	-	38	1.0	1.0	0.20	0.12	11.5	-	7.0
Ballyhane PWS	28/02/2005	-	1	-	-	101	1.0	1.0	0.22	0.13	10.7	-	7.3
Ballyhane PWS	01/11/2005	-	1	-	-	26	1.0	1.0	0.20	0.12	11.4	-	6.8
Ballyhane PWS	28/02/2006	-	1	-	-	27	1.0	1.0	0.22	0.13	11.8	-	7.0
Ballyhane PWS	03/10/2006	-	-	-	-	-	-	-	-	-	11.3	-	7.2
Ballyhane PWS	18/07/2007	-	-	2	144	15	1.0	1.0	0.25	0.15	11.3	7.5	8.3
Ballyhane PWS	20/08/2007	-	-	2	110	10	1.0	1.0	0.23	0.13	11.1	7.7	7.7
Ballyhane PWS	16/10/2007	-	-	2	142	1	1.0	1.0	0.27	0.16	11.1	7.7	7.4
Ballyhane PWS	12/11/2007	-	-	2	124	24	1.0	1.0	0.15	0.09	10.8	7.4	7.6
Ballyhane PWS	11/12/2007	-	-	2	174	102	1.0	1.0	0.23	0.14	10.9	8.0	7.5
Ballyhane PWS	23/01/2008	-	-	2	134	19	1.0	1.0	0.20	0.12	11.2	7.5	7.8
Ballyhane PWS	04/06/2008	0.080	-	1	138	29	0.1	0.4	0.22	0.13	11.1	7.2	7.3
Ballyhane PWS	29/07/2008	0.030	-	1	131	44	0.4	0.2	0.21	0.13	13.0	7.0	7.1
Ballyhane PWS	08/10/2008	0.030	-	1	135	80	0.3	5.0	0.22	0.13	11.3	7.3	7.1
Ballyhane PWS	25/11/2008	0.030	-	1	137	26	0.1	0.3	0.24	0.14	8.9	7.8	7.6
	Average	**0.04**	**1.43**	**15.64**	**136.85**	**50.24**	**0.84**	**1.10**	**0.20**	**0.12**	**10.96**	**7.51**	**7.24**

Red colour denotes result in excess of MAC

Orange Colour denotes result in excess of EPA Threshold

Blue Colour Denotes result was less than the Detection Limit (DL), where DL is equal to the numeric value shown

Sources: GSI/County Council sampling and available EPA data.

Table A1.3 - Field Water Quality Data for Ballyhane PWS SPZ Investigation

ID	Date	pH	Temp [pH]	EC	Temp [EC]	DO	Temp [DO]	Alkalinity	Comment
		[-]	deg C	uS/cm	deg C	mg/l O2	deg C	mg/l as CaCO3	
SW01	03/11/2009	5.75	11	188.2	11	-	-	-	Data measured in situ in the stream
SW02	03/11/2009	5.55	10.5	186	10.7	-	-	-	Data measured in situ in the stream
SW03	03/11/2009	5.52	-	202.1	10.4	-	-	-	Data measured in situ in the stream
SW04	03/11/2009	5.48	9.8	187.1	10.1	-	-	-	Data measured in situ in the stream
SW05	03/11/2009	5.63	10	161.8	10.3	-	-	-	Data measured in situ in the stream

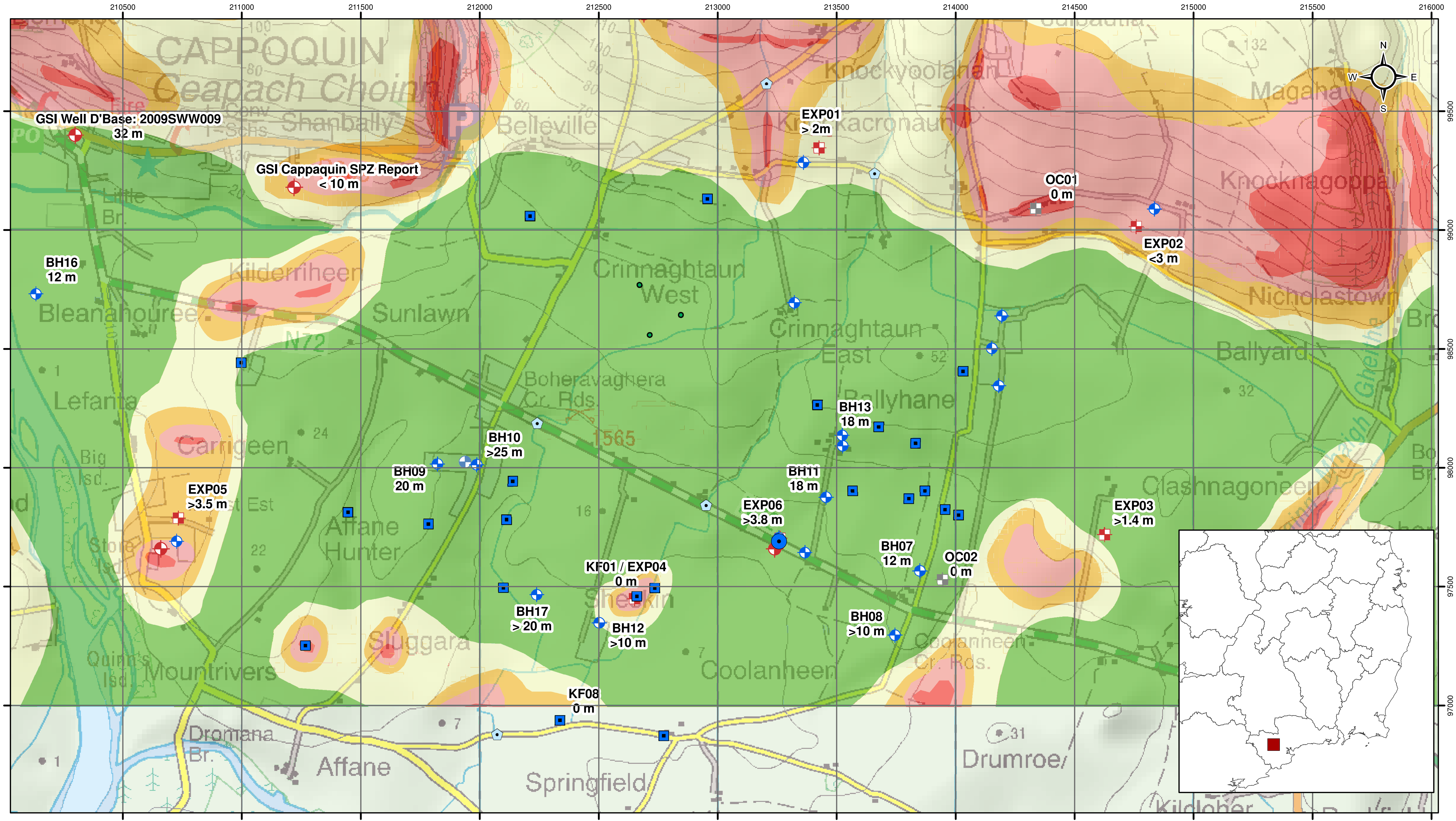

Figure A1.1 Depth to Bedrock Map

● PWS Abstraction

― River

🟥 DTB = < 1 m

▨ DTB = 1 - 3 m

🟧 DTB = 3 - 5 m

☐ DTB = 5 - 10 m

🟩 DTB = >10 m

BH07
12 m
⊕ Location ID & DTB

Note: DTB = Depth to Bedrock

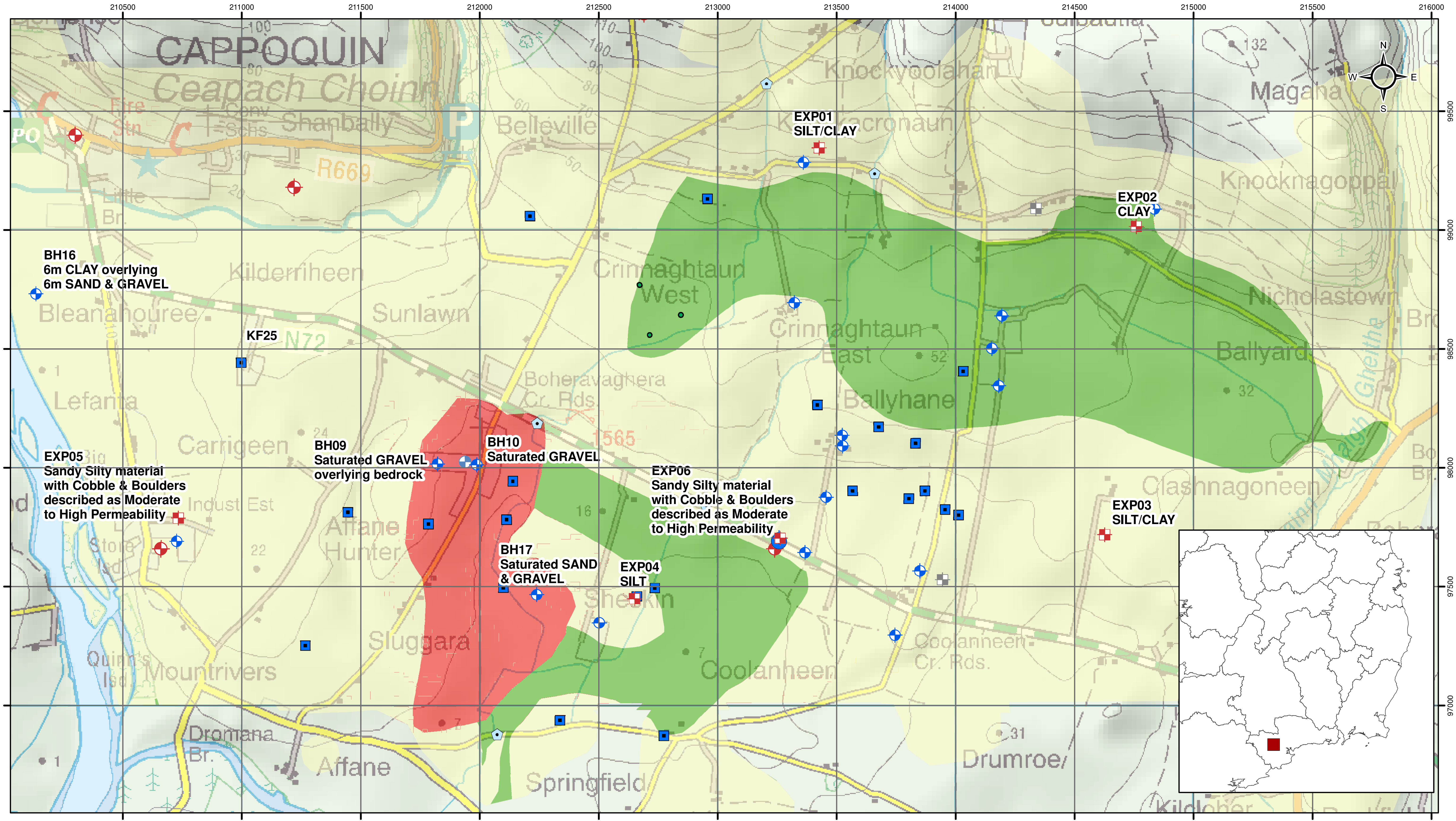

Figure A1.2 Subsoil Permeability

- ● PWS Abstraction
- — River
- 🟥 High Permeability
- ▭ Moderate Permeability
- 🟩 Low Permeability
- EXP04 SILT ▣ Location ID & Subsoil Permeability

Note: Subsoil permeability distribution also based
on the Soil & Subsoil Maps of the Area (not shown)
and on surface indicators of drainage conditions (not shown)

0 0.25 0.5
km

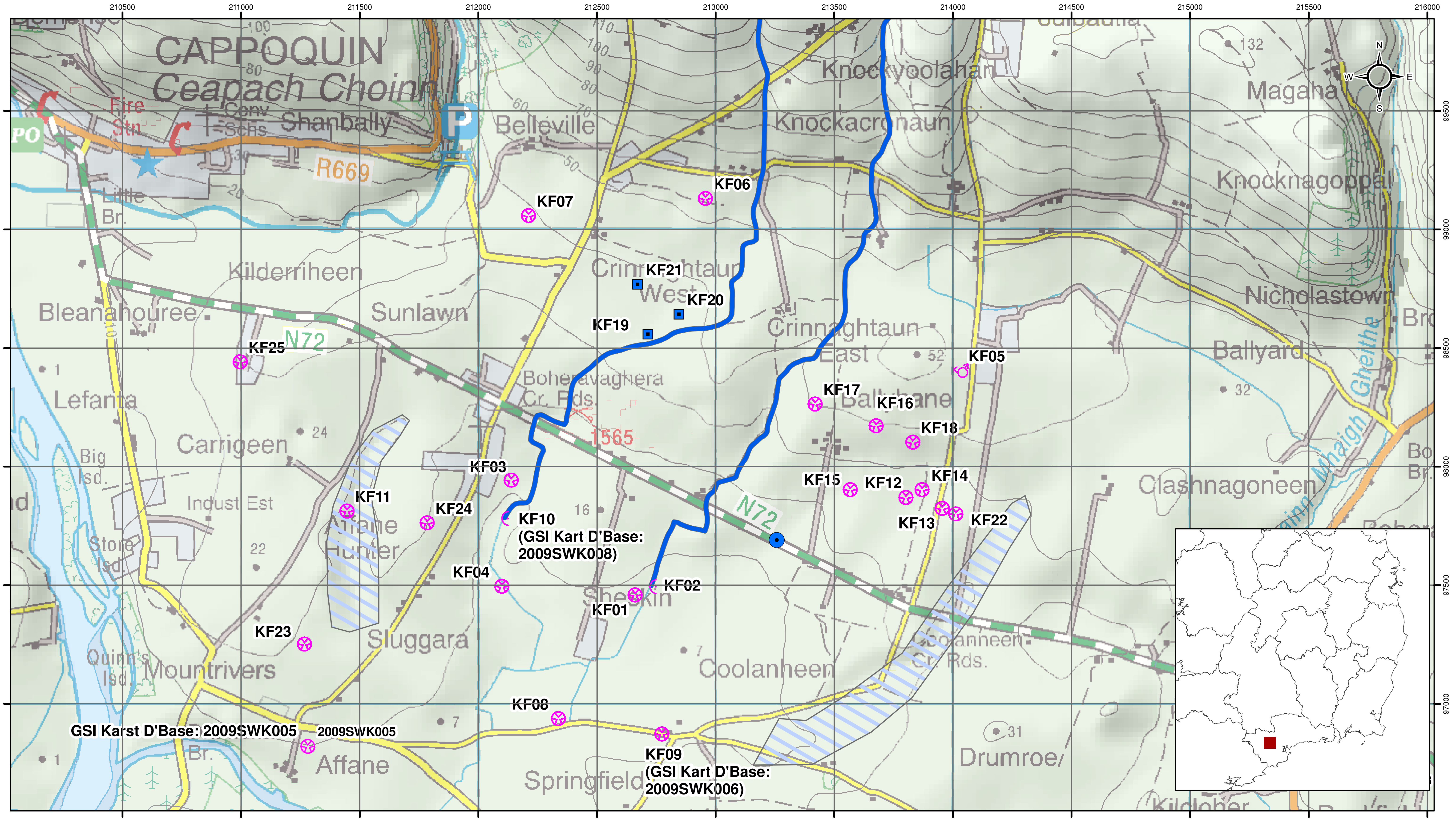

Figure A1.3 Map of Karst Features in Study Area

● PWS Abstraction

— River

Enclosed Depression

Swallow Hole

Karst Spring

▨ Dry Valley

■ Periglacial Pingo (note: periglacial pingos are not karst features)

Stream reaches upstream of stream intersection with Karst Sink Hole (Buffered 10 m on either side of stream)