Louth County Council

Establishment of Groundwater Source Protection Zones

Killineer Water Supply Scheme

Killineer Borehole

July 2011

Revision: F

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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.

Louth County Council contracted the GSI to delineate source protection zones for nine groundwater public water supply sources in Co. Louth. The sources comprised Ardee, Cooley (Carlingford and Ardtullybeg), Collon, Termonfeckin, Omeath (Lislea Cross and Esmore Bridge), Drybridge and Killineer.

This report documents the delineation of the Killineer source protection zones.

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

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1 INTRODUCTION

Groundwater Source Protection Zones are delineated for the Killineer 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 Killineer borehole source supplies water to the 10 domestic residences in the small estate adjacent to the south and east of the borehole. In this report the borehole is labelled Killineer PS.

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 Killineer PS.
- To assist the Louth 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 METHODOLOGY

A desk study of existing data sources relevant to the source was carried out prior to site visits. Site visits, site walkovers and field mapping of the study area were conducted on 30/04/2010 and 19/05/2010. An interview relating to the source was carried out on 30/04/2010 with the Louth County Council Maintenance Foreman, who is responsible for maintaining the source. Auger hole drilling for assessment of subsoil permeability and depth to bedrock for the Killineer area was carried out by the GSI in June 2007.

The locations of the point features investigated during the site visits and GSI drilling and identified during the desk study are shown in Figure A.1 (in Appendix 1). A summary of the point data collected during the site visits and field mapping is provided in Table A1.1 in Appendix No. 1.

3 LOCATION, SITE DESCRIPTION AND WELL HEAD PROTECTION

Killineer PS is located 4.2 km north-northwest of Drogheda and 1.6 km east of the M1 motorway in the townland of Killineer, as shown in Figure 1. The source is located in the middle of an area of amenity grassland in the communal space of a small housing estate adjacent to the R132 regional road (Figure 2).

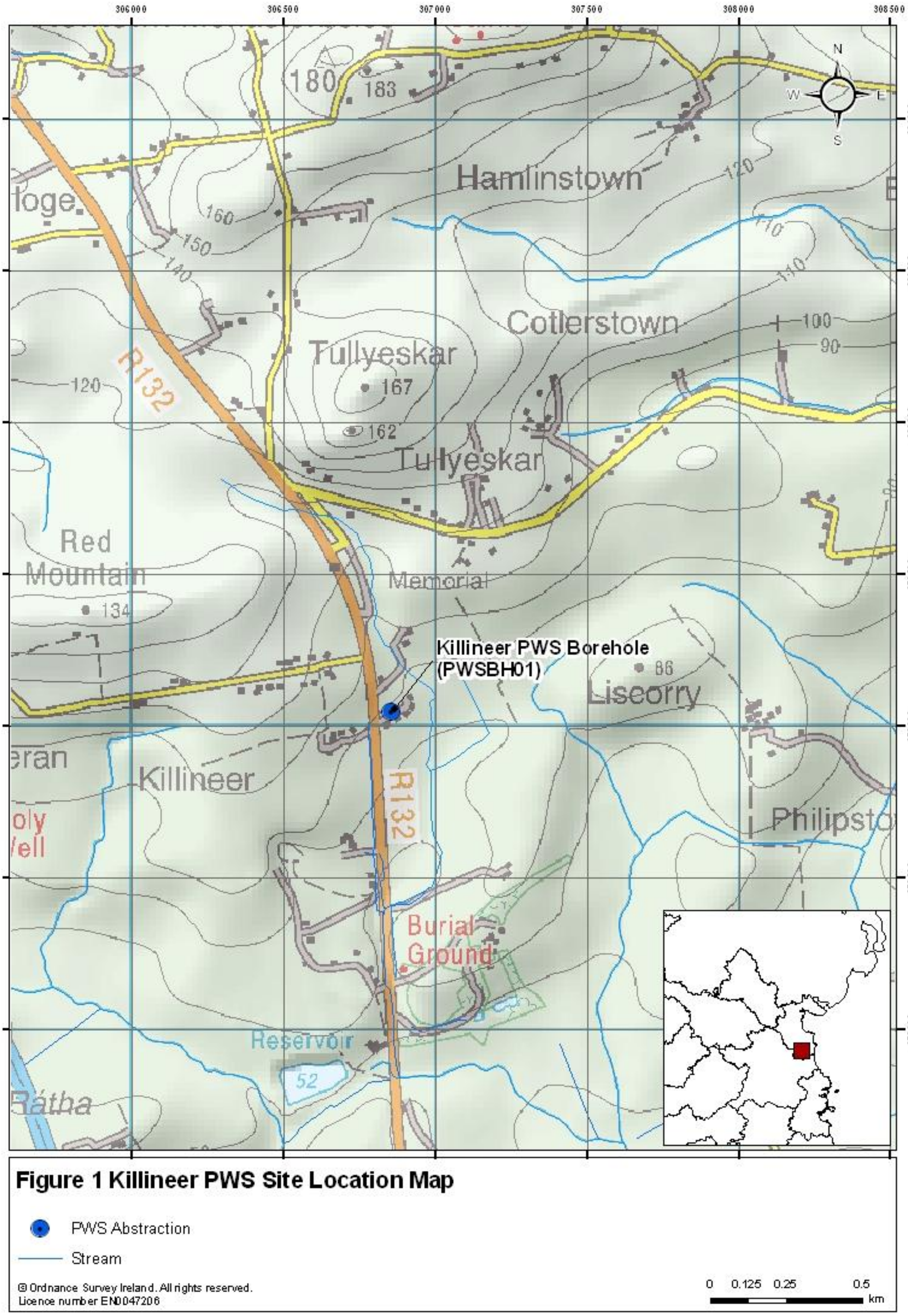

Figure 1 Killineer WSS Site Location Map

The source was drilled privately and was subsequently taken over by Louth County Council. There is no compound or fencing separating the source from the surrounding public space. The borehole is located in a small, block-lined manhole approximately 0.5 by 0.5 m diameter and covered by a 0.75 m by 1.5 m concrete slab. The mouth of the borehole is formed by a 150 mm diameter steel casing which sticks up 0.02 m above the floor of the manhole (Figure 3). The ground immediately surrounding the manhole has subsided slightly inwards around the borehole and the surrounding area slopes gently towards the borehole. It is unlikely that a grout seal was installed in the upper borehole annulus. There is a small pump house immediately adjacent to the borehole, which contains a pressure tank, electro-chlorination and a (possibly treated water) sampling tap.

Figure 2 Killineer PS Pump House

Figure 3 Killineer PS manhole chamber & manhole for the borehole

4 SUMMARY OF BOREHOLE DETAILS

The GSI well database indicates that the borehole was drilled in September 1965. Killineer PS pumps directly into the water supply distribution main feeding the adjacent houses. There are no original borehole records available for Killineer PS. Data have been collated based on site visits and discussions with Louth County Council. The data are summarised in Table 1. The average abstraction from the source is 5 m^3/day, based on Louth County Council data. The GSI well database records the yield of the borehole as 65.5 m^3/day, which is greatly in excess of the current demand.

Table 1 Summary of Source Details

Historical EPA Monitoring Code	LOU12
GSI Well Database Reference No.	2927SEW069
Borehole Name	Killineer PS
National Grid reference	306859 279045
Townland	Killineer
Source type	Borehole
Drilled	4th September 1965
Owner	Louth County Council
Elevation (Ground Level)	approx. 79.04 mAOD (i)
Depth	unknown
Depth of casing	unknown
Diameter	150 mm
Depth to rock	approx. 4 m (ii)
Static water level	unknown
Pumping water level	2.14 mb top of casing (30/04/2010)
Borehole Yield	65.5 m^3/d (iii)
Specific Capacity	4.48 m^3/d per m (iii)
Consumption (Co. Co. records)	5 m^3/day

Note (i): Elevation taken from EPA 20 m grid spacing Digital Terrain Model for Co. Louth.

Note (ii): Depth to rock estimated based on data from GSI Auger Hole KIL05 located 150 m northeast of the source.

Note (iii): From GSI Well Database.

5 TOPOGRAPHY, SURFACE HYDROLOGY AND LANDUSE

The source is located on the lower southeastern slope of the Red Mountain ridge, which reaches an elevation of 134 mAOD approximately 1 km west northwest of the source. This ridge is situated in the southeastern portion of the Louth Hills, a series of high, bedrock-cored ridges forming a ridge-and-valley landscape in mid-Louth. A small valley curves around the base of the ridge from the north. The source overlooks the southern part of the valley (see Figure 1). The ground surface in the vicinity of the source slopes southeast into the valley at a gradient of approximately 0.075.

A small stream runs through the valley below the source[1], and flows to the south where it joins into an unnamed tributary of the Boyne River at a location close to Killineer Reservoir[2]. Drainage density across the area is high (> 1 km of surface water courses per 1 km^2 area).

Land use in the area is primarily agricultural, with lands used for a mix of livestock pasture and for arable cereal crops. There is a livestock farmyard located 200 m west-southwest of the source, while a free range poultry farm is located 250 m to the north-northeast. Population density in the immediate vicinity of the abstraction point is moderately high for a rural setting, with the cluster of houses served by the borehole immediately to the east and south, and further housing upgradient to the northwest. There is no mains sewage in the area. As a consequence, domestic residences have onsite wastewater treatment systems discharging to ground.

[1] The stream is not mapped on the Ordnance Survey 1:50,000 scale map of the area but is visible on the ground and in aerial photos, and is shown on the 25-inch historical maps of the area. It is shown on Figure 1.
[2] Note: Killineer Reservoir is not associated with the source. It forms part of the Drybridge Public Water Supply Scheme

6 HYDRO-METEOROLOGY

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

Annual rainfall: 800 mm. The closest meteorological station to Killineer WSS is Drogheda (Killineer) at Killineer Reservoir, 1.2 km to the south of the source, where the average rainfall between 1970[3] and 1990 was 800 mm/yr (Fitzgerald and Forrestal, 1996).

Annual evapotranspiration losses: 532 mm. The closest synoptic weather station to the study area is Dublin Airport, 35 km to the south. Average potential evapotranspiration (P.E.) at Dublin Airport between 1961 and 1990 was 560 mm, based on Met Éireann 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 532 mm.

Annual Effective Rainfall: 268 mm. This is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is equivalent to this.

7 GEOLOGY

This section briefly describes the relevant characteristics of the geological materials that underlie the Killineer 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 Meath, Sheet 13, 1:100,000 Series (GSI, 2005) and accompanying memoir (McConnell *et al.,* 2001), the GSI Well and Borehole Databases and on bedrock outcrop and subsoil exposures encountered during site visits.

7.1 BEDROCK GEOLOGY

The bedrock map indicates that the majority of the study area is underlain by bedrock of Silurian age, classified as Silurian Metasediments and Volcanics for the purposes of the generalised rock unit map prepared by the GSI for the Water Framework Directive. The detailed bedrock geology is shown in Figure 4. Table 2 summarises the geology, with the formations shown in stratigraphic order (i.e. oldest at the base).

Table 2 Description of the Bedrock Geology

Bedrock Formation	Generalised Rock Unit Classification	Geological Description	Max thickness[4] (m)
Glaspistol Formation (GP)	Silurian Metasediments and Volcanics (SMV)	Black mudstone and quartzose greywacke	unknown
Little Harbour Formation (LT)		Calcareous greywacke and mudstone	>100
Red Man's Cove Formation (GP)		Red, green and black mudstone	unknown
Clogherhead Formation (LT)		Thickly bedded calcareous greywacke	unknown

A northeast to southwest trending fault passes 1 km northwest of the borehole. GSI Bedrock Sheet 13 indicates that the Glaspistol formation bedrock dips to the south southeast at a tilt of approximately 50 degrees.

[3] Note: Drogheda (Killineer) rainfall station opened in 1970.

[4] Maximum thickness values from McConnell *et al* (2005)

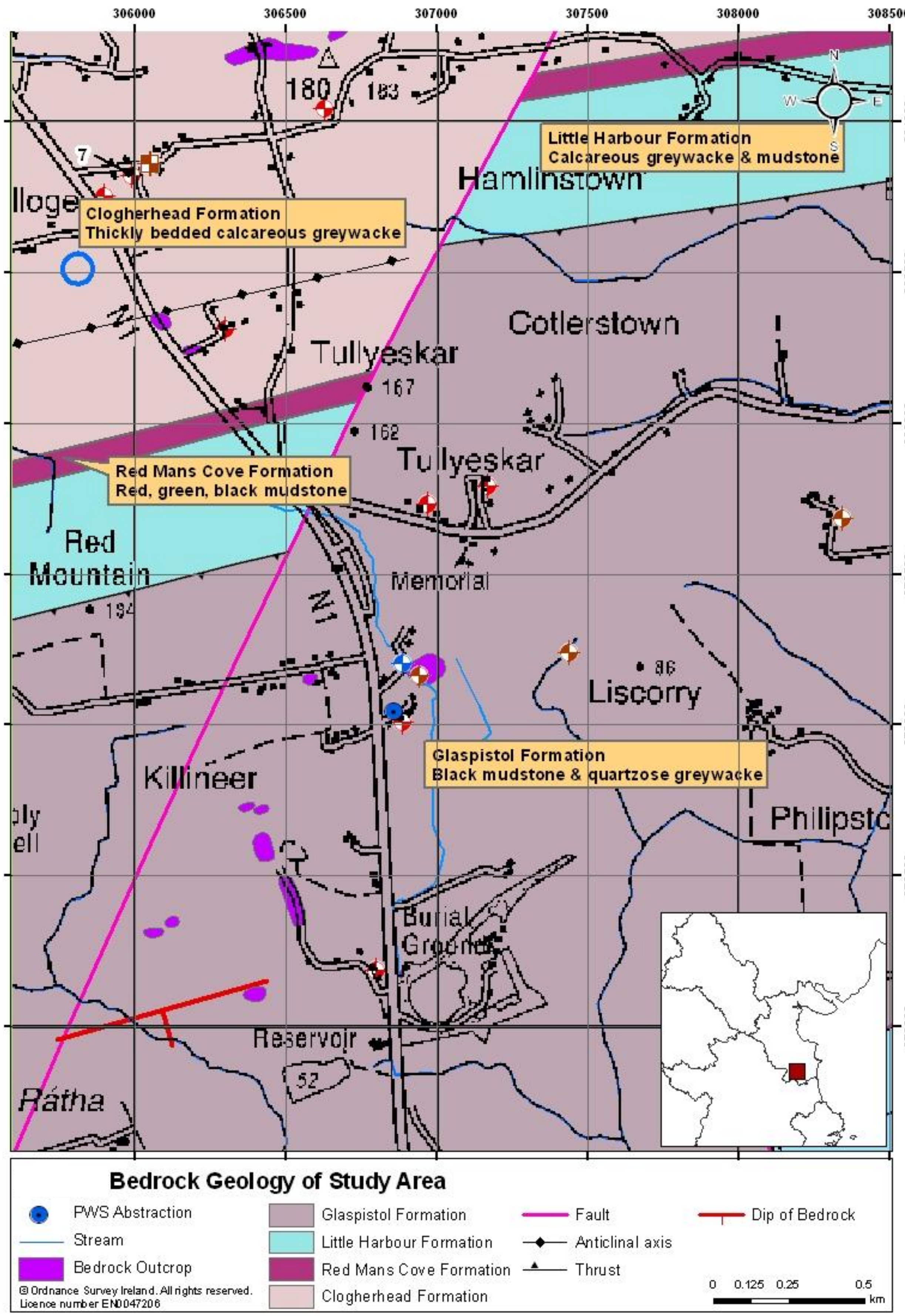

Figure 4 Bedrock geology in vicinity of Killineer WSS

7.2 SOILS AND SUBSOILS

The soils in the vicinity of the source and in the majority of the surrounding area are classified as deep, poorly drained mineral soils (AminPD) derived from mainly non-calcareous parent materials (Teagasc, 2006). On the areas of bedrock outcrop, the soils are classified as shallow, well drained soils (AminSW) derived from mainly non-calcareous parent materials (Teagasc, 2006).

The subsoil map (Teagasc, 2006), Figure 5, shows that the majority of the study area is underlain by till derived from Lower Paleozoic sandstones and shales (TLPSsS). The till in this area is described as compact and of variable thickness (An Foras Forbartha, 1981). Alluvial subsoils (A) are mapped along parts of the stream that flows east of the source. Under the GSI investigations the subsoil permeability of the till units in the study area has been classed as '***Low Permeability'***. Subsoil samples from auger holes drilled by the GSI in 2007 in the vicinity of the source, to assist in the delineation of the source protection zones, were logged in accordance with BS5930. These indicate that subsoils mapped as TLPSsS are generally comprised of CLAY with some occurrences of SILT/CLAY. Overall the subsoil permeability of the area is considered to be "***Low***". The low permeability classification is supported by the high drainage density in the area.

Extensive areas of bedrock outcrop and subcrop are mapped on the southern flank of Red Mountain to the west and northwest of the source. A small patch of outcrop is mapped 200 m north of the source, while further outcrop is mapped on Tullyeskar Hill 800 m to the north. The ridge on which the source is located and the ground across the southeastern flank of Red Mountain is free of drains and other indicators of poor drainage. Extensive rock outcrop and shallow bedrock is mapped in this area.

7.3 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) and logged evidence from drilling of GSI auger holes in the vicinity of the source. For locations of boreholes see Figure A.1 in Appendix 1.

The bedrock outcrop distribution is described above. Away from elevated areas, the thickness of the subsoils increases and is generally in excess of 5 m and often in excess of 10 m with a thickness of 21.3 m recorded in the low parts of Tullyeskar to the north of the source. At GSI auger hole KIL05, located 140 m northeast of the source, a depth to bedrock of 4 m was encountered, while at KIL01 (located 600 m east of the source in alluvial deposits), the depth to bedrock was 4.75 m. In general the data indicate that subsoil thickness increases moving away from the areas of outcrop and is between 3 and 5 m in the vicinity of the source.

8 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).

The vulnerability map indicates areas of extreme vulnerability on Red Mountain; on the southerly spur off the mountain; and, in a north-south band to the west of the R132 regional road. An area of extreme vulnerability is mapped around the outcrop 200 m north of the source. The remainder of the area surrounding the source is mapped as high groundwater vulnerability. The groundwater vulnerability map is shown in Figure 6.

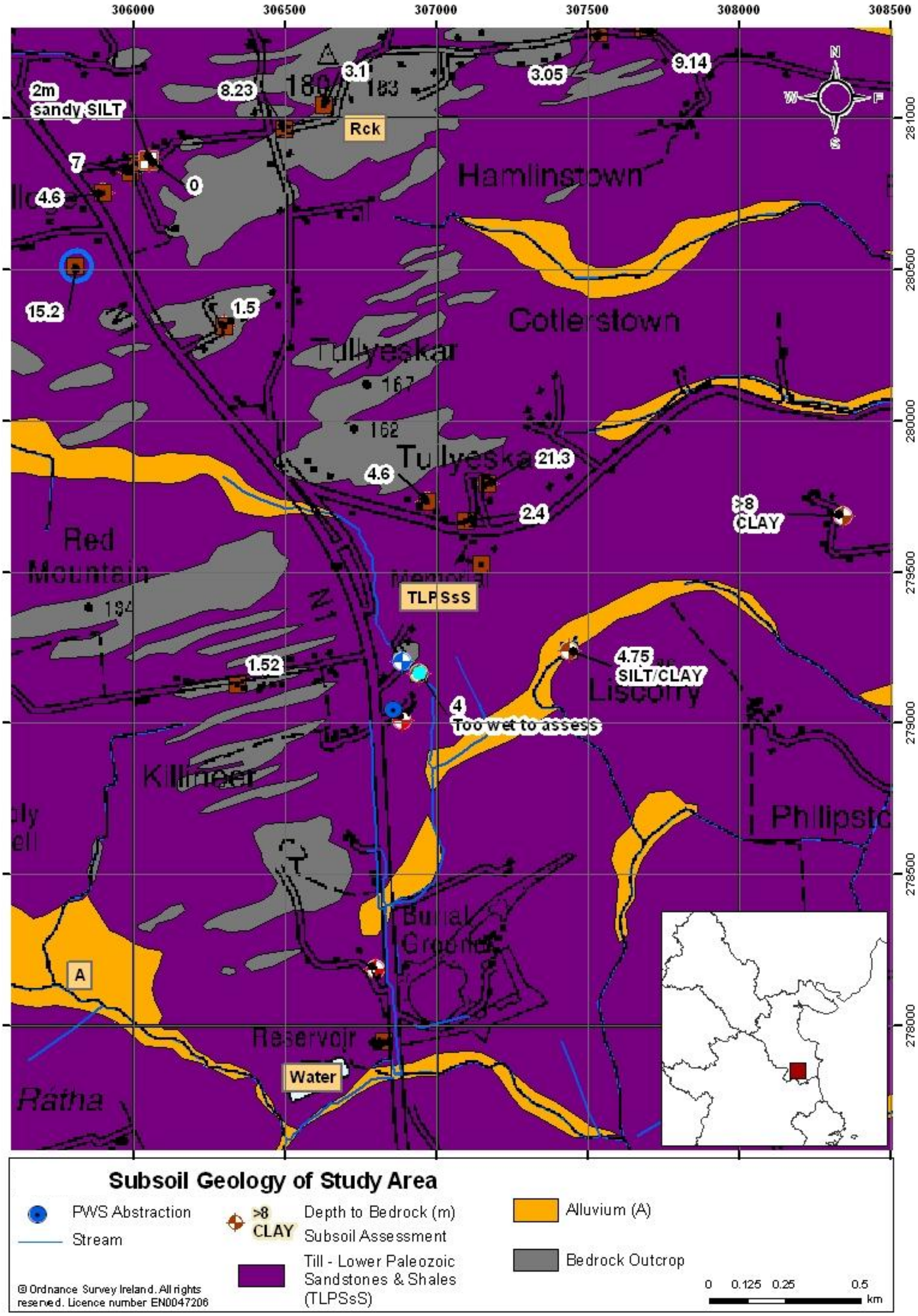

Figure 5 Subsoil geology in the vicinity of Killineer WSS

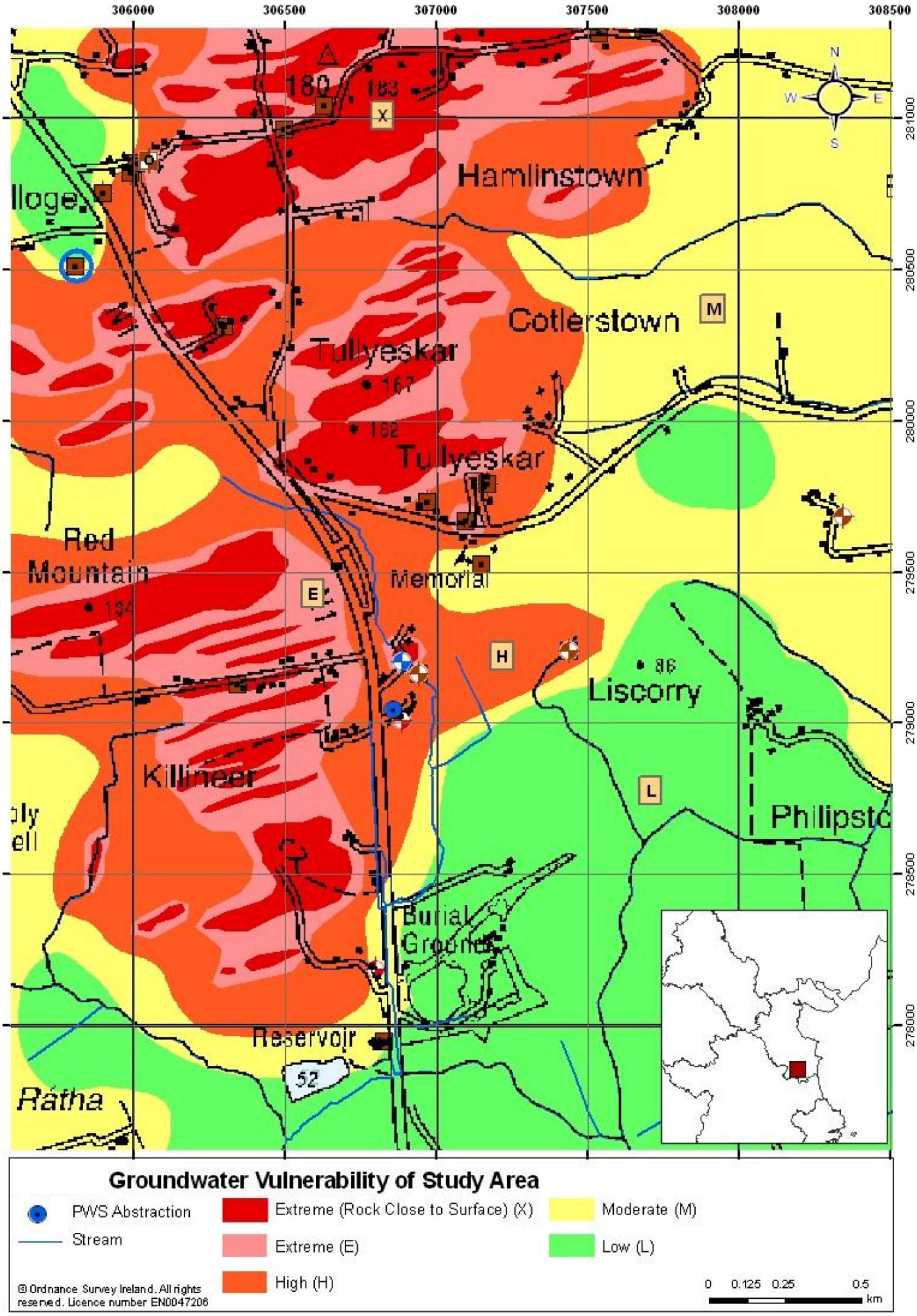

Figure 6 Groundwater vulnerability in the vicinity of Killineer WSS

9 HYDROGEOLOGY

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

- GSI and EPA Websites and Databases (April/May 2010).
- Louth County Council Staff and Local Authority Drinking Water returns.
- Groundwater Resources in the N.E. (R.D.O.) Region (An Foras Forbartha, 1981).
- Mid-Louth Regional Water Supply Strategy (Atkins, 2002).
- Hydrogeological mapping by Peter Conroy and Robert Meehan, April 2010.
- Drilling and permeability mapping carried out by GSI in May 2007.
- Met Éireann rainfall and evapotranspiration data.

9.1 GROUNDWATER BODY AND STATUS

Killineer PS is located in the Wilkinstown groundwater body (GWB) (IE_EA_G_025), which has been classified as being of Good Status. The groundwater body description is available from the GSI website: www.gsi.ie and the 'status' is obtained from the Water Framework Directive website: www.wfdireland.ie/maps.html.

9.2 GROUNDWATER LEVELS, FLOW DIRECTIONS AND GRADIENTS

The ground water level was measured at 2.14 mbtc at Killineer WSS on 30th April 2010. Full details of the water level data collected are provided in Table A1.1 in Appendix 1.

Due to the minimal abstraction rate from the borehole (5 m^3/day), drawdown during pumping is likely to be minimal and recovery of the water table to its rest level is likely to occur rapidly as soon as pumping ceases. As such, the measured water level in the source is likely to be close to the rest level. The groundwater flow direction is likely to follow the local topographic gradient southeast towards the stream. The groundwater gradient is likely to be slightly less than the topographic gradient of 0.075.

9.3 HYDROCHEMISTRY AND WATER QUALITY

Twenty three samples from Killineer WSS were collected and analysed by the EPA under the national groundwater monitoring programme between June 1993 and April 2004. Between April 2004 and March 2009 no untreated water quality samples were collected at Killineer WSS. In 2009 two untreated groundwater samples for the source were collected and analysed by the EPA on behalf of Louth County Council. The samples were collected from the untreated water tap in the source pump house. The resulting data are presented in Table A1.2 in Appendix 1.

Overall the source has a moderately high level of mineralisation as indicated by the average electrical conductivity (527 µS/cm), alkalinity (154 mg/l as $CaCO_3$) and hardness (204 mg/l as $CaCO_3$). The hydrochemistry is dominated by the calcium and bicarbonate ion pair, which indicates the presence of calcite in the groundwater flow system. This may indicate that a component of the groundwater flow comes from the calcareous greywacke of the Little Harbour Formation bedrock, which lies on the opposite side of the fault to the northwest of the source. Shallow groundwater flow across the fault, rather than deep bedrock flow paths, is considered to be the most likely pathway for generating the calcareous signature of the groundwater at the source. The TLPSsS tills overlying the area are likely to contain calcareous material derived from the same calcareous bedrock. As such, it is likely that the calcareous groundwater signature derives at least partly from dissolution of calcite within the till as recharge passes through it. The lab measured average pH is 7.64 which is slightly alkaline.

During the period for which data are available, the water quality of the source has exceeded the prescribed drinking water standards for total and faecal coliforms, and for nitrate, and is in excess of the EPA threshold for chloride.

Figure 7 shows the concentrations of faecal and total coliforms and ammonia at the source. Faecal coliforms concentrations in the untreated groundwater were above the drinking water limit of zero counts per 100 ml on three occasions while total coliforms exceeded the same limit on six occasions, one of which was coincident with the faecal events. Incidences of gross contamination occurred in the August to September period of 1996, 1998 and 1999 after which the level of exceedances drops off, although low level exceedances continue to occur, especially in the August/September period. No monitoring of coliform bacteria has taken place at the source since 2003, so the current bacteriological quality of the source is not known. No exceedances of the ammonium drinking water standard or threshold level have occurred.

Figure 8 shows the concentrations of nitrate and chloride at the source. The average nitrate concentration over the monitoring period was 44.5 mg/l as NO_3, which exceeds the WFD threshold of 37.5 mg/l as NO_3. All nitrate measurements have exceeded the threshold except for the most recent measurement in December 2009. The nitrate concentration also exceeded the nitrate DWS of 50 mg/l as NO_3 in August 1996 and 1998, September 1999 and 2000 and April 2002. Average chloride concentrations measured 34.1 mg/l which exceeds the WFD threshold of 24 mg/l. All chloride measurements over the monitoring period have exceeded the chloride threshold.

Figure 9 shows the concentrations of manganese and potassium and the Potassium:Sodium ratio at the source. None of these parameters exceeded their respective thresholds.

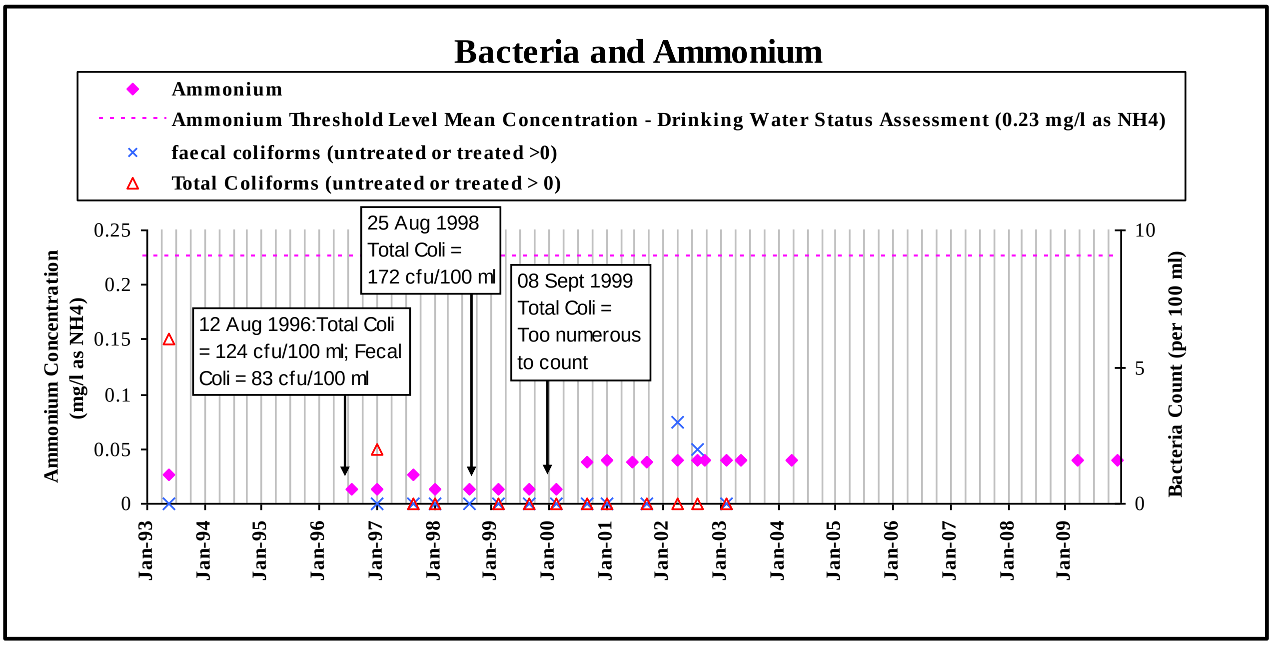

Figure 7 Graph of Bacteria and Ammonia Concentrations at Killineer PS

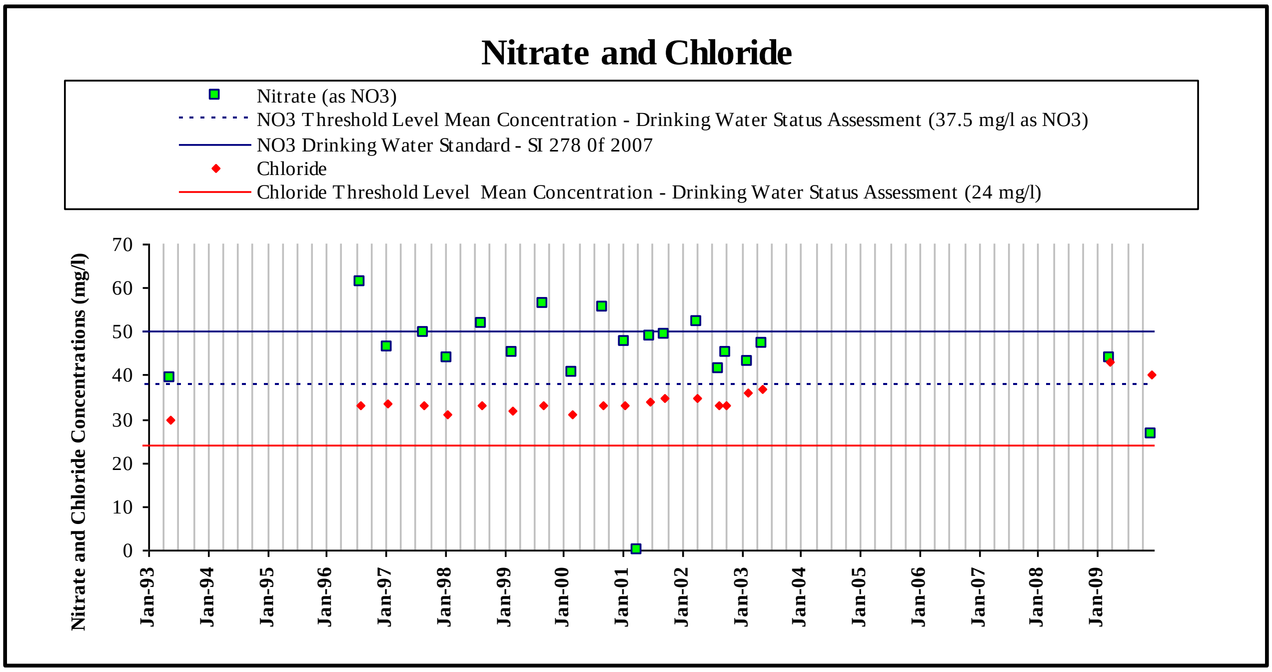

Figure 8 Graph of Nitrate and Chloride Concentrations at Killineer PS

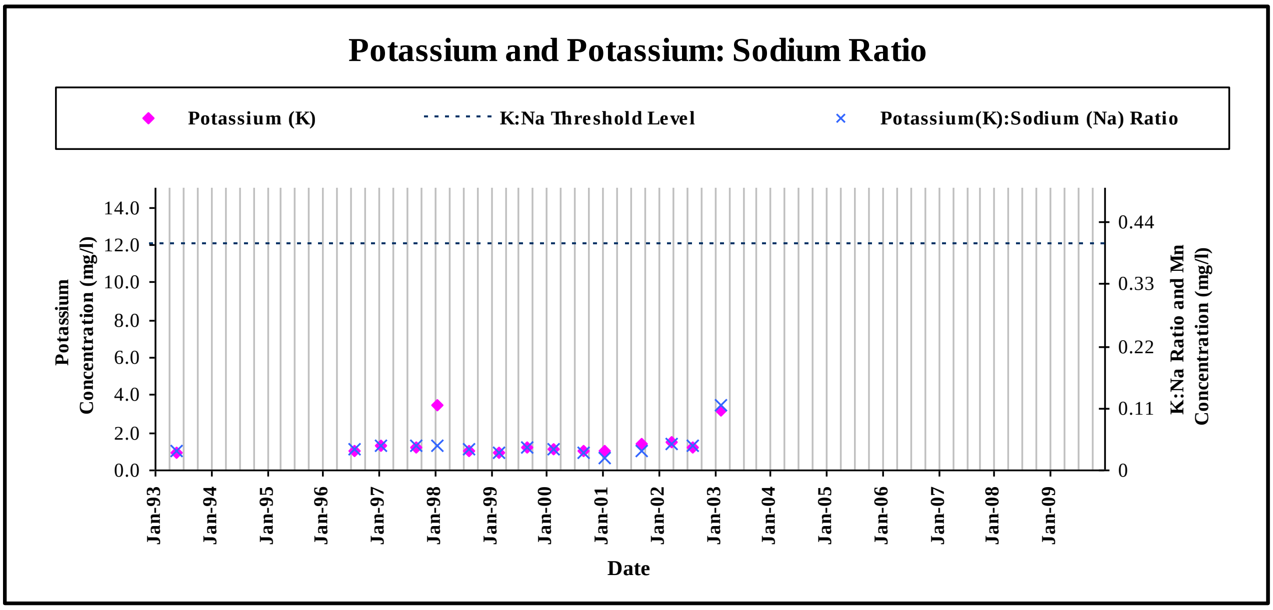

Figure 9 Graph of Manganese, Potassium and Potassium:Sodium Ratio at Killineer PS

The remainder of the parameters measured does not exceed their respective drinking water standard and have average concentrations less than their respective WFD thresholds. Heavy metal concentrations have generally been below the detection limit when measured.

In summary, nitrate, chloride and bacteriological exceedances suggest contamination from an organic waste source. Given the land use in the area and the extreme groundwater vulnerability to the northwest and west of the source, the most likely contaminant sources are grazing animals, farmyard wastes, fertilizer application on tillage areas and onsite waste water treatment systems upgradient of the source.

9.4 AQUIFER CHARACTERISTICS

The GSI bedrock aquifer map of the area indicates that the Silurian Metasediments underlying the source are classified as a *Poor Aquifer (Pl*) that is generally unproductive except for local zones. The bedrock aquifer map of the area is shown in Figure 7. The bedrock formations in the northwest of the map area are classified as a *Poor Aquifer (Pu*) that is generally unproductive.

The Wilkinstown GWB report indicates aquifer transmissivity in the Silurian Metasediments is likely to be low, perhaps less than 6 m^2/d (GSI, 2004). Using the recorded values of specific capacity and the corresponding abstraction rate Logan's approximation of transmissivity[5] estimates the transmissivity as 18 m^2/d. Aquifer storativity and thickness are also likely to be low, with aquifer effective thickness estimated to be 10 m or less (GSI, 2004).

Based on the estimated bedrock aquifer transmissivity and the aquifer hydraulic gradients, the 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);

n_e = 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 3.

Table 3 Estimated Groundwater Velocity Range

Parameter	Units	Minimum	Maximum	Average	Data Source
T	m^2/d	6	18	12	GSI (2004) and data for Killineer PS
i	[-]	0.065	0.075	0.07	Estimates based on topographic gradient
b	m	10	10	10	GSI (2004)
n_e	[-]	0.01	0.01	0.01	Typical value for fractured hard rock aquifers
v	m/d	4	13.5	8.4	

[5] T = 1.22 . Q/s_w ,where: Q = abstraction rate; and s_w = drawdown in the pumping well (Misstear *et al.*, 2006). At Killineer PS: S_w = 4.48 m^3/d per m drawdown; and Q = 65.5 m^3/d abstraction.

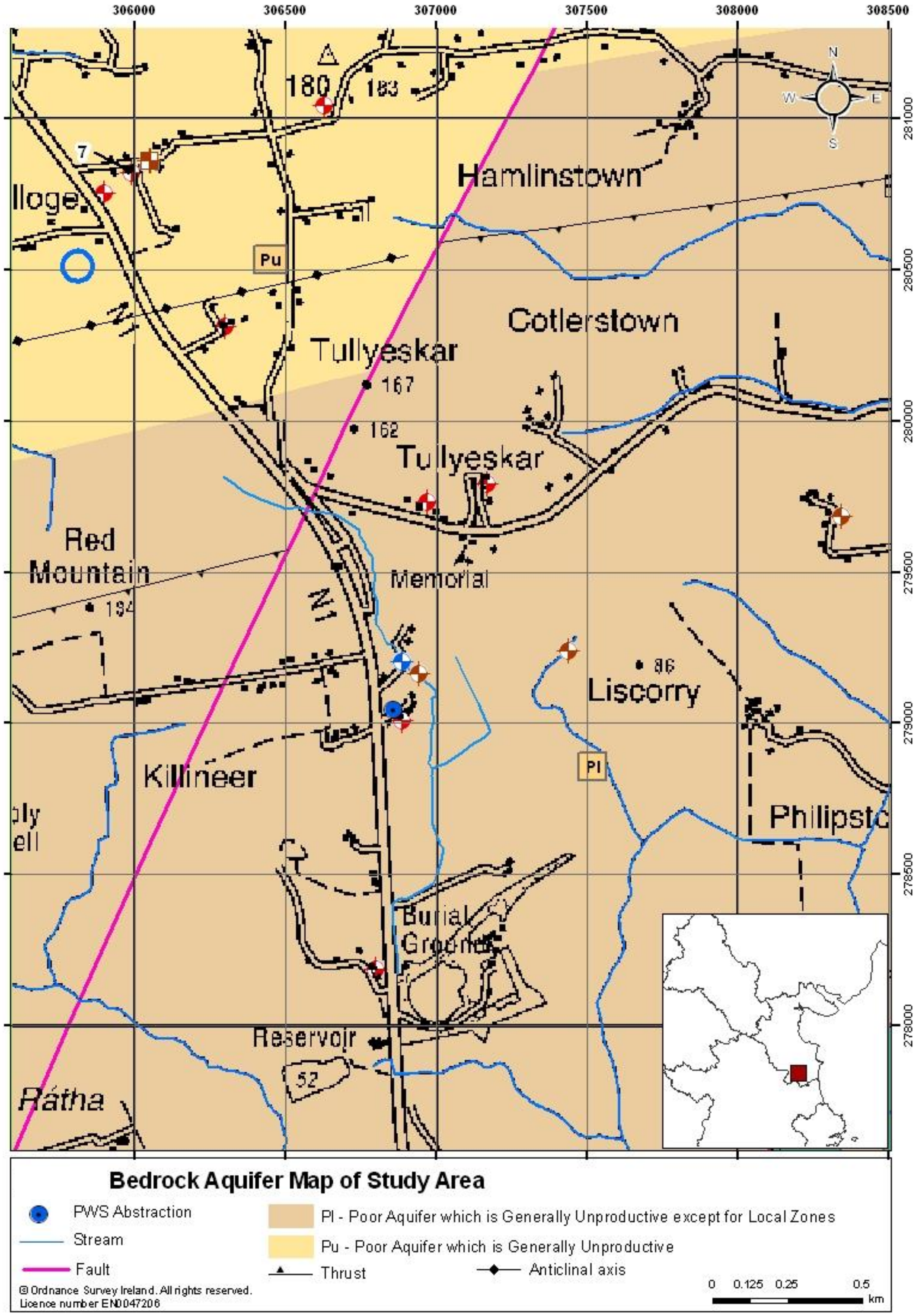

Figure 10 Bedrock aquifers in the vicinity of Killineer WSS

10 ZONE OF CONTRIBUTION

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 10.1.

10.1 CONCEPTUAL MODEL

Diffuse recharge to the groundwater system occurs across the study area from infiltration of rainfall into the ground, particularly in areas of extreme groundwater vulnerability. The volume of recharge is limited by the poor aquifer type, such that up to two thirds of potential recharge goes to surface runoff. Recharge to the ground is also inhibited by the poor drainage characteristics of the soils and subsoils. Groundwater flow is focused in the layer of shallow, weathered and more fractured bedrock approximately 10 m that occurs below the top of the bedrock surface. Groundwater flows downgradient from the recharge areas, approximately in the direction of the surface topographic gradient, and discharges into local surface water features. In the vicinity of Killineer WSS, groundwater flow is to the southeast, where it discharges into the small stream located just southeast of the borehole. Untreated groundwater at the source is polluted by coliform bacteria, nitrate and chloride. This likely to be due to the extreme vulnerability and agricultural/residential landuse upgradient of the borehole, and the poor wellhead protection and lack of grout seal at the borehole.

10.2 BOUNDARIES OF THE ZOC

The boundaries of the area contributing to the source – the zone of contribution (ZOC), which is defined as the area required to support an abstraction from long-term recharge – are shown in Figure 11. 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 the conceptual understanding of groundwater flow. The boundaries are described below along with associated uncertainties and limitations.

Diffuse recharge upgradient of the borehole supplies natural groundwater flow past the borehole, which exceeds the water supply demand of 5 m^3/day. The ZOC has been delineated therefore, on the basis of flowlines from the groundwater divide to the stream, which could plausibly be intercepted by the borehole when it is pumping. This approach has been used for delineation of ZOCs for other public water supply abstractions such as Clouncagh in Co. Limerick (Deakin, 1995).

The northeastern and southwestern boundaries are based on estimated groundwater flow lines that parallel the lie of the land and allow for an additional +/- 20^0 variation in the groundwater flow direction. These lines are based on the Uniform Flow Equation (Todd, 1980):

$Y_L = Q / (2 * T * i)$ where:

- Y_L is the maximum half-width of the ZOC
- Q is the daily pumping rate +/- X%
- T is the Aquifer Transmissivity, and
- i is background non-pumping hydraulic gradient.

Using the data from Table 3, and conservatively doubling the abstraction rate to 10 m^3/day, the maximum half-width (Y_L) of the ZOC is estimated at 6 m. The ZOC has been delineated by following symmetrical flow lines upgradient on either side of the source to give a 12 m full-width at the groundwater divide on Red Mountain. A further factor of safety has been added by allowing for a +/- 20^0 variation in the estimated south-easterly groundwater flow direction past the source. This process gives an envelope of possible ZOCs which are then combined to give an overall robust ZOC for the source.

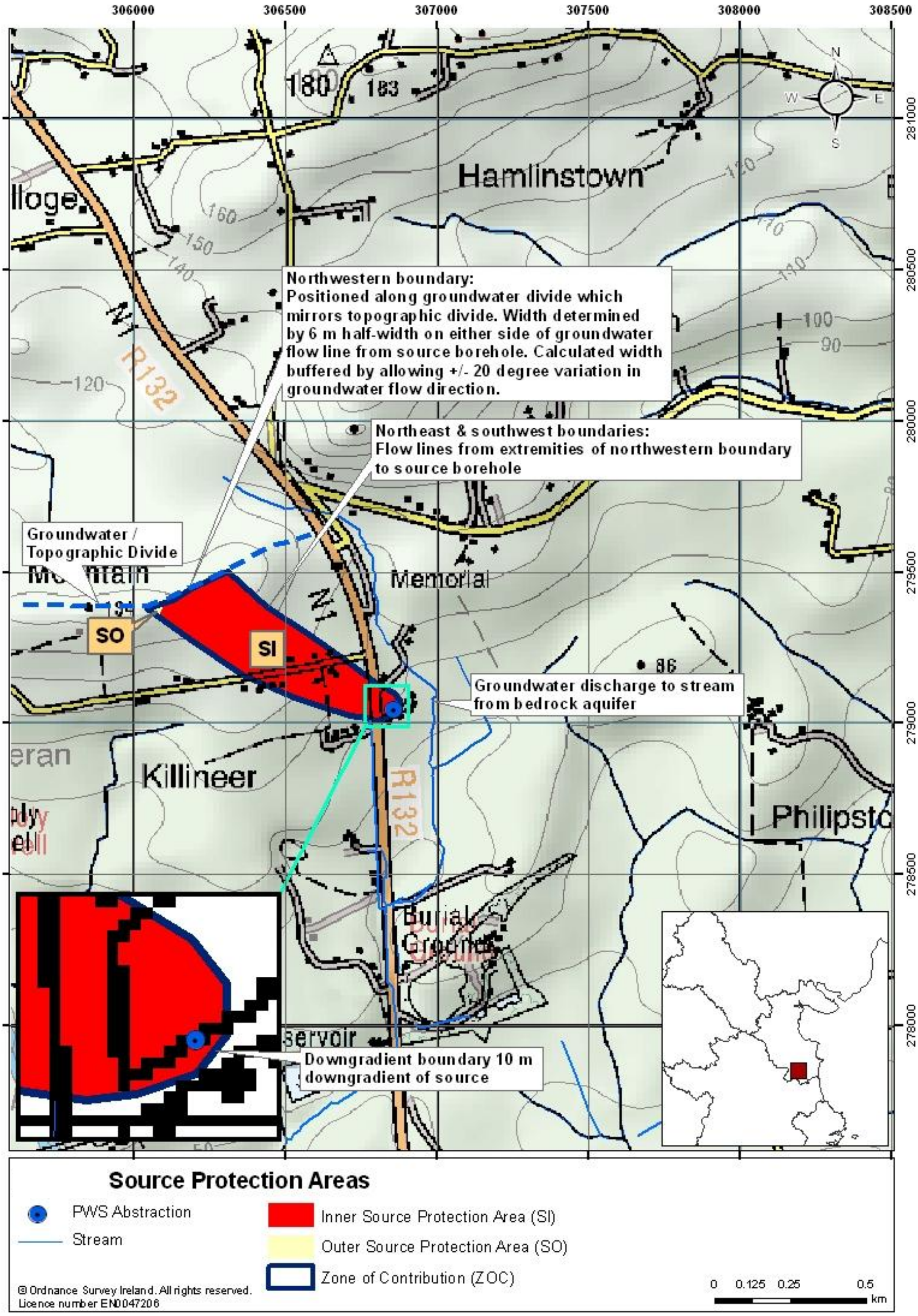

Figure 11 Source Protection Areas (SPAs) for Killineer WSS

The south east boundary is the downgradient boundary of the ZOC. This delineates the maximum downgradient distance that the borehole can pump water from and is based on the uniform flow equation (Todd, 1980).

$x_L = Q / (2 * \pi * T * i)$ where: Q is the daily pumping rate +/- X%

T is the Aquifer Transmissivity, and

i is background non-pumping hydraulic gradient.

Using the data from Table 3 and again conservatively doubling the pumping rate to 10 m^3/d, the equation indicates that the possible down-gradient ZOC extent is approximately 2 m. This distance has been rounded up to 10 m to allow for sanitary protection around the wellhead. This also gives a large safety factor with respect to the calculated extent of the boundary.

The northwestern boundary is delineated based on the topographic divide along the Red Mountain ridge, which is assumed to coincide with a groundwater divide. Groundwater recharge to the north of the divide flows away from the source, while recharge to the south, inside the ZOC, flows to the source.

Overall the delineated boundaries describe a ZOC with an area of 0.16 km^2, which is equivalent to a daily recharge volume of 41 m^3/day based on a recharge rate of 94 mm/year (see section 10.3 below). This is eight times larger that the area required to supply the current demand of 5 m^3/day. As such, the groundwater flow line approach results in a more conservative, robust ZOC that allows for the sporadic pumping regime wherein groundwater flow from within the ZOC can either be abstracted when the pump is on, or flow on past the source when it is off.

10.3 RECHARGE & WATER BALANCE

The term ‘recharge’ refers to the amount of water replenishing the groundwater flow system. The recharge rate is generally estimated on an annual basis, and assumed to consist of input (*i.e*. annual rainfall) less water loss prior to entry into the groundwater system (*i.e*. annual evapotranspiration and runoff). The estimation of a realistic recharge rate is important in source protection delineation, as it will dictate the size of the ZOC to the source (and therefore the Outer Source Protection Area). The recharge is estimated as follows.

Potential recharge is equivalent to 268 mm/yr i.e. (Annual Effective Rainfall; see Section 6).

Actual recharge has been estimated to be 96 mm/yr over the zone of contribution, which is 36% of potential recharge. This value is based on averaging of the recharge for the different settings outlined in Table A2.1 in Appendix 2.

Runoff losses: 172 mm (64% of potential recharge). Rejected potential recharge is assumed to runoff to surface water via surface and interflow.

Guidance Document GW5 (IWWG, 2005) recommends that for a PI aquifer a limit of 100 mm/yr should be applied to reflect the inability of the low aquifer storage and transmissivity to accept, store and transmit recharge volumes in excess of the recharge capacity. Where the predicted recharge based on the recharge coefficient exceeds the recharge capacity, the excess recharge goes to surface runoff. The recharge limit is applied in extremely vulnerable areas across the study area, and is supported by the high drainage density of the area. Table 4 summarises the recharge calculations.

Table 4 Bedrock recharge calculation summary

Parameter	Coefficient	Rate
Average rainfall (R)		800 mm/yr
Estimated P.E.		560 mm/yr
Estimated A.E. (95% of P.E.)		532 mm/yr
Effective rainfall		268 mm/yr
Potential recharge		268 mm/yr
Averaged runoff losses	(64%)	172mm/yr
Bulk recharge coefficient	0.36	
Recharge		96 mm/yr

Water Balance: Taking a water balance approach, the area required to sustain a 5 m^3/d abstraction rate where there is an average rate of replenishment of 96 mm/yr is 0.05 km^2, or 5 ha. As discussed above, this compares to an area of 0.16 km^2 delineated on the basis of hydrogeological concepts.

11 GROUNDWATER SOURCE PROTECTION ZONES

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

Two source areas are delineated, as shown in Figure 11:

- Inner Protection Area (SI), designed to give protection from microbial pollution. It is based on the 100-day time of travel to the supply (DELG/EPA/GSI 1999).
- Outer Protection Area (SO), encompassing the zone of contribution to the source.

The **Inner Source Protection Area (SI)** 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 velocity multiplied by the 100 day time period gives the distance travelled by the groundwater during the TOT. This distance gives the lateral extent of the buffer which must be applied around the source to form the SI. For the average groundwater velocity calculated in Section 9.4 of 8.4 m/day, the extent of the SI buffer zone is calculated at 840 m. The SI zone delineated on this basis includes almost all of the ZOC.

The **Outer Source Protection Area (SO)** occupies the western tip of the ZOC, to the west of the SI zone.

Source Protection Zones (SPZs) are shown in Figure 12, and are based on an overlay of the source protection areas with the groundwater vulnerability. The groundwater protection zones are SI/X, SI/E, SI/H and SO/X.

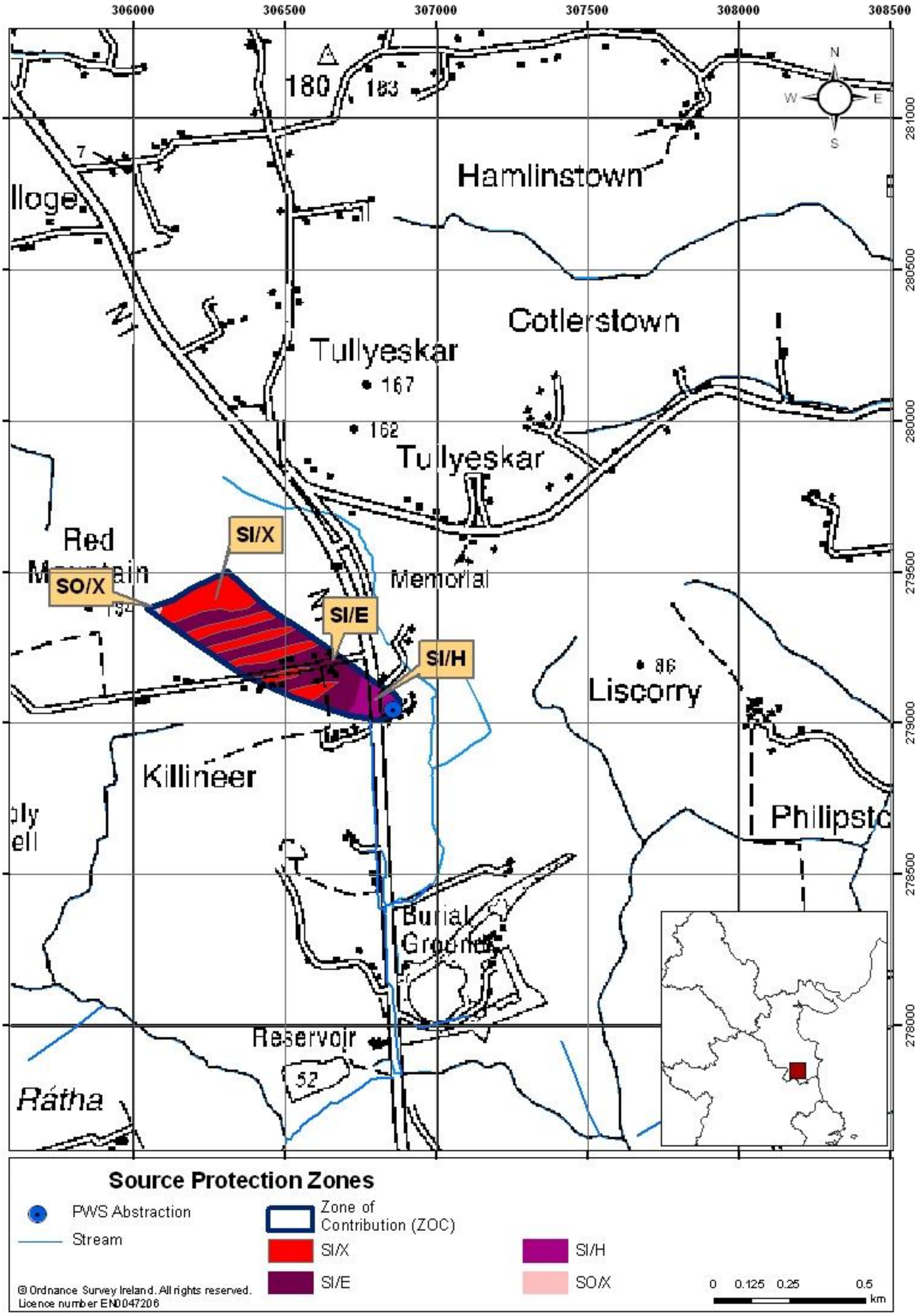

Figure 12 Source Protection Zones (SPZs) for Killineer WSS

12 POTENTIAL POLLUTION SOURCES

The main potential sources of contamination within the ZOC are:

- Direct microbial contamination of the source via the poorly sealed wellhead from animal and bird droppings. The main potential contaminants are faecal bacteria, viruses and cryptosporidium.
- There is no mains sewer in the area so all private residences within the ZOC are likely to be serviced by septic tanks or similar wastewater treatment systems which discharge to groundwater via percolation areas. The main potential contaminants are ammonia, nitrates, phosphates, chloride, potassium, BOD, COD, TOC, faecal bacteria, viruses and cryptosporidium.
- The majority of land within the zone of contribution is agricultural land, primarily pasture with some arable. It is likely that landspreading of organic matter from agricultural sources (e.g. cattle slurry) takes place within the delineated ZOC. The main potential contaminants are ammonia, nitrates, phosphates, chloride, potassium, BOD, COD, TOC, pesticides, faecal bacteria, viruses and cryptosporidium.
- Private home heating fuel tanks are likely to be located within the catchment area. The main potential contaminants are hydrocarbons.
- Roadways are present within the ZOC. The main potential contaminants are hydrocarbons and metals.

13 CONCLUSIONS

The untreated groundwater is currently impacted by microbial contamination, nitrate and chloride. Treatment is in place at the source to manage the microbial contamination issues. The source of the contamination is likely to be groundwater pollution by organic matter. There may also be a component of nitrate contamination derived from inorganic fertilizers. The sources of organic material are likely to be farmyard runoff, partially treated wastewater effluent and agricultural waste. Inorganic nitrate is likely to derive from artificial fertiliser application in tillage areas.

A conservative ZOC has been delineated using hydrogeological mapping methods based on the likely groundwater flow direction to the source, plus a buffer width to allow for a margin of error in flow direction. The delineated area is eight times greater than that required to support the actual abstraction rate. As the source is pumped sporadically and flow velocities are relatively high, it is considered that groundwater from anywhere within the delineated ZOC could reach the source within a reasonable time frame. Consequently any contaminants within that area pose a risk to the source. The ZOC has been divided into inner (SI) and outer (SO) source protection areas. The source protection zones delineated in this report are SI/X, SI/E, SI/H, SO/X and SO/E.

The Source Protection Zones are based on the current understanding of the groundwater conditions and the available data. Additional data obtained in the future may require amendments to the protection zone boundaries.

14 RECOMMENDATIONS

Improvement works at the source might usefully include:

- An upgrade of the wellhead protection at the source. In this, the mouth of the borehole should be raised above ground level, and sealed around the rising main to prevent direct contamination of the well. A concrete pad should be installed around the outer casing of the borehole and sloped away from the borehole to prevent water from ponding around the borehole casing at ground surface.

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APPENDIX 1

- Figure A1.1 – DATA POINTS IN THE VICINITY OF KILLINEER WSS
- Table A1.1 – Point Data from hydrogeological Mapping
- Table A1.2 – EPA Water Quality Data For Killineer PWS Source

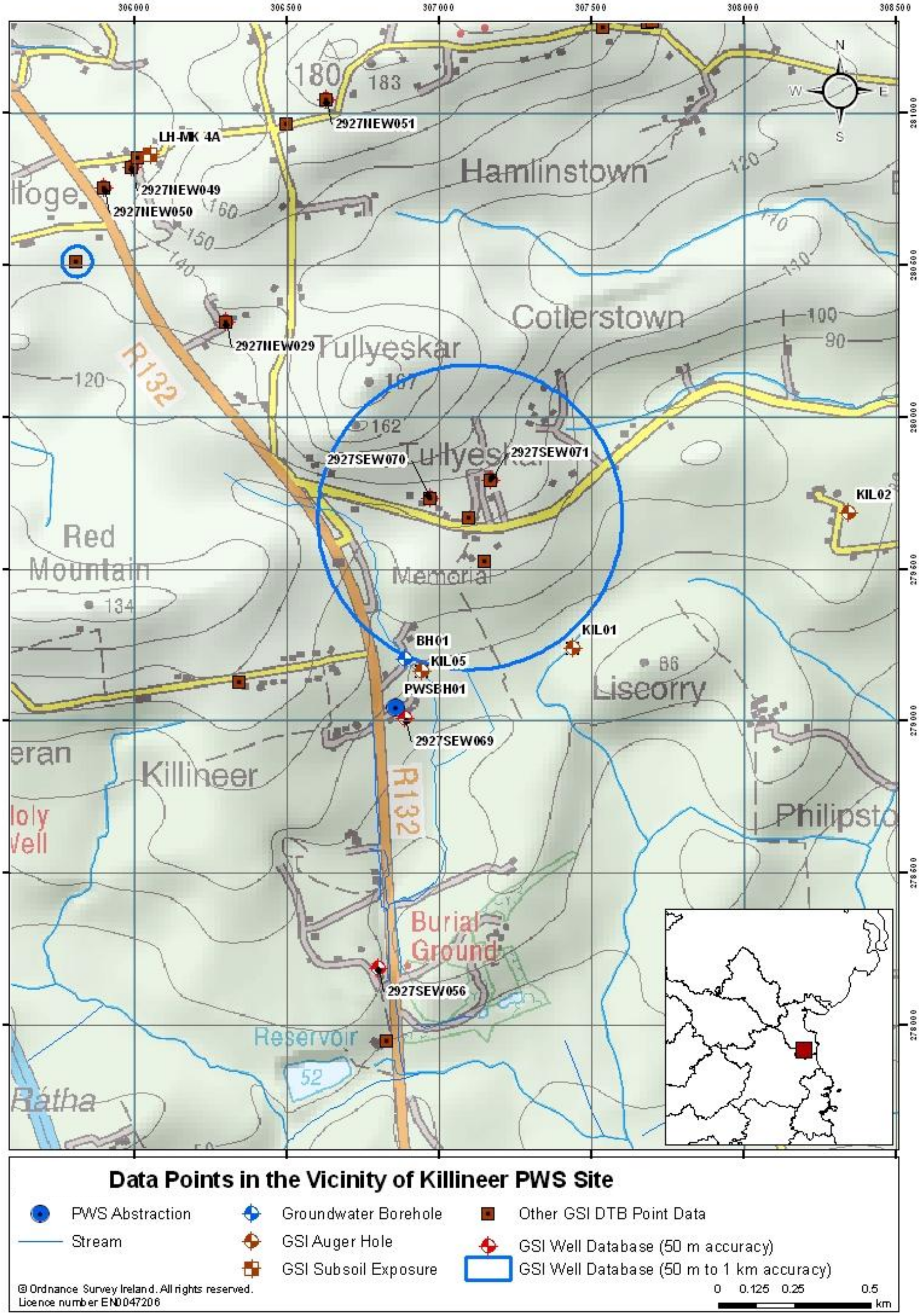

Figure A1.1 Data points in the vicinity of Killineer WSS

Table A1.1 – Point data in the vicinity of Killineer WSS

Name	Type	X	Y	Description	GWL mbtc	Total Depth (m)
					30/04/2010	
Killineer PS	Borehole	306859	279045	Killineer PWS borehole. Drilled 1965. Borehole diameter = 6-inch. 'mbtc' = metres below top of casing. 'tc' = top of 6-inch steel casing = approx 0.45mbgl. GSI Well database reports yield = 65.5 m3/day and specific capacity = 4.48m3/d/m.	2.14	
BH01	Borehole	306884	279217	Private borehole. Tap inside pump house. Borehole inside pump house. Drilled approx 2006. Total Depth approx 121 m. 'tc' = top of 6-inch steel casing = 0.38 magl	2.57	

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Table A1.2 - Louth County Council EPA Water Quality Data for Killineer PWS Source

			mg/l NO3	mg/l Ca	mg/l Mg	mg/l K	mg/l Na	mg/l Cl	mg/l NO2	mg/l SO_4	mg/l $CaCO_3$	mg/l $CaCO_3$	uS/cm	ug/l Al	ug/l Fe
GSI Name	Date	Body	NO3	Ca	Mg	K	Na	Cl	NO2	SO4	Alk	Hard	Cond	Al	Fe
	Jan-82	Threshold	37.5				150	24	0.375	187.5			800	150	
	Jan-82	DWS	50				200	250	0.5	250			2500	200	200
GSI Name	Date	Body	NO3	Ca	Mg	K	Na	Cl	NO2	SO4	Alk	Hard	Cond	Al	Fe
Killineer (EPA)	01/06/1993		39.2	61	24.3	1.0	17	30	nda	17	134	170	480	nda	0.011
Killineer (EPA)	12/08/1996		61.2	60	19.6	1.1	16	33	0.003	24	162	210	507	nda	0.050
Killineer (EPA)	22/01/1997		46.4	66	19.5	1.3	19	33	0.003	29	160	207	510	nda	0.050
Killineer (EPA)	10/09/1997		49.5	64	15.7	1.2	16	33	0.003	29	128	184	514	nda	0.050
Killineer (EPA)	26/01/1998		43.9	72	22.4	3.5	45	31	0.003	26	146	200	503	nda	0.050
Killineer (EPA)	25/08/1998		51.6	62	15.6	1.0	15	33	0.003	24	142	184	518	nda	0.050
Killineer (EPA)	02/03/1999		45.3	81	18.9	1.0	17	32	0.016	30	148	222	510	nda	0.050
Killineer (EPA)	08/09/1999		56.5	67	18.9	1.3	18	33	0.006	30	157	214	516		0.033
Killineer (EPA)	02/03/2000		40.7	65.23	17.9	1.1	17	31	nda	38	144	226	513	nda	0.020
Killineer (EPA)	13/09/2000		55.7	58	11.8	1.0	18	33	0.006	32	140	232	526	0	0.050
Killineer (EPA)	23/01/2001		47.6	60	19.1	1.0	28	33	0.006	33	168	200	531	0	0.050
Killineer (no. 10)	09/04/2001		0.0												
Killineer	25/06/2001		49.0					34	0.007				537	0	50.0
Killineer (EPA)	26/09/2001		49.2	68	21.0	1.4	23	35	0.006	33	156	230	536	nda	0.050
Killineer (EPA)	09/04/2002		52.1	67	20.1	1.5	20	35	0.006	33	158	218	533	nda	0.050
Killineer (EPA)	21/08/2002		41.6	58	14.2	1.2	17	33	0.006	33	163	239	524	nda	0.061
Killineer (no. 10)	07/10/2002		45.3					33					524	0	50
Killineer (EPA)	17/02/2003		43.1	76	16.9	3.2	16	36	0.006	33	158	236	537	nda	0
Killineer (no. 1)	19/05/2003		47.3					37	0.007			94	540	0	87
Killineer (no. 2)	20/08/2003														
Killineer (no. 10)	25/08/2003														
Killineer (no. 10)	14/10/2003														
Killineer (no. 10)	06/04/2004												545	0	50
Killineer (LHS25)	31/03/2009		43.7					43			172		585		
Killineer (LHS25)	09/12/2009		26.4					40			174		573		
	Average	mg/l	44.5	65.7	18.4	1.44	20.1	34.1	0.006	29.3	154	204	527	0.044	
		mmol/l	0.72	1.64	0.73	0.04	0.88	0.96	0.00	0.31	1.54	mmol of CaCO3 = mmol of CO3--			
		MW	62.00	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	0.72	3.28	1.45	0.04	0.88	0.96	0.00	0.61	3.07	meq of CO3-- = meq of HCO3-			
											3.07	mmol HCO3-			
		meq cations	5.65								187.31	mg/l as HCO3-			
		meq anions	5.36												

Red colour denotes result in excess of Drinking Water Standard (DWS)

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

Source: available Louth COunty Council EPA data.

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Table A1.2 - Louth County Council EPA Water Quality Data for Killineer PWS Source

		ug/l Mn	mg/l NH4	No./100ml	No./100ml	ug/l Ba	mg/l B	mg/l Cd	ug/l Cr	mg/l Cu	mg/l F	mg/l Pb	ug/l Hg
GSI Name	Date	Mn	NH4	TC	F. coli	Ba	B	Cd	Cr	Cu	F	Pb	Hg
	Jan-82		0.23				0.75	0.00375	37.5	1.5		0.01875	0.75
	Jan-82	50	0.3	0	0		1	0.005	50	2	1.5	0.025	1
GSI Name	Date	Mn	NH4	TC	F. coli	Ba	B	Cd	Cr	Cu	F	Pb	Hg
Killineer (EPA)	01/06/1993	0.009	0.026	6	0	nda	nda	nda	nda	nda	nda	nda	
Killineer (EPA)	12/08/1996	0.020	0.013	124	83	nda	nda	0.0	nda	0	0.1	0	
Killineer (EPA)	22/01/1997	0.020	0.013	2	0	nda	nda	0.0	nda	0	0.1	0	
Killineer (EPA)	10/09/1997	0.020	0.026	0	0	nda	nda	0.0	nda	0	0.1	nda	
Killineer (EPA)	26/01/1998	0.020	0.013	0	0	nda	nda	0.0	nda	nda	0.0	nda	
Killineer (EPA)	25/08/1998	0.020	0.013	172	0	nda	nda	0.0	nda	nda	0.0	nda	
Killineer (EPA)	02/03/1999	0.020	0.013	0	0	nda	nda	0.0	nda	nda	0.1	nda	
Killineer (EPA)	08/09/1999	0.001	0.013	tntc	0	0	0	0.0	1	0	0.3	nda	
Killineer (EPA)	02/03/2000	0.001	0.013	0	0	0	0	0.0	0	0	nda	0	
Killineer (EPA)	13/09/2000	0.001	0.039	1	0	0	0	0.0	0	0	0.3	0	
Killineer (EPA)	23/01/2001	0.001	0.039	0	0	0	0	0.0	0	0	0.685	0	
Killineer (no. 10)	09/04/2001												
Killineer	25/06/2001		0.039							0		0	
Killineer (EPA)	26/09/2001	0.002	0.039	0	0	50	1	0.1	2	0	0.3	1	nda
Killineer (EPA)	09/04/2002	0.002	0.039	0	3	50	1	0.1	1	0	0.2	1	nda
Killineer (EPA)	21/08/2002	0.002	0.039	0	2	50	1	0.1	1	0	0.2	1	nda
Killineer (no. 10)	07/10/2002		0.040							0	150.0		
Killineer (EPA)	17/02/2003	0.002	0.039	0	0	50	1	0.1	2	0	0.2	1	nda
Killineer (no. 1)	19/05/2003		0.040							0		0	
Killineer (no. 2)	20/08/2003												
Killineer (no. 10)	25/08/2003												
Killineer (no. 10)	14/10/2003												
Killineer (no. 10)	06/04/2004		0.040										
Killineer (LHS25)	31/03/2009		0.039										
Killineer (LHS25)	09/12/2009		0.039										
	Average		0.029	25.3	6.8				0.84	0.006	11.7		

Red colour denotes result in excess of Drinking Water Standard (DWS)

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

Source: available Louth COunty Council EPA data.

1001 GSI Sources

Table A1.2 - Louth County Council EPA Water Quality Data for Killineer PWS Source

		ug/l Ni	mg/l P	mg/l P	mg/l Se	mg/l Ag	mg/l Sr	mg/l Zn	mg/l Sb	mg/l As	[-]	%	[-]	deg C	mg/l C
GSI Name	Date	Ni	PO4	P	Se	Ag	Sr	Zn	Ant	As	K/Na Ratio (using meq)	DO (% Sat)	pH	Temp	TOC
	Jan-82	15	0.035							0.0075	0.4				
	Jan-82	20			0.01				0.005	0.001			>6.5 & < 9.5		
GSI Name	Date	Ni	PO4	P	Se	Ag	Sr	Zn	Ant	As	K/Na Ratio				
Killineer (EPA)	01/06/1993	nda	0.020					nda	nda	nda	0.03	nda	7.5		
Killineer (EPA)	12/08/1996	nda	0.010					0	nda	nda	0.04	nda	7.7		
Killineer (EPA)	22/01/1997	nda	0.010					0	nda	nda	0.04	nda	7.8		
Killineer (EPA)	10/09/1997	nda	0.020					0	nda	nda	0.04	nda	nda		
Killineer (EPA)	26/01/1998	nda	0.010					nda	nda	nda	0.04	nda	7.5		
Killineer (EPA)	25/08/1998	nda	0.010					nda	nda	nda	0.04	nda	7.7		
Killineer (EPA)	02/03/1999	nda	0.030					nda	nda	nda	0.03	nda	7.8		
Killineer (EPA)	08/09/1999	0	0.010					0		0.0	0.04	nda	7.9		
Killineer (EPA)	02/03/2000	0	0.010					0	nda	0.0	0.04	nda	7.6		
Killineer (EPA)	13/09/2000	0	0.020		0.001	0		0	0.0	0.0	0.03		7.5		
Killineer (EPA)	23/01/2001	0	0.020		0.001	0		0	0.0	0.0	0.02	31	7.5		
Killineer (no. 10)	09/04/2001														
Killineer	25/06/2001		0.020										7.7		
Killineer (EPA)	26/09/2001	1	0.020					34	nda	50.0	0.04		7.6		
Killineer (EPA)	09/04/2002	1	0.020					42	nda	50.0	0.05		7.7		
Killineer (EPA)	21/08/2002	1	0.020					47	nda	50.0	0.04		7.8		
Killineer (no. 10)	07/10/2002												7.8		
Killineer (EPA)	17/02/2003	1	0.020					43	nda	50.0	0.11		7.4		
Killineer (no. 1)	19/05/2003		0.092										7.6		
Killineer (no. 2)	20/08/2003														
Killineer (no. 10)	25/08/2003														
Killineer (no. 10)	14/10/2003														
Killineer (no. 10)	06/04/2004												7.6		
Killineer (LHS25)	31/03/2009		0.020									33.00	7.5	11.6	1.5
Killineer (LHS25)	09/12/2009		0.020									37.00	7.5	11.1	3.0
	Average		0.021					15.1			0.04	35.0	7.64	11.4	

Red colour denotes result in excess of Drinking Water Standard (DWS)

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

Source: available Louth COunty Council EPA data.

APPENDIX 2

- TABLE A2.1 - recharge coefficent table

Table A2.1 Recharge coefficient table for the area around Killineer WSS

Vulnerability	**Location in Study Area**	**Additional factors**	**% Area**	**Recharge Coefficient Guidance**		**Chosen Recharge Coefficient**	**Actual Recharge** (mm/yr)
				Inner Range	Outer Range		
Extreme (X)	Northwest and west of the source on Red Mountain.	High surface slope and high drainage density. Note: 268 x 0.6 = 160.8 mm/yr. Due to Pl aquifer category effective recharge is capped at 100 mm/yr.	41.5	80 to 90%	60 to 100%	0.6 (0.37 after recharge cap applied)	100
Extreme (E)	Northwest and west of the source on Red Mountain.	High surface slope and high drainage density. Bedrock overlain by low permeability till subsoils and shallow well drained soils. Note: 268 x 0.5 = 134 mm/yr. Due to Pl aquifer category effective recharge is capped at 100 mm/yr.	48.5	50 to 70%	45 to 80%	0.5 (0.37 after recharge cap applied)	100
High (H)	In the immediate vicinity of the source.	High surface slope and high drainage density. Bedrock overlain by low permeability till subsoils and deep poorly drained soils.	10	23 to 30%	10 to 40%	0.23	62