Environmental Protection Agency

Establishment of Groundwater Source Protection Zones

Clifden Clara Water Supply Scheme

Clifden Clara borehole

May 2010

Prepared by:
John Dillon and Coran Kelly TOBIN

With contributions from:
Dr. Robert Meehan, Consultant Geologist; Jenny Deakin TCD

And with assistance from:
Kilkenny County Council & EPS

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).

TABLE OF CONTENTS

TABLES & APPENDICES

TABLES

FIGURES

1 INTRODUCTION

Groundwater Source Protection Zones are delineated for the Clifden Clara 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 Clifden Clara borehole is the main source for the Clifden Clara Group Water Scheme. The borehole supplies approximately 50 m^3/day to the townlands of Clifden and Churchclara.

The objectives of the report are as follows:

- To outline the principal hydrogeological characteristics of the Clifden and Churchclara area.
- To delineate source protection zones for the Clifden Clara borehole.
- To assist the Environmental Protection Agency and Kilkenny County Council in protecting the water supply from contamination.

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

The borehole was drilled in July 1970 by Fogarty Drilling Ltd., Gowran, Co. Kilkenny. The borehole supplies approximately 20 houses, church, school, local farms and small businesses. It operated as a group water scheme until 2007. Operational control of the GWS has since ceded to EPS as part of the South Leinster design-build-operate (DBO) scheme.

Kilkenny County Council in partnership with Kildare, Carlow, Laois, Wexford and Wicklow County Councils have grouped together 32 previously individual rural group water schemes, spread across six counties into the South Leinster DBO.

T.J. O'Connor & Associates were appointed as Client's Representative. EPS Pumping and Treatment Systems (the DBO operators) have commenced work on the Clifden Clara scheme since 2007. Since taking over the scheme, additional treatment and security measures have been implemented at the Clifden Clara borehole. The scheme is monitored remotely using an eSCADA scheme. The eSCADA system remotely monitors flow and chlorine levels at the Cuffesgrange scheme and sends updates to EPS staff.

2 LOCATION, SITE DESCRIPTION AND WELL HEAD PROTECTION

The Clifden Clara borehole, which is operated by the EPS on behalf of Kilkenny County Council since 2007, is located approximately 5 km to the east of Kilkenny City, adjacent to the N10 national road (See Figure 1). The source is located within the Nore River catchment.

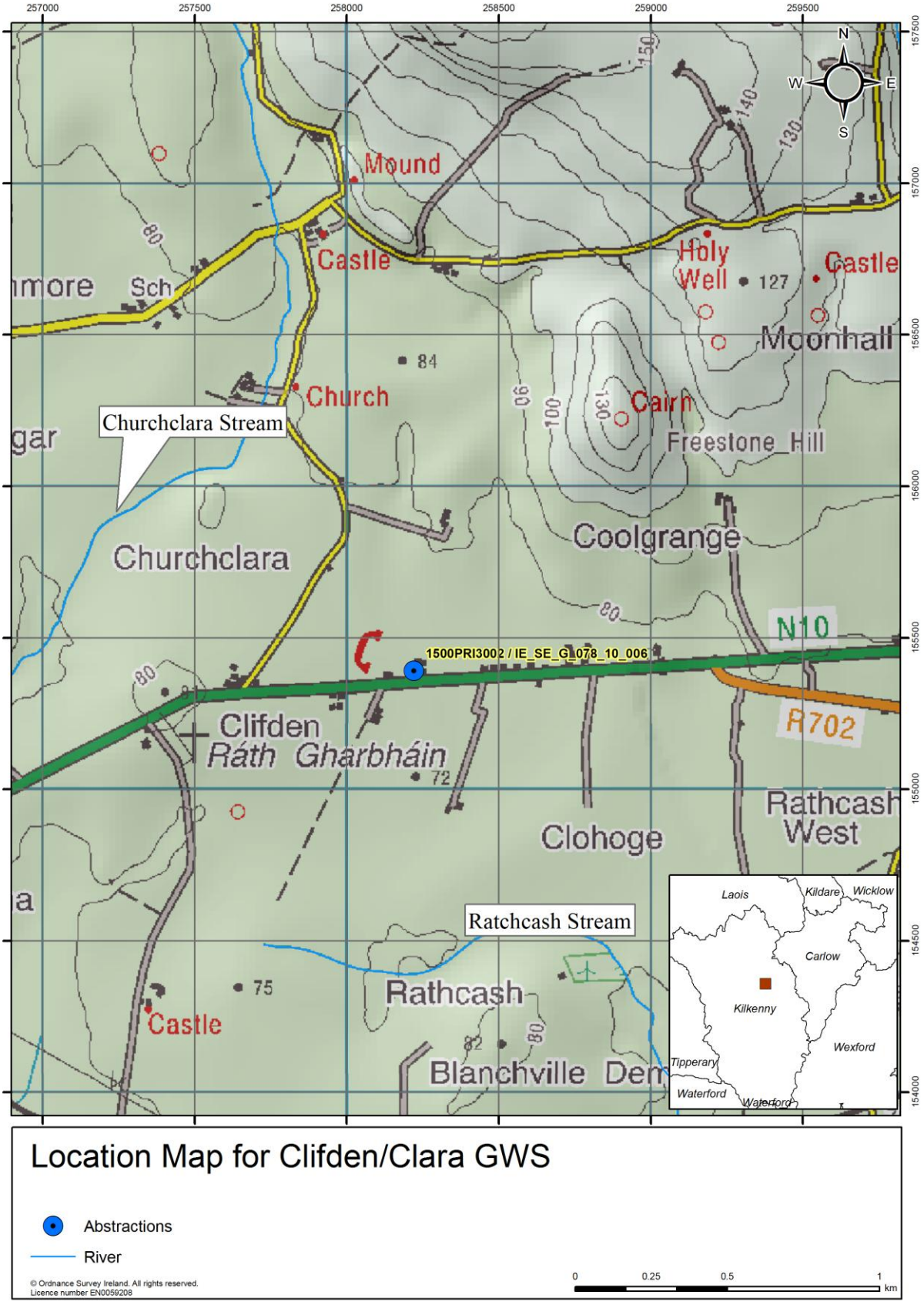


Figure 1 Location Map

The Clifden Clara source, in the townland of Clifden, has operated as a group water scheme since 1970.

The borehole is securely located within a compound. A borehole pump brings the water to the pump house where the untreated water is chlorinated and passed through a UV system. Water is pumped directly into the distribution network from the chlorine contact tank.

The annulus around the borehole is not grouted. The borehole cover and surrounding area is securely covered and the site is fenced off (Photograph 1).

3 SUMMARY OF BOREHOLE DETAILS

The Clifden Clara borehole was drilled to a depth of approximately 38 m in July 1970 with an 8" steel casing into bedrock. Drilling encountered 12 m of till (clay) material, overlying buff coloured dolomite with large water inflows from 12 m bgl to 31 m bgl. Below 31 m, the bedrock became more competent and comprised grey to dark grey limestone. An initial pumping test was completed on the borehole by the driller, with a 2.5 m drawdown achieved at a pumping rate of 34.5 m^3/hour (pers comm. Tom Fogarty).

Photograph 1 Borehole housing and treatment works

Table 3-1 Summary Details

EU Reporting Code	IE_EA_G_078_10_006
Grid reference	E258220 N135391
Townland	Clifden
Source type	Borehole
Drilled	July 1970
Owner	Kilkenny County Council
Elevation (Ground Level)	c. 76 mOD
Depth	38 m
Depth of casing	Outer casing 14 m
Diameter	0.2 m
Depth to rock	12 m
Static water level	4.04 m bgl
Consumption (Co. Co. records)	50 m^3/d
GSI Productivity Class	Class I
Specific capacity	331 $m^3/day/m$
Transmissivity (pump test data, 1970)	400 m^2/day

4 METHODOLOGY

The methodology consisted of data collection, desk studies, site visits and field mapping. Analysis of the information collected during the studies was used to delineate the Groundwater Source Protection Zones.

The initial site visit and interview with the EPS staff took place on 23/11/2009. Site walk-overs and field mapping (including measuring the electrical conductivity and temperature of streams in the area) of the study area were conducted on 28/11/2009, 01/12/2009 and 02/12/2009.

5 TOPOGRAPHY, SURFACE HYDROLOGY AND LANDUSE

The Clifden-Clara borehole is located along the N10 Kilkenny to Carlow road. The borehole is located within the River Nore catchment (Hydrometric Area 15) with Freestone Hill (183 m OD) forming the topographic boundary with the River Barrow catchment, 1 km to the east. The topography in the vicinity of the well is flat to gently undulating, with a general gentle slope towards the south. Further to the north, the land rises steeply towards Freestone Hill, and the Castlecomer Plateau 2 km further to the north. A number of unnamed streams rise on the Castlecomer Plateau and flow towards the River Nore to the west and to the River Barrow to the east.

According to the six inch maps of the area, a low drainage density exists to the northeast of the source, with a high artificial drain density located 1 km to the south. Two unnamed streams are located approximately 1 km from the source. For the purposes of this report these streams with be named the Rathcash Stream (to the south of the borehole) and the Churchclara Stream (to the west), (refer to Figure 1)

South of the borehole, a series of springs rise in the townland of Clifden and flow towards the Rathcash Stream. The nearest spring is located 150 m southwest of the borehole, with two smaller springs noted further to the south (300 m to 500 m).

Photograph 2. Small spring (SW4) 300 m south of source.

Land use in the area is primarily agricultural, with lands set to pasture or used for tillage. A number of farmyards have been noted in the area, though no farmyards were identified within 100 m of the borehole. One farmyard was noted 150 m southwest of the source adjacent to a spring (SW5). Three farmyards occur within 400–500 m of the source. The Clifden/Churchclara area has a moderate housing density (approx 15 dwellings/km^2). A number of one-off houses have been built since 2002 (less than 10). The area is under 'strong urban influence' according to the county development plan. A number of small businesses are located along the N10 national road.

6 GEOLOGY

6.1 BEDROCK GEOLOGY

This section briefly describes the relevant characteristics of the geological materials that underlie the Clifden Clara 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 the Bedrock Geological Map of Carlow-Wexford Sheet 19, 1:100,000 Series (Tietzsch-Tyler *et al*, 1994) and the GSI Karst Database.

The Bedrock Geological Map indicates that this area is principally underlain by Dinantian Pure Bedded Limestones of the Ballyadams Limestone Formation and the Clogrenan Formation (Figure 2). The Pure Bedded Limestones are underlain by Dinantian Upper Impure Limestones (Butlersgrove Formation) 0.7 km to the southwest and are unconformably overlain by Namurian Shales 1.5 km to the northeast.

The Dinantian Pure Bedded Limestones (Ballyadams Limestone Formation) are comprised of relatively clean, thick bedded limestones with intermittent clay wayboards. The presence of cherts and absence of clay wayboards distinguishes the Clogrenan Formation from the Ballyadams Formation. Extensive dolomitisation of the Ballyadams has been identified 1.2 km to the south of the source by the GSI, and is shown on the Geology Map. Dolomite was identified within the borehole and 0.8 km to the south (S1) where the new M9/M10 spur to Kilkenny is under construction (refer to Figure 2 and Photo 1). Dolomite at S1 comprised of vuggy, coarsely crystalline pink/buff dolomite. Local information suggests the dolomite extends up to the base of Freestone Hill. Bedrock exposures on Freestone Hill are comprised of pure bedded limestones. Approximately 1 km to the north of the source, borehole drilling at S2 encountered pure bedded limestones indicating the dolomite is limited in extent to the north.

A proposed extension of the dolotimised limestone area, based on field mapping is included on Figure 2. See cross section on Figure 4 for diagrammatic view across the study area.

Photograph 1 Pink/buff coloured dolomite (centre) contrasting with grey limestone imported construction material.

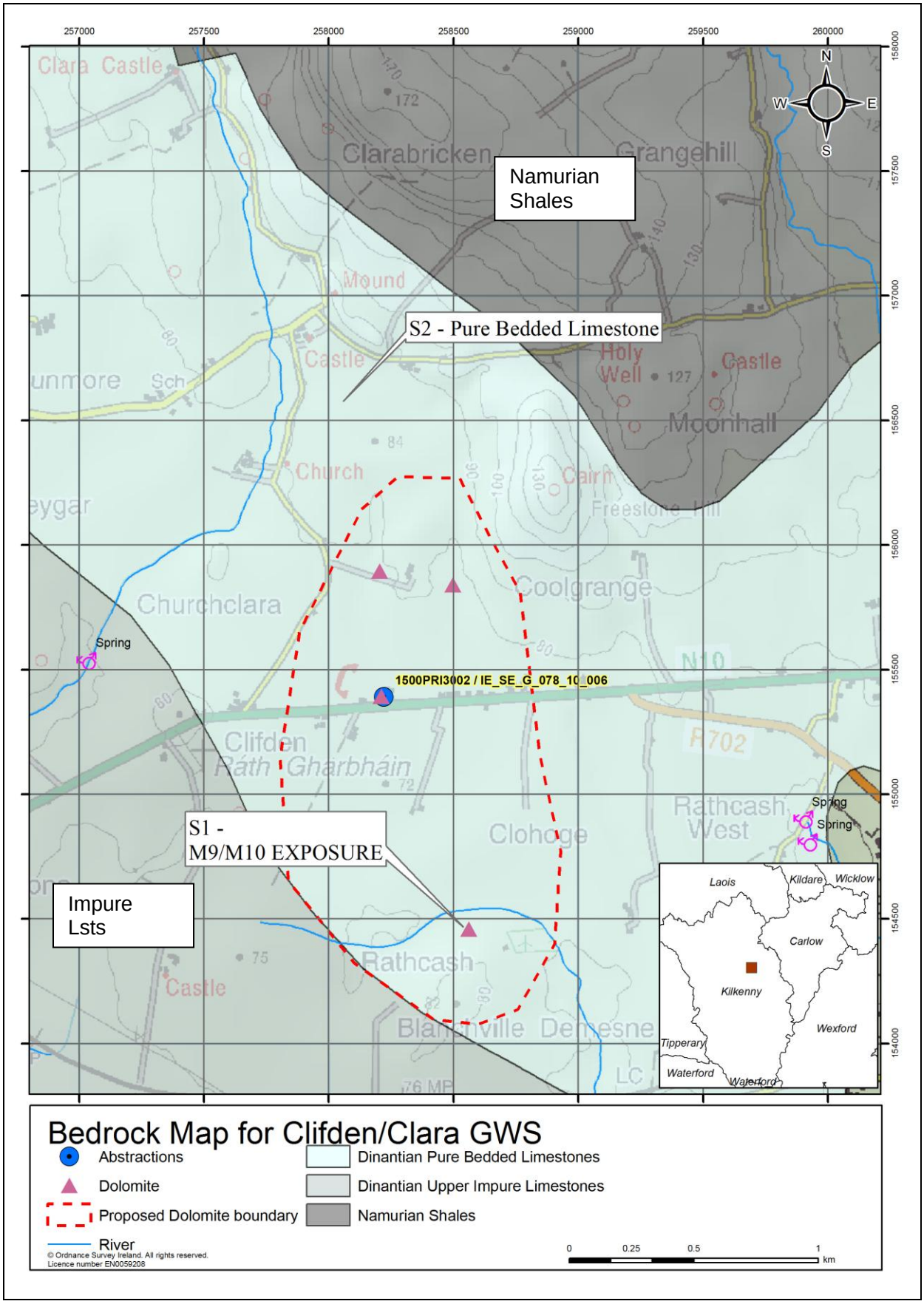


Figure 2 Geology Map

6.1.1 Karst Geology

Hydrogeological mapping (December 2009) included checking existing, known karst features around the source and searching for possible new features. The karst features listed in Table 6-1 are those recorded in the GSI Karst Feature Database within a 2 km radius of the borehole, and are shown in Figure 3.

To the west (1 km) of the source, Tobernaleabe Spring rises approximately 200 m to the south of a sinking stream. Due to the high water levels it was not possible to investigate this spring in detail. At Rathcash to the southeast, two karstic springs are located near the M10 motorway currently under construction.

The springs mapped during the current study to the south of the borehole (Clifden springs SW3–SW5) are potential karst springs, but bedrock exposures were not evident at these locations. These were the only karst features identified during the site walkover.

Table 6-1 Karst features within a 5 km radius of the Clifden Clara Boreholes Source (GSI Karst Database)

Number	Feature type	Feature name	Easting	Northing	Distance to source	Townland
K1	Spring	Tobernaleabe	257030	155540	1.1 km west	Churchclara
K2	Spring	Rathcash East Spring	255900	154900	1.6 km southeast	Rathcash
K3	Spring	Rathcash East Spring	255920	154810	1.6 km northwest	Rathcash

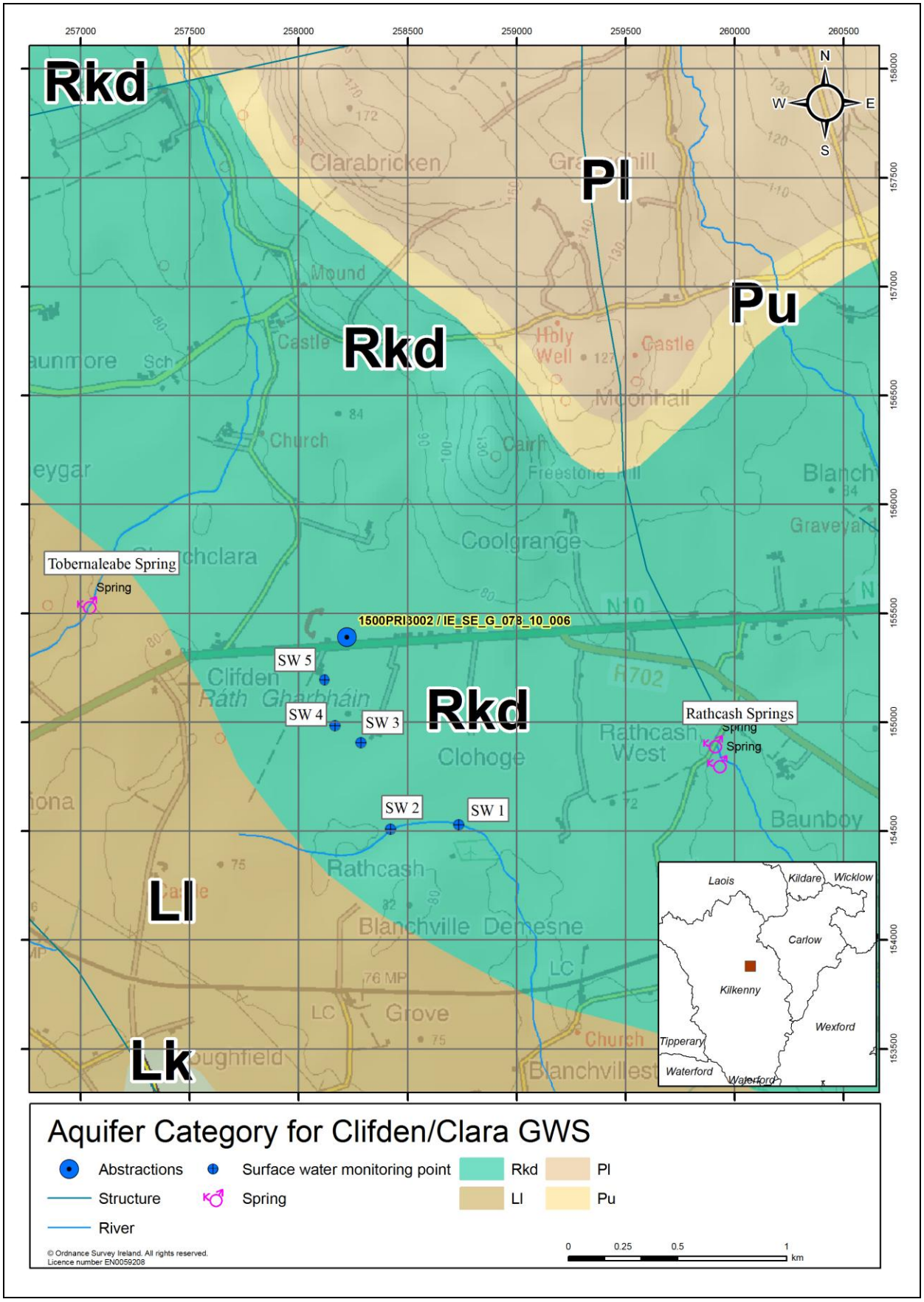
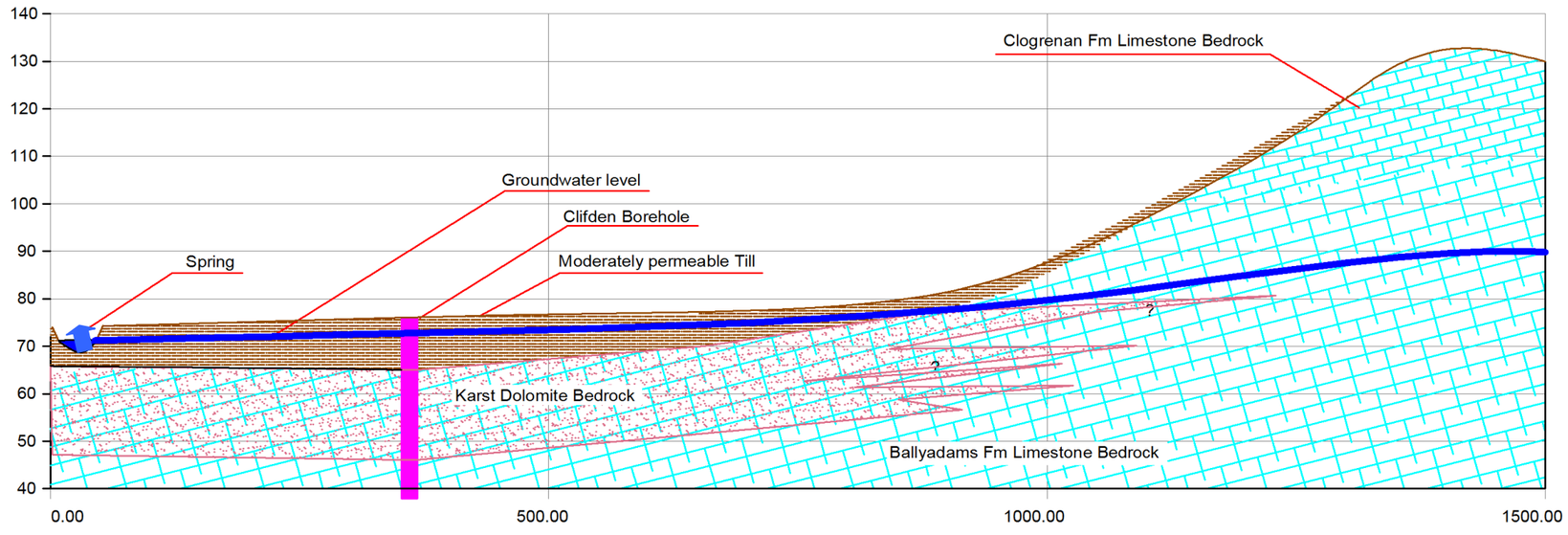


Figure 3 Aquifer Map in the vicinity of Clifden Clara

LOCATION MAP SHOWING LOCATION OF LONGITUDINAL SECTION
Scale 1:50,000



LONGITUDINAL SECTION SHOWING GEOLOGY AND GROUNDWATER LEVELS
Scale H: 1:5,000 V: 1:1,000

NOTES

1. FIGURED DIMENSIONS ONLY TO BE TAKEN FROM THIS DRAWING
2. ALL DRAWINGS TO BE CHECKED BY THE CONTRACTOR ON SITE
3. ENGINEER TO BE INFORMED BY THE CONTRACTOR OF ANY DISCREPANCIES BEFORE ANY WORK COMMENCES
4. ALL LEVELS SHOWN RELATE TO ORDNANCE SURVEY DATUM AT MALIN HEAD

Issue	Date	Description	By	C
B	11.11.09	DRAFT ISSUE FOR REVIEW	MN	

Client: EPA / GSI

Project: CLIFDEN CLARA BOREHOLE

Title: CONCEPTUAL LONGITUDINAL SECTION SW - NE

Scale @ A3: As Shown

Prepared by: M. Nolan | Checked: J. Dillon

Project Director: D. Grehan

TOBIN
Patrick J. Tobin & Co. Ltd.
Consulting, Civil and Structural Engineers,
Block 10-3, Blanchardstown Corporate Park,
Dublin 15, Ireland.
tel: +353-(0)1-8030406
fax:+353-(0)1-8030409
e-mail: info@tobin.ie
www.tobin.ie

Drawing No.: 5604-2811 | Issue: E

Figure 4 Cross Section

6.2 SUBSOILS GEOLOGY

According to GSI and EPA web mapping, the study area is dominated by till derived from Namurian Shale and Sandstones (TNSSs). However, this map depicts till at and just below the surface only, and from an examination of historical mapping data from the EPA Soil and Subsoil Mapping Project, in areas adjacent to Clifden Clara two till units occur, stacked on top of each other. These areas host till derived from limestone at depth, capped by the till derived from Namurian rocks just below the surface, which has been carried from the area of Namurian rock-outcrop 3 km to the north. The Clifden Clara locality seems to have a similar scenario occurring from secondary indicator data gathered in the current project (see below).

According to GSI and EPA web mapping, the study area is dominated by till and sand and gravel deposits derived from Namurian shales and sandstones, TNSSs and GNSSs respectively (Figure 4) with till and sands and gravels derived from limestone (TLs) occurring 0.5 km to the south. Based on information from the borehole, the underlying subsoil is comprised of 'gravelly till' to 12 m.

The number of soil and subsoil exposures is limited within the Clifden-Clara borehole study area. However, there were some exposures evident along the M9/M10 under construction 0.9 km to the south of the borehole but they were typically limited to 1–1.5 m depth. Subsoil cuttings 1 km southeast of the source were described using BS5930 as brown/red, moderately stiff, slightly sandy, very gravelly SILT with frequent cobbles and were presumed to be the TLs. Alluvial subsoil along the Rathcash stream bank is comprised of grey/light brown, laminated, slightly sandy SILT.

The soils surrounding the borehole and towards the north are mapped as 'dry' soil types: typically well drained deep mineral soils (AminDW & BminDW). Approximately 300 m south of the source and surrounding the Rathcash Stream, soils are mapped as poorly drained, deep mineral soils (BminPD).

The subsoils across County Kilkenny have been classified according to British Standards 5930 in the preparation of the Groundwater Vulnerability map for Kilkenny County Council, by the GSI. The subsoil permeability of the till unit around the source has been classed as '*Low Permeability*' in this scheme.

However, based on the moderate drainage density, presence of intensive agriculture/tillage, dominance of dry soil types, absence of rushes or other wetland indicators found during field mapping for this study, and description of the subsoils as SILT, the permeability of the subsoil in the area around the source, as well as further to the north, is felt to be towards the low end of '*Moderate permeability*' material.

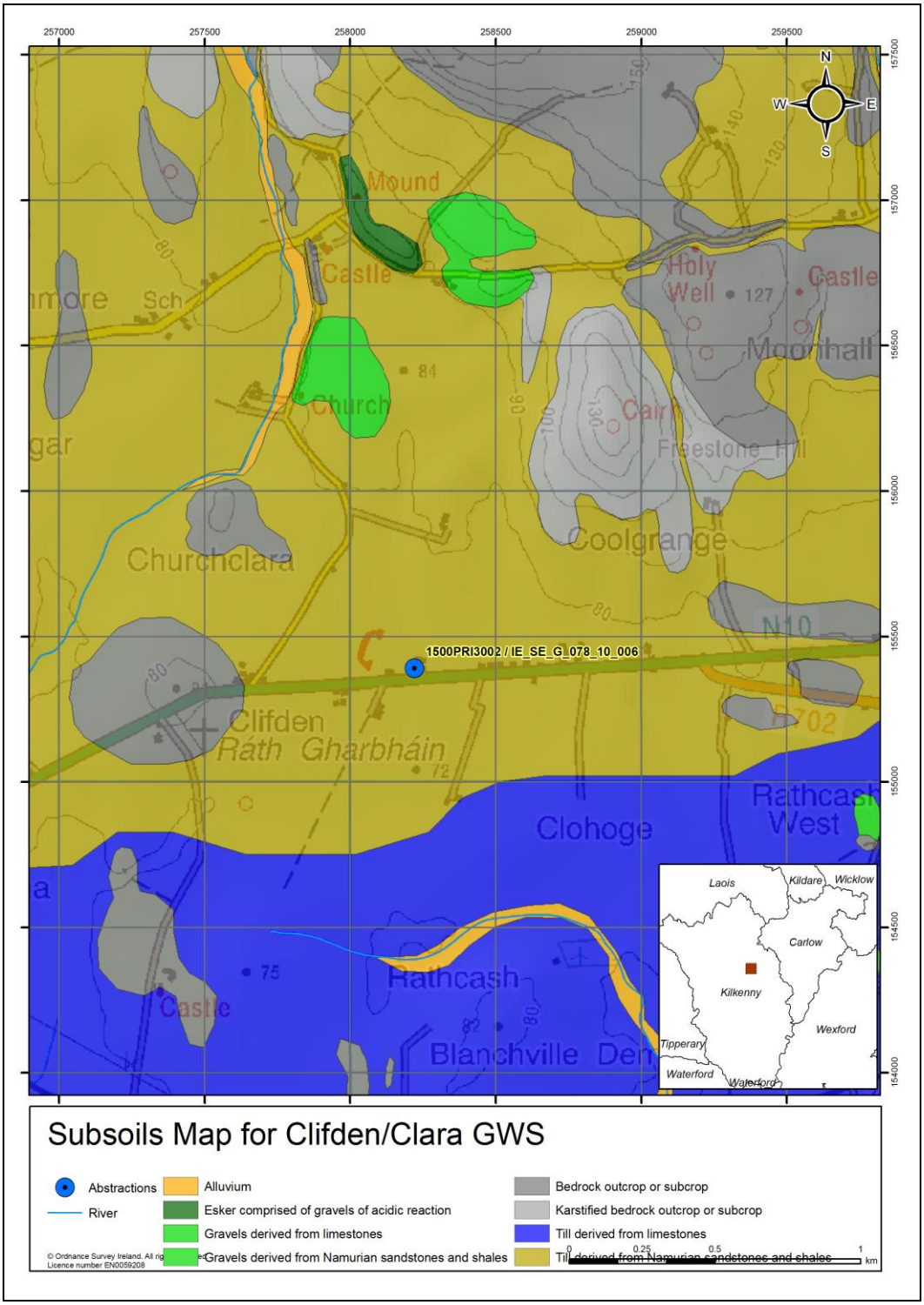


Figure 5 Subsoil Map

6.3 DEPTH TO BEDROCK

During a site walkover on the 23rd November 2009, Doran's Well Drilling was completing a well, 1 km north of the source towards the crest of a small hill. Depth to bedrock at this location (S2) was 2.2 m bgl. Along the flanks of Freestone Hill, a number of small historical quarries are located on the OSI historical maps, which also indicate a shallow depth to bedrock. Numerous bedrock exposures are evident on Freestone Hill.

Depth to bedrock at the source is 12 m. Based on the geological information acquired from the local drilling contractors, Tom Fogarty Well Drilling & Doran Well Drilling, depth to bedrock is variable, but generally approximately 10m. This together with field mapping has enabled a greater than 10m zone to be delimited about the source. Further east of the source, a number of wells identified on the GSI well database, indicate that depth to bedrock along the N10 is between 3 and 10 m.

7 GROUNDWATER VULNERABILITY

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target'. This means that vulnerability relates to the thickness of the unsaturated zone in the sand/gravel aquifer, and the permeability and thickness of the subsoil in areas where the sand/gravel aquifer is absent. A detailed description of the vulnerability categories can be found in the Groundwater Protection Schemes document (DoEHLG/EPA/GSI, 1999) and in the draft GSI Guidelines for Assessment and Mapping of Groundwater Vulnerability to Contamination (Fitzsimons *et al*, 2003).

The subsoil permeability of the till dominated by Namurian rocks around the source has been classed as '*Low Permeability*' within the County Kilkenny Groundwater Protection Scheme. However following fieldwork for the current study, including analysis of subsoil exposures, the absence of drainage ditches and wetland indicators, the area around the source appears to be well drained. Based on this the subsoil permeability is mapped as '*Moderate Permeability*' for the current scheme. Additional depth to bedrock data are available, thus, the vulnerability map (Figure 5) has been revised in this report; specifically a Moderate Vulnerability zone has been delimited around the source.

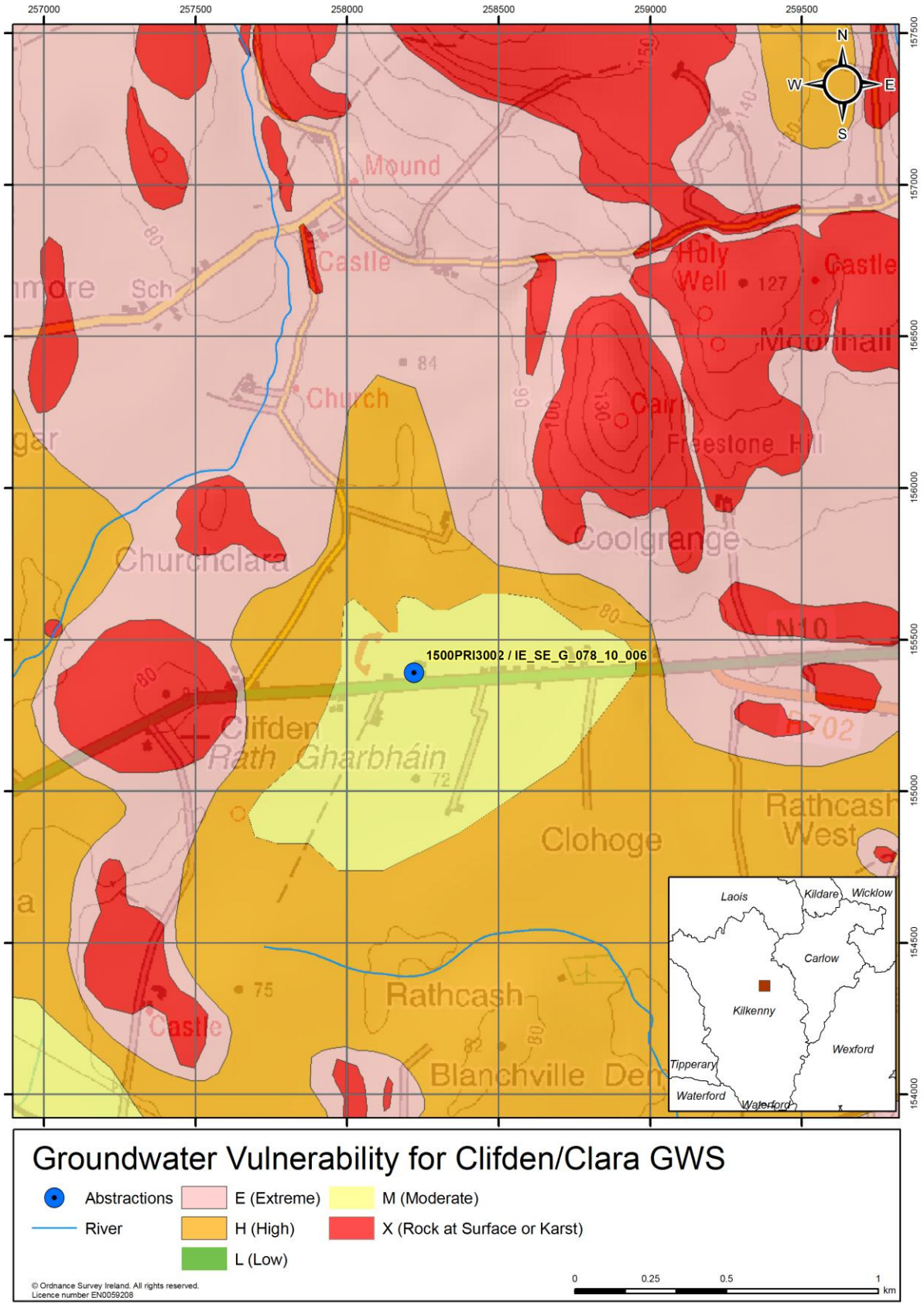


Figure 6 Proposed Groundwater Vulnerability around Clifden Clara source

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 Well Database
- County Council Staff
- EPA website and Groundwater Monitoring database
- Local Authority Drinking Water returns
- Hydrogeological mapping by TOBIN Consulting Engineers and Robert Meehan in November 2009 and December 2009.
- County Kilkenny Groundwater Protection Scheme (GSI, 2004).

8.1 GROUNDWATER BODY AND STATUS

The Clifton Clara source is located within the Kilkenny Groundwater Body which has been currently classified as being of Poor Status www.wfdireland.ie/maps.html. The groundwater body descriptions are available from the GSI website: www.gsi.ie and the 'status' is obtained from the Water Framework Directive 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: 823 mm. The closest meteorological station to Clifden Clara borehole is located at Kilkenny City. Data records exist for Kilkenny (823 mm) are based on Met Éireann data for annual average rainfall (Fitzgerald and Forrestal, 1996). Data from the Met Eireann website show that the source is located between the 800 mm and 1000 mm average annual rainfall isohyet.

Annual evapotranspiration losses: 435 mm. Potential evapotranspiration (P.E.) is estimated to be 458 mm/yr (based on data from the Met Éireann Kilkenny synoptic station). Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., to allow for seasonal soil moisture deficits.

Annual Effective Rainfall: 388 mm. The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore equivalent to this, or 388 mm/year. Section 8.6 following (Recharge) estimates the proportion of effective rainfall that enters the aquifer utilising other hydrogeological data for the area.

8.3 GROUNDWATER LEVELS, FLOW DIRECTIONS AND GRADIENTS

Groundwater levels within the Clifden Clara borehole are close to the surface: the static water level was recorded at 4.04 m bgl during the November 2009 site visit.

Groundwater levels in the surrounding area are estimated to be lower than the topographical contours to account for the absence of surface water features to the north of the borehole source. Groundwater gradients are expected to be relatively flat because the bedrock aquifer is highly permeable and are estimated to be 0.01. Accurate level data in this area could provide more conclusive information on

flow directions. Groundwater flow is assumed to broadly focus towards the spring discharge areas and the Rathcash Stream, following topography. A surface water/groundwater divide is thought to correspond with a topographical divide on Freestone Hill 1 km to the northeast of the source, beyond which groundwater flows towards the River Barrow.

8.4 HYDROCHEMISTRY AND WATER QUALITY

To investigate the relationship of groundwater to surface water, field mapping of surface water features was carried out in December 2009 which provided information on selected parameters (Electrical conductivity and temperature) and a quantitative assessment of flow. Monitoring of stream flow in the Rathcash Stream was conducted to investigate the potential groundwater discharges to the stream.

Table 8-1 provides the field data from 1st December 2009. Refer to Figure 7 for locations.

Table 8-1 Field measurements of surface water features

SW stream ID	Conductivity	pH	Dissolved Oxygen	Temperature	Notes
SW 1	342	7.4	80	6.7	Rathcash Stream Est. Flow 0.14 m^3/s
SW 2	402	7.6	66	7.1	
SW 3	513	7.5	67	9.5	
SW 4	528	7.5	61	9.9	
SW 5	531	7.6	54	10	Spring Est. Flow 0.015 m^3/s (1,300 m^3/day)

A series of springs rise 150–500 m south/southwest of the borehole source and flow towards the Rathcash stream via a series of drainage ditches. This connection is reflected in the hydrochemistry of the springs and stream which suggests that Rathcash stream is a combination of surface water and groundwater.

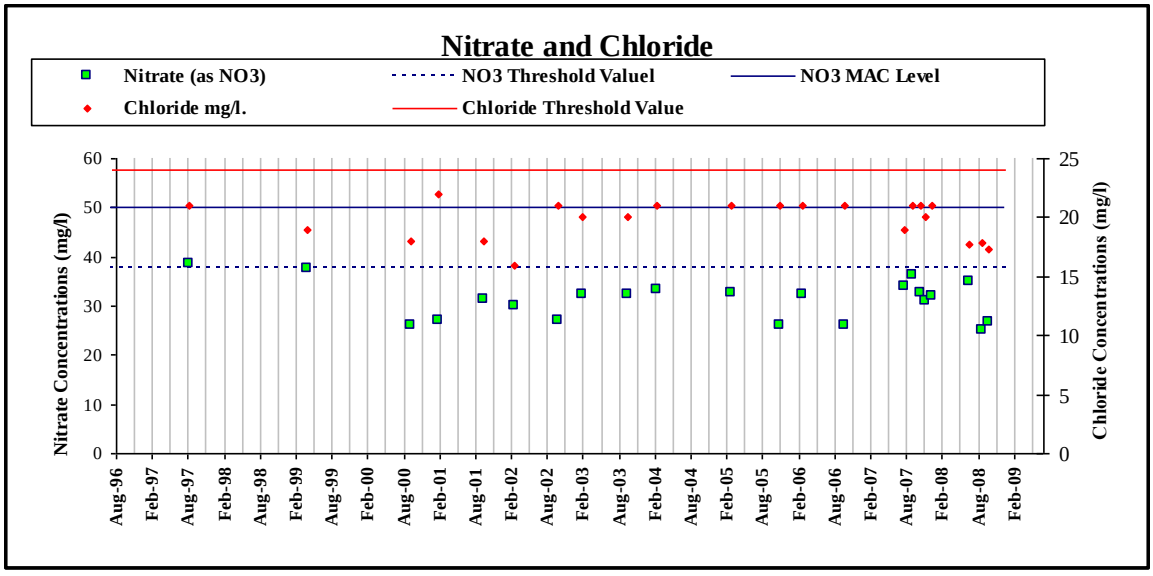
Twenty five samples were available from the EPA Groundwater Monitoring Network between 1993 and 2008. The water quality varies from moderately hard to very hard, (177 to 460 mg/l $CaCO_3$). Alkalinity ranges from 240 to 380 mg/l $CaCO_3$. The pH ranges between 7.1 and 8.3, which is alkaline. The field electrical conductivity ranges from 520 to 715 µS/cm @25°C. The hydrochemical signature is calcium/magnesium bicarbonate.

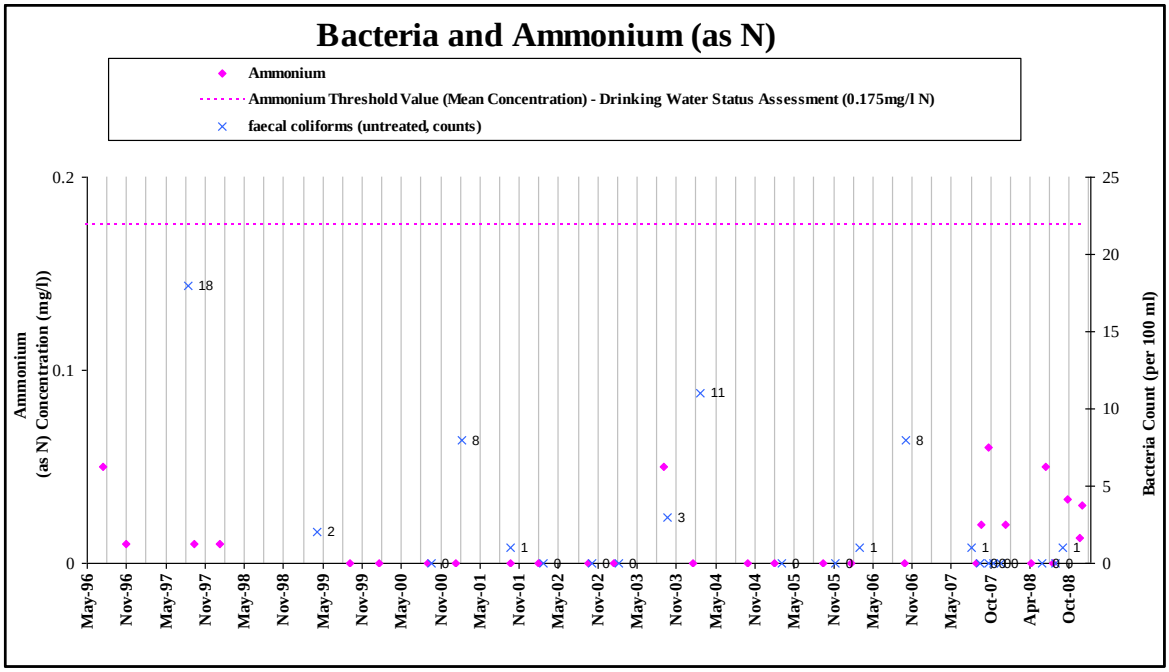
The concentration of nitrate ranges from 25.1 mg/l to 38.5 mg/l with an average 31 mg/l (as NO_3). There is no reported exceedance above the EU Drinking Water Directive maximum admissible concentration of 50 mg/l, but concentrations were occasionally above the groundwater threshold value of 37.5 mg/l (Groundwater Regulations S.I. 9 of 2010). The area around the borehole is moderately populated, and is served by septic tank systems. Some recent one off development is evident in the area. Beef, tillage and sheep farming are the main land uses in the surrounding area, with a number of farmyards noted to the north and east.

Chloride concentrations range from 16 to 22.3 mg/l, with a mean of 19.9 mg/l which is considered to be slightly above the mean natural background level of 18 mg/l (Groundwater newsletter 46, O'Callaghan Moran 2007) but is below the groundwater threshold value for saline intrusion test of 24 mg/l (Groundwater Regulations, S.I. 9 of 2010). Iron and manganese concentrations are below their respective parametric value limits in all samples.

Faecal coliforms were present in the water in 60% of samples, with gross contamination on two occasions (greater than 10 faecal coliforms per 100 ml). Potential sources include agriculture and septic tank systems. Although the concentrations are variable, numbers of faecal coliforms since 2007 are lower than previous years. No gross contamination has occurred since 2007. The large proportion of extreme groundwater vulnerability, the rapid travel times in the karstified dolomite bedrock and the land use indicates the likelihood of faecal contamination occurring.

The concentration of Sulphate, Potassium, Sodium, Magnesium and Calcium are within normal ranges. The Potassium: Sodium (K:Na) ratio is low at less than 0.25.





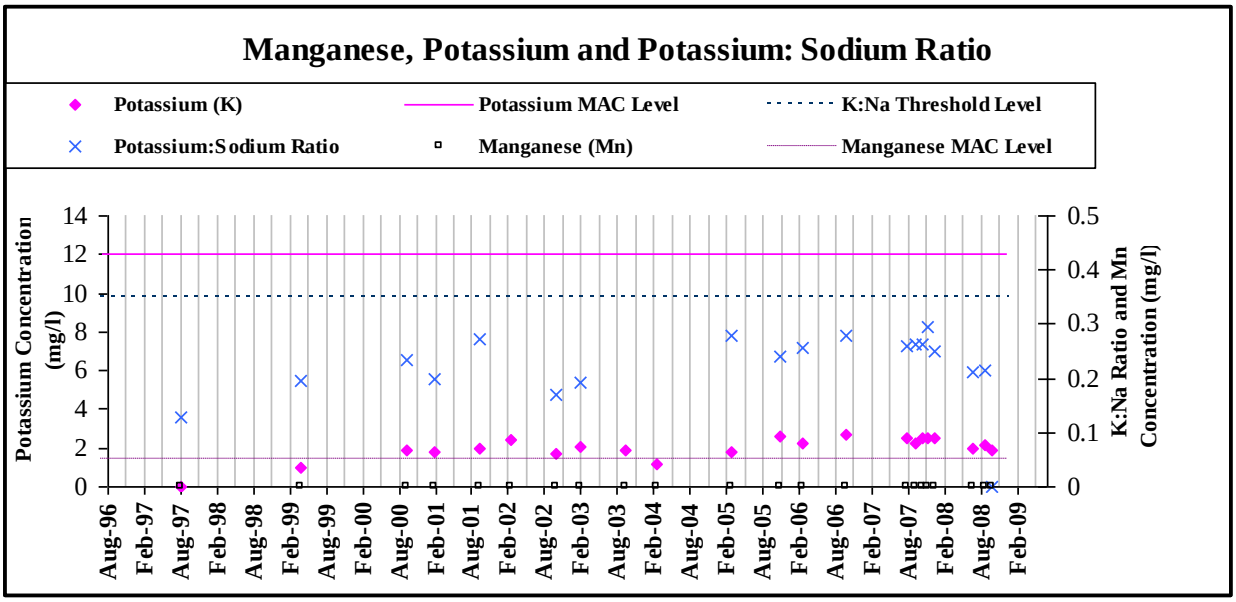


Figure 7 Water Quality Graphs

The concentrations of all other trace metals are low and/or below the detection limit of the laboratory. Slightly elevated concentrations of MCPA and Mecoprop were recorded on one occasion in December 2007. These herbicides are typically used in the control of perennial weeds in arable lands and in horticultural practices. Both herbicides are highly mobile in groundwater. Possible sources include arable land to the north of the source.

8.5 AQUIFER CHARACTERISTICS

The groundwater source is located in the Kilkenny Groundwater Body. The GSI bedrock aquifer map of the area indicates that the Dinantian Pure Bedded Limestone (Balladams Limestones) is classified as a *Regionally Important Diffuse Karst Aquifer (RKd) which is highly productive.* Groundwater velocities through fissures/conduits may be high with aquifer storage enhanced by the presence of dolomite.

From the drillers pumping test information in 1970, water levels dropped by 2.5 m while pumping at a rate of 34.5 m^3/hour (828 m^3/d). The yield of Clifden Clara borehole is 'excellent' according to GSI classification and the GSI productivity is Class I.

Using the Logan transformation (Misstear, 1998) and a calculated specific capacity of 330 m^3/m/day (based on yield tests and pumping test), the transmissivity is estimated to be 400 m^2/day. Transmissivity values throughout the aquifer are likely to vary depending on the degree of fractures/fissures and the degree of dolomitisation present.

Permeability is in the order of 21 m/day based on a saturated thickness of 19 m (the thickness of the dolomitised limestone), and porosity of the dolomite is conservatively estimated to be in the order of 2%. Groundwater velocity, assuming a gradient of 0.01 is in the order of 10.5 m/day.

The 19 m thick dolomite is considered to provide the main groundwater contribution to borehole. However, it is considered that it may be limited in areal extent towards the north. Recent drilling at S2 encountered competent pure bedded limestones to 50 mbgl (refer to Figure 2). Dolomite is mapped within the Ballyadams to the south and was encountered in the Clifden Clara borehole, S1 and the M9/M10 road cutting to the south.

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 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 critical in source protection delineation, as it will dictate the size of the zone of contribution to the source (*i.e.* the Outer Source Protection Area).

At Clifden Clara, the main parameters involved in the estimation of recharge are: annual rainfall; annual evapotranspiration; and a recharge coefficient.

Runoff losses: *116* mm. Runoff losses are assumed to be 30% of potential recharge. This value is based on an assumption of *c.* 10% runoff for 50% of the area (extreme vulnerability); 40% runoff over 30% of the area due to high vulnerability/moderate permeability subsoil; and, 60% runoff over 20% of the area (moderate vulnerability).

The bulk ***recharge coefficient*** for the area is therefore estimated to be 70%. Due to the bedrock type there is no recharge cap applied. (Guidance Document GW5, Groundwater Working Group 2005).

These calculations are summarised as follows:

Average annual rainfall (R)	823 mm
estimated P.E.	458 mm
estimated A.E. (95% of P.E.)	435mm
effective rainfall	388 mm
potential recharge	388 mm
runoff losses	30%
bulk recharge coefficient	70%
Recharge	**272 mm**

8.7 CONCEPTUAL MODEL

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

- The source under consideration in this report comprises a 37 m borehole at Clifden, Co. Kilkenny. The abstraction rate from the source is 50 m^3/day.
- GSI maps and mineral exploration indicate a varying degree of karstified dolomitised limestones in the area. The borehole source is completed within dolomitised bedrock. These features support the aquifer classification of *Regionally important karstified diffuse aquifer* (Rk_d).
- In general, the depth to bedrock is 0–3 m on elevated areas, increasing in depth towards the low-lying parts of the study area. Depth to bedrock away from the hilltops is greater than 5 m. The subsoils are reclassified (based on site specific information) for this report as being of 'moderate permeability'. Drilling encountered 12 m of overburden at the borehole source described by the driller as gravelly till.
- Groundwater flow is expected to be from the higher ground to the north and northeast, towards the borehole and spring discharge zone, following topography. The natural hydraulic gradients in the aquifer are likely to be low, approximately 0.01 (Dec 2009), reflecting the generally high transmissivity of the dolomitic limestones. At present, minimal drawdown is

induced within the well from pumping. Drawdown during pumping (at 50 m^3/d) was measured at just 0.04 m during a site visit in Dec 2009.

- Over the region, an average recharge rate of 272 mm/year is used, which is approximately 70% of the total potential recharge. The remaining 30% of potential recharge is rejected and discharge may be via land overflow during the winter months.
- The delineation of the ZOC is difficult due to shallow groundwater gradients and without accuracy level data over an extended period.
- The groundwater is of calcium/magnesium bicarbonate signature and hard. Nitrate and ammonia concentrations are below their respective PVL. The microbial analysis of the water samples indicates that the groundwater is impacted by contamination from human or agricultural sources. Herbicides typically used in arable farming were detected in the borehole on one occasion. This reflects the large proportion of the area that is extremely vulnerable.

- Limitations to the conceptual model mainly lie with a lack of information on the following:

  ⇨ Site specific depth to bedrock and localized differences in the subsoil permeability. Further information on the depth to bedrock would provide greater detail and confidence in the level of protection afforded by the subsoils and also a greater understanding of the 3D visualization and interaction of the borehole, till and bedrock.

  ⇨ Surveyed levels of groundwater levels would give a greater level of confidence to groundwater contours, flow directions and gradients.

  ⇨ Further borehole data may help define the extent of dolomitization within the Ballyadams Formation.

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 conceptualisation of the groundwater flow to the source, as described in Section 8.7 Conceptual Model.

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 to support an abstraction from long-term recharge. The ZOC is controlled primarily by (a) the total discharge, (b) the groundwater flow direction and gradient, (c) the 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.

The **Southern Boundary** is based on a combination of hydrogeological mapping, the uniform flow equation and an assumption that in general the nearby spring is in hydraulic connection with groundwater.

The uniform flow equation (Todd, 1980) is:

$xL = Q / (2\pi * T * I)$ where

Q is the daily pumping rate

T is Transmissivity (taken from aquifer characteristics)

I is background non pumping gradient.

The uniform flow equation suggests the influence of the well on the downgradient side is less than 10 m from the bore (based on an approximate transmissivity of 400 m^2/day, a natural groundwater gradient of 0.01, and a discharge of 50 m^3/d, even when an allowance is made for a 100% increase in demand). However this is uncertain and it is considered that a precautionary arbitrary distance of 30 m is used to allow for errors and variability in the aquifer parameters.

The **Northern Boundary** is based on the south-westerly groundwater flow directions from the higher ground towards the spring. The Zone of Contribution is extended to the topographic divide to allow for the high permeability in the karstified dolomitic limestones.

The **Eastern Boundary** is based on the presence of the topographical high of Freestone Hill. Freestone Hill is considered to form the boundary between the Barrow and Nore River catchments. Groundwater at Freestone Hill is considered to flow towards the borehole and springs to the south.

The **Western Boundary** is based on the presence of the Churchclara stream to the west. A groundwater divide is likely to occur between the Churchclara stream/Tobernaleabe springs to the west and borehole/Clifden springs to the south. The slight mound in this area marked with a high point of 84 m on the base map is not considered to have a significant effect on the flow directions within the underlying bedrock. However, given the relatively flat topography and low hydraulic gradients, some uncertainty exists in relation to the exact boundary. Further site investigation and water level monitoring would be required to confirm the boundary.

Water balance: Based on an abstraction of 50 m^3/day on average and the estimated recharge of 272 mm/year, a zone of contribution of 0.06 km^2 in area is calculated. Hydrogeological field mapping and the conceptual model determined an area of 0.56 km^2. Current GSI guidance states that ZOC delineation should conservatively account for 150% of the abstraction volume. The ZOC presented is therefore conservative, allowing for the groundwater discharge to the Clifden springs to the south and uncertainty in flow directions. The borehole is intercepting a small proportion of the flow in the catchment that is flowing south to the springs, so any part of the ZOC could be contributing to the borehole at any time. Further refinement of the zone of contribution will require further investigation.

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 based on the results of the hydraulic test programme, however, in this instance, the aquifer category of Rk^c, suggests that very rapid groundwater velocities are likely in this area due to karstification of the limestones. Groundwater flow can be focused and travel very fast. Results from tracing programmes in similar rock types indicate velocities in the order of hundreds of metres/day. On this basis, all of the ZOC is designated as part of the inner protection area to the source.

10 GROUNDWATER PROTECTION ZONES

Groundwater protection zones are shown in Table 10-1, 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/X. The majority of the area is designated SI/E.

Table 10-1 Source Protection Zones

Source Protection Zone	% of total area (0.56 km²)
SI/ Moderate	24.2
SI/High	26.1
SI/ Extreme	31.6
SI/Extreme (Rock close)	18.6

11 POTENTIAL POLLUTION SOURCES

The main potential sources of contamination within the ZOC are:

- Private residences within the ZOC are serviced by onsite wastewater treatment systems. 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 primarily grassland with substantial areas of tillage land. A number of farming operations are located within the source protection zone. The main potential contaminants from these sources are ammonia, nitrates, phosphates, chloride, potassium, BOD, COD, TOC, pesticides, herbicides, faecal bacteria, viruses and cryptosporidium.

- Private home heating fuel tanks are located within the catchment area. The main potential contaminants from this source are hydrocarbons.

Roadways including the current N10, are present within the ZOC. The main potential contaminants from this source are hydrocarbons and metals.

12 CONCLUSIONS

The untreated groundwater at the borehole source at Clifden is currently impacted by microbial contamination. Available data suggests that there is contamination of the source occurring probably from organic waste sources; such as untreated wastewater from unsewered areas. The SPZ delineated is based on the current understanding of groundwater conditions and bedrock geology; and on the available data. The conclusions should not be used as the sole basis for site-specific decisions. The Inner Source Protection Area and the Zone of Contribution is calculated to extend to 0.56 km².

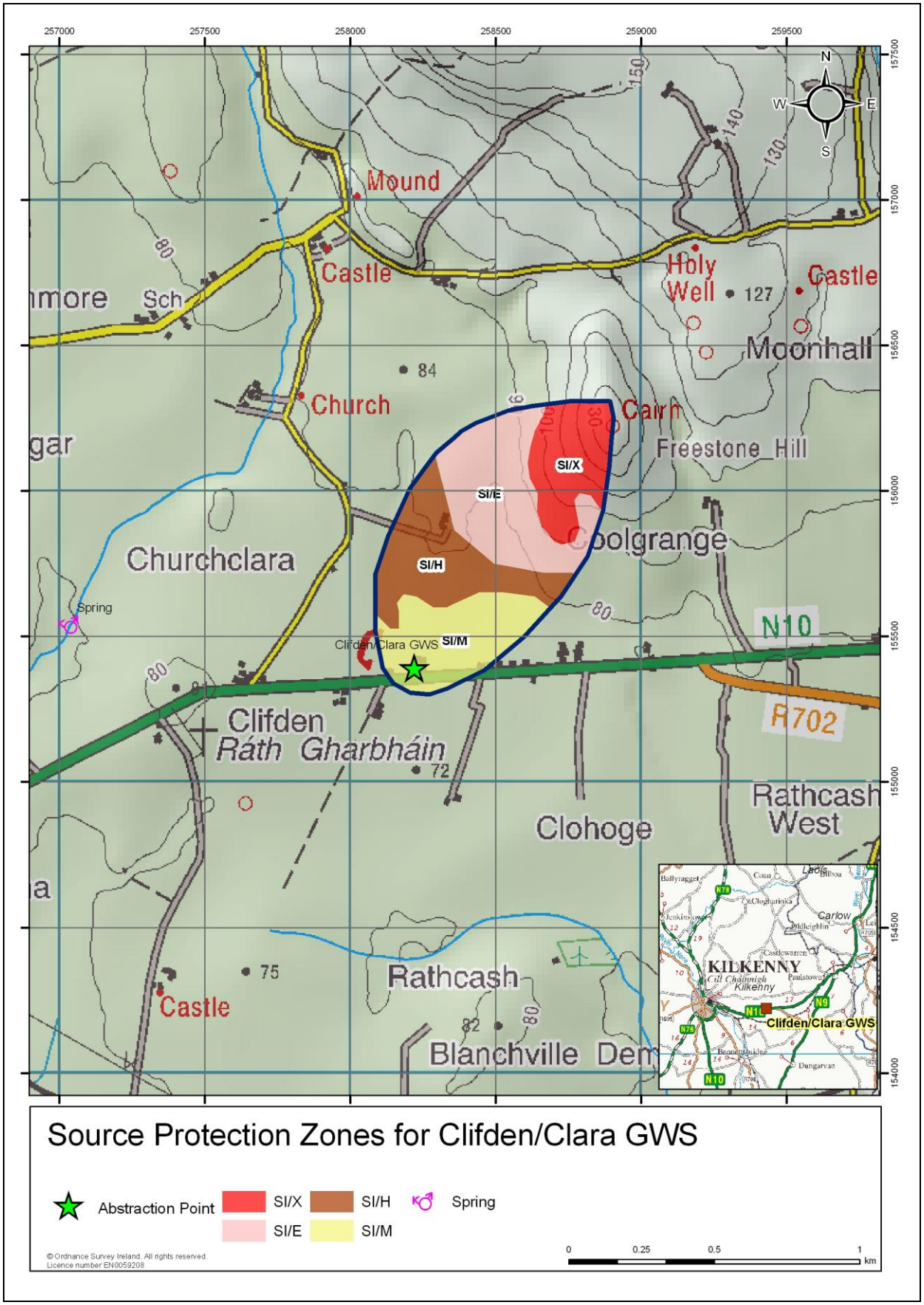


Figure 4 Source Protection Zones around Clifden Clara borehole

13 RECOMMENDATIONS

Continued monitoring water levels during the operation of the scheme should be gathered to develop a real-time database of hydrogeological information.

The source site is the area immediately around the groundwater abstraction borehole. Protection in this area is paramount to ensure that direct intentional or accidental interference is not caused to the borehole. The protection of the source site involves prevention of access and prevention of activities in the immediate proximity of the abstraction boreholes.

A cordon around the source is recommended in order to ensure that potentially polluting materials are not stored or deposited in the immediate vicinity of the source.

The ZOC of the source includes an extensive area of Extreme Vulnerability with a significant proportion of it comprising shallow rock. It is recommended therefore that an adequate barrier to Cryptosporidium must be installed as part of the water treatment system for the supply. A hazard survey is also recommended.

14 REFERENCES

An Foras Talúntais and Geological Survey of Ireland, 1981. Soil map of Ireland

Baker, G., Crean, D. and Moran, S. (2007) Establishing Natural Background Levels for Groundwater Quality in Ireland. GSI Groundwater Newsletter No. 46.

Collins, J.F. and Cummins, T. (1996) Agroclimatic Atlas of Ireland. AGMET – Joint working group on Applied Agricultural Meteorology, Dublin.

Fitzgerald D., and Forrestal, F. (1996) Climatological Note No. 10. Monthly and Annual Averages of Rainfall 1961-1990. Meteorological Service

Fitzsimons, V., Daly, D. and Deakin, J. (2003) GSI Guidelines for Assessment and Mapping of Groundwater Vulnerability to Contamination. Geological Survey of Ireland.

Geological Survey of Ireland (2004). *County Kilkenny Groundwater Protection Scheme 2004*. Report to Kilkenny County Council.

Kilkenny GWB: Summary of Initial Characterisation. www.gsi.ie

Misstear, B. (1998) The Logan Method for analyzing pumping test data. The GSI Groundwater Newsletter, No. 34, pp 9–11.

Todd, D.K., (1980) Groundwater Hydrology. Wiley and Sons 535pp

Tietzsch-Tyler, D., Sleeman, A., McConnell, B., Daly, E., Flegg, A., O'Connor, P., Warren, W., (1994) Geology of Carlow - Wexford. Geological Survey of Ireland. *1:100,000*

www.wfdireland.ie/maps.html (2008) Kilkenny GWB status

Groundwater Working Group 2005. Guidance on the Assessment of the Impact of Groundwater Abstractions. Guidance Document No.GW5. Intergovernmental Working Group on Groundwater.