Ennis Public Supply
Drumcliff Spring
Co. Clare

Groundwater Source Protection

February 2000

Prepared by:

Jenny Deakin
Geological Survey of Ireland

Assisted by:

Donal Daly, Geological Survey of Ireland
Catherine Coxon, Trinity College Dublin
David Drew, Trinity College Dublin

TABLE OF CONTENTS

SCHEDULE OF MAPS

Ennis Public Supply
Drumcliff
(Draft)

1 Introduction

Drumcliff Springs supply the public drinking water for the town of Ennis, Co. Clare. There are two main springs which rise within approximately 20 m of each other, here referred to as Drumcliff West and Drumcliff North, although a much higher flow discharges from Drumcliff North. The springs are located just outside the northern boundary of the Urban District Council (UDC) jurisdiction, on the western bank of the River Fergus between the Drehidnagower and Railway bridges.

There have been a number of hydrogeological reports written about this area, some commissioned by the UDC and some as project work based mainly in Trinity College, Dublin. This report is intended to draw together all the currently available information and to assemble it in a format which is consistent with the national source protection guidelines as set down in the joint document by the Department of the Environment and Local Government, Environmental Protection Agency and Geological Survey of Ireland (DELG/EPA/GSI, 1999).

2 Well details

Well name	: Drumcliff North	: Drumcliff West
GSI no.	: 1117SEW071	: 1117SEW070
Grid ref.	: 13295 17900	: 13289 17892
Owner	: Clare Co. Co.	: Clare Co. Co.
Well type	: Spring	: Spring
Elevation	: 4.58 m OD (Malin Head)	: 4.64 m OD (Malin Head)
Depth	: 6 m	:
Static water level	: surface	: surface
Water entry	: 3–4 m bgl and 5–6 m bgl	

Total current abstraction	: 12,000 m^3/d (2.6 Mgal/d)
Estimated safe yield (EUDC)	: 15,000 m^3/d (3.3 Mgal/d)
Estimated max. yield (EUDC)	: 20,000 m^3/d (4.4 Mgal/d)

3 Topography

There are two distinct topographical regions in the Drumcliff area. In the vicinity of the Fergus River the land lies at an elevation of less than 31 m OD (100 ft) and comprises a relatively flat plain. To the west, however, the land rises up to a height of 190 m OD (626 ft) in a north-south trending ridge.

4 Geology

4.1 Bedrock geology

The bedrock in the lower lying areas (i.e. generally less than 62 m OD) is of Lower Carboniferous Visean age and comprises predominantly thinly bedded, pale and dark grey limestones with some chert in places. There are two limestone units in the area of interest: the Burren Limestones and the Slievenaglasha Limestones. The Burren Formation is present over most of the area and is described as a pale to medium grey, fossiliferous, clean, medium to coarse grained limestone. The oldest subunit, the Ballard member, is of particular significance to Drumcliff Springs (Section 6.3) and it comprises dark grey, medium bedded, cherty, coarse grained limestones with thin shaly partings. The younger Slievenaglasha Limestones overlie the Burren Limestones and are more limited in outcrop, further to the west. These rocks are pale grey, clean, coarse grained limestones with occasional cherts and are occasionally described as being magnesian limestones which would suggest the presence of dolomite, e.g. between Bushy Park and the Shallee River, west of Ennis.

The limestones have undergone gentle folding and today generally dip at 10–15° to the west. They have been faulted in both north-south and east-west directions although the north-south direction is dominant. Jointing is common parallel to the main fault trends.

In the topographically higher area to the west, the rocks at surface are the Upper Carboniferous Namurian sandstones siltstones and shales. At the contact with the limestones, the rocks comprise shales and shaly mudstones (the Clare Shales). Further west, these grade into grey siltstones and sandstones. The Namurian rocks have not been extensively folded or faulted, although they are often well weathered in the upper few metres. The geology is illustrated on Map 1 of the Groundwater Protection Scheme.

4.2 Subsoils geology

The subsoils in the area are directly influenced by the underlying bedrock. The deposits in the low-lying limestone areas comprise mainly silty, sandy silty and gravelly sandy tills (boulder clay) dominated by limestone pebbles. Drumlins (elongated small hills oriented in the direction of movement of the glaciers) are common and are made up of mainly silt rich tills (BS5930: sandy SILT). Where subsoils in these areas are relatively thin, they are less well developed coarser grained, sandy or gravelly deposits (BS5930: sandy GRAVEL). Towards the east of the limestone area, the underlying bedrock is more shaly and this has given rise to a higher percentage of clay in the deposits (sandy SILT/CLAY).

In the western area, overlying the Namurian rocks, the subsoils have a much higher proportion of clay present in the deposit matrix which is derived from the underlying shales and shaly mudstones (BS5930: sandy CLAY or CLAY). Drumlins of the clay rich material are common but between them, and where the deposits are thin, the subsoils are less well developed and are described as broken up rock. This gives rise to coarse grained clayey gravel deposits (BS5930: clayey GRAVEL).

Alluvial deposits, comprising a mixture of clays silts and sands, are present along the river valleys in the lower lying areas. There is thin peat in the low-lying areas in ancient lake basins and more extensive peat deposits overlying the low-permeability Namurian rocks. Further details can be found in the main Groundwater Protection Scheme report and on the subsoils map of the county (Map 2) (Deakin and Daly, 1999).

4.3 Depth-to-rock

Depth-to-bedrock in the vicinity of the spring is estimated to be generally less than 1 m as there is rock cropping out at surface nearby. A large proportion of the catchment has rock present close to the surface with a thin subsoil cover of usually less than 3 m. There are also extensive areas where the depth-to-bedrock is mapped as between 3 and 10 m. In general, subsoils do not reach more than 10 m in thickness throughout the area except where drumlins are present, where the thickness of the deposits then depends upon the height of the drumlin. In these instances the subsoils may reach a thickness of more than 30 m.

5 Surface Hydrology

The Drumcliff Springs are located within the River Fergus catchment area where the surface hydrology is complex. Many of the surface water courses sink underground before rising to the surface further down-gradient and then sinking again. Depending on rainfall and water levels throughout the catchment, rivers may also vary from being losing rivers (i.e. where river water flows to groundwater through the river bed), to gaining rivers where the rivers are fed by groundwater.

A number of water tracing experiments have been carried out in the area and it appears that there are five main tributary river systems which are of significance to the springs:

(1) the Ballycullinan Lough system to the north which incorporates Lough Reagh and has been traced southwards to Ballygriffey Castle;
(2) the Shallee/Ballygriffey system which meets the Ballycullinan system north of Lough Clegan;
(3) the smaller Lough Clegan system including the lake and its tributary which rises at Fountain Cross;
(4) the Magowna system which sinks underground at Magowna and has been traced to the Ballygriffey system; and
(5) the Greenpark system to the south which sinks at Drumcarron More although is dry on occasion.

With the exception of waters in the Greenpark system, all surface waters in the area then flow eastwards along the same channel into Ballyallia Lake to the south of Pouladower Spring.

Surface drainage is poor over the Namurian rocks in the western upland part of the area, although it has been enhanced in places with the construction of drainage channels. The low-lying limestone areas (less than 31 m OD) are generally well drained outside the river channels although are subject to a certain degree of flooding during wetter periods. Some areas, such as the Greenpark system for example, flood almost every year due to variations in water levels in the catchment. A number of artificial river channels have been constructed in the area to try to address this problem, e.g. between Ballycullinan Lough and Lough Reagh. River flow is generally very variable and has a ‘flashy’ nature, responding to rainfall within a few days or less.

6 Hydrogeology

6.1 Data availability

Hydrogeological data for the area around the Drumcliff Source were obtained from the following:

- KT Cullen and Co. (1989) Hydrogeological investigation of Drumcliff springs. Preliminary report.
- KT Cullen and Co. (1990) Further hydrogeological investigations of Drumcliff springs.
- KT Cullen and Co. (1991) Draft Protection plan for Drumcliff Catchment.
- KT Cullen and Co. (1996) Investigations at Pouladower Spring for Ennis Urban District Council.
- EUDC (1992–1996) Ennis Water Supply annual reports.
- Coxon, C. (1994) Groundwater Vulnerability and Protection issues in the Lower Fergus Catchment, Co. Clare. In: Drew et al. (1995) EC COST report.
- Coxon, C. (1993) Problems in the delineation of protection zones in karst areas. Workshop on Groundwater Protection, GSI.

- GSI files.
- Limited additional fieldwork.

6.2 Spring discharge

The total discharge at the springs is difficult to measure accurately. Groundwater rises in several places in the vicinity of the public supply abstraction point and flows via various routes into the River Fergus. The whole area is also liable to flood during periods of heavy rain when the river water backs up into the spring discharge area. There have been several estimates of the total yield by a number of parties over time and these are summarised below:

Date	*Source*	*Estimate type*	*Discharge*	
Sept 1981	Nicholas O'Dwyer	2–3 day pumping test	17,000m^3/d	(3.7 Mg/d)
Aug 1989	KTC and Co.	Abstraction estimate	7780 m^3/d	(1.7 Mg/d)
Aug 1993	Dr. C. Coxon	Measured discharge estimate + abstraction, (14,170 + 9000 m^3/d)	23,170 m^3/d	(5.1 Mg/d)
Sept 1993	Dr. C. Coxon	Measured discharge estimate + abstraction, (9763 + 9000 m^3/d)	18,763 m^3/d	(4.1 Mg/d)
May 1998	EUDC	Abstraction	12,000 m^3/d	(2.6 Mg/d)
May 1998	EUDC	Safe yield	15,000 m^3/d	(3.3 Mg/d)
May 1998	EUDC	Possible yield	20,000 m^3/d	(4.4 Mg/d)

The differences in these estimates may be partially attributable to the fact that some of the values are taken during a pumping situation while others may refer to natural discharge. However, it is also probable that there is actually a significant variation in discharge at the springs as there is usually limited storage in a karstified aquifer such as that supplying Drumcliff (refer to Section 6.5), and karst springs typically respond rapidly to large rainfall events. Further north in the Burren for example, the discharge at a karst spring there increased 10–50 fold above average during a wet period (Drew 1991).

6.3 Catchment delineation

There are three effective methods for delineating catchment areas of karst springs (USEPA, 1996):

- ♦ tracer testing;
- ♦ hydrogeological mapping; and
- ♦ discharge balancing.

The tracer testing and hydrogeological mapping methodologies are the most appropriate methods for delineating the catchment area to Drumcliff. The water balance approach is not particularly useful in this instance because it is difficult to accurately measure the spring discharge in all flows, and the catchment area is only partially contributing to the springs, i.e. some of the water also discharges via the River Fergus (refer to Section 6.5).

Drumcliff Springs are supplied, in the main, from the sinking streams/rivers at Poulacorey and Drumcarron More swallow holes and are highly dependent, therefore, on the surface water catchments to each. The entire surface water catchments (i.e. surface water systems 1–5 in Section 5) must therefore be considered part of the Drumcliff Springs catchment.

A catchment area to Drumcliff springs was originally delineated by KT Cullen and Co. in their 1991 report, "Draft Protection Plan for Drumcliff Catchment". Since this Draft Protection Plan was drawn up, a number of additional water traces have been carried out by Dr. C. Coxon, in conjunction with the EUCD, which essentially confirm a number of the underground connections described as 'possible' in the draft report. These have therefore confirmed the associated catchment boundaries.

The catchment boundaries and the uncertainties associated with them are discussed below:
1. The **western boundary** of the catchment, i.e. that which overlies the Namurian bedrock, is reasonably well constrained. The bedrock has a relatively low permeability and this forces a high percentage of rainfall to run off to nearby streams. The groundwater catchment divide therefore coincides well with the surface water catchment divide and is delineated based on topography.
2. The **northern boundary** is a little less well defined. The location of the boundary between the Ballycullinan system and the Lough Atedaun system to the north is somewhat arbitrary, although its presence is highly likely based on the principles of groundwater flow. Topography is used to define the boundary to the northwest. There is no surface outlet for Lough Raha to the northwest and there has not been tracing carried out to prove the underground connections. However, based on topography, it is assumed that the underground connection is towards the Lough Atedaun system to the north and therefore it is not considered to be part of the Drumcliff catchment.
3. The **eastern boundary** is constrained by the presence of a north-south trending thin unit of less permeable cherty limestone which dips to the west and is likely to be inhibiting groundwater flow from the Pouladower catchment into the Drumcliff catchment. Despite numerous water tracing attempts in the area, there has never been a connection proven between the Dromore Lough/Pouladower Spring system to the east and the Lough Reagh/Ballygriffey Castle/Lough Clegan system. While an unsuccessful trace does not prove there is no connection and traces are only valid at water levels at which they were carried out, it is likely that groundwater in the area flows generally in a southerly direction, following the main fracture trend, and that underground flow routes do not cross the less permeable cherty limestone unit.
4. The **southern boundary** of the spring catchment is based on the surface water catchments of the Greenpark and Shallee systems and is fairly well constrained based on topography, except to the extreme southwest at Islandgar Lough where artificial drainage links this catchment with the adjoining catchment and the exact location of the divide is not known.
5. To the **southeast** of the catchment area, the boundary crosses the stretch of river between Pouladower and Poulacorey swallow hole. The river normally flows from west to east, i.e. from Ballymaquiggan Bridge towards Ballyallia Lake, with a proportion sinking at Poulacorey to pass directly to Drumcliff. Local knowledge would suggest that at certain water levels, the direction of flow may reverse such that water may flow from Pouladower Spring back towards the Poulacorey swallow hole. The flow reversal, if any, would appear to be slight (C. Coxon, pers. comm.) but is allowed for somewhat at this point by extending the catchment area further towards Pouladower than would be expected under normal flow conditions.

6.4 Hydrochemistry and water quality

There are a number of sources of hydrochemistry and water quality data for the Drumcliff source which are summarised as follows:

- EUDC annual drinking water returns 1992–1996 inclusive. Raw water 10–20 times per month. Basic C1–C2 type parameters.
- KT Cullen and Co. (1990) Further hydrogeological investigations of Drumcliff springs. Data collected on a weekly basis from November 1989–March 1990. C2–C3 type parameters.
- Groundwater Protection Scheme project October 1997 and March 1998. Two once off full analyses carried out by the State Laboratory. All major anions and cations, metals, hardness and alkalinity. Bacteriological analyses and ammonia carried out concurrently by the County Council.
- GSI files. Archival EUDC data for the years 1986–1987. C1–C2 type parameters.

The hydrochemical analyses suggest that the Drumcliff source is a moderately hard water (151–250 mg/l ($CaCO_3$)), with alkalinities of 180–272 mg/l ($CaCO_3$) and conductivities of 290–560 µS/cm. These values are all lower than would normally be expected from a typical limestone water, suggesting that the groundwater residence time in the carbonate environment is relatively short. The coefficient of variation of conductivity is also high (see Section 8) and this also suggests rapid response to recharge with flow in large conduits.

Water quality at Drumcliff fluctuates throughout the year with the poorer quality analyses being returned during the winter months and during periods of heavy rainfall. Colour, turbidity and iron have all exceeded the EC Drinking Water Directive maximum admissible concentrations (MAC) on occasion almost every year. Total coliforms and *E. coli* are also often present. Aluminium has also been found to exceed the MAC (max 0.31 mg/l Al; Sept 1994) although concentrations in the Groundwater Protection Scheme project analyses were less than the Guide Level in both cases. Nitrate concentrations are always low (<10 mg/l NO_3) and chloride levels range 20–45 mg/l Cl which are slightly higher than the background levels (10–20 mg/l) but are still not cause for concern.

Elsewhere in the limestones in the catchment area, similar problems with *E. coli.*, iron, colour and turbidity are reported (Coxon and Drew, 1998). Further information can be found in a separate report on the groundwater quality in the county (Cronin and Deakin, 1999).

6.5 Hydrogeology and conceptual model

There are two main hydrogeological units in the Drumcliff catchment:
(a) the Namurian rocks to the west of the catchment; and
(b) the limestone aquifer supplying the springs.

The Namurian rocks have a relatively low permeability; they are considered to be a poor aquifer (**Pu**) at the limestone boundary (the Clare Shales) and a locally important aquifer (**Ll**) further to the west where the siltstone and sandstone proportions increase. Groundwater movement is slow and localised, and most of the potential recharge runs off in the upper few metres of rock towards the nearest surface water channel (Deakin and Daly, 1999).

The limestone aquifer is a regionally important highly karstified aquifer (**Rk**), with localised high permeability zones which give rise to rapid groundwater velocities. Further details about the limestone aquifer characteristics can be found in the main Groundwater Protection Scheme report (Deakin and Daly, 1999). In summary, groundwater is likely to flow in three main hydrogeological regimes:
(1) an upper, shallow, highly karstified weathered zone, known as the epikarst, in which groundwater moves quickly, through solutionally enlarged conduits, in rapid response to recharge;
(2) a deeper zone, where groundwater flows through interconnected, solutionally enlarged conduits and cave systems which are controlled by structural deformation (principally in the north-south and east-west directions) and bedrock lithologies. Groundwater flows along the less permeable, cherty units until it intersects a vertical fissure; and
(3) a more dispersed slow groundwater flow component in smaller fractures and joints outside the main conduit systems.

The epikarst is thought to be relatively modern being formed after the last ice age, while the deeper karst is likely to be a remnant of not only recent solution, but also glacial and pre-glacial solution. All three groundwater flow regimes will be hydraulically connected in places with the degree of interconnection depending on the presence of less permeable bedrock units and the faults and joints associated with the structural deformation, particularly the north-south and east-west fault systems.

Recharge to the Namurian rocks is minimal as a consequence of the relatively low permeabilities. The runoff is acidic due to the shales and overlying peaty subsoils and it quickly dissolves the carbonate limestone rocks. This has resulted in a ring of swallow holes, sinks and large cave systems at the boundary between the two units where karstification processes are still active today. Numerous examples of this occur around the Burren where runoff from the Namurian rocks sinks underground into the limestones within a short distance.

Recharge in the limestones is derived from both diffuse rainfall falling over the bedrock surface and from sinking streams, swallow holes and losing rivers, i.e. point or line recharge. There is an effective hydraulic interconnection between groundwater and surface water in the karst limestone areas: much of the groundwater will spend at least some time on the surface and vice versa.

Groundwater flow to Drumcliff Springs has been traced from two main sources: Drumcarron More swallow hole to the west and Poulacorey swallow hole to the north. The dye tracing tests carried out by Dr. C. Coxon, in conjunction with the EUDC, indicate that flow to the springs can get from the Poulacorey and Drumcarron More swallow holes in less than 24 hours. Faster travel times were recorded in the north-south direction from Poulacorey to the springs (Drew, et al, 1995). A trace carried out on 24th March 1993 at medium to high water levels for example, gave a travel time of 7–9 hours (141–181 m/h) from Poulacorey to Drumcliff, while another on 21st June 1993 from Drumcarron More to Drumcliff showed the travel time to be 8.5–19 hours (67–149 m/h). Flow measurements suggest that the majority of the flow comes from Poulacorey with the Drumcarron More swallow hole only contributing in wet weather. Flow measurements also suggest that for some flow conditions, the total discharge at the springs can be accounted for by the quantities of water sinking at these two points (Drew et al., 1995). It is probable therefore that a high proportion of the flow to the springs is in direct-route, underground, solutionally enlarged conduits in the limestones, with a somewhat lesser contribution from the smaller, more diffuse network of fissures and conduits in the surrounding rock. The proportion of flow travelling through large conduits will vary with different water levels: there is likely to be more flow in the diffuse fissures at lower water levels.

The catchment boundaries of the source, as described in Section 6.3, essentially define the maximum likely extent of the area which may be feeding Drumcliff springs. However, it also incorporates the catchment area for the Ballygriffey River water bypassing the Poulacorey sink and flowing on to Ballyallia Lake. As the catchment areas for each are inextricably linked, and the proportion bypassing Poulacorey varies with different water level conditions, the entire area must be considered in protecting the source.

The actual zone of contribution to the springs may vary considerably with different water levels and at different times of the year. At high water levels, for example, smaller subcatchments, which would normally be isolated from the main flow to Drumcliff, can overflow into the main zone of contribution and can contribute to the source. Groundwater can also leave the system via other routes. Flow was traced, for example, from Drumcarron More to both Drumcliff and another spring at Drehidnagower which is further to the south outside the catchment area. At that water level therefore, only some of the swallow hole water at Drumcarron More was reaching the source, while the rest was leaving the catchment further to the south. The proportions may vary at different water levels. Flow will also bypass the source and leave the catchment via the Ballygriffey River, both in the river channel and via different conduits.

A basic water balance calculation shows that the delineated catchment area is greater than that required to feed the source, but as a relatively large proportion of water in the catchment may leave via the Ballygriffey River and other conduits at different water levels, and as the conditions are so variable, this is to be expected. As a precautionary measure the entire area must be considered.

The fluctuations in colour, turbidity, iron and bacteria are typical of a karst environment with a rapid 'flashy' response to rainfall events and short residence times. The Namurian rocks to the west of the area are likely to be the origin of most of the suspended matter while the bacteria may be coming from anywhere within the limestone area as groundwater travel times are so short. (Most bacteria and viruses in groundwater will have died off within 100 days; travel times to Drumcliff are substantially less than this.) In addition, some of the suspended matter may be originating from ancient infilled unconsolidated deposits in karst depressions and/or the epikarst. Heavy rainfall can cause temporary high water levels in these shallow zones and pulses of recharge can displace material which is normally relatively undisturbed. An example of this occurs in a karst spring in Co. Galway where suspended solids are mobilised only under very high flow conditions (Drew, 1992). In another case in Co. Galway, where the boundaries of the catchment area were found to change with different water levels, high iron and colour problems occurred under high water conditions although were acceptable at medium to low water levels. It was found that a swallow hole receiving water from a peat bog contributed 50% of the water to the spring under high water conditions but only 1% of the flow during low flow conditions (Drew, 1992).

Drumcliff Springs could therefore be considered as both a surface water and a groundwater source, derived largely from the river water sinking at Poulacorey and Drumcarron More. The river waters however, are derived largely from groundwater. This is supported by the variable hydrochemistry and water quality at the spring which seems highly dependent on rainfall and river water quality. As the surface water and groundwater systems are so well interconnected, they need to be considered together in protecting the source.

7 Delineation of source protection areas

7.1 Inner Protection Area

According to the National Groundwater Protection Scheme (DELG/EPA/GSI, 1999), delineation of an Inner Protection Area is required to protect the source from microbial and viral contamination and it is based on the 100 day time of travel to the supply. The hydrogeological mapping technique which includes flow boundary mapping and tracing was selected as the most useful method of delineating the Inner Protection Area at Drumcliff as standard numerical models, analytical equations, water balances and arbitrary radii are not applicable in karst areas.

In view of the rapid groundwater velocities in the limestones as determined by Dr. C. Coxon during the tracing tests, it is likely that all groundwater within the limestone area of the catchment could reach the source in less than 100 days, if not directly, then via the surface water courses, at least at certain times. Therefore all limestone areas are incorporated into the Inner Protection Area. An additional buffer zone of 100 m is added to the limestone boundary to the west of the catchment (overlying the Namurian rocks) to allow for groundwater movement through the sandstones and shales at the boundary area into the limestones.

Groundwater in the Namurian sandstones and shales to the west travels much slower than in the limestones as the permeabilities are significantly less. Flow is also usually towards the nearest surface water course. It is likely that a pollutant gaining access to any of the surface water courses in these areas could reach Drumcliff within 100 days and therefore they are all included in the Inner Protection Area. A 30 m buffer zone is added to each of the water channel boundaries as a precautionary measure.

The Inner Protection Area therefore incorporates all limestone areas including a 100 m buffer zone into the Namurian sandstones and shales, and all surface water courses in the Namurian sandstone and shale areas with a 30 m buffer zone added to each water channel boundary.

7.2 Outer Protection Area

The Outer Protection Area is delineated such that all groundwater within it may eventually reach the source and it is designed to protect the source from chemical contamination. At Drumcliff this will include the remainder of the catchment area as described in Section 6.3.

8 Vulnerability

Vulnerability depends on the thickness, type and permeability of the subsoils. A detailed description of the vulnerability categories can be found in the main Groundwater Protection Scheme Report (Deakin and Daly, 1999) or in the Protection Scheme document (DELG/EPA/GSI, 1999).

In the Drumcliff catchment, there are large areas of rock outcrop and subsoil thicknesses are often <3 m. This gives rise to a vulnerability category of 'Extreme' over much of the area. Within this area, shallow rock (i.e. where the soil and subsoil is usually <1 m), is specifically delineated. It was felt that this would be helpful to the local authority in controlling potentially contaminating activities in these areas as, for example, if landspreading of farmyard wastes from existing developments must be carried out, it is preferable that it should be directed towards areas where there is more than 1 m of soil and subsoil, rather than on bare rock.

As all surface water is connected to groundwater prior to reaching Drumcliff springs, an area of 'Extreme' vulnerability is delineated along all surface water channels throughout the catchment as a means of indicating the threat to the source from surface runoff of contaminants into streams. This area also comprises 30 m and 10 m buffer zones along the normal channels on the karstified and non-karstified bedrock, respectively, to highlight the risks from development in these areas. There are a number of karst features in the catchment area such as caves, swallow holes, turloughs and collapses which are all designated as points of 'Extreme' vulnerability on the vulnerability map as they provide easy access to groundwater for potential pollutants.

Outside the 'Extreme' areas, the subsoils comprise three main types: glacial till, alluvium, and peat. The tills overlying the limestone bedrock are considered to have a moderate permeability based on the grain size distribution of the deposits, the behavioural characteristics assessed using the British Standard BS5930, and the drainage and recharge characteristics of the area. The alluvial deposits are also interpreted to have a moderate permeability as they will comprise a relatively high proportion of fine grained material being adjacent to the Namurian fine grained rocks and located in small flood plains. Therefore, depending on the depth to rock, the *vulnerability* of these moderately permeable deposits will range from 'High' (3–10 m thick) to 'Moderate' (>10 m thick).

Tills in the Namurian sandstone and shale area to the west of the catchment are more clayey in nature and have a lower permeability than those in the limestone area. Peat is also generally a low permeability material. The vulnerability of these deposits therefore ranges from 'High' (3–5 m thick), through 'Moderate' (5–10 m thick), to Low (>10 m thick) depending on the depth to rock. The 'Moderately' vulnerable areas in these low permeability materials are not shown on the vulnerability map as they occur only in the tills on steep-sided drumlins where the depth to rock changes rapidly from 5 m to 10 m; it is not practical for mapping purposes to delineate the area. The peat deposits are usually <5 m thick and do not have a bearing on the vulnerability categories.

Site investigation work at particular sites of interest should always be carried out to assess both the permeability of the subsoils and the depth to rock.

The coefficient of variation (i.e. the standard deviation expressed as a percentage of the mean) of conductivity has been described by Quinlan, et al (1991) and Drew, et al (1995) as an alternative method for assessing the vulnerability of karst aquifers. High variations in conductivity in a karst aquifer are indicative of systems with rapid responses to recharge and short residence times as there is less time for chemical reaction between groundwater and the rock. Contaminants can also therefore swiftly reach the water table. A coefficient of variation of 9.1% was calculated for the conductivity results from the EUDC drinking water returns (n=141). This result suggests that the spring is located in the '*very sensitive karst aquifer*' group (coefficient of variation 5–10%) which is characterised by conduit flow and point recharge, and is considered to be highly vulnerable to contamination. It also confirms the likelihood that the source is a combination of both groundwater and surface water.

9 Groundwater protection zones

Combining the source protection areas with the vulnerability categories (see the matrix in the table below) gives the groundwater protection zones around Drumcliffe Spring which are shown on the groundwater source protection zone map (Map C).

Matrix of Source Protection Zones

VULNERABILITY RATING	SOURCE PROTECTION	
	Inner (SI)	***Outer (SO)***
Extreme (E)	SI/E	SO/E
High (H)	SI/H	SO/H
Moderate (M)	SI/M	SO/M (not shown)
Low (L)	SI/L	SO/L

Note that the SO/M zone (Outer Protection Area with subsoils 5–10 m thick), while present in some areas, is not shown on the map due to the complexity in the depth to rock and the scale of the maps (see Section 8). The appropriate Response Matrix, or Code of Practice, for various potentially contaminating activities in each protection zone should be consulted to obtain the degree of restriction necessary. Response Matrices have been developed for landspreading of organic wastes and landfills by the DELG, EPA and GSI to date, and there will be others to follow.

10 Potential pollution sources

There are numerous small farms located within the groundwater protection zones and much of the area has been developed with scattered rural domestic housing and tourist accommodation. There are also a number of petrol stations: the one adjacent to Drumcarron More swallow hole poses a particular threat to the source during periods of heavy rainfall. However, the quality of the river water in each of the four surface water systems is likely to be the primary factor influencing the water discharging at Drumcliff Springs.

11 Conclusions and recommendations

The Drumcliff Spring source is a large karstic spring which can be considered as both a groundwater and surface water source. It responds rapidly to recharge and it is generally extremely vulnerable to contamination as there is little protective subsoil cover throughout the catchment. The groundwater and surface water systems throughout the catchment area are inextricably linked and the source is therefore a difficult one to protect. The spring has a highly variable water quality which is likely to be dependent on the water quality in the rivers, particularly the surface water sinking at Poulacorey and Drumcarron More swallow holes. The overall quality however, is relatively good. Hazard mapping should be carried out in the catchment to pinpoint potential trouble areas.

12 References

Coxon, C. and Drew, D. (1998) Interaction of Surface Water and Groundwater in Irish Karst Areas: Implications for Water Resource Management. Proceedings of IAH Congress, Las Vegas, Sept. 1998.

Cronin, C. and Deakin, J. (1999) An Assessment of Groundwater Quality in County Clare. GSI Report to Clare County Council, 30 pp.

Deakin, J. and Daly, D. (1999) County Clare Groundwater Protection Scheme. Joint GSI/Clare County Council report, Draft, 73 pp.

Department of the Environment and Local Government, Environmental Protection Agency and Geological Survey of Ireland (1999) A Scheme for the Protection of Groundwater. DELG/EPA/GSI report.

Drew, D. (1991) Report to the OPW concerning the hydrology of the area in the vicinity of the proposed interpretative centre for the Burren National Park, Mullaghmore, Co. Clare, 25 pp.

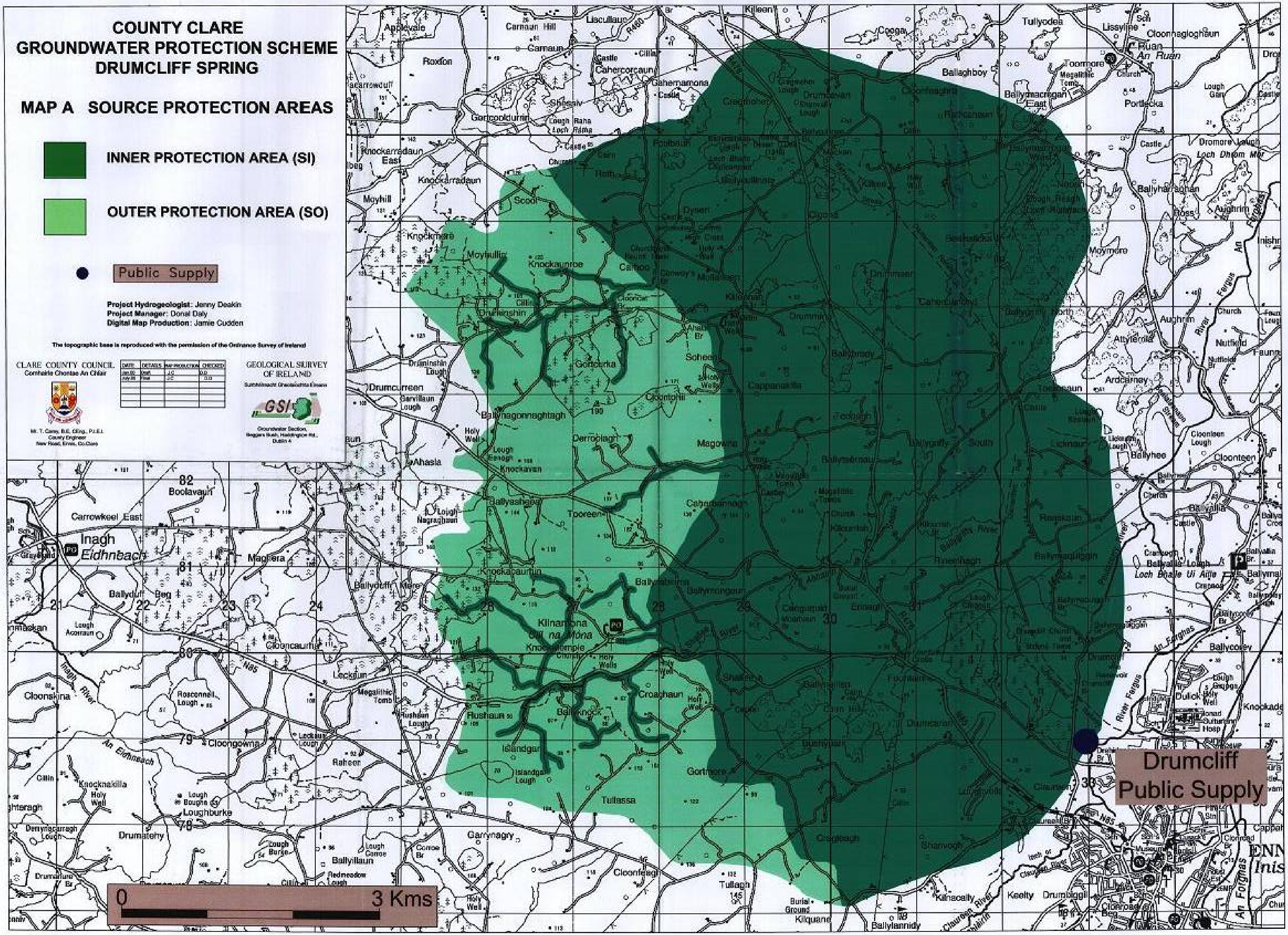
Drew, D. (1992) Water Resource Management and Water Tracing in a Lowland Karst Aquifer, Western Ireland. In Hoetzl, H. and Werner, A. (eds.), Tracer Hydrology, Balkema, Rotterdam, p. 221–225.

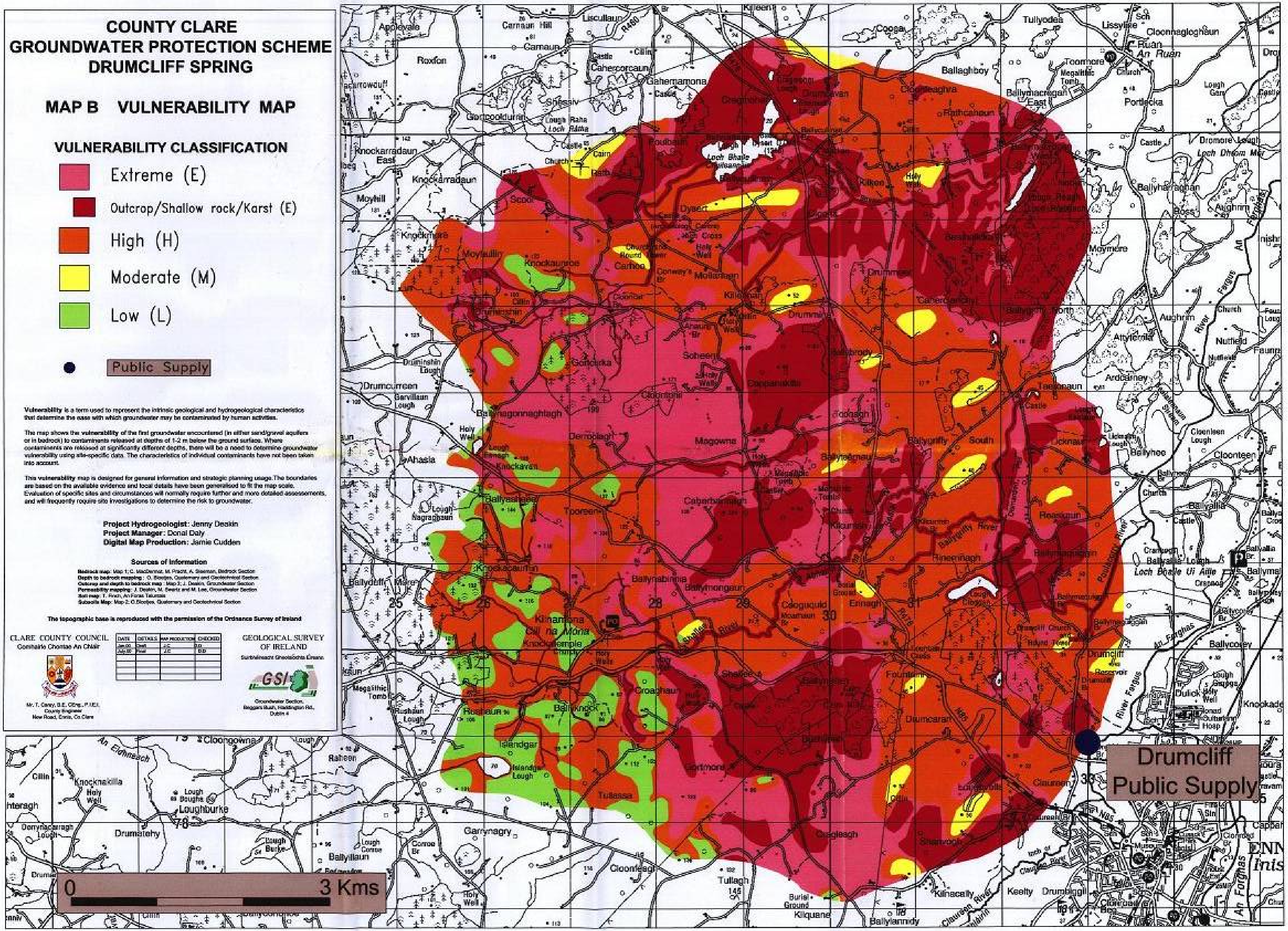
Drew, D., Doak, M., Daly, D., Thorn, R., Warren, W., and Coxon, C. (1995) National Report for Ireland. Hydrogeological Aspects of Groundwater Protection in Karstic Areas. European Union COST Action 65 Final Report No. EUR 16547 EN, p 149–169.

Quinlan, J., Smart, P.L. and Foster, S., (eds). (1991) Hydrogeology, Ecology, Monitoring and Management of Groundwater in Karst Terrains. Proceedings of Third Conference NWWA, Dublin, Ohio, 398 pp.

US Environmental Protection Agency. (1996) Guidelines for Wellhead and Springhead Protection Area Delineation in Carbonate Rocks. Prepared for the agency by Eckenfelder Inc., Tennessee.

Southern Water Global Ltd./Jennings O'Donovan and Partners. (1997) An Investigation into the Flooding Problems in the Gort-Ardrahan Area, South Galway. Final report to the OPW.


COUNTY CLARE
GROUNDWATER PROTECTION SCHEME
DRUMCLIFF SPRING
MAP A SOURCE PROTECTION AREAS
INNER PROTECTION AREA (SI)
OUTER PROTECTION AREA (SO)
Public Supply
Project Hydrogeologist: Jenny Deakin
Project Manager: Donal Daly
Digital Map Production: Jamie Cudden
The topographic base is reproduced with the permission of the Ordnance Survey of Ireland
CLARE COUNTY COUNCIL
Comhairle Chontae An Chláir
GEOLOGICAL SURVEY OF IRELAND
GSI
Drumcliff Public Supply
0
3 Kms
Inagh
Eidhnbach
Kilnamona
Cill na Móna
Ennis



COUNTY CLARE
GROUNDWATER PROTECTION SCHEME
DRUMCLIFF SPRING

MAP B VULNERABILITY MAP

VULNERABILITY CLASSIFICATION

- Extreme (E)
- Outcrop/Shallow rock/Karst (E)
- High (H)
- Moderate (M)
- Low (L)

● Public Supply

Vulnerability is a term used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities.

The map shows the vulnerability of the first groundwater encountered (in either sand/gravel aquifers or in bedrock) to contaminants released at depths of 1-2 m below the ground surface. Where contaminents are released at significantly different depths, there will be a need to determine groundwater vulnerability using site-specific data. The characteristics of individual contaminants have not been taken into account.

This vulnerability map is designed for general information and strategic planning usage.The boundaries are based on the available evidence and local details have been generalised to fit the map scale. Evaluation of specific sites and circumstances will normally require further and more detailed assessements, and will frequently require site investigations to determine the risk to groundwater.

Project Hydrogeologist: Jenny Deakin
Project Manager: Donal Daly
Digital Map Production: Jamie Cudden

Sources of Information

Bedrock map: Map 1; C. MacDermot, M. Pracht, A. Sleeman, Bedrock Section
Depth to bedrock mapping: O. Bloetjes, Quaternary and Geotechnical Section
Outcrop and depth to bedrock map: Map 3; J. Deakin, Groundwater Section
Permeability mapping: J. Deakin, M. Swartz and M. Lee, Groundwater Section
Soil map: T. Finch, An Foras Talúntais
Subsoils Map: Map 2; O.Bloetjes, Quaternary and Geotechnical Section

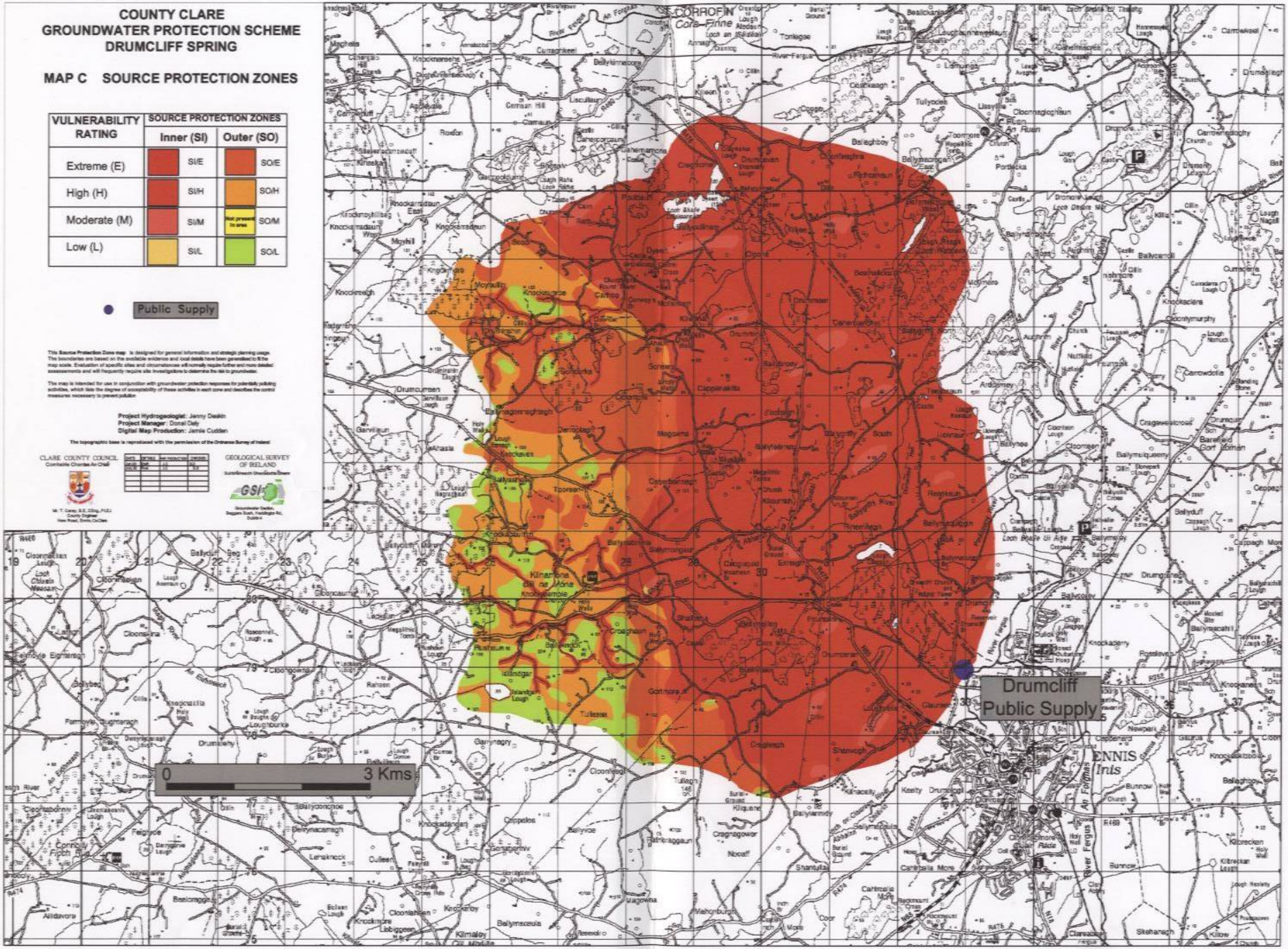
CLARE COUNTY COUNCIL
Comhairle Chontae An Chláir

Mr. T. Carey, B.E. CEng., F.I.E.I.
County Engineer
New Road, Ennis, Co.Clare

DATE	DETAILS	MAP PRODUCTION	CHECKED
Jan.00	Draft	J.C.	D.D.
July.00	Final	J.C.	D.D.

GEOLOGICAL SURVEY OF IRELAND
Suirbhéireacht Gheolaíochta Éireann

Groundwater Section,
Beggars Bush, Haddington Rd,
Dublin 4


COUNTY CLARE
GROUNDWATER PROTECTION SCHEME
DRUMCLIFF SPRING
MAP C SOURCE PROTECTION ZONES
VULNERABILITY RATING
SOURCE PROTECTION ZONES
Inner (SI)
Outer (SO)
Extreme (E)
SI/E
SO/E
High (H)
SI/H
SO/H
Moderate (M)
SI/M
Not present in area
SO/M
Low (L)
SI/L
SO/L
Public Supply
This Source Protection Zone map is designed for general information and strategic planning usage. The boundaries are based on the available evidence and local details have been generalised to fit the map scale. Evaluation of specific sites and circumstances will normally require further and more detailed assessments and will frequently require site investigations to determine the risk to groundwater.
The map is intended for use in conjunction with groundwater protection responses for potentially polluting activities, which lists the degree of acceptability of these activities in each zone and describes the control measures necessary to prevent pollution.
Project Hydrogeologist: Jenny Deakin
Project Manager: Donal Daly
Digital Map Production: Jamie Cudden
The topographic base is reproduced with the permission of the Ordnance Survey of Ireland
CLARE COUNTY COUNCIL
GEOLOGICAL SURVEY OF IRELAND
GSI
Drumcliff
Public Supply
0
3 Kms
CORROFIN
ENNIS
Inis