Ennis Public Supply
Pouladower Spring
Co. Clare

Groundwater Source Protection

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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

‘Note:
Since this report was published, the Ennis Pouladower Spring is no longer in use as a Public Water Supply. However, geological and hydrogeological information included in this report could be beneficial.

Please be aware that some maps have been updated based on improved geoscientific evidence and hydrogeological knowledge. The most up-to-date maps can be found on the Geological Survey Ireland website (https://www.gsi.ie/en-ie/data-and-maps/Pages/default.aspx).'

Table of Contents

SCHEDULE OF MAPS

ENNIS PUBLIC SUPPLY

Pouladower spring

(Draft)

1. Introduction

Pouladower spring is located approximately 3 km to the north of Ennis, rising at the north-western corner of Ballyallia Lough. Ennis Urban District Council have recently investigated the spring with a view to harnessing it to provide an additional source of drinking water for Ennis. The current source is Drumcliff Spring which is approaching the safe abstraction capacity. Pouladower spring is not currently being used by the local authority but it is being considered as a backup supply to reduce the dependency on Drumcliff Spring.

This report sets out the available hydrogeological information for Pouladower spring and puts forward a conceptual model for groundwater flow to the source. It then delineates a catchment area to the spring and addresses the issue of protecting the groundwater within it. The 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, the Environmental Protection Agency and the Geological Survey of Ireland (DELG/EPA/GSI, 1999).

2. Spring details

GSI no.	:	1117NEW065
Grid ref.	:	13343 18150
Elevation	:	5.74 m OD (Malin Head)
Depth-to-rock	:	~1 m
Static water level	:	surface
Estimated discharge	:	10,000–62,400 m^3/d

The actual discharge point of the spring varies depending on regional water levels. Under dry conditions, water flows eastwards from the spring, via a channel, towards Ballyallia lake. The area is liable to flood during periods of heavy rain however, when the lake water comes back up the channel and submerges the spring.

3. Topography

There are four distinct topographical regions in the area of interest. 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 the land rises up to a height of 190 m OD (626 ft) in a north-south trending ridge. The northern region comprises the Burren Plateau which reaches a height of 274 m (900 ft), while to the east the land rises to a height of 400 m (1312 ft) on Maghera Mountain.

4. Geology

4.1. Bedrock geology

The bedrock geology spans approximately 130 million years from the Silurian sandstones and shales in the east, through the Devonian Old Red Sandstones (ORS), the Lower Carboniferous limestones and shales, to the Upper Carboniferous sandstones and shales in the west. In general, the different rock types are associated with the different physiographical regions: the Silurian and the ORS are found in the upland regions to the east, the Lower Carboniferous is found in the low-lying areas in the Fergus River valley, and the Upper Carboniferous rocks form the upland area to the west. The rock types are summarised in Table 1.

With the exception of the Silurian rocks which are steeply dipping, the rocks generally dip 10–15° to the west and have undergone various degrees of structural deformation depending on their age and their location. In general, the oldest rocks and those located towards the south of the county are more faulted and folded than the younger rocks and those located towards the north of the county, respectively. The Silurian rocks are relatively soft and have been extensively broken up. The major fault trends in the area (north-south and east-west directions) are evident in the Old Red Sandstones and the Lower Carboniferous limestones, while the Upper Carboniferous Namurian sandstones and shales have not undergone as much deformation. Most of the rocks are also well weathered in the upper few metres.

On a more local scale there is an area of deformation, known as The Fergus Shear Zone, which trends in a narrow band from the Fergus Estuary north-northeastwards through Ennis towards Gort, and is essentially an extensive fault zone. This fault zone has particularly influenced the fault and joint patterns in the area. More detail on the individual rock types can be found in the main Groundwater Protection Scheme report and on the geology map of the county (Map 1).

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: silty sandy GRAVEL). Towards the east of the limestone area,

Table 1. Bedrock lithologies

Age	Rock type
Upper Carboniferous (Namurian)	alternating sandstones, siltstones and shales. *Includes the Clare Shales (CS), Gull Island Formation (GI) and the Central Clare Group (CCG).*
Visean limestones	well bedded pale and dark grey limestones with some chert and dolomite layers in places. *Includes the Slievenaglasha (SL), Burren (BU) and Tubber (TU) Limestones.*
Waulsortian Limestones (Wa)	massive blue or grey limestones, thinly bedded with some shales at the base and becoming shaly and cherty towards the top.
Ballysteen Limestones (Ba)	blue black fossiliferous limestones with shales and shaly limestones.
Lower Limestone Shales (LLS)	shales, shaly limestones, grey sandstones and siltstones.
Old Red Sandstone (ORS)	pale and red sandstones with interbedded mudstones, siltstones and conglomerates.
Silurian (SIL)	sandstones (greywackes) with interbedded mudstones and siltstones of varying colours from pale grey through green to purple.

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).

In the upland areas to the east, overlying the Old Red Sandstones and Silurian sandstones, siltstones and mudstones, the subsoils are typically high in both sand and clay (BS5930: sandy CLAY or clayey SAND). Drumlins are present around the foot of the mountains where the deposits are thicker. In some areas, there are also looser, more sandy deposits present (BS5930: soft SAND or silty SAND).

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 immediate vicinity of the spring is estimated from nearby trial wells and outcropping rock to be less than 1 m. 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

Pouladower Spring is located within the River Fergus catchment area where the surface hydrology is complex and is closely interlinked with groundwater. 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 by Dr. D. Drew and Dr. C. Coxon of TCD which prove underground connections between various parts of the river systems. There are also known links between many of the swallow holes and caves to surface water courses and springs. The proven traces and links are shown on the hydrogeology map of the county which is part of the Groundwater Protection Scheme report (Map 4).

There are four main river systems which are of significance to Pouladower Spring:

1. the River Fergus with its associated underground connections from the Burren area;
2. the Castlelodge River system including the northeast-southwest band of lakes at the foot of Mullaghmore (Lough Atedaun, Lough Cullaun, Ballyeighter Loughs, Muckanagh Lough and others);
3. the Moyree river system which joins the River Fergus to the north of Dromore Lough after a stretch of artificial river channel; and
4. the Inchicronan Lough system which joins the river Fergus to the south of the Moyree system, but also up-stream of Dromore Lough.

While some of the rivers rise in either the Silurian, Old Red Sandstone or Namurian rocks, the majority of each of them flows through the limestone area and they are all closely interconnected with groundwater.

Land drainage is poor over the Namurian rocks in the western upland part of the area and overlying the ORS and Silurian in the east. 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. Water levels throughout the catchment area are highly responsive to rainfall.

6. Hydrogeology

6.1. Data availability

Hydrogeological data for the area around Pouladower were obtained from the following:

- a hydrogeological study carried out at Pouladower Spring for Ennis Urban District Council (KT Cullen and Co., 1996);
- research carried out by C. Coxon and D. Drew in the area (e.g. Coxon and Drew, 1998; Coxon and Drew, 1999; Drew, 1988; Drew, 1990; Drew et al., 1995);
- a report on groundwater and karstification in mid Galway, south Mayo and north Clare (Drew and Daly, 1993);
- a report by David Drew to OPW on Mullaghmore Interpretative Centre (Drew, 1991);
- a GSI report by Donal Daly on the flooding in the Gort-Ardrahan area (Daly, 1992);
- the report by Southern Global Water to the OPW on the flooding in the Gort area (Southern Water Global Ltd./Jennings O'Donovan and Partners, 1997);
- EUDC (1992–1996) Ennis Water Supply annual reports;
- GSI files;
- Limited additional fieldwork.

6.2. Spring Discharge

Flow measurements carried out in September and October 1996 by KTC and Co., showed that the spring discharge varies from 13,000–62,400 m^3/d. The tests were conducted during fairly dry weather and the report concluded that 10,000–12,000 m^3/d was the likely low flow or sustainable yield. The high flow is more difficult to ascertain as the area is liable to flood but during the tests, the flow increased from 18,500 to 62,000 m^3/d in three days with the onset of a period of heavy rain. The maximum discharge of the spring is not known and may be higher than this recorded high flow. These variations are typical of a karst spring and there are other springs in the area which exhibit the same characteristics. Mean flows in the springs in the Burren are an order of magnitude greater than base flows, while peak discharges may be three orders of magnitude greater. Elmvale Spring for example discharges within the range ±10% of mean flow, only 10% of the time (Drew, 1990).

6.3. Catchment area delineation

Delineation of the catchment area for Pouladower Spring is complex. There is a high degree of interconnectivity between the surface water and groundwater catchments, within an extensive area of karstified limestones in which flow is unpredictable. The hydrogeology is not as well constrained by the geology and surface water hydrology as for the Drumcliff source.

There are three well known 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 selected for Pouladower as being the most appropriate with the available data, particularly due to the uncertainty in the high flow discharge measurements.

It is reasonably well established from tracing tests that the Pouladower and Drumcliff catchment areas are separate and that overlap, if any, may be small. There has never been a trace proven across the boundary and water quality at Pouladower is better and more stable than at Drumcliff which would suggest a different source of water.

Direct links have been traced to the source, at medium to high water levels, from sinks present in Dromore Lough, and (indirectly) from Lough Keagh which is located at the beginning of the artificial channel between Lough Atedaun and Ballyteige Lough. The catchment area for the spring therefore must incorporate the catchment areas to Lough Keagh and Dromore Lough, and this essentially includes the entire Fergus River catchment north of Ballyallia Lough, including the Castlelodge River system and its associated lakes.

The Moyree and Inchicronan River systems flow into the River Fergus between Ballyteige Lough and Dromore Lough. The flow between Dromore Lough and the River Fergus, after these rivers have merged, is via a small channel in which the flow regularly reverses depending on different hydrological conditions and the height of the water in the lake. This does not appear to be a seasonal variation but rather can change on a daily basis (Enda Mooney, OPW; pers comm.). Therefore at times when the flow is from east to west, i.e. from the River Fergus into Dromore Lough, the entire Moyree River system and Inchicronan Lough systems also become part of the Pouladower catchment. When flow is in the other direction, they may not.

The Fergus River and Castlelodge River catchment areas have been defined in other studies by Coxon and Drew, and their boundaries are adopted here. The Moyree River and Inchicronan Lough system boundaries are delineated based mainly on topography (see below). The surface water catchment boundaries are considered to be good approximations of the groundwater catchment boundaries as, in most instances, they occur in areas underlain by relatively low permeability rocks and associated low permeability subsoils, e.g. Silurian, Old Red Sandstone and Namurian areas. In the limestone areas, the boundaries are delineated based on tracing work and groundwater flow directions. Each segment of the catchment boundary, with its inherent level of confidence, is described briefly as follows:

1. The **western** boundary of the catchment (i.e. that which overlies the Namurian bedrock) is fairly well constrained. The groundwater catchment divide coincides well with the River Fergus surface water catchment divide as the bedrock has a relatively low permeability and the water table closely reflects topography.
2. To the **northwest**, in the Burren area, the boundary is based on the results of a number of tracing tests which are taken from D. Drew's work (Drew, 1988).
3. The **northern** boundary is dependent on the surface water catchment boundary of the River Fergus and groundwater flow characteristics (i.e. in the direction of the dip of the rocks; refer to Section 6.5). This boundary is also taken from D. Drew's work (Drew, 1988).
4. To the **northeast** of the area, the boundaries are taken from hydrogeological investigations carried out at Mullaghmore by D. Drew (1991) and in the Gort area by Southern Water Global Ltd./ Jennings O'Donovan and Partners (1997), and they are essentially the surface water catchment boundaries of the Castlelodge River and lakes system.
5. The **eastern** boundary is based on topography and the surface water catchment areas of the Moyree River and Inchicronan Lough systems.
6. The **southern** part of the catchment is the boundary with the Drumcliff Spring catchment and is controlled by the presence of a relatively low permeability cherty bedrock unit which trends in a north-south direction between the two catchments. The north-south fracturing associated with the Fergus Shear Zone (refer to Section 4.1) is also likely to be channelling groundwater in a southerly direction, thereby ensuring flow does not cross the cherty bedrock unit.

7. The **southeastern** part of the boundary is based on the catchment area of the River Fergus and is somewhat arbitrary as there is little information regarding connections between the river and Pouladower. Further tracing in the future may enable the boundary to be refined in this area.

The area as described is much larger (c. 380 km^2) than the area required to supply the source, perhaps more than 10 times larger at some water level conditions. However, it incorporates the intricately interlinked catchment areas for two major outlets of water from the system, Pouladower Spring and the River Fergus. It is difficult to isolate the actual area contributing to the spring as it will vary with different water level conditions. At high water levels, for example, smaller sub-catchments, which would normally be isolated from the main flow to Pouladower, may overflow into the main zone of contribution and contribute to the spring. Groundwater may also leave the system via other conduits connected to the main river channel. As it is possible that contaminants reaching groundwater or surface water anywhere within the catchment may influence water quality at Pouladower, the entire area must be considered in protecting the source.

6.4. Hydrochemistry and water quality

There are a number of sources of hydrochemistry and water quality data for Pouladower Spring which are summarised as follows:

- Groundwater Protection Scheme project sampling in Oct. 1997 and March 1998. Two full analyses carried out by the State Laboratory as part of the project which include all major anions and cations, metals, hardness and alkalinity. Bacteriological analyses and ammonia were carried out concurrently by the County Council.
- EUDC annual drinking water returns 1992–1996 inclusive. Raw water samples which were taken fortnightly, including basic C1–C2 type parameters (colour, turbidity, odour, pH, conductivity, nitrate, nitrite, ammonium, iron and manganese).
- KT Cullen and Co. (1996) Investigations at Pouladower Spring for Ennis UDC. Samples were taken in September and October 1996 for slightly more comprehensive analyses including C2 type parameters, and calcium, magnesium, sodium, potassium, chloride, bicarbonate, total hardness and alkalinity.

The hydrochemical analyses suggest that Pouladower spring has a moderately hard water (151–250 mg/l ($CaCO_3$)), with alkalinities of 140–185 mg/l ($CaCO_3$)) and conductivities of 314–462 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.

Water quality at Pouladower is generally relatively good with low levels of chemical contaminant indicators such as chloride, nitrate and potassium. The bacteriological analyses however, often show the presence of faecal coliforms (*E. coli*), although this is typical in a karst spring where groundwater travel times are often much less than 100 days*. Colour is the main problem parameter with respect to the EU drinking water requirements and it often exceeds the MAC. Iron is not as much of a problem as it is at Drumcliff Spring and is seldom at a level which is cause for concern.

Elsewhere in the limestones in the catchment, similar problems with *E. coli.* and colour are found, with additional problems of iron and turbidity (Coxon and Drew, 1998). Overall the water quality at Pouladower Spring is better and generally more stable than in the nearby Fergus River and at other large karst springs, including Drumcliff. As groundwater and surface water in the limestone areas are so intricately linked through the Pouladower catchment, the surface water quality is likely to play a role in the water quality at the springs. Similarly, groundwater quality will have an influence on surface water quality in the limestone areas. Data from a recent EPA report (Lucey, et al., 1999) shows the lake quality to be generally good within the catchment although Dromore Lough was considered to be strongly polluted.

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*Bacteria and most viruses will not live longer than 100 days in groundwater.

The water quality in the other rocks is also generally good. Further details can be found in a separate report on hydrochemistry and water quality which accompanies the main Groundwater Protection Scheme report (Cronin and Deakin, 1999).

6.5. Conceptual model

There are three main hydrogeological units in the Pouladower catchment:
(a) the Namurian rocks to the west of the catchment;
(b) the Waulsortian Limestones, Ballysteen Limestones, Lower Limestone Shales, ORS and Silurian rocks to the east; and
(c) the Visean limestones which are the main aquifer feeding the springs.

The Namurian rocks, Waulsortian Limestones, Ballysteen Limestones, Lower Limestone Shales, ORS and Silurian rocks have relatively low permeabilities with little or no solution occurring in the fractures, and are considered to be Poor (**P**) to Locally Important (**L**) aquifers. As a consequence, recharge is low; groundwater flow paths are often shallow and short; groundwater discharge occurs relatively quickly into nearby surface water channels; and stream density is high with ‘flashy’ flow.

The Visean 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 rapidly through a dense network of solutionally enlarged conduits, in direct response to recharge.

(2) A deeper zone, where groundwater moves through interconnected solutionally enlarged conduits and cave systems which are mainly controlled by:
   (i) bedrock lithologies. The less permeable units, e.g. chert, dolomite and clay wayboards (clay bands) inhibit vertical groundwater flow;
   (ii) the dip direction of the bedding planes. Groundwater flows down dip along the surfaces of the less permeable beds; and
   (iii) structural deformation. Groundwater flows preferentially in the north-south and east-west directions, parallel to the major fault trends. The faults are a particularly important factor for flow through the less permeable units.

(3) A more dispersed slow groundwater flow component in smaller fractures and joints outside, but usually linked to, 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.

Recharge in the catchment area is variable depending on the aquifer type. There is minimal recharge occurring in the Poor (**P**) to Locally Important (**L**) aquifers as a consequence of the relatively low permeabilities. The runoff, particularly in the Namurian rocks, is also 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 clean Visean Limestones and the Namurian rocks where karstification processes are still active today. Numerous examples of this occur around the Burren where runoff sinks underground into the limestones within a short distance of the boundary.

Recharge in the limestones is derived from diffuse rainfall on 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 there are many places where surface water sinks underground.

There have been several tracer tests conducted in the Pouladower catchment which have shown that flow in the karstified limestones is rapid. Traces carried out at medium to high water levels for example, show that water from Dromore Lough can reach the spring in 2–3 days and can travel from Lough Keagh, via Poulasheersha, to the spring in less than 2 days. The total quantity of water sinking at Poulasheersha and Dromore Lough during the tests was less than the discharge at Pouladower. Therefore, at least at some water levels, a significant proportion of flow discharging at Pouladower is coming from either a direct route channel from the Lough Keagh area, from smaller fissures in the surrounding rock, or via another, as yet untraced, route.

Work carried out by Dr. Norman Allott of TCD has shown that at high water levels, water can travel through Lake Inchiquin in 10 days, although velocities through lakes can be much slower depending on the type of lake, the inflow and outflow channels, and the water level conditions (C. Coxon, pers. comm.). Potential contaminants can therefore make their way through the catchment to the source in a relatively short time.

It is probable 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 fluctuations in colour and bacteria, and occasionally iron, 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, or the sandstones and overlying peat to the east, may be the origin of some of the suspended matter, although there may also be a contribution 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. Bacteria are a common problem in karst areas as groundwater travel times are so short, being often much less than the 100 days required for most bacteria and viruses to die off.

The northeast-southwest band of lakes in the Castlelodge River system are a particularly significant factor within the catchment area as they constitute a substantial body of water where significant dilution and sediment deposition is occurring. This, together with the input of groundwater from fissures, may account for the relatively stable, good quality groundwater which is discharging at the spring compared to Drumcliff.

Pouladower Spring is therefore considered as both a surface water and a groundwater source, derived largely from river waters sinking at Dromore and Lough Keagh. The river waters however, are derived largely from groundwater. As the surface water and groundwater systems are so well interconnected throughout the catchment, they need to be considered together in protecting the source.

7. Source Protection

7.1. Introduction

Pouladower is a combined surface water/groundwater source with a very large potential catchment area (c.380 km^2), only part of which contributes to the source at any one time. An innovative approach to delineating protection zones is therefore required which maintains a pragmatic defensible methodology and provides adequate protection for the source. Discussions were held with the EPA and the local authority and the following approach, based on adapting the national Groundwater Protection Scheme (DELG/EPA/GSI, 1999), was agreed.

It is useful at the outset to clarify the aims and objectives of delineating protection zones for karst sources, which while they are similar, are not identical to those for granular and fissured aquifers.

7.2. Aims and objectives

1. To protect groundwater in the zone of contribution to the source from contamination. There are two types of contamination under consideration, chemical and mircobial. Different protection areas are required for each (known as the Outer and Inner Protection Areas, respectively) to ensure that the concentrations of potential contaminants are lowered to within EU drinking water standards before they reach the source.
2. To provide time to react to unexpected contamination incidents within the above areas.

There are a number of points to consider in trying to achieve these objectives for a source located in a highly karstified regime, such as Pouladower Spring.

- The spring discharges from a well developed karstic aquifer with high groundwater velocities, low storage, rapid response to recharge and little protective subsoil cover. Therefore potential contaminants can gain easy access to the aquifer and be rapidly transported to the source from anywhere over a large area.
- Groundwater flow is concentrated along discrete solutionally enlarged channels which are difficult to identify.
- There is a high degree of hydraulic connection between surface water and groundwater which is variable with different water levels, and the protection zones must therefore incorporate both components of the flow regime.
- The zone of contribution to a source in a highly karstified aquifer may vary vary with different water levels and flow conditions. The area to be protected must include all potential sub-catchments, although in different flow conditions not all of the area will contribute to the source.
- Water within the catchment area does not discharge at the spring alone. The delineated area includes the catchment area for the Fergus River, although a large proportion of it bypasses the Pouladower Spring via Ballyallia Lake. A somewhat smaller proportion may also escape by other discrete channels which will also be variable in different flow conditions. As the catchment areas to each outlet, and the surface water and groundwater components of the system, are inextricably linked, the entire area must be considered in protecting the source.
- In the national Groundwater Protection Scheme (DELG/EPA/GSI, 1999), the zone delineated for bacteriological protection of the source is based on a 100 day time of travel zone (Inner Protection Area; SI) such that bacteria will have died off before reaching the source. The high groundwater velocities in karst areas usually ensure that the entire karstified area within the zone of contribution is included in the Inner Protection Area.
- The main bacteriological hazards in the catchment area of Pouladower Spring are septic tanks and farmyards which cause a relatively low level of bacteriological contamination.
- Dilution is one of the major factors in lowering contaminant concentrations (particularly low level bacteriological contamination) in the rapid conduit flow component of the karst hydrogeological regime. The catchment area is large (up to 380 km^2), the quantities of groundwater flowing through the system are high, and the lakes provide additional dilution and sedimentation capacity. This factor is considered to be more significant in a karst regime than it would be in granular or fissure flow aquifers.
- Bacteriological contamination in karst aquifers is inevitable due to the rapid groundwater velocities which do not allow the bacteria and viruses time to die off. Treatment is almost always needed at karst public supplies to maintain good quality drinking water.

7.3. Inner Protection Area

The Inner Protection Area is delineated to protect against bacteriological contamination and is normally defined by the area within which groundwater takes 100 days or less to reach the source. At Pouladower, depending on the water level conditions, groundwater from anywhere within the limestone areas may reach the source within 100 days. If the standard Inner Protection Area were delineated it would result in an extremely large area which is impractical and unnecessary for the management of potentially contaminating activities for the following reasons:

1. There is significant dilution occurring throughout the Pouladower system within the large catchment area, particularly in the lakes, which is not usually the case at other sources;
2. At sources in other aquifer types the Inner Protection Area is delineated to prevent bacteriological contamination occurring. Bacteriological contamination of karst sources is inevitable due to the rapid groundwater velocities and the high interconnectivity with surface water. Disinfection of the supply is essential.

It is considered to be more appropriate, in this instance, to delineate the area of highest risk to the source as the Inner Protection Area, to assist the local authority in prioritising resources, e.g. monitoring, hazard mapping etc. While groundwater within this area can reach the source in much less than 100 days, perhaps within 2 or 3 days, it is considered to be the area of highest risk to the source and, in the event of an accidental spill, it should provide adequate warning to increase treatment where possible or otherwise temporarily cease abstraction.

The Inner Protection Area, in this instance, therefore includes the southernmost part of the catchment closest to the source, from Pouladower Spring as far up-gradient as the band of lakes where most of the dilution is taking place. The area is bounded by the surface water catchments to the natural and artificial river channels between Lough Atedaun and the junction with the Moyree river system; the River Fergus from there as far south as Ballyallia Lake; and the boundary with the Drumcliff Spring catchment boundary. The Moyree and Inchicronan catchments are not considered to be part of the highest risk area as they only contribute to the source at certain water levels. It is also likely that groundwater from the other side of the River Fergus (from Lough Keagh onwards) will flow towards the Fergus and out of the system via the river channel.

Groundwater travels quickly through this high risk area, the medium to high flow traces suggesting velocities of 90–250 m/h, allowing advance warning of approximately 1.5–3 days, depending on proximity to the source. The area is classed as the Inner Protection Area so that it will be given the highest level of protection available.

7.4. Outer Protection Area

Outside the highest risk area, while groundwater in the limestones may still reach the source within 100 days, there is considerable dilution of potential contaminants occurring due to the number of lakes in the system and the high groundwater throughput in the karst aquifer. There may also be significant delay in travel times, at certain water levels, as water moves through the lakes. It is considered that these areas pose a significantly lesser threat to the groundwater quality at the source than the Inner Protection Area and therefore the remainder of the catchment is classed as the Outer Protection Area. The protection areas are shown on Map A.

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 Pouladower 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 Pouladower spring, 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 in the Inner (SI) and outer (SO) areas, 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 relatively clean Visean 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 loose, sandy, sandstone derived tills in the northeast of the catchment are also classed as moderate permeability. The alluvial deposits are 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, and overlying the shaly limestones, the Old Red Sandstone and the Silurian rocks in the east have a higher percentage of clay in the matrix and have a lower permeability than those in the clean 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 the low permeability materials are not shown on the vulnerability map (Map B) as they occur only in 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 relatively thin and the thickness rather than the permeability dictates the vulnerability classification. In thicker susboils areas, they are considered in light of the permeabilities of the surrounding deposits.

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

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 Pouladower 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

The SO/M zone in low permeability subsoils (i.e. 5–10 m thick) is not shown on the map due to the complexity in the depth to rock and the scale of the maps. The appropriate Response Matrix (Code of Practice) for various potentially contaminating activities should be consulted to obtain the degree of restriction necessary in each protection zone. Response Matrices for landspreading of organic wastes and landfills have been developed by the DELG, EPA and GSI to date, and there will be others to follow.

10. Land use and potential pollution sources

There are numerous small farms located within the catchment area and much of it has been developed with scattered rural domestic housing and tourist accommodation. There are also a number of petrol stations. The surface water quality may also play a role in the quality of groundwater discharging at the source although it is not likely to be as significant as it is for Drumcliff.

11. Conclusions and recommendations

Pouladower spring is a large karst spring which is considered as a combined surface water and groundwater source. It responds rapidly to recharge, is extremely vulnerable to contamination, yet is generally of good water quality. This good quality may be a consequence of the lack of potential hazards, and/or adequate dilution and sedimentation of potential contaminants occurring in the northeast-southwest trending band of lakes at the foot of Mullaghmore, and/or the significant groundwater contribution to the source from smaller fissures outside the main conduits of flow.

The catchment area for the spring is unusually large as it also incorporates the catchment area for the Fergus River water bypassing the source via Ballyallia Lake. As the catchment areas to both are closely interlinked, and the proportion bypassing Pouladower varies with different water level conditions, the entire area must be considered in protecting the source.

An innovative approach to protecting the source is therefore required which is pragmatic, defensible and yet provides reasonable protection for the source. Following consultation with the EPA and the local authority, the National Groundwater Protection methodology has been adapted to take account of the local hydrological and hydrogeological characteristics. The Inner Protection Area, which is delineated to protect the source from bacteriological contamination, comprises the area of highest risk to the source between Pouladower Spring and the lakes. It does not, in this instance, include the 100 day travel time zone which would have included the entire limestone area: this is considered to be impractical and unnecessary for the management of potentially contaminating activities for the following reasons:

1. There is significant dilution occurring throughout the Pouladower system within the large catchment area, particularly in the lakes, which is not usually the case at other sources;
2. At sources in other aquifer types the Inner Protection Area is delineated to prevent bacteriological contamination occurring. Bacteriological contamination of karst sources is inevitable due to the rapid groundwater velocities and the high interconnectivity with surface water. Disinfection of the supply is essential.

The Outer Protection Area, designed to protect from chemical contamination, encompasses the remainder of the catchment area. These protection areas are combined with the vulnerability to give the groundwater source protection zones.

If it is intended to harness Pouladower for use as a public drinking water supply to augment the Drumcliff Source, as mentioned in the KT Cullen report of 1996, it is strongly recommended that the immediate area around the source be purchased and fenced off to reduce the likelihood of surface contaminants getting into the springhead.

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