Culdaff Source

Extracted from:
County Donegal Groundwater Protection Scheme,
Volume II: Source Protection Zones December 2005

County Donegal
Groundwater Protection Scheme

Volume II: Source Protection Zones
December 2005

Holy Well, Fanad Head, County Doneg

James Holohan
Director of Services
Donegal County Council
County House
Lifford, County Donegal

Monica Lee and Donal Daly
Groundwater Section
Geological Survey of Ireland
Beggars Bush
Haddington Road, Dublin 4

Authors

Monica Lee, Donal Daly and Siobhan McLaughlin, Groundwater Section, Geological Survey of Ireland

Contributions from Vincent Fitzsimons, Groundwater Section, Geological Survey of Ireland

in collaboration with:

Donegal County Council

TABLE OF CONTENTS – VOLUME II

Volume I comprise an overall introduction, classifications of aquifers and vulnerability, and overall conclusions.

1 BALLYSHANNON PUBLIC WATER SUPPLY SCHEME 1
1.1 INTRODUCTION 1
1.2 SUMMARY OF SUPPLY DETAILS 1
1.3 METHODOLOGY 2
1.3.1 Desk Study 2
1.3.2 Site visits and Fieldwork 2
1.3.3 Assessment 2
1.4 LOCATION AND SITE DESCRIPTION 2
1.4.1 Topography, Surface Hydrology and Land Use 4
1.5 GEOLOGY 4
1.5.1 Introduction 4
1.5.2 Bedrock Geology 5
1.5.3 Karst Features 6
1.5.4 Re-Evaluation of Bedrock Geology in the Ballyshannon Area 6
1.5.5 Subsoil Geology 7
1.5.6 Depth to Bedrock 8
1.5.7 Groundwater Vulnerability 8
1.6 HYDROGEOLOGY 9
1.6.1 Introduction 9
1.6.2 Rainfall, Evaporation and Recharge 10
1.6.3 Discharge Estimates 10
1.6.4 Groundwater Levels, Flow Directions and Gradients 11
1.6.5 Hydrochemistry and Water Quality 1 4
1.6.6 Aquifer Characteristics 15
1.6.7 Conceptual Model 16
1.7 DELINEATION OF SOURCE PROTECTION AREAS 17
1.7.1 Introduction 17
1.7.2 Outer Protection Area 17
1.7.3 Inner Protection Area 19
1.8 GROUNDWATER PROTECTION ZONES 19
1.9 POTENTIAL POLLUTION SOURCES 20
1.10 CONCLUSIONS AND RECOMMENDATIONS 21

2 CARNDONAGH PUBLIC WATER SUPPLY SCHEME 23
2.1 INTRODUCTION 23
2.2 SUMMARY OF SUPPLY DETAILS 23
2.3 METHODOLOGY 24
2.3.1 Desk Study 24
2.3.2 Site Visits and Fieldwork 24
2.3.3 Assessment 24
2.4 LOCATION AND SITE DESCRIPTION 24
2.4.1 Topography, Surface Hydrology and Land Use 26
2.5 GEOLOGY 26
2.5.1 Introduction 26
2.5.2 Bedrock Geology 27
2.5.3 Subsoil Geology 27
2.5.4 Depth to Bedrock 28
2.5.5 Groundwater Vulnerability 28
2.6 HYDROGEOLOGY 29
2.6.1 Introduction 29
2.6.2 Rainfall, Evaporation and Recharge 30

2.6.3 Groundwater Levels, Flow Direction and Gradient 30
2.6.4 Hydrochemistry and Water Quality 3 3
2.6.5 Aquifer Characteristics 35
2.6.6 Conceptual Model 36
2.7 DELINEATION OF SOURCE PROTECTION AREAS 37
2.7.1 Introduction 37
2.7.2 Outer Protection Area 37
2.7.3 Inner Protection Area 38
2.8 GROUNDWATER PROTECTION ZONES 39
2.9 POTENTIAL POLLUTION SOURCES 40
2.10 CONCLUSIONS AND RECOMMENDATIONS 40

3 CULDAFF PUBLIC WATER SUPPLY SCHEME 42
3.1 INTRODUCTION 42
3.2 SUMMARY OF SUPPLY DETAILS 42
3.3 METHODOLOGY 43
3.3.1 Desk Study 43
3.3.2 Site Visits and Fieldwork 43
3.3.3 Assessment 43
3.4 LOCATION AND SITE DESCRIPTION 43
3.4.1 Topography, Surface Hydrology and Land Use 44
3.5 GEOLOGY 45
3.5.1 Introduction 45
3.5.2 Bedrock Geology 45
3.5.3 Subsoil Geology 46
3.5.4 Depth to Bedrock 47
3.5.5 Groundwater Vulnerability 47
3.6 HYDROGEOLOGY 48
3.6.1 Introduction 48
3.6.2 Rainfall, Evaporation and Recharge 48
3.6.3 Groundwater Levels, Flow Direction and Gradients 49
3.6.4 Hydrochemistry and Water Quality 5 0
3.6.5 Aquifer Characteristics 51
3.6.6 Conceptual Model 52
3.7 DELINEATION OF SOURCE PROTECTION AREAS 52
3.7.1 Introduction 52
3.7.2 Outer Protection Area 53
3.7.3 Inner Protection Area 53
3.8 GROUNDWATER PROTECTION ZONES 54
3.9 POTENTIAL POLLUTION SOURCES 55
3.10 CONCLUSIONS AND RECOMMENDATIONS 56

4 FANAD NORTH (TRI-A-LOUGH) PUBLIC WATER SUPPLY SCHEME 57
4.1 INTRODUCTION 57
4.2 SUMMARY OF SUPPLY DETAILS 57
4.3 METHODOLOGY 58
4.3.1 Desk Study 58
4.3.2 Site Visits and Fieldwork 58
4.3.3 Assessment 58
4.4 LOCATION AND SITE DESCRIPTION 58
4.4.1 Topography, Surface Hydrology and Land Use 59
4.5 GEOLOGY 61
4.5.1 Introduction 61
4.5.2 Bedrock Geology 61
4.5.3 Subsoil Geology 62
4.5.4 Depth to Bedrock 63

4.5.5 Groundwater Vulnerability 63
4.6 HYDROGEOLOGY 64
4.6.1 Introduction 64
4.6.2 Rainfall, Evaporation and Recharge 65
4.6.3 Groundwater Levels, Flow Direction and Gradients 65
4.6.4 Hydrochemistry and Water Quality 6 6
4.6.5 Aquifer Characteristics 68
4.6.6 Conceptual Model 69
4.7 DELINEATION OF SOURCE PROTECTION AREAS 69
4.7.1 Introduction 69
4.7.2 Outer Protection Area 70
4.7.3 Inner Protection Area 71
4.8 GROUNDWATER PROTECTION ZONES 71
4.9 POTENTIAL POLLUTION SOURCES 72
4.10 CONCLUSIONS AND RECOMMENDATIONS 73

5 MAGHERABEG/VEAGH PUBLIC WATER SUPPLY SCHEME 74
5.1 INTRODUCTION 74
5.2 SUMMARY OF SUPPLY DETAILS 74
5.3 METHODOLOGY 75
5.3.1 Desk Study 75
5.3.2 Site Visits and Fieldwork 75
5.3.3 Assessment 75
5.4 LOCATION AND SITE DESCRIPTION 75
5.4.1 Topography, Surface Hydrology and Land Use 77
5.5 GEOLOGY 77
5.5.1 Introduction 77
5.5.2 Bedrock Geology 77
5.5.3 Subsoil Geology 78
5.5.4 Depth to Bedrock 79
5.5.5 Groundwater Vulnerability 79
5.6 HYDROGEOLOGY 80
5.6.1 Introduction 80
5.6.2 Rainfall, Evaporation and Recharge 80
5.6.3 Groundwater Levels, Flow Direction and Gradients 81
5.6.4 Hydrochemistry and Water Quality 8 2
5.6.5 Aquifer Characteristics 83
5.6.6 Conceptual Model 84
5.7 DELINEATION OF SOURCE PROTECTION AREAS 85
5.7.1 Introduction 85
5.7.2 Outer Protection Area 85
5.7.3 Inner Protection Area 86
5.8 GROUNDWATER PROTECTION ZONES 87
5.9 POTENTIAL POLLUTION SOURCES 88
5.10 CONCLUSIONS AND RECOMMENDATIONS 88

6 PETTIGO PUBLIC WATER SUPPLY SCHEME 89
6.1 INTRODUCTION 89
6.2 SUMMARY OF SUPPLY DETAILS 89
6.3 METHODOLOGY 90
6.3.1 Desk Study 90
6.3.2 Site visits and fieldwork 90
6.3.3 Assessment 90
6.4 LOCATION AND SITE DESCRIPTION 90
6.4.1 Topography, Surface Hydrology and Land Use 92
6.5 GEOLOGY 92

6.5.1 Introduction ... *92*
6.5.2 Bedrock Geology ... *93*
6.5.3 Subsoil Geology ... *95*
6.5.4 Depth to Bedrock ... *96*
6.5.5 Groundwater Vulnerability ... *96*
6.6 HYDROGEOLOGY ... 97
6.6.1 Introduction ... *97*
6.6.2 Rainfall, Evaporation and Recharge ... *97*
6.6.3 Groundwater Levels, Flow Directions and Gradients ... *98*
6.6.4 Hydrochemistry and Water Quality ... *9 8*
6.6.5 Aquifer Characteristics ... *100*
6.6.6 Conceptual Model ... *101*
6.7 DELINEATION OF SOURCE PROTECTION AREAS ... 102
6.7.1 Introduction ... *102*
6.7.2 Outer Protection Area ... *102*
6.7.3 Inner Protection Area ... *103*
6.8 GROUNDWATER PROTECTION ZONES ... 104
6.9 POTENTIAL POLLUTION SOURCES ... 105
6.10 CONCLUSIONS AND RECOMMENDATIONS ... 105

7 REFERENCES ... 107

8 APPENDICES ... 109

LIST OF FIGURES

FIGURE 1.1. LOCATION OF BALLYSHANNON WATER SUPPLY SCHEME ... 3
FIGURE 1.2. BALLYSHANNON WATER SUPPLY SCHEME WELL FIELD AND FEATURES ... 3
FIGURE 1.3. MAPPED BEDROCK GEOLOGY OF THE BALLYSHANNON AREA ... 5
FIGURE 1.4. CONDUIT WITHIN THE BALLYSHANNON LIMESTONE, PARKHILL SPRING AREA. ... 6
FIGURE 1.5. RE-EVALUATED BEDROCK GEOLOGY OF THE BALLYSHANNON AREA (2005). ... 7
FIGURE 1.6. MAPPED SUBSOIL GEOLOGY OF THE BALLYSHANNON AREA ... 8
FIGURE 1.7. MAPPED VULNERABILITY IN THE BALLYSHANNON AREA ... 9
FIGURE 1.8. PARKHILL SPRING OVERFLOW (MAY 2003-SEPTEMBER 2004) ... 11
FIGURE 1.9. ESTABLISHED GROUNDWATER CONNECTIONS IN THE BALLYSHANNON AREA. ... 13
FIGURE 1.10. INDICATORS OF DOMESTIC AND AGRICULTURAL GROUNDWATER CONTAMINATION ... 15
FIGURE 1.11. SO AND SI AREAS AROUND THE BALLYSHANNON PUBLIC SUPPLY SCHEME BOREHOLES. ... 19
FIGURE 1.12. SOURCE PROTECTION ZONES FOR THE BALLYSHANNON WATER SUPPLY SCHEME ... 20
FIGURE 2.1. LOCATION OF CARNDONAGH WATER SUPPLY SCHEME. ... 24
FIGURE 2.2. CARNDONAGH WATER SUPPLY SCHEME WELL FIELD. ... 25
FIGURE 2.3. BEDROCK AND SUBSOIL GEOLOGY OF THE CARNDONAGH AREA. ... 27
FIGURE 2.4. MAPPED VULNERABILITY IN THE CARNDONAGH AREA. ... 29
FIGURE 2.5. MONITORING WELL LOCATIONS ... 32
FIGURE 2.6. SITE INVESTIGATION BOREHOLE LOCATIONS. ... 33
FIGURE 2.7. KEY INDICATORS OF AGRICULTURAL AND DOMESTIC CONTAMINATION ... 34
FIGURE 2.8. SO AND SI AROUND THE CARNDONAGH (TIRNALEAGUE) PUBLIC SUPPLY SCHEME. ... 39
FIGURE 2.9. SOURCE PROTECTION ZONES FOR THE CARNDONAGH PUBLIC SUPPLY SCHEME ... 40
FIGURE 3.1. LOCATION OF, AND FEATURES AROUND, THE CULDAFF WATER SUPPLY SCHEME. ... 44
FIGURE 3.2. LOCATION, TOPOGRAPHY AND SURFACE HYDROLOGY IN THE CULDAFF AREA ... 45
FIGURE 3.3. BEDROCK AND SUBSOIL GEOLOGY OF THE CULDAFF AREA ... 46
FIGURE 3.4. MAPPED VULNERABILITY IN THE CULDAFF AREA. ... 48
FIGURE 3.5. KEY INDICATORS OF AGRICULTURAL AND DOMESTIC CONTAMINATION ... 50
FIGURE 3.6. SO AND SI AREAS AROUND THE CULDAFF WATER SUPPLY SCHEME BOREHOLES ... 54
FIGURE 3.7. SOURCE PROTECTION ZONES AROUND THE CULDAFF PUBLIC WATER SUPPLY BOREHOLES ... 55
FIGURE 4.1. VIEW OF THE TRI-A-LOUGH BOREHOLE – LOOKING NORTHWEST. ... 58
FIGURE 4.2. TRI-A-LOUGH BOREHOLE – AVERAGE DAILY ABSTRACTION; JANUARY 2002-OCTOBER 2003 ... 59
FIGURE 4.3. FEATURES AROUND THE TRI-A-LOUGH BOREHOLE ... 59

FIGURE 4.4. TOPOGRAPHY, SURFACE HYDROLOGY AND SPECIAL AREA OF CONSERVATION. 60
FIGURE 4.5. BEDROCK AND SUBSOIL GEOLOGY. 62
FIGURE 4.6. MAPPED VULNERABILITY IN THE VICINITY OF THE TRI-A-LOUGH BOREHOLE..... 64
FIGURE 4.7. KEY INDICATORS OF AGRICULTURAL AND DOMESTIC CONTAMINATION (CONTINUED OVERLEAF).... 66
FIGURE 4.8. DELINEATED SO AND SI AREAS FOR THE FANAD NORTH (TRI-A-LOUGH) SCHEME..... 71
FIGURE 4.9. SPZ AROUND THE FANAD TRI-A-LOUGH WATER SUPPLY BOREHOLE..... 72
FIGURE 5.1. LOCATION AND FEATURES OF THE MAGHERABEG/VEAGH WATER SUPPLY SCHEME..... 76
FIGURE 5.2. EAST TO WEST VIEW (TOP). WEST TO EAST VIEW (BOTTOM)..... 76
FIGURE 5.3. GEOLOGY IN THE MAGHERABEG/VEAGH AREA. 78
FIGURE 5.4. MAPPED VULNERABILITY IN THE MAGHERABEG/VEAGH AREA. 80
FIGURE 5.5. KEY INDICATORS OF AGRICULTURAL AND DOMESTIC CONTAMINATION (CONTINUED OVERLEAF).... 82
FIGURE 5.6. DELINEATED SO AND SI FOR THE MAGHERABEG/VEAGH WATER SUPPLY SCHEME. 86
FIGURE 5.7. SOURCE PROTECTION ZONES AROUND THE MAGHERABEG/VEAGH WATER SUPPLY SCHEME. 87
FIGURE 6.1. PETTIGO PUBLIC SUPPLY SCHEME WELL FIELD AND FEATURES..... 91
FIGURE 6.2 PETTIGO PUBLIC SUPPLY SCHEME LOCATION MAP..... 91
FIGURE 6.3. ORIGINAL MAPPED BEDROCK GEOLOGY OF THE PETTIGO AREA..... 94
FIGURE 6.4. RE-EVALUATED BEDROCK GEOLOGY OF THE PETTIGO AREA (2005). 94
FIGURE 6.5. MAPPED SUBSOIL GEOLOGY OF THE PETTIGO AREA..... 95
FIGURE 6.6. VULNERABILITY CATEGORIES IN THE PETTIGO AREA..... 96
FIGURE 6.7. KEY INDICATORS OF AGRICULTURAL AND DOMESTIC CONTAMINATION..... 99
FIGURE 6.8. SO AND SI AREAS AROUND THE PETTIGO PUBLIC SUPPLY SCHEME BOREHOLES. 104
FIGURE 6.9. SOURCE PROTECTION ZONES FOR THE PETTIGO WATER SUPPLY SCHEME..... 105

LIST OF TABLES

TABLE 1.1 MATRIX OF SOURCE PROTECTION ZONES AT BALLYSHANNON 20
TABLE 2.1. ESTIMATED PARAMETERS FOR CARNDONAGH GRAVEL AQUIFER..... 36
TABLE 2.2 MATRIX OF SOURCE PROTECTION ZONES FOR CARNDONAGH PUBLIC WATER SUPPLY SCHEME. 39
TABLE 3.1 ESTIMATED PARAMETERS FOR CULDAFF LIMESTONE AQUIFER. 52
TABLE 3.2 MATRIX OF SOURCE PROTECTION ZONES FOR THE CULDAFF PUBLIC WATER SUPPLY SCHEME. 55
TABLE 4.1. INDICATIVE PARAMETERS FOR FANAD NORTH SAND AND GRAVEL AQUIFER..... 69
TABLE 4.2 MATRIX OF SOURCE PROTECTION ZONES FOR TRI-A-LOUGH BOREHOLE..... 72
TABLE 5.1. SAMPLE DESCRIPTIONS AND PSD IN THE GALDONAGH AREA..... 79
TABLE 5.2. ESTIMATED PARAMETERS FOR MARBLE UNIT AQUIFER. 84
TABLE 5.3 MATRIX OF SOURCE PROTECTION ZONES FOR MAGHERBEG/VEAGH PUBLIC WATER SUPPLY SCHEME. 87
TABLE 6.1. ESTIMATED PARAMETERS FOR THE LOWER IMPURE LIMESTONE AQUIFER. 101
TABLE 6.2 MATRIX OF SOURCE PROTECTION ZONES FOR THE PETTIGO PUBLIC WATER SUPPLY SCHEME..... 104

3 CULDAFF PUBLIC WATER SUPPLY SCHEME

3.1 Introduction

The objectives of the report are as follows:

- To delineate source protection zones for the Culdaff Water Supply Scheme which comprises two boreholes.
- To outline the principal hydrogeological characteristics of the surrounding area, based on the available information.
- To assist Donegal County Council in protecting the water supply from contamination.

The protection zones are delineated to help prioritise certain areas around the source in terms of pollution risk to the abstraction points. The prioritisation is intended to provide a guide in the planning and regulation of development and human activities. The protection of public water supplies is also mentioned in Circular letter SP 5-03, which was issued from the DEHLG to all County/City Managers in July 2003. The circular states that source protection zones around public water supplies should be included in all county development plans. The implications of these protection zones are further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

The report forms part of the groundwater protection scheme for the county. The maps produced for the scheme are based largely on mapping techniques that use inferences and judgements based on experience at other sites. As such, the maps cannot claim to be definitively accurate across the whole county 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.

3.2 Summary of Supply Details

GSI Number	2343NEW015
Grid ref. (GPS)	22388 44866
Townland	Culdaff Demesne
Source type	Two boreholes
Drilled	2000
Owner	Donegal Co Co
Elevation (Ground Level)	c.30 m O.D.
Depth	c. 90 m [11]
Depth of Casing	c.6 m
Diameter	12" and 9" bores
Depth to rock	c. 5 m
Static water level	Artesian
Pumping water level	m b.g.l.
Consumption (CoCo records)	c. 750 m^3/d
Pumping test summary: (i) abstraction rate m^3/d	 523 m^3/d
(ii) specific capacity	126 m^2/d
(iii) transmissivity	c. 110 m^2/d

[11] Data are inferred from the informal log obtained from the trial well at the borehole location.

3.3 Methodology

3.3.1 Desk Study

Details about the boreholes such as depth, date commissioned and abstraction figures were obtained from County Council personnel and a report by K.T. Cullen & Co. Ltd (KTC) written in 1998. Additional geological and hydrogeological information was provided by GSI and Teagasc mapping programmes (Long and McConnell, 1997; Meehan, 2004 respectively).

3.3.2 Site Visits and Fieldwork

This part of the work included the following:

- meetings with Donegal County Council staff in October 2002 and July 2003;
- water sampling in November 2002 and March 2003;
- drilling of depth to bedrock/permeability holes in the general area;
- site walkovers in May and July 2003 to further investigate the subsoil geology, hydrogeology and vulnerability to contamination.

3.3.3 Assessment

The analysis of the data utilised the field studies and previously collected information to delineate protection zones around the source.

3.4 Location and Site Description

In 1998, KTC undertook resistivity assessments in the Culdaff/Gleneely area to identify potential areas of gravel aquifer. They surveyed a number of sites including a rectangle of land stretching across the base of the valley of interest. They identified an area with development potential located approximately 150 m to the north of the present day production boreholes. Although the installation of a trial well at this location is not discussed in the report, County Council personnel have reported that no groundwater was encountered in the bedrock or subsoil at this location. A second trial well was then installed in the base of the valley (at the present source location) on the drilling contractor's recommendation.

The site is located just under 1.0 km to the south-east of Culdaff Village, in the townland of Gort (Figure 3.1). It comprises two boreholes adjacent a pump-house. The boreholes were installed in 2000 as a temporary augmentation measure.

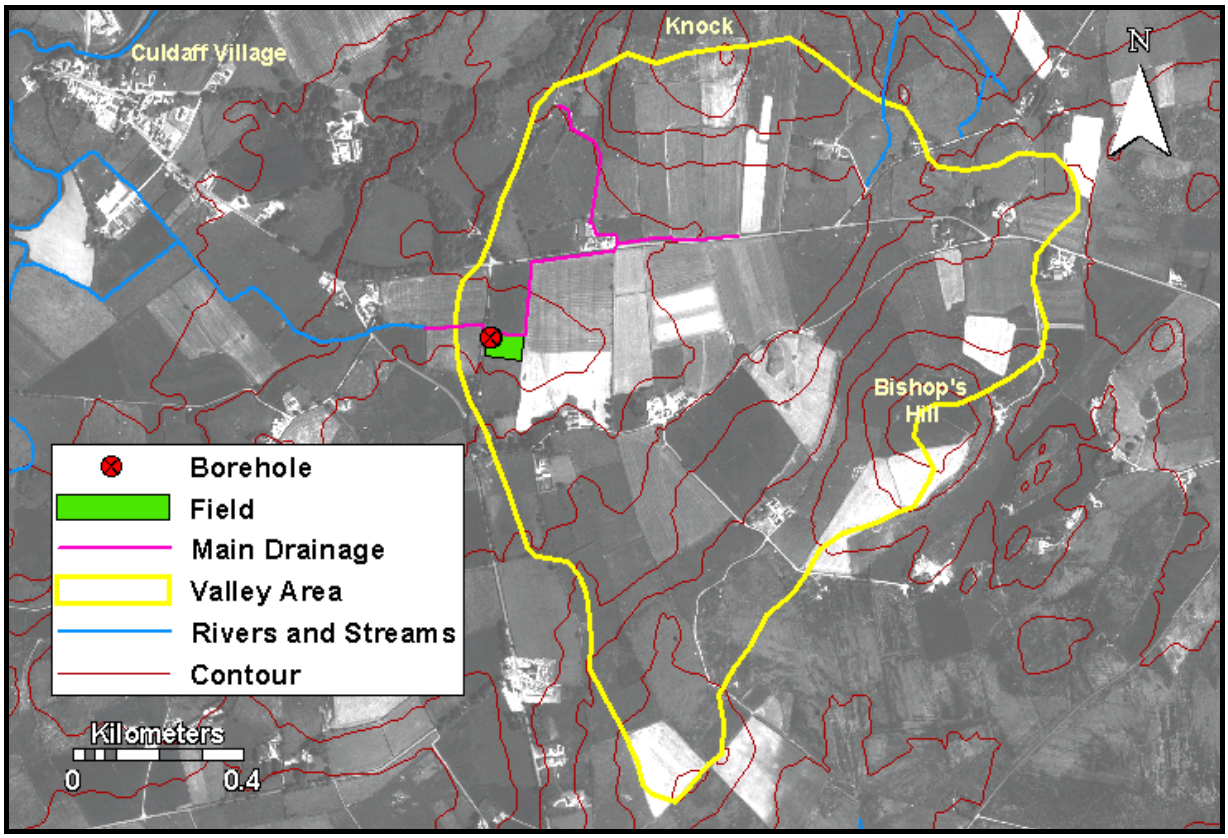

Figure 3.1. Location of, and Features Around, the Culdaff Water Supply Scheme.

The boreholes and pump house are situated in a small field (approximately 85 m by 60 m) that is bound by hedgerows on the western, southern and eastern sides and by a surface drainage channel along its northern edge (Figure 3.1). Access is gained from the road running along the western boundary and the site is secured by a padlocked gate. The boreholes are covered by large concrete plinths that are flush to the ground.

Groundwater is continually pumped from the boreholes directly into the distribution system. This is part of a comprehensive system which supplies the area around Culdaff, as far as Gleneely. The pumping rate responds automatically to demand and hence can vary as much as 650-900 m^3/d, based on recent records. Since the installation of the borehole in 2000, the average abstraction rate has increased from 100 m^3/d to the present day rate of 750 m^3/d.

3.4.1 Topography, Surface Hydrology and Land Use

The site is located near the base of a small, gently sloping valley, at approximately 30 m O.D. Moving eastwards, the valley rises to a maximum of 110 m O.D. Culdaff Bay is located approximately 1.5 km to the north of the boreholes. To the west, the land continues to gently slope down to join a lower-lying flatter area, which extends to Culdaff Bay. To the south and east of the valley the landscape is undulating to hilly.

The small, permanent drainage channel along the northern boundary of the well field flows from east to west and forms the head of a tributary of the Culdaff River. The Culdaff River is the main surface water feature in this area, flowing from the southwest to discharge into Culdaff Bay (Figure 3.2). The northern part of the valley has more artificial surface drainage channels than the central and southern valley area.

Historically the northern boundary drainage channel started further to the east, in the centre of the valley, rather than being fed by artificial drainage from the northern slopes (Six Inches to One Mile Scale Maps Series Sheet 5/5a; 1903). Also, 'Martha's Spring' was located across the road from the

production boreholes; approximately 20 m to the southwest. From local knowledge drinking water was collected from this spring, which has dried up since the abstraction from the Culdaff boreholes began.

Grazing is the main land use in this area. A number of small roads run across the valley, along which are individual houses and farms. The closest of these is located c.125 m up-gradient of the boreholes.

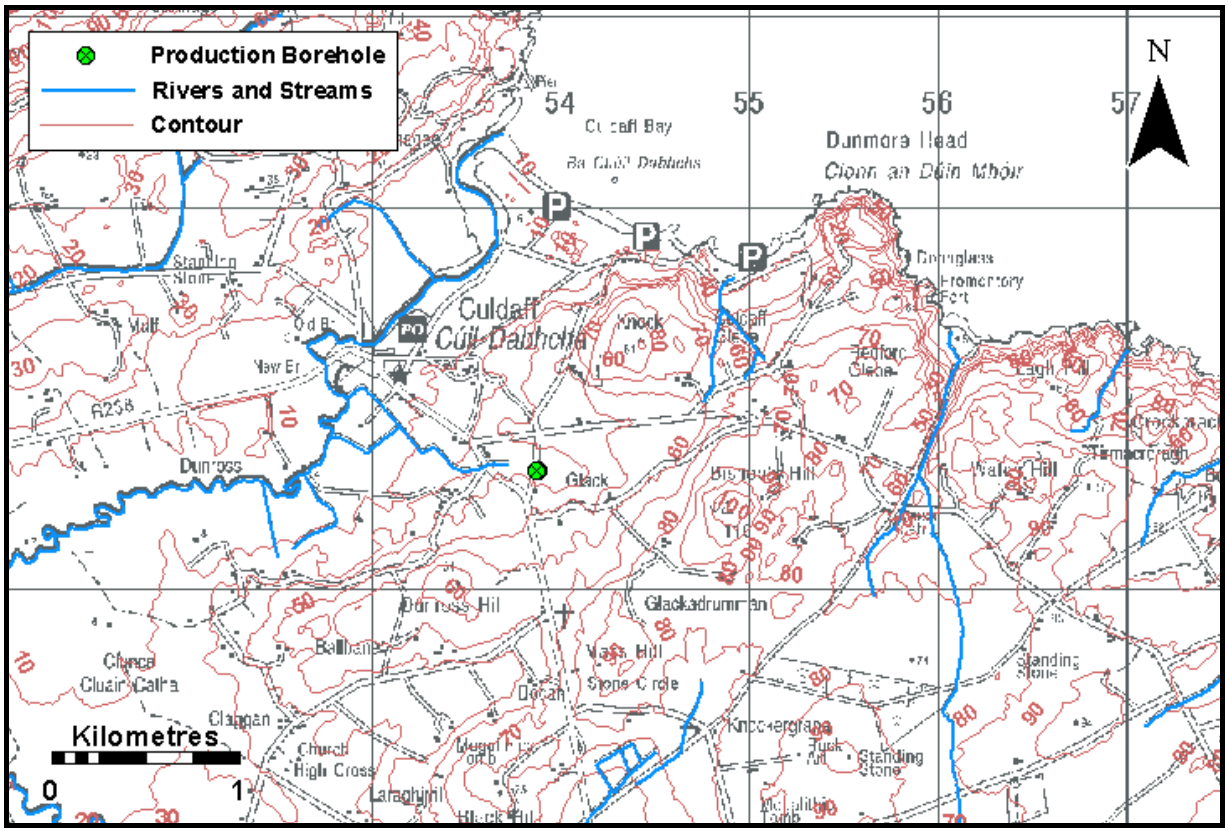

Figure 3.2. Location, Topography and Surface Hydrology in the Culdaff Area.

3.5 Geology

3.5.1 Introduction

This section briefly describes the relevant characteristics of the geological materials that underlie the site. It provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections.

Geological information was taken from a desk-based survey of available data, which comprised the following:

- Geology of North Donegal. Bedrock Geology 1:100,000 Map Series, Geological Survey of Ireland (Long and McConnell, 1997).
- Information from geological mapping in the nineteenth century (on record at the GSI).
- Forest Inventory and Planning System – Integrated Forestry Information System (FIPS-IFS) Soils Parent Material Map, Teagasc (Meehan, [illegible]4).
- Report on a Hydrogeological Investigation of the Gleneely-Culdaff Area, Co. Donegal (KTC, 1998).

3.5.2 Bedrock Geology

In the general Culdaff area, a large amount of folding and faulting has occurred. This has resulted in the formation of anticline and syncline features and the displacement of rocks along faults. However,

specifically at the boreholes' location, there are limited data about the anticline feature and the exact location of the contact between the Culdaff Limestone and Fahan Slate.

The mapped geology indicates that the boreholes are located within the Fahan Slate bedrock, although are close to the contact with the Culdaff Limestone (Figure 3.3). Due to the structural anticline feature in the valley, the boreholes are actually collared by the Fahan Slate but are mainly intersecting the underlying Culdaff Limestone.

An informal drilling log does exist for a trial well at the location of the boreholes, but it does not give any further indication of the depth of the Culdaff Limestone. The log records broken rock between 5-6 m below the ground surface and two water strikes (15 m and 64 m below ground). It also records a very fractured cavity at 42 m with a larger inflow of water. For the purposes of this report, it is assumed that the first water strike indicates the presence of Culdaff Limestone i.e. it is encountered at c.15 m below ground. It is also noted that as the Culdaff Limestone is essentially a calcium carbonate rock, there is the possibility that any fractures (e.g. at 42 m below ground) and joints may be enlarged by solution (karstification).

Generally, the Culdaff Limestone, which is located at the base of the valley, comprises a thick-bedded, dark grey, impure marble (metamorphosed limestone). Fahan Slate underlies the northern, southern and eastern valley slopes and is described as dark, fine-grained slate with thin marble and sandstone bands. These rocks are described in more detail in Section 2, Volume 1.

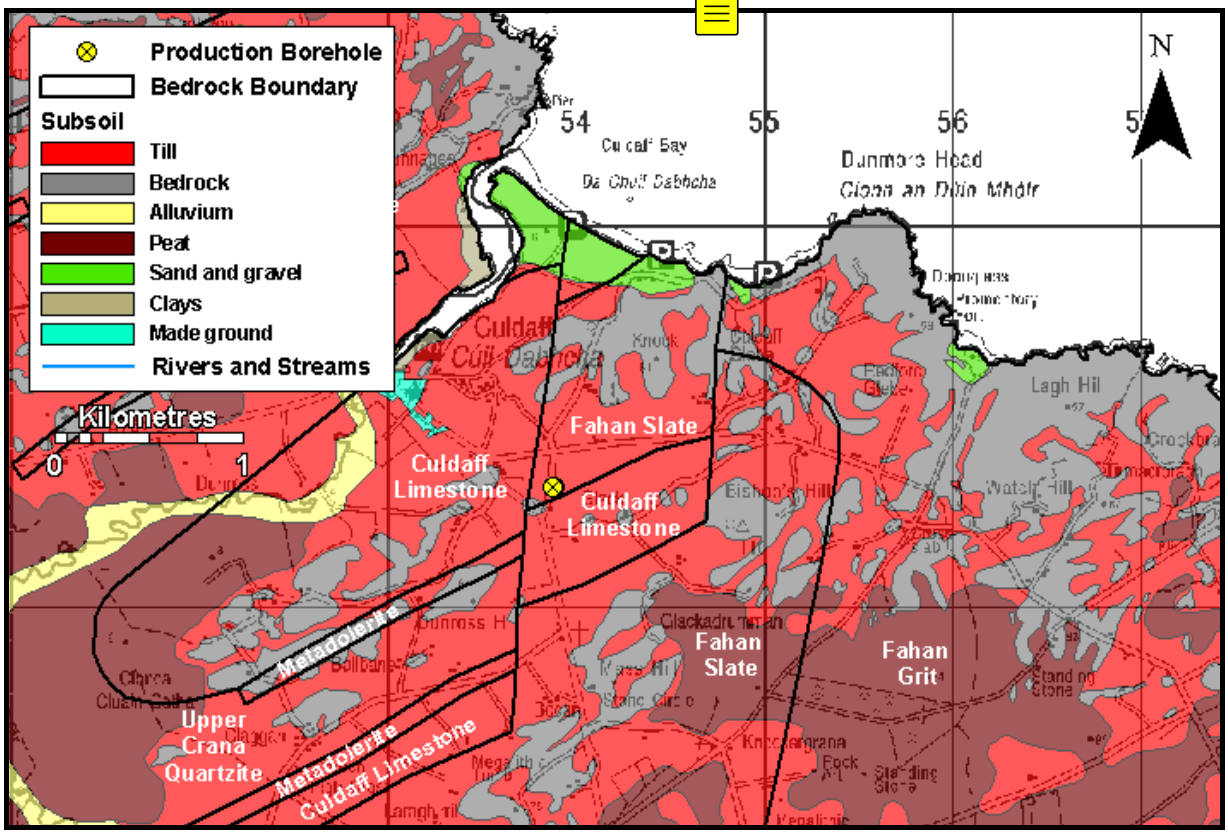

Figure 3.3. Bedrock and Subsoil Geology of the Culdaff Area.

3.5.3 Subsoil Geology

The main subsoil category throughout this general area is 'till', or boulder clay (Figure 3.3). Till is an unsorted mixture of coarse and fine materials laid down by ice. Throughout the Inishowen Peninsula, thicker till (> 3 m) is generally characterised by silt/sand sized material derived from the coarser-grained metamorphic rocks in this region.

During the GSI drilling programme, approximately 5 m of CLAY (BS 5930) was encountered close to the supply boreholes. It is probable that this material has been derived locally from the Fahan Slate

rather than from the coarser grained metamorphic rocks. It would appear that the thicker, more clay-rich subsoil is limited to the flat area at the base of the valley, in the immediate vicinity of the boreholes.

In this particular area, the till does not constitute an aquifer. Its main significance is in relation to its protective capacity of the underlying rock aquifers from infiltrating contaminants.

3.5.4 Depth to Bedrock

All available drilling information was previously compiled and a drilling programme undertaken by the GSI to ascertain the general changes in subsoil thickness and permeability throughout County Donegal. There are very few borehole data in the Inishowen Peninsula although a large number of rock outcrops have been recorded. Given the location of the outcrops in the vicinity of the Culdaff boreholes, the majority of the valley area is considered to have less than 3 m of subsoil. The exception to this is the flat area of thicker, finer-grained till around the boreholes.

3.5.5 Groundwater Vulnerability

The concept of vulnerability is fully discussed in the Section 5 (Volume I). In summary, the vulnerability category mainly relates to the protection afforded by the material overlying the aquifer, which in this instance is the subsoil. In terms of subsoil coverage, the valley area can be divided into two zones:

1) Over the majority of the valley sides and floor, the subsoil is considered to be less than 3 m thick and therefore the vulnerability is classed as 'extreme'.
2) Over a small portion of the valley floor in the vicinity of the boreholes, the depth to rock is approximately 5 m and the permeability is categorised as 'low', due to presence of clay-rich material. In this small area, the vulnerability will alternate between 'moderate' and 'high', depending on the exact thickness of the subsoil.

In addition to the protection provided by the subsoil (as represented by the vulnerability categories), the Fahan Slate, which has a relatively low permeability, will provide a high degree of protection to the groundwater in the underlying Culdaff Limestone. The main exception will be in the vicinity of the contact with the Culdaff Limestone where the Fahan Slate will be at its thinnest and most fractured. Moving away from the contact, the Fahan Slate will thicken and the protection will increase. It is probable that within a few tens of metres from the contact, vertical flow into the Culdaff Limestone will be negligible. The mapped vulnerability[12], in terms of subsoil protection, is shown in Figure 3.4.

[12] The permeability estimations and depth to bedrock interpretations are based on regional-scale evaluations. The mapping is intended only as a guide to land use planning and hazard surveys, and is not a substitute for site investigation for specific developments. Classifications may change as a result of investigations such as trial hole assessments for on-site domestic wastewater treatment systems. The potential for discrepancies between large-scale vulnerability mapping and site-specific data has been anticipated and addressed in the development of groundwater protection responses (site suitability guidelines) for specific hazards.

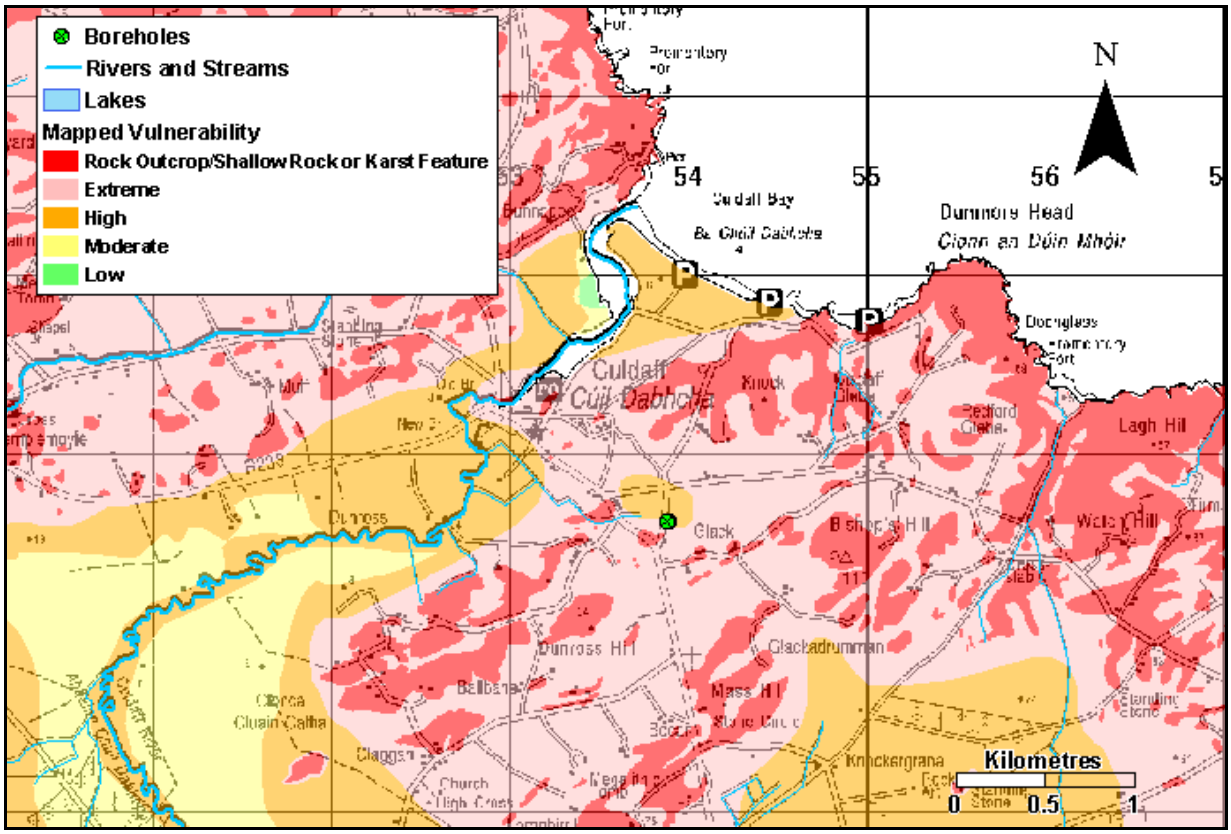

Figure 3.4. Mapped Vulnerability in the Culdaff Area.

3.6 Hydrogeology

3.6.1 Introduction

This section presents our current understanding of groundwater flow in the area of the boreholes, based on the available data. Hydrogeological and hydrochemical information for this study was obtained from the following sources:

- GSI files and archival Donegal County Council data.
- Site walkovers in May and July 2003 and a levelling survey in November 2003.
- A drilling programme carried out by GSI to ascertain depth to bedrock and subsoil permeability.
- Report on a Hydrogeological Investigation of the Gleneely-Culdaff Area, Co. Donegal (K.T.C., 1998).
- Environmental Protection Agency water quality data (2000-2003).
- Donegal County Council drinking water returns for 2002 and 2003.

3.6.2 Rainfall, Evaporation and 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 losses (i.e. annual evapotranspiration and runoff), prior to entry into the groundwater system. The estimation of a realistic recharge rate is important in source protection delineation as it is used to estimate the size of the zone of contribution (i.e. the outer source protection area). The calculations are summarised below.

- *Annual rainfall:* **1190 mm**.

  There are a number of rainfall gauges located on the Inishowen Peninsula. The nearest station (Carndonagh Rocksmount, Fitzgerald and Forrestal, 1996) is situated approximately 6 km to the

southeast of the source, at a similar elevation. It is assumed that this area will represent conditions at the source. This value is also indicated by the interpreted precipitation contour maps presented in the "Agroclimatic Atlas of Ireland" (Collins and Cummins, 1996).

- *Annual evapotranspiration losses:* **530 mm**.

  Potential evapotranspiration (P.E.) is in the region of 560 mm/yr (Collins and Cummins, 1996). Actual evapotranspiration (A.E.) is estimated as 95% of P.E., to allow for seasonal soil moisture deficits. More local measurements of evapotranspiration are not available.

- *Annual effective rainfall:* **660 mm**.

  This figure is based on subtracting evapotranspiration losses from average annual rainfall. It represents an estimation of the excess soil moisture available for either vertical downward flow to groundwater or runoff.

- *Annual recharge:* ~ **230 mm**.

  Based on the geology and subsoil within the valley, it is anticipated that approximately 65% of the effective rainfall will recharge in three main ways:

  1) The valley floor area that is extremely vulnerable and is underlain by the Culdaff Limestone (40% of area) will have a low proportion of runoff, which is supported by the lack of surface drainage. Recharge estimates are in the order of 70% (GWWG, November 2004).
  2) The valley sides that are extremely vulnerable and are underlain by Fahan Slate (c.60%) will have a higher proportion of runoff, as suggested by the higher drainage density. Approximately 50% of the effective rainfall over this area is thought to contribute to recharge.
  3) The valley floor area around the boreholes that is moderately to highly vulnerable is estimated to have maximum runoff. However, due to the limited extent of this area, the impact on the total valley runoff is considered to be negligible.

  The GSI took spot flow readings in the northern boundary drainage channel, which is the main surface water discharge point in the valley, and has never been known to run dry (F. Platt, *pers.comm*. 2003). Some 700 m^3/d was recorded in May 2003 and c.100 m^3/d in July 2003. If an average annual runoff rate of 700 m^3/d is assumed, it represents some 30% of potential recharge, which compares favourable with the 35% runoff losses estimated.

These calculations are summarised as follows:

Average annual rainfall (R)	1190 mm
Estimated P.E.	560 mm
Estimated A.E. (95% of P.E.)	530 mm
Effective Rainfall (R – A.E.)	660 mm
Estimated Recharge (65% of effective rainfall)	**430 mm**

3.6.3 Groundwater Levels, Flow Direction and Gradients

Relevant information was specifically obtained from the KTC report (1998) and communication with County Council personal and the Pat Dullea, the drilling contractor.

Water levels. The trial well and production boreholes are recorded as being artesian. It is inferred from the artesian nature of the boreholes that the groundwater is confined at this location. The confining layer may comprise either, or more likely a combination of, the overlying Fahan Slate and c.5 m of clay-rich subsoil at the base of the valley.

Flow Direction. Apart from the water levels recorded in the production boreholes, there are no other groundwater level data for valley area. However, it is inferred from the topography and surface drainage that the groundwater will move from the higher eastern valley divide (110 m O.D.), in a westerly direction, towards the Culdaff River.

Given that the Culdaff Limestone aquifer is not highly permeable, it is anticipated that the groundwater gradients are likely to reflect the valley topography. Thus a value of 0.015 is assumed.

3.6.4 Hydrochemistry and Water Quality

Hydrochemical data for the Culdaff Scheme have been obtained from the Environmental Protection Agency (2000-2003) and two sampling rounds undertaken by the GSI in conjunction with the County Council (2002-2003). The data are summarised graphically in Figure 3.5 below.

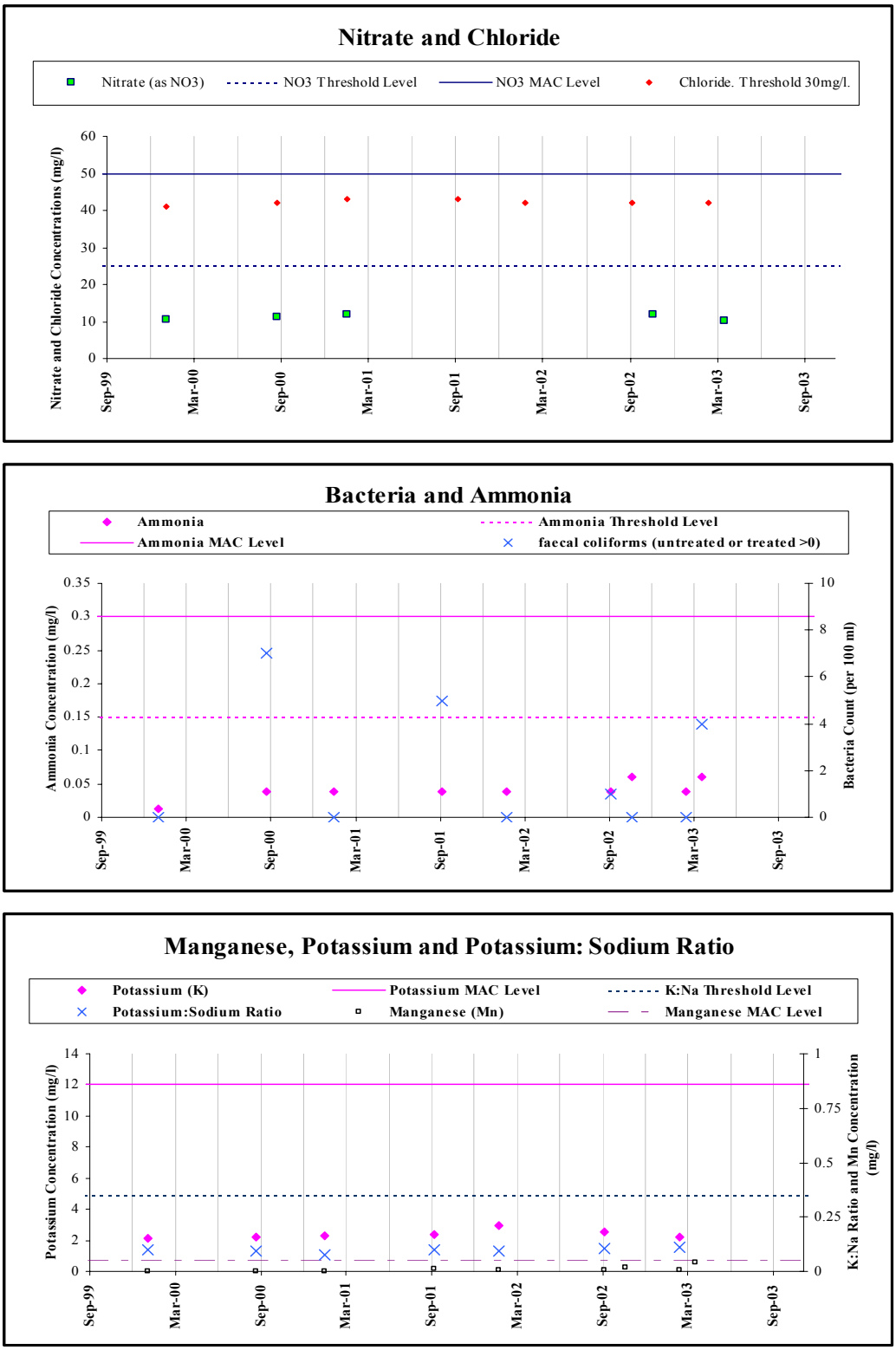

Figure 3.5. Key Indicators of Agricultural and Domestic Contamination.

The following key points have been identified from these data.

- Total hardness values are in the order of 300-400 mg/l $CaCO_3$ indicating a hard calcium bicarbonate hydrochemical signature (250-350 mg/l $CaCO_3$), bordering on very hard (>350 mg/l $CaCO_3$). The conductivity value are generally around 700-750 µS/cm.
- Of the contamination indicators assessed, the nitrate, ammonia, potassium, iron and manganese concentrations, as well as the potassium:sodium ratio, are all below their threshold levels. The level of chloride in the available samples range from 41-43 mg/l which exceeds the 30 mg/l threshold. This parameters can indicate contamination from an organic waste source. However, chloride levels are often influenced by sea spray and salty rainfall and the Culdaff boreholes are situated only 1.5 km away from Culdaff Bay. Although chloride concentrations cannot be used as a contaminant indicator with a high degree of confidence, faecal coliforms were detected in four of the nine available samples. The levels ranged from 1 count/100 ml in September 2002 to 7 counts/100 ml in September 2000. Gross contamination is not inferred from the levels of bacteria but the frequency of detection does suggest that this is an on-going issue. Further monitoring and analyses is required in order to identify any trends in these data.

From communication with County Council personnel, it is also noted that the source was previously contaminated with nitrate in the 1990s. This contamination was associated with discharge from a particular farm and is considered to be an isolated incident.

More recently (summer 2003), there have been reports of high turbidity in the drinking water. This situation would require further monitoring in order to draw any conclusions however, high turbidity has been associated with low water-table conditions in conduit (karst) flow systems (Lee and Kelly, 2003). Accordingly, it is possible that the low rainfall conditions experienced during this period may have contributed to this situation.

3.6.5 Aquifer Characteristics

The Culdaff Public Supply Scheme comprises two boreholes which abstracts water from the Culdaff Limestone bedrock aquifer. Although the boreholes are mapped within the Fahan Slate, the geological structure of the area (anticline feature) indicates that the boreholes are only collared by the Fahan Slate, and that the majority of their depth intersects and derives water from the underlying Culdaff Limestone. Due to the low permeability of the overlying Fahan Slate, it provides a protective cap over the Culdaff Limestone from potentially infiltrating contaminants. This cap will be less effective where the Fahan Slate is thinner, i.e. near the contact with Culdaff Limestone, at which point it is also likely to be more fractured.

The Culdaff Limestone is classified as a **Locally Important Aquifer** that is moderately productive only in **local zones** (**Ll**). For more information, refer to Section 4, Volume 1. The aquifer parameters have been estimated from the pumping tests undertaken by the drilling contractor and from the present day pumping situation. They are summarised in Table 3.1 below.

The specific capacity (Sc) ranges from 80-100 $m^3/d/m$. The former value is calculated from the present abstraction rate of c.750 m^3/d and 9 m drawdown, which comprises a pumping water level of 8 m below ground plus an arbitrary 1 m to account for the artesian nature of the boreholes. The latter specific capacity value is based on the pumping test data. The transmissivity (T) is in the region of 150 m^2/d, as calculated from the time-drawdown data.

The permeability can be calculated by dividing the transmissivity by the saturated thickness of the aquifer, which is estimated as c.80 m (depth of the borehole). Therefore the permeability (K) is in the region of 2 m/d. The velocity of water moving through this aquifer to the boreholes can be calculated from Darcy's Law:

$$\text{Velocity (V)} = \frac{\text{(K x groundwater gradient (i))}}{\text{porosity (n)}}$$

The groundwater gradient is assumed to be 0.015 (Section 1.6.4) and a typical effective porosity (n) for this type of rock is considered to be in the order 0.01 (1%). Thus the velocity is estimated as 3 m/d.

This general velocity assumes that the entire saturated thickness (c.80 m) is providing the water although it is more likely that a small number of fracture/cavity zone(s) are supplying the majority of the groundwater to the boreholes. The groundwater velocity is therefore likely to be significantly higher along the fracture/cavity zones.

Table 3.1 Estimated Parameters for Culdaff Limestone Aquifer.

Parameter	*Source of data*	*Value*
Specific Capacities (m^3/d/m)	Local	80-100
Transmissivity (m^2/d)	Local	150
Permeability (m/d)	Local	2
Porosity	Assumed	1%
Velocity (m/d)	Local/Assumed	3

3.6.6 Conceptual Model

- The Culdaff Public Water Supply Schemes consists of two boreholes, which abstract an average of 750 m^3/d. The boreholes are pumping water directly into the distribution system 24 hours a day. The rate automatically responds to demand and the abstraction is known to fluctuate (650 m^3/d to 900 m^3/d).
- The boreholes principally abstract water from the Culdaff Limestone, which is classified as a **Local Important Aquifer** that is moderately productive only in **local zones** (**Ll**).
- A large fracture/cavity zone is recorded at c.42 m below ground level which appears to be one of the more significant pathways for groundwater movement. Groundwater is likely to flow through interconnected, possibly solutionally enlarged, fracture zones. Outside the main fracture system, groundwater probably flows through smaller fractures and joints, as suggested by the two water strikes recorded at 15 m and 64 m below ground.
- The valley topography is likely to dictate the local groundwater flow direction around the boreholes. On this basis, groundwater will flow westwards from the eastern valley divide to the Culdaff River.
- It is inferred from the artesian nature of the boreholes that the groundwater is confined at this particular location i.e. at the base of the valley. The confining layer is assumed to be a combination of the lower permeability Fahan Slate and the clay-rich subsoil identified at this location.
- It is assumed that recharge can occur diffusely over the extremely vulnerable area of Culdaff Limestone and that a proportion of recharge will be derived indirectly from the effective rainfall falling over the area of Fahan Slate. Estimates of the amount of effective rainfall recharging the Culdaff Limestone aquifer are in the order of 430 mm/yr.
- Generally, the lower permeability Fahan Slate will act at a protective cap to the underlying Culdaff Limestone aquifer. The exception to this will along the contact between the two rocks, where the Fahan Slate will be thinner and probably more fractured.

3.7 Delineation of Source Protection Areas

3.7.1 Introduction

This section delineates the areas around the source that are believed to contribute groundwater to it, and that therefore require protection. The delineation of these areas are based on the conceptualisation of the groundwater flow pattern around the source, and are presented in Figure 3.6.

Two source protection areas are delineated:

- Inner Protection Area (SI), designed to give protection from microbial pollution;

- Outer Protection Area (SO), encompassing the zone of contribution (ZOC) to the boreholes.

3.7.2 Outer Protection Area

The Outer Protection Area (SO) is bounded by the complete catchment area to the boreholes, 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 abstraction rate, (b) the groundwater flow direction and gradient, (c) the subsoil and rock permeability and (d) the recharge in the area. The delineation of the ZOC uses:

i. hydrogeological mapping techniques and analytical modelling to determine the boundaries,
ii. a comparison of average discharge and recharge data to estimate the area required,
iii. a safety margin to allow for any variability in the groundwater flow direction, and
iv. a safety margin to account for the larger ZOC required during the drier summer months.

The delineation of the boundaries is described below.

The **northern, eastern** and **southern boundaries** are constrained by topography i.e. the valley area in which the boreholes are located. This assumes that surface and groundwater catchments are coincident. The distinct valley divide runs through the townlands of Knoc (north), Culdaff Glebe (northeast) and Glackadrumman (east and south).

The **western boundary** is on the down gradient side of the boreholes and it based on analytical modelling. From the aquifer parameters, the extent of the down-gradient influence is estimated using:

$$\text{Approximate down-gradient extent} = \frac{\text{(discharge rate)}}{\text{2 x pi x (transmissivity) x (hydraulic gradient)}}$$

where the pumping rate[13] is 1125 m^3/d, the transmissivity is taken as 150 m^2/d and the hydraulic gradient is 0.015. This gives an approximate down-gradient extent of 80 m.

ZOC Area. The data are not comprehensive enough to undertake a water balance in order to accurately estimate the catchment area. However, a comparison of the available discharge data (1125 m^3/d) and recharge data (430 mm/year, or c.1400 m^3/d) indicate that the delineated ZOC (c.1.2 km^2) is large enough to support the long term abstraction rate.

3.7.3 Inner Protection Area

According to "Groundwater Protection Schemes" (DELG/EPA/GSI, 1999), delineation of an Inner Protection Area (SI) is required to protect the source from microbial contamination and it is based on the 100-day time of travel (ToT) to the supply.

There are two main considerations with regard to the time it will take groundwater to reach the boreholes. Firstly, the velocity in the Culdaff Limestone is calculated as 3 m/d, which gives a maximum 100 day ToT distance of 300 m from the boreholes. However, as noted in Section 3.6.5, this value is based on the permeability from the *entire* borehole depth rather than focussing on the velocity in the actual fracture/cavity zones that are assumed to provide the majority of the water. Although there are no data for these particular zones, groundwater flow velocities of up to 280 m/d have been recorded in other (karst) conduit systems (Lee & Kelly, 2002). Flow rates through the fracture zones in the Culdaff Limestone are not known, however the *potential* for high groundwater velocities in these zones suggests that the entire area of Culdaff Limestone within the ZOC should be included in the SI.

The second consideration is the protective capacity of the overlying Fahan Slate. Although no data exist for this particular rock, vertical groundwater movement through greater thicknesses of the Fahan Slate is considered to be negligible. Where the rock is thinner and more fractured, vertical groundwater flow is more feasible, although is likely to be slower than flow in the Culdaff Limestone.

[13] The average abstraction rate at present is 750 m^3/d. An additional 50% is added in order to account for lower groundwater levels in summer and in the event that the abstraction may be increased in the future.

By taking account of these two main considerations, the SI incorporates:

a. The entire area of Culdaff Limestone.

b. A 50 m buffer along the northern, southern and eastern boundaries of the Culdaff Limestone. In the absence of additional data, the anticline is assumed to have a dip of 20º. Therefore at the extent of the 50 m buffer, the overlying Fahan Slate is assumed to be around 20 m thick.

c. An arbitrary buffer of 100 m around the boreholes, which takes into account the assumed 20º dip as well as the influence the pumping has on the groundwater level and flow direction around the boreholes.

These buffers also account for any possible uncertainty with the precise location of the contact between the two adjacent rock units.

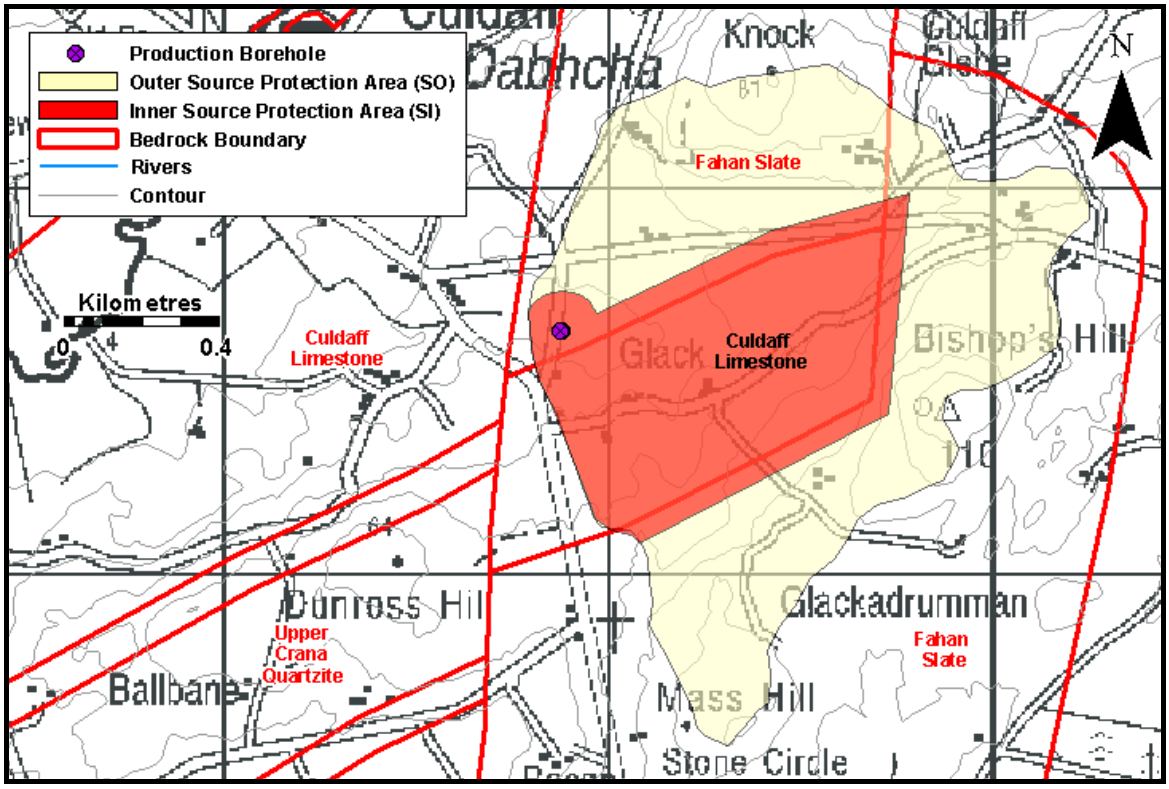

Figure 3.6. SO and SI Areas Around the Culdaff Water Supply Scheme Boreholes.

3.8 Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the two elements of land surface zoning (source protection areas and vulnerability categories) – a possible total of 8 source protection zones. In practice, the source protection zones are obtained by superimposing the vulnerability map on the source protection area map. Each zone is represented by a code e.g. **SI/H**, which represents an Inner Protection area where the groundwater is highly vulnerable to contamination.

Four groundwater protection zones are present around the Culdaff Public Water Supply Scheme (Figure 3.7), as shown in Table 3.2 below.

Due to shallow rock over most of the ZOC with slightly thicker till over a small percentage of the valley floor, the source protection area is considered be either 'extremely' or 'highly' vulnerable to contamination[14].

[14] The vulnerability zones do not take into account the protective capacity of the overlying Fahan Slate.

Table 3.2 Matrix of Source Protection Zones for the Culdaff Public Water Supply Scheme.

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

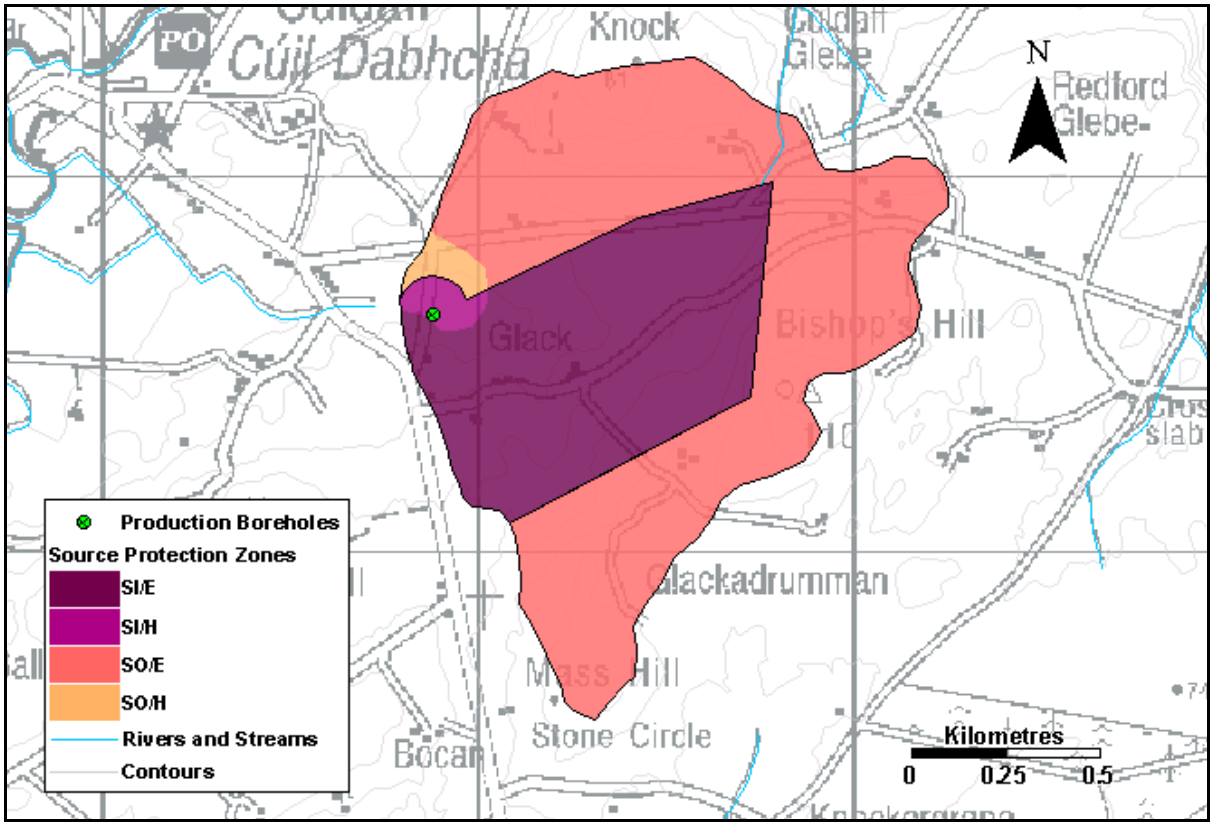

Figure 3.7. Source Protection Zones around the Culdaff Public Water Supply Boreholes.

3.9 Potential Pollution Sources

At this particular source, it was noted that cattle were drinking from the drainage channel along the northern border of well field site. The Fahan Slate and overlying clay-rich subsoil are likely to provide adequate protection against any downward movement of potential contaminants at this location. However, as the channel is less than 5 m away from the boreholes, any overtopping of the banks could result in contamination from surface inundation at the boreholes.

Agriculture is the principal activity in the SI and ZOC, with the majority of the valley area being used for pasture. Diffuse sources of contamination (organic and inorganic fertilisers, herbicides) are therefore potential hazards for the water supply. There are three minor roads which cross the ZOC, two of which are also within the SI. Oil and diesel spills along these roads are also potential hazards, as are discharges from farms (farmyard wastewater) and houses (on-site wastewater treatment

systems) along the roads. All of the potential hazards are of particular concern when they are located within SI areas that are 'extremely' vulnerable.

3.10 Conclusions and Recommendations

- The Culdaff Water Supply Scheme comprises two boreholes that together abstract an average 750 m^3/d. The boreholes pump directly into the distribution system over a 24 hour period. The pumping rate responds directly to the demand at any particular time and thus the abstraction rate has varied between 650-900 m^3/d.
- Both of the boreholes abstract water from the Culdaff Limestone. This rock unit is described as a marble rock with (possibly karstified) fracture/cavity zones, and is classified as a **locally important aquifer** that is moderately productive only in **local zones** (**Ll**).
- The ZOC is mainly constrained by topography i.e. the valley area, and assumes that the groundwater catchment mirrors the surface water catchment. The SI is based on the likelihood of fast groundwater velocities through the fracture/cavity zones in the Culdaff Limestone and assumes that the Fahan Slate provides an overlying protective layer.
- The water supply is susceptible to contamination from diffuse sources (spreading of inorganic and organic fertilisers and herbicides) and point hazards (farmyard wastewater, on-site wastewater treatment systems), especially when these are located in the SI/E zone.
- The protection zones delineated in the report are based on our current understanding of groundwater conditions and on the available data. Additional data obtained in the future may indicate that amendments to the boundaries are necessary.
- It is recommended that:
  1. livestock are prevented from gaining access to the surface drainage channel which acts as the northern boundary of the well field site. A drinking trough would be best located at the top of the field away from the boreholes.
  2. the potential hazards in the ZOC should be located and assessed especially with regard to the up-gradient proximity of farms and houses.
  3. particular care should be taken when assessing the location of any activities or developments which might cause contamination at the boreholes.
  4. full chemical and bacteriological analysis of the **raw** water at each abstraction point is carried out on a regular basis. The chemical analyses should include all major ions – ammonium, bicarbonate, calcium, chloride, magnesium, nitrate, potassium, sodium and sulphate.

7 References

Aqua-Fact International Services (no date). Summary of environmental assessment of the impact of freshwater abstraction for the use at a proposed fish processing plant at Rinmore Point, Fanad Head, Donegal. Extract from the document.

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

DELG/EPA/GSI (1999). *Groundwater Protection Schemes.* Department of the Environment and Local Government, Environmental Protection Agency and Geological Survey of Ireland.

Donegal County Council, Sanitary Services Section (July 1996). *Fanad Peninsula Water Supply – Emergency Relief Progress Report.*

Farrell E. (1989). Site investigation information including borehole and PSA information.

Fitzgerald, D. and Forrestal, F. (1996*). Monthly and Annual Averages of Rainfall for Ireland 1961-1990.* Meterological Service, Climatological Note No. 10, UDC 551.577.2(415).

Halcrow Group Ltd. (December 2001). *Review of the Groundwater Resources, Fanad Peninsula.*

Keegan M., Cantrell B., MacCartaigh M., and Toner P. (2002). *The Water Quality of Groundwater – Chapter 5* Water Quality in Ireland 1998 – 2000, EPA. Proceedings of the International Association of Hydrogeologists (Irish Group) Tullamore Seminar, 2002.

K.T. Cullen & Co. Ltd. (1992). *Proposed Groundwater Protection Policy for the Carndonagh Gravel Aquifer.* Report for Donegal County Council.

K.T. Cullen & Co. Ltd. (1998). *Report on a Hydrogeological Investigation of the Gleneely – Culdaff Area, Co. Donegal.* Report for Donegal County Council.

K.T. Cullen & Co. Ltd. (May 1998). *Groundwater Resources of the Fanad Peninsula.* Correspondence to Geological Survey of Ireland.

K.T. Cullen & Co. Ltd. (1997). *Report on the Drilling and Testing of a Water Well at Galdonagh.* Report for Donegal County Council.

Lee, M. and Daly, D. (1998). *County Donegal Groundwater Protection Scheme; Main Report*. Geological Survey of Ireland. Report for Donegal County Council.

Lee M. and Kelly C. (2003). *Boyle-Ardcarn Water Supply Scheme (Rockingham Spring). Source Protection Zones*. Geological Survey of Ireland. Report for Roscommon County Council.

Lee M. and Kelly C. (2003). *Killeglan Water Supply Scheme (Tobermore Spring). Groundwater Source Protection Zones.* Geological Survey of Ireland. Report for Roscommon County Council.

Long, C.B. & McConnell B.J. (1997) Geology of North Donegal: *A geological description to accompany bedrock geology 1:100,000 scale map, Sheet 1 and part of Sheet2, North Donegal.* With contributions from P. O'Connor, K. Claringbold, C. Cronin and R. Meehan. Geological Survey of Ireland.

Long, C. B., Mc Connell, B.J. (1999). *A Geological description of South Donegal, to accompany the bedrock geology 1:100,000 scale map series, Sheet 3/4, South Donegal.* With contributions from G.I. Alsop, P. O'Connor, K. Claringbold and C. Cronin. Geological Survey of Ireland.

McCarron Dr. S. (2002). *Aggregate Potential Mapping of County Donegal*. Geological Survey of Ireland. Report for Donegal County Council.

Meehan Dr. R. (2004). *Soils Parent Material Map.* Forest Inventory and Planning System – Integrated Forestry Information System (FIPS-IFS), Teagasc.

Met Eireann (2004). Digital rainfall and evapotranspiration grids 1971-2000.

Minerex Environmental Limited, (April 2003). *Ballyshannon and Rossnowlagh Water Supply Scheme; Groundwater Supply. Well design, drilling supervision, preliminary yield determinations, vulnerability assessment and reporting.* Report Reference 1492-067.

Minerex Environmental Limited, (July 2003). *Ballyshannon and Rossnowlagh Water Supply Scheme; Groundwater Supply. BH1, BH2, BH3, BH4 and Spring 2 pumping test supervision, monitoring, interpretation and reporting.* Report Reference 1492-103.

Mulholland & Doherty, Halcrow Water Services Ltd, (October 2002). *Fanad Regional Water Supply Scheme* – Summary Report; Supplementary Report No.2 Catchment Hydrology (Surface Water Sources); Supplementary Report No.2 Catchment Hydrology (Groundwater Sources).

Solmec, (1974). *Lough Inn Regional Water Supply Scheme Carndonagh Section – Trial Boreholes Logs and PSA*.

T.J. O'Connor & Assoc. (1989). *Lough Inn Regional Water Supply Scheme Carndonagh Section – Ground Investigation Report.*

GWWG, (November 2004). *Meeting Notes November 2004.* Water Framework Directive Groundwater Working Group; Sub-Committee on Recharge.